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REMOTE SENSING FOR WIND POWER POTENTIAL, A
PROSPECTOR'S HANDBOOK

By

J. E. Wade

P. A. Maule

G. Bodvarsson

C. L. Rosenfeld

S. G. Woolley

M. R. McClenahan

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J. E. Wade
P. A. Maule
G. Bodvarsson
Department of Atmospheric Sciences

C. L. Rosenfeld
S. G. Woolley
M. R. McClenahan
Department of Geography

Oregon State University
Corvallis, Oregon 97331

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* Now of Flow Industries, Seattle, Washington.

SUMMARY

This report describes the use of remote sensing in wind power prospecting. Remote sensing can aid in identifying and locating indicators of wind power potential from the terrestrial, marine, and atmospheric environments (ie: wind-deformed trees, white caps, and areas of thermal flux). It is not considered as a tool for determining wind power potential.

A wide variety of remotely sensed evidence is described in terms of the scale at which evidence of wind power can be identified, and the appropriate remote sensors for finding such evidence. The value of remote sensing to wind power prospecting is the ability to geographically associate a wide variety of wind indicators from the regional to local scale and to quickly pinpoint promising wind power sites.

Remote sensing can be used for regional area prospecting using small-scale imagery. The information from such small-scale imagery is most often qualitative; and if it is transitory, examination of a number of images to verify persistence of the feature may be required. However, this evidence will allow rapid screening of a large area, enabling the prospector to quickly select the most promising locations for sub-regional investigations.

Medium-scale imagery provides a better picture of the evidence obtained from small-scale imagery. At this level it is best to use existing imagery. Criteria relating to land use, accessibility, and proximity of candidate sites to nearby transmission lines can also be effectively evaluated from medium-scale imagery.

Large-scale imagery provides the most quantitative evidence of the strength of wind. Wind-deformed trees can be identified at a large number of sites using only a few hours in locally chartered aircraft. A handheld 35mm camera can adequately document any evidence of wind.

Three case studies that employ remote sensing prospecting techniques are described in this handbook. Based on remotely sensed evidence, the wind power potential in three geographically and climatically diverse areas of the United States is estimated, and the estimates are compared to actual wind data in those regions. In addition, the cost of each survey is dis-

cussed. The results indicate that remote sensing for wind power potential is a quick, cost effective, and fairly reliable method for screening large areas for wind power potential. Sites selected as having good wind power potential, based on evidence obtained from remote imagery, should be instrumented to determine important information such as: How good are the winds? At what height are they good? When are they good? How much turbulence can be expected?

The remote sensing techniques described in this handbook will identify some of the areas of strong winds in a region but not all of the areas where the wind power potential may be good. The techniques described are based on evidence of winds effect on natural features or natural features effect on winds and in some cases the winds will be strong in places where there is little or no evidence in the natural environment.

Imagery interpretation techniques are based on knowledge of how natural features at all scales interact with the wind regime. There is uncertainty still in many of these relationships. The completeness of information obtained about wind characteristics should be carefully weighed against the effort expended in gathering that information. In areas where existing data are sparse, more effort should be made to obtain remote-sensing imagery than in areas with good meteorological data where other techniques such as numerical or statistical modeling may fill in data gaps. Users of remote-sensing techniques should be aware that use of imagery, particularly high-altitude imagery, requires expert interpretation.

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REMOTE SENSING FOR WIND POWER POTENTIAL

A PROSPECTOR'S HANDBOOK

1.0 INTRODUCTION

In a manner not unlike the search for new sources of fossil fuels, wind power facility siting must rely on new, efficient techniques for large area coverage during the initial assessment or "prospecting" stage. These techniques must, in turn, accurately identify smaller areas deserving a "closer look" to determine specific "candidate" sites where an exploratory investment seems prudent.

Thus, prospecting for wind power potential proceeds from a regional or "large area" assessment to the identification of experimental sites for instrumentation with anemometers. This handbook centers on the use of remote sensing and associated interpretation techniques to assist in the reconnaissance of indicators of wind power potential.

Remote sensing must be systematically employed. Thus, this handbook is organized in a manner consistent with the primary tasks of prospecting:

1. Identification of the types of environmental phenomena which may be identified and calibrated on remote-sensing imagery.
2. Selection of the optimum imagery type, scale, and format for each environmental indicator.
3. Evaluation of the environmental or physical conditions which facilitate or most effectively use the imaging of such phenomena.
4. Interpretation of imagery and selection of ground verification techniques best suited to the identification, calibration, and mapping of key indicators.

This handbook presents an increasingly specific nested hierarchy of imagery-based wind prospecting techniques, designed for use throughout a

wide geographic range of environmental conditions. Various elements of this system provide techniques applicable to the regional energy level as well as to individuals seeking the best single site within a limited area.

Chapter 2 describes terrestrial studies of indicators of wind characteristics that serve as the framework for remote-sensing applications. Chapter 3 presents a strategy for applying remote sensing to wind prospecting studies. In Chapter 4 a catalog of the types of indicators, the appropriate scale of the evidence, applications of the evidence to wind prospecting, and limitations of the techniques are presented. Chapter 5 describes procedures for quantifying evidence from low-level aerial reconnaissance and information on techniques for conducting low-level aerial surveys. Finally, Chapters 6, 7, and 8 present case study examples of how the techniques described can be used in regional wind prospecting. The case study areas represent geographically and climatically diverse regions of the United States, and in each of the cases, estimates of wind power potential are made and verified using anemometer data. By careful use of the techniques described in this handbook, the wind prospector can quickly and inexpensively target promising areas where more detailed wind measurements can verify the wind power potential.

1.1 CONCLUSIONS AND RECOMMENDATIONS

We have shown that a variety of remotely sensed evidence related to the strength or direction of the wind is available for wind prospecting and candidate site evaluation.

For large-area analysis, small-scale imagery can be used to pinpoint areas with promising wind power potential, primarily through the use of qualitative or transitory evidence of wind speed, and/or direction.

Once the regional area is screened, sub-regional areas can be evaluated with medium-scale imagery that is often already available from agencies such as the U. S. Forest Service or Soil Conservation Service. At this level, factors relating to land use, accessibility, and proximity to nearby trans-

mission lines may be evaluated. Finally, large-scale information can be collected using helicopters or light aircraft to pinpoint specific candidate sites where ground-level investigations should be conducted. The wind information obtained in remote-sensing surveys should be validated with on-site instrumentation prior to installation of any size wind turbine.

These imagery interpretation techniques are based on knowledge of how natural features on all scales--terrestrial, marine, and atmospheric--interact with the wind regime. Many of the natural indicators can provide quantitative information on wind characteristics, but for the most part, the information obtained from remote sensing is qualitative, and in some cases, indirect or of a transitory nature. The uncertainty in all the relationships between remotely sensed wind indicators and wind characteristics should be weighed against the costs and the time expended gathering that information. Three case studies are described in this handbook in which costs, time and reliability of the information obtained are presented. A wide variety of indicators were examined in each of the case studies: Central Washington Region, New York State, and the California Desert Region. The sizes of these regions were about 12,000, 45,000, and 75,000 km², respectively. Generally it takes about 2 months to obtain existing satellite and medium-level imagery. Analysis of this imagery and preparation for a low-level survey takes 2 to 3 man days. For low-level aerial reconnaissance, 2 observers in addition to the pilot, are needed and for the California Desert Survey, just over 15 hours of flying time were used. The total cost of the California Desert remote-sensing survey was around \$3000.

In all of the three case studies the estimates of wind power potential, for the most part agree with the available wind data. The bias seems to be toward over-estimation of the strength of the wind. Based on these results, remote sensing appears to be a quick, cost effective, and adequately reliable method of selecting areas of possibly good wind power potential. Along with the essential adjunct of measurement of wind characteristics, remote sensing can provide a comprehensive picture of the wind resource potential in a regional size area or for a

whole state. In addition, other valuable information that will affect the feasibility of wind power can be obtained from remote platforms (ie: land use conflicts, accessibility and proximity to transmission lines).

This handbook by no means represents a comprehensive assessment of the potential of remote sensing in wind prospecting. Each wind prospector that applies this methodology will no doubt find new information related to wind characteristics that can be obtained from remote-sensing platforms, particularly if the meteorologist or engineer performing the survey obtains expert advice from scientists involved in studies of remote-sensing applications and modification of earth surfaces by wind.

There has been little attempt in this handbook to describe the use of surface-based remote-sensing systems such as radars, lidars, and acoustic echo sounders in wind prospecting, because the principals and potential uses of these types of remote wing sensors has been well documented by Hooke (1981) in "A Review of Remote Sensor Potential For Wind Energy Studies."

2.0 EOLIAN INDICATORS

Remote sensing in wind prospecting is being considered in this handbook as an aid to identification of the biological, ecological, and cultural characteristics of desirable wind power sites. These characteristics--often called eolian features--have been identified in past terrestrial studies as having either qualitative or quantitative relationships to the strength, persistence, or direction of the wind. The use of remote sensing was a logical extension of this ground-based work. Some of the past terrestrial research on eolian indicators of wind power potential will be described below.

Vegetation provides one of the most powerful eolian indicators of wind power potential. Trees have been used as indicators of strength and direction of wind for hundreds of years. The first to describe the use of trees in wind power prospecting was P. C. Putnam (1943) in the mountains of Vermont. He and his botanist collaborator, R. F. Griggs, developed techniques for using the degree of wind deformation in trees as a site-screening tool. These techniques have been extended to other species of trees and two additional indices of wind deformation have been developed by Hewson, et al. (1978, 1979a and b). They developed quantitative relationships between mean annual wind speed and three indices of wind effects on trees. The results of their studies indicate that trees can be used successfully to determine mean wind direction, identify the occurrence of severe wind or ice loads, and, most important, can be used to estimate mean annual wind speed. While the estimates of mean annual wind speed are subject to some uncertainty, they, nevertheless, provide a simple, inexpensive and quick method for identifying promising wind locations where more detailed measurements can verify the wind power potential. The use of trees and other biological organisms in wind prospecting has been recently described by Wade and Hewson (1980).

While the pronounced effect of wind on individual plant forms are readily visible in ground-based observation, these effects are not as apparent in any (except the lowest) remotely sensed platforms. The interpretation of

the wind's effect on vegetation from high-level platforms (ie: U-2 and satellites) requires understanding of the response of communities of plants to the wind.

Information on the response of plant communities to the wind is much less developed, but there are some observations of a general nature that can provide clues to strength of wind or its direction. Grace (1977) noted that the effect of wind on plants is similar to that of drought. This is because strong winds induce severe water stress in the plant, and plants that are better adapted to endure water stress would make up a higher proportion of the community in windier sites. Areas of large vegetation gradients where mesophytic (moist habitat plants) give way to xerophytic (dry-habitat plants) may be caused by wind-induced water stress. Additionally, plant density in windier locations would be less than in areas of light winds because xerophytic plants generally have reduced plant area above ground and extensive root systems. These adaptations help reduce water stress.

The distribution of plants is related to strength and direction of wind. According to Yoshino (1975), wind exerts a strong influence on the distribution of those plants whose seeds are scattered by the wind. Species which have light seeds generally grow in broad, open areas. Those with larger seeds grow in dense, shaded areas.

The height and number of species in a community is also related to the strength of the wind (Whitehead 1954 and 1957). Whitehead observed that the height and number of growth forms increased with decreasing wind velocity.

The presence of certain plants may contraindicate strong winds. The Saguaro cacti, for example, cannot endure very high wind speed (Dewson, 1978). Thus the areas of the Sonora Desert without this species obviously would be better prospects for wind generators than those with the plant. On the other hand, the grass *Calamagrostis nuktaensis* is found only on windy headlands of the Pacific Coast and, thus, provides a positive indicator of strong winds.

Other biological indicators from the animal kingdom can provide clues of wind that can be sensed from various levels of remote imagery. Coty

(1976) found that there is an inverse correlation between human population and the strength of the wind. Cultural indicators are those provided by humans, such as the orientation of wind breaks, transmission lines, snow fences, and other cultural features that may indicate prevailing wind direction. The transport of pollutants from industrial smoke stacks is related to strength and direction of wind and can provide direct information on the wind through the use of remote imagery.

The transport of natural particles such as dust, sand, salt, and snow also provides clues to the strength of the wind. The distance onshore to which plants are affected by salt spray is a function of the strength of onshore winds. The movement of sand grains and dune migration rate are also related to strength of wind. Winds can erode the earth's surface and transport sand and dust, and deposit sediment. The erosional and depositional eolian land forms and the characteristics of the transported sediments are indicators of the history of the winds that caused these landforms (Hiester and Pennell 1980). Relationships between the transport rate of sand particles, dune migration, and wind velocity have been described and developed by Bagnold (1942). Other studies relating geomorphological indicators to wind include Marrs and Gaylord (1979) and Lettau and Lettau (1978). Techniques for using geomorphological indicators of wind power potential have been described by Hiester and Pennell (1980), who found that geomorphological indicators provide an integrated picture of the wind regime in data-sparse areas. Sand grain sizes and dune migration rate can provide an indication of wind speed and mean wind directions in a region can be plotted on topographic maps using the orientation of eolian landforms such as deflation areas and sand dunes.

Wind, as it flows over terrain, can be accelerated, retarded, deflected, or can form turbulent eddies. The surface characteristics of the terrain are also important because the rougher the surface, the greater the difference between free air winds and winds disturbed by terrain features. Techniques for using topography to find optimum wind power sites have been described by Frenkiel (1962), Frost (1979), Frost and Nowak (1979), and Hiester and Pennell (1980). Topographic indicators used in conjunction

with wind measurements or modeling (see Meroney et al. 1978) can provide guidance in site selection and useful information on the turbulent character of wind at a site.

Patterns of snow accumulation provide indications of the strength and persistence of wind as well during the winter season. Areas of persistent snow sweep are a positive indicator of strong winds, and scour streaks where the wind has swept away snow can indicate prevailing winter wind direction.

Over water surfaces, whitecaps generally begin to form when the wind exceeds force four on the Beaufort scale (5.5 to 7.9 m/s). Areas where whitecaps and sea foam are persistent features would be prime areas for offshore wind development.

Eolian indicators described above provide tools for evaluating wind power potential. The role of remote sensing, which will be described in this report, will serve to expedite the use of these indicators and enable wind prospectors to evaluate much larger areas more rapidly.

3.0 A STRATEGY FOR APPLICATION OF REMOTE SENSING TO WIND PROSPECTING

Wind prospecting techniques may be applied to the analysis of regional windfields, site selection for major wind power generation projects, or simply for location of a single wind generator for domestic use. Prospective users of this handbook should clearly identify their project objectives so they can focus on those scales, imagery types, and wind indicators most appropriate to the project.

This guide provides the wind prospector with an inventory of types of indicators that may be identified from remotely sensed imagery, but this inventory is by no means a comprehensive list. A review of the indicators described herein may suggest other evidence associated with strong winds. After identifying the available evidence of winds in the area of interest, the type and scale of imagery may be selected.

3.1 TYPES OF INDICATORS

Indicators of wind power potential can be roughly divided into terrestrial, marine, and meteorological.

Terrestrial indicators are those indicators found on the earth's surface that provide clues to the strength of the wind. These include:

- Topographic land forms that are known to provide favorable wind power sites;
- Eolian indicators such as wind-deformed vegetation, vegetation community boundaries, areas of persistent snow sweep, sand dunes, and dune migration; and
- Cultural indicators, including snow fences, habitation patterns, and smoke plumes.

Indicators in the marine environment of surface winds include such phenomena as whitecaps, waves, ice drift, eutrophication patterns, and coastal upwelling. Meteorological indicators of low-level winds are those events or processes in the atmosphere which can provide information on the presence or absence of strong winds. Among these are orographic clouds that may be

associated with topographically accelerated winds, and frost pockets that are generally associated with light or calm winds. "Smearing" on thermal imagery is often caused by wind-induced surface temperature differences.

3.2 TYPES AND SCALES OF IMAGERY

Table 3.1 lists various types of imagery by the scale at which the imagery is acquired and the platform used.

TABLE 3.1. Various Scales of Remote Sensing and Platforms Appropriate to Each Scale

	Regional Assessment (100,000 km ²)	Area Evaluation (10,000 km ²)	Site Selection (100 km ²)
Platform	Satellite	Aircraft and U-2	Light plane or heli- copter and ground observation
Scale	Small scale 1:20,000-- 1:1,000,000	Medium scale 1:5,000-- 1:20,000	Large scale 1:100--1:5,000

3.2.1 Regional Assessment

Practical employment of such an imagery-based system, in any specific region, must be preceded by an initial screening on small-scale maps. Overlays should be prepared at a scale of approximately 1:500,000 to illustrate:

- 1) Surface wind flow patterns, as plotted from existing meteorological data;
- 2) Coincident distribution of useful vegetation types, snowfall areas, and other potential indicators; and
- 3) Resource management agencies or corporations with interests, and possibly large-scale imagery, within promising areas.

Initial screening at the regional scale (10⁵ km²) also should include identification of topographic features which may act to accelerate the

wind flowing over them, such as ridges perpendicular to the prevailing wind flow. Areas of potential interest should be identified and a Geographic Computer Search requested from any office of the National Cartographic Information Center (NCIC) of the U.S. Geological Survey. NCIC will perform a computer search of any geographic area in the U.S. at no charge to the requestor. This will yield an inventory of maps, satellite imagery, manned spacecraft, and high-altitude aerial photos of the area that are available through federal agencies. Generally, a lead time of 6-8 weeks is required to obtain high-altitude imagery.

Small-scale air photos can provide valuable associative evidence of local surface winds. Some of this evidence is transitory, such as local orographic cloud formations and waves. But when these features are regularly and predictably apparent through time in sequential photos, the consistency of regional and local winds can be qualitatively established.

Other features which suggest winds, such as dunal streaks, are found in deflation areas and are apparent in many air photos. These types of evidence are easily visible in small-scale air photos and provide additional indications of where to make closer, larger-scale inspections for quantifiable indicators such as flagged vegetation. Although features such as crown deformations of individual specimens may not be apparent, small-scale photos are valuable in plotting lower level, medium-scale air photo searches. As mentioned earlier, areas of wind-deformed vegetation are a result of regional influences and may be directly observable, especially with color or false-color infrared films.

3.2.2 Area Evaluation

To acquire medium-scale imagery, several agencies such as the U.S. Forest Service, Bureau of Land Management, Army Corps of Engineers, Soil Conservation Service, or county planning offices may be helpful. The vast majority of agency imagery consists of vertical aerial photography for stereo-viewing, mapping, or photogrammetric uses. The relative abundance and low cost of such imagery is rarely suited to the specific needs of the wind power prospector. If agency air photos reveal wind-deformed vegetation,

drifted snow, or orographic cloud effects, it is purely coincidental.

To find appropriate photos requires considerable patience on the part of both the prospector and the cooperating agency. Previous knowledge of the agency's requirements for air photo surveys and their normal timing has some advantages. There are some obvious possibilities: i.e., transportation corridors usually follow routes that are a combination of shortest distance between points and least topographic resistance--surface winds generally do the same. Therefore, the photographic files of transportation agencies and utility companies can prove quite fruitful.

Specific photo interpretation techniques must be employed in order to maximize the use of medium-scale photography. Wade and Hewson (1980) have shown that wind-deformed vegetation is an extremely valuable indicator of wind power potential. However, crown deformation of trees in forested areas is not readily apparent from single aerial photos. The use of stereo-pairs enabling three-dimensional analysis is helpful, as often only the very top of a tree will be affected in forested regions. The prospector should focus attention on broadly spaced or isolated trees, or those at the edge of a forest stand where wind exposure is greatest. Additionally, oblique photos or shadows may reveal wind-deformed tree profiles of significance.

Electronic image processing can aid in the identification of specific wind indicators on medium-scale photography. Such processing includes density-slicing of tone variations, edge enhancement, and digital processing techniques.

3.2.3 Site Selection

Once areas containing specific wind indicators have been identified on aerial photographs, aerial and/or field reconnaissance efforts may be directed toward verifying specific candidate sites for instrumentation. A few hours in a locally chartered plane with a hand-held 35mm camera and high-speed film yields the most cost-effective results. Important considerations in low level aerial surveys are discussed in Section 5 and a computer mapping technique is provided in the appendix of this guide that permits quantitative evaluation of individual wind power indicators through isotach (wind speed) maps of local windfields.

4.0 AN INVENTORY OF REMOTELY SENSED WIND INDICATORS

The following is an inventory of features that are observable in air reconnaissance or other remote sensing. Some features are of a regional nature, hence are observable from satellite elevations to U-2 airphoto reconnaissance. Depending on the remote sensing system, continual, repetitive, or almost real-time coverage may be routinely available at intervals ranging from every 30 minutes to every few days. Other features require medium-scale to large-scale aerial imagery because of their generally smaller size. Details of many of the regional-scale features may be more closely studied at these larger scales, but without proper identification from higher levels some regional features may be too large to observe at lower levels. Finally, some features may be observable only on site or from specially contracted imagery, such as low-level aircraft surveys. In utilizing remote sensing to isolate probable wind power sites or to define regional or local surface wind stream flows, all scales of all types of evidence should be kept in mind. Each section describing features is followed by a table indicating the scales of the features and useful remote sensors for detecting those features.

Since any classification of wind-related features requires some overlap between scales, these features have been classed by the environment in which they are located. However, the value of remote sensing is its ability to discover and geographically associate a variety of evidence. Cost effective surveys require observations of all possible wind evidence, and should not rely on one type of exclusive evidence.

4.1 TERRESTRIAL FEATURES

Wind-related features found on the earth's surface can be categorized as those which affect winds and those which are an effect of winds. For instance, a saddleback in a ridge will accelerate the wind flowing through the gap, whereas a deformed or wind-flagged tree is the result of strong wind.

4.1.1 Topographic Features

Topography affects surface winds at regional and local scales. It can accelerate, retard, and/or direct prevailing wind movements, and induce local katabatic winds. Features such as gaps, passes, and ridges perpendicular to prevailing wind direction can be identified from a variety of remote platforms.

Gaps through mountains are known to accelerate wind passing through them. Notable examples of this are the Columbia River Gorge, San Geronio Pass, and the Cumberland Gap. Figure 4.1 shows a LANDSAT image of the Colum-

FIGURE 4.1. A LANDSAT Image of the Columbia River Gorge. (Note the vegetation gradient indicated by changes from dark to light tones.)

bia River Gorge where local acceleration of wind flow occurs, and Figure 4.2 shows a U-2 image of a valley in Southwest Oregon where wind is topographically enhanced. Winds through the valley are accelerated as they flow over

FIGURE 4.2. A NASA U-2 Infrared Photo Shows a Major Valley (A to B) Through Mountains of Southwest Oregon. Arrow notes wind-flagged trees (see Figure 4.5).

the ridge indicated by the arrow. Other medium-scale imagery such as Synthetic Aperture Radar (SAR) and Side Looking Airborne Radar (SLAR) can vividly illustrate the shape and elevation of landforms. Figure 4.3 is an example of SLAR imagery. The light areas indicate terrain well exposed to the wind, and the darker areas are sheltered from the wind. The advantage of using radar imagery is that, given a knowledge of the prevailing wind direction, aircraft can be flown so as to illuminate surfaces well exposed to the prevailing winds.

Large-scale topographic features can be evaluated from low-level aerial reconnaissance. Frenkiel (1962) lists criteria for selecting optimum wind

FIGURE 4.3. A SLAR Image of Terrain. Light-shaded areas are well-exposed to the wind.

power sites. For a small hill, he concludes that a 30% slope would be optimum, and slopes of less than 5% and greater than 50% should be avoided. Stereo analysis of remote imagery can provide a tool for comparing the roughness of terrain at several candidate sites. However, one should remember stereo views appear to accentuate the terrain relief.

TABLE 4.1. Topographic Features, Scales of Evidence, and Useful Sensors

<u>Feature</u>	<u>Scale</u>	<u>Sensors</u>
Well-exposed ridges	Small scale	LANDSAT multi-spectral scanners (MSS)
	Medium scale	SLAR and SAR
	Large scale	Flight-level photography and visual observation
Saddlebacks and slopes which accelerate winds	Medium and large scale	SLAR, SAR, flight-level observation

4.1.2 Eolian Features

Eolian features include a wide variety of natural indicators of wind's effect. The following sections describe three types of natural features which can be used as wind indicators: vegetation, geomorphological, and cold climate features.

4.1.3 Vegetation Features

There are three scales of wind prospecting evidence using vegetation: 1) regional provinces, 2) community areas, and 3) on-site specimen wind deformation. For small-scale imagery the prospector has to depend on evaluation of wind effects on communities of plants. The distribution of plants, plant communities, and vegetation provinces are influenced by climatic conditions, elevation, and soil conditions. The distribution of plant provinces (specific communities and boundary gradients) are easily located with satellite-based visible and infrared sensors, especially the LANDSAT MSS (see Appendix A).

In areas of strong temperature gradient one might expect to see large gradients in vegetation type. Strong winds are also found in areas of strong surface temperature gradients. In the LANDSAT image shown in Figure 4.1 an area of strong gradient in the vegetation cover is also an area of strong winds.

The composition of a community may vary, depending on the strength of the wind. One would expect to find a greater number of xeric or drought-hardy species in plant communities subject to strong winds, since one of the major physiological effects of strong winds is the severe water stress they induce (Hewson 1978; Daubenmire 1947).

Medium-scale imagery can be useful in evaluating such biological signals as plant height and vegetation type. Whitehead (1957) found that the height and number of species in a community decreases as wind speed increases. Color computer enhancement may be necessary to accentuate information retrieval from small- and medium-scale remotely sensed imagery.

Perceiving regional and community distributions also helps target locations in large-scale imagery of those species whose deformation is calibrated to the average wind speed (see Rosenfeld and Maule 1979; and Wade and Hewson 1980). Figure 4.4 shows a low-flight-level aerial photograph of

FIGURE 4.4. Wind-deformed Trees Noted in Area of Strong Vegetation Gradient Shown in Figure 4.1

wind-deformed vegetation within the area shown in Figure 4.1. Figure 4.5 shows wind-deformed trees which confirm evidence of strong winds through a wind gap shown in Figure 4.2. The shape, vigor, and advance of plant

FIGURE 4.5. Trees Deformed by West Winds on the Ridge
Noted by the Arrow in Figure 4.2

communities may be determined largely by the dispersal of windborne seeds, pollen, wind or drought stress, and diseases. Plant communities of wind-dispersed plants, such as tumbleweeds, may accumulate on the downwind side of open areas such as meadows, swales, and farm fields. Blowdown of trees and tree limbs may also indicate areas of severe winds. The use of wind-deformed trees as an indicator of mean wind speed, prevailing direction, and the occurrence of severe winds is further discussed in Wade and Hewson (1980).

TABLE 4.2. Vegetation Features, Scales of Evidence, and Useful Sensors

<u>Feature</u>	<u>Scale</u>	<u>Sensors</u>
Vegetation gradients	Small scale	LANDSAT, MSS
Community composition	Small and medium scale	LANDSAT, MSS U-2 IR
Wind-deformed trees and shrubs	Large scale	Low-level aerial reconnaissance and ground-level photography

4.1.4 Geomorphological Features

Playas are evaporated lake beds where lakes may occasionally occur, sometimes seasonally. Playas are not eolian features, per se, but flat expanses of bare, loose sediment material which may be prone to deflation. Playas are mentioned because they are highly visible on LANDSAT imagery, and because wind directions and relative strength of seasonal winds may be ascertained from the orientation of playas and their deflation plumes (see Marrs and Gaylord 1979 and Carlisle and Marrs 1978). Other geomorphological features visible from LANDSAT may include other kinds of deflation areas, sand dunes, and beach terraces (see Shelton 1966, Strahler and Strahler 1978, and Sabins 1978).

Deflation areas occur where surface materials may be picked up and deposited by the wind. They are evidenced by streaks of material blown from areas where remnant vegetation is found on top of root-stabilized mounds, as in shrub coppice dunes. Although deflation areas in dunes, beaches, and playas are often more indicative of the nature of surface material and ground cover, it has been suggested that wind speed must reach 7 m/s to cause significant transport of surface, whereas others suggest a near surface threshold velocity of 4.4 m/s for most desert sands (Ritter 1978). Streaking or dunes downwind from deflation areas may indicate the prevailing direction and relative strength of surface winds. Deflation areas, in association with dunes

and sand streaks, can be observed from satellites (Shelton 1966, Marrs and Gaylord 1979, and Strahler and Strahler 1978).

Loess soils, formed from wind transported silt, are another indicator of wind deposition. Although their origin is ancient, their redistribution may provide information on recent winds too. Their depositional patterns are on a continental scale and, thus, may give evidence of direction and persistence of regional winds.

Beach strands and terraces also are visible in small-scale imagery such as LANDSAT. Prevailing wind direction and speed may be cumulatively recorded by wave erosion and deposition on shorelines. Varying water levels cause vertical displacements of shore-wave interaction, sometimes leaving a progression of beach terraces. The section of a closed shoreline suffer the greatest wave action, i.e., where beaches or beach terraces are highest and widest likely to be exposed to the strongest winds. In many cases this evidence is visible from satellites with sensors that can detect changes in surface composition and/or vegetation cover (Sabins 1978 and Lewis 1979).

There are three scales of interpretation of sand dunes: 1) dune fields, 2) individual dunes, and 3) constituent particles. The first two may be located and studied using remote sensing. The third requires field sampling and laboratory analysis.

Dunes cannot exist without upwind deflation areas to provide material. Sand source areas for desert dunes are typically loose fluvial deposits in large basin areas (Cooke and Warren 1973 and Petrov 1976). The location and orientation of dunes to their parent deflation areas can reveal locations and direction of significant winds. The length and linearity of dune fields can indicate the persistence and relative strength of directional winds. This information can be gathered from small- to large-scale imagery, as illustrated in Figures 4.6 through 4.9. Figure 4.6 shows a Skylab photograph of dune patterns in the Namib Desert; wind confluence is indicated by the orientation of the dunes. Figures 4.7, 4.8, and 4.9 show a progression of dune features available from various scales of remote sensing in the area around Wanapum Dam in Central Washington. Figure 4.7 shows a hairpin-shaped dune area as a white streak. Figure 4.8 has the same dune area in an oblique

FIGURE 4.6. The Dune Shapes Shown in this Photograph Indicate Confluence of Wind.

FIGURE 4.7. LANDSAT Image Showing the Distribution of Vegetated, Unvegetated, Mountainous, and Water Areas in Central Washington. (The white streak (near arrow) is a dune east of Wanapum reservoir).

FIGURE 4.8. Lower Light-toned Area (A) is Same Streak Noted in Figure 4.7 from ~8km (1% of Figure 4.7's Scale). (The surface throughout the vicinity appears characterized by active and remnant dunes (B): note variable soil in the cultivated circular area (C).)

FIGURE 4.9. A Barchan Dune from ~20m (2% of Figure 4.8's Scale), Confirms Present Active Nature of Dune Field Perceived at Higher Elevations. (The linearity of the dune field (see Figure 4.8) suggests persistent unidirectional winds from the west or right. Nearby Wanapum Dam has an annual average wind speed of 12 mph.)

view at a scale where active and remnant dunes are just visible. Figure 4.9 shows the slipface of an individual dune of the same area with visible ripple marks. At larger scales the use of shadows to reveal slipface orientation becomes increasingly important.

Simple dune forms (see Figure 4.10) indicate wind direction, relative wind speeds, sand sources, and sand grain characteristics. Several different dune forms occur in any dune field creating complex patterns that reflect changes in wind, vegetation, sand particles, moisture, and other factors. (See also Section 8 for a description of dune forms and associated winds by Dean 1978; see also Mabbutt 1977.)

Figure 4.11 presents a diagram which relates dune type to relative amounts of wind, sand supply, and vegetation (Ritter 1978).

It is important to distinguish between modern, active dunes caused by recent winds and inactive, or remnant, dunes which might be artifacts of ancient winds.

Modern, active dunes are characterized by a lack of stabilizing vegetation, a sharp crest line, and slides of sand down dune faces (slipfaces). Inactive or "fossil" dunes are characterized by a mantle of vegetation cover, smooth and rolling surfaces, and stabilized sand. Inactive dunes may have been stabilized by wetter modern conditions; they do not necessarily indicate that local winds have slackened in recent times. A wide range of relative dune activity may occur in the same region or even within the same dune field with active dunes riding over fossil forms. The direction and rate of travel of dunes and dune fields can be assessed by comparing a time sequence of imagery (Shelton 1966; Marrs and Marwitz 1978; Marrs and Gaylord 1979).

The size and kinds of particles that comprise dunes can give clues to the relative strength, persistence, and direction of the wind. Movement of heavier, larger particles requires stronger winds; lighter, finer particles are more readily carried longer distances. Long periods of winnowing by the wind results in the well-sorted size distributions of eolian sands averaging 0.15-0.25mm (Ritter 1978). Within a dune field, sand grains which have been flown further downwind may be characterized by being more rounded in shape, darker in color due to surface mineral coatings, and better sorted with parti-

FIGURE 4.10a. Sand Dune Forms. (The letter H is height, L is length, W is width, C is crest, and SF is slipface.)

SIMPLE SAND DUNE FORMS

H height
L length
W width
C crest
SF slipface

FIGURE 4.10b. Sand Dune Forms. (The letter H is height, L is length, W is width, C is crest, and SF is slipface.)

FIGURE 4.11. Three Common Dune Types Presented as a Function of Wind Strength, Amount of Vegetative Cover, and Supply of Sand (Ritter 1978)

cles falling within a limited size range (Petrov 1976). The source of materials can indicate direction and distance, and in some cases the rate of travel can be verified (see also Bagnold 1942, Lettau and Lettau 1978, and Kolm 1975).

Figure 4.10 shows characteristic dune forms and the prevailing wind direction indicated by these dune forms. According to Fryberger and Ahlbrandt (1978) the type of dune form is related to the persistence of the wind direction. Barchanoid dunes are common in unimodal wind regimes, transverse in wide unimodal wind regimes, longitudinal dunes in wide unimodal or bimodal wind regimes, and star dunes in complex wind regimes where more than two directions are common. Techniques for using sand dunes to predict mean wind speed are discussed in Marrs and Gaylord (1979) and Hiester and Pennel (1980). In Section 6 and 8 of this report, further examples are provided on the use of sand dunes in wind prospecting.

Ripple marks on sand surfaces are small-dimension features which form perpendicular to the wind direction. Ripples are a short-term indicator of wind flow and subject to constant change since they form in response to changes in wind patterns which occur within a day's time or less. Only by accurate measurement in the field can any quantitative data be gathered about ripple marks and its use is less reliable than other methods presented here (see Marrs and Gaylord 1979; Bagnold 1942). A summary of the kinds of information about wind speed and wind direction detectable at different scales of sand dune interpretation is given below in Table 4.3.1.

TABLE 4.3.1. Summary Table of General Information About Wind Speed and Direction Which Can Be Obtained from Sand Dune Analysis

<u>Scale</u>	<u>Wind Direction</u>	<u>Wind Speed</u>
Dune field	Relation to sand source areas	Dune migration rates (Lettau and Lettau, 1978 and Hiester & Pennell, 1980)
Dune forms	Slipface orientation	Dune form type (L.E. Dean, 1978)
Dune ripples	Ripple orientation	Ripple height and spacing (R.A. Bagnold, 1942)
Dune sand grains	Relating amounts of sorting, rounding, color change from mineral coatings	Grain size calculations (Hiester and Pennell, 1980)

Transient features such as dust plumes may be short-lived events, but recognizing them on a sequence of images can reveal their direction, rate of movement, and may lend supportive evidence to regional and local stream flow analysis. Cumulative evidence may be apparent along downwind fence rows or other places where drifting material, such as plowed topsoil, may accumulate to change surface moisture and vegetation distributions. Such drifting material requires relatively dry weather periods, since the cohesion of moist

particles may preclude wind distribution. For further discussion of wind-blown dust, see Strahler and Strahler (1978); Shelton (1966); Sabins (1978); Schmugge, et al. (1975); and Swank and Booth (1970).

