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P3.23 STABILITY ANALYSIS OF BAROTROPIC FLOW IN AN EXTREME BLOCKING EVENT LEADING TO HEAT WAVE IN GULF OF ALASKA DURING AUGUST 2004

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1. INTRODUCTION

The development of a mainly meridional circulation pattern in the midtroposphere is commonly referred to as blocking. This recurrent obstruction and/or stagnation of basic zonal atmospheric flow gives rise to difficulties in obtaining a more confident and meaningful local and regional weather forecast (Elliott and Smith 1949). It is thus of interest to develop a good understanding of the processes that in first instance lead to the formation of such circulation patterns.

Considerable theoretical efforts have been made to mimic and simulate the phenomena of atmospheric blocking, particularly those emanating from the model solutions of the quasi-geostrophic potential vorticity equation. For a recent review, see De Swart 1988.

From the synoptic-dynamic point of view, making use of the more refined and consistent surface and upper air data (Kalnay et al. 1996), numerous studies have been carried out leading to valuable insight into the forcing mechanisms that may be operative at various stages of atmospheric blocking in specific case studies. This class of studies is usually referred to as diagnostic studies.

In several of the recent observation based studies, question of role of dominant wavelength during various stages of the blocking anticyclones is addressed. Here, we continue along these lines and discuss the relative stability of the flow in terms of the scales of motion.

The restricted nature of above model solutions however does limit their applicability range. Therefore, an empirically oriented approach seems to be in place to quantify the various stability regimes of atmospheric flow. In this context, blocking may be viewed as an unstable but stationary regime in barotropic atmospheric circulation. A diagnostic/stability study of atmospheric blocking may thus be performed by partitioning the atmospheric flow into planetary- and synoptic-scale components.

In recent years, several studies have examined the relative role of each scale and their interactions as well as the nature of the interactions themselves (e.g., Tracton 1990; Marques and Rao, 1999; Lupo et al. 2007 and references cited therein). In addition to these studies, and from those of earlier pioneers (e.g., Kalnay-Rivas and Merkine 1981; Frederiksen 1982; Shutts 1983; Mullen 1986, 1987), a consistent picture emerges that the synoptic-scale plays an important role in the lifecycle of blocking events (a necessary, but not sufficient condition). Many of the studies represented above show that the magnitude of the synoptic-scale forcing is large compared to that of the planetary-scale forcing.

However, others have shown that the planetary-scale is very influential in the lifecycle of the blocking events (e.g., Haines and Holland 1998; Colucci and Baumhefner 1998). While the studies referenced in the above paragraph do not downplay the role of the planetary-scale, they do focus more on the role of synoptic-scale contributions. For instance, in their model study, Haines and Holland suggest that blocking regimes will break down when there is a substantial change in the planetary-scale flow regime. Colucci and Baumhefner (1998) focus on the role of planetary-scale deformation as a pre-conditioned environment for the formation of blocking events (Colucci 2001). These two studies together support the notion that while the planetary-scale may not itself lead to block formation and maintenance, nevertheless this scale may provide a favorable environment in the interaction with the synoptic-scale environment. Thus, a substantial change in the planetary-scale flow regime would not support blocking and these events would decay fairly quickly.

The main goal of this work is to demonstrate that abrupt changes in the planetary-scale environment can lead to the rapid decay of blocking. This work will thus look at the utility of Lyapunov exponents (Lyapunov 1966) as a diagnostic tool in blocking studies, which are calculated using planetary-scale component of the atmospheric flow. In this context, time variability of planetary-scale geopotential height and of a stability index (namely Lyapunov exponents) will be studied.

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After briefly discussing some details of the data to be used in our synoptic and dynamic analyses, the methodology of our analysis is presented in Section 2. Using the method presented in Section 2, the synoptic and dynamic analyses of a chosen blocking event is performed in Section 3. The results are summarized in Section 4.

2. DATA AND METHOD

2.1 Data

The data set used here was the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) gridded re-analyses data (Kalnay et al. 1996). This data was archived at NCAR and was obtained from the mass-store facility in Boulder, CO in the netCDF format. This re-analyzed data was the 2.5° by 2.5° latitude-longitude analyses available on 17 mandatory levels from 1000 mb to 10 mb at 6-h intervals on daily basis. These analyses include the standard atmospheric variables relevant for determination of physical properties of the atmosphere such as the geopotential height, temperature, relative humidity, vertical motion, u and v wind components and surface information. The mandatory level data were interpolated quadratically in ln$p$ to 50 mb level-increments (where p is the pressure), and these more closely resemble raw sounding information (Lupo and Bosart 1999).

2.2. Methodology

The blocking criterion of Lupo and Smith (1995a) was used here to determine the onset and termination times for the blocking event studied here. Details regarding this criterion and its application can be found in the references in Section 1. Basically, these studies employ an extended set of conditions set forth earlier by Rex (1950a,b) where a climatological study of 16 year data (1933–1949) was performed under that set of conditions.

As mentioned before, this study will demonstrate that changes in the planetary-scale flow regimes can be correlated to the onset and, more importantly, to the decay of blocking events. The techniques used here to extract planetary-scale variability have been used to extract interannual variability from a one-dimensional time series recently by Mokhov et al. (2000, 2004, and references therein) or Federov et al. (2003) and will be only briefly presented here with modifications.

