The NCAR Command Language (NCL) analysis and visualization package is now using ESMF internally for parallel grid remapping. This image was generated by the NCL team to accompany one of their examples. It shows bilinear remapping of a temperature field from an unstructured finite volume grid (48602 cells) to a 96 x 144 finite volume (FV) rectilinear grid using ESMF. *Image courtesy of the NCL team at NCAR.*
Table of Contents

Overview ........................................................................................................................................ 3
1 Introduction .................................................................................................................................. 5
2 Software framework description ................................................................................................. 5
3 Metrics .......................................................................................................................................... 6
4 Timeline and strategic objectives .............................................................................................. 6
5 Plans in brief for 2013 .................................................................................................................. 8
6 Detailed accomplishments for 2011-2012 .............................................................................. 8
   6.1 Complete a functionally mature, standardized version of ESMF ........................................... 8
   6.2 Evolve ESMF prototype capabilities and add new features as required ............................... 9
   6.3 Develop conventions and software templates that will increase the level of interoperability of ESMF components ......................................................................................... 12
   6.4 Provide ESMF training and support ....................................................................................... 12
   6.5 Develop software utilities and science gateway services ......................................................... 13
   6.6 Framework optimization and porting ....................................................................................... 13
   6.7 Advance community adoption ............................................................................................... 14
7 Project plan evaluation measures for FY2013 ......................................................................... 15
   7.1 Deliver a production version of the NUOPC Layer ................................................................. 15
   7.2 Evolve ESMF prototype capabilities and add new features as required ............................... 15
   7.3 Provide ESMF training and support ....................................................................................... 15
   7.4 Advance self-documenting code and workflow capabilities .................................................. 16
   7.5 Framework optimization and porting ....................................................................................... 16
   7.6 Advance community adoption ............................................................................................... 16
8 Impact of the ESMF project ........................................................................................................ 16
9 Publications 2011-2012 .............................................................................................................. 16
10 Sponsors ....................................................................................................................................... 17
Appendix A: Table of Acronyms ................................................................................................. 18
Appendix B: U.S. Earth system models and their associated infrastructure ................................. 20
Overview

*Please see Appendix A for acronym expansions.*

This report covers calendar years 2011 and 2012. During this time, the ESMF team completed the major functional requirements for the framework and assessed what else would be needed to realize the vision of a more coordinated and interoperable national research and prediction capability.

A major event during this period was the release in July 2011 of ESMF v5.2.0r, which satisfied the initial requirements set out for the framework. The v5.2.0r release was carefully checked for consistency of interfaces and behavior. About 77% of calling interfaces in the release were guaranteed to be backward compatible in subsequent releases. This promise of backward compatibility was particularly important for adoption and use of the framework at operational centers. Ongoing feature requests, ports to new platforms, and optimizations were prioritized by the ESMF Change Review Board. Several internal releases have followed ESMF v5.2.0r and a next public release (v6.3.0) is scheduled for summer 2013.

During 2011-2012, the use of ESMF parallel grid interpolation libraries propagated rapidly throughout the community, finding many new users and applications. An “offline” capability which takes in grid specification files and produces interpolation weights became popular, as did a Python language interface to the grid remapping (ESMP). The ESMF Core Team engaged the data analysis and visualization community and worked to get ESMF grid remapping into products such as UV-CDAT\(^1\) and NCL\(^2\). Users wrote to say that ESMF grid remapping was “indispensable”\(^3\), offered capabilities that they could not find elsewhere, and enabled modeling and analysis capabilities that were not previously possible. NCAR staff from the CESM project worked closely with the ESMF team to develop the grid remapping capabilities, and CESM migrated to ESMF for generation of most of their interpolation weights.

The ESMF team worked with NUOPC, a set of operational weather prediction centers and their research partners, to increase interoperability of ESMF applications. They released a new software package, called the NUOPC Layer, which standardizes the way that ESMF models are implemented. It includes a set of generic components, representing structured models, drivers, mediators, and connectors, some of which can be used without modification. Models and drivers can be understood in the usual way; connectors execute simple transfers and transformations, and mediators execute custom coupling code. All have initialization and run sequencing rules that help to ensure interoperability. These generic pieces enable many different coupled model configurations to be created, including hierarchies and ensembles. A dictionary for

\(^{1}\) UV-CDAT home, [http://uv-cdat.llnl.gov/](http://uv-cdat.llnl.gov/)
\(^{2}\) NCL home, [http://www.ncl.ucar.edu/](http://www.ncl.ucar.edu/)
\(^{3}\) From a NOAA PMEL staff member working with LAS and Ferret.
matching field names and a compliance checker are also included. The NUOPC Layer software and examples are bundled with the ESMF distribution.

