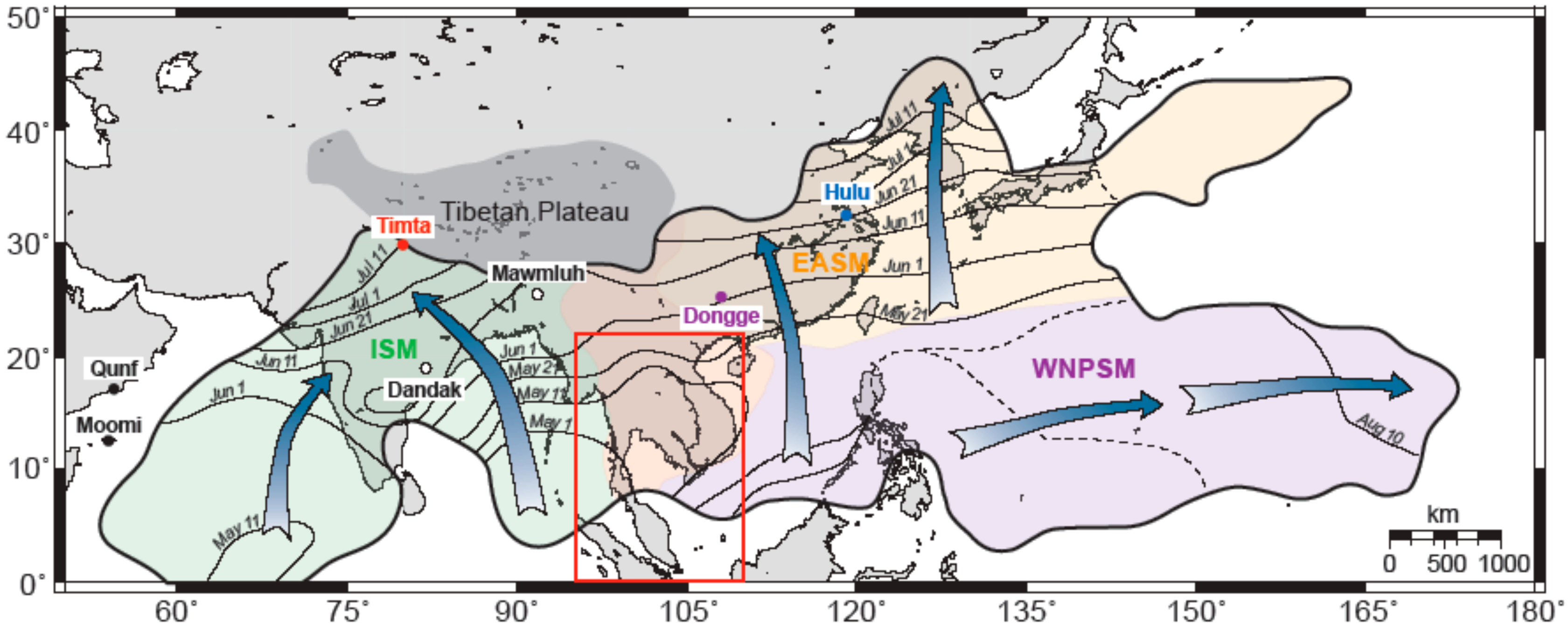
The Monsoon Asia Drought Atlas: A new tool for modeling Asian monsoon variability over the past millennium



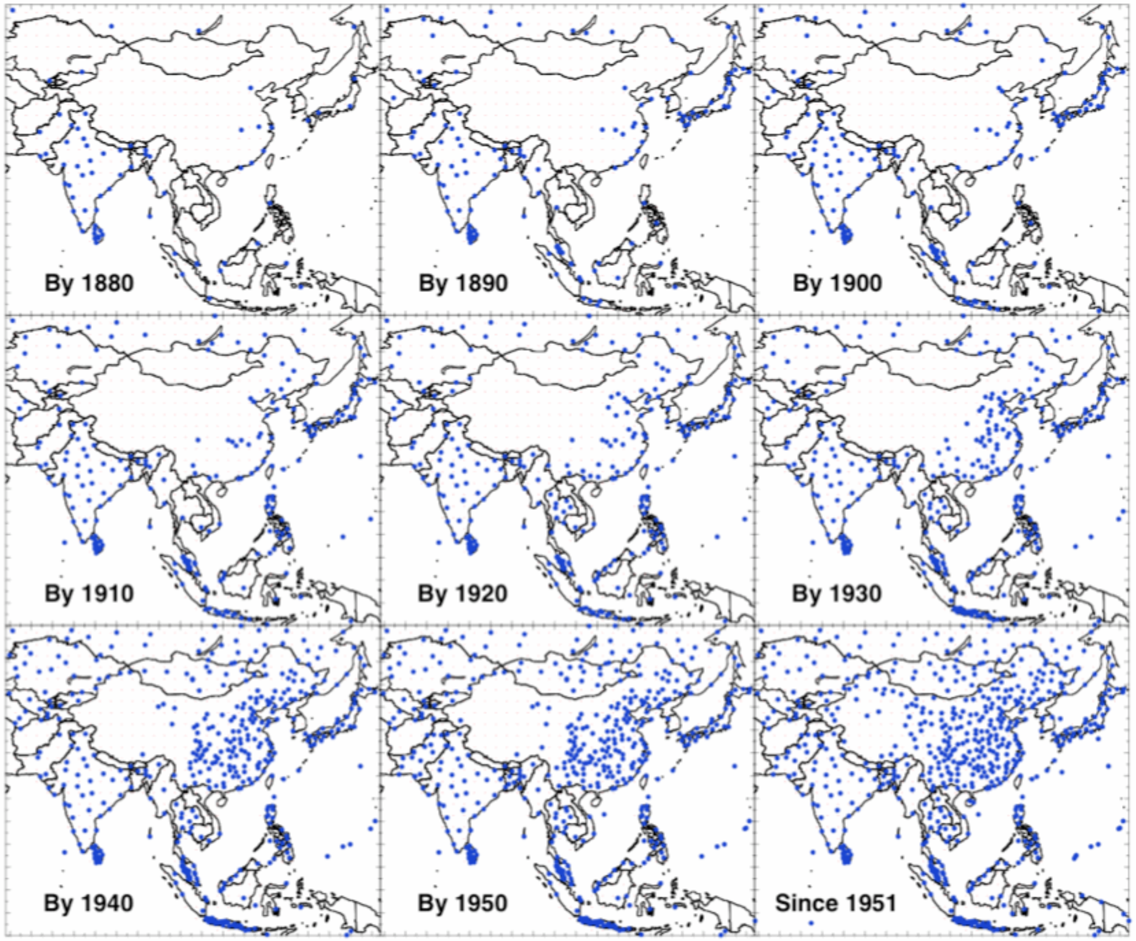
1st Asia 2K Workshop in Nagoya, Japan
August 26-27, 2010

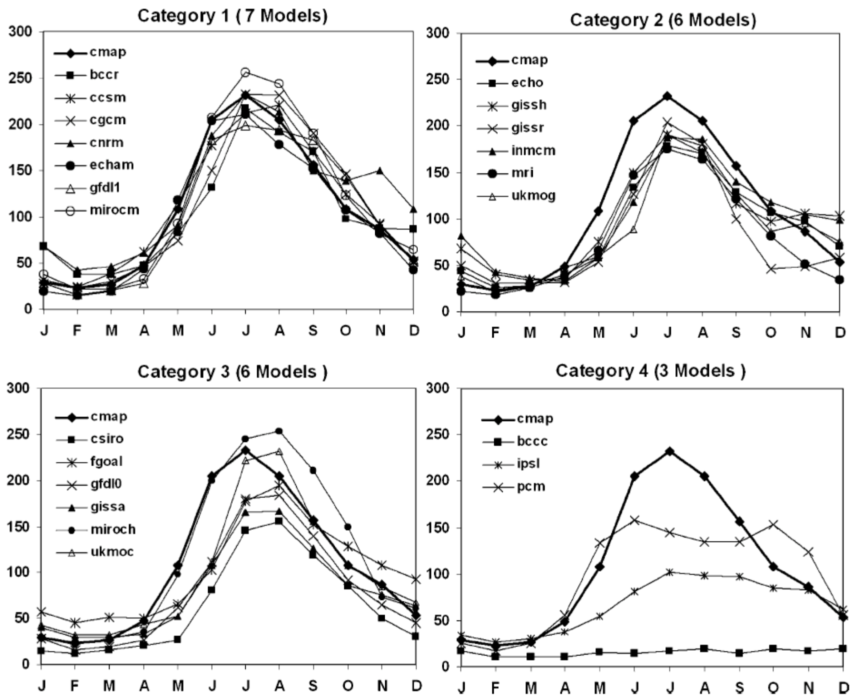
Edward R. Cook, Kevin J. Anchukaitis, Brendan M. Buckley,
Rosanne D. D'Arrigo, Gordon C. Jacoby, William E. Wright
Lamont-Doherty Earth Observatory


So why do this?

A pressing need for longer monsoon records: excepting India, most areas of monsoon Asia have few long instrumental climate records.

Asian PPT coverage: before 1940 large regions have no coverage; even before 1951 western China and Tibet are still poorly covered.





South Asian summer monsoon precipitation variability: Coupled climate model simulations and projections under IPCC AR4

R. H. Kripalani[1,2], J. H. Oh[1], A. Kulkarni[2], S. S. Sabade[2], and H. S. Chaudhari[1]

Theor. Appl. Climatol. 90, 133–159 (2007)

Fig. 1. Average monthly rainfall (mm/month) for the observed (cmap) and simulated by the 22 coupled models depicting the annual cycle (J = January – – – – – D = December) over the south Asian region. Category 1: Models simulating shape and magnitude well; Category 2: models simulating shape well but underestimating magnitude; Category 3: models simulating a shift in peak precipitation by a month; Category 4: models unable to simulate the annual cycle properly. Models are identified by their acronyms

Another reason:

22 coupled climate models used in the IPCC AR4 -- a lot of differences in simulating the summer monsoon. Long tree-ring reconstructions may provide information that could help improve the models.

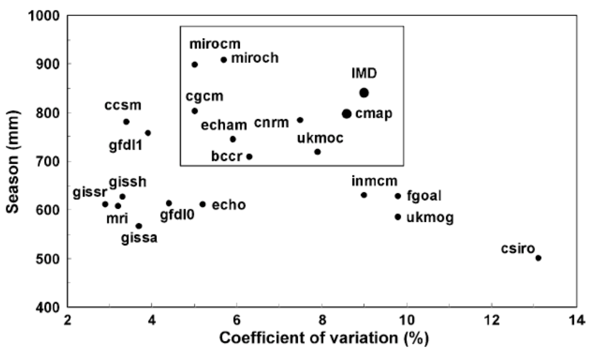


Fig. 2. Scatter plot of the mean seasonal (JJAS) rainfall in mm and the coefficient of variation (in %) for the 19 coupled models. Each dot represents the corresponding values for each model, identified by their acronyms. Observed values are depicted as cmap and IMD (see text). The models in the rectangular box are identified for projections

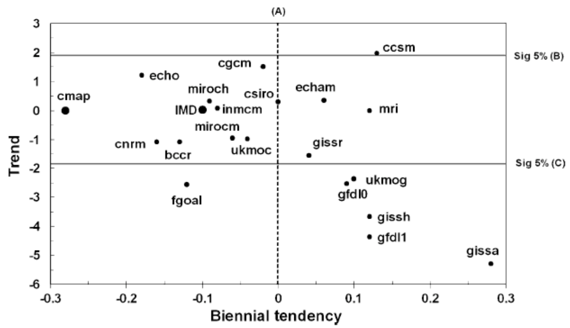


Fig. 3. Same as Fig. 2 but for the trend (Mann-Kendall statistic) and biennial tendency (lag-1 autocorrelation). Models on the left (right) of vertical dashed line A reflect (do not reflect) biennial tendency. Horizontal lines B and C indicate the trend values at 5% significance level. Models lying between the lines B and C show no trends. Models are identified by their acronyms. Values based on cmap and IMD are also indicated

Reconstructing Asian Monsoon Climate Dynamics

- **A U.S. *National Science Foundation* sponsored project "Tree-Ring Reconstructions of Asian Monsoon Climate Dynamics" began in August, 2004 and is now finished. It resulted in the recently published paper in Science:**

