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The Life Cycles of Intense Cyclonic and Anticyclonic Circulation Systems Observed Over Oceans

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1. **Technical report**

Full attention has now been directed to the blocking case studies mentioned in previous reports. Coding and initial computational tests have been completed for a North Atlantic blocking case that occurred in late October/early November 1985 and an upstream cyclone that developed rapidly 24 hours before block onset. This work is the subject of two papers accepted for presentation at the International Symposium on the Lifecycles of Extratropical Cyclones in Bergen, Norway, June 27 - July 1, 1994. This effort is currently highlighted by two features. The first is the extension of the Zwack-Okossi equation, originally formulated for the diagnosis of surface wave development, for application at any pressure level. The second is the separation of the basic large-scale analysis fields into synoptic-scale and planetary-scale components, using a two-dimensional Shapiro filter, and the corresponding partitioning of the Zwack-Okossi equation into synoptic-scale, planetary-scale, and synoptic/ planetary-scale interaction terms. Preliminary tests suggest substantial contribution from the synoptic-scale and interaction terms.

2. **Paper and presentations**

a. **Refereed paper**

Lamberty, G.L., and P.J. Smith, 1993: A Study of the Influence of Satellite Data on GLA Analyses Over the Atlantic Ocean During a Period of Blocking Anticyclone Development. Monthly Weather Review, 121, 1881-1891 (reprint enclosed).

b. **Presentations**

1) Lupo, A.R., and P.J. Smith: "Climatological Features of Blocking Anticyclones I: An Investigation of Observed Mid-Latitude Blocking Characteristics in the Northern Hemisphere". Sixth Conference on Climate Variations, 23-28 January, 1994, Nashville, TN (preprint enclosed).

2) These papers have been accepted for oral presentation at the International Symposium on the Lifecycles of Extratropical Cyclones in Bergen, Norway, June 27 - July 1, 1994 (abstracts enclosed).

Lupo, A.R., and P.J. Smith: "The Interaction Between a Mid-Latitude Blocking Anticyclone and the Precursor Cyclone Over the North Atlantic Ocean".

Smith, P.J., and A.R. Lupo: "A Diagnosis of the Lifecycle of a Rapidly Developing Marine Cyclone System".

CLIMATOLOGICAL FEATURES OF BLOCKING ANTICYCLONES I: AN INVESTIGATION OF OBSERVED MID-LATITUDE BLOCKING CHARACTERISTICS IN THE NORTHERN HEMISPHERE

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1. INTRODUCTION

In the past, several climatological investigations have been performed using large observational data (i.e., 10 years or more) in order to determine the predominant characteristics of blocking anticyclones, including favored development regions, duration, preferred seasonal occurrence, and frequency of occurrence (e.g., Rex, 1950; Triedl et al., 1981; Lejenas and Okland, 1983). Taken together, these and many other studies have shown that blocking anticyclones in the Northern Hemisphere (NH) occur most frequently from October to April over the eastern Atlantic and Pacific Oceans downstream from both the North American and Asian continental regions and the storm track regions to the east of these continents. More recently, studies have revealed the presence of a third region of block formation over western Russia near 40°E (Triedl et al., 1981; Dole and Gordon, 1983) which is associated with another storm track region over the Mediterranean and western Asia.

In the last decade, considerable attention has been paid to the relationship between blocking anticyclones and other mid-latitude features such as mid-latitude, precursor cyclones (e.g., Shutts, 1983; Colucci, 1985, 1987; Tsou and Smith, 1990). While migrating cyclones and blocking anticyclones are of different spatial and temporal scales and, in general, would seem to possess different characteristics, it has been demonstrated through model studies (Frederiksen, 1982, 1983; Shutts, 1983) and observational case studies (Colucci, 1985; Shutts, 1986) that they are dynamically linked. Tsou and Smith (1990) demonstrated a connection between intense cyclogenesis and block formation by presenting a conceptual model linking the two phenomena.

