TRANSITIONS TO BLOCKING

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Summary:

Transition periods of (a) synoptically defined blocking cases, (b) ultralong wave amplification episodes and (c) periods with abnormally large single energy conversions were studied by using daily geopotential height data for 1967-1976. It was found (i) that often the predominant amplification process (observed before the onset of the episode) is not the leading process during the event if it is a synoptically defined blocking (a)-case or an ultralong wave amplification (b)-case. (ii) For (a)-events the transition dynamics varies largely from case to case whereas in the majority of (b)-events the baroclinic activity of the ultralong waves is preferently involved in the driving of blocking waves at the transition stage. There are some blockings which are initiated by unusually large baroclinic activity of ultralong waves (baroclinic outbreaks, (c)-events). Similar episodes with unusually large nonlinear forcing by synoptic scale waves are relatively rare.

1. INTRODUCTION

1.1 Definition of the problem

Blocking of the westerlies is the best known persistent anomaly of the general circulation in middle latitudes. About 50% of observed blocking patterns persist for more than 10 days and are preferently found in relatively narrow longitude ranges, coincident with enhanced amplitudes of nearby low-frequency geopotential anomalies. One can hardly escape the impression that the blocking waves, often but not always zonal wavenumbers m=2,3,4, are in a resonant-like relation to long-term mean forcing distributions (yet the relation appears to be more complicated).

Transition to blocking takes a shorter period, 2 to 4 days, say. Ideally, we expect that transitions to blocking are characterized by the amplification of the blocking waves (this is not always the case since favourable interference of slowly migrating waves or weakening of the zonal mean flow can result in similar patterns). Accordingly, the first problem to be studied is (i) a frequency record of selected processes serving as a driving during transitions. In this context we will represent a process by the respective energy conversion in the kinetic energy budget for zonal waves m=2,3,4 (and ignore the phase aspect for simplicity). The relevant energy parameters are defined in the Appendix; reasonable care was bestowed on the evaluation of Jacobians (see Appendix).

Surveying existing literature on proposed transition processes will help to select the two most promising candidates. However, the two-times scaling of the blocking phenomenon raises a second problem: (ii) Is the main amplification process at the transition stages also the predominant process during the blocking period? Since the answer can be yes, we also include proposed mechanisms for the maintenance of blocking waves in the following brief review.

1.2 Synoptic scale forcing

The idea that synoptic eddies, migrating from the east coast of America, will enhance or maintain the blocking action over the eastern Atlantic and the British Isles was first put forward by Green (1977) and subsequently tested and elaborated by Shutts (1983, 1986), Austin (1980), Mullen (1987), to mention some of the work. Shutts (1986) gives dynamical arguments within the framework of long term means which rely on dissipative action within the blocking system and some wave-maker upstream of the block. At first sight this theory collides with the widely accepted view that transient eddies tend to dissipate the time mean state and therefore balance the external forcing response (Holopainen, 1970). But locally, in the eastern Atlantic region, the 'forcing' of the time mean flow may be dissipative and therefore transient wave action may efficiently support the climatological ridge over the eastern Atlantic, following Shutts (1986). Transition to blocking may occur when the stormtrack variance is larger than normal (and locally distorted) which explains the fact that very often the Atlantic blocking is in the long term mean position and blocking waves with m=2,3 seem to be amplified standing eddies (Speth and Meyer, 1984; Austin, 1980; Fischer, 1984). This conjecture was first publishing by Namias (1964) and supported by one example of observed blocking in Hansen and Chen (1982), as well as by simulated blocking cases with a comfortable baroclinic model (Fischer, 1984). The nonlinear interaction between synoptic scale waves and ultralong waves was shown to be a specific transition mechanism in simple barotropic models (Egger et al., 1986; Metz, 1986). The theoretical background of this mechanism is partly revealed by the spectral composition of the unstable onset-of-blocking eigenmode presented by Frederiksen (1982) which mainly involves synoptic-scale wave components.

1.3 Baroclinic activity of ultralong waves

The problem of understanding the formation of blocked circulations can be viewed as part of the pattern self-organisation problem. The theory of pattern self-organization is nearly undeveloped in the case of background turbulent behaviour of the system (that is the presence of chaotic attractors) but has reached a considerable level of understanding if simpler equilibrium states (like fixed points) are involved (Nicolis, 1980). Since fixed point phase space topology is much easier to understand, the bulk of blocking theory deals with multiple fixed points since the work of Charney and deVore (1979) and we call them CdV-theories. Recently a more advanced baroclinic CdV-model was developed by Benzi et al. (1986) who, as the predecessors, maintain that the blocking wave is in near resonance with some time independent forcing. However, this concept was critically reviewed by Tung and Rosenthal (1985) who show that near resonance fixed points in models with realistic dissipation and a multitude of nonlinear wave-wave-interactions are highly improbable. Indeed, it is hard to believe that the fundamental chaotic behaviour of large scale atmospheric flow allows for one or more separated simple attractor basins even if bimodal frequency distributions of certain large scale flow characteristics (Hansen and Sutera, 1986) seem to support this model. In the following we will promote the idea that turbulent flows repetitively excurse away from the time mean towards exceptional states [this possibility is also included in the discussion by Mo and Ghil (1987) and was reported for simpler low-order systems (Ahlers, 1980)]. As an example we show the frequency distribution of available potential energy conversions from zonal mean flow to zonal wave m=2, $C(A_zA_2)$ = BCL. The numbers BCL for the histogram in Fig. 1a (which is stable to bin variations) are taken from November-February seasons in 1967-1976. They represent non-overlapping 5-days-averages of tropospherical means north of 40°N. Moreover, they are normalized by the procedure

$$BCL^* = \frac{BCL - \langle BCL \rangle_m}{\{ \langle BCL^2 \rangle_m - \langle BCL \rangle_m^2 \}^{1/2}} \tag{1}$$

yielding a zero mean and unit variance. Since $\langle\ \rangle_m$ is a long term monthly average, we remove most of the seasonal trends from (1) but not the interannual variability, of course.

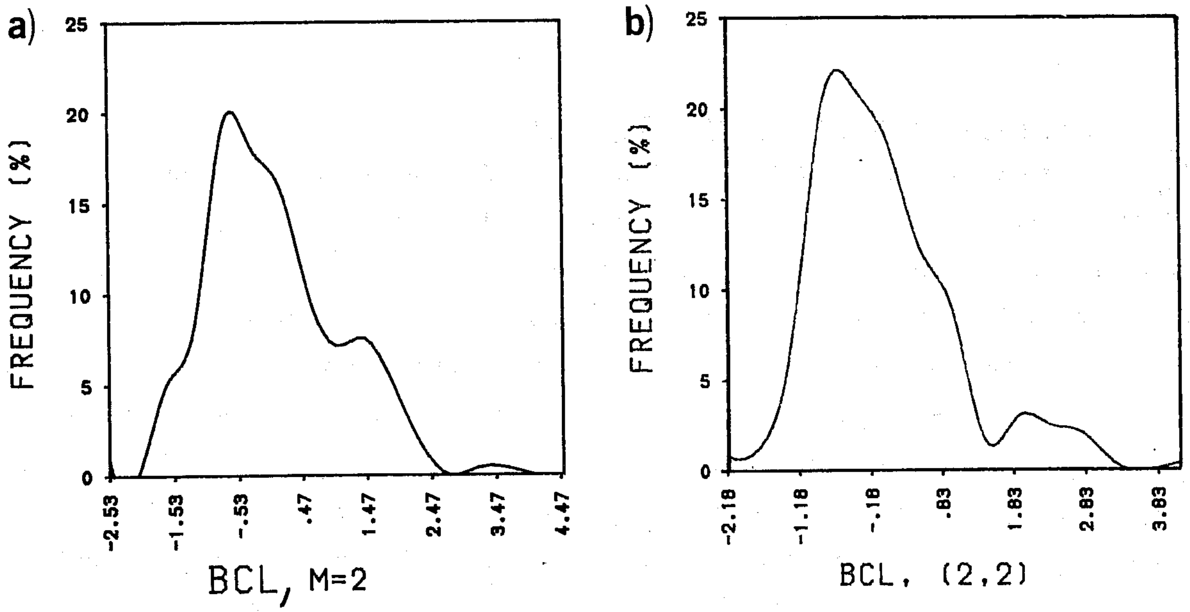

Fig. 1 Frequency distributions of (a) BCL for m=2 and all meridional modes and (b) for m=2 and the second odd meridional mode only.

