The Future of Climate Prediction

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George Mason University (GMU)

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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)

About 13 million people died in China

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

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1877 Drought had Large Space (India) and Time Scales

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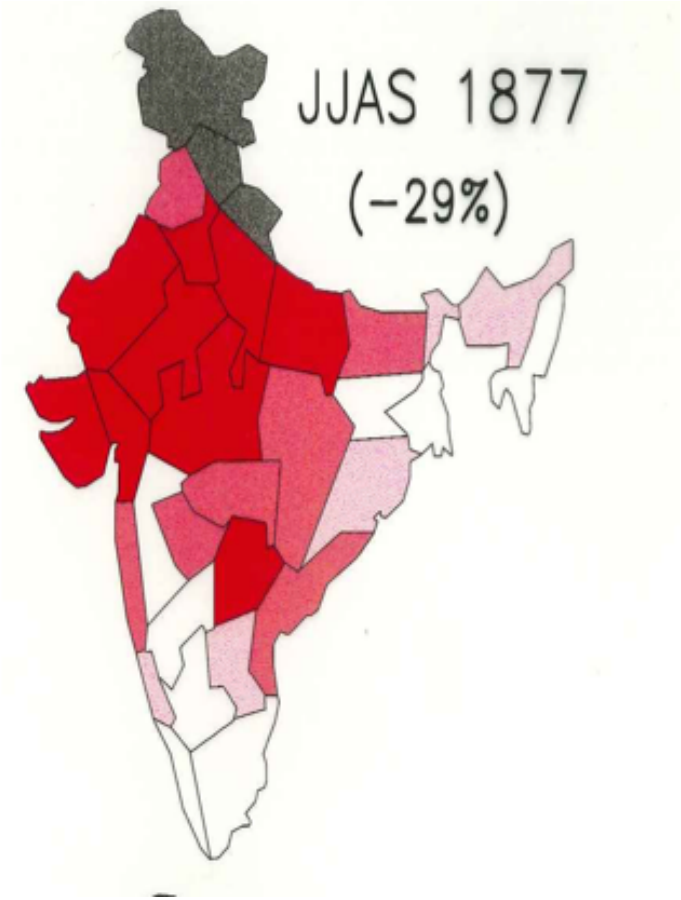

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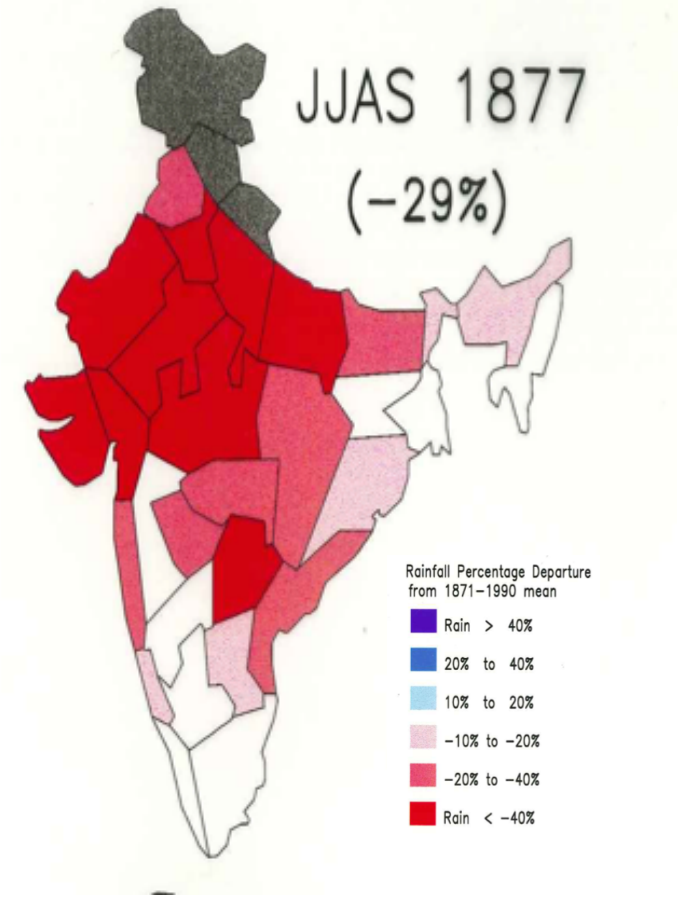
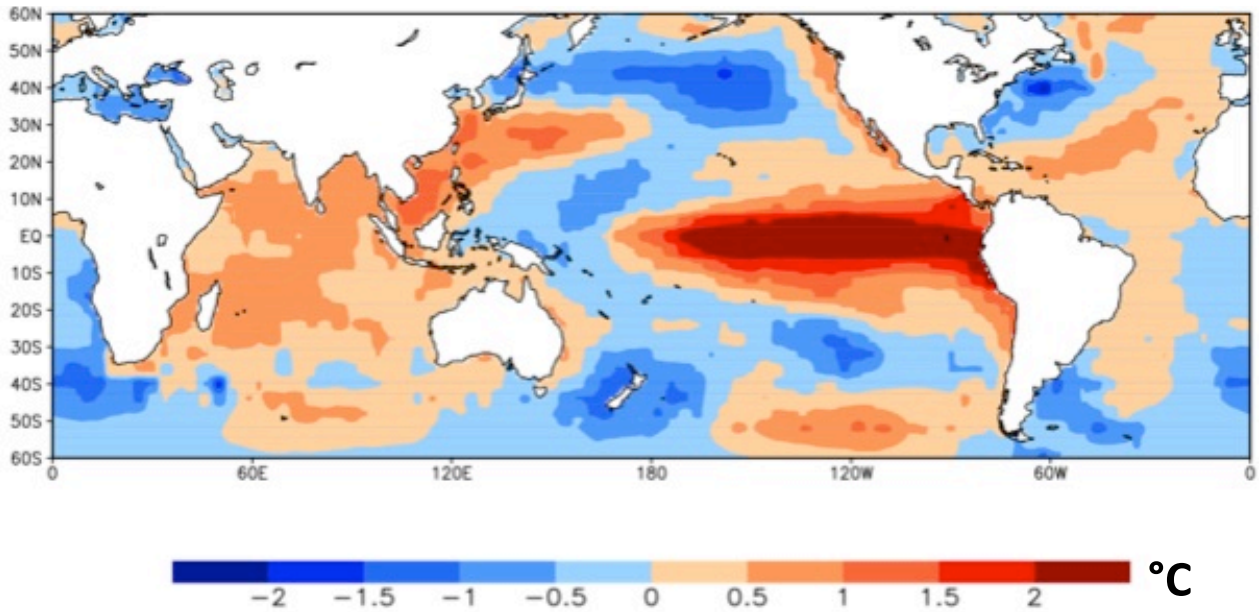


1877 Sea Surface Temp. (SST) minus Long-Term Mean SST



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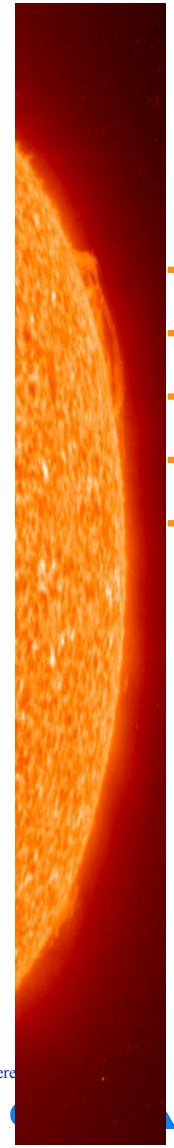
Outline

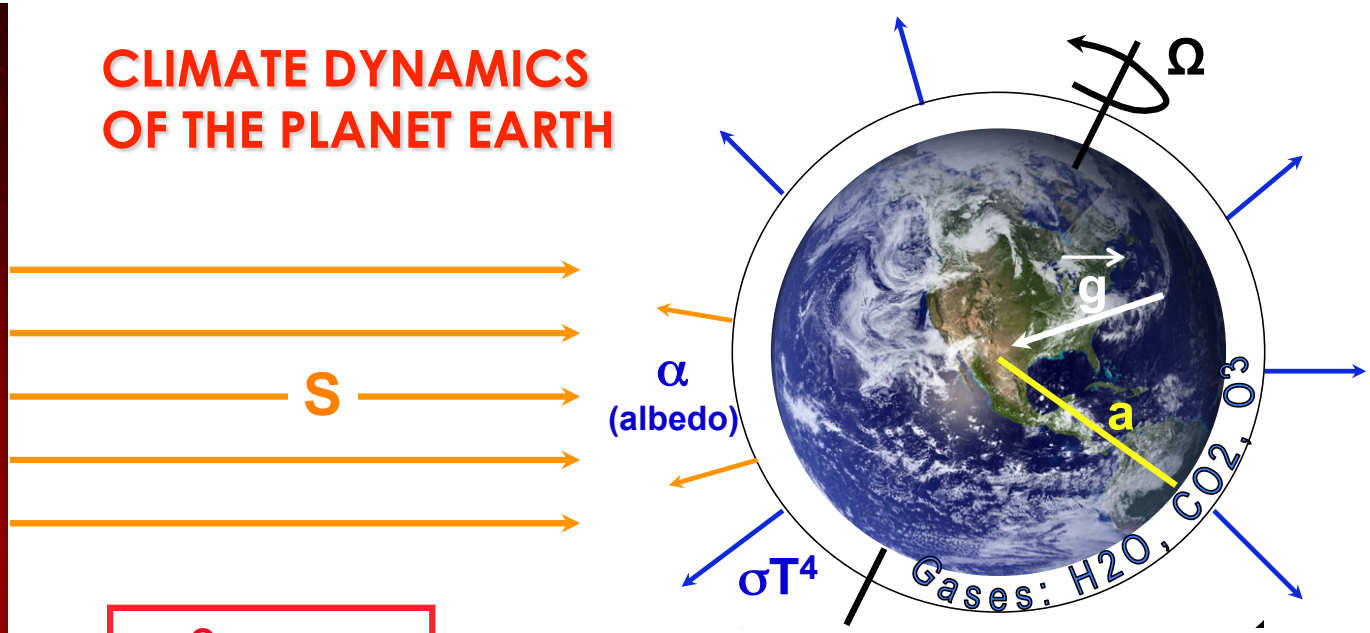
1. **Weather and Climate for Poets**

2. **Predictability of Weather and Climate**
   - Day to Day Weather (1-10 Days)
   - Seasonal Mean Climate
   - Long-term Climate Change

3. **Future of Weather and Climate Prediction**

CLIMATE DYNAMICS OF THE PLANET EARTH





$S, \begin{matrix} O_3 \\ H_2O \\ CO_2 \end{matrix}$ a, g, Ω

$\frac{\partial \bar{T}}{\partial y}, \frac{\partial \bar{U}}{\partial y}$ $\frac{\partial \bar{T}}{\partial z}, \frac{\partial \bar{U}}{\partial z}$

h*: mountains, oceans (SST)
w*: forest, desert (soil wetness)

stationary waves (Q, h*), monsoons

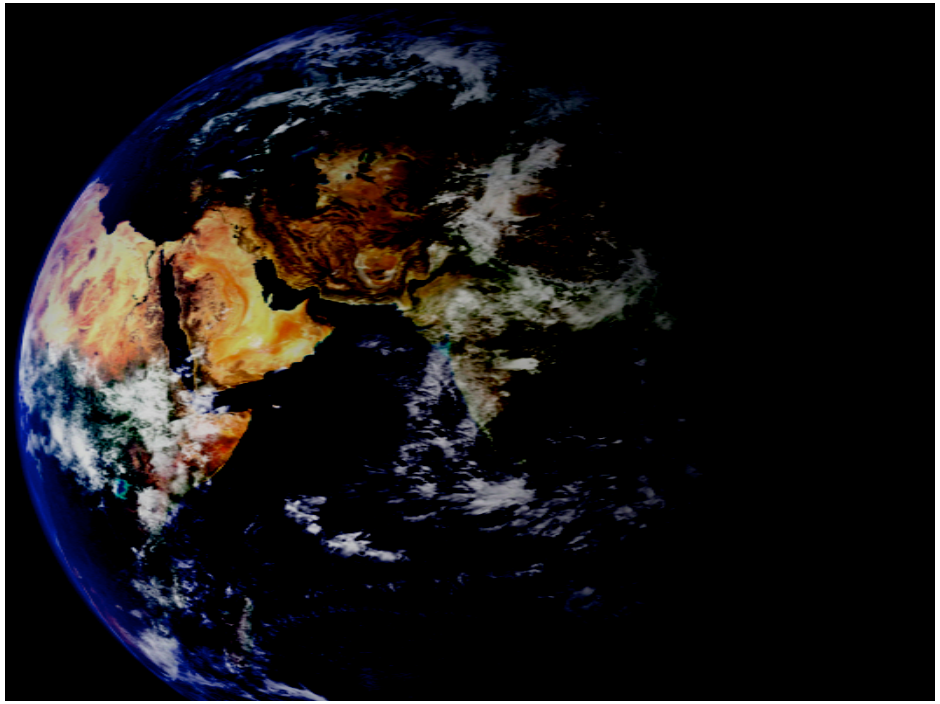
hydrodynamic instabilities of shear flows; stratification & rotation; moist thermodynamics

day-to-day weather fluctuations;
wavelike motions: wavelength, period, amplitude

WEATHER

CLIMATE

Supercomputers Solve 10-100 Million Equations to Produce Daily Weather Forecasts (Radio, TV)



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- Equations of motions and laws of thermodynamics to predict rate of change of:

T, P, V, q, etc. (A, O, L, CO_2, etc.)

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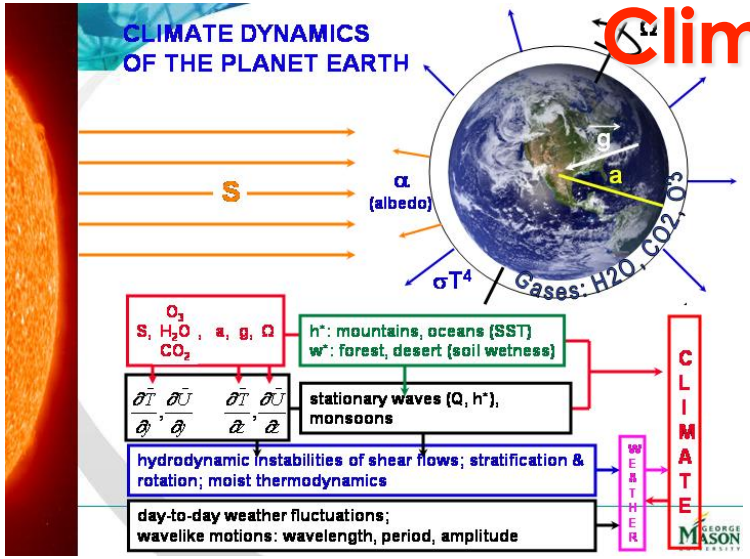
What is a Model for Weather and Climate?



