A COMPARISON OF FORECASTS FROM CRESSMAN AND OPTIMUM INTERPOLATION ANALYSES

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1. INTRODUCTION

The past several years the Global Modeling and Simulation Branch in the Laboratory for Atmospheres (formerly the Goddard Laboratory for Atmospheric Sciences or GLAS) at the NASA/Goddard Space Flight Center has been conducting research in numerical weather prediction with the FGGE data. A Cressman-type two-dimensional univariate successive correction method (SCM) of objective analysis (Baker, 1983) has been utilized to prepare the initial conditions for the numerical forecasts. More recently, however, because of the complexity of the FGGE observational database a three-dimensional multivariate statistical objective analysis method (conveniently referred to as optimum interpolation or simply as OI) has been developed. A two-dimensional version of the scheme was developed earlier at the National Center for Atmospheric Research and described fully by Schlatter et al. (1976).

In Section 2, characteristics of the SCM and OI are compared, and the OI is contrasted with the OI schemes used operationally at the European Centre for Medium Range Weather Forecasts and the National Meteorological Center (NMC) in Section 3. Some preliminary forecast results from the SCM and OI are presented in Section 4. A summary follows in Section 5.

2. COMPARISON OF CRESSMAN AND OI ANALYSIS SCHEMES

An essential part of a data assimilation system is the forecast model which provides a first guess for each analysis. In both the SCM and OI analysis schemes, the first guess is provided by the global fourth-order version of the GLAS general circulation model (GCM) described in detail in Kalnay-Rivas et al. (1977) and Kalnay-Rivas and Hoitsma (1979) and more recently in Kalnay et al. (1983). The model is based on an energy conserving scheme with all horizontal differences computed with fourth-order accuracy. A two-dimensional (latitude and longitude), 16th order Shapiro (1970) filter is applied every 2 h to the sea level pressure, wind and potential temperature fields.

There are nine vertical layers equal in sigma with a uniform non-staggered horizontal grid (4° latitude by 5° longitude). With the exception of the computation of the longwave radiation (Wu, 1980) the parameterization of the physical processes in the fourth-order model is substantially the same as in the second order model of Somerville et al. (1974).

Both the SCM and OI analysis schemes operate on constant pressure surfaces. However, the SCM is univariate in geopotential height z, the eastward and northward wind components u and v, and relative humidity RH, while the OI is multivariate in z, u, and v and univariate in water vapor mixing ratio w. The SCM is two-dimensional for the analysis of u, v, and RH and weakly three-dimensional (3-D) for z. The OI, on the other hand, is fully 3-D. At the surface, the SCM analysis is univariate in sea level pressure $p_{s\ell}$ with the surface wind data analyzed at 1000 mb over the oceans. In the OI, the analysis is multivariate over the oceans in $p_{s\ell}$, U_s, and V_s following a procedure described by Bloom et al. (1984) in which an attempt is made to maintain an Ekman balance.

For both the SCM and OI the analyses are performed on 12 mandatory pressure levels with the top level at 50 mb. A separate version of the OI scheme involves an 18-level 2-D analysis for stratospheric analysis/forecast experiments with the top level at 0.4 mb. The SCM utilizes only mandatory level data from the rawinsonde, pilot balloon, and dropwindsonde soundings, whereas the capability to utilize significant level data is currently being implemented in the OI. On the other hand, the SCM draws for all of the accepted data whereas the OI draws for a subset of accepted reports (currently up to 15 pieces of data).

3. CHARACTERISTICS OF THE GLAS, ECMWF AND NMC OI SCHEMES

In this section we compare some characteristics of the present OI with those of the OI systems in use operationally at ECMWF and NMC. ECMWF and NMC were selected for comparison because of the abundant information published about those schemes. For a more detailed description of the ECMWF data assimilation system the reader is referred to Lorenc (1981) and Bengtsson et al. (1982). The NMC analysis/forecast system is described in Bergman (1979), McPherson et al. (1979), Kistler and Parrish (1982), and Morone and Dey (1983).

Table 1 compares several of the prominent characteristics of each OI scheme. All of the upper-air analyses are multivariate in z, u, and v. Each scheme provides for a univariate moisture analysis with water vapor mixing ratio analyzed in the GLAS scheme, relative humidity in the NMC scheme, and specific humidity in the ECMWF system.

