Some Correlations between the Large-Scale Meridional Eddy Momentum Transport and Zonal Mean Quantities

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ABSTRACT

An empirical study has been made which compares the large-scale meridional eddy momentum transport with some selected zonal mean quantities by calculating correlations between them as a function of time lag and latitude. The basic dataset was the daily 200 mb geopotential and temperature grid analysis fields of the German Weather Service over an eight-year period. The results gave generally only small correlation values but show that a meridional covergence of the eddy transport leads to an increasing zonal mean wind or meridional curvature of the zonal wind component. The correlation maxima are reached at a time lag of +2 days. The same tendency can be recognized from an examination of the relation which Green found between the convergence of momentum transport and the transport of sensible heat and potential vorticity. An introductory discussion of two-dimensional models is given which focuses on the methods of parameterizing the eddy transports.

1. Introduction

For an understanding of the general circulation, climate and climatic change it has become more and more customary during the last two decades to simulate the atmospheric processes by means of numerical modeling. These models vary in their complexity. The most complex ones are the three-dimensional General Circulation Models, but they are so demanding on computer time and so physically complicated that it is not always possible to detect the main causes of climatic change. Therefore, simpler models with fewer dimensions are often more useful, because they consider more clearly the mechanisms which are responsible for the results. It is necessary of course that they contain the main mechanisms. The simplest examples in the model hierarchy are radiative equilibrium models with only zero dimensions.

A rather popular kind of model is the zonally averaged one consisting of one or two dimensions—depending on whether it is vertically averaged or not. One type of two-dimensional model is the radiation balance model which gives temperature distributions as its result under the assumption of radiation balance at the top of the atmosphere. Some prototypes are those by Budyko (1969) and Sellers (1969). Others were constructed by Manabe and Moeller (1961), Manabe and Strickler (1964), Kubota (1972) and Taylor (1976). In these models, the critical point is how to parameterize the earth's albedo and absorption in the atmosphere. No meridional eddy transport of sensible heat is included, but Manabe and Strickler (1964) need at least a convective adjustment to obtain a more realistic vertical temperature distribution. Adem (1963) even includes a meridional eddy transport of heat using a diffusion process parameterization. The radiation balance models can explain some possible climatic changes by changing the external parameters, such as the solar-constant or the CO_2 content.

With the exception of, perhaps, the turbulent heat transport, the radiation balance models neglect the atmospheric dynamics. This is different in the statistical dynamical models. They contain the full set of zonally averaged dynamic equations and obtain as a result not only temperature distributions, but also motions and energetics. They include both purely zonal mean values and the products of large-scale eddy terms. The main problem is to correctly parameterize the turbulent processes which are not explicitly known, but which force the zonal mean circulation and temperature distribution and vice versa, as was pointed out by Kuo (1956) and Arakawa (1961). Hunt (1973) showed with his model that ignoring the eddies leads to unrealistic temperature and zonal wind distributions. Schneider and Lindzen (1977) obtained better results by including at least vertical eddies. The importance of the meridional eddy momentum transport was also shown by Dickinson (1971) for tropical regions where the structure and position of the upper tropospheric jet stream came out realistically only when this transport was considered. Therefore, it is necessary to consider implicitly the eddy transports in a two-dimensional model. This has been carried out in several ways in the past.

One method of handling an eddy transport is, following Defant (1921), to use a large scale diffusion coefficient. There are different ways of determining such a coefficient. In addition, not all types of eddy transports can be treated using this method because they can sometimes be directed against the gradient as is the case for the eddy momentum transport. Williams and Davies (1965) in their model parameterized $[(T)_\lambda(v)_\lambda]_\lambda$ as well as $[(u)_\lambda(v)_\lambda]_\lambda$ by means of the meridional temperature gradient, reasoning that the forcing for the circulation is the differential meridional heating. (Here, $[\ \ ]_\lambda$ denotes the average over the longitude λ and $(\ \ )_\lambda$ is the deviation from this mean.) As a result, they obtained only one direct Hadley cell covering all latitudes. Two other authors—Leovy (1964) and Lahiff (1975)—the former in a model for the mesosphere, the latter for the tropical region, represented the eddy momentum flux as being proportional to $[u]_\lambda$ because in observational results the time average forms of both properties are rather similar, especially the latitude of the maximum.

Another less heuristic way of obtaining a parameterization concept is by linear baroclinic theory. McIntyre (1970) showed that in a developing baroclinic instability there is a countergradient eddy momentum flux. Green (1970) found that the turbulent meridional entropy flux must be proportional to the squared meridional temperature gradient and that the meridional convergence in the eddy momentum transfer is related to the transport of potential vorticity and the vertical convergence of meridional eddy heat flux. The last two quantities are conserved in adiabatic flow and can be parameterized by a diffusion model. Their combination then gives the momentum flux. This relation will be examined later in this paper. Wiin-Nielsen and Sela (1971) calculated values for the potential vorticity diffusion coefficient and stated that this parameterization concept can be used everywhere except in the boundary layer and above the tropopause because there are countergradient transports in these regions. Sela and Wiin-Nielsen (1971) then succeeded in simulating the annual energy cycle in a two-level model with an annual mean diffusion coefficient. In the annual cycle, the amplitude of some quantities was too large but the results qualitatively were rather good. Wiin-Nielsen (1972) improved the adiabatic heating function, and Wiin-Nielsen and Fuenzalida (1975) obtained better results when they brought in a time-dependent diffusion coefficient. Stone (1972, 1973, 1974) made several investigations of eddy sensible heat transport taking into account baroclinic theories which were similar to those of Green (1970). He also discussed the advantages and disadvantages of the diffusion model.

