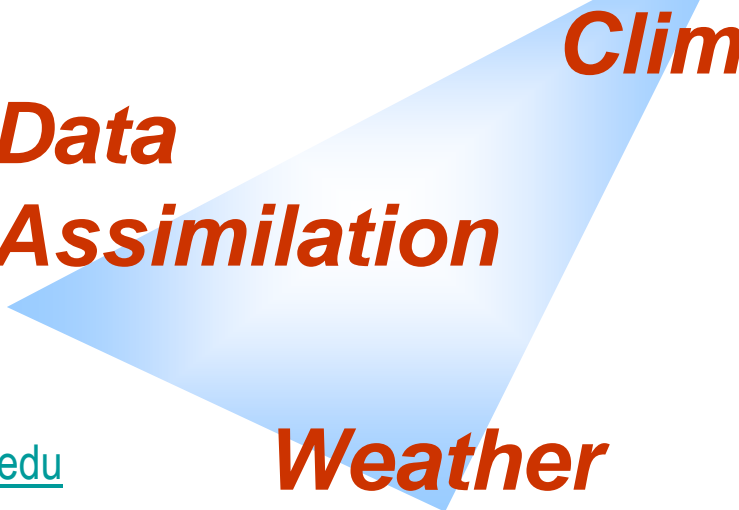# The Earth System Modeling Framework
and the Earth System Curator

Climate

Data Assimilation

Weather

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and the ESMF Joint Specification Team

February 27, 2006

The Problem of Model Coupling

- Codes that represent physical domains and processes are developed by groups of disciplinary experts, and need to be coupled together to form a climate application

- Climate modelers from different organizations need to share, exchange, and compare their codes and parts of their codes

- Scientific development of climate codes relies on the ability to:
  - introduce and modify scientific routines without a lot of technical effort
  - use models in different contexts (i.e., CAM, WACCM, CCSM, fvCAM, regional climate model, etc.)
  - produce applications that are understandable and maintainable

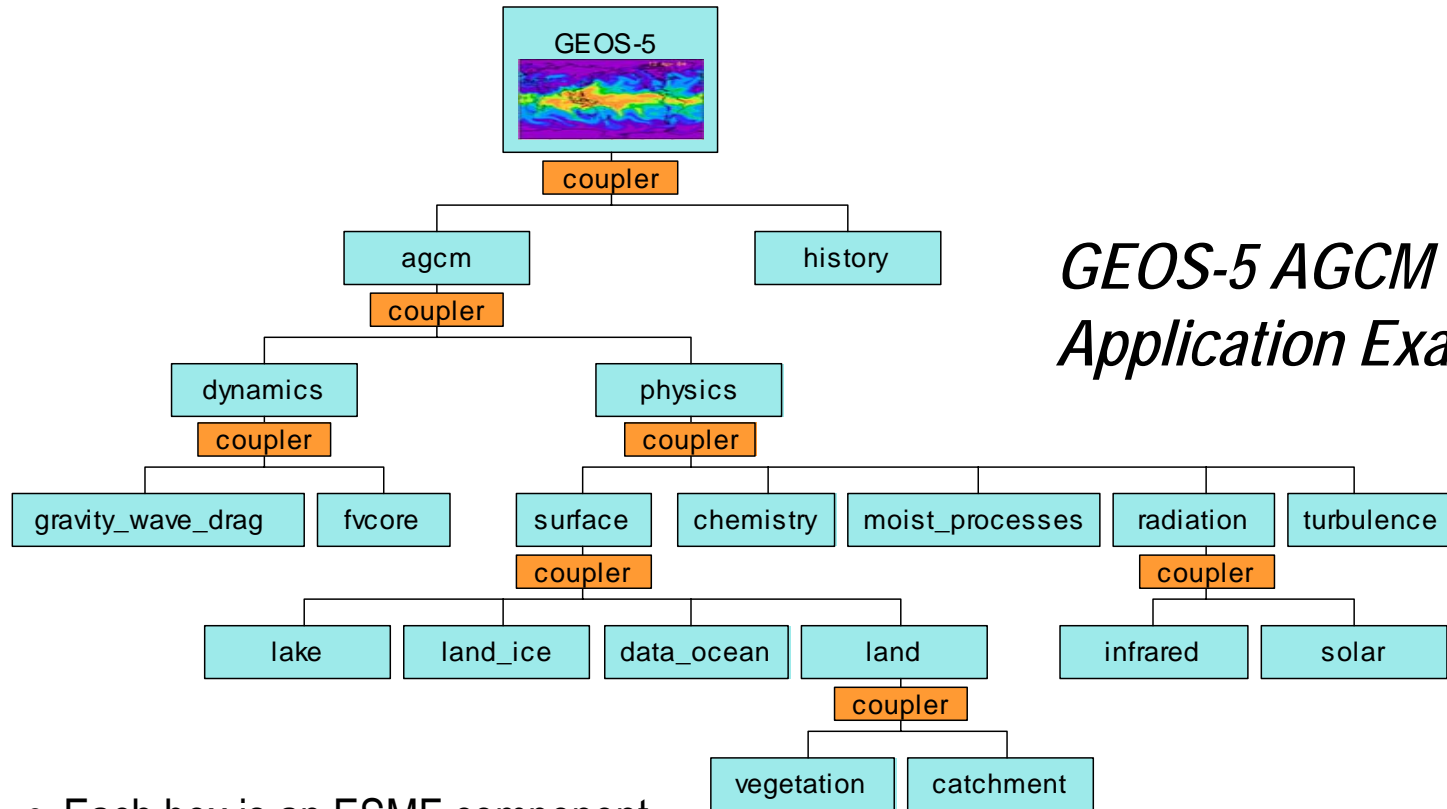- Software components address these code structure and coupling problems

