

# ATM 241 Climate Dynamics

## Lecture 1

### Introduction to Climate Dynamics

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Preface

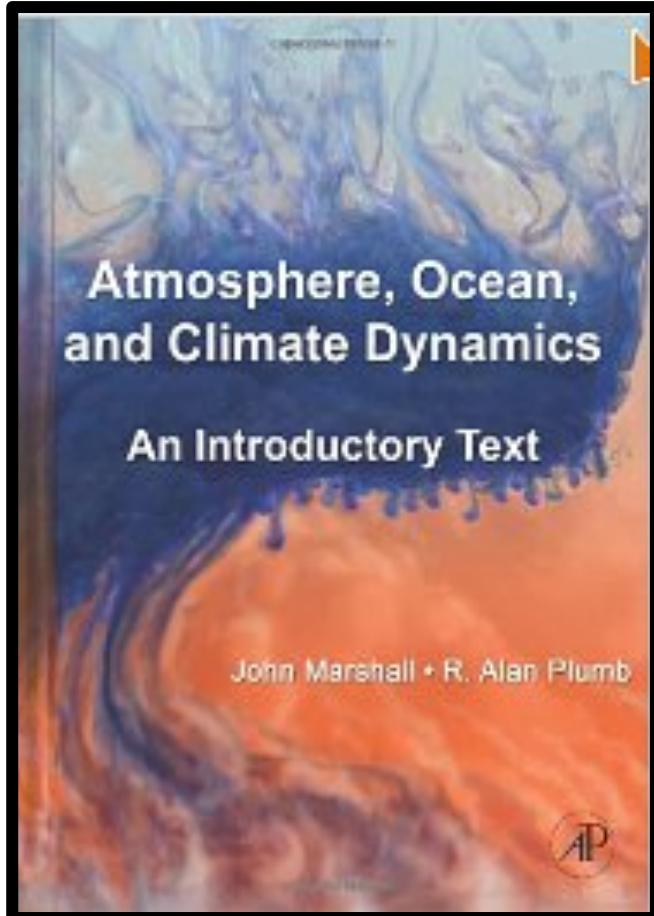


# Climate Dynamics: Outline

## Course Goals

- Understand the dynamical behavior of the Earth system
- Focus on global scales, over long time periods
- Understand the drivers of global circulation
- Understand the importance of energy in the climate system
- Understand the importance of moisture in the climate system
- Understand the processes that drive redistribution of energy and moisture
- Understand the implications of a globally interconnected climate system

# ATM 241: Primary Textbook



**Atmosphere, Ocean and Climate Dynamics:  
An Introductory Text**

John Marshall and R. Alan Plumb (2007)

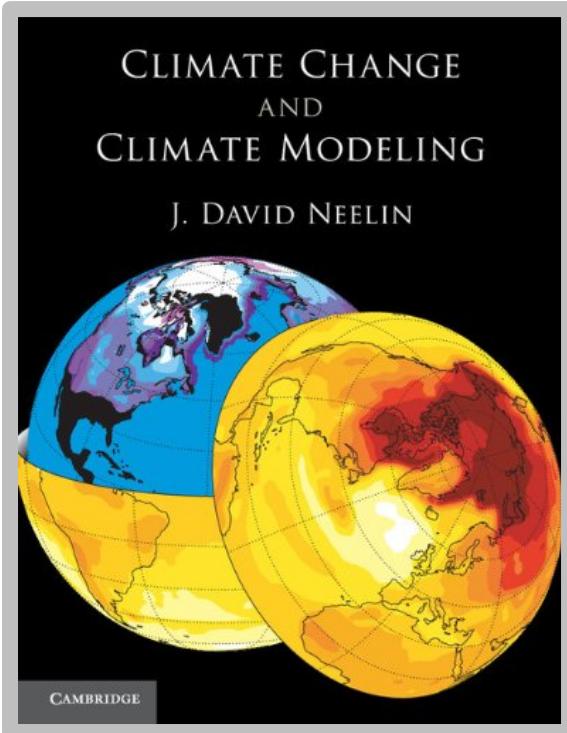
Supporting web page:

<http://marshallplumb.mit.edu/>

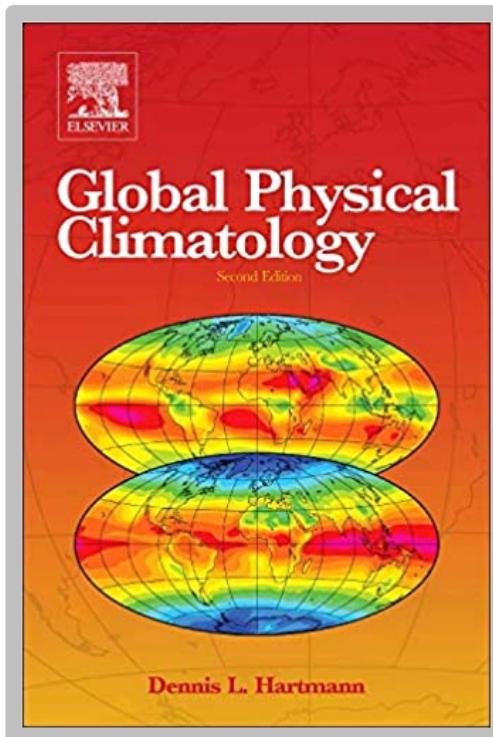
Datasets and plots from IRI/LDEO Climate Data Library:

<http://iridl.ldeo.columbia.edu/>

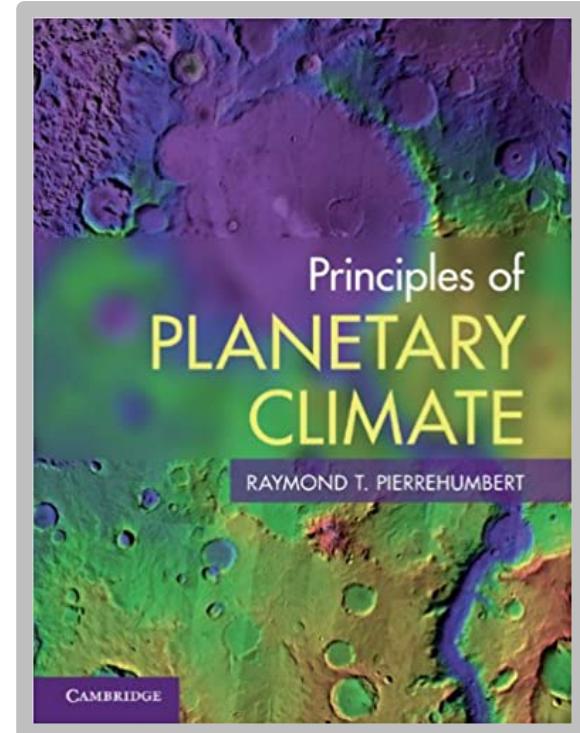
# ATM 241: Additional Reading



**Climate Change and Climate Modeling**  
J. David Neelin  
(2011)

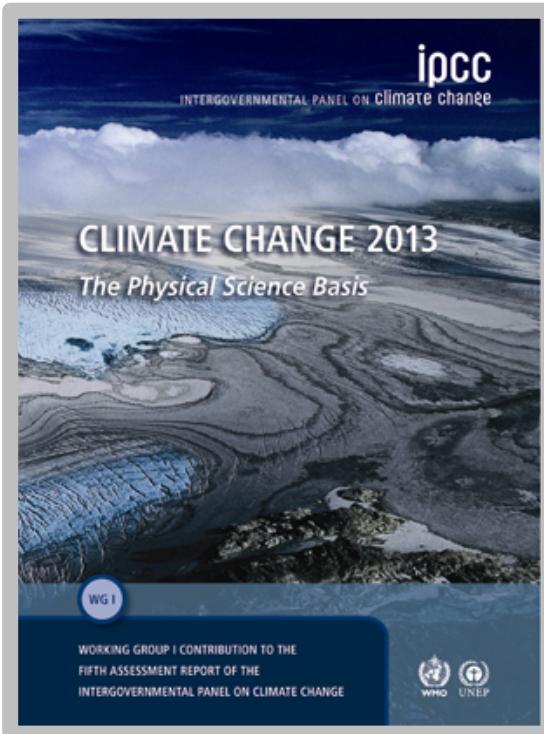


**Global Physical Climatology**  
Dennis L. Hartmann  
(2016)



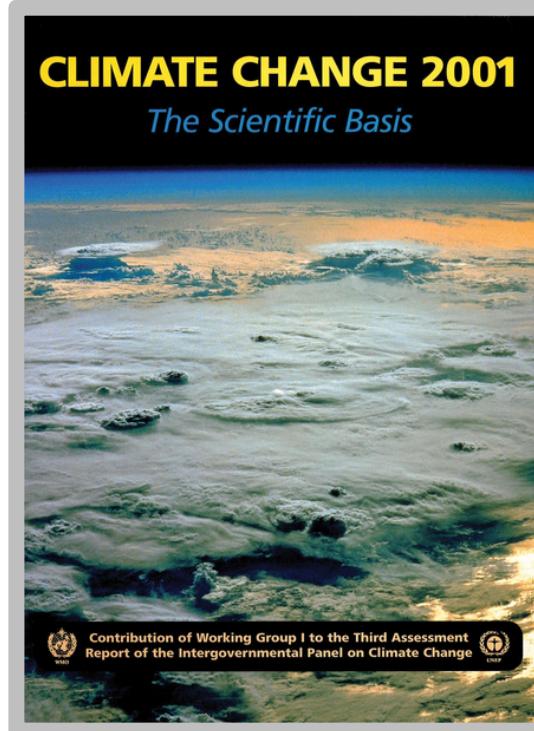
**Principles of Planetary Climate**  
Raymond T. Pierrehumbert  
(2010)

