A novel method of unraveling the possible connections between solar processes and Indian monsoon rainfall

Subarna Bhattacharyya[1], Roddam Narasimha[2]

[1] LLNL(Atmosphere, Earth and Energy Division)

[2]Jawaharlal Nehru Centre For Advanced Scientific Research (JNCASR), Bangalore, India

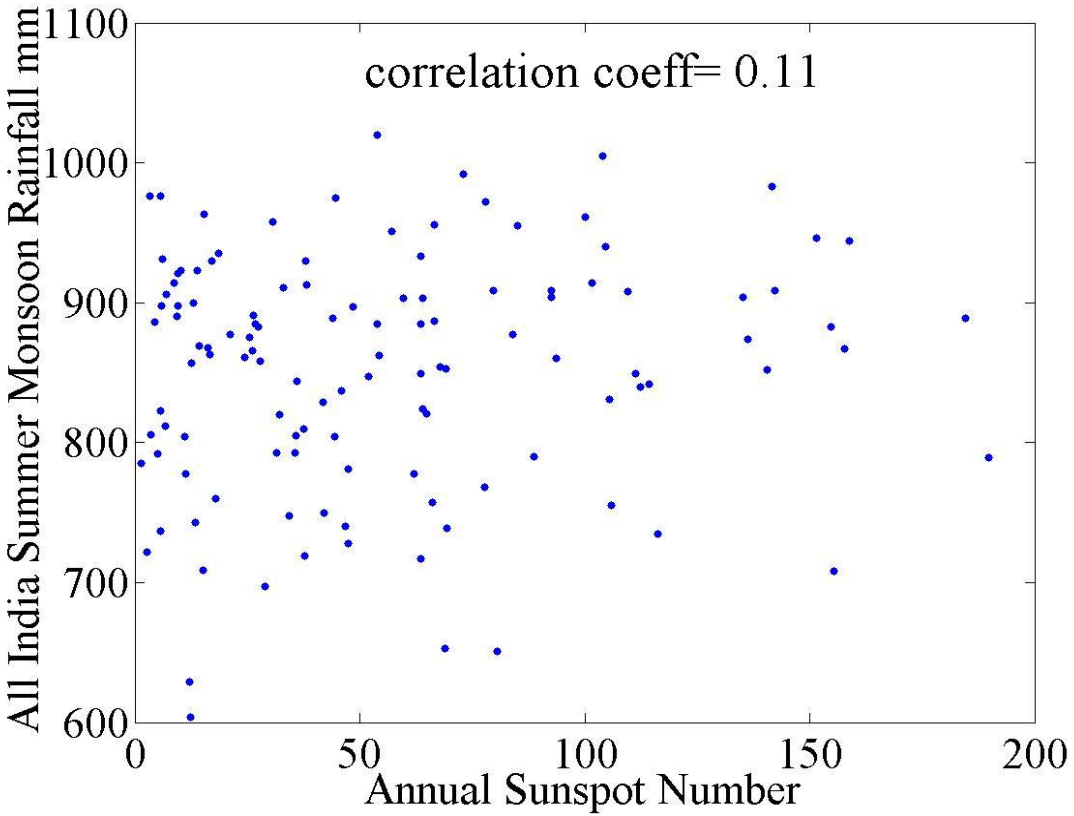
* This presentation was prepared under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, using results from my PhD Thesis, at JNC 2006, Adviser: Prof. Roddam Narasimha

Outline of the talk

- Background
- Striking similarity in Wavelet Maps of Monsoon Rainfall and solar process timeseries
- Analyzing similarities using Point Process of Wavelet transform coefficient maxima
- Surprisingly Simple Relationship between the two in wavelet space
- Spatial Variations
- Conclusions, Explanations, Possible Mechanisms

Background

Scatter Diagram



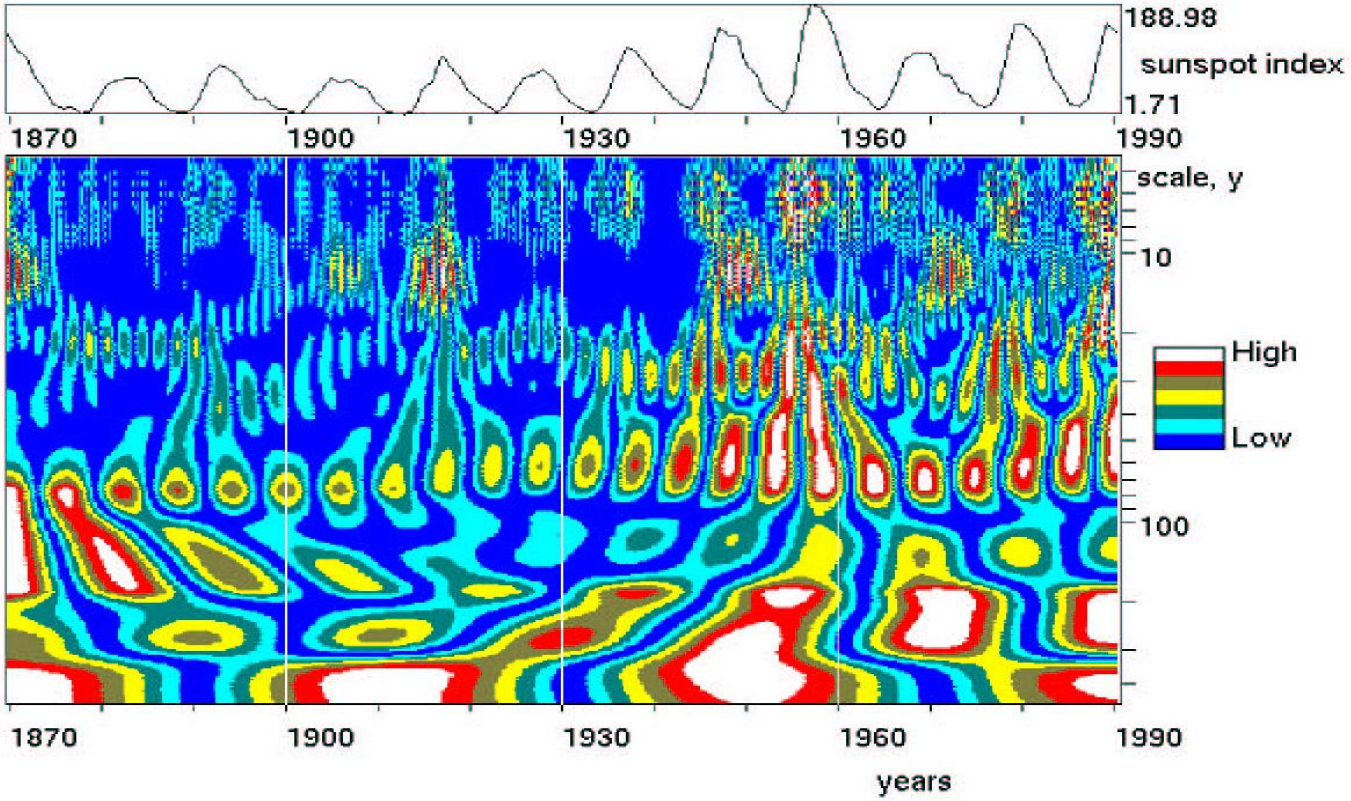
- Such poor correlations are one reason for scepticism.

