Module 2: Overview of Climate Predictability, Prediction and Verification Methods

Module Outline

- The Concept of Predictability
- Sources of Predictability
- Observations
- Statistical Models
- Dynamical Models
- Hybrid Approaches
- Data Assimilation
- Assessment of Prediction Skill
- Statistical Analysis Methods

Building Blocks of Climate Prediction

Concept of Predictability

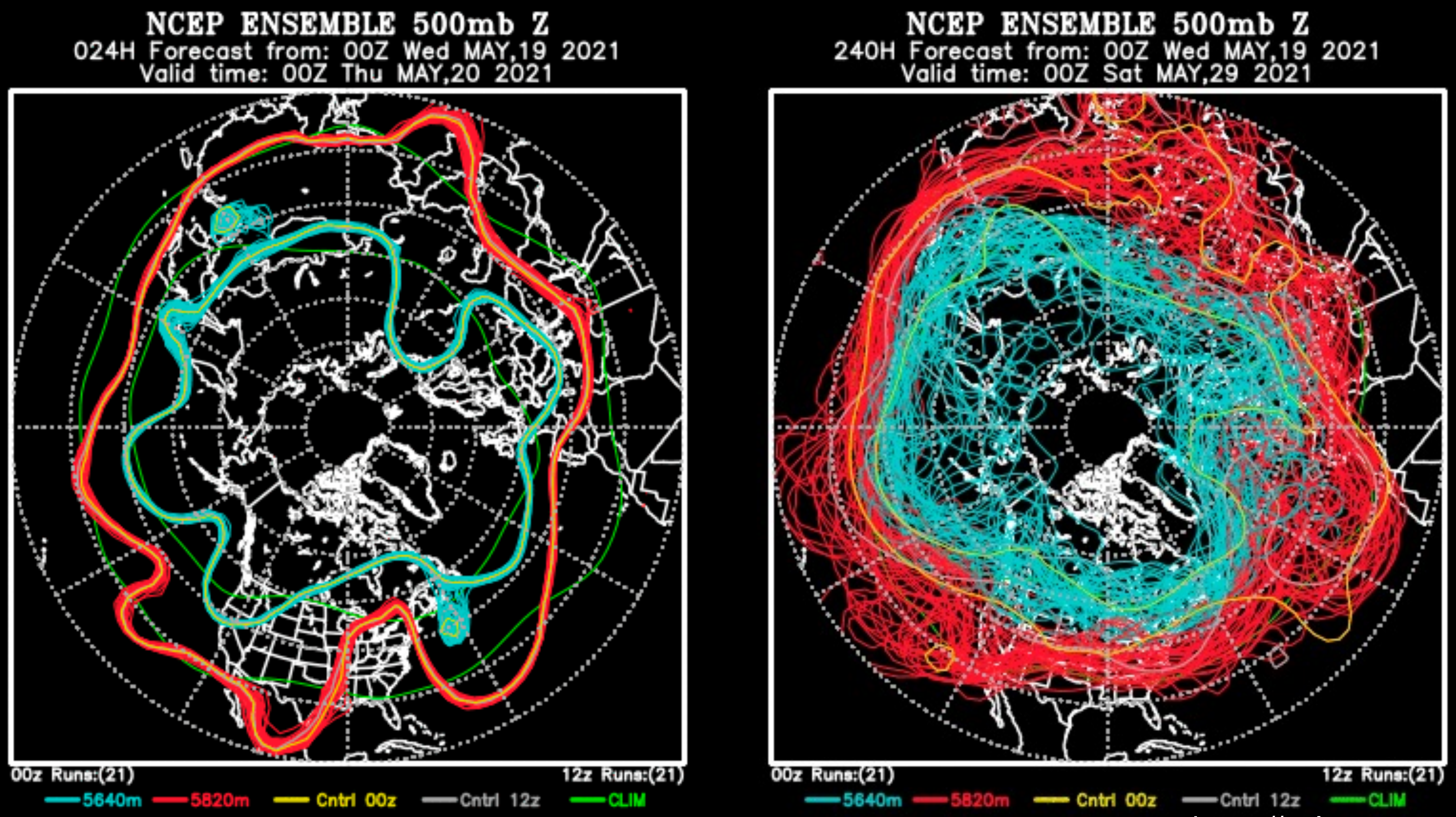
- Lorenz in 1969 defined predictability as “a limit to the accuracy with which forecasting is possible” (Lorenz, 1969a).
- Two types of predictability (Lorenz, 2006)
  - intrinsic predictability—the extent to which the prediction is possible if an optimum procedure is used
  - practical predictability—the extent to which we ourselves are able to predict by the best-known procedures, either currently or in the foreseeable future

What affects practical predictability?