Software Components

- The key characteristic of a software component is that it is composable - components can be combined to form a variety of different applications

- Component architectures are an established approach to achieving interoperability (e.g. CORBA)

- Climate codes can be represented as collections of software components

  The idea behind the Earth System Modeling Framework (ESMF) is to create a federation of reasonably interoperable software components for the climate, weather, and related communities - and the tools to couple them.

ESMF Application Example


```
                        GEOS-5
                      [  image  ]
                          |
                      [coupler]
                     /          \
                  agcm         history
                [coupler]
               /         \
         dynamics       physics
         [coupler]      [coupler]
        /        \     /    |    |        |        \
gravity_wave_drag fvcore surface chemistry moist_processes radiation turbulence
                      [coupler]                    [coupler]
                    /   |    |   \                 /        \
                 lake land_ice data_ocean land  infrared  solar
                                      [coupler]
                                     /        \
                               vegetation  catchment
```

*GEOS-5 AGCM*
Application Example

- 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

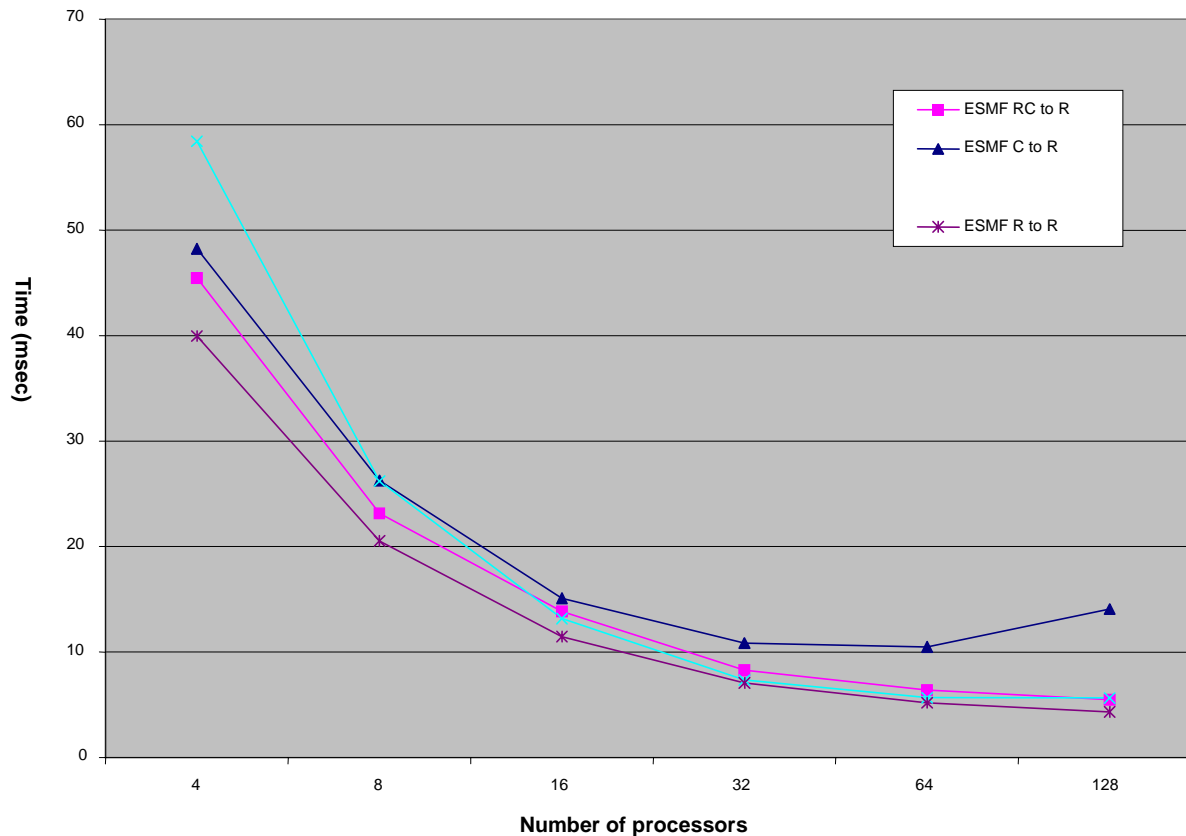- It enables the code to be coupled with other ESMF codes more easily

