The Influence of Tropical Variations on Wintertime Precipitation in California: Pineapple express, Extreme rainfall Events and Long-range Statistical Forecasts

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Outline

- Overview of Madden-Julian Oscillation (MJO)
- Synoptic Setting During Strong MJO Events and the "Pineapple Express"
- Influence on Extreme Rainfall Events in California
- Dynamical Forecasts of the MJO
- Real-Time Intraseasonal Statistical Forecasts of Western United States Rainfall

Collaborators: Dr. Wayne Higgins
Dr. Jae-K. E. Schemm (Climate Prediction Center - NCEP/NOAA

Madden and Julian Oscillation (MJO)

Since its discovery by Madden and Julian (1971) over two decades ago, the Madden and Julian Oscillation (MJO) has continued to be a topic of significant interest due to its complex nature and the wide range of phenomena it interacts with (Madden and Julian, 1994). The onset and activity of the Asian-Australian monsoon system are strongly influenced by the eastward propagation of MJO events (e.g., Yasunari, 1979; Lau and Chan, 1986). The interaction of the MJO with the extra-tropical regions has been shown to influence weather forecasts on medium-to-extended range (Ferranti et al. 1990; Lau and Chang, 1992). Furthermore, coupling with the tropical ocean via westerly wind bursts associated with the passage of an MJO significantly modify sea surface temperature (SST), surface heat fluxes (Kawamura, 1991; Zhang, 1996; Jones and Weare, 1996; Flatau et al., 1997; Jones et al. 1998; Hendon and Glick, 1997) and the structure of the thermocline in the equatorial Pacific Ocean (Kessler et al., 1996). This latter interaction has even been suggested to play an important role in triggering ENSO events (e.g., Lau and Chan, 1986; Weickmann, 1991).

Another important aspect of the MJO that has received relatively less attention concerns the predictability of intraseasonal variations. Enormous progress has been achieved in mid-latitude short-term weather forecasting over the last 30 years (e.g., Van den Dool, 1994) with useful predictability out to 6-10 days being exploited every day. At longer time scales, interannual variability is the next form of climate prediction that has been demonstrated, as well as become operational and useful. In between these two time scales, the MJO phenomenon stands out as the next candidate with potential for predictability (e.g., Lau and Chang, 1992; Waliser et al., 1999). In an early study, Chen and Alpert (1990) showed that when the MJO amplitude is large, model forecast skill of its propagation and amplitude were quite good out to 10 days. However, when the MJO amplitude was small, the forecast skill was poor. In another study, Ferranti et al. (1990) demonstrated that the skill of medium-to-extended range forecasts in the extra-tropics are significantly improved when the errors associated with the representation of the tropical intraseasonal oscillation are minimized. Lau and Chang (1992) analyzed one season of 30-day global forecasts derived from the National Centers for Environmental Prediction (NCEP) forecast model during the Dynamical Extended Range Forecasts (DERF) experiment. Their results show that the NCEP forecast model has significant skill in predicting the global pattern of intraseasonal variability up to 10 days, with the error growth of tropical and extratropical low-frequency modes less (greater) than persistence when the amplitude of the MJO is large (small). Jones et al. (2000) examined 5 years of 50-day forecasts during a Dynamical Extended-Range Forecast (DERF) experiment performed with the NCEP Medium Range Forecast (MRF) model. The MRF model shows large mean errors in representing tropical intraseasonal variations, especially over the equatorial eastern Pacific Ocean. A diagnostic analysis indicates that skillful forecasts extend only 5 to 7 days lead-time. The analysis showed systematic errors in the representation of the MJO with weaker than observed upper level zonal circulations.

References can be accessed at: www.icess.ucsb.edu/asr/mjo_refs.htm

The Madden-Julian Oscillation

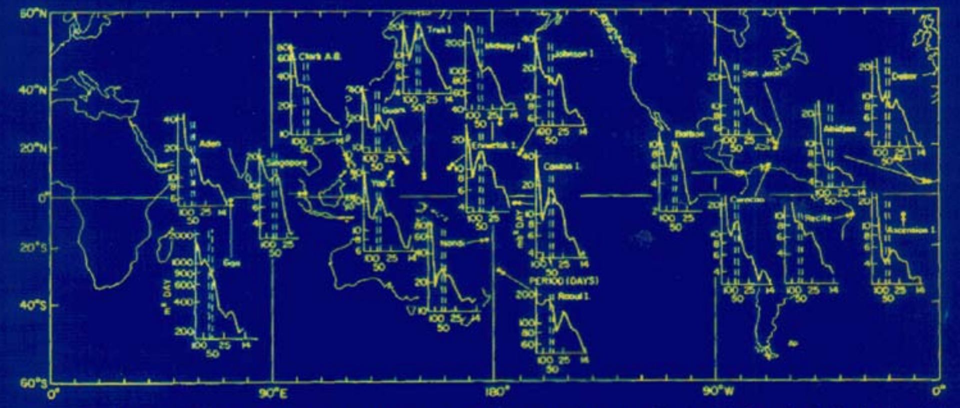


Fig. 1. Variance spectra for station pressures at several locations. Units for ordinates (mb² day) and abscissas (period in days) are indicated on spectrum for Canton Island. Ordinates are logarithmic and abscissas are linear with respect to frequency. The 40–50 day period range is indicated by the dashed vertical lines.

Madden and Julian (1972)

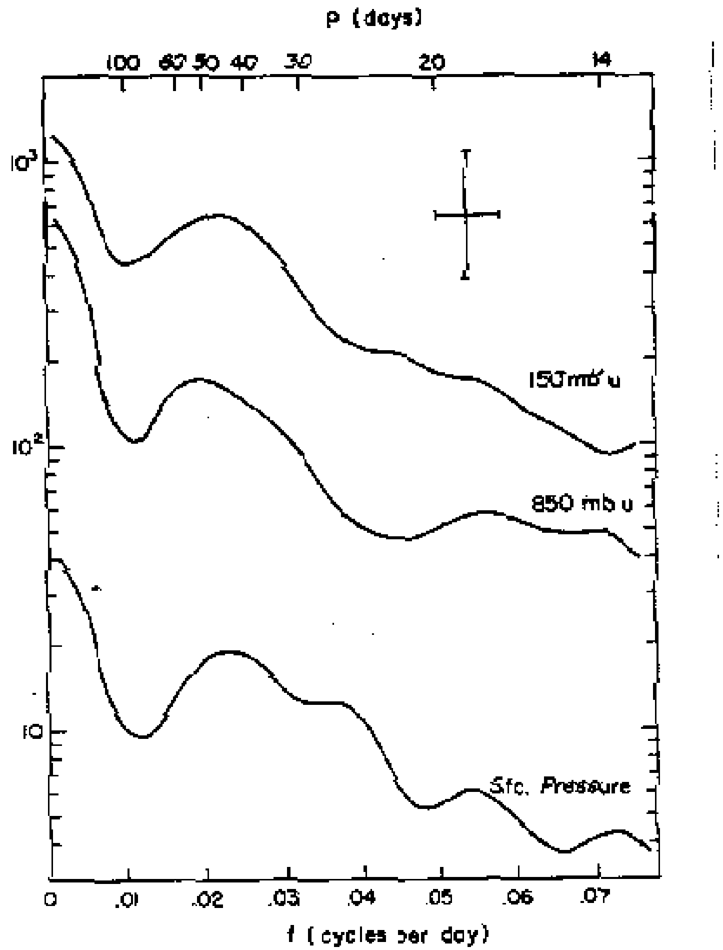
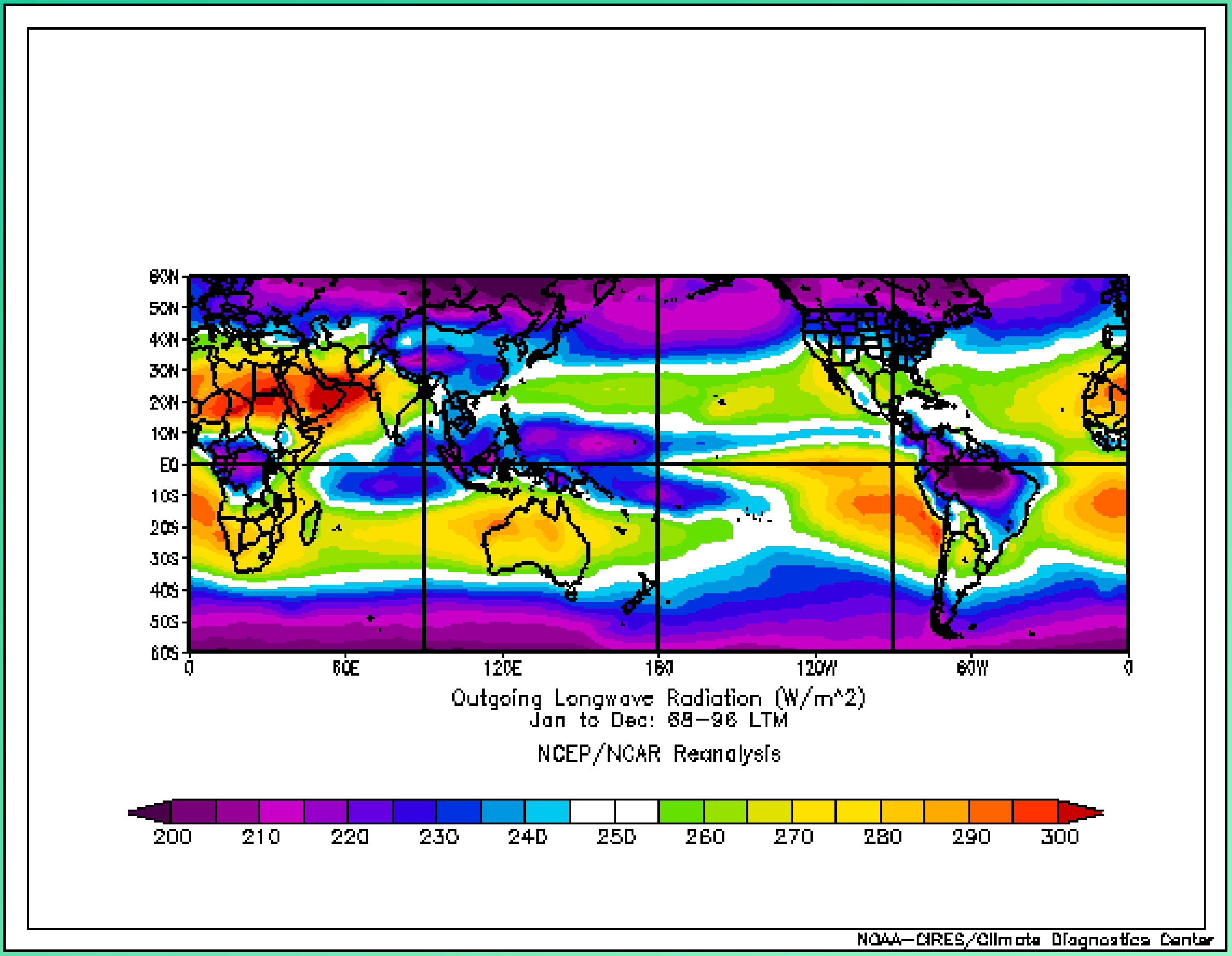
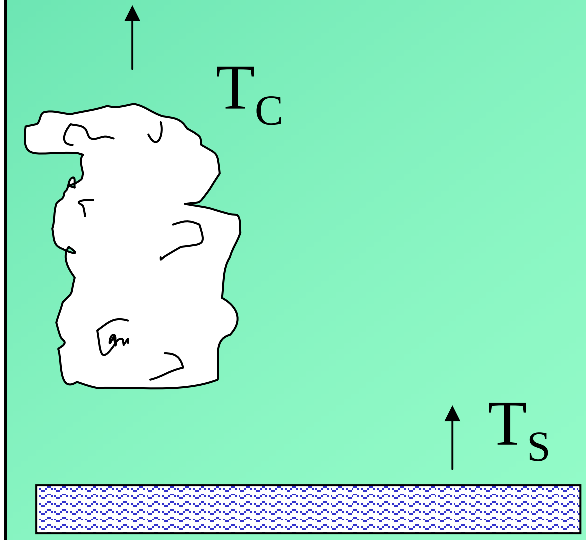