Other reasons:

- Change in solar flux is very low <0.1%
- No 'known' physical mechanism

Confidence limits [-0.07, 0.29], 95%, equals-tail test

Wavelet Maps



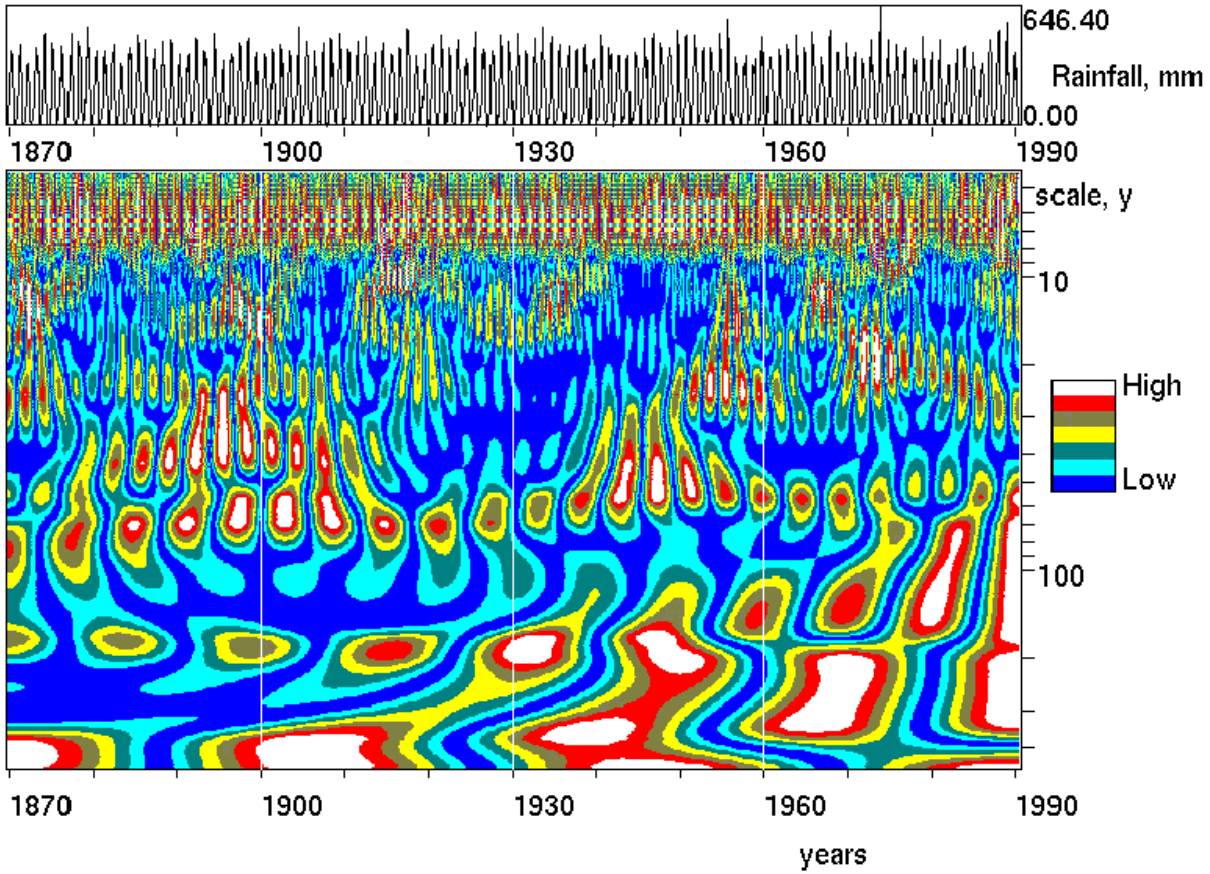
Wavelet transform co-efficients of Sunspot
[absolute values of real part; local scaling; Morlet wavelet; 477 pts]

Wavelet Transform Coefficient (WTC) map for Sunspot Number

SB & RN, EOS, Trans. AGU 2005

Note the horizontal row of blobs around the 11 years scale.

Wavelet Maps



Wavelet transform co-efficients of North East India monthly rainfall

[absolute values of real part; local scaling; Morlet wavelet; 1440 pts]

WTC map for North East India (NEI) Rainfall

Note the meandering row of blobs at about 11 years scale.