On a different front, ESMF web service interfaces were used to prototype a two-way coupling between a high performance atmospheric model and a hydrological model used for local resource management. In this arrangement, the models ran on different computers and used infrastructure established in their respective domains. The coupling looks toward a future in which computing resources are increasingly distributed and virtual, and in which there is a need to understand climate impacts in communities with their own models and information delivery systems.

Adoption efforts have shifted from implementing ESMF in codes to incorporating the more rigorous NUOPC Layer interfaces. These are already used in Navy coupled codes COAMPS and NavGEM-HYCOM, and have been prototyped in the NOAA NEMS system and GFDL MOM5. New efforts focus on Navy and NOAA codes, CESM, and GISS Model E and GEOS-5. A new NASA project will introduce an Integrated Development Environment (IDE), essentially a GUI for writing NUOPC-compliant applications.

The NUOPC Layer provides the remaining piece of functionality needed for technical interoperability. In the next stages of the project, the ESMF team will work with collaborators to better define the suite of compatible components and make it easier to access them and create new coupled applications.

Accomplishments in brief for 2011-2012:

- Delivered ESMF 5.2.0r, which satisfied initial project requirements and introduced backward compatibility of most interfaces.
- Developed ESMF grid remapping into a unique and recognized resource, with users in both the modeling and the data analysis and visualization community. An “offline” utility for interpolation weight generation and a Python interface to the grid remapping were popular additions.
- Used ESMF web services to prototype a two-way coupling between a high performance atmosphere and a hydrological model, running on different computers.
- Introduced the NUOPC Layer as a way of increasing the interoperability of model components. The NUOPC Layer introduces generic coupling components, a field dictionary, and a compliance checker.
- Utilized the NUOPC Layer successfully for multiple coupled codes, including COAMPS and NavGEM-HYCOM.
1 Introduction

The Earth System Modeling Framework (ESMF) was motivated by the growing complexity of building and coupling Earth system models. ESMF provides a set of standard software interfaces and high-performance tools for common modeling functions, thereby promoting interoperable software systems and code reuse. It has transitioned from its initial NASA sponsorship to multi-agency support and management. It is the technical foundation for model coupling for the National Unified Operational Prediction Capability (NUOPC), the NASA Modeling Analysis and Prediction Program (MAP), and a host of other programs and projects. More information about ESMF and its applications is available on the ESMF website, http://www.earthsystemmodeling.org. ESMF implementation is led by a Core Team located at the NOAA Earth System Research Laboratory.

2 Software framework description

The current ESMF distribution contains:

- Tools for building scientific components and couplers, and a set of utilities for common modeling functions (e.g., calendar management, message logging, data communications).
- Scalability of core communication routines to tens of thousands of processors.
- Concurrent or sequential execution, single or multiple executable modes.
- Representation and interpolation of unstructured and logically rectangular grids, global or regional, in 2D or 3D, during a model run or offline, with bilinear, higher order, and first order conservative interpolation options.
- Support for configuring ensemble members sequentially or concurrently.
- Complete Fortran interfaces and complete documentation, basic C interfaces and documentation.
- A comprehensive test suite with thousands of tests, including unit tests, system tests, and examples. A suite of realistically sized “use test cases” is available for separate download.
- NUOPC Layer software, including generic components, field dictionary, and compliance checker, with documentation and examples.
- Web service interfaces which enable ESMF coupled systems to be distributed across multiple computers.
- Support for ~30 platform/compiler combinations, including IBM, Cray XT, SGI, Linux, Mac, Windows, and other platforms. The complete list is available on the ESMF website.  
- A Python interface to ESMF grid remapping, ESMPy, is distributed and documented separately.

---

4 http://www.earthsystemmodeling.org/download/platforms/
3 Metrics

- Number of user downloads: 4500
- ESMF user locations worldwide are shown in Figure 1.
- Number of regularly tested platform/compiler combinations: ~30
- Number of regression tests: 4600+
- Number of people signed up for information mailing list: 2700
- Test coverage: 98% of ESMF interfaces are tested
- Source lines of ESMF code: 680,000
- Number of ESMF components: 85; number of ESMF-compatible modeling systems: 12 – see the following link for a full listing: http://www.earthsystemmodeling.org/components/

Figure 1 Location of ESMF users

4 Timeline and strategic objectives

The July 2011 ESMF v5.2.0r release represented a turning point for ESMF. In this release, the major requirements set out for ESMF were completed, and its behavior and interfaces were standardized. After this delivery, the project needed to look forward and determine was else was needed to realize the ESMF vision: a national modeling

---

5 Counts are derived from download statistics. For this chart, repeated downloads (e.g. for updated versions of the software) from the same individual are not counted multiple times
community able to utilize a set of interoperable components. The conclusions are outlined in the *ESMF Strategic Plan for 2012-2015*. There are five main activity areas:

1. Ensure that ESMF remains viable through ongoing maintenance, user support, and responsiveness to new requirements.
2. Develop capabilities and strategic partnerships that help to integrate the framework into increasingly heterogeneous and challenging computational environments.
3. Support users who are integrating ESMF into applications.
4. Build a common model architecture that increases interoperability among ESMF applications.
5. Support end-to-end modeling workflows with self-documenting models.