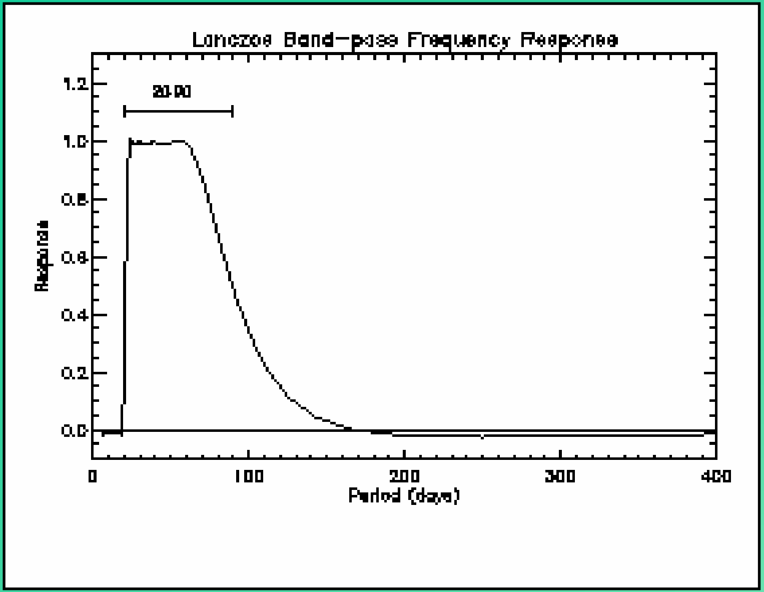
Fig. 2. Individual variance spectra for the 850- and 150-mb zonal wind component and station (sfc) pressure for the Canton Island record. The use of a logarithmic ordinate permits a constant scaling to be used for the chi-square degrees of freedom sampling analysis. This scaling [$\chi^2(0.1\%)/51$] and the bandwidth of the analysis, $\Delta f = 0.0081$ day^{-1}, are shown by the cross. Spectral densities are normalized to unit bandwidth (m² sec^{-2} day^{-1}).

Outgoing Longwave Radiation Climatology

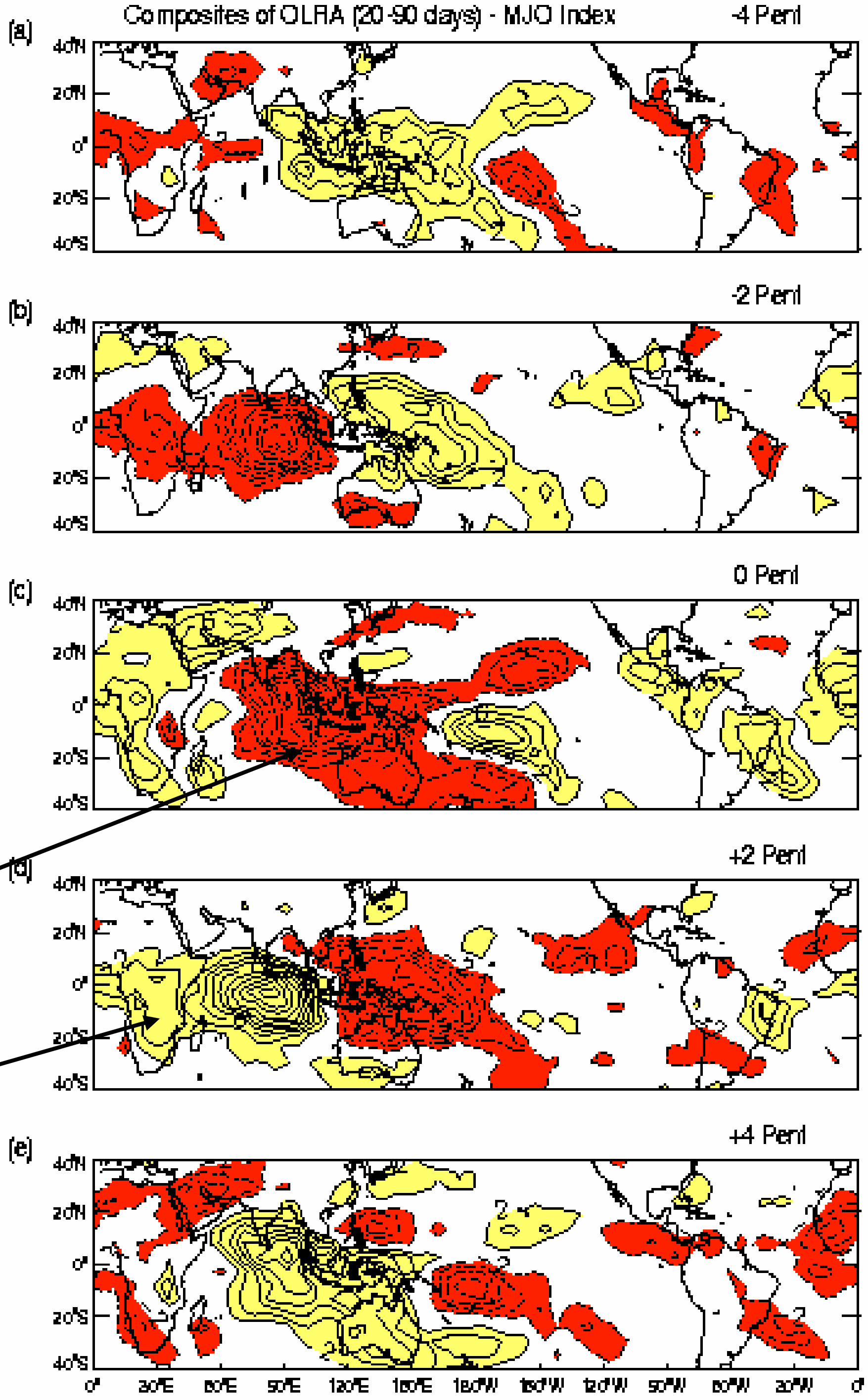




$T_C < T_S$



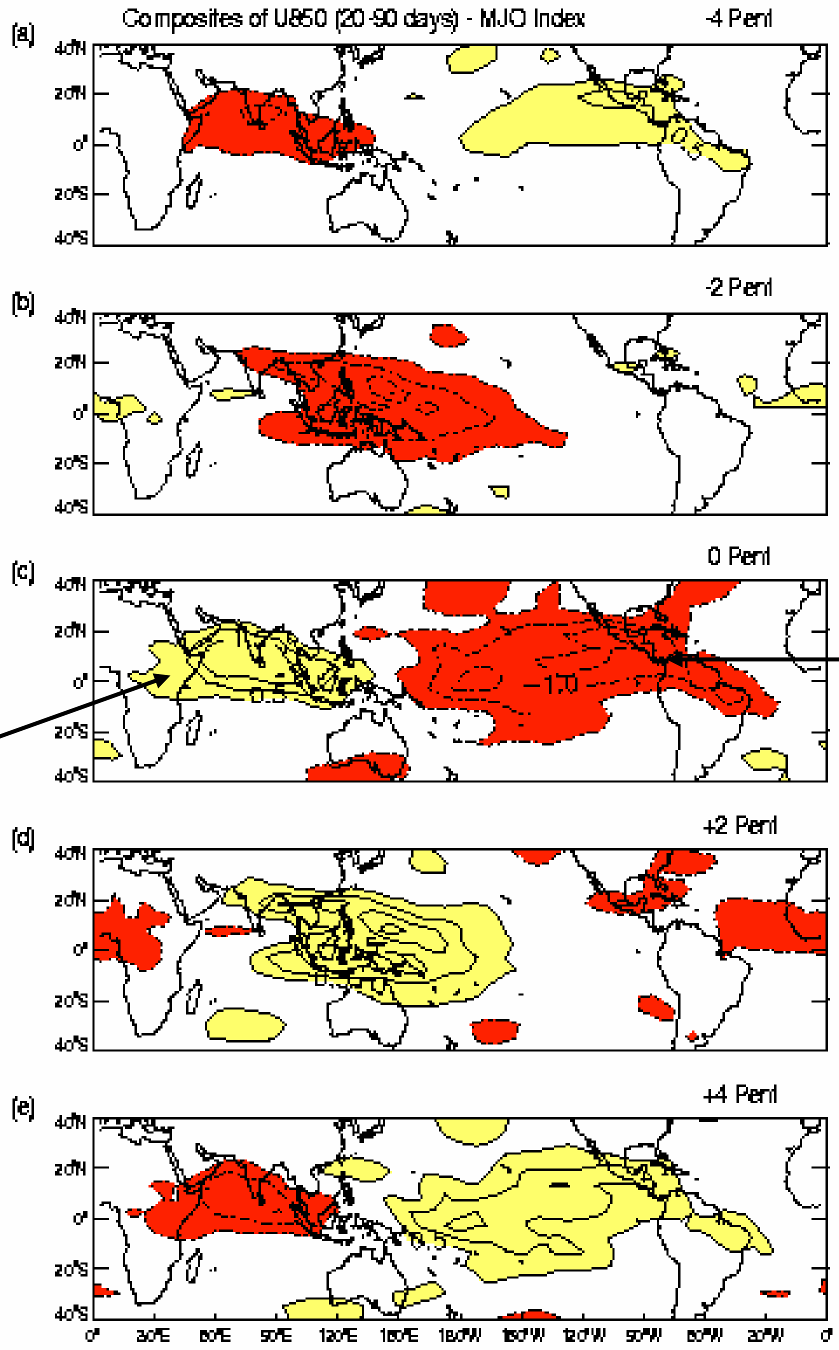
OLR Data are filtered in time (20-90 days) and composites of OLR anomalies are made