Each scheme also utilizes an analysis equation of the form

$$\underset{\sim}{A}_g = \underset{\sim}{F}_g + \sum_{i=1}^{N} \underset{\approx}{W}_i(\underset{\sim}{O}_i - \underset{\sim}{F}_{g_i}) \ , \qquad (1)$$

where N is the number of observations affecting a particular gridpoint,

Table 1. Characteristics of the GLAS OI compared with those of other systems.

Salient Features	GLAS	NMC	ECMWF
Approach	3-D; Multivariate in z,u,v Univariate in w	3-D; Multivariate in z,u,v Univariate in RH	3-D; Multivariate in z,u,v Univariate in q
Resolution	18 Levels; 4° x 5° (2-D) 12 Levels; 2° x 2.5° (3-D)	12 Levels; 3.75° Upper Air, 2.5° Surface	15 Levels; 1.875°
Autocorrelation function μ	Damped Cosine for z Damped Exponential for w	Gaussian	Bessel
Cross-correlation model	Geostrophic (scaled to 0.0 at equator)	Same	Same
Assumption of isotropy	z (Yes); u,v (No)	Same	Same
Geographically dependent μ	Yes	No	Yes (Latitudinally Dependent)
Multivariate surface analysis	Yes (Bloom, 1984; Ekman Balance)	Yes (Druyan, 1972; (Geostrophic)	Yes (Geostrophic at 1000 mb)

$(\underset{\sim}{O}_i - \underset{\sim}{F}_{g_i})$ the observation minus first guess difference at the ith observation location, $\underset{\sim}{F}_g$ the gridpoint first guess value, and $\underset{\sim}{A}_g$ the resulting gridpoint analysis value. $\underset{\approx}{W}_i$ are the so called "weight" matrices which when chosen in such a manner that the mean squared analysis error is minimized constitutes "optimum" interpolation following Gandin (1963). In the GLAS OI, covariance matrices are inverted in order to obtain $\underset{\approx}{W}_i$, while in the ECMWF (Lorenc, 1981) and NMC (Bergman, 1979) schemes, the covariance matrices are first normalized and the resulting correlation matrices are inverted. Also, in the ECMWF OI, one matrix is inverted for each analysis box which includes several gridpoints, whereas in the NMC and GLAS schemes the analysis proceeds from gridpoint to gridpoint.

For the horizontal autocorrelation of model prediction error the GLAS OI utilizes the damped cosine model suggested by Thiebaux (1975). The NMC scheme utilizes a Gaussian function (Bergman, 1979), whereas ECMWF has recently employed a Bessel function (L. Bengtsson, personal communication, 1984). The GLAS OI also employs a geographically dependent autocorrelation function. The NMC scheme assumes a global set of coefficients for the Gaussian function while the Bessel function utilized by ECMWF is latitudinally dependent.

Each OI scheme assumes geostrophy in modeling the height-wind cross correlations. However, there are significant differences in the manner in which the surface analysis is performed. The GLAS OI attempts to maintain an Ekman balance over oceans, as mentioned previously, following a procedure described by Bloom _et al_. (1984). In this approach the surface winds are assumed to be related to the surface pressure $p_{s\ell}$ via geostrophy modified by the surface drag so that

$$\frac{1}{\rho} \nabla p_{s\ell} + f \mathbb{k} \times \mathbb{V}_s - \frac{1}{\rho}\frac{\partial \pi}{\partial z} = 0 \qquad (2)$$

where $\mathbb{V}_s$ is the vector wind at the surface, f the Coriolis parameter, $\pi(z)$ the stress vector in the boundary layer, and ρ density.

4. SOME FORECAST RESULTS

In this section we present results comparing some OI and SCM forecasts. Fig. 1 contains the 500 mb height anomaly correlation scores averaged over forecasts generated from the GLAS FGGE IIIb initial conditions on 0000 GMT 7, 8, and 9 January 1979. As of this writing, only a limited number of forecasts could be compared because the vectorization of the OI code for the Cyber 205 has not been completed.

