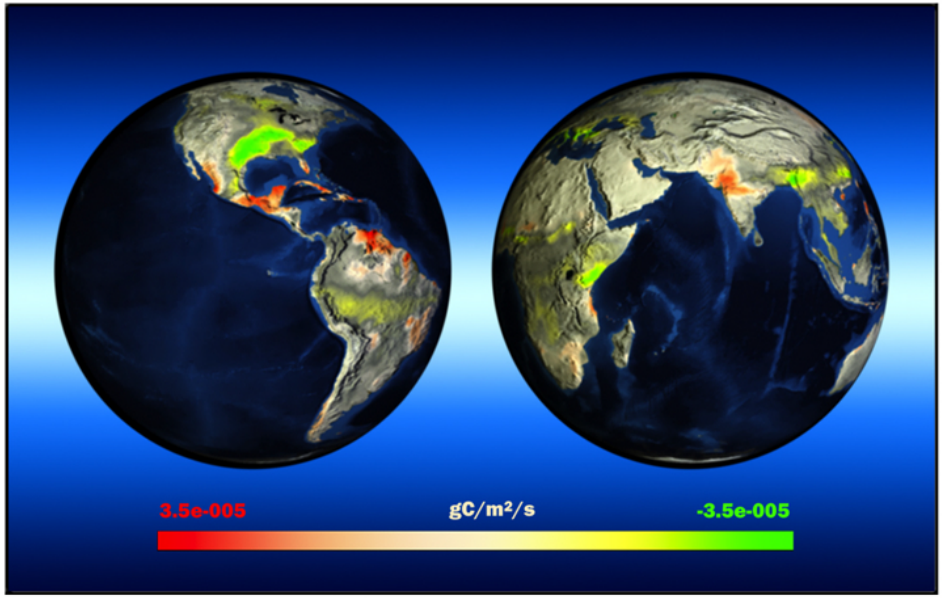
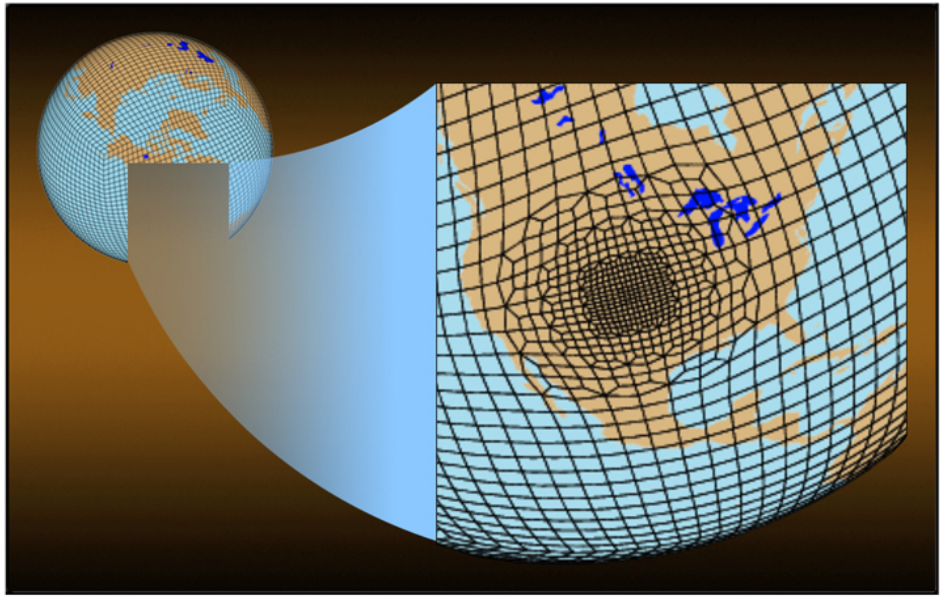
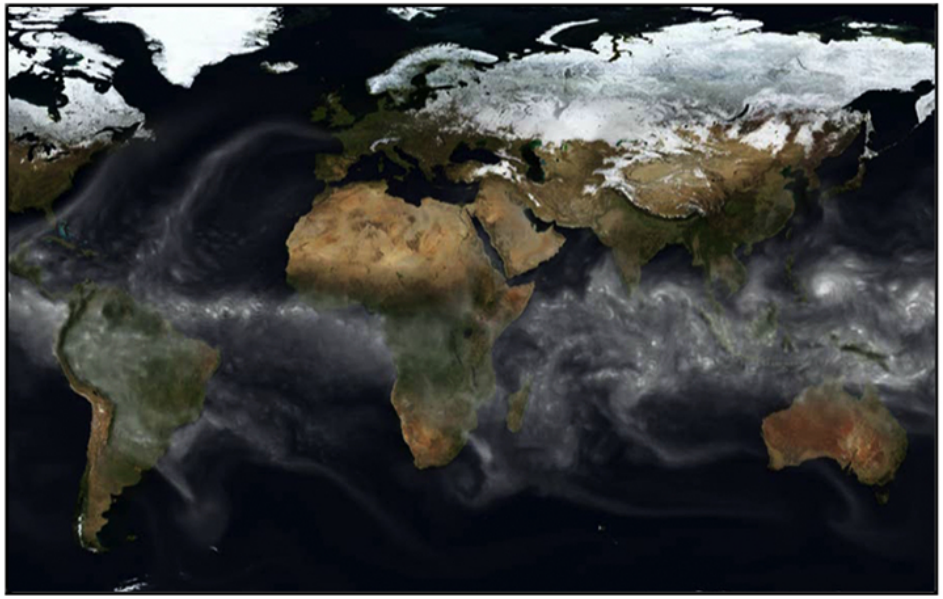
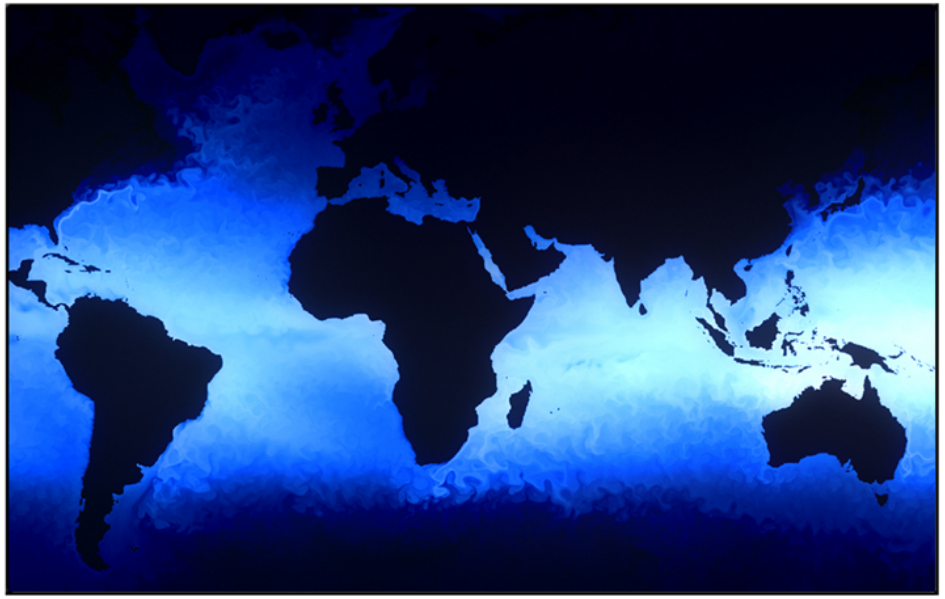
Climate Science for a Sustainable Energy Future









Bader, Koch, Klein, Jones, Thornton, Williams, Hack, Collins and Large, 9/19/2011*

