Earth System Modeling Framework: Integration in CCSM4/CESM1 and Model Coupling

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Talk Layout

- ESMF Coupling Toolkit
- Introduction of NCAR CCSM/CESM
- Cooperation between ESMF and CCSM
- ESMF conforming CCSM components
- Coupler implementation with ESMF SMM
- CCSM driver reorganization
- Metadata attribute packages in CCSM
- Towards a common model architecture and GIP
- Please don't hesitate to interrupt and ask questions

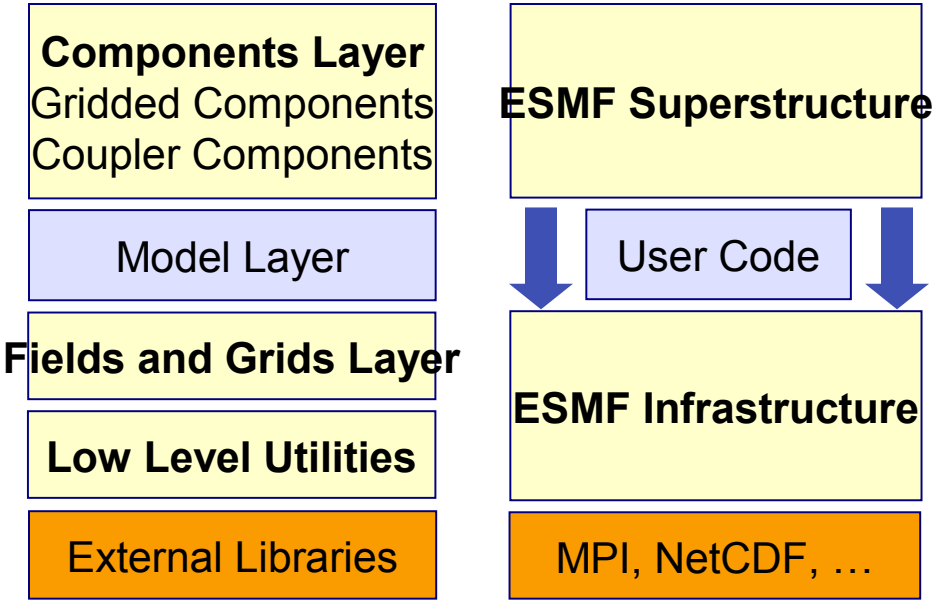
ESMF Coupling Toolkit

ESMF Coupling Toolkit

- ESMF provides a set of data structures and tools to enable coupling of Earth System Model components.
- Gridded component can be used to represent atmosphere, ocean, ice, or land that works on an intrinsic discretized Grid.
- Coupler component can be used to communicate data between gridded components. In practice, coupler component is responsible to exchange boundary conditions such as temperature, pressure, heat flux, trace gas flux, wind speed, wind stress, etc between different gridded components.
- Each gridded/coupler component provides standard initialize, run, and finalize interfaces that act as call back functions by a driver that coordinates all the components to form a coherent flow of calculations. The tasks of a modeler are eased dramatically with only needing to provide sequence control and implement component behavior during the initialize, run, and finalize phases.
- ESMF time manager provides calendars and clocks that are

Architecture

- ESMF provides a **superstructure** for assembling geophysical components into applications.
- ESMF provides an **infrastructure** that modelers use to
  - Generate and apply interpolation weights
  - Handle metadata, time management, data I/O and communications, and other functions
  - Access third party libraries



Standard Interfaces

- All ESMF components have the same three standard methods:
  - Initialize
  - Run
  - Finalize
- Each standard method has the same simple interface:

```
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
```

Steps to adopting ESMF

- Divide the application into components (without ESMF)
- Copy or reference component input and output data into ESMF data structures
- Register components with ESMF
- Set up ESMF couplers for data exchange

- Interfaces are wrappers and can often be set up in a non-intrusive way

A brief introduction of CCSM/CESM coupler

ESMF conforming CCSM components

Highlights of ESMF in CCSM4/CESM1

- ESMF compliant components are implemented and distributed with CCSM4 and CESM1. These components define and export the standard init/run/finalize methods.
- ESMF regridding weights generated from patch recovery method are used in CCSM/CESM driver to remap zonal wind derivatives at air-sea interface.
- We are currently reorganizing the CCSM/CESM driver to set up a driver level ESMF component. This, in conjunction with the introduction of ESMF metadata attribute packages in model components, enables CCSM runs to self describe simulation. We are also introducing workflow into CCSM, such that the entire process of model runs can be saved and analyzed.
- We are experimenting ESMF sparse matrix matmul in CCSM driver by replacing the MCT SMM engine with ESMF SMM engine in the atmosphere to ocean coupling process. We have observed better scalability at high processor count with ESMF SMM.