Motivation: Striking Similarity in Wavelet Maps

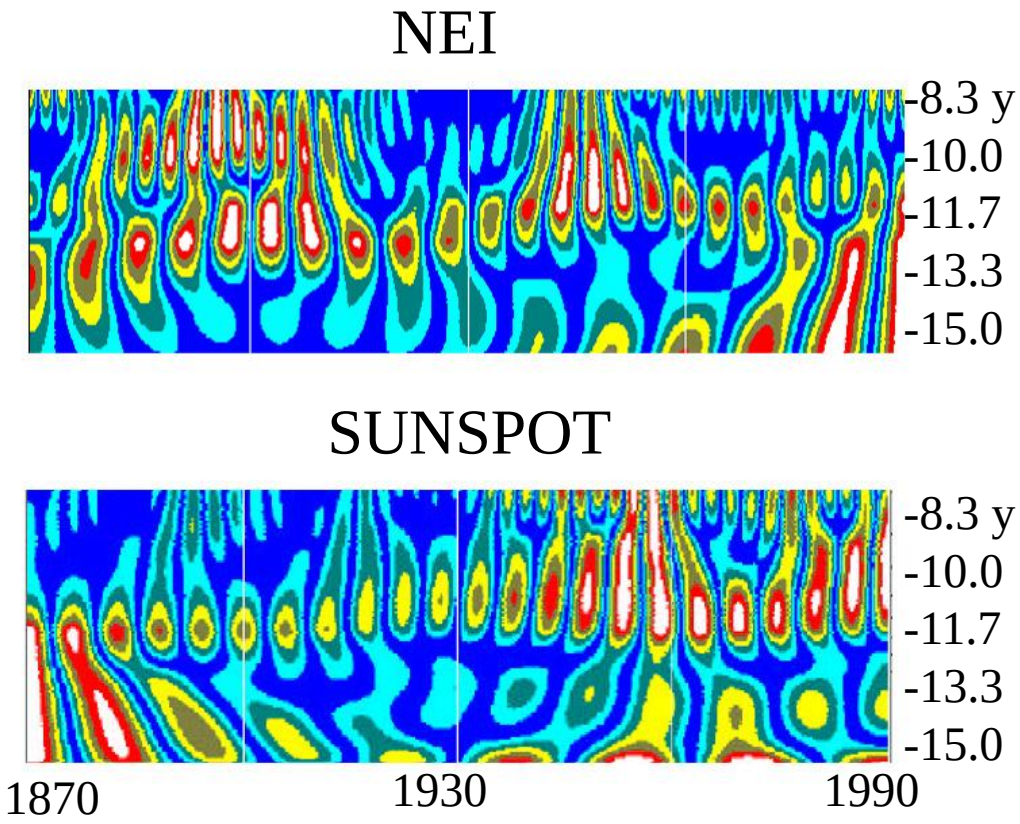


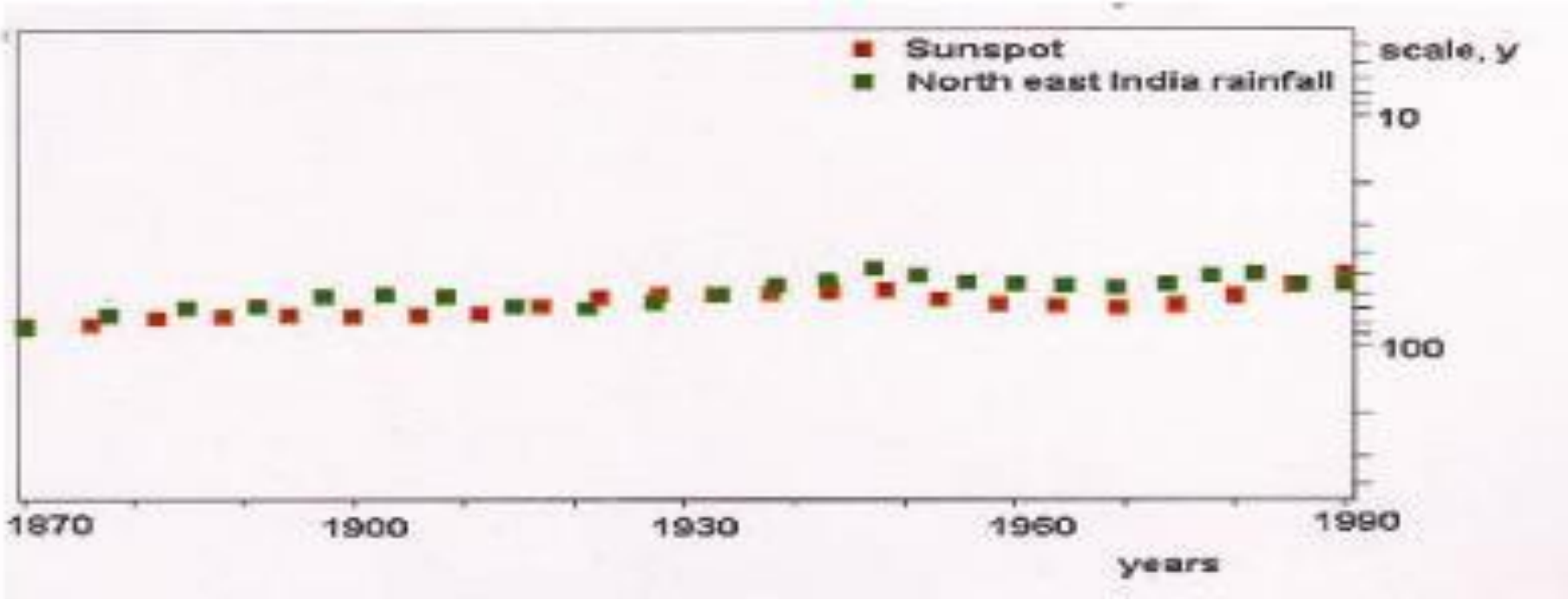
Figure shows the local maxima in NEI and Sunspot in the period range 8-16 year plotted in zoomed scale.

Note remarkable simultaneity in rainfall and sunspot WTC maxima

Kailas & Narasimha, Proceedings INSA & Current Science

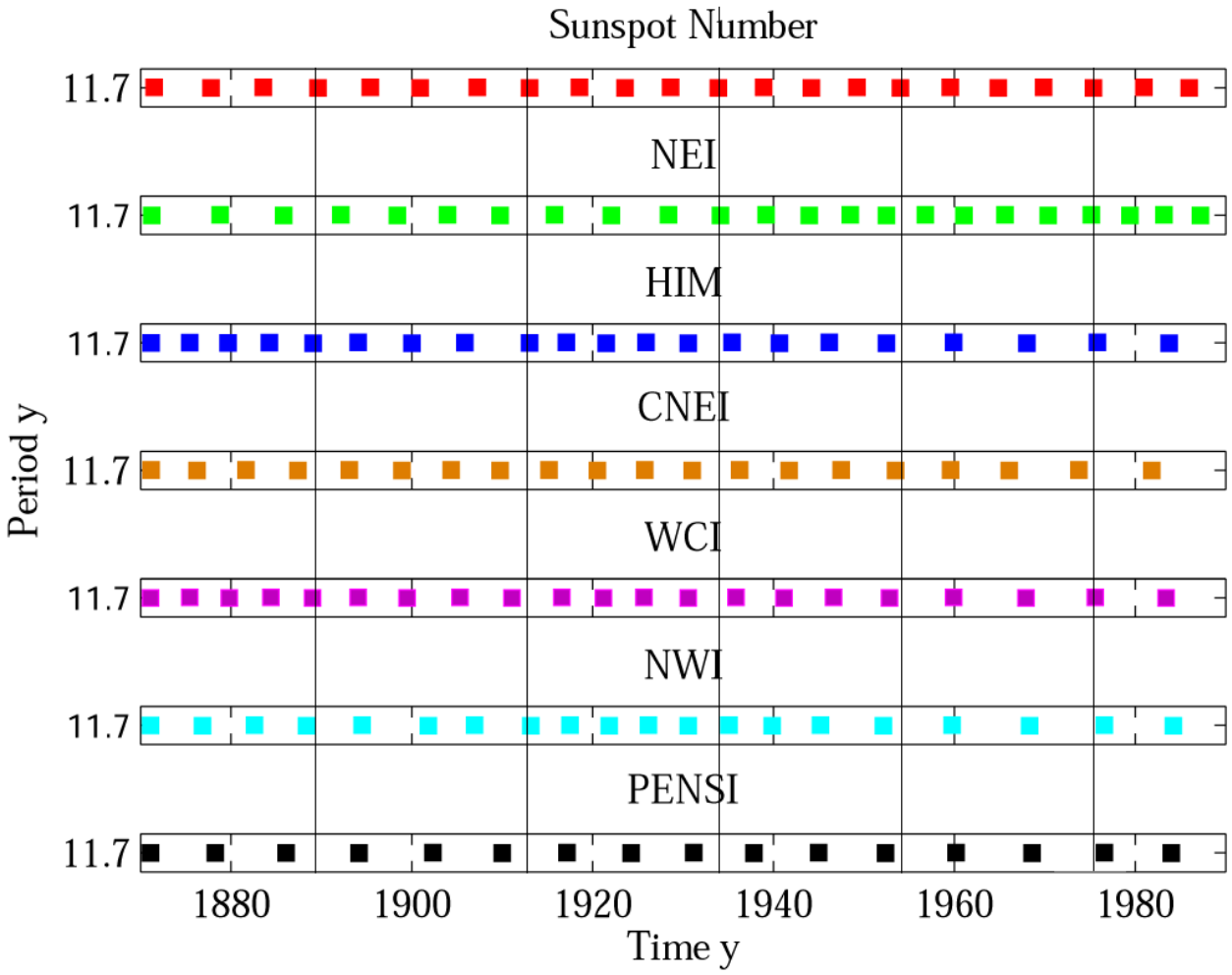
Striking Similarity in Wavelet Maps

Comparison of times of occurrence of WTC maxima of the NEI rainfall and sunspot number.