*CSSEF Science Team

- David C. Bader (LLNL)
- Dorothy Koch (DOE)
- Stephen A. Klein (LLNL)
- Philip W. Jones (LANL)
- Peter E. Thornton (ORNL)
- Dean Williams (LLNL)
- James J. Hack (ORNL)
- William D. Collins (LBNL)
- William Large (NCAR)
- *With special thanks to*
- Anthony Janetos (PNNL)

Climate Science for a Sustainable Energy Future (CSSEF) Outcome

- Global models – AOGCMs and Earth system models – that are genuinely predictive at the regional level. (mission)
- Achieved through “integrated, multidisciplinary”…”concerted, strategic research effort”. (vision)
- Introduces variation to existing paradigm - integrates core capabilities of all Labs and NCAR in a single effort

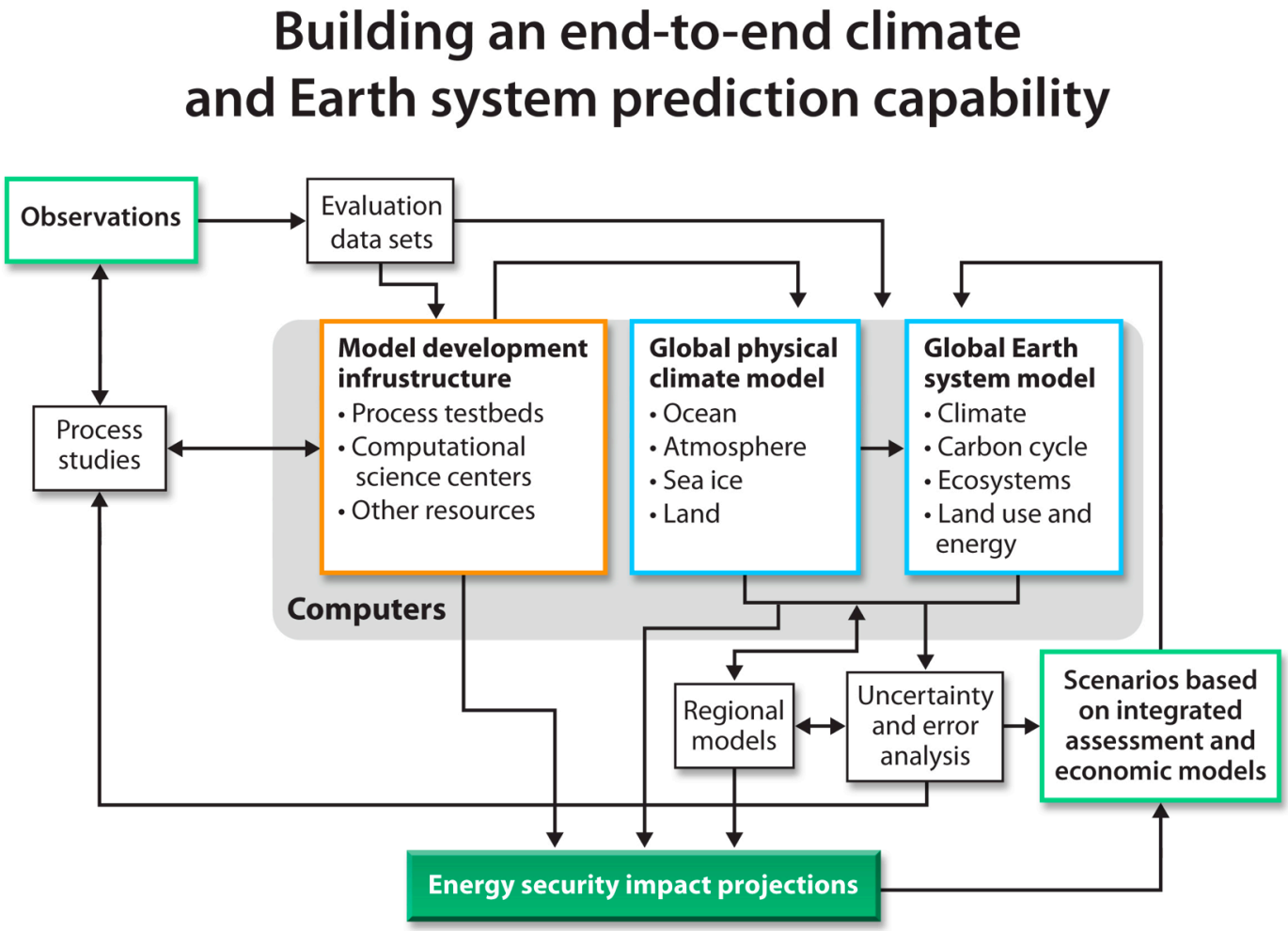


Fig. II.1. Conceptual view of an ongoing climate simulation and prediction enterprise such as the CESM project. New versions of models are developed from increased understanding gained through the integration of observations, process research and earlier model studies.

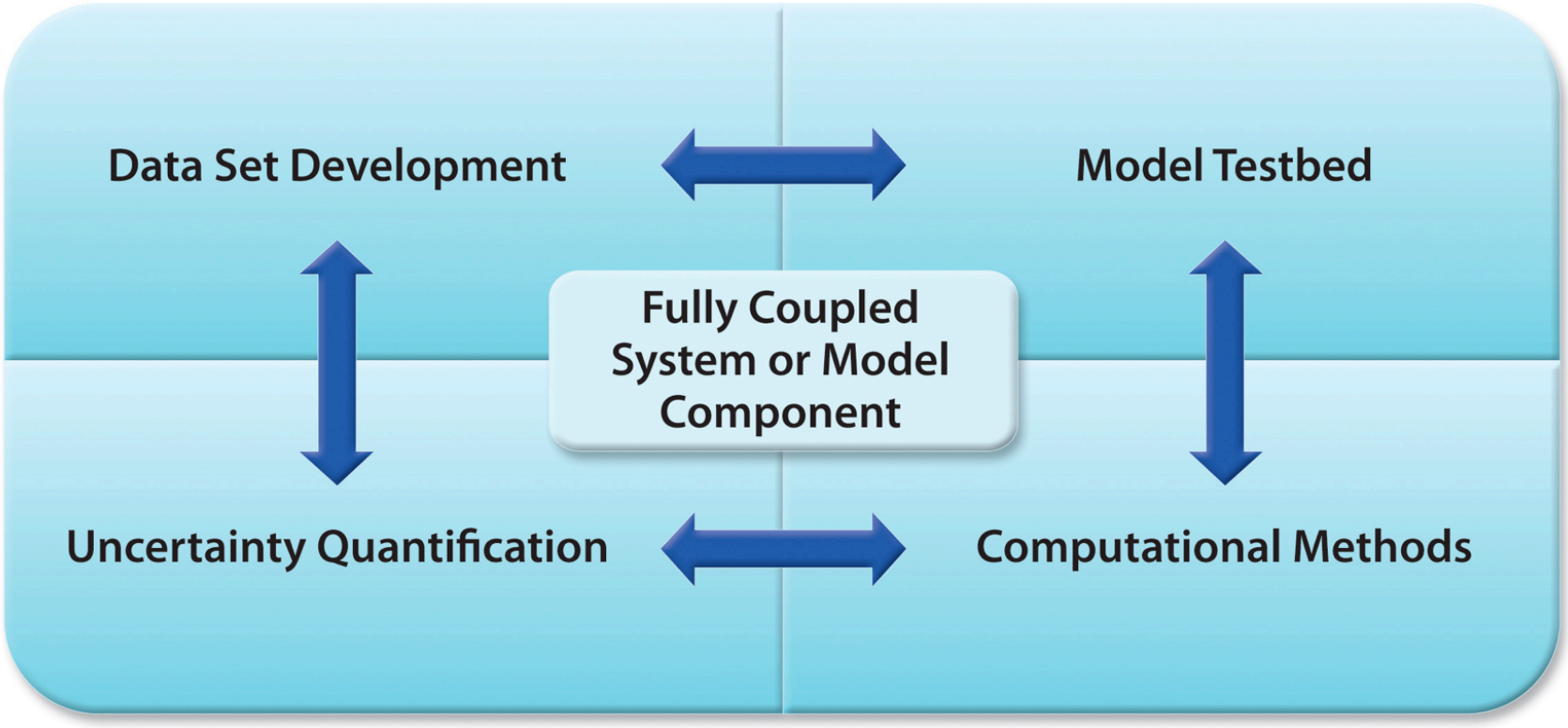
A Sustained Predictive Capability with a new Model Every 5 Years

