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Loss of Significance and Multidecadal Variability of the Madden-Julian Oscillation

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Loss of significance and Multi decadal variability of Madden Julian Oscillation.

E.Suhas and B.N.Goswami

Suhas E, B. N. Goswami. 2010: Loss of Significance and Multidecadal Variability of the Madden–Julian Oscillation. *Journal of Climate* 23:13, 3739-3751.

The behavior of the MJO

Observational knowledge about the MJO: limited to reanalysis data ~ 60 years

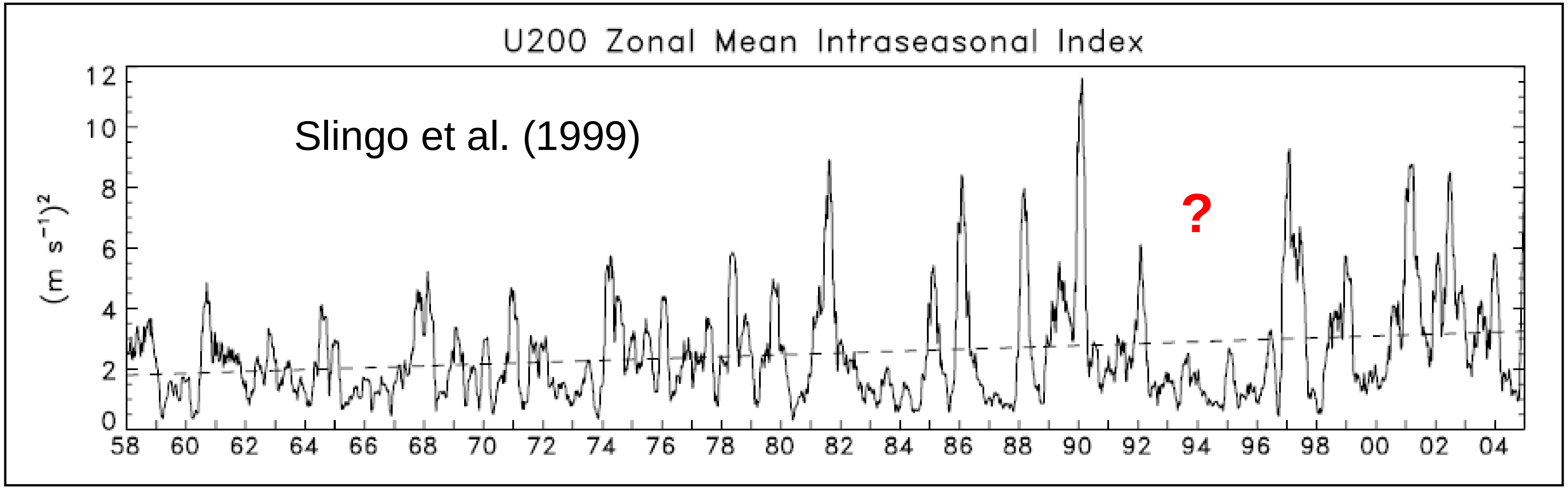
Does the MJO have a low-frequency mode of variability?

Will the MJO change as climate continues to warm?

Long-term behavior of the MJO is unknown

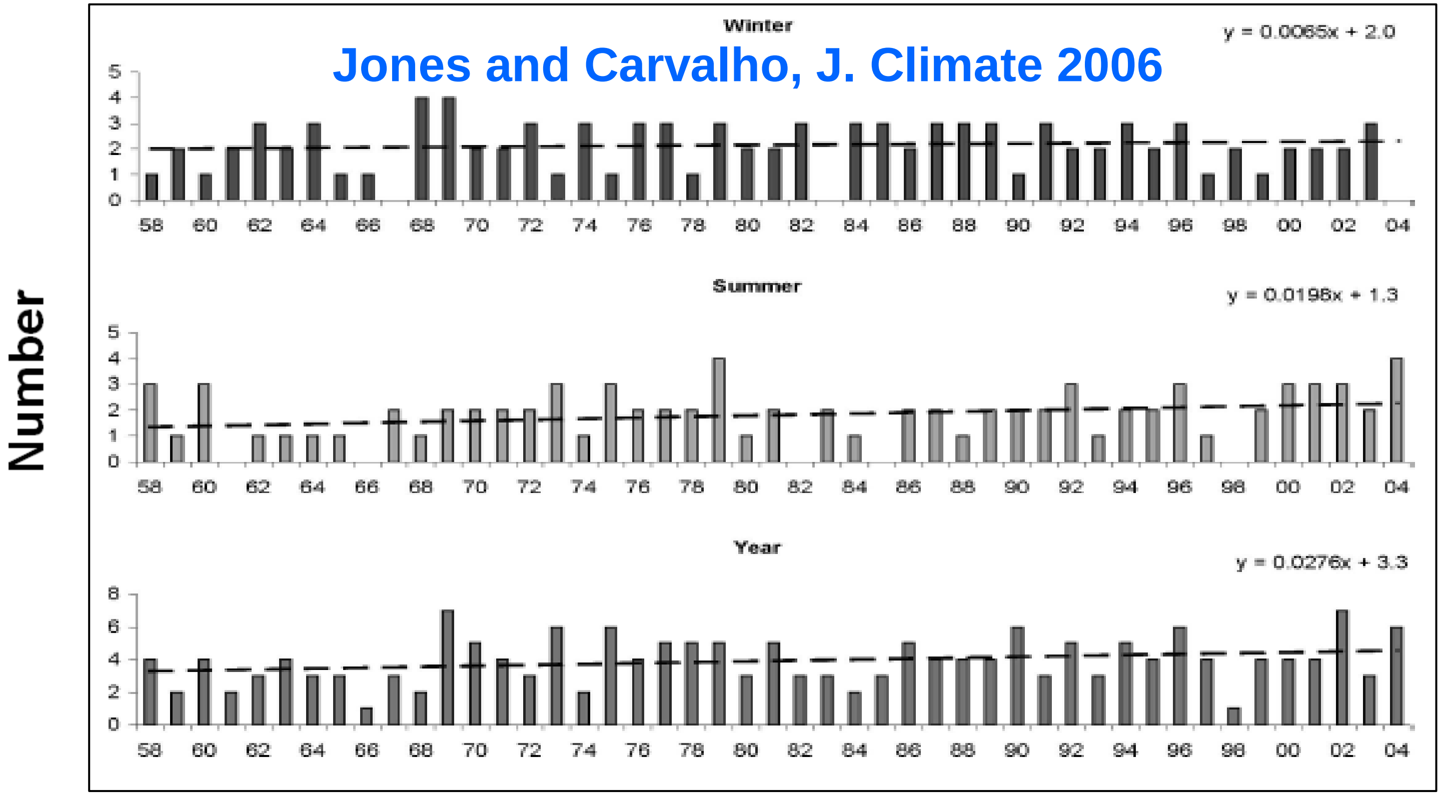
How do we identify and isolate MJO ?