Note co-occurrence of WTC maxima of both series--- but with slow changes in phase!

Point Process



Point process time series of occurrence of WTC maxima in homogeneous rainfall and Sunspot number.

Statistical Analysis of Similarities

❖ Model the temporal location of the maxima of WTC of both rainfall and sunspot indices as point processes in time.

[A point process† may be defined as a stochastic time series which in the simplest case can be represented as points or dots on a real line, for example, the instants of failure of light bulbs in a building].

†Ref: Cox (1962, 1966, 1972) and Cox and Isham (1979).

Statement of the Problem

❖ Given two point process time series data, how can one devise a statistical or mathematical method for establishing

(i) whether there is any sort of dependency between the two data sets;

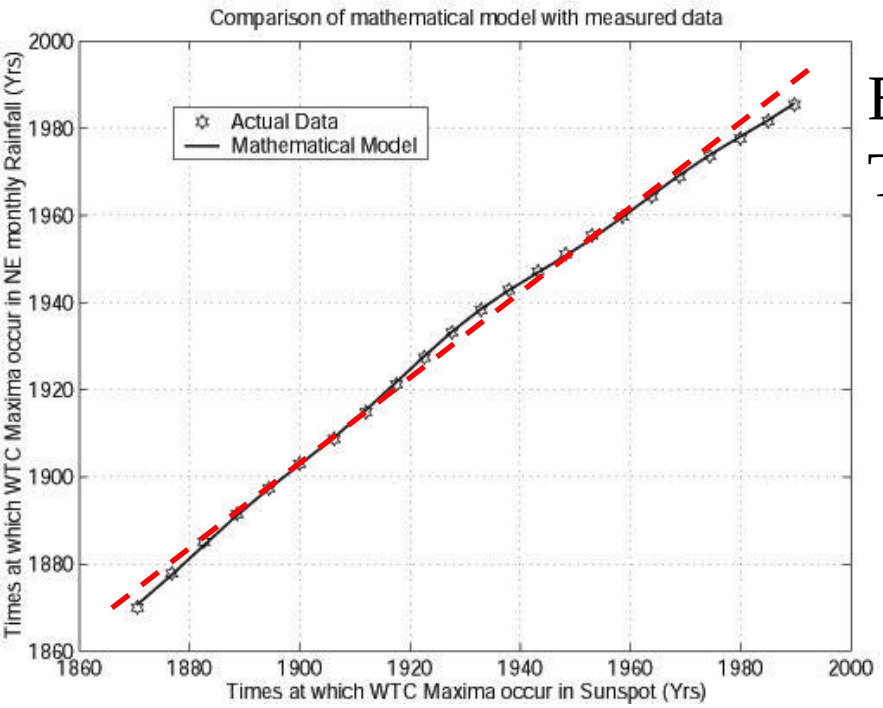
(ii) (if there exists one) how to derive the form of that dependency.

❖ This approach provides information on the phase relationship between the two point processes, more directly than any other statistical procedures in common use.

Regression Analysis Approach

- Plot the WTC time series against each other and obtain a line/curve of best fit to the data by regression.
- Model the deviations of the data from the regressed curve appropriately as systematic or stochastic.
- For systematic deviations which have periodic components, model them as a sum of sinusoidal functions with unknown time-periods and amplitudes, the values of which can be sought as solutions to an unconstrained error minimization problem.
- The superposition of the deviation model on the regressed curve provides an enhanced fit to the original data.
- The final deviations of the total model from the actual data can then be tested for stochastic fluctuations using an appropriate significance test with tight confidence levels.

