APCC Conference, St. Petersburg, 9 October, 2012

Predictability and Prediction of Summer Monsoon Rainfall over India

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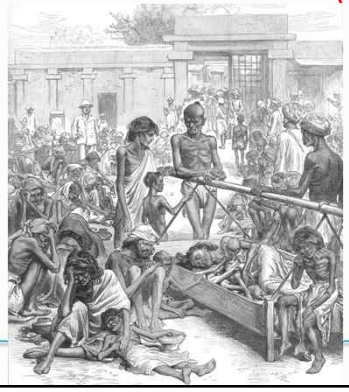
Institute of Global Environment and Society (IGES)

DelSole & Shukla (2012): Climate models produce skillful predictions of Indian summer monsoon rainfall

Great Famine of 1876-78 (India)



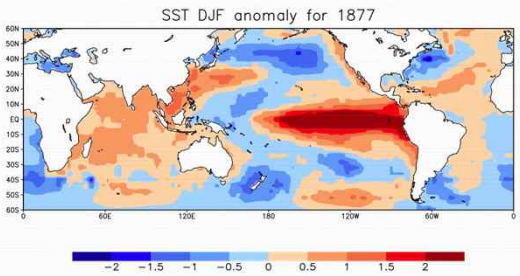
Great Famine of 1876-78 (India)

All India Monsoon Rainfall:	-29%
Drought Area:	670,000 km²
Estimated Deaths (Wikipedia):	5.5 – 8.2 million
Governance:	British Rule

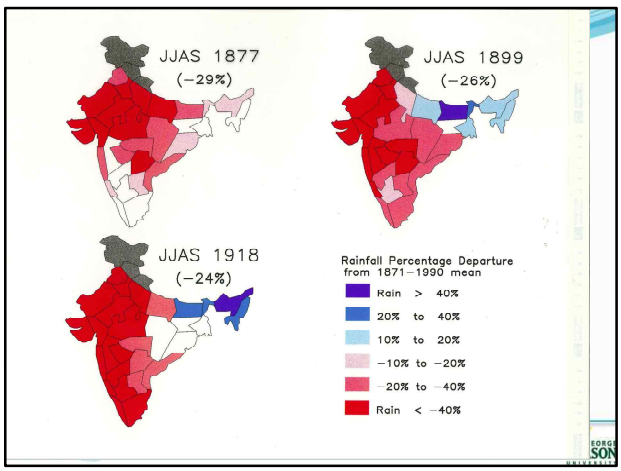
(Lord Lytton exported food from India to England)

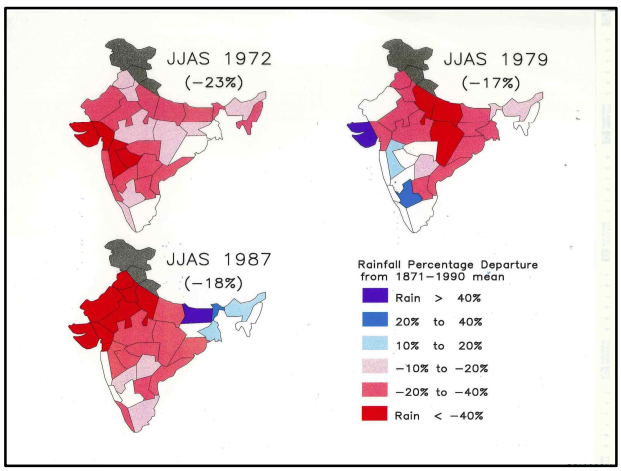
Late Victorian Holocausts (2001) by Mike Davis
El Nino Famines and the Making of the Third World

SST Anomaly for DJF 1877



Courtesy of Lakshmi Krishnamurti





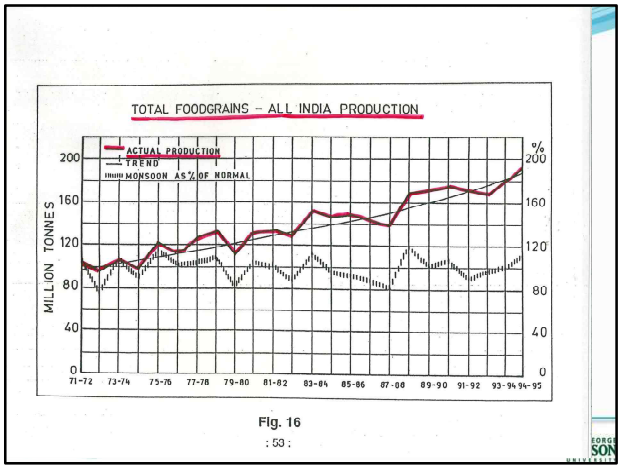
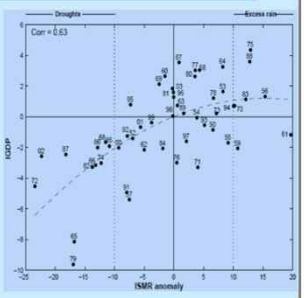


Fig. 16

: 53 :

GDP and Indian Monsoon Rainfall

Impact of a severe drought on GDP remains 2 to 5% throughout, despite the substantial decrease in the contribution of agriculture to GDP over the five decades.



Gadgil and Gadgil (2006), Economic and Political Weekly, Vol XLI no 47, p 4887-4895

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History of Forecasting Indian Summer Monsoon Rainfall (ISMR)

1877: Major ENSO; ISMR; highly deficient; great famine

1886: First official forecast (Blanford: high Spring snow cover – low ISMR)

1899: Another major ENSO; another great famine

1904: Gilbert Walker joined IMD (DGO: 1904-1924)
Regression Equations to predict ISMR
Discovered Southern Oscillation & Northern Oscillations

1924-2011: IMD: Regression Equations (16,8,6 predictors)

2009: Artificial skill; too many predictors; Data fishing (DelSole)

2012: IMD: Regression Equations + Dynamical Models

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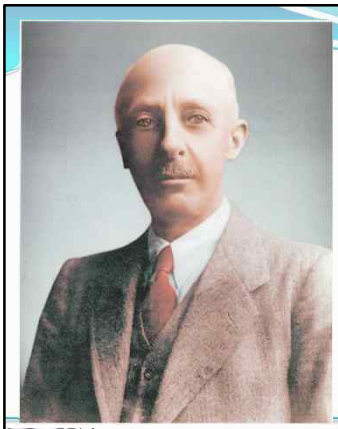

"Much has been done since 1880… but much more needs to be done."