Enhanced Tropical Convection

Suppressed Tropical Convection

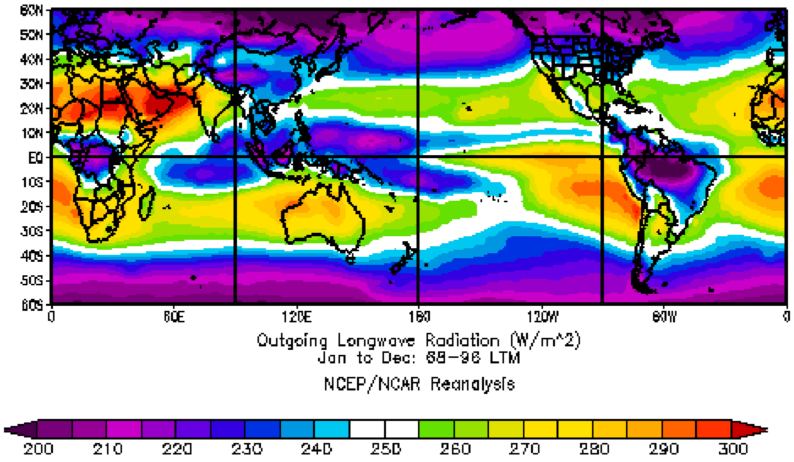
Zonal (U) wind component (850 hPa) is filtered in time (20-90 days) and composites of anomalies are made



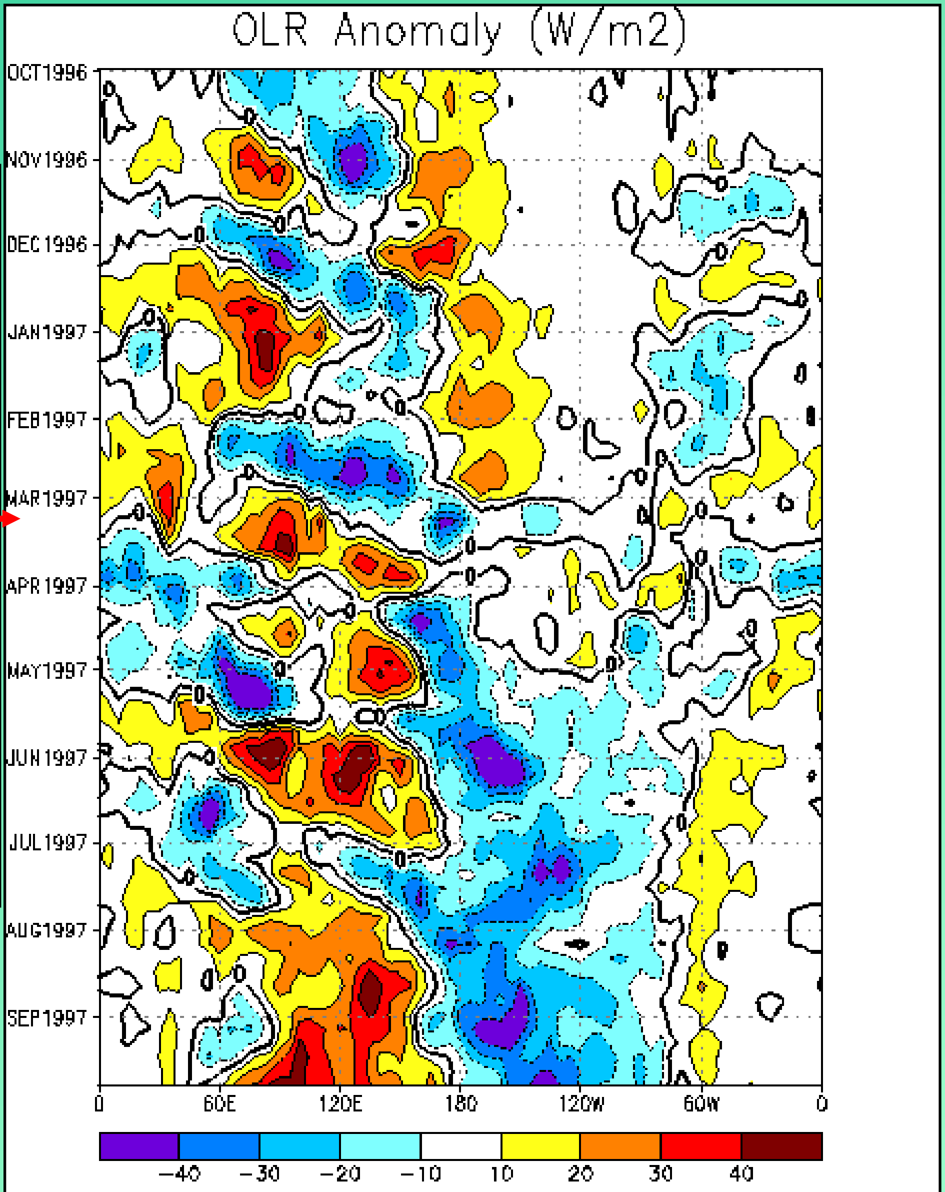
Enhanced easterlies

Enhanced westerlies

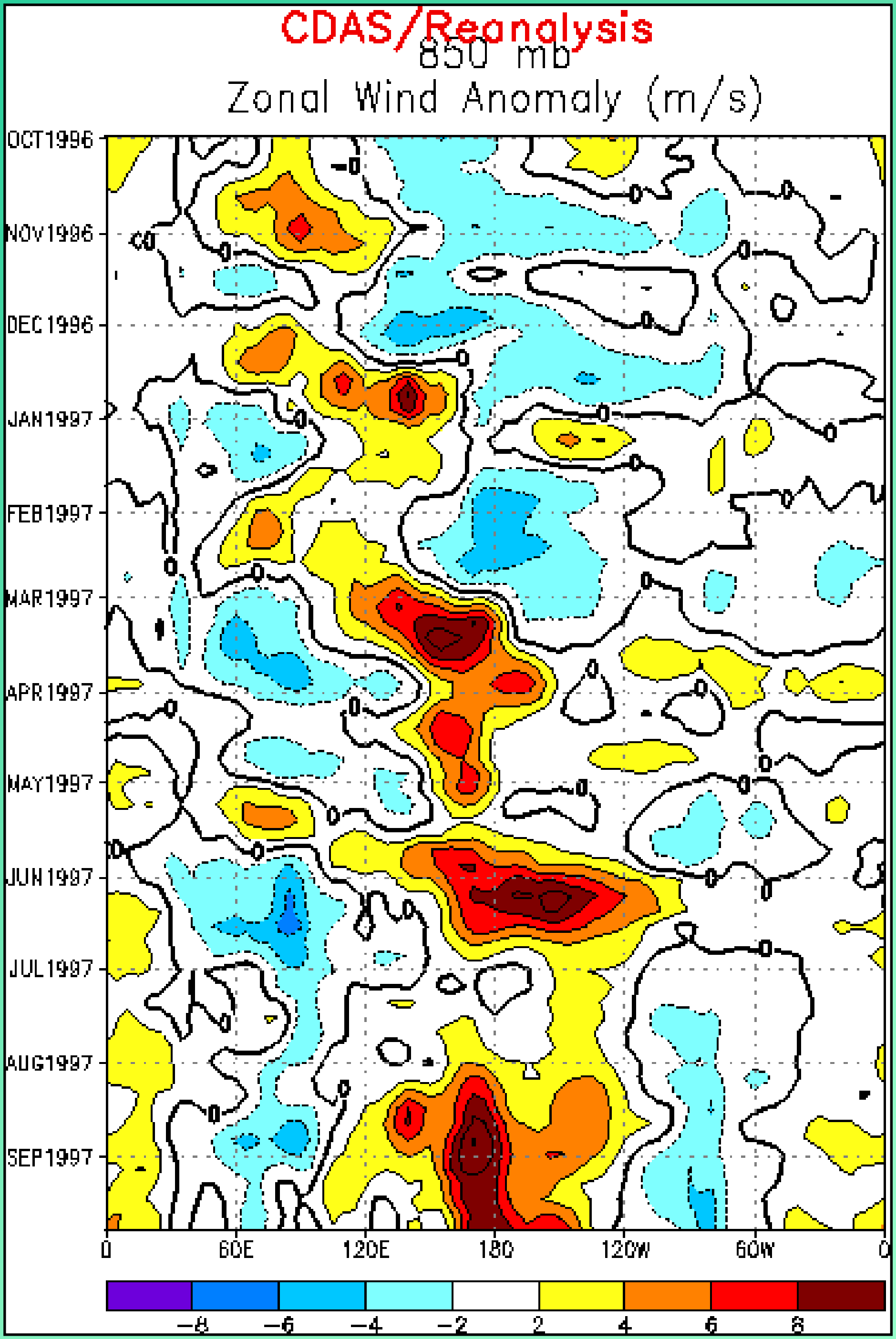
Outgoing Longwave Radiation Climatology



NOAA–CIRES/Climate Diagnostics Center



CLIMATE PREDICTION CENTER/NCEP



Tropical Intraseasonal Oscillations, MJO and the “Pineapple Express”

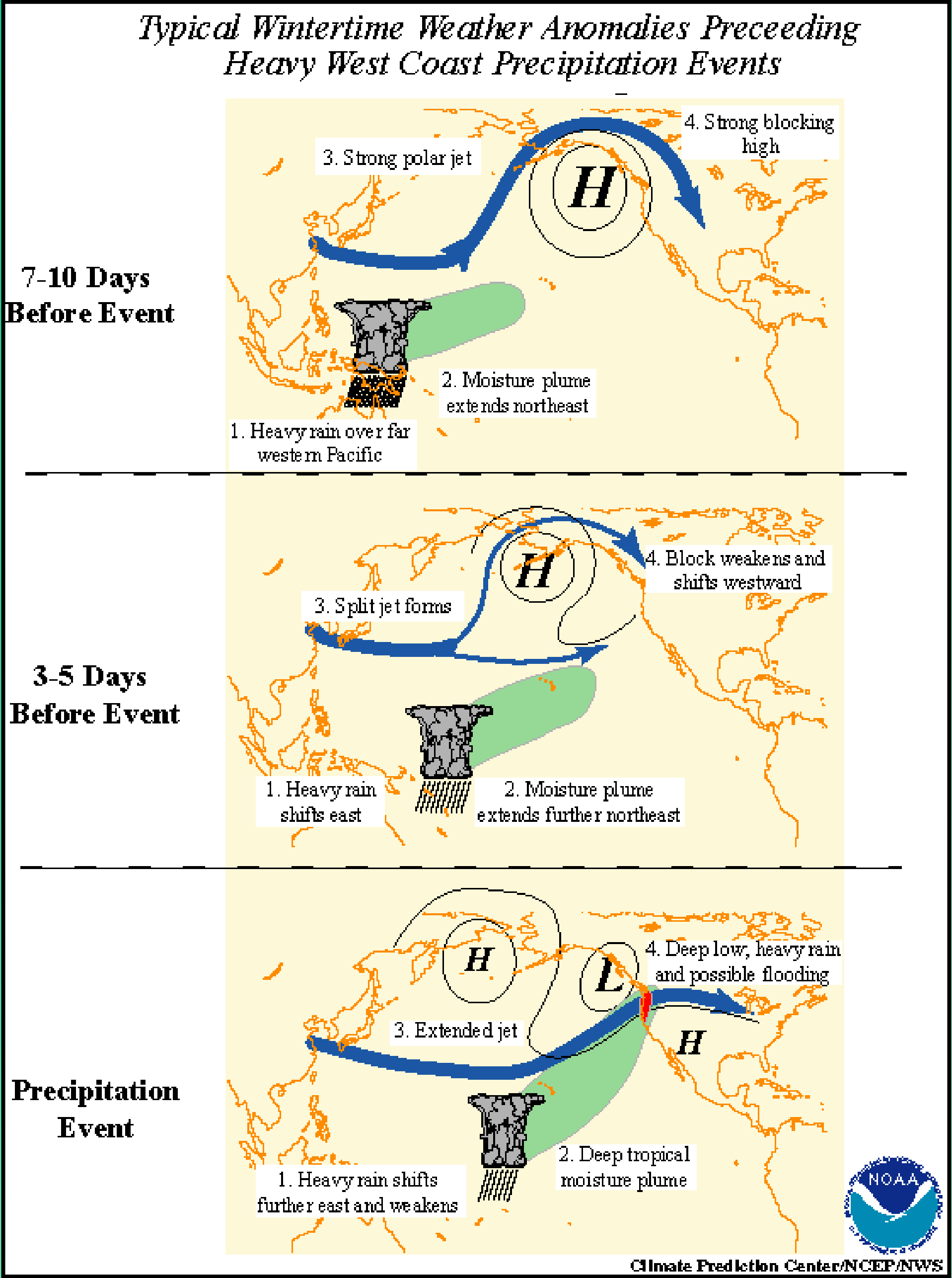
There is significant evidence that a large fraction of the precipitation and surface air temperature variability over North America during the boreal winter and summer seasons are linked to tropical variations on interannual and intraseasonal time scales. The impacts of ENSO in the U.S. have been extensively documented (Barston et al., 1999; Changnon 1999). In addition to changes in mean seasonal values, the tropical influence is also felt on extreme events. Extreme precipitation episodes in the western United States (those in the top 10% of all events) occur at all phases of the El Niño-Southern Oscillation (ENSO) cycle, but the largest fraction of these events (for the West Coast as a whole) occurs during *neutral winters between cold and warm ENSO episodes* (Higgins et al. 2000a). In the tropical Pacific, these winters are characterized by enhanced 30-60 day intraseasonal (MJO) activity. Furthermore, they are characterized by relatively small sea surface temperature anomalies (SSTA) compared to ENSO winters. In these winter seasons, there is a stronger linkage between the MJO events and extreme west coast precipitation episodes. During the winter season specifically, *Persistent North Pacific* (PNP) circulation anomalies have been linked to tropical intraseasonal variations.