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The principle objective of this three-year study is to establish a statistical link between the occurrence and intensity of the upstream cyclones and the development and characteristics of blocking anticyclones. While this study is repetitive of previous climatological studies, it is also unique in three ways. First, a comprehensive analysis is performed for a broader range of blocking characteristics, such as preferred formation regions and seasons, duration, longitudinal expanse (size), and intensity as a function of region and season. Second, an investigation of upstream cyclones that precede block formation is conducted. Finally, following the suggestion of Tsou and Smith (1990), a study of the occurrence of an intervening jet maximum between the upstream cyclone and block is included.

2. DATA AND METHODOLOGY

Three years of ECMWF gridded data analyses covering the period from July 1985 to June 1988, from the WRGP/TOGA Archive II provided by the National Center for Atmospheric Research (NCAR), were used. The ECMWF analyses are global 2.5° by 2.5° lat/lon uninitialized gridded fields composed of both surface and free atmosphere variables twice daily. The free atmosphere variables are provided for mandatory levels from 1000 to 10 mb. A thorough description of these analyses is given in Trenberth (1992). The variables used in this study were 500 mb geopotential height, 300 mb u/v wind components and sea-level pressure.

The time period chosen for this study was relatively short in order to make it practical to visually confirm blocks identified using the objective classification technique described below, to manually calculate the blocking and upstream cyclone characteristics, and to observe the relevant jet stream characteristics for each case. The formulation of a blocking definition is itself an intriguing problem since no commonly agreed upon definition of blocking exists and almost all definitions contain some subjectivity. The most well-known definition was provided by Rex (1950). In this investigation, a combination of the Rex definition and the objective criterion of Lejenas and Okland (1983) were the primary means used to define blocking events. The criterion of Lejenas and Okland (LO), which is based on the zonal index of Namais and Clapp (1951), diagnoses blocking in regions where the difference between the 500 mb geo-potential heights at 40°N and 60°N is small or negative. This definition established a consistent set of guidelines for uniformly determining the existence of an individual blocking anticyclone (antecedent surface cyclone) and its onset and termination from which lifetime (central pressure) and location (deepening rate and jet stream) statistics were derived. Two other characteristics, block intensity and size, were determined once daily at 0000 UTC and then averaged over the lifetime of the event. The size of each blocking event was determined as the distance across the anticyclone between its inflection points, while the intensity was a normalized form of the maximum daily 500 mb height value.

In addition to examining 500 mb height fields, sea-level pressure maps were examined to determine if a surface cyclone existed in association with a 500 mb short wave embedded within a larger-scale trough upstream from a quasi-stationary 500 mb ridge, a configuration suggested by Dole (1983) and Tsou and Smith (1990). Statistics on lead time of the precursor cyclones in advance of each block onset, as well as relative position and rate of cyclone development in Bergerons were kept. Also, 300 mb winds were examined to determine if a jet maximum could be located on the downstream (upstream) side of the upper air trough (ridge) and if the jet formed or existed there between the commencement of surface cyclogenesis and block onset.

Finally, the results were stratified by season and region. A complete blocking season is defined as starting on July 1 and ending June 30, consistent with Rex (1950) and Quiroz (1987). Winter, spring, summer, and fall were defined as three month periods beginning with January, April, July, and October, respectively. The NH was divided into three domains in which all events were placed based on where the event initiated. The Atlantic (AOR), Pacific (POR), and Continental (CTR) regions extended from 80°W to 40°E longitude, 140°E to 100°W, and 40°E to 140° E (Eurasian continent) and 100°W to 80°W (North American continent), respectively.

