The Madden-Julian Oscillation: It's predictability and a 100-year reconstruction

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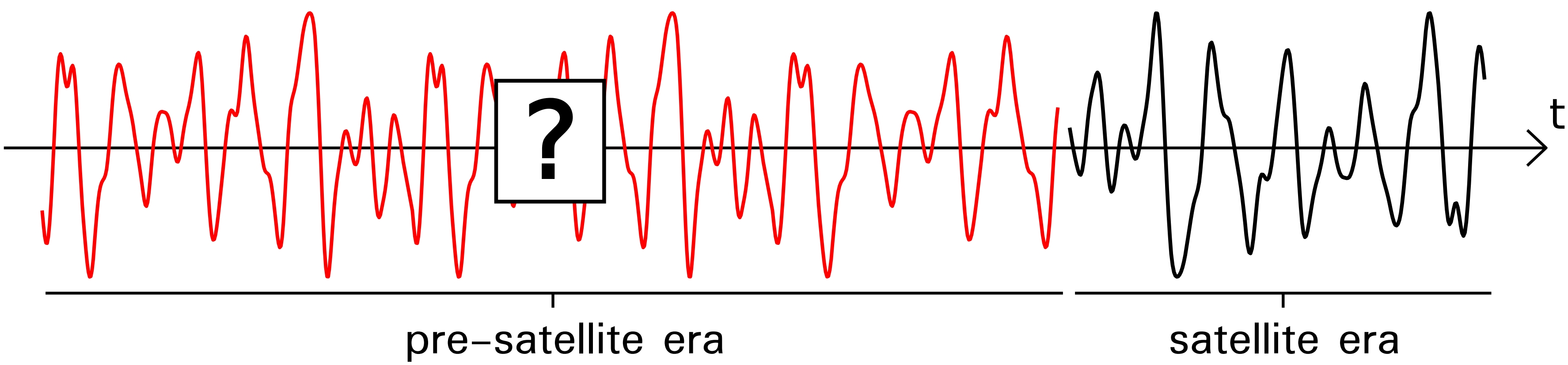
Objectives

HISTORICAL RECONSTRUCTION OF THE MJO INDEX

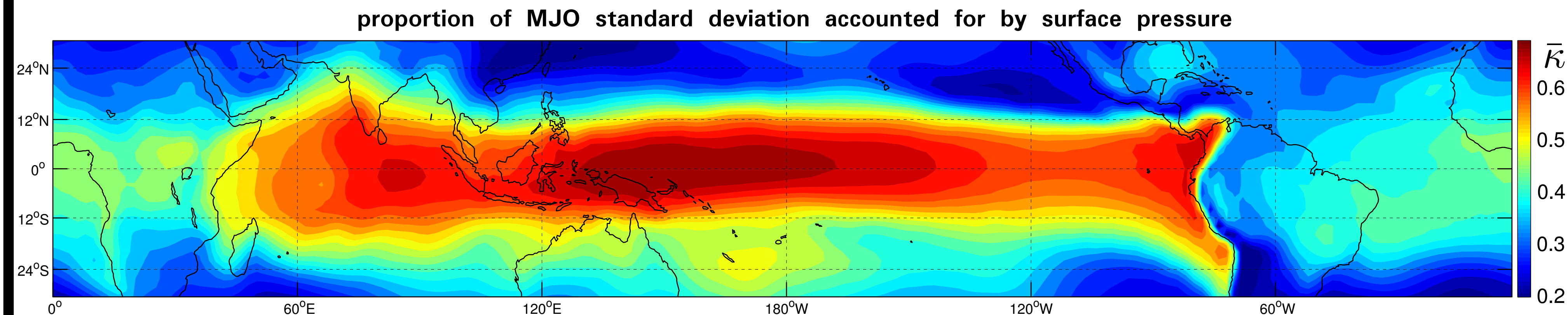
- The most widely accepted characterization of the Madden–Julian Oscillation (MJO) is the **index** developed by Wheeler and Hendon (2004)
- Index based on **satellite** outgoing longwave radiation and **reanalysis** zonal wind (200 and 850 hPa heights) ... so not defined prior to **1974**
- Would be of great interest to be able to extend this index over the **pre–satellite era**!



Wheeler, M. and H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. Monthly Weather Review, 132 (8), 1917-1932.

Reconstructing the MJO

- The **MJO has a strong signature in surface pressure** and daily measurements of surface pressure are available for **100+ years**.
- We reconstruct the Wheeler and Hendon MJO index from **1905 to 2008** based on a **mulitple linear regression** of tropical surface pressure from the 20th Century Reanalysis Project.