- Develop multiple generations of model simultaneously in parallel tracks
- Target new and expanded observational programs to model deficiencies
- Promote the development of computational science capabilities matched to Earth system simulation needs
- Quantify uncertainty in model predictions

CSSEF Overarching Research Directions

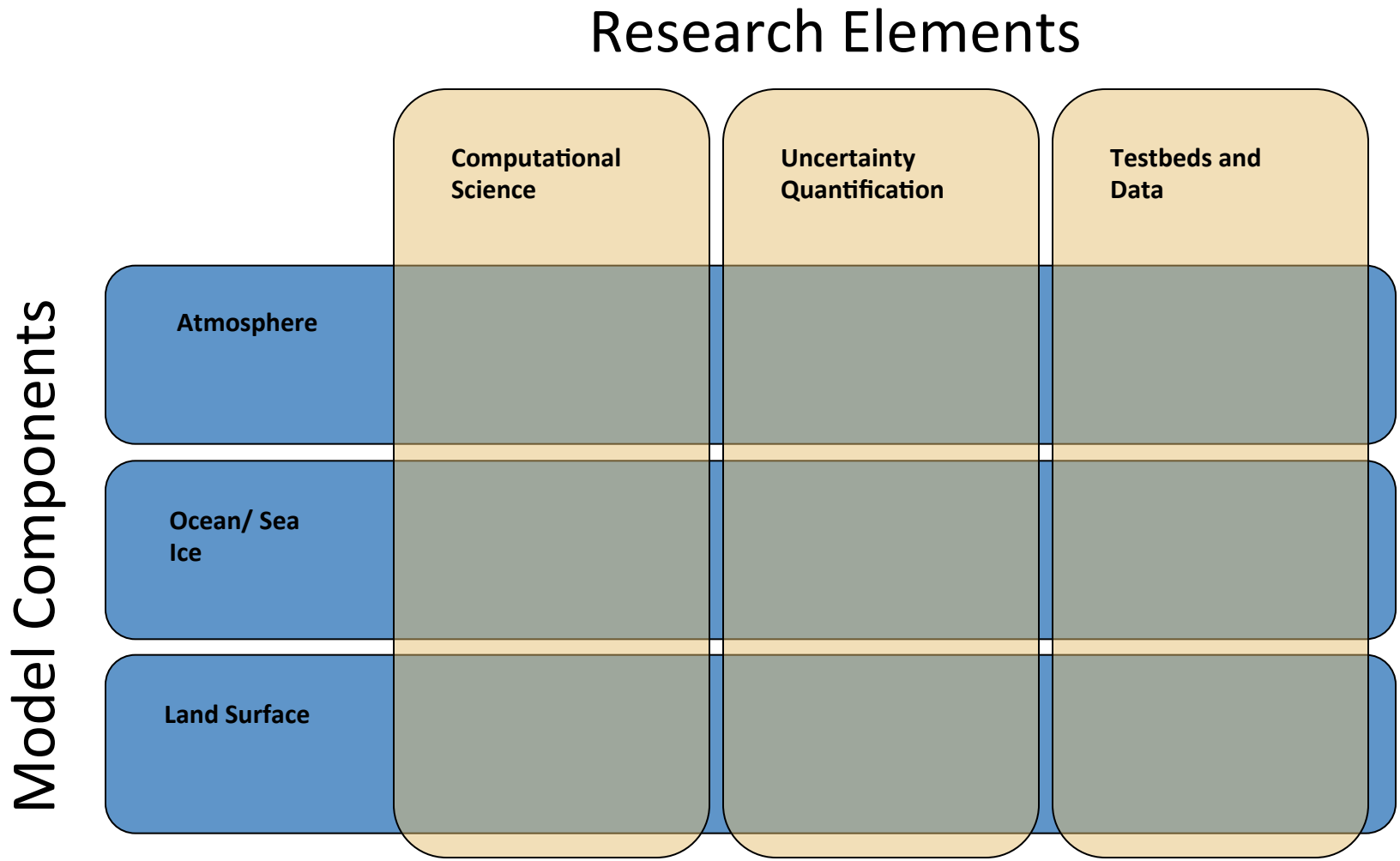
- The development, implementation, and testing of variable-resolution methodologies that enable computationally efficient simulation of the climate system at regional scales,
- The improvement of the representation of the hydrological cycle and quantification of the sources of certainty in its simulation, and
- The reduction and quantification of uncertainties in carbon cycle and other biogeochemical feedbacks in the terrestrial ecosystem

Tightly Integrated Project Focused on CESM 3 Components (2015-2020)



Relationships among the four research themes.

CSSEF Project Structure



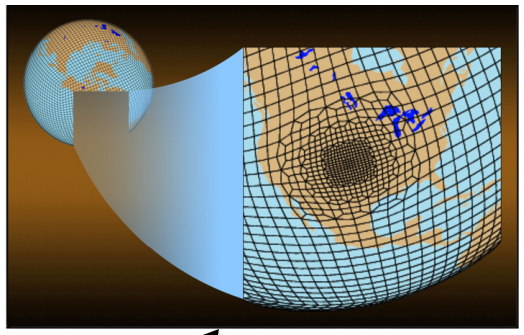
Climate Science for a Sustainable Energy Future

Cross-cutting Themes and Labs to advance CESM to address high priority DOE climate research

3 Science Themes:
- Numerics
- Testbeds
- Uncertainty Quantification

3 Components:
- Atmosphere
- Land
- Ocean and Sea-Ice

3 Research Directions:
- Hydrologic simulation improvement
- Variable-resolution numerical methods
- Carbon cycle uncertainty reduction



9 Labs:
ANL
BNL
LANL
LBNL
LLNL
ORNL
PNNL
SNL
NCAR

Where we are now – “Fast Start”

- $5M of FY 11 funding allocated
- Practicalities required to solicit relevant activities from DOE labs and NCAR to expedite funding
- Four-month task window.
- Money arrived ~July 1