ESMF in CCSM4 and CESM1

- ESMF component interfaces are included and tested in CCSM4 and CESM1
  - atmosphere, sea ice, ocean, land, and ice sheet components
  - active/data/dead versions
- No changes needed to internals of components
- Not complete: uni-processor build and ice sheet configuration
- .These interfaces define the standard ESMF initialize, run, finalize methods and pass fields through ESMF State objects.
- Fully tested with CCSM4/CESM1.

To get ESMF:
Standard installations on bluefire, jaguar, other platforms
Website:
http://www.earthsystemmodeling.org

To use ESMF with CCSM4/CESM:
Set USE_ESMF_LIB to TRUE in build config file
Set COMP_INTERFACE to ESMF in build file

Rebuild MCT based CCSM model components to ESMF compliant ones

ESMF Library

ESMFshr code

Shared code

MCT based CCSM Driver

MCT based model component

MCT -> ESMF_Array

Domain -> ESMF_ArrayBundle

Infodata -> ESMF_State Attributes

ESMF_Array -> MCT

ESMF_ArrayBundle -> Domain

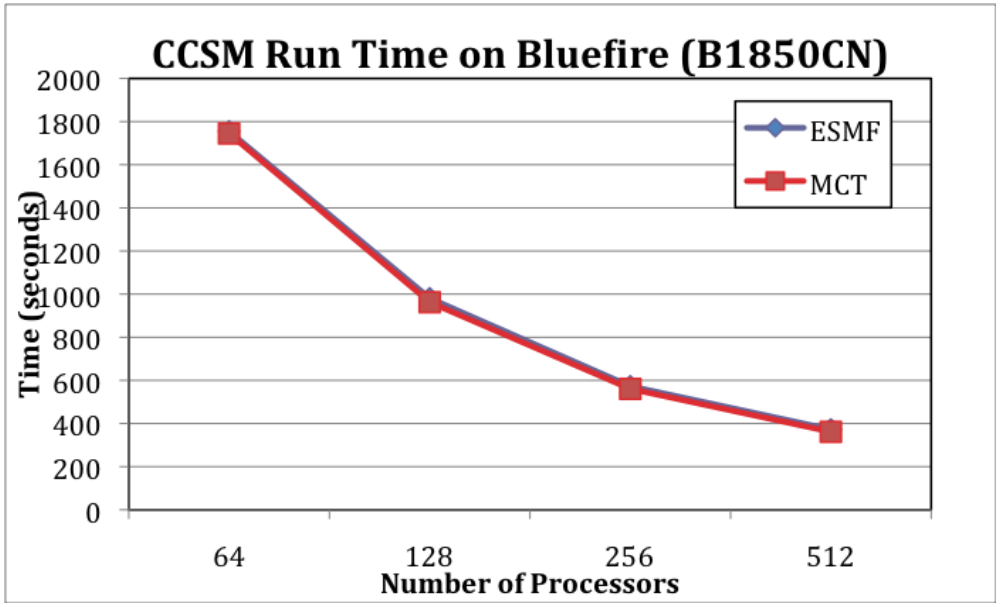
ESMF_State Attributes -> infodata

ESMF compliant model component

Data structure independent model physics

Component Overhead

- Representation of the overhead for ESMF wrapped native CCSM4 component
- For this example, ESMF wrapping required **NO code changes** to scientific modules