The first three items were present in the *Strategic Plan 2008-2010*, and are a natural continuation of previous development. However, the balance of activities has been changing over time. There are seven FTEs working on ESMF, and the amount of time spent on user support has grown from about 20% to about 50%. This is due to the growing user base for grid remapping and the receipt of funding for implementing ESMF in specific models. The remaining developer time will go to implementation of features requested by users throughout the framework, testing, porting, and optimization. A list of the many capabilities added by developers during 2011-2012 is provided in the ESMF release notes. New development is likely to include grid remapping features, requirements for data assimilation, and optimizations for accelerator-based architectures. Priorities for development are set by the ESMF Change Review Board.

The fourth item addresses a shortcoming of ESMF. The flexibility of the framework enabled many different groups to adopt it. However, variations in the implementation of ESMF at different sites limited cross-site component interoperability. The NUOPC program addressed this by working with the ESMF team to develop metadata and usage conventions along with generic code templates to standardize ESMF implementations. The development of these conventions, along with a common physical architecture for models, is referred to as a common model architecture (CMA) by the NUOPC project. A “NUOPC Layer” software package encodes many aspects of the CMA. It is bundled with the ESMF distribution and a production release is scheduled for 2013. Vetting, refining, and propagating this common model architecture will be a major thrust of the ESMF team in the coming years. Plans for NUOPC adoption for a range of applications are captured in a set of roadmaps. In 2013, the ESMF team is collaborating with modeling groups to complete couplings of MOM5 and HYCOM to NEMS, and HYCOM to CESM using the NUOPC Layer. A new initiative for 2013 will be identifying compliant components as part of a national prediction suite.

---

The fifth item, integrating ESMF with end-to-end workflows, requires not only the delivery and adoption of ESMF, but the interaction of the framework with metadata tools, data services, and collaboration environments. The scope of the ESMF activity has grown in pursuit of this goal. ESMF is now embedded in a larger activity called the NOAA Environmental Software Infrastructure and Interoperability (NESII)\(^9\) project. NESII is engaged in infrastructure efforts such as the ES-DOC project, which develops metadata standards, the Earth System CoG project, a collaboration environment linked to the ESGF data distribution system, and the NCPP Platform, which is developing software for reformatting and translating climate projection data so that it is more broadly useful. These activities help to inform ESMF development and introduce ESMF to new customers.

ESMF is now in the midst of its third funding cycle and has a diversity of funding sources. All ESMF activities remain rooted in the project’s core values of community ownership, distributed development, and open access to information.

5 Plans in brief for 2013
In 2013, the ESMF Core Team will focus on:

- Providing user support, ports, optimizations and feature additions for ESMF.
- Delivering the production release of the NUOPC Layer software, including examples, documentation, and websites.
- Implementing the NUOPC Layer in applications as described in roadmaps. For 2013, priorities are HYCOM and MOM5 oceans coupled to NEMS, and the HYCOM ocean coupled to CESM.
- Beginning organization of interoperable components into a well-defined national prediction suite.

6 Detailed accomplishments for 2011-2012
The categories and measures here are taken from the ESMF Annual Report 2010\(^{10}\).

6.1 Complete a functionally mature, standardized version of ESMF

Measures of success
- Complete the exhaustive review of ESMF interfaces and deliver the ESMF v5.2.0r release, which will mark the beginning of backward compatibility for major framework classes.

Actual performance, outputs and outcomes:
The ESMF v5.2.0 software was delivered in July 2011. It represents the completion of many of the goals set out in 2002 when the project started: a library defining and implementing a fast, portable, flexible, and comprehensive infrastructure for building and coupling Earth system models. This release initiated backward compatibility for

\(^9\) [http://www.esrl.noaa.gov/nesii/](http://www.esrl.noaa.gov/nesii/)
\(^{10}\) [http://www.earthsystemmodeling.org/plans/report_1102_esmfannual.pdf](http://www.earthsystemmodeling.org/plans/report_1102_esmfannual.pdf)
much of the ESMF application programming interface. However, following discussion on the ESMF Joint Specification Team (JST) mailing list and with the Change Review Board, some of the newer and rapidly evolving interfaces (Mesh, Location Stream, Exchange Grid, Attributes, IO) were exempted from backward compatibility. Interfaces that are backward compatible indicate this in the "STATUS:" section of their API description in the ESMF Reference Manual. 77% of interfaces were backward compatible at the time of the v5.2.0r release.

