Transfer of Sensible Heat by Transient Eddies in the Atmosphere on the Southern Hemisphere: An Appraisal of the Data before and during FGGE

HARRY VAN LOON

National Center for Atmospheric Research[1], *Boulder, CO 80307*

(Manuscript received 9 May 1980, in final form 11 July 1980)

ABSTRACT

Although the numerical, daily operational analyses for the Southern Hemisphere, in particular those made in Australia since 1972, can be used to describe large-scale features in time and space, they are not suited to computations of quantities which rely for their accuracy on the correctness of the daily analysis at individual points. This conclusion is based on the analysis of transfer of sensible heat by the transient eddies during FGGE and the years 1972–77. In addition, the Australian daily operational analyses of the Southern Hemisphere were compared with those of the U.S. National Meteorological Center, and it was found that the former are generally the better ones.

1. Introduction

Synoptic and climatological grid-point data for large parts of the Southern Hemisphere from before the First GARP Global Experiment (FGGE) are generally considered unreliable, owing to the few points of observation. Computations of circulation statistics such as momentum and heat fluxes have therefore most often been made directly with observations at the single stations and by interpolation between stations (e.g., Obasi, 1963; Robinson, 1970; Newell *et al.*, 1974); but the irregular and sparse network of upper air stations is probably inadequate for this approach (Oort, 1978). Daily analyses by computer of the temperature and height of constant pressure levels on the Southern Hemisphere, which use observations from satellites and a vertical extrapolation scheme to fill the voids between stations over the southern oceans, have been made in Australia since 1972. These analyses were used by Trenberth (1979, 1980a,b) to investigate various features of the circulation and their interannual variability, and Trenberth's results indicate that the Australian data are adequate for describing large-scale features in space and time, e.g., wavenumber 1 or monthly and seasonal pressure anomalies. The question discussed in this paper is whether it is possible to get reliable values of the meridional transfer of sensible heat by the transient eddies from the Australian operational analyses, since such values depend on the daily reliability of small-scale features. This is in contrast with the monthly and seasonal averages of areally large features treated by Trenberth.

2. Transient-eddy flux of sensible heat before FGGE

The meridional transfer of sensible heat in the transient eddies is shown as zonal averages for winter and summer in Figs. 1 and 2. The largest poleward transfer of $[\overline{v'T'}]$, where brackets denote a zonal mean and the overbar a seasonal mean, is at 45–50°S between 850 and 700 mb. The seasonally averaged transient eddy flux was obtained by subtracting from the seasonal average of the daily total eddy flux the stationary eddy flux calculated from the seasonal mean maps of v_g and T. Figs. 1 and 2 have two dubious aspects: 1) the flux in the stratosphere is directed toward the equator at levels where $[\overline{v'T'}]$ on the Northern Hemisphere reaches a second peak directed toward the North Pole (Fig. 3; and Oort and Rasmusson, 1971); and 2) the amount of $[\overline{v'T'}]$ in winter is appreciably smaller than that on the Northern Hemisphere (cf. Figs. 1 and 3), which is unreasonable when one considers the vigorous circulation on the Southern Hemisphere and the lack of transport by the stationary waves. The equatorward flux in the stratosphere will be examined in Section 3, and the size of $[\overline{v'T'}]$ will be discussed in the following.

The Australian analyses are made twice a day with observations concentrated either about 0000 or 1200 GMT. The number of observations is higher about 0000 GMT on the Australia-New Zealand side of the hemisphere and about 1200 GMT on the other side; in other words, higher near the time of local noon

[1] The National Center for Atmospheric Research is sponsored by the National Science Foundation.