# ATM 241: Additional Reading



**Climate Change 2013:  
The Physical Science Basis**  
Intergovernmental Panel  
on Climate Change

<https://www.ipcc.ch/report/ar5/wg1/>



**Climate Change 2001:  
The Scientific Basis**  
Intergovernmental Panel  
on Climate Change

<https://www.ipcc.ch/report/ar3/wg1/>

# The Climate System



# In this section...

## Definitions

- Climate
- Weather
- Climate dynamics
- Climate experiments
- Climate observations
- Climate models

## Questions

- What are the five components of the Earth system?
- Why is it important to understand the Earth system?
- How is the Earth system studied?
- How are climate experiments, observations, and models interconnected?

# Climate

## How do we define climate?

- **Climate** is the pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods.
- Climate can be contrasted to **weather**, which is the conditions of these variables presently or over short periods.
- **Climate also describes the variability of weather events**, e.g. the probability of a major rainfall event occurring in July in San Francisco, or variations in temperature that typically occur in January in Chicago.

# Climate vs Weather

## WEATHER

Tells you what to wear each day



## CLIMATE

Tells you what types of clothes to have in your closet



**Weather is what you get**

**Climate is what you expect**



NOAA National Centers for Environmental Information

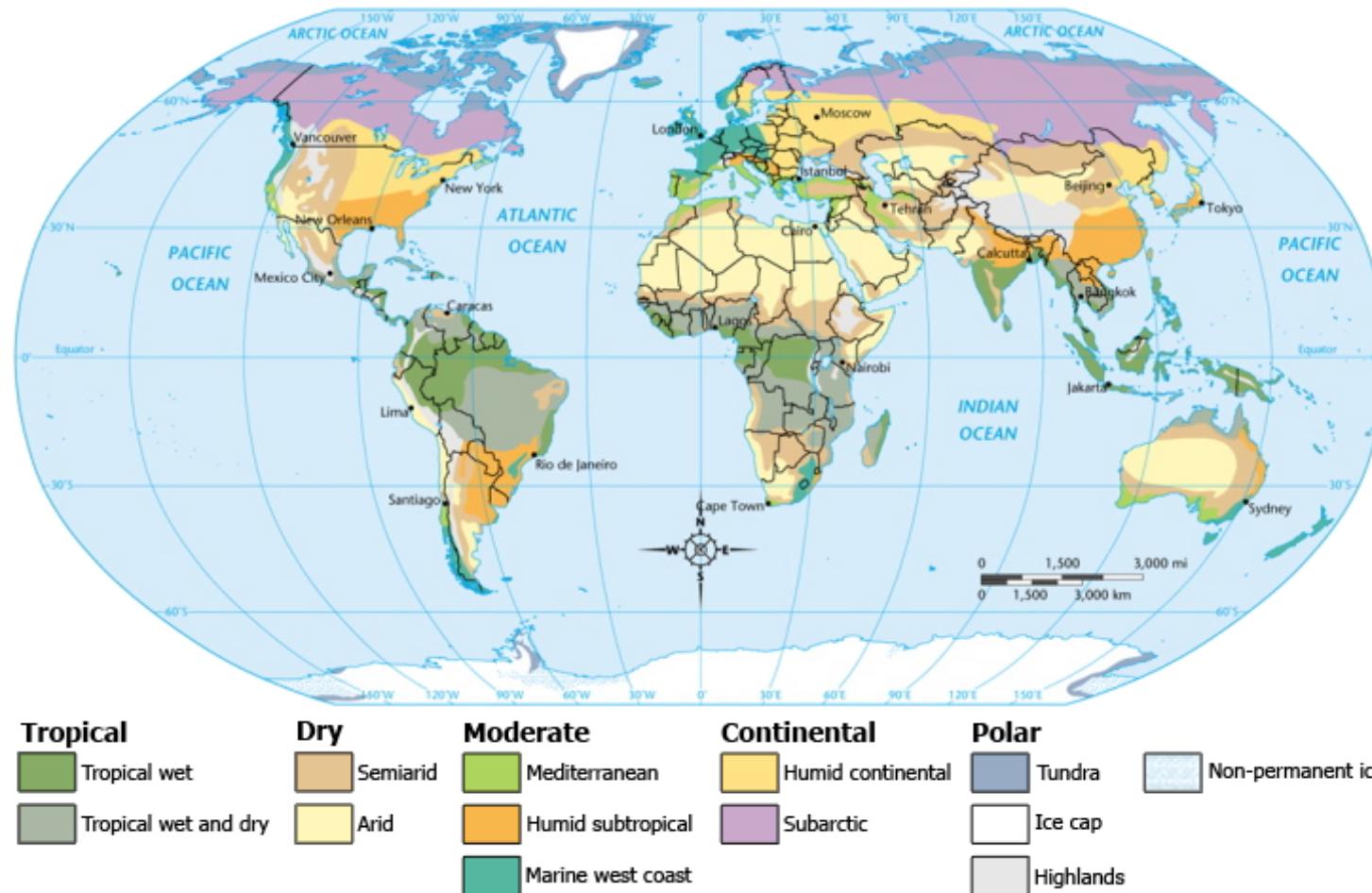
<https://www.ncei.noaa.gov/news/weather-vs-climate>

# Climate Dynamics

## What is Climate Dynamics?

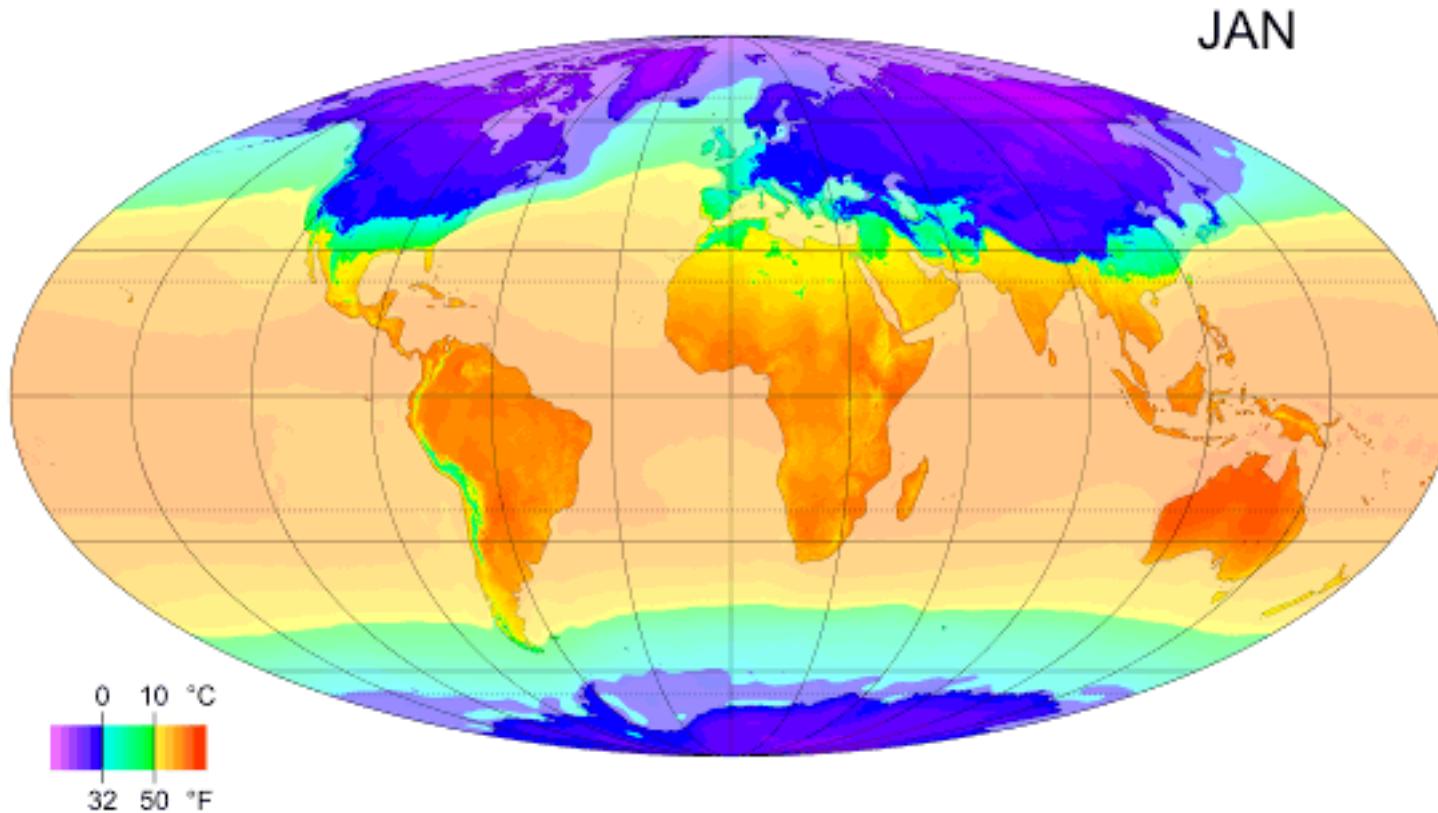
- The field of **climate dynamics** studies the processes that control the Earth system and how it evolves.
- Climate dynamics incorporates the study of **atmospheric** and **oceanic** processes as they occur over long time periods. It also includes the study of interactions between the atmosphere, the oceans, the land surface, the cryosphere, and the biosphere.