Besides the standardization work, ESMF v5.2.0rp2 contained major functional developments since the last public release, v4.0.0rp2. Regridding in v5.2.0 includes a conservative option in addition to a bilinear and higher order method, and handles poles, grid connections, masking, and regional grids. An application that allows regrid weights to be generated offline from netCDF input files is bundled with this distribution. Distributed data classes such as Fields support a halo operation in addition to regridding, redistribution, and other communication methods. The communication methods support non-blocking execution. The implementation of State, FieldBundle and ArrayBundle was completed, based on a standard, highly efficient container implementation. An Exchange Grid (XGrid) class was added that supports flux-conserving regridding on an interfacial surface layer.

Metadata handling was extended as the Attribute class in v5.2.0r provided standard packages, including support for output in the form of the METAFOR Common Information Model (CIM) XML schema.

A prototype implementation of Web Services enabled users to make their ESMF Components accessible via a SOAP (Simple Object Access Protocol) interface. By implementing a simple function call in the application driver, the user can make a Component's initialize, run and finalize routines executable through a standard web interface.

As of 2013, most ESMF applications have already converted over or have development versions that include the 5.2.0r interfaces.

6.2 Evolve ESMF prototype capabilities and add new features as required

Measures of success

- Add features as needed to regridding libraries, which may include further testing of the 3D regrid option, direct support for hexagonal elements (currently these are represented as triangles) or introducing higher order conservative weights.
- Enable users to easily set up multi-tile grids.
- Continue development and testing of prototype Location Stream, Exchange Grid, Mesh, I/O and Attribute classes and initiate backward compatibility for their interfaces.

• Unify information handling across the framework by integrating the functionality of Attributes, I/O, and Config classes, and descriptors set through data structure argument lists.
• Enable the I/O capability to accept other packages besides PIO and other formats besides netCDF.
• Maintain or reduce the number of open bug reports and feature requests.

Actual performance, outputs, and outcomes:
The first real test of the 3D grid remapping capability was in late 2012, when it was used to implement a remapping between the WAM atmospheric model and the Ionosphere Plasmasphere Electrodynamics (IPE) Model. Several bugs were found and addressed. A performance report is being prepared and will be posted on the ESMF metrics page in 2013.\(^\text{12}\)

Meshes were used heavily during 2011-2012 to remap new grids from models including ORCA, HOMME, and MPAS. Many ESMF users reported back that the software worked well and satisfied their needs.

Exchange Grids were developed further, and can now be built from either Meshes or logically rectangular grids. They have not yet been tested in earnest by users.

Shortcuts for users to set up multi-tile grids and work on Location Streams were not given high priority by the Change Review Board and were not implemented. Using the Mesh representation for multi-tile grids seemed to be a satisfactory work-around for multi-tile grids. The capability to compute higher order interpolation weights was not added either.

The modularity of the I/O implementation was improved and its relation to the Attribute class clarified. The addition of another I/O option besides the PIO package was not given high priority by the CRB and was not implemented. Attributes were extended so that they can discover and represent metadata that is set through argument lists.

No new interfaces from the Mesh, Attribute, Location Stream, or Exchange Grid classes were added to the backward compatible list.

Although it was not included in 2010 plans, the Core Team became aware of a need for a Python version of the grid remapping software. This package, called ESMPython, was first released in January 2012 and quickly found users in the data services and modeling communities\(^\text{13}\).

\(^{13}\) [http://earthsystemcog.org/projects/esmp/](http://earthsystemcog.org/projects/esmp/)
Figure 2 (a) shows that the number of open bug reports continued to grow through the period of this report. Note that inconsistencies and gaps in documentation are classified as bugs.

Figure 2 (b) shows that the number of open feature requests continued to increase faster than they could be addressed.

**Figure 2** Bug and feature request metrics. The number of bugs and feature requests inched up again. Chart (a) shows the number of open ESMF bug reports in green and new bug reports in blue, chart (b) the number of open ESMF feature requests in purple and the number of new feature requests in orange.
6.3 Develop conventions and software templates that will increase the level of interoperability of ESMF components

Measures of success
- In collaboration with NUOPC partners, deliver documents and software templates that define a common model architecture that will minimally work for atmosphere-ocean use cases, and is broadly applicable to coupling problems.
- In collaboration with NUOPC partners, deliver tracking documents that show how NOGAPS, COAMPS, and NEMS have adopted the proposed conventions, and deliver prototypes of these codes that demonstrate use of the new NUOPC Layer.