Saltzman (1968) found, also using baroclinic theory, a dependence of $[(T)_\lambda(v)_\lambda]_\lambda$ on the meridional temperature gradient and on $[(v)_\lambda{}^2]_\lambda$. As the linear baroclinic theory describes only growing waves, a weighting factor smaller than unity was introduced so that occluded lows could also be described. For the eddy momentum transport, the theory gave an expression which is proportional to the latitudinal shear of the phase velocity producing a meridional slope of the waves, which is further proportional to the square of the wave's amplitude and to a typical tilting time for baroclinic waves (Saltzman and Vernekar, 1968). The parameterizations have been employed by Saltzman and Vernekar (1971). Their results show a three cell structure and rather realistic temperature and wind profiles; the eddy activity was too weak in higher latitudes.

The question arises as to how adequate a parameterization using baroclinic theory can be since a large amount of the meridional transport is effected by standing waves. Perhaps the error is not too large as there is evidence that, if no standing waves are available, then more eddy momentum will be transported by traveling waves to satisfy the thermal forcing. In this sense, one can perhaps interpret the results of Held and Suarez (1978). They computed a truncated spectral model and found that when shorter waves were neglected, the long ones were more active.

A more sophisticated sort of two-dimensional model was developed by Kurihara (1970) containing prognostic equations for the eddy transports. This made a third-order closure hypothesis necessary, but there was no prognostic equation for $[(u)_\lambda(v)_\lambda]_\lambda$. This flux was parameterized by setting the convergence of eddy momentum flux equal to the momentum dissipation at the ground, therefore neglecting the forcing of the momentum convergence. Egger (1975) avoided the third-order closure by postulating that these correlations are identically zero. He determined (by means of a primitive equation model) all turbulent and zonal mean quantities by iteration given the zonal mean temperature at the 500 mb level.

This introductory discussion gives only a selection of zonally averaged models focusing on the choice of the parameterization of large-scale eddies. The present empirical study deals with the question of to what extent there are relations between some selected zonal mean values and the meridional eddy momentum transport. This has been done in the form of a cross-correlation analysis. The results may be useful for deciding which parameterization might be appropriate.

2. Data and data processing

The original dataset for the computations are the objectively analyzed grid fields of the German Weather Service. In this study, the 200 mb geopotential height field and the temperature fields of this and some other standard pressure levels were used. This daily dataset had been analyzed into spherical harmonics. The spatial resolution was extended to meridional wavenumber 15.

These coefficients were computed for 0000 GMT every day for the period 1969–76, inclusive and they prescribe the spatial resolution of the zonal Fourier coefficients, which were thereafter computed for every

2.5 degrees of latitude between 15 and 80°N. From the geopotential height coefficients those of the geostrophic wind components were computed.

3. Time average and mean time series of the meridional eddy momentum flux

Before presenting the results of the correlation analysis, the eddy momentum transport at 200 mb for the given period of eight years is presented. Fig. 1 contains the whole time-average and shows the familiar pattern with a maximum at 35°N and a negative extreme at 60°N (see e.g., MacDonald and Frazier, 1969 and Holopainen, 1967). Between both latitudes there is a convergence. South of 35°N, i.e., south of the mean position of the jet a divergence takes place as well as north of 60°N.

The other curves in Fig. 1 show the contribution made by the zonal wavenumbers 1 to 3, where wavenumber 2 is the main agency for transporting momentum towards the equator and is doing this already north of 45°N. The first three wavenumbers alone are responsible for more than approximately half of the whole transport, even in lower latitudes. The special behavior of wavenumber 2 can also be recognized in Fig. 2, where—in the late spring time—there are sometimes negative transports by wavenumber 2 over all latitude circles. This is not the case with wavenumber 1 or 3, nor for the sum over all zonal wavenumbers.

4. Correlations

In this section, the correlations between convergence of the meridional eddy momentum transport and zonal mean values or their derivations are presented. Most of the correlations were computed for the time scale of baroclinic waves, i.e., for a time lag of only a few days. The annual cycle of the quantities to be correlated was removed before correlating. The first correlation was made to verify part of the following relation:

$$\frac{\partial[u]_\lambda}{\partial t} = \left(f - \frac{1}{a\cos\varphi}\frac{\partial[u]_\lambda\cos\varphi}{\partial\varphi}\right)[v]_\lambda - [\omega]_\lambda\frac{\partial[u]_\lambda}{\partial p} + [F_\lambda]_\lambda - \frac{\partial[(u)_\lambda(v)_\lambda]_\lambda\cos^2\varphi}{a\cos^2\varphi\partial\varphi} - \frac{\partial[(u)_\lambda(\omega)_\lambda]_\lambda}{\partial p}. \quad (1)$$

This equation can be derived by zonally averaging the first component of the momentum equation and making use of the continuity equation (see Wiin-Nielsen, 1973).

