Module 5: Decadal Variability and Prediction; Climate Change and Climate Projection

Outline

- Introduction
- Decadal Variability
  - Atlantic multi-decadal variability (AMV)
  - Pacific decadal oscillation (PDO)
- Examples of decadal prediction
- Climate change and climate feedback processes
- Attribution and detection

Climate Change and Climate Variability

- Climate change: a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.
  - Climate change may be due to natural internal processes or external *forcings* such as modulations of the solar cycles, volcanic eruptions and persistent *anthropogenic* changes in the composition of the *atmosphere* or in *land use*.
- Climate variability: variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the *climate* on all spatial and temporal scales beyond those of individual weather events.
  - Variability may be due to natural internal processes within the *climate system* (internal variability), or to variations in natural or *anthropogenic* external *forcing* (external variability).

IPCC Glossary https://www.ipcc.ch/sr15/chapter/glossary/

Climate Prediction and Climate Projection

- Climate predictions generally refer to near-term assessments of future variability and change in climate—from months to decades.
  - Climate prediction systems usually require some sort of initialization of a model.
- Climate projections generally refer to longer-term assessments of future variability and change in climate—up to a century ahead and beyond.

Collins et al. (2020)

Decadal Variability and Prediction

- Decadal prediction is focused on the multi-year to multi-decade time scales.
  - Some examples of decadal prediction include more active hurricane seasons over the Atlantic, prolonged droughts in the United States, changing fishery regime due to SST variability.
- Sources of Predictability:
  - On the decadal time scale, anthropogenic forcing, internal variability of the climate system, and natural external forcing all contribute to the time-evolving climate.
  - Anthropogenic forcing and decadal/multidecadal variability of the climate system are important sources of predictability for decadal prediction; natural external forcing that is inherently unpredictable, such as volcanic eruptions, does not serve as a source of predictability.
- Initialized climate prediction that captures the internal decadal variability can better quantify the uncertainty range of near-term climate projection. A model’s ability in representing and predicting the decadal variability affects the decadal prediction skill.
- A good understanding of the decadal variability is important for the projection of the near-term climate changes.

Example: Climate Modes of Decadal/Multidecadal Variability

Atlantic multi-decadal variability (AMV)

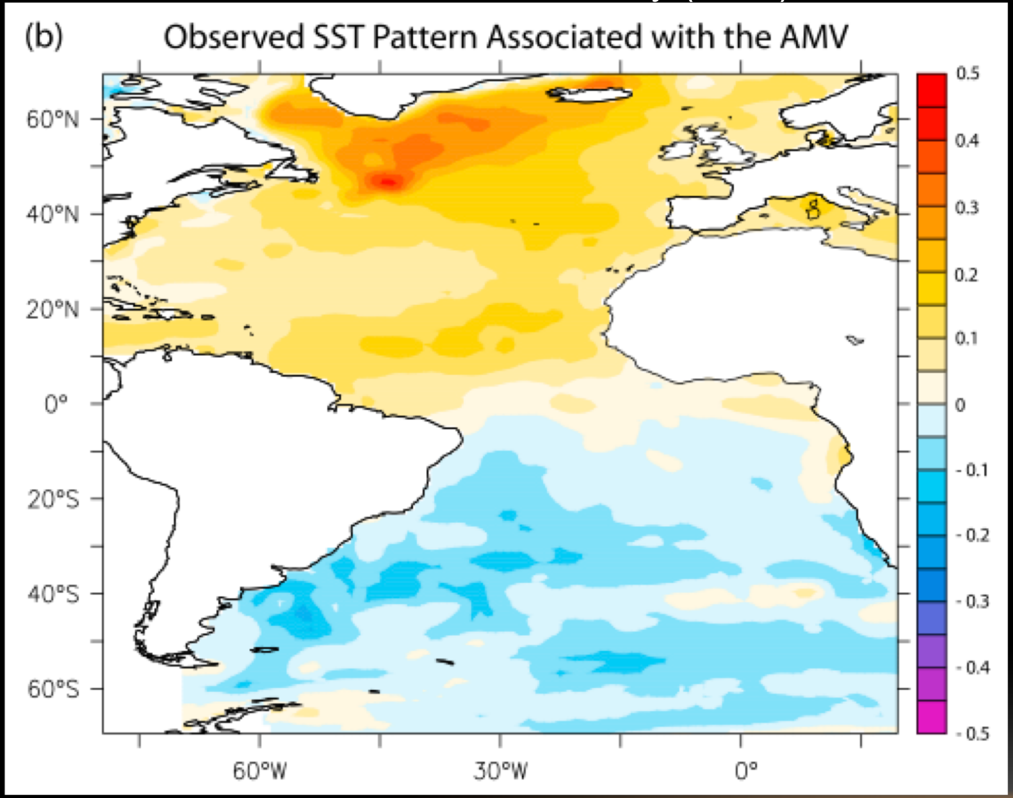


Fig 2b in Zhang et al. 2019

Pacific decadal oscillation (PDO)