MJO --- equatorially trapped,
planetary scale (Waveno:1-3), 30-60 day oscillations



- **Interannual variations in the MJO; NCEP/NCAR 1958-1997**
- **Zonal mean of U 200hPa (10°S - 10°N)**
- **20-100 day anomalies; square and apply 100 day smoothing**

CEOF analysis of band pass filtered anomaly

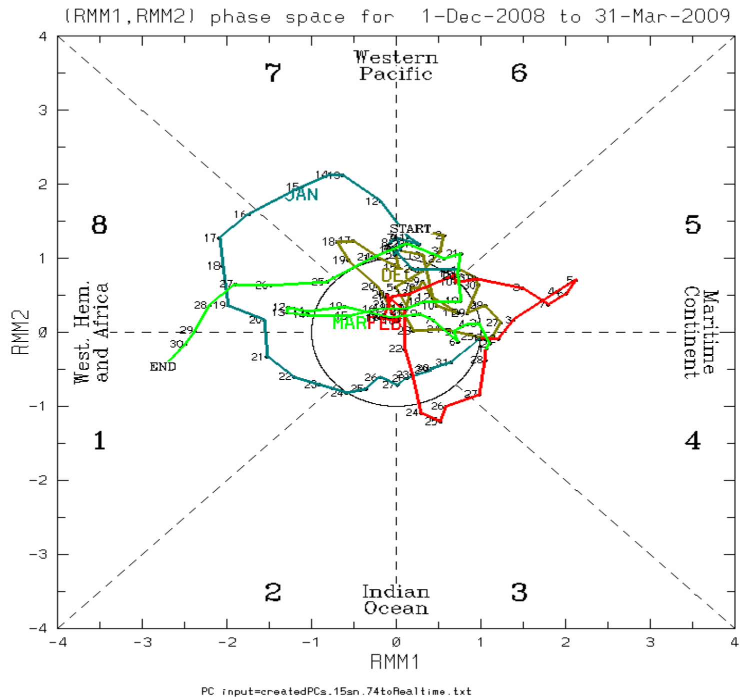


- **Positive linear trends in U200 and U850 intraseasonal anomalies in summer and winter.**
- **Positive trends in the number of summer MJO events.**

