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DOE/UCAR Cooperative Agreement for the Regional and Global Climate Modeling Program

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This progress report describes research supported by Cooperative Agreement between the University Corporation for Atmospheric Research (UCAR) and the U.S. Department of Energy (DOE) Biological and Environmental Research (BER). The purpose of the Cooperative Agreement is to provide support for an integrated research program to address key science questions relevant to the DOE Regional and Global Climate Modeling Program as part of the U.S. Global Change Research Program (USGCRP). The Cooperative Agreement funds four tasks that address key aspects of climate science, and this report provides a summary of activities for each task during the past year. As part of the Cooperative Agreement supported science, the Climate Change Prediction (CCP) group at the National Center for Atmospheric Research (NCAR), provides leadership to the Community Earth System Model (CESM) Climate Variability and Change Working Group (CVCWG) through co-chairs Gerald Meehl and Susan Bates (with DOE-funded co-chair Peter Gleckler, along with Clara Deser and Shang-Ping Xie). Over the past year CCP has played a leadership role in performing climate change simulations and analyses with the Community Climate System Model version 4 (CCSM4) and CESM version 1. These simulations and analyses made strong contributions to the federal USGCRP in several high priority areas. We have also been involved in planning for the sixth phase of the Coupled Model Intercomparison Project (CMIP6) which started in 2015. Simulations from CMIP6 will form the basis for ongoing U.S. National Assessment activities, and the IPCC AR6.

Task 1
Research Program on Modeling Future Climate Change: Effects of Increased Atmospheric Carbon Dioxide and Other Climate Forcings; Gerald A. Meehl and Claudia Tebaldi, Principal Investigators

Task 2
Future Changes in Earth's Hydrological Cycle; Aixue Hu, Principal Investigator

Task 3
Evaluation of and Improvements to Components of Climate System Models;
Brian Medeiros and Richard Neale, Principal Investigators

Task 4
Climate Modeling with Mesoscale Atmospheric Variability and Scale-Aware Physical Parameterizations; Joseph Tribbia, Principal Investigator

DOE CA Staff by Task			
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Progress since last review (2012-2017)

The following provides research highlights from the period of the previous DOE/UCAR CA from 2012-2017. Given the text length restrictions, these examples are representative of the larger body of research and model simulations performed by CA scientists during this five year period. A full list of publications from the CA since the last review in 2012 is given in the Bibliography Section D.2.

Decadal variability and predictability

Decadal timescale earth system variability has been shown to influence interannual variability. To address this problem, research was performed to relate the strength of the Tropospheric Biennial Oscillation (TBO), acting on interannual timescales, to decadal-timescale fluctuations of the Interdecadal Pacific Oscillation (IPO) in observations. The transition from positive to negative IPO in the Pacific around 2000 was associated with a higher amplitude TBO, consistent with previous IPO transitions (Meehl and Arblaster 2012). Future simulations of CCSM4 were analyzed to identify where heat goes in the system during decades when globally averaged surface air temperatures are not increasing (hiatus decades), in contrast to decades when there are rapid increases in globally averaged surface air temperature (accelerated warming decades). Accelerated warming decades in the model are characterized by more heat going into the upper ocean layers associated with the positive phase of the IPO. Hiatus decades are marked by the negative phase of the IPO (cooler than normal tropical Pacific sea surface temperatures (SSTs)) and more heat going into the deeper ocean layers (Meehl et al. 2011; 2013a). The interactions between internally generated decadal timescale variability and external forcing mainly from increasing greenhouse gases (GHGs) were quantified for decadal predictive skill both for globally averaged temperatures as well as SST patterns in the Pacific using two versions of initialization for CCSM4. The initialized model simulations out-performed the uninitialized simulations in predicting the mid-1970s shift (positive IPO) and early-2000s hiatus (negative IPO) (Meehl and Teng 2012).
To address decadal-timescale effects of solar forcing on the future earth system, coupled WACCM was used to study the possible future effects of a Grand Solar Minimum, as was seen during the Maunder Minimum in the 17^{th} century when global temperatures cooled. The model simulations showed that such a future solar minimum indeed produced somewhat less warming than in the reference RCP4.5 simulation, but when the sun recovers from the solar minimum, the warming catches up quickly to the reference case. Thus, such a future Grand Solar Minimum would delay but not stop global warming (Meehl et al. 2013b). Even though CESM1(CAM5) includes both the direct and indirect effects of aerosols (CCSM4 has only the direct effect), the overall earth system response, including forcing and feedbacks, is greater in CESM1(CAM5) compared to CCSM4. The total aerosol optical depth in CESM1(CAM5) has less negative forcing (a net positive forcing) from that source during the twenty-first century. Consequently, the change from 2006 to 2100 in aerosol direct forcing in CESM1(CAM5) contributes to greater twenty-first century warming relative to CCSM4 (Meehl et al. 2013c).
In a comparison to uninitialized earth system simulations, a multi-model ensemble from the CMIP5 ten-year decadal prediction experiments produced more warming during the mid-1970s shift and less warming in the early 2000s hiatus in both the tropical Indo-Pacific region and in