Sand scours, desert pavement, and ventifacts indicate that there are at least intermittent seasonal local winds strong enough to deport material and erode remaining rocks at the surface. Relating the orientation and exposure of these features, especially to local dunes, can indicate the direction of winds (Strahler and Strahler 1978; Mabbutt 1977). Identification of desert pavement and remnant hillocks may require low-level observations. Desert pavement is usually composed of closely-packed stones that remain where smaller, lighter materials, such as sand from a sand scour or silt from a gravel bar, have been wind-removed. The accumulation and settling of these stones causes the longest axes of the rocks to become parallel to the prevailing wind direction. The stones tend toward a stabilized accumulation, turning until least-resistant profiles are to the wind. Since desert pavement is sorted material that has evolved from unsorted material, care must be taken while observing that they are not the result of other erosional agents (i.e., water in a dry streambed). These features can be confirmed only with on-site surface observations, but a large enough expanse of such rocks may be observable from mid- to low-level photography and thermal sensors. Ventifacts are isolated stones with smooth sides tapering to sharp points. Ventifact shape is due to wind abrasion. If undisturbed, the long axis of a ventifact is parallel to the prevailing wind direction. All surface observations of features such as ventifacts and ripple marks need interpretation in relation to wind characteristics.

TABLE 4.3.2. Geomorphological Features, Scales of Evidence, and Useful Sensors

<u>Feature</u>	<u>Scale</u>	<u>Sensors</u>
Playas, loess soils, beach strands, dune fields, deflation areas, sand streaks and sand source areas	Small scale	LANDSAT MSS
Individual dunes, dust transport, and drifts	Medium to large scale	U-2 IR, SLAR, and Thermal Infrared (TIR), low-level aerial photos
Constituent particles, sand scours, desert pavement, ventifacts and ripple marks	Ground-level observation	Photographs

4.1.5 Cold Climate Features

Different seasons bring different wind patterns to most regions. Accumulations of snow and ice may occur in below-freezing conditions and are subject to wind processes. Thus, their patterns and shapes can reveal clues about the wind.

A snow field can be windblown into drifts like sand dunes. Over a period of days those drift surfaces that face the sun are subject to more direct heating and more rapid melting. This exaggerates the snow field into what are called sun cups. Because of the associated roughness, shadows, and various snow densities, sun cups may be evident to satellite multispectral scanners and scatterometers. However, they are more apparent in large-scale imagery. Their presence and pattern indicate the presence and direction of prevailing winds.

The pattern of fresh snow deposition over an area is called snow sweep. In small- to medium-scale imagery, placement and shape of these areas may

reveal surface wind flow patterns. In large-scale imagery, drifts may be apparent as they accumulate around obstacles as in Figures 4.12, 4.13, and 4.14.

Site-specific features, which would require low-level (preferably oblique) observations, include cornices (see Figures 4.14 and 4.15) and snow plaster. A related cultural feature, snow fencing, may be observed at mid- to high-flight levels. Snow fences are usually left in place throughout the year on the prevailing upwind side of such cultural features as roads and railroads, providing evidence of the presence and direction of significant winter winds. Snow cornices can reveal the location and direction of prevailing winter storm winds; however, changes in temperature or the direction of significant winds are likely to destroy them. Thus the longer-lived the cornices, the more constant the wind conditions. A more detailed analysis of the use of snow cover for inferring wind characteristics is provided in Appendix C.

FIGURE 4.12. Elongated Sun Cups and Rippled Drifts
in the Juneau Ice Field of Alaska

FIGURE 4.13. Snow Sweep (A), Snowdrifts (B), and Crescent-shaped Snow Dunes (C) Reveal Areas of Strong Wind and the Prevailing West Wind (from upper left)

FIGURE 4.14. Snow Sweep and Snow Cornices on the Ridge Crest
of the Columbia Hills (west wind from left)

FIGURE 4.15. A Snow Cornice on a Southwestern Washington Peak Indicates the Prevailing West Winds (from the right)

Ice scour is shore damage caused by accumulations of pack ice. As with beach terraces, areas of greatest damage along lake shorelines are on the prevailing winter downwind side of lakes. Affected shorelines are often relatively steep and have a bulldozed appearance. Extensive areas with significant regular displacements of surface materials may be apparent in medium- to large-scale imagery.

Rime ice is the compacted accumulation of snow plaster under long, severe cold conditions. It forms on the upwind side of obstacles, and its cumulative effects may be evidenced by ice-damaged trees. For wind power siting, areas of rime or ice damage should be avoided because of potential icing hazards.

Frozen spray accumulates on the upwind side of obstacles (see Figure 4.16). As long as air temperatures remain below freezing and water temperatures above freezing, the size and location of frozen spray buildups can indicate the direction and relative magnitude of winter winds. Since the

FIGURE 4.16. Frozen Spray Collects Along the East (Upwind/Right) Shoreline of an Island in the Columbia River Gorge in January

size of spray areas is dependent on adjacent water surface roughness (wave height) and on-shore wind strength, possible qualitative relationships of frozen spray to mean wind speed is unclear (see also Martinalli 1959; Swank and Booth 1970; Sabins 1978; Barnes and Bowley 1974; Krimmel and Meier 1975).

TABLE 4.4. Cold Climate Features, Scales of Evidence, and Useful Sensors.

<u>Feature</u>	<u>Scale</u>	<u>Sensors</u>
Sun cups and snow sweep	Small to medium scale	LANDSAT, U-2, IR, and TIR
Snow cornices, ice scour, rime icing, and frozen spray	Large scale	Low-level aerial photographs

4.1.6 Cultural Features

Many human activities are influenced by prevailing local wind conditions. Depending on their size and distribution these features are observable from satellites and various flight levels. Most of these features reveal direction of the prevailing winds.

Windmills are a cultural feature which may indicate good wind power potential; but winds are not necessarily strong, since windmills historically have been sited with regard for available water, not maximum local winds. However, if they can pump water in sheltered areas, the surrounding exposed areas might have more significant winds.

Airport runways are usually aligned parallel to the prevailing wind direction and are observable even from satellite imagery. Windbreaks and irrigation systems also give clues to the location and direction of significant winds. The orientation of windbreaks such as Lombardy Poplar, cottonwood, or eucalyptus trees are most apparent at low-flight elevations (see Figure 4.17).

FIGURE 4.17. The Orientation and Shaping of Trees near Royal, Washington, Reveal that Significant Winds Persist from the Southwest (from the left)

Modern irrigation systems are laid out to avoid water waste. Where strong winds affect irrigation systems, one would expect to see an offset of wetted, darker ground or reduced plant vigor on the less-wetted upwind parts of irrigated fields (see Figure 4.18). Although some irrigation areas are observable from LANDSAT, the orientation of systems and significant windborne water displacements require medium- to large-scale imagery (Schmugge et al. 1975).

FIGURE 4.18. Irrigation Water Displacement Caused by Strong Winds

Smoke plumes from large industrial sources can provide information on wind direction that is both short term and long term. A LANDSAT view of Central Europe (Figure 4.19) shows southwest winds in Czechoslovakia and on the Polish Plains southeast winds are indicated. Damage from smoke is clearly evident near Wawa, Ontario (Figure 4.20) and indicates a prevailing southwest wind direction. The cloud streets in the same figure provide short-term evidence of southwest winds. A more confined area of air pollu-

FIGURE 4.19. Smoke Plumes in Central Europe Indicating Southwest Winds (bottom) and Southeast Winds over the Polish Plains (right center)

FIGURE 4.20. Smoke Damage North of Wawa, Ontario, Indicates Prevailing Southwest Winds

tion damage is evident in Figure 4.21 near Ducktown, Tennessee where the prevailing wind direction is apparently west-southwest.

Depending on the culture and local climate, certain features of architecture and landscaping may provide cumulative evidence of significant local prevailing wind directions--closed porches, lee side entries to houses and barns, windcreens, and snow fences.

The Beaufort scale provides a number of large-scale natural and cultural indicators of the strength of the wind at the time it is occurring. These include the shape of flags, bending of smoke plumes from chimneys, and wind-blown dust. Large industrial plumes, evident in even small-scale imagery, may provide, through examination of a number of images, an indication of the prevailing wind direction.

FIGURE 4.21. Smoke Damage Near Ducktown, Tennessee, Provides Evidence of Prevailing West-Southwest Winds

TABLE 4.5. Cultural Features, Scales at Which They Can Be Identified, and the Appropriate Sensors Available

Feature	Scale	Sensors
Airport runways, smoke plumes, and irrigation efficiency	Small to large scale	LANDSAT, TIR, Low-level photography
Windbreaks, windmills, snow fences, wind screens, and Beaufort Indicator	Large scale	Photographs from low-flying aircraft, or ground-level observation

4.2 MARINE FEATURES

Since water covers more than two-thirds of the earth's surface, many remote-sensing systems have been deployed to analyze marine conditions. Since there is much more water surface than land surface on the planet, the wind prospector should have an interest in possible surface wind clues from water surfaces and information on the wind power potential over water may aid in the assessment of wind power along adjacent shorelines.

4.2.1 Waves and Related Features

Although waves and many other wind-related features may be considered temporal and/or transitory, it must be remembered that the wind itself is temporal and transitory. Hence naturally occurring evidence, such as waves, that give real-time information, can be useful. Repetitive recording by remote-sensing systems can provide a permanent real-time record.

White caps appear when surface wind speeds reach 7 m/s; however, significant fetch is needed before capillary waves gain a sharp enough peak to be pushed over by the winds, causing white caps (Munk 1947; Cox and Monk 1954; and Monahan 1971). In other words, 7 m/s winds will not instantly form white caps on smooth water; sufficient time and space are required. Because of the vivid spectral contrast of white cap and foam formations, over a large enough area they are discernible at satellite observations. The 7 m/s white cap threshold of wind is easily observable at all scales (see Figure 4.22).

In Figure 4.23 a wave train indicating possibly strong winds is visible on a lake in Oregon's Cascade Mountains. LANDSAT imagery in Figure 4.24 indicates vegetation cover around the lake and a ground telephoto photograph in Figure 4.25 near the lakes provides verification that strong winds occur.

Surface winds can be remotely detected and estimated over oceans by methods involving aerial surface photography, or high-level infrared or microwave radiation measurements. Recent comprehensive collection of ocean wind data was undertaken on global scales in 1978 by SEASAT through NASA's Jet Propulsion Laboratory. Remote sensing of surface winds is possible by the quantitative detection of surface small-scale roughness

FIGURE 4.22. A NASA U-2 Image near Port Orford on the Oregon Coast, (NNW winds which appear to be greater than 7 m/s are evidenced by white caps (A). Note the apparent turbulence on the lee side of the headland (B) and smooth (Dark) water in the immediate lee vicinity of upwind shore of the lake (C).)

FIGURE 4.23. SEASAT Imagery of Central Oregon Cascades. (Winds were apparently active, at least at Crescent Lake.) Note the lighter tone of a wave train on the lake (near the arrow.)

FIGURE 4.24. LANDSAT MSS Image of Central Oregon Reveals Coniferous Forest Around the Lake in Figure 4.23 (see arrow)

FIGURE 4.25. Ground-level Photographs of Vegetation Around the Lake Shown in Figures 4.23 and 4.24 Indicate Well-flagged Conifer Trees

and foam coverage. The relationships between surface wind speeds, surface waves, and foam coverage are discussed in more detail in Appendix D.

Neither gravity waves nor white caps need be present to perceive wind-stream flow patterns over an area. Wind speeds of 1 to 2 m/s obviously disturb flat water by scattering any reflection. Since water can act like a multifaceted mirror, it is called a specular surface. On a smooth surface the reflection of the sun appears as a single spot. As the surface becomes increasingly rougher, the single spot of reflection becomes an ever-larger area of sun glint. The stronger the wind, the rougher the surface and the larger the sun glint area. Likewise, the more the reflection of a point of light is scattered (diffused), the less intense the reflection (see Figure 4.26 and Sabins 1978). A specular surface reflects other electromagnetic waves besides sunlight. For instance, active sensors (those that emit their own energy beam) using microwaves measure the intensity of backscatter to

FIGURE 4.26. Sun Glint on the Ocean Surface

assess water surface roughness and deduce wind speeds. Instruments designed to measure backscatter or to perceive specular surface area qualities are called scatterometers. SEASAT was designed to measure real-time synoptic-scale water surface conditions. Combined systems, such as doppler radar, can confirm the direction and rate of travel of waves. Where bodies of water are scattered over a study area, it may be possible to perceive a near-instantaneous surface stream flow pattern for the entire area (or region) and to pinpoint the relatively windiest locations.

Surrounding surface roughness and topography must be appreciated for their effects on the relative exposure of water surfaces. With time-lapse imagery, the location, persistence, growth, and direction of wave trains can be further confirmed to analyze local and regional wind regimes and stream flows. Areas of wind shadow, where water is sheltered on the lee side of an object, are equally important when doing wind power prospecting or surface flow analysis (see Figure 4.23). Further discussions of wind effects on

water surfaces are contained in Hammond, et al. (1977); Gjessing (1978); Webster, et al. (1976); Crombie (1955) and Appendix D.

4.2.2 Upwelling

Wind blowing on a water surface from a constant direction over time causes a significant displacement of the surface water. This surface displacement, if away from a shoreline, causes upwelling of cooler waters. This temperature difference is highly apparent with thermal scanners at satellite elevations and lower (Stogryn 1967).

4.2.3 Flotsam

Flotsam such as pack ice, icebergs, algal blooms, foam, and driftwood or pollutants such as oil slicks may accumulate along downwind shorelines. Such relative accumulations in different quadrants of closed shorelines may be regarded as cumulative evidence of prevailing wind directions. The possibility of subsurface water currents must be considered, however. The thermal and spectral qualities of algae, foam, ice, and oil slicks lend themselves to satellite observations, depending on the size of the area, whereas other accumulated debris would require lower-level observations. Dust deposits streaking over extensive ocean areas have been observed with LANDSAT to locate surface wind flows, wind gaps, and wind shadows (see Otterman 1975; Barnes and Bowley 1974; Sabins 1978).

4.2.4 Eutrophication

Eutrophication is the aging process of lakes and marshes which necessarily fill with sediment over time. In the course of this research, it has been noted on remote-sensing imagery that patterns of eutrophication seem to correspond to prevailing local wind directions (see Figure 4.27). We hypothesized that, all other things being equal, the prevailing downwind quadrant of a lake would be the last area to be filled in, being the most agitated area with least sedimentation. (Further discussion and evidence of eutrophication and its relationship to wind characteristics are included in Appendix E.)

FIGURE 4.27. Eutrophication Patterns Observed in a Lake in Central Oregon (winds from lower left)

4.2.5 Harbors

Breakwaters and moorage patterns are designed to shelter watercraft from prevailing wind directions. Sailboats may reveal present surface wind conditions and watercraft tie up on the lee side of docks, if given an option (Avery 1968).

TABLE 4.6. Marine Environment Features, Scales at Which They May Be Observed, and Appropriate Sensors

<u>Feature</u>	<u>Scale</u>	<u>Sensors</u>
Waves	All scales, depending on size of survey area	Scatterometer, Visible and IR photography SLAR, SAR
Upwelling	Satellite and U-2	Thermal sensors
Ice	All scales	Visible and IR photography SLAR, SAR
Flotsam	Flight elevations	Photography, MSS
Oil slicks	All scales	Scatterometers
Eutrophication	Medium scale	Visible and IR photography

4.3 ATMOSPHERIC FEATURES

Occasional or periodic features within the atmosphere may reveal the relationship of topography to surface wind movements. Associations of this and other evidence may reveal prevailing surface wind conditions.

4.3.1 Surface Winds

Synoptic-scale wind movements can be observed and measured with satellite-borne microwave scatterometers (e.g., SEASAT). The basis of this technique is the backscatter intensity of reflected radar beams from capil-

lary waves over large regions (Jones 1979). Local area wind speeds can be more directly measured by ground-based doppler radar systems whose beams are reflected directly from air particles (Gjessing 1978; Hiester and Pennell 1980, Hooke, 1981).

4.3.2 Thermal Flux and Thermal Smear

The direction and character of surface winds is determined mostly by the orientation of surface pressure gradients, which are largely determined by differential heating and cooling of the earth's surface. These areas are very evident on geostationary satellite (GOES) imagery and Heat Capacity Mapping Mission (HCMM) satellite thermal imagery (see Figure 4.28).

FIGURE 4.28. GOES Imagery of Western North America.
Lighter tones indicate colder areas.

Although these thermal images give evidence of the temperature change of land surfaces and not the actual heating of the low-level atmosphere, it is discussed here because of this major influence on surface wind stream flows (see also Byrne 1980; Kung 1964; Sonneck 1977; Sabins 1978).

During the night the differential cooling of the earth's surface could provide indication of windy locations in a regional area. Valleys undergoing significant radiational cooling would be contrasted sharply with wind swept ridges which would be cooling less rapidly because they might be receiving heat by conduction from the winds passing over them.

Thermal smearing is a feature sometimes seen on thermal imagery. It is caused by surface temperature differences around obstacles cooled by wind. At mid- to low-flight elevations this smearing appearance can be used to locate and determine the direction of local wind flow, and may be useful in analyzing surface windstream flow. Observation of thermal smear requires expertise in imagery interpretation (Sabins 1978).

4.3.3 Orographic Clouds

Orographic clouds are caused by moist air being lifted over a topographic barrier. They are visible in thermal, visible, and radar imagery at all elevations. Their regular occurrence substantiates both the location of topographic barriers and the wind flow over such barriers from one region to another (see Figure 4.29). Direction, season, and regularity of local and regional winds may be determined by observing repetitive imagery of orographic clouds (Petterssen 1969).

4.3.4 Low-Level Advective Clouds

Though fog or low stratus clouds often form in low-wind conditions, small synoptic pressure gradients can cause advection of low clouds through gaps in topographic barriers, thus pinpointing the location of wind gaps. Prime examples are the Golden Gate and Carquinez Straits in California

FIGURE 4.29. Orographic Cloud Patterns Around a Cone-shaped Mountain in Japan. (The volcanic plume provides evidence of the wind direction associated with the cloud pattern.)

(Petterssen 1969). Katabatic winds are evident in Figure 4.30, showing clouds flowing out of the Copper River Valley of Alaska.

4.3.5 Frost/Dew

Frost or dew might be considered "negative" indicators of surface wind, since they occur when and where surface winds are calm. In an area survey, it may be revealing to note where dew or frost occur. Care must be taken to observe predawn conditions, since solar radiation will cause heating and evaporation and destroy any wind-related patterns. These patterns may be observable with visible photography or infrared photography.

FIGURE 4.30. Katabatic Winds in the Copper River Valley in Alaska are Indicated by Stratus Clouds

TABLE 4.7. Atmospheric Features, Scales of Evidence, and Sensors Available at Each Site

<u>Feature</u>	<u>Scale</u>	<u>Sensors</u>
Thermal flux	Small scale	Thermal for surface temperature regions
Clouds	Small to medium scale	VIS, MSS, TIR, IR, MW
Frost, dew, and thermal smear	Medium to large scale	VIS and TIR photography

5.0 LOW LEVEL AERIAL PROSPECTING CONSIDERATIONS

The purpose of this section is to discuss relevant characteristics of aircraft operations in an effort to enhance the efficiency and safety of low-altitude aerial surveys to document and measure evidence of wind speed and direction. In some cases, low-level aerial photography may provide all of the evidence necessary to fully document a candidate wind power site. However, in most situations the aerial survey is used to rapidly cover large amounts of territory within a study area in an effort to document specific wind evidence as a preliminary to on-site inspection.

The major advantages of aerial photography as a preliminary to ground-level inspection are:

1. The wind prospector has a chance to get the "big picture" of the study area from a better vantage point. Photographs that are taken from air reconnaissance will contain a variety of information that will mean different things to the meteorologist, engineer, planner, and utility executives.
2. Aerial photography records existing conditions (such as the position of sand dunes) and provides stop-action evidence of dynamic events (such as smoke plumes or whitecaps) that can be used with earlier or later recorded information to provide estimates of the wind strength.
3. Photographic film can detect and record information over a wavelength range twice as broad as that of the human eye.
4. Using properly selected cameras, film, and flight parameters, aerial photographs can record more spatial detail on film than can be detected by visual observation. With good ground reference data, distances along with heights and directions of selected features can also be accurately determined.

5.1 SELECTION OF AIRCRAFT

Cost and the accessibility of the selected sites are the primary criteria in deciding between a "fixed wing" (airplane) or "rotary wing" (helicopter) survey. Using 1981 costs for a fixed wing light aircraft (including pilot) vary between \$40-\$100/flight hour depending upon the type of aircraft employed and the geographical location of the study area. Selection of aircraft type should be based upon visibility from the cabin and low-speed flight characteristics. For the former criteria, a high-wing monoplane design is usually best, allowing the "clearest" side and ground views. Several models, like the Cessna 172 Skyhawk, are readily available for rental from fixed-base operators at airports throughout the country. We have employed the Cessna 172 extensively in our aerial surveys and have collected cost of operation data on its employment. Averaging 90 nautical miles of linear survey/hour at an average cost of \$34/hour, we estimate \$0.35 per linear mile of the prospective survey.

The low-speed handling characteristics of the aircraft is something best evaluated by an experienced pilot, however, a few simple guidelines can be drawn:

1. The aircraft should be capable of sustaining safe level flight at speeds of 60-65 knots at low flap settings.
2. The aircraft should be capable of a climb rate of at least 500 feet/minute throughout the range of altitudes anticipated by the survey.
3. The aircraft should have at least a 5-hour fuel endurance to assure efficiency of the survey.

Additional recommended characteristics include two VOR receivers for "resecting" locations in remote areas, and opening side windows for oblique photography. In an effort to enhance flight safety, and preserve the required flight characteristics, it is recommended that the aircraft be loaded to no more than 70% of gross weight. In mountain or desert terrain, where altitude or heat will impair climb capability, the selection of a more powerful aircraft with a constant-speed propeller may greatly enhance the success of the survey.

Helicopter surveys are considerably more expensive, but may be justified under certain circumstances, especially if inspections on the ground are incorporated with the aerial survey. The primary advantages of helicopters as survey platforms are their hover and landing capabilities. The stationary hover capability should be used sparingly for aerial surveys however, as it slows progress and creates "rotor wash" downdrafts which sometimes disturb or obscure evidence. Additionally, hover ability is limited by altitude, temperature, and wind. The ability to land and inspect ground evidence is the primary advantage of the helicopter for aerial surveys for wind power. This capability cannot be duplicated by any other means. It gives the wind prospector the opportunity to take terrestrial photos, mark objects, or collect specimens, tree cores, sand samples, etc. While such a capability is ideal in surveys with a limited number of potential sites, for larger area surveys the cost (1981 costs are \$350-\$550/hour, including pilot) may be a significant factor. In addition it should be kept in mind that:

1. Each landing significantly reduces the already limited range of the helicopter.
2. While ideal for hard to access sites, it is anticipated that most of the economically viable wind power sites will have ground access.
3. Due to vibration, helicopters are poor "fixed camera" platforms for acquiring stereo photography from which measurements may be made.

The helicopter is also suited to surveys where studies include spatial comparisons of wind using short-term ground-level anemometer measurements. Further discussion of the use of helicopters in wind power prospecting is contained in Wade et al. (1981).

5.2 LOW-LEVEL AERIAL PHOTOGRAPHY

Low-level (large scale) aerial photos are the primary means of documentation and subsequent measurement and calibration of a wide range of wind power indicators. Depending on the specific indicators used, vertical or oblique photography may be employed in assessing the wind speed and direction (see Figure 5.1 and Table 5.1).

FIGURE 5.1. Camera Positions for Aerial Photography. Vertical, 90° below the horizon, perpendicular to the ground; low oblique, $<90^\circ$ depression angle, no horizon showing; high oblique, shows the horizon.

TABLE 5.1. High or Low Oblique and Vertical Photography and Their Application as Sensors of Wind Indicators

Indicator	Vertical	Low	High
Trees	Griggs-Putnam Index*	Shadow trace*	Tree Deformation Indices
Shrubs	Shrub density	Not useful	Degree of prostrate growth and surface roughness
Dunes	Slipface angle Measurement	Type of dune	Type of dune and surface roughness
Water surface	Percent of foam coverage	Wider area	
Topographic features	Stereo analysis of terrain roughness	Slope evaluation and exposure	Slope evaluation and surface roughness

* These applications have not been tested.

5.2.1 Stereo Photography

In air reconnaissance, the location of eolian features, on the spot assessments and handheld photographic records generally suffice for area studies. However, if deemed valuable, and if facilities are available, stereo photography, or the simultaneous viewing of two overlapping photos

to produce a three-dimensional image, can add considerably to the wind power prospector's ability to measure and calibrate wind indicators. Stereo aerial photos may be obtained in two ways: (a) by aiming a hand-held camera at the same object from two separate locations, or (b) by viewing the overlap area from a sequence of photos from a fixed camera moving through space (see Figure 5.2). A more detailed discussion of stereo photography is included in Appendix F.

FIGURE 5.2: Two Methods of Obtaining Stereo Photos

5.2.2 Equipment Requirements

In an effort to minimize equipment costs, two basic formats are recommended: 1) a 35 mm motorwind camera, or 2) a 70 mm motorwind camera. The initial cost advantage of the 35 mm system can be offset by the larger area coverage and higher resolution quality of 70 mm systems.

In an effort to eliminate several of the operational headaches of the conventional 35 mm camera, the following system configuration shown in Figure 5.3 is considered optimal (cost \$450-\$950):

- 1) A good quality 35 mm single lense reflex camera with automatic exposure and an electronic shutter release;
- 2) A motor wind film advance;
- 3) An intervalometer capable of settings from 1/2 second to longer than 20 seconds;

- 4) A 250-exposure bulk film back, or a data back for date or flight recording; and
- 5) A cable or remote shutter release for additional frames if needed.

FIGURE 5.3. 35 mm Camera for Aerial Photography

- a) Variable focal length lens
- b) Motor wind film advance
- c) Intervalometer
- d) Databack for date or flight-line imprint
- e) Remote control button

Similar systems characteristics may be obtained in 70 mm film formats by employing a motorwind. Hasselblad[®], Pentax[®], or Bronica[®] cameras with an intervalometer cost between \$2700 to \$7000.

[®] Hasselblad, 10 Madison Road, Fairfield, NJ 07006.

[®] Pentax, 8363 Reseda Blvd., Northridge, CA 91324.

[®] Bronica, Hindaphoto Ink, 446 Sunrise Hwy., Rockville Centre, NY 11570.

5.2.3 Mounting Camera Systems in Aircraft

Both internal and external mounts on the aircraft may be constructed for small format camera systems. In light high-wing monoplanes, such as the Cessna 100 series, both door-type and strut-type external mounts have been successfully employed (see Figure 5.4).

Door-type external mount

Strut-type mount

FIGURE 5.4. Camera Mount Systems

These mounts may be easily transferred between different aircraft and may be used on rental aircraft without any aircraft modification. However, several serious drawbacks exist: 1) Depending on the type of aircraft, external mounts can produce serious disruptions of the airflow, resulting in asymmetric drag or disruption of aerodynamic lift. Inspection of design and construction by a representative from the Federal Aviation Administration General Aviation District Office should be made. This may result in the operation of the aircraft under the "limited" or "restricted" category. Careful flight testing in both slow flight and cruise configurations should be made prior to any low altitude use; 2) A common problem of such external mounts is wind-induced vibration which results in "blurred" photographs; 3) Additionally, changing lenses or film, or making minor camera adjustments in flight is often impossible with such designs.

Internal camera mounts can often be installed with only minor modification to the aircraft. Such mounts limit the camera use to a single airframe, but offer accessibility and operational capabilities otherwise not obtainable, without the aerodynamic limitations of external designs. Simple camera posts are readily constructed in Cessna 150, 172 and 182 aircraft by removing the existing inspection plate on the floor in front of the copilot's seat and installing a 4" circular hole in the outer skin, allowing a vertical camera port (see Figures 5.5 and 5.6).

FIGURE 5.5. Photo of a Vertical Camera Port Using Existing Inspection Plate Location and Installing an Inspection Hole in a Cessna 172

FIGURE 5.6. The Location of Inspection Plate in the Cessna 172 Cockpit

The installation of the camera port should be done by a certified airframe mechanic under FAA part 337, and noted in the maintenance log. This non-structural modification to the airframe requires only a backing ring surrounding the outer hole in the skin so that an inspection cover may be installed when not used for photography.

Whenever a camera port or open window is used for aerial photography, a chemical-type carbon monoxide (CO) detector should be carried in the cockpit. Such devices cost less than \$3 and can provide critical warning of CO buildup.

5.3 TAKING THE PHOTOGRAPHS

In order to take successful aerial photographs there are a number of important considerations including film type, exposure, use of filters, shutter speed, and light conditions. Tips on taking aerial photographs will be discussed below.

5.3.1 Type of Film

The type of film will vary according to the purpose of the project. Fast film with high ASAs will eliminate motion "blurring" at low levels for large-scale photos, whereas the slower films offer higher resolution for higher altitude work. The size and shape of anticipated wind indicators will determine your expected flight altitude and hence desired photo scale. Black and white panchromatic film has long been the standard film for aerial photography, however, many remote-sensing applications now employ the use of color film, black and white infrared film, and color infrared film. The major advantage to the use of color film is that the human eye can discriminate many more shades of color than tones of grey. The major advantage of infrared film is that the spectral sensitivity is much broader, where black and white panchromatic film is sensitive to ultraviolet and visible light, infrared film is sensitive to not only the UV and visible wavelengths, but also to reflected infrared energy. Infrared film is especially useful for such tasks as distinguishing between deciduous and coniferous trees or to

detect temperature differences in soil, water, or vegetation. There is no one film type or film speed that is ideal for all remote-sensing problems. Table 5.2 presents some of the advantages and disadvantages of various film types. For infrared sensitive films, the effective aerial film speed should be determined empirically, usually by comparison with non-infrared film in actual flight tests.

Ektachrome® color transparency (5017) film (ASA 64, 200, or 400) is the most convenient film with minimum inconsistencies. There is a range of speeds, it has moderately good contrast, and a moderate amount of graininess as compared to Kodachrome® films. The color balance tends to be bluish in aerial work, but this can be remedied by the use of a skylight (UV) filter. The E-6 processing is locally available and the film may be purchased in bulk for 35 mm cameras employing 250-exposure cassette backs.

Ektachrome® color infrared film (2443) is a "near infrared" or "false color" film originally devised for camouflage detection during WW II. This film has the advantage of superior haze penetration and sharp delineation of healthy vegetation for "flagged" tree studies. It, too, is available in bulk, however, it uses the now-obsolete E-4 processing method and must be sent back to Kodak's central processing facility at Rochester, N.Y., unless the users can process their own using an E-4 kit. Another drawback is that exposure determination is much more difficult than for conventional films, and it must be used with either a Wratten 12 or 15 filter. There is no fixed ASA speed for Ektachrome® IR film, however, we have found ASA settings of 130 to 150 to work well for aerial photos.

Black and white films are considerably less expensive than their color counterparts, although processing costs are nearly comparable. A common aerial panchromatic negative film is Kodak Plus-X (2402)®. Plus-X® has a stable ester base, moderate contrast, moderate grain, and is relatively fast. Yellow or red filters may be used to alter the contrast balance, and considerable latitude in exposure settings is achieved. This is also available in bulk for both 35 mm and 70 mm formats.

In 35 mm only, two other films have been successfully employed: Ilford® FP-4, a high-contrast photomicrography film, and Ilford HP-5 with an ultra-

(a) E-4 processing can be done at Kodak, 925 Page Mill Road, Palo Alto, CA 94304.

TABLE 5.2. A List of Film Types and Their Advantages

<u>FILM TYPE</u>	<u>ASA</u>	<u>ADVANTAGES AND DISADVANTAGES</u>
Black and White	25	Extremely fine-grained film for photos requiring sharp contrast and enlargeability; good for panoramic views when light conditions are excellent.
	125	This film has more latitude for light conditions, but retains much of the sharpness and fine grain characteristics of the slower 25 ASA film.
	400	Good for low light conditions, with telephoto lenses, or low-level aerial photography that requires high shutter speeds. However, this film tends to be grainy and has poor enlargeability.
Color	25	A high-sharpness film useful when enlarging photos (because of the fine grain). Of limited use in aerial photography because of the narrow latitude in light conditions and camera motion, especially with telephoto lenses.
	64	This film can be used under many light conditions and has sharp contrast and adequate grain characteristics for photos that may require enlargement. This film may be too slow for using telephoto lenses in an aircraft.
	200	This fast, outdoors film is more grainy than the slower ASA color films, but is more versatile where light conditions vary, or can be push-processed at 400 ASA when high shutter speeds are required.
	400	This film does not have the sharpness and fine-grain character needed for magnification work, but is useful when lighting conditions are difficult or when a telephoto lens is being used in low-level flight. Better depth of field can be achieved, but at the expense of sharpness of images taken with slower film.
Black and White IR	Variable	Is an inexpensive IR film that can be processed locally and requires no special handling. Is fine-grained, but lacks sharpness due to scattering of IR energy in the atmosphere.
Color IR	Variable	Has the same disadvantages as black and white IR, plus it is expensive takes as much as two weeks to process and processing is twice as expensive as black and white IR. The main advantage is that it can provide much more information that can be distinguished with the human eye than conventional black and white (or color) film.

thin base. Both films produced satisfactory results. HP-5 has the advantage of packing 72 exposures into a standard 35-mm cassette. This is especially useful for long lines of vertical photos when only a standard camera back is employed, but be sure to purchase the special processing reel required by this film. These specialty films require custom processing.

For further information refer to Kodak Data for Aerial Photography (publication M-29), Kodak Infrared Films (publication N-17), and Applied Infrared Photography (publication M-28).

5.3.2 Exposure

Determining the proper exposure for aerial photography can be more complicated than determining exposure for ground photography. Make exposure readings with your light meter before leaving the ground, to determine what the proper exposure for ground photography would be. (Be sure to allow for filter-factor correction.) In most cases, for low-level flights you should use about the same exposure in the air as you would use on the ground. When you are airborne, take a meter reading from about the same altitude at which you will be working. If you are at a fairly low altitude with little or no visible haze, the exposure reading should be very close to the ground exposure, and you should set the camera about halfway between the two readings. However, if you have noticeable haze, or if you are working from a higher altitude, your airborne meter reading is likely to be significantly higher than the ground reading. If this is the case, set your camera nearer to the ground reading, because your meter is probably biased by light reflected by haze and may not give a true reading of your desired subject. In any event, bracket your exposures by at least 1 stop when possible. It is a lot more economical to cover yourself adequately by taking a wide range of exposures than to re-fly a mission. Keep in mind that although high altitudes, high obliques, and high levels of haze reduce subject contrast and increase exposure latitude, these factors often contribute to a tendency to overexposure as well.

5.3.3 Filter Factor

Since the filter factor can vary from one type of film to another, be sure to check the instruction sheet packaged with the film. With most black and white films, a Kodak Wratten Filter No. 15 has a factor of about 2.5, or requires an exposure increase of about 3 stops. When a Kodak Skylight Filter No. 1A or a Kodak Wratten Filter No. 2B is used with color films, no exposure adjustment is required.

5.3.4 Shutter Speed and Lens Aperture

Since depth of focus and depth of field are insignificant factors in aerial photography, you can concentrate on the significant problem of stopping motion. Set the focus at infinity. Set the aperture at wide open. There is no need to stop down to obtain depth of field, since the entire scene is effectively at infinity. You may prefer to stop down one or two stops if your lens performs best when stopped down slightly. Then make necessary exposure adjustments by varying the shutter speed. With your lens wide open, you will be able to use the fastest shutter speed that conditions allow.

5.3.5 Making the Exposure

As you approach your subject, check to see that you attain a viewpoint that places the shadows in position for the best modeling, and that your altitude and position are correct for the best view. Using the prearranged hand signals, direct the pilot to place the aircraft in the best position. Best results are usually achieved when the pilot reduces throttle, banks the aircraft slightly, and slips it toward the subject. This keeps down engine vibrations and minimizes image movement by reducing forward motion. When subject movement is toward or away from the camera, the effect of movement is less than when the movement is at 90 degrees to the camera. The side-slip technique (toward the subject) as compared to flying past the subject (at 90 degrees) would be similar to photographing an approaching race car as compared to photographing a race car as it passes you. Most pilots who

have flown many photo assignments are aware of the advantages of the side-slip technique, but probably you will want to discuss it with your pilot in advance. Additional tips on correcting for side-slip are included in Appendix F.

