



# NESSII

## Update on ESMF, Earth System Curator, and Earth System CoG

Cecelia DeLuca and the ESMF team  
CCSM Software Engineering Working Group  
June 2, 2011



# NESII

## Outline

- NESII Overview
- NESII Projects
  - Earth System Modeling Framework (ESMF)
  - National Unified Operational Prediction Capability (NUOPC)
  - Earth System Curator
  - Earth System Commodity Governance (CoG)
  - Curator Hydrology
  - NOAA Climate Projection Pilot (NCPP)
  - TeraGrid Environmental Science Gateway
  - Global Interoperability Program



# NESTII

## The Vision

- Develop interoperable modeling components that can connect in multiple ways  
*Improve predictions and support research*
- Build advanced utilities that many models can use  
*Enable research, promote efficiency*
- Enable models to be self-describing  
*Increase understanding and defensibility of outputs*
- Create workflows that automate the modeling process from beginning to end  
*Improve productivity*
- Build workspaces that encourage collaborative, distributed development of models and data analysis  
*Leverage distributed expertise*





# NESII

## The Team

Person	Role	Location
Cecelia DeLuca	Technical Manager	ESRL
Sylvia Murphy	Operations & Project Manager	ESRL
Silverio Vasquez	Test and Integration Lead	ESRL
Gerhard Theurich	Senior Developer – architecture	CA
Bob Oehmke	Senior Developer - grids	ESRL
Luca Cinquini	Senior Developer - database	ESRL/CA
Peggy Li	Developer - performance	CA
Allyn Treshansky	Developer - metadata	CA
Walter Spector	Developer – porting	CA
Ryan O’Kuinghttons	Developer - everything	ESRL
Fei Liu	Developer - applications	New Jersey
Kathy Saint	Developer - web	Florida
Earl Schwab	Developer - utilities	CO

***NESII visitors:***  
*Tony Wong, intern*  
*and*  
*Jay Hnilo, NCDC*



# NESTII

## Earth System Modeling Framework

**Started:** 2002

**Collaborators:** Co-developed and used by NASA (GEOS-5 climate model), NOAA (NCEP weather models), Navy (global and regional models), Community Earth System Model, others

**Sponsors:** NASA MAP, NOAA NWS and CPO, NSF SEIII, DoD HPCMP

- ESMF increases code reuse and interoperability in climate, weather, coastal and other Earth system models
- ESMF is based on the idea of components, sections of code that are wrapped in standard calling interfaces



# ESMF as an Information Layer



## Applications of information layer

- *Parallel generation and application of interpolation weights*
- *Run-time compliance checking of metadata and time behavior*
- *Fast parallel I/O (PIO from NCAR/DOE)*
- *Redistribution and other parallel communications*
- *Automated documentation of models and simulations (new)*
- *Ability to run components in workflows and as web services (new)*

### Structured model information stored in ESMF wrappers

#### ESMF data structures

Standard metadata

Attributes: CF conventions, ISO standards, METAFOR Common Information Model

Standard data structures

Component

Field

Grid

Clock

### User data is referenced or copied into ESMF structures

#### Native model data structures

modules

fields

grids

timekeeping





# NESII

## ESMF Regridding

Fully parallel, portable

Working towards CF compliance for structured and unstructured grid formats

Two ways to invoke regridding:

- ESMF Offline:
  - Application which can be automatically built as part of ESMF
  - Application generates a netCDF weight file from two netCDF grid files
  - Supports SCRIP format grid files, and a custom ESMF unstructured format

```
mpirun -np 32 ESMF_RegridWeightGen -s src_grid.nc -d dst_grid.nc -m bilinear -w weights.nc
```

- Integrated:
  - ESMF library subroutine calls which do interpolation during model run
  - Can get weights or feed directly into ESMF parallel sparse matrix multiply
  - Can be used without ESMF components

```
call ESMF_FieldRegridStore(srcField=src, dstField=dst,  
                           regridMethod=ESMF_REGRID_METHOD_BILINEAR, routehandle=rh)
```

```
call ESMF_FieldRegrid(srcField=src, dstField=dst, routehandle=rh)
```



