Use of operational analyses to study the dynamics of troposphere-stratosphere interactions in polar regions

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1. Introduction

Operational analyses produced by large weather centers have been used in the past to monitor various aspects of the general circulation as well as address dynamical questions. Concerns about the problems with these analysis fields in the high southern latitudes have been expressed (Trenberth and Olson, 1988), however, so that calculations of dynamic processes with such fields might be compromised.

For a number of years we have been monitoring National Meteorological Center (NMC) analyses at 100 millibars because it is the level from which stratospheric analyses are built. In particular, we have closely examined the pressure-work term at that level which is an important parameter related to the forcing of the stratosphere by the troposphere. Rapid fluctuations typically seen in this quantity during the months of July-November, and similarly noted by Randel et al. (1987) may raise some concern about the quality of the analyses. We have investigated the behavior of the term mainly responsible for these variations, namely the eddy flux of heat, and furthermore have corroborated the presence of these variations in contemporaneous analyses produced by the European Centre for Medium Range Forecasts (ECMWF).

2. Evaluation of the pressure-work and eddy heat flux terms with operational analyses

The vertical transfer of eddy kinetics energy across a level in the atmosphere by means of boundary stresses $[\omega^* z^*]$, where ω is vertical velocity, z geopotential, brackets zonal mean and asterisk departure therefrom, can be written after a number of assumptions including the geostrophic approximation, as follows (Miller and Johnson, 1970):

$$[\omega^* z^*] \approx \frac{f}{g} (\partial[\theta]/\partial p)^{-1} \bullet [u] \bullet [v^* \theta^*] \qquad (1)$$

In this term, closely related to one component of the Eliassen-Palm (1960) flux, θ is potential temperature, u and v zonal and meridional wind, p pressure, f Coriolis parameter and g acceleration of gravity. The daily integrals of $[\omega^* z^*]$ at 100 mb between 20° and 90°S, calculated from NMC global analyses for 1986, which are similar in character to earlier years, are displayed in Figure 1. The presence of large fluctuations, peaking in the June-November period, raise the possibility that there were considerable problems with the analyses.

Of the multipliers on the right side of (1) we have isolated the erratic behavior in $[\omega^* z^*]$ to the eddy heat flux term, $[v^* \theta^*]$ in the vicinity of 55°-70°S, which can be seen in the time-latitude display in Figure 2. During this part of the year $[v^* \theta^*]$ is rather quiescent at most other latitudes. Similar displays of the zonal mean zonal winds [u] and the stability parameter $\partial[\theta]/\partial p$ reveal fairly steady behavior, incapable of producing the fluctuations in Figure 1.

As one means of checking the accuracy of the $[v^* \theta^*]$ variations, we acquired grid-point analyses from the ECMWF, and evaluated the same heat flux term at 5° latitude intervals in this region. The comparison of the NMC- and ECMWF-derived parameters is displayed in Figure 3. For the months of July-November 1986, there is good agreement of the heat flux parameters from the two centers, offering a measure of confidence in the reality of these fluctuations. Although most of the raw data going into each center's assimilation are identical, there are substantial differences in the analysis and forecast components of the two centers. Therefore such strong agreement between the two analyses would be unlikely if the NMC heat fluxes were simply erroneous. Indeed the agreement between NMC and ECMWF fields in the high southern latitudes, at least for zonal winds, has been improving in recent years (Rosen et al. 1987).

3. Vertical and longitudinal structure of eddy heat fluxes

We have evaluated the $[v^*\theta^*]$ term at other pressure levels to examine the vertical structure of this quantity in high latitudes. Plots of this quantity (not shown) reveal that the fluctuations exist at the 50-mb level and they are present down into the troposphere as low as the 300-mb level, however, decreasing in amplitude with decreasing altitude.

We used the ECMWF analyses to investigate the longitudinal structure of the eddy heat fluxes, $v^*\theta^*$. Eastward propogating features are clearly evident, as is shown, for example, in Figure 4 for 65°S. Here, we observe that, for example, between September and November, anomalies in this heat flux travel eastward, at a rate of approximately 5-10 ms^{-1}. No particular longitudinal origin of these fluctuations is apparent, indicating that these features do not result from erroneous observations at fixed sites.

4. Conclusions

We have demonstrated that fluctuations in standing eddy heat fluxes, related to the forcing of the stratosphere by the troposphere, agree in two largely independent meteorological analyses. We believe, therefore, that these fluctuations are mostly real. Further work must be performed to determine the dynamical causes and consequences of these fluctuations, of course, but for now it is reassuring at least to find that the data sets available to pursue such work are appropriate for this purpose.