The first two terms on the rhs represent the change of $[u]_\lambda$ due to the mean meridional circulation in connection with the absolute vorticity and the vertical wind shear. The first term is probably the most important one in low latitudes, but cannot be calculated when working with geostrophic winds. Besides surface friction, the eddy transports of momentum—both meridional and vertical—are responsible for a change in $[u]_\lambda$. In both cases a convergence of the flux gives rise to an increasing $[u]_\lambda$. Here we can only examine the amount to which the meridional eddy transport term adds to the change of $[u]_\lambda$. The result is shown in Fig. 3 where $([u]_\lambda(t + \delta t) - [u]_\lambda(t - \delta t))/2\delta t(\delta t \approx 1 \text{ day})$ is

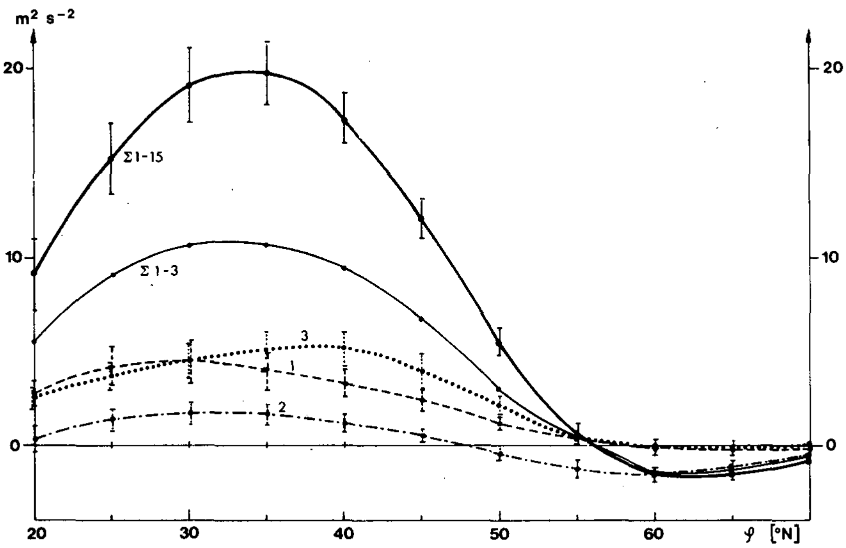

FIG. 1. Eight-year average of $[(u)_\lambda(v)_\lambda]_{\lambda,t}\cos^2\varphi$ as a function of latitude together with the contribution of some selected wavenumbers at 200 mb level. The standard deviations over the 8-year-period 1969–76 are also shown.

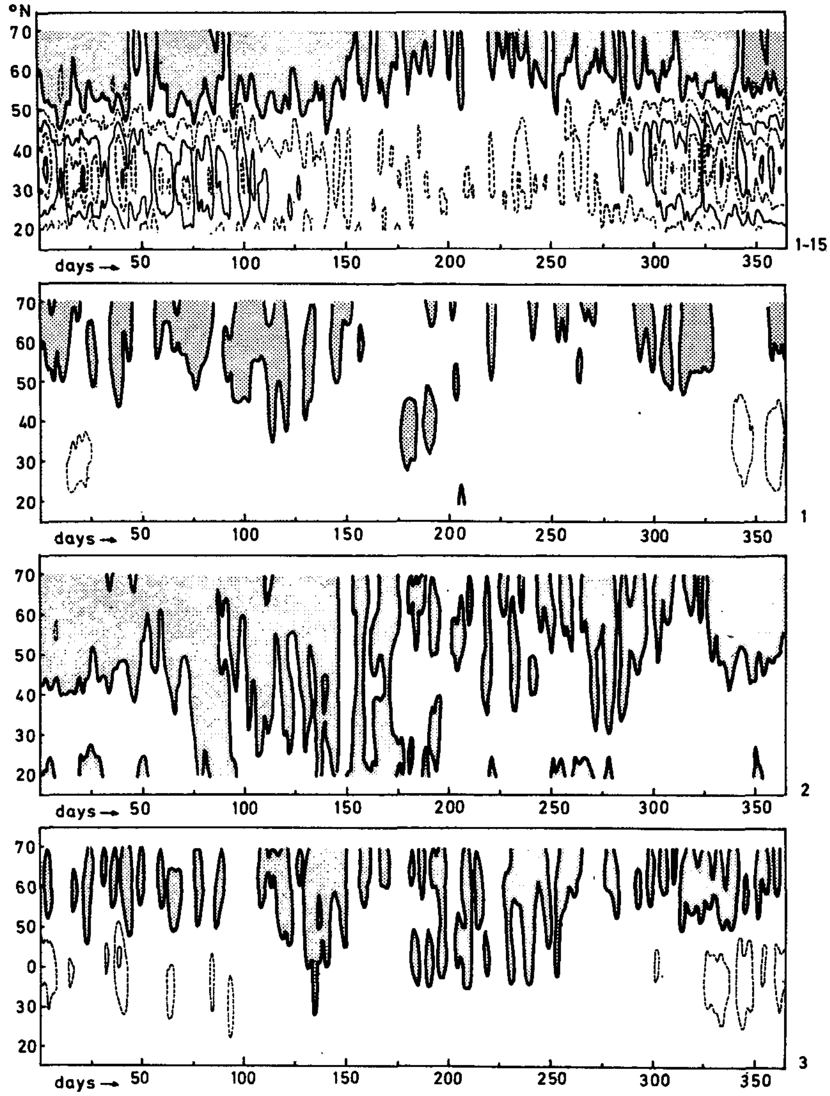

FIG. 2. Averaged annual time series of $[(u)_\lambda(v)_\lambda]_\lambda \cos^2\varphi$ as a function of latitude and for the contributions of wavenumbers 1, 2 and 3 at 200 mb. The contour interval is 10 $m^2 s^{-2}$, the areas with negative values are shaded. The period is 1969–76.