Wheeler and Hendon (2004) RMM indices

RMM1 and RMM2 indices

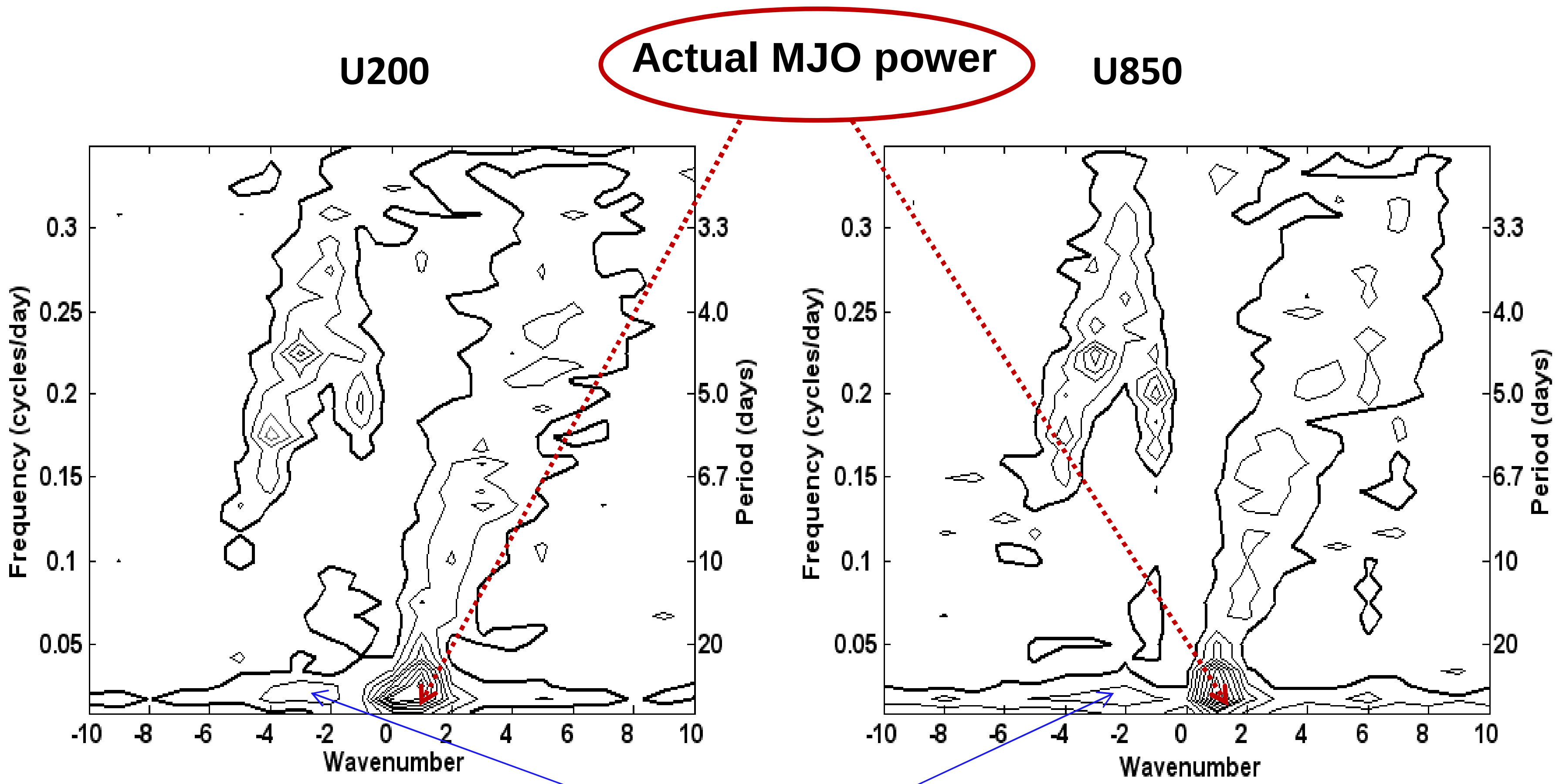
- Daily U200, U850 and OLR (1979-2010)
- Remove annual cycle
- Average 15S-15N
- Combined EOF analysis (U200, U850,OLR)
- Use (EOF1, PC1), (EOF2, PC2)



Do these indices really taken into account salient features of MJO signal?

Does the linear trend in tropical ISV is really attributed to MJO alone?

Wavenumber-frequency Spectra (Raw/Background)



Significant Westward propagating power is seen at both levels on MJO timescale

Hence ,to separate out the eastward propagating, equatorially trapped, wave no 1-3 , **true MJO power**, we use the *Wheeler Kiladis method* of **space time spectral analysis.**

Our Objective

- ✓ **Does the MJO variability show a linear increasing trend?**

- ✓ **Does the MJO have a low-frequency mode of variability (decadal)?**

- ✓ **How does the continuous warming in tropical Indian and Pacific Oceans influence the MJO?**

Wheeler-Kiladis Space-time Spectra : Methodology

Estimation of Raw power

❖ Construct daily anomalies of 59 NH winter seasons (NDJF) by removing the seasonal cycle.

❖ different 120 day segments are formed with 60 day overlap.

❖ After removing the linear trend from each segment, a complex FFT is applied in time for each latitude and time, and complex FFT is again applied in time for each latitude on the resultant Fourier coefficients.

❖ Multiplication of the result with its complex conjugates gives space-time power.

❖ The power computed by averaging each of the available segments is summed over the latitudes (15S-15N) .

Ad-hoc method of estimation of red background and statistical significance

Empirical estimation of red background

❖ Pass 1-2-1 filter through power repeatedly in both frequency and wavenumber.

frequency < 0.1 cycles/day ------ 3 times
frequency > 0.1 and frequency < 0.2 cycles/day ------ 5 times
frequency > 0.2 and frequency < 0.3 cycles/day ------ 10 times
frequency > 0.4 ----- 40 times.

3 times in wave number domain.

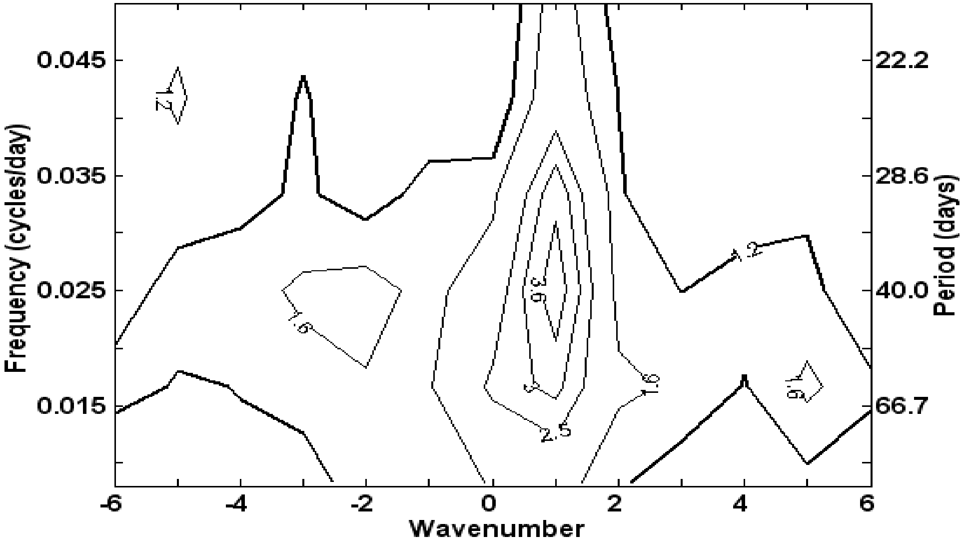
Statistical significance of space-time power

❖ Degrees of freedom of space-time power:-
2 (amplitude and phase)* 6(no. of independent lats.) *59 (no. of seasons).