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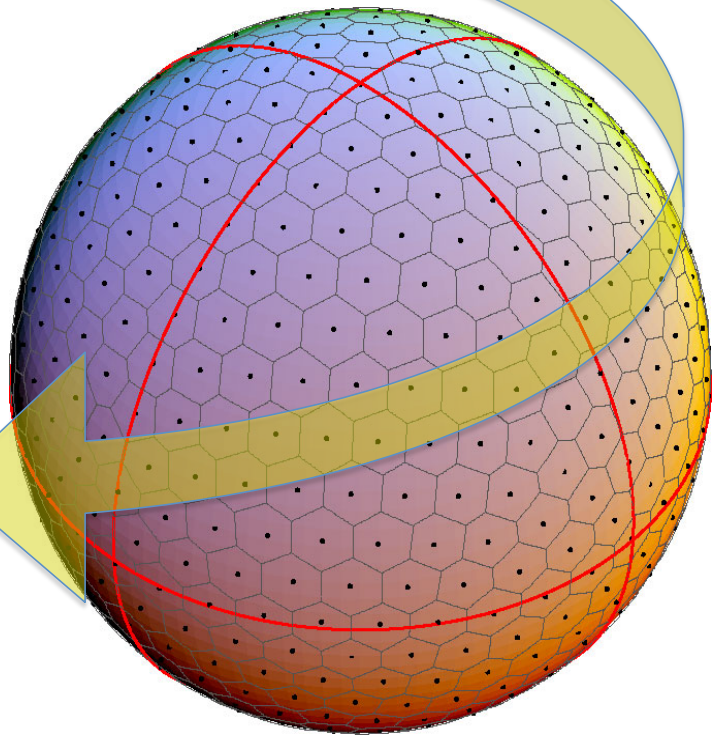

- 10 Million Equations:
  100,000 Points × 100 Levels × 10 Variables
- With Time Steps of: ~ 10 Minutes
- Use Supercomputers

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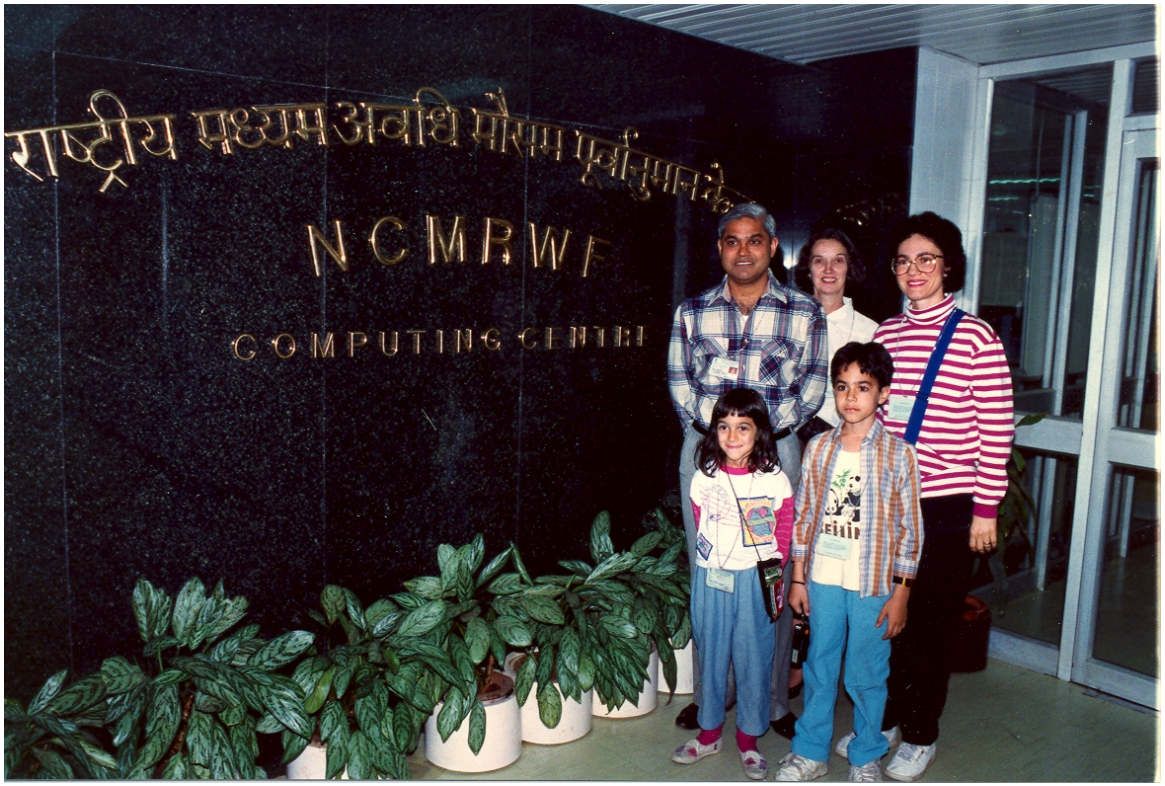
India (NCMRWF, New Delhi) Receives a Supercomputer (Cray X-MP-14)

Thanks to an agreement between President Reagan and Prime Minister Rajiv Gandhi (1987)



The supercomputer was housed in Mausam Bhavan (IMD), New Delhi; 1988

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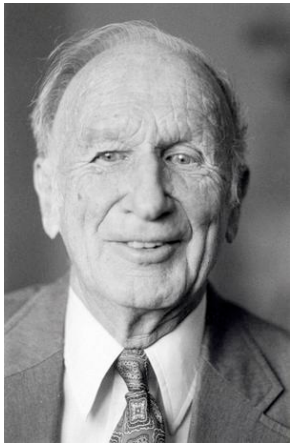
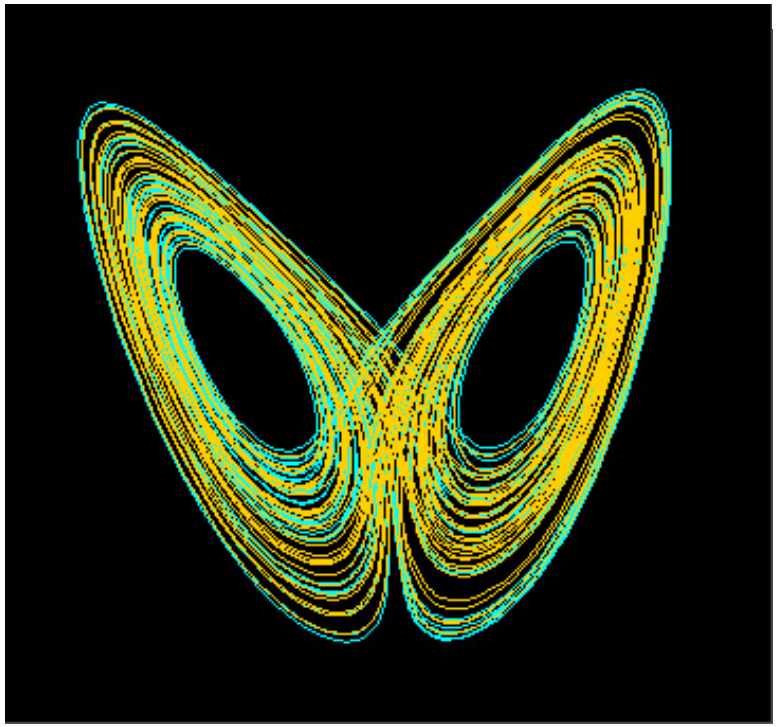


The Butterfly Effect

Chaos: Sensitive Dependence on Initial Conditions



Lorenz Model

$$\frac{dX}{dt} = -\sigma X + \sigma Y$$

$$\frac{dY}{dt} = -XZ + rX - Y$$

$$\frac{dZ}{dt} = XY - bZ$$

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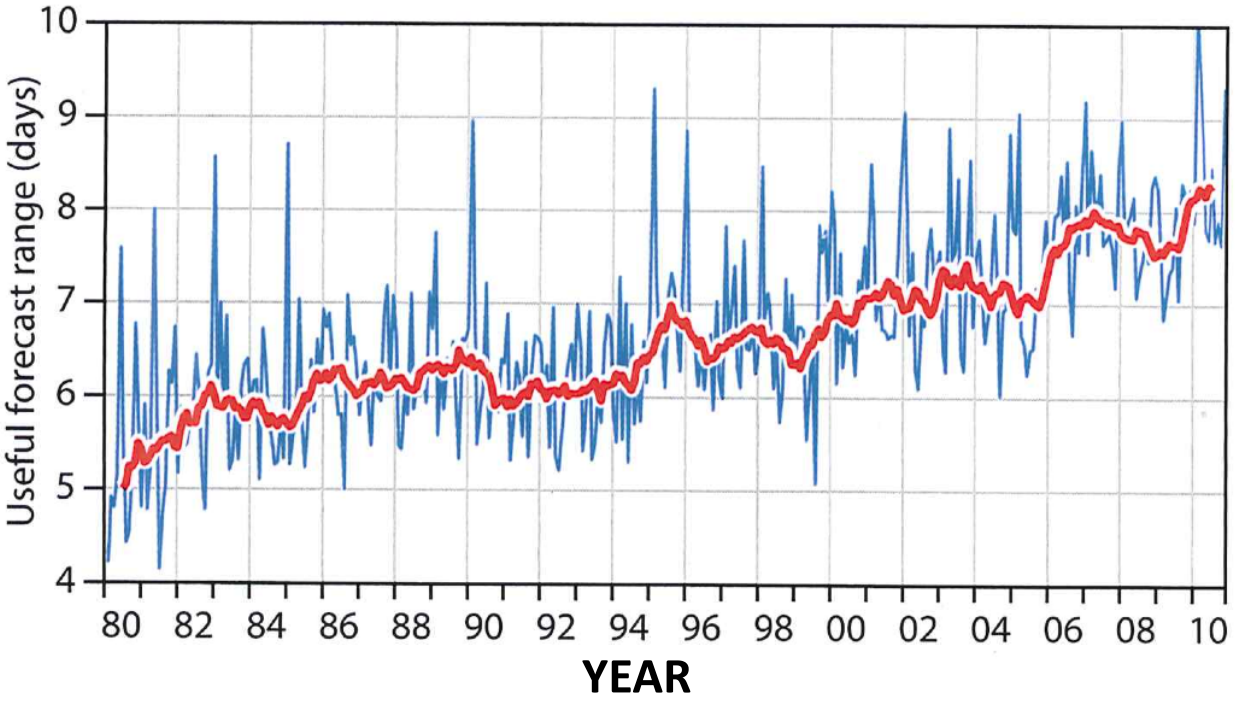
Prediction Skill of Large-Scale Weather has Steadily Improved in the Past 40 Years

1970's

Atmosphere

A Major Success Story of Atmospheric Sciences

ECMWF: Useful forecast range (days) for Europe (1980 – 2010)



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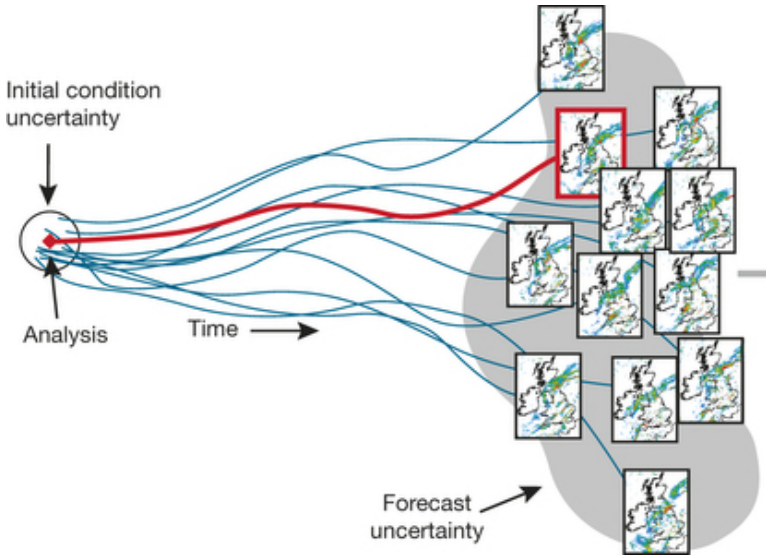
Numerical Weather Prediction

- **Chaos puts an upper limit on the range of skillful weather prediction**
- **The goal of NWP is to strive towards reaching the upper limit of deterministic weather prediction (1-2 weeks)**
- **Better initial conditions (remote sensing and advanced data assimilation systems), high fidelity models, and faster supercomputers for ensembles to predict PDF**

Ensemble Prediction



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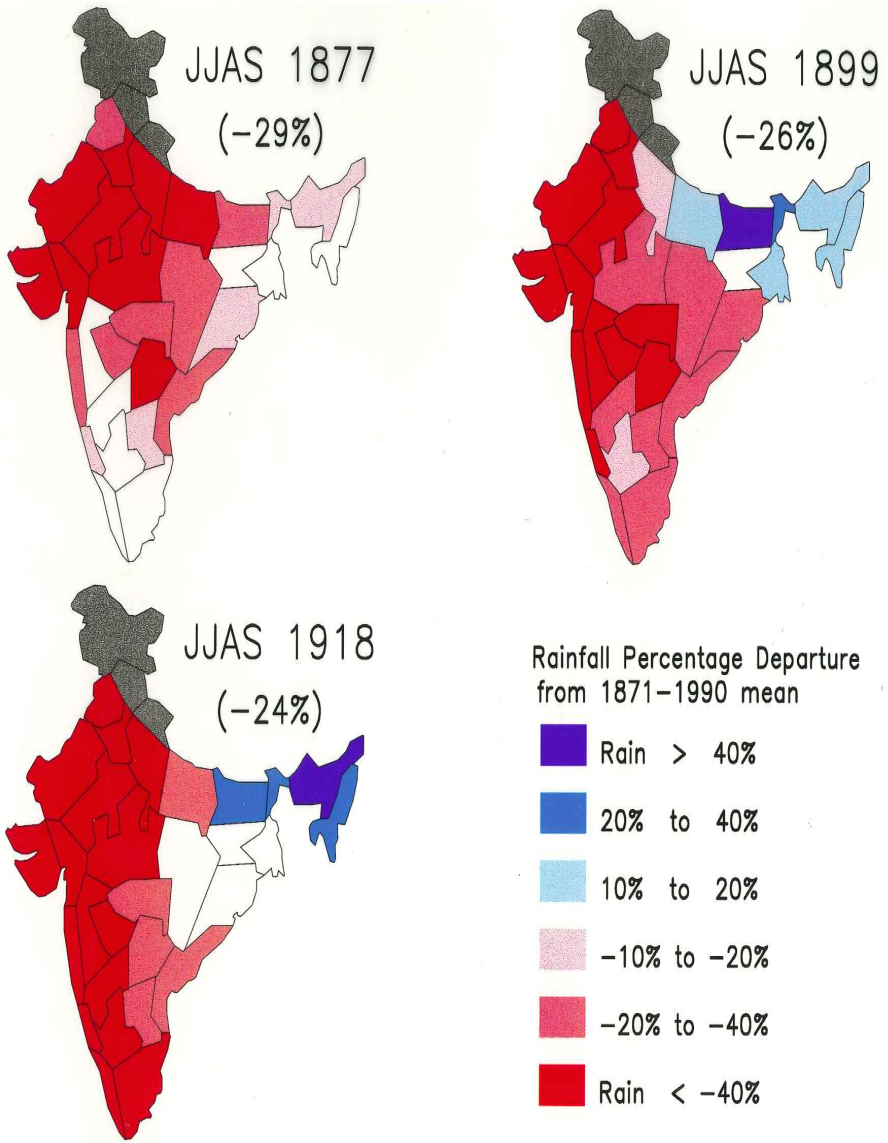
From Numerical Weather Prediction (NWP) To Dynamical Seasonal Prediction (DSP) (1975-2004)

"Predictability in the midst of chaos"

Although detailed weather cannot be predicted beyond 10-15 days, it is possible to predict large-scale seasonal averages, for example, monsoon rainfall over India because of the influence of boundary conditions at the Earth's surface (sea surface temperature, soil wetness, snow, vegetation, etc.)