correlated with $(-\partial[(u)_\lambda(v)_\lambda]_\lambda/\partial y)(t)$. This was first carried out for the eight full years regardless of the season and then also for each season separately, where spring is represented by March–May, summer by June–August, autumn by September–November and winter by December—February. There are only seven winters available because the dataset starts 1 January 1969 and ends 31 December 1976. The figures show the correlations as a function of latitude and time lag ($\Delta t = n\delta t$). The largest values are found at a time lag of zero days between 50 and 60°N. This main characteristic does not change much during the seasons except that in winter the maximum extends to 70°N and probably farther north. The values are highest in spring and autumn reaching nearly 0.7. But this is not significantly higher than 0.6, which is reached in every season; so we can conclude that the yearly average is rather representative for all seasons though the magnitude of the transport and $[u]_\lambda$ itself has a strong annual cycle (Fig. 2). In lower latitudes, the convergence explains less than half of the $[u]_\lambda$ change. In this region, other terms of Eq. (1) are probably of more importance, e.g., the mean zonal absolute vorticity transport. Starr (1973) and Peixoto *et al.* (1973) pointed out the importance of the convergence of the vertical eddy transport, which could also play a role in lower latitudes.

For a parameterization of $[(u)_\lambda(v)_\lambda]_\lambda(t)$ using $\partial[u]_\lambda/\partial t$, a correlation of the convergence of the flux with another $\partial[u]_\lambda/\partial t$ has been made, namely $\partial[u]_\lambda/\partial t$

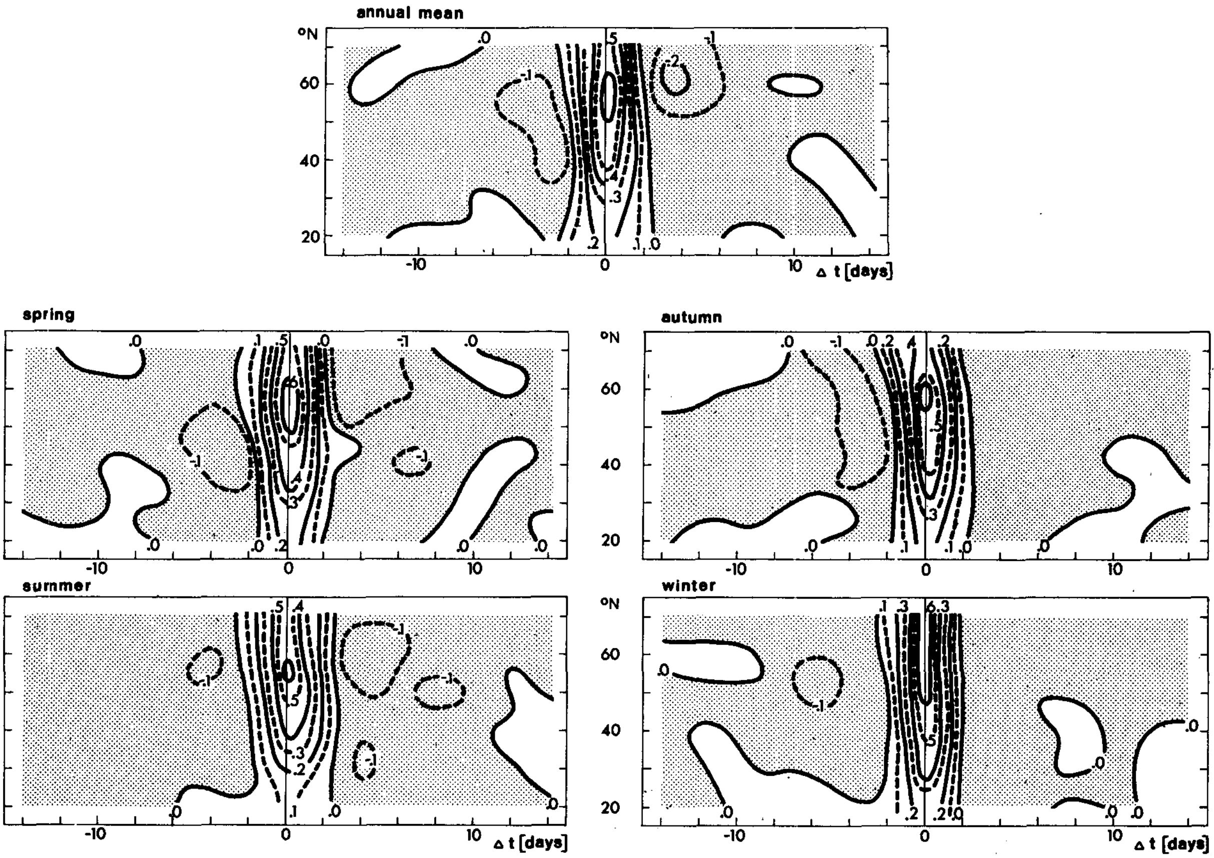

FIG. 3. Cross-correlation function of the momentum convergence, $-(\partial[(u)_\lambda(v)_\lambda]_\lambda/\partial y)(t)$, with the acceleration of the zonal wind $(\partial[u]_\lambda/\partial t)(t \pm \Delta t)$ as a function of latitude at 200 mb. $\partial[u]_\lambda/\partial t(t) \approx ([u]_\lambda(t + \delta t) - [u]_\lambda(t - \delta t))/2\delta t$ for $\delta t = 1$ day. Negative areas are shaded. The 95% significance level for the annual mean is $r = \pm 0.17$ and for one season is $r = \pm 0.30$. The period is 1969–76.

$\approx ([u]_\lambda(t) - [u]_\lambda(t - \delta t))/\delta t$ so that by means of the actual wind field and the one of the day before, a value for $[(u)_\lambda(v)_\lambda]_\lambda(t)$ could be found. The result is shown in Fig. 4. The correlation values at a time lag of zero days are still larger than 0.5 between 50 and 60°N. Then the main result is that the relation between the time change of $[u]_\lambda$ and the convergence of the momentum transport is best fulfilled in those latitudes where the convergence is positive, which means mostly north of the jet stream.