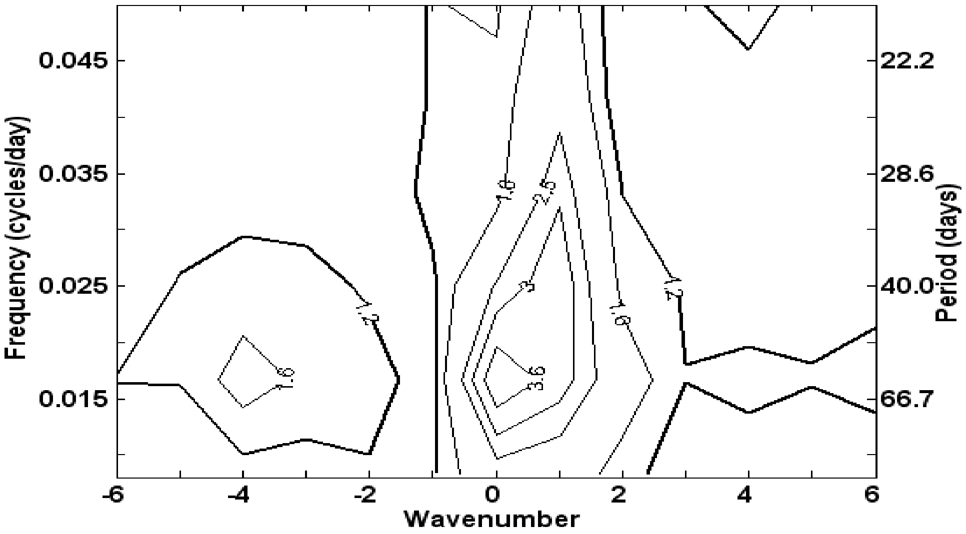
❖ compute the ratio between Raw power and red background and compare it with a Chi squared test with the corresponding no. of dof.

Nature of MJO variability:
Before and after the warming

U200 1948-1977

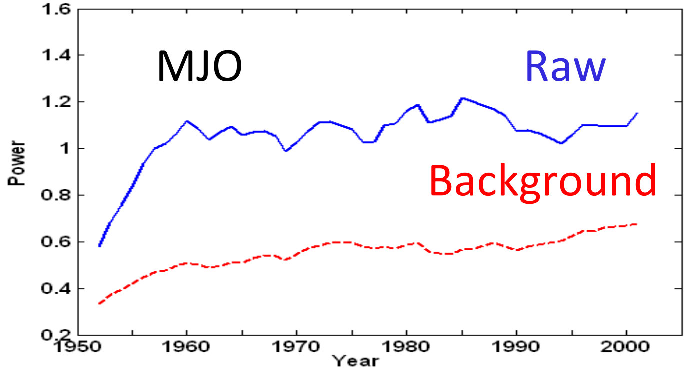


U200 1978-2006



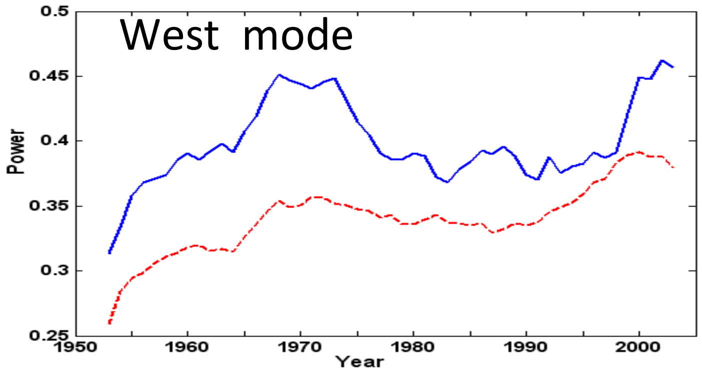
- ***Maximum power shifted from 40 days to 60 days*.**
- **Amplification of zonal mean (waveno.0) In the 20-70 day freq. band.**
- **significant power of westward mode shifted to higher wave nos.**

Raw and Background power for MJO, westward propagating mode and Zonal mean flow on 20-70 day timescale



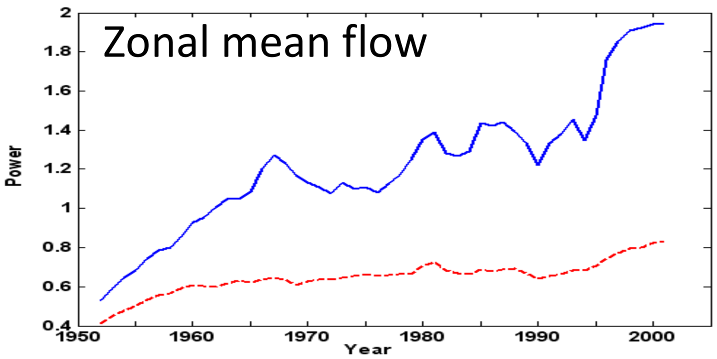
MJO

Raw----20-70day, wave no 1-3 average power using 10 yr sliding window, shows a significant increasing trend, though not as strong as the rate of increase of background power



