The Operational Hemispheric Model at the French Meteorological Service

By J. Coiffier, Y. Ernie, JF. Geleyn
EERM/CRMD

J. Clochard, J. Hoffman and F. Dupont
SCEM/Prévi-Dev

Direction de la Météorologie, Paris, France
(Manuscript received 4 November 1986; in revised form 14 January 1987)

Abstract

The general features of the new French operational spectral model are presented with emphasis on the initialization of the surface variables. By using zonal mean diagnostics, several shortcomings of the original formulations were detected. The use of corrected fields near the equator, of the increment method for vertical interpolation as well as improvements in the physics contributed to the production of better forecasts. These progresses are also documented by the informative method of the zonal mean diagnostics. Results of the screen level data assimilation in an operational framework are presented.

1. Introduction

Since the beginning of 1985 a new hemispheric spectral model (called Emeraude) has been running operationally on a CRAY 1 computer for the French Meteorological Service. The aim of this model was the production of accurate forecasts up to 4 days ahead. Although this model already fulfills its role, several problems had to be successively solved: the discrepancies between forecasted and analysed fields near the tropics, the initial shocks due to the interpolation of the variables from the analysis levels onto the model ones, onwards and backwards, and some deficiencies which were discovered within the physical parameterizations. Relevant modifications were introduced in the model and have proved to be efficient. This work was made easier by using zonal mean diagnostics which appear to be useful tools in order to point out model deficiencies and to monitor their corrections.

It has been recognized that land surface prognostic variables (surface temperature and soil water content) have an important role to play both in the forecasting model's behaviour and in the interpretation of forecast products. In order to initialize these quantities a safe and simple, but not trivial approach to the problem has been chosen. Some results obtained from operational runs of the model show the efficiency but also the limitation of the method.

2. The main features of the model

It is a classical 15-level primitive equation spectral model (Ernie, 1985). The hybrid vertical coordinate coincides with sigma at the lowest level and \( \phi \) at the uppermost level within the stratosphere (Fig. 1); it operationally works with a triangular truncation T79; it uses a leapfrog semi-implicit time integration scheme; gravity wave terms as well as mean zonal advection of vorticity and specific humidity are implicitly treated.
(Simmons and Jarraud, 1983). A reinforced horizontal diffusion has been added in order to temporarily reduce the effective truncation and to allow the scheme to remain stable with a 24-minute time step even if the wind locally grows beyond a given value (this in a way close to that of Simmons and Jarraud, 1985). A non linear normal mode initialization provides hemispherical balanced initial fields to start the model integration. The horizontal diffusion acts on vorticity, divergence, specific humidity and on the dry static energy. The use of this conservative thermodynamic quantity avoids the fictitious source of energy which occurs over mountainous areas when dealing with absolute temperature. After this formulation had been implemented in the operational model we discovered that the method has been independently proposed by Girard and Shantz (1986). The initial data are issued from an analysis (with a 2 h 45 cut-off time), based on the optimal interpolation method, which is the last step of a 6-hour intermittent data assimilation.

3. Physical Parameterizations

The main options chosen for the parameterization schemes are the following:

—radiative fluxes are computed at every time step with a highly simplified scheme: only one spectral interval for solar as well as for thermal radiation; two-stream method with gaseous optical depths precomputed in clear sky conditions, care being taken for thermal fluxes to avoid any overestimation of the exchange terms despite the linear solution; clouds diagnosed from relative humidity with assumption of random overlap; use of zonal means for part of the optical calculations.

—the boundary layer scheme is the one of ECMWF as described in Louis, Tiedtke and Geleyn (1982) and modified to take into account shallow convection (Geleyn, 1987).

—the deep convection is parameterized following the method of Bougeault (1985): mass flux type scheme with a parameterization of the detrainment and a closure assumption similar to those of the Kuo scheme; the mass flux vertical profile is taken proportional to the profile of the square root of the moist static energy excess in the cloud.

—the large-scale precipitation is parameterized using the 1983 version of the ECMWF Kessler-type scheme.

—surface temperature over land and soil water content are initialized and predicted by using a force-restore method, which will be described hereafter.