0027-0644/80/111774-08$06.00

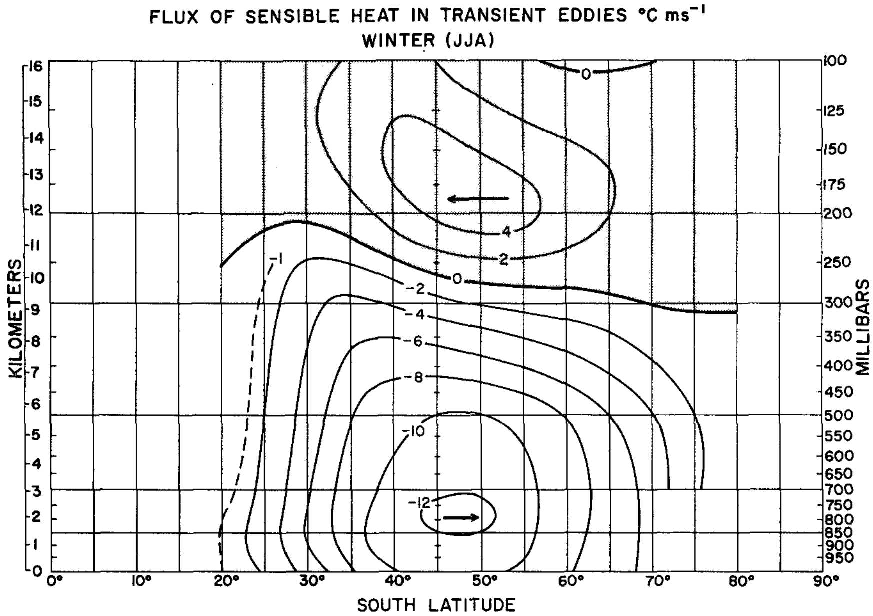

FIG. 1. Zonally averaged transfer of sensible heat in transient eddies (°C m s^{-1}) on the Southern Hemisphere in winter (JJA). Australian 2300 GMT data, 1972–77.

in both instances. Fig. 4 is a map for 2300 GMT of $\overline{v'T'}$ at 850 mb, averaged over six winters. A peak in the flux, >10°C m s^{-1}, encircles the hemisphere in the latitudes between 35 and 60°S. The dots with names next to them are the only places in this latitude belt where upper air soundings are made outside the continents and New Zealand. Near these remote islands the flux is 25–65% stronger than the flux in the regions without observations. At 45–50°S the zonal mean value at 850 mb in Fig. 1 is 12°C m s^{-1}, the values in the empty regions of this zone lie between 7 and 11°C m s^{-1}, and near the stations they are mostly ~18°C m s^{-1}; this distribution suggests that the method of analysis underestimates the flux where there are no observations, and that at 45–50°S the zonal average should be at least 33%

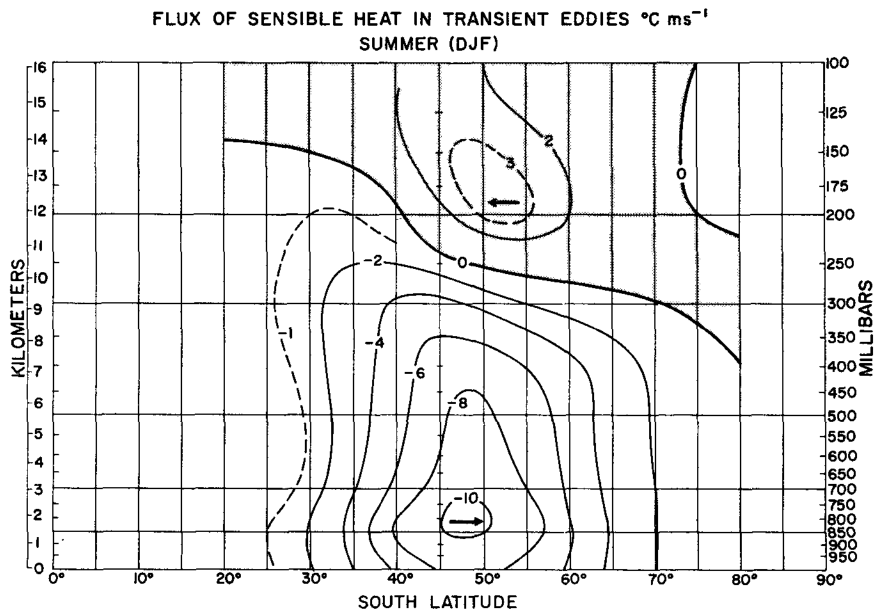

FIG. 2. As in Fig. 1 except for summer (DJF).

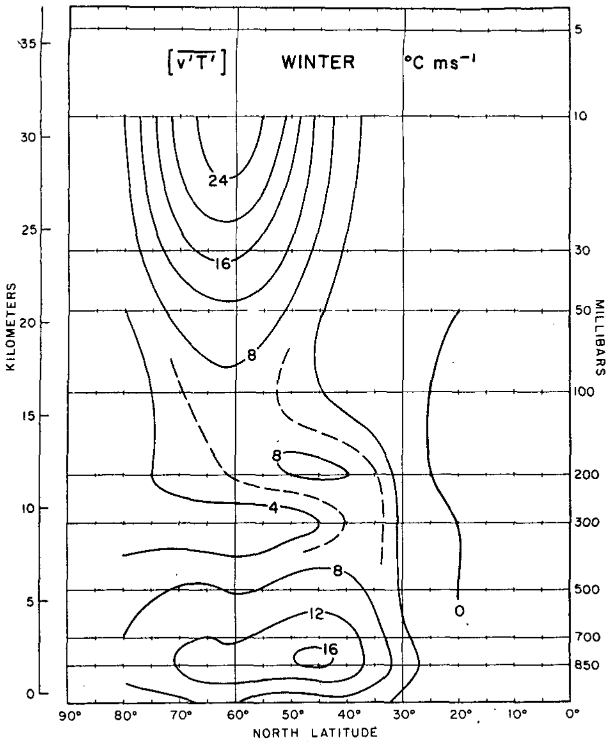

FIG. 3. Zonally averaged transfer of sensible heat in transient eddies (°C m s⁻¹) on the Northern Hemisphere in winter (DJF). NMC data, 1963/64–1977/78.