Sir Gilbert Thomas Walker
(1868-1958)

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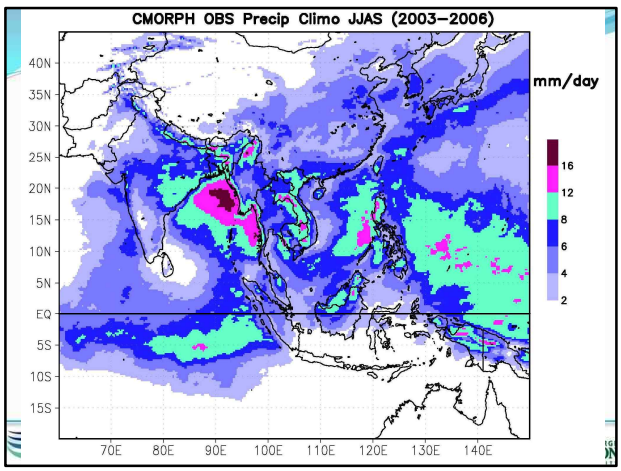
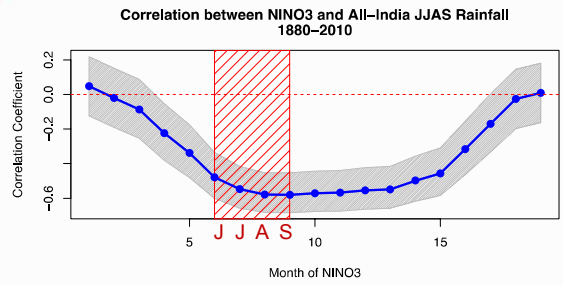
Outline

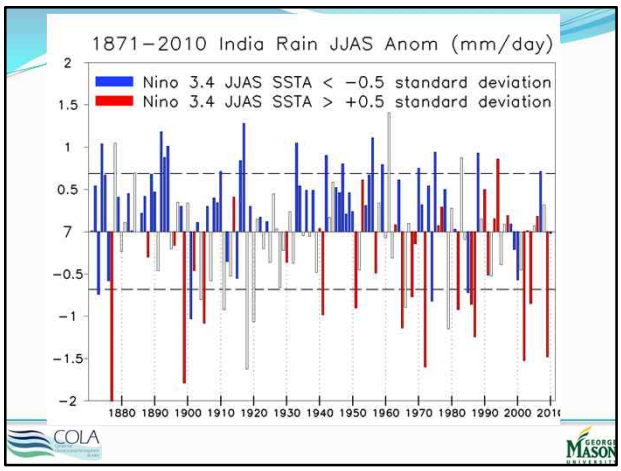
1. **Introduction**
   - ENSO-Monsoon Relationship
   - Has ENSO-Monsoon Relationship Broken Down?
   - Possible Influence of Indian Ocean SST
2. **Prediction of Indian Summer Monsoon Rainfall (ISMR)**
   - Statistical Prediction
   - Dynamical Prediction
3. **Summary**