The techniques used in these references are based on standard dynamic analysis techniques for physical systems (e.g., Lorenz 1963). In particular, the planetary-scale height fields were averaged over a 40° degree latitude by 60° degree longitude box within the blocking sector to produce one number for each time period. This process is analogous to the procedure used by Hansen (1986) in deriving the wave amplitude index, with the exception that we filtered the fields first and then averaged them within a box. They averaged the entire mid-latitude height field into a band and then filtered to obtain a single number for the time period.

A second-order, two-dimensional Shapiro (1970) filter was used on the variables in the data set in order to separate the planetary-scale wavelengths from the synoptic-scale wavelengths. Applying this filter results in a response function, which retains 2%, 44%, 80% of the signal for waves having a wavelength of 3000 km, 4500 km, and 6000 km at 45° N (or S) latitude, respectively. More details regarding the use of the filtering procedure can be found in Lupo and Smith (1995b).

Historically, the planetary-scale flow in both hemispheres has been assumed to behave as, or treated like, an oscillating pendulum (e.g., Lorenz 1963; Hansen 1986; Nese et al. 1987; Hansen and Sutera 1988). More recently, this type of physical behavior has been discussed by Lynch (2003) who also extended the analogy to describe the planetary-scale flow as a swinging “spring” in describing the behavior of Rossby wave triads.

Let us note that if the planetary-scale flow were steady-state and geostrophically balanced over a long period of time, the phase plot would approximate the harmonic behavior. However, it is apparent that the planetary-scale flow may have more than one stable state (e.g., Charney and DeVore 1979; Yoden 1985; Nese et al. 1987; Nitsche et al. 1994). Whether there are two such states or more is not the focus of this work. Here the focus is to identify a change in flow regime character and associate this with the growth or decay rate of the blocking events.

Lyapunov exponents quantify the average leading order stability properties of a dynamical system (Lyapunov 1966). Lyapunov exponents for a dynamical system can in principle be computed by several methods. Here we take the point of view that they are calculable from the linear stability analysis of the barotropic atmospheric flow under the assumption of quasi-geostrophy (Dymnikov et al. 1992). We here discuss only briefly the salient and relevant points from this study. For details, the reader is referred to Dymnikov and Filatov (1997). We thus consider a source of diagnostic tools for blocking onset and decay in the mathematical theory of stability in infinite dimensions (Ruelle 1982; Dymnikov and Kazantsev 1993). The basic premise here is that *atmospheric blocking should be thought of as an unstable* *atmospheric circulation* whose state is best analyzed by its stability characteristics, as we've stated above.

The dynamic equation of viscous incompressible barotropic fluid for the stream function ψ is given by

$$\frac{\partial \Delta \psi}{\partial t} + J(\psi, \Delta\psi) = 0. \tag{1}$$

Δ is the Laplacian operator. *J* is the Jacobian incorporating the non-linear interactions. Expanding ψ in terms of time dependent and time independent components respectively such that $\psi = \overline{\psi} + \psi'$, where $\psi' = \psi'(t)$ and $\overline{\psi} \neq \overline{\psi}(t)$. The equation of motion for linearization operator *L* is $\partial\Delta\psi'/\partial t + L\psi' = 0$, where

$$L\psi' = J(\psi', \Delta\overline{\psi}) + J(\overline{\psi}, \Delta\psi'). \tag{2}$$

The perturbation energy equation in terms of scalar product $(L\psi', \psi')$ is

$$\partial E'/\partial t = (L\psi', \psi'). \tag{3}$$

Since *L*=*S*+*K*, where *K* is the skew-symmetric part of the operator and *S* is the symmetric part of operator, the perturbation energy equation may be rewritten with *L*→ *S* in Eq. (3), that is

$$\partial E'/\partial t = (S\psi', \psi'). \tag{4}$$

Note that the stationary solution will be stable if all the eigenvalues of the operator *S* with respect to stationary solution are negative. We shall thus *take the sum of positive eigenvalues of the operator S as the characteristics of the instability of the stationary point.*

Assuming that $\overline{\psi} = \overline{\psi}(y)$, i.e., the stationary solution does not depend on zonal coordinate to mimic meridionally directed perturbation (namely, blocking) in the mainly zonal flow and using the periodic conditions for *x* and *y* and passing to finite dimensions, after some algebraic manipulation, the eigenvalue problem for the operator *S* (where *2S* = *L*+ L^*) has the form

$$\overline{u}\frac{\partial}{\partial x}\Delta\tilde{\varphi} - \Delta\left(\overline{u}\frac{\partial\tilde{\varphi}}{\partial x}\right) = \lambda\tilde{\varphi}. \tag{5}$$

Here λ's are the eigenvalues of the eigenoperator $\tilde{\varphi}$. The λ's are the characteristic exponents and are identified as the Lyapunov exponents. We shall look for the general solution of Eq. (5) in the form that depends on *x* and *y*: $\tilde{\varphi}(x,y) = \tilde{\varphi}(y)e^{ikx}$. With this transformation, we obtain the following eigenvalue equation from Eq. (5)

$$\frac{\partial \overline{\varpi}\tilde{\varphi}}{\partial y} + \overline{\varpi}\frac{\partial\tilde{\varphi}}{\partial y} = \frac{\lambda}{ik}\tilde{\varphi}, \quad \overline{\varpi} = -\frac{\partial\overline{u}}{\partial y}. \tag{6}$$