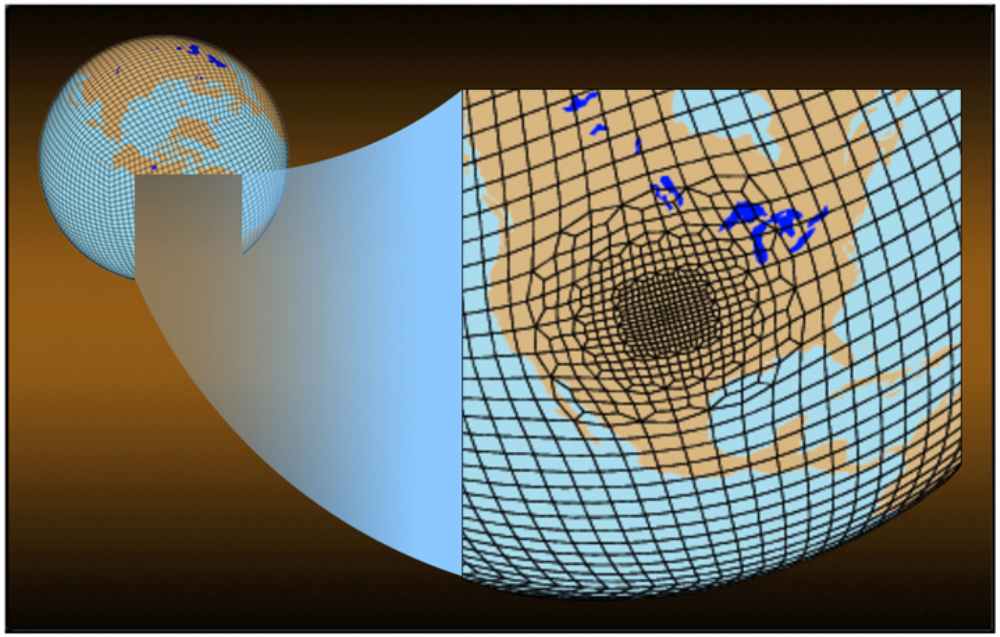
FY 11 Work Plan

e

- **"Fast Start" List of Milestones for period July 1 to October 31, 2011**
- (Draft August 18, 2011, adapted from Year 1 Milestone and Deliverable list from CSSEF Proposal pp. 178-180)
- **1.1 Atmosphere**
- **1.1.1 Data and Workflow Infrastructure**
- 1.1.1.1 *Initial design and prototype of calibration testbed, including at least one data set and metric*
- Task: Build CAM5-SE in forecast mode (LLNL)
- July 15 Obtain and build ESMF regridding utility at LLNL Computing Facility
- July 31 Generate grid descriptor files needed by regridding application
- August 15 Test robustness of regridding utility between FV lat-lon grid and CAM-SE grid and generate initial condition files for the atmosphere on CAM-SE grid
- August 31 Design and prototype analysis of atmospheric model data in testbed
- Task: Generate files of weekly SST/sea ice observations for the boundary conditions in the CAM format on SE grid (LLNL)
- September 15 Generate initial condition for land model on CAM-SE grid
- September 30 Test code to insert the SE initial conditions into the CAM initial or restart files
- October 15 Test running CAM-SE forecasts with prescribed SSTs, observed initial conditions, spun-up land
- October 31 Superficial analysis of simulation quality of the forecast against ARM data with comparison to identical forecast made with CAM-FV

Atmospheric Model Testbed

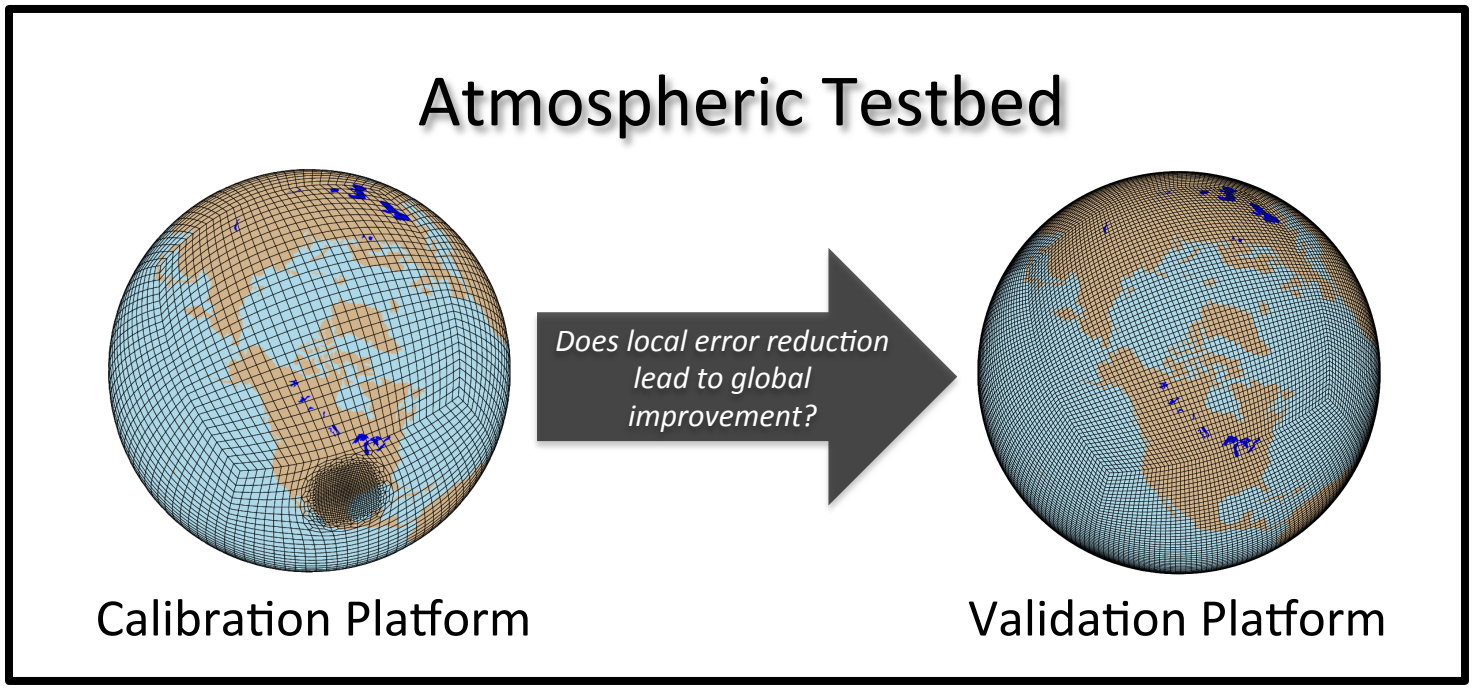
- CAM-Spectral Element initial dycore
  - Scales well to 100,000 processor cores
  - Connects to High Res Project, SciDAC, Regional Frameworks and Atmospheric Feedbacks



- High resolution
  - 1/8° resolution reproduces the observed kinetic energy spectra of k^{-3} for large-scale and $k^{-5/3}$ for mesoscale-turbulence motions

- Regionally refined

Testbed to Better Model?



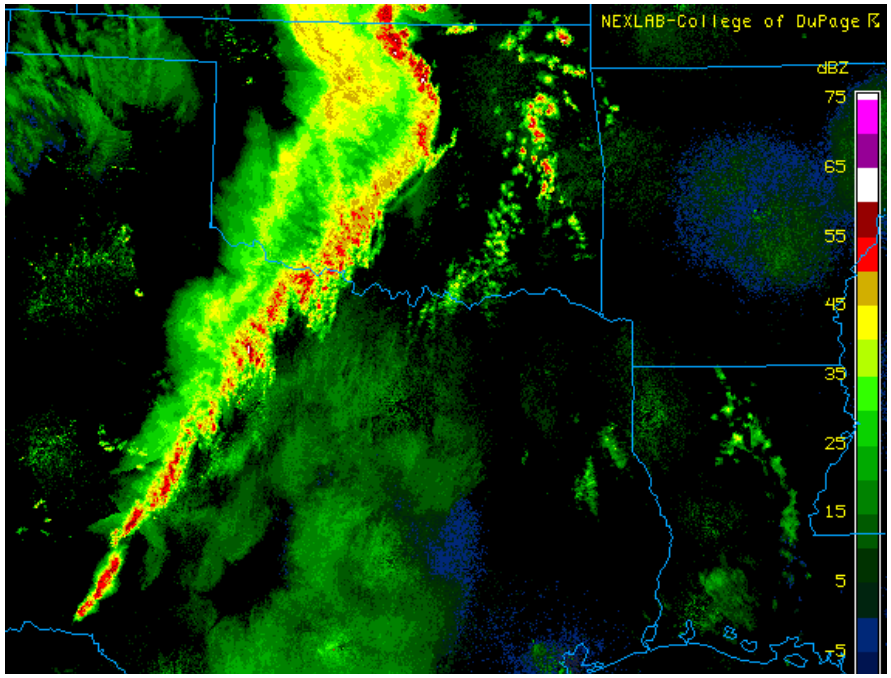
- Observations to calibration & quantify
- All atmospheric models need to be calibrated w/ observations because they contain parameterizations