If you are working from a particularly low altitude, this technique cannot be used safely since the aircraft needs room to recover. From very low altitudes, it is usually best to reduce throttle and apply several degrees of flap to reduce the airspeed even more. How much, if any, will depend on several factors. Under gusty conditions, the flaps may cause too much buffeting, which could contribute more to blurring than would using increased speed without flaps. Also, you can minimize motion by panning the camera with the subject. Be careful to avoid getting wings or struts in your photos. When you are concentrating on your subject, it is easy to look past such obstructions and not even see them.

Keep the camera from touching any part of the aircraft. If the camera is in contact with the craft, it will pick up engine vibrations, and even with a fast shutter speed you will get blurred pictures. Also, keep your body, from the waist up, from contact with the aircraft so that you will act as a shock absorber for vibrations.

Always use a lens shade to eliminate contrast reduction caused by lens flare. Use a screw-on type or tape the lens shade in place so that the wind cannot pull it off.

5.3.6 Low Light Levels

Good work can be done at dusk when surrounding light and artificial light are combined. Unfortunately, even with fast films, such exposures are always fairly long. When shooting film at dusk, or anytime when the light level is low, you will need to do everything possible to minimize problems that cause image motion. When attempting such assignments, select a camera and normal focal-length lens that will give you a large aperture ($f/2.8$ or larger) - even if it means using a smaller format than you prefer. Use a high-speed film, and be sure to have your pilot glide or slip you

toward the subject with minimum safe speed and minimum buffeting and vibration. Also, to gain additional steadiness, a gyro-stabilizer can be attached to the base of the camera. Hold your breath and carefully squeeze off several exposures.

5.3.7 Processing

Generally, low-level aerial film should receive normal processing as recommended in the film instruction sheet and in the developer or processing-kit instruction sheet. However, when your black and white film is exposed at high altitude (above 5,000 feet) or is exposed under hazy conditions, you can often obtain some contrast enhancement by extending the normal development time by about 25 to 35 percent.

5.4 SPECIAL CONSIDERATIONS FOR FLIGHT OPERATIONS

Wind evidence is commonly located in some of the most hostile flying terrain; the existence of the wind indicators is warning enough for extreme caution. It is recognized that any flight operation presents a certain element of risk to those persons involved on a given day. This risk can be minimized. Since favorable sites for locating wind evidence includes exposed ridges, desert sand areas, or wind swept snow fields, this section concentrates on flight planning and operations which may effect mission success and safety in these specific environments.

5.4.1 Mountain Flight Operations

Wind prospecting in mountainous terrain commonly concentrate on isolated flagged trees or snowswept features located predominately along ridges aligned normally (perpendicularly) to general windflow patterns. Low-level vertical and oblique photography can be successfully accomplished in these areas if care is taken in planning the flight altitudes using VFR Sectional Charts (1:500,000) in conjunction with topographic maps of the intended operational area. Terrain familiarization is essential as most photographic missions follow ridgelines and tend to "zig-zag" along a range. Frequent

check points for navigational reference, and the pilot's knowledge of terrain elevations is essential to flight safety. Following these routes does, however, preclude the use of airway radials or straight-line routes. It need not preclude the use of cross-radial or bearing fixes where facilities are available. The pilot should be aware that VHF reception is subject to line of sight and may be erratic in nature. He should therefore utilize his radio cautiously and be thoroughly competent in the use of Sectional or State Aeronautical Charts for navigation. Under no circumstances should he ever attempt cross-country flights by use of Low Altitude Enroute Charts alone, since they are intended primarily for radio navigation. He should not attempt prolonged operation above 10,000 feet in the daytime without supplemental oxygen in order to avoid the dangers of altitude hypoxia. The pilot should study all available navigation charts thoroughly when planning the flight and choose the charts which provide the most detailed data or best route information for actual use.

Most pilots are generally aware of the primary effect of air mass circulation on navigation. There are, however, certain characteristics of wind flow over mountainous terrain which deserve serious study by the pilot planning flight in such areas. This wind flow may be compared to the flow of water over a boulderstrewn river bed (see Figure 5.7).

In the mountains, terrain interference with the steady flow of wind causes lift and sink to follow logical patterns over such terrain. The shape of the terrain in its relation to the wind, the heating of slopes exposed to the sun, and the steeply sloping ridges with jagged cuts where the wind currents are accelerated by a venturi effect are all easily predictable. The moving air mass surges up and over - then being equally influenced by the opposite in terrain features on the lee side, descends with a velocity exceeding a thousand feet per minute. Terrain influence may cause the air again to rise and descend, taking on the aspect of a wave action, for as much as one hundred miles on the lee side of a mountain range. Any abrupt change in angle between the terrain and wind flow can be expected to cause moderate to severe turbulence depending upon the instability of the existing air mass. Frontal passages can generally be expected to produce moderate to

FIGURE 5.7. A Depiction of Wind Flow Under the Influence of a Relatively Stable Air Mass System

severe turbulence and wind shears that may be of such intensity that the structural integrity of the aircraft is jeopardized. The strongest periods of wind flow are often seasonal in nature. In the summer months, the strongest wind flow will be found at higher altitudes with the near the surface region often yielding thermal turbulence which can be extreme in desert areas.

Some generally acceptable rules-of-thumb for mountaineous low-level flying are:

1. Ridge-level winds in excess of 20 knots indicate that the pilot should proceed with caution. When 30 knots or more - avoid photo mission within 2000' of the terrain.
2. A mountain ridgeline should be crossed at an angle to allow the pilot to turn away from the ridge with the least amount of turn required should down drafts be encountered. When oblique photos are being taken, turbulence is less on the upwind side of the ridge. For verticals, a "dry run" should be made to establish the correct wind correction angle required to keep the aircraft correctly centered over the ridgeline.
3. Winds aloft in the mountains of the western states are predominantly westerly; however, surface winds tend to flow upward from the valley from around noon on till late evening, due to the unequal heating of the sunny slopes and shaded valleys (see Figure 5.7).
4. In late evening, a reversal of this flow pattern may exist due to the rapid cooling of the air near the ridgeline or higher peaks.
5. Generally speaking, early morning and late evening flights can be made closer to ridgeline level than during the heat of the day.

Some authorities recommend crossing mountain peaks or ridges with a terrain clearance of 50% of the land elevation. This technique, while providing safe terrain clearance, is generally unsuitable for wind prospecting or low-level photography purposes. It would seem much more sensible to conduct the flight during conditions favoring a lower altitude and to fly the valleys where possible, allowing a still-lower enroute altitude over much of

the route and requiring higher altitude only to clear the intervening ridges. Should turbulence be encountered near the ridgeline altitude, photo runs can be made from higher calm altitudes using longer focal length lenses.

It should be understood also that the inherent risk of flying over rugged terrain is somewhat increased by the lack of acceptable landing areas in event of any emergency. On the other hand, the proficient pilot will be constantly prepared to turn downslope or toward less forbidding terrain while enroute. If an emergency occurs which requires an immediate landing, he has little choice but to maintain a precise control of the aircraft as long as it will fly.

Last, but not least, file a flight plan or give regular position reports to a Flight Service Station. The benefits of such action will far outweigh any inconvenience.

Additional tips on mountain, desert and winter flying are provided in Appendix G.

5.5 DOCUMENTATION OF INFORMATION

It is extremely important to document the information obtained in the low-level survey as efficiently as possible. When so much is being observed over a period of 3-5 hours, it is easy to forget important observations. A form provided in Figure 5.8 provides a blueprint for a wind prospecting flight log. However, a detailed log is not absolutely essential; good notes written on a map may be just as useful as long as photographs are correctly keyed to each location.

Once the aerial survey is complete, then further ground level documentation of wind indicators is necessary. Wade and Hewson (1980) provide a checklist for prospecting using biological wind indicators; Appendix A provides a description of a technique for mapping the local wind field by digitizing the degree of deformation of wind-deformed trees.

The Beaufort scale (see Table 5.4) is also useful for quantifying transient evidence of surface winds noted both in the air and on the ground. A special scale for estimating surface winds over the water is presented in Table D.1 of Appendix D.

TABLE 5.4. The Beaufort Scale of Wind Force with Specifications and Speed Equivalents

Beaufort number	General description	Specifications	Limits of velocity 20 ft above level ground			
			<i>m/sec</i>	<i>km/hr</i>	<i>mph</i>	<i>Knots</i>
0	Calm	Smoke rises vertically	Under 0.6	Under 1	Under 1	Under 1
1	Light air	Wind direction shown by smoke drift but not by vanes	0.6-1.7	1-6	1-3	1-3
2	Slight breeze	Wind felt on face; leaves rustle; ordinary vane moved by wind	1.8-3.3	7-12	4-7	4-6
3	Gentle breeze	Leaves and twigs in constant motion; wind extends light flag	3.4-5.2	13-18	8-11	7-10
4	Moderate breeze	Dust, loose paper, and small branches are moved	5.3-7.4	19-26	12-16	10-14
5	Fresh breeze	Small trees in leaf begin to sway	7.5-9.8	27-35	17-22	15-19
6	Strong breeze	Large branches in motion; whistling in telegraph wires	9.9-12.4	36-44	23-27	19-24
7	Moderate gale	Whole trees in motion	12.5-15.2	45-55	28-34	24-30
8	Fresh gale	Twigs broken off trees; progress generally impeded	15.3-18.2	56-66	35-41	30-35
9	Strong gale	Slight structural damage occurs; chimney pots removed	18.3-21.5	67-77	42-48	36-42
10	Whole gale	Trees uprooted; considerable structural damage	21.6-25.4	78-90	49-56	42-49
11	Storm	Very rarely experienced; widespread damage	25.5-29.0	91-104	57-67	49-56
12	Hurricane		Above 29.0	Above 104	Above 67	Above 56

FIGURE 5.8. Wind Prospecting Data Form

[illegible]

There are a number of important parameters required to quantify information obtained from geomorphological wind indicators, such as sand dunes. To aid in assembling the needed information, a prospecting data log is presented in Figure 5.9.

FIGURE 5.9. A Prospecting Data Log for Geomorphological Indicators

	<u>Geomorphological Wind Indicators</u>
Dune Field	_____
Elevation	_____
LANDSAT Image #	_____
U-2 and Low Altitude	
Image #	_____
Date	_____
Relative Activity	_____
Season of Most Activity	_____
Percent of Vegetation Cover	_____
Implied Wind Direction	_____
Sand Source Region	_____
Rate of Dune Movement	_____
Dune Height	_____
Location of Sand Sample	_____
Mean Sand Grain Size	_____
Modal Sand Grain Size	_____
Maximum Sand Grain Size	_____
Minimum Sand Grain Size	_____
Sand Density	_____
Distance Between Sand Ripples	_____

6.0 CENTRAL WASHINGTON: A CASE STUDY^(a)

This section is a case study example of how previously described techniques for using remote-sensing information were applied in an area in Central Washington to identify locations with strong wind. In this case study, anemometers were set up at specific locations to verify estimates of wind power class based on topographic, geomorphological, or biological wind indicators.

In this section the objectives, procedures and results of this case study are described. In addition, estimates of wind power class and verification of these estimates are discussed.

6.1 OBJECTIVES

The three objectives to this case study were to:

1. Estimate the strength of the wind in the Central Washington area from information obtained from analysis of remotely sensed imagery;
2. Verify these estimates of wind strength using both existing wind data and by setting up new anemometers at specific locations where topographical, geomorphological, or biological wind indicators were available; and
3. Test various techniques for processing imagery.

Thus, the goals of this case study were both practical and heuristic. Since little was known about the wind power potential in this area, the information obtained from this study will contribute to those studies previously conducted by Baker et al. (1978), Hewson et al. (1978), and Elliott and Barchet (1980). The close proximity of the Central Washington area to Oregon State University allowed the research team to not only perform a verification of the techniques, but also conduct exploratory research

(a) This case study was conducted from October 9, 1980 to August 9, 1981.

to test other ideas and alternative approaches to collecting remotely sensed information.

6.2 PROCEDURES

The first task was to obtain LANDSAT imagery for the area being studied. This imagery was obtained from the EROS Data Center, whose address is:

U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198
Phone (605) 594-6511

After receiving the imagery, an analysis was performed to pinpoint possible indicators of wind power potential. Features of particular interest were well-exposed ridges, vegetation gradients, and sand dunes. The next step was to pinpoint the interesting features on a 1:500,000 aeronautical map. Available wind data in the region of interest was obtained to determine mean wind speed and direction at a number of locations to obtain some idea of the local wind patterns. Figure 6.1 shows the area of interest and wind data locations within that area.

The third task was to perform a low-level aerial survey to provide a closer examination of areas of suspected strong winds. Two low-level surveys were conducted in this area by this research team in October 1980 using a light aircraft. A follow-up survey was conducted in August of 1981.

After completing the analysis of information obtained from the low-level surveys, estimates were made of the wind power potential. However, in much of the area examined in this study, there are few wind data locations which could verify these results. The final task was to set up anemometers to verify the strength of the wind in those locations selected as having good wind power potential.

6.3 RESULTS

With a general knowledge of prevailing wind flow pattern obtained from Figure 6.1, it was observed that the prevailing wind direction is southwest through northwest in this part of Washington. Well-exposed ridges, perpendicular to these prevailing directions, are obviously the first thing that

FIGURE 6.1. Wind Data Available in Central Washington. (The arrow indicates direction and speed is given at the end of arrow. Locations with numbers in circles are new anemometer locations.)

one would look for in the LANDSAT imagery (i.e., Wenatchee Mts., WM in Figure 6.2). Figure 6.3 shows specially processed imagery that can be used to look for topographically-enhanced winds. Features in the LANDSAT imagery that align themselves with the prevailing wind flow patterns are of particular interest. Such features include the vegetation gradients (VG) or the sand dunes (SD) in Figure 6.2.

While the LANDSAT imagery provides information over a large area, the lack of resolution does not permit detailed analysis. The use of density slicing of shade variations can enhance certain features and aid in identification of similar smaller features. Figures 6.4 and 6.5 are enlargements of portions of Figure 6.2 and enhanced to show areas of highly reflective sand soils. The dune field east of Wanapum Reservoir (A in Figure 6.4) shows up clearly as a finger pointing east-southeast. Similar

FIGURE 6.2. LANDSAT Imagery of the Central Washington Survey Area. (The Wenatchee Mts. (WM) lie athwart the prevailing west-northwest winds. A strong vegetation gradient (VG) is noted along the north end of the Kittitas Valley, and sand dunes (SD) in the south.)

FIGURE 6.3. Terrain Representation from Digital Terrain Data in Central Washington. (Snoqualime Pass (SP) and the Columbia Gorge (CG) are evident wind gaps.)

FIGURE 6.4. Image Enhancement of LANDSAT. Note dune field east of Wanapum Dam (A). Similar reflective features are found in the Saddle Mts. (B) and Frenchman Hills (C).

FIGURE 6.5. Shows an Enhanced LANDSAT Image in Central Washington. Dark areas indicate reflective soils or possible sand dunes at Waterville Plateau (A), Beezley Hills (B), and east of the Quincy Basin (C).

features are found on the south slope on the Saddle Mountains and the west end of the Frenchman Hills (B and C of Figure 6.4). The Waterville Plateau, Beezley Hills and east of the Quincy Basin (A, B, and C in Figure 6.5) all show the same reflective pattern where the darker the color, the more reflective the surface. Highly reflective surfaces also might indicate either a tilled field or wind-deposited soils. Dunes or eolian soils may be stabilized for a variety of reasons and are not necessarily because of decreased wind strength. Low-level imagery or ground-level reconnaissance can verify the nature of the surface and distinguish active dunes whether the winds are active from those that are stabilized and the winds may or may not be strong.

Figure 6.6 shows a U-2 photo of the same finger-shaped dune east of Wanapum Reservoir taken in 1980. The position of this dune field can

FIGURE 6.6. A U-2 Photo Showing the Finger-shaped Dune East of Wanapum Reservoir on the Columbia River. (The photo was taken in July of 1980.)

be plotted along with earlier positions in 1969 (Figure 6.7), and 1973 (Figure 6.8), and in 1964 from the USGS map (Figure 6.9). The sequence of positions are all plotted in Figure 6.9. Dune movement was 44.3 m/yr. from November 2, 1964 to July 24, 1969; 95.5 m/yr. from July 24, 1969 to October 3, 1973; and 72.6 m/yr. from October 3, 1973 to July 1, 1980. Interestingly, the years 1964-1969 had below-average wind power densities at Stampede Pass and Spokane. These two stations are the only long-term data stations in this survey area. (See Elliott and Barchet, 1980.) This information on sand dune movement, in conjunction with data taken on the ground, will be used to estimate the mean wind speed of power-producing winds later in this section.

The giant eruption of Mount St. Helens on May 18, 1980, presented us with a unique opportunity to observe the redistribution of surface material by the wind. A U-2 aircraft was commissioned by the U.S. Depart-

FIGURE 6.7. Imagery of the Vantage Dune Field (Scale 1:40,000) in July of 1969

FIGURE 6.8. Imagery of the Vantage Dune Field (Scale 1:40,000) in October of 1973

FIGURE 6.9. The Position of the Finger-shaped Dune Field on: November 2, 1964 (1); July 24, 1969 (2); October 3, 1973 (3); and July 1, 1980 (4)

Department of Agriculture to take aerial photos in July of 1980 (see Figure 6.6). Figure 6.10 shows an image enhancement of Figure 6.6 in which the ash-affected areas are shown as pale blue, while areas where the ash had been redistributed are darker blue. Water is dark blue and vegetation is red. The active dune east of Wanapum Reservoir shows that the ash has been blown off the surface. Density slicing of these shade variations in Figure 6.10 enhances those areas with little or no ash (yellow areas). The slopes of east-west ridges in the Saddle Mountains, west of the Columbia River (A), are particularly noteworthy. Interstate 90 (B), the Vantage Bridge (C), and Wanapum Dam (D) also are free of heavy ash.

FIGURE 6.10. An Image Enhancement of a U-2 Photo of Ash-covered Central Washington. Yellow areas are those where ash has been removed by wind or anthropogenic processes. Landmarks include Columbia River (A), Interstate 90 (B), the Vantage Bridge (C), and Wanapum Dam (D).

6.3.1 Low Level Aerial Surveys

On October 14-17, 1980 a low-level field survey was conducted in Central Washington. During two days a four-passenger Cessna 182 was used for low-level aerial reconnaissance. In the remaining two days anemometers were set up at three locations in the survey area. During the first day of the aerial survey, the flight path (shown in Figure 6.11) started in Ephrata, proceeded northwest to Wenatchee, then south along the Wenatchee Mountains. It continued west to Cle Elum, and from Cle Elum, southeast to Thorpe then east to Ephrata. Strongly flagged trees were noted on Mission Ridge in the Wenatchee Mountains (see Figures 6.12 and 6.13) and on Lookout Mountain, southeast of Cle Elum. Good flagging was noted near Thorpe and some flagging was noted on the south end of the Wenatchee Mountains.

FIGURE 6.11. The Flight Path of the Central Washington Aerial Survey

FIGURE 6.12. Flagged Trees on Lookout Mountain

FIGURE 6.13. Flagged Trees on Mission Ridge

The next day the survey concentrated on the basin and range area, east of the Columbia River, in Central Washington. The flight path for this survey went south from Ephrata, across the Quincy Basin, over the Frenchman Hills, south along the Columbia River, and east along the Saddle Mountain Range to Paradise Flat. Then the survey team headed north to Lake Chelan, up the Chelan Valley and then back to Ephrata. Active dunes indicating prevailing west-northwest winds were found east of Wanapum Dam and west of the Potholes Reservoir (see Figures 6.14-6.17). Slightly flagged trees were noted on Chelan Mountain, but no flagging was found along the ridges above Lake Chelan. The natural vegetation over much of the Columbia Plateau is sagebrush. Flagging of sagebrush could not be distinguished from the air.

From the results of the aerial survey and analysis of the other remotely sensed imagery it was determined that five locations should be instrumented with anemometers. One location was Wahatis Peak (see site 1 in Figure 6.1) in the Saddle Mountains. The Beezley Hills were a second site

FIGURE 6.14. A Crescent-shaped Barchan Dune East of Wanapum Dam

FIGURE 6.15. The Steep Face of the Barchan Dunes is the Lee Side. (The direction of movement is west-northwest, or right to left.)

FIGURE 6.16. Wind Ripples on Dunes Shown in Figures 6.14 and 6.15

FIGURE 6.17. The Finger-shaped Dune Field East of Wanapum Dam

instrumented (see site 2 in Figure 6.1 and Figure 6.18). Also instrumented on the east side of the Columbia was the Vantage Substation (see site 3 in Figure 6.1 and Figure 6.19). On the west side of the Columbia, an anemometer was put up at Thorpe (see site 4 in Figure 6.1 and Figure 6.20) and at a former FAA radio beacon on Lookout Mountain (see site 5 in Figure 6.1 and Figure 6.21). Two anemometers were put up by Clean Energy Products of Seattle (sites 6 and 7 in Figure 6.1), which provided additional data for this study.

Sand samples were taken from the windward slope of the finger-shaped dune field east of Wanapum Reservoir and north of the anemometer at the Vantage Substation. The important parameters for the dune are given in Table 6.1, along with the way they were determined. A good description of sand sampling techniques can be found in Carver (1971).

The following calculations show how these sand dune parameters were related to mean wind speed using formulas and discussion found in Hiester and Pennell (1980).

FIGURE 6.18. Wind-deformed Sagebrush in the Beezley Hills

FIGURE 6.19. The Location of the Anemometer at the Vantage Substation

FIGURE 6.20. The Location of the Anemometer at Thorpe

FIGURE 6.21. The Location of the Anemometer on Lookout Mountain

TABLE 6.1. Sand Dune Parameters Used in Making Mean Wind Speed Estimates

Parameter	Value	Source of Estimate
Dune Movement Rate		
11/2/64-8/24/69	44 m/yr	U-2 imagery and
8/24/69-10/3/73	96 m/yr	USGS map
10/3/73-8/1/80	73 m/yr	
Dune Height	5m	Estimated from ground level observation
Sand Density	2.5g/cm ³	Laboratory measurement
Mean Grain Size	.17mm	Sieve analysis
Modal Grain Size	.18mm	and setting velocity in a water column
Maximum Grain Size	.35mm	

When the wind speed equals the impact threshold velocity, the following equation is a valid description of the wind profile

$$u(z) = \frac{u_*}{k} \ln \left(\frac{z}{z_0} \right) \quad (1)$$

where

$u(z)$ = the wind speed at height z

u_* = friction velocity

$k = 0.35$, Von Karman constant

z = height above ground

z_0 = surface roughness.

The roughness length can be determined by taking $d_{\max}$, the diameter of the largest sand grains (0.35mm), and dividing by the proportionality constant, given in Hiester and Pennel (1980), of 30, so

$$z_0 = d_{\max}/30. \quad (2)$$

The value of u_{*T} , threshold friction velocity, depends on the density of sand grains and is given by:

$$u_{*T} = A \sqrt{\frac{\sigma - \rho}{\rho} g d} \quad (3)$$

where A is a proportionality constant that equals 0.08, σ is the density of the sand, g is the acceleration of gravity, and ρ is the density of air, and d in this formula is the modal grain size.

Using the values below:

$$A = 0.08$$

$$\sigma = 2.25 \text{g/cm}^3$$

$$\rho = 1.2 \times 10^{-3} \text{g/cm}^3$$

$$g = 980 \text{cm/sec}^2$$

$$d = 0.018 \text{cm}$$

$$u_{*T} = 15.3 \text{cm/sec.}$$

Given a $z_0 = 1.17 \times 10^{-2} \text{cm}$, we can calculate a wind speed at $10m(u_{10})$ using equation 1 and the following values:

$$u_{*T} = 15.3 \text{cm/sec and is assumed to be approximately equal to } u_*$$

$$k = 0.35$$

$$z = 1000 \text{cm}$$

$$z_0 = 1.17 \times 10^{-2} \text{cm}$$

$$u_{10} = 496 \text{cm/sec} \approx 5 \text{m/sec where } u_{10} \text{ is equivalent to most frequent sand transporting wind.}$$

The magnitude of the average sand transport rate over a number of years can also be used to predict the mean wind speed using the following equation:

$$\langle \vec{q} \rangle = \frac{x \sigma H}{t} \quad (4)$$

where

x = distance of dune migration
 σ = bulk sand density
 H = height of the dune
 t = time interval between observations

If the wind always blows from the same direction at the same speed, then equation 5 could be used to determine the mean wind speed (u_*), given the sand transport rate (q);

$$q = \alpha u_*^3 \quad (5)$$

where

u_* = friction velocity

$$\alpha = C \frac{\rho}{g} \sqrt{\frac{d}{D}} \quad (6)$$

where

1.5 for nearly uniform sand
 $C = 1.8$ for typical sand found in dunes
 2.8 for sand with large variations
 d = diameter of the modal grain sizes
 $D = 2.5 \times 10^{-4}$ m a standard or reference grain diameter
 ρ = air density
 g = gravity constant

However, the conditions that would satisfy equation 5 are rarely found in nature. Equation 5 can be used with a wind distribution to derive a relation between $\langle \vec{q} \rangle$ and the long term wind speed ($\bar{V}$). This is done by evaluating the integral

$$\langle \vec{q} \rangle = \int_{u_{*T}}^{\infty} \int_0^{2\pi} \int_0^1 \vec{q}(u_*, \theta, A) \rho(u_*, \theta, A) dA d\theta du_* \quad (7)$$

where

$\vec{q}(u_*, \theta, A)$ is the vector rate of sand transport as a function of wind speed (u_*), wind direction, (θ), and dune activity (A);

A is a function ranging from 0 to 1 indicating the degree of dune activity or seasonality coefficient;

$\rho(u_*, \theta, A)$ is the normalized joint probability density function.

If we estimate $\langle \vec{q} \rangle$ as

$$\langle \vec{q} \rangle = \int_{u_*}^{\infty} q(u_*) \rho(u_*) du_* \quad (8)$$

where the vector sand transport rate is replaced by the scalar rate (i.e. equation 5), then the value of $\langle \vec{q} \rangle$ obtained in 8 will be greater than or equal to that obtained using equation 7. Conversely, if one assumes the wind speed distribution is a Rayleigh, then $\langle \vec{q} \rangle$ would indicate a minimum mean wind speed. Hiester and Pennell solved this equation analytically and presented the results graphically using the following equation:

$$\langle \vec{q} \rangle = \alpha u_{*T} f(\beta) \quad (9)$$

where $\beta = u_*/u_{*T}$ and $f(\beta)$ is shown in Figure 6.22.

First we solve for $\langle \vec{q} \rangle$ using equation 4 and values from Table 6.1 on the most recent dune movement rate

$$\langle \vec{q} \rangle = \frac{x\sigma H}{T} = \frac{73m \times 2.5g/cm^3 \times 5m}{1 \text{ year}}$$

When all the units are reduced to the same dimensions (kg, m and secs) and $\langle \vec{q} \rangle = 29 \times 10^{-3} \text{ kgm}^{-1} \text{ sec}^{-1}$, the value of α can be obtained from equation 6

$$\alpha = C \frac{\rho}{g} \sqrt{\frac{d}{D}}$$

FIGURE 6.22. Analytic Solution to Transport Equation Plot. Assuming a Rayleigh distribution of wind speeds, Equation 9 shows that the average sand transport rate depends on $f(\beta)$, which is plotted here and described analytically in Hiester and Pennell (1980).

using the constant for typical sand in dunes, $C = 1.8$ and d for the Wanapum Dune Field is .18mm

$$\alpha = \frac{1.8 \times 1.2 \times 10^{-3} \text{ gcm}^{-3}}{980 \text{ cm/sec}^{-2}} \sqrt{\frac{.18 \text{ mm}}{.25 \text{ mm}}}$$

$$\alpha = .19 \text{ kg sec}^2 \text{ m}^{-4} \quad (\text{MKS units})$$

and using the u_{*T} of 0.153m/sec calculated from equation 3, we can solve for $f(\beta)$ in equation 9, where $\langle \vec{q} \rangle = \alpha u_{*T} f(\beta)$ and $f(\beta) =$

$$\frac{29 \times 10^{-3} \text{ kg m}^{-1} \text{ sec}^{-1}}{.19 \text{ kg sec}^2 \text{ m}^{-4} \times .153 \text{ msec}^{-1}}$$

therefore $f(\beta) = 1.00 \text{m}^2 \text{sec}^{-2}$

For a $f(\beta) = 1.00$, $\beta = \sim .86$ from Figure 6.22, and since

$$\beta = \bar{u}_*/u_{*T} \quad (10)$$

$$\bar{u}_* = .86(.153 \text{m/sec}) = .13 \text{m/sec.}$$

The velocity at 10m above the surface can be estimating using

$$\bar{V}_{10} = V_T + \frac{\bar{u}_*}{k'} \ln \frac{10}{k'} \quad (11)$$

where V_T is threshold velocity which is given by

$$V_T = \frac{A}{k'} \sqrt{\frac{\sigma - \rho}{\rho}} \text{gd} \ln \frac{30k'}{d} \quad (12)$$

where k' is the roughness of the sand bed (A , k , σ , ρ , g , and d were defined in equation 3). Given the previously defined values $V_T = 3.24 \text{m/sec}$, then solving equation 11 for $\bar{V}_{10}$ we have

$$V_{10} = 3.24 \text{m/sec} + \frac{\bar{u}_*}{.35} \ln \frac{10 \text{m}}{10^{-2} \text{m}}$$

$$V_{10} = 5.8 \text{m/sec.}$$

This estimate is nearly 1m/sec larger than that obtained using sand grain size. One would expect since sand dune movement is a measure of the strength of westerly winds only that the estimates using dune movement would be less than those using grain size as multidirectional winds could move sand back and forth over a larger distance than was indicated by the net migration. Although westerly winds (WSW-WNW) occur less than 50% of the time on an annual basis, during the strong wind season they occur about 70% of the time according to long-term data from nearby Wanapum Dam.

To test the sensitivity of these estimates, we will calculate the mean wind velocity for the period 1964-1969 where we change only the dune

field movement rate to 44m/yr, the value of q would then equal $17.4\text{kgm}^{-1}\text{sec}^{-1}$, and the mean velocity for that period would be 5.5m/sec, or 8% reduction in the estimated wind speed. This is not unusual and seems to confirm the evidence from long-term data at Spokane and Stampede Pass (see Elliott and Barchet, 1980), where mean wind speeds and power densities were lower during the period 1964-1969 than during more recent years.

The accuracy of these estimates depends on the accuracy of Bangnolds theory, the assumption of a Rayleigh distribution, and the sensitivity of the sand dunes to moisture and fluctuations in wind direction. An anemometer was set up about 1/2 mile south of this dune field to provide verification of the estimates of wind speed based on sand grain size and dune movement.

Wind speeds were also predicted at Thorpe and Lookout Mountain, sites of two other anemometers. These estimates were based on wind deformation of trees. At Thorpe the mean annual wind speed is expected to be $6.2\text{m/s} \pm 1.9\text{m/s}$. At the Lookout Mountain site the predicted speed is $6.3\text{m/s} \pm 2\text{m/s}$. Three other locations in the survey area had flagged trees from which estimates could be made of mean annual wind speed. These include Mission Ridge at 6.5m/s, the southern end of the Wenatchee Mountains at 5.8m/s, and Chelan Mountain at 4.7m/s. The 95% confidence interval error bands are 2.0m/s. Figures 6.23 and 6.24 show wind-deformed trees at Lookout Mountain and a digitized deformation ratio for each tree. Figure 6.25 shows locations of expected good wind power potential based on the results of this survey.

6.4 COSTS OF THE REMOTE-SENSING SURVEY

The costs of this survey will not be broken down into as detailed a budget as the New York and California Deserts surveys because there were more experiments conducted and this survey also involved setting up anemometers to provide verification data. Among the budget items for this survey were acquisition of LANDSAT imagery. Only one LANDSAT image that covers an area of about 22,000 sq. km was needed to cover our prime survey area, but two adjacent images were also purchased to provide

TREE SPECIES : DF # 2

ALPHA: 39.1'

BETA: 3.5'

GAMMA: 1.2'

DEFORMATION RATIO: 5.0

ANNUAL MEAN WINDSPEED: 5.8 TO 8.3 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)

FIGURE 6.23. Digitized Deformation Ratio of the Douglas Fir Denoted by the Arrow at Lookout Mountain

TREE SPECIES : PP # 44

ALPHA: 35.5'

BETA: 3.2'

GAMMA: 2.8'

DEFORMATION RATIO: 5.1

ANNUAL MEAN WINDSPEED: 5.8 TO 8.4 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N) N

DO YOU WANT TO ANALYZE ANOTHER TREE? (Y OR N)...N

FIGURE 6.24. Digitized Deformation Ratio of a Ponderosa Pine at Lookout Mountain

FIGURE 6.25. Estimated Wind Power Class in Central Washington. Sites labeled G or good are likely to have mean annual wind speeds greater than 6 m/s. Those in F or fair category are likely to have winds greater than 5 m/s, and M or marginal locations will have winds greater than 3.5 m/s.

more information for the whole region. Each LANDSAT image costs \$15 and may be purchased from the EROS Data Center at Sioux Falls. Photo processing of these images so they could be included in a written report cost another \$15 per image.

Medium level imagery U-2 photos were borrowed at no cost from the Bureau of Reclamation. Imagery at the 1:40,000 scale was obtained from U.S. Department of Agriculture at a cost of \$30 or \$2 per image of a 25km² area near the Vantage Dune Field. Low-level aerial imagery was collected in a Cessna 172. Over \$300 in film and processing were spent, but in a normal survey of an area this size, film and film processing costs should be less than \$100.

Two trips in a four-passenger Cessna were made to the survey area and aircraft costs were about \$1000 just for aircraft rental and gas. Generally the cost of renting a plane with a pilot and gas included is \$55 to \$65 per hour and 5 to 7 hours would be sufficient to perform a low aerial survey of an area the size of the one in Central Washington.

Five scientist were involved in the Central Washington survey, three in the air and two on the ground. However, the ideal-sized prospecting team includes two prospectors and a pilot. One prospector navigates, records information and notes locations photographed; the other prospector takes documenting photographs and concentrates on spotting wind indicators.

6.5 VERIFICATION OF THE RESULTS AND CONCLUSIONS

Five anemometers were set up during October and November in the survey area. At one location (Wahatis Peak) vandals destroyed the anemometer and its replacement. The site was abandoned. At one location (Lookout Mountain) only two months of wind data were collected because of equipment problems and unreliable service by those who agreed to collect data. At two locations (Beezley Hills and Thorpe Bingo) data were lost because of inclement weather. In one case, ice froze the cup stationary for a number of days, and in the other, a gust of over 80 mph toppled the anemometer tower. Data for these sites and long-term data stations are shown in Table 6.2 and

TABLE 6.2. Pertinent Wind Data in Central Washington

Location	(SPEED IN M/S)												AVG
	J	F	M	A	M	J	J	A	S	O	N	D	
(Long term data)													
Stampede Pass	4.4	5.1	5.1	5.0	4.8	4.8	4.7	4.5	4.3	4.5	4.8	4.6	4.7
Ellensburg	2.0	2.9	4.3	5.2	6.1	6.2	6.2	5.5	3.8	2.9	2.2	2.3	4.2
Yakima	3.0	2.8	4.0	4.7	5.4	5.7	6.4	5.7	4.3	3.1	2.5	2.6	4.1
Connell	4.3	3.1	5.1	4.5	4.7	4.6	3.7	4.4	4.6	5.0	4.6	3.7	4.4
Mission Ridge	7.1	6.9	6.7	8.9								6.7	7.3E
Vantage Farms						5.3	6.7	4.1	4.1	2.8	3.4		4.1E
Sunnyside	5.2	6.6	7.3	7.1	5.0	5.9	6.1	6.2	5.9	5.3	6.4	5.4	6.0
Rattlesnake	5.6	8.7	9.8	8.7	9.5	x	6.0	10.1	7.9	7.7	x	6.7	8.0E
Moses Lake	2.9	2.9	3.7	3.9	4.0	3.7	3.2	2.9	3.1	2.9	2.7	2.7	3.2
Kennewick	4.2	7.8	8.1	6.7	7.8	7.3	8.0	7.1	7.0	6.7	7.1	7.7	7.1
Pasco	3.2	3.8	4.1	4.6	4.0	4.0	3.4	3.5	3.4	2.6	3.1	2.3	3.5
Ritzville	4.3	5.8	7.2				7.1	7.2	7.6	6.9	6.2	4.6	6.3E
Wanapum	2.4	3.7	6.0	5.8	7.1	7.7	6.9	6.0	4.8	4.2	4.2	3.8	5.3
Priest Rapids													3.3 (a)
(New wind data)													
Thorpe Bingo			6.6	6.6	6.0	6.0				4.2	4.2		5.1E
Lookout Mt. 1					8.3	9.5							7.1E
Stuart Anderson							7.1						7.1E
Lookout Mt. 2							7.6						7.1E
Micheal Daum													4.4 (a)
Beezley Hills	3.4	4.2	5.1	8.2		6.9	7.8	7.8		4.2	2.6		5.6E
Vantage Sub	4.7	4.0	7.3		7.0		8.7	7.4				4.6	6.0E
Boylston Mt	3.3	3.6	6.3	6.6	6.7	6.7	6.3	6.2	6.1	4.1	3.3	2.6	5.2
Kittitas MW	3.5		7.5	6.2	6.6	5.2	6.3	6.7	7.0	4.9	4.7	4.6	5.7E
Hanford													2.9 (a)

(a) indicates only annual data available and E indicates estimate based on partial data and comparison to the nearest long-term site.

all the verification data is plotted in Figure 6.25.