# The Earth System: Climate Zones



# The Earth System: Temperatures

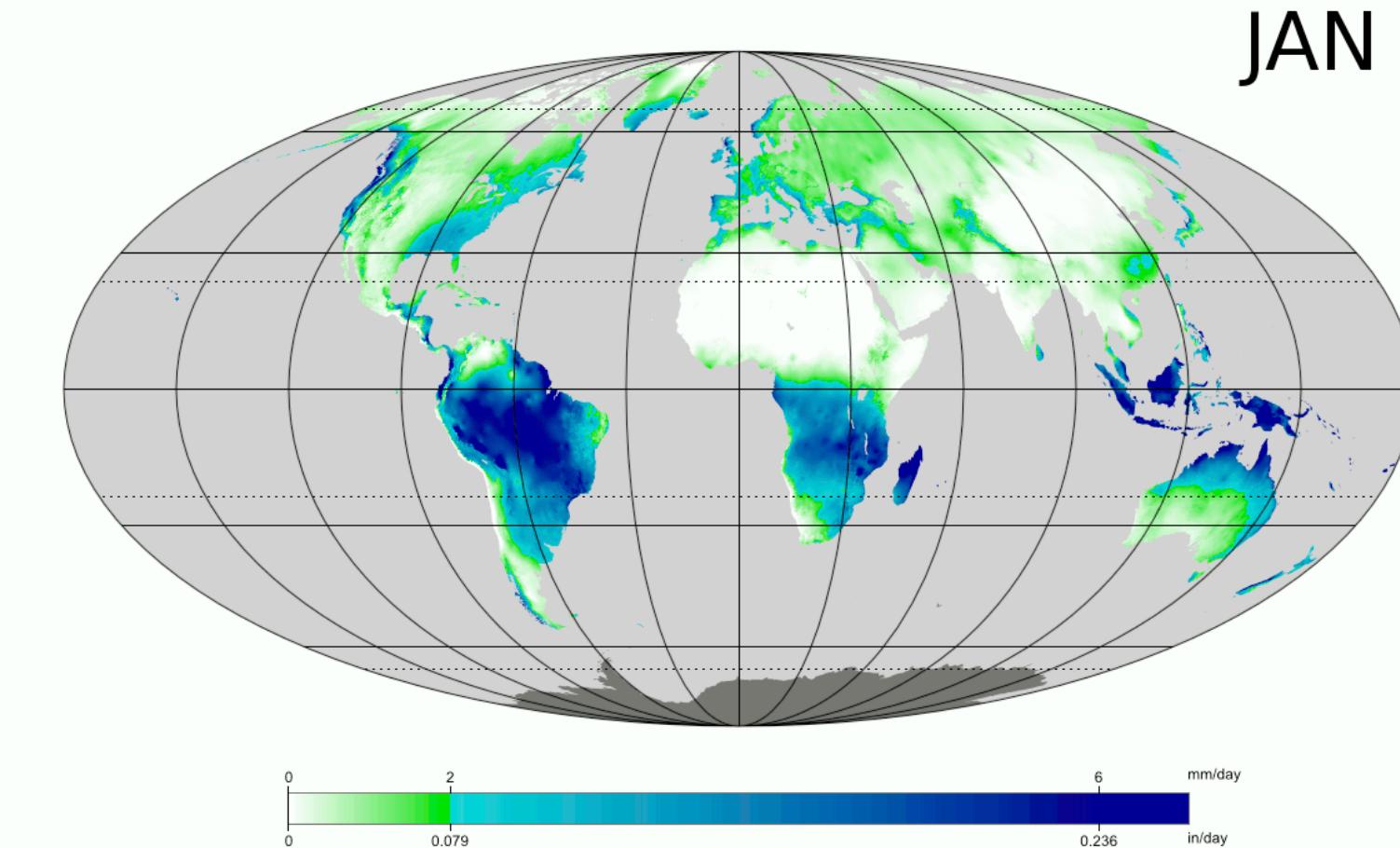
Monthly mean surface temperatures



**Author:** PZmaps, Wikimedia Commons, Feb 2009

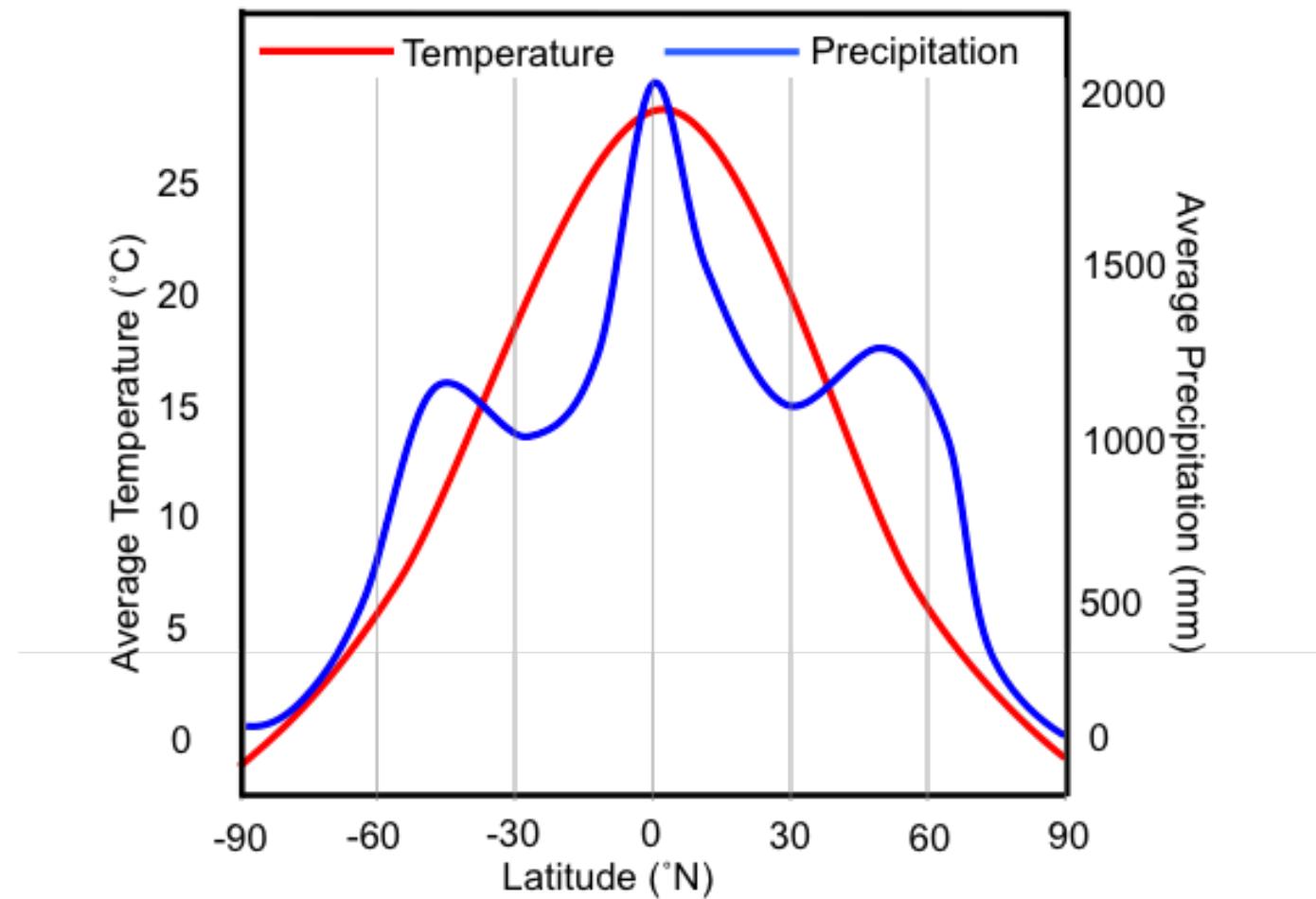
# The Earth System: Precipitation

Monthly mean precipitation



**Author:** PZmaps, Wikimedia Commons, Mar 2009

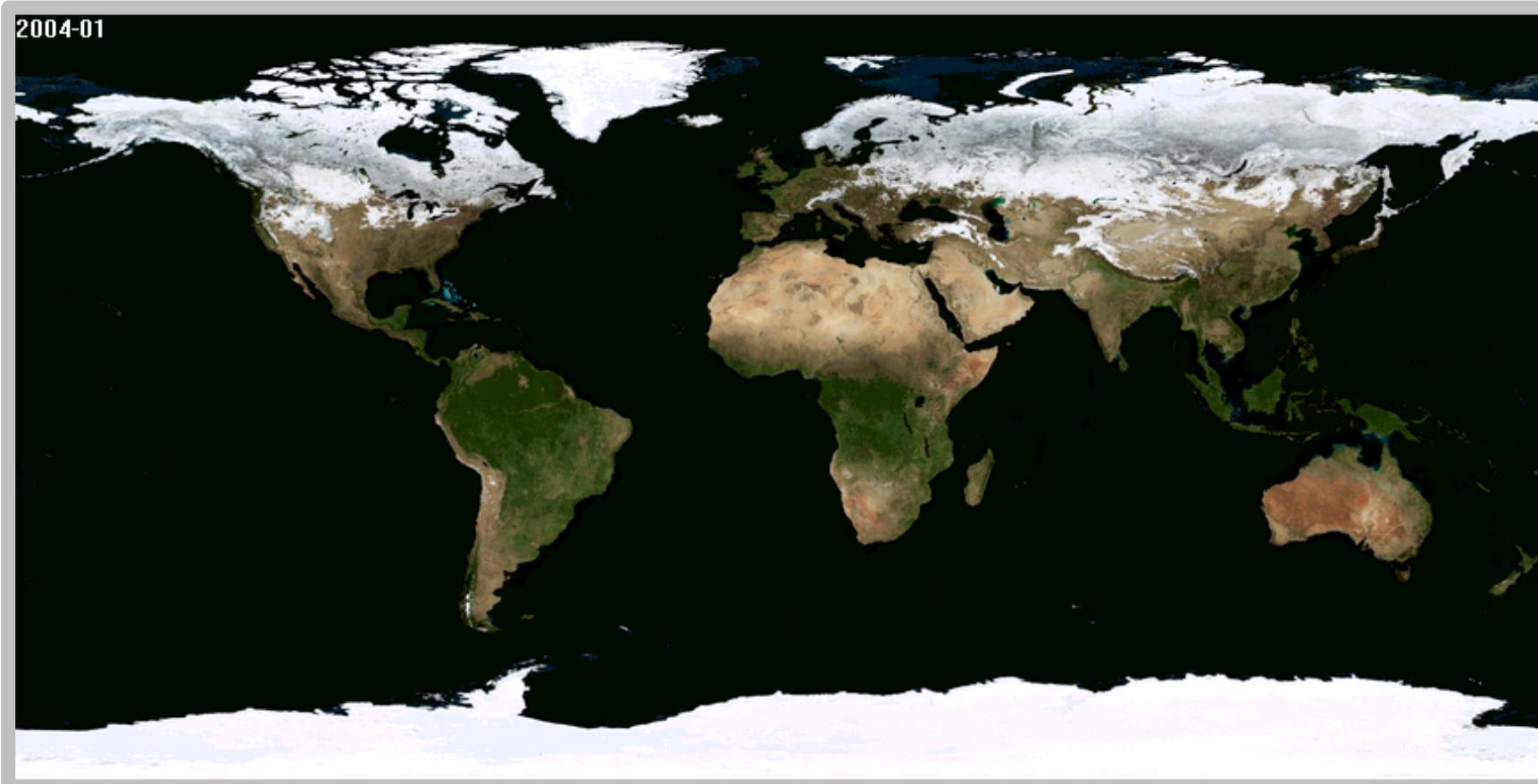