4. Treatment of surface and deep soil parameters over land

Special care was taken for initialization of the surface parameters over land (surface temperature $T_s$, deep soil temperature $T_d$, surface soil water content $W_s$ and deep soil water content $W_d$) in order to have some kind of data assimilation. The prognostic equations for these quantities are:
\[ \frac{\partial T_s}{\partial t} = CF_{net} + \frac{2\pi}{\tau_1} (T_d - T_s) \]

\[ \frac{\partial T_d}{\partial t} = \frac{2\pi}{\tau_2} (T_s - T_d) \]

\[ \frac{\partial W_s}{\partial t} = H_{net} + \frac{1}{\tau_1} \left( W_d \frac{W_{\text{max}}}{W_{\text{dmax}}} - W_s \right) \]

\[ \frac{\partial W_d}{\partial t} = \frac{1}{\tau_2} \left( W_s \frac{W_{\text{dmax}}}{W_{\text{max}}} - W_d \right) \]

where \( C = 1.1 \times 10^{-3} \text{MKS} \), \( \tau_1 = 1 \text{ day} \), \( \tau_2 = 5 \text{ days} \), \( W_{\text{max}} = 20 \text{ mm} \), \( W_{\text{dmax}} = 100 \text{ mm} \), \( F_{net}^s \) and \( H_{net}^s \) being the net (positive downward) fluxes of energy and humidity (in the latter case precipitation minus evaporation). The evaporation is computed with the Monin Obukhov similarity theory using the so-called relative humidity hypothesis:

\[ q_{\text{surf}} = q_{\text{sat}}(T_s, p_0) \cdot f(W_s/W_{\text{max}}) \]

where

\[ f(x) = \frac{1 - \cos(\pi x)}{2} \]

On the other hand, the model coupled evolution of land surface and atmosphere produces some diagnostics of temperature and relative humidity at the 2 m screen level. The interpolation between the surface and the lowest model level uses some analytical formulae derived from the Monin Obukhov theory through some simplifying assumptions.

For the dry static energy \( s = C_p T + g z \) this interpolation gives in the stable case:

\[ s(z) - s_s = \frac{s(z_1) - s_s}{b_H} \left( \ln \left( 1 + \frac{z}{z_1} (e^{b_H} - 1) \right) - \frac{z}{z_1} (b_H - b_H) \right) \]

and in the unstable case:

\[ s(z) - s_s = \frac{s(z_1) - s_s}{b_H} \left( \ln \left( 1 + \frac{z}{z_1} (e^{b_H} - 1) \right) - \ln \left( 1 + \frac{z}{z_1} (e^{b_H} - b_H - 1) \right) \right) \]

with \( b_N = \ln[(z_1 + z_0)/z_0] \) and \( b_H = \frac{k \sqrt{c_D}}{c_M} \), \( c_M \) being the drag coefficients for momentum and heat respectively.

A similar equation is used for \( q \) and the relative humidity \( (RH) \) is then diagnosed. These vertically interpolated values are then used as first guess for an analysis of \( T_{2m} \) and \( RH_{2m} \) using SYNOP data (the problems of horizontal interpolation and of orographic correction, albeit complex, are left out of this explanation). The differences between analysis and guess (so called increments) are then added to the forecasted values of \( T_s \) and \( f(W_s/W_{\text{max}}) \) to obtain values of \( T_s \) and \( f(W_s/W_{\text{max}}) \) at initial time for the next forecast. The same procedure is used for \( T_d \) and \( f(W_d/W_{\text{dmax}}) \) but with an increment multiplied by the damping factor \( \tau_1/\tau_2 \) (thus \( W_s \) and \( W_d \) have the same absolute increment). These 4 values are corrected by a relaxation towards climatology with a damping time of 12.5 days. This gives the following equations at each 6 hour-cycle:

\[ T_s = \{ (T_s)_a + [(T_{2m})_a - (T_{2m})_a] \} \times (1 - \lambda) + \lambda (T_s)_c \]