higher. That would bring $[\overline{v'T'}]$ at its peak to at least 16–17°C m s⁻¹, which is about the same as on the Northern Hemisphere (Fig. 3).[2]

The pattern of $\overline{v'T'}$ at 1100 GMT (Fig. 5) is more cellular than that at 2300 GMT; the isopleth of 10°C m s⁻¹ is not continuous round the hemisphere, and near the islands the flux is again markedly stronger than over the parts without observations. Since Figs. 4 and 5 are averages of six winters (1972–77), the differences between the two synoptic hours are too large to be discussed as sampling errors, and yet no evidence would lead one to expect such a large mean diurnal variation. The differences are too big not only in the regions without observations but also near stations (Fig. 6): At 170°W, not far from Chatham Island at 43°S, the flux between 40 and 45°S is 11°C m s⁻¹ at 1100 GMT but is 17°C m s⁻¹ at 2300 GMT which is the observing time for the station; just east of Gough Island at 40°S the flux at 2300 GMT

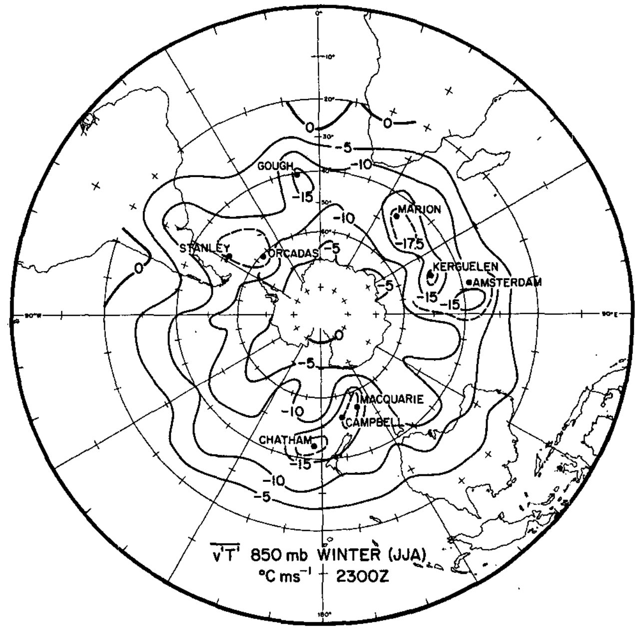

FIG. 4. Transfer of sensible heat (°C m s⁻¹) in transient eddies in winter (JJA) at 850 mb. Australian 2300 GMT data, 1972–77.

is twice as large as that at 1100 GMT, which is near the observing hour at the island.

If the values near the islands in summer (Fig. 7) are representative of much of the belt 45–50°S, the zonal average of 10°C m s⁻¹ at the peak in Fig. 2 should be higher, although not by so large a percentage as in winter since the zonal distribution obtained

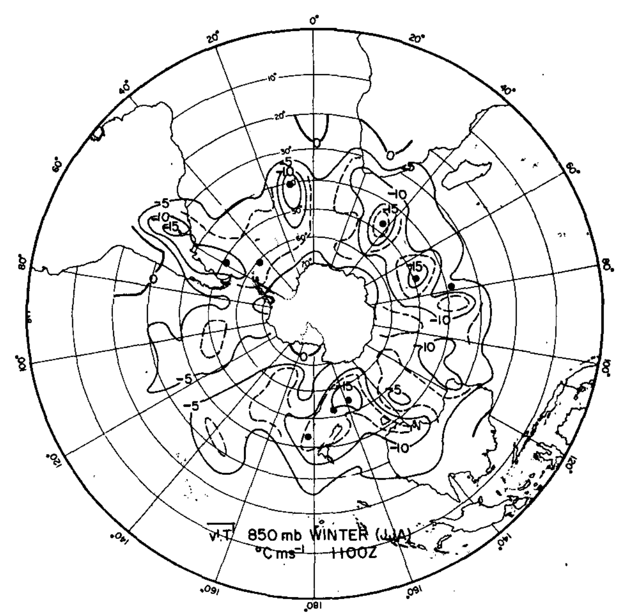

FIG. 5. As in Fig. 4 except for 1100 GMT.

[2] Recent analyses by A. Oort using a method similar to that of Newell *et al.* (1974) show maximum poleward eddy heat fluxes at 850 mb of −18°C m s⁻¹ for June–August and −14°C m s⁻¹ for December–February at ~50°S. The maxima at 200 mb are −12 and −8°C m s⁻¹ for winter and summer near 45°S. Newell *et al.* found values not much different from these (A. Oort, personal communication).