A second correlation has been carried out between $[u]_\lambda$ itself and $\partial[(u)_\lambda(v)_\lambda]_\lambda/\partial y$. One thing that this correlation can show is the period of time which passes between an extreme (maximum or minimum) of convergence and the subsequent forced extreme of the zonal wind. There is probably some justification for regarding $[u]_\lambda$ at the 200 mb level as representing the thermal wind, so it is physically also a measure of the meridional temperature gradient in the troposphere. Therefore, a parameterization using the zonal mean wind resembles that of Williams and Davies (1965).

The resulting correlation values (see Fig. 5) are relatively small. The correlation of $-\partial[(u)_\lambda(v)_\lambda]_\lambda/\partial y$ with the mean zonal wind is mostly positive for positive time lags and has a maximum value at $\Delta t = 2$ days relatively far in the north. The negative minimum for negative lags lies at about -1 to -2 days, the convergence lagging the zonal wind. These extreme values are situated farther south. The asymmetry around the zero time lag shows that a smaller than average $[u]_\lambda$ precedes a convergence of momentum transport and this drives the zonal wind which increases to a maximum approximately 2 days later. This is most pronounced at ~40°N and farther north. This main characteristic can be recognized in each season with some southward and northward variation of the maximum and minimum. The result reminds one of the cross-correlation results of Stone *et al.* (1982) between the eddy sensible heat transport and a baroclinic stability parameter. As he had a better time resolution, he obtained the result that at a time lag of half a day after a maximum transport, the stability reaches its maximum. The behavior of the two transports is thus seen to be different. While the sensible heat transport leads to a smaller meridional temperature gradient, the momentum transport gives rise to an increasing gradient.

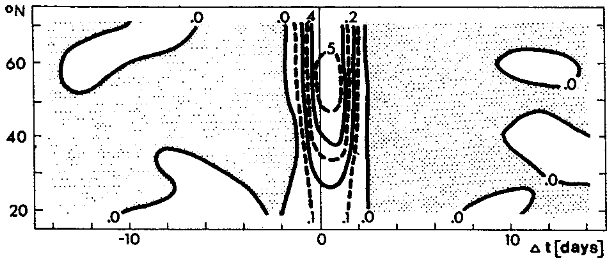

FIG. 4. As in Fig. 3 but with $\partial[u]_\lambda/\partial t(t) \approx ([u]_\lambda(t) - [u]_\lambda(t - \delta t))/\delta t$. Only the annual mean is shown.

Generally the correlation values, though sometimes significant, are probably not large enough to be of much use for a parameterization.

A similar result is obtained when comparing the (negative) meridional curvature of the zonal mean velocity, $-(\partial^2[u]_\lambda/\partial y^2)$, with the convergence of the transport (see Fig. 6). The result is rather similar because the correlation between $[u]_\lambda$ and its curvature is large (not shown here). Here too, the maximum of the correlation lies northward of the wind maximum. Only during summer is there a smaller secondary maximum near the jet. The result of Fig. 6 corresponds to that which one would obtain when correlating the transport itself with $\partial[u]_\lambda/\partial y$, which would correspond to an eddy diffusion parameterization. The result confirms the estimations of Arakawa (1961) who concluded that a flat and weak jet stream would be sharpened by the eddy momentum transports and a strong one would be decreased or would split. It should be mentioned that the correlations do not have their maximum values at the latitude where the jet normally is to be found.

For a moment we leave the time scale of "free variation" (Lorenz, 1979), with the influence of the baroclinic waves and turn our attention to a correlation between the monthly means of $[u]_\lambda$ and $-\partial[(u)_\lambda(v)_\lambda]_\lambda/\partial y$. This was done to obtain results characterizing the annual cycle which belongs to the time scale of "forced variation".

First, the monthly average of $[u]_\lambda$ and the convergence of the momentum transport, both averaged between 30 and 60°N, have been correlated. Here, no time lag was considered. The correlation coefficient averaged over eight years is 0.89. All correlation coefficients larger than 0.71 are significant with a probability of 95%, if we consider the number of degrees of freedom to be $8 - 2 = 6$. Computing the same for each latitude leads to results shown in Fig. 7. From