# NESS II

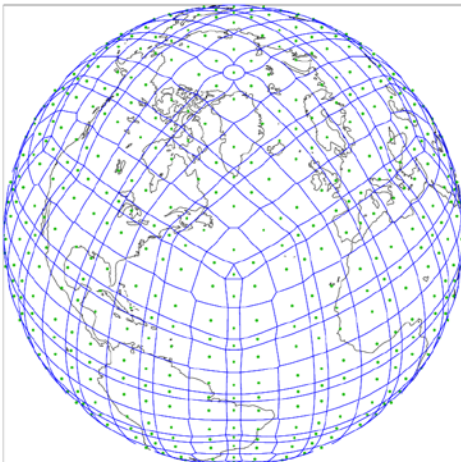
## ESMF Offline Supported Grids

- Grids with spherical (lon, lat) coordinates – any pair of:
  - Global 2D logically rectangular grids
  - Regional 2D logically rectangular grids
  - 2D unstructured meshes composed of polygons with any number of sides: triangles, quadrilaterals, pentagons, hexagons,...
  - Multi-patch grids (e.g. cubed spheres) currently supported via unstructured format

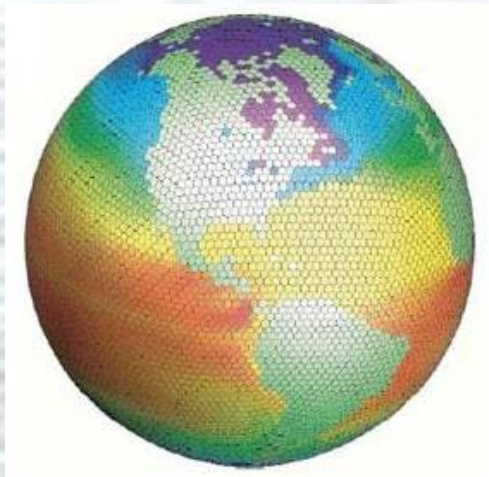
### RESULT:

*“use of the parallel ESMF offline regridding capability has reduced the time it takes to create CLM surface datasets from hours to minutes” - Mariana Vertenstein, NCAR*

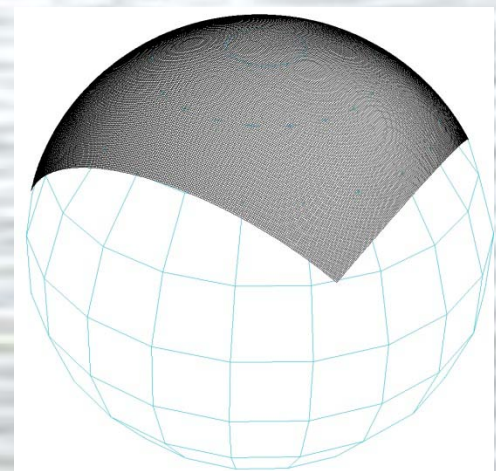
GLL control volumes



HOMME Cubed Sphere Grid with Pentagons  
Courtesy Mark Taylor of Sandia



FIM Unstructured Grid  
Courtesy ESRL GSD



Regional Grid



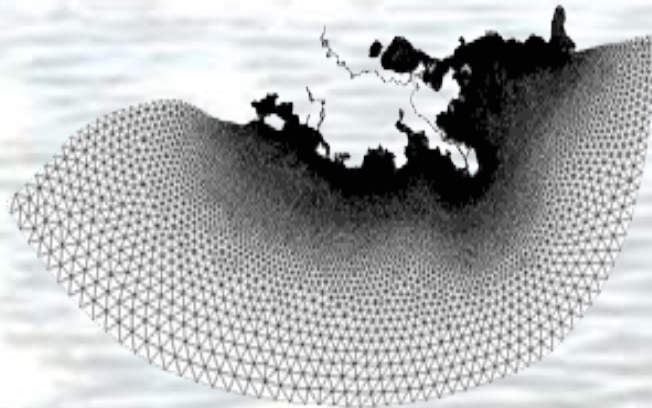


# NE S II

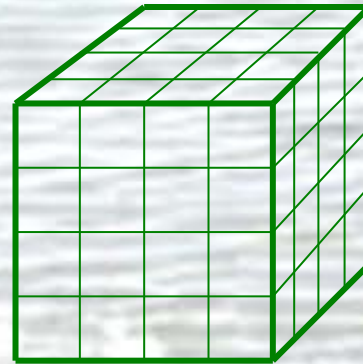
## Integrated Supported Grids

In addition, integrated regridding supports Cartesian (x,y) coordinates:

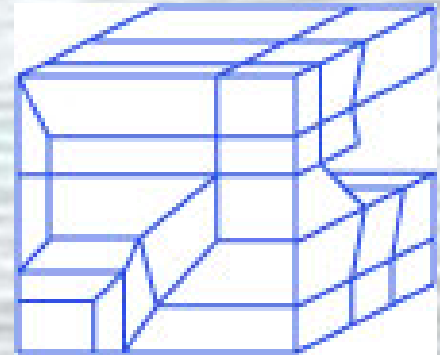
- Regridding between any pair of:
  - 2D meshes composed of triangles and quadrilaterals
  - 2D logically rectangular Grids composed of a single patch
- Bilinear regridding between any pair of:
  - 3D meshes composed of hexahedrons
  - 3D logically rectangular Grids composed of a single patch



*2D Unstructured Mesh*  
From [www.ngdc.noaa.gov](http://www.ngdc.noaa.gov)



*3D Grid*



*3D Unstructured Mesh*



# ESMF Offline Regrid Use



- **Enable CLM land model to run on any unstructured grid**
  - Grids: Land lat/lon grid to unstructured grid including HOMME cubed sphere
  - ESMF parallel bilinear mapping from lat/lon to HOMME cubed sphere allowed investigation of high resolution land model to move forward for CESM
- **Reduce noise in interpolated wind stress values**
  - Grids: CAM atmosphere lat/lon to POP ocean displaced pole lat/lon
  - ESMF patch interpolation reduced imprint of coarser resolution atmosphere grid on ocean for interpolated wind stress values.
- **Enable interpolation of POP ocean and HOMME**
  - Grids: HOMME cubed sphere atmosphere to POP ocean grid
  - ESMF conservative regridding enabled integration of a high resolution dynamical core into CAM, reduced distortion near the pole
- **Improve pole treatment for geodesic to lat/lon remapping**
  - Grids: MPAS unstructured grid to POP ocean grid
  - ESMF conservative interpolation solved problems with negative weights at the pole
- ***Also: geodesic to geodesic and other interpolation for CSU is working, NCL***





# NE S II

## National Unified Operational Prediction Capability (NUOPC)

**Started:** 2010

**Collaborators:** Tri-agency (NOAA, Navy, Air Force) consortium of operational weather prediction centers, with participation from NOAA GFDL and NASA modelers

**Sponsors:** NOAA NWS and Navy

- ESMF allows for many levels of components, types of components, and types of connections
- In order to achieve greater interoperability, usage and content conventions and component templates are needed
- This collaboration is building a "NUOPC Layer" that constrains how ESMF is used, and introduces metadata and other content standards
- The initial pilot project (to be delivered June 2011) focuses on atmosphere-ocean coupling in NCEP NEMS and Navy NOGAPS and COAMPS codes