In those locations where sand dunes or loess type soils were evident in remote imagery, estimates were made that the wind power class would be Marginal-Fair (based on the 4.9-5.8 m/sec wind speeds estimated from sand samples and sand movement data collected above Wanapum Dam). Vantage Substation, which was set up to verify these estimates, is expected to have a mean annual wind speed of 6.0 m/sec at 30m which would be equivalent to about 5 m/sec at 10m using the formula

$$V_{10} = V_{30} \left(\frac{10m}{30m} \right)^{\alpha} \quad (13)$$

where the velocity at 10m (V_{10}) is estimated from the velocity at 30m (V_{30}), the ratio of heights and a power law coefficient (α) of 0.14. At those locations estimated to have marginal to fair winds, the available data seems to confirm the estimates.

Trees were used to estimate the wind power class in four locations and in three of these locations there is data which confirm the estimates.

Based on the results given above, it appears that fairly good estimates of the mean annual wind speed can be obtained from information obtained from sand dunes and flagged trees. Although calculating minimum mean annual wind speed from sand dune data is somewhat tedious, it appears to provide reasonable estimates of wind speed. Other areas of reflective soils were assumed to have equally good winds to those near the Vantage Dunes, which is a very tenuous assumption, but the limited wind data seem to validate that assumption.

all the vegetation data is plotted in figure 2. In these locations where some or losses were evident in remote imagery, estimates were made that the wind speed class would be marginal (air based on the 1.9-2.8 m/sec wind speeds estimated from wind samples and wind movement data collected above canopy level). Vegetation destruction which was not up to verify these estimates, is assumed to have a mean annual wind speed of 2.8 m/sec at 10m which would be equivalent to about 5 m/sec at 30m using the formula

$$V_{10} = V_{30} \left(\frac{10m}{30m} \right)^{0.5} \quad (1)$$

where the velocity at 10m (V_{10}) is estimated from the velocity at 30m (V_{30}). The ratio of heights and a power law coefficient (α) of 0.5. At these locations estimated to have marginal to fair winds, the available data seems to confirm the estimate.

Trees were used to estimate the wind power class in some locations and in others of these locations there is data which confirms the estimate.

Based on the results given above, it appears that fairly good estimates of the mean annual wind speed can be obtained from information obtained from wind roses and flight trees. Although calculating minimum mean annual wind speed from some data is somewhat tedious, it appears to provide reasonable estimates of wind speed. Other areas of relative calm were assumed to have marginal to fair winds near the average winds which is a very reasonable assumption, but the limited wind data seem to validate that assumption.

7.0 NEW YORK STATE: A CASE STUDY^(a)

In many areas of the United States the strongest winds and best wind power potential occur in the winter months. Even in areas where the winds are somewhat weaker in the winter, a utility may be more interested in the winter wind power potential for a number of reasons including: the demand for energy may be greater; the cost of power may be higher; or other seasonally variable energy sources (i.e., hydroelectric and solar) may be less plentiful. For these reasons, it is important to be able to quantify the wind power potential in locations that have the strongest winds in the winter time and to evaluate the wind resource available during the winter months.

Unfortunately, this investigation found that there are some significant limitations to using remote sensing in the winter. Because of the frequent cloud coverage during the winter season, it is difficult to find high altitude imagery of surface features that may indicate strong winds (i.e., snow sweep, ice flow drift, etc.). In addition, low level aerial reconnaissance is difficult to perform because of the limited number of VFR (visual flight rules) days.

However, the results of this case study indicate that the effects of strong winter winds can be detected in vegetation using remote-sensing surveys conducted in the spring, summer, and fall. While it is difficult to determine from remotely sensed imagery, the season in which trees were deformed by the wind, if one knows that in general the summer season has weak winds, then one can infer that most of the winds come during the winter and spring. Thus, the degree of deformation can be used to rate the cold season wind power potential.

The case study that will be described was conducted in New York State where the strongest winds occur during the winter and spring months. In the following sections the objectives of the case study are outlined and the

(a) This case study was conducted June 1 and 2, 1981.

procedures that were used in New York are outlined. In addition, the low-level survey is described and estimates of the strength of the wind are presented and validated.

7.1 OBJECTIVES

The main objective of the New York area case study was to determine the efficacy of using remote sensing for wind prospecting. The New York area was chosen for four reasons. First, a large bank of summarized wind data compiled by the Atmospheric Sciences Research Center of the State University of New York (SUNY) could be used as verification data. Second, the strongest wind season is winter time, but the low-level aerial survey had to be conducted during the summer to ensure VFR weather. We felt it would be interesting to see if this restriction would be a detriment to the application of remote-sensing techniques. Third, although the terrain is complex in New York, the relief is not as dramatic as that of the Northwest or California where similar case studies were conducted. (Mt. Marcy, at 5344 ft or 1626 m, is the highest point in New York State.) Fourth, the vegetation consists of more deciduous species of trees. Forests are generally closed canopy while many cultivated fields contain hedgerows with well-exposed trees used as fences and windbreaks. This is in contrast to the coniferous forests of the Northwest and the desert and chapparal of Southern California.

7.2 PROCEDURES

The approach in applying remote sensing to wind prospecting in the New York area was divided into several tasks:

- analysis of existing meteorological data
- acquisition of high level imagery
- evaluation of topographic features
- plotting the distribution of wind data sites and
- assessment of other factors affecting development of wind energy.

The first step in any remote survey of wind power potential is an evaluation of all existing wind data. For this evaluation we used

information available in the Wind Energy Resource Atlas: Volume 4 The Northeast Region (see Pickering et al. 1980). We also summarized upper air data from Albany, Buffalo and Burlington, Vermont. These data indicated that the best wind power potential should be found along the eastern shores of Lake Erie and Ontario, on Long Island and in the Adirondack and Catskill Mountains (See Figures 7.1 and 7.2). The upper air data (see Table 7.1) indicates that above about 400 meters (1300 ft) the free air winds should exceed 6 m/s and are primarily from the southwest through west-northwest in northern New York.

FIGURE 7.1. New York Annual Average Wind Power (after Pickering et al. 1980)

FIGURE 7.2. Topographic Map of New York (after Pickering et al. 1980)

TABLE 7.1. Upper Air Data at Selected Locations in the New York Area

ALBANY, NEW YORK			BUFFALO, NEW YORK			BURLINGTON, VERMONT		
Height (m)	Direction (deg)	Speed (m/s)	Height (m)	Direction (deg)	Speed (m/s)	Height (m)	Direction (deg)	Speed (m/s)
86	263	1.8	182	245	3.5	100	230	2.5
141	263	2.3	220	244	5.5	500	228	6.0
563	280	10.3	1007	251	10.6	1000	247	7.0
1005	287	12.8	1471	264	12.8	1500	264	10.7
1469	284	14.8						

NOTE: Resultant mean speeds have been divided by a constancy factor of 0.6, (taken from Crutcher, 1959) to obtain scalar mean speed.

LANDSAT photos were obtained of New York State. The photos were analyzed to obtain information on the topography, vegetative cover, pack ice distribution, and other factors affecting wind power potential such as obvious land use conflicts. LANDSAT imagery indicates that most of the state is covered by hardwood forest (broadleaf trees) and farmland. Softwoods, or conifers, were noted primarily in the higher mountainous areas, particularly on the west slopes of ridges. These conifers are primarily spruce and fir. Pines, particularly Eastern White Pine are often found extending above the canopies of hardwoods.

According to Thompson (1966), the state is divided into nine landform regions (see Figure 7.3). These landform regions vary from mountains to valleys and plateaus to coastal lowlands. Each of these features is easily observable with the LANDSAT imagery. Our goal was to survey in as many representative landform regions as possible.

Combining the meteorological, LANDSAT, and topographic analysis, it appeared that 1) the valleys oriented southwest or west and north-south ridges should have best wind power potential; 2) the eastern shores of the Great Lakes should be good areas for deep-lake breeze penetration; and 3) the Tug Hill Plateau (see G in Figure 7.3), which has the state's highest snowfall, also looked promising. In southern New York wind data on Long Island indicates strong winds, but this area of the state is primarily metropolitan and thus was not included in our field survey.

Lastly, the distribution of wind data sites was also plotted so that our conclusions could be objectively evaluated.

With all this combined information a survey route was loosely planned, since flight weather and refueling requirements usually have a strong influence on the actual flight survey path.

7.3 RESULTS

This section of the report will describe the low-level aerial survey route, costs and time involved. In addition, estimates of wind power potential are made for the areas surveyed and the validity of these estimates is evaluated using data obtained from SUNY.

- A. Adirondack Upland
- B. St. Lawrence-Champlain Lowland
- C. New England Upland
- D. Triassic Lowland
- E. Hudson-Mohawk Lowland
- F. Appalachian Upland
- G. Tug Hill Upland
- H. Erie-Ontario Lowland
- I. Atlantic Coast Lowland

FIGURE 7.3. Landforms of New York

7.3.1 Survey Area

The survey route covered about 1700 km in 12 hours of flying time in a Cessna 172. The route shown in Figure 7.4 covered seven of the nine characteristic landforms in the state of New York. Cruising speed was usually around 100 mph, but the speed of the aircraft over areas being photographed was often 70-80 mph. Flight level was generally about 200 m (700 ft) above ground level (agl) but for photographs we often flew closer to the ground.

FIGURE 7.4. Aerial Survey Route

7.3.2 Cost of the Survey

The costs described below are only the costs of preparing, conducting and analyzing the results of the survey. We did not include in our cost estimate the travel expenses of OSU personnel to and from New York, since future surveys such as this would probably be conducted by local wind prospectors.

COST ANALYSIS - NEW YORK AERIAL SURVEY

Salaries

Survey Preparation	
3 man-days @ \$100/day*	\$300
2 day Aerial Survey	
4 man-days @ \$100/day	\$400
Survey Analysis and Report	
3 man-days @ \$100/day	\$300
Administrative Expenses	\$100
Per Diem Cost During Aerial Survey	
2 men for 2 days @ \$50/day*	\$200

Aircraft Costs

Aircraft rental includes pilot, aircraft and fuel	
11.9 hrs @ \$50/hr plus pilot meals	\$602

Imagery

Imagery acquisition, film and photoprocessing	\$100
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Miscellaneous Expenses

Printing, Postage, Parking, Pencils, Paper & Pens	\$ 50
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TOTAL DIRECT COSTS OF AERIAL SURVEY	<u>\$2,052</u>
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- * Salary cost and per diem rate reflect University salary, other payroll expenses and per diem rates. Overhead is not included. Private firms or Consultants might charge \$200-\$300/day plus overhead and a fee.

7.3.3 Aerial Survey

The results of the low aerial survey will be described for each land form region (see Figure 7.3) surveyed in the state of New York. The letters at the beginning of each section correspond to those in identifying the region in Figure 7.3.

A. Adirondack Upland. The Adirondack region contains the most rugged terrain in the state. Many summit elevations are above 1000 m, but lower mountains of the Adirondacks and Lake George were also surveyed in this region. The vegetation of the region is mostly spruce and fir at the upper elevations and hardwood forests dominate the lower elevations. The hardwood forest consists primarily of beech, maple, ash and birch. Conifers such as pines, hemlock and cedar are also found. Most of the forests are closed canopy and few trees are found in open, exposed areas. White pine is most often found by itself or a canopy of shorter hardwoods.

In the higher mountains, two peaks were examined: Lyon Mountain at 1167 m and Whiteface Mountain at 1485 m. Fir trees were carpeted on the west slope of Whiteface Mountain (see Figures 7.5a and 7.5b) and Class 3 west flagging was noted in the firs on Lyon Mountain. Class 4 fir flagging (Figure 7.6) from the southwest was noted on a 1200-m ridge east of Lake Placid.

The lower hills of the Adirondacks showed more topographic steering of the wind direction. South, southwest and west flagging were all noted along the lower hills in the Adirondack Mountain area. Class 4 flagging of pines was noted on the hills above Highway 73 from Lake Placid to Keene and Highway 9N from Keene to Elizabethtown (see Figures 7.7, 7.8 and 7.9). South-southwest Class 4 flagging of pines was noted on low hills north of Moriah. South-southwest wind flagging was noted along the low hills above Lake George; and mostly Class 4 deformation was noted in pines and spruce (Figure 7.10 a and 7.10b). Class 4 flagging was even noted on islands on the lake about 10 km northeast of Boltons Landing (Figure 7.11).

FIGURE 7.5a. Carpeting on the Slopes of Whiteface Mountain

FIGURE 7.5b. Carpeting on the Slopes of Whiteface Mountain

FIGURE 7.6. Class 4 Flagging on a 1200 m Ridge Above Lake Placid

FIGURE 7.7. A Panoramic View of the Pass from Keene to Lake Placid

FIGURE 7.8. Class 4 Flagging in the Pass from Keene to Lake Placid

FIGURE 7.9. Class 4 Flagging Above Highway 73 Between Keene and Lake Placid

FIGURE 7.10a. Class 4 Flagging Above Lake George

FIGURE 7.10b. Class 4 Flagging Above Lake George

FIGURE 7.11. Class 4 Flagged Trees on an Island on Lake George

B. St. Lawrence and Lake Champlain Lowlands. We covered the St. Lawrence River from Lake Ontario, northeast to Massena and Lake Champlain from the center of Grand Isle, south to Charlotte. The plain along the U.S. shore of the St. Lawrence River is a flat-to-gently-rolling terrace about 10 km wide, bordered by the low foothills of the Adirondacks. Many islands are found at the southwest end of the river. Grand Isle is a flat island in Lake Champlain. Along the eastern shore of the lake are the foothills of the Green Mountains. The Adirondacks are to the west.

Along the St. Lawrence, vegetation is primarily hardwoods (maple, elm and oak). Scrub pine are found on the islands or in sandy locations along the shores of the river. Pine, oak and elm are found along the shores of Lake Champlain and on Grand Isle.

The flagging along the St. Lawrence River indicates prevailing southwest winds. Class 4 and 5 flagging were noted on the many islands in Thousand Island Park (Figures 7.12, 7.13a and 7.13b). Along the shoreline

FIGURE 7.12. Class 4 and 5 (on windward shore) Flagging on an Island in the St. Lawrence Seaway

FIGURE 7.13a. Class 4 Flagging on an Island in the St. Lawrence Seaway

FIGURE 7.13b. Class 5 Flagging of Pine Trees on an Island on the St. Lawrence Seaway

Class 2 and 3 flagging predominates (Figure 7.14). At Massena, Class 2 elm and maple were noted.

Over Lake Champlain we noted Class 2 and 3 pines flagged by south-southwest winds (Figure 7.15). On Grand Isle Class 3 pine and Class 2 spruce were noted.

C. New England Upland. The Taconic Mountains are a fairly rugged range on the eastern border of New York, just east of Albany. One ridge, about 40 km east of Albany, was about 900 m high and had Class 2-3 spruce and fir flagged by west winds. Further east, in Massachusetts, Mt. Greylock at 1127 m had Class 5 fir trees flagged by west-northwest winds. A tower about 75 m high was also noted on Mt. Greylock.

FIGURE 7.14. Class 2 Flagging of a Broadleaf Tree on the U.S. Shore of the St. Lawrence Seaway

FIGURE 7.15. Class 3 Pines on Grand Isle in Lake Champlain

D. Triassic Lowland. The Triassic Lowland is a valley just north of Patterson, New Jersey. This landform region was not surveyed.

E. Hudson-Mohawk Lowland. The Hudson Valley is a 15 to 30-km wide lowland lying between the Helderberg Escarpment and Catskills on the west and the Taconic Mountains on the east. The valley runs generally north-south. The northeast end of the Shawanagunk Mountains and Bear Mountain are well-exposed highlands in this topographic region that were examined in our aerial survey.

The Mohawk Valley is a generally east-west valley that lies about 300 m below the surrounding terrain. Lake Sacandaga lies north of the eastern end of the Mohawk Valley and is oriented southwest-northeast. It is bordered by low hills of 300-500 meters.

The vegetation in the Hudson Valley is dominated by beech, maple and birch with hemlock, white pine and cedar as the dominant conifers. Oak is often found on the south and southwest slopes of ridges; whereas, maple, beech and birch are commonly found on the north and northeast slopes. On rocky ridges, oak and scrub pine predominate. The Mohawk Valley vegetation is primarily hardwoods such as maple and beech with hemlock and pine as important conifers.

Along the Hudson River little flagging was noted. On well-exposed, higher elevation ridges and peaks, west flagging was noted. Class 3-4 west flagging was noted in pines on the Shawanagunk Mountain, southwest of Kingston (see Figure 7.16). Further south, near Peekskill, Class 3 west flagging of pines was noted at Bear Mountain (Figure 7.17). Light north wind flagging, Class 1-2, was noted in the hills above West Point.

In the Mohawk Valley, the low hills above Lake Sacandaga have Class 3 southwest flagging of pines. The best flagging in the Mohawk Valley was noted at Delancan and in the low hills south of St. Johnsville where Class 2 west flagging was noted in pines. Surprisingly, no flagging was found around Utica except on the hills above the city.

FIGURE 7.16. Class 3 Flagging of Pines on the Shawanagunk Mountains

FIGURE 7.17. Class 3 Flagging of Pines on Bear Mountain

F. Appalachian Upland. The largest landform region in the state is the Appalachian Uplands, occupying nearly half the state. The surface of the area is highly irregular. In the Catskills, ridges are bulky and valleys are few and small, but often very deep. The ridgetops vary from 600-1200 m high.

The Delaware Hills, on the other hand, are low rolling hills with often no more than 100 m of local relief.

The Heldenberg Hills in the northeastern corner of the Appalachian Upland region rise about 600 m above the Hudson and Mohawk Valleys. The northeast face of the Helderbergs have steep escarpments which are the result of weather-resistant materials capping the ridges.

The vegetation of this region is dominated by hardwoods, beech, maple and birch. Conifers include Eastern White pine, hemlocks and white cedar. Hemlock and cedar, being shade tolerant, are found often in moist, shady locations and rarely on wind-swept ridges.

In the Catskills we noted Class 4 west flagging of spruce (see Figures 7.18 and 7.19) on Hunter Mountain about 60 km southwest of Albany, New York. In the Delaware Hills, near the Blenheim-Gilboa Reservoir, we noted

FIGURE 7.18. Hunter Mountain, Class 4 West Flagging

FIGURE 7.19. Class 4 Flagging at Hunter Mountain

Class 2-3 west flagging of pine and Class 3 flagging of white cedar. In the Helderberg Hills, Class 3 west-northwest flagging was noted in pines about 20 km west-southwest of Albany, New York (Figure 7.20). Another feature noted in this area is a more even and perhaps wind-carpeted canopy on the west and southwest slopes than exists on the east and the northeast slopes (see Figures 7.21 and 7.22).

G. Tug Hill Upland. The Tug Hill Upland lies about 500 meters above the Ontario lowland. This area has one of the greatest accumulations of snow west of the Rocky Mountains, with over 200 inches in some locations. Due to poor drainage, there are few farms and the area is sparsely settled. Spruce, fir, larch, pine, hemlock and white cedar are the important trees of the area. Red spruce is perhaps the most common.

South-wind flagging was noted in a few locations in the Tug Hill area. Class 3 spruce were noted near Page and New Boston and Class 3 pine near South Rutland.

FIGURE 7.20. Class 3 West-Northwest Flagging in the Helderberg Hills

FIGURE 7.21. Smooth Canopy on West and Southwest Slopes

FIGURE 7.22. Smooth Canopy on West and Southwest Slopes

H. Erie-Ontario Lowland. Of this region, only the eastern half was examined in aerial survey. The Ontario Lowland lies to the south of Lake Ontario. The region has few features, being formed beneath glacial lakes. The most notable topographic features are Oneida Lake, the Ontario Drumlins east of Syracuse, and the Lake Ontario shoreline.

The first area examined was Lake Oneida, where we found no tree-flagging along the shoreline except near the southeast corner of the lake where Class 3 west flagging of a tall pine was noted. No flagging was noted over the Drumlins east of Syracuse and along the Ontario shoreline from Soda Bay to Fair Haven. Class 2-3 southwest flagging was noted near Oswego (see Figure 7.23). South-wind flagging, Class 2-3, was noted in spruce, pine and various hardwood species from Pulaski to Stony Point (see Figures 7.24 and 7.25) and Class 2 southwest flagging was noted near Watertown.

FIGURE 7.23. Class 3 Flagging Near Oswego

FIGURE 7.24. Class 3 Conifers Along Lake Ontario

FIGURE 7.25. Class 2 Broadleaf Trees Along Lake Ontario near Stony Point

I. Atlantic Coast Lowland. This topographic area consists of Long Island and Staten Island and is the most densely populated landform feature in the state. No aerial survey was made of the area.

7.3.4 Estimates of Wind Speed Class and Verification

The results of the survey are shown in Figure 7.26, where wind power potential is estimated to be excellent, good, fair or marginal, based on observed tree flagging. These classes are broader than those in Figure 7.1 but correspond in the following manner:

Excellent = Class 7
 Good = Class 4, 5 and 6
 Fair = Class 2 and 3
 Marginal = Class 1.

The results in Figure 7.26 confirm those of the Northeast Region Wind Resource Atlas in the Adirondacks and Catskills, but provide several new areas of good wind power potential, particularly along Lake George and the

FIGURE 7.26. Estimated Wind Power Class in New York State

St. Lawrence Seaway. The major discrepancy between the survey results and the Atlas estimates is along the shore of Lake Ontario and the St. Lawrence Seaway.

After making the estimates of wind power potential, we plotted mean wind speed data obtained from Sforza (1980) (see Figure 7.27). These data were then used to compare to our remote-sensing estimates. In the Hudson Valley and the Catskill Mountains the agreement is good. The mean wind speeds in the Hudson Valley vary from 2.5-4.0 m/s. The only location with data in the Catskill Mountains is Bear Mountain, with 6.4 m/s and Binghamton at 4.5 m/s which may be representative of a typical lower elevation mean wind speed in this region.

FIGURE 7.27. Verification Wind Data for New York Survey Area

In the Taconics no data are available to confirm our estimate of Good-Excellent wind power potential.

The Mohawk Valley was rated as having fair potential based on estimated speeds in the 4.5-6 m/s range. Wind data in this area indicates winds in the 3.8-5.5 m/s range. At the Utica Airport where the mean annual wind speed is 5.5 m/s we did not note flagging (the anemometer height was 20.4 m, well above the height of most of the trees). The only flagging noted in this area was on the hills above the river. From Oneida Lake to Lake Ontario, the winds were estimated to be Marginal for wind power purposes and the data seems to verify these estimates. From Oswego to Watertown

and over the Tug Hill Upland, the estimate was Fair. Along the coast these estimates look over-generous, but Watertown, at 5.1 m/s, gives some validity to the Fair estimate for the Tug Hill Plateau area.

The St. Lawrence Seaway estimate is Good, or winds in the 6-7 m/s range, however, there are no data to verify the estimate. Over Lake Champlain the estimate is Fair. The only data locations are Plattsburg, New York (3.1 m/s) and Burlington, Vermont (4.0 m/s) which would indicate an over-estimate of the wind power potential.

Finally, the Adirondack Mountain area is classed as Good to Excellent. The only wind information available is at Whiteface Mountain which has a mean annual wind speed of 11.6 m/s.

Overall, the estimates agreed well with the data. In two areas the estimated wind power potential was greater than indicated by the data (Lake Ontario shoreline and Lake Champlain area).

7.4 CONCLUSIONS

The major conclusions in this survey are:

Aerial reconnaissance can provide a useful site-screening tool, even in a state where closed canopy hardwood forests predominate;

Although flagging is difficult to detect in individual trees, in the windiest locales we found more conifers, or conifers above a canopy of shorter broadleaf trees;

It was very difficult to identify tree genus from the air, particularly in the broadleaf trees. Fall surveys might make identification of hardwood trees more simple. With conifers, the task was less difficult where the trees were in open areas; but in closed canopies, we were uncertain of the tree types;

Beach erosion was noted along the Lake Ontario shoreline, but we could not determine from our photographs how wind may be related to this erosion. Active erosion was also noted on the lee side of the Whiteface Mountains which may be due to slides caused by snow cornices (built by the wind) breaking (under) very strong winds (greater than 20 m/s) and sliding down the slope. However, the soils that cap the peaks of the Adirondacks are very shallow and unstable surfaces are found on most of the higher peaks.

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not determine from our photographs how wind may be related to this
erosion. Active erosion was also noted on the lee side of the
shallow bays which may be due to slight caused by wave currents
(drift of the wind) breaking (about) very strong winds (about 20
20 m/s) and falling on the shore. However, the shells and the
beach of the shoreline are very shallow and unstable surface are
found on most of the higher peaks.

8.0 SOUTHERN CALIFORNIA DESERT AREA: A CASE STUDY^(a)

Wind not only affects the form of vegetation, it also has a powerful influence on the shape of the surface of the earth, particularly where the climate is arid and vegetation is scarce. Erosion and deposition by wind results in a noticeably changing landscape in deserts and along shorelines. Wind picks up and moves rock fragments from the earth surface and these airborne rock fragments may polish and groove other rock formations like a natural sandblaster. But one of the most striking effects of wind on the landscape is deposits in the form of sand dunes.

This case study describes techniques for using remotely sensed imagery for reconnaissance of eolian features, particularly in arid climates. The information obtained is used to identify areas with strong winds. The survey area and low-level flight path are shown in Figure 8.1.

This section will describe the objectives of the California Desert Case Study, the procedures used, the results and conclusions as to the value of the remote sensing in wind prospecting in arid climates.

8.1 OBJECTIVES

The main objective of the California Desert Case Study was to test the value of remote sensing in wind prospecting in an arid area with little, and often, no vegetation. The California desert was chosen for three reasons. First, a considerable amount of verification data had recently been collected in this region for the California Energy Commission, Southern California Edison and the Federal Department of Energy. Second, it was an opportunity to test the value of geological indicators of wind power potential such as sand dunes and sand scour. Finally, the vegetation in the arid region consists mainly of bushes such as creosote (*Larrea tridentata*) and saltbush (*Atriplex parryi*). We wanted to determine if wind deformation of shrubs could be observed from an aircraft.

(a) This case study was conducted June 30 through July 2, 1981.

FIGURE 8.1. The California Desert Area and Low-Level Survey Route

8.2 PROCEDURES

The approach in this case, as in the other cases, was to first examine existing meteorological data. In Southern California the only source of data we used in our initial examination was that obtained from the Wind Energy Resource Atlas, Volume 9 - The Southwest Region, Simon et al. (1980). Later, other data was obtained that was collected in more recent wind surveys conducted in the region.

Acquisition of high-level imagery consisted of obtaining LANDSAT images covering the survey area and obtaining a black and white LANDSAT composite of the whole survey area (see Figure 8.2) from the Jet Propulsion Laboratory, Pasadena, California. The next steps were to evaluate topographic features, locate aeolian features (sand dunes) from LANDSAT images, plot the location of existing wind data locations, and note prevailing wind patterns.

FIGURE 8.2. Photograph of Part of a LANDSAT Composite of the California Desert Area

In Figure 8.3 the location of data used in the Wind Atlas (see Simon et al. 1980) are noted and the estimated wind power potential for this region based on this data bank and upper air data in the region is shown in Figure 8.4. Over most of the desert area the wind power potential is

FIGURE 8.3. Location of Stations Used in Southern California Resource Assessment. Only locations with stars had summarized wind data in the Winds Energy Resource Atlas (from Simon et al. 1980).

FIGURE 8.4. Southern California Annual Average Wind Power (from Simon et al. 1980)

rated poor (Class 1) to marginal (Class 2-3). Exceptions are the San Gorgonio Pass area, Barstow-Dagget area, Granite, Tehachapi, Transverse, White and Inyo Mountains. The basic conclusion from these estimates is that except for the passes and mountains, wind power potential is poor to marginal over most of the California Desert Region.

Major topographic features and prevailing wind flow patterns were noted on a LANDSAT composite of the area which provided a integrated picture of the regional wind regime (see Figure 8.5). From LANDSAT it also became apparent that few trees would be found in the Mojave Desert or in mountains of that area. However, tree cover was noted in Great Basin, Transverse and Peninsular Ranges. Considerable vegetation was evident around the Salton Sea due to agriculture, but otherwise at low elevations, the natural vegetation is primarily desert shrubs, and in some areas, Joshua trees.

FIGURE 8.5. Streamline Analysis of Infrared Wind Flow Patterns Based on Dune Field Orientation and Topographic Channelling

A survey route was planned taking into account the many areas of restricted air space in the Southern California Desert. Possible refueling locations were noted. Because of the time of the year during which the survey was conducted, the length of runway was an important consideration when planning refueling stops. Originally scheduled during the spring, this survey was conducted in July and low-density altitude (common to the summer season) meant using more runway on takeoff, moderate turbulence

in the afternoon, and long, slow ascent rates in the Cessna 172 used as the survey craft.

Nearly 10,000 km² of the California desert are covered by sand dunes. The first step in utilizing sand dunes as wind indicators should be a comprehensive review of literature describing the dynamic interaction of wind and sand. These references include the classic work by Bagnold, *The Physics of Blown Sand and Desert Dunes* (1942) and more recent work by Lettau and Lettau (1978), Marrs and Gaylord (1979), and Hiester and Pennell (1980). These references provide information on how to interpret the information collected in the field.

In any attempt to interpret information from sand dunes one must first become acquainted with the various dune types and the process which form them. In Section 4 some of the important dune types are illustrated and Dean (1978) has classified nine characteristic dune types found in the California Desert. These include:

- 1) Transverse: A series of relatively parallel, closely spaced sand ridges, forming perpendicular or transverse to the effective sand-moving wind. This dune type appears to form most commonly on a base of bare, loose sand of relatively unlimited surface area and relatively unlimited depth.
- 2) Barchan: An isolated crescent-shaped dune with "horns" pointing downwind. This dune type appears to form most frequently on a bare, relatively smooth, non-sandy base.
- 3) Isolated Transverse Ridge: A single sand ridge formed perpendicular to the mean sand-moving wind. This dune type appears to form frequently with human aid on a base of bare, loose sand of relatively unlimited surface area with a shallow depth.
- 4) Obstacle: Sandy deposits on the windward and/or lee slopes of topographic obstacles. These types are commonly known as climbing or falling dunes, depending upon whether a sand cover is moving up or down a significant slope. A third form, longitudinal, appears to form with relatively high velocity bi-directional winds, but within the same quadrant. These dunes take the appearance of long,

linear sand ridges parallel to the mean sand-moving wind and form from a continuous sand supply in the lee of a bedrock obstacle.

- 5) Sand Sheet: A generally featureless relatively smooth area covered by a veneer of sand. Sand moving across the sand sheet may form dunes downwind.
- 6) Parabolic: Bowl-shaped dunes formed by gentle to strong winds on deep sand with a shrub or grass-covered surface. Lacustrine sands and their environments often yield this type of dune. Dunes formed by gentle winds tend to be U-shaped whereas dunes formed by stronger winds are typically more elongated, hairpin shaped. "Horns" in parabolic dunes point upwind.
- 7) Shrub-coppice: Sand mounds formed by wind in conflict with bunch or clump vegetation, in the absence of other effective sand binders, such as grasses. This dune type appears to require a smooth surface and very shallow sand.
- 8) Whaleback: Large sand waves or ridges upon which dunes of like morphology form; also known as "draa." This dune type requires unlimited sand and high-velocity winds of generally singular direction.
- 9) Sand Mountain: Relatively isolated peaked sand structures; also known as "star" dunes. This dune type appears to require unlimited sand, high velocity and multi-directional winds.

In addition to the type of dune, it is also important to know orientation, direction of movement, height, mean sand grain size, coarse fraction of sand grains, and extent of vegetation coverage.

Imagery from different levels is available to evaluate these important dune characteristics and, except for sand grain sizes, all the information can be obtained from remotely sensed imagery. LANDSAT is particularly good for distinguishing dune areas and examining regional wind flow patterns (see Figure 8.5 and Fryberger and Ahlbrandt 1978). However, resolution is a problem and detailed mapping is difficult because local variations within a dune field may be difficult to distinguish. Also, it is hard to determine if a dune is an active dune or stabilized artifact.

U-2 color infrared imagery is useful for more detailed mapping of dunes and the scale 1:32,500 - 1:130,000 is appropriate for transferring information to base maps. In addition, U-2 imagery is very amenable to stereo analysis.

For very detailed examination of dune features and local wind field patterns, low-altitude aerial reconnaissance is the best platform. Based on earlier experience by Dean (1978), and our own experience, Table 8.1 rates the various platforms in terms of effectiveness in evaluating sand dune variables.

TABLE 8.1. An Evaluation of the Effectiveness of Various Remote-Sensing Platforms for Desert Reconnaissance

Variable	LANDSAT	Altitude	
		High	Low
Sandy versus non-sandy areas	excellent	excellent	excellent
Regional wind patterns	excellent	good	poor
Dune field relationships	excellent	good	poor
Sand dune types	poor	excellent	excellent
Extent of vegetation cover	good	excellent	excellent
Vegetation species determination	poor	good	good
Local wind patterns	poor	good	excellent
Dune height and orientation	poor	good	excellent

During the low-level survey six types of photographs were taken. These include oblique color (400 ASA color print film with a 35 mm camera), oblique and vertical color infrared slides, stereo pairs (both vertical and oblique), and zoom lenses (80-210 and 70-210 mm) were often used to take both color slides and prints.

Sand dune parameters such as grain size, dune height, standard deviation, skewness, vegetation types, and dune morphology were taken from a report by Dean (1978) *The California Desert Dunes*. Information was also obtained from books and reports by Shelton (1966), Greeley (1978), and Oakshott (1971). This information, along with the information on dune field orientation and dune type collected during the low-level aerial survey, was used to estimate wind speeds and directions in the desert area.

In the mountainous areas wind-deformed trees were the primary tool used for estimating wind speed and direction. In the ranges of the Mojave Desert there were often no trees so other information such as ridge orientation, ruggedness of terrain, and rising or falling dunes were noted and used to subjectively evaluate the wind power potential. In several cases wind-deformed trees were not seen on the ridgetops, but later analysis of some of the photographs of vegetation revealed evidence of wind flagging. Thus, it is extremely important to have photographs, particularly when flying over ridgecrests, as safe flying heights may preclude "naked eye" identification of wind-deformed trees.

After incorporating the information from the topographical, geomorphological and biological wind indicators, we prepared a map of prevailing wind directions and classed areas of Marginal, Fair, Good, and Excellent wind power class. These estimates were then verified using data withheld from examination in the earlier part of the study for validation purposes.

8.3 RESULTS

This section of the case study describes the low-level aerial survey route, costs, time involved, and results of the survey.

8.3.1 Survey Area

The survey route covered about 2500 km in just over 15 hours of flying time in a Cessna 172. Flying time was only 5 hours each day, starting usually at 6 or 7 a.m. and finishing around 8 p.m. with afternoon layovers to avoid mid-afternoon turbulence and heat.

The survey route covered most of the dune fields of the California Desert and included coverage of the ridgecrests of most of the Mojave Basin mountains, the Laguna Mountains in the Peninsular Range, the Sierra Palomas, Tehachapis, and the Spring Mountains of Nevada. Flight level was generally about 300 m above ground level, but occasionally closer to the ground over ridgecrests.