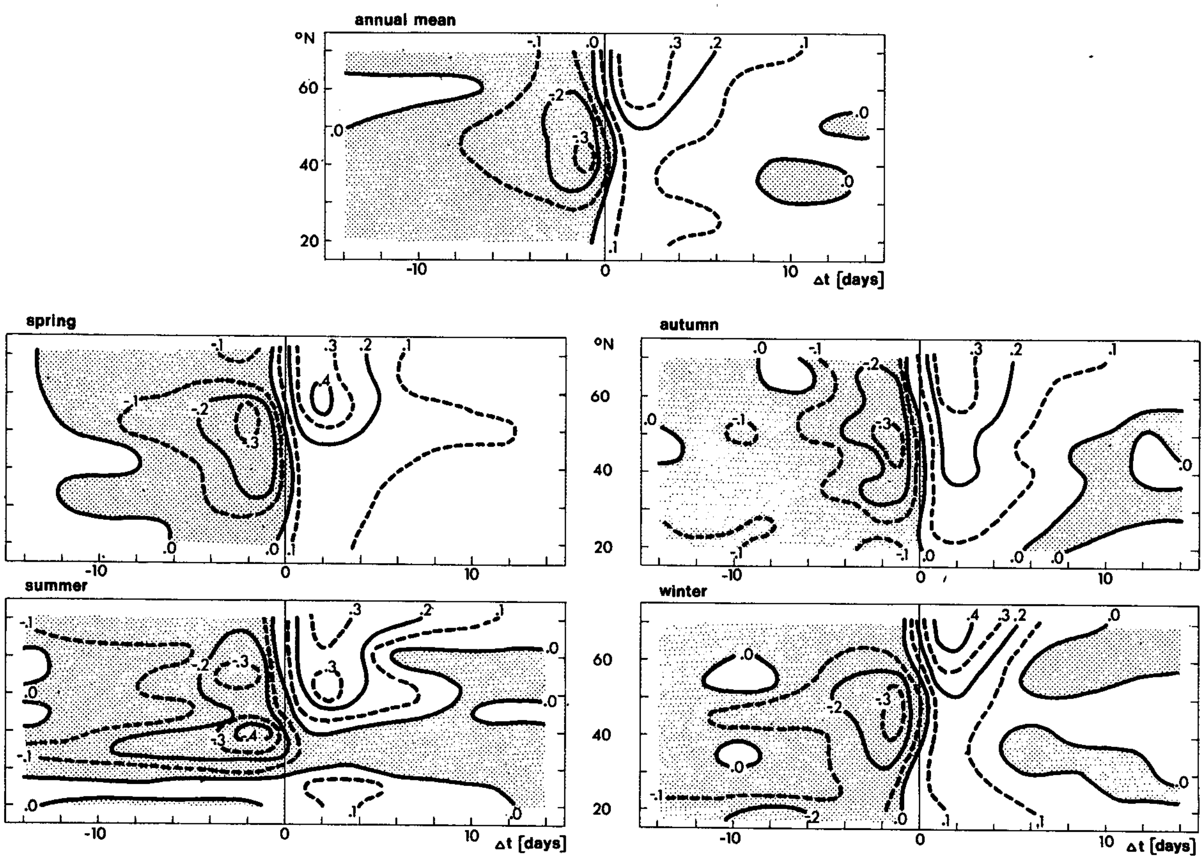

FIG. 5. As in Fig. 3 but with the zonal mean wind, $[u]_\lambda(t \pm \Delta t)$.

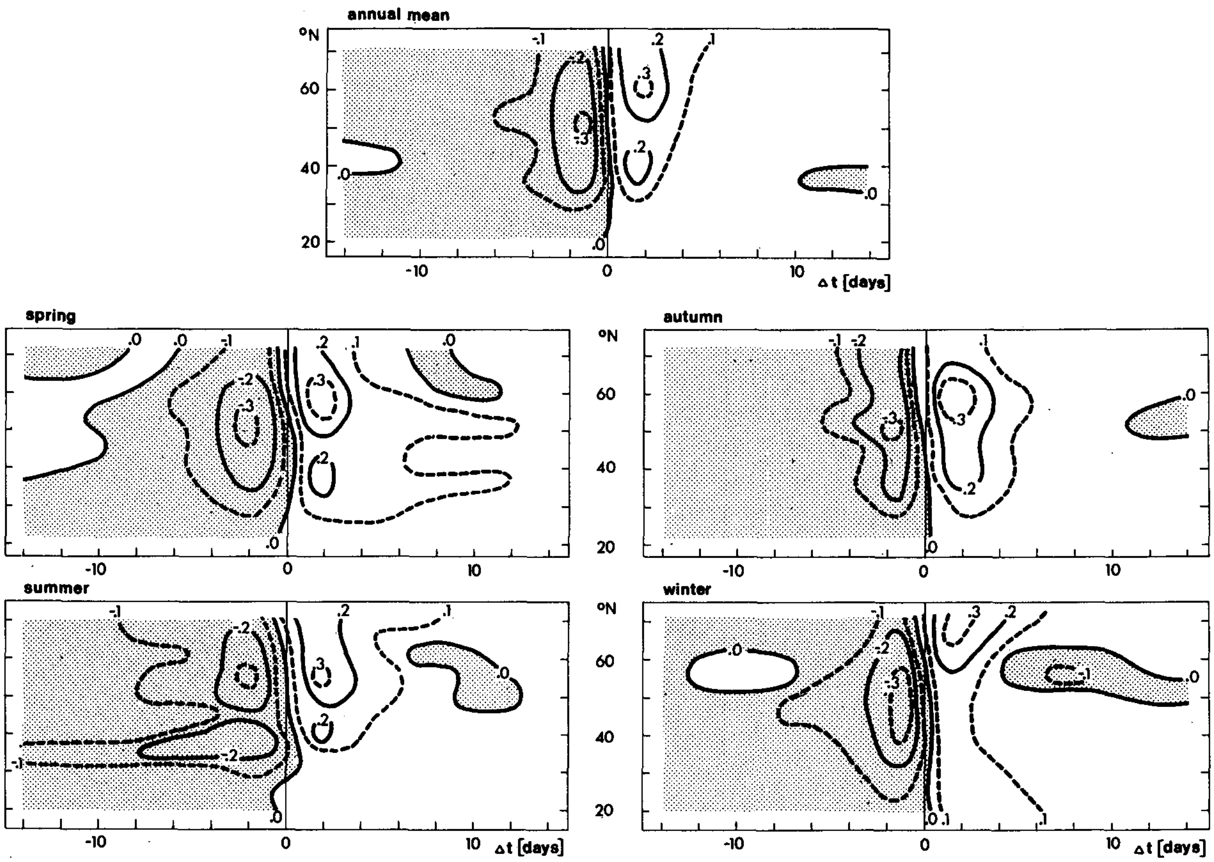

FIG. 6. As in Fig. 3 but with the curvature of the zonal wind $-(\partial^2[u]_\lambda/\partial y^2)(t \pm \Delta t)$.

the figure one can recognize that south of the jet, a large $[u]_\lambda$ is related to a large divergence of the transport and that the correlation is positive north of the jet. The correlation, however, is much smaller than the meridional averaged one and seldom reaches the significance level.