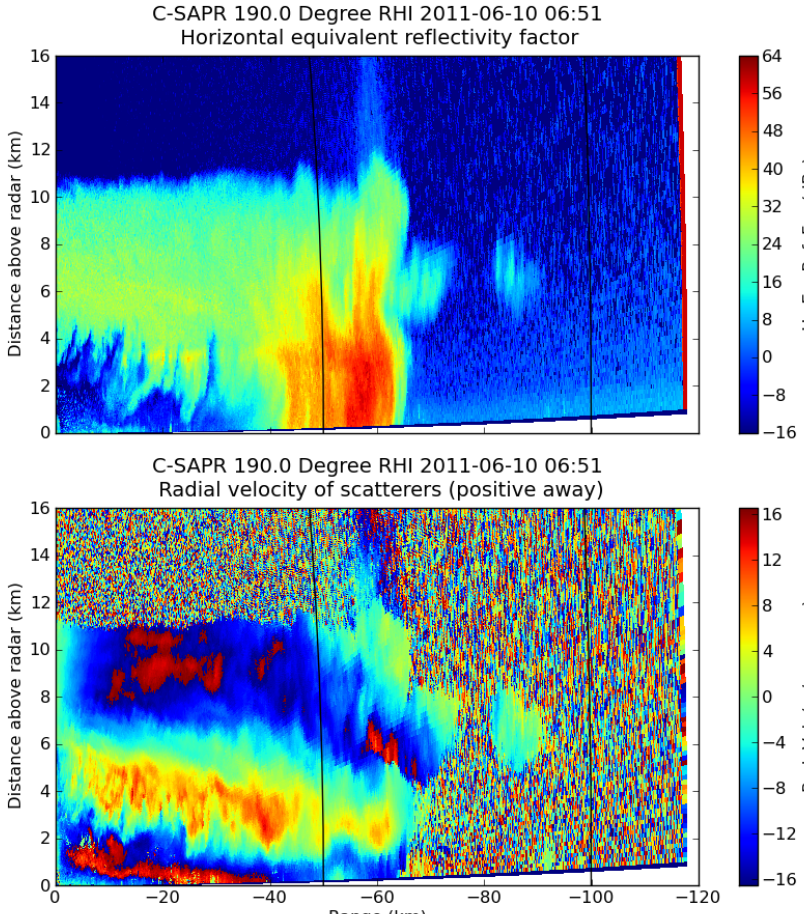
Table IV.1. Characteristics of Calibration and Validation Platforms

	Calibration Platform	Validation Platform
Model Construction	Global model with static mesh refinement above sites of interest	Global model with uniform grid
Forcing	Weather-forecast mode with nudging to analysis data on coarse outer grid	Free-running climate mode with initial condition from analysis data
Initial Resolution	1/8° fine mesh transitioning to 1°	1/8° everywhere
Uncertainty Quantification Methods	Parameter tuning: calibration of uncertain parameters with local data sets	Ensemble of simulations with parameter sets generated by parameter tuning
Data sets	Local water cycle data sets such as ACRF site data	Global data sets such as satellite or re-analysis data

Utilizing ARM ARRA Instruments

- With ARRA funds, ARM installed over 60 new advanced radars (many of which see precipitation)
- We'll use these observations in our model calibration
  - Mid-latitude Continental Convection
  - http://campaign.arm.gov/mc3e/
  - Organized Tropical Convection and MJO
  - (http://campaign.arm.gov/amie/)





ARM Data uncertainty quantification

- Apply initial uncertainty estimates to CMBE surface meteorological variables
- Uncertainty estimation based on instrument specs and meteorological conditions assigned to 1-minute measurement data sets
- Data UQ methodology:
  - Conduct various quality checks (min/max thresholds, outlier checks, time variability checks, etc) are run on 1-minute measurements of temperature, relative humidity, etc
  - Employ Principle Component Analysis for outlier identification and missing data recovery

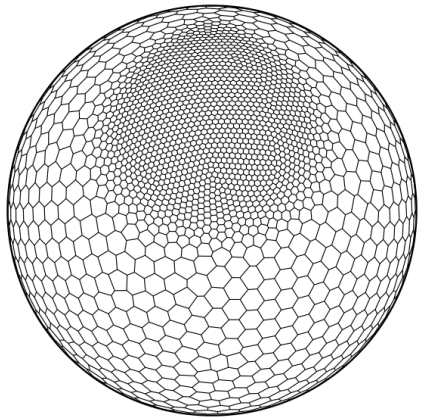
Modeling tools: Progress

- Variable resolution model (2° → 1°) being tested in aqua-planet mode
  - Precipitation & cloud statistics of high-resolution portion of the model match those of a uniform high-resolution model integration (and likewise for the low-resolution portion)
- Developing tools necessary for a regionally refined model with realistic geography
  - Enabling land-model to run on same regionally refined grid
  - Software development to enable integration with CESM scripting environment ongoing (data output, initial and boundary condition data files, etc.)

CESM Ocean Component

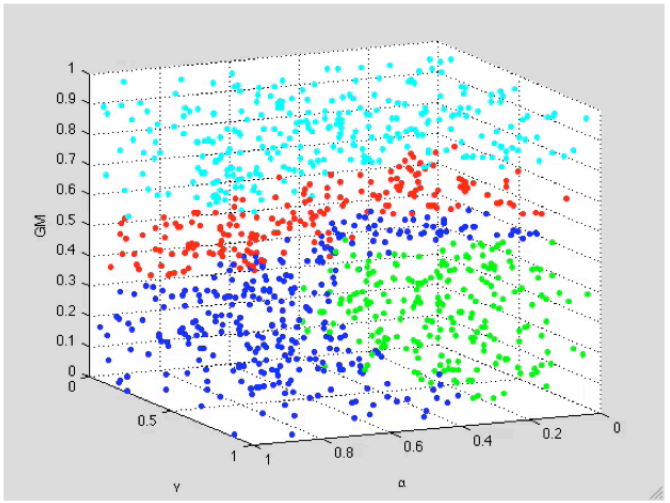
CESM3 Ocean - Codename: Anglerfish

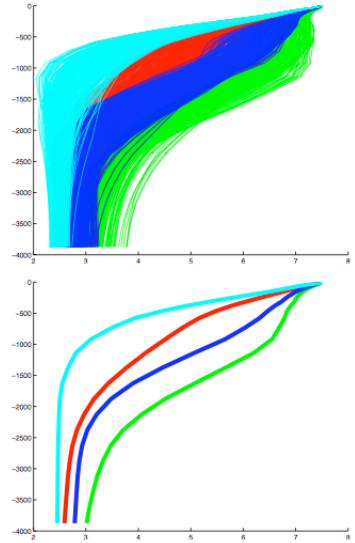
- Model for Prediction Across Scales (MPAS)
  - Variable resolution
  - New dynamics, advection
  - Two time level, implicit schemes
  - Split explicit barotropic mode, fully implicit and hybrid options
  - Hybrid vertical grid (ALE)
  - Joint LANL/NCAR



