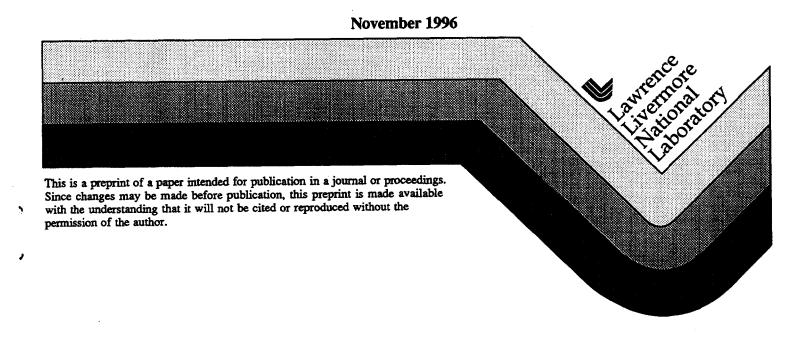# Meteorological Data Assimilation for Real-Time Emergency Response

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METEOROLOGICAL DATA ASSIMILATION FOR REAL-TIME EMERGENCY RESPONSE

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SUMMARY

The U.S. Department of Energy's Atmospheric Release Advisory Capability (ARAC) provides real-time dose assessments of airborne pollutant releases. Diverse data assimilation techniques are required to meet the needs of a new generation of ARAC models and to take advantage of the rapidly expanding availability of meteorological data. We are developing a hierarchy of algorithms to provide gridded meteorological fields which can be used to drive dispersion codes or to provide initial fields for mesoscale models. Data to be processed include winds, temperature, moisture, and turbulence.

I. DATA ASSIMILATION

The new data assimilation system incorporates significant improvements over current ARAC capabilities. The grid generator allows run-time selection of both the number of grid points and the grid resolution and is based on a continuous terrain representation rather than the current stair-step topography. Variable resolution is provided in both the vertical and horizontal coordinates. The former leads to improved representation of the meteorological fields in the critical near surface region while the latter is utilized when either topographical variation or data density warrant.

The data assimilation procedure ingests and blends data from a variety of sources. Local observations currently available to ARAC from the Air Force Global Weather Center (AFGWC) and supported site towers are being supplemented with additional data as it becomes available. Gridded analyses and forecast fields are obtained from the Fleet Numerical Meteorological and Oceanographic Center, the National Weather Service, and ARAC adaptations of the mesoscale models NORAPS and COAMPS developed by the Naval Research Laboratory.[1] ARAC is currently developing a new meteorological database and data extraction system which allows selection of all values meeting time, space, source, and other user specified criteria. The spatial range of the data is generally taken to be larger than the domain of the model simulations in order to provide the most complete set of meteorological information relevant to the problem.

The simplest class of data assimilation techniques is based on direct interpolation

$$\phi(\vec{r}, t) = \sum_k w_k(\vec{r}, t, \vec{r}_k, t_k) \, \phi_k \quad , \qquad (1)$$
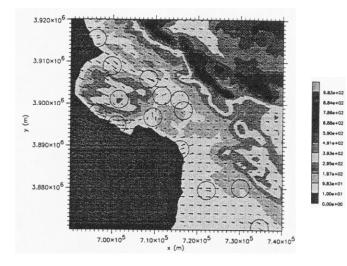
where ϕ_k are observations located at $(\vec{r}_k, t_k)$ and w_k are normalized weights which are typically monotonically decreasing functions of spatial distance or relative time. A large variety of algorithms are possible based on different choices of the weighting functions. Examples include bilinear interpolation and methods based on inverse horizontal distance squared, inverse relative height, exponential time difference, and influence radius weighting.

A second group of algorithms use the method of successive corrections which may be written schematically as

$$f_A^{j+1}(\vec{r}, t) = f_A^j(\vec{r}, t) + \sum_k w_k^j [f_o(\vec{r}_k) - f_A^j(\vec{r}_k)] \qquad (2)$$

where f_A^j is the analyzed field at $(\vec{r}, t)$ for the jth iteration, $f_o(\vec{r}_k)$ is the kth observation, and w_k^j are normalized weights. In these algorithms, the weights can be altered with each iteration to act as filters for the removal of small scale noise or errors. A typical example is the Barnes weighting scheme for which $w(\vec{r}) = \exp(-\frac{\vec{r}^2}{2\vec{R}^2})$ with $\vec{R}$ a horizontal influence radius parameter.