Major Droughts over India Have Large Space (India) and Time (Season) Scales

1877, 1899, 1918



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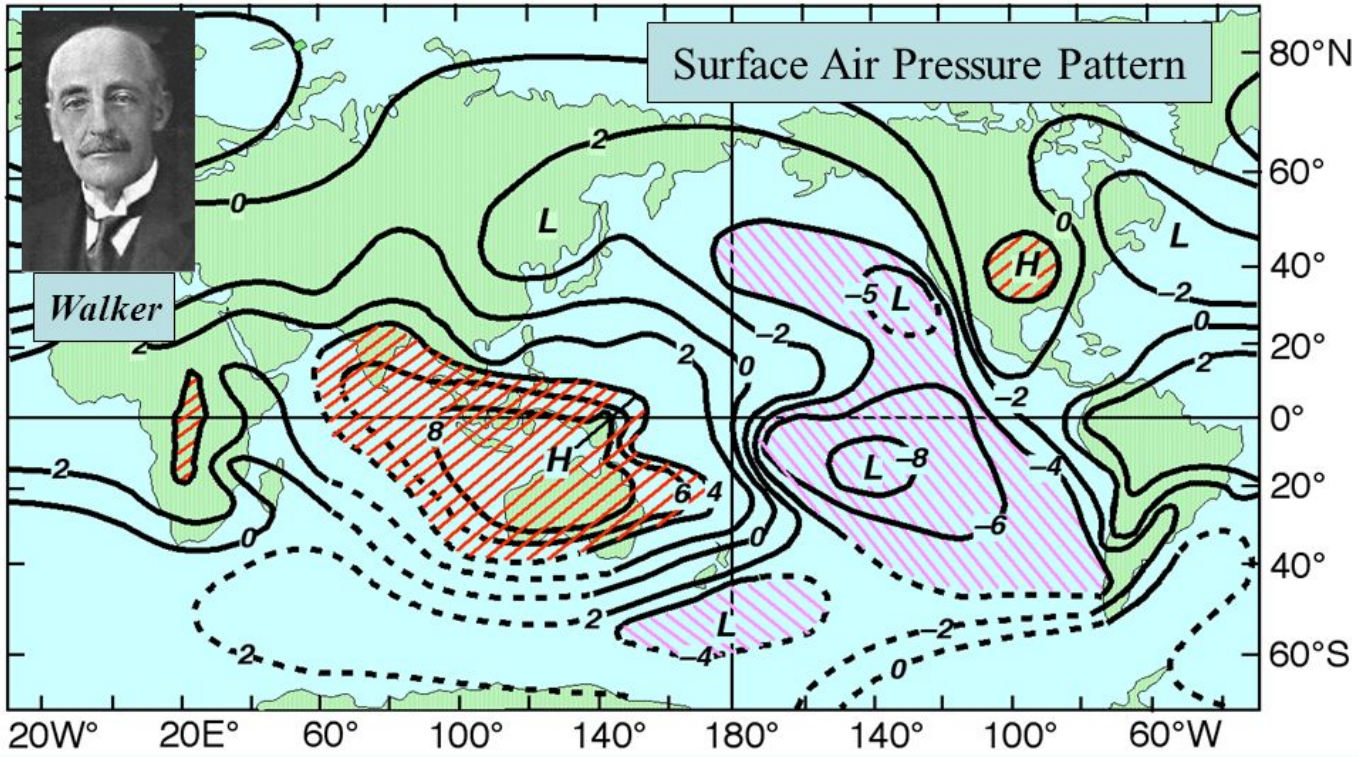
The Southern Oscillation



Correlation coefficient with respect to Darwin sea level pressure

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Rasmusson, 1984

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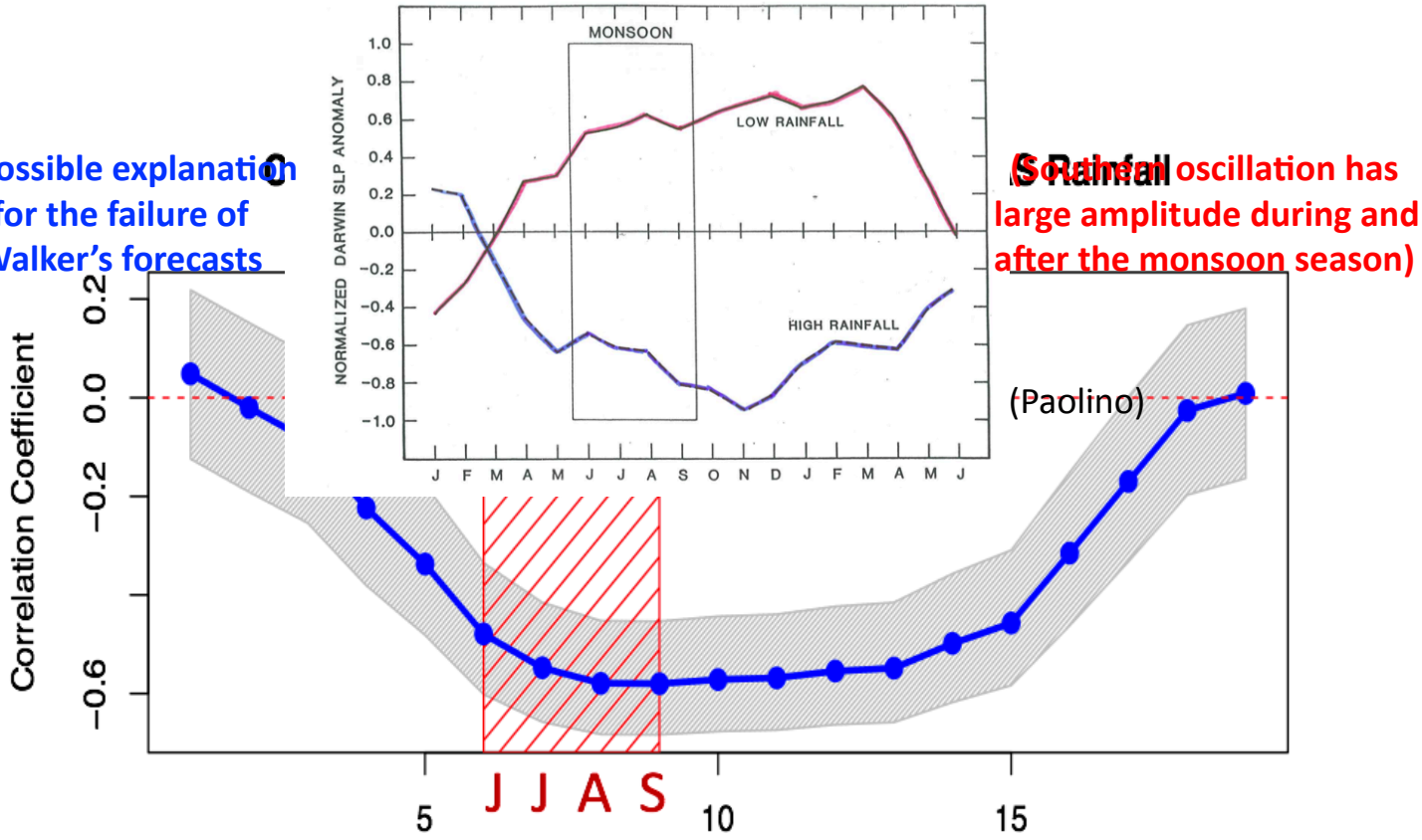
Why did empirical forecasts (using Spring ENSO) have no skill?

To predict monsoon, we must predict ENSO first

A possible explanation for the failure of Walker's forecasts



S Rainfall

(Southern oscillation has large amplitude during and after the monsoon season)

(Paolino)

(DelSole)

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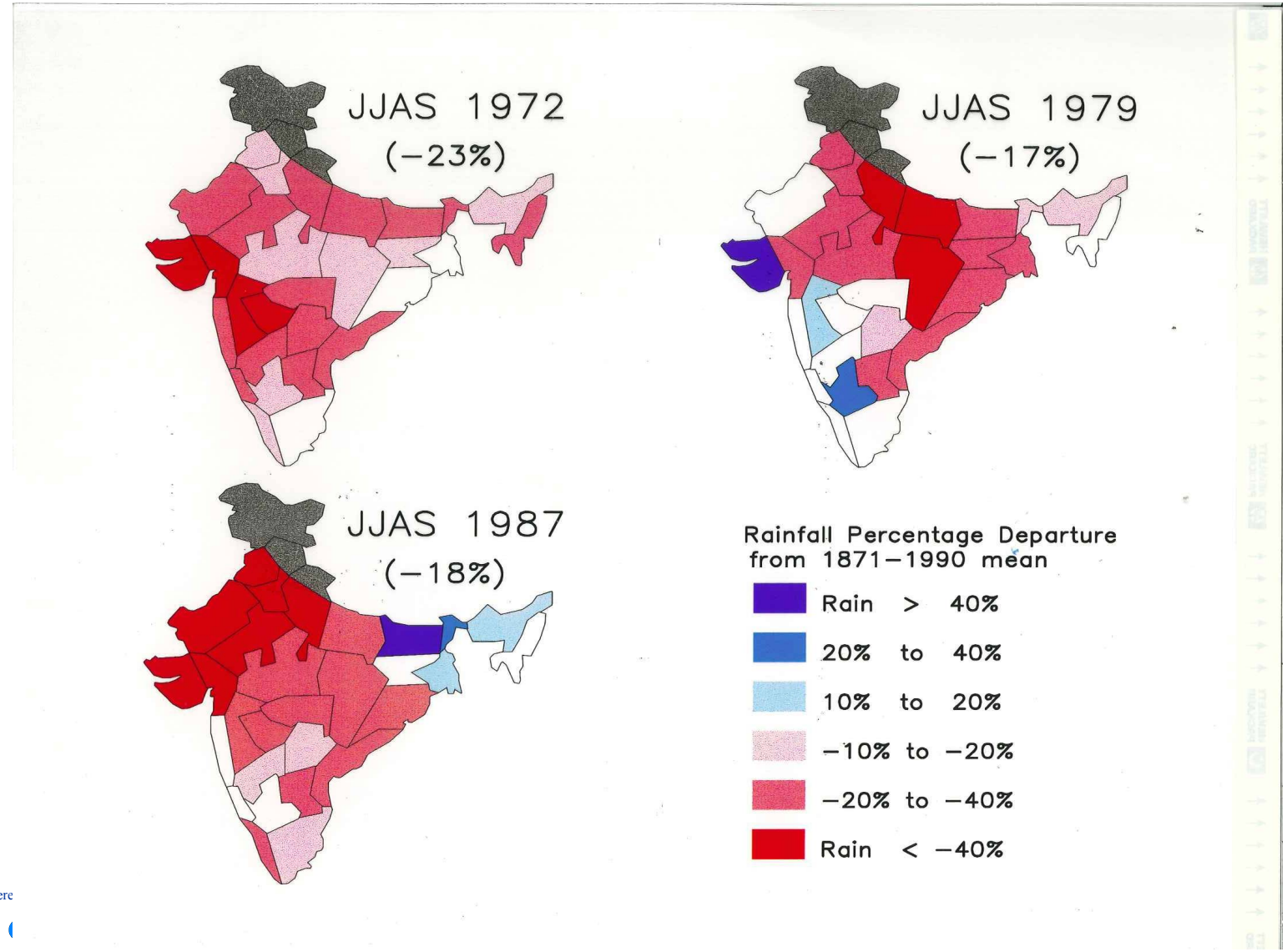