POP Heat Transport parameterization tuning (Collaboration with Hecht, Wingate, LANL)

- Leverages COSIM activities
- Using UQ approaches to examine the trade-off space with viscosity, GM, and LANS-α.
- Using GP calibration methods to reproduce output of high-resolution (eddy-resolving, parameterization-free) model run on test case with lower-resolution model plus parameterizations.
- Currently facing ocean science issue: appropriate metric for matching.
- Recently changed model setup, performing new ensemble runs for analysis and publication (target early FY12)





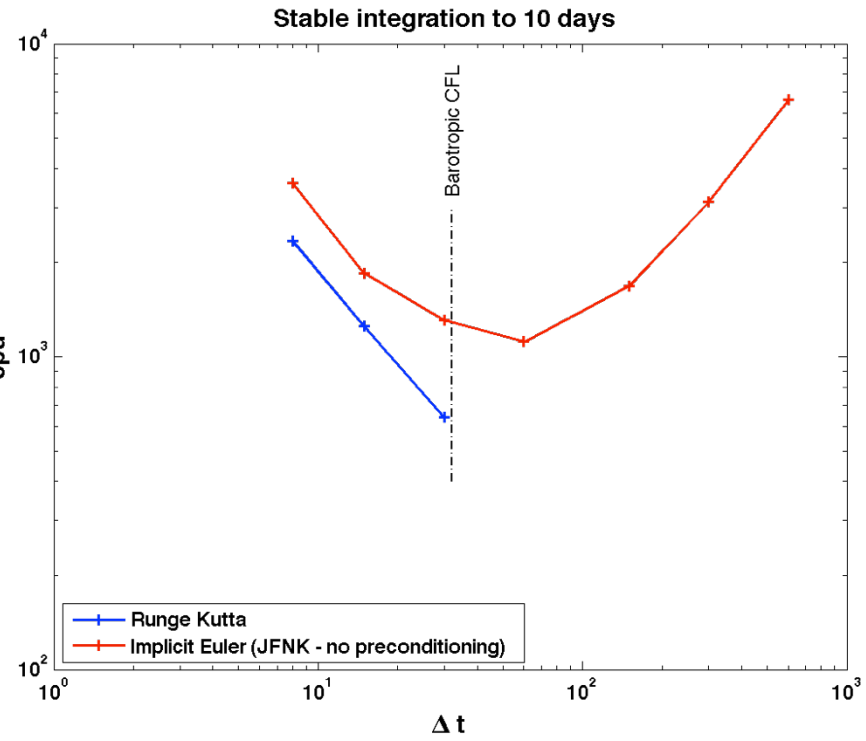
MPAS Performance

- Initial performance profiling complete
  - July milestone
- Identified low hanging fruit
  - Pointer/structure issues
  - Mask through arg lists
  - Temp removal and loop optimization
- Improvement
  - 40% in horz mixing
  - Aug 15 milestone complete
  - Propagating through code (Aug 30)

Doug Jacobsen joining Aug 22

Implicit Ocean Modeling

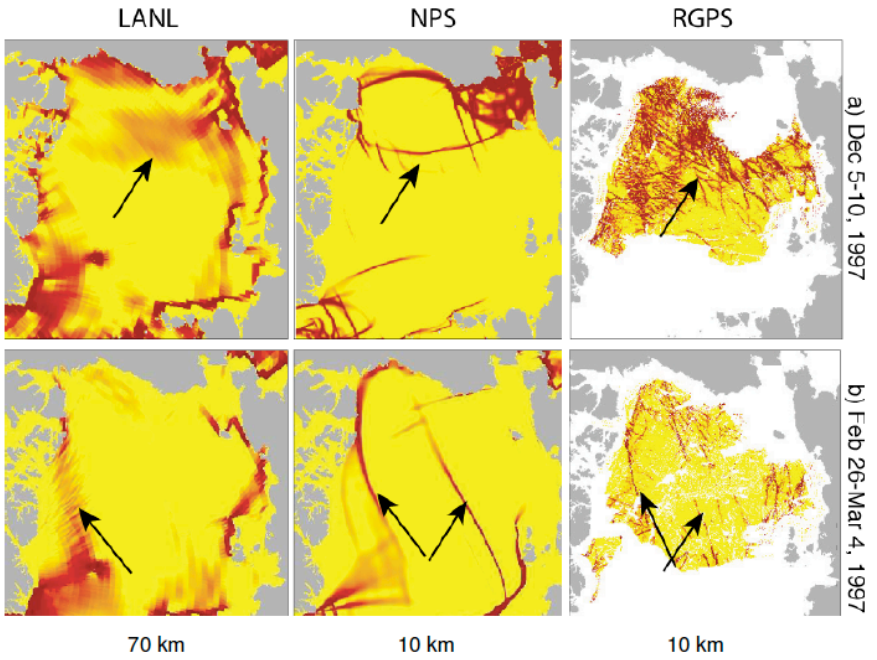
- Ocean time integration – barotropic splitting
  - Implicit: scaling, preconditioner
  - Explicit: stability
- Explicit or implicit integration of the barotropic subsystem (physics – based preconditioner)
- Explicit integration of barotropic allows code reuse, could be exascale friendly
- Implicit integration of barotropic subsystem has been implemented as a solver (semi – implicit methods, ie POP)
- Deliverables to date:
  - Implementation of unpreconditioned JFNK (Trilinos) in representative prototype (July 2011) ***– complete***
  - Implementation of barotropic solver as preconditioner in representative prototype (Aug 2011) ***– under development***
- Invited presentations:
  - SIAM Parallel Proc (Feb 2012)
  - Copper Mtn Iter Meth (March 2012)



CESM Sea Ice Component

CESM3: CICE

- Constitutive Model
  - Anisotropic fracture model: elastic-decohesive
  - Intact ice modeled as elastic
  - Leads modeled as discontinuities
  - Model predicts initiation of a lead and its orientation
  - Traction is reduced with lead opening until a complete fracture forms
  - With SNL (LDRD)



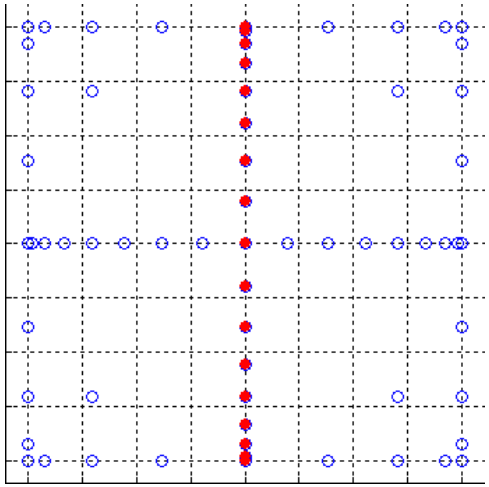
CICE Progress

- July
  - Set up repo branch
  - Defined and set up box test problem in CICE and (almost) MPM models
- Aug
  - Added new diagnostics (decohesion opening)
  - Elastic-decohesive module in CICE
  - Interfaces mostly complete
  - Baseline benchmark ready