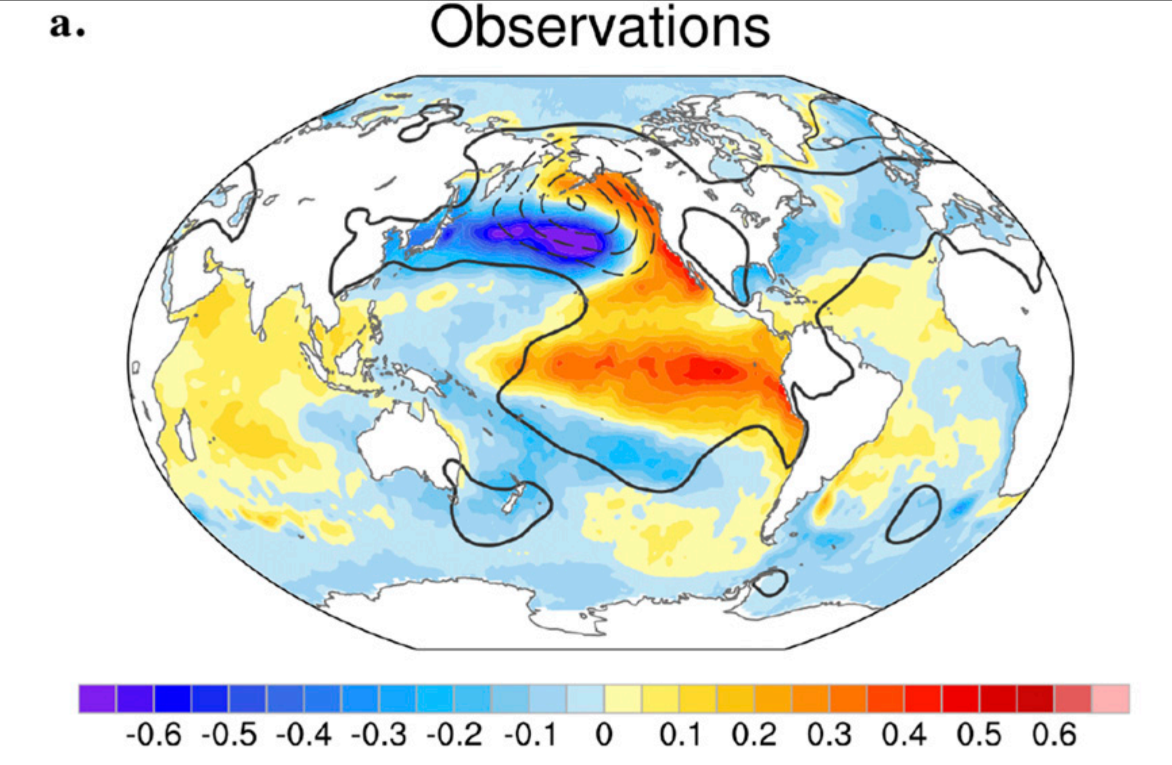
