CLIMATE & GLOBAL DYNAMICS DIVISION

Strategic Plan (2013 - 2018)

NCAR Earth System Laboratory (NESL)
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CGD Strategic Plan

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CGD Strategic Plan
Vision | Mission | Context

VISION
To benefit society as the center of collaborative Earth climate system research.

MISSION
To discover the key processes in each component of the Earth’s climate system and to understand the interactions among them; to represent this knowledge in community models that effectively utilize computing advances; and to apply these models and observations to scientific problems of societal relevance.

CONTEXT
The Climate and Global Dynamics (CGD) Division of NCAR’s Earth System Laboratory (NESL) retains its original connections to atmospheric dynamics and related energy and water cycles, but is now focused on global and climate scales. Therefore, its research has expanded to other components of the climate system: first to the underlying ocean, land and cryosphere; then beyond physics to atmospheric chemistry, biogeochemical cycles, hydrology, and ecosystems; and, most recently, to human systems. In so doing, CGD spawned the Community Earth System Model (CESM) and remains a hub of its activities. Vital elements for CESM’s development include modern parameterizations, software engineering and observational data sets. A critical level of effort is maintained in all areas through extensive collaborations with the greater CESM community, the majority of which are at Department of Energy laboratories and U.S. universities. Through the open and inclusive CESM research and development procedures, CGD realizes its vision as a source and integrator of fundamental insights into the governing processes, numerical modeling and overall behavior of the Earth’s climate system.

To fulfill its mission, CGD encourages and supports a triad of interdependent activities: fundamental collaborative research; community model development; application of these models as research tools. Virtually all CGD resources are directly or indirectly targeted at contributing to the success of the CESM enterprise, either in the immediate or longer term. Numerical models of the Earth system and its components are developed as tools for representing the totality of current understanding as derived from diagnostic studies, theory and process models. Earth system models such as CESM are perhaps the most viable means of doing so on the global climate scale. They are verified against observations of past and present climate, and used to test hypotheses and to make climate projections of both the mean state and variability of possible future climates, given plausible forcing scenarios. CESM is not intended for Numerical Weather Prediction (NWP), for which the atmospheric initial state is paramount, but is operated in NWP mode to assess targeted aspects of model performance against observations. In contrast, CESM with appropriate data assimilation capabilities is a viable tool for climate predictions that must also consider the initial states and evolution of longer time scale components of the climate system, such as the ocean, land and sea-ice, and may include ecosystems, biogeochemistry and human dimensions. Thus, we distinguish between initial value prediction problems and boundary value projection problems.

CGD has identified Earth System Modeling, Scale-Adaptive Modeling, Climate Prediction, Climate Extremes and Climate and Human Systems as its five interdisciplinary challenges. They will be tackled by cross-divisional projects, such as CESM, and by CGD’s five multidisciplinary sections. The section plans herein each include the germane elements of these challenges, as well as their own strategic foci. They also connect the sections with the directly relevant projects and CESM working groups. All CGD activities are supported by a strong foundation of facilities, services and infrastructure.

CGD’S COLLABORATIVE RESEARCH TRIAD

LOCAL (NCAR/NESSL/CGD) and COMMUNITY GOVERNANCE

Earth System Research

Fundamental Research into Atmospheric and Climate Processes

Community Model Development

ADMINISTRATION, INFORMATION TECHNOLOGY, and VISITOR SUPPORT
Interdisciplinary Challenges | Earth System Modeling

Identify and model the physical, chemical, biological, and human components that govern the climate system; quantify the certainties and uncertainties in Earth-system feedbacks on timescales up to centuries and longer.

Reliable information on expected climate conditions and impacts is needed to better inform societal decisions. Climate variability and change is determined by the functioning of the Earth's physical, chemical, biological, and human systems and the interactions among them. To further understand climate system behavior, it is critical to maintain CESM as a world-class, community-based, state-of-the-science, and comprehensive Earth System Model. This requirement depends on the translation of fundamental research on climate system processes into new and better parameterizations. It also necessitates the evaluation of model simulation behavior against process knowledge, observations and proxies from the distant past to the present.

Objectives

- Enhance capability for Earth system modeling of the physical climate system coupled with chemistry, biogeochemistry, biology and human systems.
- Improve model representation of Earth system processes through the incorporation of new components, parameterizations and dynamical cores.
- Use existing and new observations to test Earth system models at a process level and quantify the relative importance of different feedbacks.
- Enable CESM community to conduct competitive climate research on a full range of computing platforms, through specific software developments and by hosting visitors and training tutorials.
- Provide relevant datasets to the greater climate research community, accompanied by the collective knowledge gained from our experience.
- Contribute knowledge to national and international assessments (e.g. IPCC).

Interdisciplinary Challenges | Scale-Adaptive Modeling

Ensure that all CESM components use scale-adaptive techniques so that regional and global climate can be simulated concurrently.