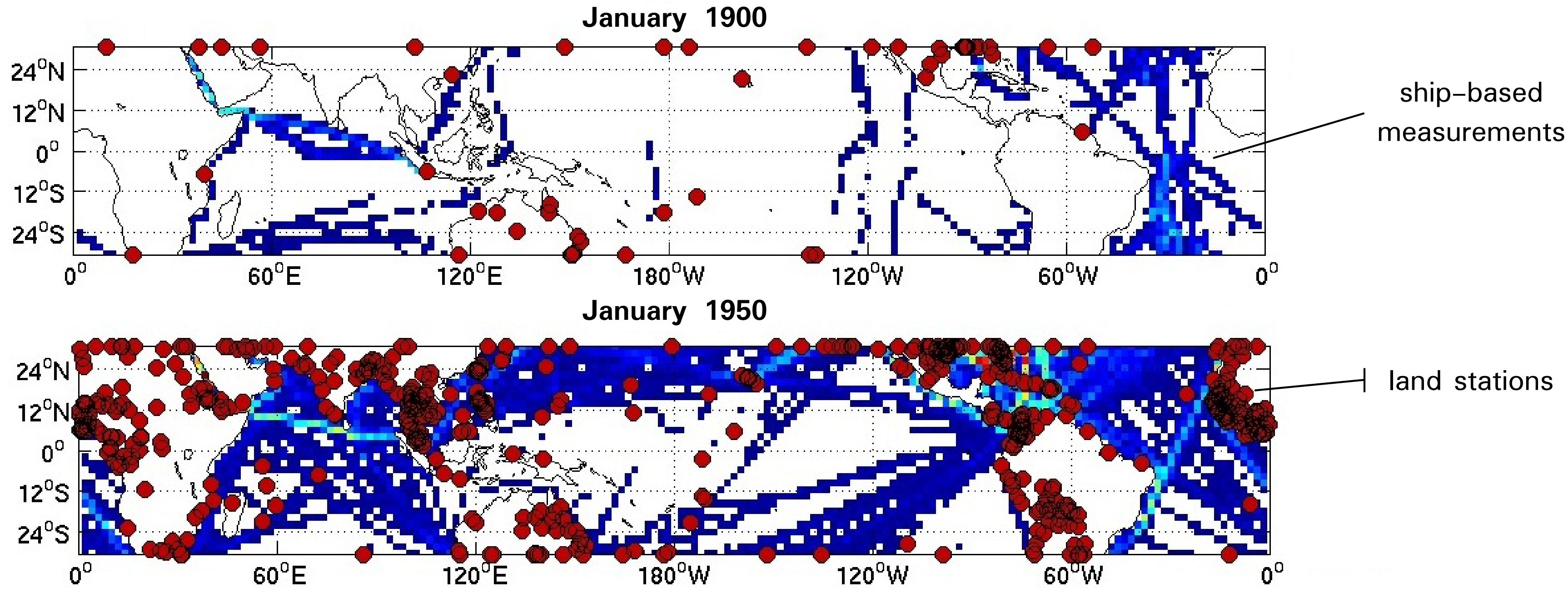


- Use time series of pressure at a number of locations ... but we need to **limit the number of locations** so that we don't overfit the model!

* Madden, R. and P. Julian, 1971: Detection of a 40-50 Day Oscillation in the Zonal Wind in the Tropical Pacific. Journal of the Atmospheric Sciences, 28 (5), 702-708.
* Donald, A. et al., 2006: Near-global impact of the Madden-Julian Oscillation on rainfall. Geophysical Research Letters. 33, L09704
* Compo et al., Review Article: The Twentieth Century Reanalysis Project, Q. J. R. Meteorol. Soc. 137: 1–28, 2011

Observation Density

- One problem with doing such a reconstruction is the heterogeneous nature of the **observing system** ... in time AND space