Timing Result: SSI Baseline vs SSI ESMF
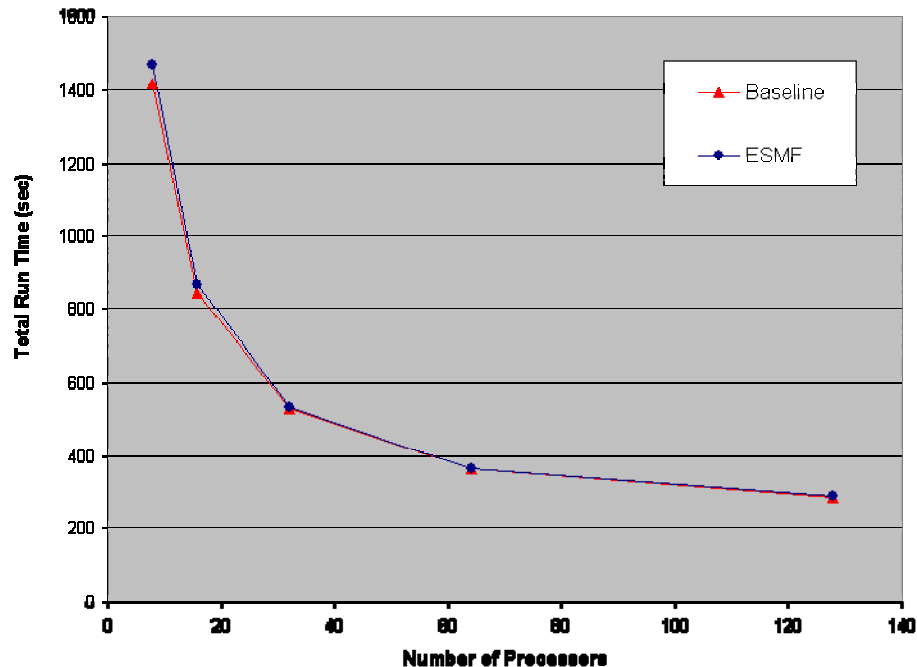
- Overhead of ESMF superstructure in NCEP Spectral Statistical Analysis (SSI), ~1% overall

- Run on NCAR IBM POWER-4

- Runs done by JPL staff, confirmed by NCEP developers

ESMF Regridding Performance

- Test of regridding of data on grids with various block-cyclic distributions using ESMF

- Grids is converted from 720x360 data points to 1080x540 data points

- Run on NCAR IBM POWER-4 by JPL staff

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

Current Development Focus

- Optimizing performance of regridding and communication routines

- Adding flexibility in handling different grids (tripole, cubed sphere, other general curvilinear coordinate grids), unstructured grids, and observational data streams

- Identification of patterns of ESMF usage and development of conventions to increase interoperability of components

Open Source Development

- Open source license (GPL)

- Open source environment (SourceForge)

- Open repositories: web-browsable CVS repositories accessible from the ESMF website

  ◦ for source code

  ◦ for contributions (currently porting contributions and performance testing)

- Open testing: tests are bundled with the ESMF distribution and can be run by users

- Open port status: results of nightly tests on many platforms are web-browsable

- Open metrics: test coverage, lines of code, requirements status are updated regularly and are web-browsable