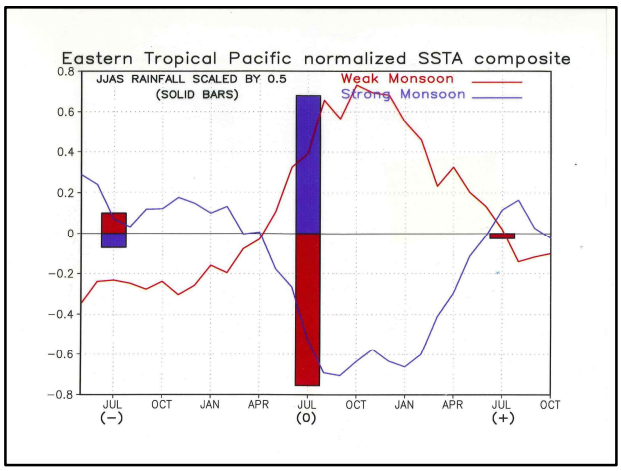
COLA



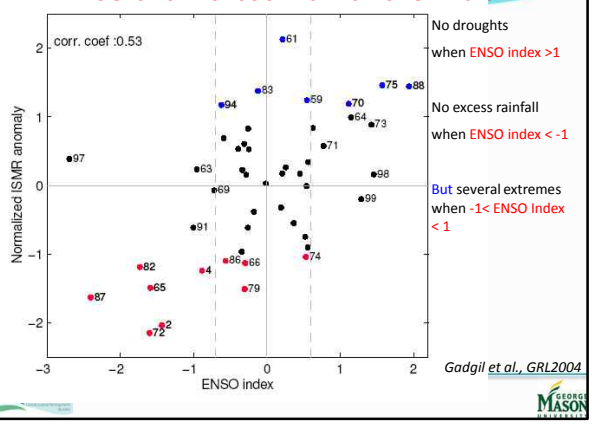
ENS0-Monsoon Relationship







ENSO and Monsoon rainfall over India

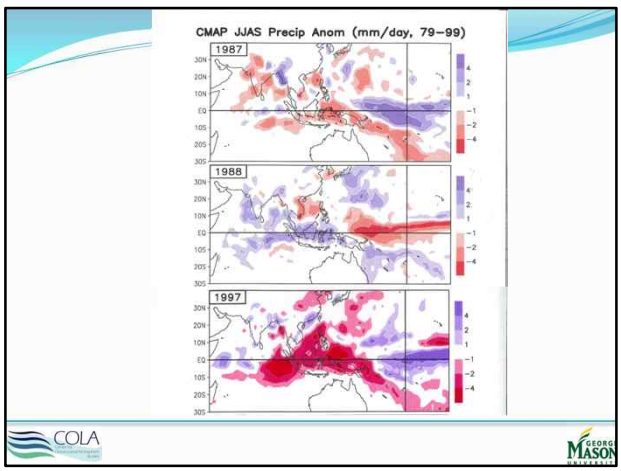


No droughts
when ENSO index >1

No excess rainfall
when ENSO index < -1

But several extremes
when -1< ENSO Index < 1

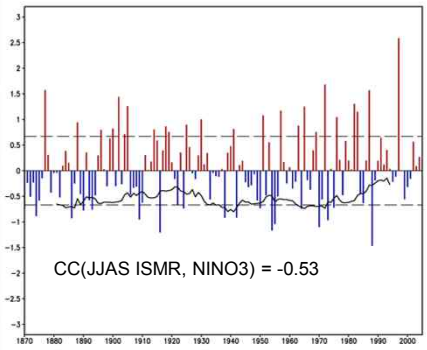
Gadgil et al., GRL2004

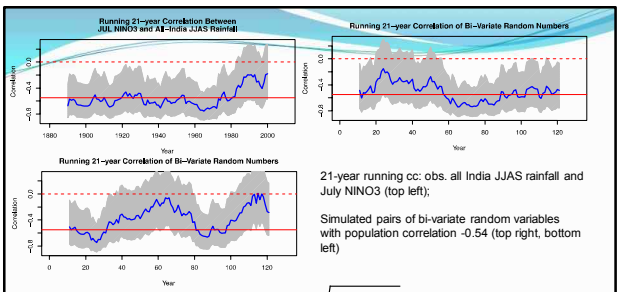


Has ENSO-Monsoon relationship broken down?

No; it is sampling variability.

JJAS NINO3 (° C) wrt 1871-1970 Mean





21-year running cc: obs. all India JJAS rainfall and July NINO3 (top left);

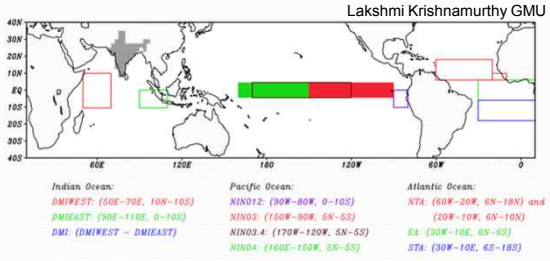
Simulated pairs of bi-variate random variables with population correlation -0.54 (top right, bottom left)

$$y = \rho x + w\sqrt{1-\rho^2}$$

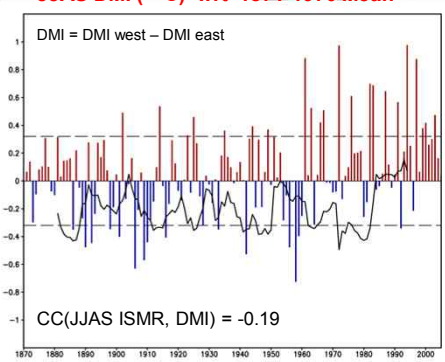
where x and w are independent, normally distributed random variables with unit variance, and ρ is a constant (less than or = 1).
Population correlation between random pairs of variables (x and y) produced by this model, will be equal to ρ.

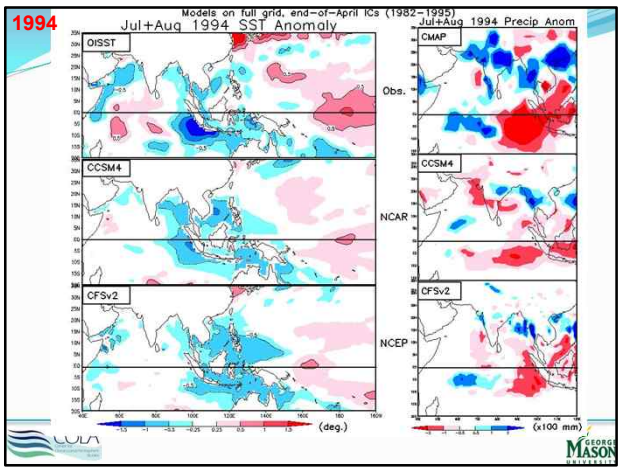
Possible Influence of Indian Ocean SST Anomalies on Predictability of Summer Monsoon Rainfall