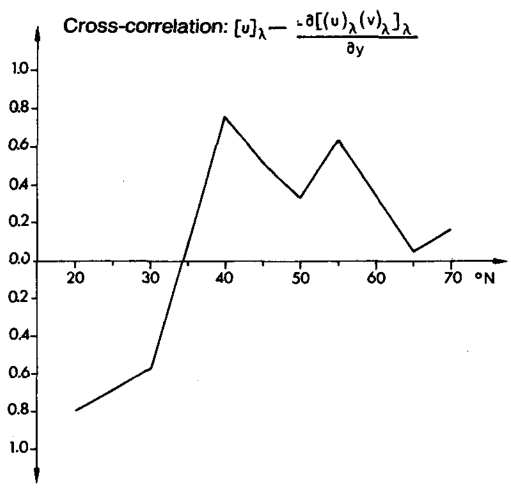

FIG. 7. Cross-correlations between monthly means of the zonal mean wind $[u]_\lambda$ and the momentum convergence $-\partial[(u)_\lambda(v)_\lambda]_\lambda/\partial y$ at 200 mb as a function of latitude. The 95%-significance level is $r = \pm 0.70$ for the period 1969–76.

Finally, as already mentioned in the Introduction, Green's (1970) hypothesis has been studied by means of cross-correlation functions. He derived for adiabatic, frictionless flow in a quasi-geostrophic case that

$$\rho_0[(v)_\lambda(Q)_\lambda]_\lambda = f\frac{\partial}{\partial z}[(v)_\lambda(\theta)_\lambda]_\lambda - B\frac{\partial}{\partial y}[(u)_\lambda(v)_\lambda]_\lambda, \quad (2)$$

where $B = \partial[\theta_0]_\lambda/\partial z$ is a measure of stability and $Q \approx (\xi + f)\partial\theta/\partial z$ is the potential vorticity. Assuming that the transport of potential vorticity and of sensible heat can be described by a diffusion model, one obtains

$$\left.\begin{aligned} [(v)_\lambda(Q)_\lambda]_\lambda &\approx -K_1\frac{\partial[Q]_\lambda}{\partial y} \\ [(v)_\lambda(\theta)_\lambda]_\lambda &\approx -K_2\frac{\partial[\theta]_\lambda}{\partial y} \end{aligned}\right\}.$$

It follows that

$$-\frac{\partial}{\partial y}[(u)_\lambda(v)_\lambda]_\lambda \approx -\rho_0 K_1\frac{\partial([\rho + f]_\lambda)}{\partial y} + \frac{1}{\partial[\theta]_\lambda/\partial z}\left[\frac{\partial}{\partial z}\left(K_2\frac{\partial[\theta]_\lambda}{\partial y}\right)\right]^{-1}. \quad (3)$$

The second term on the rhs is the stability weighted meridional change of the vertical entropy gradient, i.e., of the stability, or, in other words, the convergence of the potential isotherms.

With the three terms of the equation, two partial cross-correlations have been performed. But it must be said that this sort of correlation could be computed for only two years (1969 and 1975) because the temperature data were available only for these periods. This naturally reduces the number of degrees of freedom and changes the significance level.

Figure 8a,b shows the partial cross-correlation of the momentum flux convergence with the absolute vorticity and the baroclinic term respectively. For the vertical temperature difference, the 300 and 850 mb levels were chosen to represent the situation in the troposphere. The eddy transports and the vorticity gradient are computed with the 200 mb level values. When correlating the convergence of the momentum transport with the vorticity gradient, higher values are found than when doing the same with the baroclinic term. In Fig. 8a the largest correlations are found north of 40°N in the main convergence region of the momentum. The correlation has a negative extreme at a lag of −1 to −2 days, the vorticity gradient leading the convergence of momentum transport. At a lag of +2 days the correlation reaches its maximum like the earlier correlations in this section. The correlation values

