2.3 A FRESH LOOK AT PERSISTENT RIDGING IN THE NORTH PACIFIC

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1. Background

When persistent ridging occurs in the vicinity of the International Dateline during the cooler months of the year, it represents a major shift in the storm track across the North Pacific. These ridging events typically have a duration of 7 to 14 days, after which many turn into anticyclones. It is during these events as cold dry air moves out of the arctic toward the southeast, that the state of Alaska often experiences it s coldest temperatures of the season.

The term persistent ridging (PR) is used in this paper instead of the commonly used blocking because the latter term has a plethora of definitions. The emphasis is on PR s that reside in the greater Bering Sea region, which can roughly be delineated as lying between 160°E - 160°W and between 45°N - 65°N. This paper focuses on the October through April time frame, although ridging over the Bering Sea in the warmer months of the year is a common occurrence as well. It is hoped that an analysis of 10 mid-Pacific persistent ridge (MPR) events will enable operational meteorologists to better understand and forecast these events as they occur across the region.

2. Data & Methodology

Data for this study was taken from the NCAR/NCEP reanalysis dataset, particularly use was made of the daily mean data sets. For planetary wave analysis as discussed below, 500 mb heights were used since it is probably the most commonly used mid-tropospheric level regularly analyzed by operational meteorologists. A particular flow pattern was considered a persistent ridge if the 500 mb height gradient was 200 m for 6 days or more, along a latitude circle located between 40°N - 60°N. It is important to note that planetary wave amplitude and phase are a function of height, latitude and time of year.

3. Synoptic Description

Visual inspection of the geopotential heights off of the reanalysis data set indicates that MPR s develop in conjunction with a broad spectrum of synoptic weather patterns. Prior to onset of a MPR the flow across the North Pacific can be nearly zonal, contain of a number of short wave ridges or a high amplitude ridge in the Gulf of Alaska. Of the 10 cases investigated in this study, eight MPR s developed *in situ*. In the two remaining cases, a low amplitude ridge formed some 40-60° of longitude upstream (over eastern Siberia), moved to the east over a 3 day period, but did not amplify until they became stationary near 180°. There were several cases where a developing MPR merged with a ridge in the Gulf of Alaska to form an extremely broad ridge over most of the North Pacific. However, the primary ridge axis remained in the Bering Sea sector (150°E - 160°W)

Equally important to ridge development is the formation of a deep upstream low (or trough), as noted by a number of authors (Dole 1989, Alberta & Colucci 1991). At the 500 mb level, the height of these lows during the amplifying stage of MPR evolution ranged from 5050 m down to about 4900 m, which is common for developing lows over the western Pacific. At the onset of an MPR, the upstream low is usually 30-40° of longitude upstream, usually over northern Japan or the Sea of Okhotsk.

At the surface, some of these lows can be traced back 3 or 4 days prior to the onset of the MPR, as they first begin to be form in the vicinity of Lake Baikal. However, in other cases the upstream low is not recognizable from the ambient flow until it s over the east coast of Siberia. In short, lows that form upstream of MPR s are important since they act as sources of thermal and vorticity advection (Hartmann & Ghan 1980, Illari 1984). However, these lows do not appear to have any distinguishable characteristics from the majority of systems that commonly develop in the region. Therefore, additional factors must be involved in the formation of MPR s.

A daily composite of each of the 10 events starting six days before (day -6) the MPR first developed, and advancing each day until its start (day 0), indicates that at day -6 there are some significant height anomalies in the middle and lower stratosphere (10-70 mb levels). The overall impression is that the polar vortex shifts or is elongated in such a fashion that there are significant negative height anomalies over central and eastern Siberia with complementary positive anomalies over Scandinavia.

As MPR s decay, six cases formed large anticyclones over the Bering Sea or Alaska, one case formed a weak anticyclone over the Chukchi Sea, while the amplitude of two MPR s simply decreased over several days until the flow across the North Pacific became quasi-zonal. In one remaining case, the amplitude of the MPR slowly decreased over a 4 day period as the ridge slowly moved into western Canada.

In summary, mid-Pacific ridges develop, mature, and dissipate in a variety of synoptic conditions. This of course makes forecasting these features difficult since *a prior* pattern recognition is of limited value. As will be illustrated in the following sections of this paper, MPR s only develop when a number of atmospheric parameters work synergistically, primarily as synoptic-scale disturbances amplify pre-existing planetary waves (Hansen and Chen 1982, Colucci 1985, Wiedenmann

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et al 2002).

4. Planetary Wave Analysis

Each of the 10 events was analyzed with respect to planetary waves in order to assess what role these waves play in the evolution of MPRs. Daily 500 mb heights taken along the 55° N latitude circle at 10° longitude intervals, are used as input to a Fourier transform. Since there was no additional data filtering or smoothing, the first 18 waves are preserved. This analysis however focuses on the first four wavaes.