8.3.2 Cost of the Survey

The costs described below are only the costs of preparing for, conducting and analyzing the results of the California Desert Survey. Overhead, literature search time, and OSU personnel travel costs to and from Southern California are not included in our cost analysis since these figures might not pertain to other groups conducting similar surveys.

COST ANALYSIS - CALIFORNIA DESERT SURVEY

Salaries

Survey Preparation	
3 man-days @ \$100/day*	\$ 300
(Obtain LANDSAT imagery, locate wind data sites, and analyze high-level imagery)	
3-day Aerial Survey	
9 man-days @ \$100/day*	900
Survey Analysis and Report	
5 man-days @ \$100/day*	500
Per Diem Cost During Aerial Survey	
3 men for 3 days *	303
Aircraft Cost 15.2 hours at \$38/hour	577
Administrative Expenses	100
Imagery and Film	308
Miscellaneous Expenses	75
TOTAL DIRECT COSTS OF AERIAL SURVEY	<u>\$3,063</u>

* Labor and per diem rates reflect University rates, private firm rates may be 2 to 3 times higher.

8.3.3 Field Survey

The field survey itinerary presents a log of locations visited and special features of interest along the survey route.

The survey began in Bishop, California, which lies at the foot of the Sierra Nevadas to the west and the White Mountains to the east. Flying

south to Big Pine and east over the Inyo Mountains, through Deadmans Canyon, we encountered no natural wind indicators. The mountains in the pass (~2100 m) and into the Eureka Valley were rugged and had very little vegetation.

In the Eureka Valley we encountered the largest sand mountain in the California Desert (203 m). Climbing sand dunes were also noted on the Saline Mountains at the south end of the valley, indicating the prevailing winds are from 330° or down the valley which is oriented northwest-southeast (see Figure 8.6). At the lower southern end of the valley a large sand mountain appears to also have a prevailing direction of movement towards the southeast. However, the star dune form indicates that multi-directional winds have shaped this dune field. The dune is very active, but the dryness of the area, as much as windiness, would insure little stabilization of vegetation.

FIGURE 8.6. Climbing Dunes on the Saline Mountains

The route again turned eastward across the Last Chance Range into Death Valley. The Last Chance Range is sparsely vegetated and rugged (see Figure 8.7). Due to the remoteness of the area and to the fact that there are no roads, use of any wind power potential would be limited even if the winds were strong.

FIGURE 8.7. Last Chance Range of Southern California

We turned south again and headed down Death Valley. Near the northern end of Death Valley, east of Stove Pipe Wells, there is a large complex dune field consisting mostly of transverse dunes, with a mean dune movement

down-valley (see Figure 8.8 and 8.9). However, the dunes just north of Stove Pipe Wells appeared to be moving from the west to east out of the Cottonwood Mountains or down the Emigrant Wash.

The mountains to the east and west of Death Valley are rugged, particularly the Panamint's to the west which peak at 3368 m (Telescope Peak) and average about 3000 m along the ridgecrest. Below lies the lowest elevation in the United States (-80 m) and some of the most desolate, albeit spectacular, scenery in this country.

The Dumont Dunes (Figure 8.10) are formed on an alluvial plain with a mean dune height of 122 m. Prevailing directions for the sand mountain dune form are west and south-southwest. Just east of Highway 127, along the base of the Spring Hills, are transverse dunes that seem to be formed by south-east-southwest winds.

FIGURE 8.8. Transverse Sand Dunes Moving Down (Southeast) Death Valley

FIGURE 8.9. Transverse Dunes in California's Death Valley

FIGURE 8.10. Black Mountains are in the Foreground and in the Background are the Dumont Dunes

From the Dumont Dunes, the survey route headed east over the Shadow and Mesquite Mountains. We passed between the rugged Clark Mountain Range to the south and the Spring Mountains to the north. A road was noted along the crest of the south shoulder of the Spring Mountains. No flagging of vegetation was detected, but the orientation of the ridge with respect to the prevailing southwest-to-west winds along with seemingly good access would indicate promise for future wind power studies in the Spring Mountains.

After refueling in Las Vegas, the survey route first headed south-southwest from Las Vegas towards Mountain Pass in the Ivanpah Range, then southwest to the Barstow-Dagget area. The Mountain Pass area is a large plateau just east of Baker. The pass area is bisected by Interstate 15 which runs between Las Vegas and Barstow. No flagging was noted in the trees at the Mountain Pass summit, but trees are planted as windbreaks to break the prevailing west winds (see Figure 8.11).

FIGURE 8.11. Windbreak Trees Near Mountain Pass

Slight flagging was noted in the juniper trees in the mountains above the pass; again, the prevailing wind direction seems to be west (see Figure 8.12). Several communication facilities were noted on the peaks at Mohawk Hill and Halloran Summit. The very smooth west slope of the Mountain Pass area will probably result in sub-optimal wind flow acceleration. However, isolated areas with steeper slopes will probably experience some wind flow acceleration and have good wind power potential. Power lines through the area provide power from Hoover Dam to Los Angeles.

FIGURE 8.12. Class 2 Flagging of Juniper Near Mountain Pass

The survey for the first day ended at Mountain Pass and the survey crew spent the night in the Barstow area. The following morning we headed east from Barstow to the Barstow Dunes. East of Barstow, at Daggett, a large dune field has formed in the Mojave River floodplain. This dune area is evident as a large triangle-shaped feature on the LANDSAT image in Figure 8.2. Dune movement seems to be predominantly to the east, radiating from a western apex, indicating prevailing west winds. Small coppice dunes were often noted in the lee of bushes (see Figure 8.13). Climbing dunes were noted in the mountains 50 km east of Barstow (see Figure 8.14) and

FIGURE 8.13. Coppice Dunes Near Barstow

FIGURE 8.14. Climbing Dunes East of Barstow

north of Route 66. Further east were the very rugged Cady Mountains. The sharp relief in the terrain and lack of roads to the ridges make these mountains unlikely sites for studies of their wind power potential. Just north of the Cady Mountains we noted an area of desert pavement, indicating strong winds (see Figure 8.15).

FIGURE 8.15. Desert Pavement North of the Cady Mountains

About 70 km northeast of Barstow we encountered the Cave and Cronese Mountains. Both climbing and falling dunes were noted here (see Figure 8.16). East of the Cave Mountain and Mojave Wash is the Kelso area dune (see Figure 8.17).field which includes "The Devils Playground." Here we noted a wide variety of dune types: transverse dunes (see Figure 8.18), shrub coppice, barchan (see Figure 8.19), sand sheets, longitudinal, and a sand mountain or star dune (see Figure 8.20) that is 171 m high. A stereo view of a sanddune in the Kelso Dune Field is shown in Figure 8.21.

FIGURE 8.16. Climbing and Falling Dunes in the Cronese Mountains

FIGURE 8.17. The Kelso Area Sand Dunes (The Elevations are in Feet)

FIGURE 8.18. Transverse Dunes in the Kelso Dune Field

FIGURE 8.19. Barchan and Shrub Coppice Dunes in the Kelso Dune Field

FIGURE 8.20. Star Dune in the Kelso Dune Field Indicating Multidirectional Winds

PRINT SCALE: 1:3117
 DATE AND TIME OF PHOTOGRAPHY: 7/25/81, 0700
 AVERAGE PHOTOBASE LENGTH (P): 1.33" (0.11083')
 CAMERA FOCAL LENGTH (f): 100mm (0.32083')
 AGENCY PHOTO SOURCE: WPG - OSU

FIGURE 8.21. A Sample Stereo Image of Sand Dunes in the Kelso Dune Field

The barchan dunes east of the Mojave Wash indicate prevailing west winds. The dunes west of Old Dad Mountain indicate northwest winds and, the sand mountain or star dune indicates multi-directional winds just north of the Granite Mountains.

The survey route then turned south to the Amboy Crater area where the wind shadow of the crater indicates prevailing west-northwest winds. The dark area in Figures 8.22 and 8.23 are the parts of the lava flow in the lee of the crater that have not been covered by wind-blown sand. Climbing dunes were noted in the Calumet Mountains, east of Bristol Lake (see Figure 8.24).

FIGURE 8.22. High Altitude Vertical Photograph of the Amboy Lava Field (north is to the top). (NASA-Ames photograph)

FIGURE 8.23. Low Oblique Aerial Photograph Westward of Amboy Crater Showing the Dark "Streak." (Photograph by James Iversen 1976)

FIGURE 8.24. Climbing Dunes in the Calumet Mountains

At Dale Lake, we encountered an area of partially stabilized parabolic, transverse, and longitudinal dunes. The prevailing direction indicated by the dunes was northwest. The strongest winds are probably in the area west of Dale Lake where an extensive sand sheet lies upwind of the dunes. A bimodal wind regime through Clark's Pass is indicated by longitudinal dunes. Sand was also noted to be creeping up the Sheep Hole Mountains.

East of Twenty-nine Palms are the Cadiz Valley Dunes where we found a large actively moving dune field (prevailing wind direction 300°). The Iron Mountains and Kilbeck Hills east of this dune field should have strong winds, but poor accessibility would limit development of the wind power potential.

The route then headed southwest to Desert Center. South of Desert Center are the rugged Chuckwalla Mountains. No vegetation was noted on this 1000-1500 m range, but the winds should be fairly strong through the pass between the Eagle and Chuckwalla Mountains. This is possibly indicated by sand sheets west of Desert Center. Also, north of Desert Center in the Chuckwalla Valley, extensive sand sheets are found. Transverse dunes downwind indicate the winds are broadly from west-northwest directions.

The aircraft was refueled at Twenty-nine Palms and then the survey route headed southeast to skirt the Chocolate Mountain Aerial Gunnery Range, then turned west towards the Imperial or Algodones Dune Field, southeast of the Salton Sea. This dune field is one of the most accessible, unstablized dunes in the United States. These dunes (see Figure 8.25) are migrating at a rate of about 5 m/year (see Smith, 1978). Figure 8.26 shows the rate of migration is faster among the smaller dunes on the western margin of the dune field (see also Figure 8.25). The prevailing wind directions are west and northwest, based on the shape of the dunes. The main sand-moving winds are northwesterly. Most of the sand dunes are transverse, indicating a broad unimodal wind distribution (see Figure 8.27).

West of the Salton Sea we found a number of crescent-shaped, barchan dunes which are the result of very persistent west winds. The direction appears to be less variable on the west side of the Salton Sea than it is in the Imperial Dune Field. Shelton (1966) has shown the yearly

FIGURE 8.25. U-2 Vertical Air Photo of the Southern Algodones Dune Chain. Note: 1) Parallel dune ridges along the southwest margin of the dune chain; 2) Difference in trend between these ridges and those to the west; 3) Regular spacing of large domical dunes; and 4) Southeastward breakup of connected dunes into individual forms. (U.S. Geological Survey high-altitude photo 665 V 049, November, 1967.)

FIGURE 8.26. Map of 1953-1968 Barchan Migration Within a Field 3 km Southeast of Rest Area on U.S. Interstate 8 (after Smith 1970)

FIGURE 8.27. Transverse Dunes in the Imperial or Algodones Dune Field

movement of these dunes is about 18 m/year. In Figure 8.28 the Salton barchans are shown and successive positions of one eastward-moving barchan are noted in Figure 8.29.

FIGURE 8.28. Looking Westward (upwind) Over Cluster of Barchans Near West Shore of Salton Sea (reprinted with permission from Geology Illustrated by John S. Shelton, W.H. Freeman and Company, Copyright 1966)

FIGURE 8.29. Nearly Vertical View of Barchan by Tule Wash, West of Salton Sea, Southern California, in 1958. Retouched to show positions on other photographs taken in 1932 and 1950. Dune is 33 feet high, 400 feet between tips of horn. *Inset:* Slipface of same dune, immediately following a period of advance (reprinted with permission from *Geology Illustrated* by John S. Shelton, W.H. Freeman and Company, Copyright 1966)

The second day of the survey ended in Palm Springs and the survey crew visited the Southern California Edison Wind Energy Project near the Dever Substation. Figure 8.30 shows a high-elevation aerial image of the wind survey area just east of San Geronio Pass. This area is noted for abundant ventifact (wind-shaped rocks) and has been described by

FIGURE 8.30. Vertical Aerial Photograph Showing Features Northwest of Palm Springs: (1) Garnet Hill with abundant ventifacts and wind scour features; (2) Whitewater Hill; (3) Devers Hill; (4) Whitewater River; (5) Windy Point; (6) Banning fault trace; and (7) Mission Creek fault trace; (8) Southern California Edison Wind Energy Project. Photograph covers an area approximately 21 km by 21 km. (U.S. Geological Survey Photograph, GS-VDWU, 1-59, October 1975.)

Sharp (1964) (see Figure 8.31). The creosote bush in this area also provides evidence of the strong winds by its various degrees of prostrate growth (see Figure 8.32). The two most important dune forms in this area are the shrub coppice and sand sheet (see Figure 8.33). The prevailing sand-moving direction is west-northwest to northwest.

The following day an aerial survey was made of the San Geronio Pass area (see Figure 8.34). Deformation of the shrubs could not be detected from either the visual observations in the aircraft or later inspection of the photographs. Shrub coppice form dunes can be detected from the air and are indicative of strong winds.

FIGURE 8.31. Ventifact on Garnet Hill (Photograph by R. Greeley)

FIGURE 8.32. Wind-deformed Creosote Bush Near the Southern California Edison 3 MW Wind Turbine

FIGURE 8.33. Shrub Coppice Dunes in San Geronio Pass

FIGURE 8.34. Looking East Through San Geronio Pass

To the south, three mountain ridges were investigated in the Peninsular Range: Santa Anna, Santa Rosa, and Laguna mountains. No wind deformation could be detected in the shrubs growing on the Santa Rosa ridgecrest either by visual observation or from close inspection of photographs.

On both the Laguna and Santa Anna Mountains, no flagging was detected by visual inspection from the air at 300 m above ground level, but closer inspection of photographs using a 10-power hand lens showed strong Class 5 flagging of pines on the Laguna Mountains and Class 3 flagging of White fir on the west shoulder of the Santa Anna Mountains (see Figures 8.35 and 8.36). Lower-level aerial and ground-level inspection near Mt. San Jacinto verified Class 5 flagged pines and Class 3 flagged White fir (see Figures 8.37 and 8.38).

The Laguna Mountains and Santa Anna Mountains, despite their elevation, seem very accessible, particularly Mt. Laguna at 1892 m. Mt. San Jacinto, 3303 m, is less easily accessible, but the lower ridges on both sides of San Geronio Pass should have good wind power potential.

FIGURE 8.35. Class 5 Flagged Pines were Noted at Laguna Mountain Using 10-power Hand Lens to Examine

FIGURE 8.36. Wind-deformed Fir are Detectable on Mt. San Jacinto in This Aerial Photo Using a Hand Lens

FIGURE 8.37. A Very Low-Level Aerial Photo of Class 3 Fir on Mt. San Jacinto

FIGURE 8.38. Ground-Level Photo of Class 5 Flagged Pine on Mt. San Jacinto

The survey route returned north to the Transverse Range where we examined the Sierra Palonas, Saw Mill, and Tehachapi Mountains. In all three mountain ranges, access and exposure to the wind appeared to indicate good wind power potential. In most cases the vegetation was low growing shrubs or Live Oak that seemed to be contoured by the wind (see Figure 8.39). Where conifer trees were noted on the slopes of La Liebre Ridge in the Tehachapis, the pines exhibited strong Class 4-5 flagging (see Figure 8.40).

The survey ended in Mojave, California where Class 3 and 4 flagged pines were noted in a golf course near the airport (see Figure 8.41). Class 2 flagging was noted also in Tehachapi Valley on the journey back to Oregon.

FIGURE 8.39. Contoured Shrubs and Trees on La Liebre Ridge, Tehachapi Mountains

FIGURE 8.40. Class 4-5 Flagging of Pines Was Noted on La Liebre Ridge

FIGURE 8.41. Class 3 and 4 Flagging Noted at a Golf Course Near Mojave. Note many small trees exhibit stem-bending above where they are presumably guyed.

8.4 ESTIMATING WIND POWER

Estimates of wind power class in the California Desert were based on the following information:

- Observed tree flagging in the aerial survey;
- Sand dune parameters taken from the low-level survey and literature;
- Analysis of wind flow patterns; and
- Orientation of gaps, topographic barriers and valleys to the prevailing winds.

Estimates of mean annual wind speed based on wind-deformed trees are shown in Table 8.2 and Figure 8.42. These estimates were used to rate the wind power class for those ridgetops that had tree cover.

Estimates of mean annual wind speed based on sand dune parameters are presented in Table 8.3 and Figure 8.42. The coarse fraction size was determined by taking twice the standard deviation of the mean grain

TABLE 8.2. Estimates of Mean Annual Wind Speed at Locations with Vegetation in the California Desert Survey. Estimates are taken from relationships found in Wade and Hewson (1980).

<u>Location</u>	<u>Degree of Flagging</u>	<u>Genus</u>	<u>Estimated Mean Annual Wind Speed (m/s)</u>
Mountain Pass	2	Juniperous (Juniper)	5.6
Laguna Mountains	4	Pinus (Pine)	6.1
Santa Anna Mountains	3, 5	Abies (fir) and Pinus	7.5
Tehachapi Mountains	4-5	Pinus and Quercus (oaks)	7.8
Mohave Airport	3-4	Pinus	5.8
Tehachapi Valley	2	Pinus	4.7
Sierra Palona	4-5	Quercus	9.1

TABLE 8.3. Estimates of Mean Wind Speed Based on Sand Dune Parameters

Location	Mean Wind Direction (deg)	Mean Grain Size (mm)	Coarse Fraction (mm)	Dune Height (m)	Rate of Dune Mvmt (m/yr)	Mean Wind Velocity (m/sec)
Eureka	320	.30	1.6	203	*	7.0
Saline	120	.16	1.5	8	*	5.1
Olancha	10	.27	1.6	8	*	6.6
Panamint	180	.23	1.4	76	*	6.2
Death Valley	270-310	.12	1.6	31	*	4.1
Dumont	270	.19	1.7	122	*	5.6
Kelso	280	.33	1.8	171	4	6.9**
Barstow (E)	270	.18	1.5	15	*	5.4
(W)	270	.27	1.3	9	*	6.6
Cronese Climbing	280	.38	2.7E	*	*	7.6
Crest	280	.17	1.3E	*	*	5.3
Falling	280	.28	1.6E	*	*	6.7
High Desert (W)	270	.25	1.4	2-9	*	6.4
(E)	270	.15	1.4	2-9	*	5.0
Dale Lake	315	.19	1.6	3	*	5.6
Cadiz	310	.14	1.5	8	*	4.5
Rice Valley	300	.25	1.2	5	*	6.5
Chuckwalla	280	.17	2.1	5	*	5.1
Coachella	310	.15	1.5	5	*	4.9
Salton Sea	270	.21	1.4	6	18	5.6**
Imperial	270/320	.17	1.5	30	13	5.8**
Whitewater	290	.38	2.7	*	*	7.6

E Estimate

* No data

** Based on speed estimates using both sand grain size and dune movement

Note: Sand dune parameters taken from Dean (1978) and Greeley et al. (1978). All sand material was quartz and sand grain density was assumed to be 2.65g/cm³.

size and adding that value to the mean grain size. Estimated wind speeds were determined from relationships found in Hiester and Pennell (1980). Examples of how mean speeds are determined are presented in Section 6. Also shown in Figure 8.42 are mean wind directions from observed tree flagging and dune orientation.

Prevailing wind flow patterns and estimated wind power class are shown in Figure 8.43 and wind data are summarized in Table 8.4. These estimates are based on both quantitative information from trees or sand dunes and qualitative interpretation of wind flow patterns with terrain. Not shown on Figure 8.43 are: Mojave Airport, where the wind power potential appears to be Fair; the Tehachapi Mountains, where along La Liebre Ridge, strong flagging and some carpeting of bushes and oaks would indicate Good-to-Excellent wind power potential; Tehachapi Valley where the wind power potential appears to be Marginal; and along the Sierra Palomas, where the wind power potential appears to be Good-to-Excellent from observations of contoured shrubs and oak.

The wind power class is estimated at 27 locations. In seventeen of the general areas data were available to verify the estimates. Nine of the estimates were correct and 7 were incorrect (all but one were over-estimates). This would be expected since most of the wind data locations were near airports or in communities where the winds are likely to be weaker, and therefore may not be representative of the available wind power potential. Of the seven areas where estimates were based on biological indicators, five estimates of wind class were correct, one was incorrect, and for one area there was no wind information available. Sand dune parameters were used to estimate the wind in 20 areas (we could find wind data at only 11 of these locations). At 4 of the 11 areas with wind data, the estimates of wind power class were correct, and all of the incorrect estimates were over-estimates. Some of the error in these estimates may be due to using mean grain size rather than modal grain size and the estimates of sand grain density may be in error by as much as 10-15%.

Although the accuracy of estimates based on sand dune parameters appears to be poor, they are very good at locations where the wind data sites were near the dune field. Examples of good agreement are

FIGURE 8.43. Estimated Wind Power Class Based on Biological, Geomorphological and Topographical Wind Indicators. Numbers refer to wind data locations in Table 8.4.

TABLE 8.4. Available Wind Data in the California Desert Area

Location	Number	Mean Annual Wind Speed at 10m (m/s) (Initial Data)	Estimated Wind Power Class for the Area	Actual Power Class at this Location
China Lake	1	3.4	N/E	Poor
Daggett	2	5.4	Fair	Fair
El Centro	3	3.8	N/E	Marginal
Inko Ps	4	7.9	N/E	Excellent
Mt. Laguna	5	9.8	Good	Excellent
Needles	6	3.8	N/E	Marginal
Palmdale	7	5.1	Good	Fair
Sandberg	8	5.9	Good-Excellent	Fair
Thermal	9	3.9	Marginal	Marginal
(Verification Data)				
Victorville	10	4.3	N/E	Marginal
Edwards	11	4.2	Good	Marginal
Cartago	12		Good	
Keeler	13	3.3	Good	Poor
Lone Pine	14	4.7	Good	Marginal
Edwards	15	4.3	Good	Marginal
Mojave	16	5.3	Good	Fair
Quartzsite	17	7.2	Good	Excellent
Palmdale Airport	18	4.5	Good	Marginal
Kramer	19	4.1	Good	Poor
Pear Blossom	20	3.4	Good	Poor
Sarstow	21	3.1	Good	Poor
Coyotte	22	3.2	Fair	Poor
Silver Lake	23	3.9	Good	Marginal
Turquoise	24	5.6	Fair	Fair
Mountain Pass	25	3.3	Fair	Marginal
Mountain Pass	26	2.6	Fair	Poor
Rodman	27	6.3	N/E	Good
Joshua Tree	28	2.4	Marginal	Poor
Yucca Valley	29	4.1	Marginal	Marginal
Twenty-nine Palms	30	3.4	Marginal	Poor
Bristol	31	4.4	Marginal	Poor
Rice	32	4.1	Good	Poor
Black	33	5.9	Good	Fair
Mecca	34	3.2	Good	Poor
Salton Sea	35	4.3	Fair	Poor
Julian	36	5.2	Good	Fair
Palm Springs	37	2.7	Marginal	Poor
Indio	38	3.2	Marginal	Poor
Dever ERDA	39	6.4	Excellent	Good
Dever Sub	40	3.6	Excellent	Excellent
Not on Map				
Tehachapi Valley		4.7	Marginal	Marginal
La Liebre Ridge		7.6	Good-Excellent	Excellent
Sierra Palona		8.6	Good-Excellent	Excellent
Mojave Airport		5.3	Fair	Fair

Whitewater-Dever, Coachella-Thermal, and East Barstow-Daggett, where mean error in the estimate of mean wind speed for the three locations was 0.8 m/s. At the Kelso Dune Field, where a large over-estimate is indicated by the wind data at the Silver Lake Power Station, examination of that wind data indicates the power station is sheltered from the prevailing west winds by high hills, about 2 km to the west, and to the east by even higher hills that might deflect the flow (see Figure 8.44). Ideally, verification of the relationship between sand parameters and wind characteristics should be accomplished using anemometers set near the sand dune.

FIGURE 8.44. High-Altitude Color Infrared of the Eastern Portion of the Kelso Dunes. Arrow points to the nearest wind data location at the Silver Lake Power Station.

Although these results seem to imply wind power class is over-estimated if based on relationships between sand grain size or dune movement and mean wind speed, sand dunes can nevertheless provide useful information on wind flow patterns and can help identify some, but not all, of the better locations in an area. Also, the shape of the dune can provide clues to the frequency of the prevailing wind direction. Barchan dunes, for example, indicate more persistent direction than do longitudinal, transverse, or star dunes.

The aerial survey also presents a unique opportunity to evaluate accessibility, roughness of terrain, possible land use conflicts, and identify towers that anemometers could be mounted on and buildings that could shelter wind-recording equipment.

It is recommended that more field calibration of the relationship between mean wind speed and a sand dune parameter is needed to determine the statistical level of confidence for geomorphological indicators of wind.

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APPENDIX A

REMOTE-SENSOR TYPES AND THEIR CHARACTERISTICS
AND A MAP AND PHOTO CATALOG

TABLE A-1. A Tabular Summary of Sensor Types and Their Characteristics

Type of Sensor	Aerial Photos	Space Photos			Thermal IR	SLAR Radar	Passive Microwave
		ERTS Quasi-Polar 900 km RBV	MSS	Geostationary 40,000 km			
Mode	Passive	Passive	Passive	Passive	Passive	Active	Passive
Illumination	Solar	Solar	Solar	Solar	Thermal Emission	Self-Generated	Thermal Emission
Direction & Angle of Illumination	Time dependent, & limited, diurnal & seasonal (polar)	Limited but set by orbit	Sun-synchronous 0930 W 35°	Equatorial centered sunlit hemisphere	Hemispheric	Fully controlled by selection, not diurnal constrained	Hemispheric
Effect of Clouds	Constrained by cloud cover & shadow; fog	Cloud dependent	Cloud dependent	Cloud dependent	Cloud dependent Penetrates smoke	Almost independent, penetrates smoke	Almost independent Penetrates smoke
Wavelength	.4-.8 X 10 ⁻⁶ cm Vis. & near IR Film sensitivity limit	.5-1 X 10 ⁻⁶ cm 3 channels Photo sensor	.5-1.1 X 10 ⁻⁶ cm 4 channels 8-12 X 10 ⁻⁶ cm Photo sensor	Visible & near IR Photo sensors	3.5-5.5 X 10 ⁻⁶ cm 8-14 X 10 ⁻⁶ cm	1-3cm by choice Limited by antenna size & power	1-3cm by choice
Spectral Resolution	Pan B&W or single band or multiband Choice of film & filter	Multiband Choice of sensor & filter	Multiband Choice of sensor	Wide band or narrow band sensors	Multiband, choice of sensor	Monochromatic microwave	Usually wide band
Spatial Resolution	~1m Dependent on film, lens, altitude & focal length	~100m Dependent on sensor & electronics	~100m Dependent on scanner optics & mode	~2-3 km Dependent on sensor	~20m Dependent altitude & sensor	~20m (2 kinds) Nearly independent of distance to scene for range resolution Azimuth resolution: $\frac{D}{R \sqrt{BPRF}}$ D/2	~100m Dependent on altitude and sensor
Image Character	Synoptic, angle discrimination	Nearly synoptic, angle discrimination	Scanned, angle discrimination	Both, angle discrimination	Not synoptic, angle discrimination	Scanned, range discrimination	Not synoptic, angle discrimination
Polarization	T/No R/No or Yes	No	Some	No & Partial	No & Partial	Yes H (H/M or HV)	No and Partial
Stereo	Yes 60%	Yes 10%	Yes 10%	No	Yes	Yes 20-60%	Yes
Geometric Fidelity Factors	Displacement by Tilt & Relief	Orbital Altitude	Orbital Altitude	Near Orthographic Projection	2 scales: long & transv. flight path	2 scales: long & transv. flight path	2 scales: long & transv. flight path

ITOS (Improved TIROS Operational System)

Individual satellites in the ITOS system have been called NOAA since the formation of the National Oceanic and Atmospheric Administration.

	<u>Launch date</u>	<u>Ended operation</u>
ITOS-1 (NASA's TIROS-M)	January 23, 1970	June 17, 1971
NOAA-1	December 11, 1970	August 19, 1971
NOAA-2*	October 15, 1972	January 30, 1975
NOAA-3	November 6, 1973	August 31, 1976
NOAA-4	November 15, 1974	
NOAA-5	July 29, 1976	

ORBIT: Sun-synchronous, near polar Inclination: 102°
Altitude: 1470 km (average) Orbits per day: 12.4
Period: 115 minutes

SENSORS:

ITOS-1 and NOAA-1:

Advanced Vidicon Camera System (AVCS)	Automatic Picture Transmission (APT)
2-Channel Scanning Radiometer (SR)	Flat Plate Radiometer (FPR)
Solar Proton Monitor (SPM)	

NOAA-2 to 5:

	<u>Wavelength</u>	<u>Resolution</u>	<u>FOV</u>
Very High Resolution Radiometer (VHRR)	0.6-0.7 μ m 10.5-12.5 μ m	1 km	3400 km swath
Scanning Radiometer (SR)	0.4-1.1 μ m 10.5-12.5 μ m	4.2 and 8 km	
Vertical Temperature Profile Radiometer (VTPR) 8 channels			1350 x 60 km

Solar Proton Monitor

DESCRIPTION: Cylindrical, with solar paddles 91 x 160 cm
Dimensions: 102 x 102 x 122 cm Weight: 284 kg

PURPOSE: Observe, describe, and predict state of oceans, atmosphere, and sun
Global coverage twice daily of cloud patterns, surface temperatures, temperature profiles from surface to 30 km, and solar proton levels
Determine size and shape of Earth

GROUND STATIONS: Command and Data Acquisition (CDA) stations at Wallops, VA, and Gilmore Creek, AK

SR - Taped data received at CDA's, also direct readout to suitable equipped stations within radio range of satellite

VHRR - Primarily direct readout to S-band receivers at CDA's and Redwood City, CA

VTPR - Transmitted to CDA's; processed at NESS, Suitland, MD

SPM - Relayed from NESS to Space Environment Laboratory in Boulder, CO

DATA AVAILABILITY: National Environmental Satellite Service (NESS), World Weather Building, Camp Springs, MD 20031

SR and VHRR imagery, visible and infrared, as well as many special products such as mosaics, SST maps, ice analyses.

Nimbus

LAUNCH DATES: Nimbus 1-6: August 1964 to June 1975
 Nimbus 1-3 no longer operating
 Nimbus 4-6, one or more sensors still operating
 Nimbus G: Mid-1978

ORBITS: Sun-synchronous, near polar
 Altitude: Nimbus 1-6, 1100 km average Period: 107 minutes
 Nimbus-G: 955 km Coverage: Global, twice daily

SENSORS: Various meteorological and geophysical remote-sensing instruments
 and data transmission and processing techniques are tested on Nimbus

Nimbus-G

Scanning Multifrequency - System identical to Seasat SMMR
 Microwave Radiometer will cover polar areas
 (SMMR)

	Wavelength (μm)	Resolution	FOV	Measurement
Coastal Zone Color Scanner (CZCS)				
Channel 1	0.433-0.453			chlorophyll absorption
Channel 2	0.510-0.530			chlorophyll correlation
Channel 3	0.540-0.560	800 m	1800 km	gelbstoffe (yellow substance)
Channel 4	0.660-0.680			chlorophyll absorption
Channel 5	0.700-0.800			surface vegetation
Channel 6	10.5-12.5			surface temperature

DESCRIPTION: Butterfly-shaped; 2 solar paddles
 3X size and weight of TIROS or ESSA
 3m high by 1.5m diameter; weight, 373-909 kg

PURPOSE: Meant to succeed TIROS, but proved too expensive

Nimbus-6: Most sophisticated meteorological satellite to date
 Used with ATS-6 to develop numerical models of the atmosphere
 for Global Atmospheric Research Program (GARP)
 Provides data for TWERLE (Tropical Wind Energy Conversion and Reference Level Experiment)

Nimbus-G: Will monitor pollution of air and oceans
 Integral part of Seasat-A Program; GARP support
 Map sediments and coastal effluents
 Improve ship routing by observing polar and floe characteristics
 Long term weather prediction
 Continue Nimbus-4 measurements of long-term trend of radiation and ozone layers
 Earth's energy balance
 Atmosphere/ocean interface

ATS (Applications Technology Satellite)

	<u>Launch date</u>	<u>Position at Equator</u>
ATS-1	December 1966	150° W
ATS-3	November 1967	69° W

ORBIT: Geostationary

Altitude: 35,800 km

Inclination: 7°

SENSOR:

Spin-Scan Cloud Camera (SSCC), inoperable on ATS-1 since October 1972;
deactivated on ATS-3 in October 1975

Resolution: 3.2 km (peak sensitivity in green band)

FOV: 15,000 km

DESCRIPTION: Cylindrical

Weight: 352 kg

Height: 137 cm

Diameter: 146 cm

PURPOSE: Forerunner of SMS/GOES weather satellite system. ATS-3 still
sends data for Weather Facsimile Experiment (WEFAX)

GROUND STATION: Wallops, VA

REMARKS: Viewed Earth only in daylight

Landsat (formerly ERTS)

LAUNCH DATES: Landsat-1, July 23, 1972 (Band 4 now defunct)
Landsat-2, January 22, 1975

ORBITAL ELEMENTS:

Orbit: Circular
Altitude: 919 km
Inclination: 99° (near polar)
Period: 103 minutes
Coverage: ~82° N-S
Cycle: 18 days (Landsat-1 now follows Landsat-2 by 6 days, crossing equator at 0834 instead of 0942)

SENSORS:

	Wavelength um	Pixel size	Resolution	Image format
3 Return Beam Vidicon Cameras (used only occasionally)				185 x 185 km scenes
Band 1	0.475-0.575			10% sidelap at
Band 2	0.580-0.680	57 x 79 m	80 m	Equator
Band 3	0.690-0.830			10% forward lap
Multispectral Scanner				185 km strip image
Band 4	0.50-0.60			framed to match
Band 5	0.60-0.70	57 x 79 m	80 m	RBV scenes
Band 6	0.70-0.80			10% sidelap at
Band 7	0.80-1.1			Equator increasing toward poles

2 wide-band tape recorders

(both inoperable on Landsat-1; on Landsat-2, one inoperable, one operable for limited use)

Data Collection System (from up to 1000 platforms, each with up to 8 sensors)

DESCRIPTION: Butterfly-shaped; 2 solar paddles extend to 3.96 m

Height: 3.04 m
Diameter: 1.52 m
Weight: ~950 kg

PURPOSE: Synoptic and repetitive coverage of Earth's surface.

Provide data for agriculture, forestry, ecology, geography, meteorology, oceanology, energy and mineral resources, geology, hydrology, cartography.

GROUND DATA ACQUISITION STATIONS: Fairbanks, Alaska; Goldstone, Calif.; Greenbelt, MD. Prince Albert, Saskatchewan, and Pouch Cove, Newfoundland, in Canada; Cuiaba, Brazil; Fucino, Italy; and Rawalpindi, Pakistan.

DATA AVAILABILITY: All data received in U.S. are in public domain and can be purchased either as image products or as computer-compatible tapes from the Dept. of the Interior's EROS Data Center, Sioux Falls, SD. Data also available from NOAA in Suitland, MD, and Dept. of Agriculture, Salt Lake City, UT.