Actual performance, outputs, and outcomes:
The NUOPC Layer software was first released with ESMF v5.2.0r. It includes generic components, a Field dictionary and a compliance checker. Documentation includes a website\(^\text{14}\), a comprehensive Reference Manual, and example codes showing all major aspects of functionality. A tracking document showing adoption of the NUOPC Layer code by Navy NavGEM/NOGAPS-HYCOM, COAMPS, and NOAA NEMS models is posted on the web\(^\text{15}\). However, adoption has already grown beyond this initial set of codes. A set of roadmaps on the website shows NUOPC activities for a broader set of codes\(^\text{16}\).

6.4 Provide ESMF training and support

Measures of success:
- Improve ESMF on-line web training and add additional instructional modules.
- Support users who are integrating ESMF into applications.
- Develop an outreach plan.

Actual performance, outputs, and outcomes:
The ESMF website, documentation, examples and Frequently Asked Questions pages were updated for the 5.2.0r and subsequent releases. The initial web-based training module was not extended. However, an Integrated Development Environment (IDE) designed for training new ESMF users was funded by NASA late in 2012.

User support has grown from about 20% of the development team time to about 50% of the time of the development team. Feedback from users is consistently positive regarding the quality of support.

One of the members of the NESII group was identified as a outreach lead. She developed a listing of relevant conferences and alerts the team to imminent deadlines. This has been effective but could be improved.

\(^{14}\) http://www.earthsystemcog.org/projects/nuopc/
\(^{15}\) http://www.earthsystemcog.org/site_media/projects/nuopc/paper_1211_adoption.doc
\(^{16}\) http://www.earthsystemcog.org/projects/nuopc/roadmap/
6.5 Develop software utilities and science gateway services

Measures of success:
- Deliver an ESMF release that includes the ability to run an ESMF component as a web service.
- In collaboration with a modeling group, demonstrate how ESMF Attributes can enable model code to be self-documenting, with metadata automatically archived to a portal.

Actual performance, outputs, and outcomes:
The option for running ESMF components as web services was delivered with ESMF 5.2.0r.

Working with collaborators from Purdue University and NCAR, the ESMF team delivered an end-to-end workflow system. This tool enables CESM runs to be configured and submitted through a GUI, and to output both model output data and comprehensive simulation metadata to the Earth System Grid, where the metadata can be searched and browsed. The workflow is in use in courses at Purdue (see Zhao et al. 2011 in Publications).

Another team created a self-describing workflow using CESM, WRF, and ROMS. These were coupled and run in an ESMF workflow and the Attribute class was used to document the configuration (see Turuncoglu et al. 2012 in Publications).

6.6 Framework optimization and porting

Measures of success:
- Minimal performance burden for working code. (Target <5% overhead for ESMF component and regridding methods vs. native packages.)
- Continued demonstration of performance viability for petascale and other emerging computing architectures.
- Requested ports delivered.

Actual performance, outputs, and outcomes:
Users and internal tests indicate that continued development has not degraded performance and ESMF still represents <5% overhead for most applications.
Three performance reports were generated in 2011-2012. One was an update to a previous test of the ESMF sparse matrix multiply in a simplified setting; the other two measured the performance of the sparse matrix multiply implemented in the CESM coupler, compared to the original version of the code. Figure 3 indicates that the performance is comparable. The ESMF time, which was slightly faster for this test, also includes the cost of wrapping CESM native data structures.

ESMF was ported to new computing platforms during 2011-2012 without major issues.

6.7 Advance community adoption

Measures of success:
- Number of ESMF components available should reach 100 in 2011.
- Number of ESMF applications in routine use or operations. Goals for 2011 include having at least one more ESMF code transition to production or operations.
- Demonstrate a coupling interface between ESMF and OpenMI in the hydrology domain.

There are currently about 85 ESMF components, and 12 ESMF-based coupled modeling systems. The coupled COAMPS code was transitioned to operations since the last report. Appendix B shows the status of major codes in the modeling community with respect to ESMF adoption.

A two-way coupling between an ESMF applications and OpenMI applications was prototyped in a coupling project that involved the Community Atmospheric Model (CAM) and the Soil Water Analysis Tool (SWAT), which predicts stream flow. The motivation is to introduce climate inputs into the SWAT model, feed information about local and regional surface processes back into the climate model, and ultimately provide more accurate information on water availability. This is a "reach" effort because the scales of the climate model and hydrological model are currently so different. However, over the next five to ten years climate models are expected to increase in resolution and models like SWAT to cover increasingly large domains.

