The Earth System Modeling Framework
and Earth System Curator

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and the ESMF Joint Specification Team

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The Challenge of Model Coupling

• Software components that represent geophysical domains and processes are developed by groups of disciplinary experts, often at different sites

• These components are coupled together to form Earth system models

• Model developers and users must be able to:
  ◦ combine, exchange, and compare components
  ◦ introduce and modify scientific routines without a lot of technical effort
  ◦ use the same component in a variety of coupling scenarios
  ◦ produce multi-component models that are understandable, extensible, and maintainable

ESMF, a software component framework, is designed to address these challenges
The Earth System Modeling Framework

- ESMF provides tools for turning model codes into components with standard interfaces and standard drivers.
- ESMF provides data structures and common utilities that components use for routine services such as data communications, regridding, time management, configuration, and message logging.

Outputs and outcomes ...

- Open-source, collaboratively developed software utilities and coupling interfaces, exhaustive test suite, documentation, support and training.
- A federation of geophysical components that can be assembled in multiple ways, using different drivers and different couplers.
- A Earth science organization that has focused interactions at many levels: software engineer and support scientist, technical and scientific manager, scientist, director, sponsor.
- An extended community with strong connections and many diverse science options.
## ESMF Components

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<thead>
<tr>
<th>Scope</th>
<th>Description</th>
<th>Status</th>
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*Proto = working prototype, in progress*

*Prod = in production/operations*
### ESMF Components (cont.)

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ESMF Projects and Programs

**Battlespace Environments Institute**

*Sponsor:* Department of Defense, through 2010  
*Partners:* DoD Naval Research Laboratory, DoD Fleet Numerical, DoD Army ERDC, DoD Air Force Weather Agency

The Battlespace Environments Institute is developing integrated Earth and space forecasting systems that use ESMF as a standard for component coupling.

**Modeling, Analysis and Prediction Program for Climate Variability and Change**

*Sponsor:* NASA, through 2010  
*Partners:* University of Colorado at Boulder, University of Maryland, Duke University, NASA Goddard Space Flight Center, NASA Langley, NASA Jet Propulsion Laboratory, Georgia Institute of Technology, Portland State University, University of North Dakota, Johns Hopkins University, Goddard Institute for Space Studies, University of Wisconsin, Harvard University, more

The NASA Modeling, Analysis and Prediction Program is developing an ESMF-based modeling and analysis environment to study climate variability and change.

**Community Sediment Transport Model**

*Sponsor:* ONR, through 2009  
*Partners:* USGS, Woods Hole Oceanographic Institute, DoD Naval Research Laboratory, DoD Army ERDC, Rutgers University, more

This research and applications team is creating a community modeling system for sediment transport, using ESMF as the coupling standard.
ESMF Projects and Programs (cont.)

Integrated Dynamics through Earth’s Atmosphere  
**Sponsors:** NASA, through 2007  
**Partners:** NOAA CIRES, NOAA NCEP  
The IDEA project will extend the upper boundary of the NOAA NCEP Global Forecast System to incorporate near-space components, using ESMF.

ESMF Integration with the Space Weather Modeling Framework (SWMF)  
**Sponsor:** NSF, through end 2006  
**Partner:** University of Michigan  
The SWMF is being wrapped as an ESMF component to facilitate coupling between Earth and space components. This project also introduces 3D coupling into ESMF.

ESMF Integration with the Center for Integrated Space Weather Modeling (CISM)  
**Sponsor:** NASA, through end 2006  
**Partners:** University of Maryland, NCAR HAO, Boston University, more  
Together the ESMF team and the University of Maryland are developing a multiple-executable strategy to couple ESMF and CISM components.