Asian Monsoon Failure and Megadrought During the Last Millennium

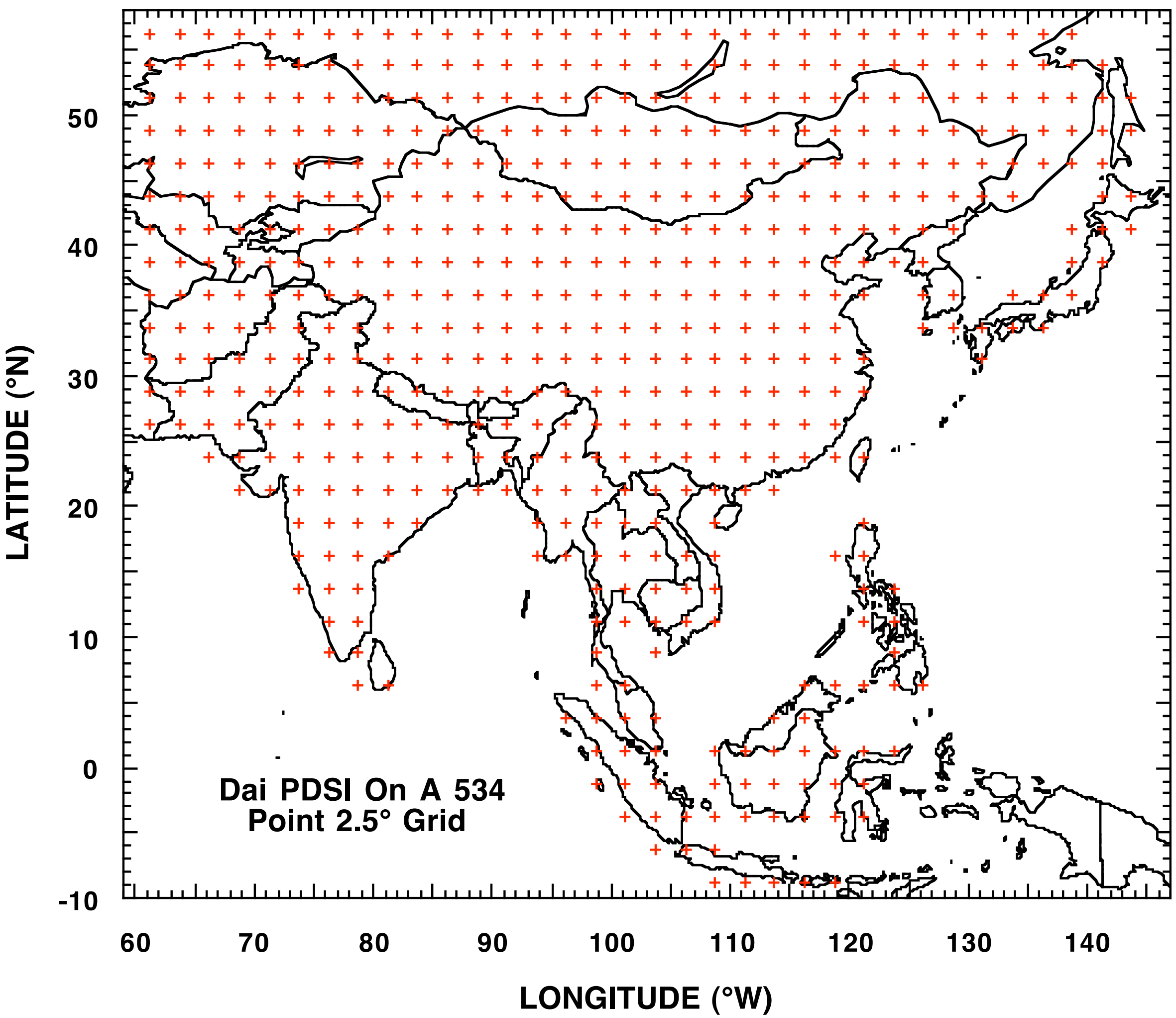
Edward R. Cook,[1*] Kevin J. Anchukaitis,[1] Brendan M. Buckley,[1] Rosanne D. D'Arrigo,[1] Gordon C. Jacoby,[1] William E. Wright[1,2]

23 APRIL 2010 VOL 328 SCIENCE www.sciencemag.org

The main research product of this project is the *'Monsoon Asia Drought Atlas' (MADA)*

- Patterned after the highly successful North American Drought Atlas (NADA; Cook and Krusic, 2004);
- Gridded drought reconstructed over Asian monsoon land areas;
- The Asian monsoon metric reconstructed: the monsoon season (JJA) Palmer Drought Severity Index (PDSI);
- The PDSI data source: Dai-Trenberth-Qian gridded data;
- The target field: June-July-August average PDSI on a 534 point 2.5° grid;
- The proxy data set: 327 annual tree-ring chronologies;
- The method of reconstruction: Ensemble Point-by-Point Regression (EPPR).

The Asian Monsoon Reconstruction Target Field



<u>The Dai-Trenberth-Qian PDSI Data</u>

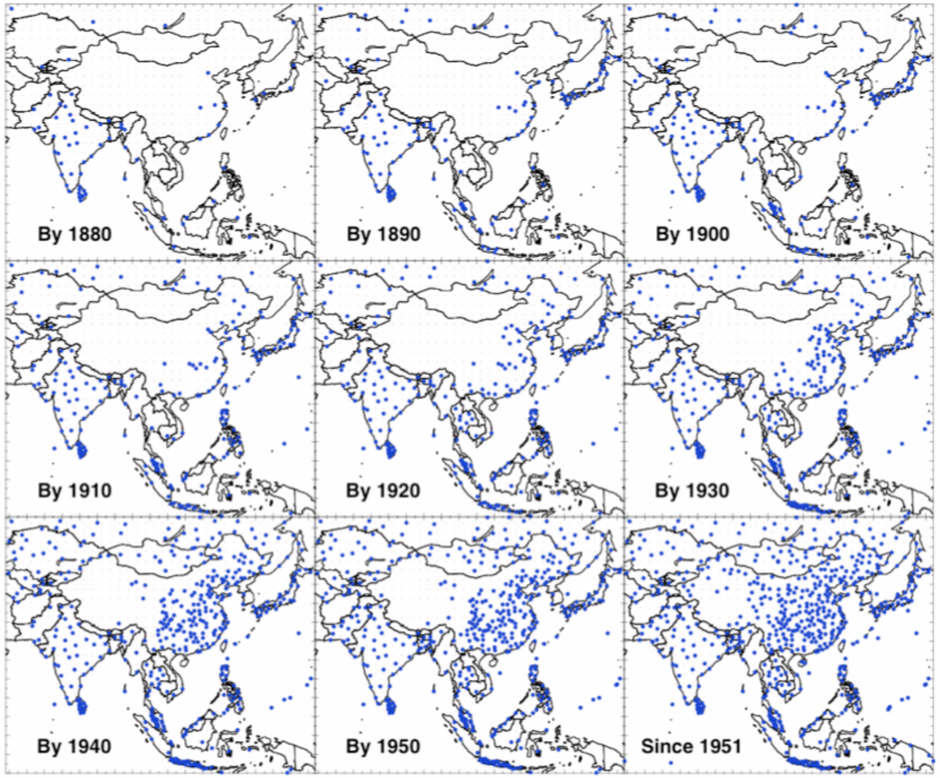
Dai, A., K.E. Trenberth, and T. Qian, 2004: A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. *Journal of Hydrometeorology* 5:1117-1130.

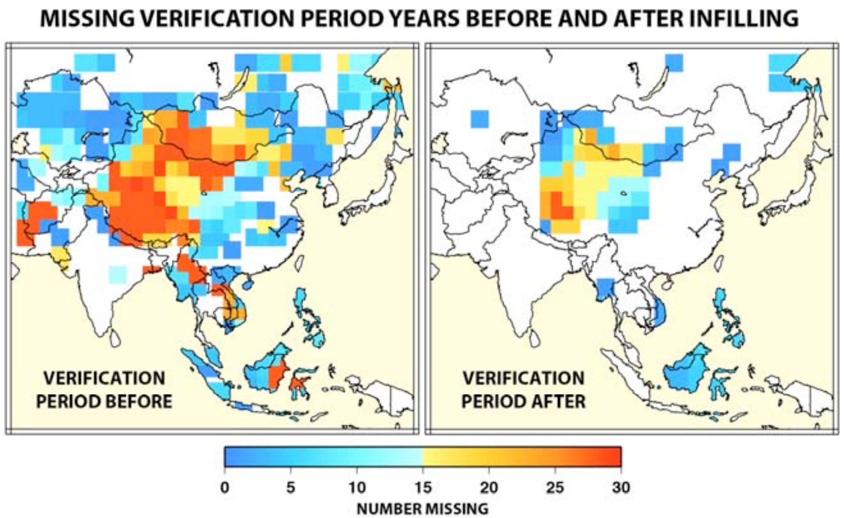
Dai Palmer Drought Severity Index data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA.
http://www.cdc.noaa.gov/cdc/data.pdsi.html

Nominal time coverage: 1870-2005, but extremely noisy in some regions at the grid point level and many missing values and outliers over significant parts of Asia prior to 1951.

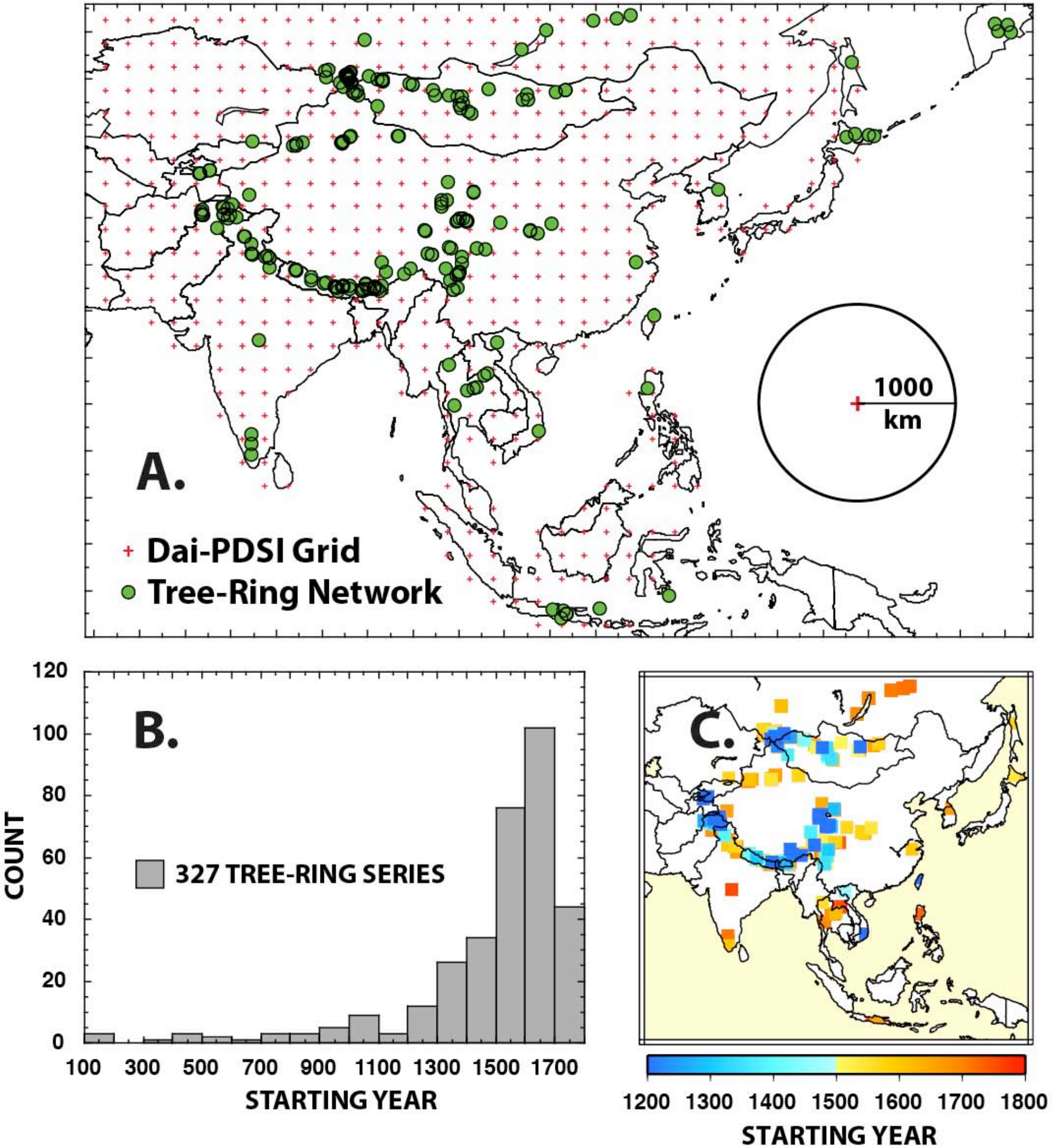
Gridded Dai PDSI data since 1951 mostly serially complete and best quality - used for calibration - **1951-1989 (39 years)** - outer year determined by the common end year of tree rings.

Gridded pre-1951 Dai PDSI data has reasonable single-station coverage for interpolation back to 1920 - used for verification - **1920-1950 (31 years)** - but 22% of the data were missing and had to be estimated where possible!