Contributions to Core

Past

- Configuration Manager (Arlindo da Silva, NASA GSFC)
- SCRIP Regridding (Phil Jones, LANL)
- I/O (WRF)

Current

- Representation and regridding of 3D grids
  Bob Oehmke, University of Michigan (est. Sept 06)
- C++ interfaces
  Tim Campbell, NRL Stennis (est. Sept 06)
- Representation and manipulation of observational data streams
  Will Sawyer, NASA GMAO (est. June 06)

Upcoming:

- Direct intercomponent data transfers via State put and get
  Alan Sussman, University of Maryland (est. Sept 06)
- Support for grids that are composites of general curvilinear coordinates, e.g., cubed sphere
  Ed Hill, MIT (est. Dec 06)

ESMF Programs

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 will develop an ESMF-based modeling and analysis environment to study climate variability and change.

Integrated Dynamics through Earth's Atmosphere and Space Weather Initiatives

Sponsors: NASA, NSF, short term

Partners: *University of Michigan/SWMF, Boston University/CISM, University of Maryland, NASA Goddard Space Flight Center, NOAA CIRES*

ESMF developers are working with the University of Michigan and others to develop the capability to couple together Earth and space software components.

Battlespace Environments Institute

Sponsor: Department of Defense, through 2010

Partners:

DoD Naval Research Laboratory, DoD Fleet Numerical, DoD Army ERDC, DoD Air Force 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.

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

The ESMF team is working with data specialists to create an end-to-end knowledge environment that encompasses data services and models – strong emphasis on metadata development

Some Codes Using ESMF

- NOAA GFDL atmospheres and MOM4 ocean
  ESMF option in spring 2006 public FMS release

- NOAA NCEP atmospheres, analysis
  GFS ensemble system running under ESMF

- NASA GMAO models and GEOS-5
  Running ESMF in production since April 2005

- NASA/COLA Poseidon ocean
  Running under ESMF as part of GEOS-5

- LANL POP ocean
  Prototype of POP component complete, waiting on grid support

- NCAR WRF
  WRF runs as ESMF component, new WRF/HYCOM coupling using ESMF from DoD

- NCAR CCSM
  ESMF utilities in CAM/CCSM3; using ESMF to develop single executable version

- MITgcm atmosphere and ocean
  MITgcm can run as ESMF component and ensemble

- Space Weather Modeling Framework
  Option to run entire SWMF as an ESMF component

More Codes Using ESMF

- DoD Navy HYCOM ocean
- DoD Navy NOGAPS atmosphere
- DoD Navy COAMPS coupled atmosphere - ocean
- DoD Army ERDC WASH123 watershed model
- NASA GISS
- UCLA coupled atmosphere – ocean
- NASA Land Information Systems (LIS) project
- DoD Air Force GAIM ionosphere (just starting)
- DoD Air Force HAF solar wind (just starting)

Other codes coming in through ESMF-based NASA MAP climate variability program, EPA, universities

Components and Cyberinfrastructure Beyond the U.S.

PRISM and ESMF

- PRISM is a European climate framework

- 22 partners: leading climate researchers and computer vendors, includes MPI, KNMI, UK Met Office, CERFACS, ECMWF, DMI

- ESMF and PRISM are working together through a NASA grant (PI, Max Suarez) and the World Climate Research Program (WCRP) to develop strategies for interoperability and common conventions

- MOM4 ocean model at GFDL was used to demonstrate how one model can be instrumented to run in both PRISM and ESMF
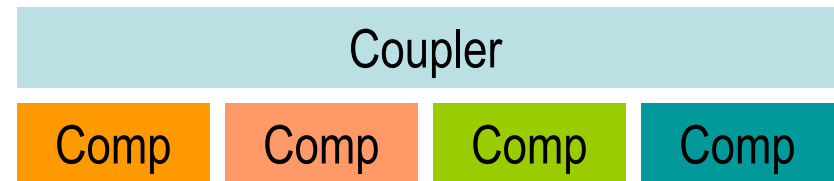
PRISM and ESMF Differences ...