globally averaged surface air temperature in closer agreement with observations (Meehl and Teng 2014). Additionally, surface air temperature anomalies for the 2016-2035 period in the 30-year predictions initialized in 2006 are about 16% less than the uninitialized projections. The slowdown in the rate of global warming in the early-2000s is not evident in the multi-model ensemble *average* of traditional future earth system simulations. However, a number of *individual* ensemble members from that set of models successfully simulated the early-2000s hiatus when naturally-occurring earth system variability involving the Interdecadal Pacific Oscillation (IPO) coincided, by chance, with the observed negative phase of the IPO that contributed to the early-2000s hiatus. The CMIP5 multi-model decadal hindcasts showed that if the recent methodology of initialized decadal simulations could have been applied in the mid-1990s using the CMIP5 multi-models, both the negative phase of the IPO in the early 2000s as well as the hiatus could have been simulated, with the multi-model average performing better than most of the individual models (Meehl et al. 2014).

When the IPO/PDO is in phase with the eleven-year sunspot cycle, there are positive SLP anomalies in the Gulf of Alaska and nearly no anomalous zonal SLP gradient across the equatorial Pacific. When the two indices are out of phase, positive SLP anomalies extend farther south in the Gulf of Alaska and west into eastern Russia, with a strengthened anomalous zonal equatorial Pacific SLP gradient and larger magnitude and more extensive negative SST anomalies along the equatorial Pacific. In the North Atlantic, when the North Atlantic Oscillation (NAO) is in phase with the sunspot peaks, there is an intensified positive NAO sea level pressure (SLP) pattern. When the NAO is out of phase with the solar peaks, there is the opposite pattern (negative NAO) (van Loon and Meehl 2014).

Research results quantified decadal predictive skill for regional precipitation regimes in the Pacific Rim using the CMIP5 models (Meehl and Teng 2014). Following from these studies, in a unique effort, an initialized decadal prediction was published that was based on a hypothesized physical process involving a buildup of off-equatorial western Pacific ocean heat content being triggered by an El Niño Southern Oscillation (ENSO) interannual event to produce a decadal transition of the IPO. The prediction initialized in 2013 showed a 2015-2019 IPO transition to positive with associated accelerated rates of global mean surface temperature increase for the 2013-2022 prediction period (Meehl et al. 2016a).

In another two studies involving processes associated with the IPO in connection to high latitude processes, research showed that Antarctic sea ice expansion in the early-2000s was mostly a product of internal decadal variability associated with the negative phase of the IPO (Meehl et al. 2016b).