Traditionally, regional climate simulations use high resolution in a limited domain with boundary conditions provided by a global, coarse-resolution climate model. This method is ill-posed, however, and very strong damping of the solution is required near the edges of the domain. In addition, there is typically no up-scaling effect from the regional climate model simulation back onto the global climate model. An improved methodology is to use static, variable mesh grids so that the resolution is high over regions of interest, with a smooth change to coarse-resolution over the remainder of the globe. This method has its own problems because there can be effects of the grid where the resolution is changing. All components of the CESM need to be able to run on global variable mesh grids, as well as uniform grids, so that CESM can use this methodology to make regional climate simulations, that interact with the global.

Objectives

- Adapt all CESM components to give high quality results at a variety of uniform global horizontal resolutions from a few hundred kilometers to a few kilometers, as well as increasing vertical resolution.
- Develop scale-adaptive parameterizations in all CESM components so that they can take advantage of grids that vary by order a factor of 10 around the globe.
- Use CESM to make regional climate simulations with very high resolution in particular areas (e.g. North America, coastal oceans) or to address specific research topics (e.g. the regeneration of coral reefs; remote influences of small-scale orography).
Predict the time-evolution of global and regional climate on timescales from a month or less to perhaps a decade by considering external forcing as well as the initial conditions and evolution of more climate system components than just the atmosphere; quantify the factors that contribute to climate predictability on these scales.

Climate variations on monthly to multi-year timescales can have enormous social, economic, and environmental impacts, making skilful climate predictions invaluable information for society and policymakers. Enhancing our foreknowledge of climate variability can help mitigate the negative impacts on human and biological populations, making climate prediction on these time scales an especially important social and science frontier. Future variations in weather patterns and climate, and their corresponding impacts on the biosphere, will be strongly influenced by both the forced climate change signal and the natural intrinsic variability of multiple climate system components. The translation of physical climate variables into use-relevant information for decision makers is a significant research challenge.

Objectives

- Improve understanding of intrinsic climate variability and mechanisms.
- Quantify inherent predictability constraints of our prediction systems.
- Evaluate practical prediction system design methods, including the best initialization strategies and understanding of the calculation, application, and consequences of bias adjustments in climate predictions.
- Further current initialized climate prediction capabilities through the development of a coupled ocean-atmosphere assimilation system, and then extend the scope to data assimilation in other climate components such as sea-ice, land and biogeochemical cycles.
- Identify reasons for greater predictive skill in some regions compared to others, with particular regard, initially, to precipitation over land.
- Quantify factors that contribute to uncertainty in climate predictions on time scales from months to years.

Improve understanding of climate change contributions to extreme events, as well as the associated environmental and societal impacts.

Climate change contributes to a growing number of weather and climate extremes, including record high temperatures, heat waves, severe droughts, heavy rains and intense storms. Given the disproportionate impacts, a major challenge for CGD’s climate modeling is the ability to foresee how a warming world might alter the occurrence and magnitude of extremes, so that society can build resilience. In addition to rapid events, large climate-related impacts can occur due to gradual changes in average temperatures, sea ice cover, sea level, precipitation, snowfall and ocean acidity, for example. To meet this challenge, our efforts are increasingly directed towards improving and analyzing observational data sets, with greater emphasis on diagnostic studies and risk assessment. Together with targeted model developments, they strengthen our ability to work with the integrated assessment community toward reducing the vulnerabilities of human and natural systems with the integrative assessment community.

Objectives

- Improve attribution of extreme events to particular causes through understanding of the relevant processes and climate phenomena.
- Expand capacity to project the impacts of extreme events on natural and human systems.
- Increase capacity to inform adaptive strategies to changing risk of extremes, through integrated assessment modeling that includes human systems, agriculture, biogeochemistry, water resources, and ecosystems.
- Strengthen partnerships with researchers from the ecological, hydrological and social sciences.
INTERDISCIPLINARY CHALLENGES | CLIMATE AND HUMAN SYSTEMS

Understand and model how human systems influence, and are influenced by, the physical climate system; evaluate climate change impacts as well as mitigation and adaptation response options.

Climate impacts and our response options depend not only on how climate changes in the future, but also on future societal trends. A scientifically informed response to the climate change issue therefore requires understanding of how socio-economic factors may evolve in the future and how they might interact with a changing climate. Models and understanding of human systems and interactions, especially with respect to land use, must be improved to better account for a wide range of plausible human development pathways. Other foci will be quantifying the risks to agriculture, urban areas and coastal regions posed by climate change, extreme events and air pollution in combination with societal changes. Community-oriented tools and approaches to these topics can leverage wider pools of expertise and speed progress. CGD is establishing a Climate and Human Systems Project (CHSP) to foster these activities and to work with the CESM Societal Dimensions Working Group (SDWG).