Skylab

	<u>LAUNCH DATE</u>	<u>CREW</u>	<u>DURATION</u>
Skylab 1	May 14, 1973	Unmanned	Estimated 10 years
Skylab 2	May 25, 1973	Conrad, Kerwin, Wertz	28 days
Skylab 3	July 28, 1973	Bean, Garriott, Lousma	59 days
Skylab 4	Nov. 16, 1973	Carr, Gibson, Pogue	84 days

ORBITAL ELEMENTS:

Apogee:	439 km	Inclination:	50°
Perigee:	423 km	Period:	93.2 minutes
Velocity:	27,515 km/hr	Coverage:	50° N-S; scattered

SENSORS:

	<u>Wavelength</u>	<u>Resolution</u>	<u>FOV</u>	<u>Film</u>
Multispectral photographic camera (S190A)	0.5-0.6 μ m	30 m		B/W Pan
	0.6-0.7	28		
	0.7-0.8	67	163 km	B/W IR
	0.8-0.9	67		CIR
	0.5-0.88	57		Color
	0.4-0.7	24		
Earth terrain camera (S190B)	0.4-0.7 μ m	15 m		Color
	0.5-0.7	15	110 km	B/W
	0.5-0.88	30		CIR
Infrared spectrometer (S191)	2 bands rang- ing from 0.39-15.99 μ m			
Multispectral scanner (S192)	13 bands rang- ing from		69 km swath	<u>Products</u> Single band B/W images
	0.41-12.5 μ m			3 band false color images CCT's
Microwave radiometer/ scatterometer and altimeter (S193)	2.2 cm		11 km diameter circle	
L-Band radiometer (S-194)	21 cm	$\pm 1.0^\circ$ K		<u>Temperature range</u> 0-350°K

(continued)

GEOS-3

(Geodynamics Experimental Ocean Satellite)

LAUNCH DATE: April 9, 1975

ORBIT: Circular

Altitude:

Apogee: 848 km

Perigee 839 km

Inclination: 114.9°

Period: 101.7 minutes

SENSORS:

Radar altimeter

Coherent and noncoherent C-band transponders

S-band instrumentation

Laser retroreflectors

Doppler transmitters

DESCRIPTION: Octahedron 132 cm wide topped by truncated pyramid
16 solar cell panels

Gravity-gradient stabilization scissors boom assembly with end
mass of 45 kg extends to 6.5 m in orbit plane

Height: 81 cm

Weight: 340 kg

PURPOSE:

Measure geometry of oceans, topography of surface, currents, and
circulation.

Land and ice tracking.

Fulfill oceanographic, geodetic, and radar calibration requirements.

Used with ATS-6 in satellite-to-satellite tracking experiment.

HCMM (Heat Capacity Mapping Mission)

LAUNCH DATE: April 1978

Expected lifetime: One year

ORBIT: Circular, sun-synchronous, crossing Equator at 0200 and 1400 hours

Altitude: 600 km

Cycle: $1\frac{1}{2}$ to $3\frac{1}{2}$ days

Repeat coverage for thermal inertia measurements every 8 days

SENSOR:

	<u>Wavelength</u>	<u>Resolution</u>	<u>Swath Width</u>	<u>Data format</u>
Heat Capacity Mapping Radiometer*	0.5-1.1 μm 10.5-12.5 μm	500 x 500 m at nadir	700 m	1:4,000,000-scale imagery; Space Oblique Mercator Projection (SOM)
No tape recorder				

*Scanner-adapted Nimbus-5 Surface Composition Mapping Radiometer (SCMR)

SPACECRAFT:

Weight: 130 kg

Diameter: 76 cm

Height: 118 cm (solar paddles extend to 2.9 m)

PURPOSE:

Measure reflected solar energy

Determine heat capacity of rock types

Collect temperature data

Monitor soil moisture, thermal effluents, plant canopy temperature, snow cover

GROUND STATIONS: Fairbanks, Alaska, Goldstone, Calif., Rosman, N.C., in the U.S.
Shoe Cove, Newfoundland, Canada; Madrid, Spain; and Ororral, Australia.

DATA AVAILABILITY: Will be mailed to Principal Investigators from GSFC.

Standard products: Calibrated tapes, corrected or uncorrected
Positive and negative transparencies and prints of
daytime temperature and albedo nighttime
temperature, temperature difference,
thermal inertia (T.I.)

Magsat
(Magnetic Field Satellite)

LAUNCH DATE: 1979-1980

Expected lifetime: 4-8 months

ORBIT: Quasi sun-synchronous dawn-dusk plane

Inclination: 97°

Altitude:

Apogee: 550 km

Perigee: 325 km

SENSORS:

Triaxial fluxgate magnetometer

Alkali vapor scalar magnetometer

Deployable boom

Attitude transfer subsystem

Pulsed, near-infrared optical system

Redundant, self-calibrating, 3-axis measurement to 5 arc sec

Passive reflectors on magnetometer platform

Measurement range: ± 3.0 arc minutes

Acquisition range: ± 0.5 degrees

Magnetic cleanliness: Spacecraft magnetic field at sensor: Less than 1 gamma

DESCRIPTION:

Weight: 165 kg

Power: 72 watts (total average)

PURPOSE:

Update maps of Earth's magnetic field.

Update navigation charts.

Produce geomagnetic field models.

Produce crustal anomaly maps.

EROS visual aids: 2469, 2585

REMARKS: Also known as AEM (Advanced Explorer Mission)-C

MAP AND PHOTO CATALOG

I. MAPS

Current United States Geological Survey Maps are shown on Indexes to Topographic Maps. Each index covers one or more states. For more details write or phone any Mapping Center National Cartographic Center Office listed in Section IV locations of NCIC Offices.

A. FEATURE SEPARATES

Feature separates are now available for new metric topographic maps published by the Geological Survey at scales of 1:25,000 and 1:100,000. To compile these maps, major features were divided into classes, and a separate drawing was made for each class to be printed in each color.

You can order a film positive or negative of each drawing. Two or more drawings can be combined to form a B&W composite on a single piece of film.

Current USGS topomaps are shown on indexes. Each index covers one or more States.

B. COLOR SEPARATES

You can order a separate film positive or negative of each color shown on a USGS topographic map.

Generally speaking, on most maps: Black shows cultural features and names. Blue shows water features and names. Red shows highway classifications, built-up areas, and U.S. land survey lines. Green shows areas of woodland, orchards, and vineyards. Brown shows topographic features. Purple shows unverified data on photo-revised maps.

Two or more separates can be combined on a single film.

C. OUT OF PRINT MAPS

You can order B&W photo enlargements from microfilm of out-of-print USGS topomaps. A USGS map is out-of-print when the sales stock of the map

has been depleted and USGS has decided not to reprint it.

Successive editions of out-of-print maps provide a treasury of information that can be used to trace changes that have occurred in a given area.

There is no index of out-of-print maps, but USGS publishes a current *Index to Topographic Maps*. These indexes are useful for pinpointing the area for which you want out-of-print maps.

D. LAND-USE AND LAND-COVER AND ASSOCIATED MAPS

USGS is now compiling land-use and land-cover maps of the entire United States. They are based on USGS maps at scales of 1:250,000 or 1:100,000.

Land-use and land-cover is shown in 9 general categories and 37 sub-categories. A set of four associated maps (overlays) of each land-use and land-cover map shows: Political units; Hydrologic units; Census county subdivisions; and Federal land ownership.

E. SLOPE MAPS

Slope maps delineate areas that have certain critical ranges of slope. The slope (or gradient) is usually expressed as a percentage, based on the ratio of vertical to horizontal distance on the ground. Different slope zones are usually shown by different colors.

Very few slope maps have been published. Because most of them have been prepared to meet a specific request, no standard set of zone categories has been developed.

F. DIGITAL TERRAIN TAPES

The tapes are digital records of terrain elevations. They are available in 2 basic formats: a complete 7.5-minute quadrangle and a complete 2X1 degree quadrangle.

Applications of the tapes are limited only by the accuracy of the original maps used to produce the tapes. For example, they have been used to graphically display slope, direction of slope, and terrain profiles between designated points.

The *Digital Terrain Tapes User Guide* explains the development, format, and accuracy of the tapes, and it provides complete ordering instructions.

G. MAPS ON MICROFILM

You can order current and out-of-print USGS topomaps on positive or negative 35-mm microfilm.

The microfilm rolls are sold by State only. If complete State coverage is required, your order should include adjacent States.

The rolls of microfilm enable you to maintain a complete file of current and out-of-print USGS topomaps in a small space and at very low cost.

Each roll contains as many as 500 maps at a reduction ratio of 20X. The rolls may be ordered on silver-based or diazo film.

II. AIR PHOTOS

Contact prints or enlargements may be order from USGS or other government agencies. For more details write or phone any NCIC Office or the EROS Data Center (see Section IV). Request a Geographic Computer Search Inquiry Form and a current price list.

A. AIRCRAFT PHOTOS

Aircraft photos provide continuous coverage of many areas. Most negatives are 9"x9" (22.86x22.86 cm). Orders are accepted for either stereoscopic (three dimensional) or pictorial (two dimensional) overlap. Enlargements can be made to an exact ratio or to a specific scale. All orders are custom processed. Request a *NASA Aircraft Photography Order Form* and a *Geographic Computer Search Inquiry Form*.

B. SPECIAL AIRCRAFT PHOTOS

You can order prints of NASA research photos in B&W, color, or color infrared. Coverage is limited, but it includes most major metropolitan areas of the United States. Some of the photos have filled the demand

for "a photo of my home town."

Most of the photos provide high-altitude, small-scale coverage. Cloud cover is present in some photos, but most coverage clearly shows ground features such as roads, farms, and cities.

C. MANNED SPACECRAFT PHOTOS

Experimental photos from the Apollo, Gemini, and Skylab manned spacecraft programs can be ordered from the EROS Data Center.

Coverage of limited areas of the Earth was acquired by the Apollo and Gemini missions. Skylab coverage is available for limited test sites between 50°N and 50°S.

For details, write or phone any NCIC office or the EROS Data Center and request a booklet on *The EROS Data Center, a Manned Spacecraft Photography Order Form*, and a *Geographic Computer Search Inquiry Form*.

D. LANDSAT IMAGERY

Landsat circles the Earth roughly 14 times each day. From an altitude of 920 km (570 miles), it provides repetitive coverage of the Earth's features.

For each scene, Landsat transmits B&W data for four spectral bands (green, red, and two bands in the near infrared). B&W images from all four bands can be ordered for each scene. Orders are also accepted for false-color composites of individual scenes.

Request a booklet on *The EROS Data Center, an Order Form for Landsat Standard Products, a Selected Coverage Order Form With Map*, and a *Geographic Computer Search Inquiry Form*.

E. COMPUTER-ENHANCED LANDSAT SCENES

All Landsat scenes received after February 1979 have been improved by radiometric and geometric corrections, edge and contrast enhancement, and haze removal. Improvement of earlier scenes is limited to strip removal, edge enhancement, contrast stretch, and synthetic line generation.

False-color prints of these computer-enhanced scenes are offered on either Cibachrome or Kodak 2212.

For details, write or phone any NCIC office and request factsheets on the *EROS Digital Image Enhancement System* and the *EROS Digital Imagery Processing system*, a list of available computer-enhanced scenes, and a *Computer-Enhanced Landsat Products Order Form*.

F. TRANSFORMED PRINTS

Twin low-oblique aerial photos have been made of a few selected areas of the United States. Uniform-scale B&W prints can be made from the twin low-oblique negatives by using a fixed transforming printer to remove scale distortions caused by the 20-degree camera tilt.

The transformed image is trapezoidal rather than square. Pairs of either twin low-oblique convergent or transverse transformed prints can be viewed stereoscopically.

For details, write or phone any NCIC office and request a leaflet on *Low-Oblique Photography*, an *Aerial Mapping Photography Order Form*, and a *Geographic Computer Search Inquiry Form*.

G. MICROFILM

You can order cassette microfilm copies of USGS Photoindexes; NASA aircraft photography; Apollo, Skylab, and Gemini photography; Landsat imagery; and other data stored at the EROS Data Center.

Cassettes of 16-mm microfilm are available in B&W and/or color.

The cassettes can be used to set up an aerial and space imagery browse file or to acquire blocks of data for general research.

H. COMPUTER COMPATIBLE TAPES

Computer Compatible Tapes (CCTs) are used to digitally enhance individual Landsat scenes for use by researchers in agriculture, geology, hydrology, and other natural resource studies.

CCTs are available on standard 1/2"-wide (12.7 mm) magnetic tapes. They can be ordered in a 9-track format at 800 or 1600 bpi.

The number of CCTs required (one to four) for the digital data corresponding to one Landsat scene depends on the format requested.

I. 35-MM SLIDES

You can order 35-mm mounted slides of Landsat false-color composites and color/color-infrared Skylab and NASA photography over selected Major U.S. Metropolitan Areas, and other 35-mm slides that are available from the public affairs files.

Mounted 35-mm color duplicates are prepared from available printing masters.

III. INDEX SYSTEMS

A. SEARCH AND INQUIRY SYSTEMS - PHOTOINDEXES

Photoindexes are available for almost all Geological Survey aerial mapping photos. The indexes show the assembly of prints in standard 7.5-minute, 15-minute, and 30-minute quadrangle units.

Some 50,000 photoindexes are currently available. The indexes enable you to select prints covering the area you are interested in. Individual aerial mapping photos are not geographically accessible and are not identified by the Aerial Photography Summary Record System (APSRs).

B. AERIAL PHOTOGRAPHY SUMMARY RECORD SYSTEM

The Aerial Photography Summary Record System is an NCIC-operated computer data bank describing U.S. airphoto holdings of major government agencies and of private mapping concerns.

The holdings are summarized in State catalogs, called State-based graphics. Agency codes are displayed on State outline maps over areas covered by the projects. Accompanying microfiche provides data on the individual projects.

C. MICROGRAPHIC INDEXES SEARCH AND INQUIRY SYSTEMS

The indexes provide a low-cost, accurate source of information, and they enable you to make geographic searches on your own.

Photos from manned spacecraft flights, USGS, NASA, National Ocean Survey, Agricultural Stabilization and Conservation Service, have been filmed on 105x148 mm (4.134"x5.827") microfiche. The microfiche shows the imagery date, frame number, scale, film type, and holding agency.

D. GEOGRAPHIC SEARCH AND INQUIRY SYSTEMS

You may request a computerized search to locate available aerial and space imagery of a specific area.

As a result of the search, you will receive a computer listing of available imagery and a decoding template for interpreting the computer printout.

IV. LOCATIONS OF NATIONAL CARTOGRAPHIC INFORMATION CENTER OFFICES

National headquarters

National Cartographic Information Center
U.S. Geological Survey
507 National Center
Reston, VA. 22092
703-860-6045
FTS 928-6045

Mapping Center NCIC offices

Eastern Mapping Center
National Cartographic Information Center
U.S. Geological Service
536 National Center
Reston, VA. 22092
703-860-6336
FTS 928-6336

Mid-Continent Mapping Center
National Cartographic Information Center
U.S. Geological Service
1400 Independence Road
Rolla, MO. 65401
314-341-0851
FTS 277-0851

Mid-Continent Mapping Center(cont.)
National Cartographic Information
Center
National Space Technology Labs.
Building 1100
NSTL Station, MS 39529
601-688-3544
FTS 494-3541

Western Mapping Center
National Cartographic Information
Center
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA. 94025
415-323-8111, ext. 2427
FTS 467-2427

State Affiliate NCICs

NCIC has established affiliated offices with many State governments.
For the nearest one, ask your Mapping Center NCIC office.

Rocky Mountain Mapping Center
National Cartographic Informa-
tion Center
Box 25046, Stop 504-Federal
Center
Denver, CO. 80225
303-234-2326
FTS 234-2326

EROS Data Center
U.S. Geological Survey
Sioux Falls, SD. 57198
605-594-6511, ext. 507
FTS 784-7151

APPENDIX B

WIND FIELD MAPPING UTILIZING FLAGGED TREES AS INDICATORS OF SPEED AND DIRECTION

APPENDIX B

WIND FIELD MAPPING UTILIZING FLAGGED TREES AS INDICATORS OF SPEED AND DIRECTION

by Stuart G. Woolley

Assessment of a given site for wind power potential may be undertaken, utilizing the known response of certain trees, such as Douglas fir (*Pseudotsuga menziesii*) and Ponderosa pine (*Pinus ponderosa*), to long-term exposure to prevailing winds. The response of these trees is given by the Deformation Ratio (D) which is calculated as:

$$D = \alpha/\beta + \gamma/45^\circ \quad 1 \leq \frac{\alpha}{\beta} \leq 5$$

where α is the angle formed by the crown and the trunk on the leeward side; β is the angle formed by the crown and the trunk on the windward side; and γ is the degree of stem deflection. Mean velocity ($\bar{V}$) is obtained from D by:

$$\bar{V} = .95 D + 2.3$$

where $\bar{V}$ is the mean annual velocity in meters per second (see Hewson et al. 1979).

A three-stage hierarchical data acquisition procedure may be utilized to progressively assess a candidate site. The following example is taken from a study of wind power potential at Prairie Peak, Oregon. The general procedure should be applicable to many sites where target vegetation exists.

STAGE 1 - REGIONAL ANALYSIS

Maps of regional wind flow are examined in conjunction with topographic maps. In the case of Prairie Peak this examination indicated the site was well exposed to the prevailing winds in all seasons. In this case, generalized wind power potential maps compiled by Baker et al. (1978), covering the entire state of Oregon also were available. These maps revealed that the site was located among areas considered to have good wind power potential. Once this stage of the analysis was completed, we saw the need for further assessment.

STAGE II - AERIAL RECONNAISSANCE

This stage was undertaken using hand-held 35 mm photographic equipment and light aircraft. Either helicopter or fixed-wing aircraft may be used. Both types of aircraft were utilized in the Prairie Peak study to assess their relative merits. In both cases, flights were flown at approximately 4000 feet (1219 m.) to provide a nearly horizontal view of ridge top trees (Figure B-1). All flights were flown during periods of calm to avoid the introduction of additional tree deformation. Flight safety is enhanced by flying during calm periods, as the combination of low altitude and low airspeed serves to make the aircraft more vulnerable to low-level turbulence. The basic advantage of the helicopter is its ability to land at the study site to verify the existence of target vegetation and for ground access where a road system is lacking. Otherwise its use does not seem justified because it costs approximately ten times more than use of the fixed-wing craft.

Qualitative analysis of the photographs acquired at the study site indicated sufficient deformation of trees to proceed to the final stage.

FIGURE B-1. Ridge-level View of Wind-deformed Trees

STAGE III - ACQUISITION OF TERRESTRIAL PHOTOGRAPHS

Utilizing an appropriate sampling procedure, a number of trees at the site must be photographed to provide data points for development of the computer-generated map of the wind field. At each sample point the following data must be acquired:

1. Photograph of the entire tree - This image must be acquired from a position normal to the prevailing wind direction as indicated by the direction of flagging. A hand-held 35 mm camera with 50 mm lens is suitable for this purpose.
2. True vertical and scale - These data may be determined by having an assistant stand to one side of the tree holding a graduated staff with spirit level attached.
3. Elevation - This may be acquired with a field altimeter of sufficient accuracy to allow for mapping on a topographic base map.
4. Temperature - This may be acquired with a standard bulb-type thermometer for the purpose of altimeter corrections.
5. Direction of flagging - This is determined by aligning a compass with the most elongated branches of the tree, allowing for mapping of wind direction over the study area.
6. Location - The sample points must each be accurately plotted on a suitable base map.

It is critical that each tree be thoroughly inspected in the field for non-wind influences on deformation. Careful examination should be made for mechanical damage due to ice, sand, or salt spray. The area around the tree should be assessed for the possibility of soil creep or other mass movement that could result in deformation of the trunk.

At Prairie Peak, 45 samples were photographed. They were analyzed for deformation using an interactive computer program described by Kimerling et al. (1979). The output of this program provided a Deformation Ratio value and a range of wind speed (Figure B-2). For the Prairie Peak study, the mean wind speed value (of the wind speed range) was utilized as a representative value. Use of the computer-assisted analysis increased the accuracy of D value assignment, as tests with four different interpreters yielded the same results.

TREE SPECIES : DF # 1

ALPHA: 42.4'

BETA: 13.6'

GAMMA: 7.2'

DEFORMATION RATIO: 3.3

ANNUAL MEAN WINDSPEED: 4.4 TO 6.4 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)

FIGURE B-2. Example of Computer Output with Photograph of Corresponding Tree

PRODUCTION OF LOCAL WIND FIELD MAP

The final product of these techniques is a map of the local wind field at the hub height of the wind turbine being considered. The production of this map requires that calculated velocities be adjusted to the hub height through the use of the power law which is expressed as:

$$V_a = V_b \left(\frac{z_a}{z_b} \right)^\alpha$$

where V_b is the velocity at tree height, V_a is the velocity at hub height, z_a is hub height, and z_b is the height of the tree, α is the power law coefficient. The value of α has been shown to vary widely with surface roughness and other variables (Irwin 1979). An α value of 0.14 was used for the Prairie Peak area.

The corrected wind speed values are then utilized as "E values" in the SYMAP program, developed by the Harvard University Laboratory for Computer Graphics and Spatial Analysis. This program allows for the interpolation of a continuous surface in the regions where there are no data points based on the distances to and values of the neighboring points. This continuous surface is represented by contours representing lines of equal wind speed, or isotachs (Figure B-3) and isogons or equal wind direction (Figure B-4). Examination of the map produced allows for identification of areas of consistent high winds and, therefore, high wind power potential. The Deformation Ratio Program is attached to this report.

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FIGURE B-3. Maps of Equal Wind Speed Inferred from the Degree of Wind Deformation of Trees

FIGURE B-4. Maps of Equal Wind Direction Inferred from Measurement of the Direction of Tree Wind Flagging

DEFORMATION RATIO PROGRAM DESCRIPTION

Program Language: Tektronix 4051 BASIC

Length: 162 statements

Memory Requirement: 8k bytes

Peripheral Devices: SAC digitizer, data cassette, Tektronix Hard Copy Unit (optional)

This program allows the wind prospector to compute the deformation ratio and the associated mean annual windspeed range (Wade and Hewson) from terrestrial photographs of wind-flagged trees. Parts of the tree needed for calculating the deformation ratio are digitized using a SAC sonic digitizer. Digitized coordinates for these points are used to calculate the deformation ratio and plot a schematic diagram of the tree that serves as a visual check of the digitized coordinates. The mean annual windspeed range is then calculated from the deformation ratio using the Wade-Hewson regression equations.

Program Flowchart

Variable List

<u>Variable</u>	<u>Type</u>	<u>How Used</u>
X	array	X tree parameter coordinate
Y	array	Y tree parameter coordinate
Q\$	simple	Answers to interactive queries
J\$	simple	Tree species label
J	simple	Tree number
D	simple	Length of vertical reference line
A	simple	Direction angle of vertical reference line
X1	simple	X coord. for bottom of vertical line
Y1	simple	Y coord. for bottom of vertical line
X3	simple	X coord. for top of vertical line
K1	simple	Coordinate rotation parameter
K2	simple	Coordinate rotation parameter
K3	simple	Coordinate rotation parameter
K4	simple	Coordinate rotation parameter
M6	simple	Maximum X coordinate
M7	simple	Minimum X coordinate
M8	simple	Maximum Y coordinate
M9	simple	Minimum Y coordinate
D1	simple	Tree length
C	simple	Tree inclination (gamma)
D2	simple	Left branch angle parameter
D3	simple	Left branch angle parameter
D6	simple	Left branch angle parameter
S	simple	Left branch length parameter
R	simple	Left branch length parameter
A1	simple	Left branch angle
D4	simple	Right branch angle parameter
D5	simple	Right branch angle parameter
A2	simple	Right branch angle
A3	simple	Branch angle ratio
N	simple	Deformation ratio
V	simple	Lower mean annual windspeed
W	simple	Upper mean annual windspeed

<u>Variable</u>	<u>Type</u>	<u>How Used</u>
K1	simple	Viewport parameter
K2	simple	Viewport parameter
K3	simple	Maximum X for viewport
T	simple	Tape file number

DEFORMATION RATIO PROGRAM LISTING

```

100 CALL "RATE",1200,1,0
110 INIT
120 DIM X(7),Y(7)
130 SET DEGREES
140 PRINT "LDEFORMATION RATIO PROGRAM"
150 REM WRITTEN BY A. JON KIMERLING (7-79)
160 PRINT "JINITIALIZE DIGITIZER FOR COORDINATE DETERMINATION"
170 PRINT "TYPE 'READY' WHEN DONE..."
180 INPUT Q$
190 PRINT "JARE DATA TO BE PLACED ON A TAPE FILE? (Y OR N)..."
200 INPUT Q$
210 IF Q$="N" THEN 230
220 GOSUB 1460
230 PRINT "LTYPE TREE SPECIES LABEL..."
240 INPUT J$
250 PRINT "TYPE TREE NUMBER..."
260 INPUT J
270 PRINT "JDIGITIZE THE FOLLOWING TREE PARAMETERS:"
280 PRINT "JBOTTOM OF VERTICAL LINE "
290 INPUT @40:X(1),Y(1)
300 PRINT X(1),Y(1)
310 PRINT "TOP OF VERTICAL LINE "
320 INPUT @40:X(2),Y(2)
330 PRINT X(2),Y(2)
340 PRINT "TOP OF TREE "
350 INPUT @40:X(3),Y(3)
360 PRINT X(3),Y(3)
370 PRINT "BOTTOM OF TREE "
380 INPUT @40:X(4),Y(4)
390 PRINT X(4),Y(4)
400 PRINT "WINDWARD BOTTOM BRANCH OF TREE SEGMENT"
410 INPUT @40:X(5),Y(5)
420 PRINT X(5),Y(5)
430 PRINT "LEEWARD BOTTOM BRANCH OF TREE SEGMENT"

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440 INPUT @40:X(6),Y(6)
450 PRINT X(6),Y(6)
460 PRINT "BOTTOM POINT ON TREE FOR ALPHA/BETA CALCULATION"
470 INPUT @40:X(7),Y(7)
480 PRINT X(7),Y(7)
490 PRINT "J ARE THESE CORRECT? (Y OR N)...";
500 INPUT Q$
510 IF Q$="N" THEN 270
520 PRINT "L"
530 REM CALCULATE DIRECTION ANGLE OF VERTICAL LINE
540 D=((X(2)-X(1))^2+(Y(2)-Y(1))^2)^.5
550 A=ACS((Y(2)-Y(1))/D)
560 REM TRANSLATE COORDINATES TO LOWER LEFT OF TREE
570 X1=X(1)
580 Y1=Y(1)
585 X3=X(2)
590 FOR I=1 TO 7
600 X(I)=X(I)-X1
610 Y(I)=Y(I)-Y1
620 REM ROTATION EQUATIONS
630 K1=COS(A)*X(I)
640 K2=SIN(A)*Y(I)
650 K3=COS(A)*Y(I)
660 K4=SIN(A)*X(I)
670 IF X3<X1 THEN 710
680 X(I)=K1-K2
690 Y(I)=K3+K4
700 GO TO 730
710 X(I)=K1+K2
720 Y(I)=K3-K4
730 NEXT I
740 REM FIND MIN/MAX X AND Y VALUES
750 M6=100
760 M7=0
770 M8=100

```



```

780 M9=0
790 FOR I=1 TO 7
800 IF X(I)>M6 THEN 820
810 M6=X(I)
820 IF X(I)<M7 THEN 840
830 M7=X(I)
840 IF Y(I)>M8 THEN 860
850 M8=Y(I)
860 IF Y(I)<M9 THEN 880
870 M9=Y(I)
880 NEXT I
890 REM COMPUTE DEFORMATION RATIO PARAMETERS
900 REM 1. TREE INCLINATION = GAMMA
910 D1=((X(3)-X(4))^2+(Y(3)-Y(4))^2)^.5
920 C=ACS((Y(3)-Y(4))/D1)
930 REM 2. LEFT BRANCH ANGLE = BETA
940 D2=((X(3)-X(5))^2+(Y(3)-Y(5))^2)^.5
950 D3=((X(5)-X(7))^2+(Y(5)-Y(7))^2)^.5
960 D6=((X(3)-X(7))^2+(Y(3)-Y(7))^2)^.5
970 S=(D6+D2+D3)*.5
980 R=((S-D3)*(S-D2)*(S-D6)/S)^.5
990 A1=2*ATH(R/(S-D3))
1000 REM 3. RIGHT BRANCH ANGLE = ALPHA
1010 D4=((X(3)-X(6))^2+(Y(3)-Y(6))^2)^.5
1020 D5=((X(6)-X(7))^2+(Y(6)-Y(7))^2)^.5
1030 S=(D6+D4+D5)*.5
1040 R=((S-D5)*(S-D4)*(S-D6)/S)^.5
1050 A2=2*ATH(R/(S-D5))
1052 A3=A2/A1
1053 IF A3<5 THEN 1070
1055 A3=5
1060 REM COMPUTE DEFORMATION RATIO
1070 N=A3+C/45
1080 REM COMPUTE ANNUAL MEAN WIND SPEED FROM WADE-HEWSON REGRESSION
1090 U=(0.95*N+2.3)*0.82

```

```

1095 W=(0.95*H+2.3)*1.18
1100 REM PLOT TREE AND VERTICAL LINE
1110 WINDOW M6-0.5,M7+0.5,M8-0.5,M9+0.5
1120 K1=ABS(M6-M7-1)
1130 K2=ABS(M8-M9-1)
1140 K3=K1/K2
1150 VIEWPORT 0,50*K3,0,50
1160 REM DRAW HORIZONTAL LINE FOR BASE OF TREE
1170 MOVE M6-0.5,Y(4)
1180 DRAW M7+0.5,Y(4)
1190 REM DRAW VERTICAL LINE
1200 MOVE X(1),Y(1)
1210 DRAW X(2),Y(2)
1220 REM DRAW TREE
1230 MOVE X(4),Y(4)
1240 DRAW X(7),Y(7)
1250 DRAW X(3),Y(3)
1260 DRAW X(5),Y(5)
1270 DRAW X(6),Y(6)
1280 DRAW X(3),Y(3)
1290 HOME
1300 REM PRINT RATIO VALUES
1310 PRINT "TREE SPECIES : ";J$;" # ";J
1320 PRINT USING 1325:A2
1325 IMAGE "JALPHA: ",2D.1D,""
1330 PRINT USING 1335:A1
1335 IMAGE "BETA: ",2D.1D,""
1340 PRINT USING 1345:C
1345 IMAGE "GAMMA: ",2D.1D,""
1350 PRINT USING 1355:N
1355 IMAGE "JDEFORMATION RATIO: ",2D.1D
1360 PRINT USING 1365:U,W
1365 IMAGE "JANNUAL MEAN WINDSPEED: ",2D.1D," TO ",2D.1D," METER/SEC"
1370 PRINT "JINDEX NUMBERS TO TAPE? (Y OR N) ";
1380 INPUT Q$

```

```

1390 IF Q$="N" THEN 1420
1400 PRINT @33:J$;J1A11A21C1N
1410 PRINT "TAPE TRANSFER COMPLETE"
1420 PRINT "JDO YOU WANT TO ANALYZE ANOTHER TREE? (Y OR N)...";
1430 INPUT Q$
1440 IF Q$="N" THEN 1600
1450 GO TO 230
1460 REM INITIALIZE TAPE FILE
1470 PRINT "REWIND AND EJECT PROGRAM TAPE, INSERT DATA TAPE"
1480 PRINT "TYPE 'READY' WHEN DONE...";
1490 INPUT Q$
1500 PRINT "JENTER TAPE FILE #...";
1510 INPUT T
1520 FIND T
1530 PRINT "ARE DATA ALREADY ON TAPE FILE #";T;" ? (Y OR N)...";
1540 INPUT Q$
1550 IF Q$="N" THEN 1590
1560 ON EOF (0) THEN 1590
1570 INPUT @33:Q$
1580 GO TO 1570
1590 RETURN
1600 CLOSE
1610 PRINT "JGOOD BYE"
1620 END

```

APPENDIX C

 

APPENDIX C
ON INFERRING WIND POWER POTENTIAL FROM
SNOW COVER DISTRIBUTION

by Gudrun Bodvarsson

INTRODUCTION

Snow on the ground may be transported and redistributed by winds in much the same manner as wind-blown sand in a sand field, with formation of similar types of surface relief, which may serve as evidence of the action and characteristics (general speed and direction) of the prevailing winds. Snow is a light material, which, once fallen to the ground, is readily picked up and transported in large quantities over open terrain and re-deposited more or less unevenly, depending on the area topography, the characteristic roughness of the surface, and the strength and direction of the wind. Snow, like sand, is transported by saltation, and also in turbulent suspension; usually, a significant fraction of fallen snow becomes subsequently redistributed by winds of at least 2 to 3 m/s. However, there are differences between the susceptibility of snow and sand to wind transport which must be kept in mind when attempting to infer wind characteristics from observations of snow cover.

FACTORS AFFECTING WIND TRANSPORT OF SNOW

Snow comes in a variety of forms and physical states, depending on meteorological conditions during time of fall, which determines how easily it may be moved about by winds. These properties (specifically, particle structure, sizes, cohesiveness and density) may also, (and usually do) change in a short time after falling to the ground. They are influenced mainly by environmental temperature and wind strength.

Snow comes as single crystals of various shapes, or combinations of crystals; flakes, which are crystals that have become stuck together while falling; or as opaque, white grains with diameters usually on the order of millimeters. Newly fallen snow in a cold dry region where temperatures are well below freezing (-10°C or less), and light winds of speeds no more than

a couple of meters/sec, is usually light, fluffy, and has density less than 0.1 gm/cm^3 . At higher temperatures, more nearly freezing (0°C), and/or stronger winds of at least 7-8 m/s, snow density is slightly greater, or generally on the order of a few tenths of gm/cm^3 . The increase in density of snow specifically caused by wind is the result of breaking up of snow flakes into smaller grains as particles collide with one another, and the general packing effect of the wind on the surface. Furthermore, snow density nearly always increases with time after initial fall; i.e., snow surface tends to harden with age.

The top of a snow cover may be stabilized by melting in the uppermost few centimeters of the snow surface, even in regions where temperatures are persistently below freezing, due to heating by daytime insolation. This may be followed by refreezing at night through cooling by long-wave radiation under clear skies. Under overcast, near-freezing conditions, trapping of long-wave radiation between the snow surface and cloud cover (greenhouse effect), and/or sensible heat gains from warmer overlying air, may also contribute to partial thawing and often subsequent freezing within snow cover. Any amount of liquid precipitation will often quickly form a crust at the surface of the snow.

Though somewhat hardened snow may still be broken up and moved by winds, much higher wind speeds are required to do so. Thus, compared to sand, active snow transport is likely to be more or less sporadic or intermittent. limited possibly to hours or days immediately following a period of snowfall, depending on conditions; the wind blowing of sand is relatively unaffected by influences other than the wind, rain, the slow weathering processes and stabilization by encroaching vegetation.

THE REDISTRIBUTION OF SNOW BY WIND

In fairly open country (the type of area commonly considered for possible wind power utilization) blown snow during active snow drift conditions is redistributed with respect to the local topography in such a way that, characteristically, there is depletion of snow in areas of relatively high wind stress, while significant snow deposition occurs in sheltered areas

where wind speeds are low. Exposed points of higher wind speeds, where snow cover tends to be eroded away, are typically the crests and windward sides of hills, ridges (Figures 1-3; Figure 6) or other protruding topographic features or obstacles (e.g., houses, etc.). At sharp local steepenings, such as sharp ridgecrests, there is a tendency for accumulation of snow to occur in the form of cornices (Figures 4 and 5), which tend to grow

FIGURE C-1. Flow Across a Slope. Acceleration regions are designated A, deceleration regions L. (Perla and Martinelli 1978)

FIGURE C-2. Flow Over a Blunt Ridge. The windspeed gradient at B (BL) exceeds the gradient at A (AL). Hence, the shear at B is greater than the shear at A. Gradients reduce on the decelerating or lee side of the ridge. (Perla and Martinelli 1978)

FIGURE C-3. Windflow Over a Surface. The shearing force of the wind depends on the gradient of the windspeed at the surface. The gradient at the surface is represented by the slope of line OL. (Perla and Martinelli 1978)

FIGURE C-4. Basic Structure of a Snow Cornice. (Perla and Martinelli 1978)

FIGURE C-5. A Large Cornice at Rottalsattel, Near Lunghfranjoch, Switzerland. (Photo by Roch) (Perla and Martinelli 1978)

FIGURE C-6. Snow is Eroded from Acceleration Regions and Redeposited in Deceleration Regions. Four examples of transport are shown: A, transport from the windward to the lee side of a ridge; B, transport to a region of increasing slope steepness; C, transport into gullies from side and top; and D, transport through notches in a ridgecrest. (Perla and Martinelli 1978)

with light to moderately strong winds (less than 10 m/sec), but erode with strong winds (greater than 20 m/sec). Sheltered areas are topographic depressions and the leeward sides of hills, ridges or other obstacles (see e.g. Figures 6 and 7) where snow depth thickening commonly reaches several feet in thickness. Snow cover is also often thicker along edges of forests, cities, and in forest clearings, where wind speeds are locally reduced. Snow cover thickening along forest edges is often observed to extend into and outward from the forest on the windward side to distances about five times the heights of the trees.