Extremes

Arblaster and Alexander (2012) analyzed extreme maximum temperatures in a new observational dataset and found them to be significantly cooler over Australia, southern Asia, Canada and South Africa during strong La Niña events compared to El Niño events and significantly warmer over the contiguous United States and southern South America. Two versions of the Community Climate System Model (CCSM3 and CCSM4) were then contrasted for their ability to capture these relationships given their very different simulations of ENSO. While both models capture some aspects of the observed regional changes across the globe, the fidelity of the ENSO simulation appears to be crucial for simulating the magnitude and sign of the extreme maximum temperature relationships. Over the U.S. in particular, the CCSM3 composite pattern of maximum temperature extremes with ENSO is weak and opposite in sign to that observed. The CCSM4 is much improved over the CCSM3, capturing the observed increase in U.S. maximum temperature extremes during La Niña with realistic amplitude, pattern and statistical significance. In a future emissions scenario using the CCSM4, the contrast between maximum temperature extremes during El Niño and La Niña events strengthens over Australia whereas it weakens slightly over the U.S. Research on the attribution of Australian extreme heat events of 2013 and 2014 found that the heat was due to a combination of an unusual circulation pattern, but externally-forced background warming exacerbated the warming (Arblaster et al. 2014; Hope et al. 2015).

Projections of changes in heat extremes and changes in population were merged to provide improved estimates of impacts of heat extremes (Jones et al. 2015). Following from a previous study, new research on temperature extremes showed how the ratio of U.S. daily record high maximum temperatures to daily record low minimum temperatures would increase as a function of future warming over the U.S. (Meehl et al. 2016c).

Looking at another aspect of heat extremes, a medium ensemble simulation with 15 members for the 21st century was analyzed to separate the effects of GHGs and aerosols, in particular the dynamic impact, on the determination of heat extreme duration in the tropics (Xu et al. 2015).

A 12,000-year CAM3 simulation, which provided ample samples of extreme events, was analyzed to demonstrate the importance of the planetary wave patterns in organizing the location and timing of heat waves at various locations in the Northern Hemisphere (Teng et al. 2013; Teng and Branstator 2017). Additional research addressed how changes in a future warmer climate would affect heat waves in the Great Plains by changing the temperature variability. Results showed that for future heat waves in the Great Plains, atmospheric circulation plays a secondary role compared to the effects of land-atmosphere interaction (Teng et al. 2016).

A systematic comparison of waveguide and circumglobal teleconnections for all seasons showed that the changing mean states affect waveguide and circumglobal teleconnections in both the reanalysis and simulations from the CMIP5 models. In addition, a linear stationary wave model was applied to help interpret the dynamic relationships in the reanalysis and models (Teng and Branstator 2012).

A number of observational studies indicating a connection between atmospheric rivers and extreme precipitation events were confirmed in the 0.5° CCSM4 simulations that have sufficient resolution to capture these rivers. Analyses were performed on the RCP simulations to show how changes in atmospheric rivers affect extreme precipitation. Results showed how there are shifts in the latitude of future atmospheric river landfalls (Shields and Kiehl 2016a), and the "Pineapple Express" was well-simulated in 0.5° CCSM4 (Shields and Kiehl 2016b).

The impacts of sea level rise on the statistics of storm surges were quantified using a novel methodology (Kopp et al. 2014; Kopp et al. 2015; Buchanan et al. 2016).

Bio-geochemistry (BGC)

The development and release of CLM4.5 included substantial improvements to the model targeted at investigation of the permafrost-carbon feedback including improvements to permafrost hydrology, vertically-resolved soil carbon/nitrogen cycling, and a new fractional snow cover area parameterization (Swenson and Lawrence 2012). The permafrost-carbon feedback was weak (in CLM4.5) through the end of the 21st century, but amplified strongly in the 22nd and 23rd centuries under RCP8.5. Forcing datasets and methods for an international permafrost-carbon model intercomparison project were also developed and distributed. A significant paper documented present and future permafrost simulations from earth system models (Slater and Lawrence 2013).