Objectives

- Improve projections of societal trends that are relevant to assessing impacts and options for climate mitigation and adaptation.
- Improve capacity to link integrated assessment models to CESM for the investigation of human-Earth system interactions.
- Improve assessments of impacts, adaptation and mitigation by better accounting for socio-economic change and its interactions with the climate system.
The Atmospheric Modeling & Predictability (AMP) section’s research focus is increasing understanding of the atmosphere and its role in the climate system through modeling studies and representing that understanding in improved atmospheric models. With the CESM Atmospheric Model Working Group (AMWG), we share responsibility for development of the Community Atmosphere Model (CAM) within the CESM project. We also advance the scientific understanding of the dynamics and predictability of large-scale atmospheric climate variability on time scales of days to decades. The atmosphere above the stratosphere and chemistry at all altitudes are shared responsibilities with NCAR’s High Altitude Observations (HAO), the Atmospheric Chemistry Division (ACD), and the respective CESM Whole Atmosphere (WAWG) and Chemistry Climate (CCWG) Working Groups.

**Foci**

**Aerosols/Chemistry in Climate with Accurate Tracer Transport**
Aerosols and their interactions with Clouds and Precipitation are a critical part of the climate system. We will pursue advances in simulating aerosols and clouds, including more accurate and efficient treatment of aerosol and chemical transport. We will help advance aqueous phase chemistry as well as gas phase. To better understand aerosol and cloud interactions, we will develop advanced treatments of cloud microphysics and precipitation processes, including in convective clouds.

**Explore the Weather Climate Interface**
The next generation of atmospheric models used for climate studies, such as CAM, will need to accurately and concurrently simulate circulations from the mesoscale to the planetary scale. Mesoscale and regional scale phenomena are important drivers of localized high-impact weather events, but they may also play a larger role in determining climate though upscaling processes. Global high-resolution models, as well as models with regional grid refinement, will enable investigation of these interactions. Areas of special focus include the role of organized convection in warm-season precipitation and the role of atmospheric mesoscale circulations in driving coastal upwelling.

**Space-time Scale Adaptive and Consistent Physics**
A key element will be development of a suite of CAM physics parameterizations with scale-adaptive capability over a wide range of GCM space-time resolutions. Our job will be to develop resolution-insensitive convection, moist turbulence and cloud macrophysics schemes; and impose solid consistency among the parameterized sub-grid turbulence, aerosol, cloud and radiation processes. The interactions between parameterizations and the dynamical core will be rationalized across scales.

**Predictive Science from Intra-seasonal to Decadal Lead Times**
Beyond weather timescales, interactions with the ocean, ice and land surfaces become increasingly important, and we will use initialized seasonal and decadal simulations to enhance the predictive capability of intra-seasonal to inter-annual climate phenomena like the Madden-Julian Oscillation and the El Niño-Southern Oscillation. These simulations can provide leading-edge guidance for associated adaptation and migration strategies. A key aspect of such initialized experiments is collaborative efforts in coupled data assimilation to employ available observations optimally. Decadal and longer climate projections will continue to be examined in light of these predictive science studies, providing state-of-the-art estimates of climate sensitivity as well as regional impacts and their uncertainty.

**Confronting Models with Observations**
We will lead modeling studies and model development activities aimed at enhancing the predictive power of CESM across timescales, thus paving the way to a unified climate modeling/prediction platform. Since many systematic model errors on climatic scales are already evident in the first few timesteps of a model simulation, short forecasts initialized from NWP analyses can be used to evaluate different parameterization schemes and reduce model biases, especially when combined with intensive process level observations from DOE ARM sites, for example. These efforts will begin with a focus on interactions between the parameterized moist physics and explicit dynamics at the shortest timescales using an initialized forecast approach (e.g. the CAPT protocol and CAM data assimilation with DART).
The Climate Analysis Section (CAS) is primarily engaged in documenting and understanding observed climate, including its mean state, variability and change. We study the atmosphere, ocean, cryosphere, and terrestrial components of the climate system and the interactions among them. Areas of emphasis include the global water and energy cycles, atmospheric general circulation, decadal predictability, El Niño–Southern Oscillation, polar climate, and modes of climate variability. We provide leadership to the national and international climate research communities through our contributions to climate data assessment, model evaluation especially of CESM, production and dissemination of climate data sets and CESM simulations, training of graduate students, postdocs, and early career scientists, and committee memberships and editorships. Direct contributions to CESM are conducted through its Climate Variability and Change Working Group (CVCWG).

Foci

Diagnostic analysis of climate variability and change
Empirical studies of observed climate variability and change constitute a cornerstone of CAS research activities. In addition, model ensembles are a powerful tool for understanding the relative roles of internal variability and external forcing in observed climate variability and trends over the 20th century, and in projected variations and trends over the 21st century. A major CAS-led project of the CVCWG will be the production of a 40-member CESM ensemble of historical and future simulations. This “Large Ensemble,” along with 20th century simulations, will be disseminated to the wider climate research community via the CVCWG website and the Earth System Grid.