The Asian Monsoon Tree-Ring Network



Common First Year:
1786

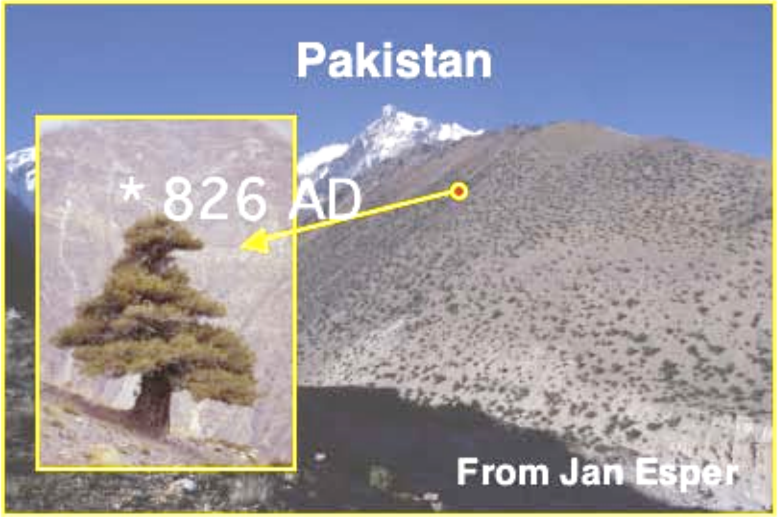
Common Last Year:
1990

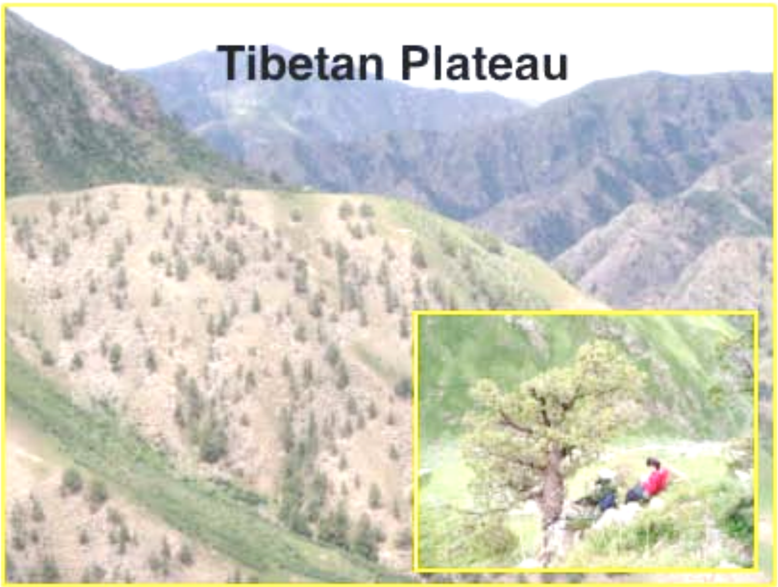
Teak

Tropical Pines

Ancient Conifers in Vietnam

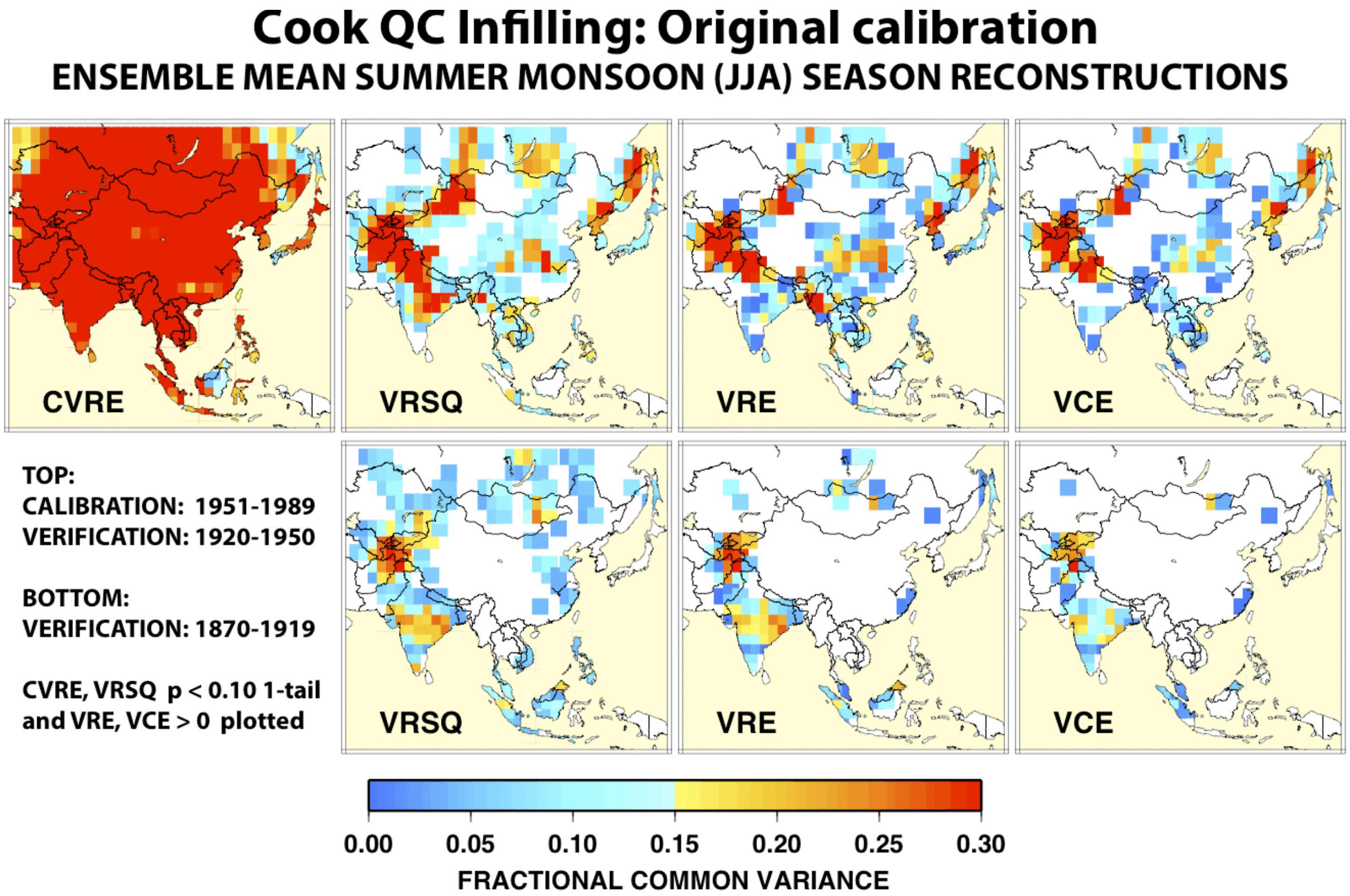
Conifers in High Asia





Method of Climate Field Reconstruction

Ensemble Point-by-Point Regression (EPPR): The mean of 24 ensemble members is presented here

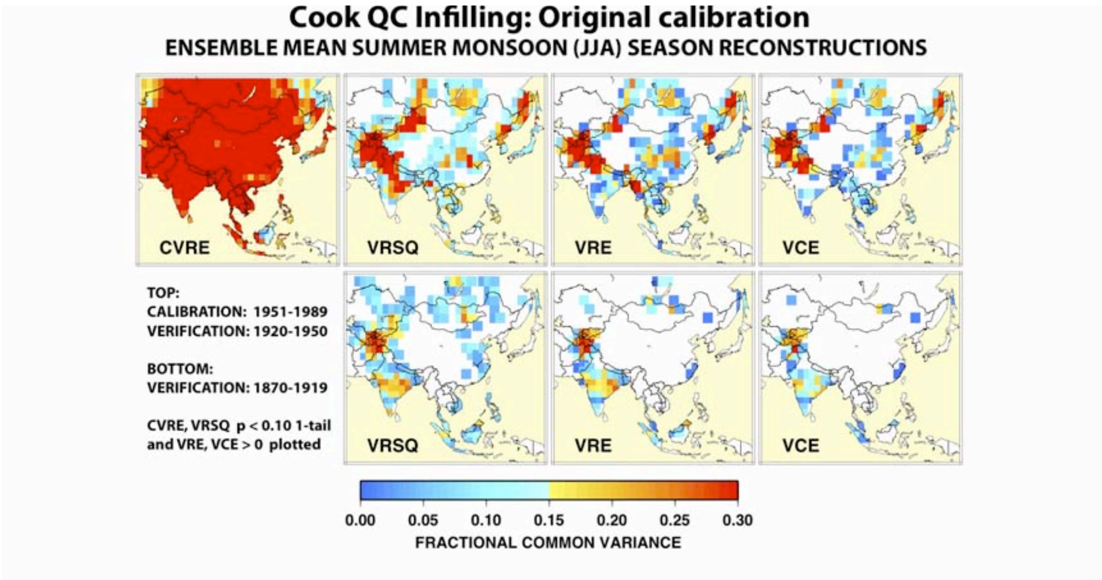


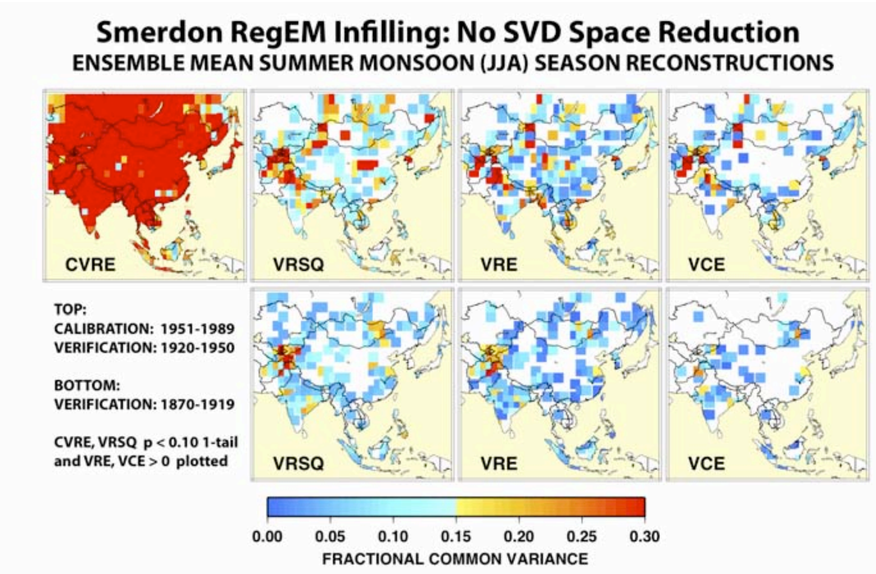
After the MADA was produced based on the Dai PDSI grid with some missing values replaced by monthly means, an alternative version of the Dai PDSI grid was produced with all data infilled back to 1870 using *Regularized Expectation Maximization (RegEM)*. Doing so provided a way of testing the robustness of the MADA based on EPPR.

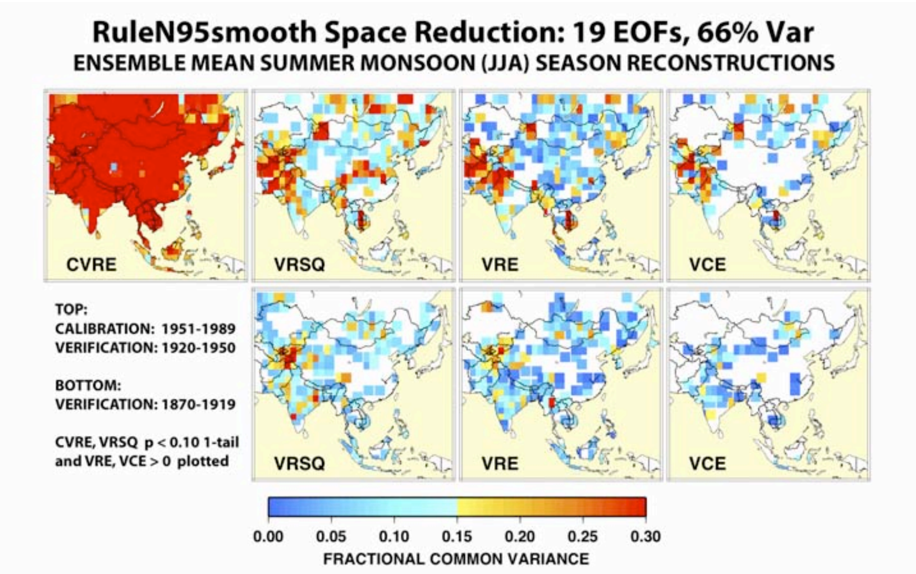
Analysis of Incomplete Climate Data: Estimation of Mean Values and Covariance Matrices and Imputation of Missing Values

TAPIO SCHNEIDER

- Regularized EM algorithm provides framework for estimation of missing values and covariance matrices in incomplete, rank-deficient data
- Different regularization approaches can be used within regularized EM algorithm (and should be tested):
  - Tikhonov/ridge regression
  - Truncated TTLS
  - Tapered covariance functions etc.