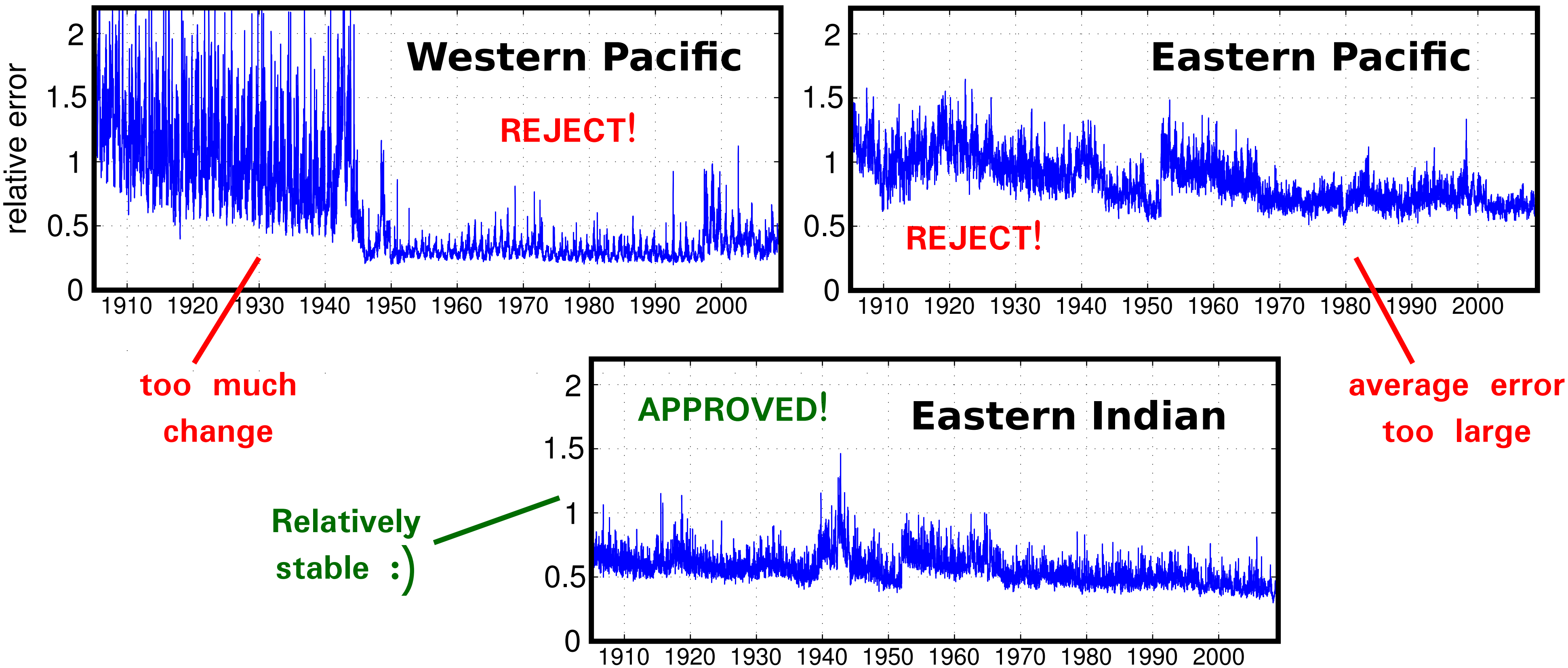


- Reanalysis is performed using a Kalman smoother with **56–member ensembles**: for each variable we have time series of **mean** and **variance**

- It turns out that **the ensemble variance is related to observation density**. i.e., as the observations become more sparse, the variance (uncertainty within the ensemble) increases

Restricting Predictor Locations

- We use the ensemble spread to reject regions that: **[i]** have too strong a trend in ensemble spread (the observation system changed too much over the last century) and **[ii]** have a large mean spread (the observations are too sparse over the full record)

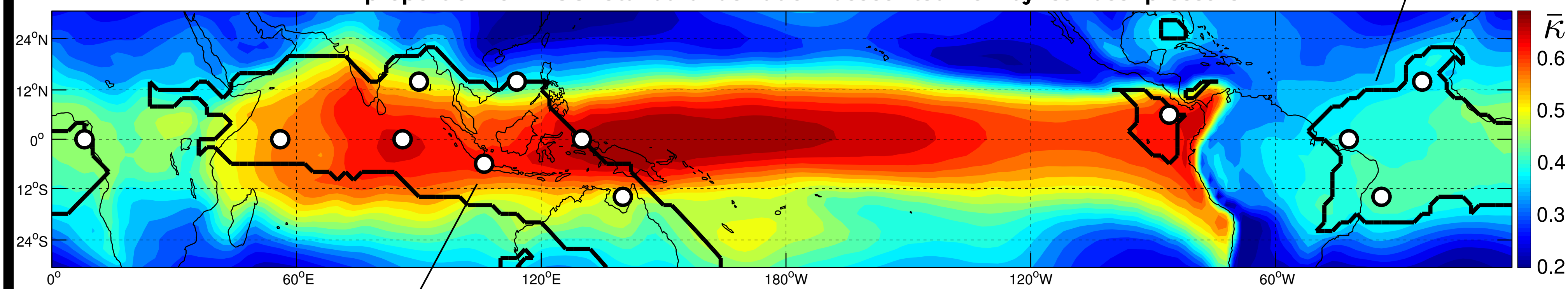


Final Selection of Predictors

- Reject regions if they fail to meet the **following restrictions**:

1. mean relative error $>$ 0.8
2. relative error changes by $>$ 67%
3. explained less than $1/3$ of MJO index standard deviation

restricts regions for choosing predictors

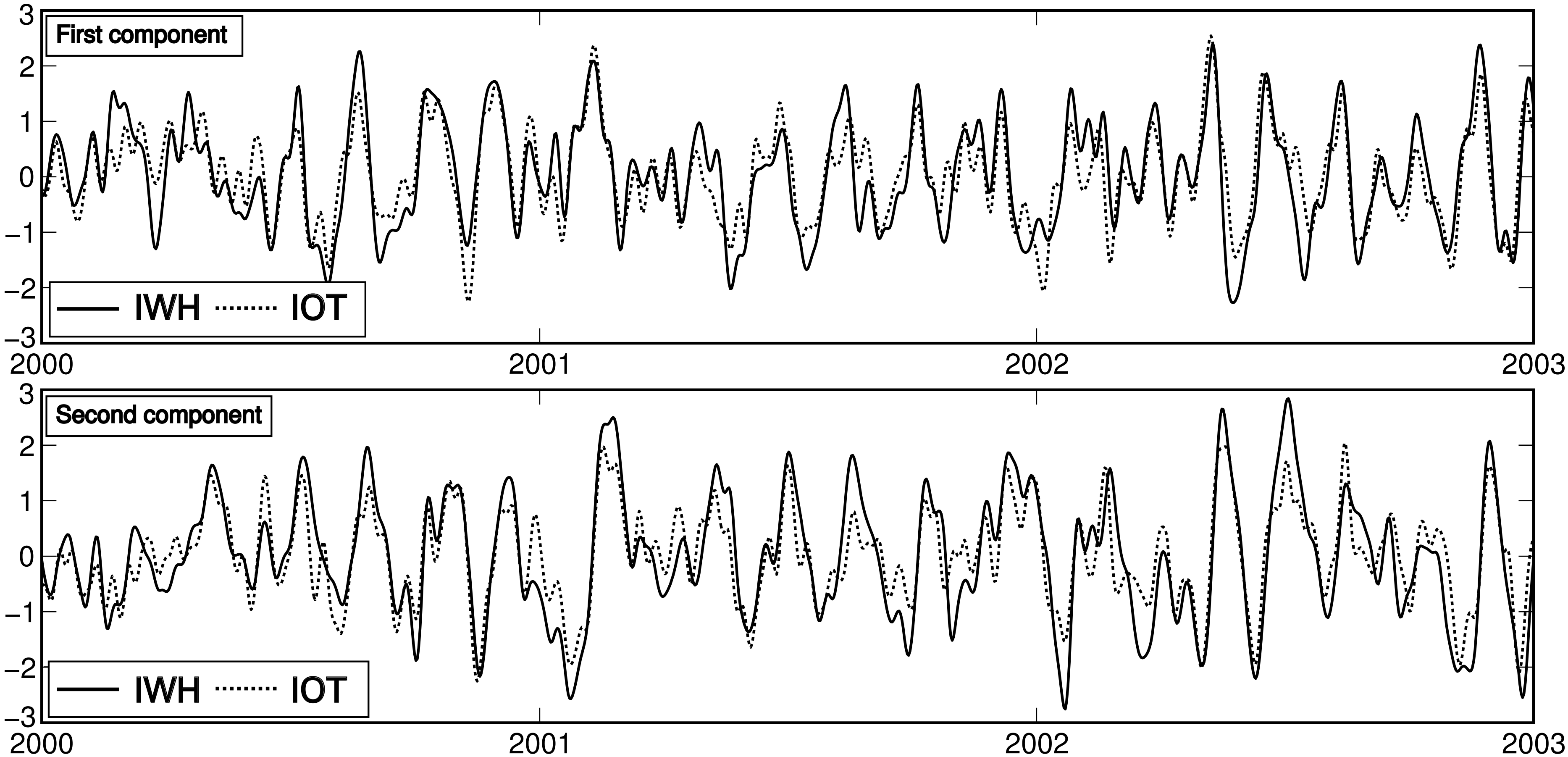


- Chose **12 locations**. Took pressure time series at these locations and filtered out seasonal, interannual, and high freq. $(>10$ days$)$ variability

- These time series of pressure, along with Hilbert transforms, were **regressed** onto the MJO index and then **hindcast over the 1905 to 2008** period to give a reconstruction of the MJO.