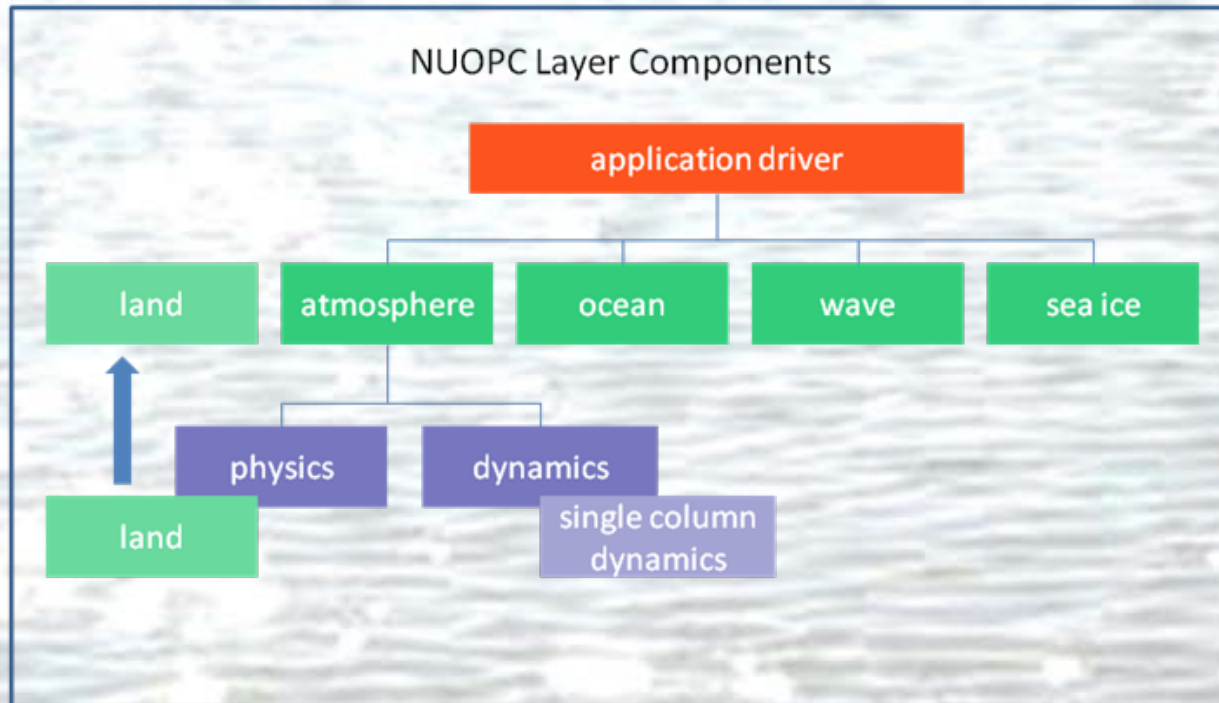




# NESTII

## A Common Model Architecture

*NUOPC partners have agreed on a subset of components whose interactions will be standardized*





# NE SII

## NUOPC Layer prototype

- Establish an architecture in which major components are siblings. The initial design supports explicit coupling and concurrent or sequential execution of components.
- Allow inheritance from generic component templates.
- Couple components with pre-fabricated connectors.
- Standardize the number and function of phases of initialize, creating a standard setup pattern.
- Constrain the data that may be sent between components with standardized field data structures and a CF-based field dictionary.
- Implement a compliance checker to provide feedback during component development.
- Use compatibility checking to determine if required import fields for a component were supplied. Other run-time reporting alerts users to any issues with compliance.



# NESS II

## Interoperability impact

- Component templates and generic connectors make it easier for modelers to create compliant systems since they can reuse existing code and patterns
- Constraining and clearly defining initialize phases ensures that components fit into standard drivers.
- Constraining Field data structures and metadata ensures that the data communicated between components is understood
- The ESMF layer ensures that components fit together into an executable application. Detailed reporting provides the model developer with the insight necessary to debug and rectify code quickly.





# NE S III

## Earth System Curator

**Started:** 2005

**Collaborators:** METAFOR , NCAR, DOE PCMDI, Earth System Grid Federation, NOAA GFDL, Georgia Institute of Technology

**Sponsors:** NSF SEIII, NASA MAP, NOAA GIP

- Intergovernmental Panel on Climate Change (IPCC) assessments rely on data generated by Coupled Model Intercomparison Projects (CMIPs), where different scenarios are tested across many models
- For the last IPCC assessment, there was little metadata available about the runs performed
- The Curator project collaborated on a comprehensive metadata schema for climate models, and implemented a metadata display in the Earth System Grid data distribution portal



## ESG Metadata Display



### Simulation Metadata: HadGEM2-ES piControl

Full Name: Hadley Global Environment Model 2 - Earth System 3.1 Pre-industrial Control (1860 - 2360)

[BACK TO SEARCH](#)

- HadGEM2-ES
  - Realm: Earth system
  - Aerosols
    - Realm: Aerosol
    - Physical Domain: Atmosphere
      - Aerosol Emission And Conc
      - Aerosol Model
      - Aerosol Transport
  - Atmosphere
    - Realm: Atmosphere
    - Physical Domain: Atmosphere
      - Atmos Convect Turbul Cloud
        - Atmos Cloud Scheme
        - Cloud Simulator
      - Atmos Dynamical Core
      - Atmos Advection
      - Atmos Orography And Waves
      - Atmos Radiation
  - Atmospheric Chemistry
    - Realm: Atmospheric chemistry
    - Physical Domain: Atmosphere
      - Atm Chem Emission And Conc
      - Atm Chem Gas Phase

**Description:** The HadGEM2-ES model was a two stage development from HadGEM1, representing improvements in the physical model (leading to HadGEM2-AO) and the addition of earth system components and coupling (leading to HadGEM2-ES). [1] The HadGEM2-AO project targeted two key features of performance: ENSO and northern continent land-surface temperature biases. The latter had a particularly high priority in order for the model to be able to adequately model continental vegetation. Through focussed working groups a number of mechanisms that improved the performance were identified. Some known systematic errors in HadGEM1, such as the Indian monsoon, were not targeted for attention in HadGEM2-AO. HadGEM2-AO substantially improved mean SSTs and wind stress and improved tropical SST variability compared to HadGEM1. The northern continental warm bias in