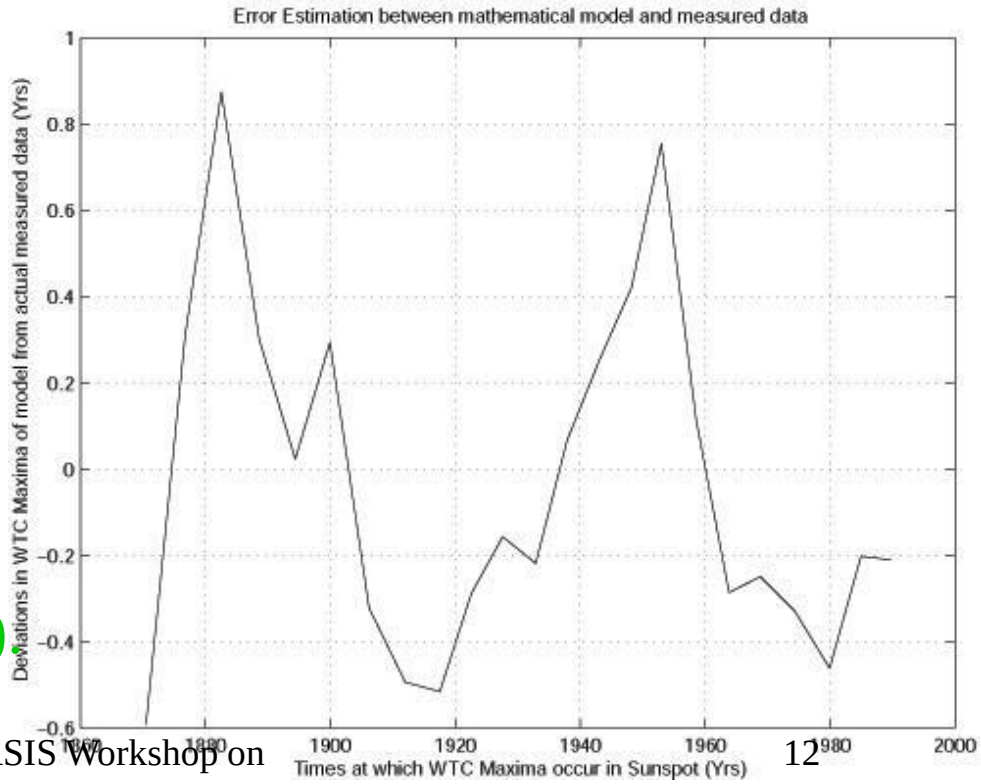
Results



Best Fit for NEI –Sunspot WTC –

$T_R = 59.33 + 0.97\,T_S + F_{Per}(T_S) + F_{sto}(T_S)$

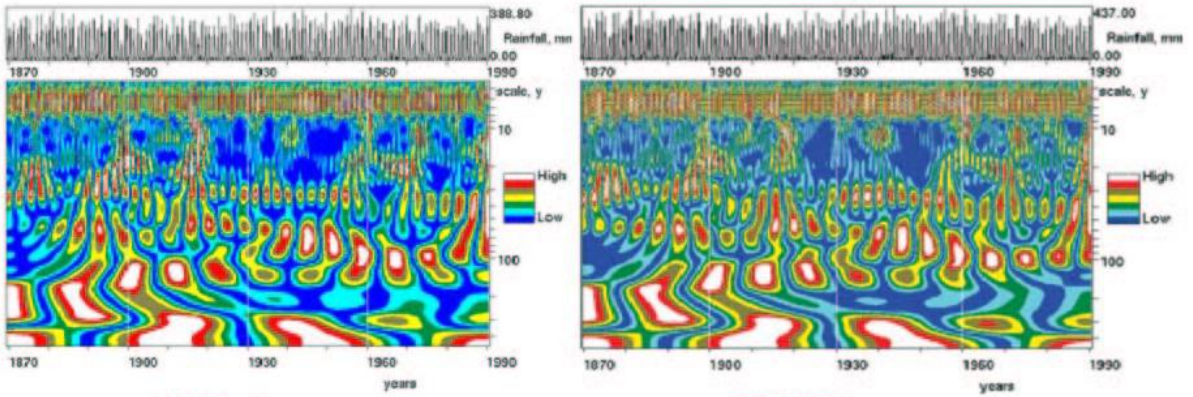
Linear Periodic Stochastic



Deviations from regressed line:

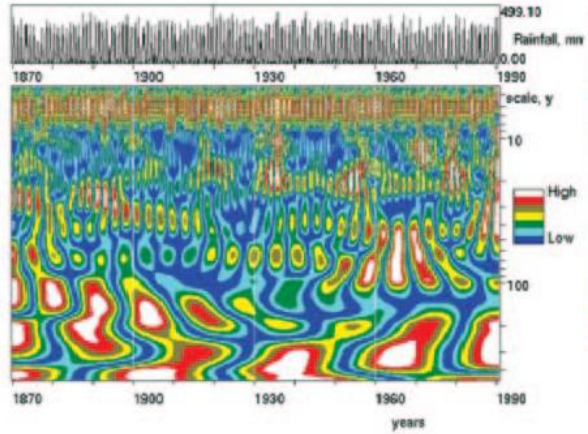
$F_{Per}(T_S) = 2.89 \sin(2\pi(T_S-1870)/125.26 - 1.55) + 0.81\sin(2\pi(T_S-1870)/41.76 - 1.39)$

Spatial Variation

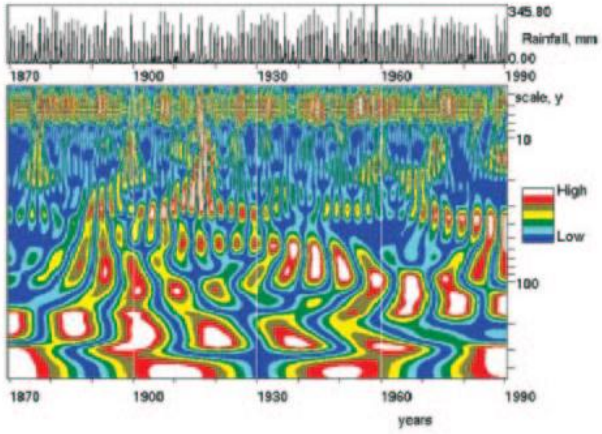


HIM

WCI

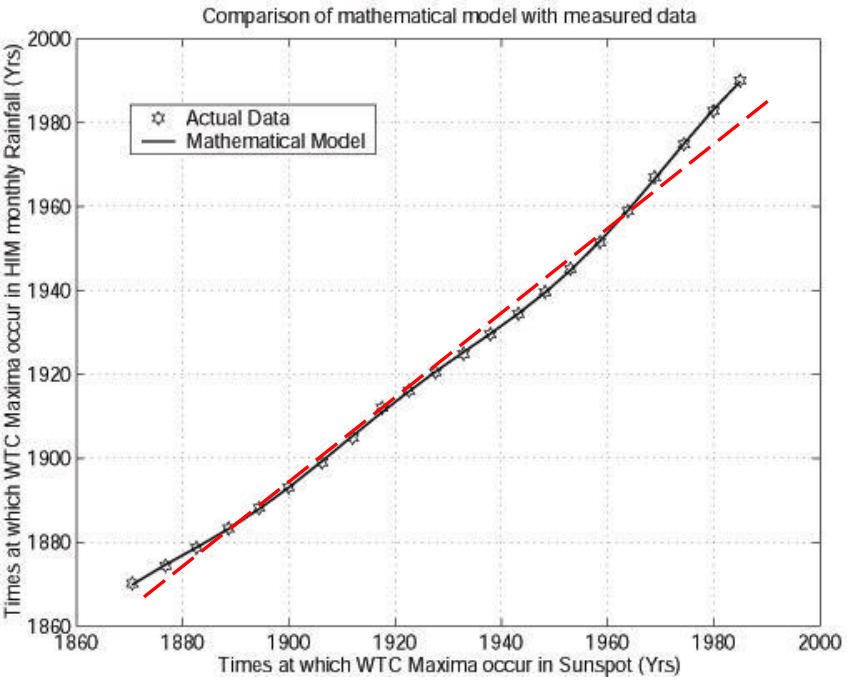


CNEI



NWI

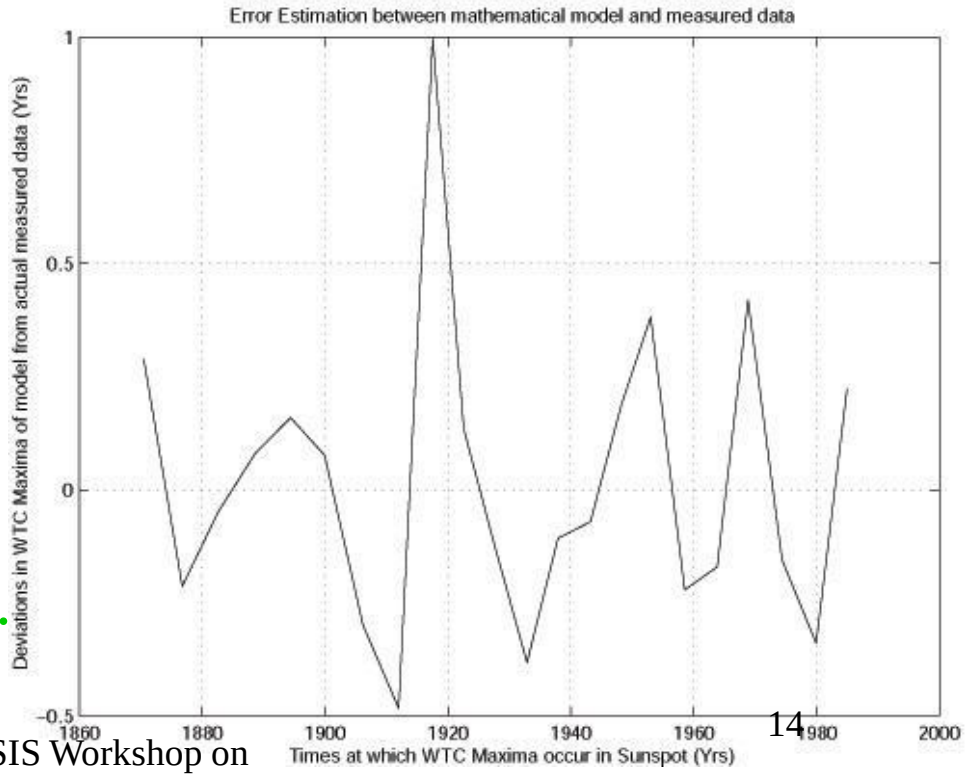
Results (contd)