A factorial series of offline land model experiments for the period 1850 to 2300 with CLM4.5 were analyzed to examine the permafrost-carbon feedback. These experiments included controls, constant CO2, constant temperature, constant precipitation, carbon only (rather than carbon and nitrogen), and targeted parameter sensitivity experiments. Analyses showed that the permafrost-carbon feedback is strongly dependent on the decomposability of deep soil carbon and is relatively insensitive to deep soil nitrogen mineralization (Lawrence et al. 2015). The feedback in CLM4.5 BGC is relatively weak by the end of the 21st century, but amplifies strongly in the 22nd and 23rd centuries under RCP8.5. Additional analyses indicated that the hydrological response to permafrost thaw, which in CLM is towards a drying trend, affects the carbon cycle response. The drying accelerates soil carbon decomposition on the one hand, but reduces methane emissions with the combined effect of drying actually decreasing the overall Global Warming Potential of permafrost thaw (Lawrence et al. 2015).

Groundwater depletion is a threat to food security both in the U.S. and abroad, but quantifying human withdrawals at regional scales is highly uncertain. A promising method to quantify human withdrawals of groundwater used model output from CLM to remove climate induced water storage variability from GRACE data. From this technique, groundwater depletion has been observed in Northern India, the Middle East, and the United States. These estimates of human groundwater withdrawal are sensitive to model estimates of water storage; model biases project directly into the residual groundwater estimates. Consequently, a soil resistance parameterization was developed that greatly improves GRACE-based groundwater withdrawal estimates in semiarid regions by reducing biases in CLM soil evaporation. After improving the CLM simulation of water storage variability, a much clearer picture of human induced groundwater loss was obtained from the GRACE data (Swenson and Lawrence 2015). Subsequent research has further interpreted GRACE-era terrestrial water trends (Fasullo et al. 2016).

CLM4.5 projected significant soil drying due to increased drainage following permafrost thaw, even though permafrost domain water inputs are projected to rise (net precipitation minus evaporation > 0). CLM predicts that drier soil conditions will accelerate organic matter decomposition, with concomitant increases in carbon dioxide (CO2) emissions. Soil drying, however, strongly suppresses growth in methane (CH4) emissions. Considering the global warming potential (GWP) of CO2 and CH4 emissions together, soil drying weakens the CLM

projected global warming potential (GWP) associated with carbon fluxes from the permafrost zone by more than 50% compared to a non-drying case (Koven, Lawrence and Riley, 2015).
CA scientists led by David Lawrence helped spearhead and contribute to the development of the International Land Model Benchmarking package, including applications of ILAMB to CLM simulations to aid in CLM5 development and assessment.

