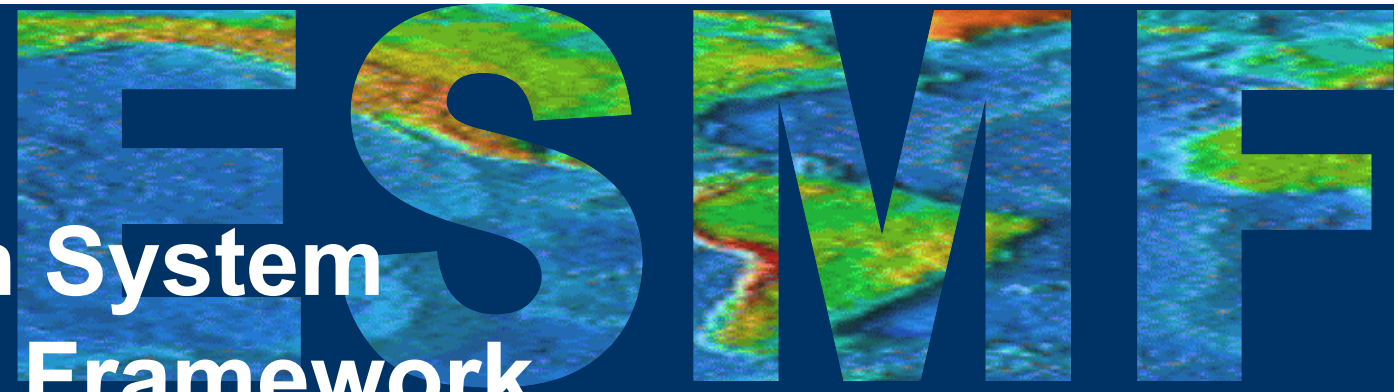


The Earth System Modeling Framework

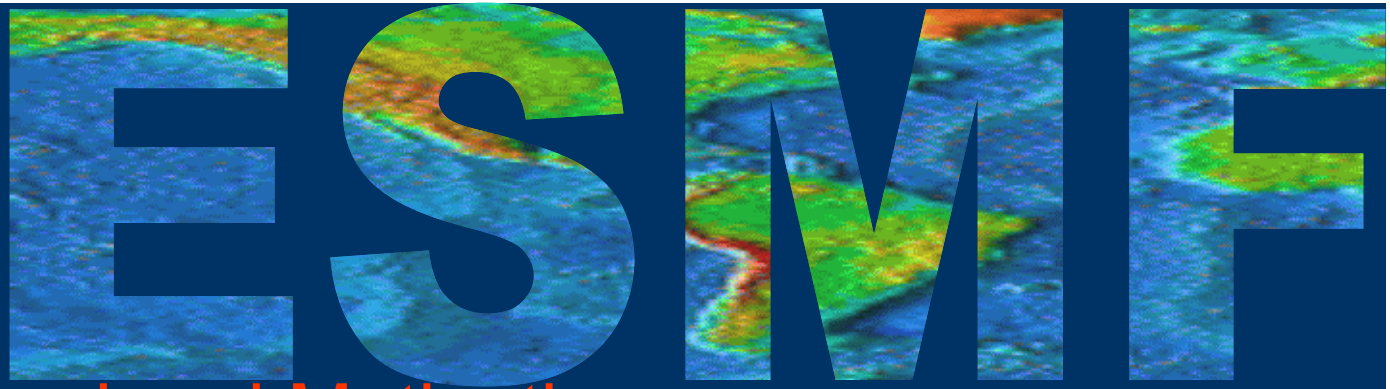
Developing a Community Sediment Model

February 20, 2002

Cecelia DeLuca

Scientific Computing Division

NCAR



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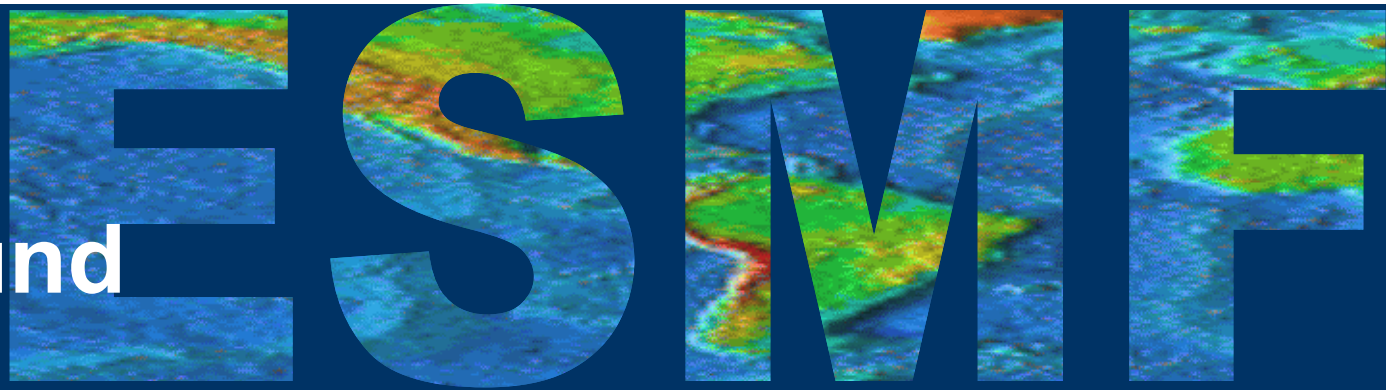
- Background and Motivation
- ESMF Design Overview
- ESMF Codes
- Milestones
- Development Plan
- Beyond 2004: ESMF Evolution