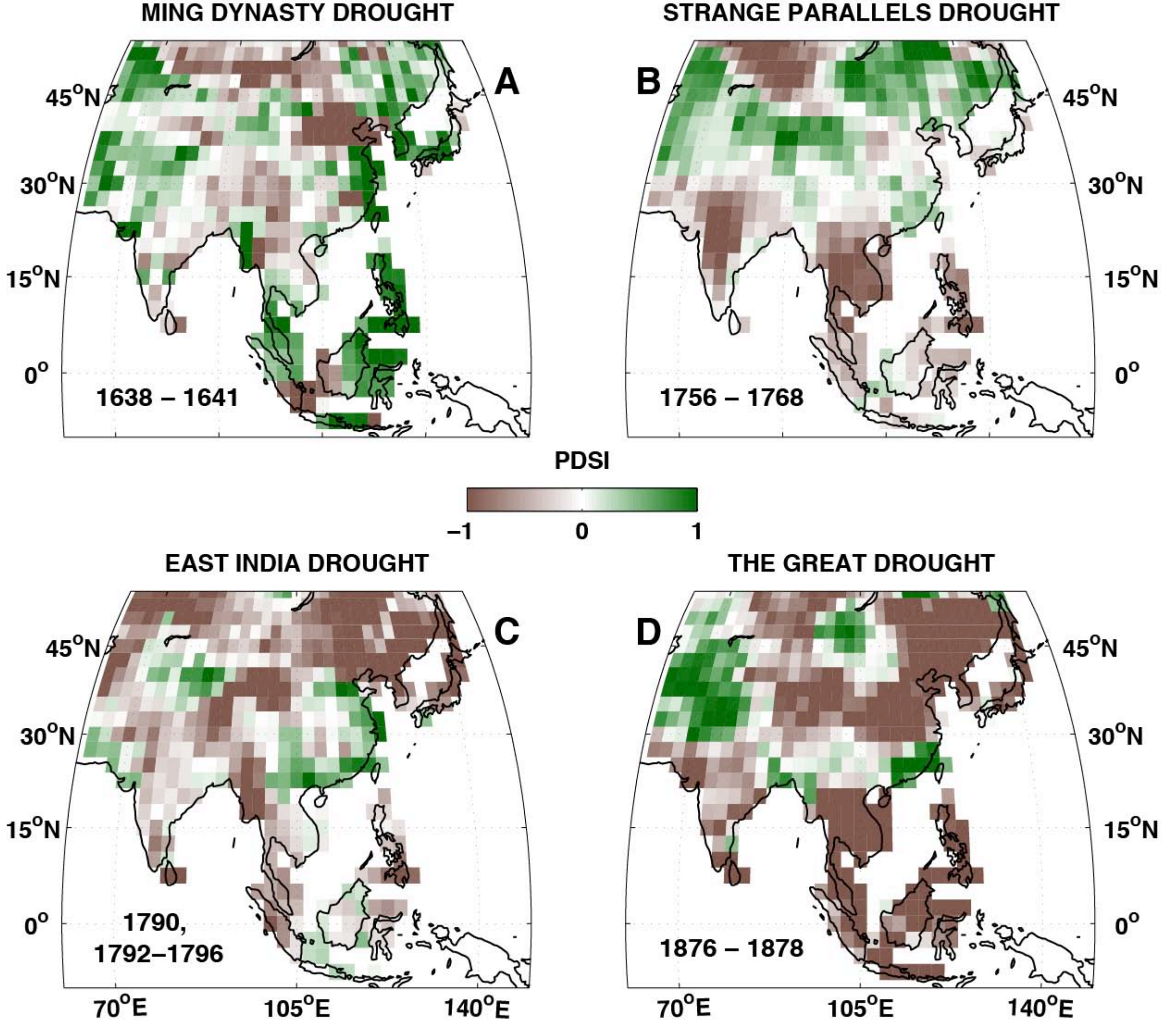

Cook QC Infilling: Original calibration
ENSEMBLE MEAN SUMMER MONSOON (JJA) SEASON RECONSTRUCTIONS
CVRE
VRSQ
VRE
VCE
TOP:
CALIBRATION: 1951-1989
VERIFICATION: 1920-1950
BOTTOM:
VERIFICATION: 1870-1919
CVRE, VRSQ p < 0.10 1-tail
and VRE, VCE > 0 plotted
VRSQ
VRE
VCE
0.00 0.05 0.10 0.15 0.20 0.25 0.30
FRACTIONAL COMMON VARIANCE


Smerdon RegEM Infilling: No SVD Space Reduction
ENSEMBLE MEAN SUMMER MONSOON (JJA) SEASON RECONSTRUCTIONS
CVRE
VRSQ
VRE
VCE
TOP:
CALIBRATION: 1951-1989
VERIFICATION: 1920-1950
BOTTOM:
VERIFICATION: 1870-1919
CVRE, VRSQ p < 0.10 1-tail
and VRE, VCE > 0 plotted
VRSQ
VRE
VCE
0.00 0.05 0.10 0.15 0.20 0.25 0.30
FRACTIONAL COMMON VARIANCE


RuleN95smooth Space Reduction: 19 EOFs, 66% Var
ENSEMBLE MEAN SUMMER MONSOON (JJA) SEASON RECONSTRUCTIONS
CVRE
VRSQ
VRE
VCE
TOP:
CALIBRATION: 1951-1989
VERIFICATION: 1920-1950
BOTTOM:
VERIFICATION: 1870-1919
CVRE, VRSQ p < 0.10 1-tail
and VRE, VCE > 0 plotted
VRSQ
VRE
VCE
0.00 0.05 0.10 0.15 0.20 0.25 0.30
FRACTIONAL COMMON VARIANCE

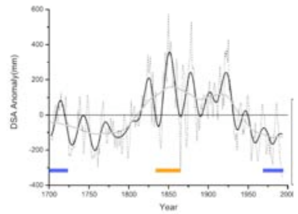
Some Reconstructed 'Historical' Droughts in Full Spatial Detail now from the MADA

Shen et al. 2007. **Exceptional drought events over eastern China during the last five centuries**. *Climatic Change* 85:453-471.



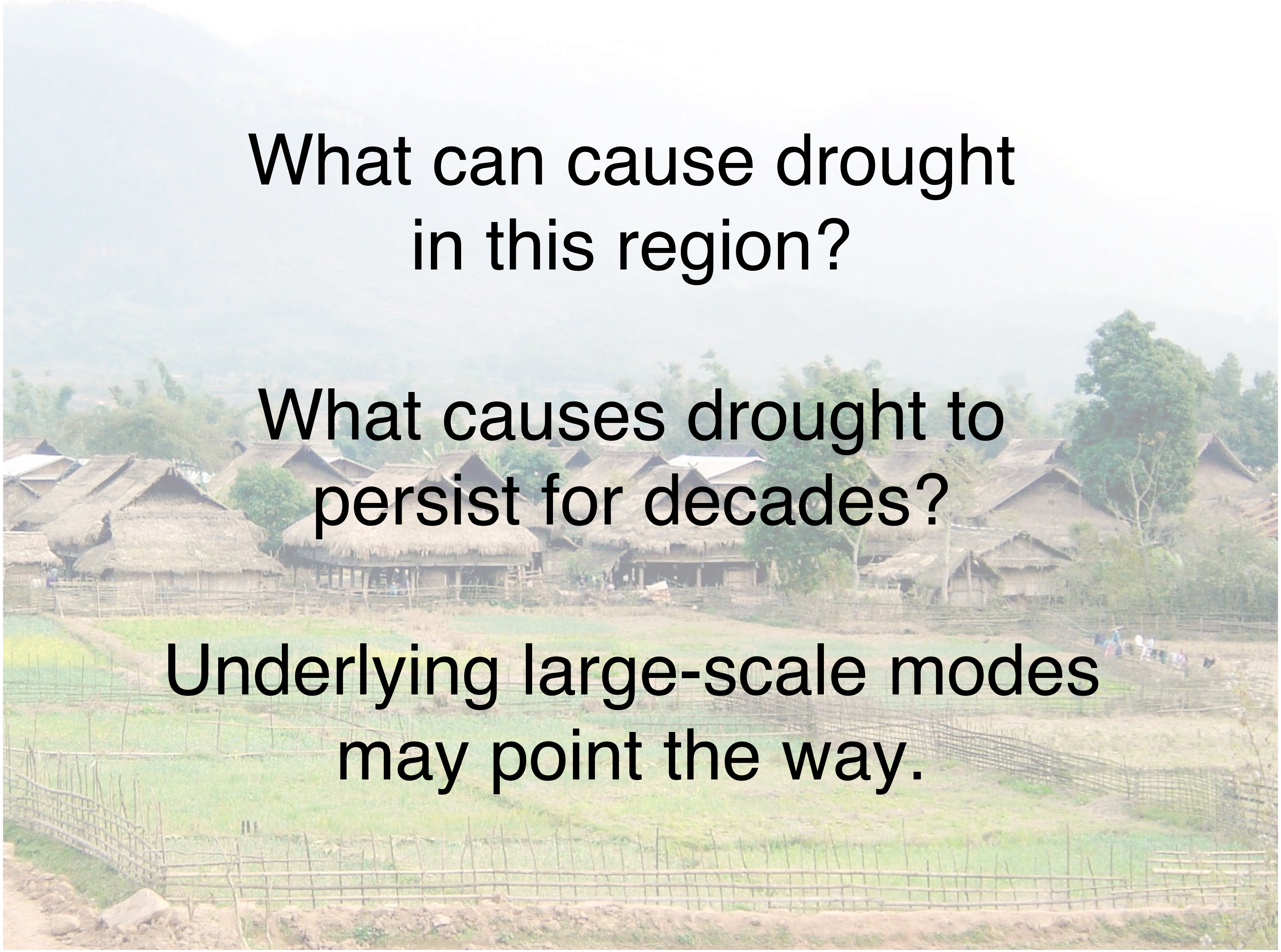
Lieberman, V. 2003. ***Strange Parallels: Southeast Asia in a Global Context, C. 800-1830, Vol. 1.*** Cambridge University Press, Cambridge.

Grove, R. 2007. **The great El Niño of 1789-93 and its global consequences: reconstructing an extreme climate event in world environmental history.** *The Medieval History Journal* 10:75-



Dasuopu snow accumulation from Takata et al. 2009, PNAS

Davis. M. 2001. ***Late Victorian Holocausts: El Niño, Famines, and the Making of the Third World***. Verso, London.



What can cause drought in this region?

What causes drought to persist for decades?

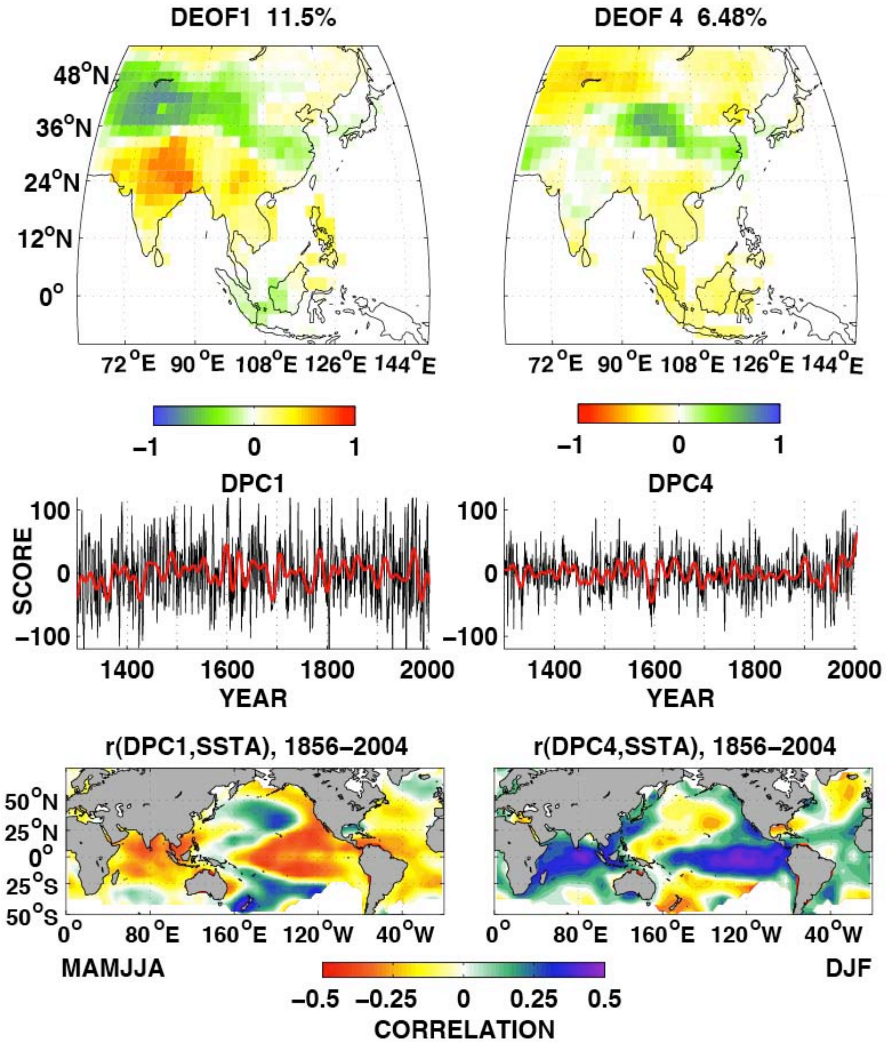
Underlying large-scale modes may point the way.

Distinct EOF Analysis

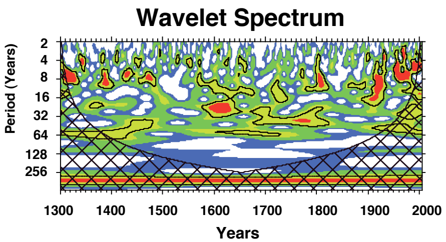
(Dommenget. 2007. Evaluating EOF modes against a stochastic null hypothesis. *Climate Dynamics* 28:517-531)

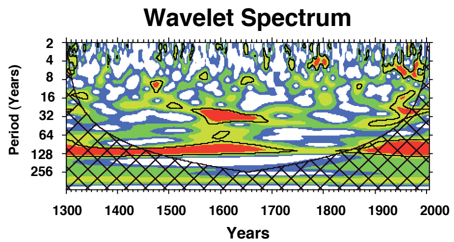
Analysis of Two Extracted Modes in the MADA

Dominant same-sign loadings over India and Southeast Asia, with opposite sign loadings over the Tibetan Plateau, northern Pakistan, and the Pamir and Tien-Shan Mountains.



