## $\rightarrow$ **1. Introduction and Background** Introduction pue **Background**

The Madden-Julian oscillation (MJO) produces variations in low-level winds over the<br>east Pacific warm pool that force variability in summertime precipitation, and an<br>associated modulation of tropical cyclones. Recent studi The Madden-Julian oscillation (MJO) produces (e.g. Walisersummertime MJO-related variations may be predictable up to 2-3 weeks in advance associated modulation of tropical cyclones east Pacific warm pool that force variability in summertime precipitation, and an EPIC2001 experiment, expressed in terms of 200 hPa et al. 1999). As shown below, one such event occurred during the . Recent studies have shown that these variations in low-level winds over the velocity potential. **the** 

## **Air-Sea Interaction in the Tropical Northeast Pacific Boreal Summer Intraseasonal Variability and**   $\boldsymbol{G}$ U  $\mathbf O$ 99  $\overline{\phantom{a}}$ eal  $\overline{\mathbf{5}}$  $\overline{\mathbf{d}}$  $\boldsymbol{G}$  $\overline{\phantom{a}}$ unme  $\mathbf{\Omega}$ Ctio  $\blacksquare$  $\blacktriangledown$  $\overline{\mathbf{5}}$ <u> The Contract of the Contract</u> Ufr  $\overline{\phantom{a}}$  $\overline{\phantom{0}}$  $\frac{9}{5}$  $\overline{\Phi}$ 689  $\overline{\phantom{a}}$  $\blacktriangle$  $\mathbf O$ O  $\overline{\phantom{a}}$  $\overline{\phantom{a}}$  $\Omega$  $\overline{\mathbf{z}}$  $\boldsymbol{\omega}$ **ar**  $\bullet$ **The Co ap**  $\blacksquare$  $\overline{\phantom{a}}$  $\boldsymbol{\Phi}$ ≕  $\boldsymbol{\omega}$ **IIty**  $\boldsymbol{\omega}$  $\overline{\phantom{a}}$  $\overline{\mathbf{z}}$  $\overline{\mathbf{U}}$ D<br>O 30 ific

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filtered zonal wind (7.5 A more generalized lag-correlation analys region in precipitation and winds is as dominant as anywhere in the Tropics. Spectral analysis indicates that a strong intraseasonal peak (~50 days) in the east MJO wind anomalies into the tropical eastern north Pacific during summertime. Pacific warm pool occurs then (see below). The intraseasonal spectral peak in this o N-12.5 <sup>o</sup>N averaged) shows significant eastward propagation of N averaged) shows significant is of NCEP reanalysis 30-90 day bandpass  $Q_{\rm t}$ 

**and by variations in eddy activity, including**  iding<br>Iding **DO** 

> Intraseasonal SST variance during summertime maximizes over the<br>east Pacific warm pool (see right), with another maximum in a band<br>just to the north of the equator. The intraseasonal band (30-100 days)<br>explains about 30% o just to the north of the equator. The intraseasonal band (30-100 days) over the east Pacific warm pool during summertime. explains about 30% of the total SST variance (including interannual) east Pacific warm pool (see right), with another maximum in a band Intraseasonal SST variance during summertime maximizes over the

The equatorial variance maximum is likely associated with tropical<br>instability waves, having a dominant period closer to 30 days than the<br>40-50 day periodicity associated with the MJO. The equatorial variance maximum is likely associated with tropical 40-50 day periodicity associated with the MJO. instability waves, having a dominant period closer to 30 days than the



SSTs within t<br>about 1/8 of a **SSTs in the :<br>during sumn<br>coherence sc<br>While phase<br>SSTs within t** pool and<br>Maloney equi

alth  $\overline{5}$  $\boldsymbol{c}$ iquared between SST and precipitation is also sitraseasonal band across the east Pacific warm I<br>traseasonal band across the east Pacific warm I<br>agging SST by a 1/4 phase (~10 days) when they a<br>ough at increasing lags towa **Doo** significant (0.3-<br>pool, with colo dted

Coherence<br>0.4) in the in<br>precipitation spatially, although at increasing lags toward the north. **0.4) in the intraseasonal band across the east Pacific warm pool Coherence squared between SST and precipitation is also significant (0.3** precipitation lagging SST by a 1/4 phase (~10 days) when they are colocated precipitat<br>patially,

**easterly waves and tropical cyclones.**

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The MJO-rel<br>variations ir<br>latent heat f<br>this region. **this region. variations in latent heat flux during MJO events. In fact, The MJO-related variations in wind speed contribute to latent heat flux anomalies are primarily wind-driven over**  related variations in wind speed contribute to<br>in latent heat flux during MJO events. In fact,<br>it flux anomalies are primarily wind-driven ove

Analysis of June-October Intraseasonal SST Analysis  $Q_t$ June October Intras **Basona**  $\boldsymbol{\omega}$  $\overline{O}$ 