The global water and energy cycles in the climate system and models
Components of the hydrological cycle that we study include water vapor, precipitation, evapotranspiration, soil moisture, runoff, stream flow, atmospheric moisture. Our energy research includes radiation, transports of different components of energy, and surface fluxes and how these vary and change remain major outstanding issues. The diurnal cycle, annual cycle, variability, extremes, and trends and their links to global warming and geoengineering are explored using multiple datasets and models.

Attribution and predictability of climate variability and change
Understanding and attributing observed climate variations to specific causes is central to CAS science. Therefore, in addition to our diagnostic work (see above), we plan to conduct historical simulations using the atmospheric component of CESM. These simulations will be forced by the observed history of sea surface temperature, sea ice, and greenhouse gas concentrations and other radiative forcing agents, in various combinations, to reveal causal links in the climate system. Specific areas of interest include: the role of Arctic sea ice loss in global climate change; the probability of future surface melting across the Antarctic ice sheet; linkages between polar and tropical climate variability; and variability and change in the global water and energy cycles, including droughts, floods, monsoons, tropical cyclones. Building on our physical understanding of climate phenomena, we plan to pursue decadal predictability studies using novel techniques.

The Climate Data Guide
CAS is a leader in the assessment of observational data used to develop and evaluate Earth system models. As such, CAS is a key point of contact for climate scientists seeking advice on and access to a wide variety of observational data sets. Towards this end, we will continue to evaluate observations and promote their reprocessing and reanalysis into global fields and to make these products publicly available through portals such as our own Data Catalog. We plan to expand and improve the Climate Data Guide (CDG), a community-focused website documenting the strengths, limitations, and applications of climate data sets. The National Research Council has recognized the CDG as an exemplary resource needed for advancing climate. The CDG will include more data sets covering all components of Earth system and will entrench strong community participation through the gathering and dissemination of expert user guidance from experienced data users.

CESM evaluation
Leveraging our expertise and knowledge of observational data sets, climate phenomena, and diagnostic analysis, we shall continue to play a leadership role in the evaluation of CESM. This activity will include training graduate students and university scientists into the CESM evaluation process. A new initiative aimed at developing targeted model benchmarks to assist in the development and tuning of CESM is also included in this activity. The work will draw on insights from both the existing CESM and multi-model archives (e.g. CMIP) to bolster the rationales used for evaluating the component and coupled CESM models with observations. Its long-term goals may also include the development of an objective model tuning methodology for CESM.
The science driver of Climate Change Research (CCR) is the evolution over decadal and longer timescales of global and regional climate in the past and into the future and the related interactions with human systems. CCR applies models for Climate Predictions initialized with observations, Climate Projections of long-term forced change, Climate Hindcasts of past observed change, and Integrated Assessments. At the heart of all CCR activities is accounting for the processes, interactions and feedbacks among the elements of the physical and human climate systems, and understanding the uncertainties that produce a range of responses to a variety of natural and anthropogenic forcing. Direct contributions to CESM are conducted through CESM’s Climate Variability and Change Working Group (CVCWG), Societal Dimensions Working Group (SDWG), and Paleoclimate Working Group (PWG). There is also major CCR leadership and participation in the CGD-wide Climate and Human Systems Project (CHSP).

**Foci**

**Model and scenario development, evaluation, and uncertainty characterization**

The applicability of climate and integrated assessment models depends on reliability as reflected in the understanding of uncertainties and limitations of the models themselves. To improve the usefulness of climate model projections, we conduct in-depth evaluations of model simulations of past and present climates, as well as model development guided by specific observations. Additionally, we address a major uncertainty lying in the scenarios of societal change (e.g. energy use policies, demographics) used to produce emission scenarios used in Climate projections.

**Physical and human processes, forcing and feedbacks**

The processes and feedbacks that produce the climate system response to forcing and govern interactions with society must be understood and quantified. They can be biophysical (e.g. cloud, vegetation, ecosystem) or human (e.g. economic, technological, demographic). Thus a major thrust in CCR is an intensive study of processes, feedbacks and responses in the system on timescales longer than years. Can such understanding in the context of changing external forcing help us quantify the reliability of modeled future climates scenarios and societal impacts?

**Climate variability, internally generated and externally forced**

A major challenge in understanding past, present, and future variations of weather and climate is assessing the relative contributions of internally generated modes of climate variability and externally forced response (e.g. increasing greenhouse gases or changes in aerosol content). This science involves our focused analyses of observations and model simulations. Ensembles of simulations of past climate response to relatively well-known observed forcing (e.g. solar cycle variations, volcanic eruptions, orbitally-driven insolation and greenhouse gas emissions) will be used to quantify the forced response compared to past records, while sensitivity, single forcing or long control runs, combined with diagnostic studies of observations, will provide an enhanced understanding of climate variability and change.