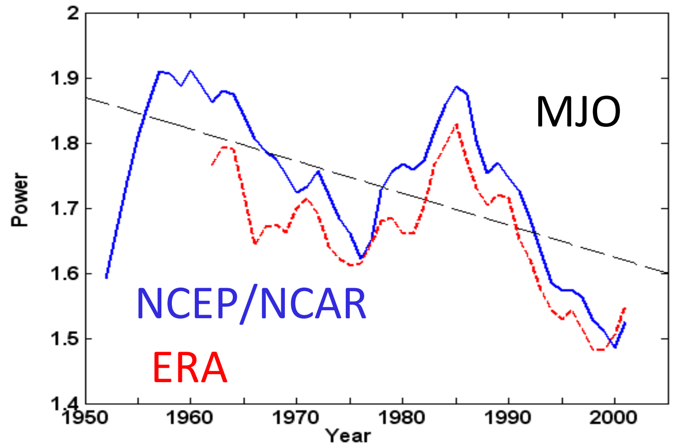
Westward propagating mode

Raw----20-70day, wave no -4 to -2 average power using 10 yr sliding window, shows a significant increasing trend, though not as strong as the rate of increase of background power

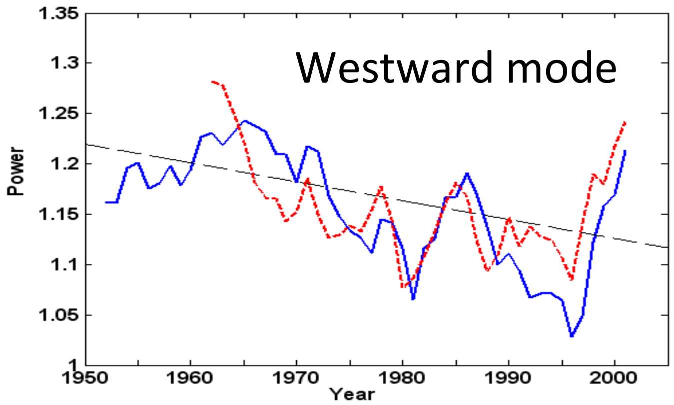


Zonal mean flow

20-70day, wave no zero average power using 10 yr sliding window, shows a significant increasing trend much above the increase in background power.

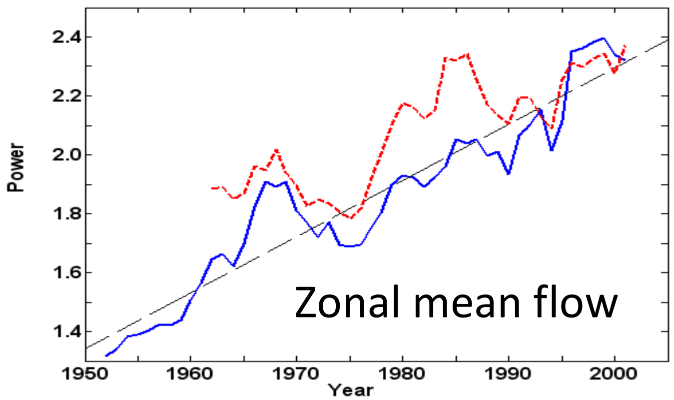


To examine the long term trend and variability we define an MJO metric as the Raw/background power averaged over wavenos. 1-3 in 20-70 day period band.



The MJO index for the period 1948-2006 through a 10 yr sliding window shows a linear decreasing trend with a ~30yr multi decadal variability riding over it.

Similar index for the westward mode also show a decreasing trend.



A steady significant increasing trend is observed in the zonal mean index, computed similarly

Certain questions remains to be answered……………..