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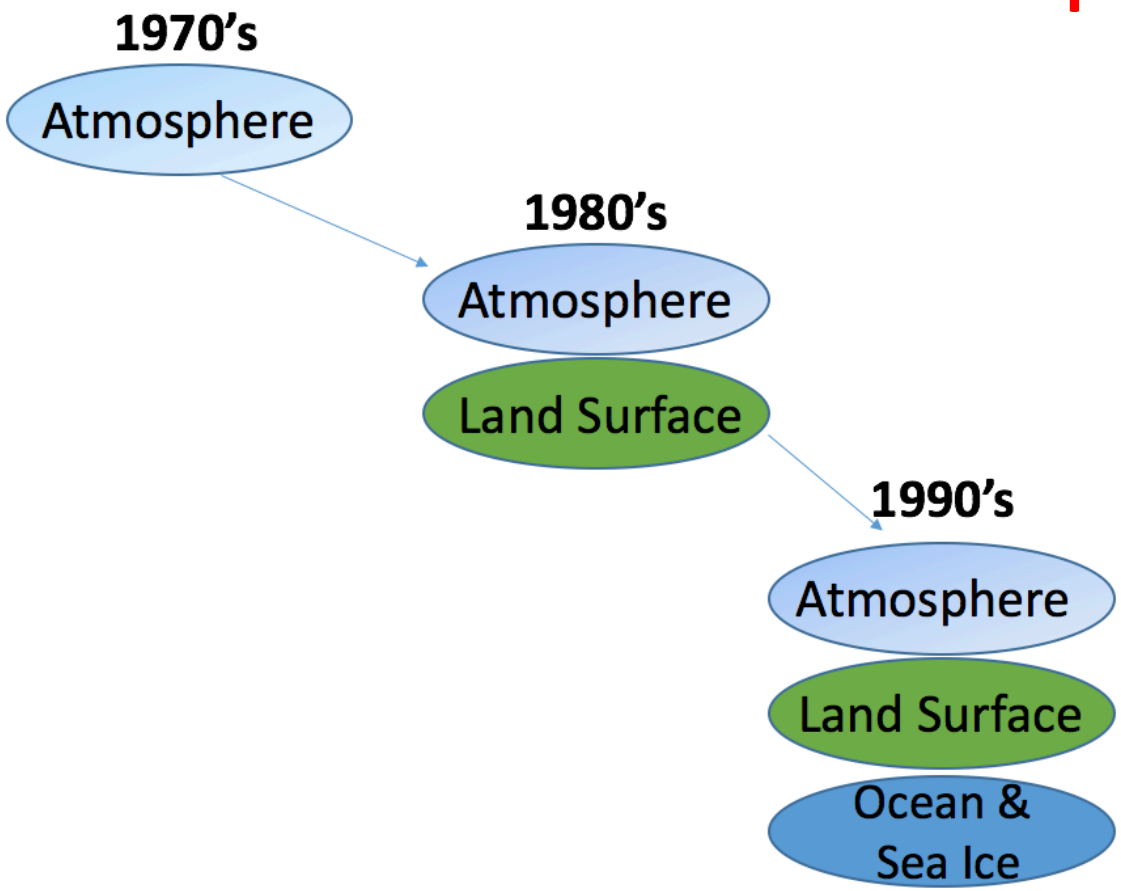
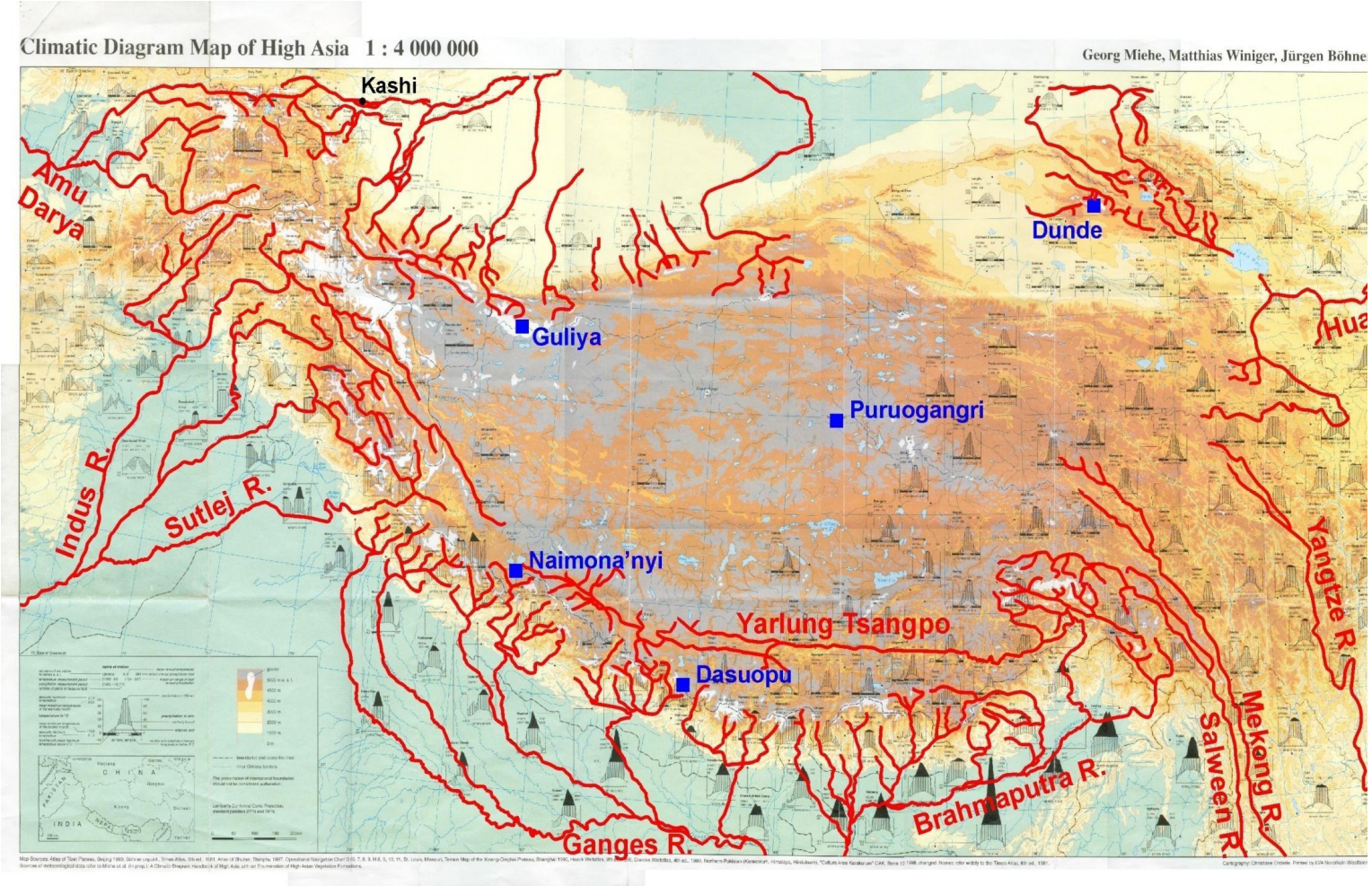
From Atmospheric Models, to Coupled Ocean-Land-Atmosphere Models



Predictability of Indian Summer Monsoon Rainfall

- After 50 years of modeling, coupled ocean-atmosphere dynamical models show statistically significant skill in prediction of seasonal mean rainfall over India. This skill comes almost entirely from skill in prediction of tropical SST (ENSO).
- The errors in the current monsoon forecasts are not due to intrinsic limits of predictability, but inadequate observations and lack of high-fidelity models.
- Empirical methods of predicting Indian summer monsoons show no statistically significant skill.

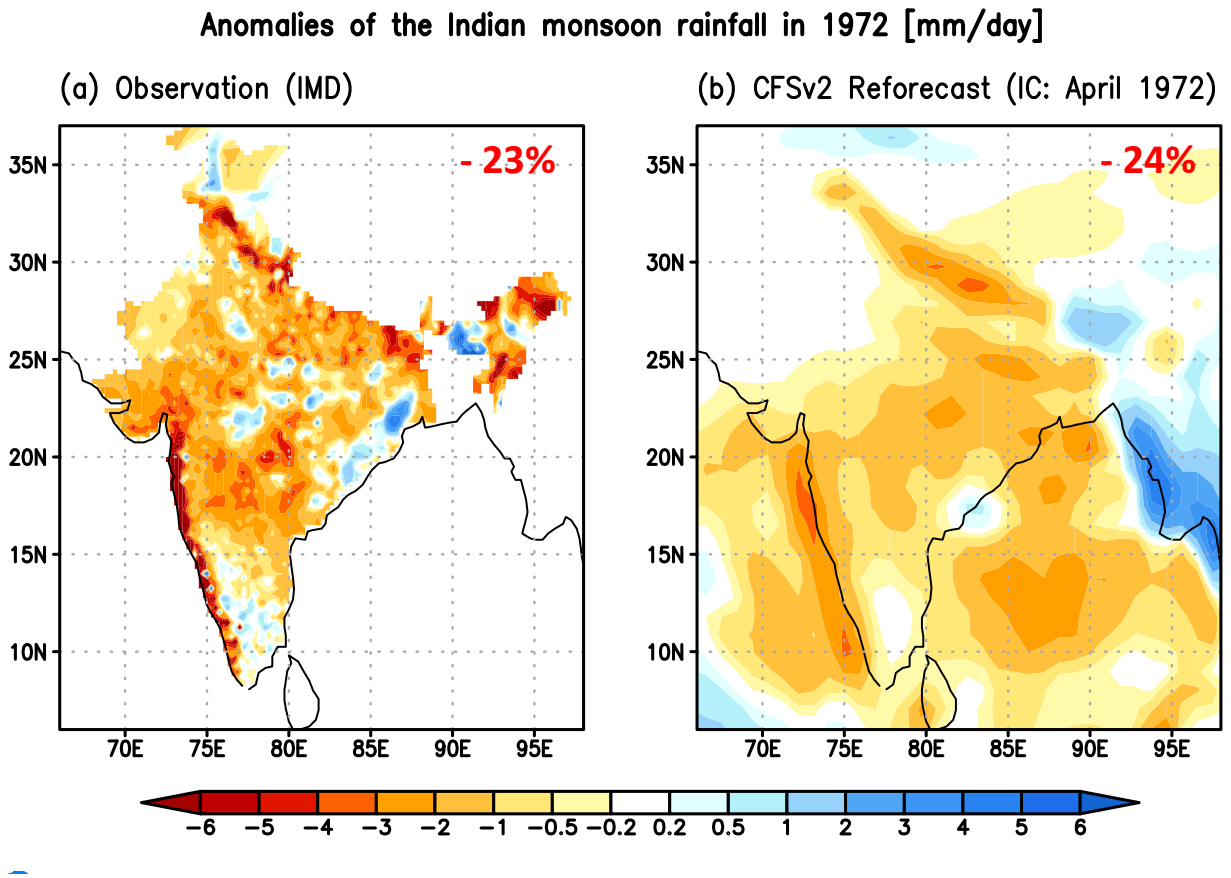


Himalayan glaciers store about 12,000 cubic kilometers of freshwater in ~15,000 glaciers and are the lifeline for millions of people (IPCC, 2007)

Forecast (April 72, IC) and Observed (IMD) Rainfall Anomalies for JJAS 1972 (mm/day)

Observed IMD

Forecast CFSv2



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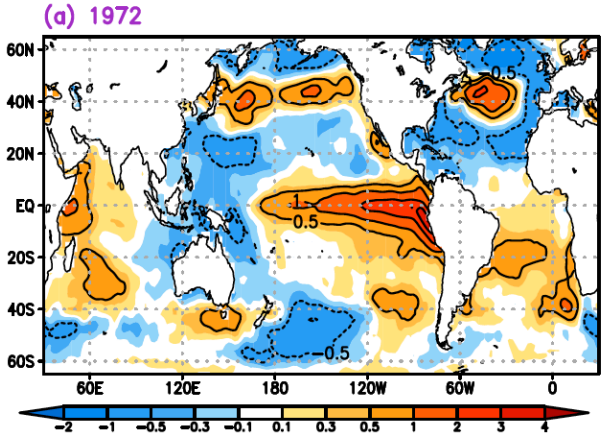
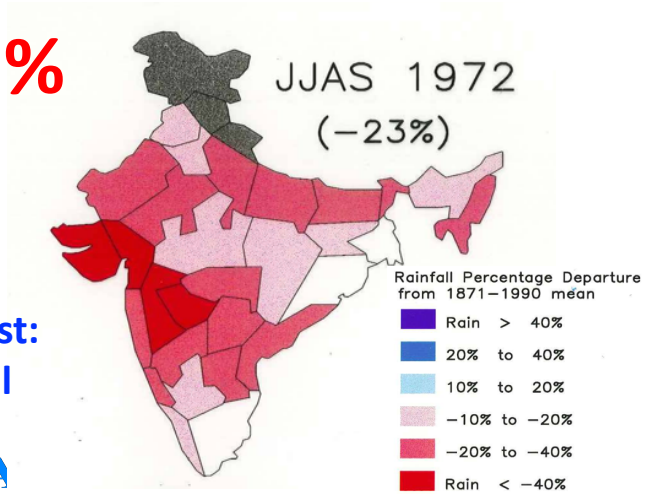
ENSO & ISMR (obs) for JJAS 1972 and 1997

1972

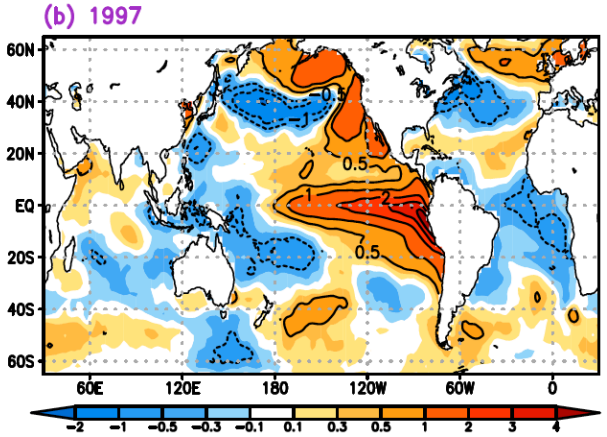


- 23%

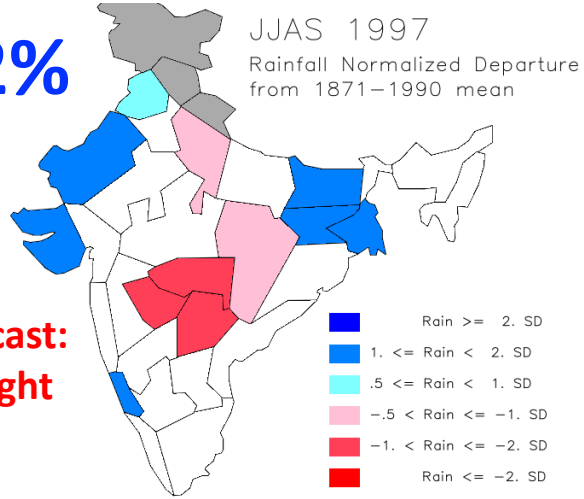


IMD Forecast: Normal

1997



+ 2%



IMD Forecast: Drought

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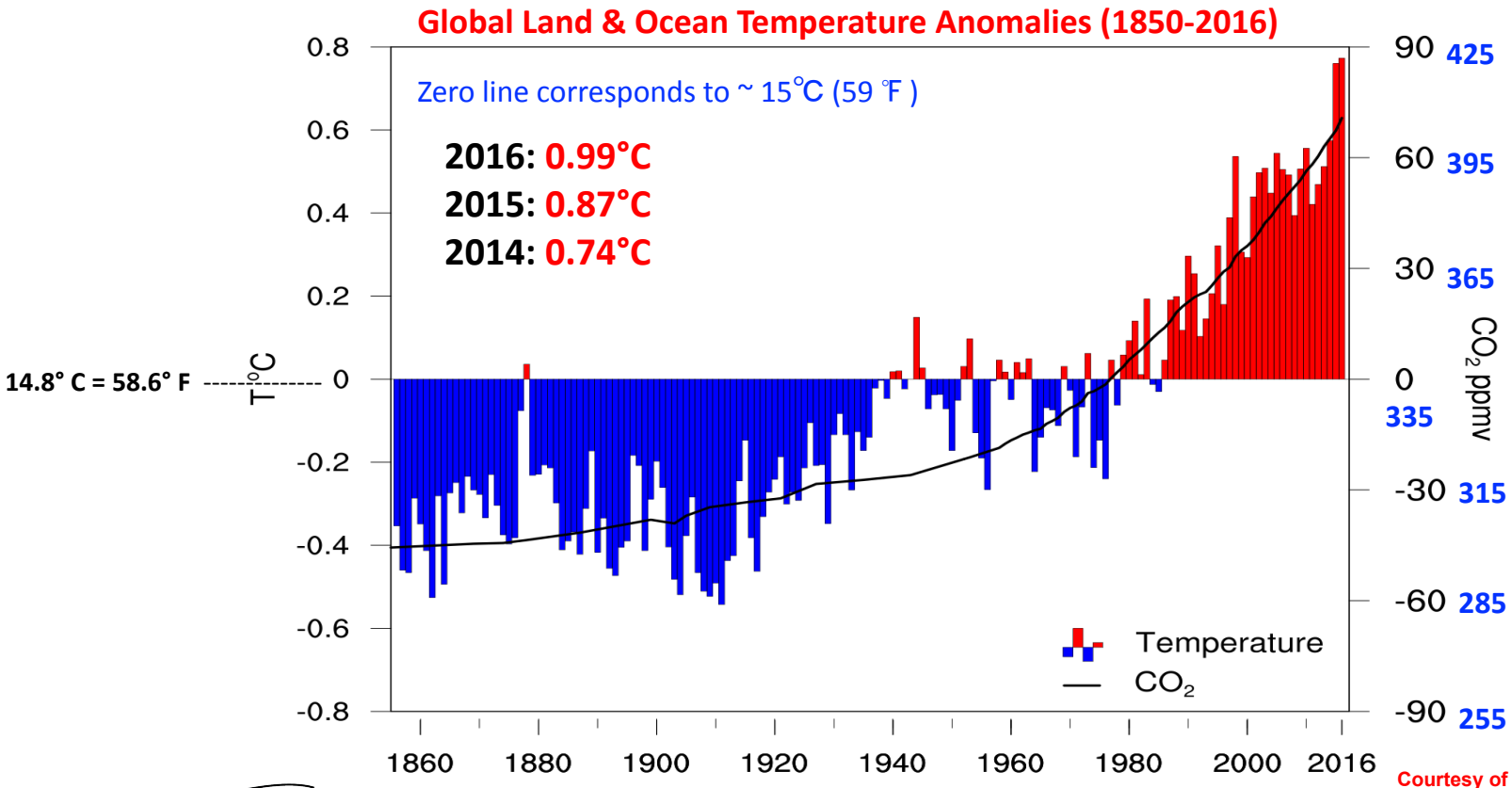
An Elegant Science Question:

Are increases in greenhouse gases responsible for increase in global mean temperature (global warming)?