As may be seen in Fig. 1, if a limit of useful skill is assumed to be 60, then there is skill out to around 4.5 to 5 days for both the OI and SCM. This level of skill is reasonable considering the rather coarse resolution of the forecast model (4° latitude by 5° longitude by 9 levels). The close agreement in the scores for the OI and SCM forecasts with the OI only slightly less skillful than the SCM after 4.5 days is somewhat surprising considering the small number of data utilized by the OI (up to 15 pieces) compared to the SCM (all available data).

On a regional basis noticeable differences in the OI and SCM predictions are apparent as may be seen in Fig. 2 for the 24 and 48 h sea level pressure forecasts. The cyclone position and central pressure at 24 h are more accurately predicted from the OI initial conditions. Similarly, the forecast of the ridging behind the cyclone is more accurate with the OI at 24 and 48 h.

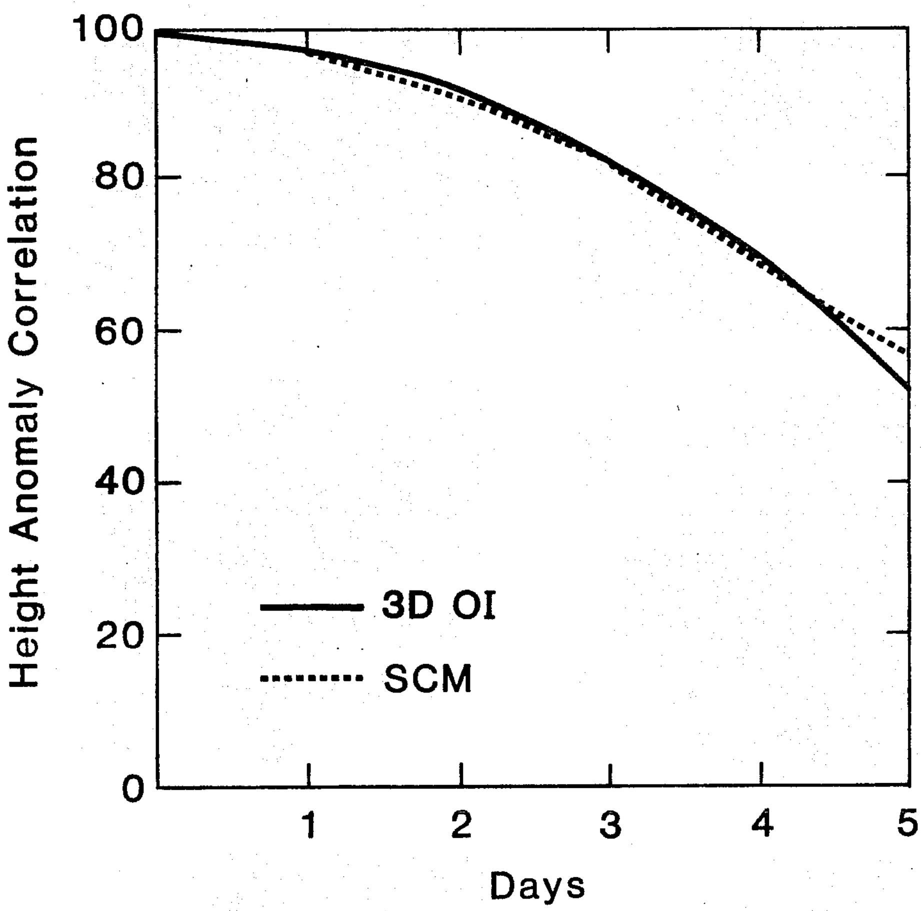

Fig. 1. 500 mb height anomaly correlation scores for the Northern Hemisphere extratropics (30°-86°N) averaged over three forecasts.