- **No significant performance overhead**

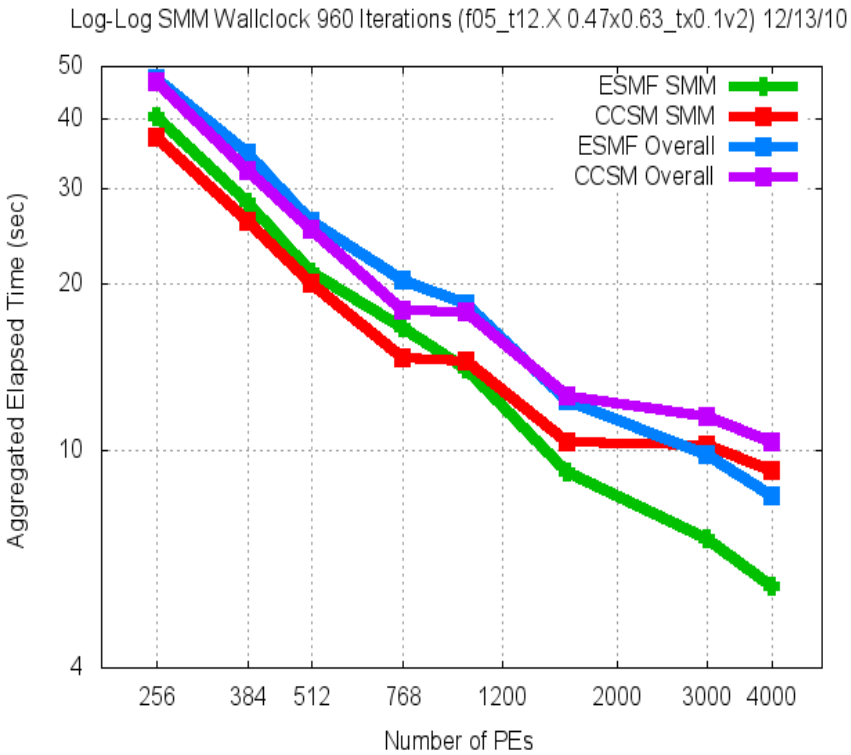
  (< 3% is typical)

- Few code changes for codes that are modular

- Platform: IBM Power 575, bluefire, at NCAR
- Model: Community Climate System Model (CCSM)
- Versions: CCSM_4_0_0_beta42 and ESMF_5_0_0_beta_snapshot_01
- Resolution: 1.25 degree x 0.9 degree global grid with 17 vertical levels for both the atmospheric and land model, i.e. 288x192x17 grid. The data resolution for the ocean model is 320x384x60.

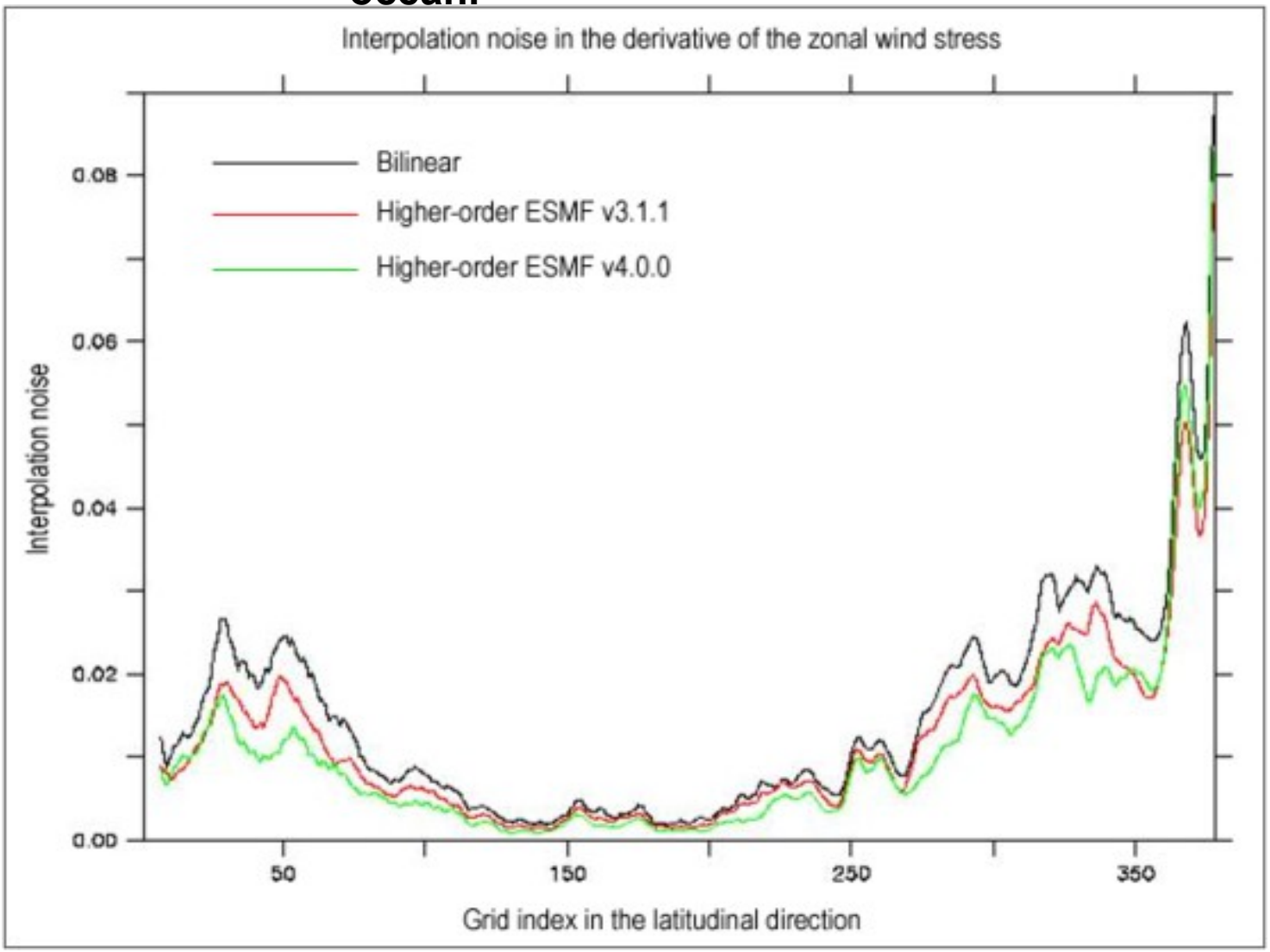
Performance analysis of ESMF SparseMatMul