# Temperature and Precipitation



[https://commons.wikimedia.org/wiki/File:Relationship\\_between\\_latitude\\_vs.\\_temperature\\_and\\_precipitation.png](https://commons.wikimedia.org/wiki/File:Relationship_between_latitude_vs._temperature_and_precipitation.png)

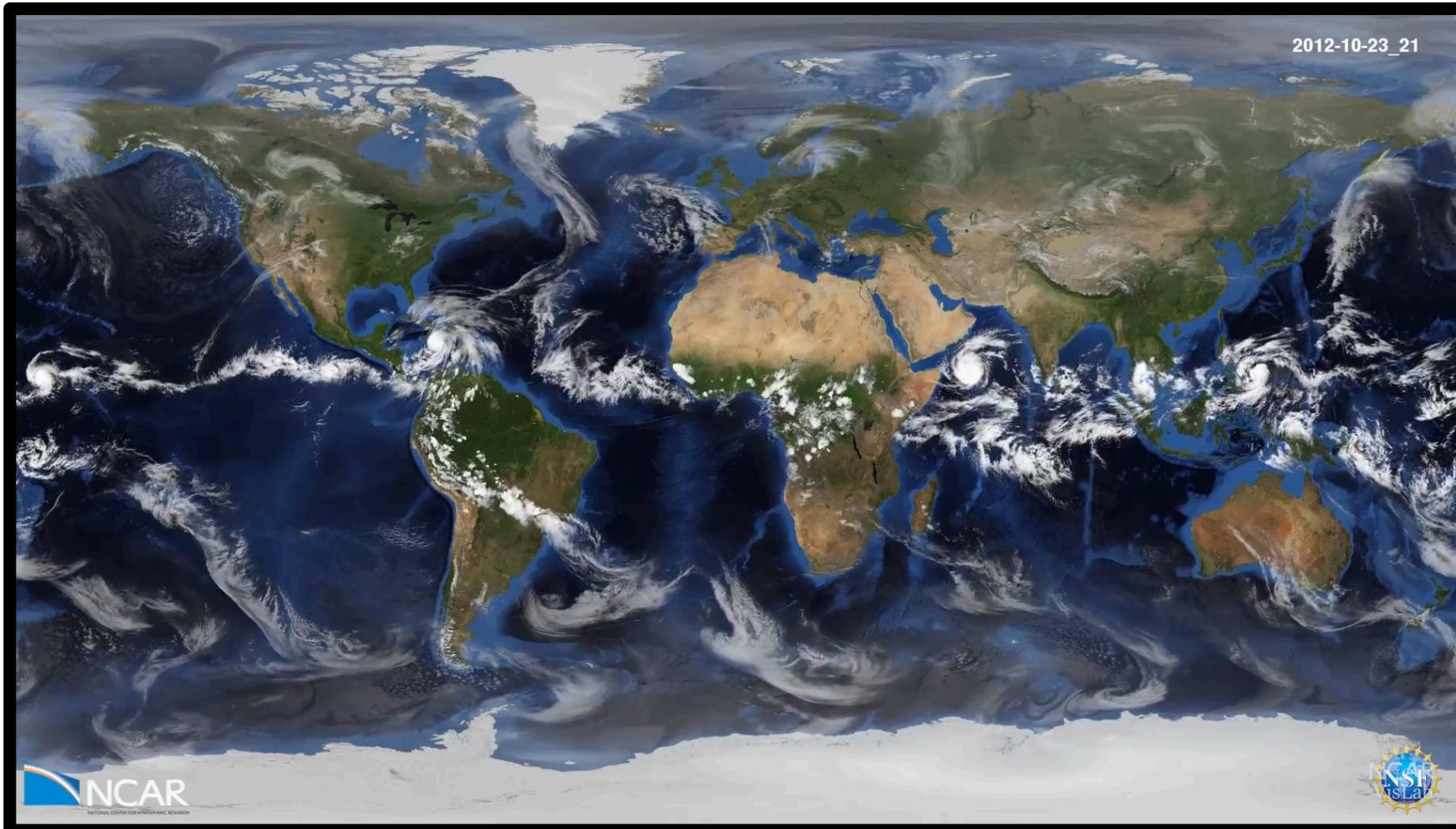
# The Earth System: The Land Surface

Satellite Imagery (clouds digitally removed)