In principle, one should solve this equation to obtain the spectrum of eigenvalues λ, which depend upon $\overline{\varpi}$. Note $\overline{\varpi}$ is the vertical component of the relative vorticity for the stationary component of the stream function. Here, we make use of the Dymnikov et al. (1992) conjecture which suggests a strong correlation between the sum of the positive Lyapunov exponents (eigenvalues of the linearization operator of barotropic flow) and the domain integrated enstrophy, that is

$$\sum_i \lambda_i^+ \approx \int_D \left|\overline{\varpi}\right|^2 (y)\,dxdy. \tag{7}$$

Eq. (7) can be obtained from Eq. (6) by first writing Eq. (6) in finite difference form and then using a know algebraic relation. Let us add here that a numerical implementation of equation for *L* via Crank-Nicholson scheme in Dymnikov et al. (1992) using data for a three-year period after applying a 15-day filter (planetary-scale) on domains D over the North Atlantic and Western Europe establishes the validity of Eq. (7).

Summarizing, to the extent that the average time for $\overline{\varpi}$-trajectories to diverge decreases as the sum of the positive Lyapunov exponents increases, we get a preliminary indication of how physical quantities, such as enstrophy, can be viewed as forecasting indicators.

Thus, the time variability of right hand side of Eq. (7) represents the relative stability of the barotropic flow. Development of a mainly meridional perturbation (*y* dependence only of ψ) signifies relative stability of the flow which we interpret as blocking under the working assumption of Dymnikov et al. (1992) conjecture . Note that right hand side of Eq. (7) refers to area averaged vorticity squared as mentioned earlier.

In the context of atmospheric blocking, the result can be illustrated by using the following observation from Lupo and Smith (1995a): Before blocking, there always exists upstream of the block, a ridge accompanied by an amplifying short wave within 0.5 of ridge wavelength.

Given that the ridge and the short wave are associated with increasing gradients, the Lupo-Smith observation can be understood as the creation of sufficient instabilities to trigger the transition from zonal flow to blocking. Furthermore, initial data observations as in Lupo and Smith (1995a) as well as in Wiedenmann et al. (2002), indicate a strong correlation between the Block Intensity (BI) and the average (unintegrated) anti-cyclonic vorticity in the neighborhood of the blocking state. We next discuss in some detail the time variability of the mean planetary-scale geopotential height and of the Lyapunov exponents for a selected isolated blocking event occurring in midlatitude Northern Hemisphere to illustrate the methodology presented above.

We shall thus make use of the above relationship given by Eq. (7) between the enstrophy and the sum of positive Lyapunov exponents to study the relative stability of the barotropic flow harboring a blocking event.

3. ANALYSIS

We shall first perform synoptic and then a dynamic analysis of the stability of the NH region of the atmospheric flow where the selected blocking event occurred.

3.1 Synoptic Analysis

An isolated single blocking event occurring in Gulf of Alaska during the boreal summer of 2004 is studied in some detail as our illustrative case study example. The block onset was on 02–05 August, its maturity phase was during 05–20 August and its decay stage was during 20–28 August. The blocking lasted for 23 days.

The height formation pattern (taken at 500 mb) that leads to identification of blocking anticyclones on an upper air chart can conveniently be quantified in terms of BI. The BI gives the combined effect of planetary-scale as well as the synoptic-scale height pattern formation simultaneously.

According to Wiedenmann et al. (2002) definition of BI, the BI for the considered blocking event averaged over its entire lifecycle is 2.44 which implies a moderate strength blocking. The blocking flow was located in the region encompassing 260^o E to 160^o E and 80^o N to 5^o N.

The midtropospheric synoptic features of the blocking event are displayed in Fig. 1 and Fig. 2. Figure 1 displays the 500 mb analyzed geopotential height after the block onset stage (10 August), during the maturity stage (18 August) and towards the end of the block decay stage (26 August). Figure 2 displays the temperature field distribution at 500 mb during its peak activity duration. The blocking event occurred 05 August through 28 August 2004. Figure 2 displays the midtropospheric temperature field distribution averaged over the entire blocking lifecycle.

We have compared the BI with the area averaged synoptic-scale and planetary-scale height tendencies

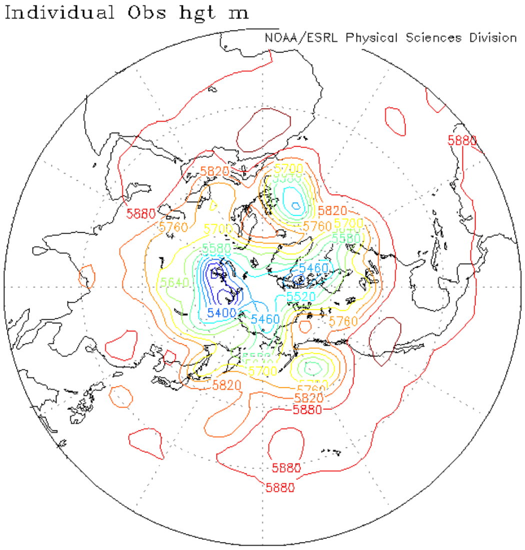

Fig 1a. The 500 mb analyzed height for 0000 UTC 10 August 2004 for the blocking event over the Pacific ocean which lasted from 1 August 2004 through 28 August, 2004. The analyzed 500 mb height is plotted every 60 m. In the region of the atmospheric flow encompassing the blocking the maximum geopotential height is 5880 m.