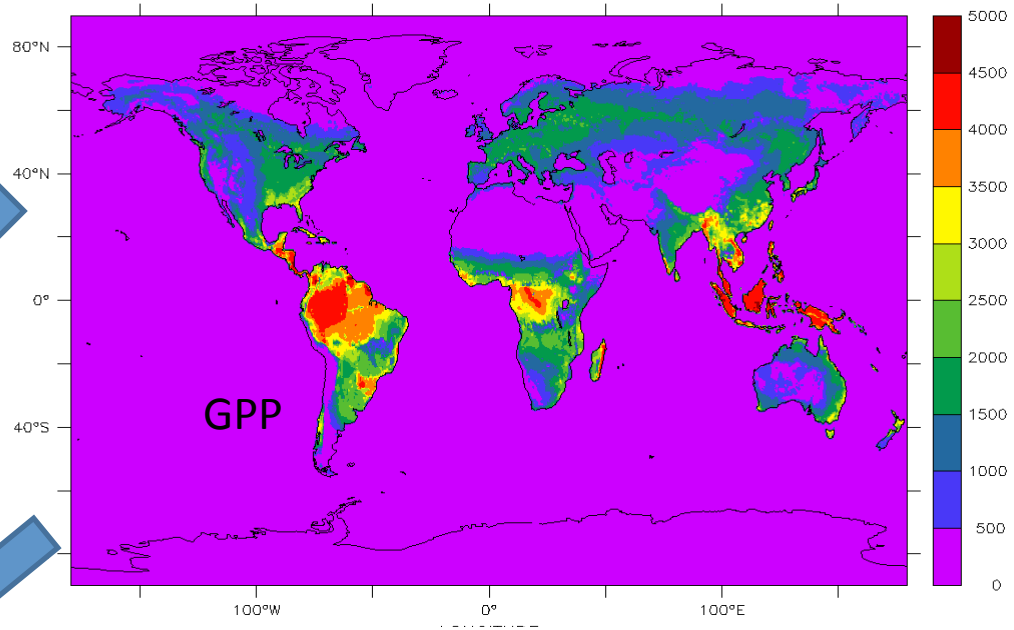
Strategy for CSSEF land model UQ

(connects to Carbon Cycle Feedbacks, AmeriFLUX, future TES experiments)

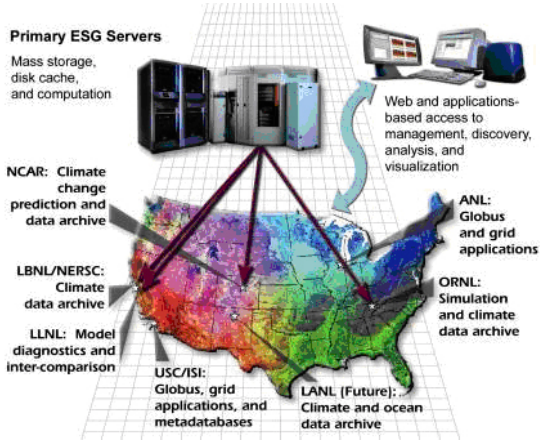
Parameter space sampling strategy



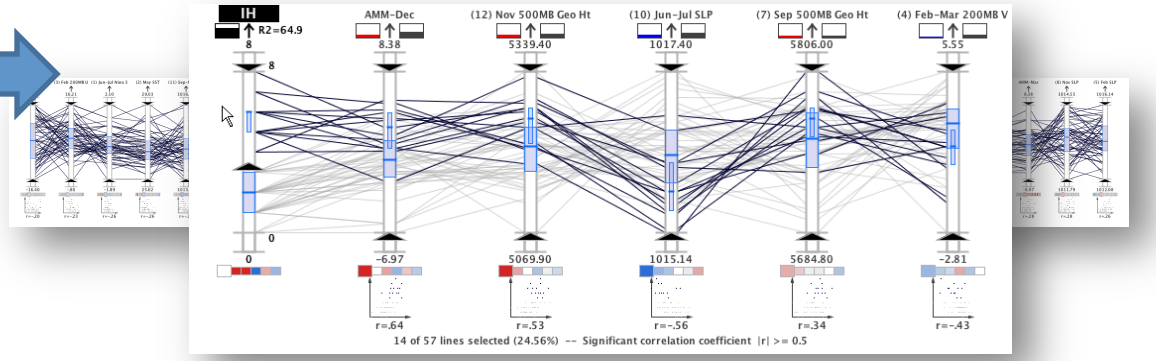
Ensemble of global and point simulations



Data publication to ESG



Visualization



CSSEF: Early result

Uncertainty Quantification

Land | Carbon cycle uncertainty reduction

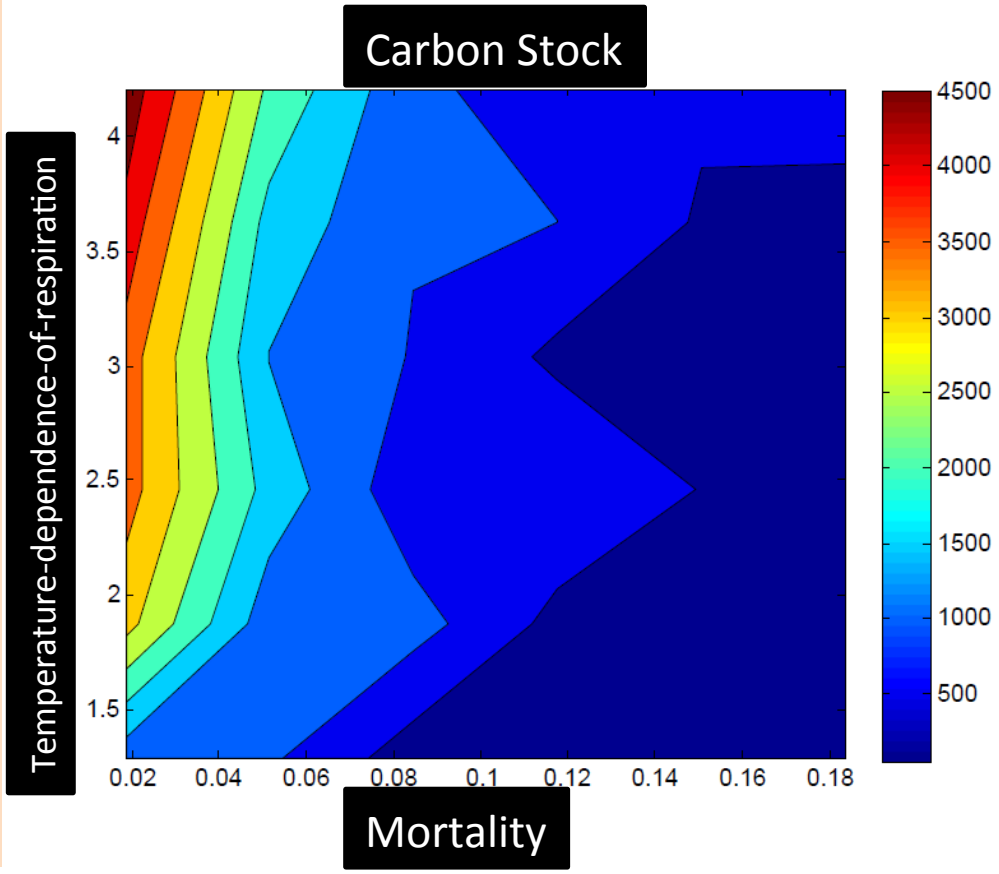
3000 Community Land Model simulations with different parameter combinations at Niwot Ridge flux site run for 1000 years by ORNL

