Further Experimentation with an Imposed Southern Boundary for Large-Scale Numerical Weather Prediction

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ABSTRACT

Experiments with a global, 2½° primitive equation model show that for periods of one week a wall placed at the equator does not appreciably affect the results of a forecast of large-scale mid-latitude atmospheric flows. The success of the hemispheric model depends on the lack of distortion of the mean and eddy quantities of the large-scale processes in the subtropical region.

1. Introduction

In a previous paper (Baumhefner, 1971) the effect of an imposed southern boundary on numerical weather forecasting in the Northern Hemisphere mid-latitudes was examined in detail. Two major questions were left unanswered in that research: 1) How does the reduction of the horizontal resolution of the model affect the results? and 2) What is the fundamental reason

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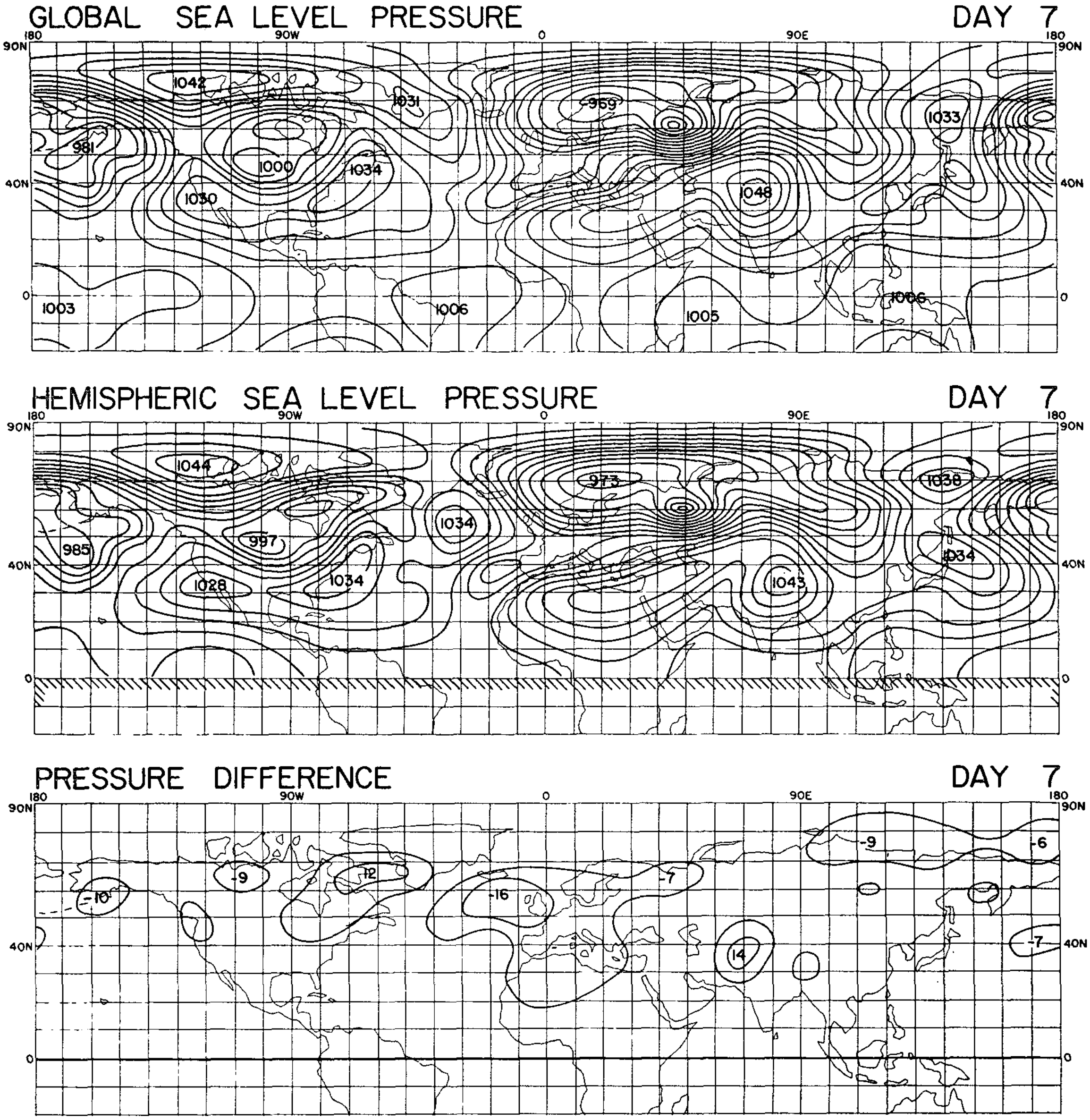