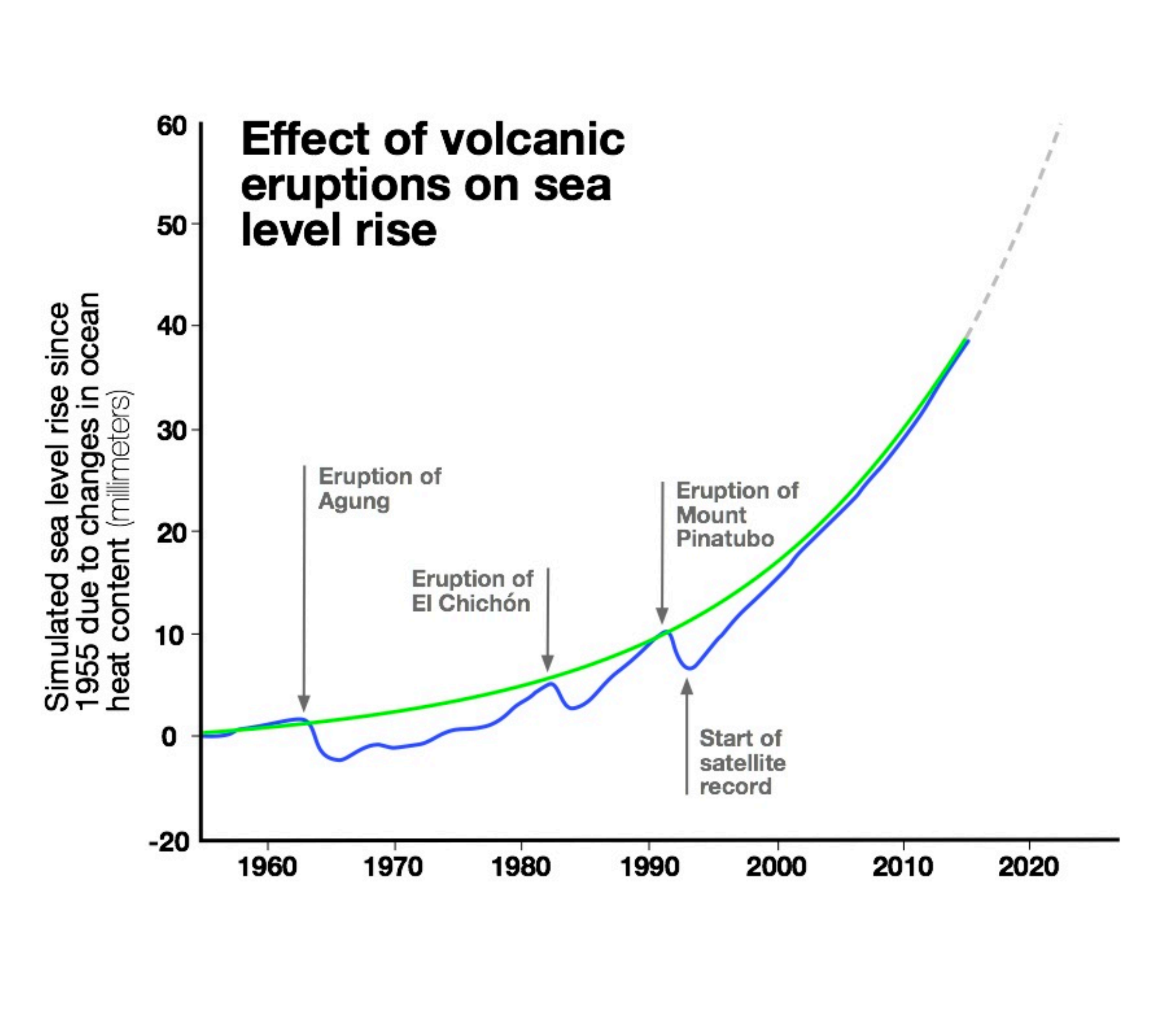