Figure 1a does not indicate a multitude of simple attractors but reveals a 'plateau' in the vicinity of $BCL^* \approx 1$. This plateau develops into a secondary maximum, if BCL^* is only computed for the second odd meridional model of m=2 (Fig. 1b).

The first maximum ('mode 1') in Fig. 1 reflects the cruizing of the atmospheric state around the average (=zero) with some dispersion of states. The second smaller maximum ('mode 2') displays repetitive excursions away from the normal (=time average) state toward extreme states characterized by large normalized BCL^*-values ≈ 1 (denoting a distance of approximately one standard deviation away from normal). It is shown by Schilling (1988a,b) that major blockings result from 'mode 2'-events of the BCL^* distribution and that unusual large values of BCL^* are not balanced by other energy conversions (which would be necessary for any equilibrium). Therefore, it is hard to believe that both 'modes' are due to simple attractors; repetitive excursions to extreme states may be another possibility to create bimodal frequency distributions and to explain the oscillatory behaviour between two 'modes' of atmospheric action. In the following sections we will refer to them as 'turbulent modes' in contrast to the 'resonance modes' of CdV-theories.

Linear baroclinic instability theories only find marginally unstable ultralong wave disturbances and we are accustomed to relate baroclinic activity to the synoptic scale. In a series of papers the present author has developed the hypothesis that initially amplified ultralong waves with favourable vertical structure can show a growth due to nonlinear baroclinic instability which is comparable or even larger than that of synoptic scale waves (Schilling 1982, 1984, 1986, 1988a,b). The condition of favourable vertical structure does not necessarily imply a large westward tilt of the ultralong wave's vertical axis. On the contrary, since these waves are already amplified (they are in phase with the climatological mean!) and the meridional heatflux of that waves depends on the amplitudes at different heights, a large heatflux is possible even for a small westward tilt of the vertical axis. Hansen and Chen (1982) have analyzed an example of Pacific blocking where the ultralong waves baroclinic activity clearly dominates the initialisation processes. They provide for an illustration of an idea of Gall et al. (1979) that circumpolar anisotropy of synoptic scale wave baroclinic activity will force a large scale variation of the ω-field which supports the large scale baroclinic activity.

The idea of considerably large ultralong wave baroclinic activity is supported by observational evidence provided by Paulin (1970), Steinberg et al (1972), Wiin-Nielsen et al (1963) and Ponater (1985). Blocking simulations with baroclinic activity of ultralong waves as important factor were reported by Schilling (1982), Chen and Shukla (1983) and Tenenbaum (1982).

We want to concentrate on these two processes; however a third specific transition mechanism may be the nonlinear redistribution of energy within the pack of long waves ($m \leqslant 5$). It is, on the average, as important to the kinetic energy development in the ultralong wave range as the synoptic-scale forcing (Schilling, 1987). In the same study it was found that barotropic interchange with the zonal mean flow, either directly or via the bottom topography, is not important to the budget of ultralong wave kinetic energies (on the average).

2. METHODOLOGY AND DATA

In previous studies it was found that a unique mechanism of blocking maintenance does not exist; the variety of potentialities is nearly exhausted in different cases (Ponater 1985, Schilling, 1986). It seems, however, that two of them: (A) the nonlinear wave-wave-interaction with smaller synoptic scales and (B) the baroclinic activity of the ultralong blocking wave, are more often present within an ensemble of blocking periods than other possible mechanisms (Ponater 1985, Schilling 1986). According to the latter author (A) was present in 22% and (B) in 43% of the blocking cases during 1967-1976, partly in combination with another mechanism or with one another. In Schilling (1986) it was attempted to define types of blocking due to the leading energy input during the blocking period. Although it was found that certain patterns of energy feeding of blocking waves were preferred, the assignation of some blockings to a certain type was not satisfactory and a considerable amount of cases could not be assigned to any type. Therefore, a third objective of this paper is (iii) whether dynamically better founded blocking definitions can provide for a deeper insight into the processes which lead to the formation of blockings. We will study the three main questions (i)-(iii) above for (a) synoptically defined cases and compare with the results for events (b) adequately defined by blocking-numbers or (c) by unusually large single energy conversions. Since we only use circumpolar averaged energy quantities, we have to filter out cases which necessarily deserve a local description. To this end we use the blocking number of Schilling (1986)

$$B1 = \frac{K_{2-4} L_c^2}{U_T^2 \, L_{crit}^2} \qquad (2)$$

where K_{2-4} is the tropospherically averaged kinetic energy of waves with m=2,3,4; L_c is the wavelength belonging to the wavenumber squared which is the centroid of the kinetic energy spectrum; U_T is the tropospheric zonal mean vertical wind shear and L_{crit} stands for the Rossby radius of deformation (involving the static stability σ_o). Schilling (1986) gives some evidence for the fact that blockings with responding circumpolar averaged energetics are selected by the condition $B1/\langle B1 \rangle_m \approx 1.5$. In this study we only use (a)-cases where B1 exceeds that threshold value. We suppress the star notation for normalized quantities from now on.

3. RESULTS

3.1 Synoptically defined blocking cases

We adopt our blocking definition from Egger (1978) and Schilling (1986) who used a minimum period length of 5 days and at least one closed isoline in the blocking high (for a 4 dam representation). Accordingly, an Atlantic blocking catalogue (1967-1976) was prepared by the author. Pacific blockings during the same period were selected from the catalogue by Treidl et al. (1981). The ensemble consists of 65 cases, fulfilling the B1-criterion of section 2. Figures 2a, b show bivariate frequency distributions of the following transition parameters: (a) ΔK_{2-4} = average of K_{2-4} over 4 days after the onset of blocking minus average of K_{2-4} over 4 days before the onset, baroclinic conversion $C(A_z A_{2-4}) = BCL_{2-4}$ averaged over the period beginning 4 days before and ending 4 days after the onset of blocking, (c) the same average except for the nonlinear forcing by synoptic-scale waves, $BTPLS_{2-4}$. The conversion BCL_{2-4} is intended to represent $C(A_{2-4}K_{2-4})$ which was also computed but is not as reliable as BCL_{2-4}. Nevertheless, the correlation between the two baroclinic conversions is well established especially when BCL is large (Fig. 9b).