Background



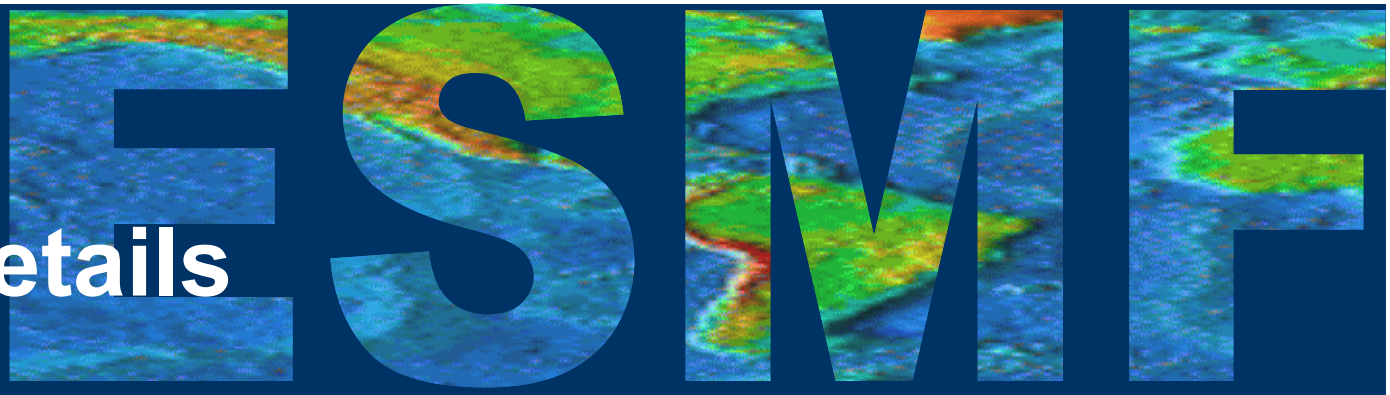
NASA's Earth Science Technology Office proposed the creation of an Earth System Modeling Framework (ESMF) in a September 2000 NASA Cooperative Agreement Notice:

> "Increasing Interoperability and Performance of Grand Challenge Applications in the Earth, Space, Life and Microgravity Sciences"

Earth system modeling collaboration with roots in the Common Modeling Infrastructure Working Group developed three linked proposals in response:

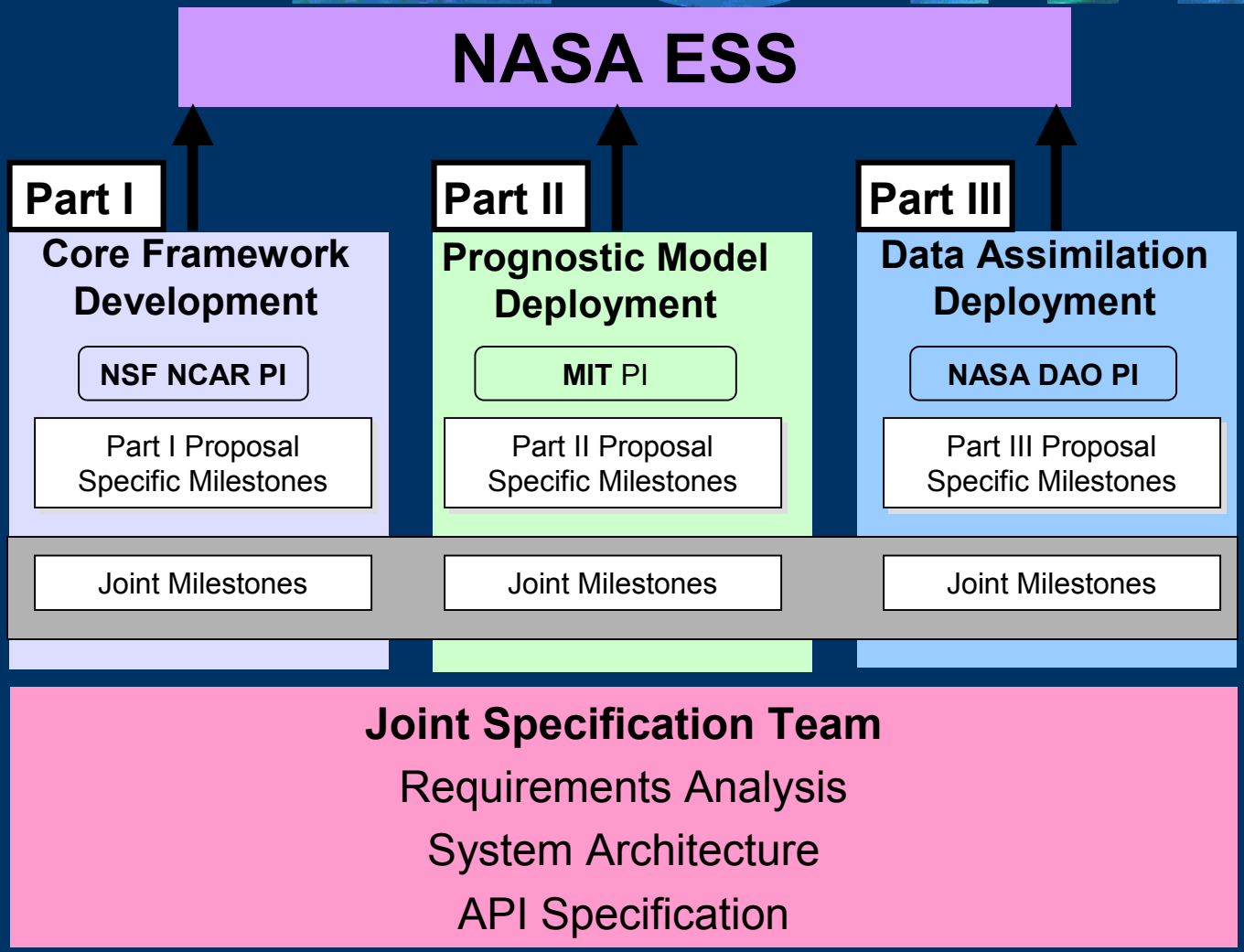
Part I: Core ESMF Development (PI: Killeen, NCAR)
Part II: Modeling Applications (PI: Marshall, MIT)
Part III: Data Assimilation Applications (PI: da Silva, NASA DAO)