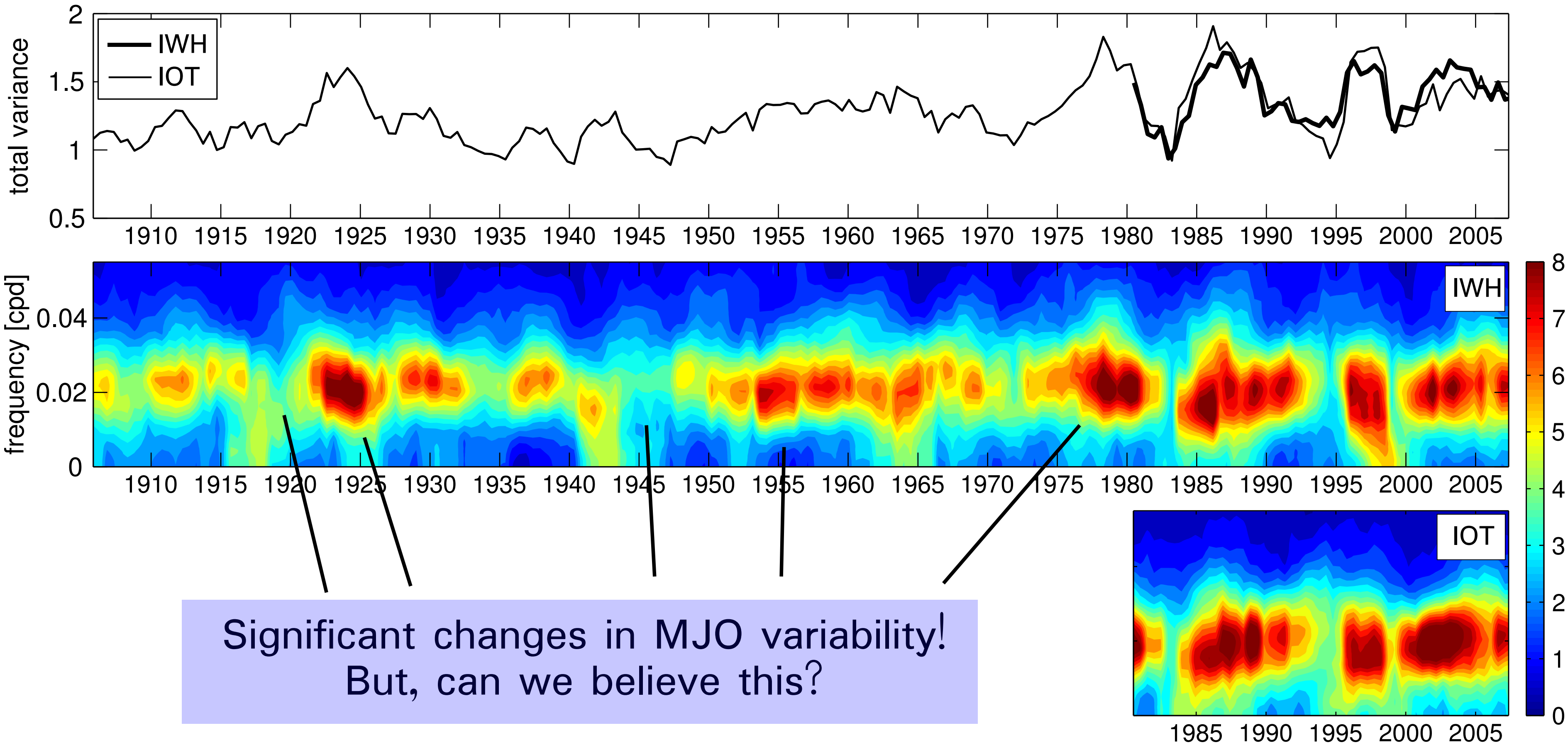
The Reconstructed Index

- The reconstructed index (IOT) explains 67% of the variance of the Wheeler and Hendon index (IWH). Corresponds to a correlation of ~0.82.



Low Frequency Behaviour

- 3–year running **variance** and **power spectra** match over the common period
- In general, the reconstruction behaves well over the common period.... but can we trust the hindcast over the **pre–satellite era**?