- Replaced CCSM4/CESM1 atmosphere -> ocean remapping with ESMF SparseMatMul based remapping.
- This substitution was not yet made in the component overhead comparison



- Versions: ESMF: 4[illegible] M: ccsm4_0_rel08 (the April 1st release)
- Resolution: f05_t12 (fv 0.47x0.63 atmosphere/land, tripole 0.1 ocean or 576x384 atmosphere/land and 3600x2400 ocean)
- Configuration: Dead components

The patch recovery regridding weights generated from ESMF regridding package lowers the noise in zonal wind stress derivatives at air-sea interface and results in a smoother wind curl field for the ocean.

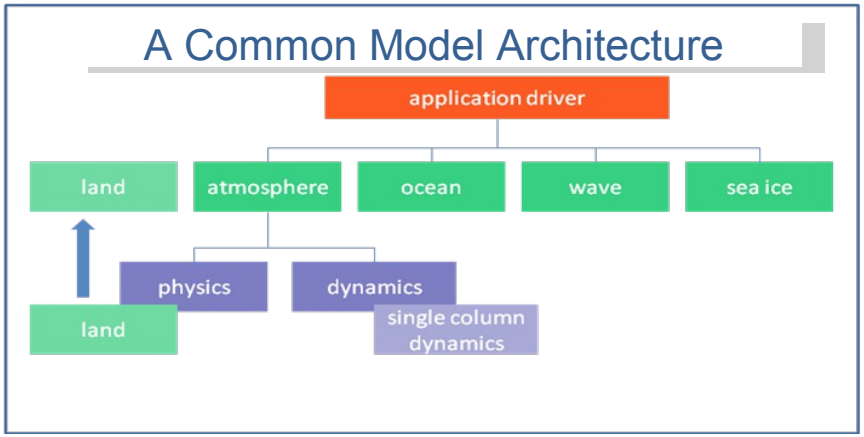


Recent development with CESM

- Introduce attribute packages and metadata in every CESM model component
- Reorganize CESM driver so that it's completely represented by an ESMF component. Still supports the old MCT approach.
- Upcoming changes include rewrite the Distgrid/Array representation by Grid/Field representation, etc.

Towards a Common Model Architecture and GIP

A Common Model Architecture



- The US Earth system modeling community is converging on a common modeling architecture
- Atmosphere, ocean, sea ice, land, wave, and other models are ESMF or ESMF-like components called by a top-level driver or coupler
- Many models are componentizing further

ESMF-enabled systems include:

Navy Coupled Ocean Atmosphere Mesoscale Prediction System / Wavewatch III
Navy Operational Global Atmospheric Prediction System
Hybrid Coordinate Ocean Model – CICE Sea Ice