Climate models are tools to answer this question



Courtesy of Jim Hurrell

Temp: 1901-2000 mean: 14.8 C, 58.6 F CO2: April 2016 ~ 403 ppm

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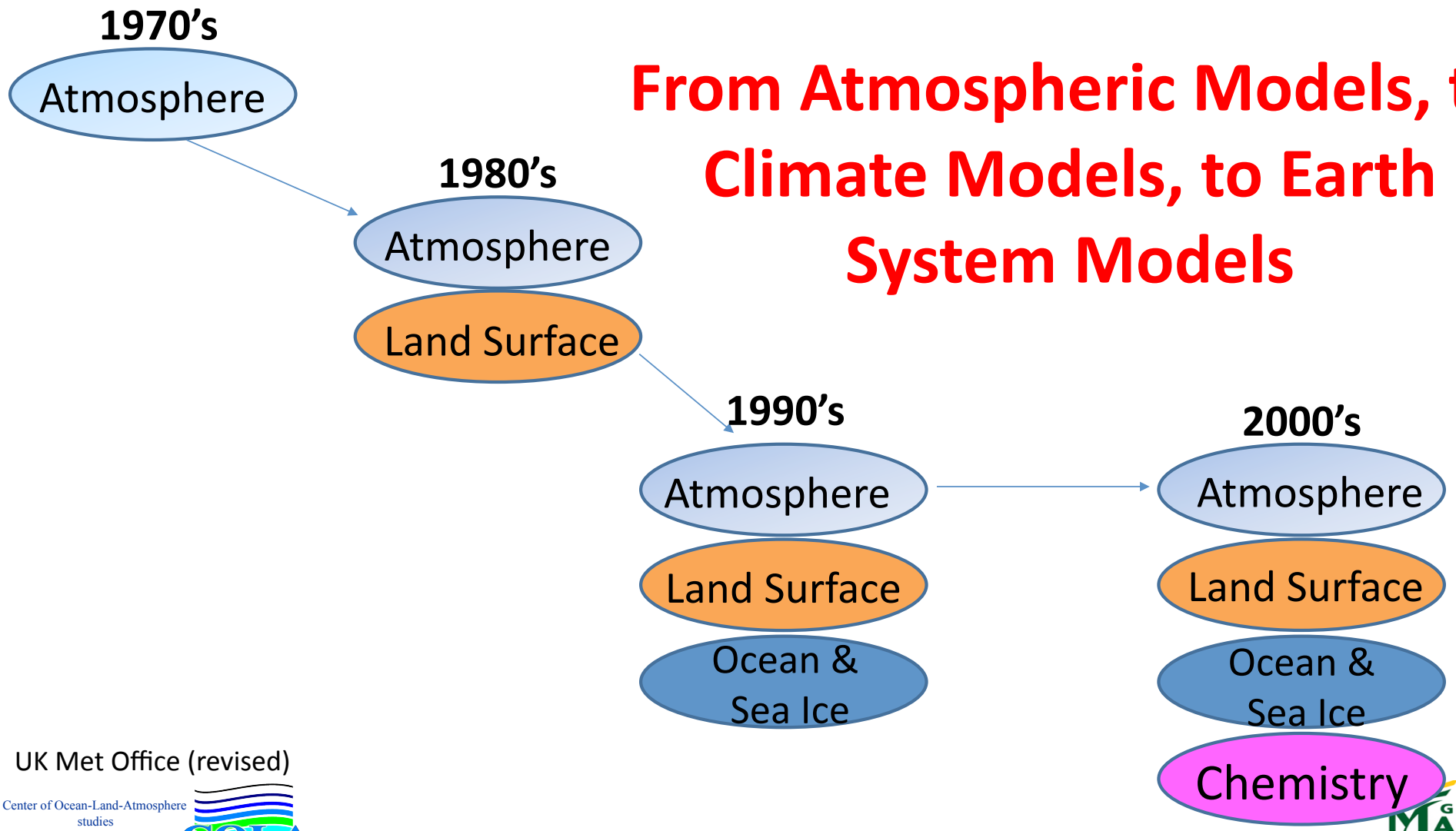
From Atmospheric Models, to Climate Models, to Earth System Models



UK Met Office (revised)

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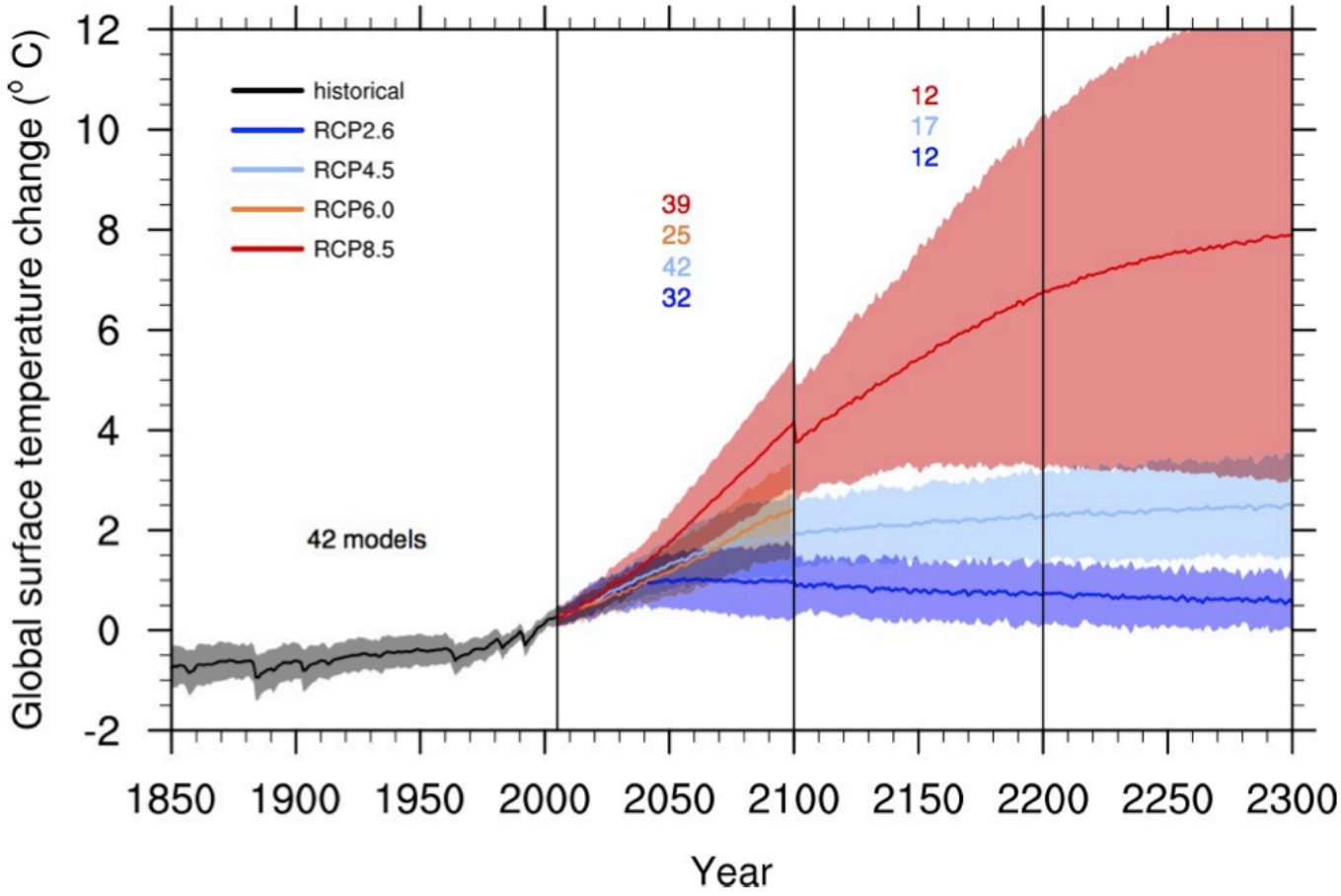
Change in Global Surface Temperature



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Are Human Activities Responsible for Recent Climate Change?

- Are concentrations of greenhouse gases (GHG) increasing in the atmosphere? YES
- Do human activities increase GHG? YES
- Is global mean temperature increasing? YES
- Does increase in GHG cause global warming? YES

Therefore, YES, human activities are responsible for recent global warming

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The New York Times

19 January 2014, Nicholas Kristof (US Survey)

Q: Are there signs that:

Aliens have visited Earth- **77%** **"Yes"**

Humans are causing climate change- **44%** **"Yes"**

USA: Assault on facts; Assault on reason

Q: Is human activity the main cause of Global Warming?

Democrats- 66% "Yes"
Republicans- 24% "Yes"

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Science, Ideology and Policy in the USA:

A Puzzle

Percentage of Democrats/Republicans who said that news of global warming was exaggerated (Gallup)

	1998	2004	2008	2014	2016
Democrats	23%	22%	18%	18%	12%
Republicans	34%	60%	59%	68%	59%

Thanks: Ed Maibach, Center for Climate Change Communication (GMU)

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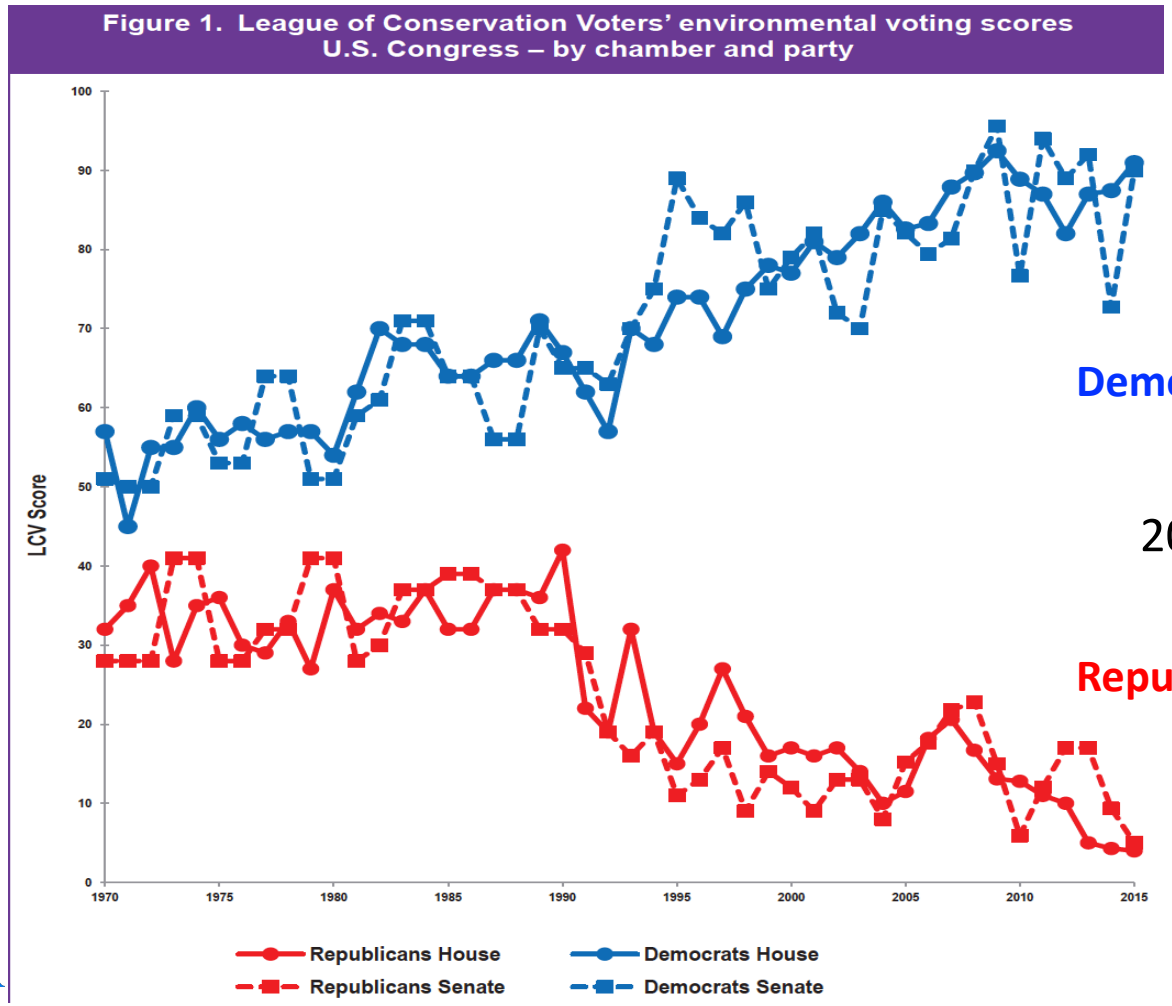
US Congress Environmental Voting Scores