3. SEASONAL AND REGIONAL CHARACTERISTICS OF BLOCKING ANTICYCLONE EVENTS

A total of 63 NH blocking anticyclone cases, an average of 21 annually, were found in the three-year period exhibiting, a broad formation region over the Pacific Ocean (160°E to 130°W), a well-defined maximum over the eastern Atlantic Ocean (10°W), and a secondary maximum at 40°E over the Ukraine and western Russia. These results correspond with those of Triedl et al. (1981), and Lejenas and Okland (1983). In the sample, the total number of days and days on which there was at least one blocking event were 540.5 and 460.5 (42.4% of all days), respectively, i.e., there were 80 (7.3% of all) days in which there were simultaneous blocking events. The average duration of a NH blocking event was 8.6 days. Most blocking events lasted 5 to 7 days (34 events), with a rapid decrease in the number of events persisting longer than 10 days (17 events) of which most (13 events) were AOR and CTR blocking events. Stratifying the results by region shows that blocking events were more numerous over AOR (29 events) than over POR (19 events) or CTR (15 events). The monthly summary (Fig. 1) demonstrates that over the AOR (POR), blocking activity was higher from November to June (November to March, July, and August) than at any other time of the year, while the CTR displayed little seasonal variation in blocking occurrences. The largest and smallest total number of days, 201.5 and 7.45 (58.5% and 21.9% of each season's days), occurred in the winter and summer, respectively. Examining the total number of days by region revealed that blocking occurred on 23.7%, 13.7% and 11.9% of all days over the AOR, POR, and CTR, respectively, and these were distributed similarly to the regional block occurrences. Also, AOR and CTR blocking events were more persistent than POR blocking events (approximately 9 days vs. 8 days). Winter (summer) blocking events over both oceanic regions were the most (least) persistent overall. The average durations in the CTR were similar for all seasons except for all since, which was dominated by one unusually persistent event.

The average intensity (BI) and standard deviation of BI for all 63 bases was 3.55 and 1.0, respectively. The distribution of the vents was nearly normal with respect to the mean (Fig. 2), a conclusion that was confirmed at the 99% confidence level by fitting a normal distribution to the BI data and performing a chi-square goodness-of-fit test. All blocking events falling within one standard deviation of the mean were classified as moderate (46 events), those falling below 2.55 as weak (8 events), and those above 4.55 as strong (9 events). An examination of regional (seasonal) intensities demonstrates that AOR (fall and winter) blocks were on the average stronger than their POR and CTR (spring and summer) counterparts. An examination of the half-wavelength (size) of blocking events demonstrates that ARO and CTR blocking events were larger than their POR counterparts in all but the summer season with AOR, POR, and CTR blocking events being comparatively largest in the winter, summer, and transition seasons respectively. CTR and AOR blocking events were of similar size and their seasonal variation in size followed the seasonal variation in the latitudinal positioning of the storm tracks. In the POR, where the seasonal variation in the storm track location is much less evident, there was no regular seasonal variation in the size and latitude of blocking anticyclones. Finally, a comparison of block size with the block intensity results indicates that more intense blocks may also be larger. The correlation coefficient between these two variables was 0.47, a result determined to be significant at 99% using a Z-score test assuming the null hypothesis, or no relationship exists.

4. A COMPARISON OF BLOCKING ANTICYCLONES TO THEIR PRECURSOR CYCLONES

One of the goals of this investigation was to establish a statistical link between the frequency and intensity of precursor, upstream cyclones and block formation using the conceptual model proposed by Tsou and Smith (1990). The applicability of this model was examined for each of the 63 cases included in this study. This examination revealed that *all* 63 blocking events could be identified with an upstream, precursor cyclone using the criteria discussed in section 2. The mean deepening rate for all 63 cyclones (Fig. 3), the 29 AOR cyclones, 19 POR cyclones, and 15 CTR cyclones were 0.99, 10.5, 1.11, and 0.71 Bergerons, respectively. In the winter, 17 of 21 preceding cyclones developed explosively, while in the transition seasons approximately half the total number of cyclones were explosive developers. However, in the summer none of the preceding cyclones were explosive. A comparison of the precursor cyclogenesis intensity wit the block intensity discussed earlier suggests that a relationship exists between the two. The correlation coefficient between these two parameters was 0.31, significant at the 95% confidence level, implying that stronger blocking anticyclones developed when preceded by stronger cyclones. A regional partitioning of these results revealed that 72%, 42%, and 33% of AOR, POR, and CTR blocking events were preceded by explosive cyclones, respectively, and each region exhibited a seasonal trend comparable to the NH sample. Finally, precursor surface cyclones could always be found 10° to 50° upstream from the center of the ridge at block onset, with cyclogenesis commending typically 24 - 72 h before block onset. Regarding the correspondence to a 300 mb jet maximum, such a maximum appeared prior to (after) the onset (commencement) of blocking (surface cyclogenesis) between the blocking ridge and the upstream 500 mb trough in each of the 63 cases.