Strong same-sign loadings over the eastern Tibetan Plateau and central China, with opposite sign loadings elsewhere.



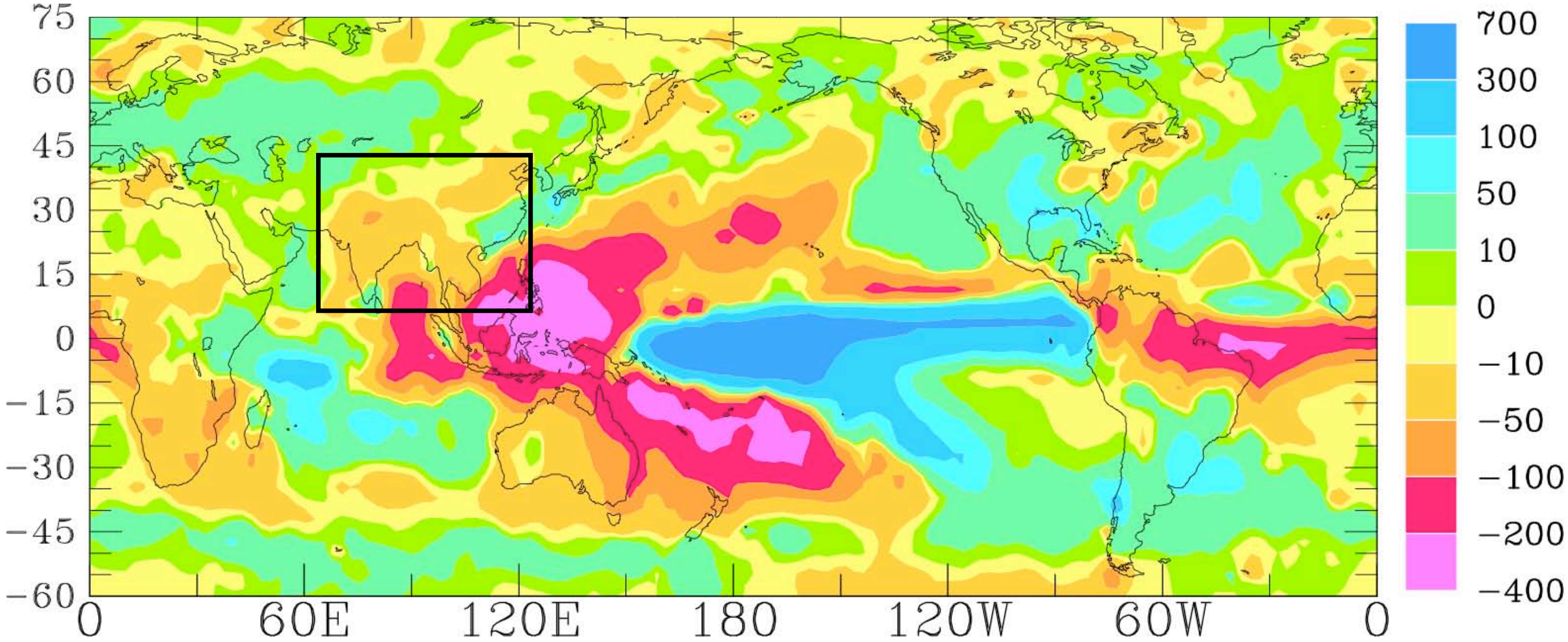


DEOF1 mode concurrent with pre-monsoon/ monsoon season tropical SSTs; interdecadal ENSO or IPO mode?

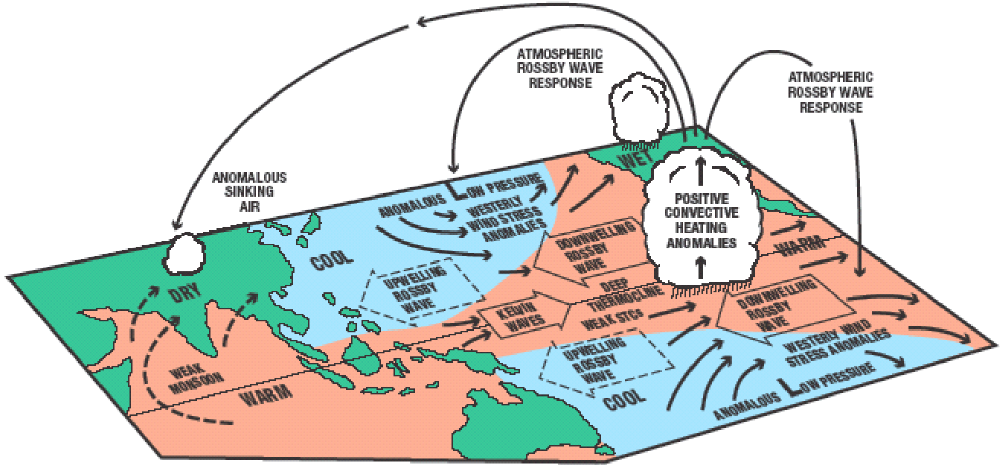
DEOF4 mode lags winter (DJF) season tropical Pacific and Indian Ocean SSTs; canonical 'cold tongue' ENSO mode?

Annual precipitation anomaly (mm) for typical El Niños

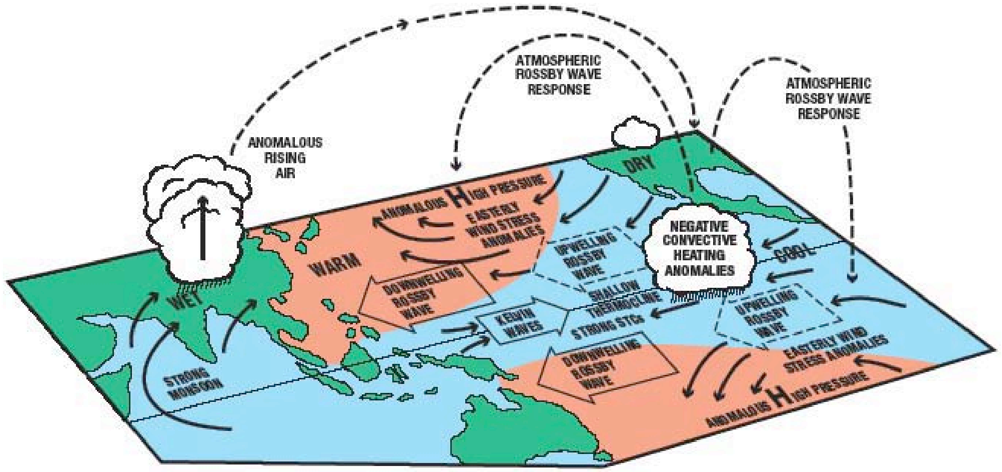
El Niño brings drought to Monsoon Asia



(from Dai and Wigley, 2000)



Positive IPO
Drought over India



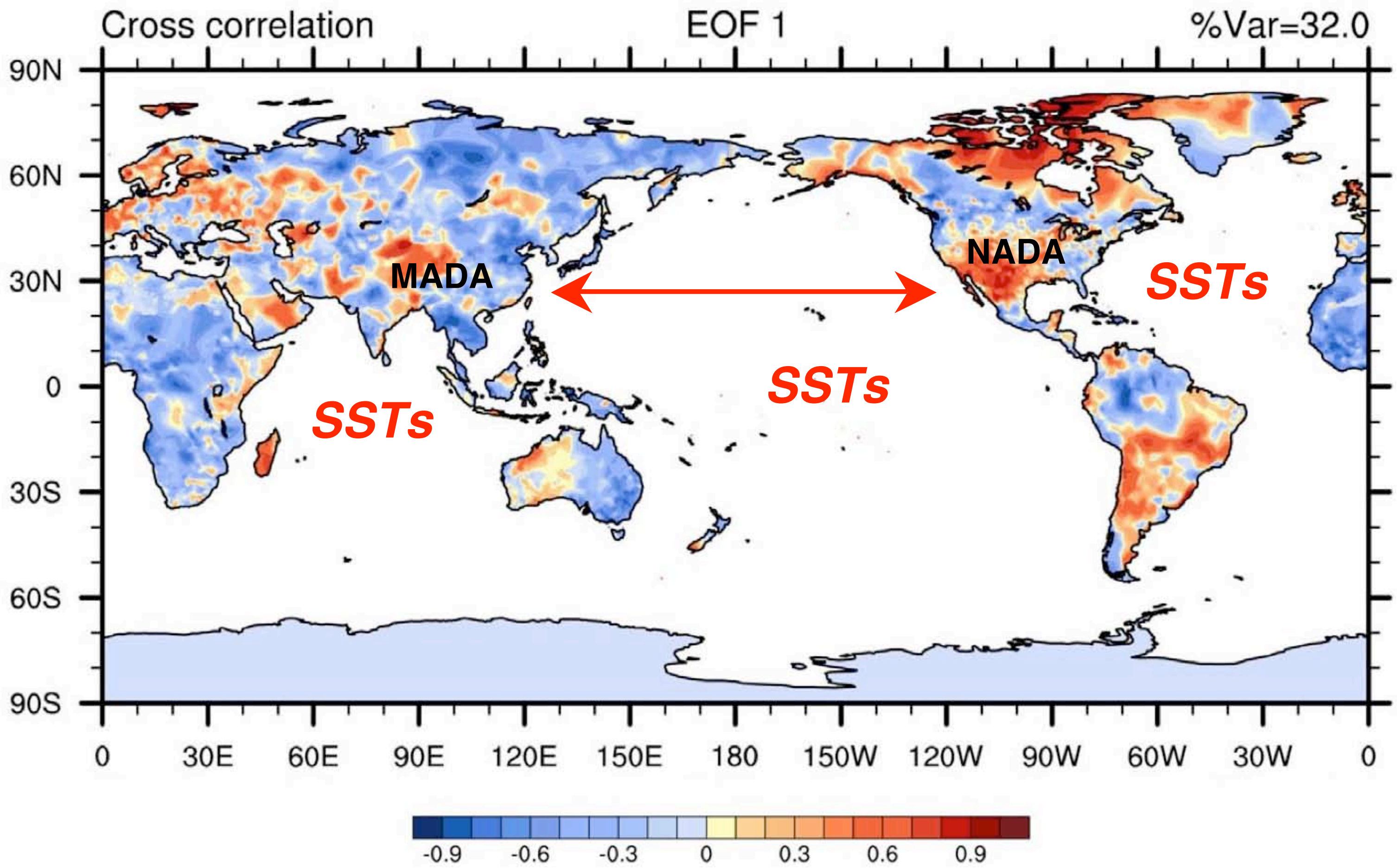
Negative IPO
Drought over Great Basin

Interdecadal Pacific Oscillation (IPO): multi-decadal variability over most of the Pacific, whereas PDO only over north Pacific region. Involves tropical to mid latitude air-sea interactions, wind-forced Ocean Rossby waves near 20˚N - 25˚S. Distinct from ENSO.

(from Meehl and Hu, 2006, J.Clim)

So what about trans-Pacific Basin teleconnections between Asia and North America with global SSTs as the bridge?