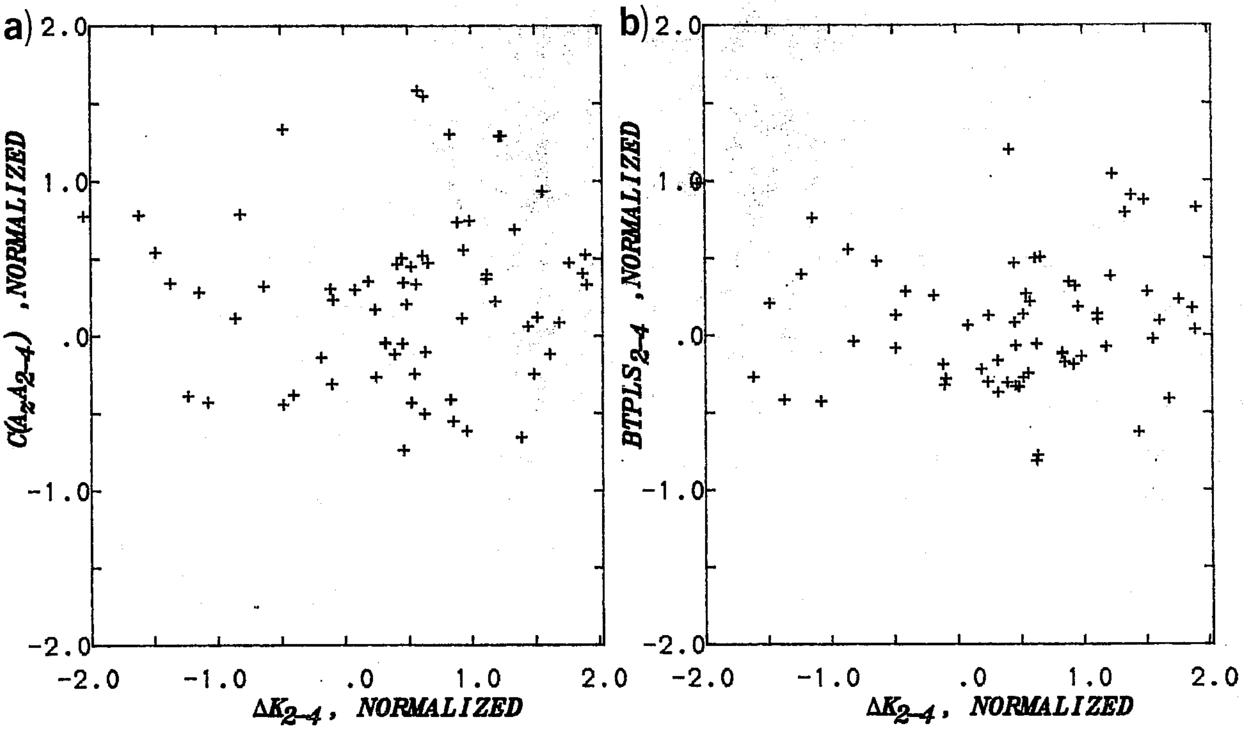

Fig. 2 Bivariate frequency distributions of (a) $\{ \Delta K_{2-4}, C(A_zA_{2-4}) = BCL_{2-4} \}$ and (b) for $\{ \Delta K_{2-4}, BTPLS_{2-4}$ = synoptic-scale wave forcing $\}$.

Figure 2 displays the growth of K_{2-4} in a majority of cases (72%), but some events are dominated by other waves/wave groups. The transition is not only characterized by one energy input. About 70% of the cases show above-normal baroclinic input BCL_{2-4}, and in a smaller fraction of the cases $BTPNL_{2-4}$ supports the growth of the blocking wave. There is a large scatter of points (each for one case) and the picture is by no means clear. In order to answer problem (i) above, we present Fig. 3a, showing that below normal BCL_{2-4} is not always compensated by above-normal $BTPNL_{2-4}$ or vice versa. About one quarter of synoptic blocking cases is characterized by below normal BCL_{2-4} <u>and</u> $BTPNL_{2-4}$ indicating that other processes come into play. Next, we switch over to problem (ii) by looking at the bivariate frequency distribution of $\Delta BTPNL_{2-4}$ and ΔBCL_{2-4}, where Δ stands for the average difference between 4 days before and 4 days after the onset, as before (Fig. 3b). Again, the hypothesis that the amplification mechanism is essentially the same as the

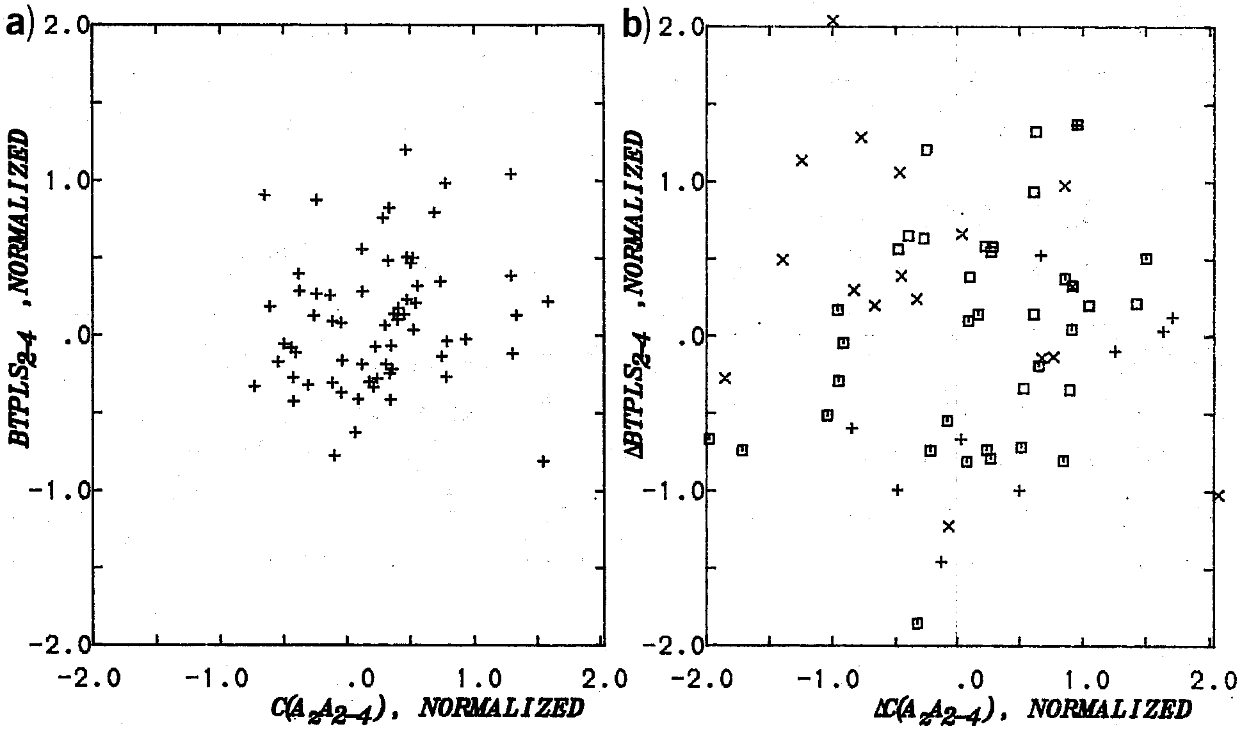

Fig. 3 Bivariate frequency distributions of (a) $\{ BCL_{2-4}, BTPLS_{2-4} \}$ and (b) for $\{ X = \Delta BCL_{2-4}, Y = \Delta BTPLS_{2-4} \}$. The meaning of the symbols is: dotted square → X>0 and Y>0; blank square → X<0, Y<0; + → X<0, Y>0; x → X>0, Y<0.

maintenance mechanism cannot be verified since there is a 32%-probability for an above-normal transition energy conversion to become below-normal at the first stage of blocking, irrespective of the nature of that conversion. The last problem (iii) was studied by an EOF-analysis of the triplets $\{ BCL_{2-4}, \Delta K_{2-4}, BTPNL_{2-4} \}$, each for one blocking case. Since each EOF explains approximately 33% of the variance it is clear that a specific cooperation pattern does not work in (a)-cases. In order to summarize we state that (i) above normal baroclinic activity of ultralong waves is present in the majority of transition periods but the scattering of cases is large and not unique transition energetics can be discerned; (ii) the transitions energetics are not necessarily the same as the maintenance energetics of synoptically defined blockings; (iii) systematic cooperation between the two major input candidates is not found and the variety of input combinations is larger than indicated by EOF1 alone. As a by-product we find from an EOF-analysis of the triplets $\{ \Delta BCL_{2-4}, \Delta K_{2-4}, \Delta BTPNL_{2-4} \}$ that it is most likely that all three quantities increase simultaneously (EOF1, 55% of variance, no overlapping with EOF2 since the first and second eigenvalues are sufficiently different). However, we observe a larger rate for $BTPNL_{2-4}$ than for BCL_{2-4} during the transition.

3.2 Events defined by $B1^* > 1$

An ultralong wave amplification event is defined by a period of at least 4 days with normalized blocking number $B1^*$ exceeding 1. The episode is extended by those days before or after the previously defined period which are characterized by $B1^* > 1$ but separated by at most 3 days with $.2 \leqslant B1^* < 1$. According to the examples shown in Fig. 4 we find that $B1^*$ events frequently coincide with synoptically defined blockings, the rest denotes strong ridging with similar dynamical background. The ensemble of $B1^*$ events consists of 47 cases.