Practical predictability depends on

1. the physical system under investigation
   - For example, tropical cyclones are more predictable than tornados
2. the available observations and data assimilation
   - Weather forecasts can be regarded as an “initial value” problem, and skillful weather forecasts require accurate initial conditions
3. the dynamical prediction models
   - Model biases often affect the forecast skill

The Butterfly effect: NCEP Ensemble Forecasts (500-mb Geopotential Height)



https://psl.noaa.gov/map/images/ens/ens.html#nh

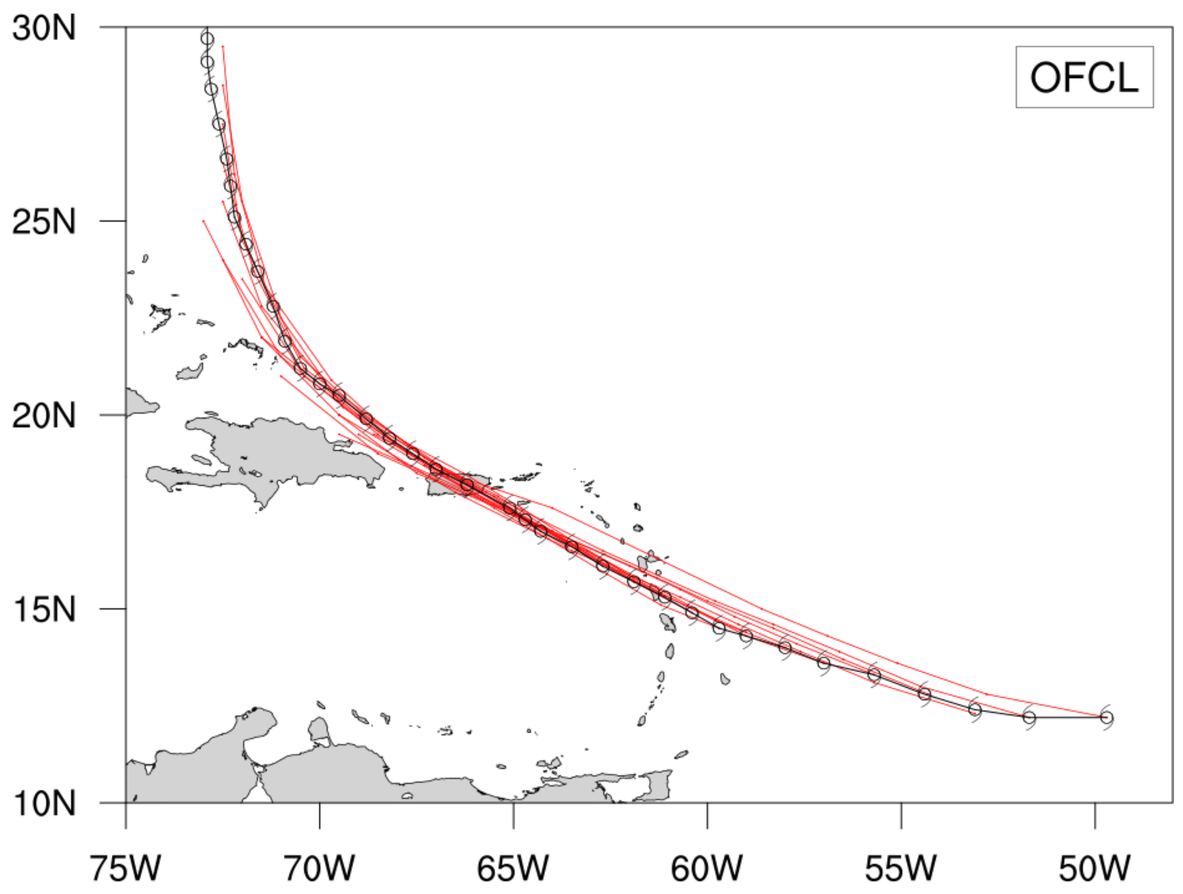
- The spread among ensemble members is often inversely proportional to skill. At 24 h, the ensemble members cluster together, indicating high predictability while the large ensemble spread at 240 h is associated with low predictability.
- Lorenz (1965) estimated the “limit of predictability” for weather as about two weeks.