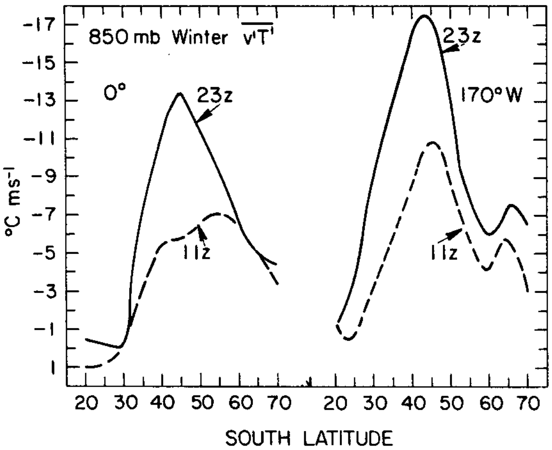

FIG. 6. Meridional sections of $\overline{v'T'}$ at 0° and 170°W in winter at 850 mb. Australian data at 1100 and 2300 GMT.

from the analyses is more even in summer (cf. Figs. 4, 5 and 7). The zonal mean transient-eddy flux of sensible heat in summer on the Southern Hemisphere, despite the probably underestimated numbers, is somewhat stronger at its peak than that on the Northern Hemisphere in summer (cf. Figs. 8 and 9). Fig. 8 also illustrates the near absence of sensible heat transfer toward the pole by the quasi-stationary eddies on the Southern Hemisphere (see, e.g., van Loon, 1979).

The weaker flux over the ocean areas without stations than in the limited regions near the few island stations is not peculiar to the Australian analy-

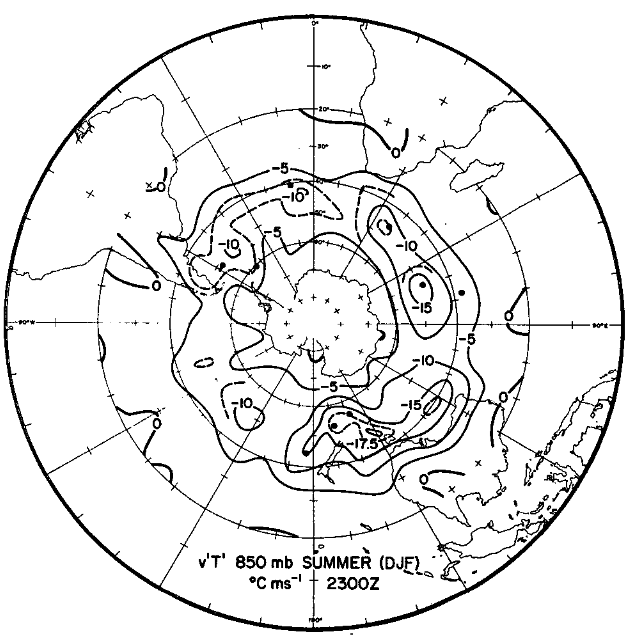

FIG. 7. As in Fig. 4 except for summer (DJF).

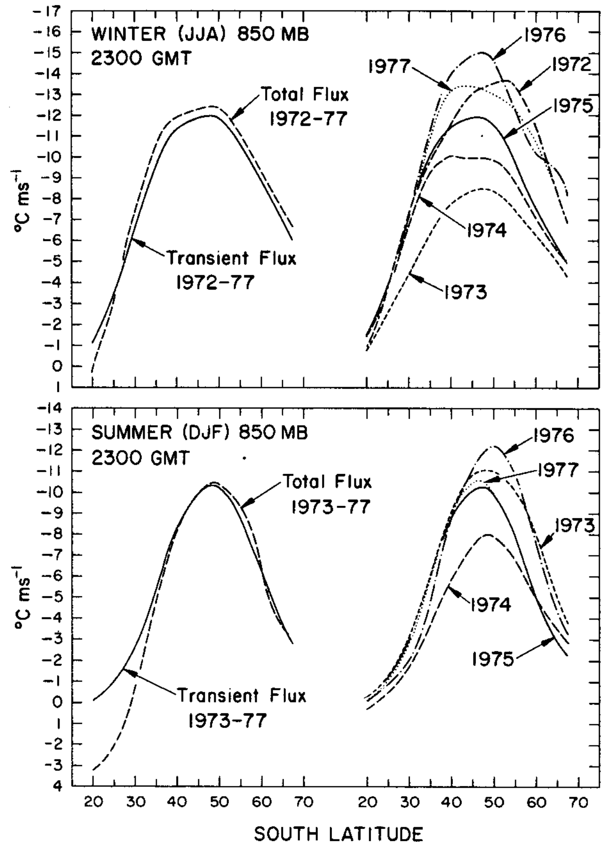

FIG. 8. Zonally averaged transfer of sensible heat, total and transient-eddy flux at 850 mb, in winter and summer on the Southern Hemisphere. Australian 2300 GMT data. On the right: $[\overline{v'T'}]$ in single seasons.