Model errors and model improvements
In the Community Climate System Model, version 4 (CCSM4), one of the largest biases in sea surface temperature (SST) is located in the North Atlantic (e.g. Danabasoglu et al., 2012). This is a common error in many models, and results from the Gulf Stream separation point being located too far north and its path across the basin being too zonal. Through air-sea fluxes, the SST errors impact the overlying atmosphere, most notably storm track location. Experiments were conducted testing various bottom topography and lateral viscosity configurations to determine their importance in steering this flow. Additionally, a vorticity budget analysis was conducted on both high and low resolution models to determine which terms balance Gulf Stream flow. Results showed that the biases in the CCSM4 in sea surface temperature and salinity within the Gulf Stream region are reduced the most by smoothing the bottom topography as well as decreasing the lateral viscosity; however, while vorticity budget terms were affected, these changes did not have a significant effect on the Gulf Stream path. Barotropic vorticity diagnostics confirm that the subtropical gyre is characterized by an inviscid balance primarily between the applied wind stress curl and bottom pressure torque (Schoonover et al. 2016).
Biases in air-sea fluxes were also investigated within the CCSM4 in Bates et al. (2012). The authors provide a new baseline for assessment of flux variance at annual and interannual frequency bands in future model versions and contribute a new metric for assessing the coupling between the atmospheric and oceanic planetary boundary layer (PBL) schemes of any model. Variance on annual time scales has larger error than on interannual time scales and different processes cause errors in mean, annual, and interannual frequency bands. Air temperature and specific humidity in the CCSM4 atmospheric boundary layer follow the sea surface conditions much more closely than is found in observations. Sensible and latent heat fluxes are less of a negative feedback to sea surface temperature warming in the CCSM4 and the model's PBL allows for more heating of the ocean's surface.
With regard to how to deal with model errors, a study of model tuning showed that such tuning does influence perceived model performance (Sanderson and Knutti 2013). Studies of cloud processes showed model deficiencies in the southeast Pacific stratocumulus regimes (Medeiros et al. 2012). Problems with representing shallow convection appear to be at the heart of such errors, in CESM and across the CMIP5 archive (Nuijens, Medeiros, and co-authors, 2015a,b; Medeiros and Nuijens, 2016). Complementary studies demonstrated the role of mixed phase clouds in model systematic errors in Arctic wintertime temperature inversions (Pithan et al. 2014).
A long-standing error in the energy formulation of the atmosphere was discovered in the Community Atmosphere Model (CAM). This error was not present in earlier versions of CCM but was introduced in the first release of CAM. By comparing ten-year AMIP simulations using the correct and incorrect energy formulations we showed that the error did not have a

significant impact on the simulations. Thus the error does not invalidate the hundreds of papers published using CAM simulations (Williamson et al. 2015).

Response to forcings and future change

An influence of short-lived pollutants on global mean sea level rise was documented (Hu et al., 2013c), and the uncertainty of projected future regional sea level rise due to internal variability was addressed (Hu and Deser, 2013). Effects of historical volcanic aerosols on the response of the earth system to greenhouse gas forcings, including a quantification of significant impacts and effects of continental ice retreat on the future earth system, were quantified (Hu et al. 2013a).

The effect of natural variability on feedback estimates using the CESM1 Large Ensemble was investigated to show that the spread in feedback estimates from this 40-member ensemble accounts for about 25% of the variability introduced in the entire CMIP3 archive (Jonko et al. 2013).

Research documented the main patterns of forced response in CMIP5 (and CMIP3) models used to develop a pattern scaling technique (Tebaldi and Arblaster 2014). A novel sensitivity study quantified the impact on the earth system of an idealized large-scale deployment of solar panels over desert regions (Hu et al. 2016). Results showed that the solar panels acted to cool the system somewhat, with greater impacts in some regions.

Xu and Xie (2015) demonstrated the similarity of sulfate and other aerosols in the mid-latitude atmospheric temperature response. The underlying sea surface temperature changes were shown to play in instrumental role in determining the overall responses in the mid-latitude troposphere.

With regard to defining model characteristics, two papers addressed the subject of model independence, describing a new methodology which was implemented in the current U.S. National Climate Assessment (Sanderson et al. 2015a,b). The sensitivity of regional change to global measures of changes (radiative forcing/global average temperature change) was addressed in order to characterize the effects of different scenarios at regional scales (Tebaldi et al. 2015). Further research demonstrated what combination of forcings would be required to reach the Paris targets (Sanderson et al. 2016), and also showed the benefits of mitigation for future heat extremes under RCP4.5 compared to RCP8.5 (Tebaldi and Wehner 2016)

High latitude processes

One of a number of studies addressing processes and mechanisms associated with high latitude Atlantic Meridional Overturning Circulation (AMOC) connections included a paper describing the impacts of a collapsed AMOC on regional and global heat balance (Hu et al. 2013b). An example representative of several papers studying the influence of a closed vs. open Bering Strait on the mean and high latitude climate was one that documented the effect of different background climates (present day, 15 thousand years before present day, and 112 thousand years before present day) (Hu et al. 2015). A study that addressed various features of regional sea level rise at different latitudes highlighted the west Pacific and showed intensified Pacific trade winds to be a dominant factor associated with the steady warming of the Indian Ocean and the negative phase of the IPO in the Pacific (Han et al. 2014).

