48

TITLE: Variational Objective Analysis for Cyclone Studies

INVESTIGATOR:

Gary L. Achtemeier
Climate and Meteorology Section
Illinois State Water Survey
2204 Griffith Drive
Champaign, IL 61820
(217) 333-0689

SIGNIFICANT ACCOMPLISHMENTS DURING THE PAST YEAR:

Five major components of this project are:

1. **MODEL I.** Requires satisfaction of the two nonlinear horizontal momentum equations, the integrated continuity equation, and the hydrostatic equation.
2. **MODEL II.** Requires satisfaction of MODEL I plus the thermodynamic equation for a dry atmosphere.
3. **MODEL III.** Requires satisfaction of MODEL II plus the radiative transfer equation. Brightness temperatures and skin temperature are introduced as dependent variables.
4. **MODEL IV.** Requires satisfaction of MODEL III plus a moisture conservation equation and a parameterization for moist processes. Moisture is introduced as a dependent variable.
5. **INITIAL ANALYSIS.** Makes the variational models more responsive to the observations. Thorough analysis of all phases of the data representation, gridding and initial analysis/model interface.

Significant accomplishments during 1987-88 are summarized with regard to each of the major project components.

I. MODEL I

A. The completion of MODEL II allowed for the testing of the variational method for the complete set of dynamic equations. The tests were determined whether the MODEL I vertical velocity formalism was posed correctly as it wasn't as rigorous as are the other model formalisms. The results of the test revealed that there was little or no coupling of the "observed" vertical velocity with the other adjusted variables. In other words, the adjustment simply didn't "see" the divergent part of the observed wind. It was found that the adjusted vertical velocities converged toward a solution of the vorticity theorem that gave vertical velocity patterns similar to those of one of the NMC numerical prediction models that was operational during 1979.

This information was used to develop a new MODEL I that includes as constraints the two nonlinear horizontal momentum equations, the hydrostatic equation, and a particular solution of the vorticity theorem that satisfies the constraints that the vertical integrals of the vorticity theorem and of the divergence vanish at the top of the model domain. In theory, this formulation strongly couples the divergence of the observed wind into the adjustment for the winds and there are no "variational models within variational models" as was required for the first version of MODEL I.

The variational equations for the new version, MODEL I.2, are more complex than for the old version, MODEL I.1. After the higher order terms are moved into forcing functions, the equation set reduces to three diagnostic equations; geopotential height, divergence, and vorticity. The latter two are solved for the velocity potential and stream function in order to get the adjusted winds. Boundary condition problems inherent in these Poisson equations are well known. We tested four methods for retrieving the velocity potential and steam function (Bijlsma, 1986, MWR 114, 1547-1551; Shukla and Saha, 1974, MWR 102, 419-425; Endlich, 1967, J. METEOR, 6, 837-844; Schaefer and Doswell, 1979, MWR 107, 458-476.) The method of Schaefer and Doswell seems to work best for the staggered grid of MODEL I.2. This problem of boundary conditions is a subject of continuing investigation including personal communications with R. Endlich.

Theoretical development and programming of MODEL I.2 (extensive programming was required to implement MODEL I.2) have been completed and tests will begin soon.

B. Precision moduli sensitivity testing was done with MODEL I.1 to determine which variables are crucial to the convergence of the method. Fifteen runs of MODEL I.1, beginning with "standard" precision moduli calculated from observations or formulas linking with observations, were done with standard precision moduli selectively multiplied by 0.1 or 10.0. RMS residuals, a measure of how well the constraints are satisfied, were plotted for each cycle out to four cycles. The MODEL I.1 solution method was found to be sensitive to the horizontal velocity (if too accurate) and the developmental component of the horizontal velocity tendencies (if too inaccurate); the solution for the horizontal momentum equations diverged. A similar sensitivity test will be done for MODEL I.2.