5. SUMMARY AND CONCLUSIONS

A three-year climatology of blocking anticyclones from July 1985 to June 1988 was derived from ECMWF analysis fields. A combination of several published criteria together with a subjective examination of the 500 mb charts each day was used to define and study the characteristics of Northern Hemisphere blocking anticyclones. Also, an investigation into the presence of precursor cyclones, their characteristics, and their statistical relationship to block formation was conducted. The results were stratified by region and season, with the former being partitioned into three regions, AOR, POR and CTR, based on the results of earlier studies (e.g., Triedl et al., 1981; Dole and Gordon, 1983) suggesting that three preferred block formation regions exist in the NH.

An examination of the results of this three-year investigation demonstrates that the total frequencies, total days, duration, and preferred formation regions of blocking anticyclone events were similar to the results of the 30-year investigations of Triedl et al. (1981), and Lejenas and Okland (1983). A quantitative examination of block intensity and size revealed that winter blocking events were more intense, more persistent, and larger than their summer counterparts. Also, a correlation (significant at the 95% confidence level) between blocking anti-cyclone intensity and size exists.

An examination of precursor cyclones revealed that the conceptual model of Tsou and Smith (1990) reasonably described the formation of *every* event. In the winter (summer), the majority of (none of) the cyclones that preceded blocking anticyclones developed explosively. It was also shown that a

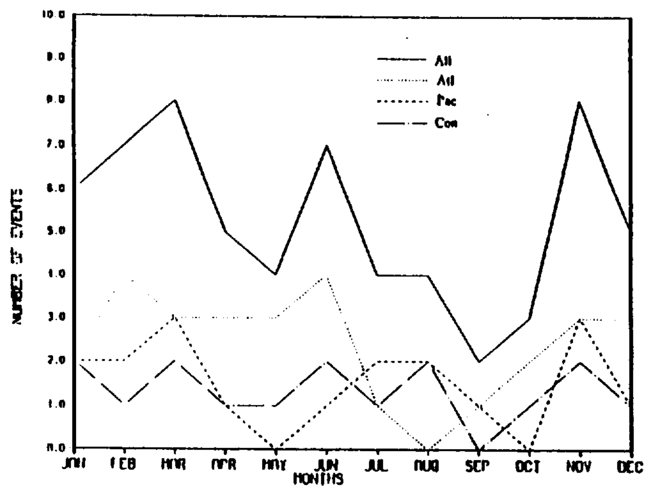

Figure 1. A monthly summary of blocking anticyclone frequency of occurrence for the three-year sample, Atlantic (AOR), Pacific (POR), and Continental (CTR) events.

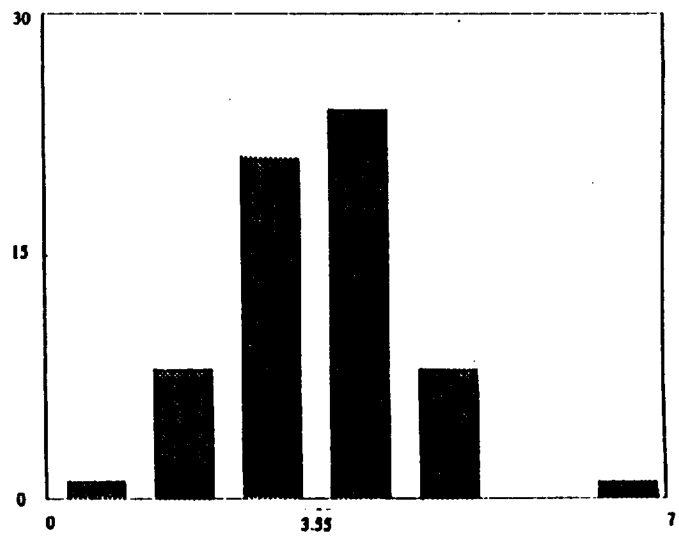

Figure 2. Distribution of block intensities with respect to the mean where the y-axis is the number of events and the x-axis is intensity.