-- Large-scale comparisons of the MADA and NADA --

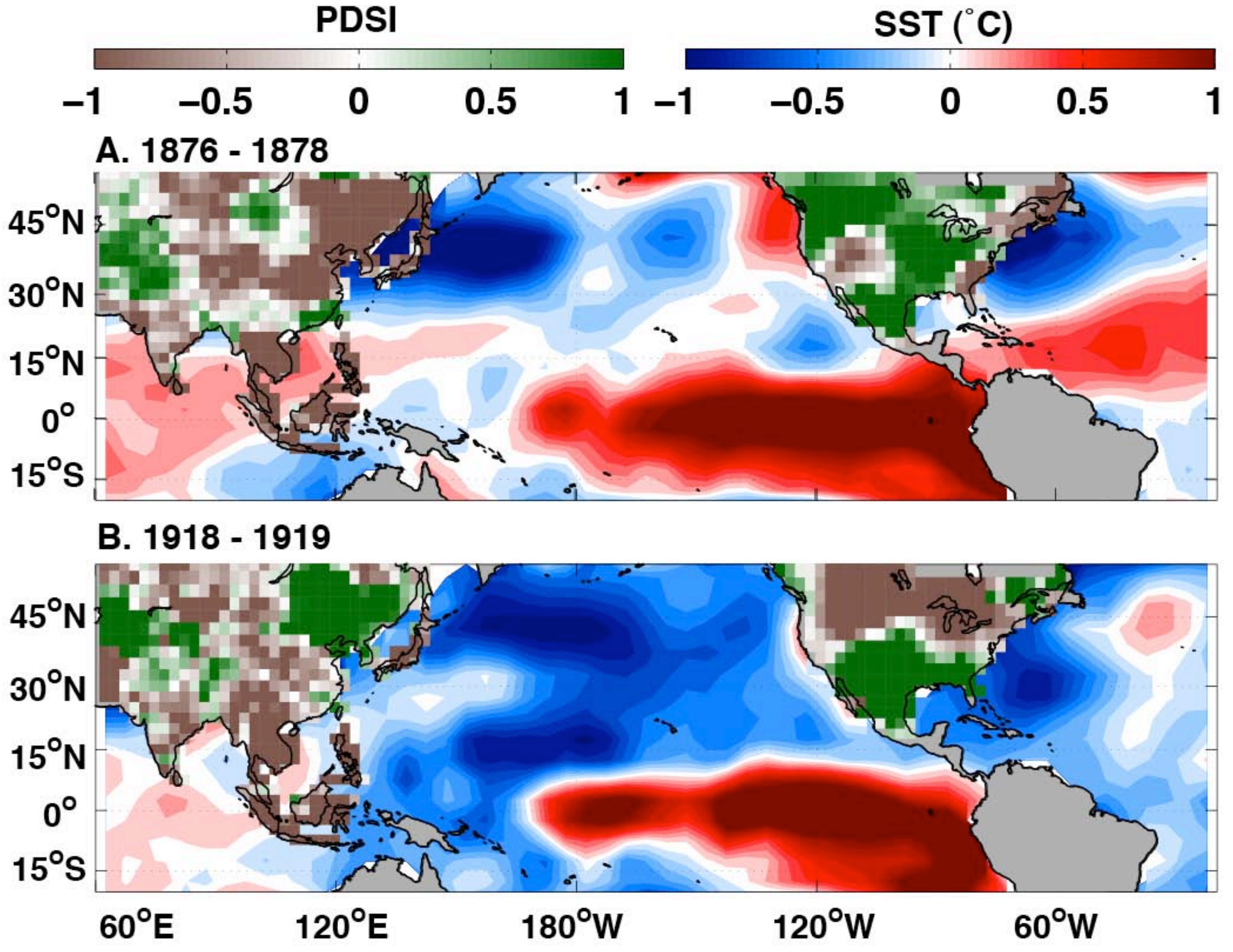


Correlation of PC time series from IPO with 13-year low-pass filtered land precipitation (1901-2000).

(from Meehl and Hu, 2006, J.Clim)

Comparisons of MADA and NADA and DJF SSTs for Two Great El Niños in 1876-1878 and 1918-1919

Overall patterns of *dry over Asia* and *wet over North America* are consistent with expectation, but the spatial details differ in 'non-canonical' ways, due perhaps to differences in non-tropical Pacific SSTs.



Proxy-Surrogate Reconstruction (PSR)
first introduced by Nick Graham

An analog technique for the combined use of proxy records and model results . . .

Climatic Change (2007) 83:241–285
DOI 10.1007/s10584-007-9239-2

Tropical Pacific – mid-latitude teleconnections in medieval times

**Nicholas E. Graham · Malcolm K. Hughes ·
Caspar M. Ammann · Kim M. Cobb ·
Martin P. Hoerling · Douglas J. Kennett ·
James P. Kennett · Bert Rein · Lowell Stott ·
Peter E. Wigand · Taiyi Xu**

Model Used for PSR Tests

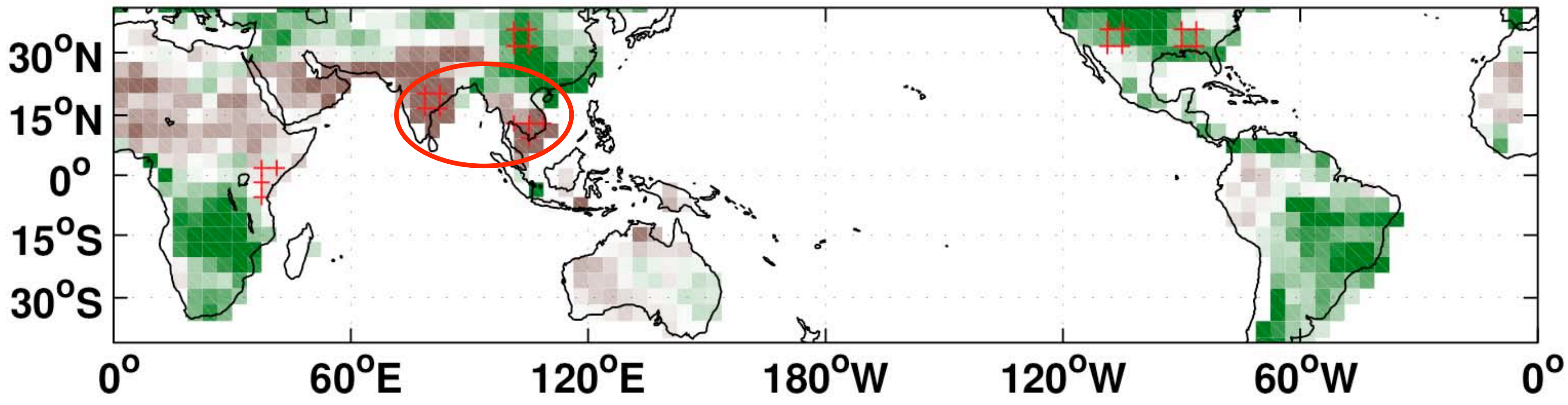
COSMOS MILLENNIUM MPI [*Jungclaus et al*]

Atmosphere model ECHAM5, the ocean model MPIOM, and modules for land vegetation (JSBACH) and ocean biogeochemistry (HAMOCC). Model experiments are carried out using the COSMOS ASOB model with ECHAM5 in T31/L19 and MPIOM in GR3.0/L40 resolution. Ensemble of five simulations spanning the time 800 AD to 2005 AD, applying reconstructions of natural forcing (volcanic aerosols and Total Solar Irradiance, TSI) and anthropogenic forcing (land-cover changes, greenhouse gas emissions).

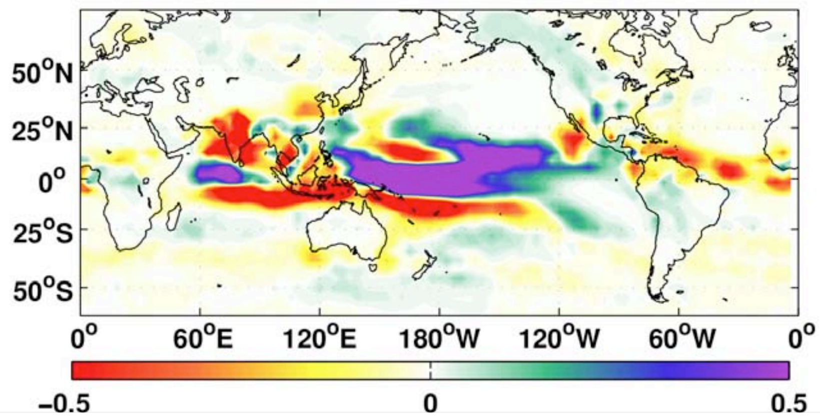
Tropical Asian Severe Drought COSMOS Analogs

Constrain analogs with observed Bidoup Nui Ba and Dandak < -1 PDSI

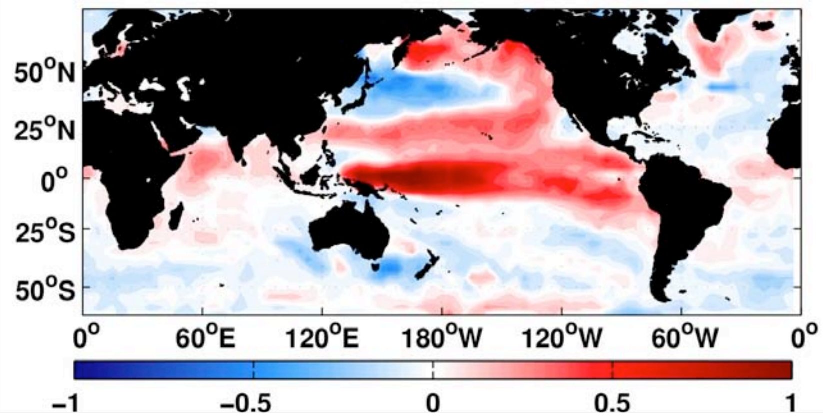
JJA Model PDSI anomalies 11 yr Butterworth Filter, n = 156 from 6000 model years



Convective precipitation anomaly (mm/day)



SST anomaly (°C)

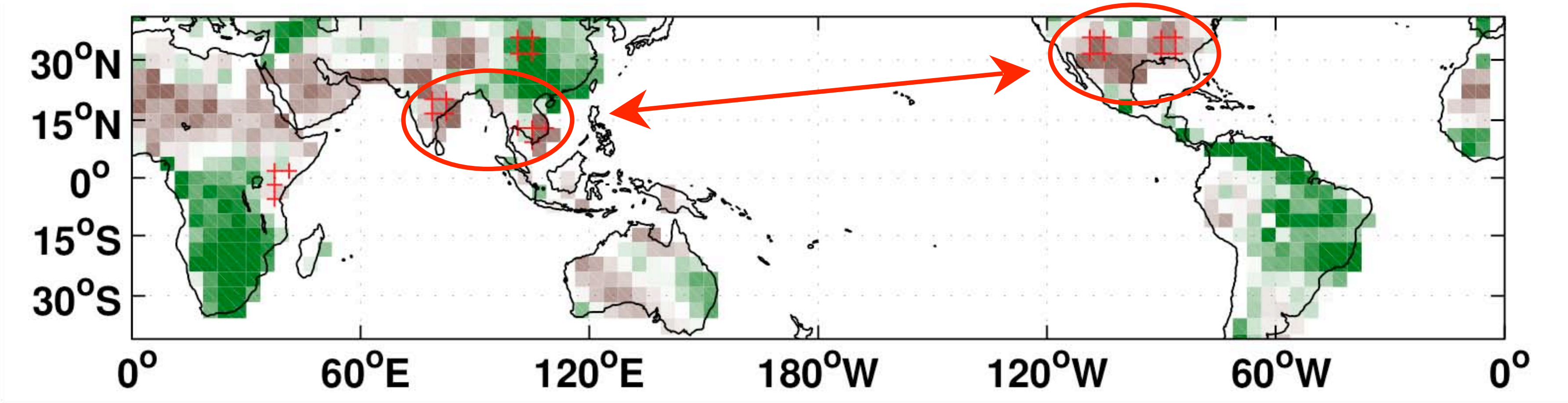


Anchukaitis, Cook, Buckley, Jungclaus et al. in preparation

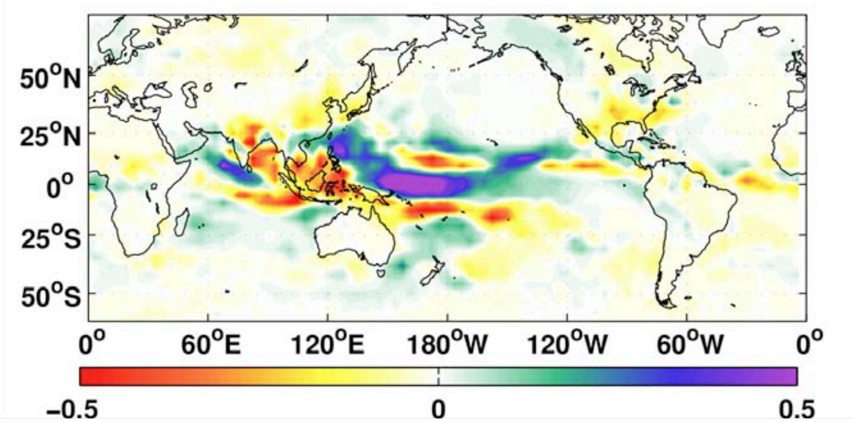
Asian + North American Drought COSMOS Analogs

Constrain analogs with observed sign of Bidoup Nui Ba, Dandak, and North America

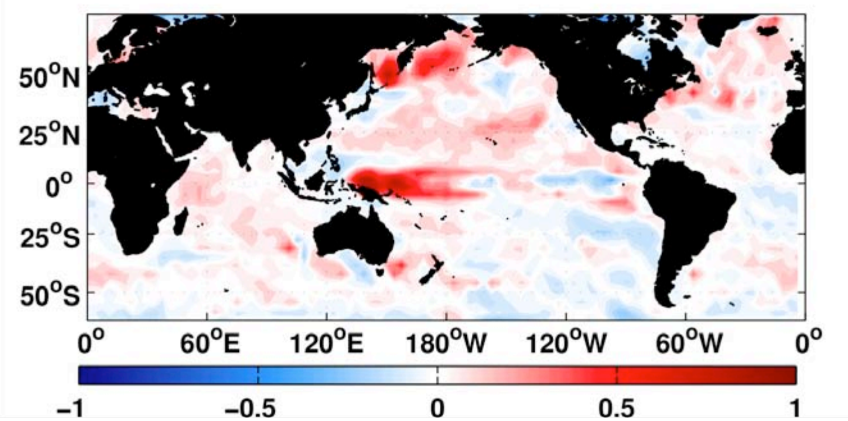
JJA Model PDSI anomalies 11 yr Butterworth Filter, n = 98 from 6000 model years



Convective precipitation anomaly (mm/day)



SST anomaly (°C)



Anchukaitis, Cook, Buckley, Jungclaus et al. in preparation

A possible role for El Niño Modoki?

