ATMS 521: Climate Analysis, Variability, and Prediction -- Course Introduction

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Outline

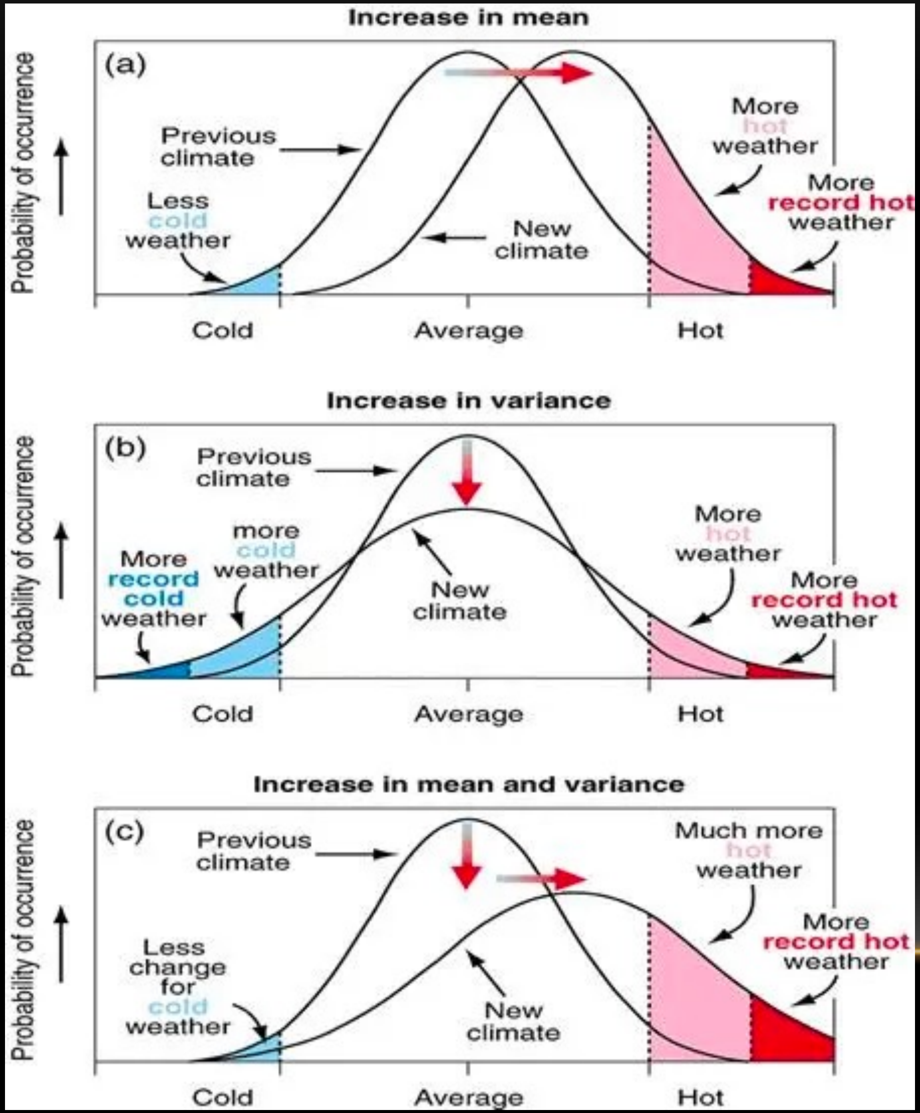
- Climate vs. weather
- Natural and human-induced climate variations
- Climate variability and prediction on different time scales
- Basis of climate prediction
- Applications of climate prediction

Climate vs. Weather

- Weather: the fluctuating state of the atmosphere around us, characterized by the temperature, wind, precipitation, clouds and other weather elements
  - associated with rapidly evolving weather systems, such as midlatitude cyclones, etc.
  - limited deterministic predictability: individual weather systems are not predictable beyond two weeks
- Climate: the average weather in terms of the mean and its variability over a certain time-span and a certain area (i.e., a statistical description of weather)
  - Varies from region to region
  - Varies in time (from subseasonal, seasonal, interannual, decadal to much longer time scales)
- We will focus on the temporal variations of climate and use “climate variability” and “climate variations” exchangeably.
- Climate change: systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer (AMS Glossary)

Baede et al. (2018)

Climate vs. Extreme Weather: An example



Heatwaves in a changing climate

Increase in mean

Increase in variance

Increase in mean and variance

- Climate change can be associated with changes the "mean" or/and "variances" (related to extreme weather).
- Climate and weather are "connected".