The typical scenario linking the pattern of tropical rainfall associated with the MJO to extreme precipitation events along the west coast is characterized by a progressive (i.e. eastward moving) circulation pattern in the tropics and a retrograding (i.e. westward moving) circulation pattern in the midlatitudes of the North Pacific. Typical wintertime weather anomalies preceding heavy precipitation events in the Pacific Northwest are as follows (Fig. 1):

7-10 days prior to the event: Heavy tropical rainfall associated with the MJO shifts eastward from the eastern Indian Ocean to the western tropical Pacific. A moisture plume extends northeastward from the western tropical Pacific towards the general vicinity of the Hawaiian Islands. A strong blocking anticyclone is located in the Gulf of Alaska with a strong polar jet stream around its northern flank.

3-5 days prior to the event: Heavy tropical rainfall shifts eastward towards the date line and begins to diminish. The associated moisture plume extends further to the northeast, often traversing the Hawaiian Islands. The strong blocking high weakens and shifts westward. A split in the North Pacific jet stream develops, characterized by an increase in the amplitude and spatial extent of the upper tropospheric westerly zonal winds on the southern flank of the block and a decrease on its northern flank. The tropical and extratropical circulation patterns begin to “phase” allowing a developing midlatitude trough to tap the moisture plume extending from the deep tropics.

Tropical-Extratropical Interaction associated with Madden-Julian Oscillation

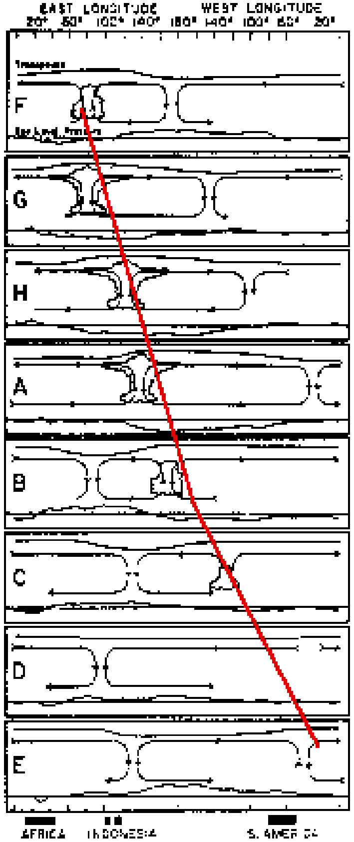


Climate Prediction Center/NCEP/NWS

Figure 1. Schematic representation of eastward propagation of tropical convective anomalies associated with the Madden-Julian Oscillation, changes in the Jet Stream and precipitation events in the Pacific Northwest.

Precipitation event: The pattern of enhanced tropical rainfall shifts further to the east and weakens. The deep tropical moisture plume extends from the subtropical central Pacific into the midlatitude trough located off the west coast of North America. The jet stream at upper levels extends across the North Pacific with the mean jet position entering North America in the northwestern United States. Deep low pressure located near the Pacific Northwest coast can bring up to several days of heavy rain and possible flooding. The tropical moisture plumes are often referred to as “pineapple express” events by the weather forecasting community, so named because significant amounts of the deep tropical moisture traverse the Hawaiian Islands on its way towards western North America. Throughout the evolution, retrogression of the large-scale atmospheric circulation features is observed in the eastern Pacific-North American sector. Many of these events are characterized by the progression of the heaviest precipitation from south to north along the Pacific Northwest coast over a period of several days to more than one week. However, it is important to differentiate the individual synoptic-scale storms, which generally move west to east, from the overall large-scale pattern, which exhibits retrogression. Since there is considerable case-to-case variability in these events, the above scenario should be viewed as typical.

Madden-Julian Oscillation
(a.k.a. Intraseasonal, 40-50, 30-60 Day Oscillation)



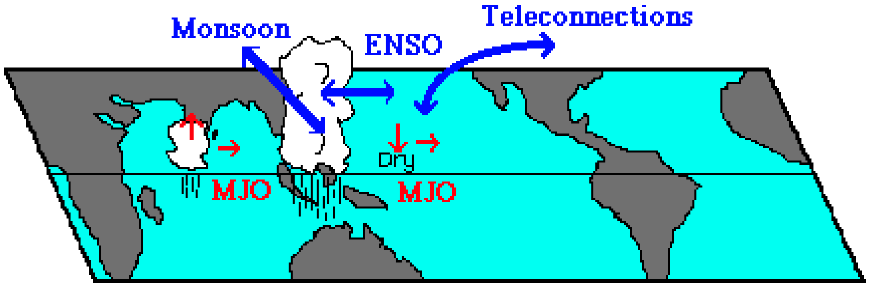
Madden and Julian (1971)

General Characteristics

* Eastward Propagating
* Equatorially Trapped
* Zonal Wavenumber One (-Two)
* Baroclinic
* Eastern Hemisphere
    ~5 m/s Phase Speed
    Strong Interaction with
        Clouds, Rain, Surface Wind,
        Large-Scale Circulation
* Western Hemisphere
    ~10 m/s Phase Speed
    Modest/Weak Interaction with
        Large-Scale Circulation
    Weak/No Interaction with
        Clouds, Rain, Surface Wind
* Favors Austral Summer Conditions
* Signficant Year-to-Year Variability

Including, but not limited to:
Madden and Julian, (1971, 1972, 1994); Murakami (1976); Yasunari (1979, 1980); Lau and Chan (1983, 1985, 1986); Weickman (1983), Nakazawa (1986); Knutson and Weickman (1987); Chen and Murakami (1988); Chen et al. (1988); Gray (1988); Hendon and Liebman (1990); Wang and Rui (1990a); Lau et al., (1991); Hendon and Salby (1994); Salby and Hendon (1994)

Major MJO Climate Influences



1. Asian Monsoon

- **Onset and Break Periods** (e.g., Yasinari, 1979, Cadet, 1986; Lau and Chan, 1986; Wang and Rui, 1990)

2. Equatorial Pacific Thermocline Variability

- **Westerly Wind Bursts** (e.g., Luther et al., 1983) ⇒

  Ocean Kelvin Waves (e.g., McPhaden and Taft, 1988) ⇒

  Connection to El Nino (e.g., Enfield, 1987; Lau and Chan, 1988; Weickman, 1991; Kessler et al., 1996)

3. Midlatitude Teleconnections

- **Midlatitude Circulation Anomalies** (e.g., Kiladis and Weickman, 1992) and **Medium-to-Extended Range Weather Forecasts** (e.g., Ferranti et al., 1990).

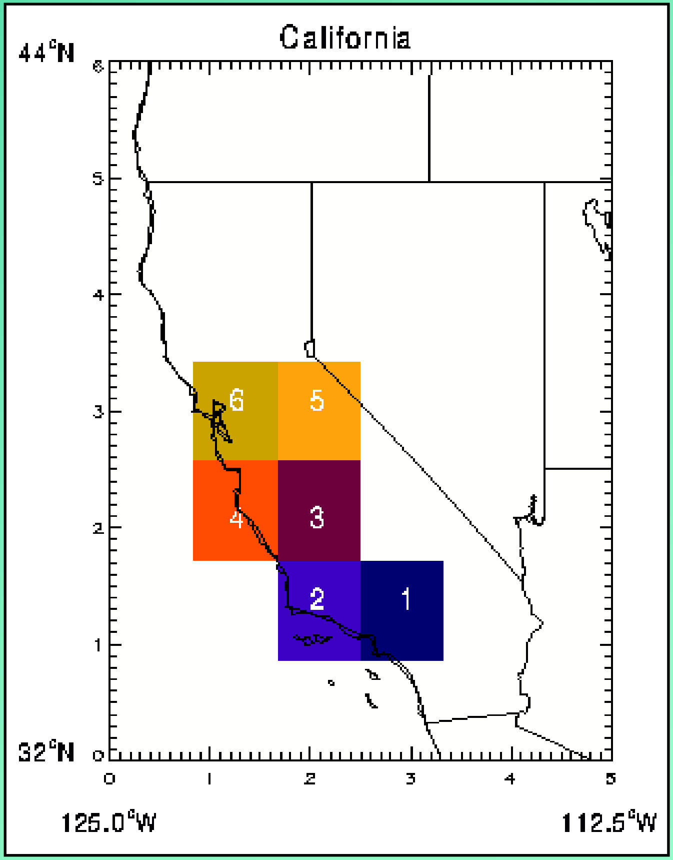
Occurrence of Extreme Precipitation Events in California and Relationships with the Madden-Julian Oscillation

Motivation

- **High frequency of Intense rainfall can lead to damaging floods**
- **Precipitation in the western United States is modulated by tropical variability**
- **Interannual: ENSO**
- **Intraseasonal: eastward propagation of the MJO modulates precipitation in California; location of convective anomalies favors wet (dry) events**
- **Are Extreme events in California more likely during active periods of the MJO?**