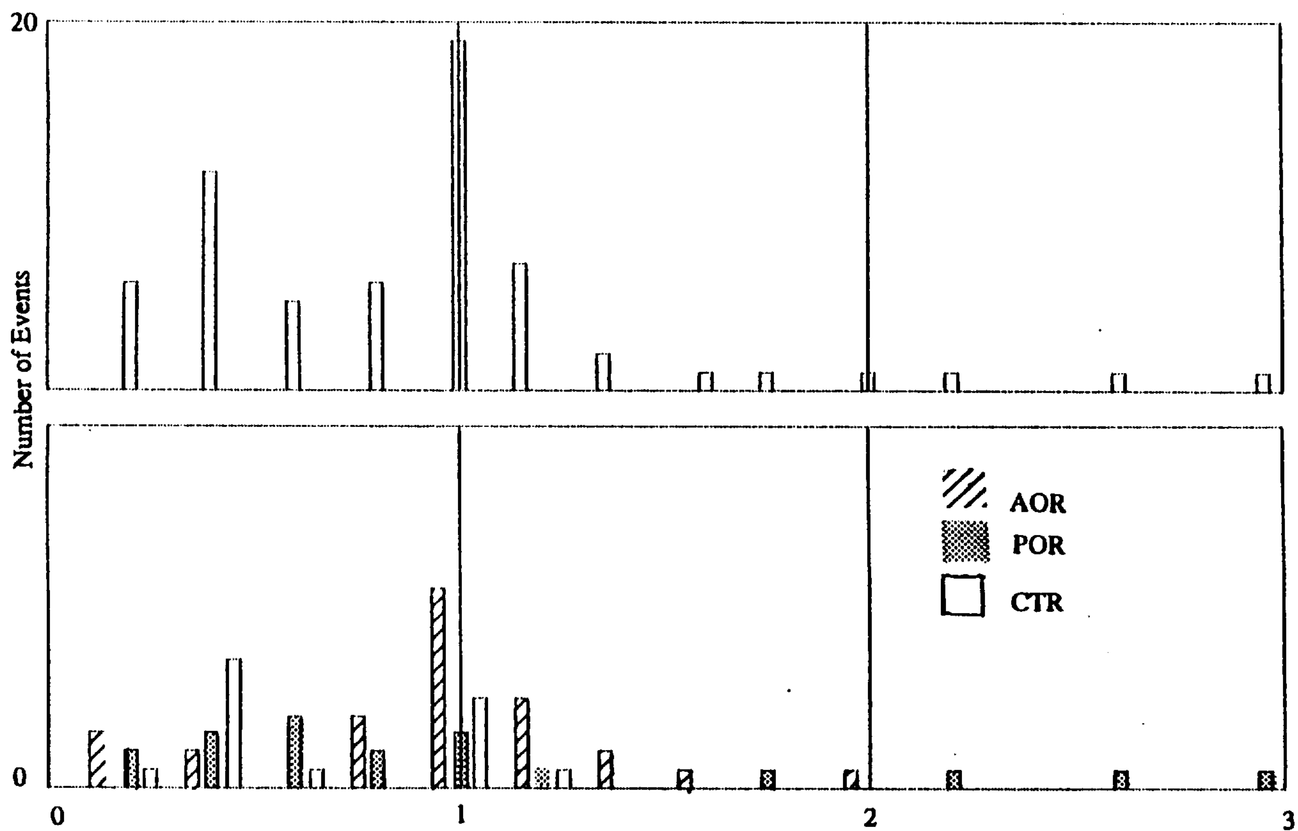

Figure 3. The 12-h deepening rates of cyclones preceding block formation for the entire three-year sample (top) and the Atlantic (AOR), Pacific (POR), and Continental (CTR) region events (bottom). The y-axis is the number of events and the x-axis is 12-h deepening rate (Bergerons).

positive correlation also exists between the intensity of the preceding cyclogenesis and the resulting blocking anticyclone. Interesting differences emerged when comparing the intensity of the preceding cyclones between oceanic and continental domains suggesting there may be fundamental differences in the synoptic-scale forcing for land and ocean blocking events.