Fig. 1. Top: global 7-day forecast of sea level pressure. Contour interval is 5 mb, and highs and lows are indicated in whole millibars. Middle: hemispheric 7-day forecast of sea-level pressure for a boundary placed at equator. The contour interval is 5 mb. Bottom: pressure difference, global minus hemispheric forecasts at 7 days. The contour interval is 5 mb, and maximum errors are in millibars.

for the relative comparable skill of the hemispheric model with a wall at the equator? The previous experiments made use of a 5° latitude by 5° longitude grid which tends to truncate the synoptic-scale systems to some extent (Baumhefner, 1970). It was also found by Wellck *et al.* (1971) that the intensity of the eddy kinetic energy in mid-latitudes for the 5° model was underestimated when compared to the actual atmosphere. Therefore, two of the previous experiments were repeated using a horizontal mesh of $2\frac{1}{2}°$ latitude by $2\frac{1}{2}°$ longitude. Nearly all of the physical processes are the same in each model; however, the $2\frac{1}{2}°$ formulation did not contain the mountain blocking routine during these experiments.

The "control" or "reference" case, which is used to compare the modified runs, is a global prediction using 6 December 1967 as the initial data. It should be pointed out that the December data set is different from the initial data used in the 5° experimentation. The new data set contains a higher level of eddy activity in both hemispheres than the previous set and is therefore a more severe test for the hemispheric wall case. A 7-day forecast was generated with the global model using a geostrophic initialization for the wind