Project Details

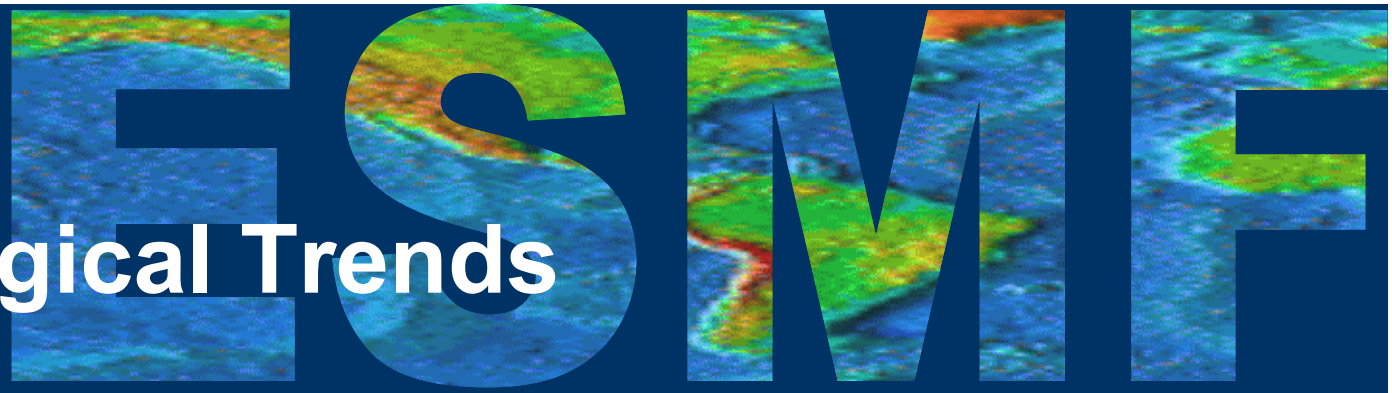


Collaborators:	NASA/GSFC-DAO, NASA/GSFC-NSIPP, LANL, ANL, University of Michigan, MIT, NCAR-SCD, NCAR-CGD, NCAR-MMM, NOAA/NCEP, NOAA/GFDL
Term:	3 years
Start:	February 2002
Staff:	18 new software engineers total
Budget:	$9.8M

Project Organization



Technological Trends

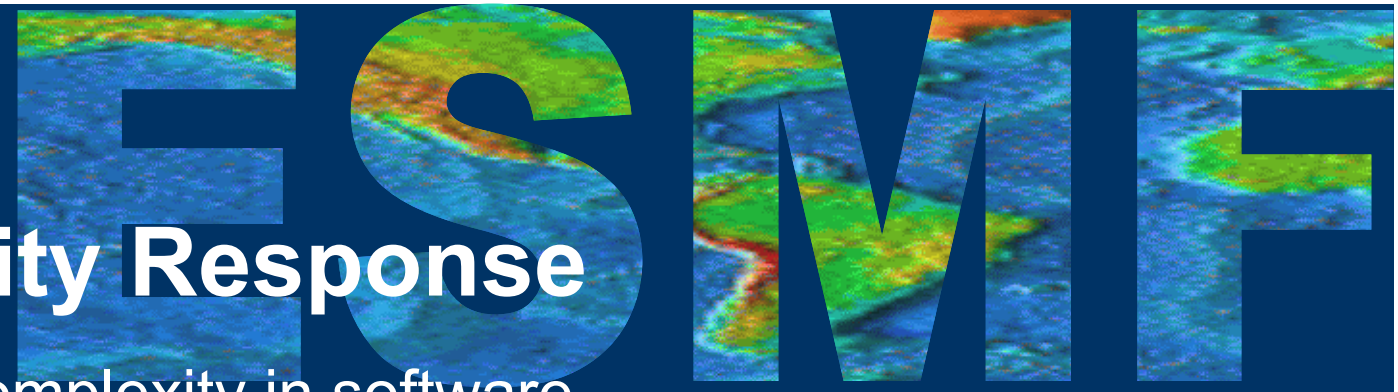


In climate research and NWP…

increased emphasis on detailed representation of individual physical processes; requires many teams of specialists to contribute components to an overall coupled system

In computing technology…

increase in hardware and software complexity in high-performance computing, as we shift toward the use of scalable computing architectures

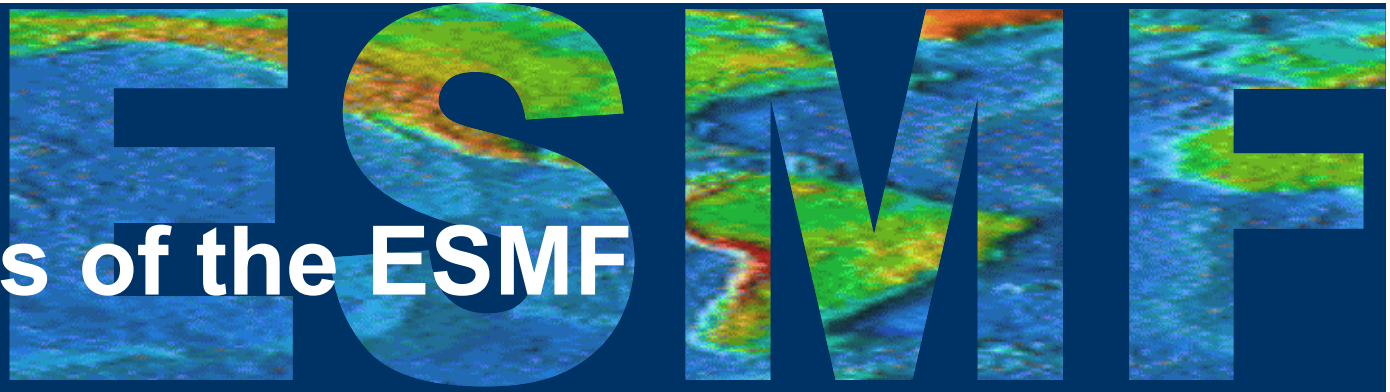


Community Response

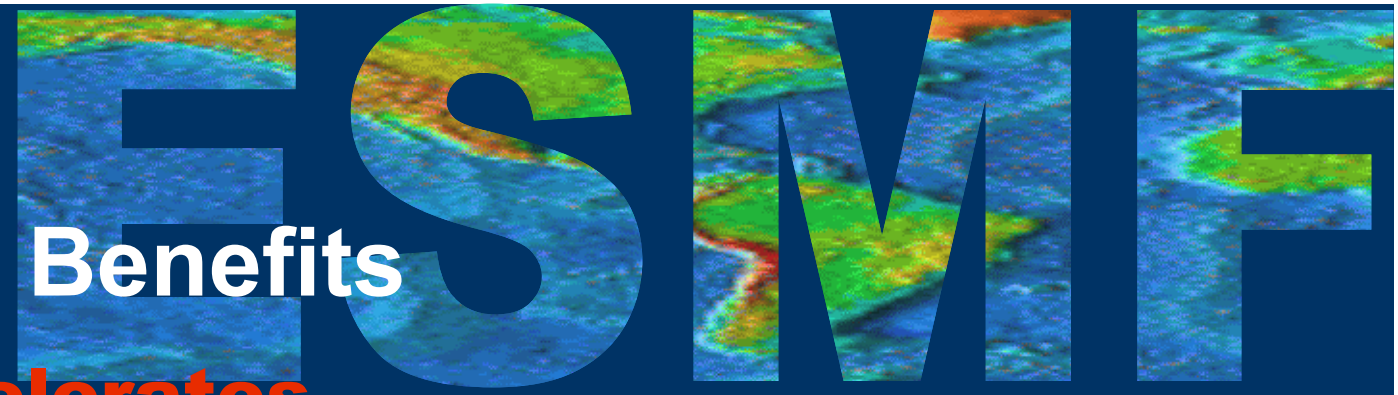
- Managing complexity in software
  - **Abstraction of underlying hardware to provide uniform programming model across architectures**
  - **Modular design for interchangeable dynamical cores, parameterizations, and components**
- and beyond …
  - **Community building at small and large scales to address common problems**
  - **Increased reliance on tools for collaboration to support distributed development model, to increase software development efficiency**
- Development of prototype frameworks
  GFDL (FMS), NASA/GSFC (GEMS), NCAR/NCEP (WRF), NCAR/DOE (MCT), etc.

