

CESM Projects Using ESMF and NUOPC Conventions

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Outline

- ESMF development update
- Joint CESM-ESMF projects
- ESMF applications: Earth System Prediction Suite
- Looking forward: Cupid development environment

6.3.0r: Jan 2014

Many features and improvements were added since the last public release, including:

- **Grids that have elements with an arbitrary number of sides** can be represented and remapped in parallel during model run (used to be just offline)
Requested by U.K. Met Office modelers and others to support during-run grid remapping of model components on icosahedral and pentagonal-hexagonal grids
- **Generate dual grids** so that non-conservative remapping methods can be performed on grids that are defined on cell centers (already supported on corners)
Requested by NASA GMAO modelers and others as a convenience
- **Add parallel nearest neighbor interpolation methods**
Requested by the Community Earth System Model group to support downscaling
- Users can **select between great circle and Cartesian line paths** when calculating interpolation weights on a sphere
Requested by NRL and NOAA space weather projects for accurate grid remapping involving the long, narrow grid cells in flux tubes, and others
- Component interfaces support **fault tolerance** through a user-controlled “timeout” mechanism
Requested by NCEP EMC to support fault tolerance in ensembles

Coming Next in ESMF and NUOPC

- Extend ESMF data classes to **recognize accelerators** and extend component classes to **negotiate for such resources** in multi-component coupled systems
Advance toward a long-term goal of more automated and optimized mapping of multi-component models to hardware platforms
- **Integrate the MOAB finite element mesh library** into ESMF and compare and potentially replace ESMF's original finite element mesh library
Infrastructure development in collaboration with DOE and other ESPC partners
- Enable grid remapping to have a **point cloud or observational data stream destination**
Requested by surface modelers for remapping to irregular regions, and by NASA GMAO and other groups engaged in data assimilation
- **Introduce higher order conservative** grid remapping methods
Requested by multiple climate modeling groups
- Python interface to the ESMF grid remapping library – **ESMPy** - has a more intuitive, “Pythonic” interface

<https://www.earthsystemcog.org/projects/esmpy/>

NUOPC Additions to ESMF

National Unified Operational Prediction Capability (NUOPC) is a consortium of operational weather centers and their research partners.

It addresses the issue that ESMF implementations at different sites require metadata and behavioral conventions to interoperate.

The NUOPC Layer adds to ESMF:

- A formalism that describes and splits the phases of initialization
- A formalism for checking and reporting whether component requirements are satisfied during the run sequence
- Code templates for drivers, models, mediators (couplers) and connectors, and example applications showing a variety of model interactions (e.g. explicit, semi-implicit, implicit coupling)
- Compliance checkers

HYCOM in CESM

- ONR-funded effort to introduce HYCOM into CESM using ESMF with NUOPC conventions.
- Motivated by interest on the part of Navy and HYCOM developers to compare coupled HYCOM to POP, and participate in CESM community.
- NCAR CSEG redesigned the CESM coupler to support NUOPC Layer interfaces, leveraging previous work with ESMF.
- ESMF team introduced and is testing HYCOM within the NUOPC implementation of CESM.

***Status:* HYCOM is running and validated standalone in the NUOPC version of CESM, currently working on data exchanges.**

Related Projects

Also funded through ONR ...

Replacement of ESMF finite element mesh with DOE MOAB code

- (ESMF team) Incorporated MOAB into the ESMF build (in 6.3.0r release)
- (U Wisconsin) Added the ability to redistribute a mesh, needed for ESMF grid remapping, other changes as needed

Experiments with accelerators

- (U Chicago/ESMF team) Starting to write prototype code to explore interactions of multiple approaches when combined, e.g. OpenCL and OpenACC in different coupled components

More on accelerators: Initial questions and considerations

- Can components that use different programming models (OpenCL, OpenACC, Intel-MIC-Directives, ...) run under the same single ESMF executable?
- Do the different programming models provide enough control for a component to decide at run-time whether to use a specific accelerator device or not?
- Is it possible to uniquely identify the available devices? Across programming models? Across the distributed parts of a component? Across components?

Status: Jayesh Krishna (ANL) has been working with the ESMF team to develop a set of prototype codes that explore these questions

Next steps

- Offer access to device information through ESMF: enough to guide a driver component to do component placement.
- Support data references for the most efficient exchange between sequential components that are placed on the same compute resources.
- Prototype the inter-component negotiation of distributions by looking at the optimization problem of model grid distribution within the mediator component.
- Explore the possibility of *automated* construction of interleaved component based on the discovered resources and hints provided by the components during the initialization negotiation.

ESMF online regridding for CESM - why?