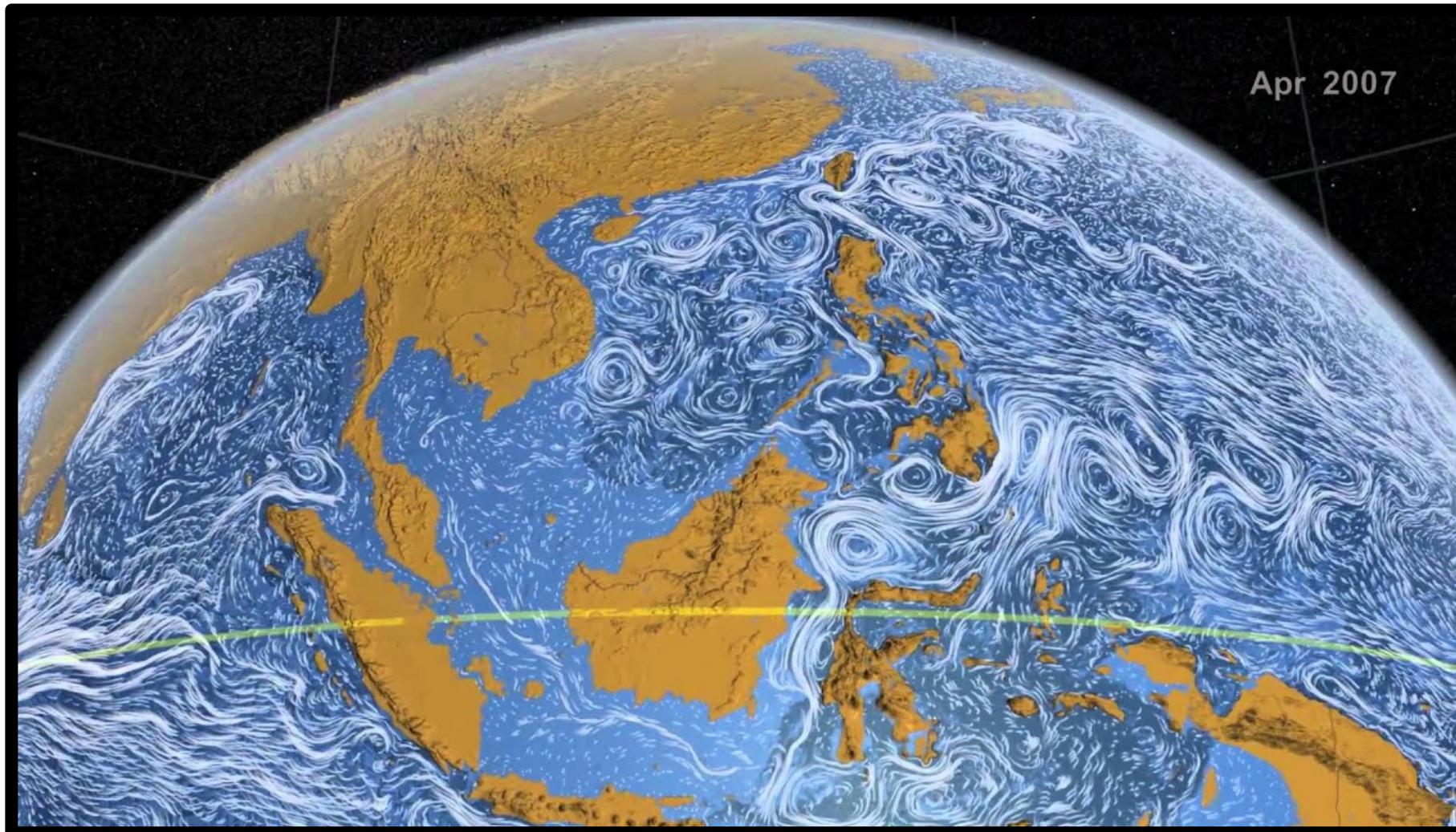
**Author:** NASA images by Reto Stöckli, 2004

# The Earth System: Atmospheric Dynamics



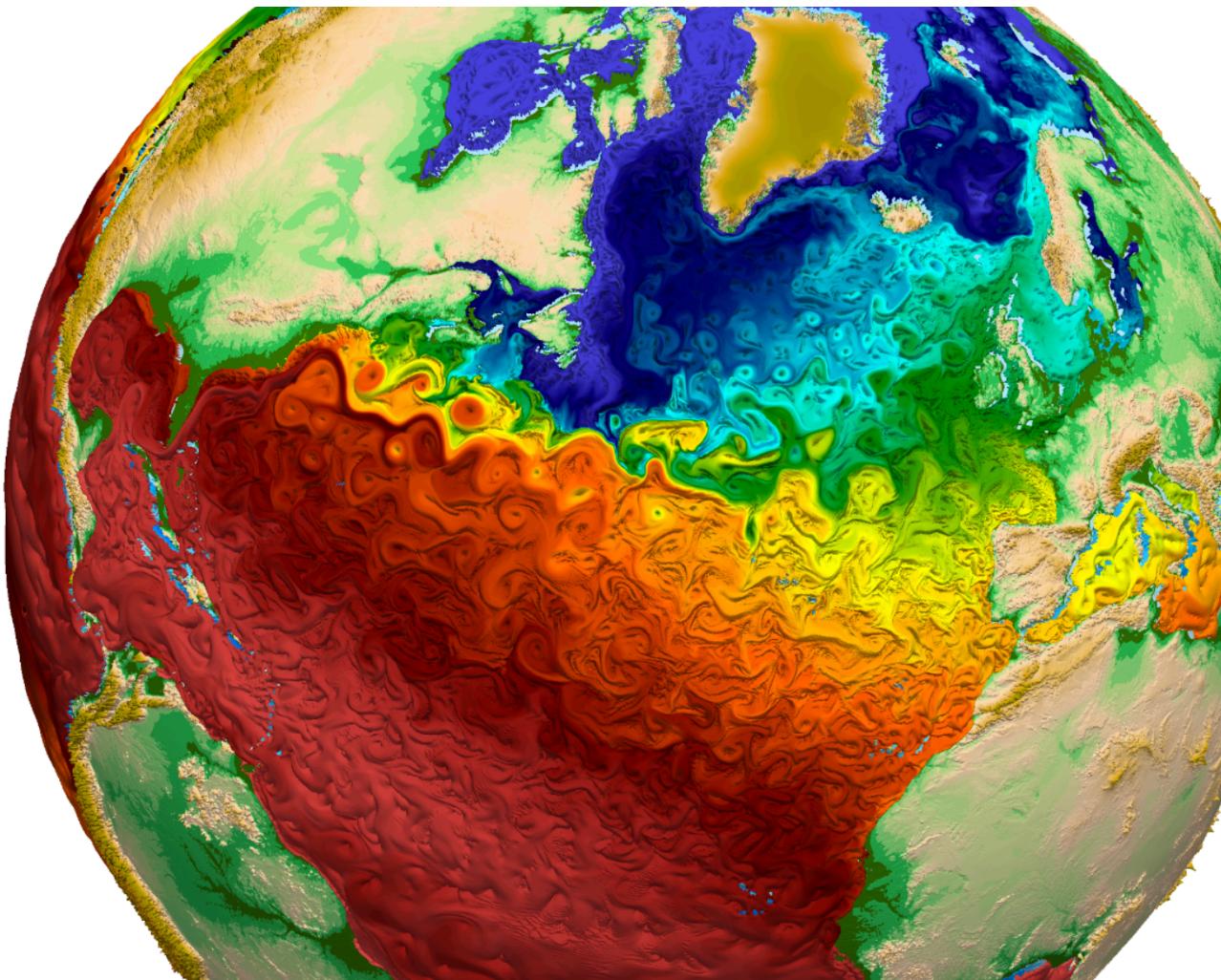
NCAR Simulated Global Weather <https://www.youtube.com/watch?v=UmiB4Ynd9AI>

# The Earth System: Ocean Dynamics



NASA Perpetual Ocean <https://www.youtube.com/watch?v=CCmTY0PKGDs>

# The Earth System: Ocean Dynamics



US DOE E3SM (left) Simulated ocean current speed and (right) concurrent ocean temperature

# More Videos

**Global Storm-Resolving and Large-Domain Large-Eddy Simulations with ICON LEM**

<https://www.youtube.com/watch?v=ji4nno-fsvw>

**NASA Simulated clouds and aerosol**

[https://www.youtube.com/watch?v=Hv-t\\_1ofrhU](https://www.youtube.com/watch?v=Hv-t_1ofrhU)

**NASA Global Cloud Modeling with GEOS-5**

<https://www.youtube.com/watch?v=mlvLX7YvI88>

**NCAR/DOE FV CAM5 Simulation at 0.25 degree global grid spacing**

<https://www.youtube.com/watch?v=cNyftYdjt-Q>

**US DOE Simulation of the Global Ocean with E3SM**

[https://www.youtube.com/watch?v=RN\\_dsLIIIAI](https://www.youtube.com/watch?v=RN_dsLIIIAI)