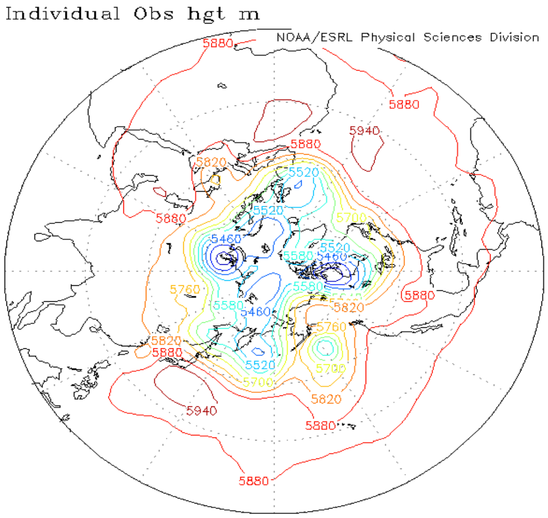

Fig 1b. Same as Fig. 1a, except for 0000 UTC 18 August, 2004 (peak activity period). The Rex shaped blocking pattern is clearly noticeable. The maximum 500 mb geopotential height in blocked flow in Gulf of Alaska is 5880 m.

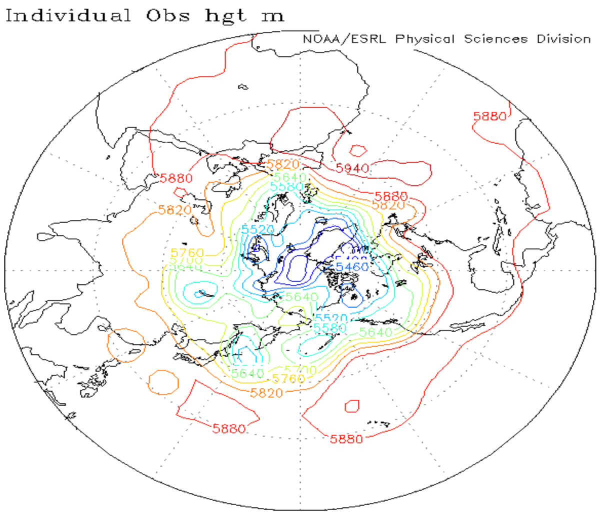

Fig 1c. Same as Fig. 1a, except for 0000 UTC 26 August, 2004 towards the end of decaying stage. Note the dissolving high pressure system in Gulf of Alaska.

(Fig. 3 and Fig. 4) over the entire lifecycle of the blocking and have found that synoptic-scale eddy heights have played a dominant role in initiating the onset and decay stages of the considered blocking event. Here, we display in Fig. 4 the synoptic-scale eddy height tendency for the entire lifecycle of the blocking event, whereas Fig. 3 displays the BI, both calculated at 500 mb.

The synoptic-scale eddy height at 500 mb is defined as the difference between the observed and the mean planetary-scale height at this isobaric level. The oscillatory behavior is indicative of area averaged synoptic-scale ridge-trough dominance for the advection of the heat wave. A positive difference corresponds to the high pressure system/ridge, whereas the negative difference corresponds to the formation of a trough.

When stratified across the entire troposphere, we noticed that the (blocking) area averaged synoptic-scale eddies grow in amplitude in lower troposphere (925 mb) relative to upper troposphere (250 mb) and play an increasingly domient role in destabilizing the basic zonal state and thus initiating the onset and then the decay of the blocking state.

Let us here further note that climatologically, the considered blocking event is the longest blocking event in East Pacific region for the year 2004 (July 2004 to June 2005). Our this finding is in agreement with the 3 year blocking persistency estimates by Lupo and Smith (1995a) and by Barriopedro et al. (2006) after taking into account the regional stratification. This blocking

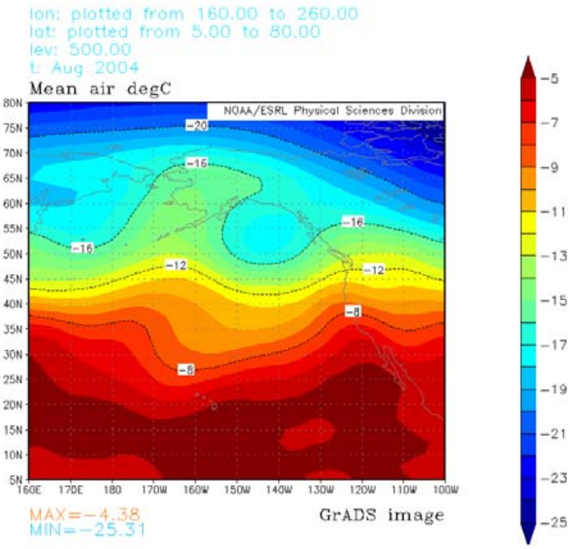

Fig. 2. The 500 mb analyzed temperature field (^{o}C) of the unstable atmospheric flow region that encompasses the blocking event shown in Fig. 1 for August 2004. Below normal temperature is in north of the blocking ridge, whereas above normal temperatures are noticeable south of the blocking high.