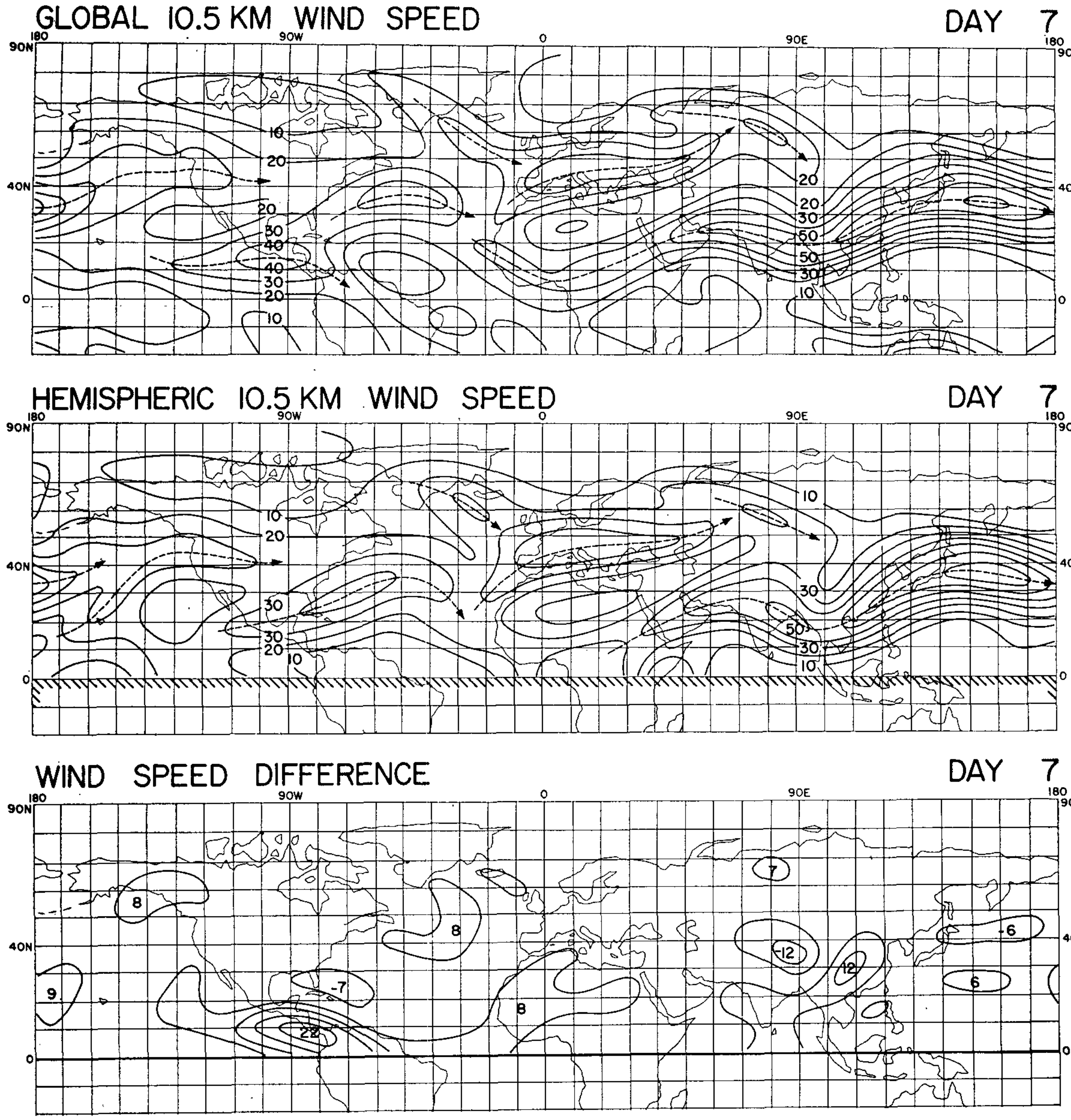

FIG. 2. Top: global 7-day forecast of 10.5-km wind speed. The contour interval is 10 m sec^{-1} and arrows indicate paths of velocity maximum. Middle: hemispheric 7-day forecast of 10.5-km wind speed. The contour interval is 10 m sec^{-1}. Bottom: wind speed difference at 7 days between global and hemispheric forecasts. The contour interval is 5 m sec^{-1} and maximum errors are in meters per second.

fields. The initial moisture fields were a climatological average for December.

A wall or boundary was placed in the model at the equator and a 7-day forecast was produced using the same initial data as for the global case. The boundary conditions imposed at the wall are the so-called "free slip" conditions (condition No. 2, Baumhefner, 1971). Comparisons of the actual differences, mean zonal quantities, and mean eddy quantities are made between the global prediction and the hemispheric prediction at the end of the forecast.

2. Forecast comparisons

The results of the bounded forecasts are compared in Figs. 1–3. The surface pressure for Day 7 is illustrated for both cases along with the actual difference between the forecasts (Fig. 1). The close similarity of the pressure patterns at the end of 1 week is quite apparent. Previous experiments with the 5° model were also quite similar at the end of the forecast. The difference map reveals a tendency for the difference between cases to be in the longer waves with their amplitudes reaching the 10-mb range. Most of the