ESMF
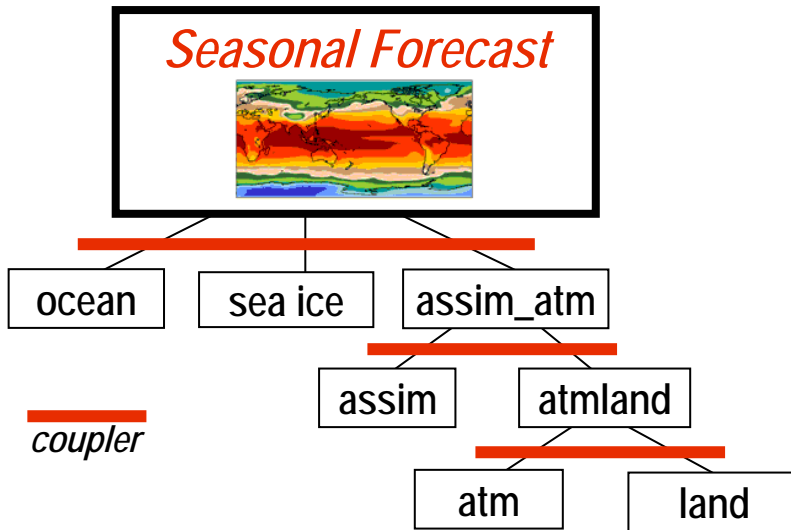
- Components are generally in the same executable
- Components are often nested
- Multiple couplers
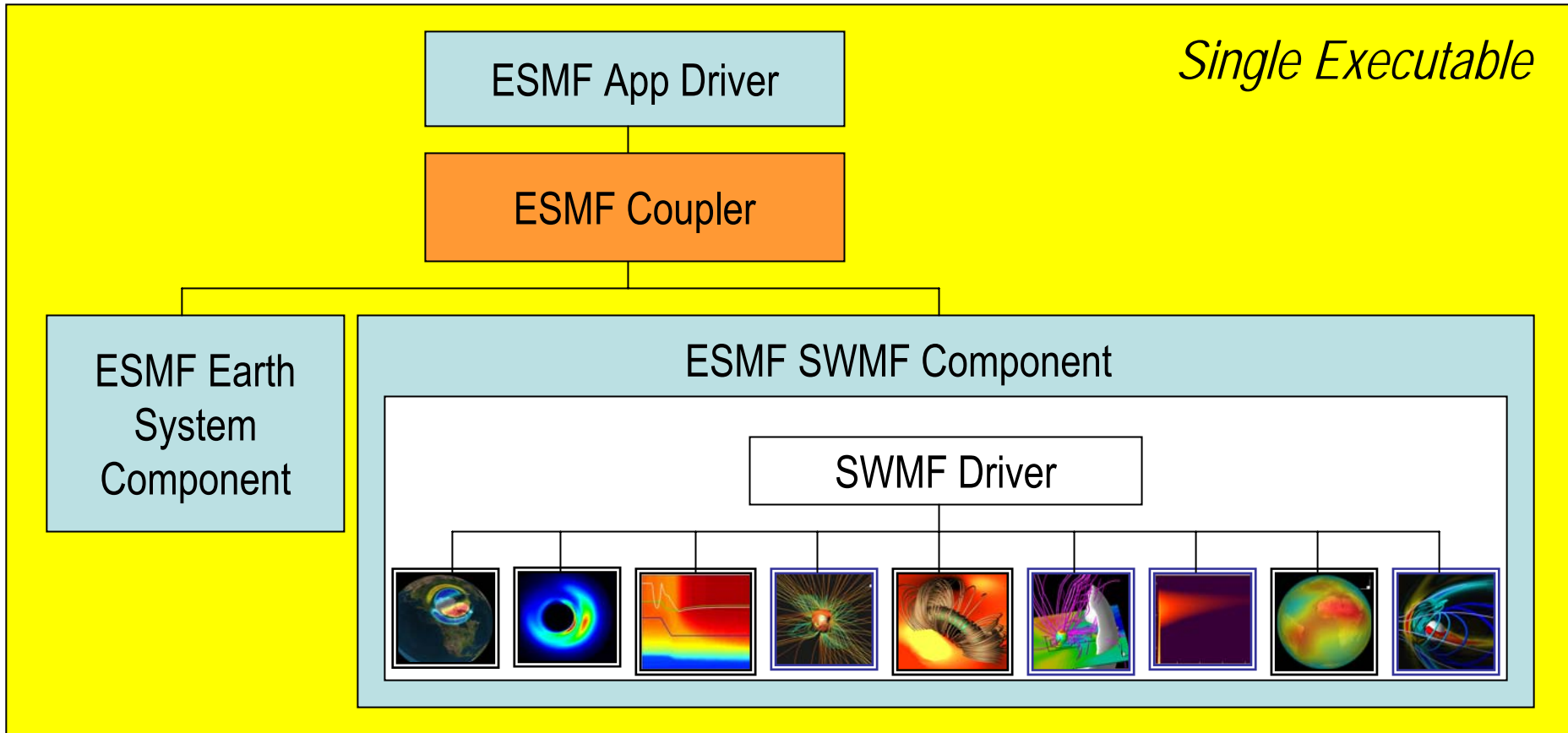- Data is passed through states at the beginning and end of method execution