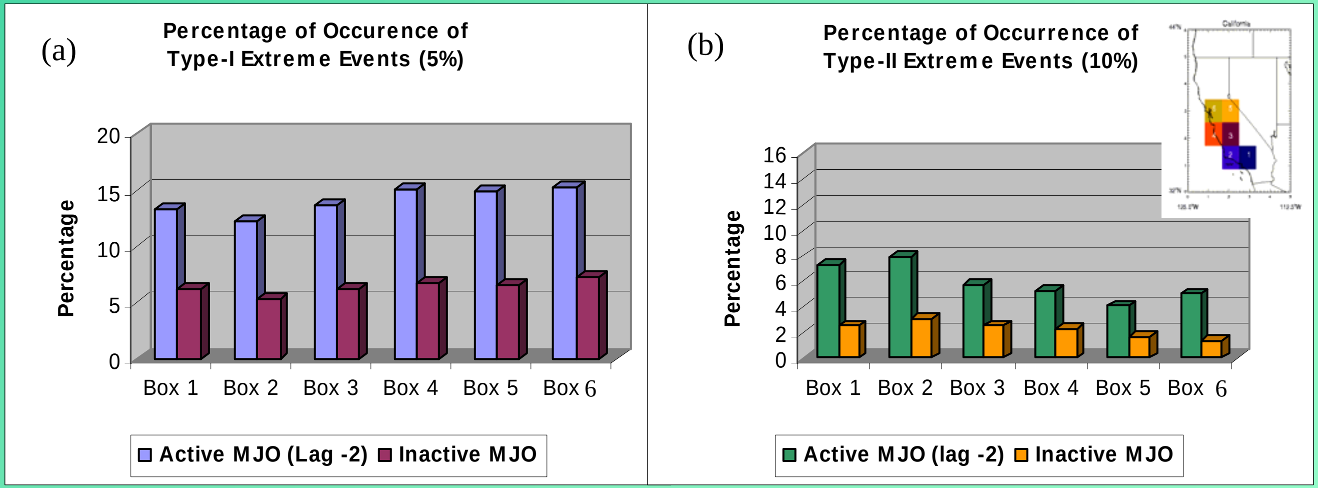
Data Sets

- **Tropical Convection: 5-day averages of Outgoing Longwave Radiation (OLR) (Jan 1979 - Dec 1996)**
- **Zonal Circulation: 5-day averages of U at 200 and 850 mb from NCEP/NCAR reanalyses (Jan 1958 - Dec 1996)**
- **MJO: band-pass Lanczos filter (20-90) days**
- **Daily observed precipitation from gridded hourly station data (2.0° lat x 2.5° lon). Jan 1958-Dec 1996**
- **Select six grid boxes over California; Compute 5-day total precipitation**
- **Definition of *Extreme Event***
- ***Type-I*: 5-day total ≥ 5% of the average annual precipitation**
- ***Type-II*: 5-day total ≥ 10% average annual precipitation**
- ***Type-III*: 5-day total ≥ 15% average annual precipitation**



Influence of the MJO on Extreme Rainfall Events in California

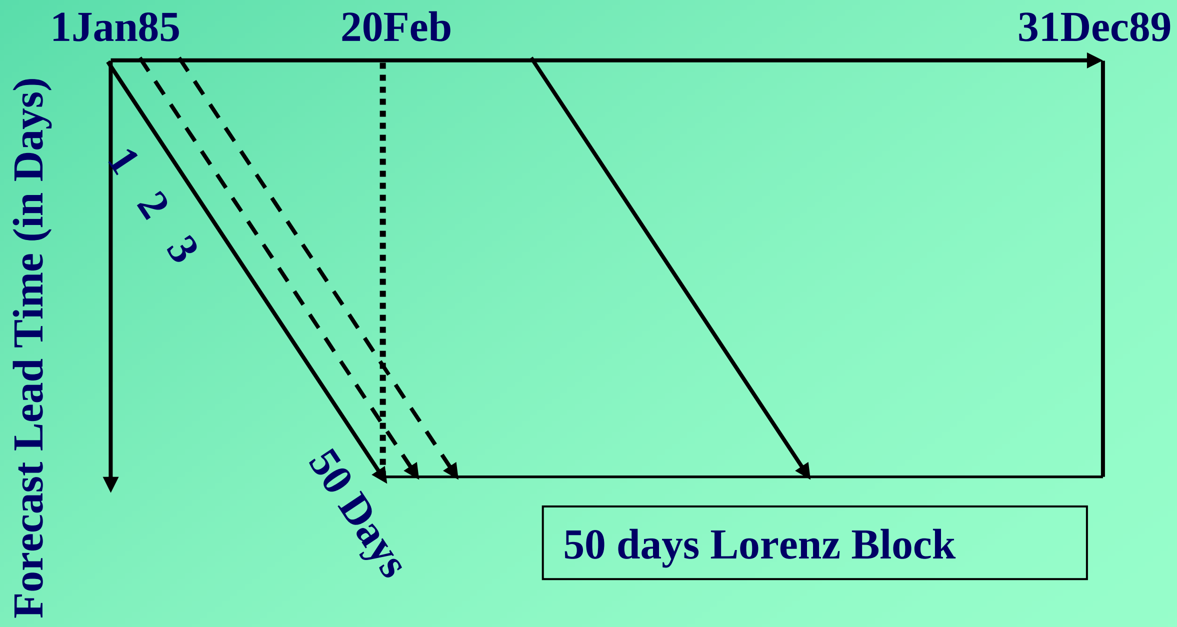
The occurrences of extreme precipitation events in California were also investigated by Jones (2000). Daily-observed precipitation from gridded hourly station data from January 1958 to December 1996 was used to define extreme events. Based on 5-day precipitation totals, three types of extreme events were defined. Type I was defined when the 5-day total precipitation exceeded 5% of the total annual precipitation, type II if the 5-day total precipitation exceeded 10% of the total annual precipitation and type III if the 5-day total precipitation exceeded 15% of the total annual precipitation. In order to investigate possible linkages between extreme precipitation events and the activity of the MJO, six gridboxes were selected over the state of California. The number of extreme events in each of the six grid boxes was counted for the active and inactive MJO periods defined by the lag composites of U850 anomalies. The figure below shows the total number of occurrences of extreme events of types I and II during active and inactive MJO periods (expressed as percentages from the sample size). The results show that more than twice as many extreme precipitation events of types I and II occur in Central and Southern California when tropical circulation anomalies are large and associated with the MJO.

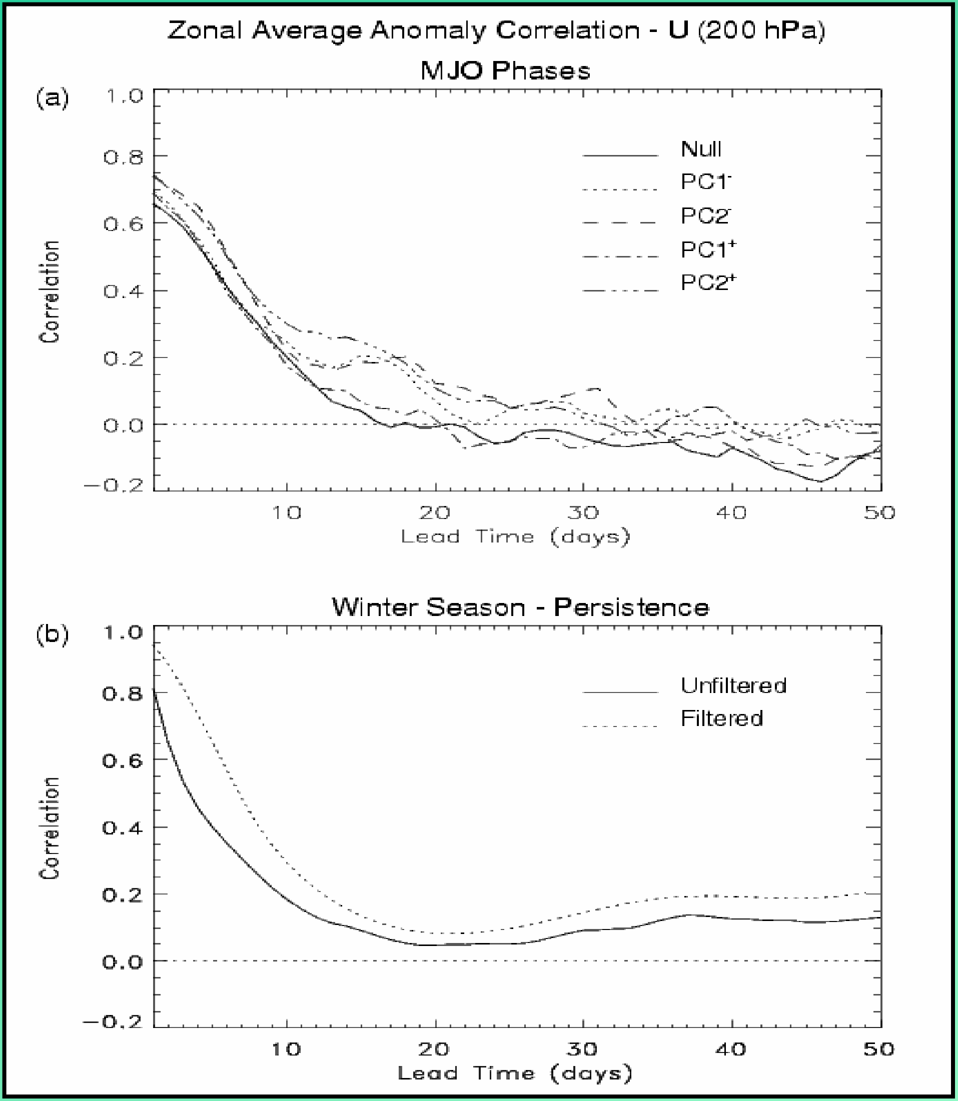


(a) Percentage of Type-I (5%) extreme events that occur during active and inactive MJO periods. (b) Same as in (a), but for Type-II (10%) events. Sample sizes are 439 pentads for active MJO and 356 pentads inactive MJO. Percentages are expressed as occurrences from the sample size. The locations of each grid box are shown in the inset in (b) (After Jones, 2000).