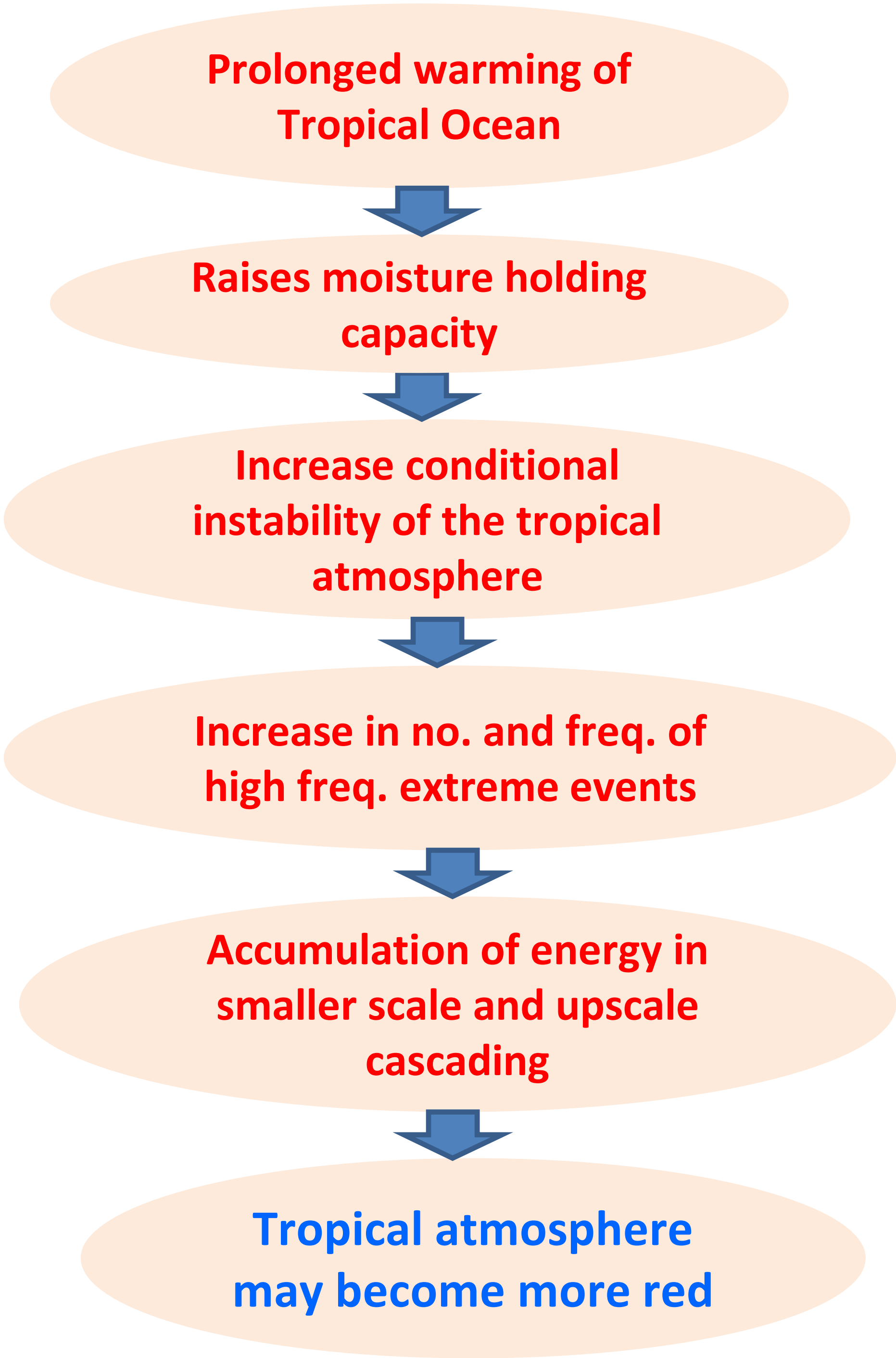
- ✓Why is MJO loosing its significance even though the atmosphere and ocean are warming?

- ✓ What is responsible for the multidecadal variability of significant MJO power?

- ✓ Why is the red background is increasing?

- ✓Why then is the power of MJO not increasing at the same rate as the red background?

Hypothesis


Prolonged warming of Tropical Ocean
Raises moisture holding capacity
Increase conditional instability of the tropical atmosphere
Increase in no. and freq. of high freq. extreme events
Accumulation of energy in smaller scale and upscale cascading
Tropical atmosphere may become more red

❖ ***To answer why the MJO power is decreasing and that of zonal mean is increasing We hypothesize that the zonal mean may be becoming more energetic through energy exchange with the MJO.***

Scale Interaction through KE exchange

The classical Lorenz approach separates the motion into zonal mean and eddy, and stationary and transient. ***Kinetic energy exchange between zonal mean and different scales can be estimated using the formula derived by Saltzman (1957)*** for the wave number domain and expanded by Hayashi (1980) for use in the frequency domain.

He derived the equations for the rate of growth of KE of a scale (wavenumber n) as it interacts with the zonal mean flow or with any other scales.

To test our hypothesis we **shall follow the procedure adopted by Saltzman.**

the kinetic energy exchanges between zonal mean flow and different waves were computed at 200hPa employing the method proposed by Hayashi (1980).

Primitive equations of motions on spherical co-ordinate

$$\frac{\partial u}{\partial t} = -\frac{u}{a\cos\varphi}\frac{\partial u}{\partial \lambda} - \frac{v}{a}\frac{\partial u}{\partial \varphi} - \omega\frac{\partial u}{\partial p} + v\left(f + \frac{u\tan\varphi}{a}\right) - \frac{g}{a\cos\varphi}\frac{\partial z}{\partial \lambda} - F_1 \qquad (a)$$

$$\frac{\partial v}{\partial t} = -\frac{u}{a\cos\varphi}\frac{\partial v}{\partial \lambda} - \frac{v}{a}\frac{\partial v}{\partial \varphi} - \omega\frac{\partial v}{\partial p} - u\left(f + \frac{u\tan\varphi}{a}\right) - \frac{g}{a}\frac{\partial z}{\partial \varphi} - F_2 \qquad (b)$$

$$\frac{\partial \omega}{\partial p} = -\left(\frac{1}{a\cos\varphi}\frac{\partial u}{\partial \lambda} + \frac{1}{a}\frac{\partial v}{\partial \varphi} - \frac{v\tan\varphi}{a}\right) \qquad (c)$$

$$\frac{\partial z}{\partial p} = -\frac{RT}{gp} \qquad (d)$$

$$\frac{dT}{dt} = \frac{h}{C_p} + \frac{\omega RT}{C_p p} \qquad (e)$$

Growth or decay of KE of a given scale n is given by

$$\frac{\partial K(n)}{\partial t} = \sum_{\substack{m=-\infty \\ m\neq 0}}^{\infty} \Bigg\{ U(m)\left(\frac{1}{a\cos\varphi}\Psi_{uu_\lambda}(m,n) + \frac{1}{a}\Psi_{vu_\varphi}(m,n) + \Psi_{\omega u_p}(m,n) - \frac{\tan\varphi}{a}\Psi_{uv}(m,n) \right)$$

