PERSISTENT WAVE STRUCTURES AND WESTERN DROUGHTS

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ABSTRACT

We propose that anomalous sea surface temperatures and polar ice extent caused and maintained the highly persistent large-scale tropospheric wave structure over North America during the winter of 2014. This wave structure led to a persistent regime of dry weather in the western US and cold, wet weather in the Midwest and eastern US. The sea surface temperature anomalies acted as waveguides. The polar ice extent anomaly acted to maintain a meridional feedback of polar wave energy, oriented along a narrow longitudinal range, which stabilized and reinforced the existing stationary wave over North America.

The research testing this conjecture is ongoing, based on analyses of archived sea surface temperature data, polar ice extent data, and comparisons between similarly persistent winter weather patterns during other years. It is our hope that this effort will contribute to a broader understanding of dominant large-scale wave modes in the troposphere—modes that are determined in any particular case by a finite roster of thermal and geographic forcings.
(KEYWORDS: persistence, drought, Rossby wave, polar ice extent, sea surface temperature)

INTRODUCTION

Identification of and theoretical research into the large-scale wave structure of the atmosphere dates back to the late 1930's and the 1940's with the pioneering work of Carl-Gustav Rossby (Rossby, 1939, 1945). Rex (1951) began inquiries into persistence in the wave structure with observational studies establishing the 'Rex block' blocking pattern in the jet stream. In his 1953 article, Smagorinsky attempted to reconcile two competing causal mechanisms for wave structure: Sutcliffe's (1951) theory of continentality, which proposed that wave structure was caused by thermal contrasts between oceans and landmasses, and Charney and Eliassen's (1949) proposal that wave structure was primarily due to variations in landmass orography.

However, as a research topic, little theoretical work has been done on the causal basis of large-scale waves in recent years. A successful predictive theory of wave structure has yet to be devised. Although the research mentioned above has offered some theoretical foundation for interpreting the quasi-permanent long wave structure in mid-latitudes, the fact remains that forecasts stemming from our most sophisticated operational dynamical prediction models fail to forecast the onset of these quasi-permanent patterns and furthermore can only predict their demise a few days ahead of time. In short, there appears to be a sudden adjustment in wave pattern over the entire hemisphere in response to some imbalance, and once the new pattern is established, it can persist for weeks (Rex, 195)). Research to date has failed to identify the imbalance mechanism that gives rise to the hemispheric adjustment. These issues are central to seasonal forecasting (forecasts on the order of months and seasons). At the ECMWF (European Centre for Medium-range Weathers Forecasts), there has been an impetus to improve the interaction between ice and the atmosphere by coupling the current model with a high-resolution ocean-wave-sea ice model (ECMWF, 2012). There is hope that this coupling will extend the predictability limit of the model that is currently about 2 weeks. In essence, meteorologist and oceanographers worldwide are striving to produce products that offer valued information seasonally.

Our research proposes to investigate the highly persistent atmospheric wave structure observed over North America during January and February, 2014. At the earliest stage of our research we are accessing re-analysis data sets and examining the monthly long wave patterns over the eastern Pacific Ocean, continental USA and Canada, and the western Atlantic Ocean. In parallel with analysis of these long wave patterns, we are documenting the

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snowfall in northern and southern California by accessing records from the snow laboratories in the Sierra Nevada Mountains. We pay particular attention to the snowfall events in the context of the monthly wave patterns. The precipitation and snow in the Sierra often come in short busts, two or three events over the monthly time frame in an otherwise dry/sunny environment. The study thus couples different scales—one a monthly pattern of synoptic or large scale and events of a few days duration.

Following the data analysis phase of work, a low-order model that incorporates physical processes of potential importance to establishment of the quasi-permanent pattern will be undertaken. The processes we consider include land surface/sea surface differences ("Sutcliffe's idea"), the asymmetric structure of the polar ice cap, orographic influences ("Charney-Eliassen" mechanism), and the albedo variance over the ocean/landmass due to, for example, the presence or absence of snow cover. There are several low-order climate models that hold promise for including these processes (e. g., Roebber, 1995).

MATERIALS AND METHODS

Our ongoing research has four principle tasks:

1) Use observed and re-analysis data to characterize the nature of this wave anomaly by comparing it to winter 'normal' states (long term mean trends).