II. MODEL II.

MODEL II was completed near the end of the first year of the current 3-year effort. As reported in the NASA MSFC FY87 Global Scale Atmospheric Processes Research Program Review, slow divergence was found in the solution for the middle layers of the model atmosphere. Subsequent analysis of the behavior of MODEL II has revealed the following:

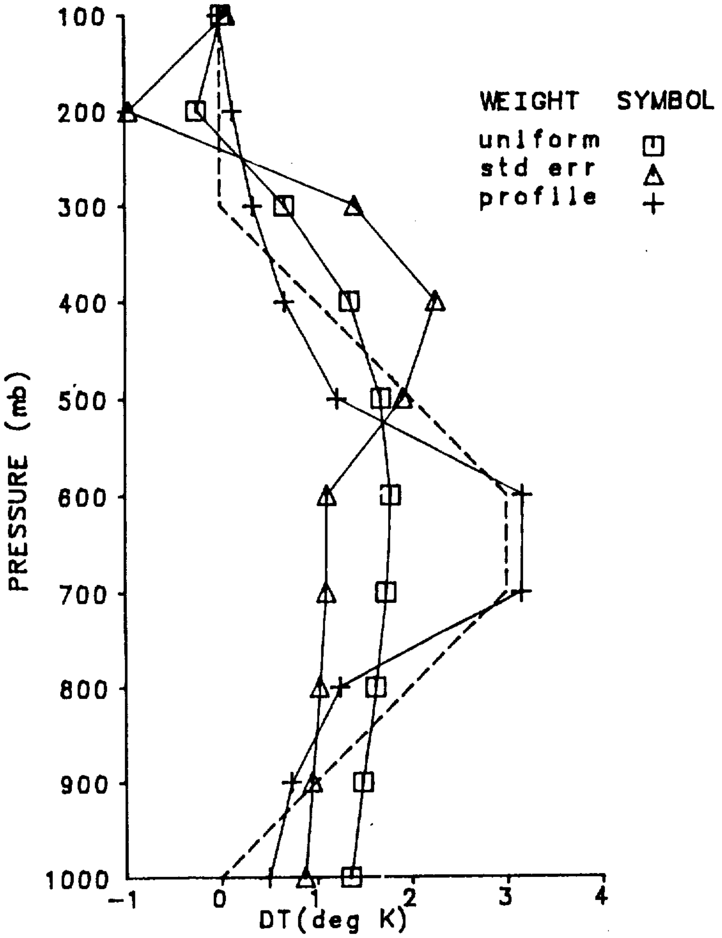
a) The adjusted vertical velocities in MODEL I were weakly coupled with the initial vertical velocities. The solution wandered toward the vorticity equation rather than the continuity equation. The solution order that readjusted the winds to satisfy the continuity equation did not force the solution toward the initial vertical velocity. A solution for the problems with vertical velocity coupling has been briefly described in connection with MODEL I.2.

b) The initial vertical velocity must not have large error or else the adjusted temperature tendencies will have large error. Kinematic vertical velocity methods make no allowance for the discontinuity in stability between the troposphere and stratosphere. Large stratospheric kinematic vertical velocities produce large erroneous temperature tendencies. In an attempt to correct this problem, Barb Chance coupled adiabatic vertical velocities with the kinematic divergence of the horizonal wind through a variational algorithm that weighted the velocities through static stability, relative humidity and cloudiness. Her method was modified to blend adiabatic and kinematic vertical velocities through static stability alone.

