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Project Summary

Spatial and Temporal Interpolation of NEROS Radiosonde Winds

O. Russell Bullock, Jr.

This text summarizes a research program whose objective was the determination of a most appropriate numerical method for the spatial and temporal analysis of free atmospheric, radiosonde derived wind observations for the North-East Regional Oxidant Study (NEROS) pollutant transport model being developed at the Environmental Sciences Research Laboratory of the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. The analysis was performed by automated data processing with some restrictions in computer execution time and storage area.

Previously developed methods of spatial and temporal data analysis were reviewed and their applicability to the NEROS effort evaluated. Evaluation was based on tests with actual radiosonde data and with data sets produced through numerical model initialization procedures. In all cases, the desired result was a 7 by 6 grid of wind vectors in latitude and longitude space at discrete pressure levels for every hour during a three data test period.

Optimization of applicable spatial analysis schemes was completed and error statistics were calculated based on agreement between the analyzed gridpoint values and the data values at various locations within the NEROS test region. Two types of input values were used during the optimization tests. Actual observational data were obtained from the National Weather Service radiosonde network for one test, and artificially generated data were produced for a second separate test.

Linear and curvilinear time interpolation methods were tested two ways. For one test, time interpolation procedures were applied to the input data sets to produce artificial hourly radiosonde sounding data that were then spatially analyzed. For the other test, spatial analysis was performed with the data available at the actual observation times and the resulting gridpoint values were then interpolated in time to produce the hourly analyses.

This Project Summary was developed by EPA's Environmental Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

As a part of the development of the North-East Regional Oxidant Model (NEROS) atmospheric pollution transport model, a technique for the spatial and temporal analysis of radiosonde derived wind observations was required. For this study, two-dimensional spatial grids of wind values were desired at various constant pressure levels and at hourly intervals The idea of producing one three-dimensional grid for every hour does not apply in this case because the analyses at each pressure level were performed separately, using only the data available on the pressure level of the analysis. In the same respect, the temporal analysis was performed separately due to lack of a generally applicable scaling relation between space and time for radiosonde winds

As the name implies, the NEROS project is primarily investigating oxidant transport in the Great Lakes and Northeast regions of the United States and in the southernmost portions of Ontario, Canada. Figure 1 shows this region of interest within the interior solid outline. Also shown is the placement of the 7 by 6 computational grid-point array designated for the study of radiosonde wind analysis. Notice that the exterior grid points are located outside the NEROS region in order to isolate any boundary value assumptions that are often required for numerical analysis schemes.

Measurements of wind are usually taken in terms of the direction from which the air is flowing and the speed of flow. However, most applications in numerical modeling required that the wind be defined in terms of the orthogonal spatial components of the air flow vector. Nevertheless, many philosophical reasons have been proposed for the use of both vector decompositions, the spatial components of the wind vector (u,v) and the wind direction and speed. Therefore, an investigation of both schemes was performed.

Some contemporary schemes for the spatial analysis of wind use separate scalar analyses of vorticity (ζ) and divergence (δ) to define the final wind field using the Helmholtz equation. By analyzing these parameters defined by the total wind field, ambiguous vector decomposition is not a concern.
However, the Helmholtz equation

$$V = \vec{k} \cdot \nabla \Psi + \nabla \chi \qquad (1)$$

relates the fields of the stream function (ψ) and the velocity potential (χ) to the wind field, not to ζ and δ. The definitions

$$\nabla^2 \Psi = \zeta \text{ and } \nabla^2 \chi = \delta \qquad (2)$$

present two intermeshed Dirichlet problems. Many methods have been proposed to solve various permutations of this multiple boundary value problem, and some of the more popular solutions were tested for their applicability to the spatial analysis of radiosonde winds on the grids chosen for this research effort.

Time interpolation of radiosonde winds can be accomplished by schemes as simple as linear interpolation or as complex as forward-backward numerical atmospheric modeling. For the purposes of this research, temporal analysis was limited to schemes of linear interpolation or curve fitting of the individual data points at the observation times. The most important question with respect to time interpolation is whether to use it on radiosonde sounding data to create artificial hourly soundings that are then spatially analyzed, or to use time interpolation on the grid-point values previously obtained from spatial analyses of actual data.

Procedure

Radiosonde data were obtained from normal 0000 Greenwich mean time (GMT) and 1200 GMT National Weather Service observations and from special 0600 GMT and 1800 GMT observations taken specifically for the NEROS project. The data obtained for normal sounding times were from 24 stations scattered in and around the NEROS modeling region; data for special times were observed at only 7 of these 24 stations. The locations of all stations sampled for this study are shown in Figure 2.