Basis for Climate Prediction

- We all know the butterfly effect…
- *When we can not predict the atmosphere in three weeks, how can we predict it a few seasons ahead?*
- *Q1: What do we predict on the subseasonal and longer time scales?*
  - We can not expect the level of specificity from climate prediction as from weather forecasting: monthly mean or seasonal mean vs. hourly weather
  - Probabilistic forecasts vs. deterministic forecasts
- *Q2: Where does the predictive information come from?*

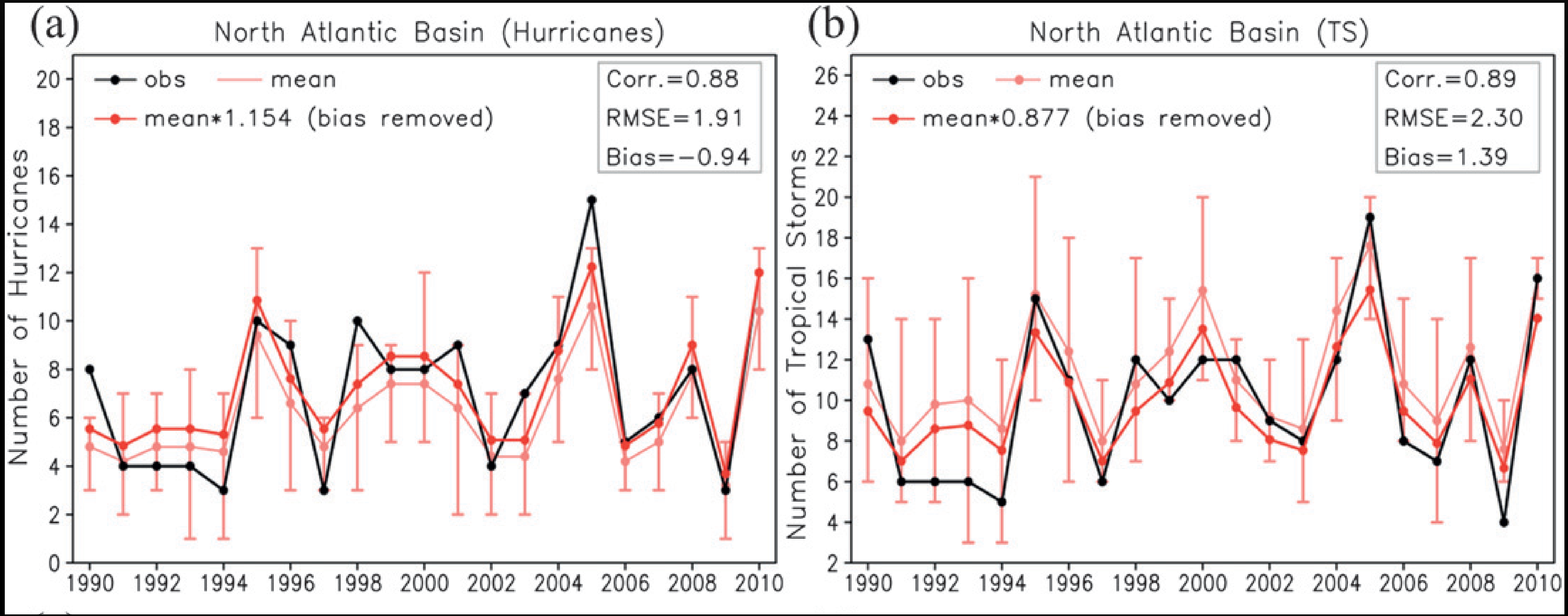
Skillful Track Forecasts for Hurricane Maria

- On the synoptic time scale, we can predict the track and intensity evolution of a hurricane
- An example for Hurricane Maria (2017) is shown on the right (NHC Tropical Cyclone Report: Hurricane Maria, Pasch et al. 2019, https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf)
- All the official forecasts issued from the time of Maria's formation correctly showed that the hurricane would strike Puerto Rico.