The atmospheric model is implemented as an ESMF component and is wrapped with an OpenMI interface, which facilitates the communication with the OpenMI-compliant hydrological model. The hydrological model, driver, and the two OpenMI wrappers physically exist on a personal computer running Windows. The ESMF component itself exists on a multi-threaded Linux computer. An ESMF web services interface is used to bridge the two computer platforms. Figure 4 shows the configuration. Since the initial implementation, the WRF model has become

17 http://www.earthsystemmodeling.org/metrics/performance/
18 http://www.earthsystemmodeling.org/components/
available through CESM, with an ESMF interface, and this will be used as the target atmospheric model. A regional atmospheric model more closely matches the scale of SWAT and will make more sense for more realistic experimentation with the system. See Publications for Goodall et al. for more information on this project.

![Diagram](image.png)

Figure 4 Coupling of ESMF and OpenMI components for modeling a hydrological system. The driver and hydrological component are run on a personal computer, while the atmosphere is run on a high performance cluster.

7 Project plan evaluation measures for FY2013

7.1 Deliver a production version of the NUOPC Layer

Measures of success
- Release of ESMF that includes a fully tested, documented, and vetted NUOPC Layer.

7.2 Evolve ESMF prototype capabilities and add new features as required

Measures of success
- Add features as prioritized by the Change Review Board to ESMF.
- Promote additional interfaces to backward compatible status.

7.3 Provide ESMF training and support

Measures of success:
- Maintain or reduce the number of bug and feature requests.
- Develop on-line training environment for ESMF.
- Support users who are integrating ESMF into applications.
7.4 Advance self-documenting code and workflow capabilities

Measures of success:
- In collaboration with a modeling group, demonstrate how ESMF Attributes can enable model code to be self-documenting.

7.5 Framework optimization and porting

Measures of success:
- Minimal performance burden for working code. (Target <5% overhead for ESMF component and regridding methods vs. native packages.)
- Continued demonstration of performance viability for accelerator-based computing architectures.
- Requested ports delivered.

7.6 Advance community adoption

Measures of success:
- All major U.S. Earth system models can operate with NUOPC interfaces.
- Initiate a code suite that identifies interoperable model components.
- Advance the climate-hydrology application by switching the atmosphere to a regional model and generating initial science results.

8 Impact of the ESMF project

Widespread use of ESMF represents a paradigm shift in the way weather, climate, coastal, and related models are constructed. Through ESMF standard interfaces, community governance, and shared tools, large centers are more easily able to collaborate on infrastructure needs and exchange codes. The end result is an Earth science community better equipped to explore basic research issues and to answer questions about the changing environment.

9 Publications 2011-2012


### 10 Sponsors

ESMF sponsors include:

- NRL Earth System Prediction Capability
- NRL National Unified Operational Prediction Capability
- NOAA Climate Program Office
- NOAA NWS National Unified Operational Prediction Capability
- NASA Computational Modeling Algorithms and Cyberinfrastructure Program
- NASA Modeling Analysis and Prediction Program
- National Science Foundation
### Appendix A: Table of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADCIRC</td>
<td>Advanced Circulation Model for Coastal Ocean Hydrodynamics</td>
</tr>
<tr>
<td>AR5</td>
<td>IPCC 5th Assessment Report</td>
</tr>
<tr>
<td>BEI</td>
<td>Battlespace Environments Institute</td>
</tr>
<tr>
<td>CESM</td>
<td>Community Earth System Model</td>
</tr>
<tr>
<td>CICE</td>
<td>Los Alamos sea ice model</td>
</tr>
<tr>
<td>CMIP5</td>
<td>5th Coupled Model Intercomparison Project</td>
</tr>
<tr>
<td>COAMPS</td>
<td>Coupled Ocean/Atmosphere Mesoscale Prediction System</td>
</tr>
<tr>
<td>CoG</td>
<td>Commodity Governance project</td>
</tr>
<tr>
<td>CSDMS</td>
<td>Community Surface Dynamics Modeling System</td>
</tr>
<tr>
<td>ES-DOC</td>
<td>Earth System - Documentation</td>
</tr>
<tr>
<td>ESGF</td>
<td>Earth System Grid Federation</td>
</tr>
<tr>
<td>ESMF</td>
<td>Earth System Modeling Framework</td>
</tr>
<tr>
<td>FMS</td>
<td>Flexible Modeling System</td>
</tr>
<tr>
<td>GEOS-5</td>
<td>Goddard Earth Observing System Model</td>
</tr>
<tr>
<td>GFDL</td>
<td>Geophysical Fluid Dynamics Laboratory</td>
</tr>
<tr>
<td>GFS</td>
<td>Global Forecast System</td>
</tr>
<tr>
<td>GIP</td>
<td>Global Interoperability Program</td>
</tr>
<tr>
<td>GISS</td>
<td>Goddard Institute for Space Studies</td>
</tr>
<tr>
<td>GO-ESSP</td>
<td>Global Organization of Earth System Science Portals</td>
</tr>
<tr>
<td>HOMME</td>
<td>Higher Order Method Modeling Environment</td>
</tr>
<tr>
<td>HYCOM</td>
<td>Hybrid Coordinate Ocean Model</td>
</tr>
<tr>
<td>IMaGe</td>
<td>Institute for Mathematics in the Geosciences</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IPE</td>
<td>Ionosphere Plasmasphere Electrodynamics Model</td>
</tr>
<tr>
<td>MAP</td>
<td>Modeling Analysis and Prediction program</td>
</tr>
<tr>
<td>MAPL</td>
<td>Modeling Analysis and Prediction program Layer</td>
</tr>
<tr>
<td>METAFORE</td>
<td>common Metadata For climate modelling digital repositories</td>
</tr>
<tr>
<td>MOM5</td>
<td>Modular Ocean Model 5</td>
</tr>
<tr>
<td>MPAS</td>
<td>Model for Prediction Across Scales</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NavGEM</td>
<td>Navy Global Environmental Model</td>
</tr>
<tr>
<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
</tr>
<tr>
<td>NCPP</td>
<td>National Climate Predictions and Projections Platform</td>
</tr>
<tr>
<td>NCL</td>
<td>NCAR Command Language</td>
</tr>
<tr>
<td>NEMS</td>
<td>NOAA Environmental Modeling System</td>
</tr>
<tr>
<td>NESII</td>
<td>NOAA Environmental Software Infrastructure and Interoperability</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>NRL</td>
<td>Naval Research Laboratory</td>
</tr>
<tr>
<td>NSF</td>
<td>National Science Foundation</td>
</tr>
<tr>
<td>NUOPC</td>
<td>National Unified Operational Prediction Capability</td>
</tr>
<tr>
<td>NWP</td>
<td>Numerical Weather Prediction</td>
</tr>
<tr>
<td>Short Form</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>PCMDI</td>
<td>Program for Climate Model Diagnosis and Intercomparison</td>
</tr>
<tr>
<td>pWASH123</td>
<td>parallel WAterSHed 1-2-3D model</td>
</tr>
<tr>
<td>ROMS</td>
<td>Regional Ocean Modeling System</td>
</tr>
<tr>
<td>SCRIP</td>
<td>Spherical Coordinate Interpolation and Remapping Package</td>
</tr>
<tr>
<td>SWAN</td>
<td>Simulating WAves Nearshore model</td>
</tr>
<tr>
<td>SWAT</td>
<td>Soil Water Analysis Testbed</td>
</tr>
<tr>
<td>UV-CDAT</td>
<td>Ultrascale Visualization - Climate Data Analysis Tools</td>
</tr>
<tr>
<td>WAM</td>
<td>Whole Atmosphere Model (a configuration of GFS)</td>
</tr>
<tr>
<td>WRF</td>
<td>Weather Research and Forecast model</td>
</tr>
</tbody>
</table>
Appendix B: U.S. Earth system models and their associated infrastructure

<table>
<thead>
<tr>
<th>Models</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1. CESM</td>
<td>I1. ESMF X</td>
</tr>
<tr>
<td></td>
<td>I2. CESM driver X (default)</td>
</tr>
<tr>
<td></td>
<td>I3. FMS</td>
</tr>
<tr>
<td></td>
<td>I4. CSDMS</td>
</tr>
<tr>
<td></td>
<td>I5. Web protocols X (via ESMF web services)</td>
</tr>
<tr>
<td>M2. WRF</td>
<td>X</td>
</tr>
<tr>
<td>M3. GEOS-5</td>
<td>X</td>
</tr>
<tr>
<td>M4. Model E</td>
<td>Recently funded X</td>
</tr>
<tr>
<td>M5. COAMPS and NOGAPS/NavGEM</td>
<td>X</td>
</tr>
<tr>
<td>M6. HYCOM</td>
<td>X</td>
</tr>
<tr>
<td>M7. NUMA</td>
<td>X</td>
</tr>
<tr>
<td>M8. GFS, NEMS and FIM</td>
<td>X</td>
</tr>
<tr>
<td>M9. CFS</td>
<td>X</td>
</tr>
<tr>
<td>M10. GFDL</td>
<td>Partial (MOM4) X</td>
</tr>
<tr>
<td>M11. ROMS and surface models</td>
<td>X</td>
</tr>
<tr>
<td>M12. Various impacts models</td>
<td>X</td>
</tr>
</tbody>
</table>