All analysis was performed using ASCII-FORTRAN programming on the UNIVAC 1183 computer at the National Computer Center, Research Triangle Park, North Carolina. The first task performed was a survey of contemporary spatial analysis schemes for scalar quantities. Next, an investigation of wind decomposition into orthogonal spatial components and direction-speed components was undertaken. This investigation included a comparison of accuracies in the matching of known values of wind to results obtained by both methods. An optimum procedure for the spatial analysis of wind using the Helmholtz equation was developed, and its accuracy was compared with that of the wind decomposition schemes. Finally, the accuracy of a combination of the optimum spatial analysis scheme and a linear time interpolation scheme was tested by attempting to match 0600 GMT and 1800 GMT observations using data from only 0000 GMT and 1200 GMT. The testing of this combination of schemes was performed by using spatial analysis as the first phase of the operation, followed by the temporal analysis, and also by using the reversed order of analysis.

Results

The survey of spatial analysis schemes showed that a distance-based data point weighting scheme performed well for all applications to radiosonde data. While there are other such schemes that use a less complicated formulation for data point weighting, none of them were able to produce results with such spatial consistency while conserving the important features present in the data.

No significant difference was found between the "u-v" and "direction-speed" wind decomposition schemes in their ability to match known wind values in both ordered and scattered position arrays. However, it is understood that the complexity of the actual wind field has an important effect on the relative ability of these schemes to adequately describe the wind field.

It was found that spatial wind analysis using the Helmholtz equation can be very complicated and founded on a number of inconspicuous assumptions. The boundary value problem for the stream function may be solved by making various assumptions about the velocity potential and the wind vectors at the boundary of the analysis region. Similarly, the velocity potential can be determined with an assumption about the stream function and the boundary wind.

A contemporary scheme for generalizing these assumptions, was found to produce acceptable results. In this procedure, a preliminary wind analysis is performed by any means preferred. An adjustment is then made to this wind field by forcing it to have the vorticity and divergence content determined by a separate analysis of each. Vorticity and divergence analyses were based on point estimates as determined by a computational method in which triangular configurations of wind observations are used.

Some investigators have noted that the size and shape of these data point triangles may have an effect on the quality of the vorticity and divergence estimates obtained. Therefore, performance statistics were obtained for the wind analysis scheme using these estimates and an optimum triangle size and shape criterion was determined for the applications of this study. A maximum size restriction of 100,000 km^2 was determined to be appropriate. A measure of triangle shape was based on the ratio of the maximum triangle vertex angle to the minimum vertex angle. A maximum restriction of about 4.0 was found to produce the best results.

Time interpolation results using curve fitting of the grid-point values obtained at 0000 GMT and 1200 GMT showed great spatial discontinuity in the interpolated grids for 0600 GMT and 1800 GMT. Therefore, simple linear time interpolation was used for the purposes of this study. The results suggest that the best performance is obtained by first performing the spatial analysis to produce grids for the data times and then using time interpolation of the grid point values. The differences are somewhat dependent on the pressure level of analysis, but the statistics invariably show that the procedure using spatial analysis first is most accurate.

Records of computing time used to d

these tests showed that the most accurate procedure was also the fastest. The spatial analysis requries a complete inventory of all data points and rather time costly mathematical operations. Performing the spatial analyses first eliminates the need for a full spatial analysis for every time that the grids are needed. Instead, the spatial analyses are done only for the times when data is actually available and the time interpolation produces the final grids.

Conclusions

The wavelength dependent filtering efficiency offered by the Barnes analysis scheme is a useful tool for the production of spatially consistent wind fields that contain the important features found in the actual data.

The decision of which wind decomposition method to use must be made based on the complexity of the data field and the scale of the features desired in the final analysis.

The use of the Helmholtz equation to determine wind fields allows vorticity and divergency constraints to be applied to the final wind analysis. These constraints may be very useful for operations such as modeling wind flow over complex terrain

When time and space must be dissociated in the radiosonde wind analysis due to lack of a scaling parameterization between them, the spatial analysis should usually be performed first because of the advantages of computation speed, and the possibility of improved accuracy.

Recommendations

Results of the work described in this document pertaining to the use of the Helmholtz equation to define the wind field and the use of separate time and space analyses should be considered preliminary.

Suggestions for further research work include the following.

1. Investigation into more specialized cases in which the manipulation of vorticity and/or divergence as they apply in the Helmholtz equation would be most productive. An example would be the modeling wind flow over complex terrain.
2. Further study into the use of curvilinear time interpolation of spatial grid points. Preliminary indications are that a control on the field of time rate changes used to define the spline or polynomial curves at the data points would greatly improve the spatial continuity obtained in the grids for the intermediate times.

__O. Russell Bullock, Jr.__ is with Environmental Sciences Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.
__Francis S. Binkowski__ is the EPA Project Officer (see below).
The complete report, entitled "Spatial and Temporal Interpolation of NEROS Radiosonde Winds," (Order No. PB 84-232 545; Cost: $11.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Environmental Sciences Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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