ses but is also characteristic of the analyses made at the U.S. National Meteorological Center (NMC). The mean transient-eddy flux at 850 mb in the two winters of 1976 and 1977 (Fig. 10) shows this defect clearly; but in addition there are flaws in the NMC maps which are not present in the Australian ones: for example, the insert map on Fig. 10 shows that the peaks of $[\overline{v'T'}]$ are at fairly low latitudes, well on the equatorward side of the average west-wind maximum. The Australian analyses, in contrast, yield a peak of 15°C m s^{-1} between 45 and 50°S in the winter of 1976, and one of 13.5°C m s^{-1} in 1977, both considerably stronger than the peaks in the NMC analyses and on the poleward side of the jet stream. In the NMC analyses, however, the direction of $[\overline{v'T'}]$ in the stratosphere is toward the South Pole (Fig. 11).

Another problem in the data illustrated in Fig. 12 which shows $[\overline{v'T'}]$ in five single winters at 850 and 700 mb at the two synoptic hours in the Australian analyses. At 700 mb the 1100 GMT values generally are higher than those at 2300 GMT, whereas at 850 mb they are lower at 1100 GMT than those at 2300 GMT.

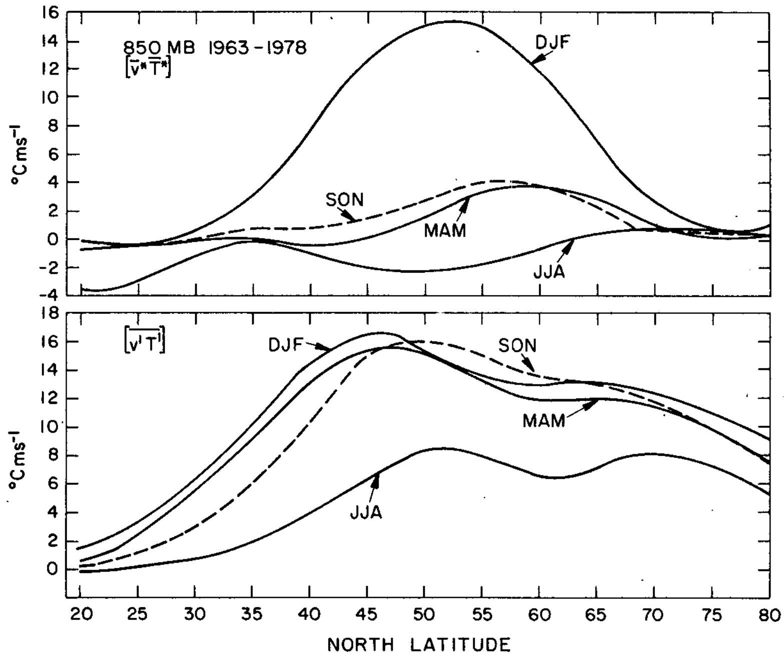

FIG. 9. Top: Stationary-eddy transfer of sensible heat on the Northern Hemisphere (°C m s^{-1}) seasonal means. Bottom: Transient-eddy transfer of sensible heat on the Northern Hemisphere.

3. The northward transient-eddy flux in the stratosphere

The calculations of total and transient-eddy flux by means of Australian data yielded a flux directed toward the equator in the lower stratosphere in all seasons with its peak near 200 mb (Figs. 1 and 2); the zero line separating southward and northward flux lies in the mean position of the tropopause and has similar seasonal changes. In the Northern Hemisphere (Fig. 3; and Oort and Rasmusson, 1971) and in the calculations for the Southern Hemisphere by Newell *et al.* (1974), who used a method of interpolation between stations, the poleward flux decreases from a maximum in the lower troposphere to a minimum near the tropopause, whence it rises to another maximum near 200 mb.

One radiosonde station will suffice to show that the daily synoptic analyses from Melbourne must be wrong in the lower stratosphere (Table 1): at 850 mb there is hardly any difference in the value of the flux computed from the winds and temperatures observed at the station (113 observations at 1200 GMT out of a possible 184) and from the daily temperatures and geostrophic winds at the grid points. At 200 mb, however, the observations yield a poleward flux of -18.0°C m s^{-1}, whereas computations from the neighboring grid-point values give an equatorward flux of 13.1°C m s^{-1}.