5. Acknowledgments

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6. References

Eliassen, A. and E. Palm, 1960: On the transfer of energy in stationary mountain waves. Geof. Publ. Geoph. Norv., 22, 1-23.

Miller, A.J. and K.W. Johnson, 1970: On the interaction between the stratosphere and troposphere during the warming of December 1967-January 1968. Quart. J. R. Met. Soc., 96, 24-31.

Randel, W.J., D.E. Stevens, and John L. Stanford, 1987: A study of planetary waves in the southern winter troposphere and stratosphere. Part II: Life cycles. J. Atmos. Sci., 44, 936-949.

Rosen, R.D., D.A. Salstein, A.J. Miller and K. Arpe, 1987: Accuracy of atmospheric angular momentum estimates from operational analyses. Mon. Wea. Rev., 115, 1628-1639.

Trenberth, K.E. and J.G. Olson, 1988: Evaluation of NMC global analyses. NCAR Technical Note TN-299+STR, 82 pp.

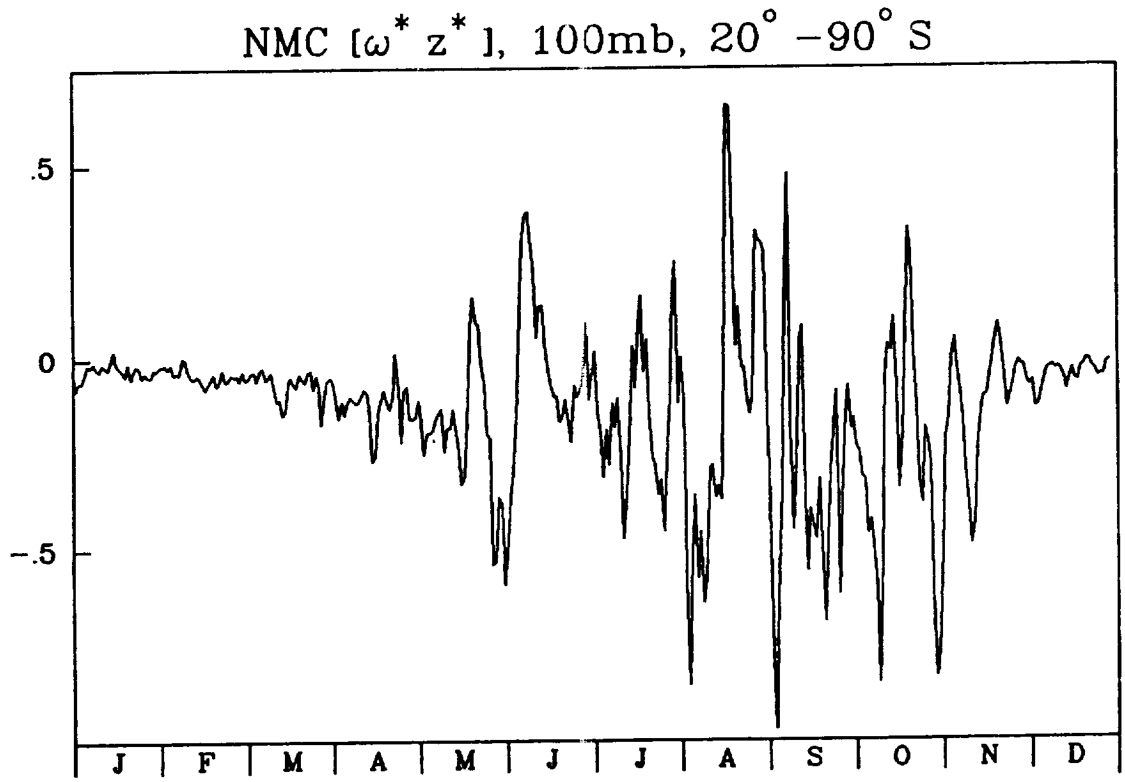

Fig. 1 Daily values of the pressure-work term from NMC analyses at 100 mb integrated between 20° and 90°S during 1986. Units are Wm^{-2}.