Properties | Grids | Inputs | References | Experiment | Conformances

#### Boundary Conditions

- land DMS emissions:** Dataset is derived from Spiro et al. (1992). It is represented as a constant rate of 0.86 Tg[S]/yr
  - Input Target Component: Atmosphere piControl
  - Input Time Transformation Type: Exact
  - Input Frequency: 5 days
- well\_mixed\_gas\_N2O:** The N2O concentrations used were taken from the recommended CMIP5 dataset. HadGEM2-ES requires atmospheric concentrations of N2O in units of mass mixing ratio (mmr). A conversion factor of 44.013/(28.964e9) was used to convert units from values supplied in ppbv.
  - Input Target Component: Atmosphere piControl
  - Input Frequency: 30 minutes
- surface\_NOx\_emissions:** For NOx surface emissions, contributions from land-based anthropogenic sources, biomass burning, and shipping from Larmarque et al. (2010a) were added together and re-gridded on to an intermediate 1x1 degree grid in terms of kg(NO)/m2/s. Added to these were a contribution from natural soil emissions, based on a global and monthly distribution provided by GEIA on a 1x1 degree grid (<http://www.geiacenter.org/inventories/present.html>), and based on the global empirical model of soil-biogenic emissions from Yienger and Levy II (1995). These were scaled to contribute an additional 12 Tg(NO)/year. The total emissions were then re-gridded on to the model's N96 grid and a small adjustment applied to conserve the original global totals.
  - Input Target Component: Atmospheric Chemistry piControl

*This screen shot shows a real CMIP5 run as it appears in an ESGF portal*

**RESULT:**  
*MUCH more information about climate models used in assessments, in browsable, searchable form*



# NESSII

## Earth System CoG

**Started:** 2009

**Collaborators:** NCAR, Earth System Grid Federation, University of Michigan, CU Community Surface Dynamics Modeling System

**Sponsors:** NSF CDI

- Project hosting and indexing with connections to data and analysis services through the Earth System Grid Federation (ESGF)
  - Workspaces for collaborative model building, evaluation and analysis
  - Templates for project layout so information is easy to find
  - Peer or parent/child connections between projects
  - Multiple modes of communications between projects (e.g. broadcast news to all children)
- Pilot project is 2012 workshop on comparison of atmospheric dynamical cores (previously supported 2008 workshop)





# NE S II

## 2008 Dynamical Core Colloquium on CoG

715

**COG**  
Curator Commodity Governance

Welcome, **admin**. | Django Admin | Change Password | Log out

[COG Home](#) [COG Admin](#)

[Dycore-2008 Home](#) [Code](#) [Trackers](#) [Support](#) [Governance](#) [Contact Us](#)

**Dycore-2008 Site Index**  
Home  
Modeling Groups  
Logistics  
Announcement  
Keynote Speakers  
RegOnline How To  
Travel Reimbursements  
Procedures  
Student Logon Tests  
Printing  
Bluevista laptop file transfer via Email  
References  
Model Output Format  
Tutorials  
Test Cases  
new topic  
Newpage  
newpage2

**Dycore-2008 Administration**  
Update Project  
Add Child Project  
Add New Page  
Edit This Page  
Add Attachment  
Dycore-2008 Blogs  
List All Blogs  
Add New Blog  
Dycore-2008 Documents

### Dycore-2008 : NCAR ASP 2008 Summer Colloquium on Numerical Techniques for Global Atmospheric Models

This is a page for the NCAR ASP summer colloquium to be held in Boulder June 2-13, 2008. The primary organizers are: Peter H. Lauritzen (CGD, NCAR), Christiane Jablonowski (University of Michigan), Mark Taylor (Sandia National Laboratories) and Ramachandran D. Nair (IMAGe, NCAR)

Sponsored by NCAR ASP, NASA and DOE.