Best Fit for HIM –Sunspot WTC –

$T_R = -76.03 + 1.07\,T_S + F_{Per}(T_S) + F_{sto}(T_S)$

Linear Periodic Stochastic



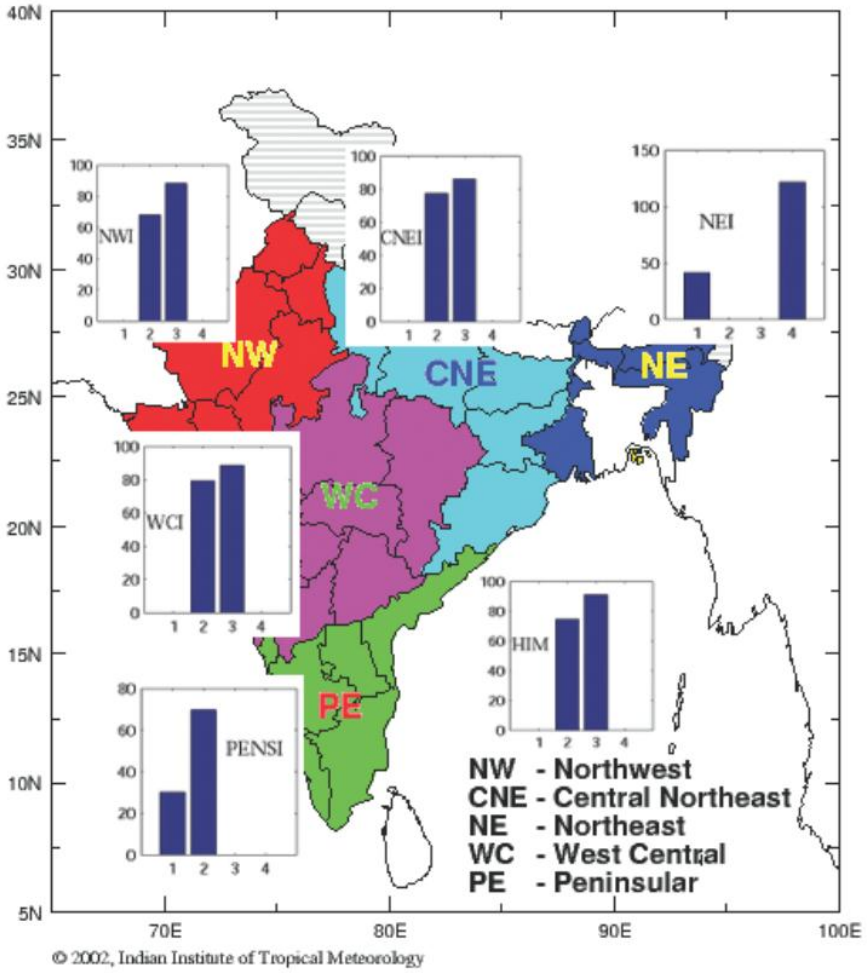
Deviations from regressed line:

$F_{Per}(T_S) =$

$5.42 \sin(2\pi(T_S-1870)/110.28 + 1.29)$

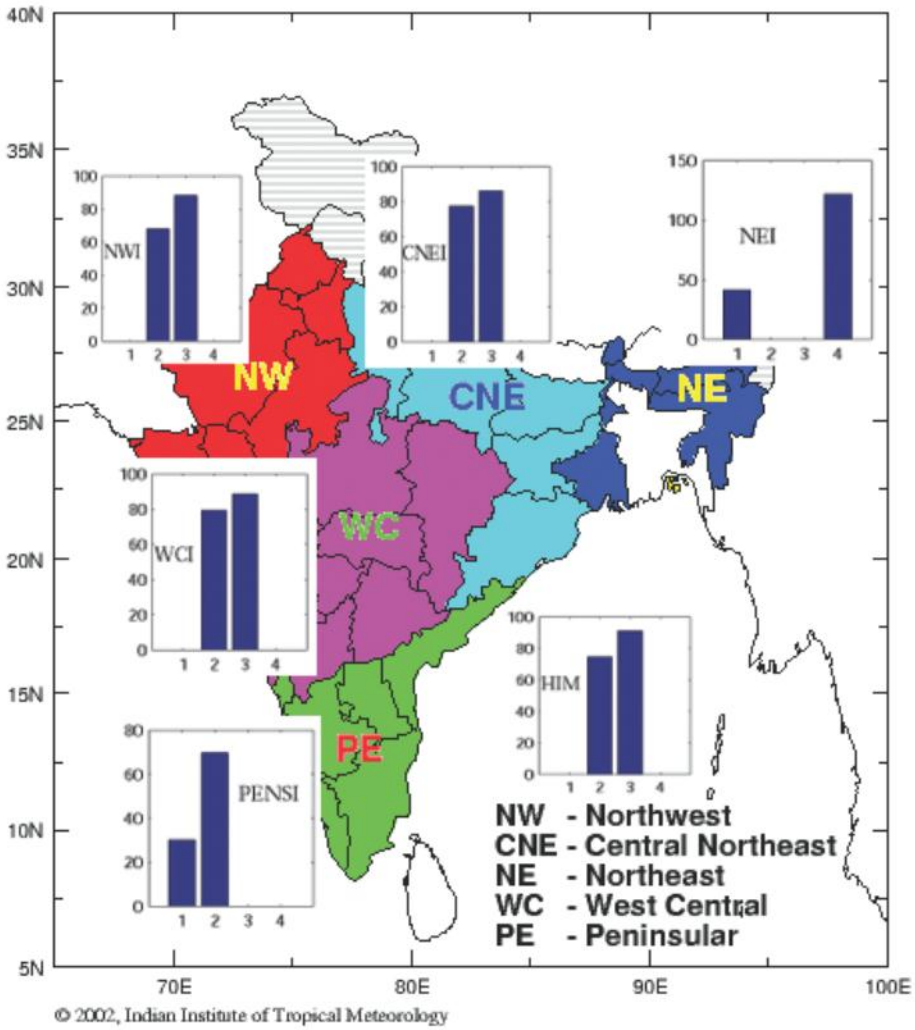
$+ 3.31 \sin(2\pi(T_S-1870)/68.88 + 2.88).$

Spatial Variation



Homogeneous rainfall map of India showing the amplitudes for different period bands obtained from regression analysis. Band 1: 30—60 y, Band 2: 60—80 y, Band 3: 80—100y, Band 4:100-122 y

Spatial Variation



Homogeneous rainfall map of India showing the periods obtained from regression analysis.
Band 1: 30—60 y, Band 2: 60—80 y,
Band 3: 80—100y, Band 4: 100-122 y

Conclusions

❖ Regression analysis reveals a nearly linear trend with small systematic and stochastic deviations from the regressed line.

