GEOG 401
Climate Change
Earth System Models
Historical Climate Changes

Global Land and Ocean Temperature Anomalies, January-December

Why use a climate model?

• No observations from the future
• No other planet earth to experiment with
• Models help predict future changes
• Models help understand the processes related to change
• Models can be tested by simulating past climate and comparing results with observations
How do climate models differ from each other?

- Different models have a wide range of complexity in terms of:
  - Spatial resolution—horizontal and vertical
  - Time step
  - Domain (global, regional, point)
  - Processes represented interactively vs. prescribed

Model Complexity

- Simplest global climate model:

\[(1 - a)S\pi r^2 = 4\pi r^2 \varepsilon \sigma T^4\]  
Radiative equilibrium model

- Increasing complexity

Include more processes
FAQ 1.2, Figure 1. Schematic view of the components of the climate system, their processes and interactions.
Figure 1.1. Historical Development of Climate Models. [Figure source: Climate Change 2001: The Scientific Basis, Contribution of Working Group 1 to the Assessment Report of the Intergovernmental Panel on Climate Change, p. 46. Used with permission from IPCC.]

Figure 1.2. The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown explicitly in the modified version of the colored pages.
Spatial Resolution

Schematic for Global Atmospheric Model

Horizontal Grid (Latitude-Longitude)

Vertical Grid (Height or Pressure)

http://celebrating200years.noaa.gov/breakthroughs/climate_model/welcome.html

Spatial Resolution

Figure 5.4. Geographic resolution characteristics of the perspectives of climate models used in the IPCC assessment Reports: FAR (1990), SAR (1995), TAR (2001), and AR4 (2007). The figure shows a more detailed perspective of the differences in horizontal grid resolution. The model resolution is determined by the number of grid points used in the model. The higher the resolution, the more detailed the model can be. The figure also shows the impact of the model resolution on the accuracy of the predictions.
What makes Earth System Models Different from their Predecessors?
Models and Observations

Importance of observations to models

- “Without data, the models are just abstractions.”
- Model optimization (calibration)
- Model evaluation (validation)
- Data assimilation

Importance of models to interpreting data

- Models allow use of observations in development and refinement of theory
Optimization

- Many components of large complex models use parameters whose values must be specified by the modeler
- To better constrain parameter values, models can be tested against observations
- The model is “optimized” by adjusting parameter values to obtain model output that best fits observations

Uses of Observed Data in Modeling Context

- Forcing variables
- Characterization (parameter values)
- Optimization variables
  - Calibration
  - Validation
Model Evaluation

(c) Temperature anomaly (°C)

Year

Santa Maria
Aging
El Chicon

Model Evaluation

Temperature Change [°K]

Year


-1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5

-1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5

R-85RM72v
SRESB
SRES-A1B
SRES-A2
SRES-A01
Pezev
Model Evaluation

![Model Evaluation Diagram](image)

Figure 6.5: Mean annual precipitation, observed and simulated, based on the North American river basin. The Shriver-Pederson Center merged rainfall data. The blue lines show the observed precipitation, and the red lines show the simulated precipitation. The black line indicates the difference between the observed and simulated data. The bars represent the range of values for each month, with the lightest color indicating the lowest precipitation and the darkest color indicating the highest precipitation.

Model Evaluation

![Model Evaluation Diagram](image)

Figure 1.1: Mean global surface air temperature (Briffa et al., 2005), relative to the mean 1961 to 1990 values, and as projected in the TAR (GCM), 1990, 2010, 2030, 2050, 2070. The "best estimate" model projections from the TAR and GCM are in solid lines with their range of estimated projections shown by the shaded areas. The TAR did not have "best estimate" model projections but rather a range of projections. Annual mean observations (Section 3.2) are depicted by dark circles and the thick black line shows decadal variations obtained by smoothing the time series using a 10-year filter.
Model Evaluation

Figure 8.11. Normalized RMSE error in simulation of climatological patterns of monthly precipitation, mean sea-level pressure and surface air temperature. Recent AOGCMs (circa 2005) are compared to their predecessors (circa 2000) and earlier. Models are categorized based on whether or not any flux adjustments were applied. The models are grouped against the following observation-based datasets: Climate Prediction Center Merged Analysis of Precipitation (CMAP; Saha et al., 1996) for precipitation (1900–1999), European Centre for Medium-Range Weather Forecasts 40-year reanalysis (ERA40; Uppala et al., 2005) for sea-level pressure (1960–1999) and Climatic Research Unit (CRU; Jones et al., 1998) for surface temperature (1861–1990). Before computing the errors, both the observed and simulated fields were mapped to a common 4° x 5° latitude-longitude grid. For the earlier generation of models, results are based on the unciled output from control runs (specifically, the first 30 years, in the case of temperature, and the first 20 years for the other fields), and for the recent generation models, results are based on the 20th-century simulations with climatological periods selected to correspond with observations. (In both groups of models, results are insensitive to the period selected.)
Data Assimilation

The Satellite Data Assimilation System
- Data acquisition
- Built on the EALCO model and the wealth products at CCRS
- Multi-source data integration & assimilation
- High-level products generation
- Ecosystem future scenarios & assessment

Data Assimilation

Sequential, intermittent assimilation

Sequential, continuous assimilation

Non-sequential, intermittent assimilation

Non-sequential, continuous assimilation
### Reanalysis Datasets

- Gridded historical climate datasets
- Continuously updated
- Produced by assimilating observations into a numerical weather prediction model
- Examples: NCEP/NCAR, MERRA, ECMWF, JRA-25

### Uncertainty

- **Parametric uncertainty** – many processes are “parameterized” based on empirical measurements; “correct” parameter values are often not well known
- **Structural uncertainty** – inadequate (incomplete or incorrect) mathematical representation of processes
- **Residual uncertainty** – arises from uncertainty in external forcing
- **Intrinsic uncertainty** – essential randomness of the system – our inability to fully describe the processes producing variability


**Emissions and Concentration Scenarios**

- Changes in atmospheric GHG concentrations are driving climate change
- Emissions are driving the GHG concentration changes
- Future emissions depend on a host of socio-economic and technological factors
- Future human behavior is not predictable in a deterministic sense
- Scenarios are developed from “what if?” type questions
- Scenarios are used to explore possible futures

**Concentration Approach**

- TAR and AR4 model experiments were done using a set of GHG concentration scenarios from the Special Report on Emission Scenarios (SRES, IPCC, 2000)
- Approx. 40 SRES scenarios can be divided into four main group A1, A2, B1, B2
- A subset of the SRES scenarios was used by each modeling group to simulate future climate
Emissions Scenario Approach

• With the advent of Earth System Models, GHG concentrations are interactively calculated in the model
• With ESMs it is now possible to use emissions scenarios instead of concentration scenarios
• New approach being used for AR5: Representative Concentration Pathways (RCPs)

RCPs

• Named for the forcing in 2100
• RCP 3-PD: peaks at 3.0 W m^-2 and declines to 2.6
• RCP4.5
• RCP6.0
• RCP8.5