**Decadal and centennial and longer term prediction, projection, and predictability**

Given our ongoing climate hindcast, prediction and projection experiments, we will continue to take a leadership role in coordinated international modeling activities such as CMIP and PMIP. These activities constitute the NCAR contribution to an invaluable multi-model dataset that is a resource for the international climate science community, the US National Assessment, and IPCC assessments. Quantifying the predictability of the climate system provides the framework to evaluate what is possible and how much better we can do with improvements in models and understanding.

**Impacts, extremes and response options**

Extreme weather and climate events typically have some of the greatest negative impacts on human society and natural systems, so an understanding of past and present extreme events may provide insight to future extremes and thus inform response options. Such options could involve adaptation to reduce impacts, mitigation by re-thinking energy and land use strategies, applying alternative economic policies, or resorting to geoengineering, possibly combined with other mitigation methods. Such actions may take a number of decades to fully employ, and CCR model simulations provide a quantitative link between response options and the size and nature of the consequent climate changes.
The Oceanography Section (OS) endeavors to discover the key physical and biogeochemical processes in the ocean and sea-ice and understand their interaction with other components of the Earth system. In conjunction with the CESM Ocean Model (OMWG), Polar Climate, (PCWG) and Biogeochemistry (BGCWG) Working Groups, we represent these marine processes in the ocean and sea-ice components of CESM, including those used for Paleoclimate. These models, together with observations, are used to understand the role of the ocean and sea-ice in natural climate variability and climate change. An emphasis will be the effects on marine ecosystems because of their feedbacks on climate through the carbon cycle and the direct societal connection.

**Foci**

**Understanding ocean processes and representing them in models**

With the CESM community, we aim to maintain state-of-the-science ocean and sea-ice models both for fundamental curiosity-driven research and for climate system science using CESM. In anticipation of the global finer and regionally refined resolution capabilities of the next generation ocean models, new parameterizations of additional key processes and improvements in extant schemes will all need to be made scale-adaptive.

**Understanding the role of ocean and sea-ice processes in large-scale climate variability and change**

Because the ocean and sea-ice have much longer memory than the atmosphere, we will seek to advance understanding of their roles in modes of climate variability (e.g. ENSO) and in climate change. Research questions of particular interest are: to what extent does the natural variability of the ocean arising from instability of currents contribute to atmospheric variability via air-sea interaction; and how do the ocean and sea-ice respond and feed back to climate forcing?

**Coastal oceans and climate downscaling and upscaling**

Given the natural resources and economic assets of coastal margins and their vulnerability to climate change, we will improve the representation of these regions in CESM. We will then investigate the interactions between the coastal zone and the open-ocean and other components of the climate system. In particular, downscaling of global climate model simulations will help us to understand better how climate change might threaten the coastal oceans and their ecosystems, such as coral reefs. We will use regional, high resolution models to discover how processes in the coastal region might influence the larger scale climate system.

**Initialized climate prediction**

On monthly to multi-year time horizons, the initial state and temporal evolution of the ocean and sea-ice components of the climate system play an important role in predicting climate variations. In collaboration with AMP and DART scientists in CISL, and leveraging existing ocean and atmosphere ensemble data assimilation systems, we will develop a coupled ocean-atmosphere data assimilation system for use with the CESM that addresses the need for ocean initialization in climate prediction. We will extend the scope of our initialized prediction capabilities by building sea-ice and biogeochemical data assimilation systems. We will participate in the processing, validating, analyzing and disseminating of the predicted ocean and ice related climate variables.

**Marine biogeochemical and ecosystem processes**

Ocean ecosystems play an important role in regulating natural and anthropogenic responses in global biogeochemical cycles. Therefore, we will continue to develop models of marine ecosystems, with links to higher trophic levels, and to examine the influences of the ocean's mesoscale and sub-mesoscale variability. We will also develop explicit representations of ocean chemistry, particularly with respect to ocean acidification and its consequences. Furthermore, biogeochemical tracers will be used to evaluate the physical processes that mediate ventilation in the ocean model.

**Sea-ice and high-latitude processes, variability, and predictability**

The effects of anthropogenic climate change are emerging first and most strongly in high latitude regions. The implication is that sea-ice plays a significant role in global climate and its change, with effects on atmospheric processes, ecosystems, and human systems. Therefore, we are investigating sea-ice predictability on seasonal to century timescales, sea-ice interactions with ecosystems and society, and changes in high latitude extreme events.
Earth’s land surface affects climate and atmospheric composition through a variety of meteorological, hydrological, ecological, and biogeochemical processes that scientists in the Terrestrial Sciences Section (TSS) identify and try to understand. Together with the CESM Land Model (LMWG) and Biogeochemistry (BGC-WG) Working Groups, we develop the Community Land Model (CLM), including land use, ecosystems and biogeochemical cycles, as the land model component of CESM. We also use remote sensing, advanced analytical techniques, and observational analyses as tools to study the role of the terrestrial biosphere in the Earth system. Research in TSS necessarily spans a broad knowledge of the relationships among the biosphere, hydrosphere, geosphere, and atmosphere. Thus, TSS provides a focal point for CGD and university ecological and hydrological research, and it is also the natural link to human interactions through its involvement in the CHSP and SDWG.