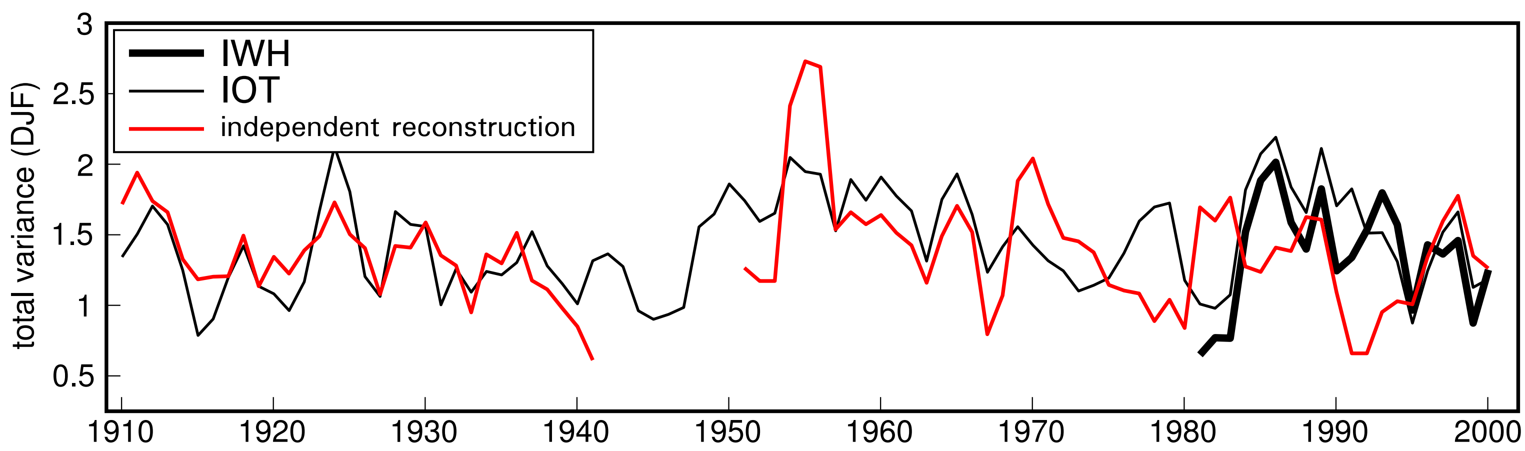


Validation

- We will perform a **second reconstruction** using the following selected **environmental variable**s:
  - Air temperature at Darwin, Australia
  - Precipitation at Booby Island, Australia
  - Sea level at San Diego, Californa
  - Surface pressure at/near Jakarta, Indonesia

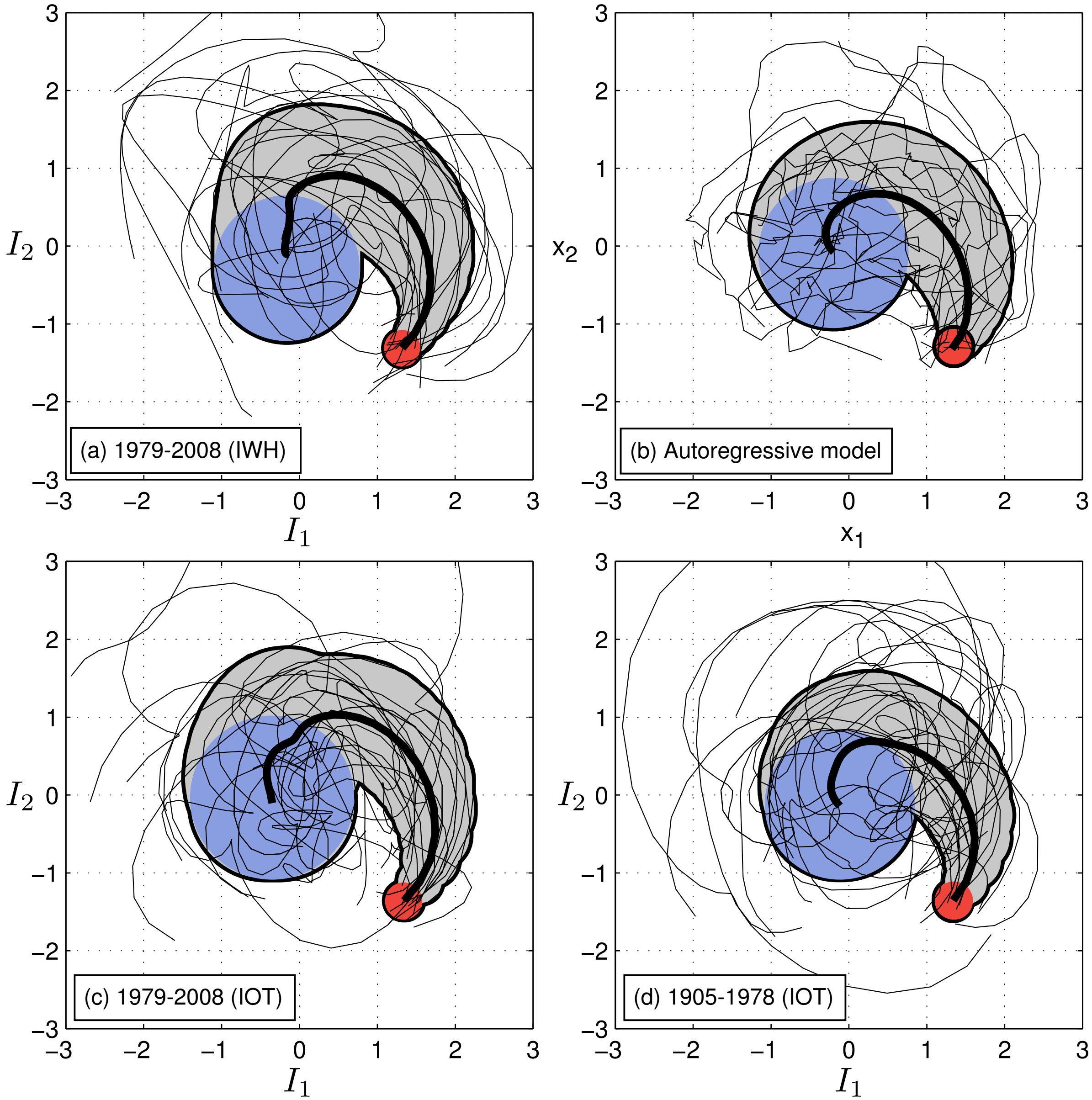
all variables have a connection with the MJO