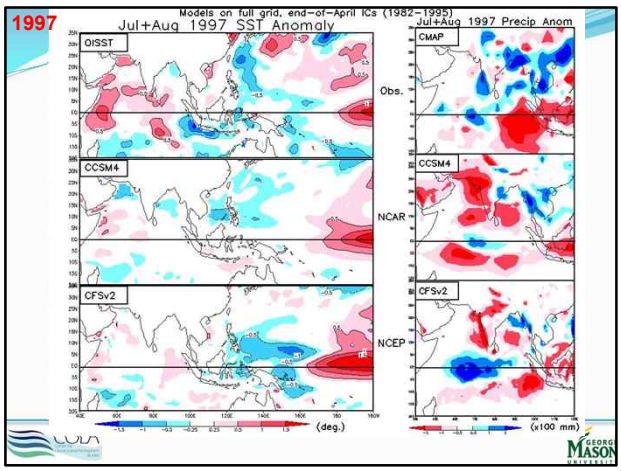
Lakshmi Krishnamurthy GMU



JJAS DMI (° C) wrt 1871-1970 Mean

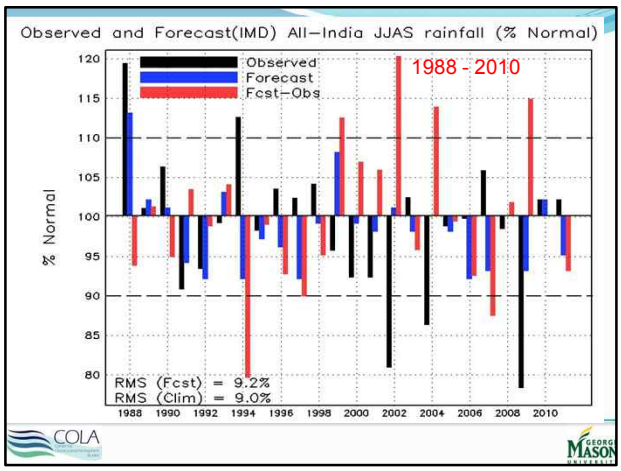


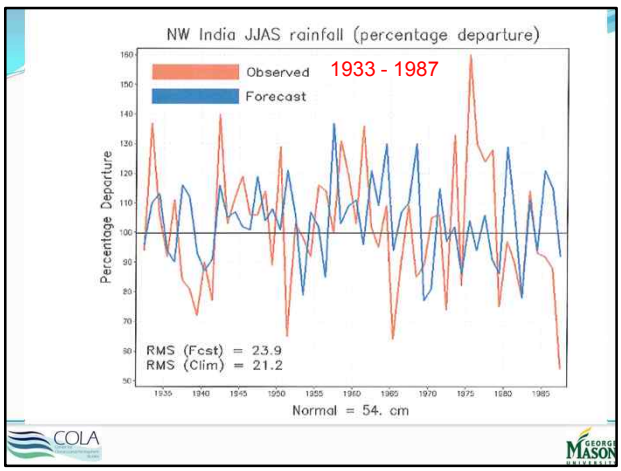




Statistical Prediction of ISMR

What is the skill of historical (operational) forecasts issued in April/May
for ISMR?



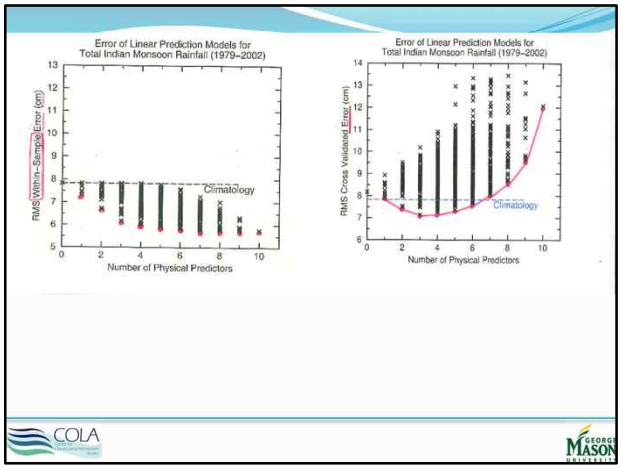


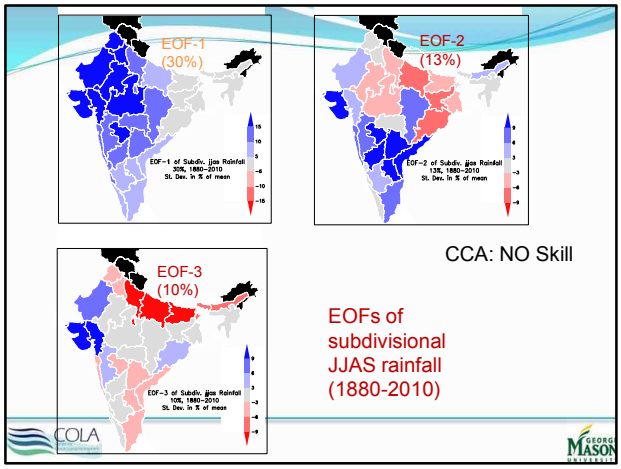
Operational IMD Forecasts Have No Skill

Possible causes for failure of skillful empirical forecasts:

1. Questionable procedures for selecting predictors (fishing!)

2. Too many predictors (over-fitting)





DelSole and Shukla (2012)

- **Canonical Correlation Analysis (CCA) for 1880-1959 for May SST & Indian Subdivisional rainfall. (No Skill)**
- **CCA: May SST and all India rainfall (1880-1959): 3 SST patterns; significant skill. In-sample CC = 0.54.**
  (This is the highest possible CC using antecedent SST.)
- **No skill in independent sample for 1960-2005.**
  No skill even in the In-Sample CCA for 1960-2005
  (Statistical prediction has no future!)

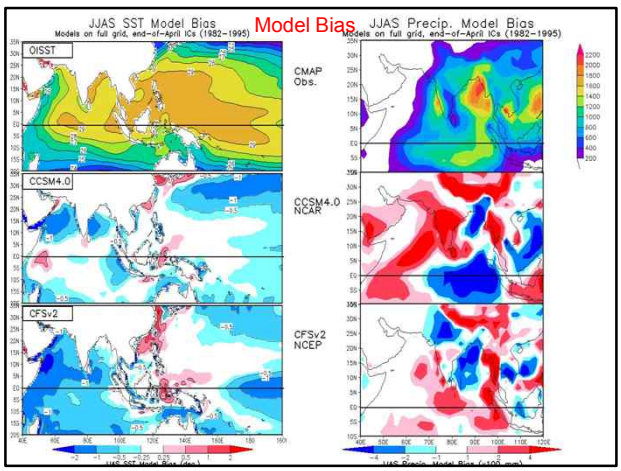
Prospects for Dynamical Prediction of JJAS Mean Monsoon Rainfall

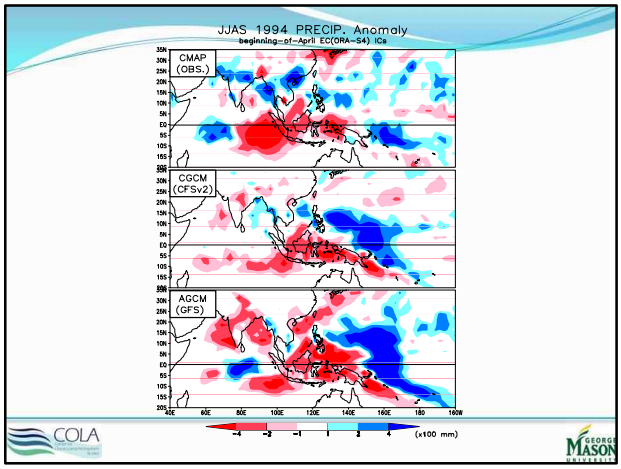
- Model Fidelity and Predictability
- Hindcasts using CFS and ENSEMBLES Models