Foci

**Land processes in the Earth system**
Earth’s land surface – its ecosystems, watersheds, cities, and people – is the critical interface through which natural and human systems affect, adapt to, and mitigate global environmental change. Research in TSS aims to discover and to understand the physical, chemical, and biological processes by which Earth’s land surface influence climate and atmospheric composition. Scientists use this knowledge to formulate and validate the integration of disciplinary process models into CLM and to discover new land-atmosphere interactions and their impact on climate. The interacting processes include: surface biogeophysics and hydrology; wetlands, groundwater, and cryospheric processes; biogeochemical cycling of carbon, reactive nitrogen, and phosphorus; ecosystem demography; and disturbance (wildfires, insects, and land use).

**Confronting models with observationally-based data**
Land model development and evaluation requires multidisciplinary observations and advanced analytical techniques to constrain models and to gain confidence in simulated land-atmosphere feedbacks. Innovative techniques are needed to confront models with multiscale observations that include: leaf trait databases, air-land flux measurements; catchment hydrology studies; ecosystem manipulation studies; large-scale remote sensing (leaf area, snow, albedo, and soil water); and atmospheric analyses of CO2 and isotopes. Advanced data assimilation and model data-fusion techniques are used to quantify and understand model biases.

**Linking climate to natural and human systems**
CLM is increasingly used as a tool to assess climate change impacts on eco-systems and their services, hydrological systems (including drought and flooding), agriculture, and urban environments, as well as to assess socioeconomic pathways for adapting to and mitigating climate change. To these ends, CLM is a comprehensive representation of current understanding of the relevant interactions among physical, chemical, biological, and socioeconomic processes. TSS focus areas are agriculture security, water resources, urbanization, habitat, land use and land cover change, and wildfire.

**Enhancing terrestrial system science**
Land models have moved beyond their initial focus on hydrometeorology to simulate the interacting physical, chemical, biological, and human components of the Earth system. Through CLM and CESM, TSS scientists have become the partner of choice for the university ecological, environmental science, and biogeoscience communities to engage in Earth system modeling. TSS scientists host undergraduate and graduate students, post-doctoral research associates, and university faculty to expand their research beyond core disciplinary perspectives to include large-scale geophysical Earth system models. A particular focus is to entrain traditional experimental and observational scientists who have critical observations, theories, or process models. Scientists also participate in national and international short-courses and tutorials related to land-atmosphere modeling.
Community models must be state-of-the-science, easy to use, well documented, extensively tested, widely available, and efficient on a broad spectrum of modern computational platforms. Ensuring these attributes are maintained in all CGD’s community models is the responsibility of CGD’s CESM Software Engineering Group (CSEG) and the CESM Software Engineering Working Group (SEWG). Related activities include responding to user help requests via a web bulletin board, managing all model releases, and continual monitoring and improving model performance. CSEG’s most important function is to provide modern Software Engineering support to all CGD sections and projects, as well as to all CESM Working Groups, including the Land Ice Working Group (LIWG), which otherwise has no direct NCAR involvement. CSEG also runs a testing database for CESM Software developers to track and prioritize upcoming model changes, as well as to document associated problems.

Priorities

**Simulation Support**
CESM simulation support is targeted to provide the CESM community with a single code base that enables out-of-the-box capabilities for the entire modeling process. This single code base supports model parameterization development, and minimizes computational resources. It also supports carrying out “grand challenge” experiments that address unprecedented model resolutions and complexity on the latest HPC architectures.

**Facilitate fundamental climate research**
CSEG develops model software that minimizes required knowledge of the underlying code and hardware complexity. The software is robust, yet flexible and easily extensible in order to permit the addition of new science.

**DATA Diagnostics and Analysis**
CSEG, with NCAR’s Computational Information Systems Laboratory (CISL), will provide model data processing that reduces data volume, without sacrificing scientific quality, in order to address the much slower enhancements in data storage capability compared to computational performance. The product will be kept compatible with evolving CESM diagnostic packages that compare model output to observational data and metrics.

**Community Datasets**
Community datasets encompass output from climate model experiments, post processed model data and value added observationally based datasets. They are extensively used by CGD scientists, university collaborators and research partners. Currently, community data sets are available on-line from a variety of locations, including the CESM website (http://www.cesm.ucar.edu/experiments); the Earth System Grid Federation (http://www.earthsystemgrid.org); CISL’s Community Data Portal (https://cdp.ucar.edu); and the Geographic Information Systems NCAR initiative (https://gis.ucar.edu) from the CISL Research Data Archive (http://rda.ucar.edu). In addition, CGD contributes to the CMIP3 and CMIP5 archives at the Program for Climate Model Diagnosis and Intercomparison (http://www-pcmdi.llnl.gov). The CESM site provides value added information such as model configuration, experiment design, and visual diagnostics.