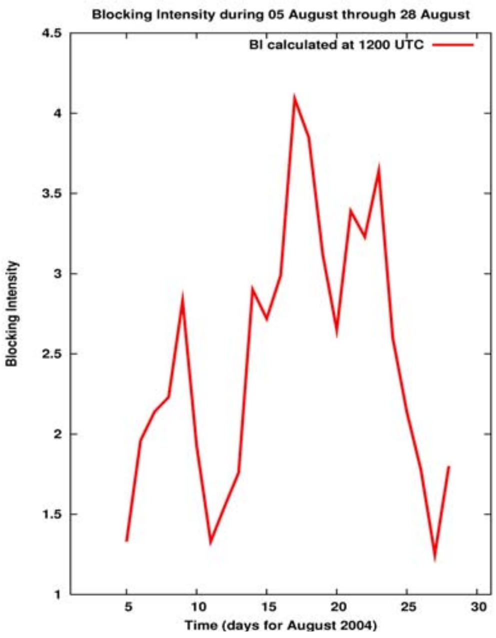

Fig 3. The daily BI calculated at 1200 UTC for the entire lifecycle (05–28 August 2004) of the blocking event. Note the rapid oscillatory behavior during onset and decay stages.

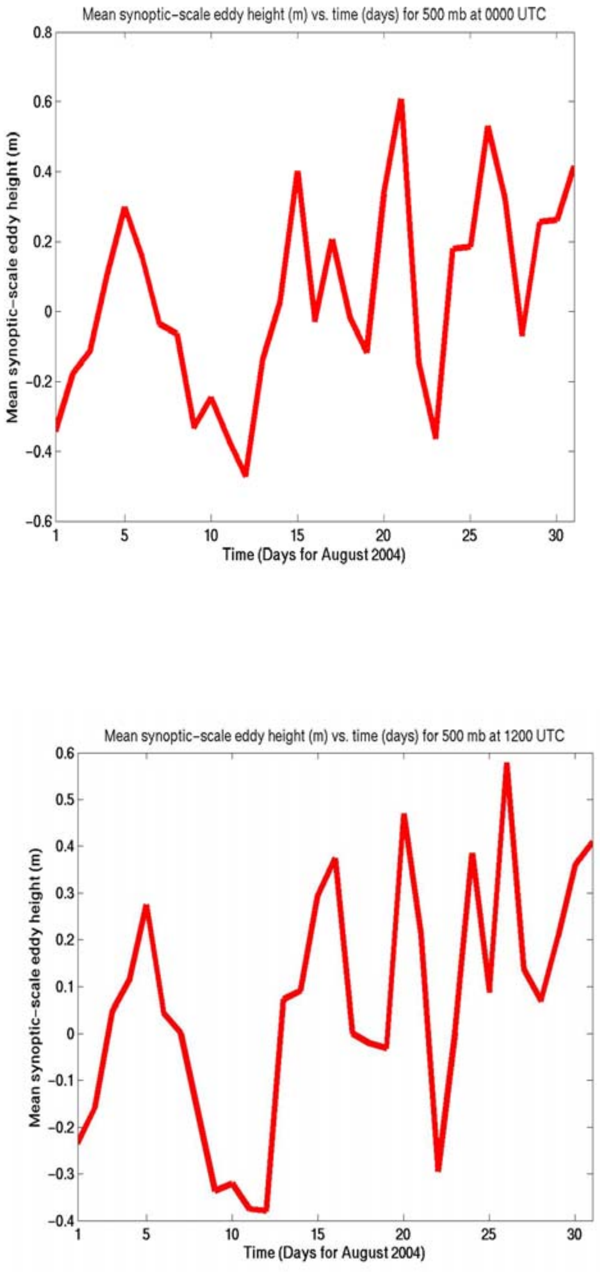

Fig. 4. Upper panel: A diagram of mean 500 mb geopotential synoptic-scale eddy height (m) for 0000 UTC along abscissa with respect to time (days) along ordinate for a stationary box (260^o E to 160^o E and 5^o N to 80^o N) in the mid-latitude Northern Hemisphere flow for the entire month of August 2004. Daily 6 hourly data is used here. *Lower panel:* Same as in the upper panel expect for 1200 UTC. The eddy amplitude at 1200 UTC is larger than at 0000 UTC because of different forcings at these times.