PRISM

Coupler			
Comp	Comp	Comp	Comp

- Components are generally in separate executables
- Components are generally not nested
- Single coupler
- Data is transferred through put/get
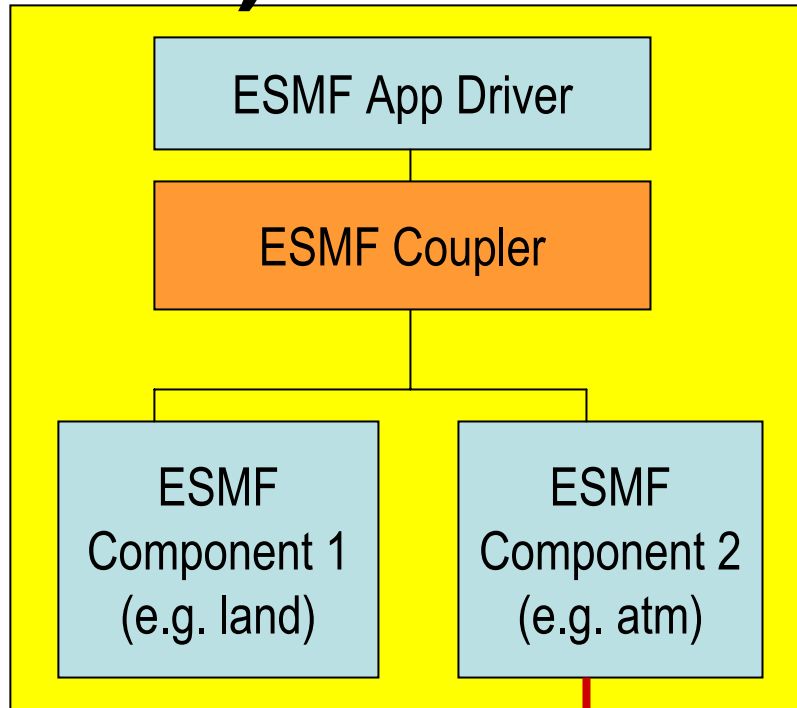- Data can go from anywhere to anywhere in another component

Earth/Space Coupling (SWMF)

- The entire Space Weather Modeling Framework is wrapped as an ESMF component
- The SWMF component can communicate data to one or more Earth system components
- The application is run using an ESMF driver
- The application runs as a single executable

More Earth/Space Coupling (CISM)

Multiple executables

- Coupling ESMF to Center for Integrated Space Weather Models (CISM)
- Work just starting
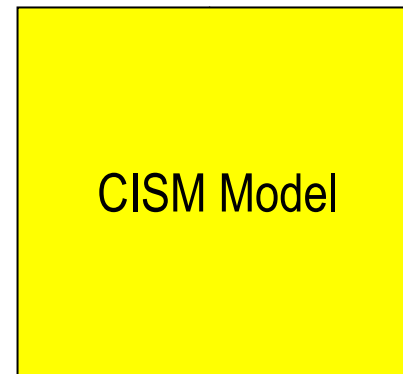
InterComm data transfer and sequencing

- InterComm is used for data transfers between an ESMF application and a CISM model
- These are in separate executables
- InterComm is wrapped in ESMF_StatePut() and ESMF_StateGet() commands so that it presents a standard interface on the ESMF side
- Data transfers can be from anywhere, to anywhere

ESMF and CCA

- The DOE Common Component Architecture is a general high performance computing framework that covers many different domains, and is offering web and Grid service interfaces

- Collaborators include LANL, ANL, LLNL, ORNL, etc.

- ESMF components can be readily adapted to run in CCA drivers, demo presented at SC2003

Model Metadata and Earth System Curator

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, 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:

- Coordinated growth of ESMF and PRISM
- Opportunities to develop smarter tools (e.g. compatibility, assembly) based on extended and shared metadata

Summary

- ESMF uses software components to structure climate and other Earth system models

- Many groups are using ESMF

- The ESMF team and others are working to bridge organizational, national, and disciplinary boundaries via 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 couple and use them