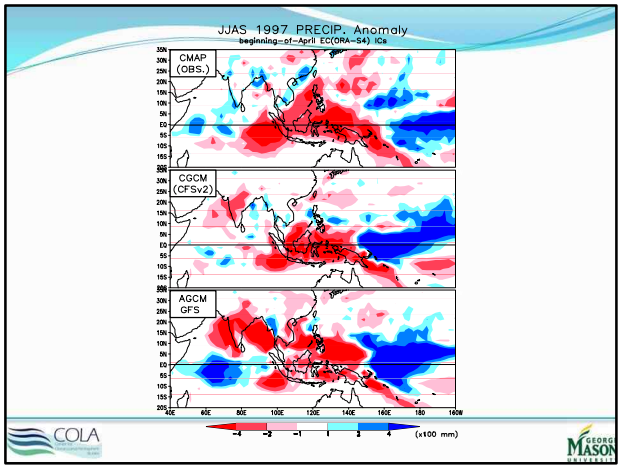
Hypothesis

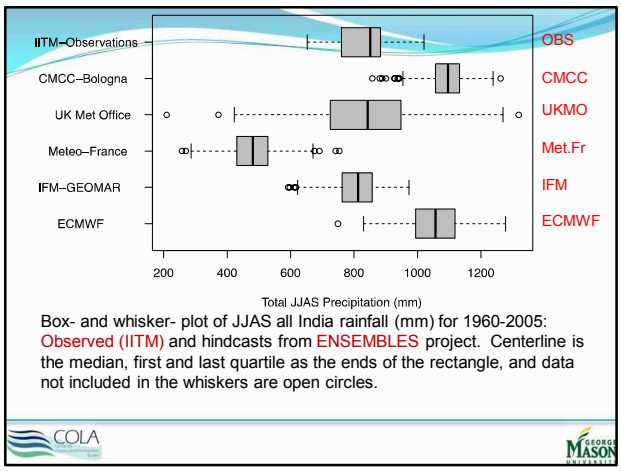
Models that simulate climatology "better" make better predictions.

Definition: Fidelity refers to the degree to which the climatology of the forecasts (including the mean and variance) matches the observed climatology

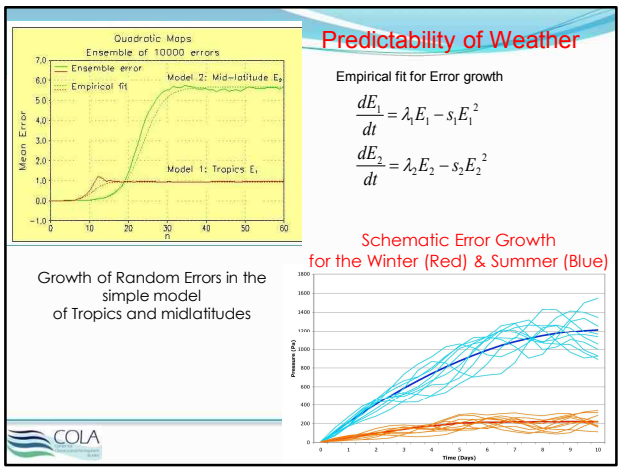


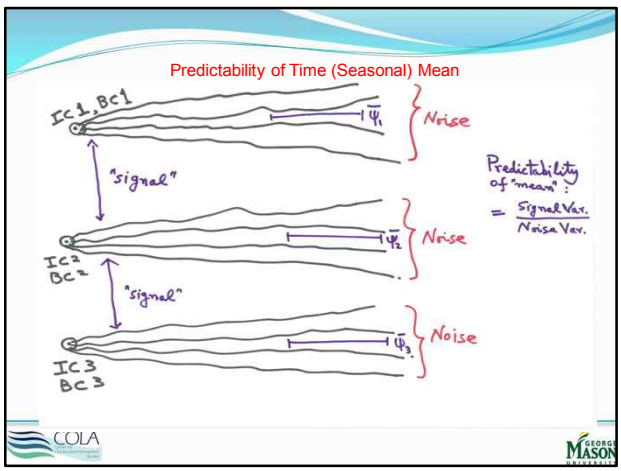


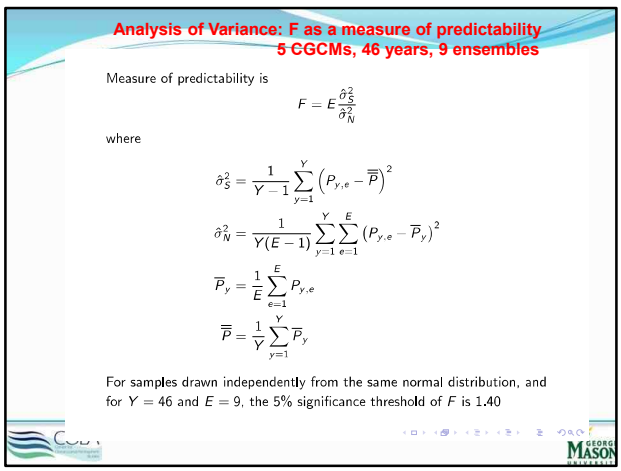


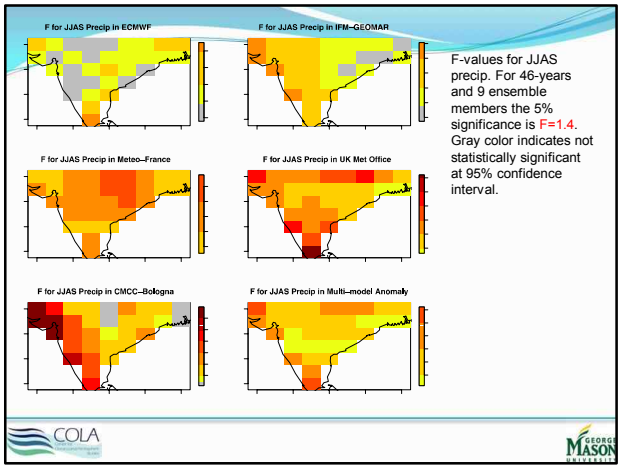


Box- and whisker- plot of JJAS all India rainfall (mm) for 1960-2005: Observed (IITM) and hindcasts from ENSEMBLES project. Centerline is the median, first and last quartile as the ends of the rectangle, and data not included in the whiskers are open circles.