Table 1 shows a composite mean amplitude and standard deviation for each of the first four waves. Notice that wave 2 dominates while the remaining three waves are of roughly equal amplitude (Colucci *et al* 1981). The climatological amplitude of waves 1 & 2 during the winter months is on the order of 100 m according to the study of Reiter and Westhoff (1981). Wave 1 ridge however is normally found near the Greenwich meridian, with a trough over the mid-Pacific. The ridges of wave 2 are in a climatological sense located near 75° E (western Asia) and 105° W (North America). Inspection of each event shows that only in the Feb 23-March 8, 1999 case, was the amplitude of wave 1 significantly larger than any other wave. In this particular event, wave 1 ridge regressed from 80° W to 80° E over and 11 day period, during which time its amplitude varied from 100-200 m.

Table 1: Ten event composite amplitudes

	mean (m)	std (m)	std/mean
wave 1	76	28	0.37
wave 2	120	27	0.23
wave 3	77	28	0.36
wave 4	79	77	0.23

The other nine events are dominated by wave 2 ridge located in the mid-Pacific (Austin 1980). Waves 3 & 4 are important as well, however the amount of time that a either one of these waves ridge is in phase with the observed ridge, is limited in time when compared to wave 2. On occasions waves 5 & 6 are also significant, but they usually only make a contribution for several days at a time.

It should be noted that the development of a MPR corresponded to a pre-existing planetary wave at the same location for 9 out of the 10 cases studied. These planetary waves usually increase in amplitude as the ridge builds. Equally important is the development of the upstream planetary trough. At the onset of a MPR, the upstream trough is often more developed than the ridge, in other words the trough is closest to its maximum depth (as a result of the constructive interference of two or three planetary wave troughs), in relation to the amplitude of the ridge. The initial planetary wave ridge which the MPR is coupled to, may change wavenumbers throughout the course of the event, generally ±1 wave.

With regard to the coupling between planetary waves and the development of a MPR, the following scenario is suggested. A planetary wave ridge of modest to large amplitude should pre-exists near the location where the MPR forms. Typically this will be wave 2 (50-80° west of its climatological position) but at times waves 3 & 4, or some combination of these three waves (figure 1). A well developed planetary trough should also reside 30°-60° of longitude upstream of the ridge. A synoptic-scale low forms over east Asia and subsequently moves into a planetary trough as it deepens. At the same time the amplitude of wave 1 trough which is typically located over the mid-Pacific, must be decreasing. Both the retrograde nature and the low amplitude wave 1 during the lifetime of most MPRs, suggests that a traveling component of wave 1 is interfering with the stationary component, an important aspect of the linkage between planetary waves and persistent ridging noted by Quiroz (1987).

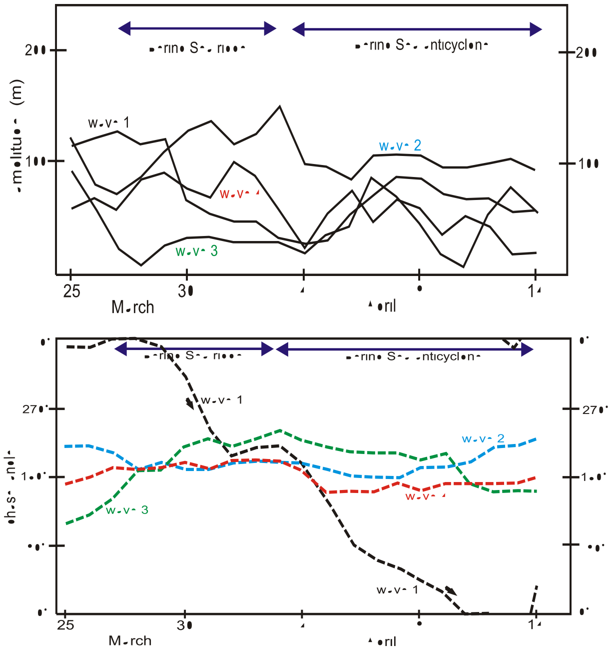

Fig 1. March-April 2002

5. OLR Anomalies

In order to investigate a correlation between Outgoing Longwave Radiation (OLR) anomalies and persistent ridging in the mid-Pacific, seven day averaged OLR anomalies were constructed for each of the ten events. A composite of the ten events was then constructed as well. The fist selected time period spans the seven day period prior (days -6 to 0 to the development of a MPR, while the second period spans the first seven days of the event (days 1 to 8). The composite for days -6 to 0 shows significant negative OLR anomalies straddling the equator between 70°E and 110°E with a smaller area of positive anomalies lying between 140°E and 170°E. The composite for days 1 to 8 indicates that the area of negative anomalies has shifted to the east and now lies between 100°E and 160°E.