All official track forecasts for Maria from the time of genesis (1200 UTC 16 September) up to shortly before landfall in Puerto Rico (0000 UTC 20 September).

Seasonal Prediction of Atlantic Basin-Wide Tropical Cyclone Activity by the GFDL HiRAM Model



- Observations are shown by black lines and circles, while magenta lines and circles represent the ensemble mean of the climate model prediction. The maximum and minimum counts of the model forecasts for each year are indicated by error bars.
- We can not expect to predict the evolution of individual storms on the seasonal or longer time scales, but some statistics, such as the basin-wide storm counts, are predictable.

Weather Forecast in Champaign, IL

Current conditions at

University of Illinois - Willard (KCMI)

Lat: 40.03°N **Lon:** 88.28°W **Elev:** 741ft.

Fair

86°F

30°C

Humidity	43%
Wind Speed	SW 14 G 24 mph
Barometer	30.08 in (1018.1 mb)
Dewpoint	61°F (16°C)
Visibility	10.00 mi
Heat Index	86°F (30°C)
Last update	25 May 10:53 am CDT

More Information:

- Local Forecast Office
- More Local Wx
- 3 Day History
- Mobile Weather
- Hourly Weather Forecast

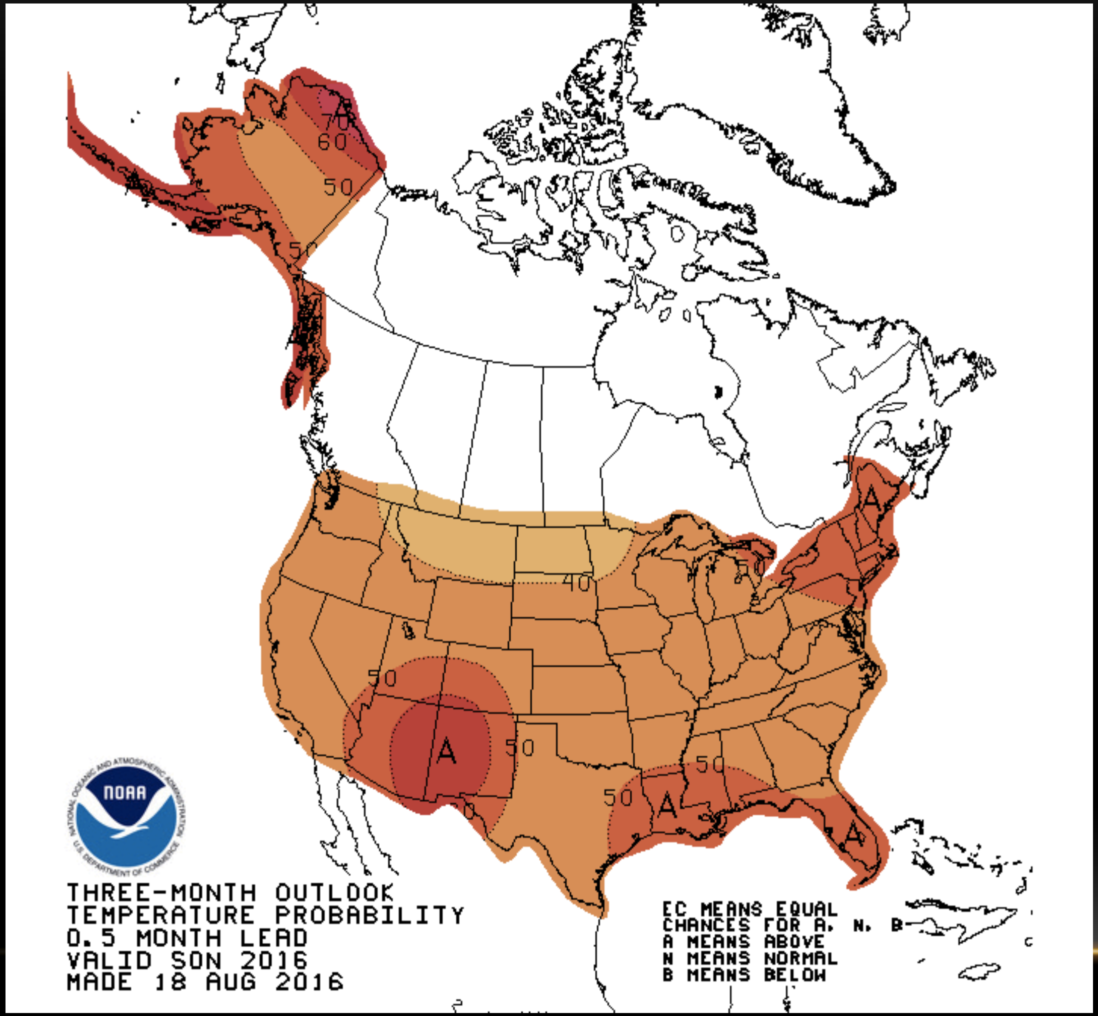
Extended Forecast for

Champaign IL

Today	Tonight	Wednesday	Wednesday Night	Thursday	Thursday Night	Friday	Friday Night	Saturday
20%	40% 50%	30%		60%	90%	30%		
Slight Chance T-storms	Chance T-storms then Chance Showers	Chance Showers	Mostly Clear	Partly Sunny then Showers Likely	Heavy Rain	Chance Showers	Mostly Cloudy	Mostly Sunny
High: 86 °F	Low: 67 °F	High: 84 °F	Low: 59 °F	High: 81 °F	Low: 60 °F	High: 66 °F	Low: 48 °F	High: 68 °F

https://forecast.weather.gov/

CPC Seasonal Outlook (Temperature SON 2016)



- Instead of predicting specific values, the probability of the three temperature categories is predicted (normal, above, and below normal)
- Some kind of time average (e.g. pentad, monthly or seasonal mean) is usually used, which removes part of the weather noise
- Although not very specific, climate prediction could still aid decision making, for example, in agricultural planning.