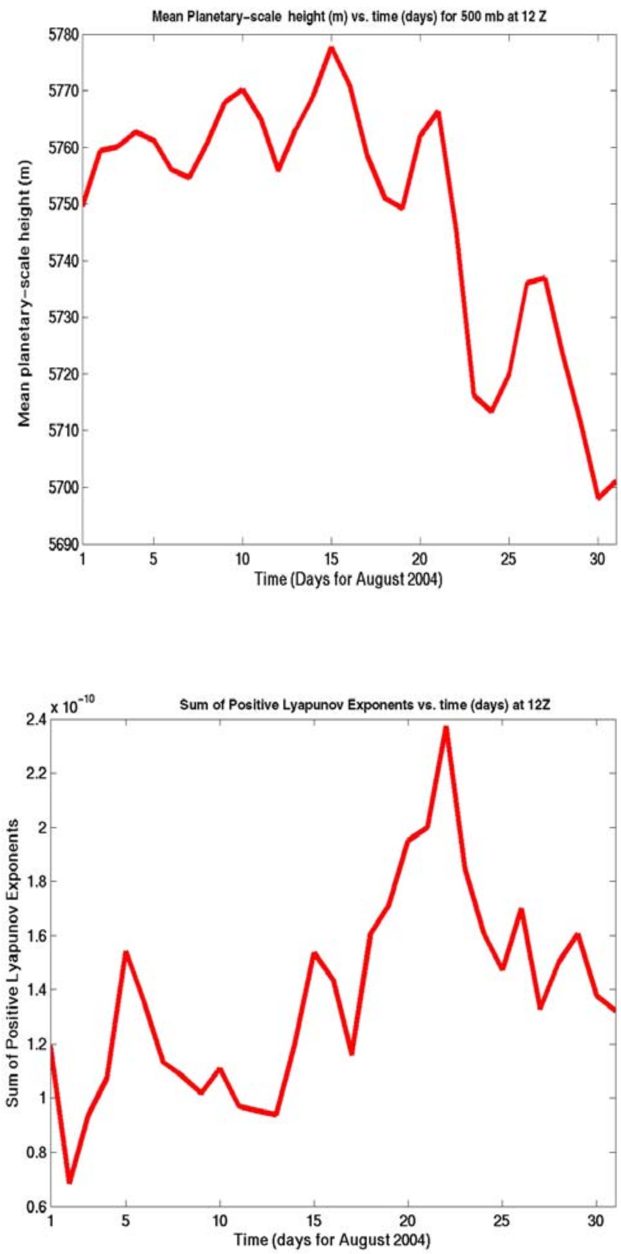

Fig. 5. Upper panel: A diagram of mean planetary-scale 500 mb geopotential height (m) along abscissa with respect to time (days) along ordinate for a stationary box (260^o E to 160^o E and 5^o N to 80^o N) in the mid-latitude Northern Hemisphere flow. Daily 6 hourly data is used here for 1200 UTC. *Lower Panel :* A calculation of area averaged enstrophy using Eq. (7) for the blocking event displayed in the upper panel which occurred during 05-28 August, 2004.The relative stability level changes at onset and decay stages.

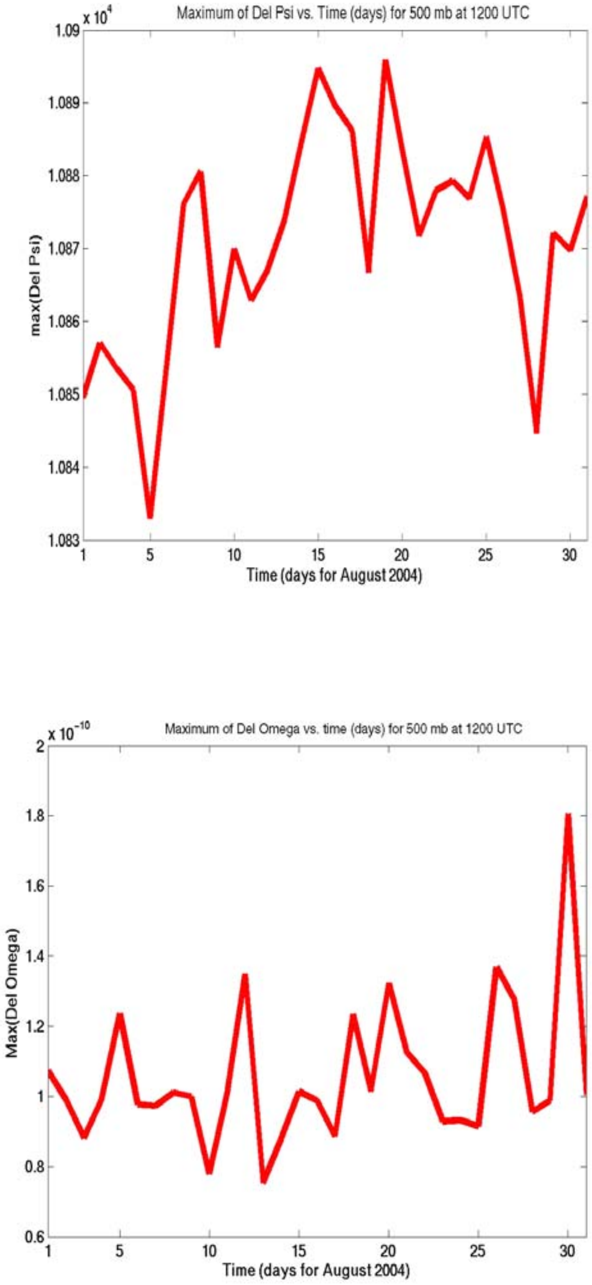

Fig. 6. Upper panel: A diagram of area averaged max ($\nabla\psi$) along abscissa with respect to time (days) along ordinate for a stationary box (260^o E to 160^o E and 5^o N to 80^o N) in the mid-latitude Northern Hemisphere flow. Daily 6 hourly data is used here for 1200 UTC. *Lower Panel:* A calculation of area averaged max (ω_a) for the entire life cycle of the blocking event displayed in the upper panel which occurred during 01–31 August, 2004.

event impacted the downstream regional weather over the continental US. The west cost of mainland continental US experienced mild summer for August of 2004. This is an instance where occurrence of midtropospheric level blocking affects the regional weather though the blocking is not occurring at exactly over that region, as already pointed out in Section 1.