Models included in the table:

M1. the Community Earth System Model (CESM) from NSF/DOE\(^{19}\);
M2. the Weather Research and Forecast (WRF) model and emerging Model for Prediction Across Scales (MPAS), developed mainly at NCAR\(^{20}\);
M3. the NASA Goddard Space Flight Center GEOS-5 model\(^{21}\);
M4. Model E from the NASA Goddard Institute for Space Studies\(^{22}\);
M5. the Navy regional and global models COAMPS\(^{23}\) and NOGAPS/NavGEM, respectively\(^{24}\);
M6. the HYbrid Coordinate Ocean Model (HYCOM)\(^{25}\);
M7. NUMA (Non-hydrostatic Unified Model of the Atmosphere) from the Naval Postgraduate School\(^{26}\);
M8. the NOAA Global Forecast System\(^{27}\), the NOAA Environmental Modeling System (NEMS)\(^{28}\), and the FIM and NIM models from NOAA ESRL\(^{29}\);

---

\(^{19}\) Community Earth System Model website, [http://www.cesm.ucar.edu/](http://www.cesm.ucar.edu/)


\(^{22}\) Description of GISS ModelE, [http://www.giss.nasa.gov/tools/modelE/](http://www.giss.nasa.gov/tools/modelE/)


\(^{24}\) NOGAPS website, [http://www.srh.noaa.gov/srh/ssd/nwpmodel/html/nogaps.htm](http://www.srh.noaa.gov/srh/ssd/nwpmodel/html/nogaps.htm)


\(^{26}\) NUMA website, [http://faculty.nps.edu/fxgirald/Homepage/Link_to_NUMA.html](http://faculty.nps.edu/fxgirald/Homepage/Link_to_NUMA.html)


\(^{28}\) NEMS website, [http://www.emc.ncep.noaa.gov/?branch=NEMS](http://www.emc.ncep.noaa.gov/?branch=NEMS)
M9. the NOAA Climate Forecast System (CFS)\textsuperscript{30};
M10. GFDL climate models\textsuperscript{31};
M11. the Regional Ocean Modeling System (ROMS) and a suite of surface models being
developed by the Community Surface Dynamics Modeling System (CSDMS)\textsuperscript{32}; and
M12. a set of service-based hydrological, agricultural, and impacts models that are focused
on delivery of local and regional products\textsuperscript{33}.

Infrastructure software:
I1. the Earth System Modeling Framework (ESMF), under NASA, DOE, NOAA and NSF
funding, and the National Unified Operational Prediction Capability (NUOPC) Layer,
under Navy and NOAA funding\textsuperscript{34};
I2. the CESM driver and underlying Model Coupling Toolkit, largely funded by DOE\textsuperscript{35};
I3. the Flexible Modeling System, from NOAA GFDL\textsuperscript{36};
I4. CSDMS modeling tools, based on the Common Component Architecture (CCA), now
funded by NSF\textsuperscript{37};
I5. and, for models focused on local and regional products, web service-based
frameworks and protocols\textsuperscript{38}.

\textsuperscript{29} FIM website, \url{http://fim.noaa.gov/}
\textsuperscript{30} CFS website \url{http://cfs.ncep.noaa.gov/}
\textsuperscript{31} CM2M and CM2G website, \url{http://www.gfdl.noaa.gov/cm2m-and-cm2g}
\textsuperscript{32} ROMS website, \url{http://www.myroms.org/}, and CSDMS component website,
\url{http://csdms.colorado.edu/wiki/CMT_run_models}
\textsuperscript{33} See for example SWAT website, \url{http://swat.tamu.edu/}, OMS website,
\url{http://www.javaforge.com/project/oms}
\textsuperscript{34} ESMF website, \url{http://www.earthsystemmodeling.org}, and NUOPC website,
\url{http://www.nws.noaa.gov/nuopc/}
\textsuperscript{35} CESM CPL7 website, \url{http://www.cesm.ucar.edu/models/ccsm4.0/cpl7/}
\textsuperscript{36} GFDL FMS website, \url{http://www.gfdl.noaa.gov/fms}
\textsuperscript{37} CSDMS Modeling Tool website, \url{http://csdms.colorado.edu/wiki/CMT_information}
\textsuperscript{38} For example, OpenMI website, \url{http://www.openmi.org/}