$$+V(m)\left(\frac{1}{a\cos\varphi}\Psi_{uv_\lambda}(m,n) + \frac{1}{a}\Psi_{vv_\varphi}(m,n) + \Psi_{\omega v_p}(m,n) + \frac{\tan\varphi}{a}\Psi_{uu}(m,n) \right)$$

$$-\frac{1}{a\cos\varphi}\frac{\partial}{\partial\varphi}\left[\cos\varphi\left(U(m)\Psi_{vu}(m,n) + V(m)\Psi_{vv}(m,n)\right)\right] - \frac{\partial}{\partial p}\left(U(m)\Psi_{\omega u}(m,n) + V(m)\Psi_{\omega v}(m,n)\right)\Bigg\}$$

$$-\left[\Phi_{uv}(n)\frac{\cos\varphi}{a}\frac{\partial}{\partial\varphi}\left(\frac{U(0)}{\cos\varphi}\right) - \Phi_{vv}(n)\frac{1}{a}\frac{\partial V(0)}{\partial\varphi} + \Phi_{u\omega}(n)\frac{\partial U(0)}{\partial p} + \Phi_{v\omega}(n)\frac{\partial V(0)}{\partial p} - \Phi_{uu}(n)V(0)\frac{\tan\varphi}{a}\right]$$

$$-\left[\frac{1}{a\cos\varphi}\Phi_{uz_\lambda}(n) + \frac{1}{a}\Phi_{vz_\varphi}(n)\right] - \left[\Phi_{uF_1}(n) + \Phi_{uF_2}(n)\right] \qquad (1)$$

Where

$$\Psi_{ab}(m,n) = A(n-m)B(-n) + A(-n-m)B(n) \qquad \Phi_{ab}(n) = A(n)B(-n) + A(-n)B(n)$$

where a and b are any two dependent variables, and A and B are their respective Fourier transforms. Equation (1) is the equation for the rate of change of kinetic energy K(n) for a particular wave number n.

It can be sorted out to make it physically interpretable.

In a symbolic form equation (1) can be expressed as

$$\frac{\partial K_n}{\partial t} = <(K_m, K_p) \cdot K_n > + < K_0 \cdot K_n > + < P_n \cdot K_n > + F_n \qquad (2)$$

The calculation of rate of kinetic energy(KE) involves four important processes.

- **The transfer of KE to the scale of wave number n from pairs of other wavenumbers m and p (triad interaction). It is restricted by a trigonometric selection rule, i.e. n = m+p or n = |m-p| for an exchange.**

- The gain of kinetic energy of a given 'wavenumber n' when it interacts with the zonal mean flow.

- The growth of kinetic energy of a given wavenumber from the eddy available potential energy of the same scale.

- Friction.

Zonal to wave exchange of kinetic energy

$$< k_0 k_n > = -\left[\Phi_{uv}(n)\frac{\cos\varphi}{a}\frac{\partial}{\partial\varphi}\left(\frac{U(0)}{\cos\varphi}\right) - \Phi_{vv}(n)\frac{1}{a}\frac{\partial V(0)}{\partial\varphi} + \Phi_{u\omega}(n)\frac{\partial U(0)}{\partial p} + \Phi_{v\omega}(n)\frac{\partial V(0)}{\partial p} - \Phi_{uu}(n)V(0)\frac{\tan\varphi}{a}\right]$$

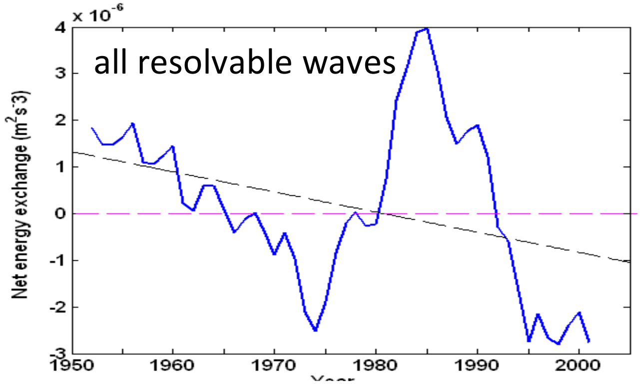
(3)

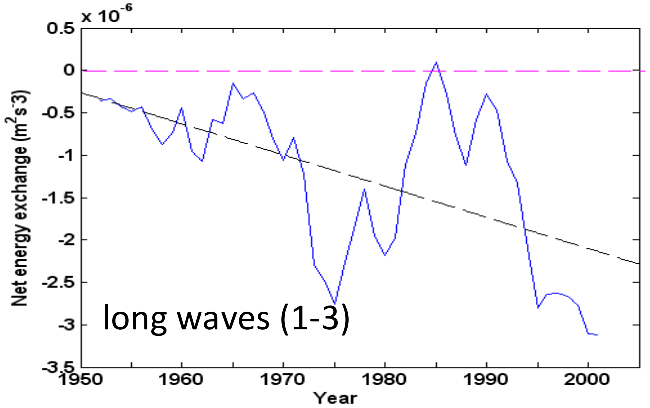
where *Kn* and *K0* represent the kinetic energy of wave number *n* and wave number 0 (the zonal mean) respectively;