NASA GEOS-5 Atmospheric General Circulation Model

NOAA National Environmental Modeling System
NOAA GFDL MOM4 Ocean

NCAR Community Earth System Model
Weather Research and Forecast Model

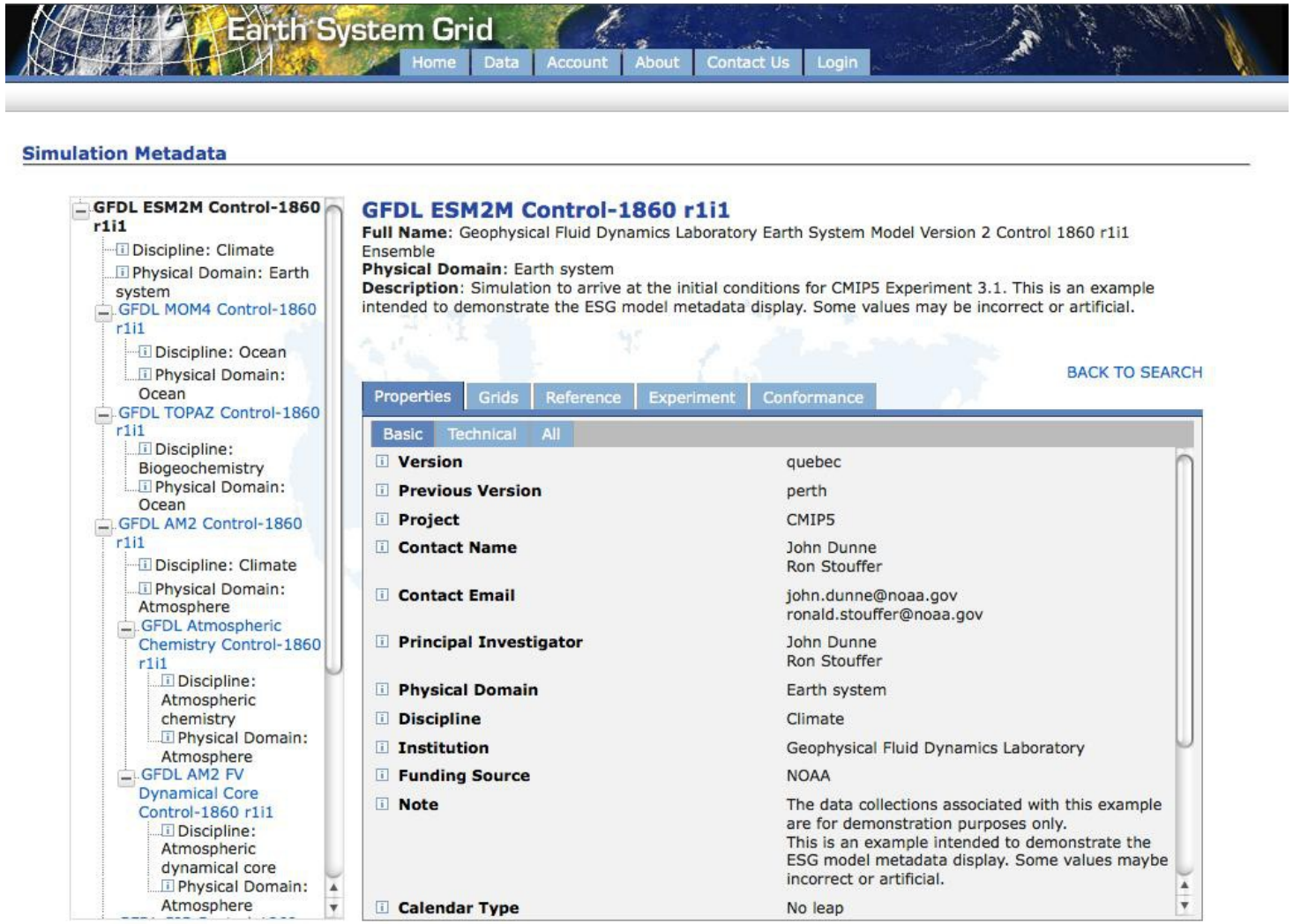
HAF Kinematic Solar Wind-GAIM Ionosphere

pWASH123 Watershed-ADCIRC Storm Surge Model

Features and Benefits:

- Interoperability promotes cross-agency knowledge transfer and collaboration
- Portable, fast, fully featured toolkits enhance capability
- Cost savings from code reuse
- Automatic compliance checking for ease of adoption