2) Find correlations if any exist with associated states of proposed large scale forcing mechanisms, such as:
    a. SST anomalies in the Gulf of Alaska and off the New England coast
    b. anomalies in the longitudinal orientation of the arctic polar ice extent
    c. topographical forcings due to ocean/landmass and mountain/lowland terrain differences.

3) Synthesize these forcing states to propose a wave choice mechanism that establishes a causal link from these forcings to the atmosphere's choice of a specific waveform or range of waveforms.

4) Extend this wave choice mechanism into a broader theory of persistent, large scale wave structures based upon the above-mentioned energetic and topographic forcings and geometric necessity, to yield a narrow spectrum of possible waveforms when given any particular forcing regime.

Figure 1. Mid-latitude ocean and land surfaces. The figure is centered vertically on the indicated line through 40°N latitude; this is the line used in figure 2. Edited image from *National Geographic Atlas of the World*, 5th Edition, 1981, National Geographic Society, Washington, D. C.

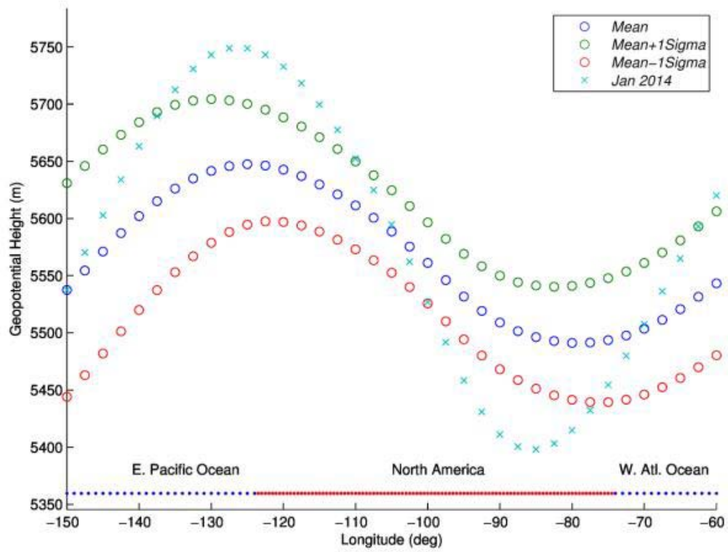

Figure 2. Mean monthly trend (dark blue circles) 500mb geopotential heights along the 40°N latitude line, compared to the almost +/- 2-sigma extent of the peaks of the monthly mean data for January 2014 (light blue x's). Image made in MATLAB from ESRL-NCEP monthly reanalysis data.

What Illustrates a Persistent Wave Structure?

The strong amplification of the western high pressure/eastern low pressure pattern of Jan-Feb 2014 is illustrated here (Figures 1 and 2) by the contrast of the mean monthly trend (dark blue circles) in 500mb geopotential height taken over the re-analysis data's period of record, 1979-2014, to the almost +/- 2-sigma extent of the peaks of the monthly mean data for January 2014 (light blue x's). This data is restricted to a 40°N latitude line, along the indicated longitude range.