The ESMF aims to unify and extend these efforts

Objectives of the ESMF



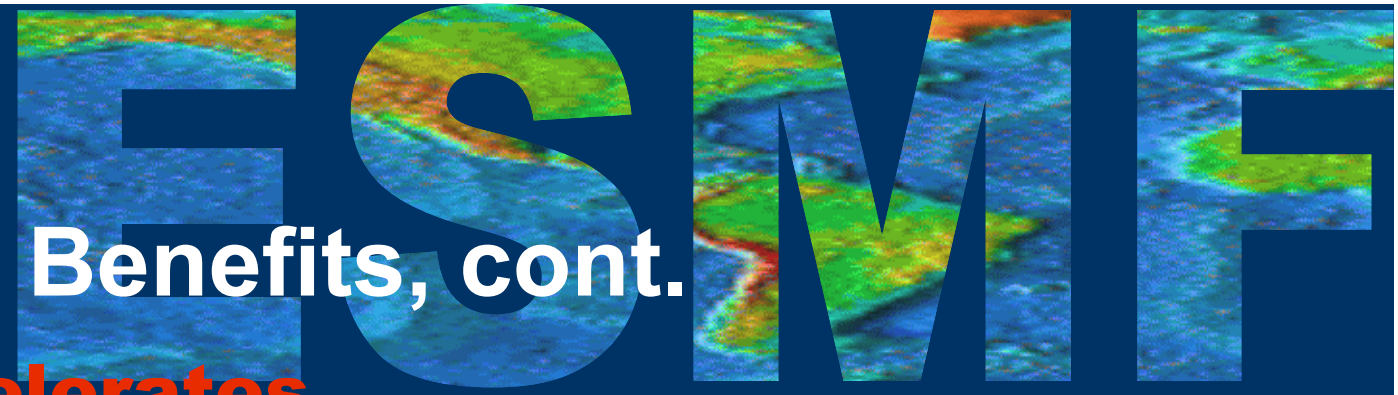
1. Facilitate the exchange of scientific codes (interoperability)
2. Promote the reuse of standardized technical software while preserving computational efficiency
3. Focus community resources to deal with changes in computer architecture
4. Present the computer industry and computer scientists with a unified and well defined task
5. Share overhead costs of the housekeeping aspects of software development
6. Provide greater institutional continuity to model development efforts



Scientific Benefits

ESMF accelerates advances in Earth System Science

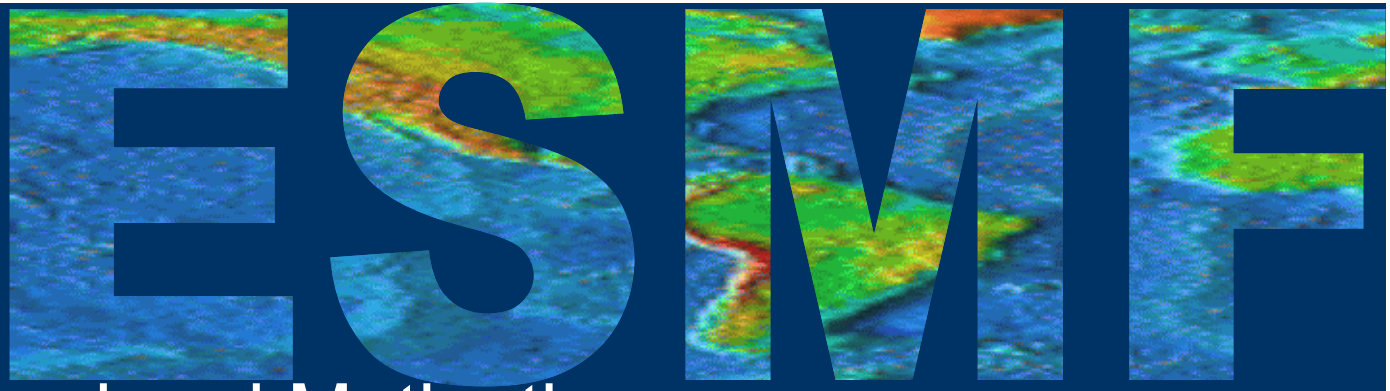
1. **Eliminates software barriers to collaboration among organizations**
   - Easy exchange of model components accelerates progress in NWP and climate modeling
   - Independently developed models and data assimilation methods can be combined and tested
   - Coupled model development becomes truly distributed process
   - Advances from smaller academic groups easily adopted by large modeling centers



Scientific Benefits, cont.