Common Model Architecture in Climate Metadata



CMIP5 metadata display in Earth System Grid, developed by the Earth System Curator project in collaboration with E.U. METAFOR

From Common Model Architecture to Interoperability

- ESMF component interfaces alone do not guarantee technical interoperability – ESMF can be implemented in multiple ways
- Also need:
  - A common physical architecture – the scope and relationships of physical components (e.g. land surface as subroutine or component?)
  - Metadata conventions and usage conventions (e.g. who can modify component data?)
  - The next steps for modeling infrastructure involve encoding these conventions in software tools and templates

National Unified Operational Prediction Capability

- National Unified Operational Prediction Capability (NUOPC) is a consortium of operation weather prediction centers
- Developing a standard implementation of ESMF across NASA, NOAA, Navy, Air Force and other modeling applications
- Defining a target level of interoperability involving multiple aspects of code – EXAMPLES:

  Component interface*. Components have a standard calling interface to facilitate generic drivers and communication protocols. Standardization does not include specification of what specific fields are actually in the import and export state.*

  Timekeeping*. Metadata and conventions for timekeeping enable modelers to understand without code inspection whether components can be coupled together.*

  From: Final Report from the National Unified Operational Prediction Capability (NUOPC) Interim Committee on Common Model Architecture (CMA), June 18, 2009.

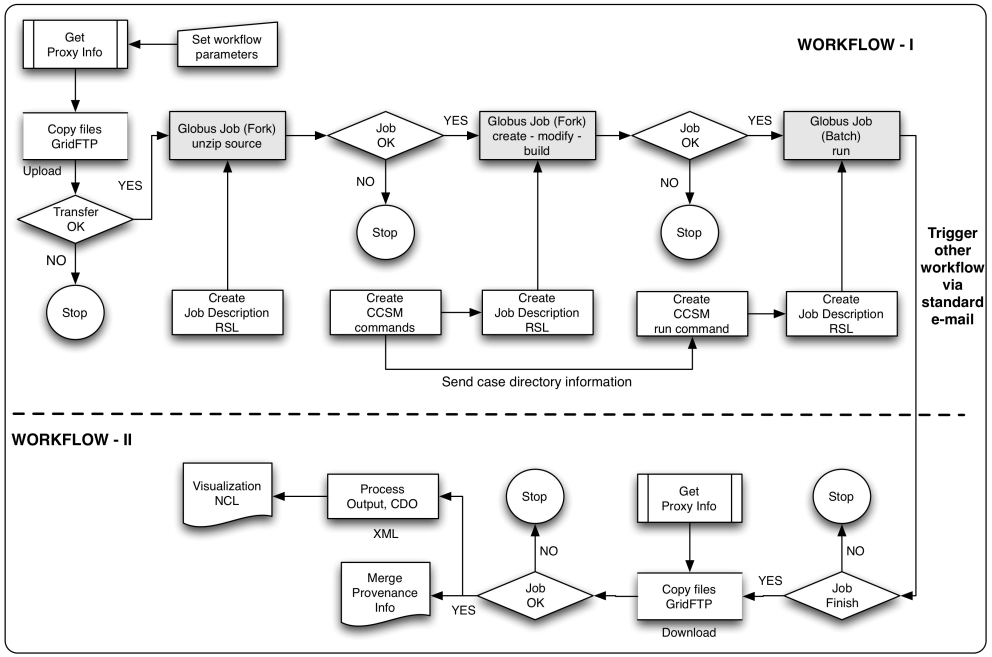
NUOPC Compliance Checker

- Designed as a way to encode and check conventions
- Presence of standard ESMF Initialize, Run, and Finalize methods and the number of phases in each
- Timekeeping conforms to NUOPC conventions
- Fields or FieldBundles (not Arrays/ArrayBundles) are passed between Components
- Which Fields are passed through import States and export States
- Required Component and Field metadata is present

Global Interoperability Program

- Global Interoperability Program (sponsor NOAA)
  - Support for multi-agency projects that cross domain boundaries and integrate along modeling workflows
  - Supports ESMF (and other) development and applications
  - http://gip.noaa.gov

New work with ESMF includes exploration of:
•self-documenting, end-to-end workflows
•integration and interfacing with other frameworks
•increasing usability
•new computing platforms and algorithms



ESMF-enabled CCSM workflow implemented using Kepler

Concluding Remarks

- Progress of CCSM4/CESM1
- CCSM driver reorganization
- Metadata attribute packages in CCSM