\[ T_d = \{ (T_d)_a + \frac{\tau_1}{\tau_2} [(T_{2m})_a - (T_{2m})_a] \} \times (1 - \lambda) + \lambda (T_d)_c \]

\[ W_s = \{ (W_s)_a + W_{\text{max}} \cdot f^{-1}(RH_{2m})_a \}

\[ - f^{-1}(RH_{2m})_a \} (1 - \lambda) + \lambda (W_s)_c \]

\[ W_d = \{ (W_d)_a + W_{\text{dmax}} \cdot f^{-1}(RH_{2m})_a \}

\[ - f^{-1}(RH_{2m})_a \} (1 - \lambda) + \lambda (W_d)_c \]

with \( \lambda = 0.002 \) (for 6 hours) where the subscripts \( g, a \) and \( c \) refer to guess field, analyzed and climatological values respectively.

5. Results

This model was tested with 13 initial situations extracted from the FGGE data set and it was compared with our former hemispheric model (10-level, T42 spectral model and a rather rough physics). It appears that the improvements can be attributed for one part to the resolution but also for the other part to more accurate physical parameteri-
These results have been confirmed by computing the verification scores for a year. Correlation coefficients between forecasted and observed tendencies for the 1000 mb geopotential height gives evidence of the improvement of 24 h forecasts as well as 96 h ones over Europe even with the symmetry assumption linked to the hemispheric spectral integrations (Fig. 3). The disastrous results that can be observed from May to August 1986 need an explanation. An unfortunate mistake was introduced in the analysis code, which led to an erroneous surface wind field in some data void areas. It must be noted that both erroneous initial conditions for the model runs as well as wrong verification analysis contributed to the low values of the correlation coefficient, turning to "tragedy", for August 1986.

6. Matching of the tropical initial data

The model gives a symmetrical circulation with respect to the equator (i.e. the meridional wind velocity is zero at the equator). Nevertheless, this assumption provides unrealistic fields in the equatorial belt. On the other hand, the analysis uses as a guess field near the equator (0° to 14° North) a mixing between climatology, persistence and ECMWF previous analysis. This procedure led to:

![Diagram](image-url)

**Fig. 2** Improvement of RMS (North of 30°N) obtained with 13 integrations from FGGE dataset due to the increase of vertical resolution in the lowest layers (A), to the increase of horizontal resolution T42→T79 (B-A) and to a new physics (C-B). The "C" values of RMS are indicated along the ranges.

![Diagram](image-url)

**Fig. 3** Evolution of correlation coefficients between observed and forecasted tendencies of 1000 mb geopotential heights over Europe (forecast ranges 24 h and 96 h).
local imbalances which gave strong initial tendencies for the meridional wind (Fig. 4a).
In order to alleviate this discordance between forecasted fields and analysed ones, the guess field for the analysis is now slightly modified so that it has the same zonal averages as the fields from the model. The effect of this procedure reduces the strong initial tendencies (Fig. 4b).

7. Vertical interpolation of increments

The values of the variables at model levels were obtained by means of a polynomial vertical interpolation from the analyzed data at pressure levels. In the same way, final values had to be interpolated (or extrapolated) to provide forecasts at pressure levels. This procedure has proven to lead to false profiles near the tropopause as well as in the lowest layers for relative humidity (Fig. 5a). The implementation of the increment method based on the vertical interpolation of the differences between analyzed and guess fields from analysis onto model levels succeeds in improving the initialization of temperature and of specific humidity within the lowest layers.

---

**Fig. 4a, b** Zonal mean of meridional wind tendencies averaged over the four 6-hour integrations of the data assimilation cycle before tropical data matching (a) and after (b). [thick full line follows 0 value; thin lines indicate positive values; dotted lines indicate negative values; contour interval is 1 ms⁻¹ day⁻¹].

