

# A COOPERATIVE AGREEMENT TO MODEL FUTURE CLIMATE CHANGE

The U.S. Department of Energy (DOE) has supported climate change research at the National Center for Atmospheric Research (NCAR) since 1978. A DOE/UCAR Cooperative Agreement for the Regional and Global Climate Modeling Program has been in place since 1997 with DOE's Office of Science and the University Corporation for Atmospheric Research (UCAR) to model future climate change and conduct extensive analyses into how the climate system responds to various climate forcings. This research also evaluates and improves components of climate and Earth system models, performs process studies using model versions of varying complexity and resolution, and applies climate dynamics to climate change. One unique contribution is its role within the Climate Variability and Change Working Group in connection to the Community Climate System Model/Community Earth System Model (CESM). On average, this project produces 30 peer-reviewed papers each year. To ensure Cooperative Agreement science is integrated into national and international research agendas, scientists play leadership roles in the CESM, World Climate Research Programme, National Research Council, and in climate assessments. Climate change simulations performed as part of the Cooperative Agreement have made major contributions to the Intergovernmental Panel on Climate Change assessment reports.

## **TASK 1: RESEARCH PROGRAM ON MODELING FUTURE CLIMATE CHANGE: EFFECTS OF INCREASED ATMOSPHERIC CARBON DIOXIDE AND OTHER CLIMATE FORCINGS**

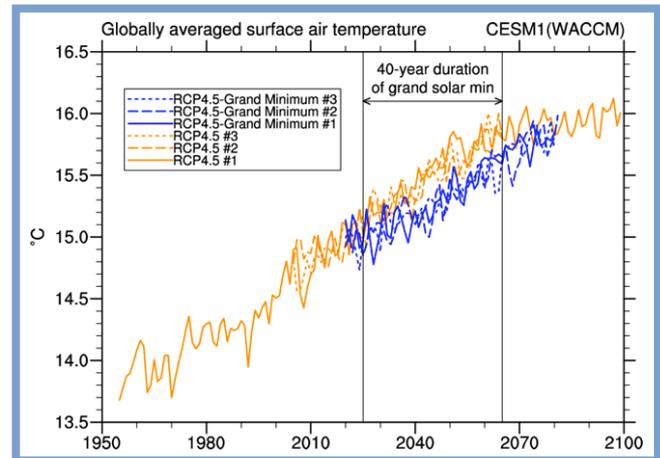
*Led by: Warren Washington and Gerald Meehl,  
Principal Investigators*

State-of-the-art, global, climate and Earth system models are employed to address future climate change in the context of the natural variability of the atmosphere, ocean, sea-ice, land/vegetation, hydrological and carbon cycle components of the Earth system. Research includes identifying spatial and temporal patterns in model results that are associated with climate change, especially on regional scales. This task seeks to identify the dynamical processes that produce these patterns and to provide an interpretation of the model projections. For example, a future decrease of solar irradiance is shown to slow down, but not stop, global warming.

## **TASK 2: FUTURE CHANGES IN EARTH'S ATMOSPHERIC HYDROLOGICAL CYCLE AND THE RESPONSE OF ECOSYSTEMS TO CLIMATE CHANGE**

*Led by: Jeffrey Kiehl, Principal Investigator*

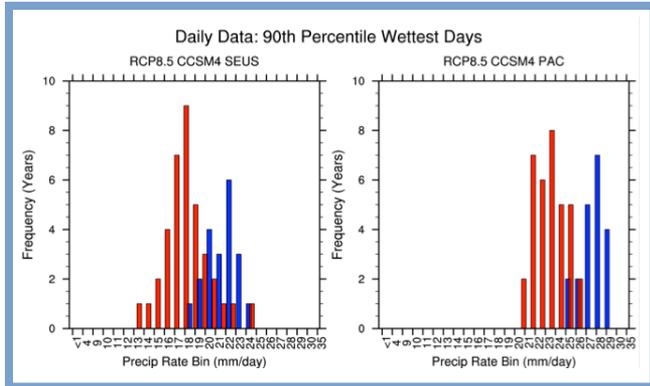
Simulations of CESM are analyzed for both present and future climates to quantify the relative contributions of various dynamic



*Time series of globally averaged surface air temperature anomalies ( $^{\circ}\text{C}$ ) relative to the 1986-2005 reference period for the CESM1(WACCM) standard RCP4.5 simulations (orange lines) and the grand solar minimum experiment (blue lines). The duration of the grand solar minimum experiment is indicated from 2025-2065.*

## SCIENCE QUESTIONS ADDRESSED

- How can we better quantify certainty of long-term climate change? How is certainty related to the factors that produce spread in future climate change projections?
- What is the time evolution of the statistics of regional climate over the next decades?
- How will future hurricanes and tropical cyclones behave, and how will regional precipitation and temperature extremes evolve in the future?
- How much and how fast will sea-level rise, both globally and regionally?
- What processes determine the response of the hydrological cycle to future greenhouse forcing, and how do these atmospheric moisture processes determine the spatial distribution of surface precipitation and evaporation?
- How do these moisture feedback factors depend on model horizontal resolution?



