APPLICATION OF DIGITAL IMAGE ANALYSIS TECHNIQUES TO
THE GEYSER'S DATA AND TOPOGRAPHY

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APPLICATION OF DIGITAL IMAGE ANALYSIS TECHNIQUES TO THE GEYSER'S DATA AND TOPOGRAPHY

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INTRODUCTION

This paper describes the results of digital image analysis and techniques applied to acoustic sounder data and topographic relief in the Geyser's region. Application of two dimensional digital Fourier transformation is a common technique used in image analysis. First an image is transformed and then the transformation is filtered to stress high or low spatial frequency variations and an inverse transformation is applied for image enhancement. The two dimensional fast Fourier transform (2DEFT) therefore represents the spatial variability of a photographic image. The spatial variability of topography in complex terrain can be represented in this way and insight into degree of complexity and dominating spatial wavelengths can be gained. This was performed for a 16 km square digitized topographic map of the Geyser's region with 63.5 m resolution.

It was also of interest to compare facsimile recordings of acoustic sounder data to optical turbulence measurements. Since the darkness of the recording is a function of the temperature structure parameter $C_T$, it was necessary to digitize photographic negatives of these chart recordings. $C_T$ could then be related to the index of refraction structure parameter $C_n$ through the standard deviation of the log of laser light intensity $\sigma_l$ measured with an optical anemometer.
RESULTS

This section is divided in two parts. The first part describes the results of a 2DFFT of Geyser's area topography. The second part describes the results of digitizing the acoustic sounder records and comparing to optical turbulence measurements.

The Fourier transform simplifies, in one respect, interpretation of complex topography by presenting data on a spacial frequency or wavelength basis. The 2DFFT, however, doesn't look like anything a person actually sees unless one looks at a transparency of intensity proportional to altitude through a lens at twice the focal length rather than in focus. The variability of the transform from corner to corner does correspond to the axis of the original image but individual points on and off the axis do not correspond to individual points on the digitized topography. In a 2DFFT highly variable terrain tends to spread out the transform coefficients to higher values at smaller spatial wavelengths. Regularly varying terrain would cause peaks and valleys in the Fourier coefficients. These characteristics can be compared for different geographic locations and questions like the following can be answered more easily:

1. Which potential location for complex terrain studies is more complex?
2. What are the scales of regular oscillation in the terrain?
3. What is the relative importance of these regular terrain features?

To answer the first question a comparison is necessary between 2DFFT's. The latter two questions can be answered by looking at the 2DFFT generated for the Geyser's region. The next paragraph describes the generation and interpretation of the 2DFFT.
A data file of digitized topography with 63.5 metre resolution was obtained for the area surrounding the location of the 1979 ASCOT intensive experiment. Since the array size for a 2DFFT must be a power of 2, a 256 by 256 array of altitude versus position was selected. This corresponds to an area 16.26 km on a side. A contour map of this area is shown in Fig. 1. The contours interpolated on this map were much coarser than the 63.5 m resolution actually used in the 2DFFT. Also altitude above sea level was given in 50 m increments. The highest area (Cobb Mountain) corresponds to a height of 1439 m and the lowest point was 278 m above sea level. The resultant contours of Fourier coefficients from the 2DFFT are shown in Fig. 2. These were hand drawn from a false color image of the 2DFFT. The center of the 2DFFT corresponds to a spatial wavelength of the topograph array size of 16.26 km. The corners and sizes correspond to wavenumber space representations of the two horizontal axes Fourier coefficients. The Nyquist spatial wavelength is twice the maximum resolution or 127 meters. The value of the Fourier coefficient is highest at the center of the 2DFFT and equals 256 squared times the average height above sea level (656 m). The high value at the center means that a complicated map would reproduce itself exactly at a spatial wavelength corresponding to the size of the map. What is of real importance is how the 2DFFT varies along the diagonals from corner to corner in the 2DFFT. Going from the lower right to the upper left corner of the 2DFFT corresponds to variability associated with going from southeast to northwest corner of the topography shown in Fig. 1. Inspection of the digitized topography in Fig. 1 shows that the topography varies much more regularly along the southwest to northeast diagonal than the other diagonal with about eight ridge valley systems of
similar widths. These and other features are also shown in the 2DFFT in Fig. 2. Inspection of Fig. 2 reveals the following:

1) Along the diagonal from lower right to upper left (southeast to northwest) there is much more high spacial frequency variability than along the other diagonal. The presence of many higher frequency bands above once per 8 km may be due to stream erosion features off the main ridges. Inspection of the actual peaks in the coefficients of the 2DFFT show bands at 1.4, 3.2, and 8.2 km wavelengths. Rotation of the topography 45° would cause a more symmetric appearance along the two diagonals because the ridge systems would affect each diagonal similarly.

2) Along the diagonal from lower left to upper right (southeast to northwest) the Fourier coefficients associated with longer wavelengths than 8 km are generally lower than the value of coefficients along the other diagonal. However, similar bands appear at about 2 km wavelength indicating the importance of the eight ridge features.

3) The band on each diagonal at about 8 km is due to the fact that southeast half the topography is more complex than the northwest half.