ESMF accelerates advances in Earth System Science

2. **Facilitates development of new interdisciplinary collaborations**
   - Simplifies extension of climate models to upper atmosphere
   - Accelerates inclusion of advanced biogeochemical components into climate models
   - Develops clear path for many other communities to use, improve, and extend climate models
   - Many new model components gain easy access to power of data assimilation



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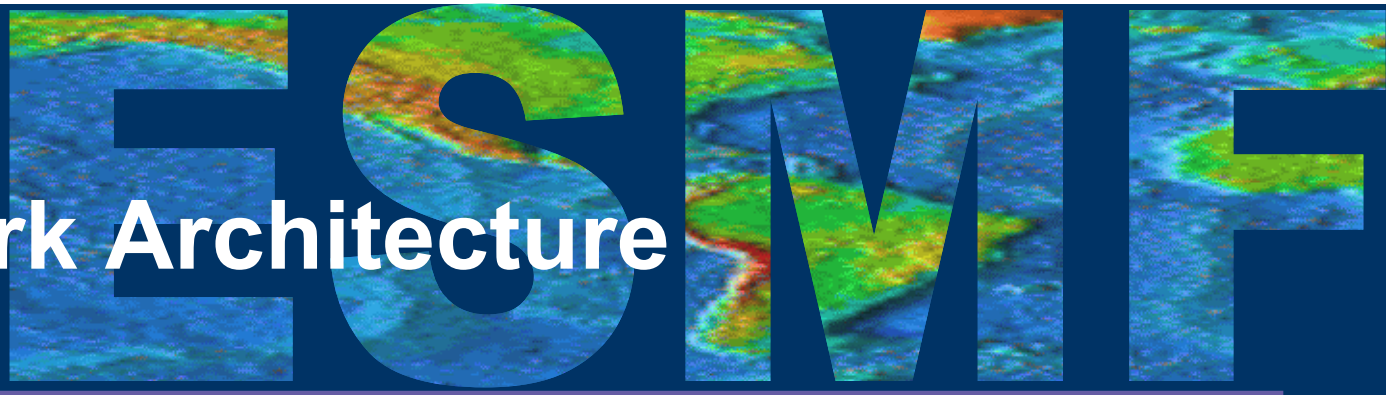
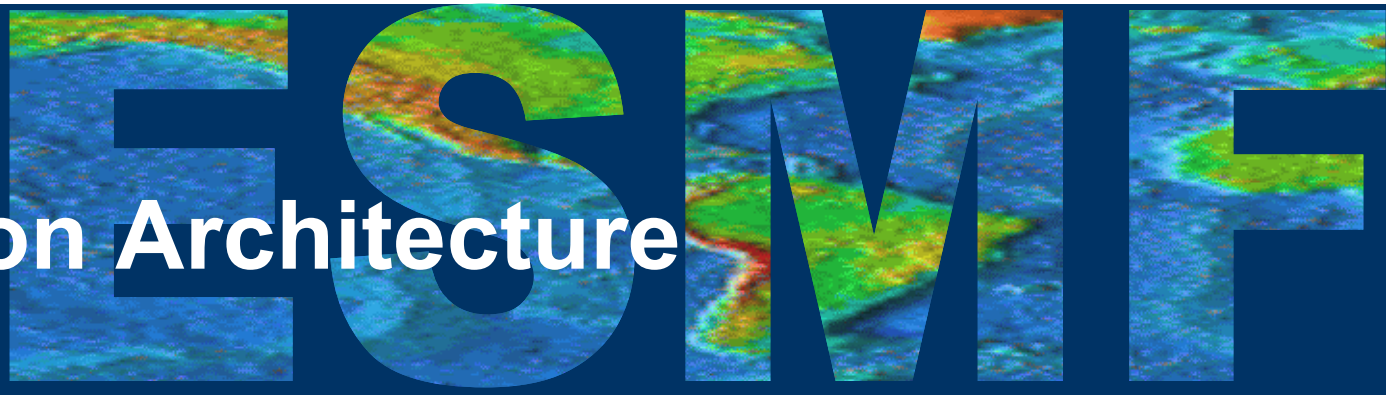
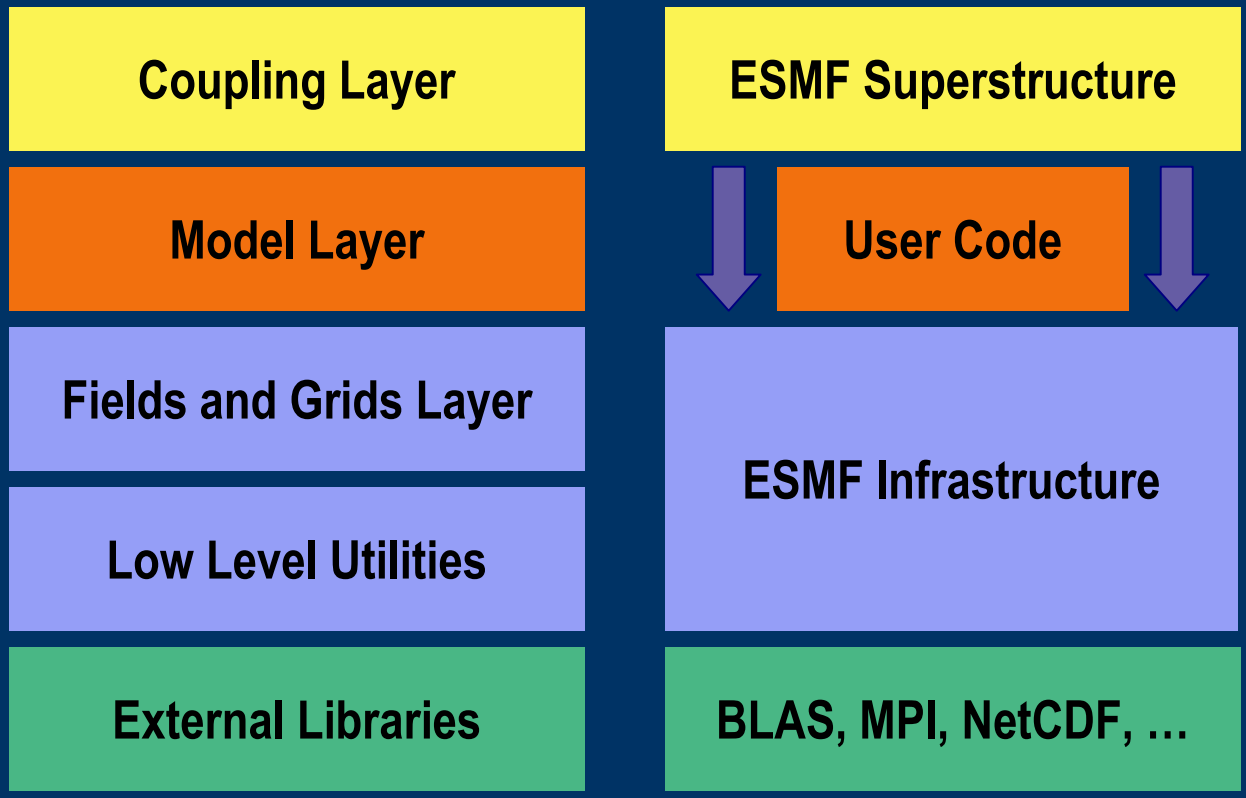
Framework Architecture

