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DETERMINATION OF SEA LEVEL PRESSURE FROM THE LFM AND NGM

[Editor's Note: The attached article, authored by Norman Phillips and Dennis Deaven, NMC, describes the different methods that the LFM and NGM utilize to derive sea-level pressure. One of the known deficiences of the NGM product is the excessive high surface pressure forecast by the model during the summer months in the Southwest. This problem is related to the NGM model's method of reduction to sea-level pressure. The NGM also fails to fit observed sea-level pressure reports closely in other areas and at other times of the year because it does not use these observations in the sea-level pressure calculation. NMC does not plan to consider changes in this NGM procedure until after the model has a full radiation and diurnal cycle, and after some success in forecasting bottom layer temperatures in the western states has been achieved. These later changes are scheduled for this summer. In the meantime, it is important for forecasters to become familiar with sea-level pressure biases and develop work-arounds such as using 850-mb heights instead of sea-level pressure in areas of high terrain.]

Determination of sea-level pressure in the LFM and in the NGM

- N. Phillips and D. Deaven, 29 January 1986

I. THE LFM

1. A streamfunction (ψ) is derived from the forecast vorticity at 500 mbs by solving the following equation for ψ .

$$\nabla^2 \psi = \zeta_{500} .$$

This streamfunction is then inserted in the right side of the "balance equation" to determine a balanced geopotential (ϕ = g x z) field at 500 mbs:

$$\nabla^2 \phi_{bal} = \nabla \cdot f \nabla \psi + 2 \left[\frac{\partial^2 \psi}{\partial x^2} \frac{\partial^2 \psi}{\partial y^2} - \left(\frac{\partial^2 \psi}{\partial x \partial y} \right)^2 \right].$$

2. A hydrostatic geopotential at 500 mbs is derived hydrostatically from the forecast surface pressure(p_G), the model terrain height (z_G) and the forecast model temperatures in its sigma layers. Symbolically, this is done by numerical integration of the hydrostatic equation in the following form:

$$\phi_{500} = g z_G + R \int_{500}^{p_G} T \, d\ln p$$

3. The difference field, δ , between these two 500-mb geopotential fields

$$\delta = \phi_{bal} - \phi_{500}$$

is constructed. All output fields of geopotential on an isobaric surface will then be modified from the direct hydrostatic value for that surface by addition of this difference field:

$$\phi_{output} = \phi_{hydro} + \delta$$

The purpose of this modification is to minimize the effect on the output geopotentials of the external gravity waves that can appear in the LFM forecast from the imposition of the LFM's lateral boundary conditions. (This "noise" is almost completely absent in the NGM.) The modification works in the LFM because these external gravity waves have little vorticity associated with them at the wave lengths that can exist on the LFM grid.

4. The LFM sea-level pressure will eventually be derived from a geopotential at 1000 mbs. This geopotential at 1000 mbs is constructed in several steps.

   a. A temperature T_G at the LFM ground is defined by using a lapse rate of 6.5 deg per km downward from the forecast temperature in the middle of the second LFM sigma layer. A fictitious temperature T_0 at 1000 mb is constructed from the same lapse rate.

   (Note that the LFM boundary-layer temperature is ignored.)

b. The so-called "SHUELL" method is used to define the vertical mean temperature to be used in a hydrostatic computation from the forecast surface pressure at the LFM ground height to get the hydrostatic geopotential at 1000 mb. This method considers the values of T_G and T_O arrived at in step a.

(1) If both T_O and T_G are less than 290.6K (17.5C), the mean temperature is the average of T_O and T_G.

(2) If only T_O exceeds 290.6, the mean temperature is the average of T_G and 290.6 .

(3) If both T_O and T_G exceed 290.6 (the warmest case), the mean temperature is set to the average of T_G and a modified value of T_O:

$$T_O' = 290.6 - 0.005(T_G - 290.6)^2$$

The overall effect of this is to lower the mean temperature used below ground when that mean temperature is warm. This technique was derived by J. Newell and F. Shuman around 1970 to allow crudely for the US practice of (a) using the "plateau correction" (derived by Bigelow around the turn of the century for western stations), and (b) the practice of using a time-mean shelter temperature instead of the instantaneous shelter temperature in reporting a sea-level pressure in the station synoptic reports.

c. The hydrostatic 1000-mb geopotential is then modified by adding δ from step 3.

d. A provisional sea-level pressure is then derived from the modified 1000-mb geopotential by a hydrostatic integration over the small vertical distance from 1000 mb to sea-level. (The temperature used in this minor step is derived from the 1000-500 thickness temperature.)

5. The final step is the so-called "tendency correction". Before the forecast is started, an analysis is made of sea-level pressure reports. A field of derived sea-level pressure from steps 1-4 is also calculated at the initial time (t=0). The difference between these fields at t = 0 is saved. At <u>all</u> output times (including t=0), this difference is added to the field of sea-level pressure arrived at by steps 1-4. The result at t=0 is that the LFM <u>output</u> of sea-level pressure at the beginning of the forecast agrees very closely with all synoptic reports---<u>no matter what the values are of surface pressure, ground height, and temperatures in the sigma layers of the model.</u>

II. THE NGM

A much simpler procedure is used.

1. A sea-level pressure is derived directly instead of first deriving a 1000-mb geopotential. To get this sea-level pressure, a temperature profile is constructed with a lapse rate of 6.5 deg per km starting from the forecast temperature in the bottom layer of the model (about 160 meters above the model ground). A surface temperature T_G and a sea-level temperature T_O are defined from this profile. They are subjected to the same SHUELL correction used in the LFM, to obtain a mean temperature to use in a hydrostatic integration from the model surface pressure and height down to sea-level.

2. To maintain consistency between outputs of sea-level pressure, 1000-500 mb thickness, and 500-mb height, the 1000-mb height (geopotential) field is derived from the sea-level pressure obtained in step 1. (Since the 1000-mb surface is close to sea-level, a standard value of the density is used in this minor hydrostatic calculation.)

III. Main differences

The main differences between the LFM and NGM sea level procedures are

1. The barotropic geopotential correction used in steps 1-3 for the LFM is not used for the NGM.
2. The temperature profile used for the LFM ignores the bottom layer temperature of the model.
3. The "pressure tendency correction" is not used for the NGM.

According to J. Stackpole, the bottom layer temperature of the LFM is ignored because experience in the late 1960's (with the Shuman-Hovermale 6-layer model upon which the LFM was based) showed that those temperatures gave erratic results, partly because the model had an extremely crude diurnal heating scheme.

The pressure tendency correction is not used in the NGM because tests have shown that an independent sea-level pressure analysis could be worse over oceanic regions than that produced by the above NGM procedure at t=0. (This is because the RAFS analysis for the NGM model variables uses wind data when analysing geopotential, and it has not yet been possible to introduce this aspect into a special RAFS sea-level pressure analysis for this correction.) Furthermore, it is doubtful whether this "correction" procedure would be useful for the NGM since the uncorrected sea-level pressure from its forecast variables depends on the temperature in its bottom layer instead of a less variable temperature several hundred mbs above the ground. The ignoring of the bottom layer temperature in the LFM procedure explains why the LFM sea-level pressure is often a poor indicator of frontal positions in the western half of the US. The lifted index from the LFM does depend on the bottom layer LFM temperature. It is therefore often used by forecasters to see where the LFM has forecast the edge of the cold air mass. On the other hand, the NGM procedure will not reproduce the low (e.g. 1008) sea-level pressures common in the southwest in summer until introduction of radiation makes it worthwhile to re-examine the possibility of imitating the empirical method used for sea-level pressure in the western states.