http://www.cpc.ncep.noaa.gov/products/predictions/long_range/seasonal_info.php

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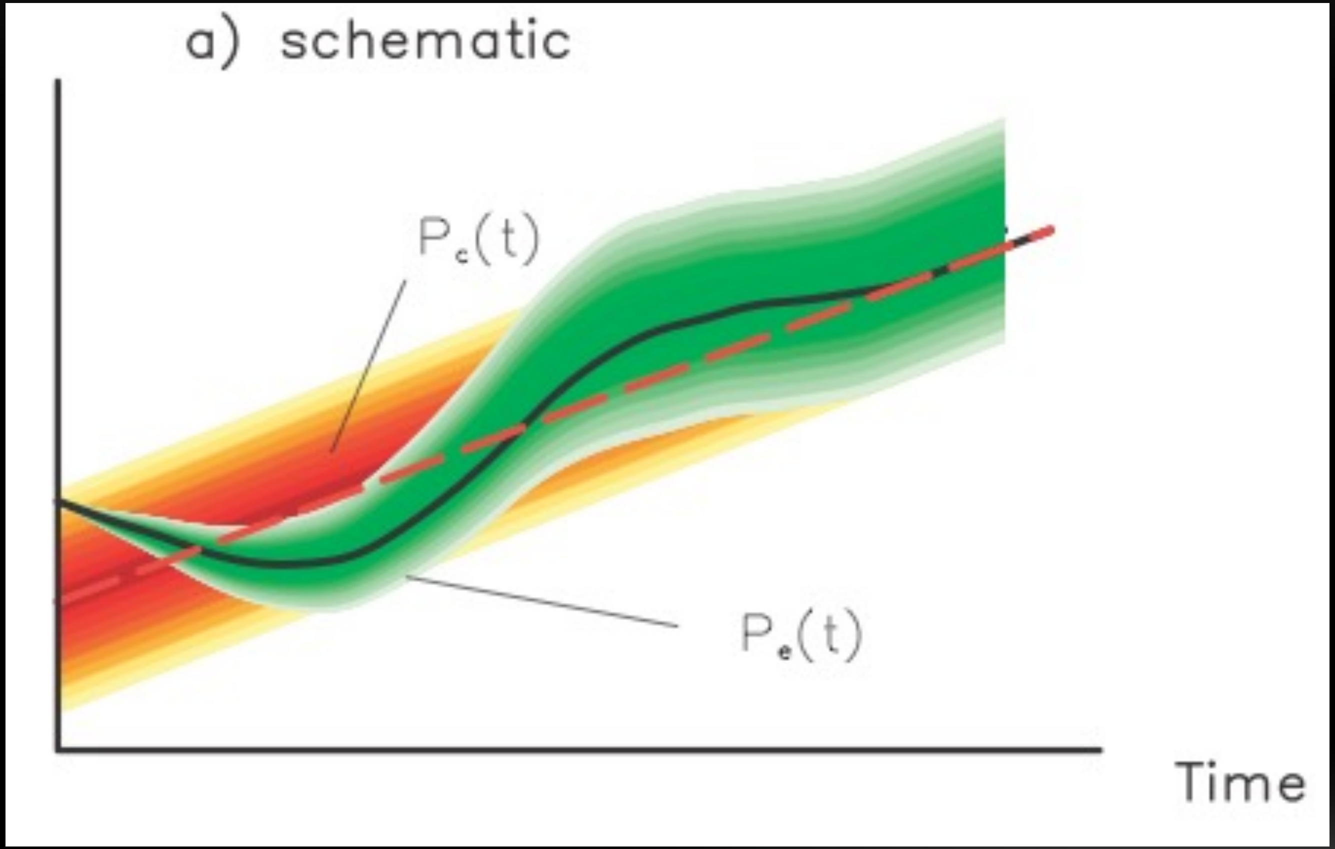
  - We can not expect the level of specificity from climate prediction as from weather forecasting: monthly mean or seasonal mean vs. hourly weather
  - Probabilistic forecasts vs. deterministic forecasts
- *Q2: Where does the predictive information come from?*
  - Climate prediction can be regarded as a mathematic problem different from weather forecasting and is associated with different sources of predictability

Initial-value problem vs. boundary-value problem

- Short-range weather forecasts: an initial value problem. Accurate initial conditions and proper use of the information (i.e., data assimilation) are critical for skillful prediction
  - Lorenz (1965) estimated the the limit of deterministic predictability for weather as about two weeks, but factors external to the atmosphere were not considered in the estimate.
- Climate prediction: two different perspectives
  - A boundary-value problem or forced-response problem: The atmosphere is modulated by the boundary conditions from the ocean, land and cryosphere (Brankovic et al., 1994) and/or external forcing (such as anthropogenic emissions and volcanic eruptions), which can provide sources of predictability for the atmosphere.
  - Initial conditions still matter: If we focus on the global climate system, the atmosphere, ocean, and land are just different components of the climate system. The initial conditions of the land and ocean are important for skillful prediction of some low-frequency modes. This perspective takes into account that there are interactions between atmosphere, ocean and land, instead of the atmosphere being passively forced by the other components.

Climate Predictability from Initial Conditions and External Forcing



Schematic diagram of time-evolving distributions under external forcing:
Pc(t):The yellow–red shading represents the climatological distribution and contains no information from the initial conditions.
Pe(t): an ensemble of predicted states evolving from a specific tight cluster of initial conditions. Eventually, Pe(t) converges to Pc(t) as the influence of the particular initial conditions is lost. The red dashed and black solid lines represent the time-evolving means of the two distributions.

References

- NAS report: "*Assessment of Intraseasonal to Interannual Climate Prediction and Predictability* ", Section 2.1-2.2
- Chen, J., & Lin, S. (2013). Seasonal Predictions of Tropical Cyclones Using a 25-km-Resolution General Circulation Model, *Journal of Climate*, *26*(2), 380-398.
- Branstator, G., & Teng, H. (2010). Two Limits of Initial-Value Decadal Predictability in a CGCM, *Journal of Climate*, *23*(23), 6292-6311.