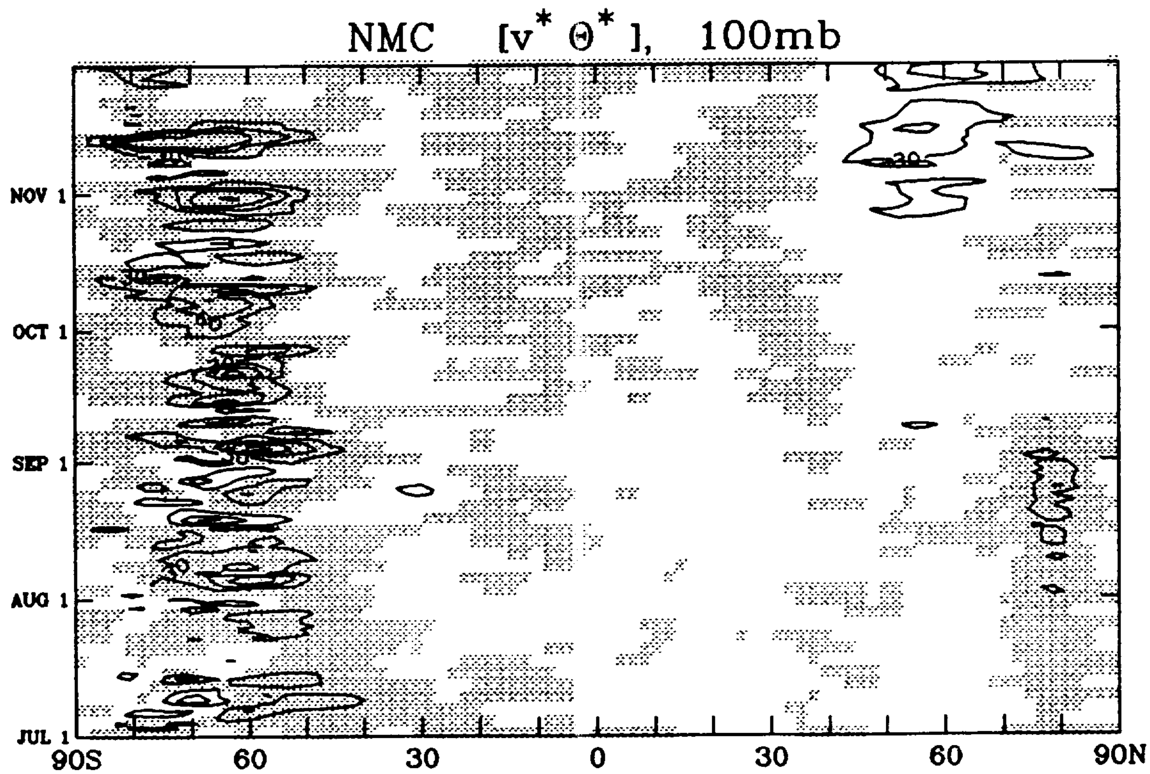

Fig. 2 Daily zonal means of eddy fluxes of heat at 100 mb from NMC analyses from pole to pole during July-November 1986. Negative values are shaded. Contours are 30 ms^{-1} °K, with 0 contours not plotted.

