Community Software Standards and Infrastructure for R2A

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Elements of R2A

**Objects?**
- Model components
- Datasets
- Metadata
- Scripts and workflows
- Diagnostics

**Actions?**
- Goal-setting
- Prioritization
- Software co-development
- Model intercomparison and analysis
- Training
- Program review
- Organizational co-development

**Assumptions?**
- Enabling infrastructure
- Access to code and information
- Supportive communication and organizational structure
The Earth System Modeling Framework (ESMF) offers standard interfaces for model components and an architecture for model construction.

Standard, community-developed component interfaces support a broad understanding of the requirements for integrating research components with operational components, and allow multiple groups to contribute components to coupled development and operational system.

https://www.earthsystemcog.org/projects/esmf/
Standard Component Interfaces

All ESMF components have the same three standard methods (these can have multiple phases)

- Initialize
- Run
- Finalize

Each standard method has the same simple interface:

```c
call ESMF_GridCompRun (myComp, importState, exportState, clock, ...)
```

Where:
- `myComp` points to the component
- `importState` is a structure containing input fields
- `exportState` is a structure containing output fields
- `clock` contains timestepping information

Interfaces are wrappers and can often be introduced in a non-intrusive way, i.e. ESMF is designed to coexist with native model infrastructure
Grid Remapping for Coupling

Uniquely fast, reliable, and general – interpolation weights computed in parallel in 3D space to support distributed development of *model components* and model coupling

Supported grids (include reduced Gaussian, MPAS, FIM, ORCA, tripole, cubed sphere, etc.)

- Logically rectangular grids, meshes, and observational data streams
- Global and regional grids, 2D and 3D grids

Supported interpolation methods:

- Nearest neighbor, higher order patch recovery (e.g. Khoei et al. 2007), bilinear and 1st order conservative methods

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

*Flexible, fast grid remapping tools support data transformations that enable new components from the research community to be incorporated into operational systems.*

*Some supported grids ...*
The National Unified Operational Prediction Capability

- The National Unified Operational Prediction Capability (NUOPC) is a consortium of operational weather prediction centers and their research partners.
- NUOPC developed the ESMF-based NUOPC Layer software to increase interoperability of model components.
- NUOPC introduces a set of pre-fabricated model component templates for building coupled systems.

**NUOPC Generic Components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
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<tbody>
<tr>
<td>Driver</td>
<td>Harness that initializes components according to an <em>Initialization Phase Definition</em>, and drives their Run() methods according to a customizable run sequence.</td>
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<tr>
<td>Connectors</td>
<td>Implements field matching based on standard metadata and executes simple transforms (e.g. grid remapping, redistribution). It can be plugged into a generic Driver component to connect Models and/or Mediators.</td>
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<tr>
<td>Model</td>
<td>Wraps model code so it is suitable to be plugged into a generic Driver component.</td>
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<tr>
<td>Mediator</td>
<td>Wraps custom coupling code (flux calculations, averaging, etc.) so it is suitable to be plugged into a generic Driver component.</td>
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Simple driver (a) and schematic of COAMPS (b).
NUOPC Interoperability Layer

An interoperability layer on top of ESMF that adds:

- Definitions for model component interactions during Initialize, Run, Finalize
- Extensible, generic components that implement the component interactions above
- A field dictionary, based on Climate & Forecast (CF) metadata conventions, as the basis for a standard identification of fields between components
- Component Explorer and Compliance Checker tools that report component incompatibilities detected during run-time
- Static compliance checking and code generation via the Cupid Integrated Development Environment

https://www.earthsystemcog.org/projects/nuopc/
The Earth System Prediction Suite (ESPS) is a collection of weather and climate modeling codes that use ESMF with the NUOPC conventions.

Currently, model 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

https://www.earthsystemcog.org/projects/esps/
## ESPS Code Status

### ESPS Coupled Modeling Systems

<table>
<thead>
<tr>
<th></th>
<th>NEMS and CFS</th>
<th>COAMPS</th>
<th>NavGEM</th>
<th>GEOS-5</th>
<th>ModelE</th>
<th>CESM</th>
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<tr>
<td>Model Driver</td>
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### Legend
- Components are NUOPC compliant and the technical correctness of data transfers in a coupled system has been validated.
- Components and coupled systems are partially NUOPC compliant.

The many community and federal models available with NUOPC interfaces allows operational centers to leverage and test a variety of components more easily.

From Theurich et al. 2015, in submission
Earth System Framework Description Language (ES-FDL)

A common language and associated tools for describing the functional scope and characteristics of modeling infrastructure.