*Output of nine models running test case 5-0-0 (Mountain-induced Rossby wave): 700 hPa zonal wind at day 15. The test starts with balanced and isothermal initial conditions. A 2-km-high Gaussian-hill-shaped mountain is placed at [90degE, 30degN] (not shown) to trigger Rossby waves. The test evaluates the treatment of the orography and reveals numerical noise (especially at later days). [Image courtesy of Christiane Jablonowski.]*

**Search**  
  
Go  
Advanced Search

**Project Connections**  
This Parent Child Peer  
Dycore-2008  
CoG  
Curator  
Publish Dycore-2008 News

**Project Related News**  
**Dycore-2008: sample news**  
Meeting next tuesday [More »](#)  
*admin @ 2011/05/11 03:05:35*

**Dycore-2008: Agenda**  
Agenda is now available. Click on "All Documents" [More »](#)  
*admin @ 2011/03/18 04:03:35*  
[More Project News »](#)

*CoG prototype includes data search, wikis, and communications*

**NEXT:** Users will be able to save ESGF datasets, LAS analysis and visualizations and other artifacts back to the workspace



# NESSI

## Curator Hydrology

**Started:** 2009

**Collaborators:** University of South Carolina, University of Michigan

**Sponsors:** NOAA GIP

- A new perspective on climate impacts modeling
- Instead of what do we “put in” the climate model ...
- How do we create a **linked network of models** that multiple communities can use?



# NESTII

## Design Goals

Goals	Strategies
Modeling systems can be reconfigured easily for including different models or solving different problems	Leverage model interface and data standards
Modeling systems are highly accessible and can be integrated into workflows that include analysis, visualization, and other processing of outputs	Service oriented architecture
Communities formed around local/regional modeling and climate are able to utilize the social and technical structures that have evolved in their domains	Models retain their native codes, computing platforms, and data formats as much as possible





# NESSI

## Climate-Hydro Coupling

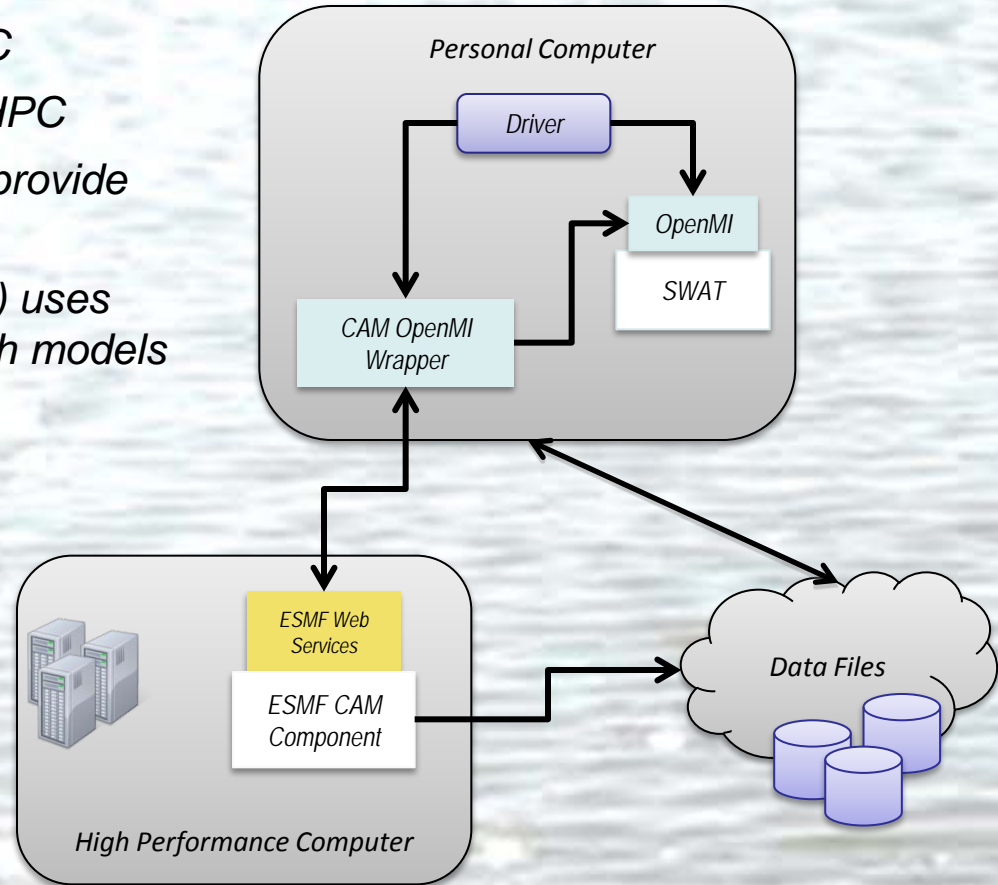
- Hydrological impact studies can be improved when forced with data from climate models [Zeng *et al.*, 2003; Yong *et al.*, 2009]
- Ideally the coupling would be two-way
- A technology gap exists:
  - Many hydrological models run on personal computers
  - Most climate models run on high performance supercomputers
- Existing frameworks: ESMF (climate/weather) and OpenMI (hydrology) can connect these types of models
  - ESMF and OpenMI components can be operated as web services that can be used to communicate across a distributed network
  - Both ESMF and OpenMI are widely used