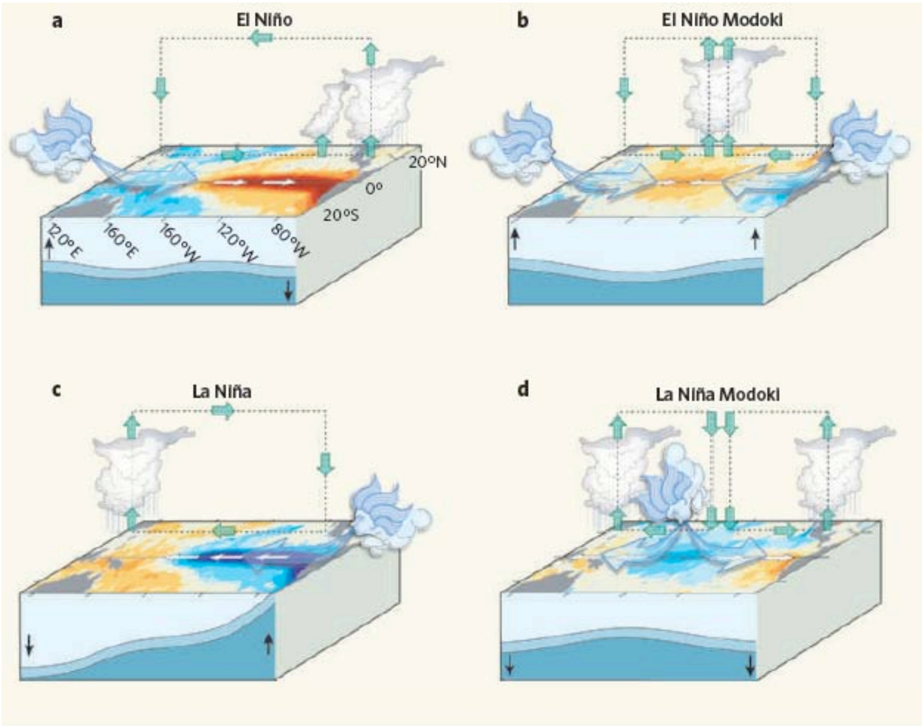
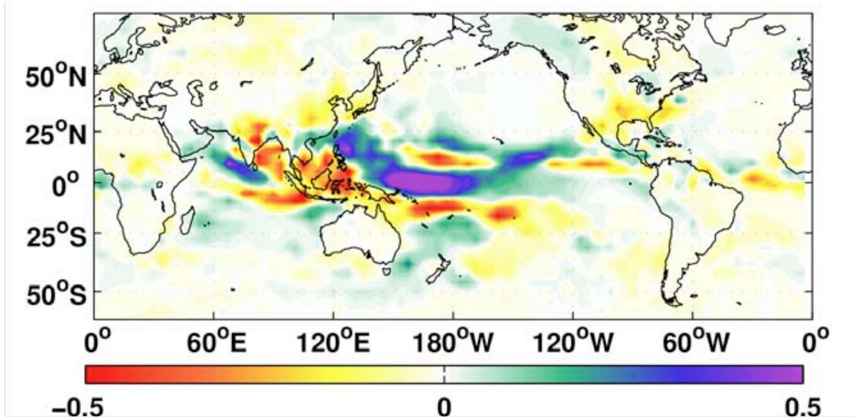


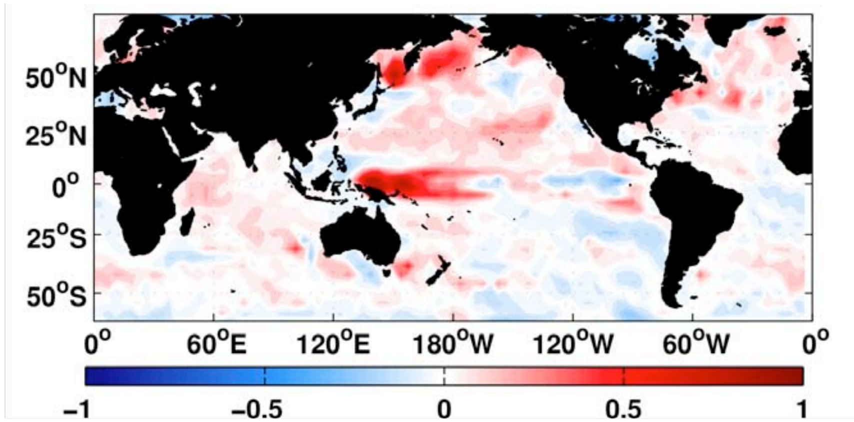
Figure 2 | Anomalous conditions in the tropical Pacific. **a**, An El Niño event is produced when the easterly winds weaken; sometimes, in the west, westerlies prevail. This condition is categorized by warmer than normal sea surface temperatures (SSTs) in the east of the ocean, and is associated with alterations in the thermocline and in the atmospheric circulation that make the east wetter and the west drier. **b**, An El Niño Modoki event is an anomalous condition of a distinctly different kind. The warmest SSTs occur in the central Pacific, flanked by colder waters to the east and west, and are associated with distinct patterns of atmospheric convection. **c**, **d**, The opposite (La Niña) phases of the El Niño and El Niño Modoki respectively. Yeh *et al.*[3] argue that the increasing frequency of the Modoki condition is due to anthropogenic warming, and that these events in the central Pacific will occur more frequently if global warming increases.

(Ashok and Yamagata 2009, Yeh et al. 2009)

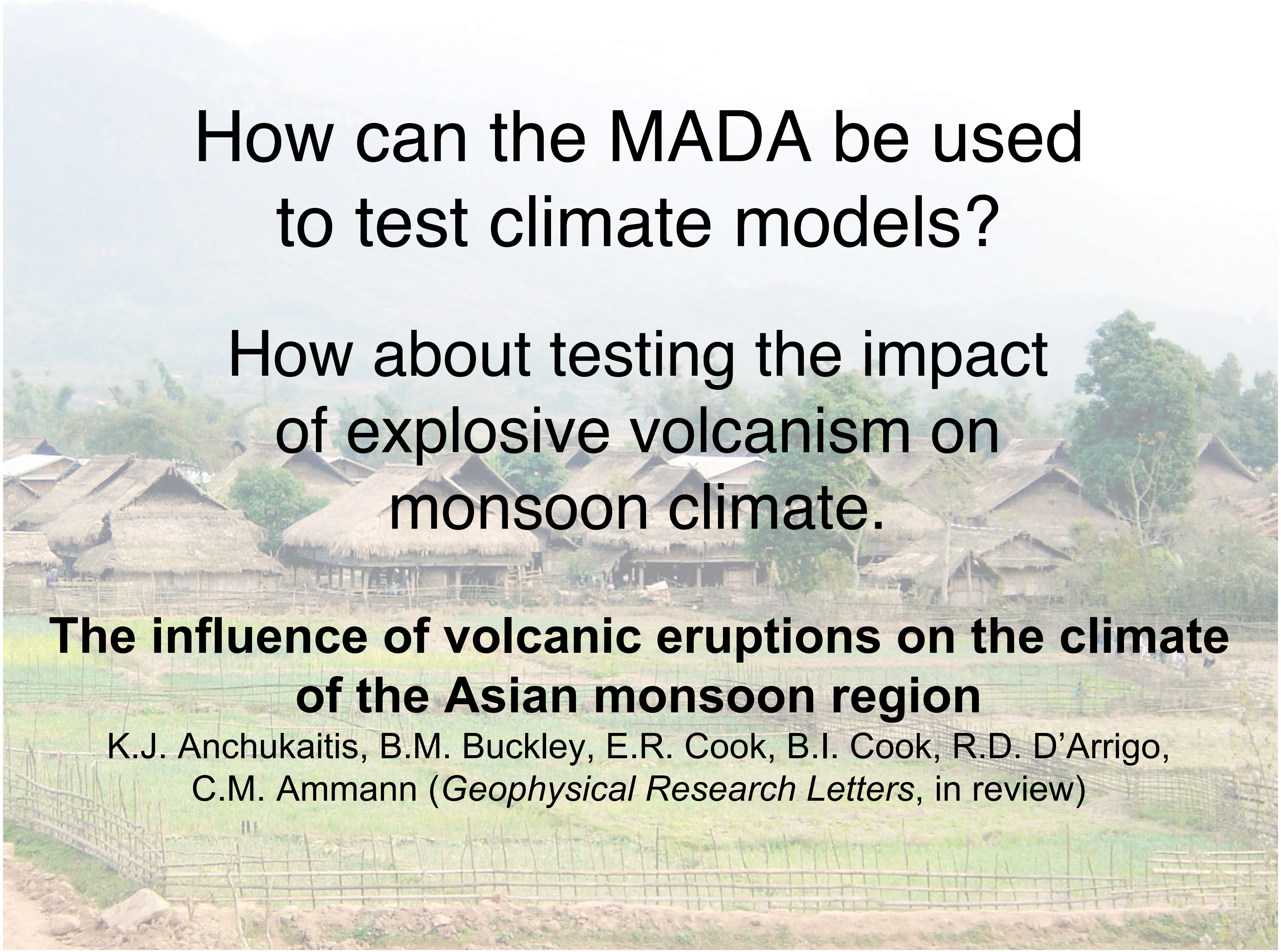
Convective precipitation anomaly (mm/day)



SST anomaly (°C)



Anchukaitis, Cook, Buckley, Jungclaus et al. in preparation



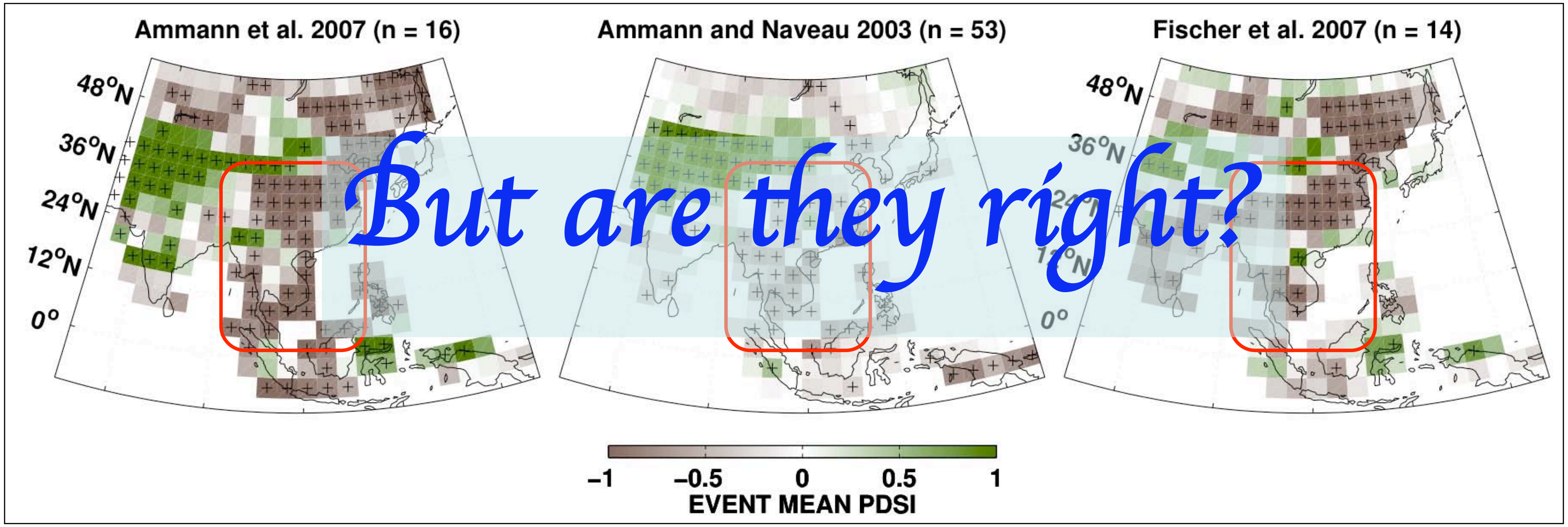
How can the MADA be used to test climate models?

How about testing the impact of explosive volcanism on monsoon climate.