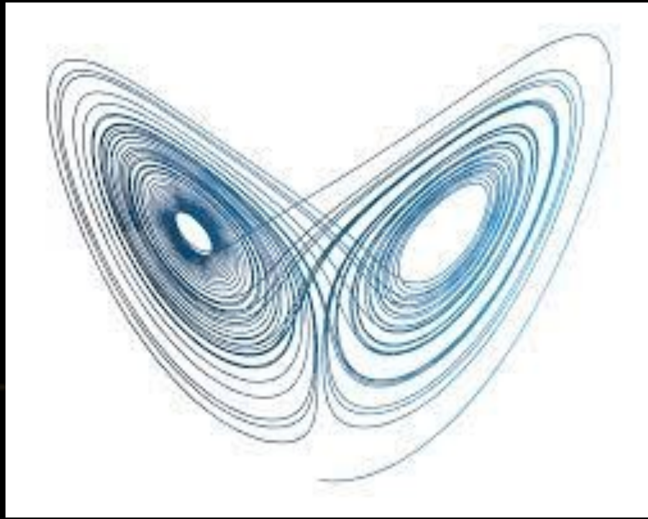
From https://climatesight.org/2012/04/03/climate-change-and-heat-waves/

What contributes to climate variations?

- Natural Climate Variations
  - Internal variability of the climate system
  - Natural external forcing
- Human-induced Climate Variations

Natural Climate Variations: Internal variability

- Internal variability:
  - Due to the nonlinear interactions and different response times of the climate components, the climate components are never in equilibrium but are constantly evolving.
  - Internal variability exists even in the absence of external forcings, such as the North Atlantic Oscillation (NAO), the Madden-Julian Oscillation (MJO), and the Pacific-North American pattern (PNA).



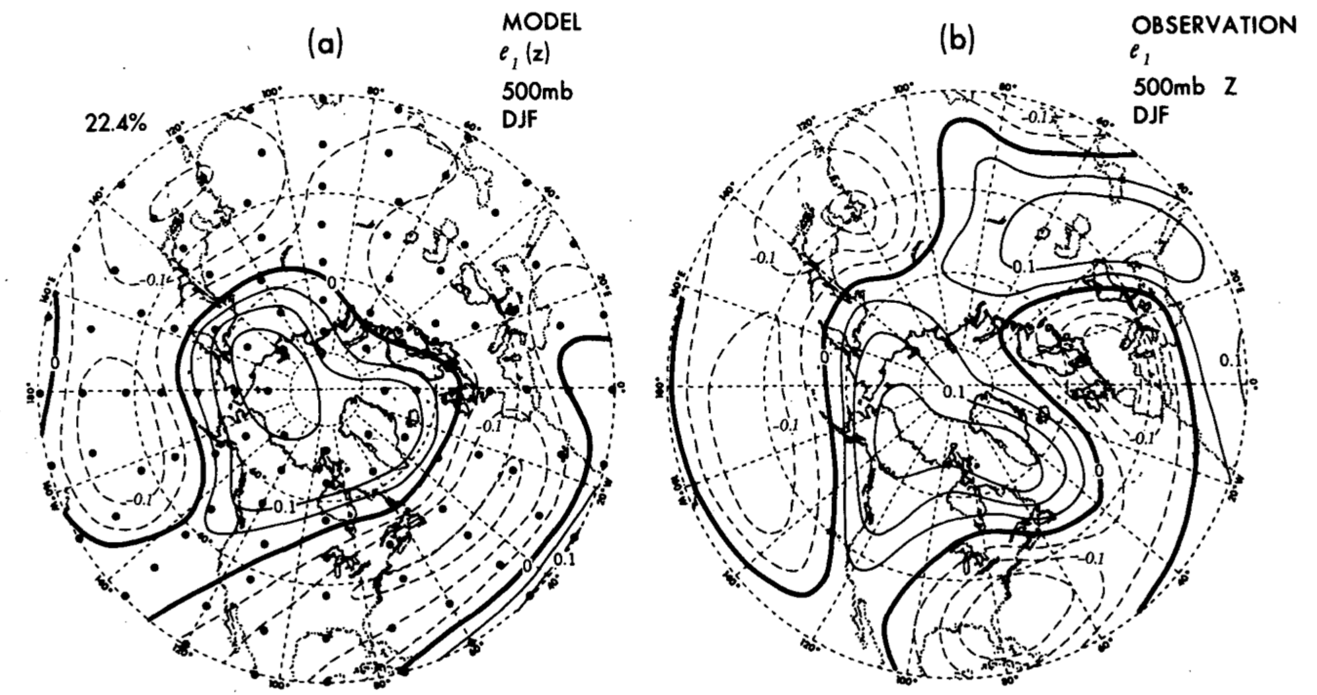


FIG. 5. Distributions of the first eigenvectors of normalized monthly mean 500 mb height field for winter, for (a) model and (b) observations (see Appendix). The solid dots in (a) indicate the grid points used in the eigenvector analysis.