# The Earth System

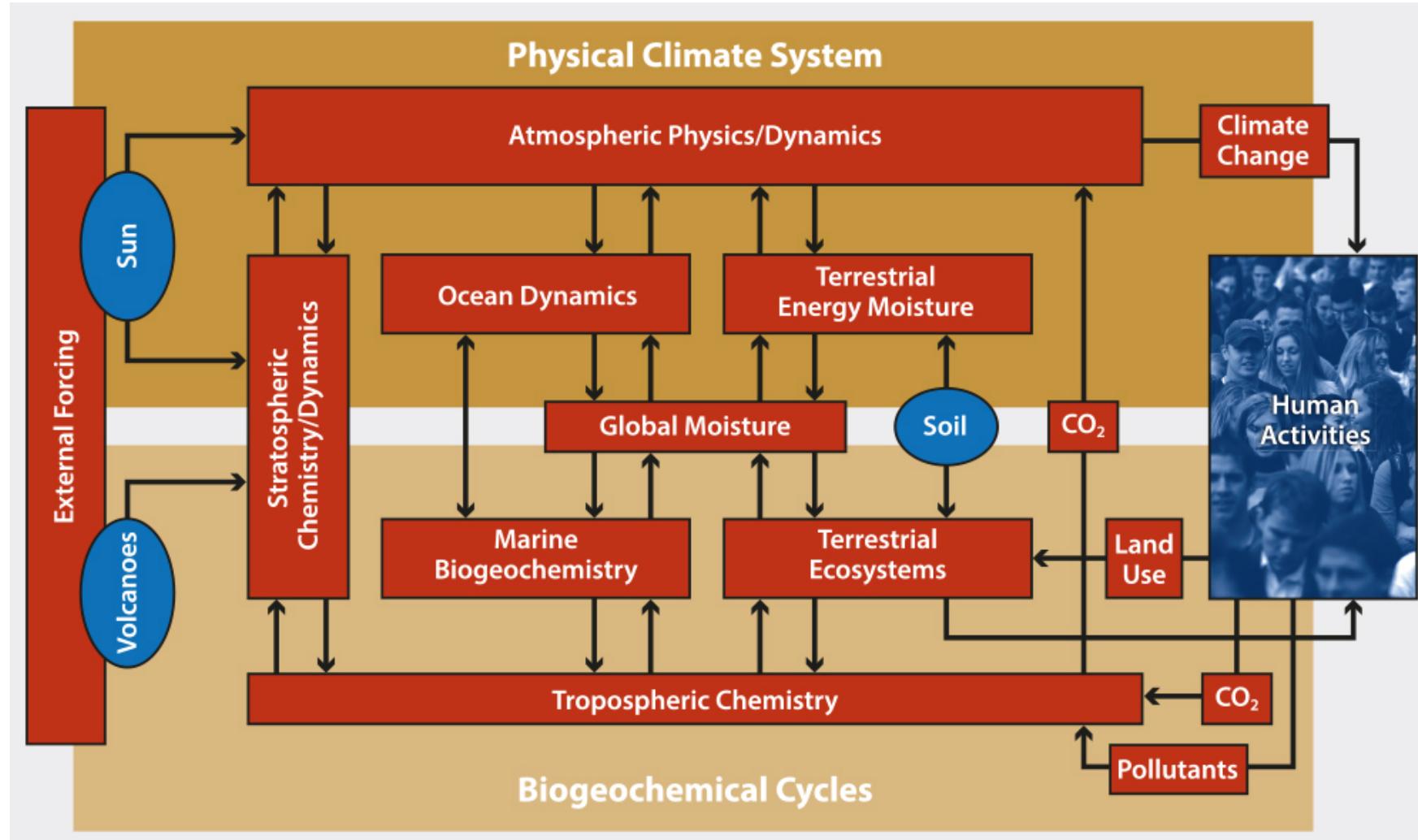
What are the components of the Earth system?

- **Atmosphere**
- **Hydrosphere (Oceans and Water)**
- **Land and Land Surface**
- **Cryosphere (Sea and Land Ice)**
- **Biosphere**

- When talking about the **coupled human-Earth system** it is also typical to include **humans (the anthropogenic component)**

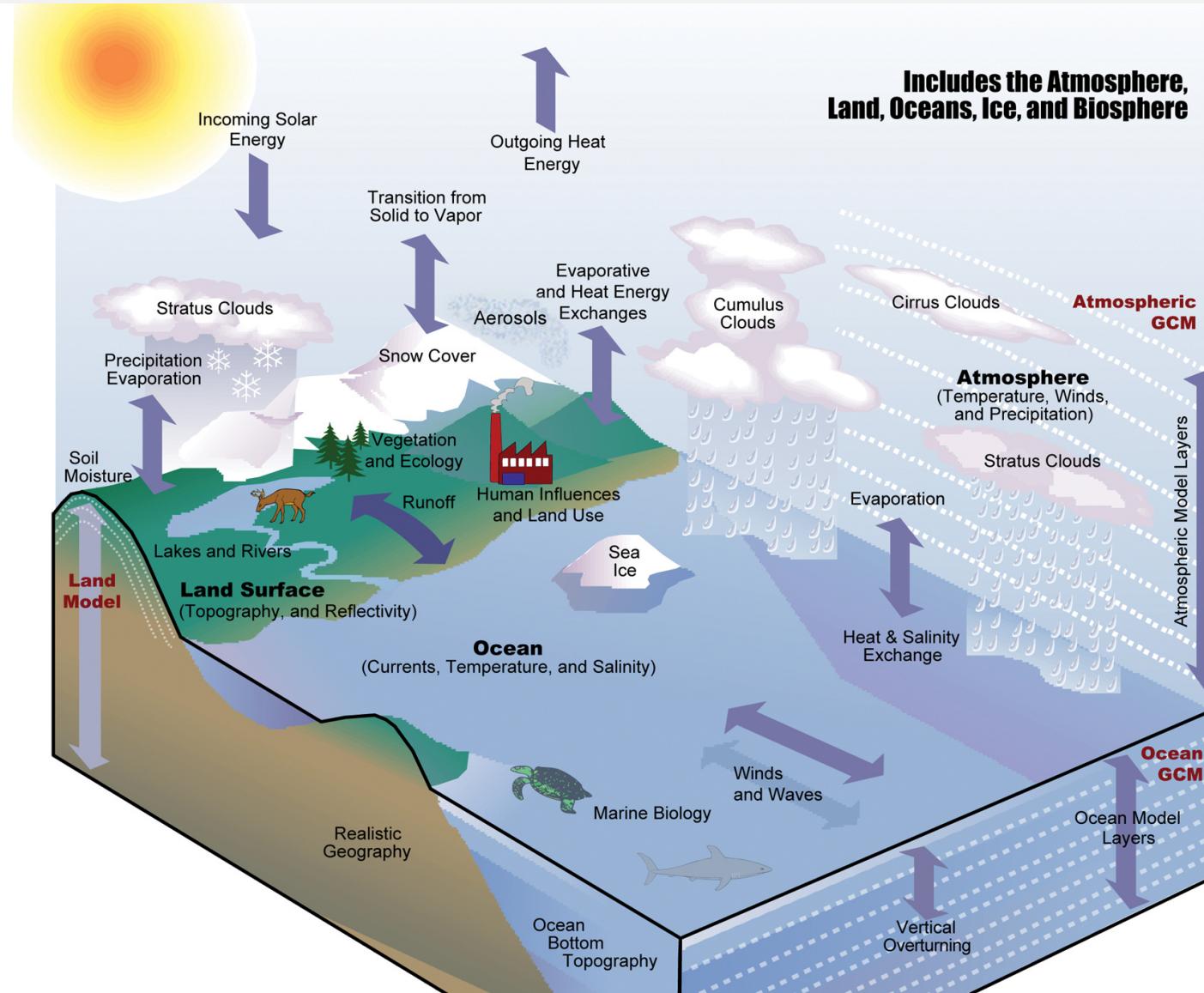
# Bretherton Diagram (simplified)



The Bretherton diagram (NASA 1986) is a famous visualization of the interconnectedness of the Earth system.