Uses of the ES-FDL:

• to describe and understand infrastructure software
• to discover modeling infrastructure with desired functionality
• to identify how different software packages compare in functionality
• to indicate how two (or more) infrastructure packages may connect or interact in order to support complex functions and cross-disciplinary interactions

ES-FDL is a forward-looking initiative that aims to connect the ESMF infrastructure being used at NOAA with infrastructure from related disciplines used in the research and operational communities (e.g. hydrology, agriculture)
Model intercomparison and joint evaluation is a consequence of having more component choices.

The Earth System CoG environment support national and international projects like the Dynamical Core Intercomparison Project, HIWPP, and CMIP.
Overview of CoG

CoG is a collaboration environment and hub to connect projects in the Earth sciences.

It hosts and links into networks software development projects, model intercomparison projects (MIPS), events, and workshops.

It includes a configurable search to datasets on ANY Earth System Grid Federation (ESGF) data node.

It provides projects with a wiki and customizable navigation to wiki content.

It supports the organization of complex networks of projects and provides a consolidated look at this content across a project’s network.

It provides services for Earth system model metadata collection and display (through ES-DOC tools)

Some of the 70+ projects currently hosted on CoG include:

• NOAA’s High Impact Weather Prediction Project (HIWPP)
• Atmospheric Dynamical Core Model Intercomparison Project (DCMIP)
• Reanalysis Data for CMIP5 (Ana4MIPs)
• Observational Data for CMIP5 (Obs4MIPs)
• National Unified Operational Prediction Capability (NUOPC)
• National Climate Predictions and Projections Platform (NCPP)
• Earth System Documentation (ES-DOC)
• Earth System Prediction Capability (ESPC)
Earth System Documentation (ES-DOC) is an international effort to develop tools to describe Earth system models in order to better understand and utilize model data. The tools are based on the Common Information Model (CIM) metadata standard.

**CIM**
A metadata standard used to describe Earth system models. This includes simulations, experiments, and computing resources used by those models. The CIM is now being leveraged by a variety of international model intercomparison projects.

**Questionnaire**
A customizable package to generate questionnaires that **CREATE** model documentation.

**Viewer**
A browser plugin to **DISPLAY** model documentation. It can be embedded directly into web pages but is also available via the Search or Comparator tools.

**Comparator**
A web-based tool to **COMPARE** CIM metadata records currently stored in the CIM archive. Comparison can be output as CSV files or HTML renderings.

**Search**
A publicly accessible portal to **SEARCH** on and **VIEW** model documentation.

CMIP5 (the Coupled Modeling Intercomparison Project) is the international modeling effort underlying the IPCC assessments. Metadata describing the models used can be viewed at the link below.

https://www.earthsystemcog.org/projects/es-doc-models/
Motivated by the need to collect model metadata for model intercomparison projects

Generates customizable ESM model questionnaires on the fly

Cupid Development Environment

Cupid is a development tool to make adoption of ESMF/NUOPC infrastructure *faster, easier, and more appealing* for both research and operational communities.

Goals:

- help developers **understand** how the NUOPC API is used in a specific application
- accelerate **creation** of new NUOPC components
- simplify **modification** of existing NUOPC applications
- provide a streamlined **training** environment by combining a diverse set of development tools into one application
Cupid is a Plugin for Eclipse

Cupid adds ESMF/NUOPC-specific features to the Eclipse IDE

![Image of Eclipse IDE features]

- Fortran source code editor
- NUOPC view
- Project explorer
- Console for viewing output
Understand what’s there:
Create an outline of an ESMF/NUOPC Application
Check for issues:
Static Compliance Checking

NUOPC View
- compact outline of NUOPC component source code
- linked with source code editor
- contextual reference documentation
- compliance issues shown in red

NUOPC provided.
- If the incoming clock is valid, set the internal stop time to one time step interval on the incoming clock.
- Time stepping loop, from current time to step time, incrementing by time step.
- For each time step iteration, the Model and Connector components Run() methods are being called according to the run sequence.
Write compliant code: In-place Code Generation
R2A component and collaboration infrastructure used throughout NEMS

Coupled NEMS, incl. coupler description and schematic:
http://cog-esgf.esrl.noaa.gov/projects/couplednems/
NESII Collaborators and Customers

- NOAA ESRL GSD/PSD, GFDL, NCDC, PMEL, NCEP Environmental Modeling Center
- NASA JPL, Goddard Space Flight Center, GISS
- DOE PCMDI, Argonne National Laboratory, ORNL, Sandia
- DoD NRL Stennis and Monterey, Naval Oceanography, Army ERDC, Air Force Weather Agency
- NCAR Community Earth System Model, WRF, MPAS, HAO, Unidata
- University of Michigan, Purdue University, University of South Carolina, University of Colorado, Colorado State University, Georgia Institute of Technology
- GO-ESSP, CUAHSI, CSDMS, OpenMI, OGC, CCA, METAFORE
- Delft Hydraulics, British Atmospheric Data Center, CERFACS, IPSL, Univ. Reading, UK Met Office, DKRZ, MPI
- Many more ...