A third class consists of minimum variance methods,[2] which include statistical or optimal interpolation. Such techniques are used to blend gridded fields and observations for
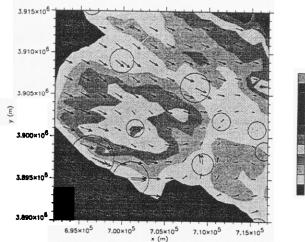
Figure 1: Diablo Canyon winds at 10 m AGL. Every other wind vector is plotted. The circles indicate the location of the surface wind observations.

Figure 2: Enlargement of the wind field from previous figure surrounding the release site. Every other wind vector is plotted.

the initialization of ARAC's forecast models and will be incorporated into the data assimilation system.

The data assimilation process can be performed either by using a fully three-dimensional analysis or by dividing the problem into levels and executing independent horizontal and vertical analyses. The latter category contains both split vertical-horizontal approaches in which profiles are constructed first to provide values on each horizontal level or split horizontal-vertical approaches in which data is interpolated first horizontally and then vertically, the choice depending on the type of data available.

Vertical profiling methods are based on an idealized treatment of atmospheric structure as a set of layers, e.g. the surface layer, the boundary layer, the free atmosphere, etc. Different interpolation methods and empirical parameterizations are then used for each layer depending on atmospheric conditions. An active area of current development concentrates on techniques for the blending of surface, tower, and upper air data. Work is also underway to treat spatially varying surface and meteorological parameters, including the boundary layer height and the surface roughness length.

The generation of wind fields involves a few special considerations. The inclusion of map projections requires appropriate adjustments of length scales and directions. Interpolation and parameterization may be performed in either speed and direction or u and v components. In some cases, the vertical wind component may be similarly determined.

However, w data is not typically available. Further, many of our applications require the wind field to be non-divergent, a property which is not *a priori* guaranteed by the interpolation methods discussed above. An adjustment procedure based on the variational principle[3] is therefore performed to provide the vertical wind component and produce mass-consistent winds.

One of ARAC's needs is for an extremely robust data assimilation algorithm which is capable of treating sparse observational data sets and has the computational performance for an immediate real-time assessment. This implies the ability to extrapolate robustly to regions far from any potential data source. There is also a requirement based upon ARAC operational experience for maintaining the observational values in the final output field, particularly those located near the release site. A straightforward approach to meet these requirements is split vertical-horizontal interpolation with an assortment of vertical profiling methods and weights.

Our initial applications have focused on wind fields. Preliminary results from two cases will be discussed in the following sections. No attempt was made to optimize model parameters or to quality control the data, although tests were performed to check robustness of the results for a reasonable range of parameters. The vertical coordinate was chosen to be that used by ARAC's new dispersion and non-hydrostatic mesoscale models, $\sigma_z = \frac{z - z_g}{z_{top} - z_g}$, where z_g is the ground elevation and z_{top} is the height of the top of the grid.
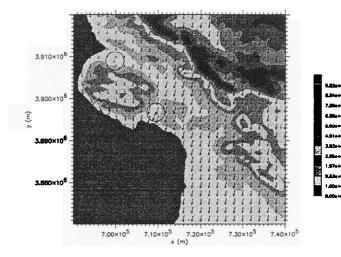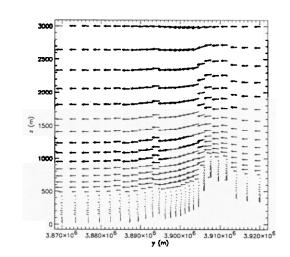
Figure 3: Diablo Canyon winds at $\sigma_z = 0.208$. Every other wind vector is plotted. The circles indicate the location of the three sodar observations.
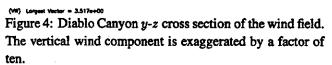

(W) Largest Vector = 3.517e+00

Figure 4: Diablo Canyon y-z cross section of the wind field. The vertical wind component is exaggerated by a factor of ten.