CGD also facilitates access to a wide variety of observational data sets, vets their suitability for climate studies and model evaluation, transforms them into user-friendly formats and global fields, and disseminates information on their strengths and limitations through the Climate Data Guide (http://climatedataguide.ucar.edu) and the CAS Data Catalog (http://www.cgd.ucar.edu/cas/catalog) websites.

**Priorities**

**Development**
CGD will continue to acquire, evaluate, improve and restructure datasets as well as develop climatologies and high-level derived products (e.g. energy budgets derived from the major reanalysis data sets). Data from satellites (e.g. NASA’s A-train constellation) will be exploited in order to achieve our scientific objectives. Descriptions of the datasets used to evaluate the model experiments including their strengths and weaknesses is an ongoing effort spearheaded by the Climate Data Guide (climatedataguide.ucar.edu).

**Delivery**
Observational and model datasets are available on a variety of grid structures and data formats. CGD, in collaboration with CISL, will develop NCAR Command Language (NCL) interfaces to simplify use and reconfiguration of these datasets. To facilitate efficient access and distribution, CGD will continue to partner with CISL and others to take advantage of new data delivery methods.
Facilities & Services | Tutorials

CGD’s community outreach activities include hosting tutorials. Every summer CGD hosts a week-long Community Earth System Model (CESM) tutorial for graduate students and early-career scientists. The selection process is carefully orchestrated to ensure the maximum impact: only one student per advisor; and a student body with expertise over a wide range of scientific disciplines. To further the outreach efforts, the tutorial, lectures and exercises are made available via the web. Feedback has been overwhelmingly positive, with many students visibly increasing their CESM involvement afterward.

In addition to the CESM tutorial, CGD partners with CISL to run tutorials training scientists in the use of the interpreted NCAR Command Language (NCL). Numerous classes are given throughout the year in Boulder, at UCAR universities, and at other research organizations around the world. NCL is one of the fastest growing interpreted languages in the geosciences, and CGD’s support of the NCL project helps prepare young scientists with the programming tools they need to easily and effectively analyze model and observationally based data sets in a variety of formats.

Priorities

Expansion

Every year the demand for the CESM tutorial continues to outstrip the number that can be accommodated by roughly a factor of two. An obvious future goal is to be more successful in reducing the backlog in demand by increasing the number of students, at least for some number of years. The tutorial committee is considering many avenues to do so, including online possibilities, that will preserve the current productive atmosphere and not unduly increase staff time.
The Administrative Group, a critical component of CGD’s governance and infrastructure, provides scientific management, as well as budget, planning, and other specialized support services to the Division and its Sections. We are committed to CGD’s mission, and we further its goals by instilling a sense of common purpose and facilitating division research, while ensuring compliance with rules and regulations. We employ extensive knowledge and expertise of administrative and management functions to assist our staff with understanding processes, meeting challenges, and resolving issues. We foster collaborative working relationships and facilitate effective communication between colleagues, partners, funding organizations and the public.

We endeavor to be an invaluable source of professional support to our diverse staff and external communities. We strive to maintain an organized, efficient, and productive workplace environment, while upholding the highest levels of service and integrity.

CGD’s web presence (www2.cgd.ucar.edu) exists to facilitate collaborations, to share our tools, and to convey and highlight our science. It serves to distribute relevant information easily and effectively by streamlining everyday processes and by using a functional, visually appealing design that is based on a strategic approach to content organization. Thus the site provides a consistent and enhanced user experience.

The CGD Information Systems Group (ISG) provides a stable, progressive, and flexible computing environment for the development of climate models, climate research, and the attendant administrative tasks. The user community consists of over 120 full time staff scientists, software engineers, and administrative staff located at the NCAR Mesa Lab, with over 350 collaborators from sister institutions and universities on six continents. We provide multilayered support to these users in the form of infrastructure services (e.g. FTP, e-mail, web), local desktop support, data storage (1 petabyte), small scale high performance computing (HPC), and computing security.

The growing complexity, sophistication, and breadth of climate model development continue to push the practical bounds of computing resources within the division. This especially applies to the high cost of data storage and high performance computing cycles. By maintaining close communications with the staff, we will focus on providing targeted cost effective solutions to meet research requirements.

A very robust visitor program exists within CGD and is essential to its success. Therefore, we invest in local infrastructure support to attract visitors and to ensure they can make the most productive use of their time. The visitor program provides opportunities for scientific visits from days to a year or more; often with no prior expectations. The program sometimes nurtures and maintains long-term scientific interactions with university, government and international collaborators. Enhanced interaction with the university community allows us to play a more direct role in the education and training of the next generation of scientists.