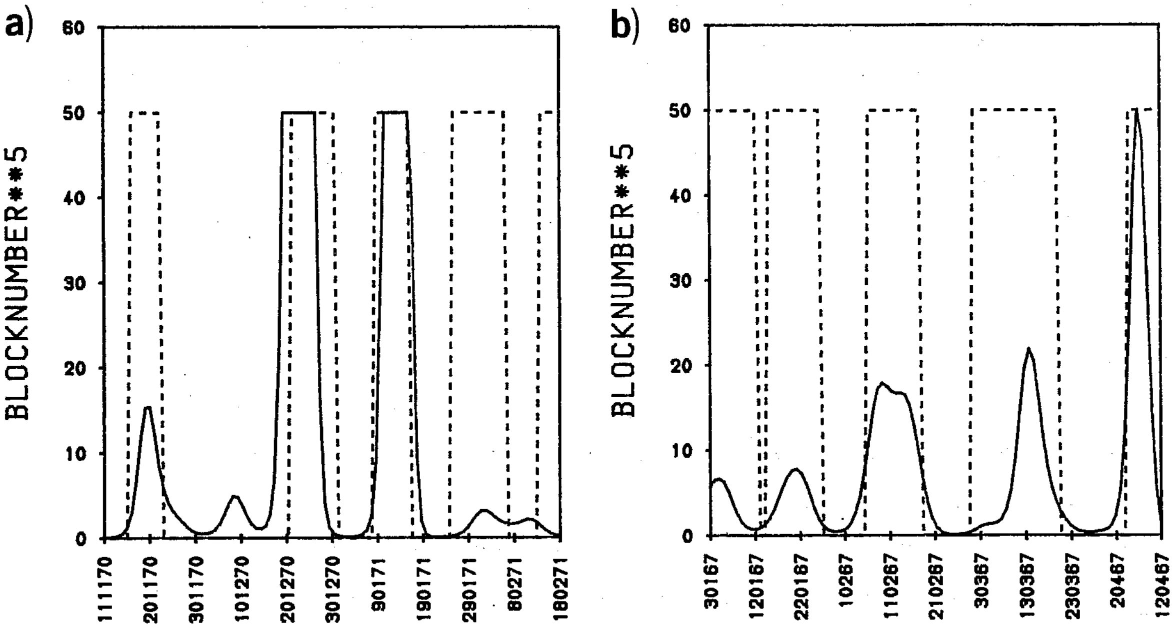

Fig. 4 Two daily sequences of normalized $B1/\langle B1\rangle_m$ (continuous curve, values > 50. were set constant). Dashed curve: Blocking periods (see text for catalogues; no further selection adopted).

First we discuss problem (i) by looking at Fig. 5. The definitions and plotting conventions are as in subsection 3.1. In all cases the ultralong waves' ΔK_{2-4} has increased at the transition stage (and the first stage of the event). In 77% of the (b)-cases an above-normal BCL_{2-4} serves for an energy injection; $BTPNL_{2-4}$ is above-normal in only 55% of the cases and no definite conclusion on the role of this input can be made. We tend to conclude that BCL_{2-4}, the baroclinic activity of the packet of ultralong waves, plays the major role at the transition stage. The correlation between the two inputs seems to be about the same as in (a)-cases and again, below-normal BCL_{2-4} is not necessarily compensated by above-normal $BTPNL_{2-4}$ in single cases (Fig. 6a). In 13% of the cases neither mechanism can explain the amplification of K_{2-4} and other processes have to be invoked. As to the problem (ii) we find from Fig. 6b that an above-normal energy flux in the transition period has a 25%-chance to change the sign at the first stage of an event. It is slightly lower than for (a)-cases. Problem (iii) is studied by

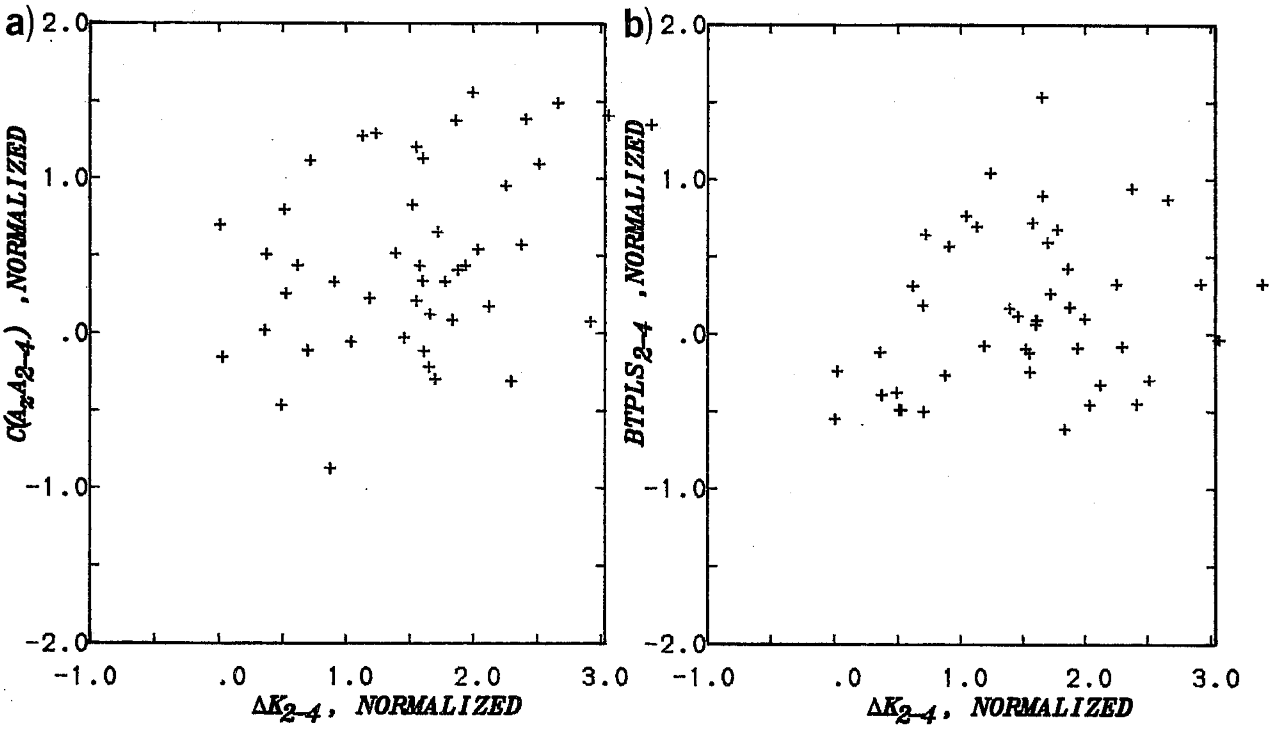

Fig. 5 As Fig. 2, except for $B1^* > 1$ events.

performing an EOF-analysis of the triplet $\{ BCL_{2-4}, \Delta K_{2-4}, BTPNL_{2-4} \}$. Now, the EOF1 only explains 44% of the variance, EOF2 explains 31% (a slight overlapping of EOF1 and EOF2 is indicated by the difference of the first two eigenvalues). EOF1 describes the simultaneous increase/decrease of all three quantities with a certain preference to BCL_{2-4}. It may indicate that the two main conversions tend to cooperate during the amplification of the blocking wave. The second EOF states the sole forcing of K_{2-4} by BCL_{2-4}. Now, the EOF analysis of the triplets $\{ \Delta BCL_{2-4}, \Delta K_{2-4}, \Delta BTPNL_{2-4} \}$ gives no additional information since the three eigenvalues are too similar.