**boreal summer. significant 50 day peak over the east Pacific warm pool during A spectral analysis using eight years of TMI SST data indicates a**  Only the climatological seasonal cycle was removed A spectral analysis using eight years of TMI SST data indicates a<br>significant 50 day peak over the east Pacific warm pool during<br>boreal summer. Only the climatological seasonal cycle was removed<br>before the spectra were com explains a large fraction of the intraseasonal SST variance in this before the spectra were computed. As will be shown below, the MJO

of convection to the a<br>during periods of MJO Surface MJO westerly (easterly) anomalies are associated with an enhancement<br>(suppression) of convection over the warm pool, and a suppression (enhanceme<br>of convection to the east of 110°W (see below left). <sup>Wind jets appe</sup> during periods of MJO easterly anomalies (not shown). **of convection to the east of 110 (suppression) of convection over the warm pool, and a suppression (enhancement) Surface MJO westerly (easterly) anomalies are associated with anW (see below left).** Wind jets appear to be active  **enhancement** 

> **support MJO convection over the east Pacific warm suggesting that wind-evaporation feedback may help significant coupling between latent heat flux and An analysis from TAO buoys and TRMM indicates a pool during summertime. precipitation over the east Pacific warm pool (see left),**  crecipitation o<br>suggesting tha<br>suggesting tha<br>support MJO c An analysis fro<br>Significant cou **OOLL MJC** is from TAO buoys and TRMM indicates a<br>i coupling between latent heat flux and<br>ion over the east Pacific warm pool (see left),<br>ig that wind-evaporation feedback may help<br>IJO convection over the east Pacific warm summertime

**warm pool during summertime, gneratedA significant 50-day intraseasonal spectral peak in SST occurs in the east Pacific easterly wave and tropical cyclone activity. destructively to the climatologicalprecede MJO precipitation anomalies by 5-10 days.**  sasterly significant 50-d.<br>varm pool during  $\overrightarrow{0}$ **S** ဂ En **oC over the east Pacific warm pool during an MJO lifecycle. SST anomalies**  malle  $\frac{1}{2}$ NBM Ver th  $\vec{0}$ ဝံ ဖွ  $\mathbf \Phi$ D  $\mathbf{F}$ ecip **Vay**  $\boldsymbol{\omega}$  $\Rightarrow$ intraseasonal spectral peak in SST occurs in the east Pacific<br>ummertime, gnerated in large extent by the MJO. SSTs vary by up<br>Pacific warm pool during an MJO lifecycle. SST anomalies<br>itation anomalies by 5-10 days.  **wind field, and by 2) MJO-induced variations in in large extent by the MJO. SSTs vary by up** 

about 1/8 of a cycle (~5 days). Interestingly, no coherence occurs between warm SSTs within the warm pool, SSTs north of 14 While phase vectors broadly indicate an in-phase relationship for intraseasonal coherence squared is significant and exceeds 0.4 across much of the warm pool. **during summertime. SSTs in the 30-90 day band are coherent across the east Pacific warm pool**  Maloney and Kiehl (2002) who used Reynolds SST data. pool and equatorial SST in the intraseasonal band, contradictinguwn  $\overline{S}$ uared is significant and exceeds 0.4 across much of the warm<br>vectors broadly indicate an in-phase relationship for intraseaso<br>oe warm pool, SSTs north of 14ºN tend to lag those to the sout<br>cycle (~5 days). Interestingly, n 0-90 c<br>ertim Č qay band ne. Usin<br>is signi<br>s broad Using a reference SST time series was at 9 lug **d are coher**<br>I a reference **Prent across** for a series of the series of SCT time series of SCT time series of the series of the series of  $\sim$  $\mathbf \Phi$ N tend to lag those to the south by Seri eus  $\boldsymbol{\Phi}$ ast : Pacific<br>s at 9ºN, the results of N, 92 varm pool.<br>easonal<br>south by W, o warm<br>s of

**6. Conclusions**

**A full reference list can be found in Maloney and Esbensen (2006), in press in** 

Maloney and Esbensen (2006), in pres

can be found in

*Monthly* 

6. Conclusions<br>Satellite and buoy da<br>wind variations over<br>supported by wind-i **anomalies are generated both by 1) vector mean winds adding constructively or supported by wind-induced latent heat flux variability. These latent heat flux wind variations over the east Pacific warm pool during June-October that are Satellite and buoy data show that the MJO is associated with strong precipitation and**   $\Omega$ lata show that the MJO is associated with strong precipitation and<br>r the east Pacific warm pool during June-October that are<br>induced latent heat flux variability. These latent heat flux<br>rated both by 1) vector mean winds a

*Weather Review***.**

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the Department of Commerce.