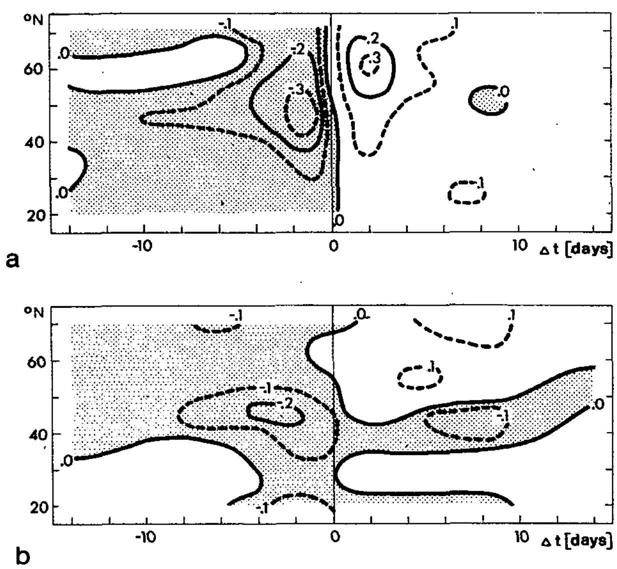

FIG. 8. (a) Partial cross-correlation function of the momentum convergence $-(\partial[(u)_\lambda(v)_\lambda]_\lambda/\partial y)(t)$ with the absolute vorticity gradient $\partial[f+\xi]_\lambda/\partial y(t \pm \Delta t)$; the isotherm convergence $(1/\partial[\theta]_\lambda/\partial z)[\partial/\partial z(\partial[\theta]_\lambda/\partial y)]$ is eliminated. (b) Partial cross-correlation function of the momentum convergence $-(\partial[(u)_\lambda(v)_\lambda]_\lambda/\partial y)(t)$ with the isotherm convergence $(1/\partial[\theta]_\lambda/\partial z)[\partial/\partial z(\partial[\theta]_\lambda/\partial y)](t \pm \Delta t)$; the absolute vorticity gradient $\partial[f+\xi]_\lambda/\partial y$ is eliminated. The vertical differences are formed between the 300 and 850 mb level. The other values are taken from the 200 mb level. Negative areas are shaded; 95% significance level is $r = \pm 0.30$ for the years 1969 and 1975.

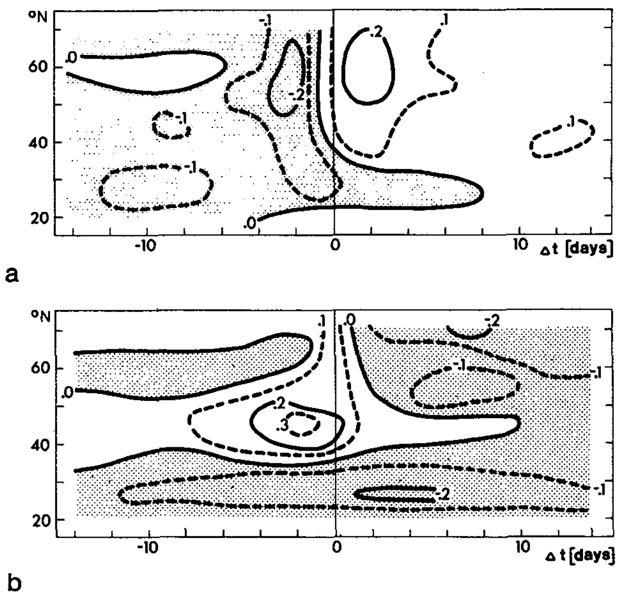

FIG. 9. As in Fig. 8, but the baroclinic term is given by the slope of the isotherms $(1/\partial[\theta]_\lambda/\partial z)(\partial[\theta]_\lambda/\partial y)$; $\partial[\theta]_\lambda/\partial y$ is an average between 300 and 850 mb.

of the momentum transport convergence with the baroclinic term are even smaller and the values are also mostly negative for negative lag with a minimum in nearly the same latitudinal belt. The time scale is a little larger. One reason for the small correlation values may be that the temperature values are differentiated twice and therefore are relatively noisy.

To avoid this, Fig. 9 shows similar partial correlations but this time for another form of the baroclinic term, namely $1/(\partial[\theta]_\lambda/\partial z)(\partial[\theta]_\lambda/\partial y)$, the slope of the potential isotherms. This term does not appear in Eq. (3) but is a measure of baroclinic instability. Indeed, the correlation values are then more significant for the baroclinic term (Fig. 9b), but the partial correlation with the vorticity term is modified in a way such that the values are smaller.

However, in the end, both types of partial correlations are of similar order of magnitude.

5. Conclusions

A series of cross-correlations between the convergence of the eddy momentum transport and some selected zonal mean values as a function of latitude and time lag has been computed.

The first correlation was a partial verification of the zonally averaged momentum equation made by correlating the eddy momentum transport convergence with $\partial[u]_\lambda/\partial t$. This correlation is rather strong in higher latitudes at a time lag of $\Delta t = 0$ days and still greater than 0.5 for an $\partial[u]_\lambda/\partial t$ formed using the difference between t and $t - \delta t$. Therefore, it is possible to calculate the momentum transport with past and present zonal mean values of the zonal velocity.

As seen in the Introduction, a parameterization of the eddy transports by $[u]_\lambda$ is more customary. This variable corresponds closely to the thermal wind or the meridional temperature gradient (William and Davies, 1965; Leovy, 1964; Lahiff, 1975). The correlations performed with $[u]_\lambda$ show that there are maxima correlation values greater than 0.3, but at time lags different from zero. There is a negative extreme when the transport convergence lags the zonal mean values by ~1–2 days and a positive one for a time lag of 2 days in the other direction. That means that there is a time difference of a few days between the forcing and its effect, which should be taken into account when parameterizing.

The result is very similar to that which is obtained by correlating the meridional curvature of $[u]_\lambda$ with the transport convergence. It was suggested by Arakawa (1961) that the jet can be sharpened, smoothed or split by large-scale eddy processes. It should, however, also be emphasized that the correlation maxima usually are situated northward of the jet axis.

Finally, the relation found by Green (1970) was examined. His equation expresses a linear relationship between the meridional convergence of the eddy momentum transport and both the potential vorticity and sensible heat transport. Two kinds of partial correlations were calculated using two different baroclinic expressions, one for the convergence of the isotherms and one for the slope of the isotherms. With the first form, the correlation with the convergence was weak but stronger with the vorticity gradient and vice versa for the second form. The correlations are generally rather small so that only a small amount of the eddy terms can be explained by the zonal mean quantities and only for a time lag not equal to zero; and so one can conclude that these relationships are probably of no more use for a parameterization than the zonal mean wind.

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