Some runs failed to give physical results

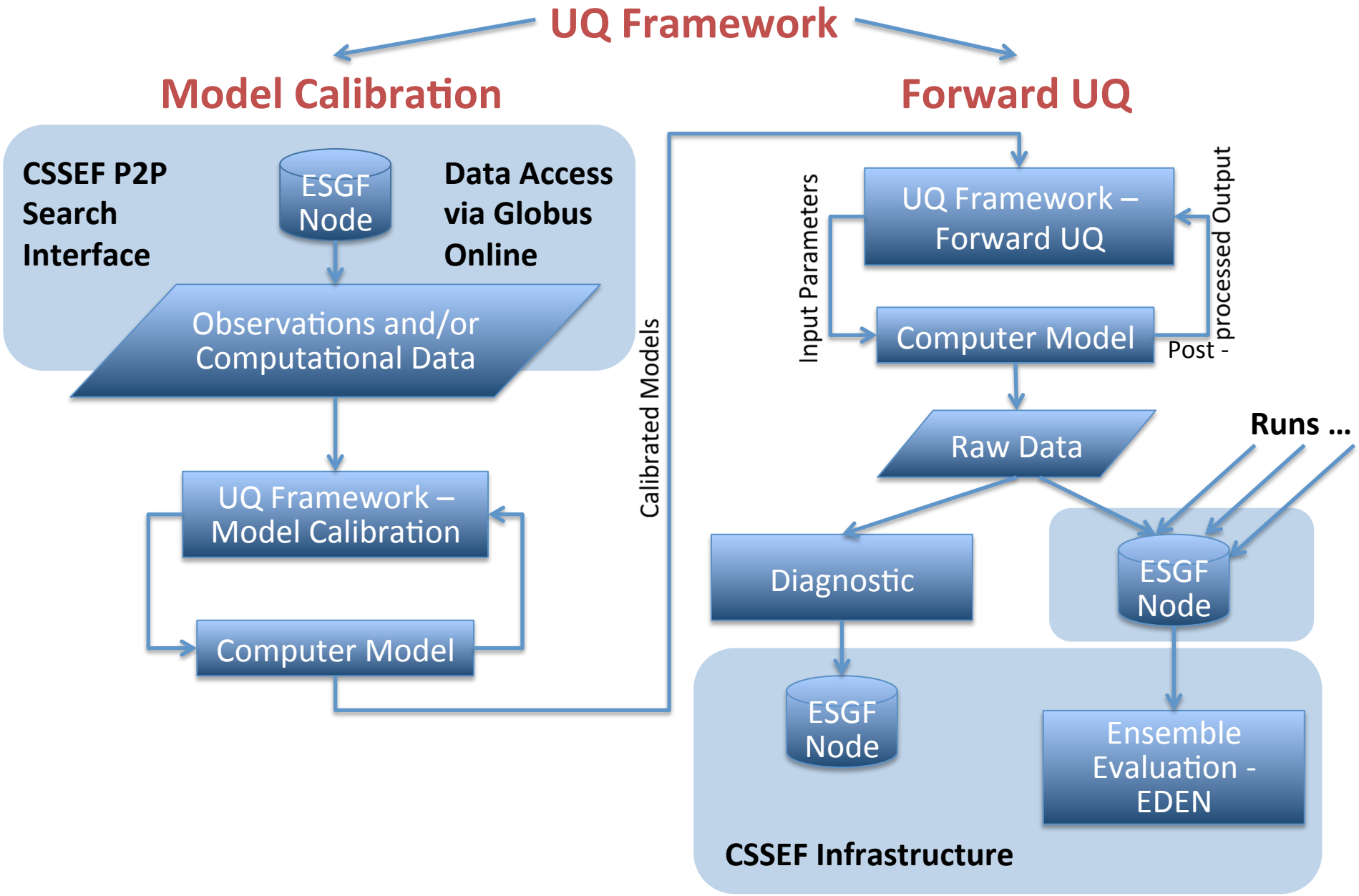
Model output passed to SNL for UQ analysis

This research is team effort!

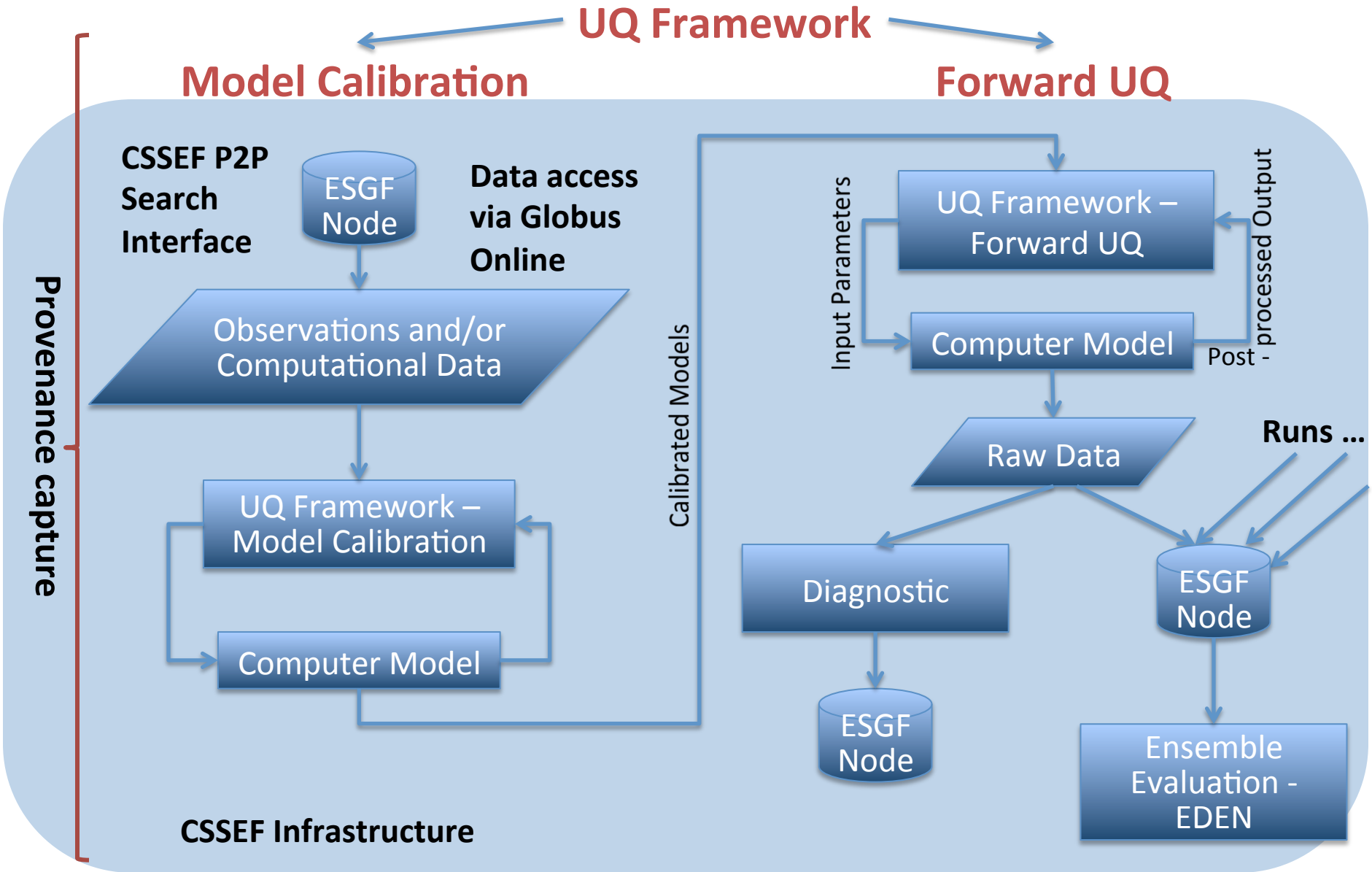
Figure: Effects of 2 parameters, tree mortality and temperature-dependence-of-respiration, on carbon stock



UQ Use Cases - 4 Months



Future UQ Use Cases



What's Next?

- November meeting to compare results to plans
- Scoping of project to budget realities
- Developing full 1, 3 and 5 year plans against proposal and realities of progress.

Thank you

Questions?