❖These results indicate a strong connection between solar processes and monsoon rainfall around the 11 year period and enable quantitative studies of phase relationships.

Possible Explanations & Hypotheses

Haigh's Hypothesis: Solar Irradiance 200-320 nm UV contributes strongly to solar heating in the middle atmosphere, largely through Ozone absorption.

Meehl's Hypothesis: (Top-down & Bottom-Up Approach)

Kodera: Stratosphere-Troposphere Interactions
Cane-Zebiak Model
Ruzmaikin: Stochastic Resonance model
Extreme Ultra Violet (EUV) Radiation?

Possible Explanations & Hypotheses

Meehl's Hypothesis: (Top-down & Bottom-Up Approach)

Reduction in cloud cover during solar maxima

↓

warming of ocean surface waters across the tropical Pacific,

↓

enhanced evaporation and transport of water vapor by the trade winds to convergence zones.

↓

Increased precipitation in the convergence zones strengthens the Hadley and Walker circulations, with associated increases in trade winds and equatorial upwelling,

↓

lower sea surface temperatures in the eastern equatorial Pacific (van Loon et al., 2004).

↓

Enhanced subsidence produces fewer clouds in the eastern equatorial Pacific and expands the subtropical regions, allowing even more solar radiation to reach the surface to produce a positive feedback (Pierrehumbert, 1995) that further magnifies the climate response (Meehl et al., Science 2009).

Possible Mechanisms

Haigh's Hypothesis

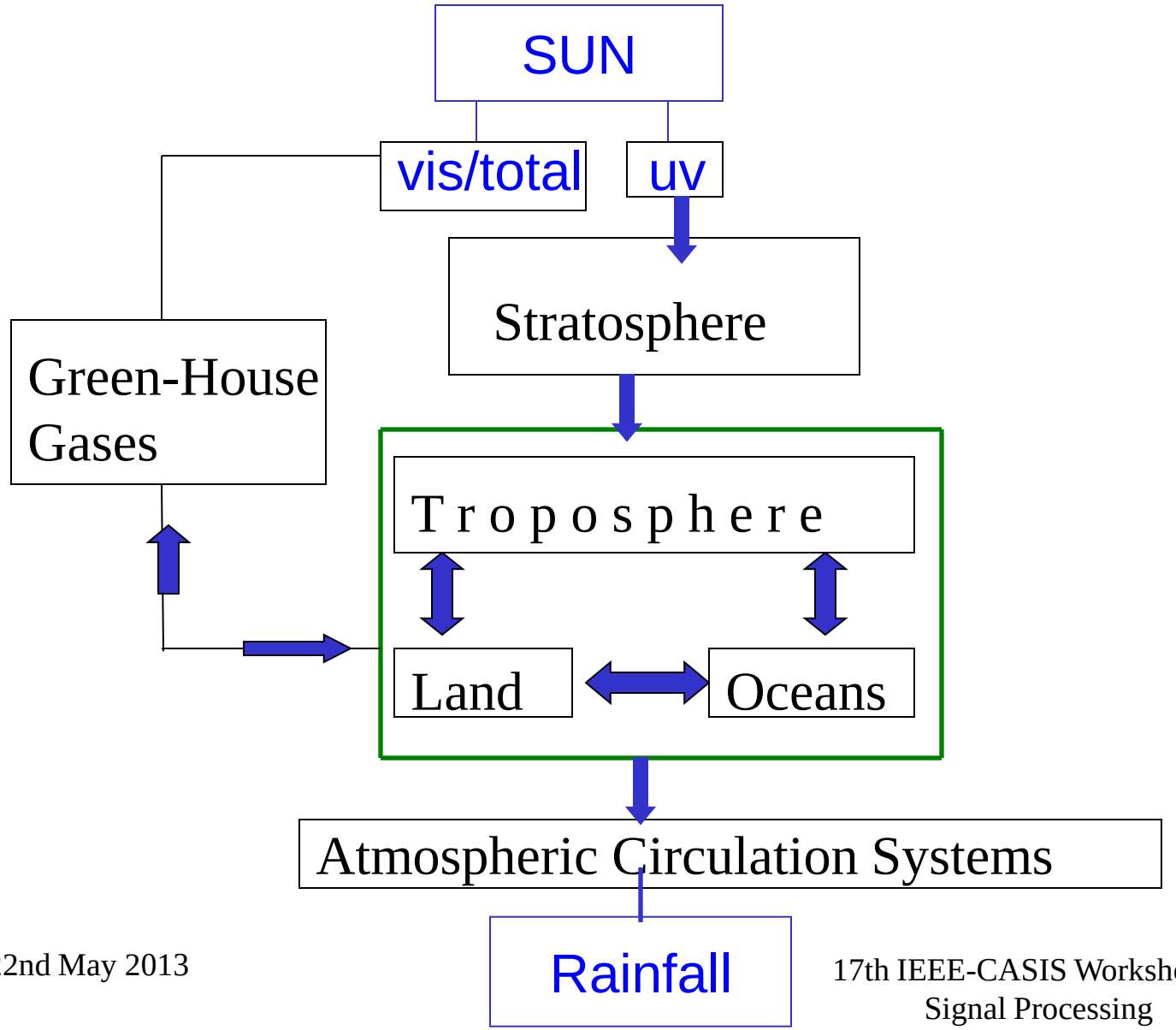
Haigh(2004, 2011)

- % change in short wave radiation very low (approx 0.1)
- % change in uv radiation is high (3.5-7% approx)

- Affects stratosphere through Ozone
- Stratosphere-Troposphere coupling can lead to changes in temperature.
- Coupled atmosphere-ocean shows greater response than atmosphere alone with prescribed observed SST.

Effect of atmosphere on ocean is important

Possible Model



THANK YOU

Back Up Slides:Conclusions

❖ Regression analysis reveals a nearly linear trend with small systematic and stochastic deviations from the regressed line.

❖Suitable (periodic) function models for the systematic deviations have been obtained through an unconstrained error minimization scheme, providing potentially useful information on periods and phases.