Extreme precipitation events comparing the standard fully-coupled CESM 1° (blue) and 0.5° (red) atmosphere/land model coupled to a 1° ocean/ice model. Extreme precipitation is computed by finding the 90th percentile for wettest days for each year. Histogram frequencies represent one event as the average of each year's wettest days, i.e., the max frequency is 20 (years).

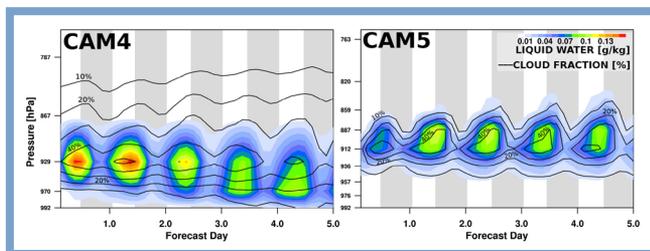
and thermodynamic processes acting as feedbacks to the hydrological cycle in Earth's climate system. Present-day climate simulations are compared to a collection of observations—satellite and surface-based—to quantify the accuracy of the CESM simulated hydrological processes. Changes in specific humidity, cloud properties, transports, and overall moisture budgets are compared for the various forcing agents applied in future climate simulations.

The standard fully coupled CESM 1° resolution model compared to a version of moderately higher resolution (0.5° atmosphere/land) translates into the half-degree version producing wetter days with more extreme values.

### TASK 3: EVALUATION OF AND IMPROVEMENTS TO COMPONENTS OF CLIMATE SYSTEM MODELS

Led by: David Williamson, Richard Neale, and Brian Medeiros, Principal Investigators

Under this task, research involves examining, evaluating, and improving coupled models and model components in an attempt to verify both the processes and resultant stationary and time-varying climate phenomena. These include the numerical approximations for fluid flow on the sphere (through methods of establishing their validity and desirability rather than actually developing the methods



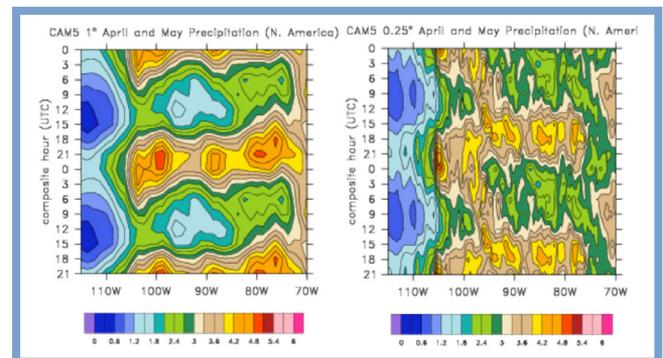
A month of cloud forecasts of the subtropical southeast pacific are combined to show the composite five-day forecast, with the older CAM4 on the left and the newer CAM5 on the right.

themselves), the complete suite of sub-grid scale parameterized processes for the individual components, and the coupling of all these components (through experiments in simplified regimes such as aqua-planets). Compared to CAM4, the new CAM5 model has substantially revised cloud physics, leading to a more realistic cloud structure with clear layers below and above a well-defined cloud layer. Both models show a daily cycle of cloud cover with more clouds at nighttime and a thinning cloud layer during the daytime that is in general agreement with observations.

### TASK 4: CLIMATE MODELING WITH MESOSCALE ATMOSPHERIC VARIABILITY AND SCALE-AWARE PHYSICAL PARAMETERIZATIONS

Led by: Joe Tribbia, Principal Investigator; Sungsu Park, Co-Investigator

A comparison of global, mesoscale-resolving models (1/4° – 1/8° resolution in the atmosphere and 1/10° resolution in the ocean) with the standard 1° resolution coupled climate simulations and projections is used to understand and quantify limitations and uncertainties. Such coupled climate models that include mesoscale variability in the atmosphere and ocean are now usable because of the increase in computer power over the last five years. The challenge of this research task is to understand and use atmospheric models with advanced physical parameterizations.



Precipitation composited by hour for the spring season over North America for CAM5 1° (left) and CAM5 0.25° (right). The propagating precipitation in the 0.25° composite precipitation is orographically driven by the Rocky Mountains, which does not occur at the coarser 1° resolution.

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### Project Website

<http://climatemodeling.science.energy.gov/projects/cooperative-agreement-climate-change-prediction-program>