Democrats

2015

Republicans

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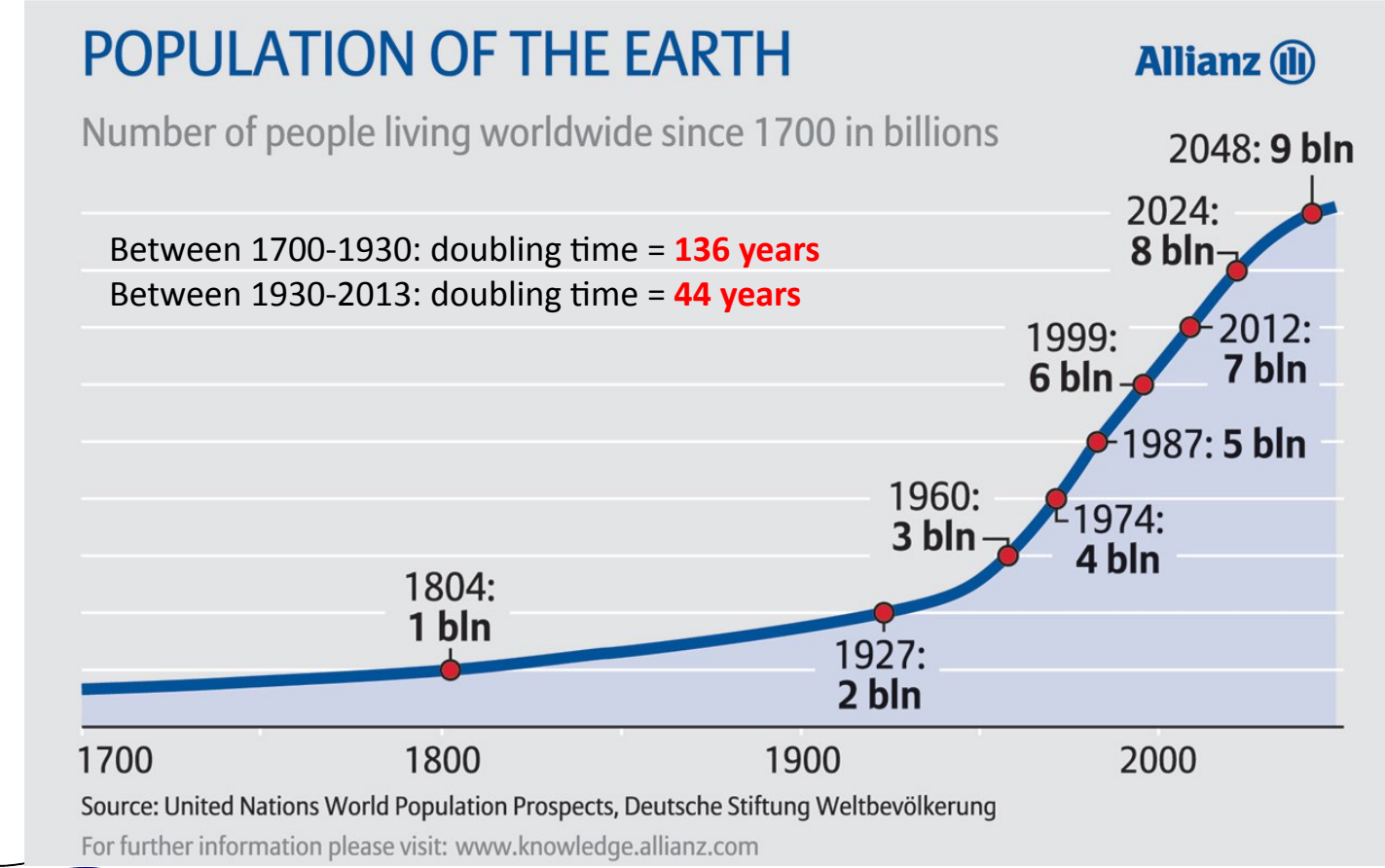
Anthropocene: The Human Age

- The '**Anthropocene**' is a term widely used to denote a new geological epoch that recognizes humanity's impact on the planet, in which many geologically and environmentally significant conditions and processes are profoundly altered by human activities.

Holocene: 8,000 years ago – present
Pleistocene: 1.8 million – 8,000 years ago
Pliocene: 5.3 million – 1.8 million years ago

Current & Future Population



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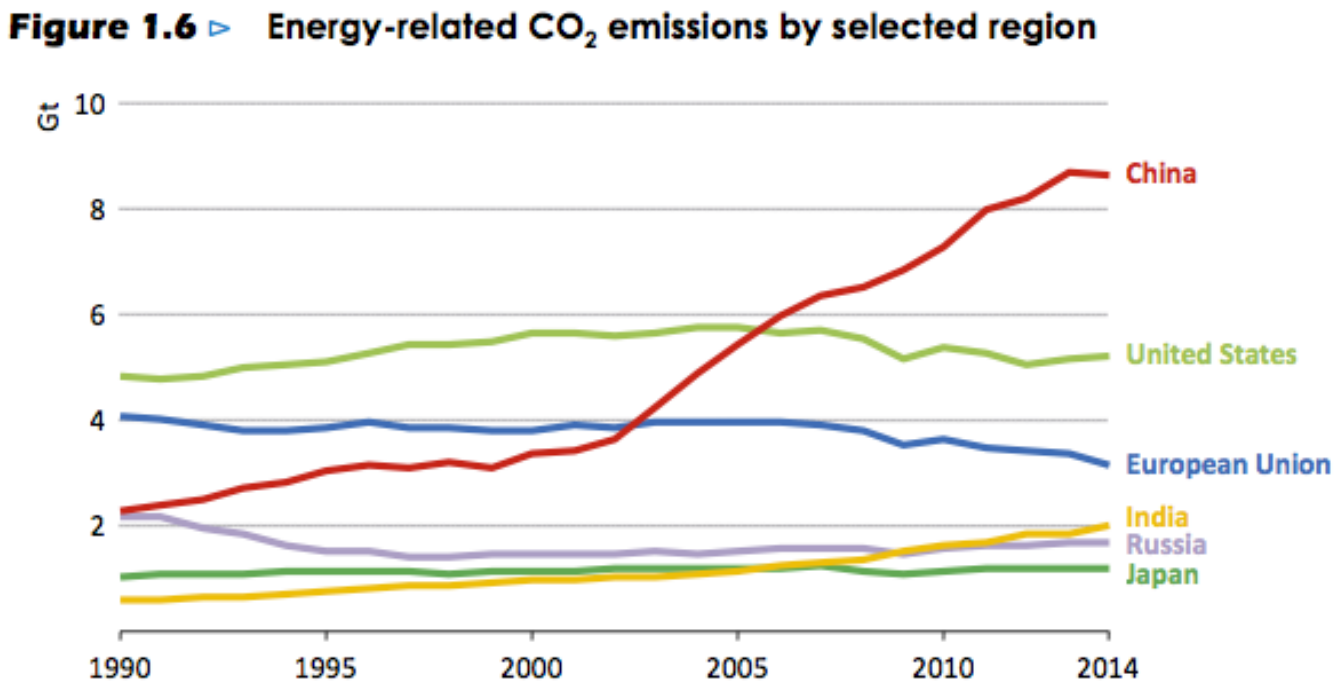
Energy-related CO2 Emissions by Region



Int. Energy Agency (IEA)
World Energy Outlook Special Report

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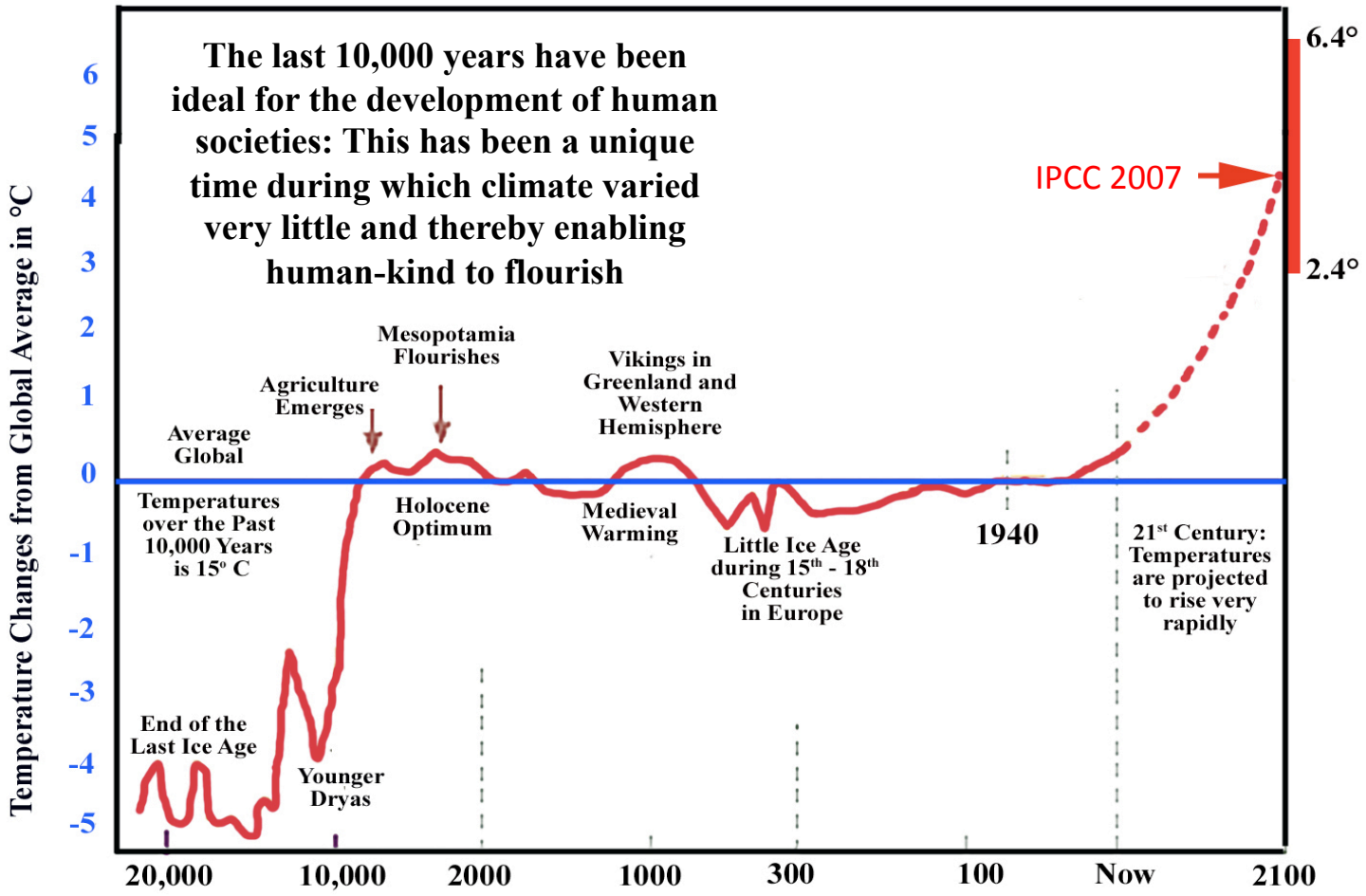

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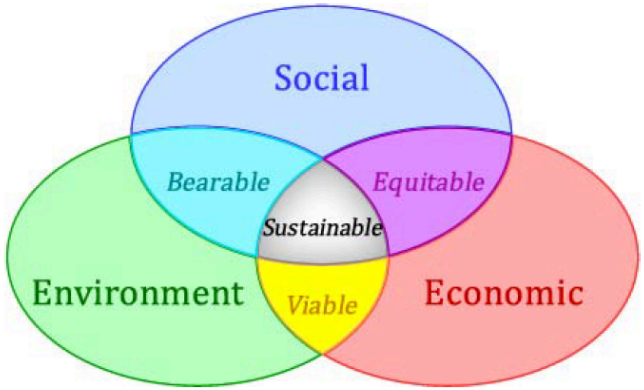
Sustainable Development

"The balance of economic growth, social justice, and environmental health that meets the needs of present generation and enables future generations to meet their needs."

987)

The Brundtland Report



Overlapping Themes of the Sustainability Paradigm (Theis & Tomkin, 2012)

Global Inequality in Income and Carbon Emissions

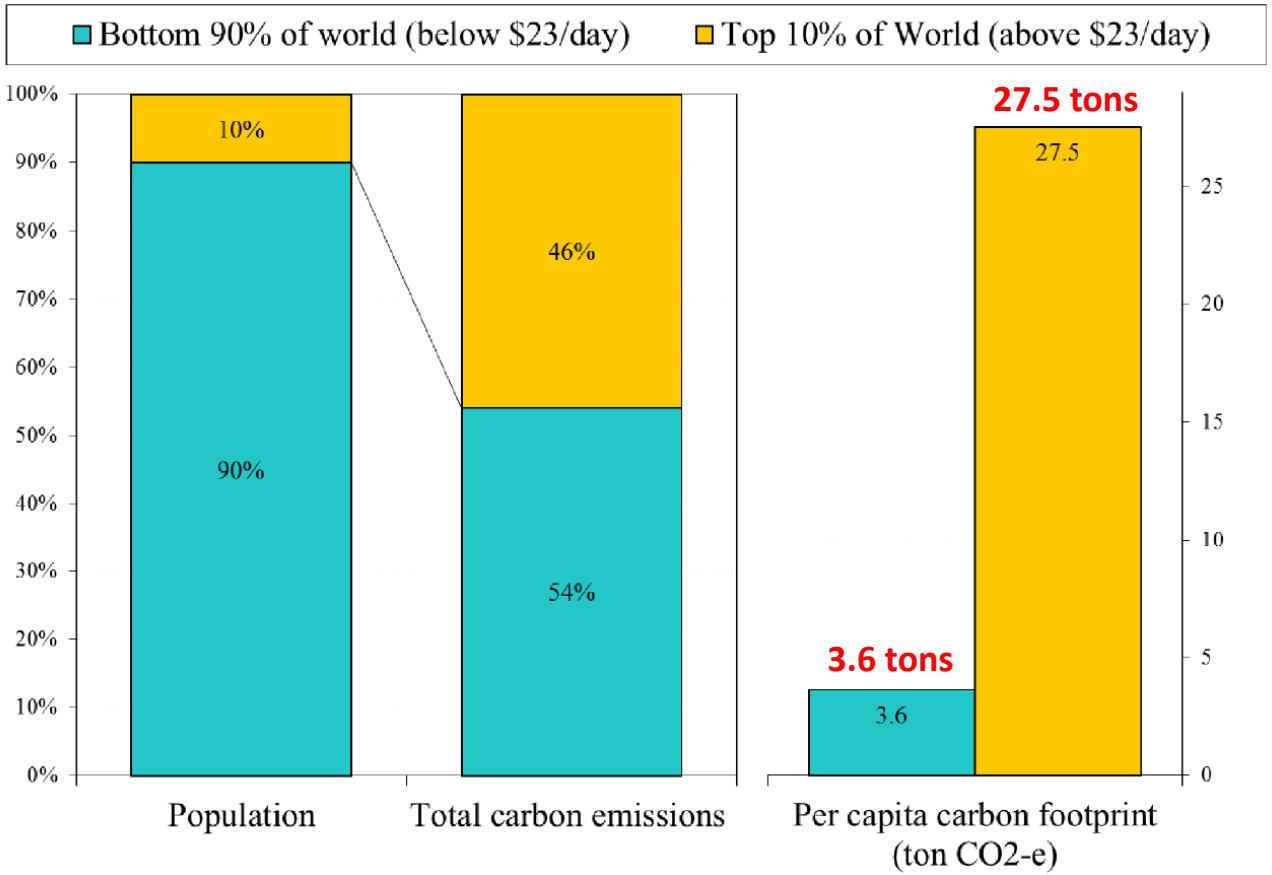


Figure 2: Global inequality in carbon emissions.