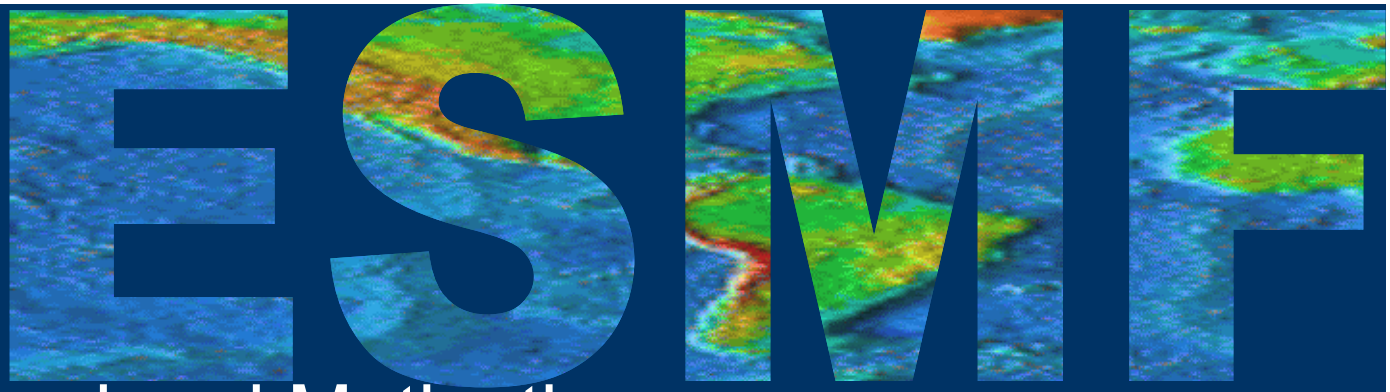


Components and Coupling		gridded component interface collective data transfers/coupling collective I/O
Fields and Grids	**Fields**	field description/metadata field and field set data field /O
	Grids	grid description/metadata grid decomposition
	Parallel Utilities	transpose, halo, etc. abstracted machine layout
Low-Level Utilities		event alarms performance profiling I/O primitives communication primitives, etc.

Application Architecture







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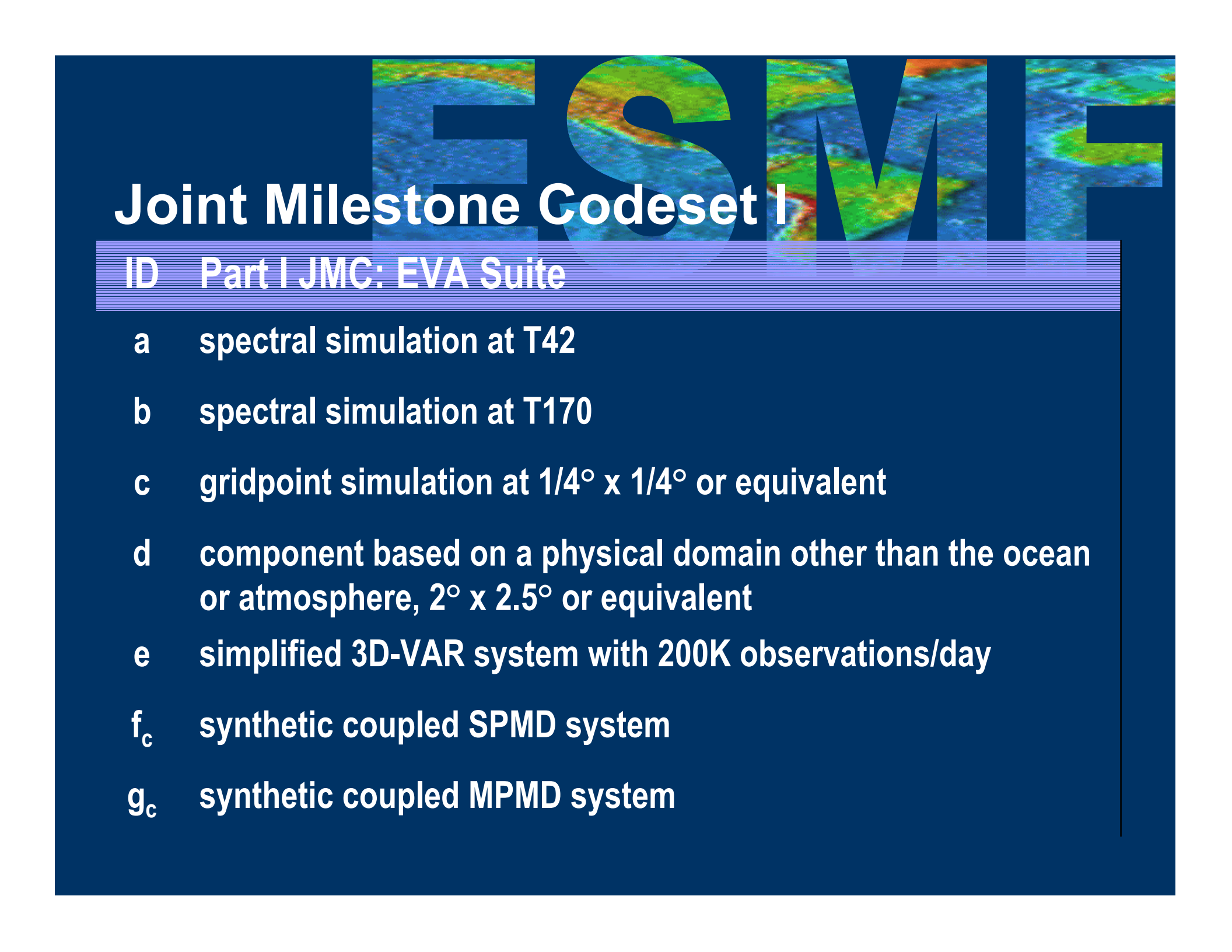
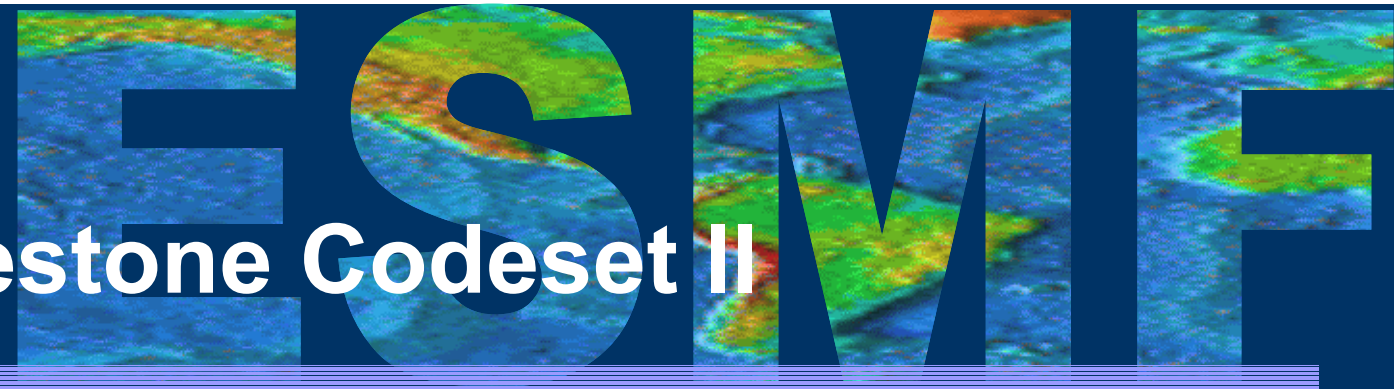