II. APPLICATION : DIABLO CANYON

We provided wind fields for a dispersion model simulation[4] using data from the Diablo Canyon tracer experiment conducted by the Pacific Gas and Electric Company[5] during the period August 31 to September 17, 1986. The site near San Luis Obispo on the central California coast exhibits complex fine-scale topography and a variety of atmospheric conditions.

The performance of the diagnostic analysis is strongly correlated with the density and distribution of measurements and the terrain resolution. At Diablo Canyon, meteorological observations were collected from eighteen surface stations, including an ocean buoy, and three sodars bracketing a hill just north of the release site. Wind fields were generated at 15 minute intervals reflecting the frequency of collected data. The simulations used a 50 km by 50 km by 3 km grid with 1 km resolution in the horizontal and 31 graded vertical levels with 10 m resolution near the ground.

The first tracer experiment began at 16Z August 31, 1986. For the next ninety minutes, the winds were light and variable near the release site. Subsequently, a stronger generally onshore flow developed. Figure 1 shows the interpolated surface wind fields at 10 m AGL for 18Z August 31, 1986. Circles surround vectors plotting the observational wind data. The funneling and directional shifts of the surface winds in the valleys to the north and east of the hill near the release site are clearly visible in Figure 2 which shows an enlargement of the upper left quadrant of Figure 1.
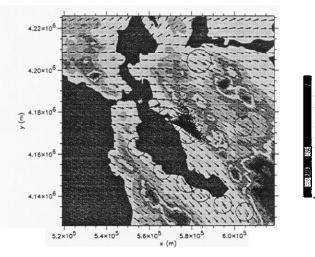
Figure 3 plots the interpolated upper level wind fields generated from the sodar data. The winds shift from west to north with increasing elevation. This shearing is evident in the vertical cross section of Figure 4 taken through the x coordinate in the middle of the grid. All vertical levels are plotted to show the grading of the meteorological grid in the vertical. The wind fields in Figure 4 have been adjusted to be non-divergent and tangential to the ground at the surface. The horizontal components of the surface winds are not significantly altered by the non-divergence adjustment procedure - the change in horizontal wind speed and direction due to the adjustment is less than the typical observational error.

III. APPLICATION : OPERATIONAL RESPONSE

We extracted observations from the new ARAC meteorological database and generated wind fields for various release scenarios. These simulations demonstrated that the computational performance of the models was sufficient to provide real-time assessments.

One of our examples involved a release from a site in the San Francisco Bay area. Figure 5 shows the 10 m AGL wind field, the surface observations, and the instantaneous particle positions 1 hour after a release began from the center point of the grid. The grid is 100 km by 100 km by 3 km grid with
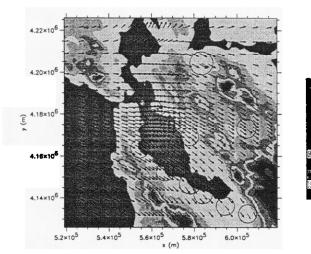
Figure 5: Surface wind field at 10 m AGL. Every third wind vector is plotted. The circles indicate the location of surface wind observations.

Figure 6: Surface wind field on a graded mesh at 10 m AGL for the same data as in the previous figure. Every third wind vector is plotted.

81 grid points in the horizontal and 31 in the vertical, with a finest vertical resolution of 10 m near the ground.

Figure 6 shows the 10 m AGL winds and observational data for a graded grid using the same domain and number of grid points but with a finest horizontal resolution of 0.5 km. The agreement with Figure 5 indicates that the results are robust with respect to gridding and topographic resolution. The ability to use graded meshes will provide ARAC with improved treatment of long range transport problems.

IV. FUTURE DEVELOPMENT

Work is presently underway to treat meteorological data other than winds and to build improved atmospheric parameterizations, interpolation algorithms, and successive correction methods. Three-dimensional analyses and optimal interpolation methods will also be developed in the future. In addition, we are working on incorporating approaches for the generation of gridded turbulence fields from either semi-empirical parameterizations or forecast models for use in dispersion simulations.

ACKNOWLEDGEMENTS

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