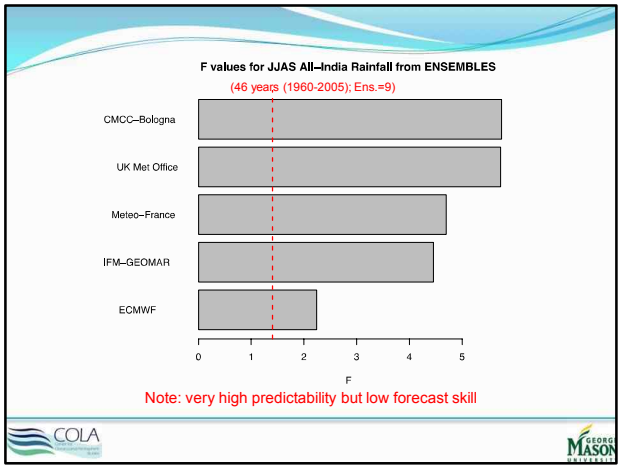




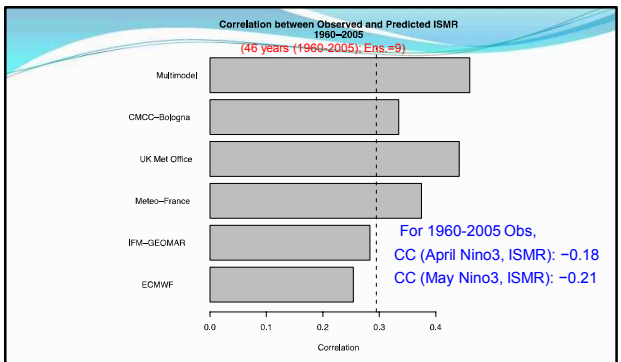




F-values for JJAS precip. For 46-years and 9 ensemble members the 5% significance is F=1.4. Gray color indicates not statistically significant at 95% confidence interval.

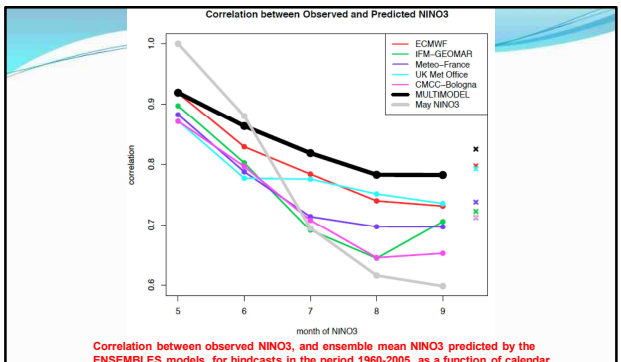


Note: very high predictability but low forecast skill

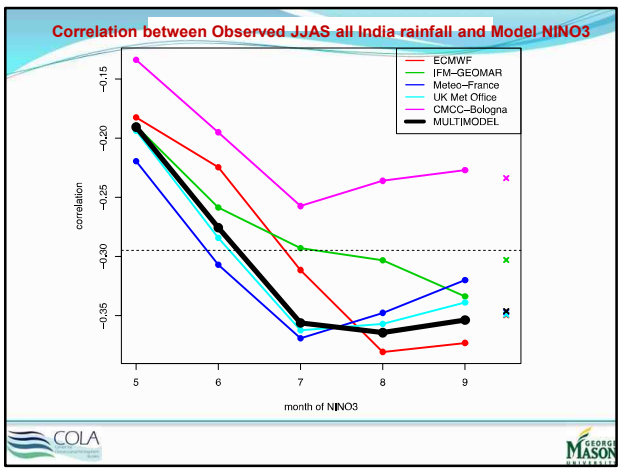


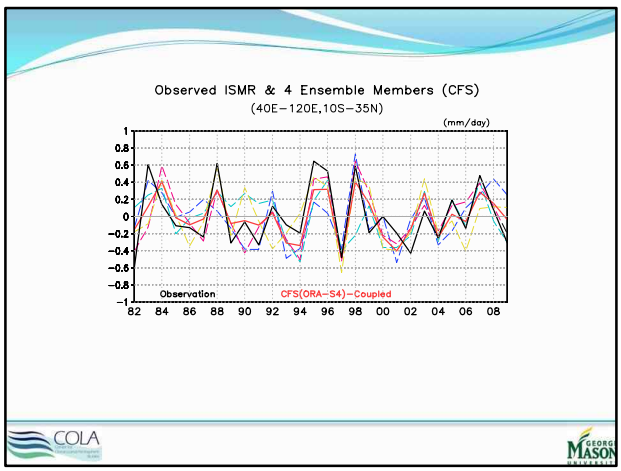
For 1960-2005 Obs,
CC (April Nino3, ISMR): −0.18
CC (May Nino3, ISMR): −0.21

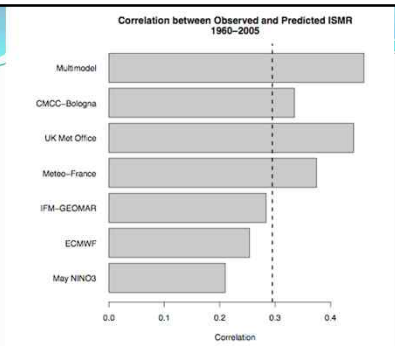
Correlation between observed and predicted JJAS all-India rainfall for hindcasts in the ENSEMBLES data set for the period 1960-2005. All-India rainfall in dynamical models is defined as the total land precipitation within 70E − 90E and 10N − 25N .



Correlation between observed NINO3, and ensemble mean NINO3 predicted by the ENSEMBLES models, for hindcasts in the period 1960-2005, as a function of calendar month. Also shown is the correlation between observed NINO3 and the least squares prediction of NINO3 based on the observed May NINO3 value (thick grey). The 'x'-symbols on the far right give the correlations between the observed and predicted JJAS NINO3 index.







(46 years (1960-2005); Ens.=9)

For 1960-2005 Obs,
CC (April Nino3, ISMR): −0.18
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Correlation between observed and predicted JJAS all-India rainfall for hindcasts in the ENSEMBLES data set for the period 1960-2005. All-India rainfall in dynamical models is defined as the total land precipitation within 70E – 90E and 10N – 25N .
Last row shows empirical prediction using observed May NINO3.