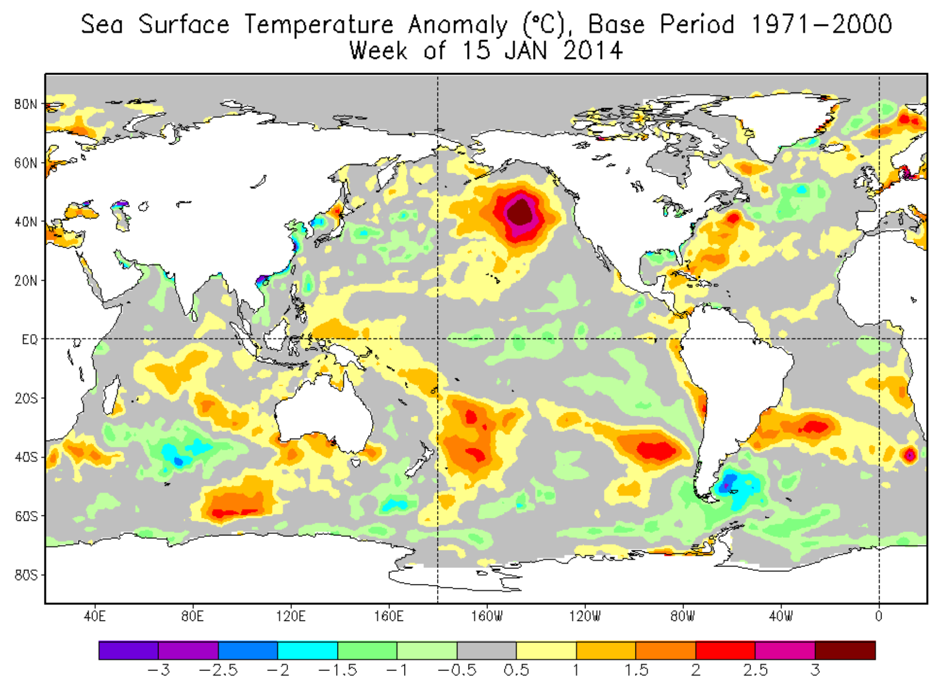

Figure 3. Global SST anomaly for week of 15 Jan 2014. Credit: NOAA NCDC
www.ncdc.noaa.gov/teleconnections/enso/indicators/sea-temp-anom.php

Sea Surface Temperatures

Figure 3 shows a strong, positive SST anomaly in the Gulf of Alaska, and a weaker one over the Atlantic off the US east coast. Our research proposes that the energy and water vapor fluxes such anomalously warm water areas provide may have acted as waveguides to channel and maintain the persistent wave structure observed during Jan-Feb 2014.

Figure 4. Polar view of arctic sea ice extent, January 2014. Credit: NSIDC/NIC MASIE product. (MASIE: Multisensor Analyzed Sea Ice Extent)
ftp://sidads.colorado.edu/DATASETS/NOAA/G02186/png/masie_all_r00_v01_2014015_4km.png