# NESTII

## Prototype Climate-Hydro System

- *SWAT (hydrology model) runs on PC*
- *CAM (atmospheric model) runs on HPC*
- *Wrappers for both SWAT and CAM provide OpenMI interface to each model*
- *Driver (OpenMI Configuration Editor) uses OpenMI interface to timestep through models via wrappers*
- *Access to CAM across the network provided by ESMF Web Services*
- *CAM output data written to NetCDF files and streamed to CAM wrapper via ESMF Web Services*
- *Using prototype to explore feasibility of 2-way coupling*



From Saint, iEMSs 2010





# NE S II

## Target Coupled System



- Target system informed by exploration of parameter space for different strategies (estimated SWAT and CAM run times and transfer times)
- SWAT covering southeast U.S. coupled to CAM/CLM – purple region
- Restricting finest SWAT resolution to watersheds of interest (Neuse and Savannah) makes calibration somewhat easier
- SWAT forced by CAM fields (precip, temperature, wind speed, etc.); ET from SWAT nudges values in CAM





# NESSI

## TeraGrid Environmental Science Gateway

**Started:** 2008

**Collaborators:** NCAR CISL and CESM, Purdue University

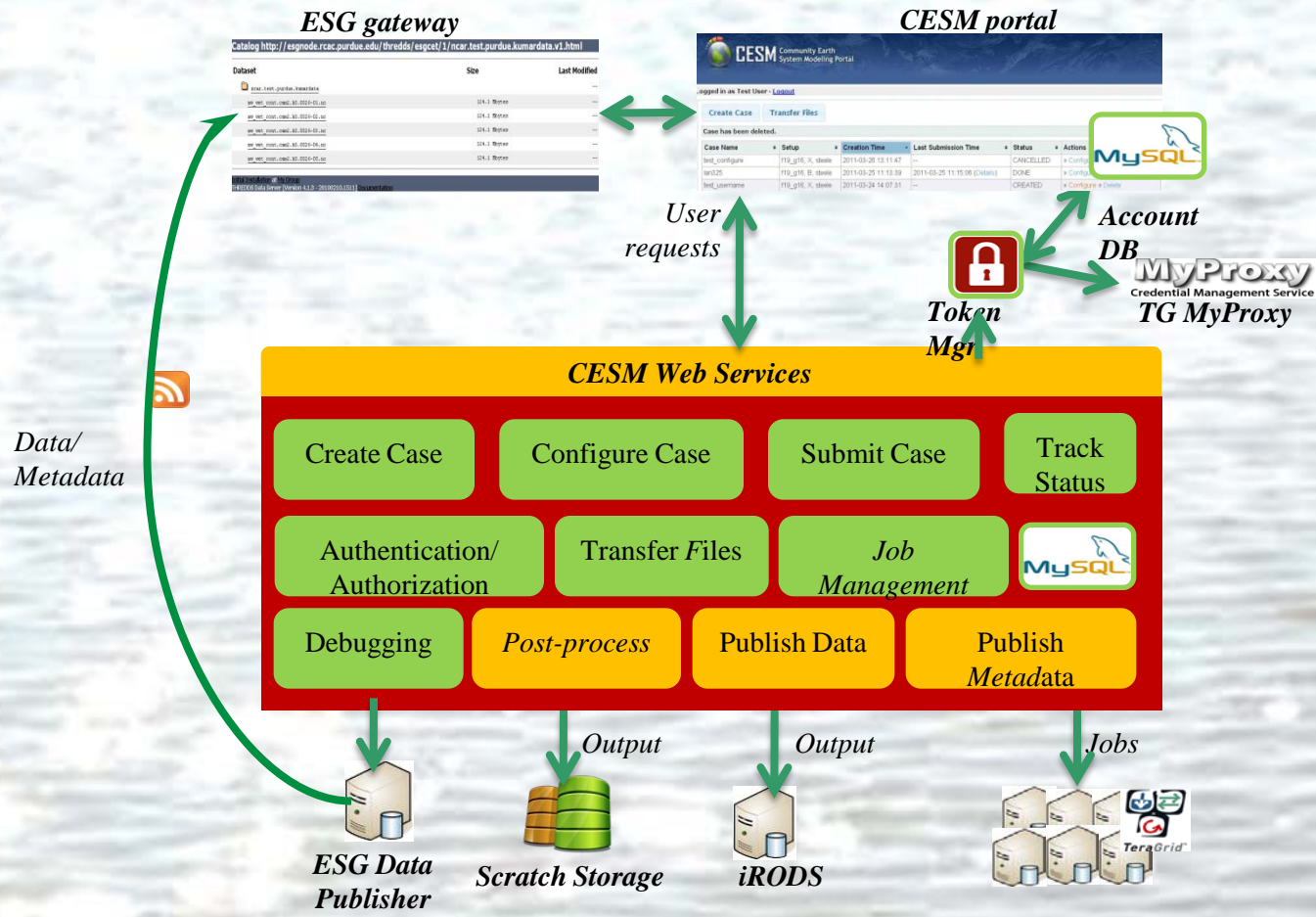
**Sponsors:** NSF TeraGrid

- Creates an end-to-end, self-documenting workflow for running the Community Earth System Model (CESM)
  - GUI configuration and submission of runs through the Purdue CESM portal
  - ESMF is used within CESM to organize and output extensive model metadata
  - Data and metadata is archived back to an Earth System Grid Federation Gateway, where it can be searched and browsed
  - Currently have a working prototype



# NEST II

## Gateway Architecture





# NESII

## NOAA Global Interoperability Program

**Started:** 2009

**Collaborators:** NOAA GFDL, PMEL, GSD, and NCDC, Unidata, NCAR, CSU, University of Michigan

**Sponsors:** NOAA CPO

- GIP builds software infrastructure that
  - can be used in the weather, water, and climate disciplines, and for training modelers
  - integrates and automates workflows
- NESII lead DeLuca coordinates the project