In a high latitude application of Pacific decadal variability research noted earlier, a tropical Pacific connection to high latitude processes involved with Antarctic sea ice showed that Antarctic sea ice expansion in the 2000s was mostly a product of internal decadal variability associated with the negative phase of the IPO (Meehl et al. 2016a)

Model hierarchy

Experiments modifying computational aspects of the model were performed to determine their effect on the vertical distribution of heating. Doubling the vertical resolution to 60 levels produced the same parameterized heating from each component in the region of interest (Williamson 2013a). Dividing the parameterization time step by a factor of 4 resulted in the same net parameterization heating, but the partition between components changed, with some individual component heating rates varying by 50% (Williamson 2013b).

A default CAM5 aquaplanet configuration was developed (Medeiros et al. 2016). Numerous experiments were performed along the way to assess the role of aerosol in the aquaplanet system as well as sensitivity to dynamical core and model physics. The favored approach used the predicted sea-salt flux as the only aerosol emission source. The largest discrepancy with AMIP-type simulations was in the tropospheric ice: the aquaplanet tends to have more of its ice as snow rather than cloud ice crystals. To understand the origin of this difference, an experiment with the 3KW1 SST pattern was run to break the zonal symmetry (Williamson et al. 2012); the tropical circulation weakened but the ice/snow partitioning remained the same, so the conclusion was that bias arises due to lack of dust to act as ice nuclei. Assumptions about aerosol could impact climate sensitivity, but sensitivity to physics and dynamics could be as large. The CFMIP aquaplanets exhibit substantial spread, even without aerosol effects, mostly due to differences in the shortwave feedback of subtropical clouds (Medeiros et al. 2015). The CAM5 aquaplanet was subsequently used to illustrate aerosol influences on climate feedbacks (Gettelman et al. 2016). The aquaplanet framework was also extended to include a slab ocean model (Zhang et al. 2016; Benedict et al. 2017), which will allow examination of surface temperature feedbacks.

A study with CESM showed that the 21st Century southern hemisphere jet shift is distinct from the cloud response (Kay et al. 2014), contrary to the notion that the clouds simply shift along with the jet. Some follow-on experiments were conducted with the CAM5 aquaplanet to examine the role of cloud radiative effects on the large-scale circulation (and jet position in particular). Those experiments used a fixed SST, and little sensitivity was found.

A fundamental aspect of the aquaplanet configuration is that it allows the full global model to be investigated with reduced complexity. A further reduction in the form of radiative-convective equilibrium (RCE) was implemented in CAM5. The CAM5 RCE configuration uses a uniform, warm SST with no planetary rotation with simplified boundary conditions that represent tropical averages. In Reed et al. (2015a), this configuration is introduced and used to investigate the model sensitivity to increased horizontal resolution as well as to lower boundary condition. The resulting climate is quite similar to the standard model's tropical climate, but convection becomes self-organized and the organization manifests differently depending on resolution and lower-boundary condition. The results were extended to grid spacings down to 7 km using a reduced planetary radius; the organization continues to vary with resolution while the cloud structure is degraded at the highest resolutions (Reed and Medeiros 2016). A novel methodology was applied to a set of RCE simulations to show that the temperature response of extreme precipitation is tied to changes in organized convection (Pendergrass et al. 2016).

High resolution and scale aware parameterization

A version of NCAR-CAM5 was developed using the Spectral Element dynamical core that, at 25km horizontal grid spacing, replicated the fidelity of the same model integrated with a 100km grid spacing as measured by the Taylor diagram metric used by the CESM Atmospheric Model Working Group (Bacmeister et al. 2014). Additionally, a more robust simulation framework through improved parameterizations was developed that coupled the 25 km resolution atmosphere to a 0.10^{o} ocean (Small et al. 2014).