Joint Milestone Codeset I

ID Part I JMC: EVA Suite

- a spectral simulation at T42
- b spectral simulation at T170
- c gridpoint simulation at 1/4° x 1/4° or equivalent
- d component based on a physical domain other than the ocean or atmosphere, 2° x 2.5° or equivalent
- e simplified 3D-VAR system with 200K observations/day
- f_c synthetic coupled SPMD system
- g_c synthetic coupled MPMD system

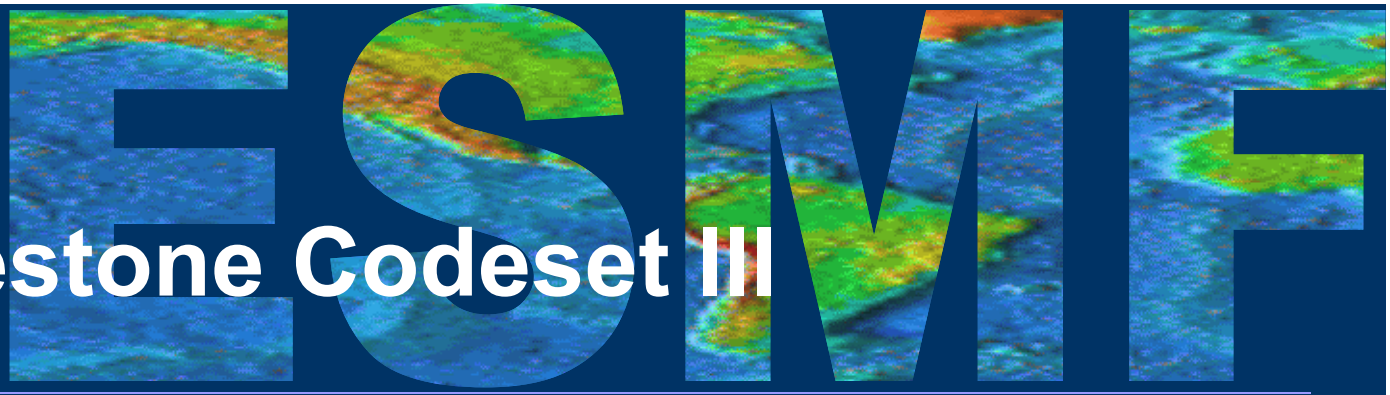


Joint Milestone Codeset II

Source ID Part II JMC: Modeling Applications

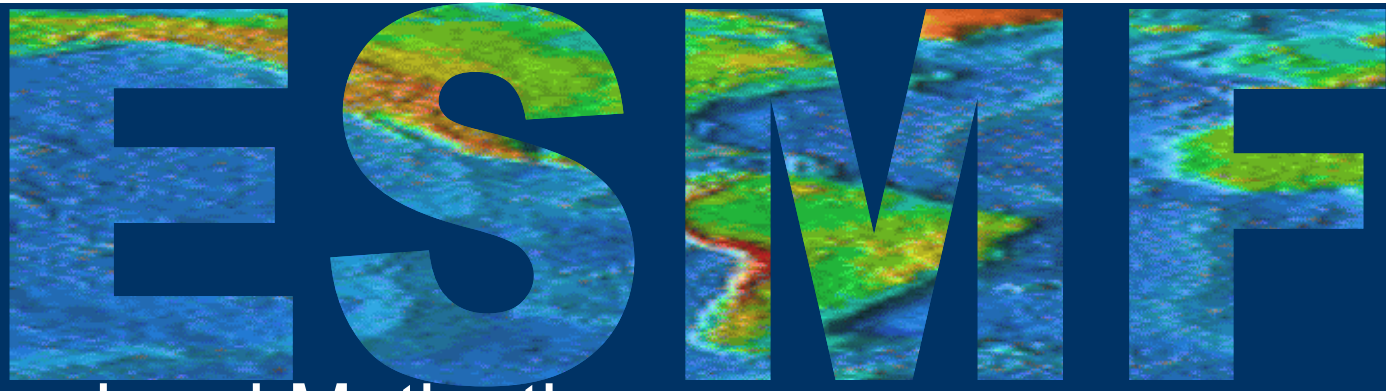
Source	ID	Part II JMC: Modeling Applications
GFDL	h	FMS B-grid atmosphere at N45L18
	i	FMS spectral atmosphere at T63L18
	j	FMS MOM4 ocean model at 2°x2°xL40
	k	FMS HIM isopycnal C-language ocean model at 1/6°x1/6°L22
MIT	l_c	MITgcm coupled atmosphere/ocean at 2.8°x2.8°, atmosphere L5, ocean L15
	m	MITgcm regional and global ocean at 15kmL30
NSIPP	n_c	NSIPP atmospheric GCM at 2°x2.5°xL34 coupled with NSIPP ocean GCM at 2/3°x1.25°L20
NCAR/LANL	o_c	CCSM2 including CAM with Eulerian spectral dynamics and CLM at T42L26 coupled with POP ocean and data ice model at 1°x1°L40