3.2 Dynamic Analysis

Fig. 5 (upper panel) displays the area averaged planetary-scale height for the entire lifecycle of the block. We note that during the mature phase of the block life cycle, the height attain its maximum value. Note a positive height anomaly during the blocking period. The average heights within the box starts falling until just before the block decay (day number 21). This suggest changes in the behavior of the planetary-scale flow regime. The presence of multi peak structure in the area averaged 500 mb mean geopotential height is indicative of change in the height pattern due to variations in the external facings on diurnal scale. Similar fluctuations were noticed in several other case studies. For details of case studies in SH, see Athar et al. (2007a,b).

Fig. 5 (lower panel) displays the time variability of sum of positive Lyapunov exponents. Comparing Fig. 4 that gives the tendency of synoptic-scale eddies with the regional Lyapunov exponents, we note that between 20 and 25 August, the sum of the Lyapunov exponents increases considerably, indicating the rise in the instability in the planetary-scale flow which correlated well in time with the rise in amplitude of synoptic-scale eddies. The same observation holds for the blocking onset duration (02-05 August). The blocking state being an anticyclone is a high pressure system. We thus conclude that the synoptic-scale ridge formation leads to a rapid decay of the blocking high. We further note that the area averaged planetary-scale height also drops rapidly during the same duration thus confirming our conceptual picture.

Calculation of the Lyapunov exponents following Eq. (7) for our entire lifecycle of the blocking event under study demonstrates a relationship between these value and upper panel of Fig. 5. From Fig. 5 (lower panel), we note that the area averaged enstrophy reaches a minimum shortly after block onset and is at a relative minimum during the lifecycle of this blocking event. This is also consistent with the view that, in a quasi-barotropic flow, the planetary-scale flow should be strongly barotropic, and that the blocking state represents a minimum state of enstrophy [and entropy see e.g., Dymnikov and Filatov (1995)]. Since these correlate to the positive Lyapunov exponents and are relatively small here indicate that negative values of fluid trapping (again implying more predictability, or a more stable condition) grow in concert with the intensity of the blocking event.

We also note from lower panel of Fig. 5 that after the onset of the blocking state, the sum of positive Lyapunov exponents attain relatively lower positive values. Thus, the blocking (a mainly meridional circulation pattern) is more stable than the more frequent zonal flow.

To access the utility and robustness of the Dymnikov et al. (1992) conjecture, we have calculated numerically two other indicators of flow regime change and they are displayed in Fig. 6. Here we have made use of the observed vorticity instead of using Eq. (7) which defines the reduced relative vorticity only. The calculation for both the flow change indicators is carried out at 500 mb.

Following Skiba (2002), it can be concluded that if either the maximum absolute value of $\nabla\psi$ or maximum absolute value of $\nabla\omega_a$ increase the flow is becoming increasingly unstable. Conversely, decreasing gradients of both ψ and ω_a lead to increasingly more stable atmospheric regimes. Here ψ is the stream function of the flow and ω_a is the absolute vorticity. An examination of Fig. 6 provides additional support for the observation that the changes in the planetary-scale flow leads to instability of the basic zonal flow.

During blocking events, this implies that once the blocking event established itself, the planetary-scale flow is relatively more predictable. We note that the Lyapunov exponents give a relative change and are thus alone not sufficient to identify the blocking event unambiguously. The fluctuating behavior of the sum of positive Lyapunov exponents depicted in Fig. 5 (lower panel) is a commonly occurring phenomenon in nonlinear unstable dynamic systems (Lorenz 1963, Legras and Ghil 1985).

Another interesting observation is that a comparison of positive height anomaly and the sum of the positive Lyapunov exponents for the entire life cycle of the blocking event under discussion indicates a strong positive correlation between the two as a function of ln$p$. A comparison of lower panel with upper panel in Fig. 5 reveals this correlation at 500 mb.

This correlation holds for all mandatory levels between 300 mb and 925 mb for the entire duration of the chosen blocking event further justifying the usefulness of Lyapunov exponents as a simple diagnostic tool. Deep blocking anticyclones extending from upper to lower troposphere may thus be diagnosed for their stability characteristics in terms of regional Lyapunov exponents under the assumption of barotropic and quasi-geostrophic atmospheric flow.

3.3 Discussion

Changes in the nature of the planetary-scale flow can be correlated with block onset and decay supporting the general implications of the work of Tsou and Smith (1990), Haines and Holland (1998), Colucci and Baumhefner (1998), and that the planetary-scale provides an important contribution to blocking lifecycles by providing a favorable environment for the blocking event to occur, in spite of the large contributions by the synoptic-scale flow and interaction components of the forcing.