**Fig. 5a, b** Zonal mean of specific humidity tendencies averaged during the 24 first hours of the integration from 10.01.85-00Z using direct interpolation (a) and increment interpolation (b). [same conventions as for 4a, b except for contour interval which is .2 g·kg⁻¹·day⁻¹].
8. Effects of improved physics

The zonal means of temperature and specific humidity tendencies (Fig. 6a, b) averaged over 13 days of October 1985 indicate the main problems associated with the former version of our physical package: too much convective activity, temperature biases (too cool, too warm and much too cool when going upwards through the atmosphere) and a sinking of the top of the boundary layer easily traced in the tropics by a drying. The successful correction of most of these deficiencies was the result of four changes:

(i) Inclusion of liquid water sustention in the cloud profile used in the convection scheme in order to regulate con-
vective activity;

(ii) Parameterization of shallow convection inside the vertical diffusion scheme to avoid the boundary layer collapse;

(iii) Inclusion of the thermal exchange terms in the radiative scheme (previously cooling to space approximation);

(iv) Parameterization of the orographic gravity wave drag.

The effect of these changes can be observed on the same zonal means as before over 13 days of October 1986 (Fig. 7a, b). The excess of heating associated with a convective drying near the ITCZ for the low troposphere (500–900 mb) disappeared as a result of the more realistic convective cloud profile (i). The elimination of the strong humidity tendencies in tropical areas (moistening of the planetary boundary layer, drying above) show the efficiency of the shallow convection parameterization (ii). The improvements in the radiation scheme (iii) contributed to suppress the temperature biases (too warm troposphere associated with too cool stratosphere). Finally the orographic gravity wave drag parameterization (iv), which has been recently introduced, reduced the excessive cooling of the stratosphere near the North pole.

The better behaviour of the mean temperature of the low troposphere essentially due to the improvements in the convective cloud profile and in the radiation scheme (which were implemented in November 1985) is emphasized by the time evolution of the mean forecast error for 1000 mb and 500 mb geopotential heights at 72 hours (Fig. 8).

The wrong behaviour of the model during August 1986 seems to be not too detrimental with respect to the mean forecast error. This fact is probably due to the random character of the above-mentioned analysis error.

9. Evolution of the surface variables

The behaviour of the surface variables in the operational model has also been investigated: Fig. 9 shows the evolution of the mean values of $T_s$ and $T_d$ over all land points in 5 days of assimilation. The starting point of the first step is taken without increments ($T_d=T_{air}, T_d=T_{dlim}$). One notices the quick adaptation to a good simulation of the diurnal cycle (no important mean increments, lagged and damped variations of $T_d$ against $T_s$). Of course this good behaviour of the average could result from the com-
pensation of errors, either of geographical character or with a diurnal wave structure. Figs. 10a, b show this not to be the case at least for data rich areas. When dealing with relative humidity the results are not as good as for temperature. The simulation of the mean soil water content is less continuous than that of temperature (Fig. 11) and some rather large local increments can be detected in some areas. This is not too surprising given the fact that we have to rely on our $f(\delta \cdot f^{-1})$ operator and that humidity SYNOP measurements are certainly far less representative than temperature ones. However the very recent replacement of the relative humidity formulation for land surface evaporation fluxes by the formula proposed by Royer (1981) results in some improvements.

10. Conclusion

The replacement of the 10-level T42 spectral model by a 15-level T79 one with more sophisticated physics in February 1985 contributed to improve significantly the operational forecasts up to 4 days ahead. Several modifications introduced in the initial fields (analysis near the equatorial belt, vertical interpolation of the increments) contributed to eliminate the shocks that were observed during the first hours of the model integration. The biases of the model, which were detected by looking at the zonal mean tendencies, have been progressively corrected by improving several physical parameterizations (convective cloud profile, radiation scheme, shallow convection, gravity wave drag). The initialization of the surface variables like temperature or water content over land uses screen level observations. The method we are using in order to assimilate these data seems to be good enough to reproduce the diurnal cycle, for the surface temperature essentially.

Acknowledgements

The authors would like to thank all the people who contributed to building and implementing the new forecast model at the French Meteorological Service. They also thank their colleagues who are in charge of...
objective analysis for their fruitful collaboration. Thanks also to Patricia Bonvalet for patient typing.

References


Geleyn, J.F., 1987: Use of a modified Richardson number for parameterizing the effect of shallow convection. (Submitted to the *Journal of the Meteorological Society of Japan*).