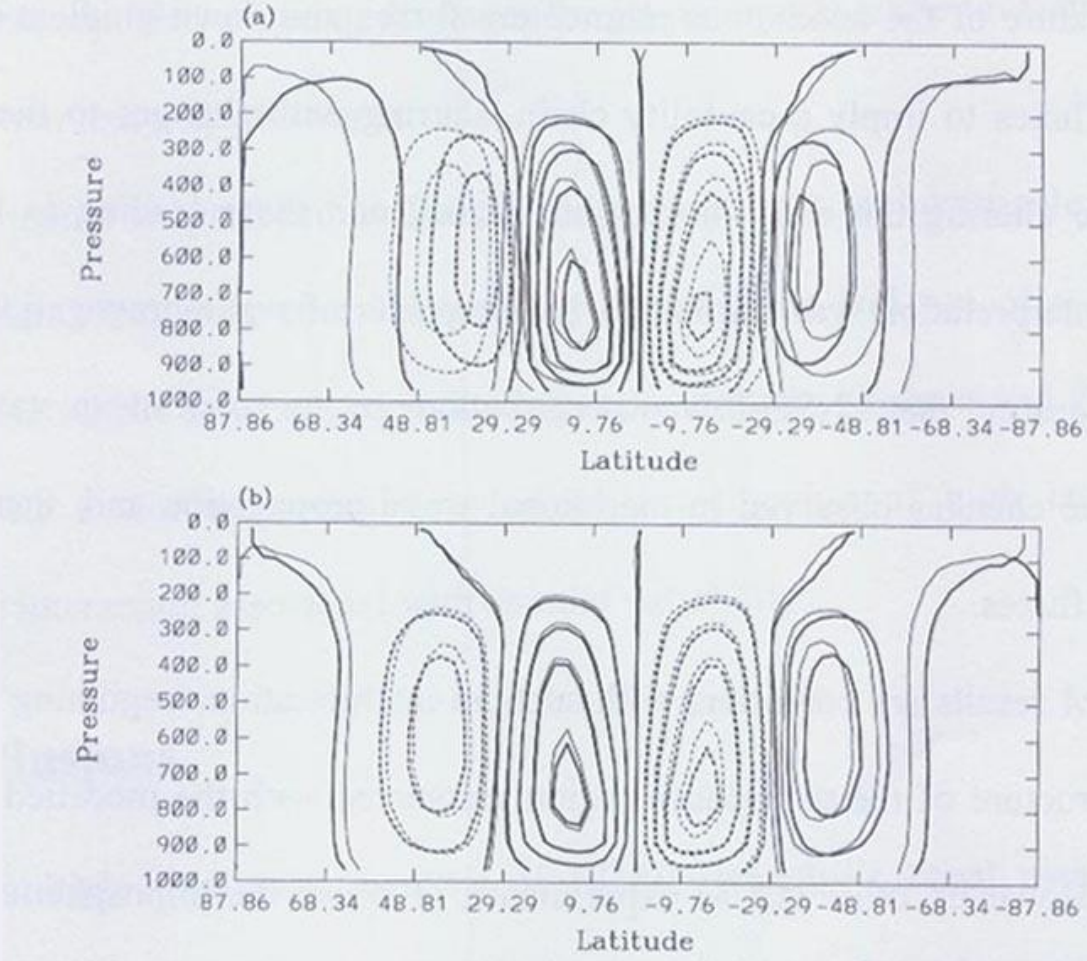
❖ These models provide an excellent fit to the point process time series of the WTC maxima obtained from actual data for rainfall and sunspots.

❖ Statistical significance tests on the residual stochastic deviations suggest with 99% confidence that they are sample fluctuations obtained from normal distributions (Lilliefors test).

Reasons for long controversies

- Nonstationarity of process not recognized (so classical spectral analysis misleading)
- Solar activity effects cumulative over decadal scale (so climate affected, not weather)
- Strength of strato-tropospheric couplings not appreciated earlier
- Possibility of spatial variability, perhaps caused by long-period displacement of atmospheric circulation cells, not appreciated.

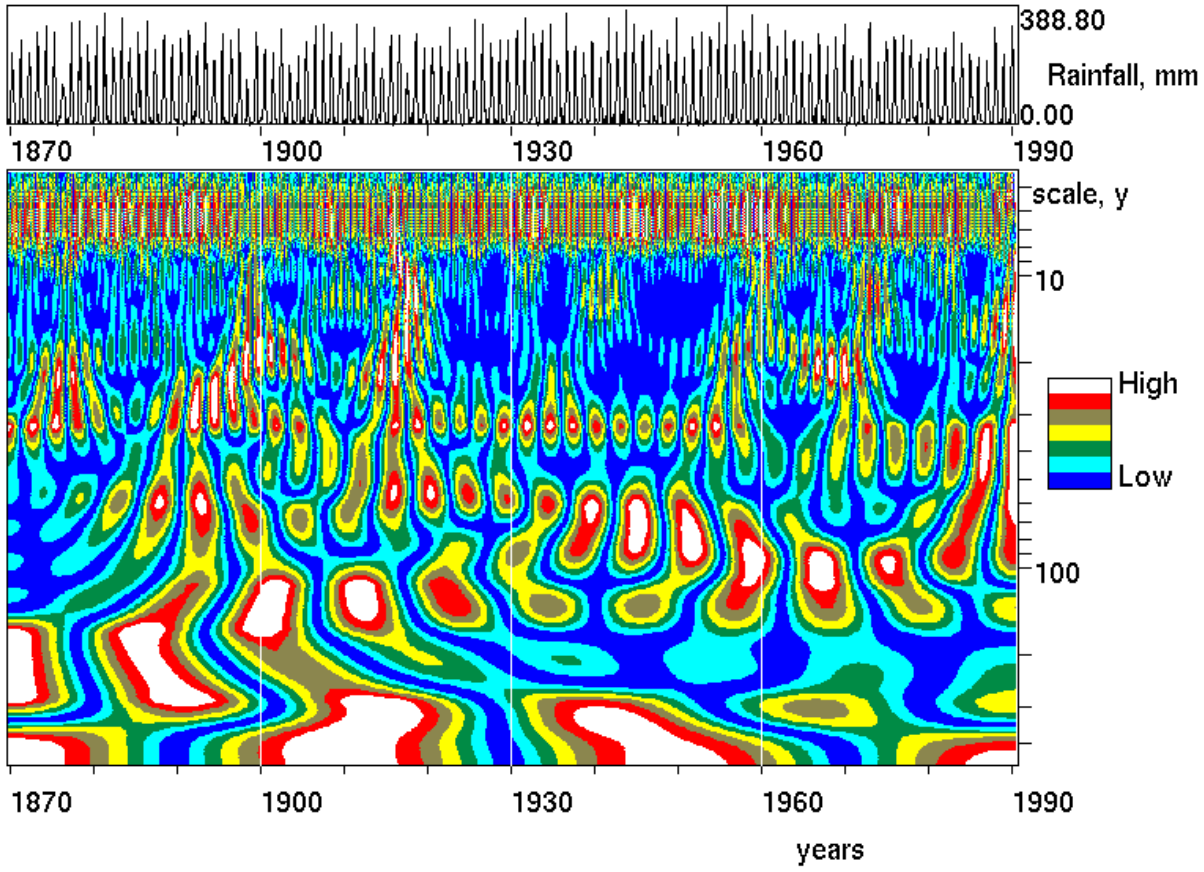
Possible Mechanisms



Haigh's simulations show

- spatial variation in magnitude (even sign) of effect
- Displacement of Hadley (and other coherent) cells
- Dynamic, not just energetic; atmospheric (and oceanic) circulation is affected.

Wavelet Maps



Wavelet transform co-efficient of HIM monthly rainfall
[absolute values of real part; local scaling; Morlet wavelet; 1440 pts]

WTC map for Homogeneous Indian Monsoon (HIM) Rainfall

Note the meandering row of blobs at about 11 years scale.