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A Diagnosis of the Life Cycle of a Rapidly Developing Marine Cyclone System

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Desired session: Session III: Cyclone Life Cycles
Format: Oral or Poster

This paper describes a diagnosis of the life cycle of an extratropical cyclone system that formed and decayed over the North Atlantic Ocean during the fall of 1985. Using 2° lat x 2.5° lon NASA/Goddard Laboratory for Atmospheres analyses, the Zwack - Okossi methodology is used to diagnose the forcing mechanics responsible for the evolution of both surface and upper-air features associated with the cyclone system. The surface cyclone was distinguished by rapid cyclogenesis that occurred in a preexisting trough and then rapid decay that followed an 18 hour period of modest development. Cyclogenesis, which was represented by a 6 mb central pressure decrease (1.35 Bergerons) during the first 6 hour period, was followed by a comparable pressure decrease during the development phase and then an abrupt 6 mb increase during the first 6 hours after the time of minimum central pressure (989 mb). Cyclogenesis occurred as cyclonic vorticity advection and warm air advection maxima, which were strongest in the upper troposphere/lower stratosphere, encountered a pre-existing surface geostrophic vorticity maximum. During the ensuing map times, these mechanisms continued to dominate as they propagated downstream in advance of the surface and upper-air cyclonic features. Finally, the positive forcing mechanisms moved sufficiently downstream to either reduce or change the sign of the forcing within the cyclonic circulation region. At this point the positive forcing mechanisms were unable to overcome the influence of adiabatic cooling and the cyclone decayed. In addition to these key development features, the paper will explore the importance of latent heat release, boundary-layer sensible heating, and the traditionally less significant forcing processes. Also, the importance of the vertical distribution of the various forcing processes will be examined.

The Interaction Between a Mid-Latitude Blocking Anticyclone and the Precursor Cyclone Over the North Atlantic Ocean

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desired session: Session II: planetary-scale/synoptic-scale interactions

format: Oral or poster

This paper examines the life cycle of a mid-latitude blocking anticyclone and its relationship to a precursor surface cyclone, with particular attention given to interactions between the synoptic and planetary scales during the block's development phase. The data for this study were NASA/Goddard Laboratory for Atmospheres' 2.0^{o} x 2.5^{o} lat/lon gridded global analyses available at 6-h intervals. The relative importance of all atmospheric forcing mechanisms responsible for development, maintenance, and decay of both events at the surface and 500 mb are diagnosed using the Zwack-Okossi equation. On 29 October 1985, a surface cyclone developed rapidly within a preexisting surface trough over the western North Atlantic in response to favorable upper-air support. At 500 mb, an associated short wave embedded within a large-scale trough also developed rapidly with development being particularly notable in the ridge portion of the short wave. At 300 mb, a jet maximum developed in the downstream (upstream) portion of the upper air trough (ridge) following rapid surface cyclogenesis. Finally, on 30 October, a blocking anticyclone formed over the central North Atlantic south of Greenland and Iceland and persisted until 5 November. Surface cyclogenesis was forced primarily by upper-tropospheric cyclonic vorticity advection and warm air advection maxima and lower-tropospheric latent heat release superimposed over a surface geostrophic vorticity maximum. The short-wave ridge, and ultimately the blocking anticyclone, developed primarily as a result of an area of upper-tropospheric anticyclonic vorticity advection, enhanced by the intensifying jet maximum. Development slowed and/or ceased when areas of favorable tropospheric forcing moved out-of-phase with the surface and/or upper air features. Synoptic/planetary-scale interactions will be explored using a scale-partitioned form of the Zwack-Okossi equation. Included will be an assessment of the importance of the synoptic and planetary-scale forcing components, their interactions, and the vertical distribution of the forcing processes.