As more regionally refined grids are introduced (e.g. MPAS, SE) – need to:

- minimize the number of mapping files that are needed
- simplify and streamline workflow for generating new user grid configurations

Will be a requirement for run-time adaptive mesh refinement

ESMF is the only tool that currently delivers this capability

Status: Prototype implementation has been done and is being updated for newest coupler

ESMF Grid Remapping

Uniquely fast, reliable, and general – interpolation weights computed in parallel in 3D space

Supported grids:

- Logically rectangular and unstructured grids
- Global and regional grids
- 2D and 3D grids

Supported interpolation methods:

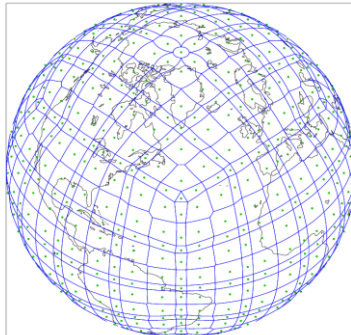
- **Nearest neighbor**, higher order patch recovery, bilinear and 1st order conservative methods

Options for straight or **great circle lines**, masking, and a variety of pole treatments

Multiple ways to call ESMF grid remapping:

- Generate and apply weights using the **ESMF API**, within a model
- Generate and apply weights using **ESMPy**, through a Python interface
- Generate weights from grid files using **ESMF_RegridWeightGen**, a command-line utility

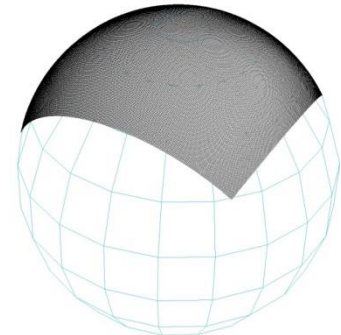
Some supported grids ...



HOMME Cubed Sphere Grid with Pentagons
Courtesy Mark Taylor of Sandia



FIM Unstructured Grid



Regional Grid

Types of ESMF Use by Major Model/Modeling Center

	Wrap components	Remap grids	Couplers and coupled system construction
NCAR/Partners Community Earth System Model	Yes	Yes	In progress
Navy global and regional models (COAMPS and NavGEM-HYCOM)	Yes	Yes	Yes
NOAA ESRL and GFDL	Yes (FIM for NEMS, MOM5 for NEMS and GEOS-5)	No	No
NOAA NCEP/EMC	Yes	Yes (NEMS)	Yes (NEMS)
NASA GEOS-5	Yes	Yes	Yes
NASA Model E	In progress	In progress	In progress
Modelers with new dynamical cores and grids: HOMME (NCAR/Sandia), MPAS (NCAR/LANL), ORCA (Met Office), hydrological and surface modelers, others ...	No	Yes	No
Data and viz: DOE UV-CDAT, IRIS (Met Office), NCL, PyFerret, GRADS team (COLA), others ...	No	Yes	No

Yes

Planned or in progress

The Earth System Prediction Suite

- The Earth System Prediction Suite (ESPS) is a collection of major weather and climate modeling codes that use ESMF interfaces with the NUOPC conventions.
- **The ESPS makes clear which codes are available as ESMF components and modeling systems.**

Draft inclusion criteria for ESPS:

https://www.earthsystemcog.org/projects/esps/strawman_criteria

- Individual components and coupled modeling systems may be included in ESPS.
- ESPS components and coupled modeling systems are NUOPC-compliant.
- A minimal, prescribed set of model documentation is provided for each version of the ESPS component or modeling system.
- ESPS codes must have an unambiguous public domain, open source license, or proprietary status. If the code is proprietary, a process must be identified that allows credentialed collaborators to request access.
- Tests for correct operation are provided for each component and modeling system.
- There is a commitment to continued NUOPC compliance and ESPS participation for new versions of the code.

Model Codes in the ESPS

**Currently, components in the ESPS can be of the following types:
coupled system, atmosphere, ocean, wave, sea ice**

Target codes include:

- The Community Earth System Model (CESM)
- The NOAA Environmental Modeling System (NEMS) and Climate Forecast System version 3 (CFSv3)
- The MOM5 and HYCOM oceans
- The Navy Global Environmental Model (NavGEM)-HYCOM-CICE coupled system
- The Navy Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) and COAMPS Tropical Cyclone (COAMPS-TC)
- NASA GEOS-5
- NASA ModelE

ESPS Code Status

LEGEND	
 Compliant	 (Completion date) In progress
 Candidate	

Coupled Modeling Systems							
	NEMS	CFSv3	COAMPS / COAMPS-TC	NavGEM- HYCOM-CICE	GEOS-5	ModelE	CESM
	2014	2014			2015	2015	2014
Atmospheres							
GFS/GSM							
NMMB							
CAM							2014
FIM	2014						
GEOS-5 FV					2015		
ModelE Atm						2014	
COAMPS Atm							
NavGEM							
NEPTUNE							
WRF							2014
Oceans							
MOM5							
HYCOM							
NCOM							
MPAS-O							
POP							2014
Ice							
CICE	2014	2014			2014	2014	2014
Wave							
WW3	2014		2014		2014		2014
SWAN							

Spanning major climate, weather, and ocean codes, ESPS is the most direct response to calls for common modeling infrastructure yet assembled

Cupid Development and Training Environment

Cupid is a tool designed to make ESMF training and development simpler, faster, and more appealing