- The regression is not as good (explains only 39% of the variance) but we can see that it **lends credence** to the low frequency variability in IOT



- Also **validated** the reconstructed index by examined the **stability** of the connection between the MJO and the environmental variables.

Loss of MJO Predictability



- Ensembles of MJO events which pass through the same point show behaviour reminiscient of a damped harmonic oscillator.
- Model as a stochastically forced, damped, harmonic oscillator using an autoregressive process:

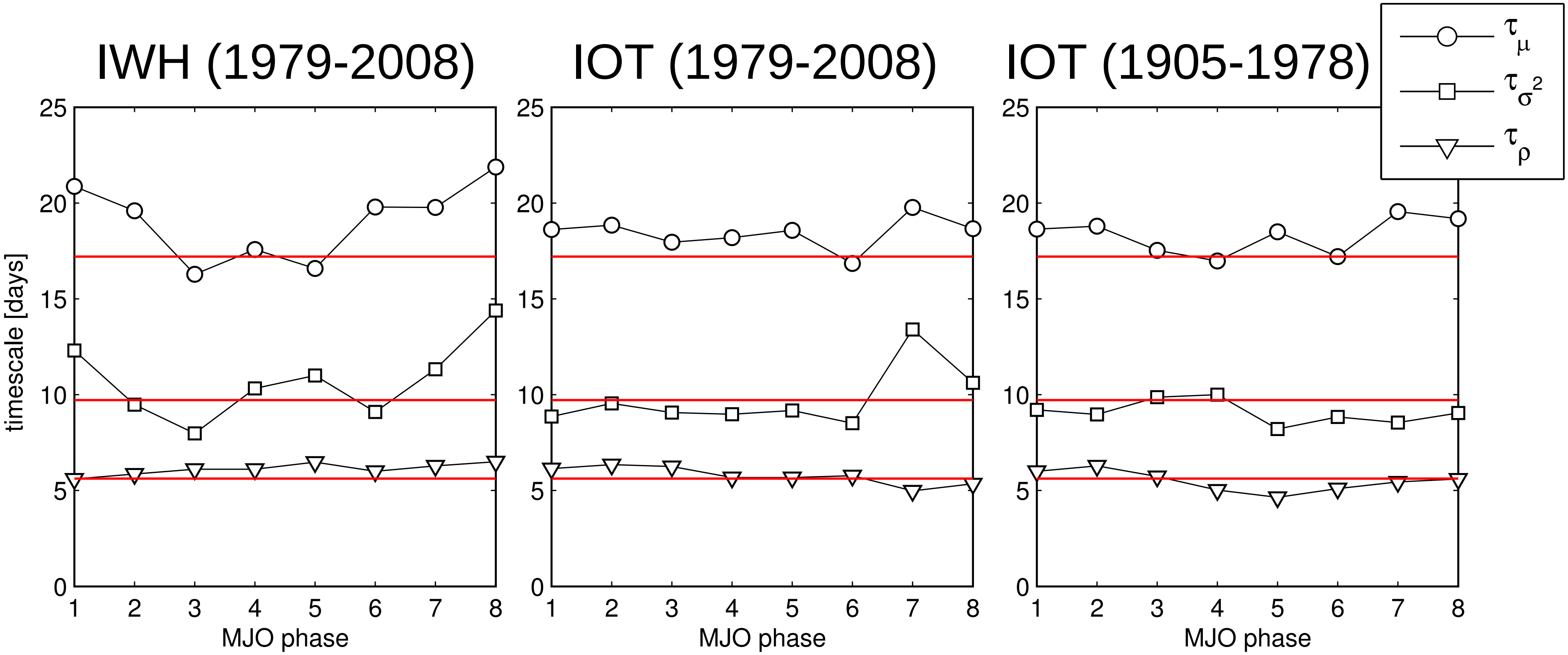
$$\boldsymbol{x}_t = \boldsymbol{A}\boldsymbol{x}_t + \boldsymbol{\epsilon}_t$$

with three parameters:

1. rotation period P
2. damping timescale τ_1
3. autoregressive forcing timescale τ_2