Fig. 1a in Newman et al. 2016 © American Meteorological Society. Used with permission

Example: Volcano masks quickening pace of sea level rise



- Volcanic eruptions can lead to a temporary cooling of the planet and a decrease in the ocean heat content, which ultimately lowers sea level.
- The solid blue line is the average sea level rise of climate model simulations that include volcanic eruptions.
- The green line is the average from model simulations with the effect of volcanic eruptions removed, showing a smooth acceleration in the rate of sea level rise due to climate change.
- Sea level rise is expected to follow the gray dotted line unless there is another major volcanic eruption.

From https://sealevel.nasa.gov/news/56/volcano-masks-quickening-pace-of-sea-level-rise/

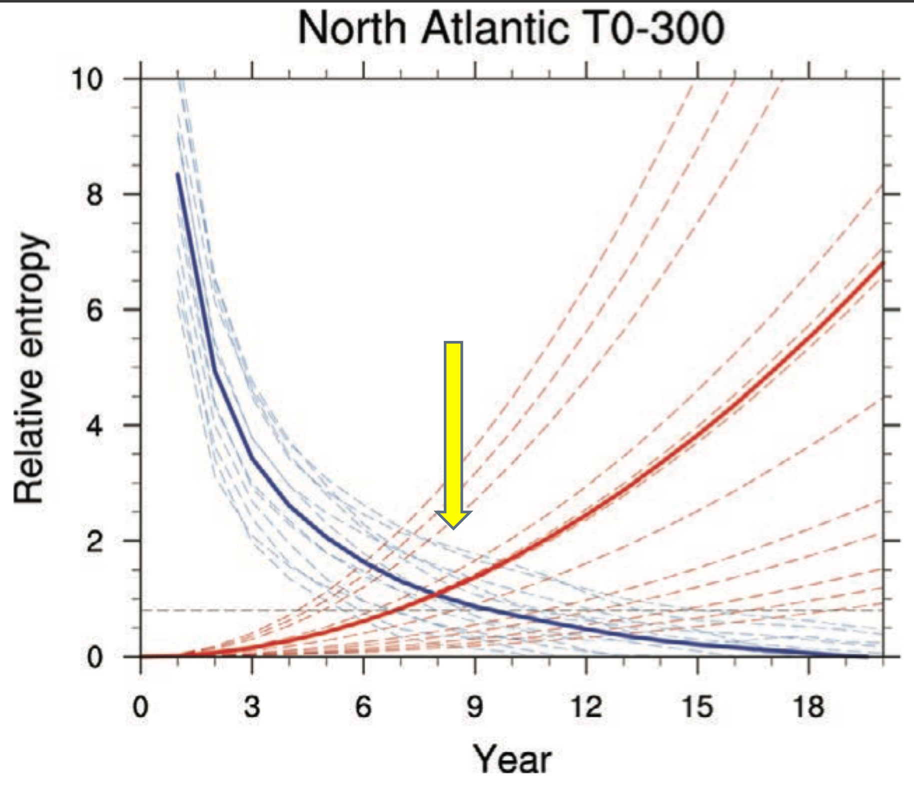


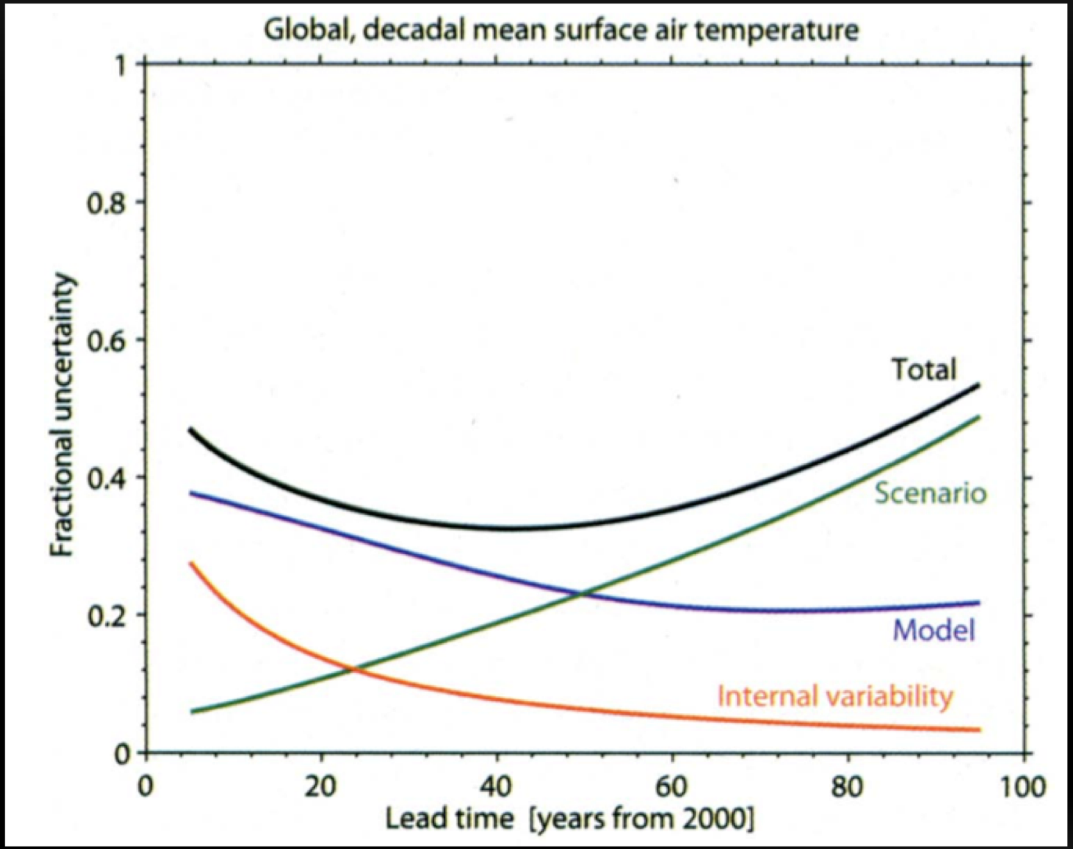
FIG. 2. Predictability of upper 300-m temperature of the North Atlantic for 12 CMIP5 models resulting from initialization (dashed blue lines) and the response to RCP4.5 forcing (dashed red lines). Here, predictability is indicated by the information contained in perfectly predicted distributions, as measured by relative entropy. The thick solid lines are multimodel averages of the relative entropy. The crossover point near year 8 for the multimodel averages is where information originating in the initial conditions (blue line) begins to be exceeded by information resulting from external forcing (red line). The horizontal dashed line indicates the 90th percentile of relative entropy from ensembles of approximately 18 random states drawn from a control run. (From Branstator and Teng 2012.)