III. MODEL III.

Three variational models that incorporate the four radiative transfer equations for the four TOVS microwave channels as constraints and the four brightness temperatures and the skin temperature as new dependent variables are in various stages of development. These models are:

a) MODEL 3a consists of the radiative transfer equations with rawinsonde temperature and brightness temperatures as adjustable variables. It was apparent that this formalism would be just another retrieval algorithm. Therefore the main reason for derivation of MODEL 3a was to gain understanding of the behavior of four integral equations as dynamic constraints. Solutions were by matrix inversion and an iterative technique. An unexpected result from MODEL 3a was that the retrieval is sensitive to the vertical distribution of the temperature weights. Figure 1 gives an example of the response of the adjustment to the vertical distribution of temperature weights. The standard atmosphere was used as the true temperature and the true brightness temperatures were calculated from it. Then a 3C temperature anomaly (dashed line in Fig. 1) was introduced into the first guess temperature and MODEL 3a was asked to retrieve the true temperature. The best retrieval more closely matches the anomaly curve. The curve connected by the squares in Fig. 1 shows the results of this effort when the temperature weights were uniform (as is done with most retrieval methods). If the temperature uncertainty is doubled at the location of the anomaly, then the retrieval follows the line given by



the pluses; the correct temperature profile has been mostly restored. This finding may be useful for retrievals across the tropopause.

b) MODEL 3b consists of MODEL 3a plus the u and v geostrophic equations and the hydrostatic equation. This model couples the satellite temperatures to the three dimensional wind and height fields. It was tested with the 00 GMT 11 April 1979 SESAME data with the result that the SAT analysis filled a deep trough over the high plateau areas of the southwest U.S. by 30 m. This anomaly may be traceable to high skin temperatures. (Skin temperature was treated as true in MODEL 3b.)

c) MODEL 3c consists of MODEL 3b but with skin temperature as an adjustable variable. Varying the skin temperature increases the complexity of the variational equations. MODEL 3c is still under development.

IV. MODEL IV.

No significant progress has been made to date.

V. INITIAL ANALYSIS

a) A three-pass version of the Barnes objective analysis method has been implemented. This method has been found to reduce short wavelength noise in derivatives of gridded fields by up to 70% (Laplacians of height fields.)

b) A vertical velocity method that blends adiabatic vertical velocities with the divergence of the observed wind has been implemented. The blending is done as a function of the static stability.

RESEARCH PLANS FOR THE NEXT YEAR

1. Complete MODEL I.2, run, and verify (top priority)
2. Combine the new MODEL I.2 with the thermodynamic equation to produce a new MODEL II.
3. Complete the studies with the radiative transfer models (3a-3c) and develop theory to combine with model II into model III.
4. Develop a variational methodology for moisture.
5. Investigate a new objective interpolation method developed by F. Caracena (JAS 44, 3753-3768) that allows for the direct interpolation of derivatives from the observations and modify the vertical velocity algorithm to include vorticity advection.

LIST OF PUBLICATIONS PREPARED IN 1987-1988

Achtemeier, G. L., 1987: On the Concept of Varying Influence Radii for a Successive Corrections Objective Analysis. Mon. Wea. Rev., 115, 1760-1771.

Achtemeier, G. L., 1987: A 3-pass near optimum Barnes method for the univariate objective analysis of mesoscale phenomena. 3rd Conf. Mesoscale Proc., Vancouver, B.C., Canada, 21-26 Aug. 1987, 126-127. (Poster paper)

Achtemeier, G. L., 1988: Variational Blending of Space Observed Radiance with Conventional Weather Data Through Coupling Radiative Transfer with the Truncated Navier-Stokes Equations. European Geophysical Society XIII General Assembly, Bologna, Italy, 21-25 March 1988, Annales Geophysicae, 6, 97.

Achtemeier, G. L., and H. T. Ochs III, 1988: A Variational Objective Analysis - Assimilation Method, Part I: Development of the Basic Model. (Submitted to Tellus 20 April 1988)

Achtemeier, G. L., S. Q. Kidder, and R. W. Scott, 1988: A Multivariate Variational Objective Analysis - Assimilation Method, Part II: Case Study Results with and without Satellite Data. (Submitted to Tellus 20 April 1988)

Achtemeier, G. L., 1988: Modification of a Successive Corrections Objective Analysis for Improved Higher Order Calculations (Submitted to Mon. Wea. Rev. 15 April 1988)