# Processes and Features of the Earth System

...as represented in global Earth system models



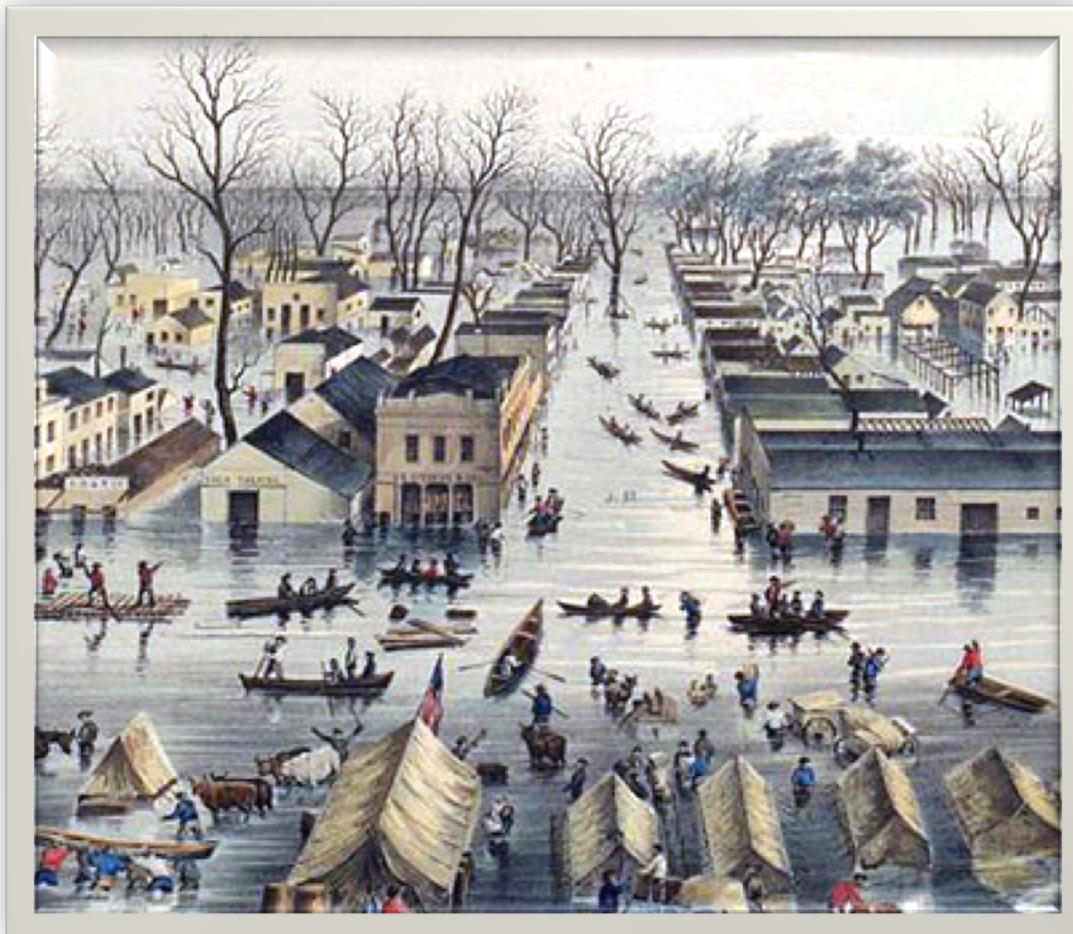
# Understanding the Earth System

## Why is an understanding of the Earth system important?

- Agriculture
- Water availability (Droughts / Floods)
- Ecosystem maintenance
- Weather variability
- Extreme events
  - Tropical cyclones
  - Atmospheric blocking
  - Heat waves / cold spells
  - Atmospheric rivers
  - Extratropical cyclones
  - Wildfires
- Sustainability
- Energy Usage and Planning
- Air Quality
- Sea Level Rise

**Claim:** An understanding of regional and global climate is one of the most important factors for long-term social and economic planning.