Dynamical Prediction of the Madden-Julian Oscillation

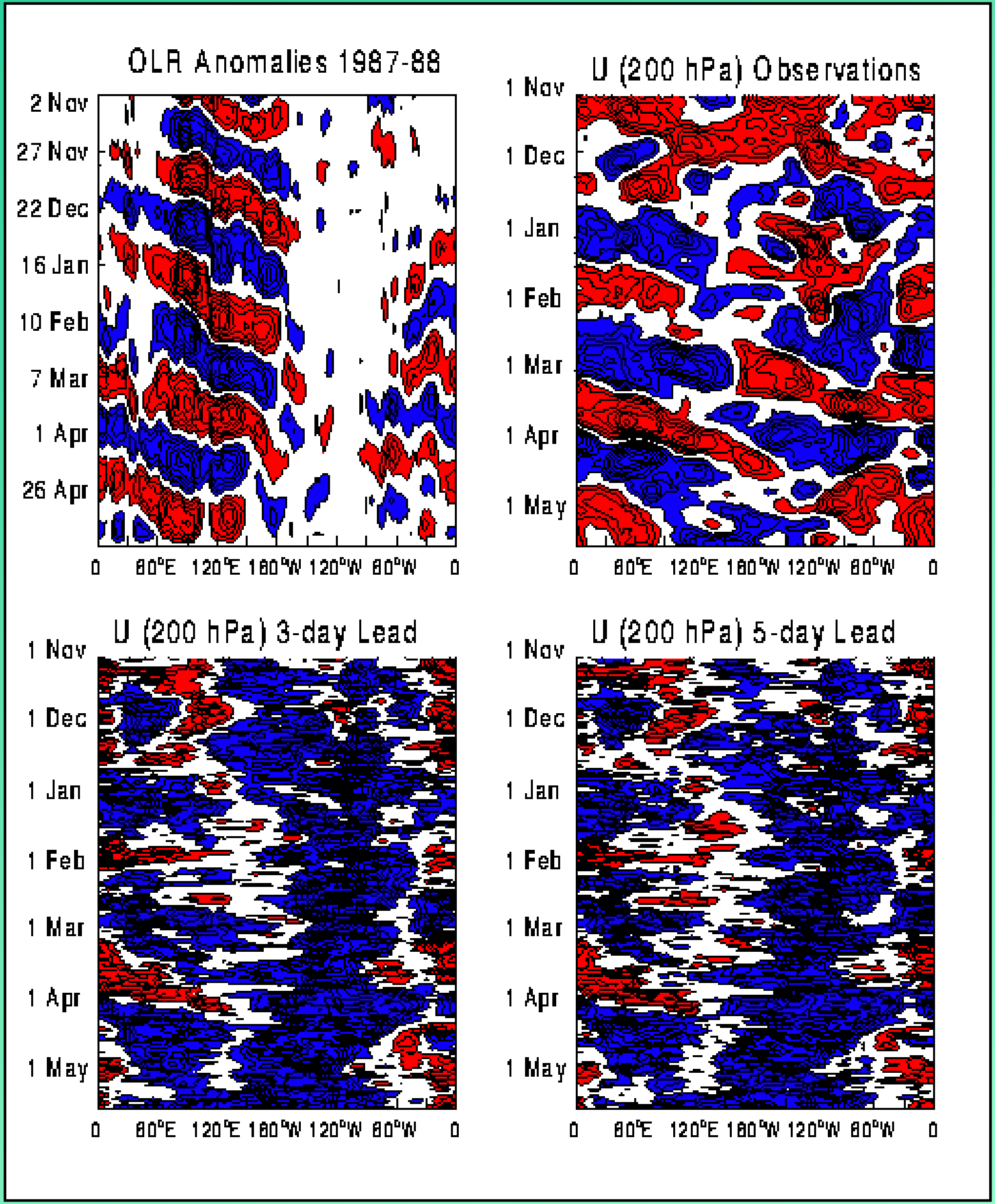
Our ability to forecast the tropical intraseasonal oscillation with dynamical models is still quite limited. Jones et al (2000) examined 5 years of 50-day forecasts during a Dynamical Extended-Range Forecast (DERF) experiment performed with the NCEP Medium Range Forecast (MRF) model. The MRF model shows large mean errors in representing tropical intraseasonal variations, especially over the equatorial eastern Pacific Ocean. A diagnostic analysis indicates that skillful forecasts extend only 5 to 7 days lead-time. The analysis showed systematic errors in the representation of the MJO with weaker than observed upper level zonal circulations. Waliser et al. (1999), for instance, developed a statistical model based on field-to-field decomposition of pentads of band-passed outgoing longwave radiation (OLR). The statistical model has significant skill in predicting the oscillation over the Eastern Hemisphere at lead-times from 5 to 20 days.





(a) Zonal average of the anomaly correlations in U (200 hPa) shown in Figs. 8 and 9 and the different phases of the MJO: PC1$^-$ (dotted), PC2$^-$ (dashed), PC1$^+$ (dash-dotted) and PC2$^+$ (long dash-short dash). Also displayed is the zonal average for the Null case (solid). (b) Zonal average of the anomaly correlations between verification and forecasts of U (200 hPa) obtained by persistence. Persistence is calculated using all days in the four winter seasons and shown for unfiltered (solid) and filtered (dotted) time series.

MJO - DERF Forecast - 1987/88



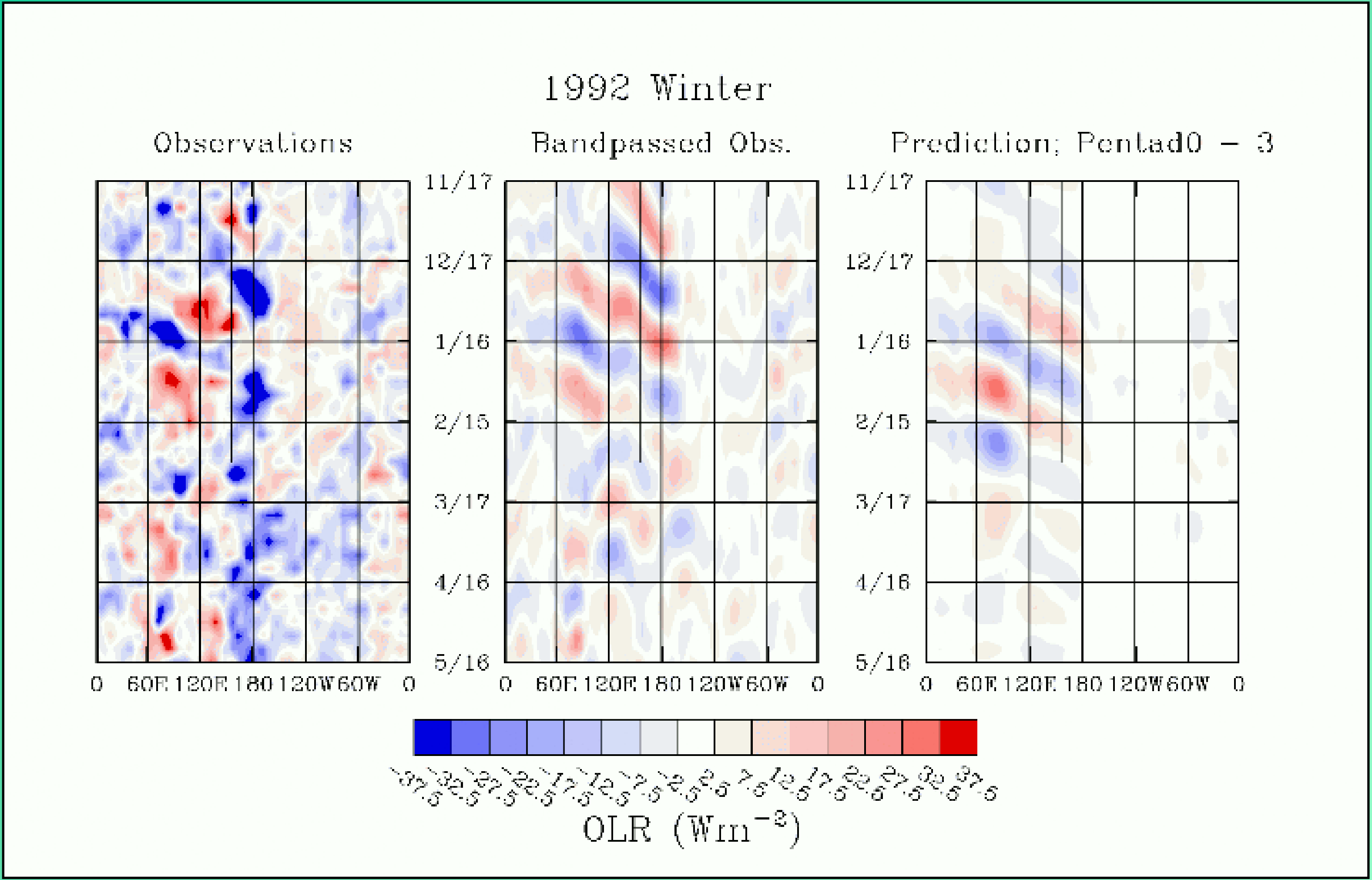
OLR: Red < 5 W m^{-2} U200: Red < 2 m s^{-1}

Statistical Prediction of the MJO

Waliser, Jones, Schemm and Graham

- **Band-passed (30-70 days) OLR pentads (1979-96)**
- **Predictors: two most recent pentad maps T_{N-1} T_N**
- **Predictands: future OLR pentads T_{N+1}, T_{N+2} … T_{N+9}**
- **Method:**
  - **For each T_{N+j} , j=1,9**
  - **Singular Value Decomposition (SVD) between all the predictor sets (T_{N-1} , T_N) and the predictands (T_{N+j})**
  - **Provides a set of “modes” for each lead time**

- **SVD procedure performed on first 11 years of data and tested on the remainder 7 years**



Time-longitude plots of 3-pentad OLR prediction (right; "Pentad0 + 3"), along with validating total (left) and band-passed (center) OLR anomalies, for 1992 northern hemisphere "winter". Data are averaged between 10°S and 10°N. Negative OLR values are shaded and indicate positive rainfall anomalies. Lines at 150°E extending from the beginning of the period through February indicate the overlapping COARE Intensive Observation Period at the site of the central IMET ocean / surface flux mooring.

Real-Time Long-Range Statistical Forecasts of the Western United States Rainfall

Statistical Forecasts of Intraseasonal and Seasonal Variations of Precipitation and Temperature over the Western United States