Additionally, supporting evidence for the change in planetary-scale flow regimes comes from examining the Lyapunov exponent (flow stability) calculations. Fluid trapping values and the area integrated enstrophy values (Fig. 5 and Fig. 6, lower panels) fall to a minimum during the lifetime of the block in the blocked region in agreement with what would be expected for each blocking event implying that the planetary-scale flow became unstable around the time of block onset and decay for the case study presented here. This observation was confirmed by studying all blocking events (a total of 123 events) for the 3 year period (2002–2004) both for NH as well as for SH (for details, see Athar et al. 2007a,b).

It is possible that the planetary-scale flow at these two times moved from one (geostrophically) stable state to another, and the corresponding behavior of the other metrics shown in Fig. 6 corroborate this interpretation. Thus, the methodologies shown here, which are relatively easy to generate, have at least some value as a diagnostic tool for atmospheric phenomena. They may even have value as a metric for predictability, however, more study is needed in order to adequately demonstrate such value.

Earlier studies have used statistics to make a similar point (Lejenas and Oakland 1983). However, decay can occur when there is no longer active synoptic-scale support for the events, when the synoptic-scale impacts negatively on the blocking events, or when the planetary-scale flow regime changes character.

4. SUMMARY AND CONCLUSIONS

Suitability of barotropic mid latitude NH flow is studied in terms of Lyapunov exponents as a diagnostic tool for atmospheric blocking. Dymnikov et al. (1992) conjecture is used which correlates the sum of positive Lyapunov exponents with the enstrophy. Two diagnostic tools (namely, the mean geopotential planetary and synoptic-scale eddy height and the Lyapunov exponents) providing valuable information about the change in the flow pattern during the blocking event are estimated.

Dynamic and Synoptic diagnosis of a relatively long lived and extreme blocking event occurring in boreal summer of 2004 in Gulf of Alaska is performed. This blocking event resulted in a high pressure system that persisted in Gulf of Alaska for the entire month of August resulting in a heat wave (4.6^o F higher than normal 1971–2000 mean temperatures in Alaska region).

The presence of a unusually long duration blocking pattern over Gulf of Alaska forced warm air pole ward resulting in warm air advection over the continental Alaska.

It is noted that the planetary-scale height variation in the atmospheric flow follow the changes in the flow during the blocking event which are characteristically different than the unblocked flow pattern upstream as well as downstream. The typical 500 mb planetary-scale geopotential height variation for the considered blocking event over its entire lifecycle ranged approximately between 80 m to 100 m.

The above observation is true irrespective of whether the blocking event occurs entirely over land, over sea or partially over land and partially over sea (Athar et al. 2007a,b). This may indicate more dominating role played by the different scales and their interactions of atmospheric flow (as noted in earlier studies too) once the blocking sets in instead of orographic forcings.

Lyapunov exponents can quantify the average predictability and stability properties of a dynamical system without the need to explicitly solve for the flow streamfunction under the working assumption of Dymnikov et a. (1992). Thus, Lyapunov exponents (i.e., the eigenvalues of the linearlized decomposition of the steady state flow) may thus be used as a diagnostic tool especially in blocking studies. The role of the planetary-scale flow in onset, maintenance as well as in decay of a selected NH blocking event is discussed in terms of Lyapunov exponent time variability.

At least for the selected case studied here, the regional Lypunov exponents seems to characterize the stability of the planetary-scale flow in barotropic circulation faitfully. The stability theory (Lyapunov exponents) is thus investigated in order to evaluate its use as a simple diagnostic tool. A simultaneous knowledge of the two diagnostic tools however seems to provide a more reliable scenario for the existence/occurrence, sustenance as well as decay of a blocking event. Regional Lyapunov exponents based on Dymnikov conjecture gives only the relative stability of the flow. Planetary-scale geopotential height variations alone however do not provide any underlying insight into the dynamics and stability of the atmospheric flow during the blocking period. A simultaneous estimate of both should suffice to establish the presence and the overall dynamic stability behavior of the flow. The above observation made in this study finds some justification in light of previous studies mentioned in Section 1 where it was concluded that both the planetary-scale as well as synoptic-scale wavelengths seems to play some role in essentially all stages of entire lifecycle of blocking. Though depending upon the specific case study, the relative strength of the role seems to vary.

The synoptic-scale wavelength dominance is noticed in the present case during the onset and decay stages of the blocking under the assumption of barotropic atmospheric flow in quasi-geostrophic balance. This observation is supported by first isolating the time variability of the synoptic-scale eddies during the entire lifecycle of the blocking event and then comparing it with the sum of planetary-scale and synoptic-scale wavelength contributions via BI calculation.

Combining with the results presented in Athar et al. (2007a,b), where Lyapunov exponents for SH blocking events during the 3 year period (2002–2004) were calculated, we may arrive at a tentative conclusion that Lyapunov exponents seems to mimic the (in)stability of the planetary-scale atmospheric flow during blocking event and may thus qualify as a climatologically reliable diagnostic tool for atmospheric blocking over both hemispheres.

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