Predictability Timescales

- Estimated timescales for **loss of predictability** for ensembles of MJO events initialized in different phases
- Timescales are different for the **different statistics**. Also, there is some dependence on phase, not reproduced by the reconstruction.
- Capture the relationship amongst the timescales using a simple stochastically forced, damped harmonic oscillator model with **a single set of parameters.**



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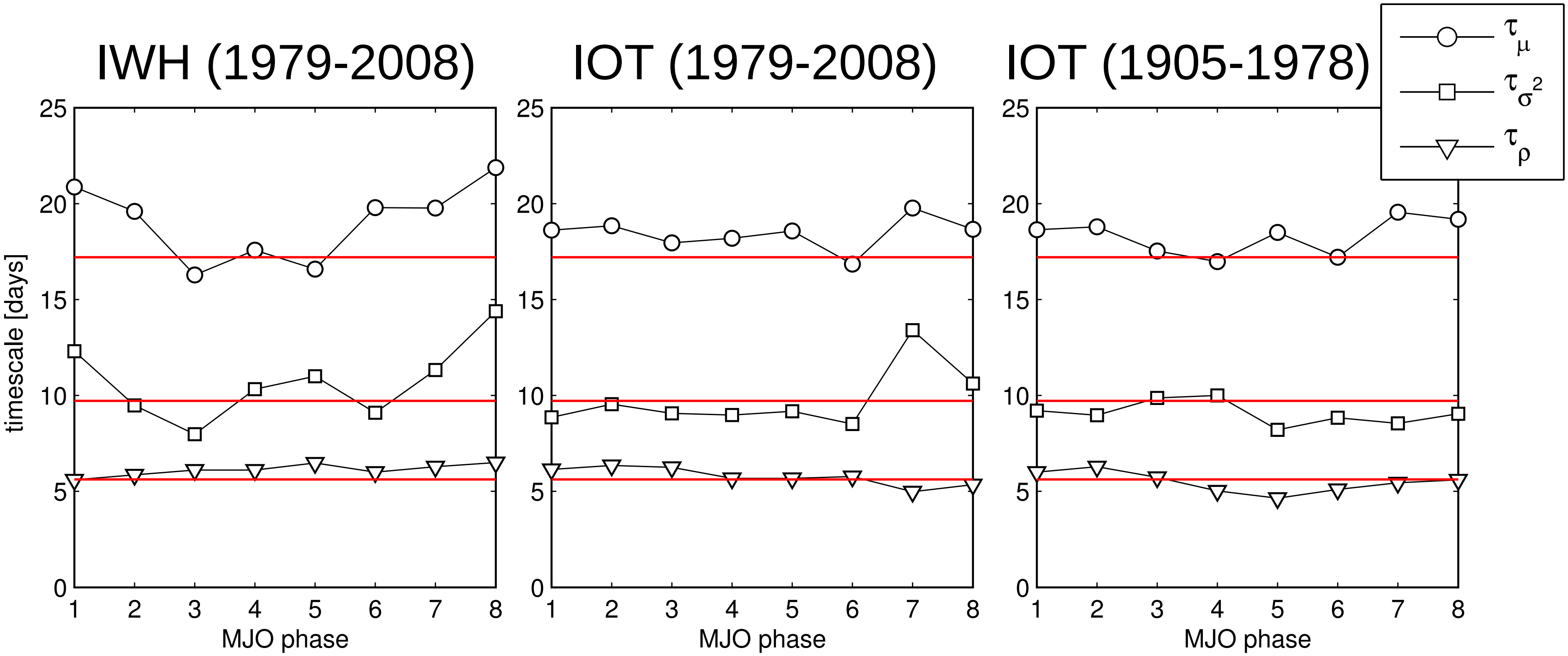
- Timescales are different for the **different statistics**. Also, there is some dependence on phase, not reproduced by the reconstruction.
- Capture the relationship amongst the timescales using a simple stochastically forced, damped harmonic oscillator model with $\boxed{P = 50\ \mathrm{d},\ \tau_1 = 15\ \mathrm{d},\ \tau_2 = 2.5\ \mathrm{d}}$



Summary

- Using long records of pressure from a reanalysis we have **reconstructed** the MJO index over the period **1905 to 2008**.
- The **number of pressure predictors was limited** by taking into account (i) the relationship with the MJO, (ii) decorrelation lengthscales, and (iii) the quality of the reanalysis.
- The reconstructed index accounts for **69% of the variance** of the Wheeler and Hendon index and its **temporal and spectral properties match well** over the shared period and are validated over the historical period.
- Predictability time scales of the MJO, as described by **three measures,** give a rich and complex view of **MJO predictability**.
- Behaviour can be **modeled** by a simple coupled AR(1) process inspired by a **damped harmonic oscillator**. One parameter set describes the MJO well.
- Reconstructed MJO index will be made **available online** in the near future.