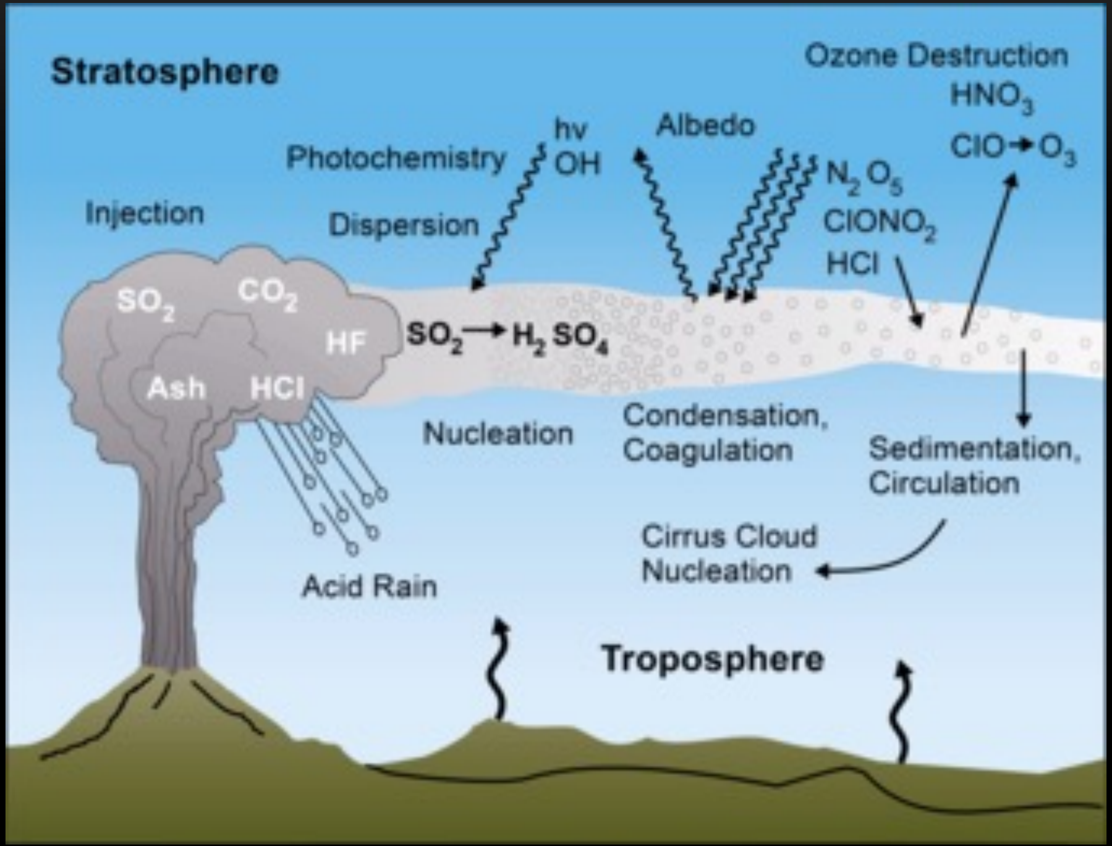
- The model has 9 vertical levels with a truncation at 15 wavenumbers. It is driven by the annual cycle of insolation, SST and ozone concentration that do not vary from year to year (From Lau 1981 © American Meteorological Society. Used with permission)
- The model produces a dominant mode of climate variability similar to the observations.

See https://en.wikipedia.org/wiki/Lorenz_system#/media/File:A_Trajectory_Through_Phase_Space_in_a_Lorenz_Attractor.gif

Natural Climate Variations: External forcings

- External forcings:
  - such as the solar radiation or the large amounts of aerosols ejected by volcanic eruption into the atmosphere, may cause variations in the radiative forcing and thus climate variations

See Tonga eruption:
https://www.youtube.com/watch?app=desktop&v=zoMRwyNhqJ4



https://www.usgs.gov/programs/VHP/volcanoes-can-affect-climate

- Volcanic gases like sulfur dioxide can cause global cooling, while volcanic carbon dioxide has the potential to promote global warming.
- The eruption of Mount Pinatubo in 1991 cooled the Earth's surface for three years following the eruption, by as much as 1.3 degrees F at the height of the impact.