These patterns are consistent with the

correlation that Weickmann et al (1985) found when they used 28-72 day filtered data, between OLR anomalies in the eastern Indian Ocean and extreme western Pacific Ocean (EI/WP) and 250 mb streamfunction anomalies over the Northern Hemisphere. Enhanced convection (negative OLR anomaly) over the EI/WP region causes the eastern extension of the East Asian Jet to retract from the western Pacific (Lau and Boyle 1987), as low pressure forms over East Asia and higher than normal pressure over the central Pacific. These pattern anomalies provide an environment in which MPR s can develop. Inspection of OLR anomalies for each event indicate that five out or the 10 cases had pattern that was a duplicate of the composite. Four cases were in partial agreement, in other words, they contained an area over the EI/WP that indicated significant negative anomalies but non-existent or weak positive anomalies toward the dateline. One case had a pattern that was for unknown reasons, completely reversed as compared to the composite.

6. Wind Anomalies

The association between wind anomalies, particular the East Asian Jet Stream and blocking over the Pacific ocean has been noted by Rex (1950a) and Dole (1989) to name a few. Inspection of a 10 event composite of three day (days -1, 0, +1) averaged 300 mb zonal winds centered along 140° E, indicates that south of 40° N there are substantial negative anomalies with positive anomalies lying to the north of 40° N. There is considerable case-to-case variability depending on where the upstream low is positioned. Using a 10 case composite, wind anomalies located off the east coast of Japan start to develop around days -7 to -5, and slowly increase in magnitude reaching 15-20 m/s by day -2. In the tropics, there are noticeable wind anomalies as well. Stretching from about 120°E to the dateline, speeds of the easterly winds are reduced, in some areas, easterlies become light westerlies.

As a further indicator of wind anomalies over east Asia and the western Pacific, streamfunction anomalies were constructed (not shown) following the technique described by Weickmann et al (1985) for high pass data. Both the East Asian (EAS) and Pacific (PAC) streamfunction indices clearly show a increase in negative values leading up to day 0. Negative values of both of these indices is indicative of higher than normal heights over Southeast Asia, lower than normal heights in the southwest North Pacific and higher than normal heights over the greater Sea of Okhotsk region.

Dole (1986) found that prior to the development of high amplitude persistent Pacific low/ridge couplets, that the EAJS had shifted north of its mean climatological position . He also noted the development of a sub-tropical jet in the vicinity of the dateline extending toward the Hawaiian Islands. The wind analysis of the 10 MPR cases supports the findings of Dole and further suggests the north shift in the jet is the result of enhanced convection over the EI/WP which then produces an anomalous circulation center in the southwest Pacific which also facilitates the formation of a sub-tropical jet stream centered near the dateline.

7. Conclusion

This study has investigated 10 cases of persistent mid-Pacific ridging and found that multiple atmospheric parameters must be in alinement in order for these events to develop. MPR s form within a wide variety of synoptic pattens, frequently there is some type of pre-existing higher pressure located over the central North Pacific. There is also evidence that significant height anomalies form in the middle stratosphere over eastern Siberia in conjunction with a elongation of the polar vortex toward Siberia and a reduction in heights just to the north of Scandinavia. It was also found that seven of the ten cases evolved into large anticyclones over the greater Bering Sea region.

There is a high correlation between MPR s and mid-latitude planetary waves. In particular, most but not all MPR s develop near a pre-existing planetary wave, with waves 2-4 between the dominate components. Composite analysis of the 10 events that wave 2 has the highest amplitude of all the waves. Of equal importance to MPR formation is the reduction in the amplitude of wave 1, which climatologically has a persistent trough located across the North Pacific.

In addition, significant links between MPR s and OLR anomalies was shown via the use of seven day composite analysis. Wind anomalies associated with the East Asian Jet Stream and in the tropics develop prior to the onset of MPR s and are linked in part to enhanced convection and outflow over the eastern Indian and extreme western Pacific Oceans.

In summary, a MPR will develop if a deep low/trough over east Asia is able to constructively interfere and hence amplify pre-existing planetary waves of wavenumber 2-4. In conjunction with the movement of a deep low/trough out of eastern Siberia, enhanced tropical convection between 80°E -120°E shifts the western half of the EAJS further to the north, giving it an exagerated southwest-northeast trajectory. The limited number of MPR s that form each season is due to the fact that all these factors must occur almost simultaneously.

Close monitoring of the afore mentioned atmospheric parameters should give operational meteorologists the confidence to forecast these events despite considerable run-to-run variability in the extended range numerical simulations. Guidance from numerical models should be checked in order to see if model MPR forecasts are consistent with the conceptual model proposed in this study.

Future work will consist of a study of summer-time MPR evolution as well as comparing and contrasting persistent ridging that occurs in the Gulf of Alaska and western Canada with mid-Pacific events.

8. References

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