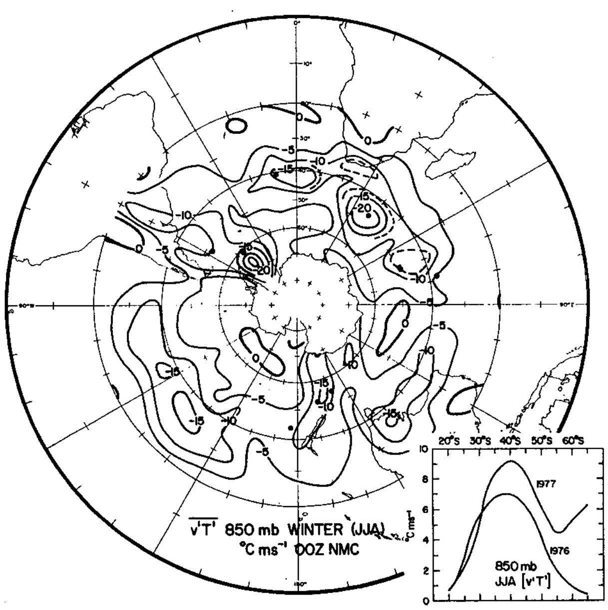

FIG. 10. As in Figs. 4 and 5 except with NMC 0000 GMT data for 1976 and 1977.

4. Transient-eddy fluxes during FGGE

At the time of writing the NCAR data archives contained Australian daily analyses till the end of

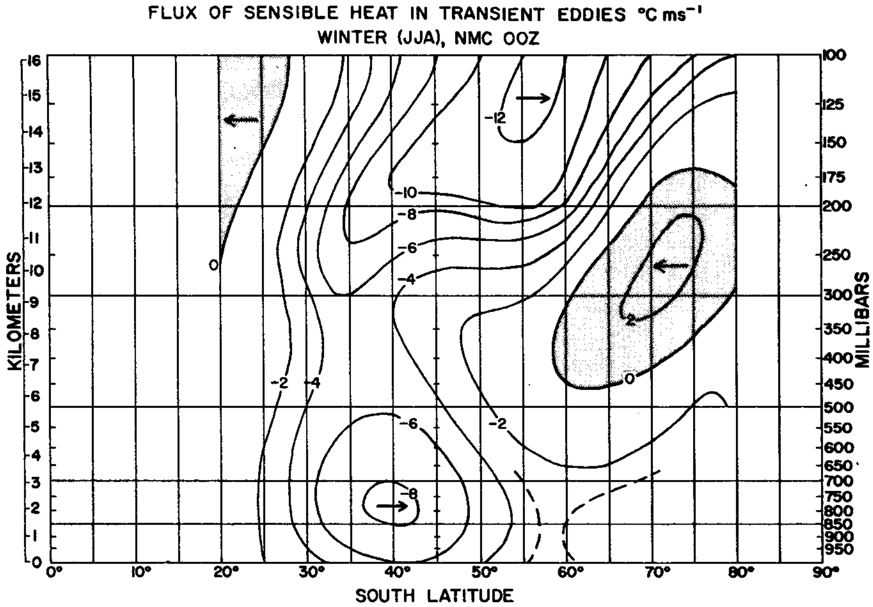

FIG. 11. Same as Fig. 1, but with NMC 0000 GMT data for 1976 and 1977.

May 1979—i.e., five months of the FGGE period—and NMC analyses till the end of July 1979. From these months three have been arbitrarily chosen for comparison with the years before, and for comparison of the Australian and NMC analyses.

In Fig. 13, $[\overline{v'T'}]$ shows the expected seasonal rise from January to May at 850 mb; the strongest fluxes, in 45–50°S, are in all three FGGE months above the mean for the month (1972–77), although in January barely so. In January the means of 1972, 1974 and 1975 were above the FGGE mean (Table 2), whereas in March the FGGE mean exceeded all those of the previous years, and in May only the value in 1977 was as large as that in 1979. A possible interpretation of these numbers is that the observations from the drifting buoys may not have been numerous and widespread enough in January 1979 to affect the daily analyses much, and that the analysis in the later