Human-induced Climate Variations

- Anthropogenic perturbations of the atmospheric composition
  - Increasing concentration of greenhouse gases: The amount of CO2, for example, has increased by more than 30% since pre-industrial times.
  - Anthropogenic aerosols: such as black carbon, sulfate aerosols
- Land-use change: a change in the use or management of land
  - such as changes in agriculture and irrigation, deforestation, reforestation, or urbanization.
  - Land-use change results in changing the physical and biological properties of the land surface and thus the climate system.

*Climate feedback (such as the water vapor feedback) may amply climate change induced by anthropogenic forcing.

Baede et al. (2018)

Different Climate Time Scales

- We will examine variations and predictions of climate on different time scales.
  - Subseasonal prediction – there are different definitions of the subseasonal time scale. We define subseasonal as the time scale from 2 weeks to 3 months
  - Seasonal: 3-12 months
  - Interannual prediction – A prediction from one to several years
  - Decadal prediction – A prediction over the next 10 years
  - *You may also see:*
    - *extended-range forecast: a forecast beyond 10 days and up to 30 days*
    - *long-range forecast: a forecast from 30 days up to 1 year*
    - *subseasonal to seasonal* (S2S): covers from 2 weeks to 12 months and includes the seasonal time scale.

Baede et al. (2018)

Different Climate Time Scales (cont'd)

- Different "drivers" are dominant on different time scales
- Also, Different climate components have different response times
  - Troposphere: typically from days to weeks
  - Stratosphere: typically a few months.
  - Oceans: typically decades but up to centuries or millennia
  - Biosphere: the response time scale varies widely. It may respond fast to climate anomalies such as droughts but very slowly to some imposed changes.

Basis of Climate Prediction

- *If we can not predict how high the temperature will be at 9AM in three weeks, how can we predict the climate conditions skillfully three months later?*
- The basis of climate prediction:
  - Probabilistic vs. deterministic
  - Sources of climate predictability exist for climate prediction: include natural modes of variability (e.g., ENSO, MJO, QBO), slowly varying climate components (e.g., sea ice, soil moisture, and ocean conditions), and external forcing (e.g., aerosols)
  - Windows of high predictability: Sources of predictability exist on different time scales, which are associated with forecasts of opportunity

Application of Climate Prediction/Projection: agriculture

- Climate has a profound influence on crop growth, development and yields; on the incidence of pests and diseases; on water needs; and on fertilizer requirements

Shall we plant soybean or corn?

Figures from usda.gov

Figure sources:
https://www.usda.gov/media/blog/2019/07/29/corn-americas-largest-crop-2019
https://ipad.fas.usda.gov/photo_gallery/pg_details.aspx?regionid=che&FileName=79&PhotoTitle=Soybean

Application of Climate Prediction/Projection: water management

Should we release water or not?

How to build a cost-effective and safe dam?

https://public.wmo.int/en/bulletin/managing-water-resources-climate-information

Application of Climate Prediction/Projection: energy management

- Sub-seasonal forecasts can help a trader identify deviations, adjust their expectations accordingly and therefore improve the hedging strategy (Orlov et al. 2020; Nature Energy).
- Skillful temperature prediction can contribute to skillful prediction of electricity demand and reduce costs for the electricity-generation industry (Teisberg et al. 2005, BAMS)
- Estimations of the interannual variability of renewable energy resources are important for successful assessment and management of renewable energy installations (Jerez et al. 2013)

General Approaches of Climate Prediction

- Statistical (or empirical) forecasting
  - makes forecasts by using observational data of current and past states of the weather or climate to fit (or train) a statistical model
  - Examples: regression models; analog forecasts; machine learning
- Numerical climate prediction with dynamical models
  - uses mathematical (dynamical) models of the atmosphere or Earth system to predict the weather or the climate
- Hybrid prediction
  - Combines dynamical prediction with statistical methods, such as statistical downscaling

Forecast verification

- Forecast verification (or evaluation) is a critical aspect of the forecast improvement process and is also fundamental to informing forecast users regarding their reliability, skill, accuracy, and other features in order to aid optimal use.
  - Scientific: To inform forecast system development and improvement
  - Administrative: To monitor forecast performance over time or justify a new supercomputer acquisition
  - User-oriented: To help users make better decisions

Caio et al. 2018

Course Topics

- Module 1-Overview of Earth’s Climate System
- Module 2-Overview of Climate Predictability, Prediction and Verification
- Module 3-S2S Variability and Prediction
- Module 4-Interannual Variability and Prediction
- Module 5-Decadal Variability and Prediction, Climate Change
- Module 6-Climate Models and Downscaling

References

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- Caio et al., 2018: Forecast verification for S2S time scales, http://s2sprediction.net/resources/documents/sub-projects/Ch17-S2S-forecast-verification-chapter-S2S-wiki.pdf