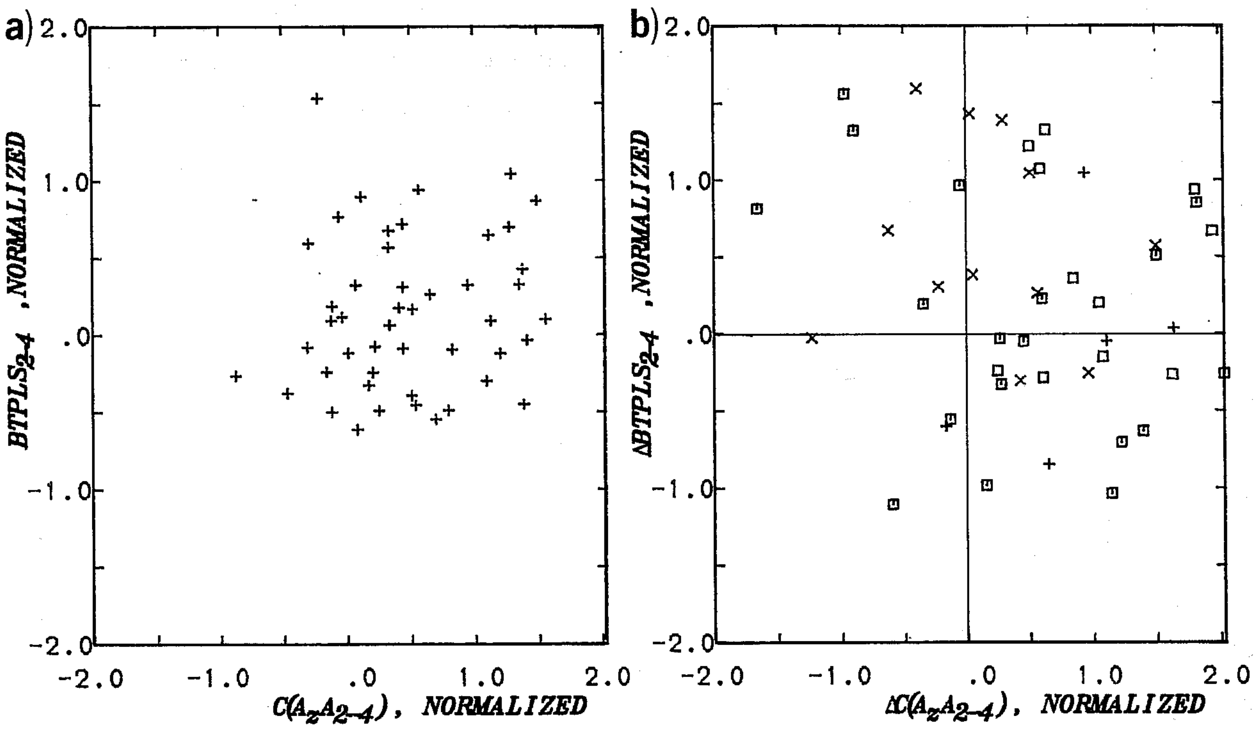

Fig. 6 Same as Fig. 3, except for $B1^* > 1$ events.

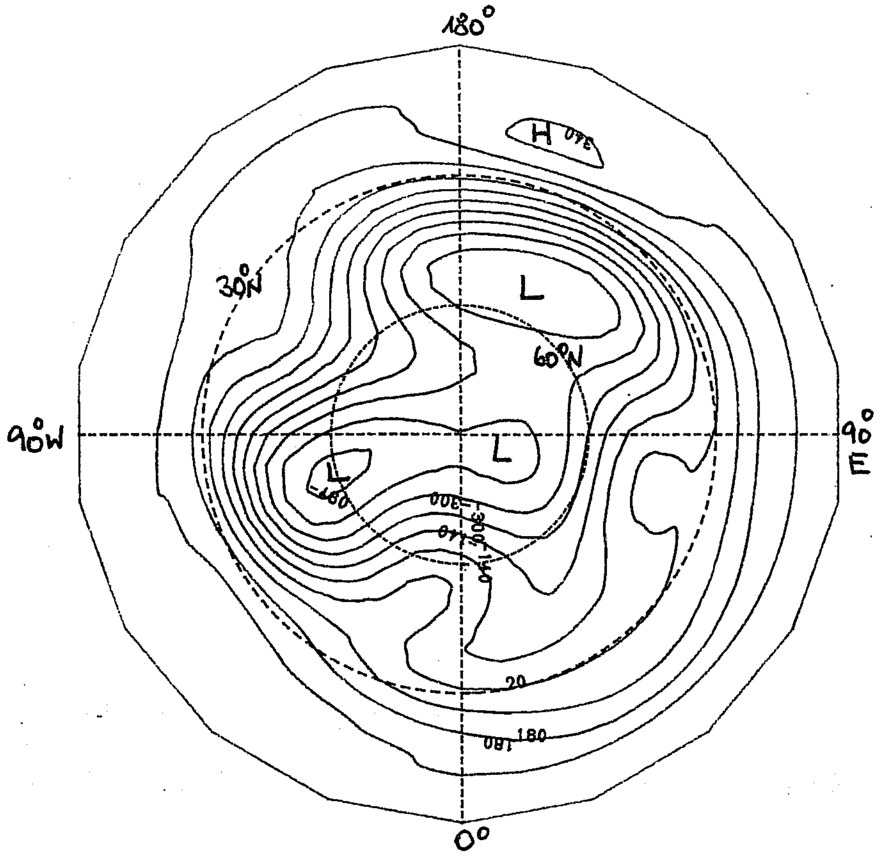

Fig. 7 Composite of the first 5 days of selected B0 events in winter (NDJF).

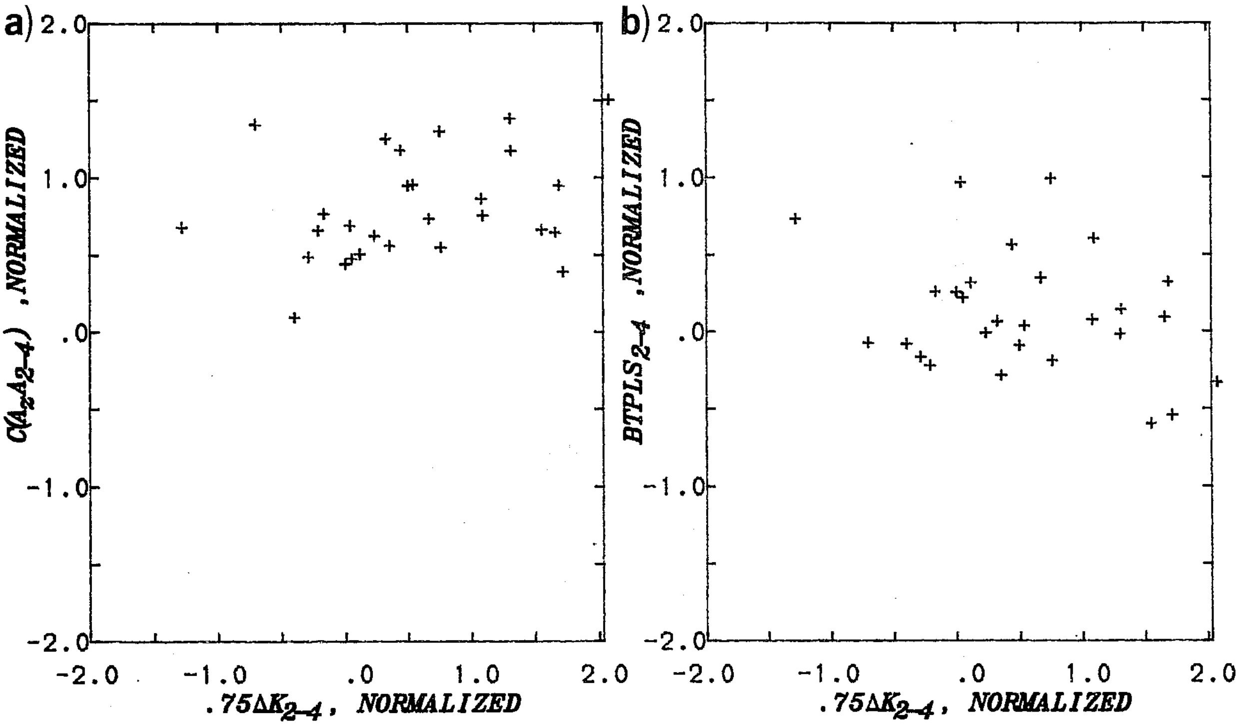

Fig. 8 Same as Fig. 2, except for $BCL_{2-4}^{*} > 1$ events.