4) The higher frequency bands have about half the value for the Fourier coefficients than found at 8 km spacial wavelengths.

5) The coefficients are relatively symmetric about the diagonals demonstrating the predominate southeast-northwest and southwest-northeast orientation of the topography.

Obviously, comparisons with 2DFFT's of similar scale topography would be more useful in defining important parameters. It is interesting to note
that the wavelength bands of 2 km and 8 km and measured nighttime drainage wind speeds of about 1.5 m/s found in a companion paper,² imply frequencies close to once per 27 minutes and 2 hours. These peaks were found in the autospectral analysis of wind speeds in the region. This may be coincidental but should be investigated further in future analysis.

The next part of this section describes the results of digitizing photographic negatives of the acoustic sounder record near Thorn 7. Figure 3 shows the location of the acoustic sounder below the laser path used for optical anemometry. The difference in height of the beam and the acoustic sounder was about 30 meters. This is the height where the first usable signals for the acoustic sounder arrive. Figure 4 shows the acoustic sounder record for the period studied. This period was 12 hours beginning at midnight July 19, 1979. Each four hour segment was digitized with 200 line elements up to two hundred meters (i.e., 1 meter per line). The lines were chosen from computer 3-D data simulations like the one shown in Fig. 5. This helped to determine the edges of the picture and where the acoustic data began. Five line scans above 30 m were averaged at this point and the resulting data is plotted in Fig. 6 for the three four-hour segments. The height of the line is inversely proportional to the darkness of the photograph which in turn is proportional to the temperature structure parameter \( C_T \). The periodic large single peaks correspond to timing marks on the record and were not included in the subsequent analysis. Ten minute average values of the inverse of the data plotted in Fig. 6 were calculated and compared to optical turbulence over the laser path shown in Fig. 7. The mathematical
basis for this relationship relates the log amplitude variance of the laser intensity $\sigma_I$ to $C_T$ by the equations

$$\sigma_I^2 \sim k^{7/6} L^{11/6} C_n^2$$

and

$$C_n^2 \sim C_T^2$$

where $L$ is the path length, $k$ is the wavenumber and $C_n$ is the index of refraction structure parameter. These equations assume long path homogeneous isotropic atmosphere where humidity variations are negligible. Though differences appear in the comparison shown in Fig. 7, the correlation function shows a significant (F test $<<.01$) positive peak correlation (0.52) with higher values at night and late morning and simultaneous decrease in the early morning. These differences and the unsymmetric shape of the correlation function may be due in part to the fact that the optical turbulence is not always uniform along the path and the sounder is looking at only part of the path. For example, heating in the morning occurs first on one side of the path and then the other consistent with the hump on the left side of the correlation function. In the 1980 ASCOT experiment digitized data from the doppler acoustic sounder may improve this comparison.

CONCLUSIONS

Two dimensional Fourier transform of topographic relief have been shown to be useful to understanding the spacial variability in the
Geyser's region of complex terrain. An interesting correspondence of regular spatial variability of topography with temporal regularities of wind speed variation was found which may or may not be coincidental. Digitized acoustic sounder records showed an expected relationship of optical turbulence to acoustic return signal strength.

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REFERENCES


KS, NB/1193z/D132
FIGURE CAPTIONS

Figure 1. Digital topography height contours of 63.5 m resolution topography with only 317 m resolution horizontal and 50 m resolution vertical of 16 km square Geyser's region.

Figure 2. Contours of two-dimension fast Fourier transform of 63.5 m topography of region shown in Fig. 1.

Figure 3. Cross section of laser path showing location of acoustic sounder about 30 m below near Thorn 7 part of the path.

Figure 4. Acoustic sounder record for 19 July 1979 for sounder shown in Fig. 3 starting at 0:00 PST and going to 12:00 PST.

Figure 5. Three dimensional plot of density for a section of photographic record of acoustic sounder data shown in Fig. 4.

Figure 6. Digital scans of three four-hour segments shown in Fig. 4 averaged 5 meters above 30 meter starting height for the sounder record.

Figure 7. Comparison of time histories of the photographic record function of $C_T^2$ from acoustic sounder record and $\sigma_I$ from the optical turbulence of the laser beam with their correlation function plotted below.

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TOPOGRAPHY CONTOURS

Figure 1

TOPOGRAPHY CONTOUR INTERVAL IS 50 METRES. MAXIMUM CONTOUR IS 1100.
GRID ORIGIN UTM COORDINATES ARE: X= 520.0 KM, Y= 4285.1 KM, Z= 300 MASL.
MESH INTERVALS ARE: DELX= 0.317 KM, DELY= 0.317 KM, DELZ= 50 METRES.
Two dimensional Fourier transform of Geyser's Terrain Contours of Fourier coefficients

Wavelength space

Figure 2
SIDE VIEW OF LASER PATH IN GEYSER'S REGION

Laser beam (average elevation over terrain 32.3 m)

- Optical anemometer receiver
- Aminoil pipeyard
- Acoustic sounder location

Thorn

Laser transmitter 686 m

500 m

625 m

500 m
Figure 5
Figure 7