# NESS II

## Building Along Workflows

	Climate Simulations	Application of Climate Information	Weather and Water Forecasting	Training Modelers
Model Utilities and Coupling	<ul style="list-style-type: none"><li>• Standardized analysis workflows for climate models</li><li>• Metadata display for CMIP5</li><li>• ESMF in CESM</li></ul>	<ul style="list-style-type: none"><li>• The NOAA Climate Projection Pilot</li></ul>	<ul style="list-style-type: none"><li>• A common model architecture for operational weather centers (NUOPC)</li><li>• NOAA Environmental Modeling System (NEMS)</li><li>• Geodesic grids in NEMS</li></ul>	<ul style="list-style-type: none"><li>• Summer School in Atmospheric Modeling</li><li>• The Art of Climate Modeling course</li></ul>
Metadata Standards				
Data Services and Workflows				



# NE S II

## Building Across Disciplines

	Climate Simulations	Application of Climate Information	Weather and Water Forecasting	Training Modelers
Model Utilities and Coupling	<ul style="list-style-type: none"><li>• ESMF core support</li><li>• Hydrological-climate coupling with ESMF and OpenMI modeling frameworks</li></ul>			
Metadata Standards	<ul style="list-style-type: none"><li>• Gridspec integration into the Unidata LibCF library</li></ul>			
Data Services and Workflows	<ul style="list-style-type: none"><li>• Merger of Ferret and CDAT analysis services</li></ul>			

**RESULT:**  
*Better  
coordination of  
infrastructure  
development  
across disparate  
groups*



# NESTII

## The Vision

- Develop interoperable modeling components that can connect in multiple ways  
*Improve predictions and support research*
- Build advanced utilities that many models can use  
*Enable research, promote efficiency*
- Enable models to be self-describing  
*Increase understanding and defensibility of outputs*
- Create workflows that automate the modeling process from beginning to end  
*Improve productivity*
- Build workspaces that encourage collaborative, distributed development of models and data analysis  
*Leverage distributed expertise*





# NE SII

## Questions?

- For more information, links and references, see our newish group page: <http://esrl.noaa.gov/nesii/>