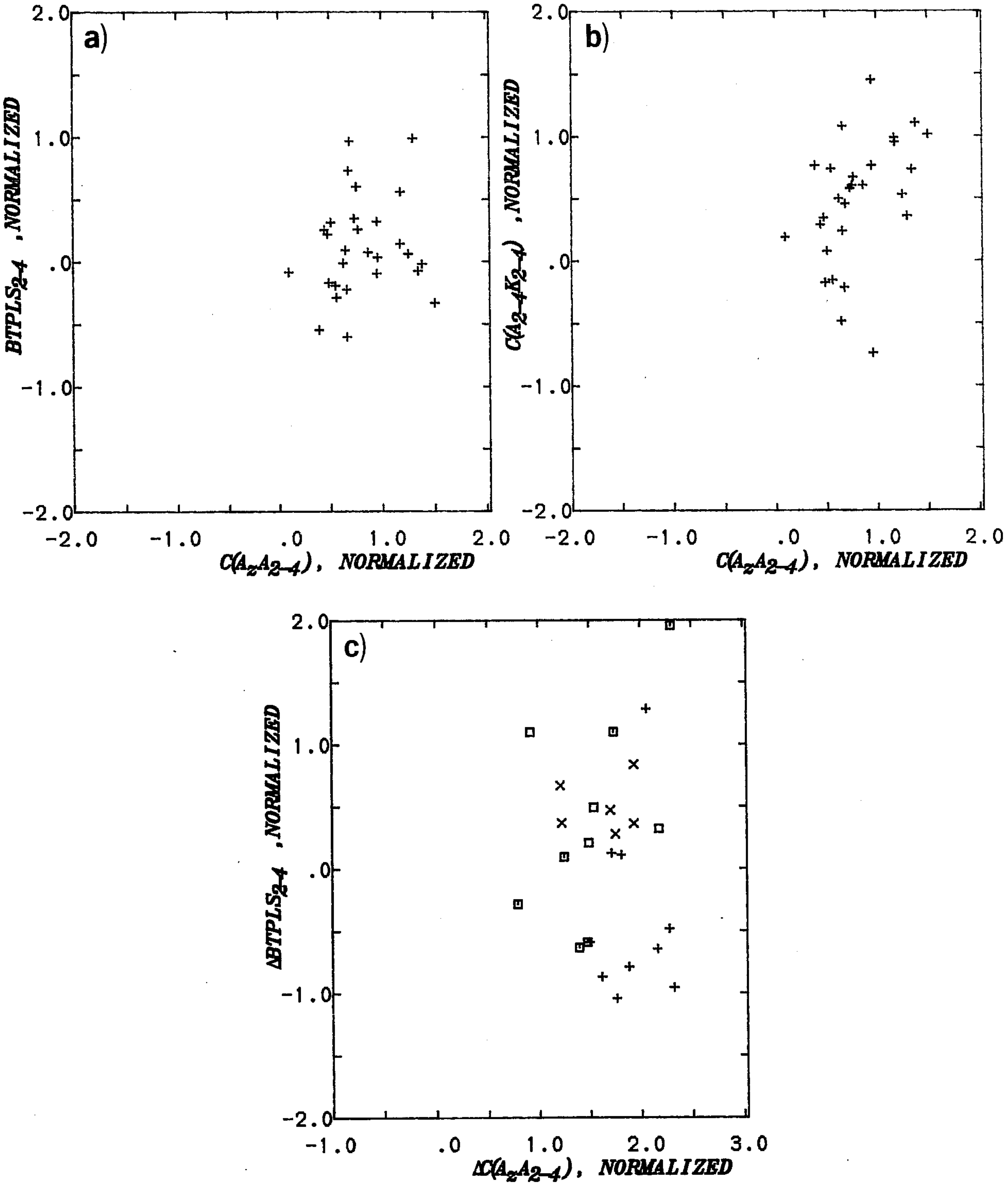

Fig. 9 (a) Same as Fig. 3a, except for $BCL^{*}_{2-4} > 1$ events.
(b) Same as Fig. 9a, except for $\{ BCL_{2-4}, C(A_{2-4}K_{2-4}) \}$.
(c) Same as Fig. 3b, except for $BCL^{*}_{2-4} > 1$ events.

3.4 Nonlinear outbreak events ($BTPLS^*_{2-4} > .75$)

For the reason of symmetry we should look at events like the B0's of the last subsection, but with $BTPLS^*_{2-4}$ playing the role of BCL^*_{2-4}. As seen from Fig. 10 the connection with blocking is not as clear as for the B0's if a composite of the first 5 days of the summer events is an indicator. Now we count 13 persistent periods with anomalous $BTPLS^*_{2-3} > .75$ (the threshold value $BTPLS^* > 1.$ would have yielded only one case!). All but one events are recorded for April to September, in contrast to B0-events where the majority is observed in winter and spring. Regarding the problem (i) the input pattern is quite clear: $BTPLS_{2-4}$ serves for an above-normal input in all cases and BCL_{2-4} is also above-normal with the exception of 3 cases (Fig. 11).

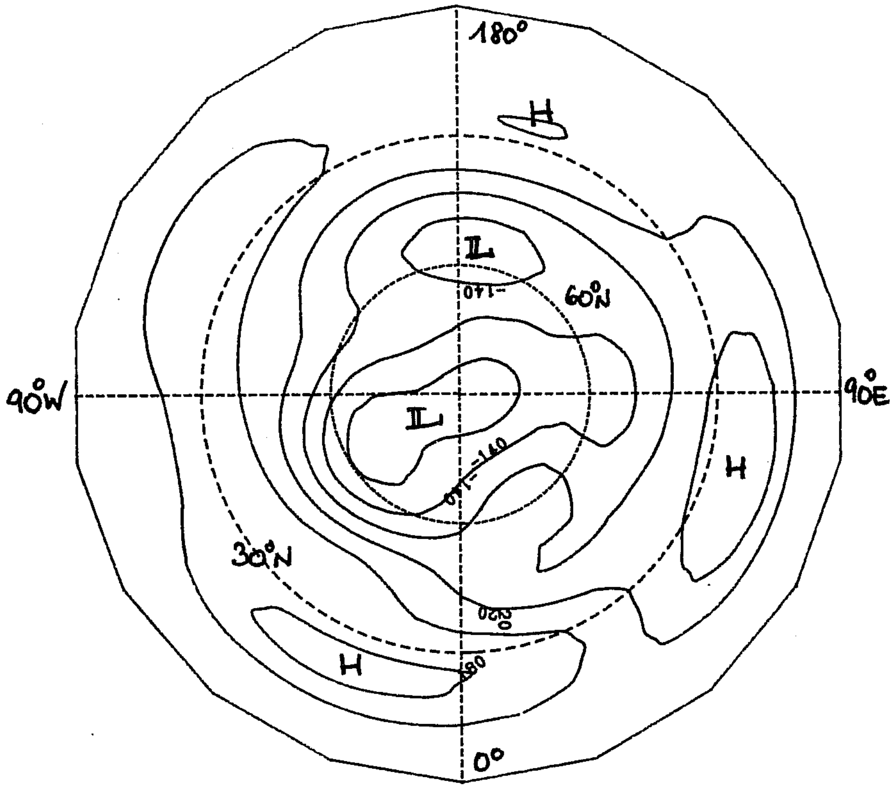

Fig. 10 Composite of the first 5 days of $BTPLS_{2-4} > 1$ events in summer (JJAS).

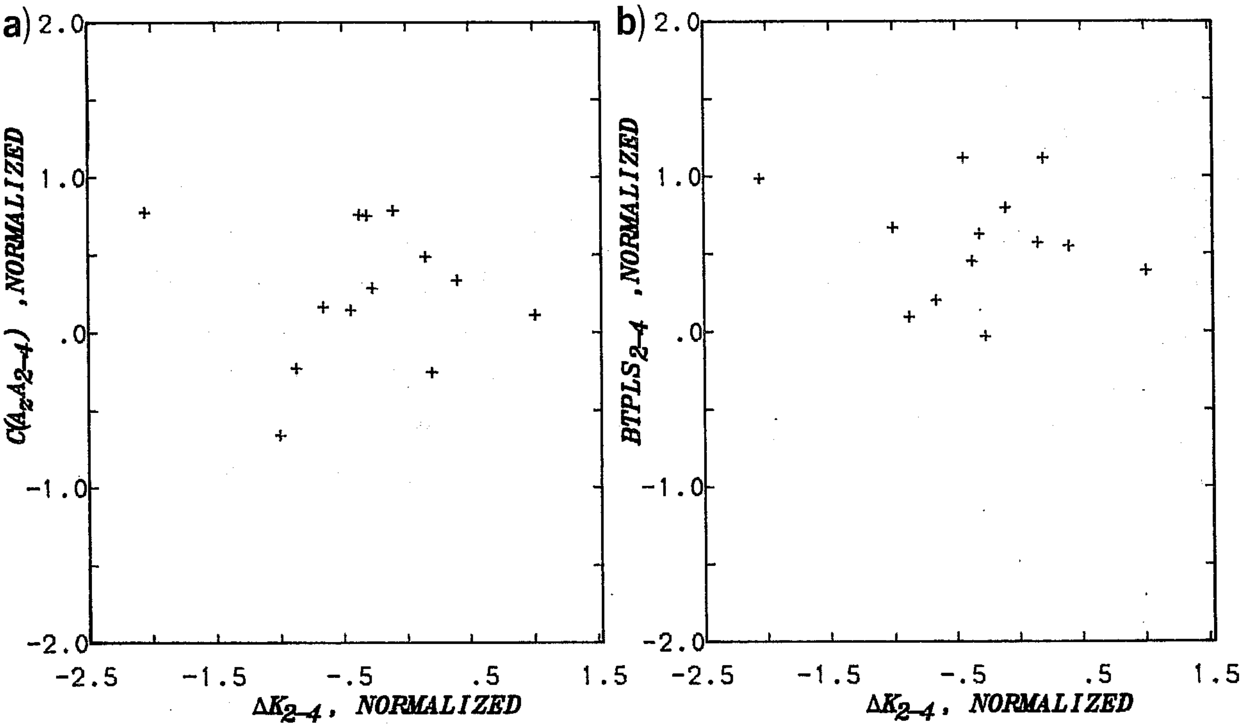

Fig. 11 Same as Fig. 2, except for $BTPLS_{2-4} > 1$ events.