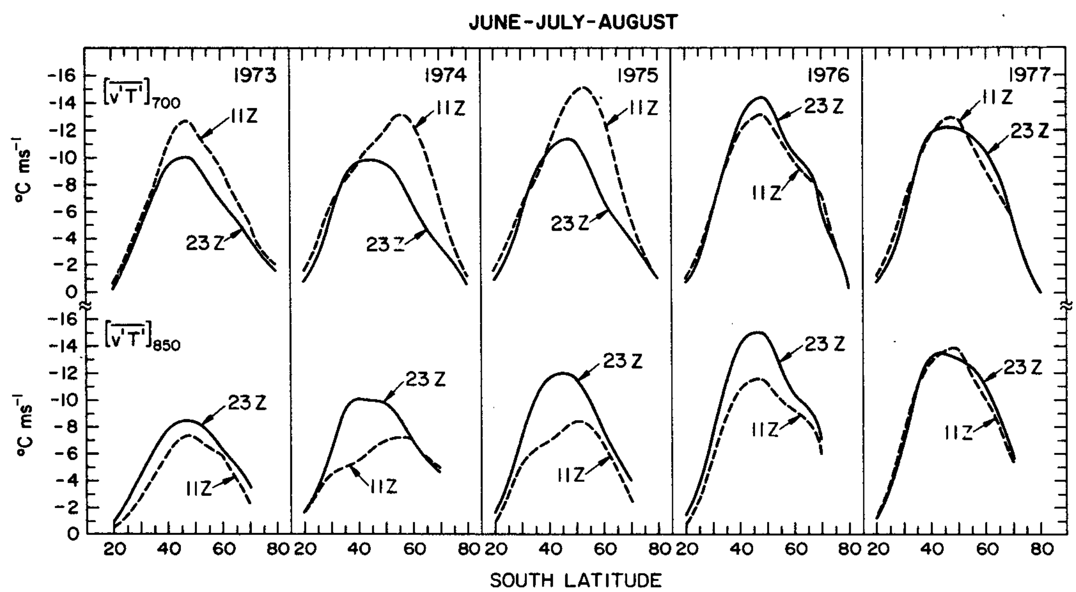

FIG. 12. Top: $[\overline{v'T'}]$ at 700 mb at 1100 and 2300 GMT. Bottom: The same at 850 mb. Units are °C m s⁻¹.

TABLE 1. Comparison of $\overline{v'T'}$ from the soundings at Punta Arenas (53°S, 71°W) with the average of $\overline{v'T'}$ at the points 50 and 55°S at 70°W from the Australian daily analyses. Means are for the winters (JJA) of 1975 and 1976; units are °C m s^{-1}.

	Punta Arenas	Analyses
850 mb	−11.7	−13.0
200 mb	−18.0	+13.1

months benefitted from the then more extensive network of buoys. The flux at 200 mb (Fig. 13, bottom) was toward the South Pole, but the numbers are unrealistically small [cf. Newell *et al.* (1974), their Fig. 7.11].

The distribution in May of $\overline{v'T'}$ at 850 mb in Fig. 14, computed from the Australian analyses, indicates that although there is still some bias toward maxima near island stations, the reports from the buoys appear to have reduced this bias substantially. The NMC analyses were used to compute the map of $\overline{v'T'}$ for May 1979 in Fig. 15, which should be compared with Fig. 14. The maps are markedly different, and although the judging of the quality of the two sets of analyses must necessarily be subjective, my opinion is that the operational Australian analysis

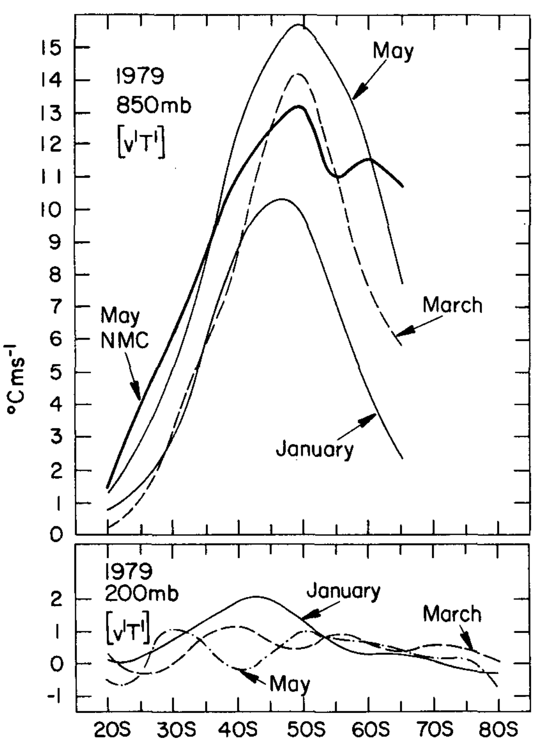

FIG. 13. Top: $[\overline{v'T'}]$ on the Southern Hemisphere in January, March and May 1979, based on the Australian 850 mb maps; and $[\overline{v'T'}]$ for May 1979, based on the NMC 850 mb maps. Units are °C m s^{-1}. Bottom: $[\overline{v'T'}]$ on the Southern Hemisphere at 200 mb in January, March and May 1979. The sign conforms to the direction of flux on the Northern Hemisphere, i.e., poleward flux > 0.

TABLE 2. Values of $[\overline{v'T'}]$ at the latitude of their peak at 850 mb in single months before FGGE, and the value of the mean at the peak for these months. Also the value at the peak in FGGE. Units are °C m s^{-1}.

	1972	1973	1974	1975	1976	1977	Mean	1979
January	10.4	8.2	11.0	11.5	9.7	9.9	9.9 (50°S)	10.2 (45°S)
March	—	12.9	8.6	9.1	13.4	12.8	11.4 (50°S)	14.2 (50°S)
May	11.5	8.9	8.8	12.7	12.3	15.6	11.1 (45°S)	15.6 (50°S)

was superior to NMC's during FGGE, as it was before FGGE. Some reasons for this opinion about the NMC analyses are the unrealistically low zonal mean values of $[\overline{v'T'}]$, the position of the maximum flux on the equatorward side of the mean westerly peak, and the peculiar maximum flux in high latitudes to the east of the Antarctic Peninsula both before and in FGGE. Given the circumstances, it would be difficult to produce an operational analysis of the troposphere on the Southern Hemisphere better than the one from Melbourne. Still, it is evident that sensitive calculations, such as those of eddy fluxes, should not be performed with data from the operational analyses but rather be postponed till the final analyses have been done in which every available observation presumably has been taken into account, and the biases revealed in the operational analysis methods have been corrected.