# Extreme Events

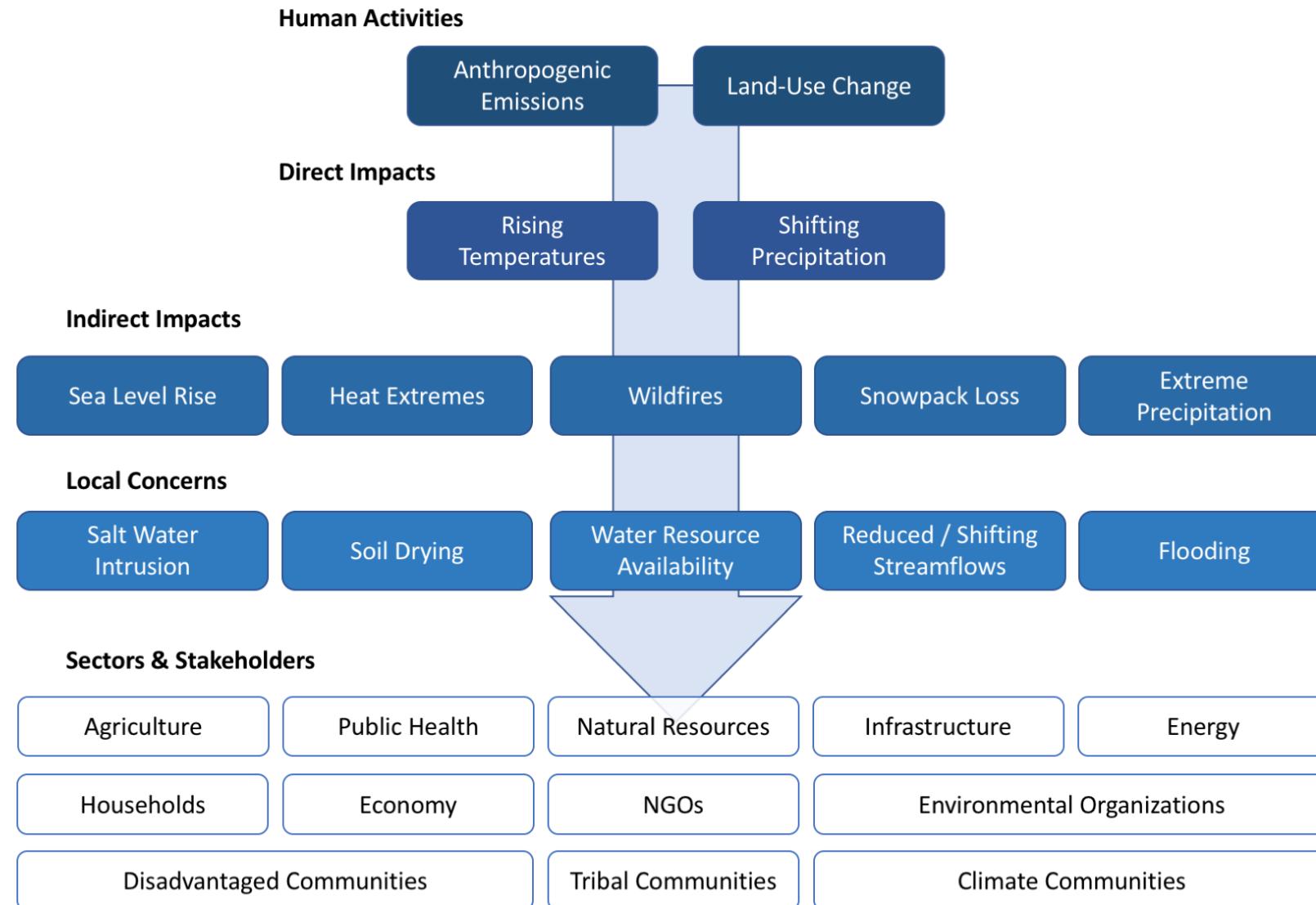


**Figure:** A depiction of the 1862 floods in Sacramento, California Old Town.

**“Those who do not learn history are doomed to repeat it.”**

**“Those who do not study climate are doomed to be unprepared for changing and extreme weather.”**

# Understanding the Earth System: Climate Change



# Understanding the Earth System: Sea Level Rise



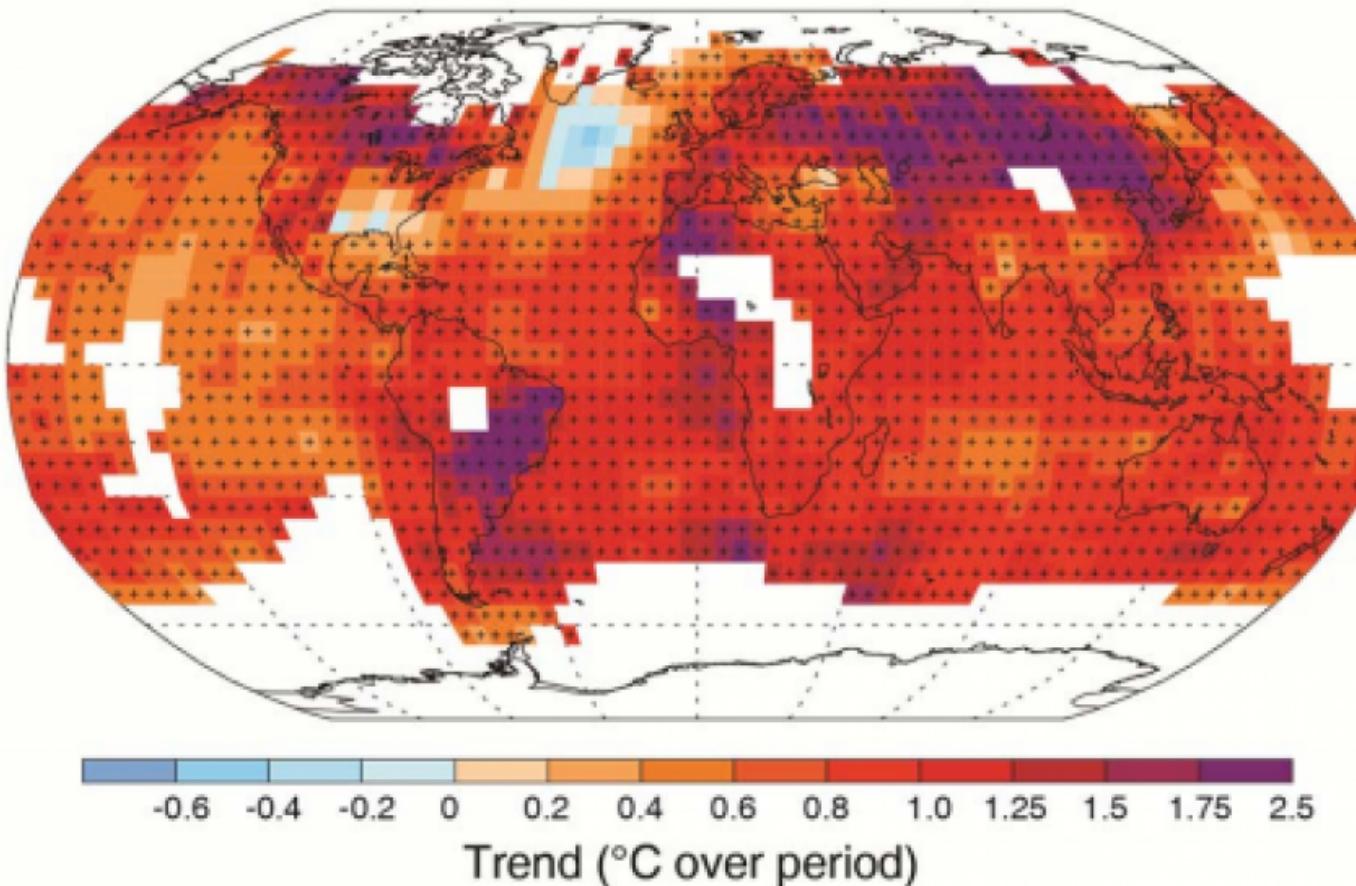
**Figure:** A map of the San Francisco Bay Area and susceptibility to sea level rise (Weiss and Overpeck 2011).

**Dark red:** Flooded areas under 3 feet of sea level rise.

**Yellow:** Flooded areas under 18 feet of sea level rise.

# Climate Change and Rising Temperatures

Observed change in average surface temperature 1901–2012



**Figure:** Global warming trends are indisputable and expected to continue under increases in atmospheric greenhouse gas concentrations.

# Understanding the Earth System

How is the Earth system studied and understood?

**Three key aspects:** Experiments, Observations, Models

## Climate Experiments

- Scientific procedures undertaken to test a hypothesis about the climate system.
- Purposeful changes are made to the input variables and outputs observed and quantified.

## Climate Observations

- Measurements taken of the climate system in situ or with remote sensing (such as from satellites).
- Datasets that are built upon a global and continuously growing observational network.

# Understanding the Earth System

How is the Earth system studied and understood?

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## Climate Experiments

- Understanding the response of atmospheric gases to radiation in a laboratory
- Investigating the effect of organic and inorganic fertilizer on carbon storage

## Climate Observations

- Atmospheric carbon dioxide concentration (time series from monitoring stations)
- Mountain snow depth measurements (satellites, flyovers and pillow stations)
- Surface temperature and precipitation (satellites, weather stations)

# Understanding the Earth System

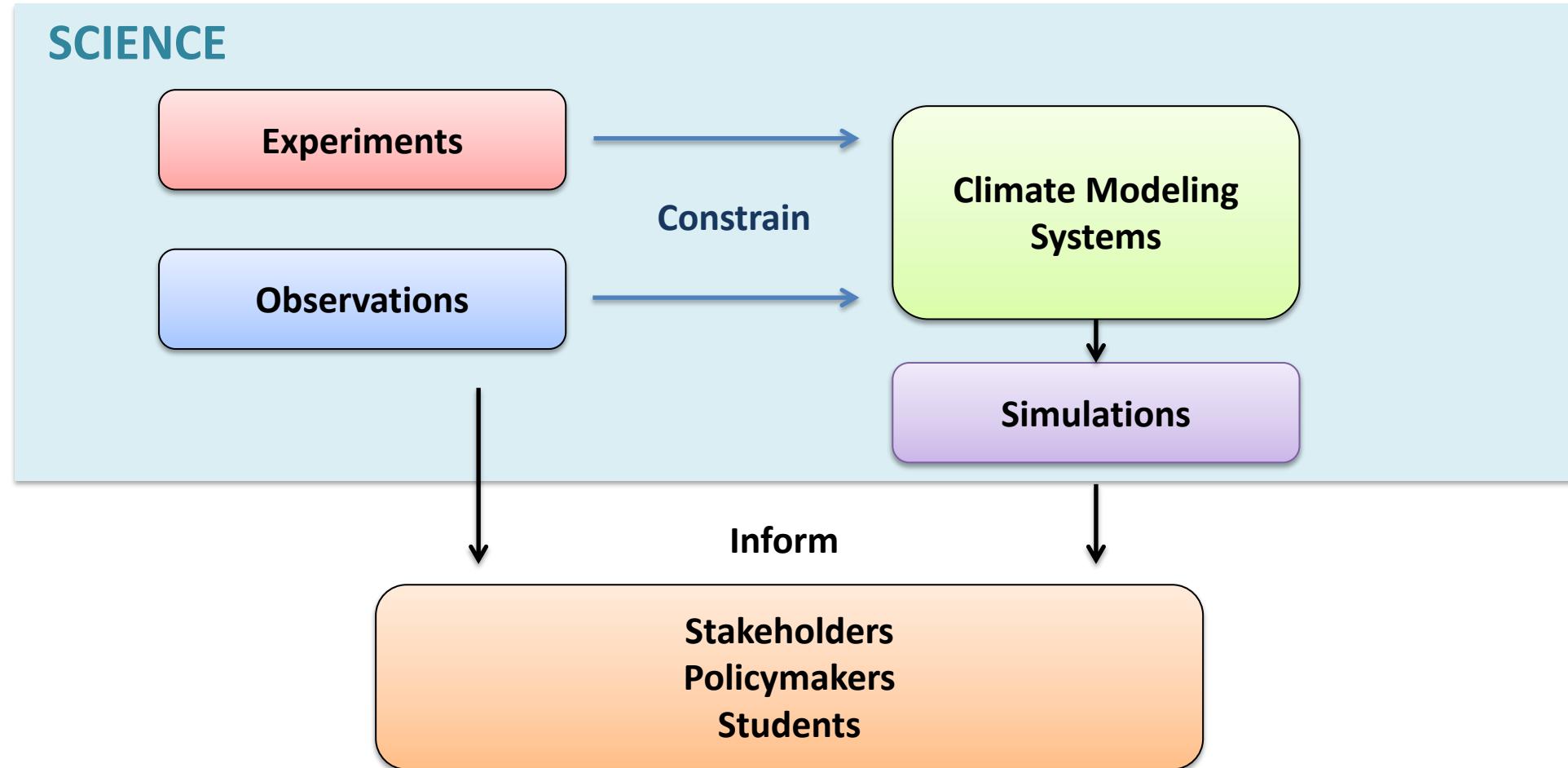
How is the Earth system studied and understood?

**Three key aspects:** Experiments, Observations, Models

## Climate Models

- **Mathematical representations** of the Earth system built using fundamental laws of physics (conservation of mass, conservation of energy, etc.)
- Vary from very simple “back of the envelope” calculations to massive multi-million-line programs run on massive supercomputing systems.
- **Goal:** To understand interdependency and variation in the Earth system, and as a virtual laboratory for experimenting on the Earth.

# Understanding the Earth System



# Where Next?

**Lecture 2:** Energy in the Earth system

**Lecture 3:** The structure of the Earth's atmosphere

**Lecture 4:** Atmospheric stability and convection

**Lecture 5:** The general circulation of the Earth's atmosphere

**Lecture 6:** Subgeographic flow and the boundary layer

**Lecture 7:** Global structure of the ocean

**Lecture 8:** The oceanic circulation

**Lecture 9:** The wind-driven circulation

**Lecture 10:** Oceanic convection and the thermohaline circulation

**Lecture 11:** Climate oscillations

**Lecture 12:** Paleoclimate and climate change

# ATM 241 Climate Dynamics

## Lecture 1

### Introduction to Climate Dynamics

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Thank You!