FIGURE C-7. Examples of Natural Accumulation Zones in a Mountain Basin. The accumulation zones shown by arrows depend on the prevailing wind direction. (Perla and Martinelli 1978)

Following appreciable snowfalls, which generally are fairly uniform over large areas, small-scale variations in snow depth, i.e., over distances well within kilometers, can be brought about by winds within hours or days, and may range from practically zero up to as much as 5 to 10 meters. However, for essentially constant overall winds and generally similar meteorological conditions, roughly the same qualitative distributions of snow cover depths should recur at the same seasons, year after year, in the same area.

Under very light surface wind conditions, i.e., speeds no more than 2 to 3 m/s, snow tends to be fairly evenly distributed over the ground surface. When present in scant quantities only, snow is usually spread out in

small flat sheets, which become larger and more diffuse as snowfall increases (see e.g. Koenig 1962). Upwind slopes of hills may receive slightly greater amounts of falling snow than the leeward sides.

There is usually little snow transport in forest and cities, where surface resistance to wind is relatively high. Snow depths in forests, moreover, generally remain low, as trees also tend to intercept falling snow. Snow depth in cities is also affected by variations in surface temperatures within the city.

SNOW SURFACE FEATURES AND THEIR RELATION TO WIND

Probably the most quantitative evidence of wind speeds and direction may be obtained from observation of specific snow surface features; namely snow waves, ripples, barchans, dunes, and sastrugi (as shown in Figure 8). Each type of microrelief, its size and orientation is strongly dependent on wind speeds and directions. Each type tends to form above a certain minimum and range of wind speed blowing at the time of active snow drift.

SNOW WAVES AND RIPPLES

Small snow waves are transverse snow surface undulations, analogous to those seen on an ocean surface. They are oriented at right angles to the wind and move along slowly over the surface in the same directions as the wind. Snow waves represent alternating erosion and deposition of the snow surface. A typical snow wave has a length on the order of meters, a height of several centimeters, and moves at speeds of centimeters per minute.

Snow waves which were from 3 to 15 meters long and with heights from 5 to 20 cm were observed on the snowfields of Hokkaido by Kobayashi and Ishida (1979). They formed at wind speeds of at least 7 m/s, as measured at roughly 1 meter above the surface of a snow cover at least 10 cm thick, and moved along at speeds of 2 to 10 cm/min. The wavelengths of the waves appeared to be related to the scales of wind turbulence.

Ripples have lengths typically several centimeters, height in millimeters, and move with speeds of a fraction of a cm/min. They form under light wind conditions.

FIGURE C-8(a-f). Varieties of Wavy Features. (a) Ripples, (b) Sastrugi, (c) Pits (in Antarctica), (d) Longitudinal dune (in Antarctica), (e) Snow barchan (in Antarctica), (f) Snow-waves. (Kobayashi and Ishada 1979)

BARCHANS, DUNES, SASTRUGI, AND PITS

Barchans and dunes are depositional features, analogous to the same typical forms occurring on windblown sand fields. Barchans are arc-shaped forms, likely to be found in various sizes with winds of around 5-8 m/s (Koenig 1962). Barchans were observed by Kobayashi and Ishida (1979) to form a minimum 1-meter height wind speed of 11 m/s, and their speed of travel was about 3 cm/min. Dunes or ridges are longitudinal forms associated with strong winds, as are common during cyclonic storms or blizzards. Their sizes and shapes also vary from small to long and from linear to diffuse, depending on abundance of snow cover. According to Kobayashi and Ishida (1979), dunes began to form when 1-meter height winds exceeded 15 m/s.

Sastrugi and pits indicate erosion of the snow surface. Sastrugi are aligned along the wind direction, and move, as observed by Kobayashi and Ishida (1979), with speeds of about 1 cm/min. Sastrugi and pits occur with wind speeds somewhat higher than those associated with ripples.

RECOMMENDATIONS AND CONCLUSIONS

Repeated observations over a time period of years in a given area of similar snow cover distribution relative to topography, and of the same characteristic microrelief (waves, dunes, barchans, etc.) can provide some indication of the speed and direction of the surface winds predominating in the area during the snow season. Thus, for a first look in a limited, specific, snow-covered region chosen for further investigation in wind power prospecting, it is probably adequate to make several surface observations by aerial photography extending over a number of years on scales and altitudes appropriate for detection of small-scale relief. For a closer examination of a given, smaller area which appears to contain promising wind power sites, it is useful to make several observations within the same seasons. In addition, good general knowledge of the areas climate, the general meteorological conditions and their variation over the year is desirable, especially the most probable wind conditions and the frequency or probability of occurrence of heavy snowfalls or snow storms. It would be

valuable, in particular, to know the time elapsed since the most recent occurrence of appreciable snowfalls with each observation, and/or to time a number of successive observations to be performed over intervals of hours or days immediately following a heavy snowfall, preferably with a few on-site visits. This would make it possible to monitor short-term and/or longer-term changes in the physical properties or shape of the snow surface, including movement, if any, of specific features (waves, dunes, barchans, etc.) that may have formed. Thus, some indication could be obtained of the probable time scales (hours, days, weeks) of susceptibility of snow to wind redistribution in the area, and hence the probability of a given remote snow surface observation as representative of wind conditions at the time of the observation.

Extensive, reasonably accurate snow depth measurements are fairly laborious, as are any methods requiring ground level information, and the information obtained is probably not important enough to warrant the effort. However, a photogrammetric method giving terrain elevations and snow depths of accuracies within about 0.3 m is possible, and is described by Cooper (1965). Possible techniques for remote observation of physical properties of snow surfaces, particularly wetness and temperature, are discussed by Meier (1975).

Following all possible positive evidence that can be gathered from snow surface observations, direct on-site wind measurements at one or more selected sites may then be undertaken for an appropriate length of time for the final verification of conditions favorable for harnessing wind power.

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APPENDIX D

ON REMOTE SENSING OF SURFACE WINDS OVER WATER WITH EMPHASIS ON APPLICATIONS TO WIND POWER PROSPECTING

APPENDIX D
ON REMOTE SENSING OF SURFACE WINDS OVER WATER
WITH EMPHASIS ON APPLICATIONS TO WIND POWER PROSPECTING
by Gudrun Bodvarsson

INTRODUCTION

In addition to various other scientific and practical applications, methods of remote detection of surface winds over oceans and lakes, as well as over land, are fundamental to regional wind prospecting. Unlike land, natural water surfaces possess features which are quantitatively indicative of strength and general direction of surface winds prevailing at the time of observation. These wind-related properties are: the small-scale surface waves; ripples and corrugations ("roughness"); and, when winds are strong, the extent of the surface foam cover. Sea surface temperature distributions may also indicate wind-related ocean circulations due to characteristic regional wind fields. By means of photographic detection or radiometric measurements of surface roughness and foam coverage, winds near the surface may be estimated, even to spacecraft altitudes, within a couple of meters/second, and its general direction to within a few tens of degrees. Remote detection of surface winds over water may be important not only in assessing the wind potential over the water-covered areas but also in assessing the wind power potential along adjacent shorelines where surface wind conditions may be similar.

Techniques or methods employed in remote-surface wind sensing over water are microwave and infrared radiometry and scatterometry, performed from U-2 aircraft or spacecraft; and for relatively low altitudes, aerial photography of the water surface. Scatterometric techniques are sensitive essentially to surface roughness; surface photography and radiometric measurements are sensitive to the effects of both roughness and foam cover.

THE RELATIONSHIP BETWEEN WINDS, SURFACE WAVES AND FOAM COVERAGE

The familiar wavy character of surfaces of oceans and lakes bears the well-known evidence of wind action. Winds exert stress on the

air-water interface, transfer energy across it and give rise to the generally broad spectra of surface waves typically observed over the oceans. Winds are also ultimately responsible for the ocean-wide surface currents. Ocean waves range in lengths from a few centimeters (i.e., capillary waves) to sometimes hundreds of meters (such as long gravity waves); heights vary, respectively, from a few millimeters to several meters. Under strong wind conditions there is usually vigorous wave breaking, and the sea surface is more or less covered with foam; the air-filled patches and streaks of froth or "white water" result from the wave breaking.

Waves

The state of the sea, i.e., the spectrum of waves observed at any time at any point on the ocean surface, depends on the surface wind field, both at and previous to the time of observation. A prominent presence of relatively short and steep surface waves implies recent wind action and wave generation within the area or nearby. If centimeter-scale capillary waves and wavelets are conspicuously present, there is invariably significant surface wind action, and frequently, active growth of a wave spectrum is taking place. However, a predominance of long gravity waves, (such as the smooth swell observed on open seas or breakers on shores on either calm or windy days) indicates the presence of the characteristic longest-lived, farthest-traveled remnants of decaying wave spectra, which may have been generated thousands of kilometers away. Characteristically, short sea surface waves are generated in a short time; they grow faster and attenuate more rapidly after wind action has ceased than do longer wave components. They also propagate with lower phase velocities than longer waves, and a spectrum of ocean waves moving predominantly in a given direction tends to become dispersed in a short time, with the longer components moving ahead of the shorter ones. Thus shorter waves are relatively conspicuous in developing wave spectra, while long waves tend to predominate in decaying ones. Generally, an observed ocean wave spectrum may contain wave components of many origins.

The typical development of a sea wave spectrum being actively generated by a surface wind of uniform strength, which has persisted for a certain minimum length of time in a region of a minimum length (fetch), begins with the rapid growth of short wave components of the spectrum, followed by gradual and slower development of increasingly longer waves. The longer wave components receive much of their energy from shorter waves. The shortest waves of the spectrum quickly reach their maximum amplitudes. However, the growth in height continues more slowly among longer wave components, until the wave spectrum reaches the "fully developed" state. The fully developed state is characterized by a maximum at a certain wave length or frequency which is dependent on the wind speed. The saturated "equilibrium range" occupies most of the spectrum on the high-frequency side of the peak, and follows a characteristic decrease with the inverse fifth power of the frequency. The "undersaturated" low-frequency region of the spectrum could attain greater heights if the energy transfer from the wind were increased. During growth of a wave spectrum there is movement of the peak towards lower frequencies and, in general, the stronger the winds, the lower the frequency at the peak of the fully developed spectrum (see Figures D-1a and D-1b).

Duration times and fetches required for fully developed seas and wind speeds in oceanic regions are, as indicated in Table D-I, generally of the order of several hours, or tens of hours, and hundreds of kilometers, respectively. In the fully developed state the rate of energy transfer to the surface by the wind is balanced by an equal rate of dissipation by the surface waves; the dissipation is accomplished essentially through wave breaking.

The process by which ocean waves are generated is believed to be a combination of a "resonance" mechanism proposed by Phillips (1957) and an "instability" mechanism suggested by Miles (1957). The former is a resonance forcing by wind-advected turbulent air pressure fluctuations moving in phase with certain of the wave components whose phase velocities correspond to the motion of the pressure fluctuations. That mechanism is most effective for the waves in their initial stage of development. In

Sea—General		Wind				Sea				
Sea State	Description	Wind Force (Beaufort)	Description	Range (knots)	Wind Velocity (knots)	Wave Height (Feet)			Minimum Fetch (nmi)	Minimum Duration (hours)
						Average	Significant	Avg. to Highest		
0	Sea like a mirror	0	Calm	<1	0	0	0	0	...	...
	Ripples with the appearance of scales are formed; but without foam crests	1	Light Air	1-3	2	0.05	0.08	0.10	5	18 min
1	Small wavelets, still short but more pronounced; crests have a glassy appearance, but do not break	2	Light Breeze	4-6	5	0.18	0.29	0.37	8	39 min
	Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	3	Gentle Breeze	7-10	8.5	0.6	1.0	1.2	9.8	1.7 hrs
2	Small waves, becoming larger; fairly frequent white horses	4	Moderate Breeze	11-16	10	0.88	1.4	1.8	10	2.4
					12	1.4	2.2	2.8	18	3.8
3					13.5	1.8	2.9	3.7	24	4.8
					14	2.0	3.3	4.2	28	5.2
4	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray.)	5	Fresh Breeze	17-21	16	2.9	4.6	5.8	40	6.6
					18	3.8	6.1	7.8	55	8.3
5	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray).	6	Strong Breeze	22-27	19	4.3	6.9	8.7	65	9.2
					20	5.0	8.0	10	75	10
6	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. (Spindrift begins to be seen)	7	Moderate Gale	28-33	22	6.4	10	13	100	12
					24	7.9	12	16	130	14
7	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well marked streaks along the direction of the wind. Spray affects visibility.	8	Fresh Gale	34-40	24.5	8.2	13	17	140	15
					26	9.6	15	20	180	17
					28	11	18	23	230	20
					30	14	22	28	280	23
					30.5	14	23	29	290	24
					32	16	26	33	340	27
					34	19	30	38	420	30
					36	21	35	44	500	34
					37	23	37	46.7	530	37
					38	25	40	50	600	38
					40	28	45	58	710	42

TABLE D-1. Wind and Sea Scale for a Fully Developed Sea. (From Stogryn 1967)

FIGURE D-1a. Spectral Growth From a Flat Calm Ocean With a Wind of 40 Knots 19.5 Meters Above the Sea Surface. (From Pierson, Tick and Baer 1966)

FIGURE D-1b. The Low-frequency Intermediate and Equilibrium Ranges of the spectrum $\phi(\omega)$. Arrows indicate the direction of further development; the broken curve indicates the shape of the spectrum at a later time in a duration-limited situation. (From Phillips 1958b)

the latter type process, a pressure wake created on the lee side of a wave already formed acts to promote further growth of the wave. This mechanism is favorable to the growth of short waves of larger amplitude, moving with phase speeds lower than the wind velocity. At the extreme short end of the spectrum, ruffling of the surface by the wind triggers the development of small-scale capillary waves and wavelets, whose presence is observed to be increased at minimum wind speeds of about 6 to 7 m/s owing to the Kelvin-Helmholtz instability (Munk 1947). This phenomenon is also consistent with observations of a tendency for wave breaking and foam formation to increase abruptly at around those wind speeds (e.g. Nordberg et al. 1971). The "critical" wind speed for the occurrence of the Kelvin-Helmholtz instability may be observed to vary slightly, depending on the air-sea temperature difference (thermal stability) and the height of the anemometer. For example, increased surface roughness and wave breaking are often observed to occur at lower wind speeds in the winter than in the summer due to the thermal instability associated with the relatively warm ocean (Munk 1947). Wave breaking involves primarily the short-wavelength regions of the spectrum, and occurs generally at points of the sea surface where the slope and the vertical accelerations are high, such as when a shorter wave overrides a longer one.

Sea Foam

Sea foam occurs in distinct patches or "whitecaps" of varying size. They are a result of the breaking of individual waves. Sea foam may also occur as "streaks," which are elongated, thin, semi-opaque features, generally aligned in the direction of the wind. The distributions and orientations of foam streaks are due to convergence and divergence patterns at or near the surface associated with wind-induced circulations of the type described by, e.g., Langmuir (1938) and McLeish (1968). The fraction of the sea surface covered by foam may be assumed to be roughly proportional to the area-average mass of turbulent water or foam produced per unit time and area on the sea surface by the wave breaking. For a fully developed sea the residence time of foam is approximately equal to the rate at which

energy is received from the wind, and the foam coverage is a rough (linear) function of the surface wind speed. Observations of the relationship between surface foam coverage and surface wind speed by Ross, Cardone and Conaway (1970), are shown in Figure D-2. At winds less than 10 m/s, the foam coverage is negligible, or less than 1% of the sea surface. At appreciably higher wind speeds the foam coverage becomes significant. For example, at speeds of about 25 m/s foam coverage has been observed to be about 30% (e.g., Nordberg et al. 1971). In Figure D-2 there is a foam cover (both whitecaps and/or streaks) increase observed of roughly 0.5-1% with each m/s of wind for low to moderate winds (up to about 15 m/s); and at higher values

FIGURE D-2. Percent Foam Coverage Determined From the Brightness Temperature (T_b) Relationship Compared to Observations and to Semi-empirical Calculations. (From Ross, Cardone and Conaway 1970)

of the wind velocity it increases at the slightly greater rate of about 2-4%/m/s. Foam streaks, which are generally absent at low wind speeds, begin to form at about 10 m/s; their area coverage relative to that of whitecaps increases with the wind speed as shown in Figure D-3 (Ross and Cardone 1974).

FIGURE D-3. Observed Ratio of Streaks to Whitecaps Versus Wind Speed.
 (From Ross & Cardone 1974)

In fetch-limited situations and generally underdeveloped seas, the energy dissipation by the waves will be somewhat less than the energy transfer by the wind to the ocean surface; the foam cover will not have reached its maximum extent possible for that wind strength. Foam coverage observations may thus be expected to yield wind speeds somewhat lower than those of the actual winds at the surface. Dependence of (whitecap) foam cover on fetch and wind speed for duration-limited situations, according to Ross and Cardone (1974), is shown in Figure D-4. It is seen that a surface wind speed of 22.5 m/s requires a fetch of at least 600 km for the maximum foam coverage of 22%.

The foam cover that would be created on the surface of a fresh water lake for the wind speed would be considerably less than that over a sea surface, owing to differences in salinity. Sea water foam contains a greater number of smaller, more slowly rising air bubbles, and it resides longer on the surface than fresh water foam (Monahan and Zietlow 1969b). Fresh water foam begins to form at wind speeds of about 7 to 8 m/s roughly

FIGURE D-4. Predictions of Whitecap Density Versus Fetch for Duration Unlimited Conditions. (From Ross and Cardone 1974)

similar to sea water foam, and Monahan and Zietlow (1969b) observe a "time constant" of 2.54 sec for fresh water foam as compared to 3.85 sec for sea water.

The portion of the wave spectra on the surfaces of oceans and lakes most related to wind speeds are the shortest waves and ripples of lengths (3-5 cm.). These shortest waves are generated by the wind and dissipated in its absence very quickly. The distribution of their heights and lengths, or sea slopes, is sensitive to wind speed for low to moderate winds. Root-mean-square (rms) values of sea surface slopes vary roughly as the wind speed (see Figure D-5) up to about 14 m/s (Cox and Munk 1954). Above 14 m/s the effect of the wind on the surface roughness grows and foam cover increases significantly for stronger winds. Both surface roughness and foam coverage can be detected quantitatively by photography, radiometric or scatterometric measurements and wind speed and directions can be estimated. Supplementary observations on ocean wave spectra may also be useful for

FIGURE D-5. Mean Square Slope Components and Their Sum as Functions of the Wind Speed, W , Measured 41 Feet Above Sea Level. (Open circles and continuous regression lines for clean surfaces; solid circles and dashed lines for slick surfaces.) (From Cox and Munk 1954)

purposes of determining if a sea is fully developed. The energy dissipation rate indicated by the foam coverage represents the rate of energy input and thus the strength and duration of the wind.

PRINCIPLES AND METHODS FOR REMOTE SURFACE WIND DETECTION

Methods applied in the remote sensing of surface winds over water generally employ aerial photography or microwave and infrared measurements performed at various altitudes by means of airborne or spaceborne sensors. Remote detection of surface winds over the oceans by aerial photography involves estimation of the strength of surface winds from observations primarily of the sea surface foam coverage, and occasionally, from the surface roughness as inferred from sun glitter. These are carried out with relatively simple equipment, typically at low aircraft altitudes, and are best suited for local surveys. Microwave and infrared techniques, on the other hand, require more specialized sensors and sensor systems. However, they are operable over a wider range of altitudes and permit rapid and efficient scanning of the general surface wind conditions over more extensive areas, such as those normally carried out by spacecraft.

Aerial Photographic Methods

Probably the simplest and most economical techniques of relevance to wind power prospecting are visual and/or photographic observations of the sea state for inferring the strength of prevailing surface winds. Under conditions of appreciable winds, rough estimates of the wind speeds, and frequently, the general wind direction, may be deduced from observations of the coverage and character of the sea surface foam. As previously discussed, approximate relations have been developed between wind speed and sea surface foam coverage (see Figures D-2 through D-4). On photographs taken at aircraft altitudes (300-500m) individual foam patches may be delineated by e.g. color densitometry. The fraction of the foam-covered sea surface may be estimated by, for example, excision and weighing of "cut-outs" of the photograph images; a technique used and described in greater detail by Monahan (1969a). An approximate value of the wind speed (normally based on

averages of several photographs) may then be inferred from the estimated foam or whitecap coverage and the wind speed-foam cover relation. Foam streak alignment may also give a rough indication of the general wind direction.

Under conditions of fairly clear weather and when surface winds are weak, rough estimates of the wind speed and direction as well may alternatively be obtained from observation of sun glitter cast by the water surface. Useful empirical relations between wind speed and surface roughness in terms of sea surface slope statistics have been derived by Cox and Munk (1954) from observation of sun glitter over the ocean near Hawaii with calm to moderate surface winds. Ocean surfaces are practically never specular; they always possess more or less of a wavy form. A light beam incident upon a small area of the wind-roughened sea surface will be reflected and scattered in various directions, depending on the lengths, amplitudes and orientation of the surface waves, as well as the angle and direction of the incident (solar) light beam. The most familiar observation on water surfaces is the appearance, due to the surface waves and undulations, of the sun's image to an observer as thousands of "bright lights," each arriving from a point of the surface where the slope is just such as to reflect a ray incident from the sun towards the observer. The sun glitter is nearly always spread out diffusely over an area somewhat larger than that which would be occupied by a perfectly specular image; the spread of the glitter depends directly on surface roughness. The further each bright light is from its ideal specular point the rougher the surface and steeper the wave slopes.

By densitometer analysis of the brightness of the sun glitter appearing on photographs taken of the sea surface at various (known) angles with respect to the sun, Cox and Munk (1954) obtained upwind/downwind and crosswind root-mean-square (rms) surface slopes, their spectral distributions and relations to the wind speeds at 12.5 meters above the surface, as shown in Figure D-5 and D-6. The rms slopes are seen (Figure D-5) to attain maximum values (of about $\tan^2 16^\circ$) for a wind speed of about 14 m/sec and above. For wind speeds 5 to 10 m/sec, the slope spectra (Figure D-6)

FIGURE D-6. Period Spectra of Variance of Sea Surface Elevation (Upper Panels) and of Slope Regardless of Direction (Lower Panels). (Solid lines for clean surfaces; dashed lines for slick surfaces.) (From Cox and Munk 1954)

indicates that the highest values (steepest slopes) are associated with the shortest waves (i.e., waves with periods less than a few seconds).

Microwave and Infrared Methods

Microwave and infrared techniques applied in the remote sensing of surface winds exploit the characteristics by which wind roughened, foam-covered water surfaces emit, reflect and scatter at these longer (infrared and microwave) wavelengths of the electromagnetic spectrum. Radiation in the microwave and infrared regions, (with wavelengths on the order of centimeters and microns), emerges from the ocean surface as a result of both infrared emission and pure scattering and reflection. The reflectivity and scattering characteristics of the water surface depend strongly on its wind-related properties (i.e., foam coverage). Estimates of the surface wind speed from surface roughness or foam coverage may also be obtained by the often called "passive method" of measurement of microwave radiation received from the surface. On the other hand "active" methods are those by which measurements are made of the radiation back-scattered and reflected upon illumination of the surface with a microwave beam. The remote detection of the surface properties related directly to the wind speed (i.e., roughness and foam cover) is accomplished generally by microwave measurements. However, with passive methods, measurements of infrared radiation are often performed simultaneously to obtain the sea surface thermometer temperature, generally required in the interpretation of the microwave measurements.

The earth's surface, including the oceans, receive the predominantly visible and infrared portion of the environmental radiation directly from the sun and diffusively from the sky. A significant amount of this electromagnetic energy is in turn reflected and scattered back towards the sky by the earth's surface. Microwave radiation, which constitutes a very minor portion of the environmental radiation, undergoes reflection and scattering at the ocean surface in a manner analogous to that of visible light, similarly dependent on the surface roughness as well as the extent of the foam cover. Unlike for visible light, a significant proportion of the radiation in the microwave and infrared ranges is due to thermal (blackbody) radiation by the surface, rather than reflection and scattering. Any surface such as the oceans radiates electromagnetic energy somewhat like a

blackbody. For an "imperfect" blackbody, like the ocean, the fraction of blackbody radiation is defined by the "emissivity" in accordance with Planck's law which gives the energy density of (monochromatic) radiation at any given wavelength as a unique function of the absolute temperature ($^{\circ}$ Kelvin) of the surface or object. This function is characterized by a peak value of the radiance at a wavelength which is dependent on the temperature, and the value of that wavelength is smaller (larger), implying higher (lower) energy of the blackbody radiation for higher values of the temperature. Temperatures at the earth's surface and lower atmosphere are on the order of 300° K, at which the wavelength of maximum thermal (blackbody) emission lies in infrared wavelengths, while in contrast, the temperatures of the outer layer of the sun radiating energy into space, is several thousand degrees, such that the solar radiation received by the earth is predominantly in the visible range. The microwave portion of the radiation emerging from the ocean surface, containing these contributions from both thermal emission and that due to scattering and reflection, is known as the "apparent brightness temperature," (i.e., the equivalent radiance blackbody temperature; sometimes given in terms of the apparent emissivity), of the (ocean) surface. The intensity of the brightness temperature and its variation with the angle from the vertical is related to the surface roughness and foam coverage, such that, given the thermometric temperature of the ocean surface and the brightness temperature of the overhead sky, the wind speed may be determined from passive radiometric measurements performed at specific values or ranges of nadir angles. The surface roughness - dependent variations with angle from the vertical differ for the two (horizontally and vertically) polarized components of the microwave brightness temperature. The horizontally polarized component is characteristically sensitive to the roughness effects over the range of angles from about 30° to 70° from the vertical, with a maximum sensitivity occurring at about 50° (see Figures D-7a, D-7b and 8-D). The vertically polarized component, on the other hand, does not show such dependence. According to observations (Figure D-8) by Hollinger (1971) and theoretical results by Stogryn (1967), there is an approximate linear increase in brightness temperature for the

FIGURE D-7a. Temperature of Horizontally Polarized Radiation as a Function of Angle (Upwind Case). (From Stogryn 1967)

FIGURE D-7b. Temperature of Vertically Polarized Radiation as a Function of Angle. (From Stogryn 1967)

FIGURE D-8. Measurements at 1.41, 8.36 and 19.34 GHz of the Vertical and Horizontal Components of Brightness Temperature and the Percentage Polarization, Defined as the Ratio of the Difference of These Two Components to Their Sum, at 55° Incidence Angle, Plotted Versus Wind Speed (From Hollinger 1971)

horizontally polarized microwave components on an order of about 0.4 to 1.0°C per m/s of surface wind speed for nadir angles of about 55°; depending slightly on the microwave frequency.

At wind speeds well above 15 m/s, the surface increasingly attains emission characteristics associated with foam in proportion to the amount of foam coverage. Foam has a higher emissivity than the foam-free water surface, and the apparent brightness temperature increases further beyond that due to roughness alone. Foam-induced increases in brightness temperature over that due to roughness may be observed at nadir angles where the brightness temperature of a rough foam-free surface would be the same as that of

a specular surface, whereas it would be higher if the surface were foam-covered. The emissivity of foam increases with the foam thickness (see Droppelman 1970).

Variations with nadir angle of horizontally and vertically polarized components of foam-induced microwave brightness temperature, as given by Stogryn (1972), are shown in Figures D-9 and D-10. Figure D-10 is from observations in a surf zone. Increases in brightness temperature due to foam are generally of an order of 1.0°C per 1% foam coverage (Figure D-11), or about 1.0°C m/s of wind speed (see Ross, Cardone and Conaway 1970) for fetch-limited conditions.

FIGURE D-9. Emitted Temperature of Foam at 19.4 GHz. (From Stogryn 1972)

FIGURE D-10. Brightness Temperature of Surf Zone at 37 GHz. (From Stogryn 1972)

FIGURE D-11. Percentage Foam Cover Versus Brightness Temperature. Linear relation inferred from observations. (From Ross, Cardone and Conaway 1970)

With the active methods the sea surface is illuminated with a polarized beam of controlled intensity and frequency over a range of nadir and azimuth angles. Measurements can be made of the return signal resulting from the surface backscattering. With sufficient energy of the emitted beam, measurements may be performed over a wide range of altitudes requiring only that attenuation of the microwave radiation due to absorption by the atmosphere, be taken into account. Such techniques permit estimation of both the approximate speed and direction of the surface winds. In general rough surfaces are characterized by less reflection or backscattering of vertically incident microwave radiation than smooth surfaces. However, for rough surfaces more backscattering tends to occur for illumination at other angles. Figure D-12 and D-13 show results of backscattering cross sections obtained from theoretical calculations as well as data for 14-16 knot (7-8 m/s) winds (Figure D-12) and 23-26 knot (12-13 m/s) winds (Figure D-13).

FIGURE D-12. Backscattering Cross Section For (a) Vertically Polarized and (b) Horizontally Polarized Emission Characteristics at 8.91 GHz. (From Wu and Fung 1972)

FIGURE D-13. Backscattering Cross Section (a) Vertically Polarized and (b) Horizontally Polarized Emission Characteristics at 8.91 GHz. (From Wu & Fung 1972)

Observation of reflection of incident infrared radiation by a water surface have been made by Petri (1977). As shown in Figure D-14, an "effective average" reflectance was obtained for vertical illumination of a water surface (at Chesapeake Bay Bridge Facility, 18m above water) with a $1.06 \mu\text{m}$ laser beam. At higher altitudes their sensitivity is limited for shorter wavelengths due to atmospheric absorption effects. For wavelengths greater than about 6 cm, the wavelength of the microwaves begin to exceed the lengths of many of the wavelets contributing to the surface roughness.

Usually, high-altitude radiometric measurements are performed at infrared and microwave frequencies in order to provide correction for attenuation by the atmosphere as well as the ocean surface temperature. As indicated

FIGURE D-14. Average Effective Lambertian Reflectance Versus Wind Speed.
(From Petri 1977)

previously, microwave attenuation in the atmosphere and sea surface temperature (for passive methods) must be known in order to determine sea surface roughness, foam cover and surface wind speeds from microwave data. Infrared radiometers are very sensitive to temperatures of the earth's surface and atmosphere. Data on sea surface temperatures are sometimes useful for their own sake, as sea surface temperature distributions may be indicative of the presence and influence of characteristic wind fields on the movement of water at and beneath the surface. For example, the relatively cool surface waters just offshore along the west coasts of the United States and Peru are the result of upwelling of cooler water from depths below driven by strong, persistent long-shore winds.

Ocean wave spectra and wave statistics may be obtained by remote measurements with (continuous-wave or discrete-pulse) profilometers or altimeters; or by means of imaging radars (e.g. "synthetic aperture radars"). Profilometers or altimeters operated aboard aircraft or spacecraft at microwave or infrared frequencies, measure variations of surface heights along a given track of the surface from which wave spectra are obtained. The motion of the aircraft with respect to that of the surface wave components and noise in the data due to pitch and roll accounted for and filtered out. Imaging radars provide two-dimensional surface height fields, from which wave spectra are obtained by Fourier analysis techniques.

SEASAT Sensors and Sensor Systems

The present day's technology permits rapid and efficient collection of large amounts of data on surface winds and other geophysical parameters on global scales via satellite. Sensors and sensor systems employed on satellite missions include active and passive devices for measuring radiation in the spectral regions from visible light to microwaves. They are operated simultaneously at several different frequencies, through each frequency providing data necessary or complementary to data obtained at other frequencies. The data gathered by the satellite-borne sensors is transmitted to the earth for processing and extraction of information.

A recent comprehensive collection of ocean-related data was undertaken on a global scale in 1978 by SEASAT through NASA's Jet Propulsion Laboratory. The satellite was launched in June, 1978, encircled the earth 14 times daily for 3 months at an altitude of about 800 km, covering 95% of the global oceans every 36 hours. The spacecraft carried sensors to obtain data on surface wave heights, internal waves, sea surface temperatures, atmospheric water, sea ice features, and ocean topography. The on-board sensor systems consisted of a SEASAT-A scatterometer system (SASS); a scanning multichannel microwave radiometer (SMMR); a radar altimeter (ALT); a synthetic aperture radar (SAR); and a visible and infrared radiometer (VIRR). Data for the deduction of surface winds were obtained by the SASS and the SMMR.

The SASS is an active microwave wind sensor, which illuminates the

sea surface with four fan-shaped beams; two octagonal beams, each 500 km wide, on each side of the SEASAT groundtrack. It transmits with a frequency of 14.6 GHz (wavelength 2.1 cm) and measures a return signal, slightly Doppler-shifted, with a spatial resolution of about 50 km over a region of 200 to 700 km on either side of the spacecraft. Surface winds are determined to within about 2 meters/second for the range from 4 to 26 m/s, and the general wind direction to about $\pm 20^\circ$. The SMMR, designed to measure primarily sea surface temperatures, operates at frequencies 6.6, 10.7, 18.21, and 37 GHz (wavelengths ranging from 4.5 to 0.8 cm) for both horizontal and vertical components of radiation. The SMMR scanned the right side of the spacecraft with a swath width of about 600 km, and had a spacial resolution of about 100 km for 6.6 GHz to about 22 km for 37 GHz. It measured sea surface temperatures with an accuracy of about $\pm 0.5^\circ\text{C}$; surface wind speeds to about ± 2 m/s within the range of about 7 to 50 m/s and, in addition, liquid water and water vapour, which were used in part as corrections for atmospheric attenuation for the SASS. The ALT is a short-pulse (3-nsec) nadir-viewing altimeter, operated at 13.5 GHz with swath widths from 2.4 to 12 km, depending on the sea state. It measured heights with a precision of about 10 cm for sea states less than 20 m, and was able to estimate significant wave heights to within ± 0.5 m, or 10%. The SAR, an imaging radar, was operated at 1.275 GHz, looking to the right side of the satellite at an angle centered at 20° off the nadir. With a swath width of about 100 km and a spacial resolution of about 100 km, the SAR measured ocean wave spectra to wavelengths more than 50 m, and was also able to recognize sea ice features, icebergs, land-water boundaries, and could penetrate to the surface through major storms. The VIRRR, sensitive to visual light from 0.49 to 0.94 μm and infrared radiation from 10.5 to 12.5 μm , provided information on cloud conditions and surface and cloud top temperatures. The SASS and the SMMR operated nearly continuously throughout the mission; the VIRRR nearly continuously for about two months, and the ALT only intermittently with a total of about 70 days of data collection.

CONCLUSIONS AND RECOMMENDATIONS

Surface winds can be remotely detected and estimated over oceans and lakes by methods involving aerial surface photography, or airborne or spaceborne infrared or microwave radiation measurements. Remote sensing of surface winds is possible by the quantitative detection of surface small-scale roughness and foam coverage. Both these surface properties are related to the prevailing wind speeds; surface roughness by its characteristically short time scales of response to the wind, and foam coverage by its relationship to the rate of energy transfer and dissipation at the water surface. The reliability and accuracy of wind estimates by the various methods discussed would be well within requirements of wind energy prospecting purposes.

Choices of methods in practice depend essentially on information and technical means available; dimensions of areas to be assessed; time and cost of operations or labor, etc. When rapid, efficient and preferably inexpensive scanning of surface winds in a large region is needed, (distances e.g. thousands of kilometers), as for example in the initial stages of wind power prospecting on a regional or global scale, a preferred first step would be the acquisition of pertinent data or information already available from e.g. previous satellite missions, and other sources (References on partially released results from the SEASAT mission in 1978 may be obtained in Science, 204(4400) 1979.) Useful information accompanying data on surface winds would include synoptic surface and/or low-level air pressure charts, because these, owing to relationships to corresponding geostrophic wind fields, particularly over open areas such as the oceans, could serve as useful guides in inferring or assessing the probable wind conditions in data-sparse areas, as well as variations of the wind fields in time.

When little or no surface wind information exists for a given region, surface winds (qualitative) may be readily determined from aircraft observations of the conditions of an ocean surface. In wind power prospecting only areas of significant wind strength, as indicated by e.g. appreciable foam cover, are likely to be of interest and warrant further consideration. These can be immediately identified either visually or

from photography. A foam-free water surface (sea or lake) indicates, as previously indicated, wind speeds below about 6 or 7 m/s; for slight, barely visible foam cover (less than 1%), winds are probably between 6 to 10 m/s, while a conspicuous foam cover in the order of 10-20% would be associated with quite strong wind speeds of 15-25 m/s.