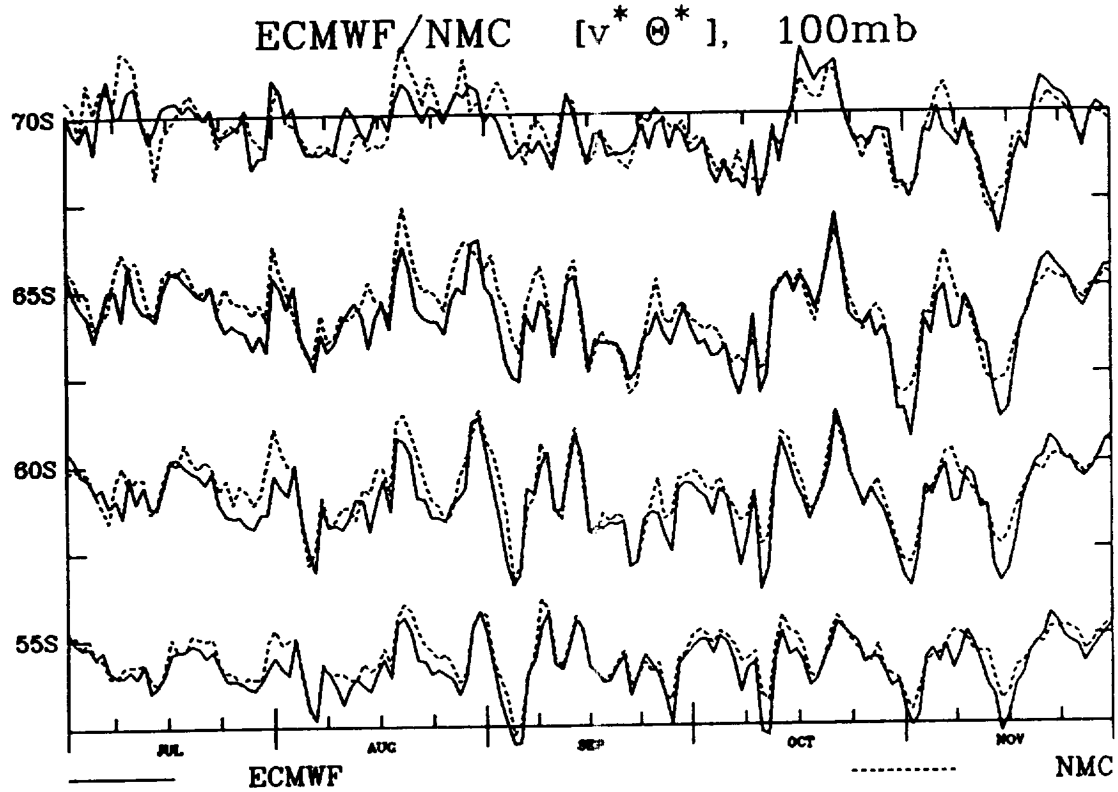

Fig. 3 Daily zonal means of eddy fluxes of heat at 100 mb from ECMWF and NMC analyses at 55°, 60°, 65° and 70°S during July-November 1986. Spacing between tick marks on the ordinate is 100 ms^{-1} °K.

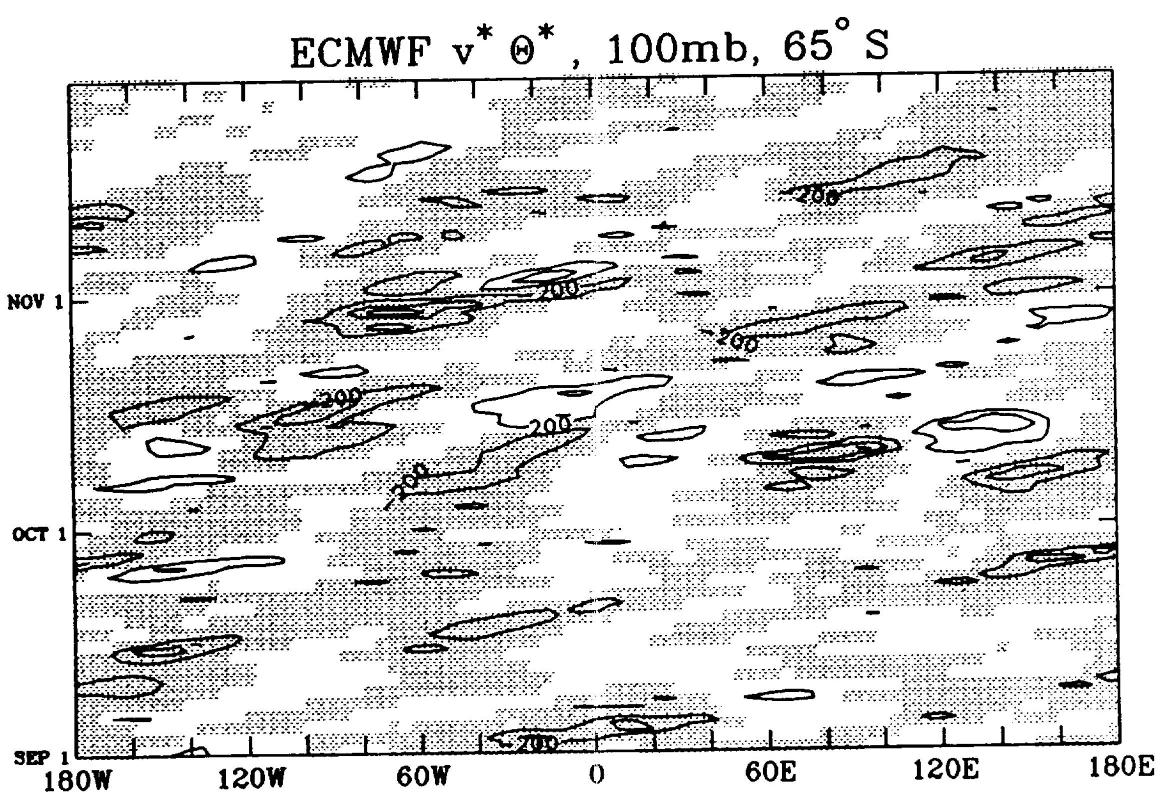

Fig. 4 Daily eddy heat fluxes at 100 mb from ECMWF analyses at 65°S every 5° in longitude during September-November 1986. Negative values are shaded. Contours are 200 ms^{-1} °K, with 0 contours not plotted.