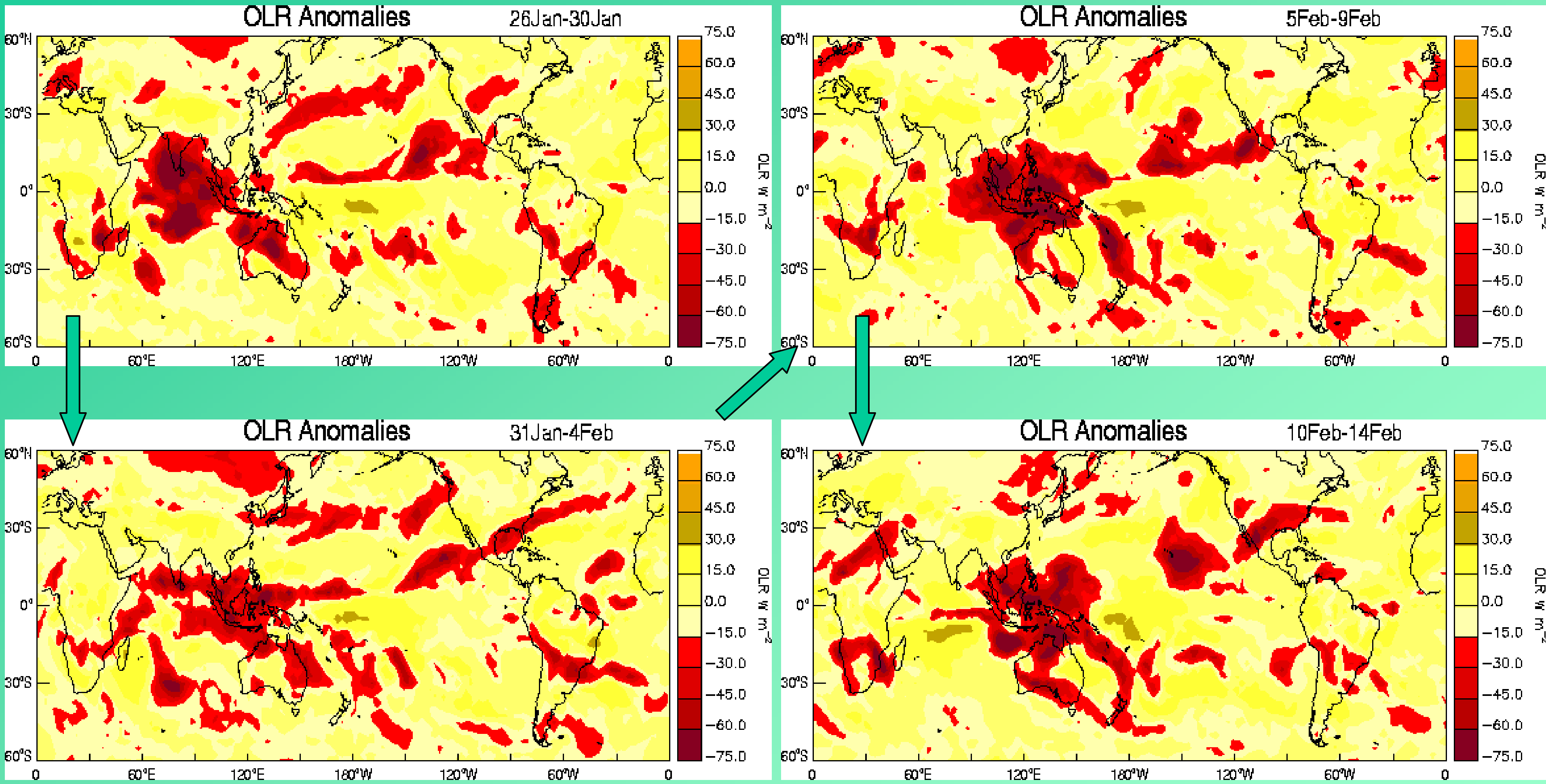
Funding Agency: NOAA-CLIVAR-Pacific Program

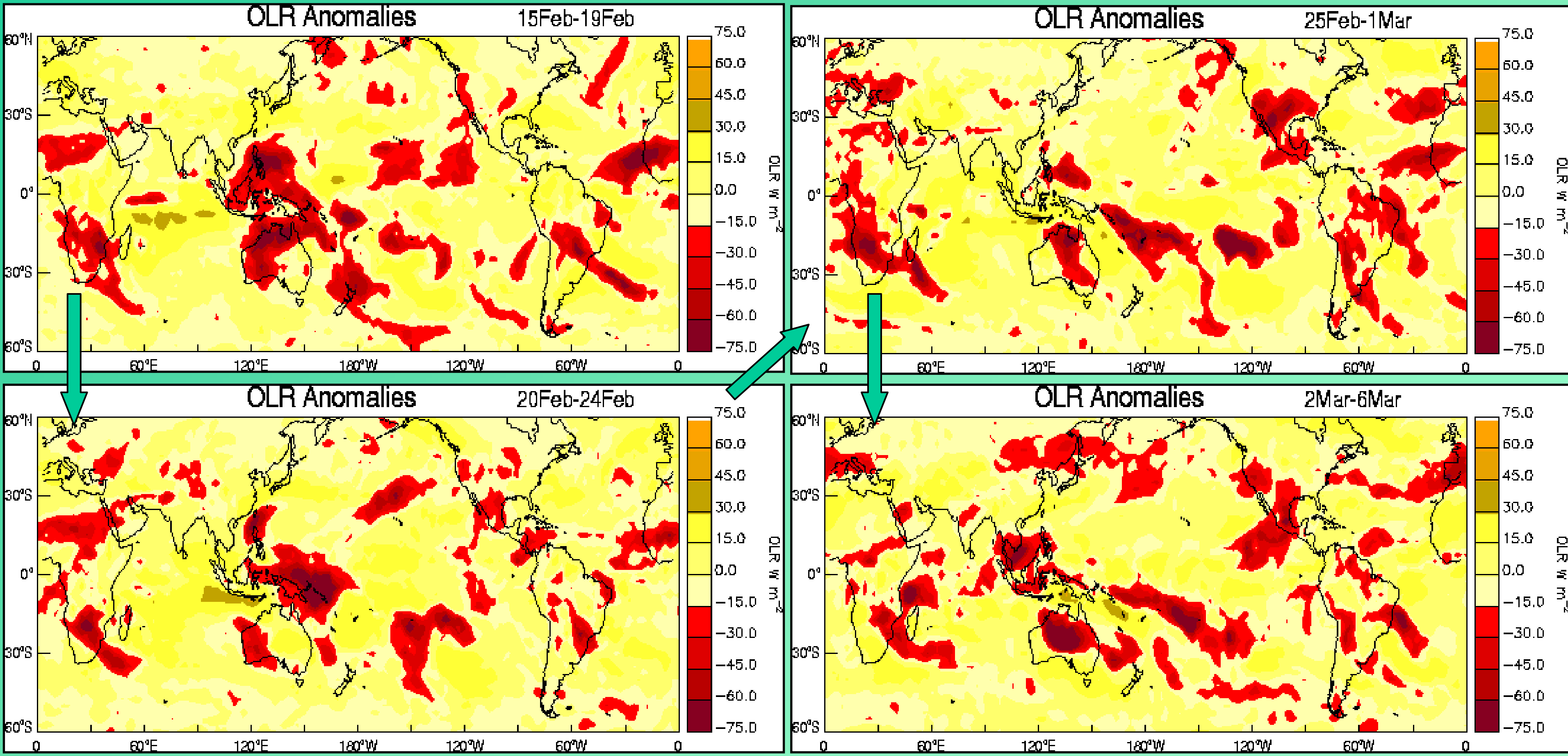
Principal Investigator: Dr. Charles Jones

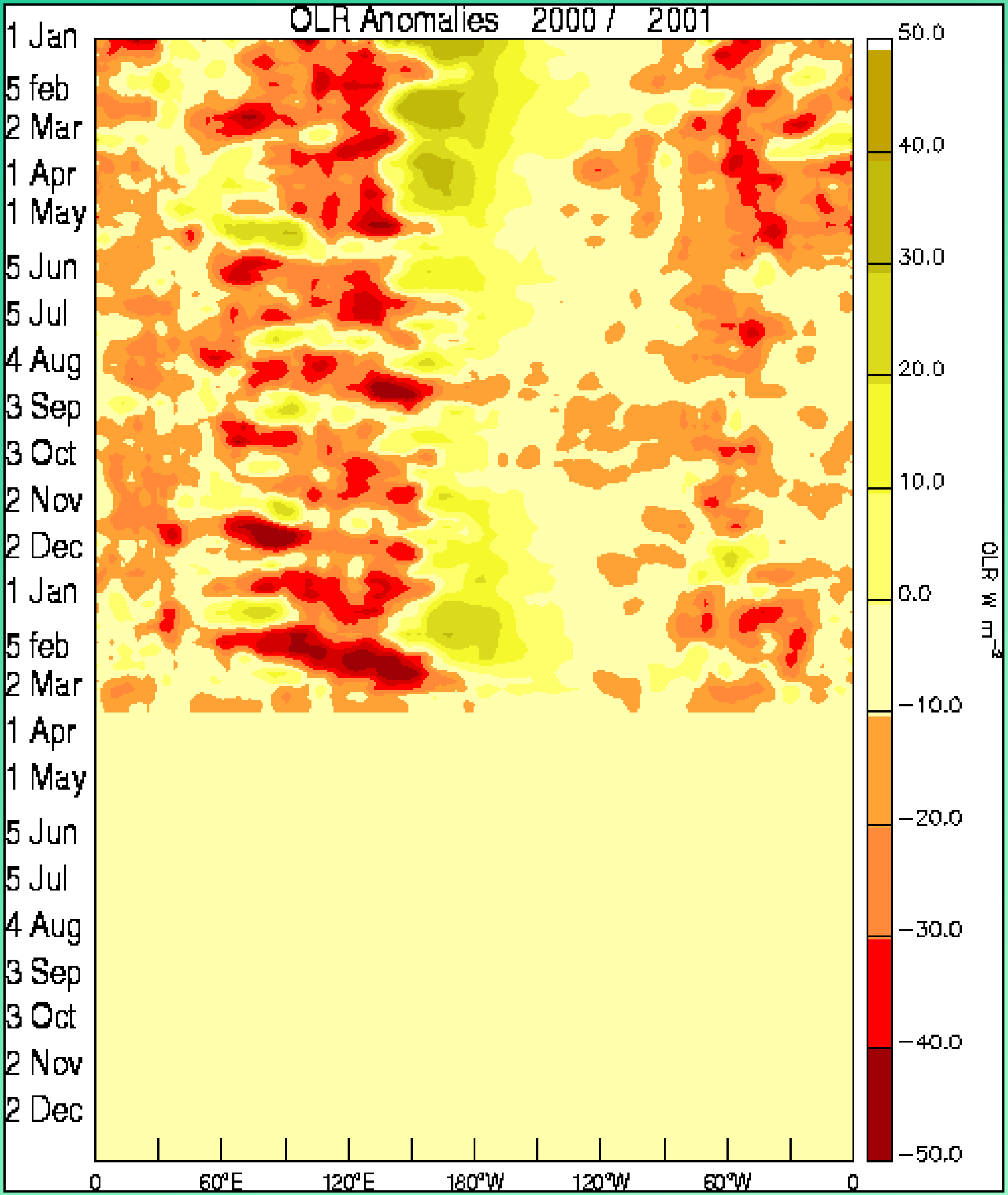
Abstract

One of the main scientific goals of the Climate Variability and Predictability – Pacific Program (CLIVAR-Pacific) is to determine and test hypotheses for improving seasonal-to-interannual prediction. The CLIVAR program also motivates the examination of the influence of intraseasonal variations on seasonal predictability. The main goal of this project is to investigate the intraseasonal and seasonal predictability of precipitation (P) and surface air temperature (Ta) over the western United States. The objectives are: 1) Implement experimental real-time statistical forecasts of the Madden-Julian Oscillation (MJO); 2) Determine the relative importance of tropical intraseasonal (MJO) and interannual (ENSO) variations in accounting for intraseasonal predictability of P and Ta. 3) Assess the contribution of seasonal variations in the MJO activity to the seasonal predictability of P and Ta. 4) Implement experimental real-time statistical intraseasonal and seasonal forecasts of P and Ta.