Role of Initial Conditions and External Forcing

For the upper 300m ocean temperature over the North Atlantic

- Initialization has the potential to improve skill in the first 8 years.
- The predictability originating in the initial conditions (blue line) begins to be exceeded by that resulting from external forcing (red line) around year 8.
- The time at which initialized predictions cannot be discerned from randomly generated variability is model-dependent and is also dependent on the variable of interest and the region of interest.

Sources of Uncertainty in Climate Prediction/Projection



The relative importance of different sources of uncertainty in decadal-mean global-mean surface air temperature. From Hawkins and Sutton 2009 © American Meteorological Society. Used with permission

- Three sources of uncertainty
  - Internal variability (related to initial condition uncertainty)
  - Model uncertainty (resolution, model physics, dynamic core, etc.)
  - External forcing uncertainty (i.e., different CO2 concentration pathways)
- Model uncertainty is dominant for lead times up to 50 yr.
- Scenario uncertainty is much weaker than the internal variability in the first 20 years and becomes important at multidecadal lead times

How to deal with uncertainties: Ensemble Prediction

- To address initial condition uncertainties:
  - Initialize the model on consecutive days or different seasons.
  - Optimal perturbation method: the singular vectors method or breeding vectors method is used to identify fastest growing initial errors and create ensemble members.
  - Ensemble Kalman filter: analyses of observations are created by using the forecast model and observations to update an ensemble of previous analyses, accounting for analysis, model, and observational errors.
- Model uncertainties:
  - Multi-model ensemble
  - Single model ensemble with stochastically perturbed parameterization tendencies

(Also see Section 2.9 ”Dynamical Models”)

References

- Branstator, G., and H. Y. Teng, 2012: Potential impact of initial- ization on decadal predictions as assessed for CMIP5 models. *Geophys. Res. Lett.,* **39,** L12703, doi:10.1029/2012GL051974.
- Collins M, Barreiro M, Frölicher T, Kang SM, Ashok K, Roxy MK, Singh D, Tedeschi RG, Wang G, Wilcox L and Wu B (2020) Frontiers in Climate Predictions and Projections. *Front. Clim.* 2:571245. doi: 10.3389/fclim.2020.571245
- Hawkins, E., and R. Sutton, 2009a: The potential to narrow uncertainty in regional climate predictions. *Bull. Amer. Meteor. Soc.,* 90, 1095-1107.
- Meehl, G., and Coauthors, 2009: Decadal prediction: Can it be skillful? *Bull. Amer. Meteor. Soc.,* **90,** 1467–1485.
- Meehl, G. A., Goddard, L., Boer, G., Burgman, R., Branstator, G., Cassou, C., Corti, S., Danabasoglu, G., Doblas-Reyes, F., Hawkins, E., Karspeck, A., Kimoto, M., Kumar, A., Matei, D., Mignot, J., Msadek, R., Navarra, A., Pohlmann, H., Rienecker, M., Rosati, T., Schneider, E., Smith, D., Sutton, R., Teng, H., van Oldenborgh, G. J., Vecchi, G., & Yeager, S. (2014). Decadal Climate Prediction: An Update from the Trenches, Bulletin of the American Meteorological Society, 95(2), 243-267.