The increase of K_{2-4} as a result of enhanced synoptic-scale wave forcing is not as well exemplified as in B0 cases (Fig. 11). EOF analysis for 13 cases is relatively doubtful and is not discussed in detail here. For example, the simultaneous development of BCL_{2-4}, ΔK_{2-4} and $BTPLS_{2-4}$ is only represented by EOF3 which explains 33% of the variance. We conclude that in the atmosphere the synoptic scale forcing of ultralong waves alone is not capable to explain the transition to blocking even if large above-normal values are attained for this flux. This is not to say that $BTPLS_{2-4}$ plays no role in the formation of blocking since in (b)- and (c)-cases there was a tendency for $BTPLS_{2-4}$ to cooperate with BCL_{2-4} especially when this input is large. Moreover, circumpolar averaging might have masked important systematic contributions being concentrated at certain locations (see subsection 1.2).

4. A MODEL FOR BAROCLINICALLY INDUCED PHASE SPACE EXCURSIONS

The last section of this paper is devoted to a more detailed explanation of 'turbulent modes' of the flow as introduced in section 1 alternatively to the 'resonant modes' of CdV-theories (e.g. Benzi et al., 1986). To this end we adopt a low-order spectral model of the quasi-geostrophic equations formulated in two vertical layers for a β-plane channel in midlatitudes of width W = 6000 km. The basic model is described in Schilling (1984) and we will present the spectral configuration only schematically in Fig. 12a as well as the triad interactions by Fig. 12b (some omissions are made for simplicity).

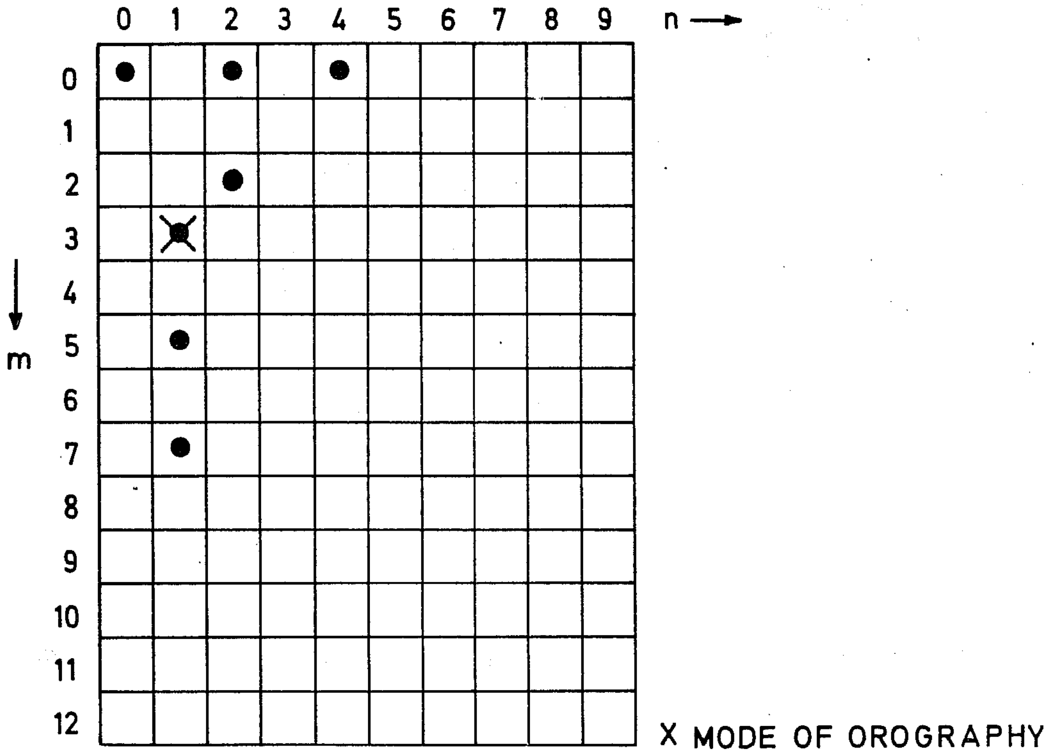

Fig. 12 (a) Spectral configuration of the low order model

Zonal wavenumber m=3 is forced by orography and determines the fixed points of the model. Zonal wavenumber m=2 is the blocking wave in this context and is driven predominantly by nonlinear interactions with other waves and by baroclinic input via nonlinear interaction with U_T, the zonal mean vertical wind shear (globally averaged). Note, however, that this wave interacts with (5,1) nonlinearly via the (3,1)-orography. Variable U_T stands for the temperature contrast between the lateral walls and is time dependent due to the baroclinic activity of all waves and a Newtonian-like heating $\kappa(U_* - U_T)$ with realistic constants κ (= $1.25 \times 10^{-6}\ s^{-1}$) and U_* (equivalent to 33° K temperature contrast). The smaller scale waves m=5 and m=7 are not defined by the internal dynamics of our low-order model but are described by a random walk model with a characteristic decay time of 2 to 3 days. On the one hand these waves should represent the perturbations from many unresolved waves via

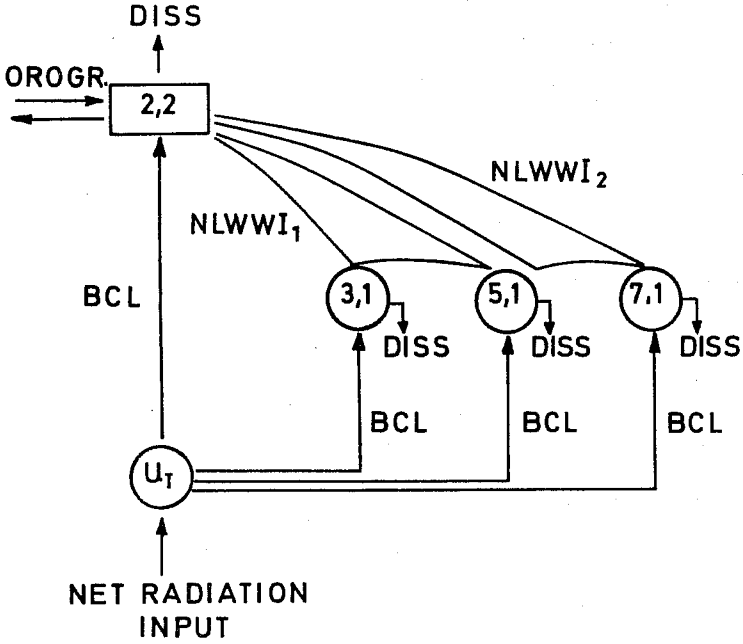

Fig. 12 (b) Triad interaction structure of the low order model (some omissions are made for simplicity).

the well established triad interaction equations. Figure 13 shows a transient episode of large growth of the blocking wave (solid curve) which is representative for a multitude of similar events. As indicated by Fig. 14 this event is mainly driven by baroclinic conversions (name BCL to be consistent with former definitions). Indeed, this model event is a baroclinic outbreak episode (compare with subsection 3.3). However, it would never occur if synoptic-scale forcing by m=5 and m=7 is missing. Further detailed analysis of this event (not shown) reveals (a) that it develops very far away from any stable fixed point of the model and (b) that orography practically plays no role in the energetics of that event. Nevertheless, it provides for some triggering since it is not possible to find this kind of events without orography in the model. Last but not least we note that the kinetic energy of m=2 is the by far largest contribution in the perturbation energy spectrum (Fig. 13) and a blocking is expected in all probability.