Wind speed over the warm pool is<br>enhanced during periods of MJO westerly<br>anomalies and enhanced precipitation, wi<br>suppression of wind speed during MJO<br>easterly periods (see above). **easterly periods (see above). suppression of wind speed during MJO anomalies and enhanced precipitation, with enhanced during periods of MJO westerly Wind speed over the warm pool is xith**<br>with

Wind speed anomalies associated with t<br>MJO appear to be caused both by<br>intraseasonal vector wind anomalies adc<br>to the climatological southwesterly flow,<br>and by variations in eddy activity, includ<br>easterly waves and tropica **to the climatologicalWind speed anomalies associated with the intraseasonal vector wind anomalies added MJO appear to be caused both by southwesterly flow,**  ldded the

For example, the suppression of wind speed<br>during MJO easterly periods appears to be<br>about equally due to easterly anomalies add<br>to the climatological southwesterly flow and<br>suppression of eddy variance (see left). suppression of eddy variance (see left). to the climatologicalabout equally due to easterly anomalies added during MJO easterly periods appears to be For example, the suppression of wind speed southwesterly flow and added<br>and  $\sigma$ 

Intraseasonal Precipitation vs. TAO Buoy Latent Heat Flux

TAO

**Buoy** 

Latent<br>He

 $\ddot{a}$ 

**Flux** 

NS.

Precipitation

Intraseasonal



## $\mathbf{\hat{S}}$ **3. Analysis of Intraseasonal SST Analysis** of Intraseasonal **1SS**





A lag<br>indica the MJO index, the implications of which will become apparent below. **the east Pacific warm pool during June-October (see below). A lag correlation between the MJO index (multiplied by -1) and intraseasonal SST**  important factor in controlling east Pacific warm pool SST during summertime.**indicates that the MJO index explains about 40% of the intraseasonal SST variance in**  the east P portant<br>e MJO ir **J COITE ation**<br>ates that the ្ម<br>ខ  $\sigma$ etween the MJO index (multiplied by -1) and intraseasonal SST<br>MJO index explains about 40% of the intraseasonal SST variance<br>rm pool during June-October (see below). Thus, the MJO is an<br>ontrolling east Pacific warm pool SS Thus, the MJO is an SST leads  $\overline{5}$ 





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level westerly flow (e.g. Maloney and SobelRecent modeling work also suggests that wind-evaporation<br>feedback supports MJO convection in this region (Maloney<br>and Esbensen 2005), and is consistent with the more<br>generalized view that wind-evaporation feedback supports MJO convection across the Tropics in regions of mean lowgeneralized view that wind-evaporation feedback supports and Esbensen 2005), and is consistent with the more feedback supports MJO convection in this region (Maloney Recent modeling work also suggests that wind-evaporation



## N. **2. Analysis of the June-October MJO Analysis of the June** October MJO

We conduct an analysis of the MJO in the east Pacific warm pool during June-<br>1998-2005 using satellite and buoy data. Enhanced TAO array measurements<br>for EPIC2001 were available from 2000-2004. for EPIC2001 were available from 2000-2004. We conduct an analysis of the MJO in the east Pacific warm pool during June-October of 1998-2005 using satellite and buoy data. Enhanced TAO array measurements associated -October c<br>s associate of<br>dgd

**Intraseasonal SST variations in the east Pacific will be related**

 **to the MJO** 

**using the tropical equatorial MJO index of Maloney and Kiehl (2002).**

The

MJO index, as described in Maloney and Kiehl (2002).

are linearly combined to form an

The principal components of the leading EOFsHemisphere, substantial zonal wind variance also is captured in the east Pacific. right). Although peak variance for these EOFsrepresent a quadraturepair that defines the eastward propagating MJO (see leading EOFsof the 30-90 day equatorial averaged 850 hPa

occurs in the Eastern

zonal wind

to show that intraseasonal SST anomalies of even lesser magnitude than shown below variations.the response is apparent, with warm SST anomalies that precede enhanced convection are likely important for producing realistic MJO convective variability . index.convection. This asymmetry is similar if being stronger and more widespread than the corresponding cold anomalies after **peak variations in SST can be as high as 1 (negative) SST anomalies by 5-10 days over the warm pool (see below). Peak to significant events. Suppressed (enhanced) convection typically precedes positive**  Significant MJO<br>composite MJO **composite MJO event is created (as a function of lag in days) bySignificant MJO events are defined as maxima of the index exceeding 1** composite MJ<br>ignificant ev<br>inegative) SS<br>peak variation<br>he response is b show that intrase<br>re likely important nvection. Precipitation anomalies west of 110 Maloney and Kiehl (2002) used an atmospheric GCM coupled to a slab ocean events are defined using minima of the MJO o W are not associated with strong SST **oC over an MJO lifecycle. averaging these**  An asymmetry in σ, **and a** 



**NJO** Compo