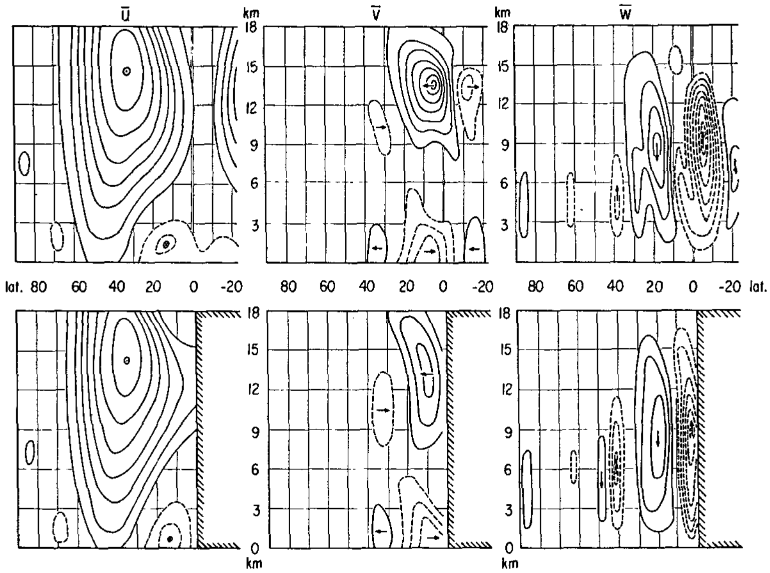

Fig. 3. Top left: longitudinally averaged zonal wind component at Day 7 for the global forecast. Solid lines are westerly winds, dashed easterly, and contour interval is 5 m sec⁻¹. Top middle: longitudinally averaged meridional wind component at Day 7 for the global forecast. Solid lines are southerly winds, dashed northerly, and the contour interval is 0.5 m sec⁻¹. Top right: longitudinally averaged vertical wind component at Day 7 for the global forecast. Solid lines are sinking motion, dashed rising. The contour interval is 0.2 cm sec⁻¹. Bottom left: same as top left for the hemispheric forecast. Bottom middle: same as top middle for the hemispheric forecast. Bottom right: same as top right for the hemispheric forecast.

change between forecasts is concentrated in the mid-latitude belt where the baroclinic waves are most active. The rms difference between predictions of surface pressure for the region between 30 and 70N was found to be 6.3 mb at Day 7. This value is higher than the value (4.3 mb) computed for the 5° mesh experiment. When the global forecast is compared to real atmospheric observation after 2 days, the rms values approach 8 mb in mid-latitudes. The $2\frac{1}{2}°$ rms value between cases at 7 days is still well below the limit of usefulness for forecast skill. The S_1 score for the $2\frac{1}{2}°$ case was almost identical to the coarse-mesh calculation.

A comparison of the speed field at 10.5 km at Day 7 is illustrated in Fig. 2. The wind speed configurations for the hemisphere model are very similar to the global integration. The meanders of the subtropical jet stream are reproduced accurately in the bounded forecast at the end of 1 week. The largest discrepancy between the two cases occurs near the equator in the Western Hemisphere where the difference reaches 25 m sec^{-1} in the vicinity of a cross-equatorial jet. The maximum differences throughout the rest of the map reach only 10 m sec^{-1}.

These results along with the previous 5° mesh experiments substantiate the relative accuracy of a hemispheric model when compared to a global model for short-range forecasts of the order of 1 week or less in mid-latitudes. This, of course, applies only to the large-scale motions that the $2\frac{1}{2}°$ model can adequately resolve. The following section will attempt to show why these scales of motion were unaffected by the inclusion of a wall at the equator.

3. Mean zonal quantities

If a boundary or wall is placed at the equator in an atmospheric prediction model, the Hadley circulation must undergo a certain amount of distortion. This distortion can be examined by plotting various zonal mean parameters for the global and hemispheric forecasts. Fig. 3 displays the zonal means for both cases at Day 7 of the zonal wind ($\bar{u}$), the meridional wind ($\bar{v}$), and the vertical motion ($\bar{w}$). The zonal wind profile is almost unaffected by the wall at the end of 7 days with differences the order of 2 m sec^{-1}. The change in the meridional wind is more noticeable: the magnitude of the northward component in the upper troposphere near the equator has been reduced by a factor of 2. The trade component (lower tropospheric $\bar{v}$) is nearly the same in the subtropics for both the bounded and global experiments. The most significant change occurred in the $\bar{w}$ fields. The upward branch of the Hadley circulation is located south of the equator in the global case, whereas the inclusion of the wall forces the upward branch to be north of the equator. The magnitudes of the vertical motion in both cases are similar ($\sim$1–2 cm sec^{-1}). It is important to note that the sinking branch of the circulation remains at the same latitude in the wall case and is relatively undisturbed as compared to the global integration. Therefore, the distortion of the Hadley circulation, as shown in the $\bar{v}$ and $\bar{w}$ fields, caused by the insertion of a boundary at the equator extends only 10–15° of latitude away from the boundary. The feedback of the distorted upward branch of the Hadley circulation to