Summary

•Canonical Correlation Analysis (CCA) for 1880-1959 for May SST & Indian Subdivisional rainfall. (No Skill)

•CCA: May SST and all India rainfall (1880-1959): 3 SST patterns; significant skill. In-sample CC = 0.54.
(This is the highest possible CC using antecedent SST.)

•No skill in independent sample for 1960-2005.
No skill even in the In-Sample CCA for 1960-2005
(Statistical prediction has no future!)

Summary

• Model's ability to simulate SST and Q in West Pacific and Indian Ocean are critical for accurate monsoon prediction.

• Analysis of Variance (F test) calculation for 5 coupled model ("ENSEMBLES" Project) seasonal predictions for 46 years, 9 member ensembles show high predictability ISMR, but skill of hindcast for 1960-2005 is rather modest.

• Coupled O-A models for monsoon prediction is the future.

Summary

More than 100 years of statistical forecasting of Indian monsoon rainfall shows no skill.

After 50 years of model development, for the first time, current climate models produce skillful forecasts of monsoon rainfall.

This skill comes mainly because of models' ability to predict tropical Pacific SST variations.

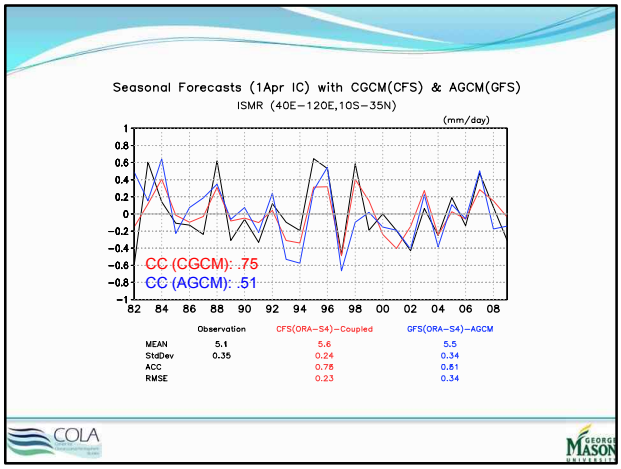
Thank You!

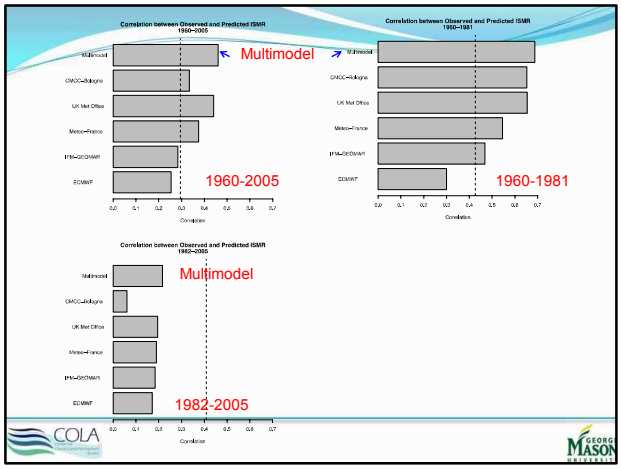
Any Questions?

The Tale of Two Monsoon Seasons

All India JJAS Monsoon Rainfall as % of Normal

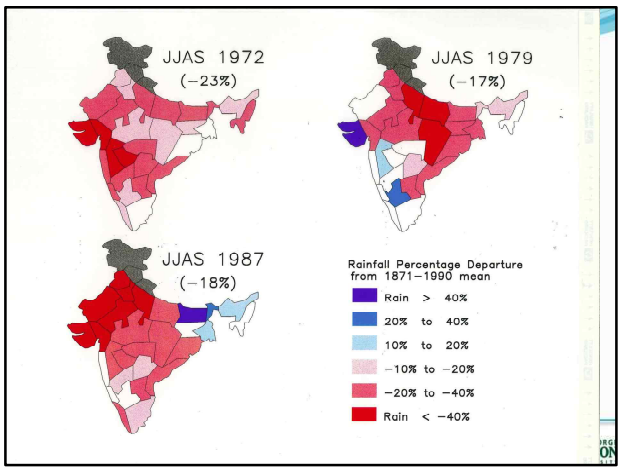
	Actual	Forecast (IMD)
1994	+13 %	-8 %
1997	+2 %	-8 %

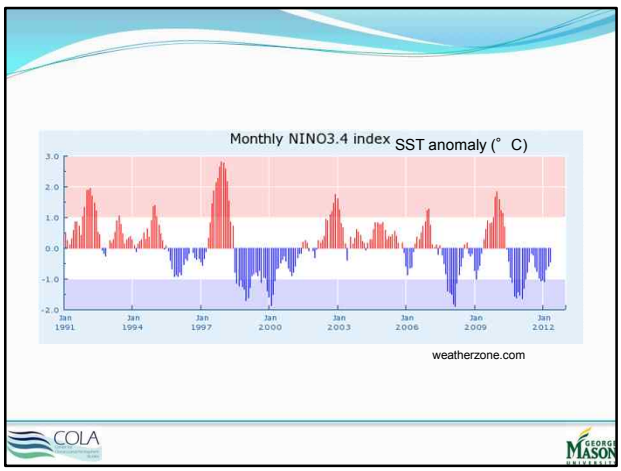


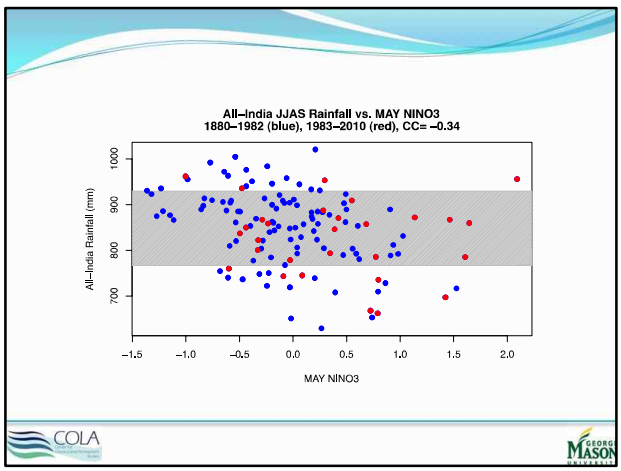


Correlation between JJAS All-India Rainfall and SST indices

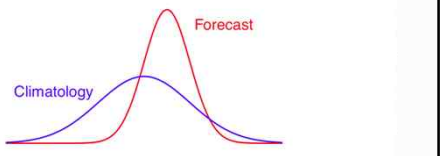
	1880-1959			1960-2005		
SST Predictor	April	May	JJAS	April	May	JJAS
canonical predictor trained in 1960-2005	–	–	–	NA	NA	0.39*
canonical predictor trained in 1880-1959	0.47*	0.54	0.66	0.10	0.15	**0.34**
NINO3	-0.21	**-0.41**	**-0.60**	-0.18	-0.21	**-0.45**
canonical tendency predictor trained in 1960-2005 (w/ Jan)	–	–	–	0.46*	0.54*	0.6
NINO3 tendency (w/ Jan)	**0.24**	**0.43**	**0.60**	**0.44**	0.38	**0.51**