In only moderately large areas (i.e., hundreds of kilometers) chosen for more careful investigation, a semi-quantitative remote sensing of surface winds will be performed at a number of points, chosen so that adequate information is obtained on the surface wind field in the area. Measurements or observations are generally carried out via aircraft, and are repeated and extended sufficiently in time so that information on the time variability of the wind field is obtained. Once a reliable assessment has been completed on the basis of remote detection methods of the general surface wind conditions, including its strength, general direction and seasonal or other characteristic time variations for the area of interest, extensive ground-based measurements of surface winds may then be undertaken at promising candidate sites before final selections are made for wind power utilization.

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APPENDIX E

A STUDY OF APPARENT WIND RELATED SURFACE FEATURES
IN THE HIGH DESERT OF SOUTH CENTRAL OREGON

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A STUDY OF APPARENT WIND RELATED SURFACE FEATURES
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by Peter A. Maule

INTRODUCTION

Oregon State University is testing various remote sensing resource survey techniques for wind power development. On 27 May 1982, a fixed wing aerial reconnaissance-photographic mission through the high desert of northern Lake County in south central Oregon was conducted. This report describes the purpose of that survey, the procedures used, conclusions of the survey, and recommends further work.

PURPOSES

The purposes of this study flight were at least four-fold: 1) To generally expand knowledge of eolian processes in arid environments, with hope that these processes might further remote sensing for wind power siting; 2) To become familiar with this area because it is close, and we have an existing wind data base for the area; 3) To identify and locate eolian features for further study and can be reached by ground surveys; and 4) To test one hypothesis in particular that had arisen from the combination of observations of high-level infrared imagery (NASA U-2 false color infrared images, 1:135,000 scale) and casual observations made on earlier travels through the area. The hypothesis was: the morphogenesis (evolution of shape) of lakes could be influenced by prevailing winds. Should this be substantiated, it should assist local and regional stream flow analyses of surface winds, using shorelines observed both in the field and/or in remote sensing imagery at most scales.

PROCEDURE

Each member of the crew was equipped with a 35 mm camera and various types of slide film. One camera, with a telephoto lens, was equipped with high-speed Ektachrome slide film because of motion problems associated

with long lenses. The crew left Corvallis, Oregon (#1), in a previously contracted fixed-wing Cessna-172. (Numbers, e.g. #1, refer to successive points illustrated on map of flight route, Figure E-1.) The plane was

FIGURE E-1. Map of Oregon. Numbers locate features described in text, progressing along survey flight path.

refueled in Albany (#2), and proceeded southeast, across the Cascades to the northwest corner of Lake County (Figure E-2).

The first notable feature (#3) is known as "Hole in the Ground," a 3-mile wide phreatic crator, i.e., an explosive steam eruption scar caused by molten material surfacing in a large shallow lake (Figure E-3). The symmetry of the crator and the uniformity of geologic material diminishes the variable causes of local vegetation distributions. We thus hoped to isolate evidence of wind influence. However, north slope versus south slope exposures apparently are the prevailing micro-climatic causes for the distribution of the Ponderosa pines and junipers in the area, with alkali-tolerant rabbit brush in the floor of the crator. Trees did not appear flagged by

FIGURE E-2. Detail of U.S.G.S. 1:500,000 Shaded Relief Map of Oregon, Illustrating the Location of Most Features in Northern Lake County, Oregon Described in Text

FIGURE E-3. Eastward View of "Hole in the Ground," Fort Rock Visible in Upper Right Distance

present day winds nor was evidence of winds at the time of eruption (12-10,000 years ago) observed.

The flight path proceeded eastward about 15 miles to another landmark of the Oregon high desert, Fort Rock (#4) (Figure E-4). Fort Rock is the remnant tephra core of a volcanic cinder cone that erupted in the same post-Pleistocene lake as did Hole in the Ground. The softer surrounding

FIGURE E-4. Northward View of Fort Rock. Note dark shadow of wave terrace incised into base of southwest facing cliffs, lower left.

cinder cone was subsequently eroded away. Clearly observable from the air is a combination of details that illustrate how the cone and remaining core were apparently eroded by wave action from a southwest direction. The remnant wave terrace is most prominently incised into the southwest facing cliffs. This erosive action also caused the core to be breached on the south side. The remnant of a deposition bar extends towards the northeast, which would have been on the lee side of the island of Fort Rock. The lineation of these combined features clearly illustrates that for the duration of the lake, 13,000-8000 years before present, prevailing winds were from the southwest at this location.

The next area investigated was the Christmas Lake Valley (#5). Easily observable from the air is a relic erg, (large area of sand), with vegetated, complex longitudinal dunes facing generally east (Figure E-5).

FIGURE E-5. View from the Northeast of Stabilized Dunes at Fossil Lake

This erg lies in the northeast quadrant of the once lake-filled basin. In addition to the relic dunes there is a superimposed active dune field. Individual dunes within this active field are complexly shaped, showing seasonal wind shifts from the northwest to southwest (Figure E-6).

The flight then proceeded towards the southeast. A range fire scar of undetermined age was observed to have progressed and grown through the sagebrush ground cover from a westerly direction (#6) (Figure E-7).

Near the eastern border of Lake County is Alkali Lake (#7). Relic and active dunes of various types formed from the southwest were observed throughout the area. A landing was made to allow ground observations, but distances were too great and time too short to reach undisturbed dunes (Figure E-8). It was noted that the dunes seem to override an alkali pan. Back in the air it was observed that subsequent alkali deposits exist on

FIGURE E-6. View from the West-Southwest of Active Dunes at Fossil Lake

FIGURE E-7. View from the Northwest of Range Fire Scar

FIGURE E-8. Active Dune Slip Face in the Alkali Lake Area

lower slopes of relic dunes, indicating at least partial reflooding of the area since dune formations began to develop from the southwest. Also observed were the remnant high water shoreline of the post-Pleistocene lake that covered this region and the subsequent lower shoreline terraces as the lake retreated. The maximum water height of this lake reached at least 200 feet up on the presently arid local slopes. The continuity and extent of these shorelines are clearly observable, especially with the rapid and comprehensive view permitted from a flight such as this (Figure E-9). It became clear that southwest facing slopes of these successive shorelines were more severely and cleanly eroded while northeast slopes were more gradual and appeared to have overburdens of sedimentation.

The lowest of these remnant shorelines surrounds the immediate area of Alkali Lake; and in wet years it may still mark seasonal high-water levels. It was noted how the residual lake rests in the northeast quadrant of the closed concentric shorelines.

Our flight proceeded to the southwest, penetrating deeper into the basin-range province of northeast-southwest trending fault blocks. Among

FIGURE E-9. View from the Northeast of Relic Shoreline. Terraces of late Pleistocene lake on southwest facing slopes above Alkali Lake area.

those that came into view was the >2000-foot high Abert Rim, which dramatically emphasized how local surface winds would be topographically channeled in a northeast-southwest orientation. Alkali Lake and the area of features just described lie on the extended northeast axis of the graben (dropped fault block depression) that contains Abert Lake.

Numerous playas (seasonal dry lakes) were then observed. At one point, several could be viewed and compared at one time (#8) (Figures E-10 and E-11). A consistent trend in their appearance was confirmed by their shapes and distribution suggesting morphogenesis by persistent forces, at least since the Pleistocene. These playas, some small some large, are each found in the low point of their respective basin. While none of these playas illustrated evidence of fluvial (running water) erosion or deposition, it was apparent that each basin was more gradually sloped on the southwest quadrant and more steeply sloped on the northeast quadrant. Our flight occurred in a period of warming weather that followed substantial spring rains, allowing a vivid observation (Figure E-11). The color and tonal contrasts between lower wet soils and higher drier slopes showed clearly

FIGURE E-10. Numerous Playas from ~4,000 Flight Level

FIGURE E-11. Playas; Southwest is to the Right

that the lowest point of each of these depressions lies in the northeast half or quadrant of each respective playa. The longer, more gradual slopes extend to the southwest from the dark low points, while the slopes to the northeast proved invariably to be the steepest, even occasionally terraced. With one notable exception (explained later), this pattern was consistent even though underlying structural considerations were investigated. It should be pointed out that the entire region is a uniform, continuous distribution of Columbia River Basalt flows. The shaping of these playas has not resulted from the weathering or volcanic intrusions of or by differing lithic (rock) materials. The described pattern persists in level areas and in depressions that occur in variously tilted surfaces of uniform volcanic material. The persistent vector (from southwest to northeast) of playa morphogenesis appeared to be unrelated to the slope, structure or composition.

The one notable exception to the over-all pattern is Summer Lake (#9), which is probably the largest playa of south-central Oregon. This extensive body of water clearly rests in the southwest sector of its respective basin (clearly observable in LANDSAT images, Figure E-12). However, this anomaly to the otherwise consistent pattern of low points being in the northeast sector of observed playas, is clearly surface structurally induced. The low point of this graben (lowered fault block) lies against the talus slopes (loose rock debris at the base of a slope) of the upthrust cliffs of Winter Ridge (Figure E-13). These features, and their relationships, were clearly visible from the air.

Our flight crossed the extensive dune field that extends to the northeast from Summer Lake (Figure E-14). This erg (sand field), the largest in central Oregon, has been repeatedly stabilized by occasional re-growths of the nearby lake. Amongst these dunes that revealed various ages and degrees of stabilization, the pattern of remobilizations appeared to be consistently from the southwest.

Our flight then headed to the northwest, passing to the east of Silver Lake (#10). It was an earlier observation of this lake on high-level NASA U-2 reconnaissance imagery that gave rise to the question of patterns of eutrophication. In the eutrophication (aging) of the lake, the shrinkin

FIGURE E-12. LANDSAT View of Study Area; north is to Upper Left. Summer Lake is in lower center, its associated dune field extending northeast. Fossil Lake (playa) dunes are in upper center. Note many white areas of numerous playas.

FIGURE E-13. Looking Southeast Past the North End of Winter Ridge, Summer Lake is in the Background

FIGURE E-14. View from the South of Summer Lake. Note alkali deposits amongst dunes.

body of water has remained deepest in its northeast sector. In the years since the U-2 photograph was taken, the winters have been mild; and this basin of otherwise ponded snowmelt runoff has become a grazed grassland. Because of the cultural intrusion it was not further investigated.

Proceeding to the northwest the flight passed Table Rock Mountain, a flat-topped prominence, centrally located to this area of interest (#11). Road accessibility and communication facilities on top were noted as advantageous to possible future siting of an anemometer.

After about 6 hours of flying time a refueling stop was made at Bend, Oregon (#12) before returning to Corvallis (#1).

CONCLUSIONS AND RECOMMENDED RESEARCH

Preliminary wind data from south-central Oregon shows that present prevailing winds are from the southwest. This flight allowed comprehensive geographic observations that strongly indicate that southwest winds, strong enough to generate eroding waves against northeast shorelines and able to remobilize exposed unconsolidated sedimentary material into ergs and dunes, have persisted in this area for at least the past 13,000 years.

Eutrophication of lakes and playas appears to be strongly related to local prevailing wind patterns, where composition structure and fluvial influences do not otherwise dominate morphogenesis. The suspicion here is that consistent wave train development agitates downwind sectors of water bodies sufficiently to preclude precipitation of suspended materials in those areas and may even actively erode downwind shores. In contrast, upwind sectors experience sedimentation without erosion, resulting in more gradual and smooth slopes. Hence the down wind end of these water bodies is the last to fill.

The value of these observations for wind power prospecting purposes is twofold: 1) Where these processes are obviously presently active they may be used to infer regional surface wind and stream flow patterns; 2) Geologic evidence may record the persistence (in this case) or record changes in local wind regimes. This last conclusion relates these observations to the field study of pre-historic climatic changes.

Similarly, the sand hills of Nebraska have apparently been deposited for many millennia from wind gaps in the Rocky Mountains that today are recognized for their high wind power potential (Medicine Bow, Wyoming).

Stabilized, geologic evidence should not be discounted in wind power prospecting. While it is true that changing features of topography and ground cover may change best-case siting of maximum wind strengths and exposures at the earth's immediate surface, these changes can be heavily influenced by the wind itself. Furthermore, that local stabilization of eolian features may have occurred does not necessarily mean that wind regimes have been regionally, or even locally, altered. It may be that the local relief of dune formation causes a local separation zone of surface

wind flow (which retards saltation, i.e. surface particle movement by wind and accelerates further sedimentation and stabilization). Low-level anemometry in such areas should not be expected to reveal the wind speeds that produced stabilized dunes, because of the possible wind separation zones caused by the dunes themselves.

Suggested research takes several directions and involves separate disciplines which include: 1) The reciprocal effects of dune morphogenesis and local surface winds requires further quantifying field study; 2) Even though it appears obvious, as reported here, the relationship of playas and lake morphogenesis to local wind characteristics should be quantitatively established for the scientific record; 3) Detailed local ground survey studies of the areas described here should be made to further test the geological evidence of a continuous 13,000-year wind regime; 4) Wind power research is justified at numerous places throughout south-central Oregon, based on the evidence gained of existent significant winds.

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APPENDIX F

STEREO PHOTOGRAPHIC TECHNIQUES

APPENDIX F

STEREO PHOTOGRAPHIC TECHNIQUES

1. STEREO PHOTOGRAPHY

Complimentary oblique stereo aerial (COSA) photos were suggested by J.L. Rich in 1950. W.B. Hall of the University of Idaho has expanded and improved the technique and its use during the past twenty-five years. COSA photos are low to high oblique stereo photos where the optic axes of the stereo pair converge upon the same central point. Therefore, the fields from the two camera stations are approximately the same, or overlap 100%. The first photo of the pair is taken in a direction nearly perpendicular to the flight path of the aircraft (behind the strut if a high wing aircraft is used). Once the photo of the wind indicator is taken, the view is tracked precisely in the viewfinder until a second photo is made several seconds later. Time between exposures is determined by (1) the distance from the camera to the center of the field of view, and (2) the speed of the aircraft. Table F-1 has been compiled for use with 35 mm format cameras:

TABLE F-1. COSA Photo Guide

HEIGHT ABOVE GROUND-FT(M)	SHUTTER SPEED/TIME INTERVAL AIRCRAFT SPEED		LENS FOCAL LENGTH	FILM ASA
	> 80 KTS	80-100 KTS		
500-1000(125-300)	1/1000/1 sec	1/1000/1/2 sec	28-50mm	64-400
1000-2000(300-600)	1/500/1-3 sec	1/1000/1-2 sec	35-55mm	64-100
> 2000(> 600)	1/500/3+ sec	1/500/2+ sec	50-100mm	25-100

2. VERTICAL AERIAL PHOTOGRAPHS

Stereo-vertical photographs provide the simplest and most commonly used form of imagery for photogrammetric measurements. Both 35 mm and 70 mm film formats may be successfully employed to provide low-level vertical aerial photographs of wind power indicators. However, there is no simple,

consistent system of acquiring hand held vertical aerial photos. Larger format cameras should not be used at low altitudes unless they are commercial versions equipped with image motion compensation. Helicopters are rarely used for vertical aerial photography due to inherent vibration problems associated with attaching cameras to their airframes. However, several very low cost modifications may be made to light aircraft which provide excellent results.

As with COSA images, vertical stereo photography requires overlap of image area from two discrete locations. Ideally, the aircraft follows a straight and level flight path with a vertically aimed camera timed to trigger at time intervals allowing a photo to be taken which overlaps the image area of the preceeding photo by 60%. Of course, this requires that the altitude of the aircraft is adjusted for all wind conditions, and that the ground speed and height above ground level are precisely known. (See Figure F-1.)

FIGURE F-1. Vertical Stereo Photos Overlap the Image

Prior to a photo flight some map computations should be made to determine the correct parameters for successful stereo aerial photos. First, the wind prospector needs to identify the areas having the greatest probability of wind indicators (prominent ridgelines, mountain passes, sand areas, etc.) and to note their locations on maps. Secondly, he needs to connect these areas together to make an efficient photo mission. Items to be computed in preparing the photo mission are:

1) Flying height above ground level (AGL)

Select the scale of the photo most appropriate to the wind indicator to be photographed, then determine the lens you will be using (generally 50 mm, 100 mm, or 250 mm) and calculate the required height above ground level:

$$H_{AGL} = \text{focal length (m)} \times \text{scale denominator}$$

$$\text{Example: } 0.025\text{m} \times 2500 = 125\text{m AGL}$$

Since aircraft instruments read only in English units, convert the height in meters to feet: 125 m 410 feet

2) Flying height above mean sea level (MSL)

Break flight lines into segments whenever elevation changes of more than 100 m occur, then for each segment adjust the flying height by adding the elevation (in feet) of the target (TGT) area to the height above ground level.

$$H_{TGT} + H_{AGL} = H_{MSL}$$

3) Cycle rate (photo frames per second) (see Table F-2):

TABLE F-2. Aerial Photogrammetric Table (for use with 35 mm camera and 50 mm lens)

ALTITUDE (AGL) FEET	NEGATIVE SCALE	GROUND COVERAGE FEET	TIME INTERVAL BETWEEN EXPOSURES(sec)					
			60% OVERLAP			40% OVERLAP		
			SPEED MPH			SPEED MPH		
			100	110	120	100	110	120
500 ft	1:3,000	234 X 350	0.95	0.87	0.80	1.43	1.30	1.19
1000	1:6,000	469 X 700	1.91	1.74	1.59	2.86	2.60	2.39
2000	1:12,000	937 X 1400	3.82	3.47	3.18	5.73	5.21	4.77
3000	1:18,000	1406 X 2100	5.73	5.21	4.77	8.59	7.81	7.16
4000	1:24,000	1875 X 2800	7.64	6.94	6.36	11.45	10.41	9.55
5000	1:30,000	2344 X 3500	9.55	8.68	7.95	14.32	13.02	11.93
6000	1:36,000	2812 X 4200	11.45	10.41	9.55	17.18	15.62	14.32
7000	1:42,000	3281 X 4900	13.36	12.15	11.14	20.05	18.22	16.70
8000	1:48,000	3750 X 5600	15.27	13.88	12.73	22.91	20.83	19.09
9000	1:54,000	4219 X 6300	17.18	15.62	14.32	25.77	23.43	21.48
10000	1:60,000	4687 X 7000	19.09	17.36	15.91	28.64	26.03	23.86

The following formula may be used to calculate the number of frames per second required to achieve a specific overlap % for stereophoto coverage:

$$R = \frac{1.69 \times V \times f}{P \times H_{AGL}} \times \frac{100}{100 - \emptyset V}$$

where: R = Cycle Rate (frames/second)
V = Aircraft Ground Speed (knots)
P = Film format (inches)
H_{AGL} = Flying height (feet)
 $\emptyset V$ = Overlap percentage
f = Focal length

3. DETERMINING SCALE FROM OBLIQUES

Aerial photography for precise measurements, mapping, or other photogrammetric applications should be performed by specialized firms which have suitable equipment, aircraft, and experience in this field. However, there may be occasions when you must determine approximate scale from aerial oblique photographs. Obviously, this is more difficult than determining scale from verticals. Scale on a vertical photograph remains essentially the same for all portions of the print. Scale on obliques changes from the bottom of the photo to the top. To determine scale on a vertical, use the ratio of the focal length of the lens to the altitude of the aircraft:

$$\text{Scale} = \frac{\text{lens focal length}}{\text{altitude of aircraft}}$$

Thus, if you have a 100 mm (4-inch) lens on a 120 roll-film camera at 1,000 feet:

$$\text{Scale} = \frac{4\text{-inch (lens)}}{1000 \text{ ft}} = \frac{1 \text{ inch}}{250 \text{ ft}}$$

One inch on this film will equal 250 feet on the ground.

If this same negative (assuming it is nominally 2-1/4 x 2-3/4 inches) is enlarged full-frame to an 8 x 10-inch print (4X), 4 inches on the print will equal 250 feet on the ground.

If the altitude is unknown, scale can be determined by comparing the length of a known object to its length on the photograph. (Autos make a good reference. Approximate length is about 18 feet.)

$$\text{Scale} = \frac{\text{object length in photo}}{\text{true length}}$$

However, in an oblique photo, the scale of the picture decreases from the bottom (nearest the camera) to the top (farthest from the camera). In Figure F-2, the scale at the bottom is about 1 inch to 100 feet. At the top, the scale is about 1 inch to 1,000 feet, and through the center of Figure F-2 1 inch equals about 400 feet.

Camera-Look Angle = Position of Optical Axis of Camera

FIGURE F-2. Camera-Look Angle

Finding oblique scales is difficult, so only three positions of the photograph are considered in the oblique scales table (Table F-3). These give an approximation of scale for oblique photos. The table shows scales for 35 mm cameras with 50 mm lenses, 2-1/4 x 2-1/4 cameras with 80 mm lenses, and 4 x 5 cameras with 163 mm lenses. With the horizon at the top edge of the field of view over flat terrain, the camera-look angle should be about 15 degrees.

TABLE F-3. Oblique Scale Table

FOCAL LENGTH OF LENS		Vertical Scales (1,000-feet altitude)*			
		NEGATIVE SCALE Film Actual Image Size	GROUND AREA COVERED† (in feet)		
			35mm Format	2 1/4x2 3/4 in. Format	4x5 in. Format
50mm	1.97 in	1 in=508 ft	455x710	-	-
80mm	3.15 in	1 in=317 ft	295x435	715x870	-
100mm	3.94 in	1 in=254 ft	240x350	570x700	-
127mm	5.00 in	1 in=200 ft	-	-	800x1000
135mm	5.32 in	1 in=189 ft	175x255	425x520	755x945
150mm	5.91 in	1 in=169 ft	160x230	380x495	675x845
163mm	6.42 in	1 in=156 ft	-	-	625x780
200mm	7.87 in	1 in=127 ft	120x175	290x355	510x635
250mm	9.84 in	1 in=102 ft	95x140	230x280	410x510
305mm	12.00 in	1 in= 83 ft	80x115	185x230	330x415

* To find scale or coverage at other altitudes, multiply by factors of 1,000.
(For 500 feet, multiply by 5; for 2,000 feet, multiply by 2, etc.)

† Rounded to nearest 5 feet.

3.1 Scales for Other Altitudes

To find scale at other altitudes, multiply the values in the table below by the appropriate altitude factor of thousands of feet.

$$\text{Scale} = \frac{\text{Altitude}}{1,000} \times \text{Table Value}$$

- Example: 1. For an altitude of 2,000 feet, multiply the values in the table by 2.
2. For an altitude of 3,400 feet, multiply the values in the table by 3.4.

TABLE F-4. Oblique Scales (1,000-foot altitude)

Camera Look Angle	Frame Position	35 mm	2 1/4 x 2 1/4	4 x 5
HIGH OBLIQUES	15°	1 in = 15,000 ft		
		1 in = 2,000 ft	1 in = 1,200 ft	1 in = 600 ft
		1 in = 1,000 ft	1 in = 600 ft	1 in = 300 ft
	30°	1 in = 1,700 ft	1 in = 1,800 ft	1 in = 800 ft
		1 in = 1,000 ft	1 in = 600 ft	1 in = 300 ft
		1 in = 700 ft	1 in = 400 ft	1 in = 200 ft
	45°	1 in = 900 ft	1 in = 800 ft	1 in = 400 ft
		1 in = 700 ft	1 in = 500 ft	1 in = 200 ft
		1 in = 600 ft	1 in = 300 ft	1 in = 200 ft
LOW OBLIQUES	60°	1 in = 700 ft	1 in = 500 ft	1 in = 300 ft
		1 in = 600 ft	1 in = 400 ft	1 in = 200 ft
		1 in = 500 ft	1 in = 300 ft	1 in = 200 ft
	75°	1 in = 600 ft	1 in = 400 ft	1 in = 200 ft
		1 in = 500 ft	1 in = 300 ft	1 in = 200 ft
		1 in = 500 ft	1 in = 300 ft	1 in = 200 ft

Scales are constant
along these lines

3.2 Print Scales

If the photos are printed optically, the scale will be altered for the final print. To find the new scale, use Table F-5 below.

TABLE F-5. Print Scales

Film Size	Print Size (Inches)	Linear Enlargement	Area Enlargement
35mm	4x5* (6)	4.24x	19.71x
	5x7" (7.5)	5.32x	30.80x
	8x10" (12)	8.51x	78.85x
2 1/4 x 2 1/4	5x5	2.92x	4.93x
	9x9	4.00x	16.00x
4x5	8x10	2.00x	4.00x

*Length dimensions cropped—actual dimensions at the stated enlargement are the values in parentheses.

To find the scale on the print (print scale), divide the negative scale by the linear enlargement.

$$\text{Print Scale} = \frac{\text{negative scale}}{\text{linear enlargement}}$$

Example: The negative scale for a vertical photograph (2-1/4 x 2-1/4) from 1,000 feet altitude is 1 inch = 317 feet. Scale for a 9 x 9-inch print would be 1 inch = 317 feet ÷ 4. Print scale is 1 inch = 79.25 feet.

4. STEREOGRAM CONSTRUCTION

The following step-by-step procedure may prove useful in the construction of stereograms for the study of eolian indicators. The techniques presented here are from Avery (1977).

1. Determine the geographic locale of the prints from maps or photo index sheets; record all photographic data that might be lost after prints are trimmed. Then, clean all print surfaces thoroughly.
2. Locate principal points and conjugate principal points; pinpoint with fine needle holes.
3. Draw in flight lines for the overlapping pair; use a sharpened chinamarking pencil or a soft lead pencil so that the lines may

be easily removed later. Measure and record the average photo base length.

4. Delineate the desired view within a space about 5.5 cm wide as measured along the flight line. Enclose this view with parallel lines drawn exactly at right angles to the flight line. Transfer the identical view to the overlapping print by using a stereoscope. Draw these lines with a hard pencil so as to indent the emulsion surface.
5. Orient prints with shadows falling toward observer; then mark the delineated portions to be cut as left (L) or right (R).
6. Recheck all items (steps 1 through 5). Be sure you have recorded the following data before cutting out views:
 - a. Locality - county, state, etc.
 - b. Project symbol, roll and exposure numbers
 - c. Print scale
 - d. Date and time of photography
 - e. Average photo base length
 - f. Camera focal length
 - g. Agency responsible for photography, such as U.S. Department of Agriculture
7. Cut out the two views on a sharp paper cutter and align flight line (be sure to check left and right notations). Tape the two views about 1.5 to 2 mm apart by using a strip of transparent tape on underside. Check stereoscopic fusion and alignment with a lens stereoscope.
8. Trim the stereopair in height to fit a standardized format such as a card reference file. Mount on card with rubber cement or gun arabic and record data from step 6 on back of the card.

For more detailed instructions on how to construct stereograms, see Bernstein (1968).

Locality: Barstow, California
Project Symbol: WPG - OSU
Print Scale: 1:3117
Date and Time of Photography: 7/25/81, 0700
Average Photobase Length (P): 1.33" (0.11083')
Camera Focal Length (f): 100mm (0.32083')
Agency Photo Source: WPG - OSU

FIGURE F-3. Sample Stereogram of Sand Dune near Barstow, California

Examples of Possible Photogrammetric
Calculations from Sample Stereogram

Print Scale = S = 1:3117

Average Photobase Length = P = 1.33" (0.11083')

Camera Focal Length = f = 100 mm (0.32083')

Flight Elevation Above Ground Surface = H = 1000'

Parallax Measurements (Using Parallax Wedge)

Top of Dune (at slipface)	54.4 mm
- Base of Dune (at slipface)	-53.9 mm
= dP	= 0.5 mm

$$dP = 0.5 \text{ mm} (0.00167')$$

Height of Object (sand dune) = h

$$h = \frac{H \times dP}{P + dP} = \frac{1000' \times 0.00167'}{0.11083' + 0.00167'}$$

$$h = 14.8'$$

Ground Distance = d

(Determined from radial plotting, or graphic triangulation. This is the distance from the dune base, at the slipface bottom, to the point directly beneath the dune crest, or top of the slipface, at ground level below the sand.)

$$d = 0.09'' \text{ on photo or } 23.4' \text{ on the ground}$$

Sand Dune Slipface Angle = θ

$$\text{Tangent of Slipface Angle } \theta = \frac{\text{sand dune height (h)}}{\text{ground distance (d)}}$$

$$\tan \theta = \frac{14.8'}{23.4'} = 0.6325$$

$$\text{Angle } \theta = \text{about } 32^\circ$$

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APPENDIX G

FAA TIPS FOR MOUNTAIN, WINTER AND DESERT FLYING

FAA Tips for Mountain Flying

These Do's and Don't's of Mountain Flying deserve very careful consideration by any pilot who plans to conduct flight operations in mountainous country. A pilot inexperienced in such country may well have thousands of hours of flying time; however, if he cannot control his aircraft smoothly, efficiently and in general accord with these age-old rules or guidelines, he has no business in the mountain area.

1. The flight should be arranged to avoid topography which would prevent a safe forced landing.
2. Sufficient altitude should be maintained at all times to permit gliding to a reasonably safe landing area.
3. The flight should be made along routes that includes populated areas and well-known mountain passes.
4. Sectional charts are much better than World Aeronautical Charts (WAC) for details of air pilotage. Study them thoroughly for altitude over the route and for obvious check points. Prominent peaks often make good check points.
5. Believe your compass. Your compass, with proper variation, deviation and wind correction, is the only device you can rely upon to get you out of trouble, but watch for compass irregularities in areas of local magnetic disturbance, usually marked on maps.
6. Don't fly in light aircraft when the winds aloft, at your proposed altitude, are above 35 miles per hour. Expect winds to be of much greater velocity over mountain passes than reported a few miles away from them. This is very important.

7. Know your wind direction at all times; compare it to water as it flows up, over and down the mountain ranges. Watch for abrupt changes of wind direction and velocity in the mountains.
8. Don't fly near or above abrupt changes of terrain such as cliffs or rugged areas. Very dangerous turbulence may be expected, especially with high winds.
9. Don't fly up the middle of a canyon at any time. It is better to fly along one side or the other so that you will be in a better position to execute a 180-degree turn. Also, never fly so far up the canyon that a downdraft might trap you.
10. Don't get excited if you get in a downdraft. It will usually cease, leaving enough altitude above the ground to maneuver a plane safely away. Do not count on this in extremely turbulent air or in canyon areas, however.
11. When encountering a severe downdraft, use full power and maintain best rate of climb speed for the altitude at which you are operating. Guard against stalling the plane and fly out of the downdraft immediately to an area of updraft or smoother air.
12. Realize that the actual horizon is near the base of the mountain. The mistake of using the summit of the peaks as the horizon will result in the aircraft being placed in an attitude of constant climb. This could inadvertently lead to a stall from which a recovery may be impossible.
13. Approach mountain passes with all the excess altitude possible. Downdrafts of as much as 1,500 to 2,000 feet per minute may be encountered on the leeward side. Approaching the passes over a ridge will reduce this effect considerably. A clearance of 1,500 to 2,000 feet is preferred on windy days.

14. Expect winds above 10,000 feet to be prevailing westerlies in most western state areas.
15. Approach passes and ridges at a 45-degree angle so that you will be able to turn 90 degrees to the low country, instead of 180 degrees, if you encounter too great a downdraft.
16. Many experienced pilots advise that an inexperienced pilot who plans to land at a high altitude field should make a power approach and a power wheel landing. This procedure is definitely advisable in gusty air.
17. When parking an aircraft on sloping terrain, be alert to the possibility of fuel siphoning overboard. In many aircraft fuel systems this can be avoided by placing the fuel selectors in the off position while the aircraft is parked or tied down.
18. When taking off into the wind in a narrow canyon with several sharp bends, Down Air may be encountered without warning.
19. Remember that very seldom is a flight in mountainous area purely routine -- learn to expect the unexpected.
20. Remember that you, the pilot, have complete responsibility for the Go-No-Go decision based on the best information available. Do not let compulsion take the place of good judgment -- Know you can go or stay on the ground!

FAA Tips for Winter Flying

Winter flying is not particularly hazardous if you, the pilot, will use a little extra caution and exercise good judgment in analyzing weather situations.

By observing the following precautions, winter operation of your aircraft will be a lot safer.

1. Thoroughly familiarize yourself with your aircraft and engine handbooks in order to know intimately all systems and the recommended winter operation procedures.
2. Know that winter's low temperatures can change the viscosity of engine oils, reduce the effectiveness of the storage battery, and precipitate metal failures in various component parts of your aircraft with little or no warning. For this reason, engine preheat is essential for the engine as well as the cockpit area.
3. Conduct your preflight planning and flight preparation with thoroughness to detail and appropriate to the intended operation.
4. Remember that winter daylight hours are few and plan your flight accordingly. If your night experience is limited, be aware that night operation in winter can impose a special hazard all its own.
5. In making your business appointments, always give yourself an out by informing your contact that you intend to fly and will arrive at a certain time, unless the weather conditions are unfavorable.
6. Remember that a VFR pilot should avoid taking chances if the weather is marginal. Stay on the ground! A marginal weather operation in the winter is doubly hazardous since a pilot may be severely handicapped in selecting either an alternate course of action or change in destination.

7. Study the trend of the weather religiously in order to operate with maximum safety. Check all available weather information.
8. Never fly into snow or rain showers which obscure the terrain. Use your good judgment and the 180° turn before you lose forward vision and become a statistic.
9. Do not attempt to fly on instruments or on top of an overcast if you are not instrument-rated, current AND flying a properly equipped aircraft.
10. Never attempt to take off with frost, ice or snow on the windshield, or on the wings and control surfaces of your aircraft.
11. Be forewarned that many pilots have inadvertently been placed on instruments, following a take-off in beautiful VFR weather, in aircraft that had been parked outside overnight. The condensation of moisture in the heater ducting completely covered the windshield from the inside. When conducting such an operation, make sure that the heater and air vents have purged the moist air prior to take-off.
12. Never be too proud or ashamed to ask a local operator or Accident Prevention Counselor for advice about local flying conditions. They are probably more familiar with the local flying conditions than you.
13. Have the following items checked for winter operation: Cabin heater system for operation and leaks (CARBON MONOXIDE CAN BE DEADLY), exhaust system, windshield defrosting system, engine idle speed, carburetor heat, brakes, etc.
14. Remember that during let-down, it may be difficult to keep the engine warm enough for high power operation, if needed. It may be desirable to use considerably more power than normal during approaches to avoid excessive engine cooling. Remember that a rapid throttle operation may result in engine failure.

15. Be alert during winter months for white-out conditions. Due to snow covered terrains, haze, and falling snow, you could find yourself on instrument conditions with a complete loss of visual contact.
16. Remember that depth perception is faulty when attempting to land on unbroken snow-covered surfaces or at night in marginal weather conditions.
17. Remember that YOU, the pilot, have complete responsibility for the GO, NO-GO decision based on the best information available -- DO NOT let compulsion take the place of good judgment.

SAFETY IS NO ACCIDENT

Desert Wind Conditions

Experienced pilots in the desert region have some specific advice on the subject of desert wind conditions.

There is an old axiom that says: "What you don't know won't hurt you," but desert-flying pilots should revise this to read: "What you don't see may hurt you." They refer specifically to the thousands of small "whirlwinds" or "twisters" or "dust devils" encountered over southwestern U. S. deserts.

In flight, you can spot these "twisters" miles away, as they spiral upward with a characteristic column of sand, dust, and even small twigs and grass. The birds also can spot them, and you will see hawks and buzzards nonchalantly riding these rising and twisting currents of air to great heights. These birds are merely riding the thermals for enjoyment.

However, even if you do have wings, don't emulate these birds. After all, if one of these birds fails to get home on time, no one will worry; if you fail to arrive on time, it will give local pilots a lot of trouble buzzing around barren wastes looking for you. So when you see these "twisters" admire them all you want, but alter your course to miss them.

There are "twisters" which you cannot see. It's very embarrassing to have one flip your plane over and pile it up on the ground while you are taxiing or if you encounter one near the ground. At least you can salvage your pride somewhat by avoiding all those you can see. When landing, watch for these little disturbances on desert airports. Adjust your airspeed to compensate for better control in case a "twister" jumps you.

It is further emphasized by one experienced pilot that no pilot, while landing a light plane, should continue on such a landing after noticing a "whirlwind" on the airport moving in a direction which might contact the airplane during landing or landing roll. These winds are very turbulent and have put airplanes out of control on final approaches and landing rolls.

An airplane would have a better chance against these troublemakers if, when evasion is impossible, the airplane were facing them as they approached. In other words, never turn your back on a "whirlwind", especially while taxiing airplanes of the tricycle-gear type. Pilots should be on the watch for dust and sandstorm areas and avoid them when possible. These conditions can suddenly place a VFR pilot on instruments and have caused numerous accidents.