The influence of volcanic eruptions on the climate of the Asian monsoon region

K.J. Anchukaitis, B.M. Buckley, E.R. Cook, B.I. Cook, R.D. D’Arrigo, C.M. Ammann (*Geophysical Research Letters*, in review)

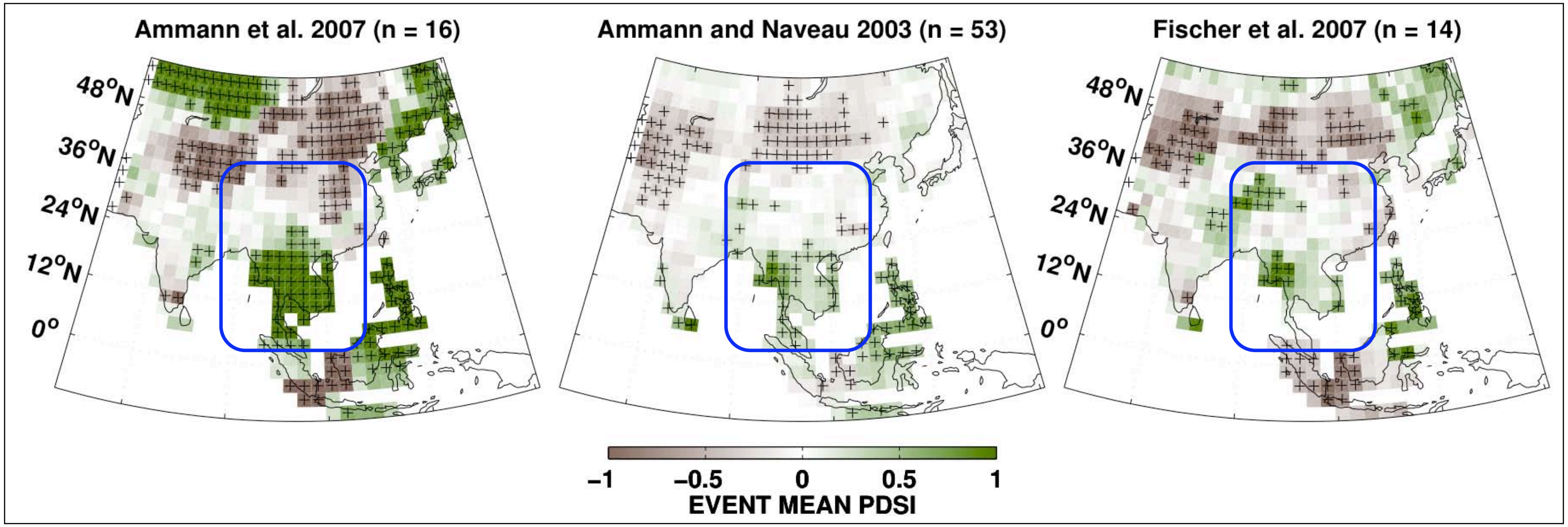
Climate models say that explosive volcanism should produce drought in East and Southeast Asia.

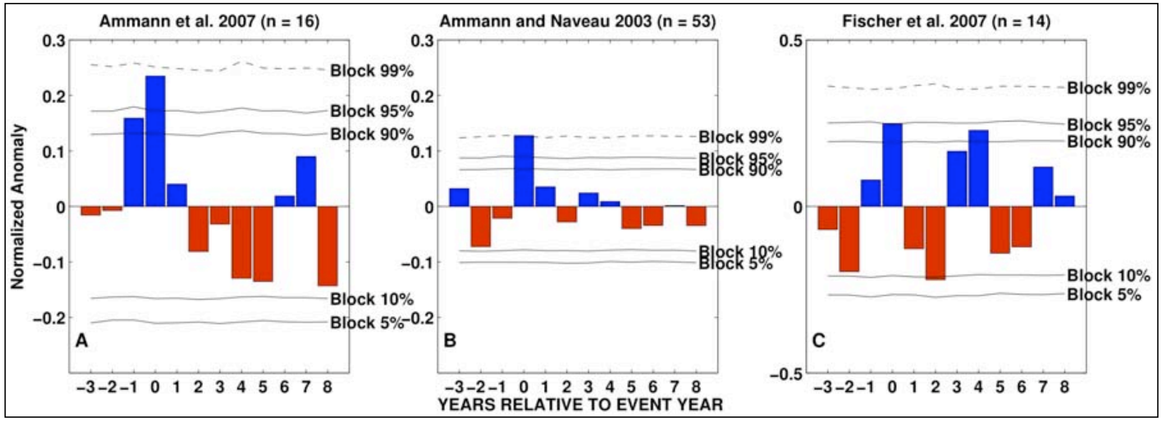


PDSI values derived from the millennium forced simulation of the NCAR CSM 1.4 [*Ammann et al.*, 2007] and composited by the number of volcano key years indicated.

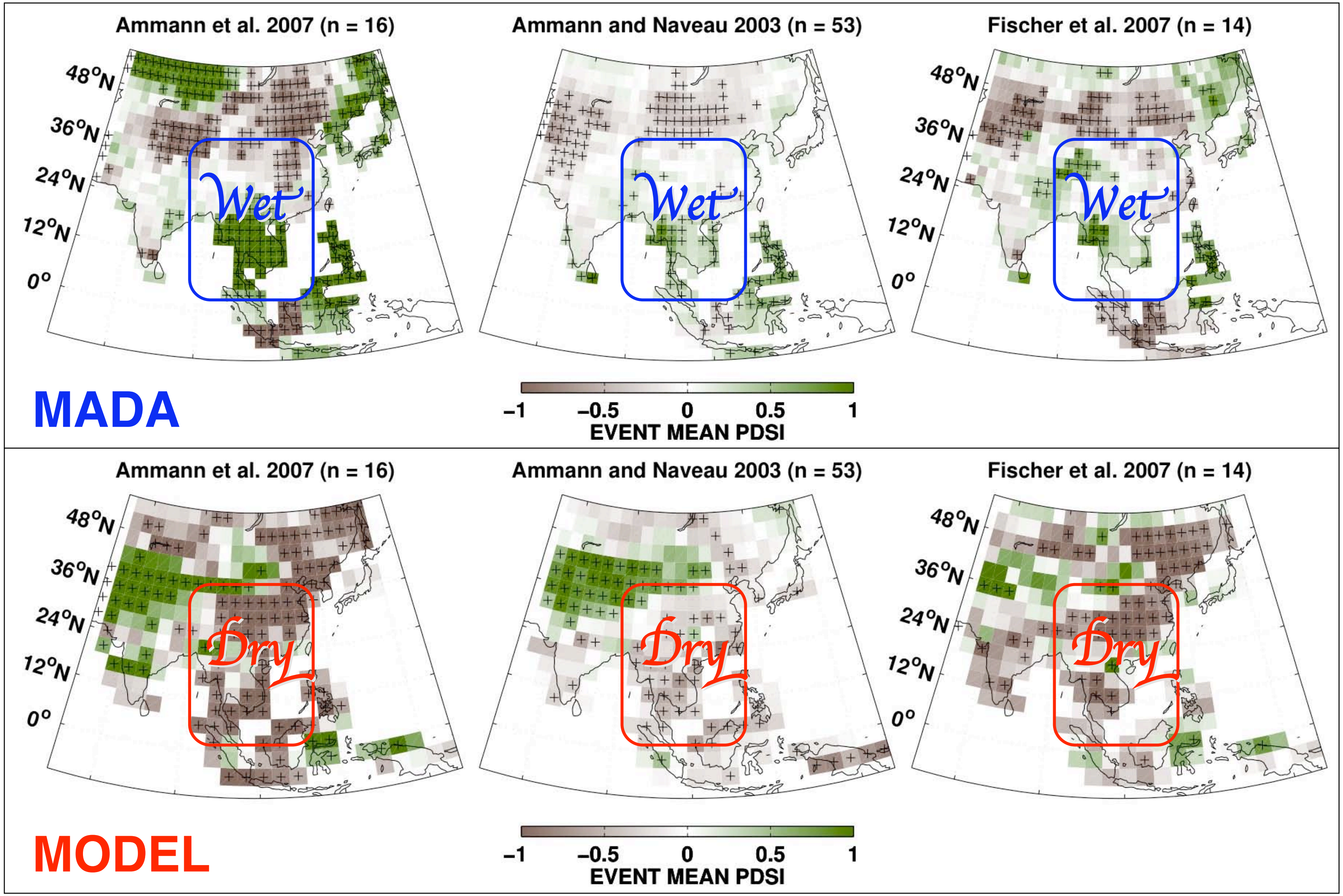
Source	Event Years (CE)
Ammann et al. [2007]	1258, 1259, 1269, 1278, 1279, 1452, 1453, 1600, 1601, 1641, 1809, 1810, 1815, 1816, 1884, 1903
Ammann and Naveau [2003]	1443, 1452, 1459, 1463, 1490, 1504, 1512, 1522, 1554, 1568, 1571, 1586, 1595, 1600, 1605, 1619, 1622, 1641, 1660, 1665, 1674, 1680, 1693, 1712, 1721, 1728, 1737, 1744, 1749, 1752, 1760, 1774, 1789, 1794, 1808, 1813, 1815, 1823, 1831, 1835, 1861, 1880, 1883, 1890, 1902, 1903, 1911, 1928, 1953, 1963, 1968, 1974, 1982
Fischer et al. [2007]	1586, 1596, 1600, 1641, 1673, 1809, 1815, 1823, 1831, 1835, 1883, 1903, 1963, 1982

After compositing volcano key year patterns of PDSI in the MADA based on the same three separate published key year lists and testing using superposed epoch analysis we get:





The model results do not agree with the MADA, which suggests a deficiency in the NCAR CSM 1.4 model.



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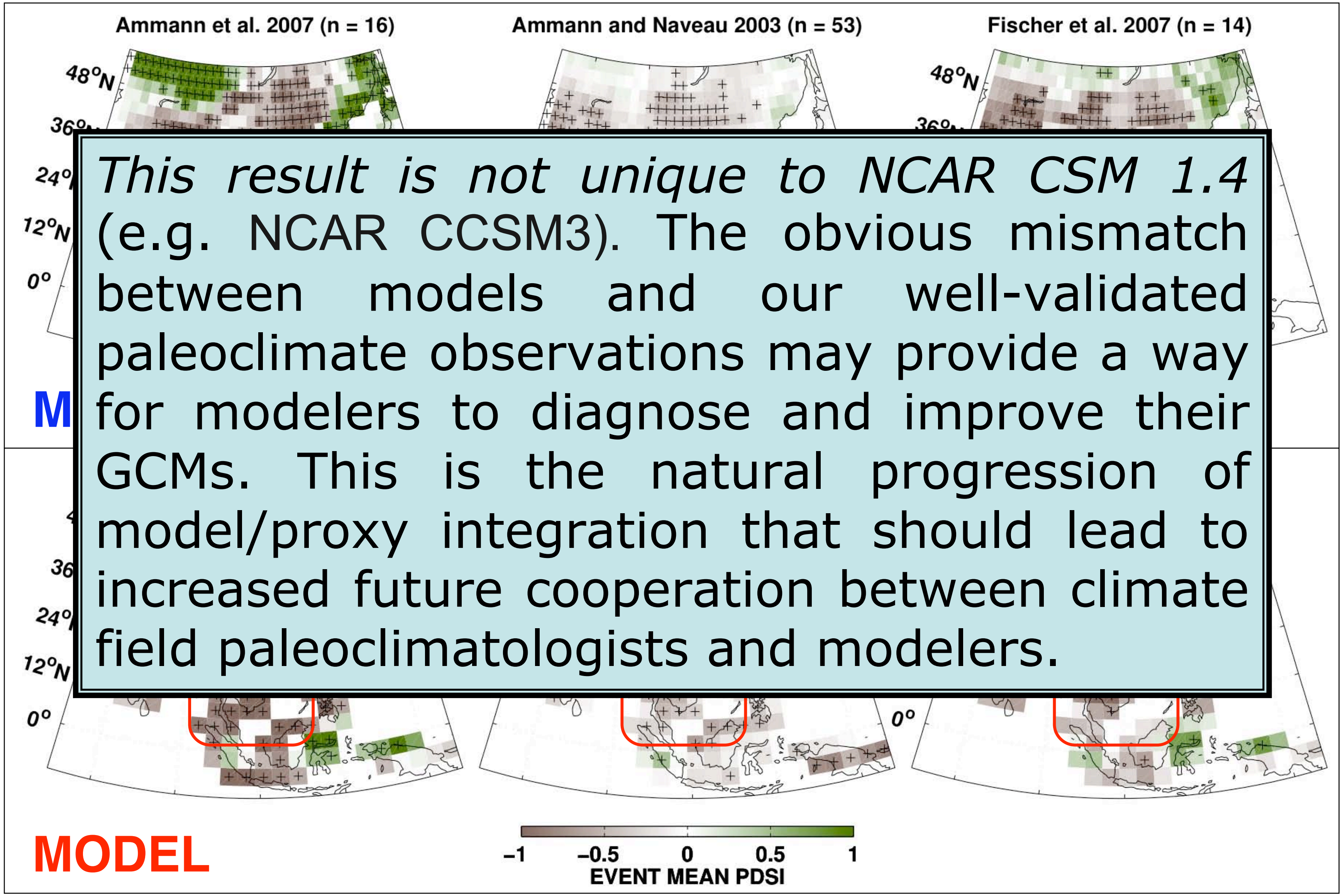

This result is not unique to NCAR CSM 1.4 (e.g. NCAR CCSM3). The obvious mismatch between models and our well-validated paleoclimate observations may provide a way for modelers to diagnose and improve their GCMs. This is the natural progression of model/proxy integration that should lead to increased future cooperation between climate field paleoclimatologists and modelers.

Conclusions

- A Monsoon Asia Drought Atlas (MADA) based on gridded PDSI has been developed from a network of climatically sensitive tree-ring series using ensemble point-by-point regression (EPPR);
- EPPR appears to work well in noisy data situations where both the climate grid and tree-ring network are sub-optimal for reconstruction;
- EPPR also appears to be reasonably robust to changes in the climate data grid based on different infilling and smoothing methods;
- The MADA covers the past millennium and reveals numerous periods of monsoon failure and megadrought - some in the historical record and others previously unknown;
- The cause of these droughts is most likely tied to SSTs in the tropical Pacific (ENSO) and to larger-scale Pacific basin conditions (IPO).
- Tests of volcanic forcing of monsoon climate over Asia using the MADA suggest that coupled climate models are not correctly modeling the impact of this forcing over Asia.

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