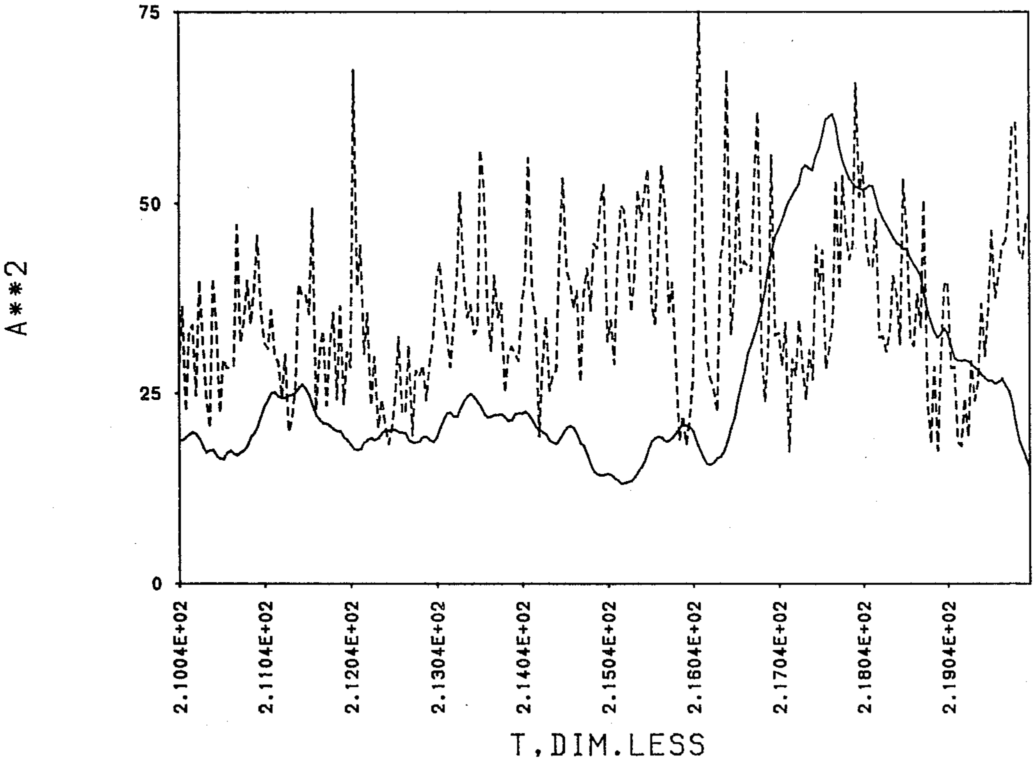

Fig. 13 Total energies in a 200 d-period of a long run of the low-order model. Solid curve: total energy wave m=2 (n=2), the blocking wave. Dashed curve: sum of the total energies of all other perturbations. The unit is m^2/s^2, the time unit 1=5.5 days.

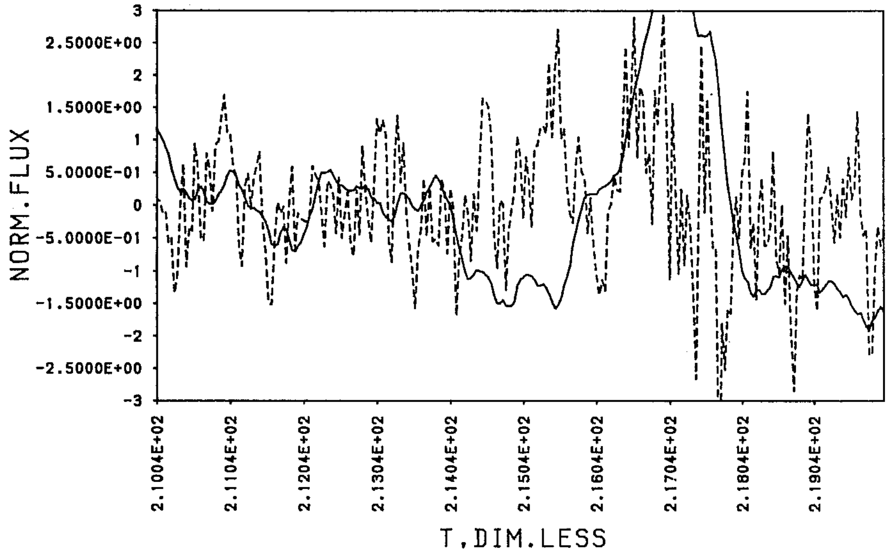

Fig. 14 Same as Fig. 13, except for energy conversions related to the blocking wave m=2 (n=2). Solid curve: $C(A_zA_{22})$=BCL ~ $C(A_{22}K_{22})$. Dashed curve: barotropic interaction of m=2 (n=2) with all other wavy perturbations. Both conversions are normalized by procedure (1).

5. CONCLUSIONS

In this paper we have studied three main objectives: (i) a survey of the role of synoptic-scale wave forcing and baroclinic activity in the transition energetics for a sequence of different episode definitions where a following definition more or less describes a special case of the preceding one. The (a)-cases show a very scattered input pattern with a weak tendency to enhanced baroclinic activity. One interpretation may be that the two processes are not really involved in the formation of blockings and appear therefore to be random. Here we support another hypothesis: the large scatter stems from very weak definition of events by geopotential anomalies or their synoptic counterparts, the closed isohypses. From an energetics point of view geopotential anomalies are the result of a mixtum compositum of a priori not negligible processes rather than an indicator for a certain dynamical process. In (b)-cases we find a preference of above-normal baroclinic activity of ultralong waves being predominant in (c)-events by definition. Synoptic-scale wave forcing of ultralong waves is not negligible in transition energetics (ii) Predominant energy conversion before the onset need not preserve the predominance at later states in (a)- and (b)-events. Before the onset of B0's [(c)-events] baroclinic activity of the ultralong wave packet is frequently above-normal (as in later stages of development). (iii) A systematic cooperation of synoptic-scale forcing and baroclinic activity is not entirely missing in all three categories of events but a statistically significant measure of the correlation between the two inputs in question can not be established. The B0 subclass of amplification and blocking events is the only one which appears to be very easy to understand. We find a clear input (anomalous baroclinic activity) - output (K_{2-4} amplification) relation; provided that the duration of a B0 is long enough a major blocking event will result. Another point of interest was the explanation of bimodality observed for hemispherically averaged second-order eddy indices. Here some evidence was given that B0-like episodes alternatively can explain bimodal behaviour of large scale flow in the presence of chaotic attractors.

APPENDIX

The energy parameters used above are ($\bar{x}$ = zonal average, $x' = x - \bar{x}$)

$$K_m = (p_B/g) \left[1/2 \left\{ \frac{\partial\psi_m}{a.\cos\psi\ .\ \partial\lambda} \right\}^2 + 1/2 \left\{ \frac{\partial\psi_m}{a\,\partial\psi} \right\}^2 \right]_{40°}^{85°} \tag{A}$$

$$C(A_m K_m) = (p_B/g) \left[f_o \cdot \omega_m \cdot \partial\psi_m / \partial p \right]_{40°}^{85°} \tag{B}$$

$$BTPLS_m = (p_B/g) \left[\psi_m\, J(\psi_{1-5}, \nabla^2\psi_{6-12})\big|_m + \psi_m \cdot J(\psi_{6-12}, \nabla^2\psi')\big|_m \right]_{40°}^{80°} \tag{C}$$

$$A_m = \left[(p_B/g\sigma_o)\ 1/2 \left\{ \frac{\partial\ \phi_m}{\partial p} \right\}^2 \right]_{40°}^{85°} \tag{D}$$

$$C(A_z A_m) = - \left[(p_B/g\sigma_o) \frac{h_m}{\Delta p_j^2} \left\{ J(\psi', \bar{h})\big|_m + J(\bar{\psi}, h')\big|_m \right\} \right]_{40°}^{85°} \tag{E}$$

where $[\ ]_{\phi_1}^{\phi_2}$ is an average over the latitude band $\phi_1 \leqslant \phi \leqslant \phi_2$ and the depth of the troposphere, $h_m = g\Delta z_m$, σ_o is a globally averaged measure for static stability. The evaluation of the Jacobi's was made by spectral decomposition and a difference scheme in latitude ϕ such that every triad conserves energy and enstrophy separately. For details see Egger and Schilling (1983).

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