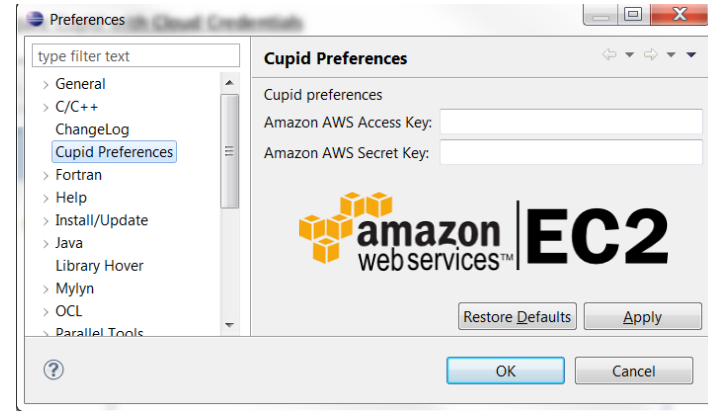
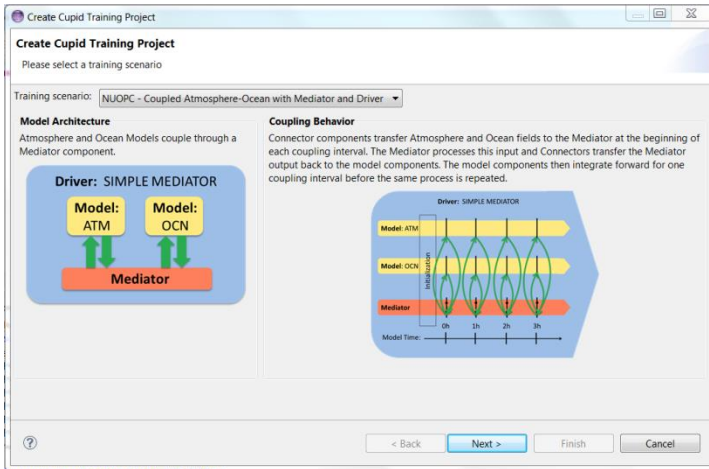
- NOAA CIRES, GA Tech, and NASA GISS/GSFC collaboration
- Funded through the NASA Computational Modeling Algorithms and Cyberinfrastructure (CMAC) program
- Plugin for Eclipse-based “Integrated Development Environment” or IDE
- Customized for ESMF applications with NUOPC conventions

***Status:* Cupid is a working prototype expected to be ready for first public release in FY14.**

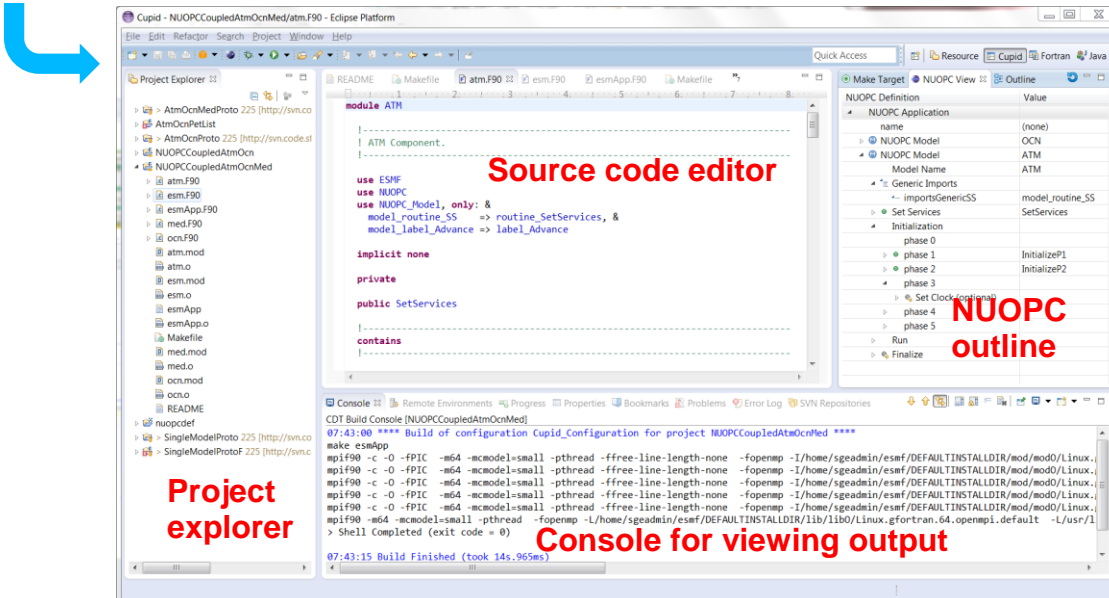
- <https://earthsystemcog.org/projects/cupid/>
- [Cupid Feature Overview and Tutorial](#)

Cupid Development and Training Environment

Run locally or on a cloud



Select sample code or model



- Pick a training problem (or coupled model)
- Generate a framework-aware outline of the source code
- Navigate around the source code using the outline
- Use an editor to modify the source code
- Automatically generate code needed for NUOPC compliance
- Compile and run locally or on a cloud (currently Amazon Web Services)

Questions?