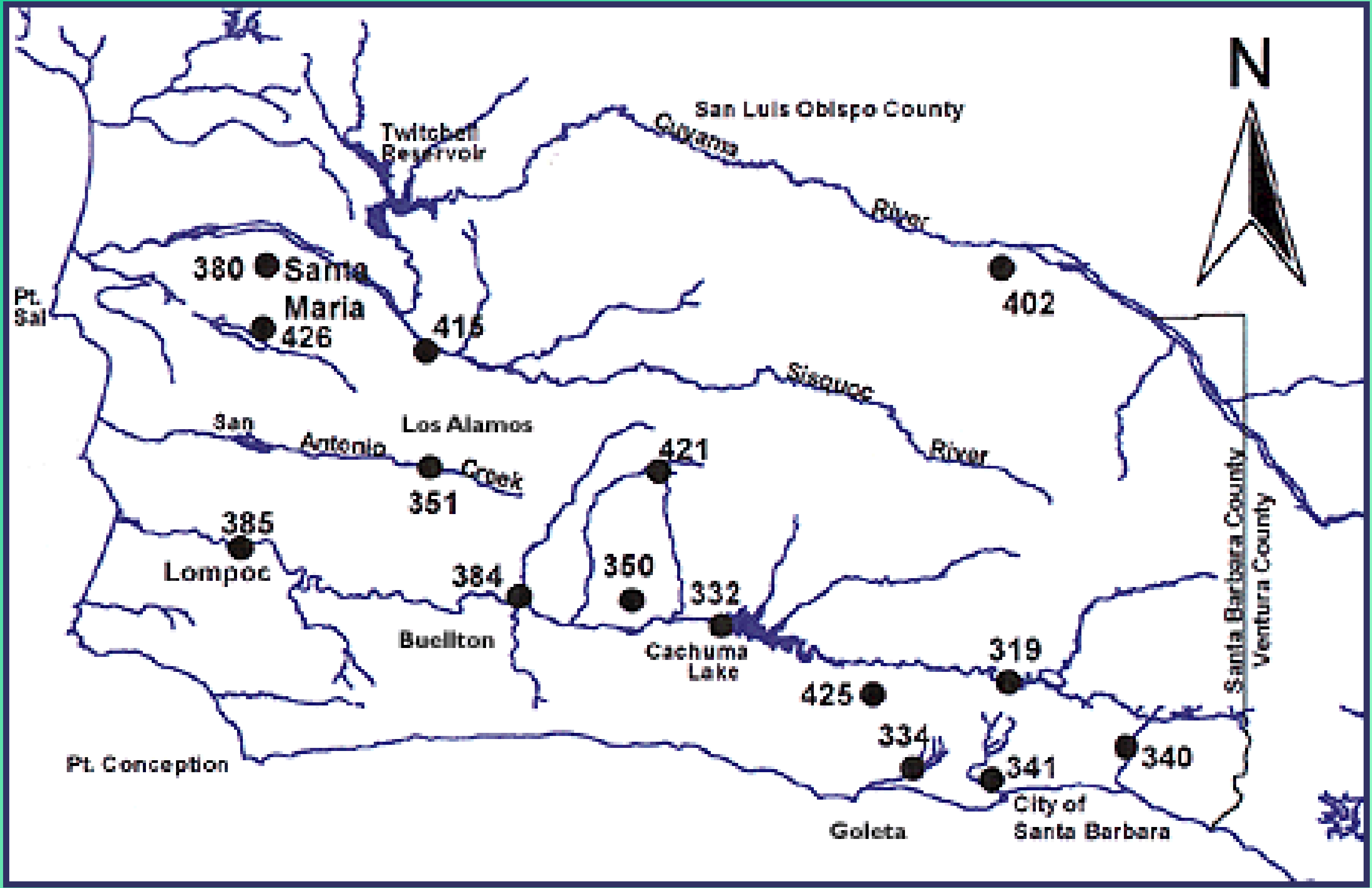
Example of possible tropical-intraseasonal interaction associated with MJO



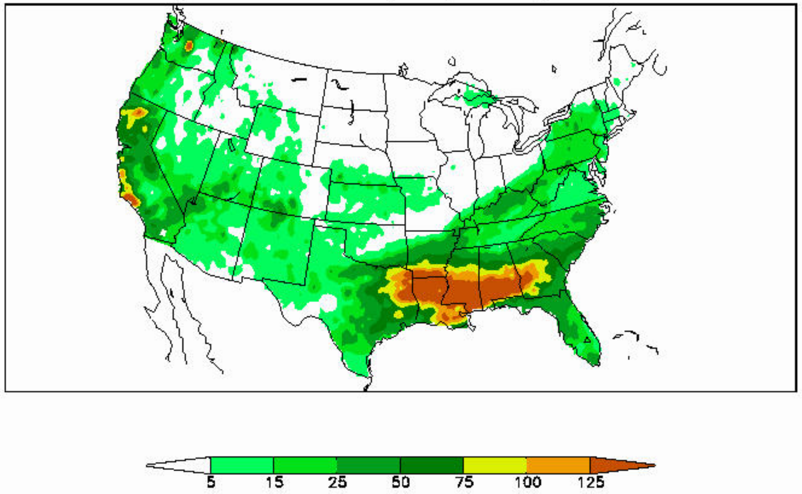

OLR Anomalies
15Feb-19Feb
OLR Anomalies
25Feb-1Mar
OLR Anomalies
20Feb-24Feb
OLR Anomalies
2Mar-6Mar
60°N
30°S
0°
30°S
60°S
0
60°E
120°E
180°W
120°W
60°W
0
75.0
60.0
45.0
30.0
15.0
0.0
−15.0
−30.0
−45.0
−60.0
−75.0
OLR W m⁻²


OLR Anomalies 2000 / 2001
1 Jan
5 feb
2 Mar
1 Apr
1 May
5 Jun
5 Jul
4 Aug
3 Sep
3 Oct
2 Nov
2 Dec
1 Jan
5 feb
2 Mar
1 Apr
1 May
5 Jun
5 Jul
4 Aug
3 Sep
3 Oct
2 Nov
2 Dec
0
60°E
120°E
180°W
120°W
60°W
0
50.0
40.0
30.0
20.0
10.0
0.0
−10.0
−20.0
−30.0
−40.0
−50.0
OLR w m^{-2}

March 5, 2001



Current Rainfall Data: For past 24 hours as of 8:00 a.m on date indicated March 5, 2001. Amounts are preliminary and subject to change. Santa Barbara County Public Works Dept.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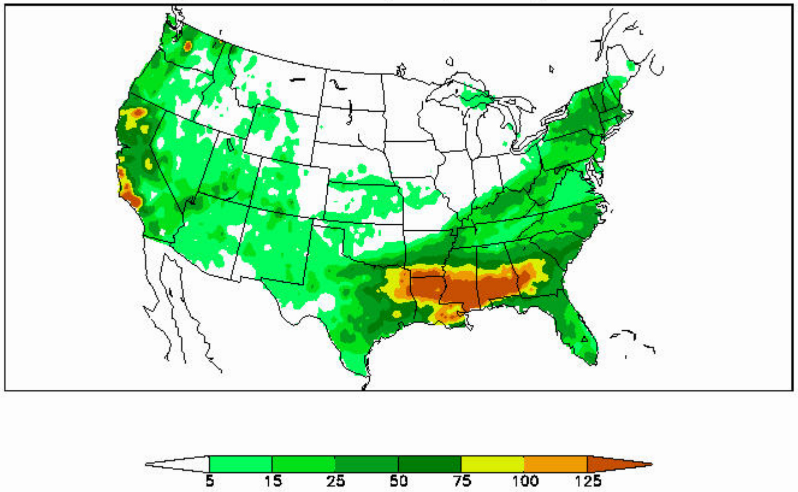
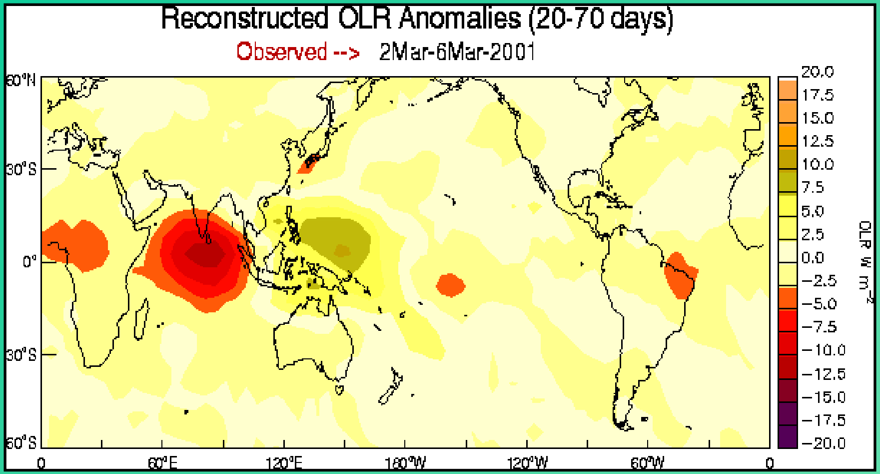
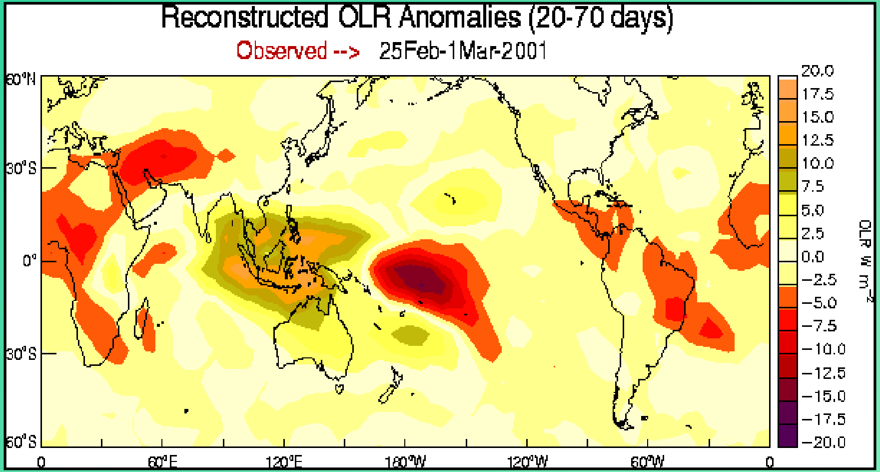
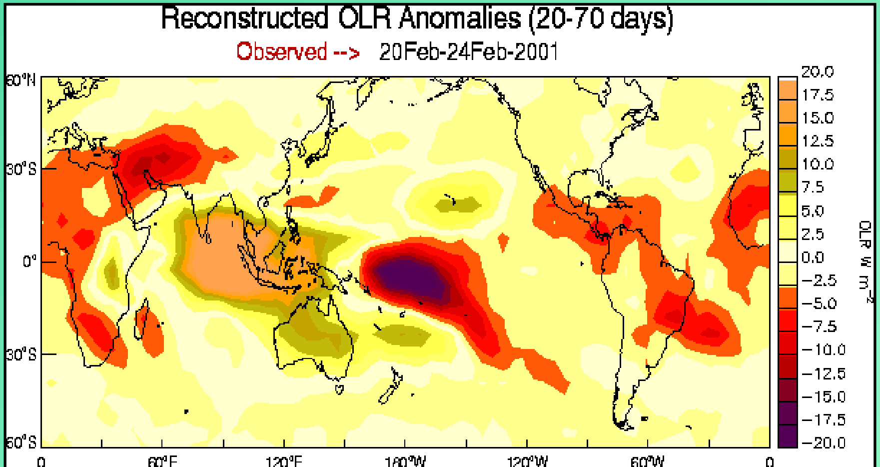

7-day accumulation (mm) ending 20010306







Work is in progress to:

- Develop real-time statistical forecasts of the MJO

- Develop real-time statistical forecasts of rainfall

- Further information about this research can be accessed at: http://www.icess.ucsb.edu/asr/