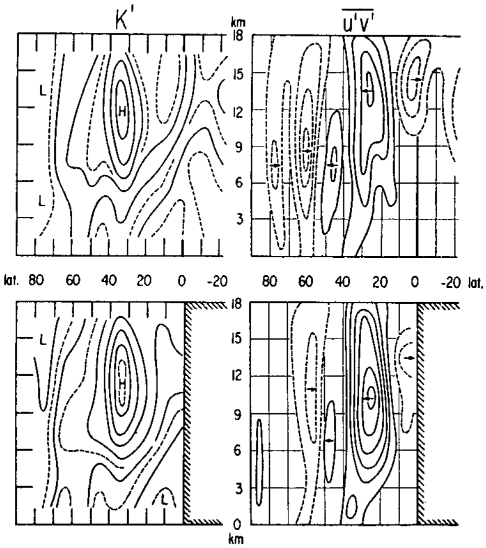

FIG. 4. Top left: zonally averaged eddy kinetic energy at Day 7 for the global forecast. The contour interval is 4.0×10^5 cm^2 sec^{-2}. Top right: zonally averaged eddy angular momentum flux at Day 7 for global forecast. The contour interval is 1.0×10^5 cm^2 sec^{-2}. Bottom left: same as top left for the hemispheric forecast. Bottom right: same as top right for the hemispheric forecast.

large-scale eddies in mid-latitudes appears to require a time frame longer than 1 week.

4. Mean eddy quantities

The zonal means of such quantities as eddy kinetic energy (K'), eddy momentum transport ($\overline{u'v'}$), eddy heat transport ($\overline{v'T'}$), and eddy water vapor transport ($\overline{v'q'}$) were also compared in a manner similar to that of the previous zonal mean quantities. In general, the eddy quantities were in close agreement with each other when the bounded and global cases are compared. The profiles of the eddy kinetic energy and the eddy momentum transport, shown in Fig. 4, illustrate this point. The patterns of the two cases are nearly identical; however, the magnitudes are somewhat different. The largest discrepancy appears in the low-level eddy momentum transport in the tropics: the bounded case produced higher values of northward transport than the global case.

The difference between the profiles of eddy heat and moisture transport (not shown) was also quite small. The transport of heat and moisture away from the tropical regions by the eddy motion was virtually unaffected at the end of 7 days by the insertion of the wall at the equator.

5. Concluding remarks

From the experiments presented here and in the previous study (Baumhefner, 1970), it is reasonable to conclude that a wall placed at the equator does not appreciably affect the prediction of large-scale atmospheric flows for a period of less than 1 week. Forecasts for longer than 1 week should include interhemispheric exchanges. The more accurate handling of the synoptic scales by the $2\frac{1}{2}°$ model did little to modify the original conclusions of the first paper.

The key factors in the success of the hemispheric model appear to be the minimum distortion of the mean and eddy quantities in the Northern Hemisphere subtropical region. The distortion of the upward branch of the Hadley circulation had little effect on the large-scale atmospheric processes north of 15N. The initial data used for these experiments were Northern Hemisphere winter cases in which the upward branch of the Hadley circulation is at its southernmost location. One would assume that the mean tropical circulations would be even less distorted by a wall at the equator in the other seasons of the year except, perhaps, in the area of the summer Indian monsoon.

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