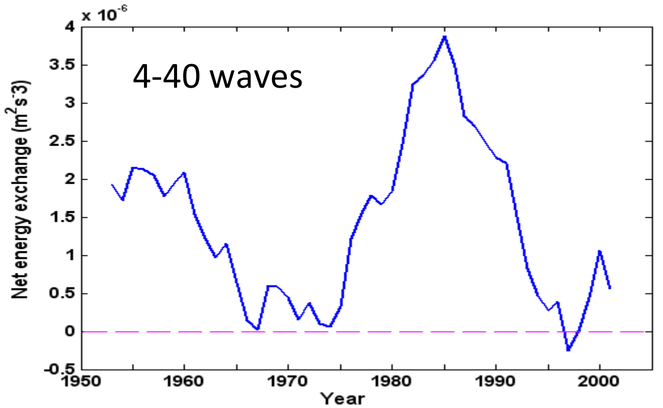
Eqn (3) is the conversion of the kinetic energy of the zonal mean to kinetic energy of wave number *n*.

This is more or less a barotropic energy exchange that invokes the covariance among the zonally averaged motion and the eddy flux of momentum.

Energetics: Exchange of KE between waves and zonal mean flow at 200 hPa







Positive (negative) sign of exchange indicates that zonal mean is loosing (gaining) energy to (from) waves.

The net kinetic energy exchange between zonal mean flow and waves exhibits a multidecadal oscillation and also shows a negative trend indicating that the zonal mean is steadily gaining energy from the waves.

The exchange of the net KE between zonal mean flow and planetary scale long waves (1 to 3) that KE always flows from planetary scale waves (MJO) to zonal mean flow and it also shows a linear increasing trend.

The transfer of KE from planetary scale waves to the zonal flow diminishes during high MJO activity and becomes substantial when the MJO power decreases.

The multidecadal variability of energy transfer from the MJO scale to zonal scale is closely linked with the multidecadal oscillation of significant MJO power .

Sensitivity to calculation of red background

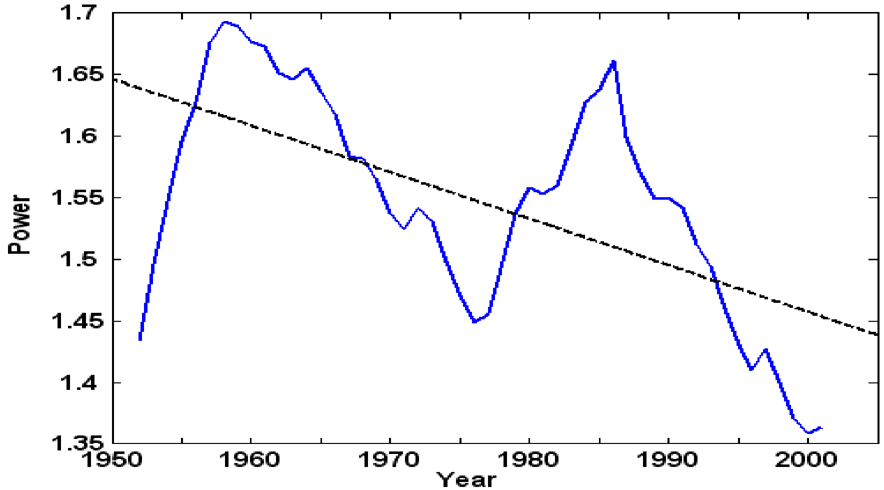
Multi-decadal variability and trend may be the by product of empirically estimated background noise spectra.

Objective estimation of background power

We followed **Hendon and Wheeler (2008)** method

- **Calculate average symmetric and anti symmetric spectra**
- **Reduce the MJO power to half**
- **Apply inverse FFT in time**
- **Fit Gilman et al (1963) red spectra**

***Objectively estimated background power is systematically higher than empirical one*.**



Role of ENSO and IOD

- We repeated the analysis by removing variability associated with IOD and ENSO.

- N.H. winter MJO variability and trend are not associated with known multidecadal variability.

Conclusions

In this study, we mainly focused on the ***changes in significant N.H. winter MJO activity on longer time scale and the importance of isolation of MJO variance from the red background.***

- **Using filtered MJO indices to explain MJO variability may mislead since some of the variance explained by them could come from the red background nature of tropical atmosphere. Also a fraction of the ISV in the period range between 20 and 70 days can come from significant westward propagating low frequency disturbances.**

- **Through normalized wave number frequency power spectra it was seen that the significant MJO power shows a decreasing trend and multidecadal variability.**

- **Energetics analysis at 200hPa shows that the supply of kinetic energy from planetary scale to zonal mean flow has increased, making the zonal mean flow more energetic in recent years. Also, there is a multidecadal variability in the net exchange between zonal mean flow and waves that appears to be directly linked to the multidecadal variability of MJO activity.**

- **The warming of the tropical ocean is increasing the moisture holding capacity of tropical atmosphere, making it more conditionally unstable. This may lead to more high frequency events accumulating energy in the smaller scales, which may eventually cascade energy to planetary scale and zonal mean flow and making them more energetic.**

- **The cascading of energy may not be restricted only to MJO scale but may also be distributed among other space and time scales making the atmosphere more red. MJO is loosing more energy to other scales and zonal mean in particular than gaining from convective feedback in a warming environment.**

- **Multidecadal variability of N.H. winter MJO is internally driven.**