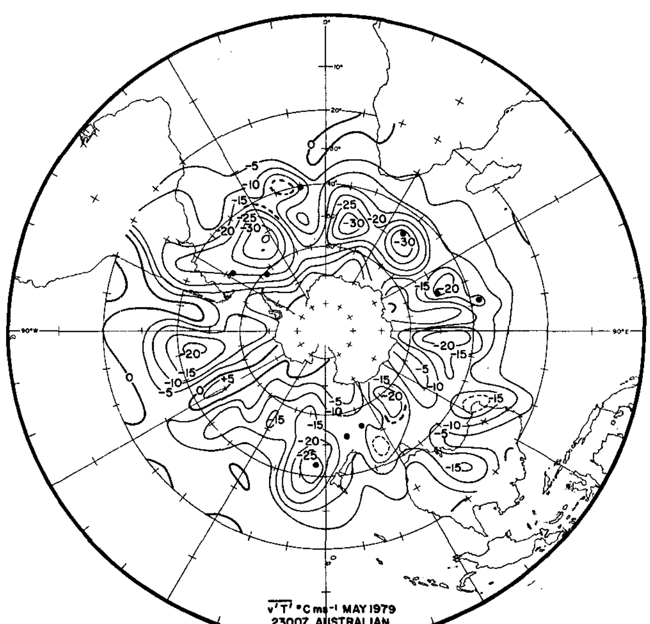

FIG. 14. Transient-eddy flux of sensible heat in May of 1979 based on the Australian 850 mb analysis. Units are °C m s^{-1}.

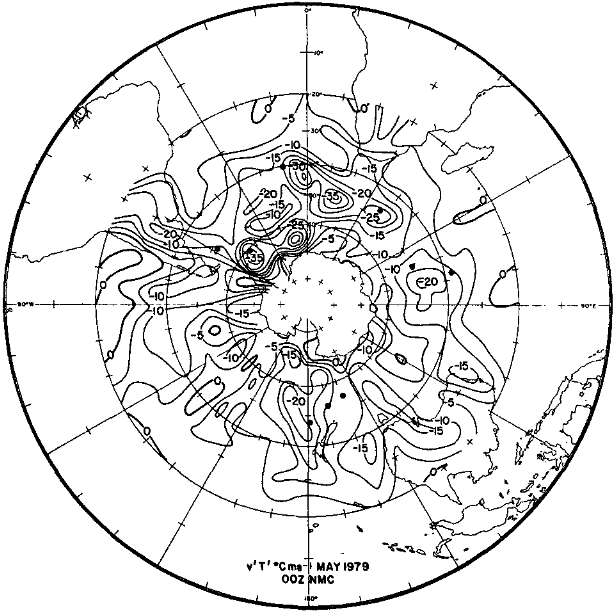

FIG. 15. As in Fig. 14 except based on the NMC 850 mb maps.

REFERENCES

Newell, R. E., J. W. Kidson, D. G. Vincent and G. J. Boer, 1974: *The General Circulation of the Tropical Atmosphere and Interactions with Extratropical Latitudes*, Vol. 2, The MIT Press, 371 pp.

Obasi, G. O. P., 1963: Atmospheric momentum and energy calculations for the Southern Hemisphere during the IGY. Sci. Rep., No. 6, Planetary Circ. Proj., MIT, 354 pp.

Oort, A. H., 1978: Adequacy of the rawinsonde network for global circulation studies tested through numerical model output. *Mon. Wea. Rev.*, **106,** 174–195.

——, and E. M. Rasmusson, 1971: Atmospheric circulation statistics. NOAA Prof. Pap., No. 5, 323 pp. [Printing Office, Washington, DC].

Robinson, J. B., Jr., 1970: Meridional eddy flux of enthalpy in the Southern Hemisphere during the IGY. *Pure Appl. Geophys.*, **80,** 319–334.

Trenberth, K. E., 1979: Interannual variability of the 500 mb zonal mean flow in the Southern Hemisphere. *Mon. Wea. Rev.*, **107,** 1515–1524.

——, 1980a: Atmospheric quasi-biennial oscillations. *Mon. Wea. Rev.*, **108,** 1370–1377.

——, 1980b: Planetary waves at 500 mb in the Southern Hemisphere. *Mon. Wea. Rev.*, **108,** 1378–1389.

van Loon, H., 1979: The association between latitudinal temperature gradient and eddy transport. Part I: Transport of sensible heat in winter. *Mon. Wea. Rev.*, **107,** 525–534.