Safa et. al. 2016

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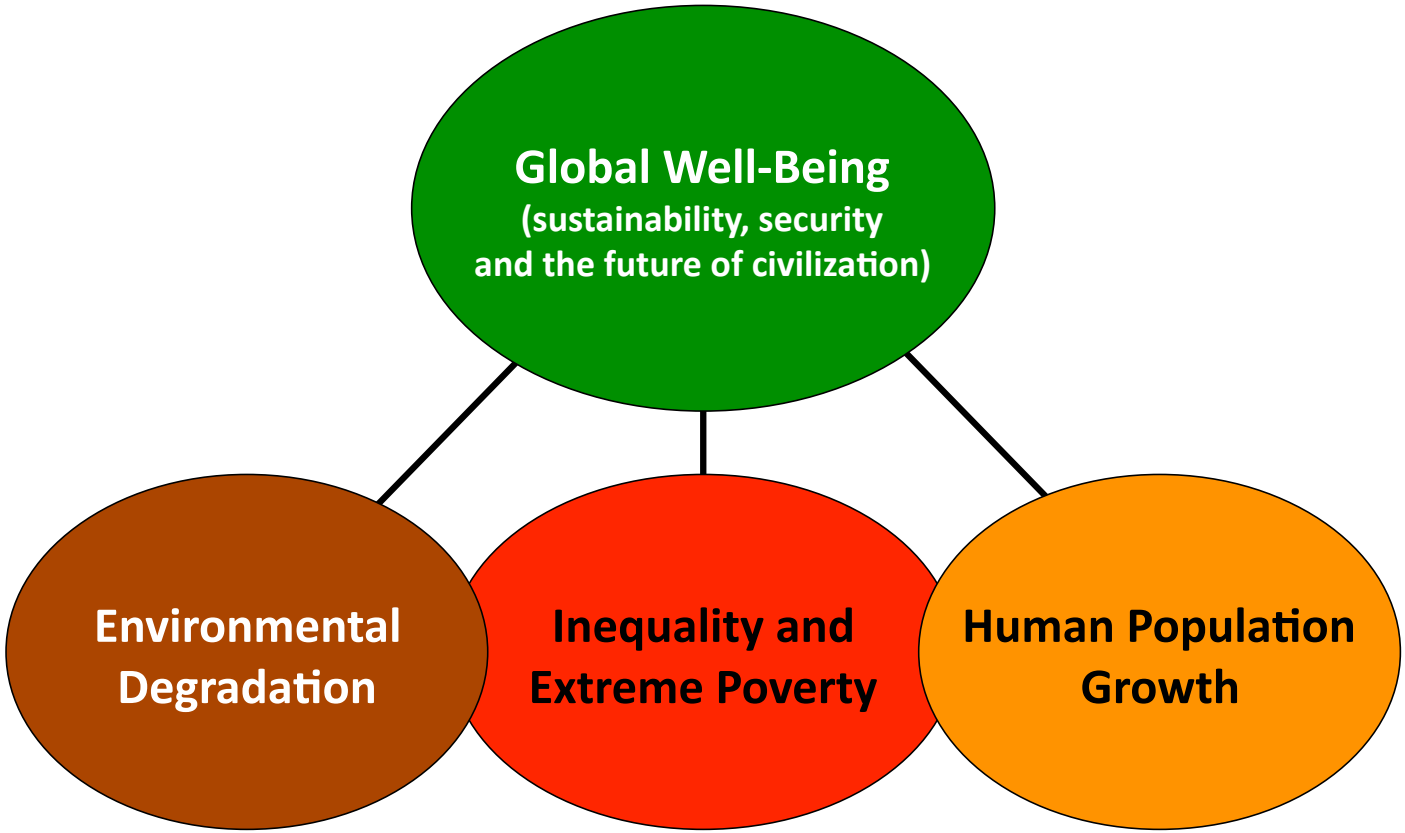
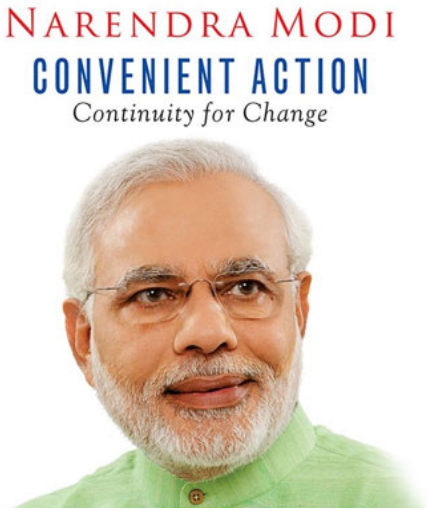
The Future: The Global Challenge



The Paris Agreement



"*India is an independent country, and there is no pressure on us from any country or any person. But there is pressure. When we think about the future generations and what kind of world we are going to give them, then there is pressure. Climate change itself is a huge pressure.*"

COP21 · CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

Prime Minister Narendra Modi,
joint press conference with Obama, Delhi, January 2015

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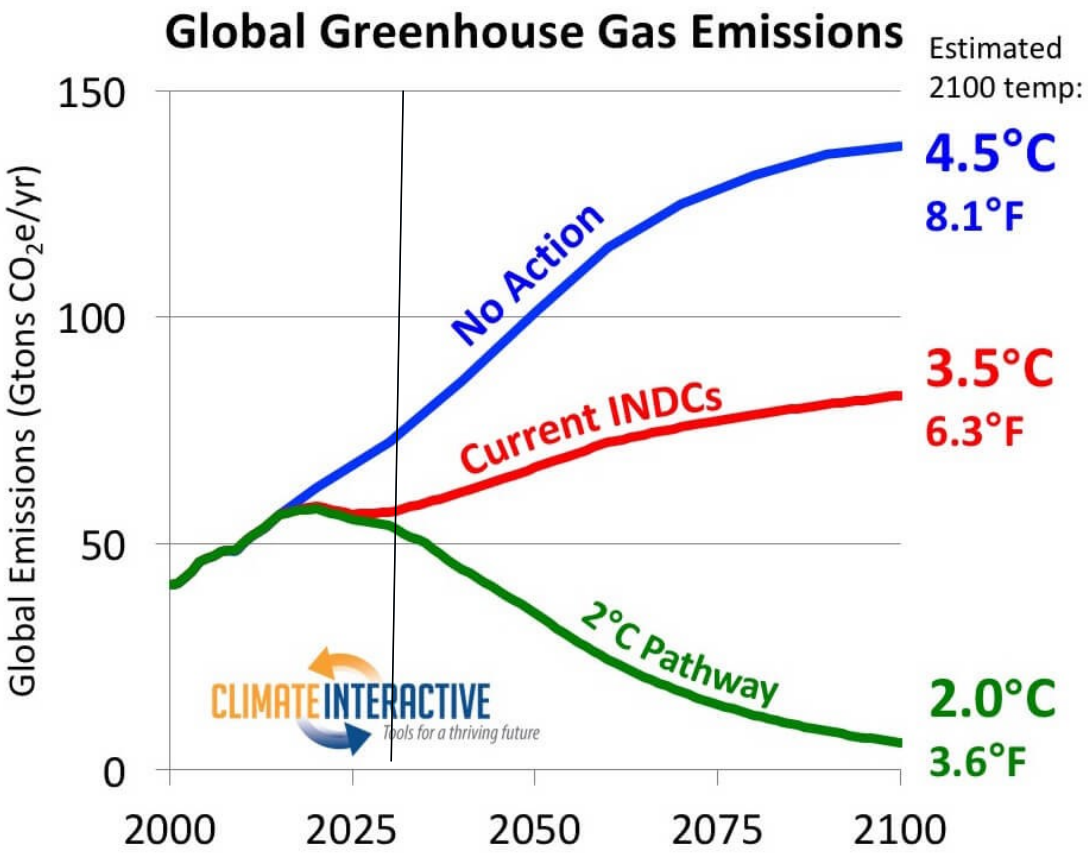
Projected Climate Change Per COP21

INDC:
Intended Nationally Determined Contributions

Current INDC's agreed in Paris COP21 (final in Apr. 2016) expire in 2030; the graph at right assumes that commitments continue beyond 2030 (vertical line).



27 October 2015, www.ClimateScoreboard.org

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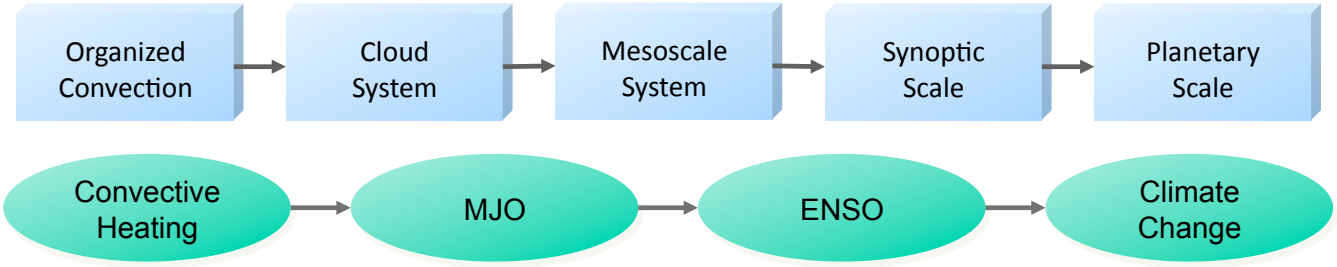
Seamless Prediction of Weather and Climate

From Cyclone Resolving Global Models to Cloud System Resolving Global Models

1. **Planetary Scale Resolving Models (1970~): *Δx*~500Km**
2. **Cyclone Resolving Models (1980~): *Δx*~100-300Km**
3. **Mesoscale Resolving Models (1990~): *Δx*~10-30Km**
4. **Cloud System Resolving Models (2000 ~): *Δx*~3-5Km♪**



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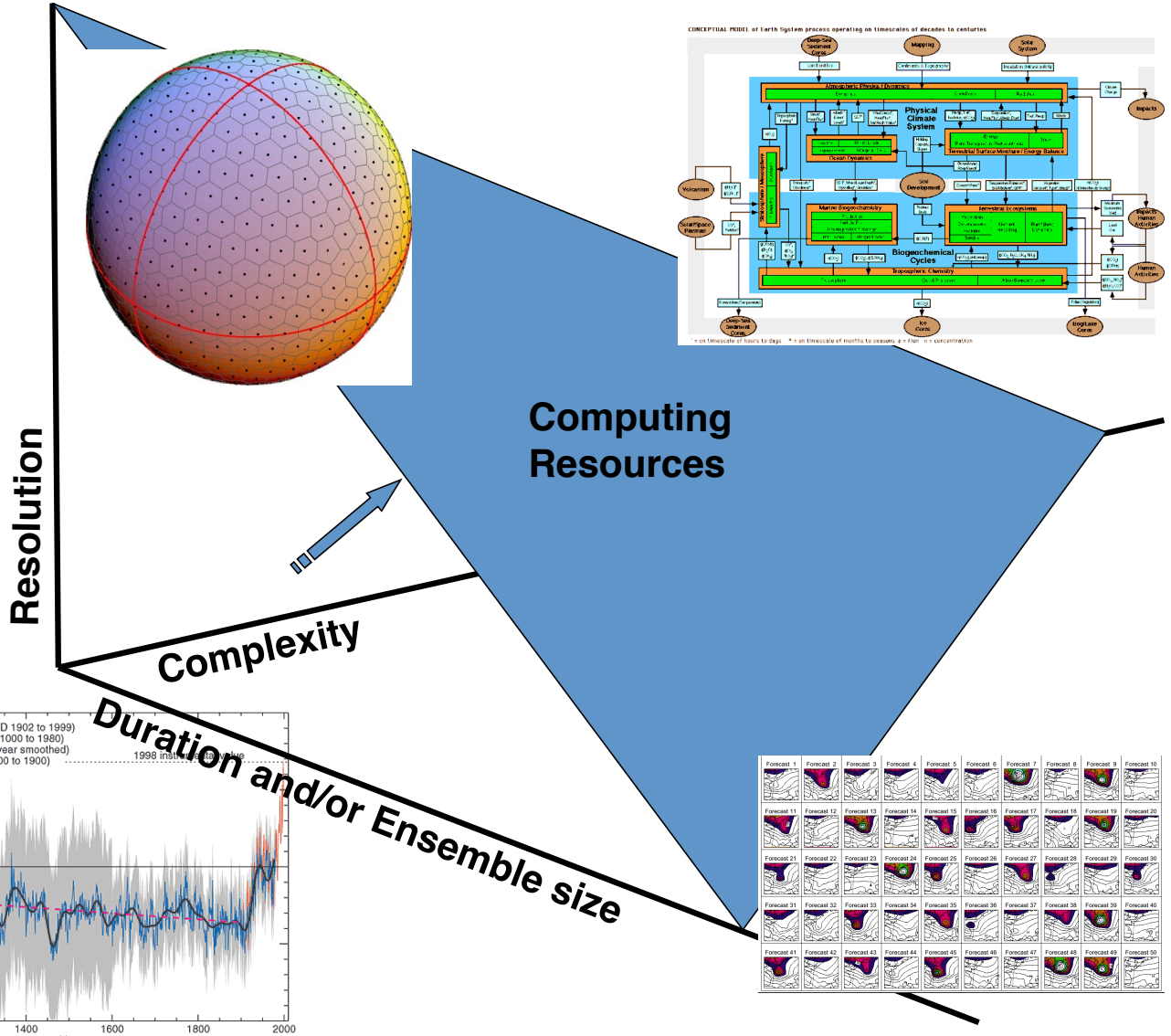

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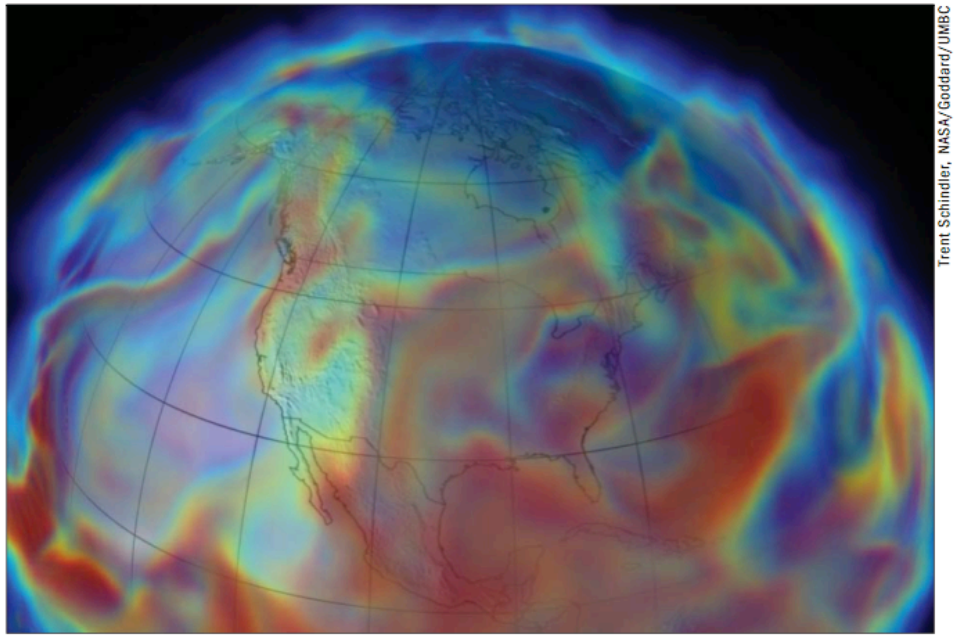
A CERN for climate change?