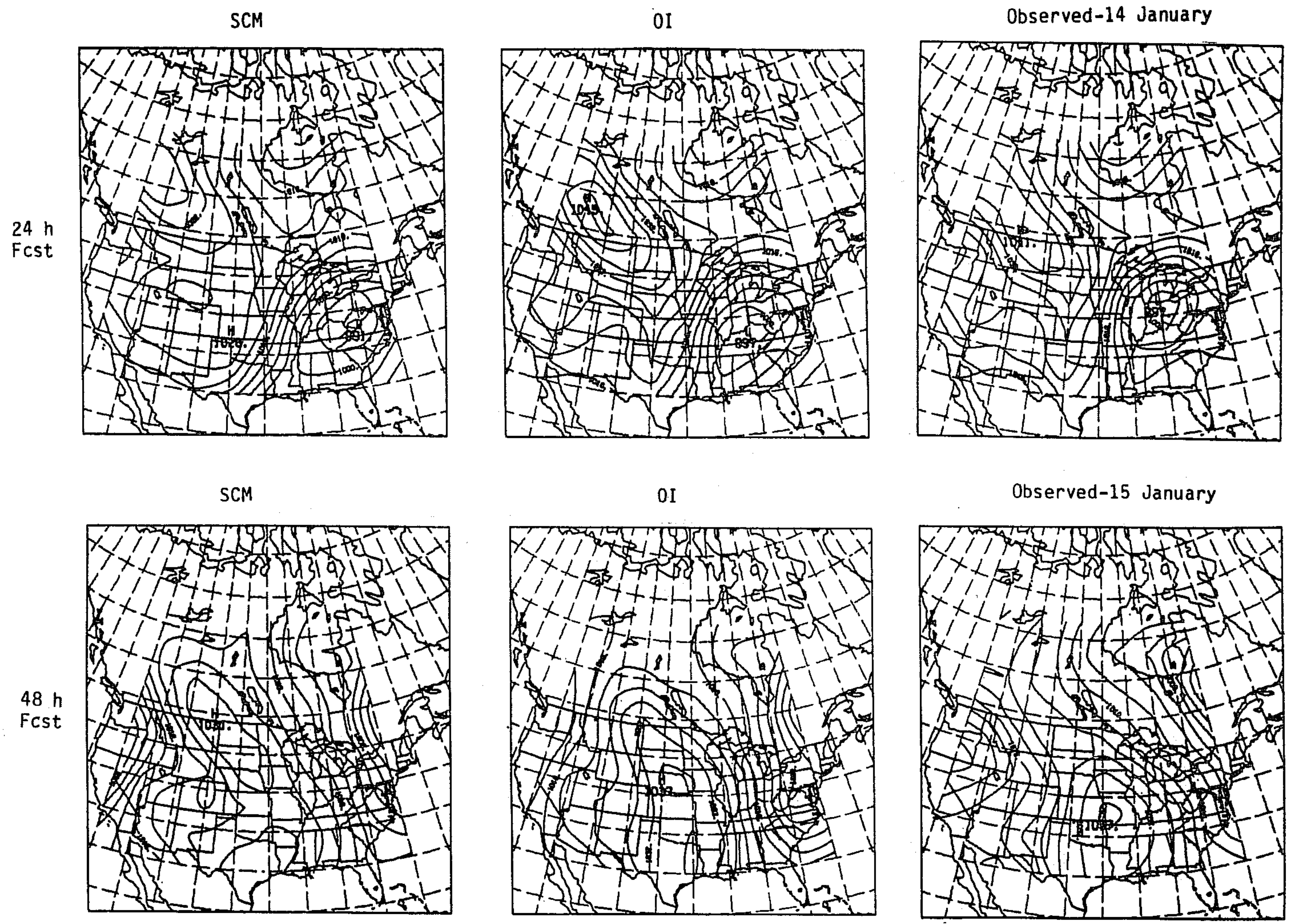

Fig. 2. SCM and OI sea level pressure forecasts from 0000 GMT 13 January 1979.

5. SUMMARY

Two different objective analysis schemes have been utilized for research in numerical weather prediction at the NASA/Goddard Space Flight Center. A Cressman-type (SCM) objective analysis scheme has been used extensively for impact studies with the FGGE data. More recently, a 3-D, multivariate optimum interpolation (OI) analysis procedure has been developed and is currently being vectorized for the Cyber 205. Some novel features of the OI include a multivariate surface analysis over the oceans which maintains an Ekman balance and a geographically dependent correlation function.

In the preliminary experiments conducted thus far, the OI exhibits forecast skill comparable to that of the SCM for the first 4.5 days and is only slightly less skillful thereafter. This occurs in spite of the small number of observations allowed to affect a gridpoint (up to 15 pieces of data).

In the future, a careful evaluation of the forecast skill of the OI relative to that of the SCM will be conducted for an identical set of observational data. High-resolution forecast experiments will also be performed as well as experiments with a flow-dependent correlation function.

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