In the area of scale-aware physics for high and multiscale resolution atmospheric modeling, a unified deep and shallow convection parameterization, UNICON, was developed that was designed from the outset to be grid-scale independent (Park 2015a,b). UNICON performed extremely well in standard 100km grid spacing atmospheric simulations, vastly improving the simulation of the Madden Julian Oscillation and the diurnal cycle of precipitation.

Research showed that the details matter regarding how atmosphere and ocean are coupled in high resolution climate model simulations with impacts on simulation of extremes in the model (Zarzycki et al. 2015).

Reed et al. (2015b) explored the impact of using CAM5 with the spectral element dynamical core (CAM5-SE) versus the finite volume dynamical core (CAM5-FV) and concludes that the dynamical core has a significant impact on storm intensity and frequency, with CAM5-SE producing higher frequency, more intense tropical cyclones relative to CAM5-FV. An important technical result from this analysis was the recognition that in order to correctly capture high resolution winds, the CESM atmosphere-ocean fluxes had to be computed on the finer of the two grids. Historically, they were calculated on the ocean grid. However, this analysis led to the decision to move flux calculations from the nominally 1^{o} ocean grid onto the 0.25^{o} atmosphere grid (Zarzycki et al. 2015).

Data and model simulations

Listed below are the data and simulations made publicly available from 2012-2017 (grouped by fiscal year).

- 10/2012-09/2013: 30 TB of CESM data were added to the CMIP5 archive, representing approximately 40 new CESM1/CAM5 experiments. Additional data analysis and postprocessing tasks included beginning to run the CESM CVCWG Group CESM1/CAM5/BGC “Large Ensemble” set of runs, as well as other CESM experiments performed by DOE-CA funded NCAR staff.
- 10/2013-09/2014: 20 TB of CESM data were added to the CMIP5 archive, representing 34 new CESM1/CAM5 and CESM1/WACCM experiments. Additional data analysis and postprocessing tasks included continuing the CESM CVCWG “Large Ensemble” set of runs (200+ TB of model data). DOE-CA staff were key consultants for the CESM Paleoclimate Working Group CESM1/CAM5 “last millennium ensemble” (200+ TB) as well as other CESM experiments performed by DOE-CA funded NCAR staff.

- 10/2014-09/2015: 16 TB of CESM data were added to the CMIP5 archive, representing 37 new CCSM4/CAM4, CESM1/CAM5 and CESM1/WACCM experiments. Additional data analysis and post processing tasks included the completion of the CESM CVCWG CESM1/CAM5/BGC “Large Ensemble” (320+ TB of model data).
- 10/2015-09/2016: 20 TB of CESM data from the “medium ensemble”, a large initial condition ensemble of RCP4.5, were added to NCAR's existing archive. A perturbed physics ensemble of simulations also was produced using alternative configurations of CESM1-CAM5 for both the historical period 1920-2005 and RCP8.5 in the future. CCSM4 0.50^{o} simulations were made publicly available as were data from a large ensemble with aerosols fixed at year 2000 values. DOE-CA-funded scientists ran and post-processed seasonal forecast data for the NOAA Climate Prediction Center (CPC) North American multi-model ensemble (NMME). Six month forecasts with six members for the period 1981-2004 were performed and post-processed for NOAA CPC. ENSO analysis from these data was completed and a much larger suite of seasonal forecasts over the historic record was performed, which consisted of one year forecasts and 10 ensemble members for the period 1981-2010 that involved significant additional output data, including high frequency data.
- 10/2016-present: A large ensemble of simulations limiting temperature increase to under 2°C were run and made available. New simulations included extensions of CESM1/CAM5/BGC decadal prediction runs from 620 members to 2,480 in total. Data from these runs will be made public in fall 2017.

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