Spanning the Gap Between Models and Datasets: Earth System Curator  
**Sponsor:** NSF, through 2008  
**Partners:** Princeton University, Georgia Institute of Technology, Massachusetts Institute of Technology, PCMDI, NOAA GFDL, NOAA PMEL, DOE ESG, more  
The ESMF team is working with data specialists to create an end-to-end knowledge environment that encompasses data services and models.
New Directions

• Internal (Beta) Release ESMF Version 3.0.0 (May 2006)
  ◦ Very general multi-patch data structures
  ◦ Sparse matrix multiply for regridding can handle curvilinear coordinate grids and unstructured grids
  ◦ New data structures will be the building blocks for a variety of methods on cubed sphere, tripole, and other grids
• Extension into new domains and coupling to other frameworks
  ◦ Space weather (coupling to SWMF models, CISM models, AFWA models)
  ◦ Air quality
  ◦ Hydrology (OpenMI)
• Increased support for C/C++ (contrib. Tim Campbell/NRL, Balazs Fekete/UNH)
• Extension into a new coupling paradigm (contrib. Alan Sussman/University of Maryland)
  ◦ Multiple executable
  ◦ Direct intercomponent data transfers via State put & get
• Observational data streams (contrib. Will Sawyer, NASA GMAO)
• Regular 3D grids and regridding (contrib. Bob Oehmke, University of Michigan)
• Each box is an ESMF component
• Data in and out of components are packaged as State types with user-defined fields
• Every component has a standard interface to encourage “swappability”:
  subroutine Comp_Run(comp, importState, exportState, clock, rc)
• Hierarchical architecture enables the systematic assembly of many different systems
• Coupling tools include regridding and redistribution methods
One-Box Approach

- It is also possible to “wrap” an entire existing model with ESMF, without needing to change internal data structures, by just creating one component box.
- This is lightweight in terms of performance.
- It enables the code to be coupled with other ESMF codes more easily.

**Timing Result: SSI Baseline vs SSI ESMF**

- Overhead of ESMF superstructure in NCEP Spectral Statistical Analysis (SSI), ~1% overall.
- Run on NCAR IBM POWER-4.
- Runs done by JPL staff, confirmed by NCEP developers.
ESMF Distribution Summary

- ESMF distribution includes
  - Tools to create components, couplers, and ensembles
  - Standard utilities such as regridding, data communications, time management, and message logging
- Fortran interfaces and complete documentation
  - Reference Manual (500+ pages)
  - Users Guide
  - Developers Guide
- 2000 unit tests, system tests, examples bundled with source distribution
- Many C++ interfaces (needed by hydrological models)
- Serial or parallel execution (mpiuni stub library)
- Sequential or concurrent execution
- Single executable (SPMD) and limited multiple executable (MPMD) support
- Support for ensembles
ESMF Platform Support

- IBM AIX (32 and 64 bit addressing)
- SGI IRIX64 (32 and 64 bit addressing)
- SGI Altix (64 bit addressing)
- Cray X1 (64 bit addressing)
- Compaq OSF1 (64 bit addressing)
- Linux Intel (32 and 64 bit addressing, with mpich and lam)
- Linux PGI (32 and 64 bit addressing, with mpich)
- Linux NAG (32 bit addressing, with mpich)
- Linux Absoft (32 bit addressing, with mpich)
- Linux Lahey (32 bit addressing, with mpich)
- Mac OS X with xlf (32 bit addressing, with lam)
- Mac OS X with absoft (32 bit addressing, with lam)
- Mac OS X with NAG (32 bit addressing, with lam)

- User-contributed g95 support
- Currently porting to NEC
Highest Priorities

- Usability
  - Simplifying build and software interfaces
  - Improving documentation
  - Completing, fixing bugs in, and optimizing existing functions
  - Adding better tutorial materials and realistic code examples
- More grids! Support for representing and regridding general curvilinear coordinate grids, unstructured grids, and observational data streams
- Numerical accuracy of methods
- Performance optimization
- Customer support and training
Earth System Curator

- Recognizes that climate models and datasets are described by similar metadata
- **Proposes standards for climate model metadata, especially in the areas of model configurations, components, and grids**
- Works with umbrella groups developing metadata standards (e.g. CF, NMM, GO-ESSP) to integrate model and data metadata
- Works with ESG, GFDL, CCSM, PCMDI, PMEL and others to extend databases used for MIPs and IPCC so that they have a better representation of models themselves

**Anticipated result:**

- Opportunities to develop smarter tools (e.g. query, compatibility, assembly) based on extended and shared metadata
Summary

- ESMF uses software components to structure climate and other Earth system models
- The ESMF team and others are working to bridge organizational, national, and disciplinary boundaries via high-performance software infrastructure
- The Earth System Curator is introducing component constructs to metadata schema and combining ESMF components with data services
- The idea is to create a federation of interoperable Earth system components and the tools to support scientific workflows