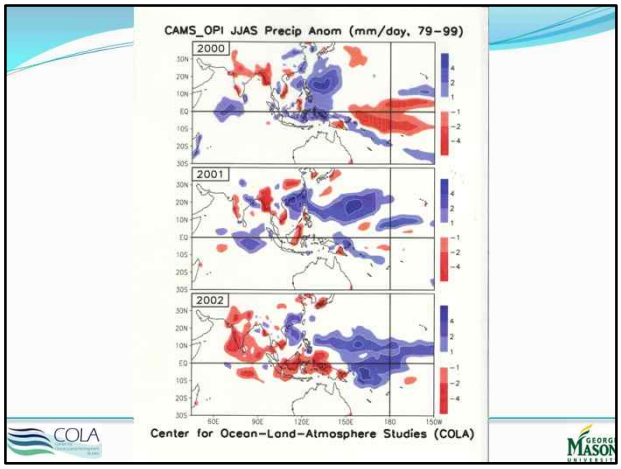
Fundamental Definition of Predictability

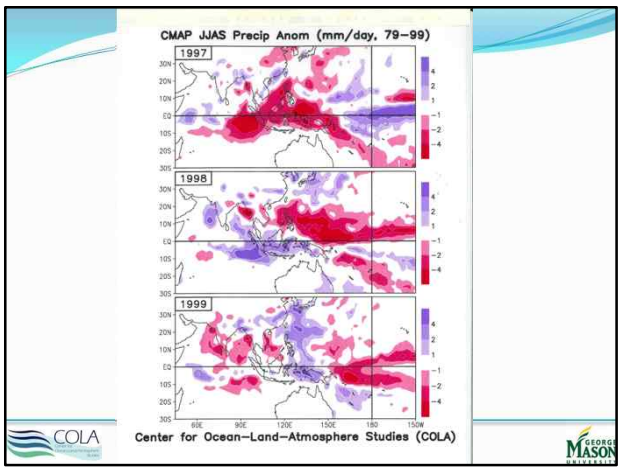


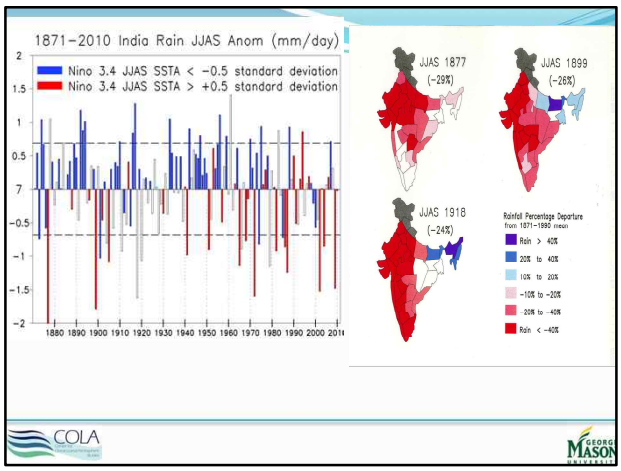
A variable $y_{t+\tau}$ is **defined** to be unpredictable at lead τ if, for all x_t,

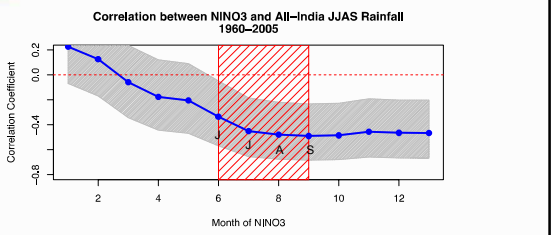
$$p(y_{t+\tau}|x_t) = p(y_{t+\tau})$$

forecast distribution *climatological distribution*







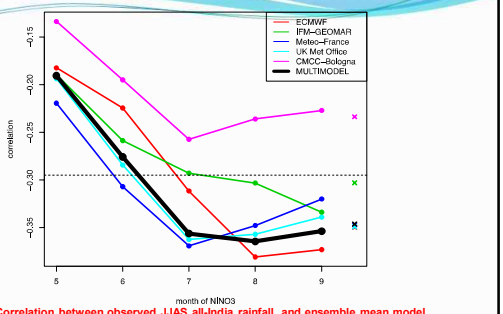


Time lagged correlation between all-India JJAS Monsoon Rainfall and the NINO3 index during the period 1960-2005. The red hatching indicates the JJAS period, the horizontal red dashed line indicates zero, and the grey shading indicates the 95% confidence interval for the time lagged correlation.

Fundamental barriers to advancing weather and climate diagnosis and prediction on timescales from days to years are (partly) (almost entirely?) attributable to gaps in knowledge and the limited capability of contemporary operational and research numerical prediction systems to represent precipitating convection and its multi-scale organization, particularly in the tropics.

(Moncrieff, Shapiro, Slingo, Molteni, 2007)

Low skills in current dynamical seasonal predictions are not due to intrinsic limits of predictability, but due to large errors in ICs and models.
(a la NWP: large dedicated effort; slow & steady progress)



Correlation between observed JJAS all-India rainfall, and ensemble mean model predicted NINO3 index, for hindcasts from the ENSEMBLES data set during 1960-2005. The 'x'-symbols on the far right give the correlations for the JJAS NINO3 index in each model. The correlation with the mean of all models is shown as "multimodel."