Within the visitor program, the most active and involved are Affiliate Scientists, who are nominated and go through a rigorous appointment process. CGD commits ongoing support for their regular visits, which are expected to enhance our overall science program significantly and to foster enduring collaborations. We also designate a select number of “CGD Named Visitors.” It is anticipated that these visitors will leave behind a tangible contribution to the division program. This is also an opportunity to honor past CGD staff for their contributions to CGD’s history and success through the use of their names.
Glossary of Terms

CESM community – The sum total of all individuals contributing to any facet of the CESM project. The principal sponsors are the National Science Foundation and the Department of Energy (DOE), so naturally the majority hail from U.S. universities, DOE national laboratories, and NCAR.

Climate – Statistics, in particular moments and correlations, of the weather.

Climate change – The change in the distributions of the climate mean and weather and climate variability due to a change in the forcing. Such forcing changes can be due to solar variability, volcanic activity or anthropogenic influences.

Climate extremes – Marked deviations from the mean state. Familiar examples are droughts, floods, heat waves, very strong winds.

Climate hindcast – (historical and paleoclimate) – Given datasets of past climate forcing and boundary conditions, a simulation of past climate states that can be compared to either instrumental or proxy records.

Climate prediction – (intra-seasonal to decadal) – Given a specified initial state of components of the climate system, in addition to the atmosphere, a prediction of the future climate mean and variability, along with an estimate of the uncertainty.

Climate projection – (centennial time scales) - Given a specified future forcing scenario, a projection of the future climate mean and variability given specified, though uncertain, forcing, but not necessarily accurate initial states.

Cryosphere – The Earth’s surface that is predominantly water in its solid state.

Data assimilation – The process of synthesizing model solutions and observations to give a consistent analysis of the state of a system. In CGD we are primarily concerned with state of the Earth (Coupled Climate) system for climate predictions.

Diagnostic studies – Analysis of observations, including NWP operational analyses and reanalyses.

Mean state (of the climate system) – Statistics of the weather, primarily temporal and spatial averages over 10 or more samples, e.g. averages of January or annual averages.

Modes of climate variability – Large scale, relatively low frequency (compared to weather) variations in the atmosphere-land-ocean state. Familiar examples include ENSO (El Nino Southern Oscillation) and the North Atlantic Oscillation.

Numerical Weather Prediction (NWP) – Detailed forecasts of the weather produced by numerical models similar to CAM that depend primarily on initial conditions produced by data assimilation and limited in length by predictability. Current skill is less than 10 days.

Paleoclimate – A climate state from the distant past to as recent as the last millennium.

Predictability – An intrinsic property of a physical system measuring the sensitivity of system predictions to changes in the initial state or the forcing.

Weather – The detailed evolution of the atmosphere, e.g. diurnal temperature, precipitation.

Acronyms

ACD – Atmospheric Chemistry Division
AMP – CGD’s Atmospheric Modeling and Predictability Section
AMWG – CESM’s Atmospheric Modeling Working Group
ARM – Atmospheric Radiation Measurement
BGCWG – CESM’s Biogeochemistry Working Group
CAM – Community Atmosphere Model
CAPT – Cloud-Associated Parameterization Testbed
CAS – CGD’s Climate Analysis Section
CCR – CGD’s Climate Change Research Section
CCWG – CESM’s Chemistry-Climate Working Group
CESM – Community Earth System Model
CGD – NCAR’s Climate and Global Dynamics Division
CHSP – CGD’s Climate and Human Systems Project
CISL – NCAR’s Computational & Information Systems Laboratory
CLM – Community Land Model
CMIP – Coupled Model Intercomparison Project
CSEG – CESM Software Engineering Group
CVCWG – CESM’s Climate Variability and Change Working Group
DART – CISL’s Data Assimilation Research Testbed
DOE – Department of Energy
ENSO – El Nino, Southern Oscillation
ESP – Earth System Prediction
IPCC – Intergovernmental Panel on Climate Change
ISG – CGD’s Information Systems Group
HAO – NCAR’s High Altitude Observatory
LIWG – CESM’s Land Ice Working Group
LMWG – CESM’s Land Model Working Group
MM – Micrometeorological Model
MJO – Madden Julian Oscillation
NCAR – National Center for Atmospheric Research
NCL – NCAR Command Language
NESL – NCAR Earth Systems Laboratory
NWP – Numerical Weather Prediction
OMWG – CESM’s Ocean Model Working Group
OS – CGD’s Oceanography Section
PCWG – CESM’s Polar Climate Working Group
PMIP – Paleoclimate Modelling Intercomparison Project
PWG – CESM’s Paleoclimate Working Group
SDWG – CESM’s Societal Dimensions Working Group
SEWG – CESM’s Software Engineering Working Group
TSS – CGD’s Terrestrial Sciences Section
UCAR – University Corporation for Atmospheric Research
WAWG – CESM’s Whole Atmosphere Working Group