Providing reliable predictions of the climate requires substantial increases in computing power. Tim Palmer argues that it is time for a multinational facility fit for studying climate change

This winter has seen unprecedented levels of travel chaos across Europe and the US. In particular, the UK experienced the coldest December temperatures on record, with snow and ice causing many airports to close. Indeed, George Osbourne, the UK's Chancellor of the Exchequer, attributed the country's declining economy in the last quarter of 2010 to this bad weather. A perfectly sensible question to ask is whether this type of weather will become more likely under climate change? Good question, but the trouble is we do not know the answer with any great confidence.



Trent Schindler, NASA/Goddard/UMBC

A global approach to a global problem Modelling the climate may require a unified strategy for computing.

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In Physics World by Tim Palmer

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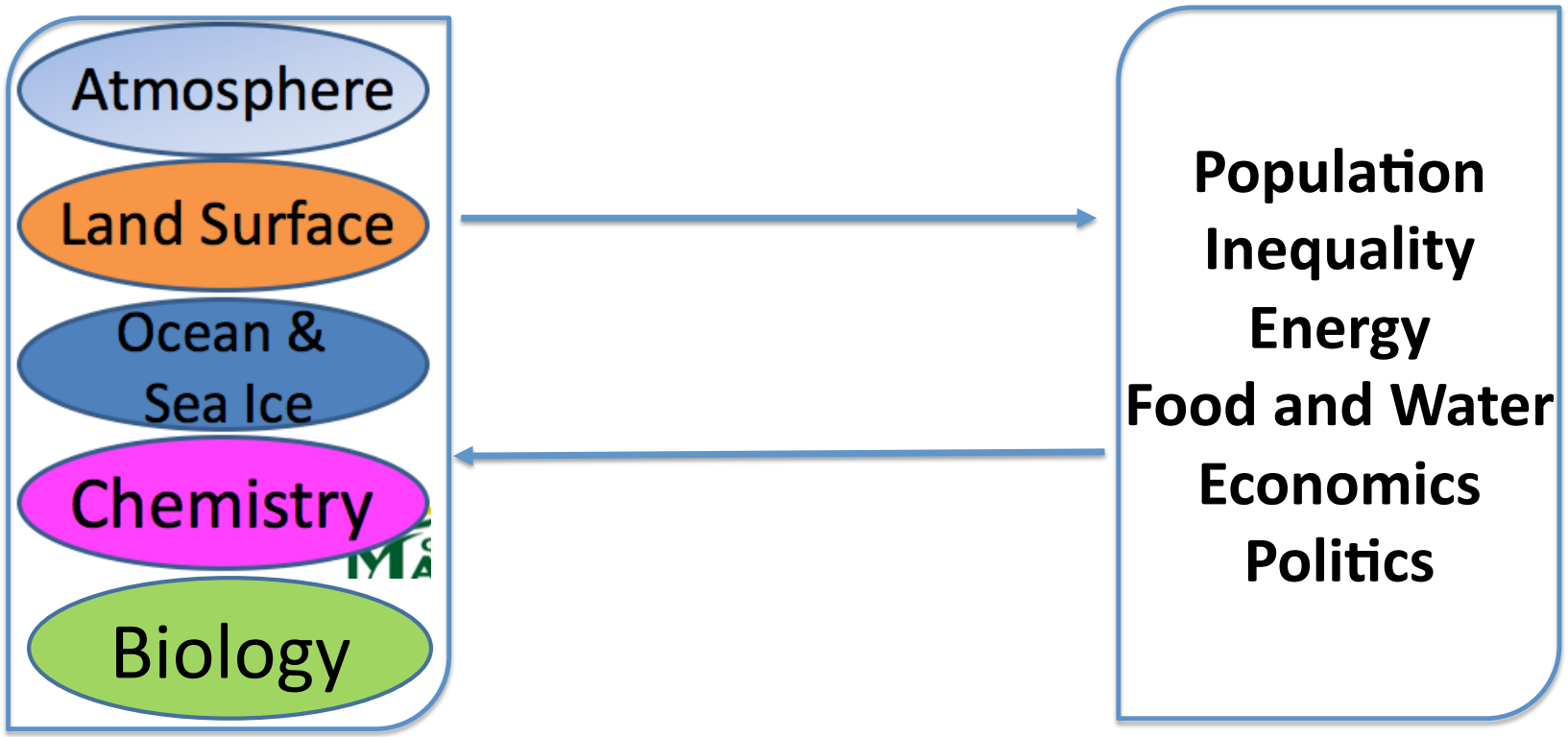
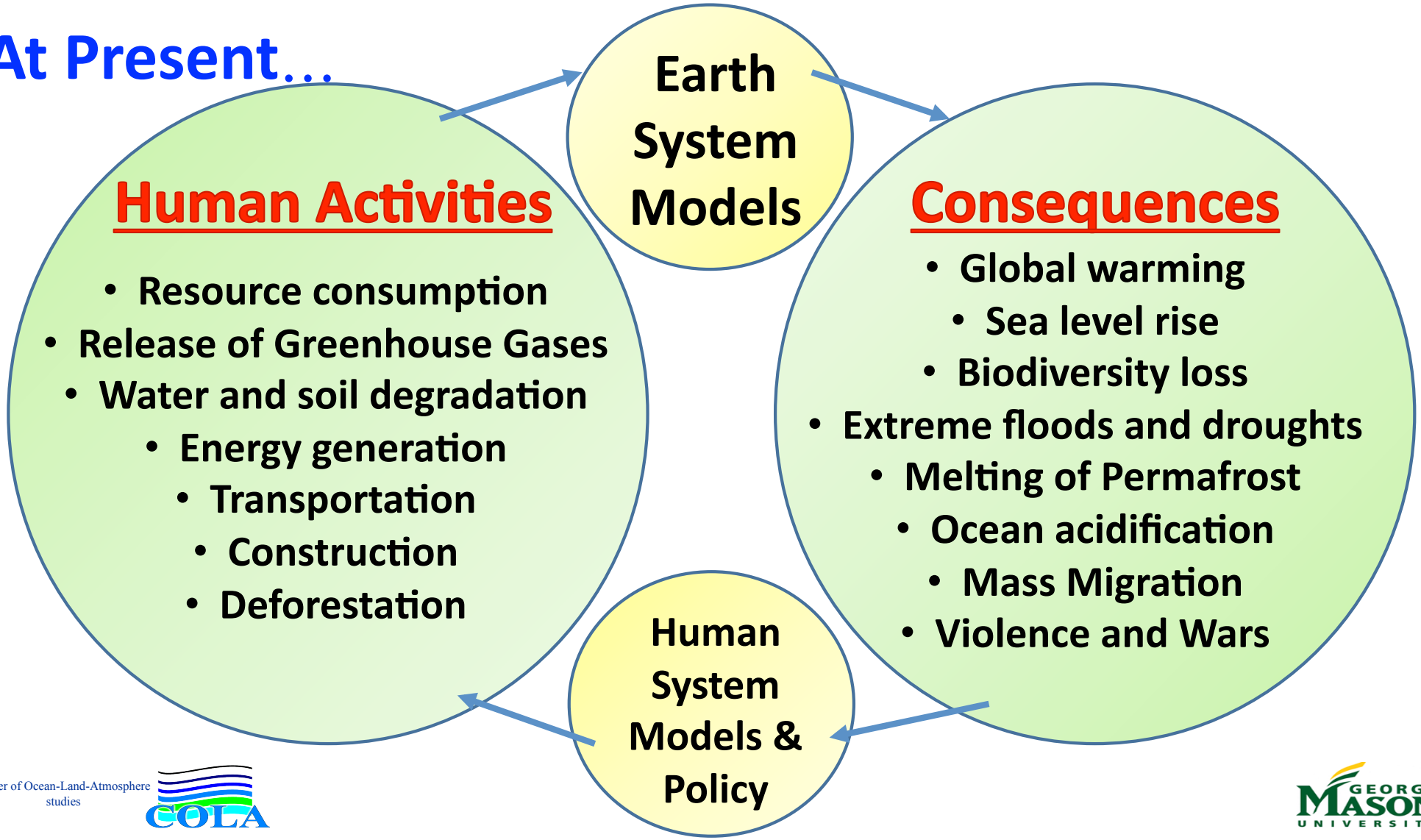
Interactive Earth Systems and Human Systems



At Present…



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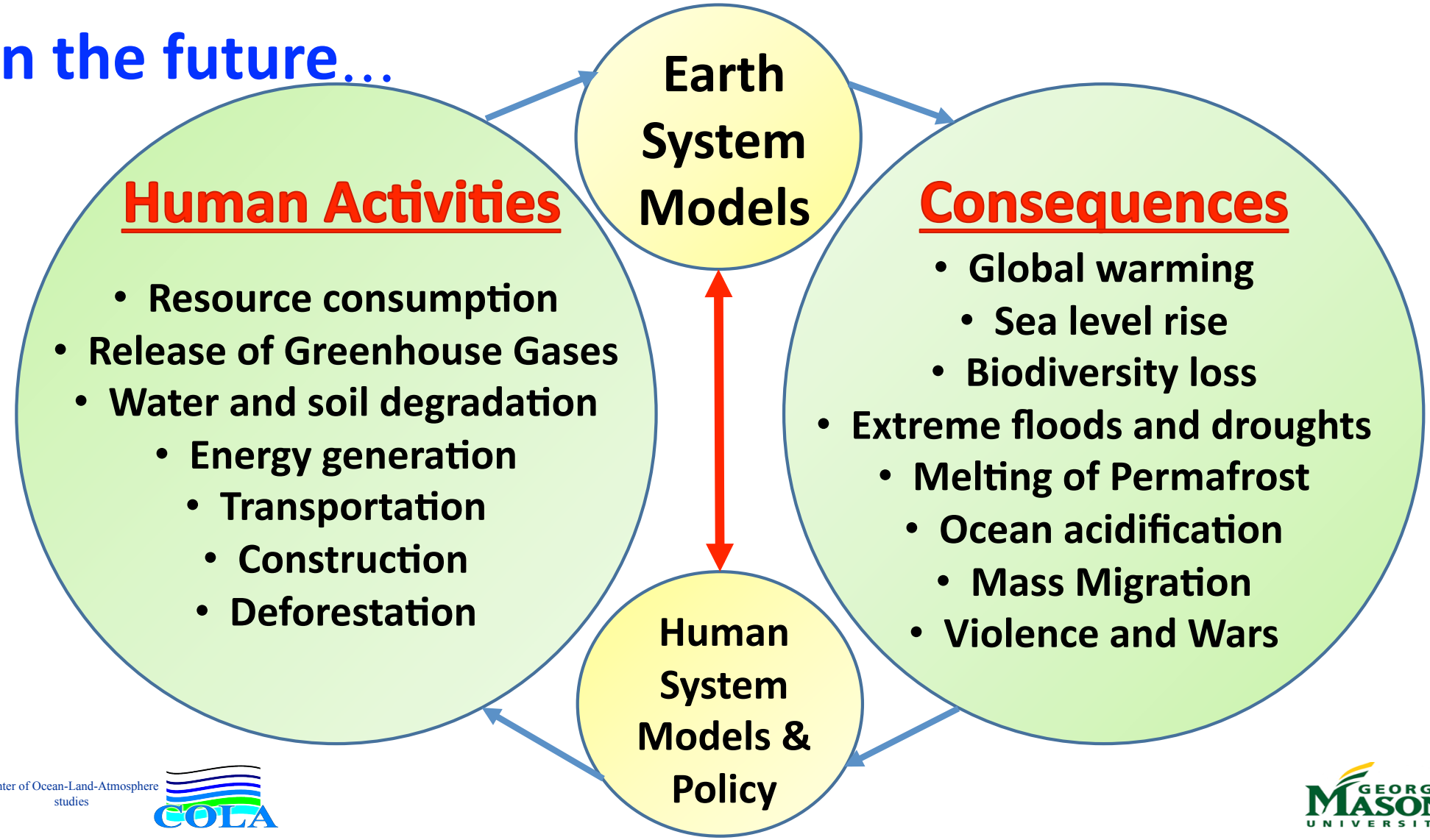
In the future…



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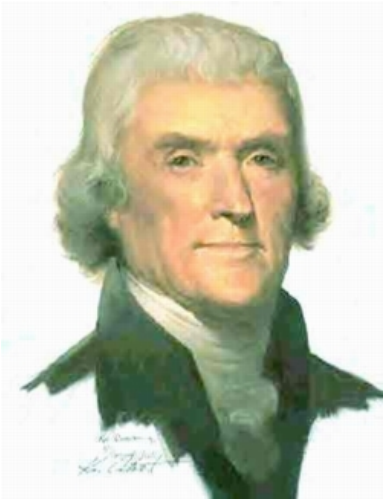
Challenges and Prospects for the Future

Sustainable and equitable development of all societies in an unequal world is a global challenge.

1. Extremely High Resolution (cloud system resolving) weather and climate prediction models and high resolution observations
2. Advanced Earth System Models: Interactive Physical-Chemical-Biological Systems
3. Advanced Human System Models: Interactive Social-Economic-Political Systems
4. Interactive Earth System Models and Human System Models



" --- laws and institutions must go hand in hand with the progress of the human mind. As that becomes more developed, more enlightened, as new discoveries are made, new truths discovered and manners and opinions change, with the change of circumstances, institutions must advance also to keep pace with the times."

Thomas Jefferson

Letter to George Wythe, August 13, 1790

THANK YOU!

ANY QUESTIONS?