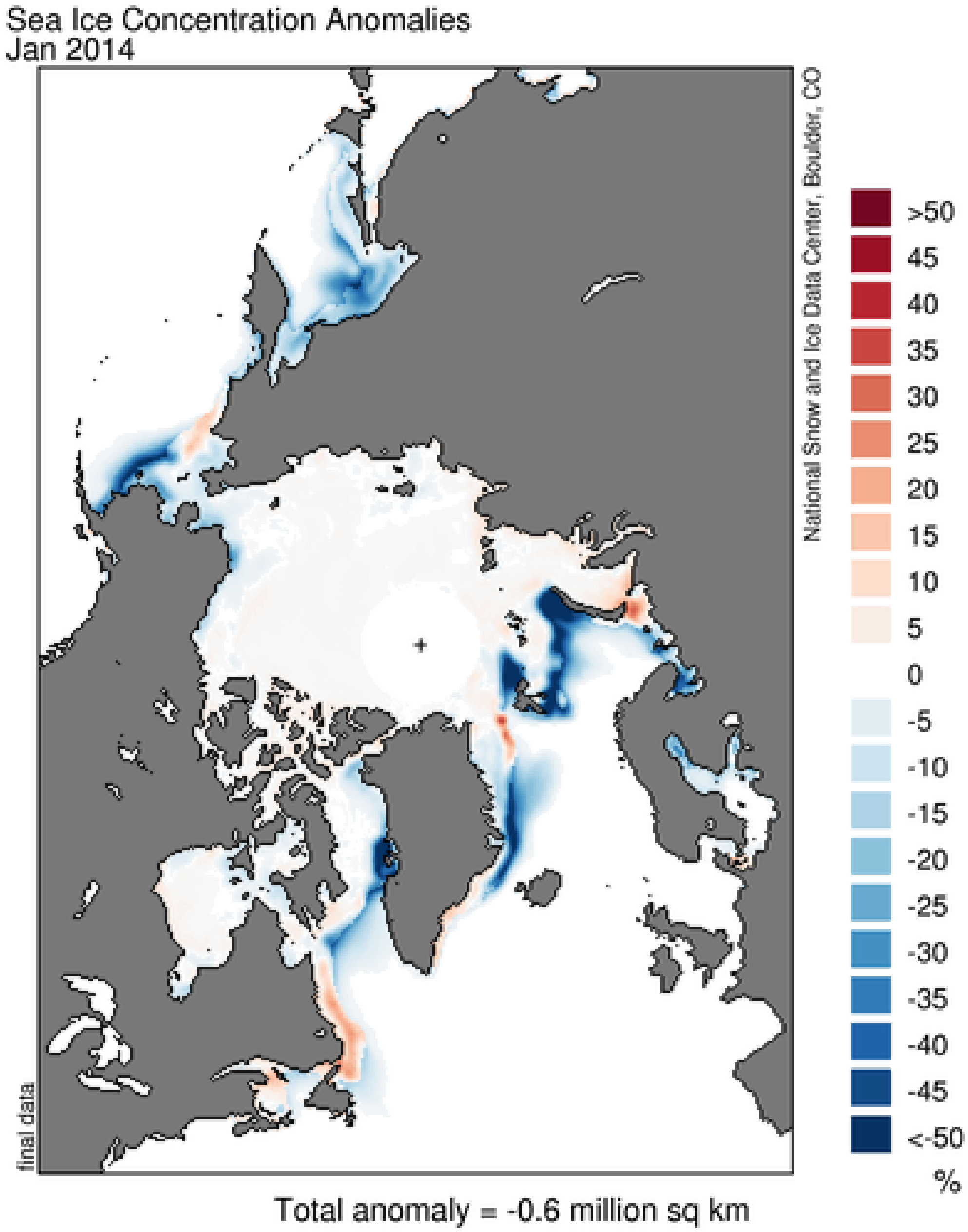

Figure 5. Arctic sea ice extent anomaly, January 2014. Credit: NSIDC/NIC MASIE product ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/Jan/N_201401_anom.png .

Polar Sea Ice Extent

The polar regions share a striking similarity when compared to the equatorial regions: the polar regions are much smaller in areal extent. The Arctic sea ice extent also shows large—and changeable—longitudinal deviations from radial symmetry. Figures 4 and 5 present views from directly above the north pole of the mean sea ice extent for January, 2014 (Figure 4), and the corresponding sea ice extent anomaly (Figure 5).

Differences in albedo or surface temperature along such longitudinal gradients could provide energetic input or reinforcement for particular wave structures. We surmise that relatively small longitudinal differences from polar ice extent mean states may thereby act to influence and maintain wave structures in the mid-latitudes, such as the persistent wave structure used here as our case study.

RESULTS AND DISCUSSION

How energy propagates in waves from the large equatorial area to the small polar region must subscribe to the basic physics principles that describe wave propagation in a fluid medium. These principles include nodes, waveguides, reflection by a barrier, superposition, and the geometric restrictions on the creation and focusing of standing waves. The use of these principles should allow a path towards analysis of large scale atmospheric waves, even in such a complex system.

According to our theory, these changeable energetic forcings acted together with fixed topographic forcings to result in the observed pattern of wave persistence during the period in question. This wave pattern, so strong in amplitude and so persistent in time duration, is a pattern we feel is well suited to serve as a case study in order to try to connect changeable large scale forcings (SST states, polar ice states) and fixed forcings (topography) to the atmosphere's choice of a particular wave structure. Our continuing research efforts will therefore be a mixture of empirical analysis of observation and re-analysis data, and theoretical work to try to find this physical basis for atmospheric wave choice. For the theoretical work, we will be using simplified versions of the ocean/landmass system into which we will introduce simple forcing regimes, in order to model at a basic level the most salient energetic and orographic features of the Pacific Ocean-North America winter system.

SUMMARY

Although much work needs to be done before we can claim any results, we feel this line of inquiry to be very promising. The elucidation of the causal basis of the large-scale atmospheric wave structure is overdue. It bears the promise of providing a basis for constructing a predictive model for wave behavior on a seasonal time frame. Such an outcome, if it comes to fruition, could prove highly useful to predict seasonal precipitation totals for the western United States and other regions—a type of prediction which at this point we do not a have model capable of forecasting successfully. It is our hope that our research will help provide a foundation for subsequent work towards these goals.

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