Joint Milestone Codeset III



Source ID Part III JMC: Data Assimilation Applications

Source	ID	Part III JMC: Data Assimilation Applications
DAO	p	PSAS interface layer with 2O0K observations/day
	q_c	CAM with finite volume dynamics at 2°x2.5°L55, including CLM
NCEP	r	Global atmospheric spectral model at T170L42
	s	SSI analysis system with 250K observations/day, 2 tracers
	t	WRF regional atmospheric model at 22km resolution CONUS forecast 345x569L50
NSIPP	u_c	ODAS with OI analysis system at 1.25°x1.25°L20 resolution with ~10K observations/day
MIT	v	MITgcm 2.8° century / millennium adjoint sensitivity



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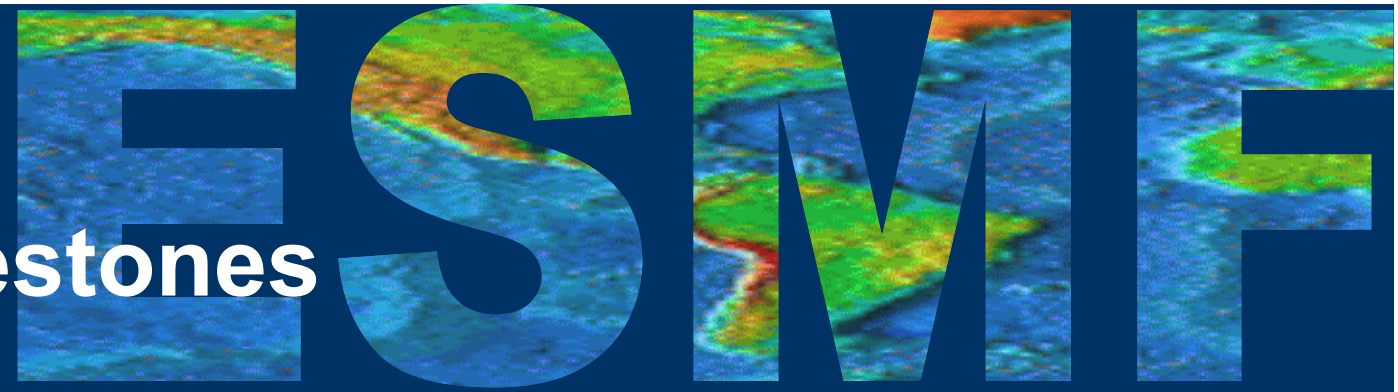
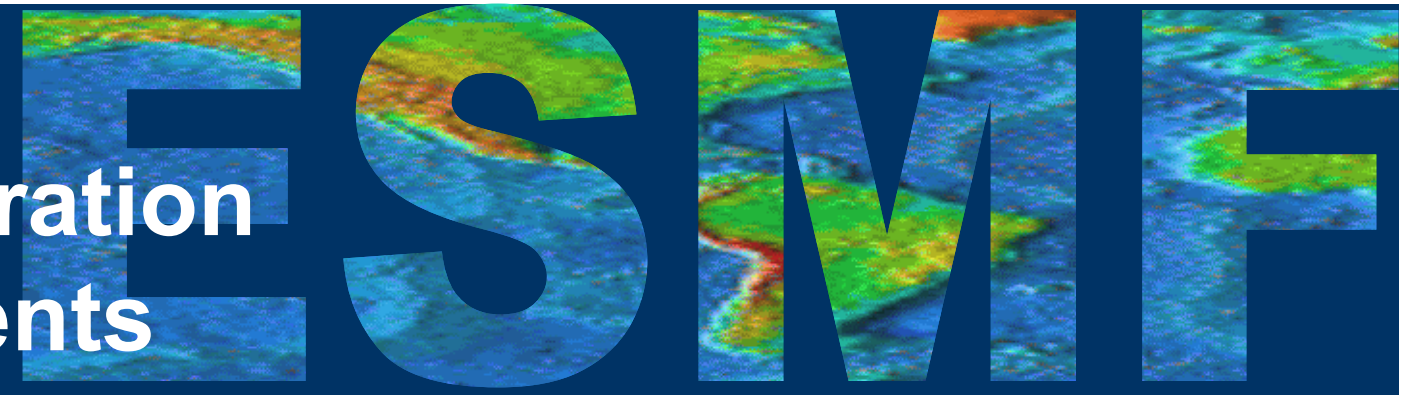


Final Milestones

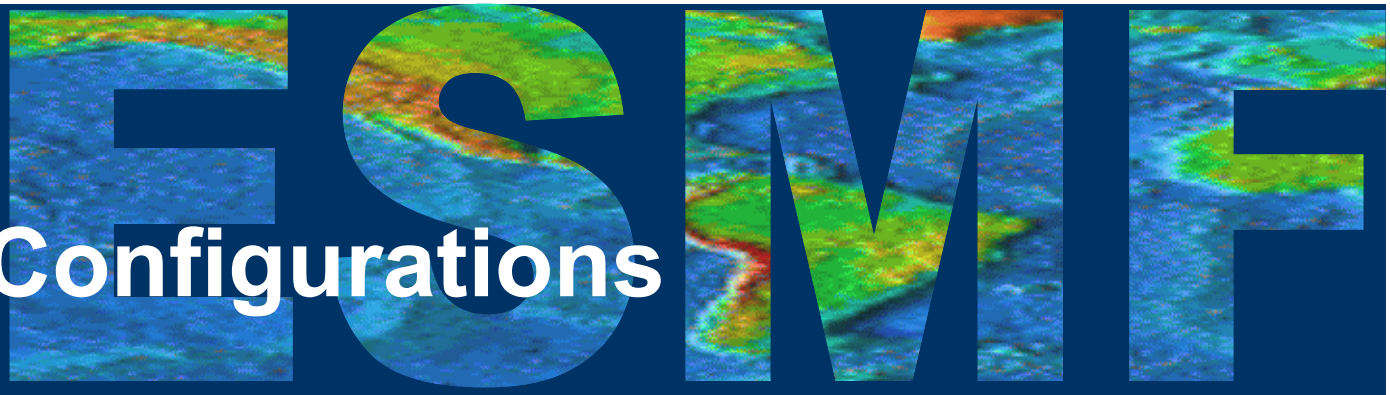
- **Tested, optimized core ESMF software**
  - Many platforms, including commodity clusters
- **All JMC codes will achieve full ESMF compliance**
  - Major Modeling Efforts
    CCSM, FMS, MIT, NCEP, GEMS, WRF
  - Major Data Assimilation Efforts
    Atmospheric: NCEP, DAO
    Oceanic: NSIPP, MIT

Demonstration Experiments

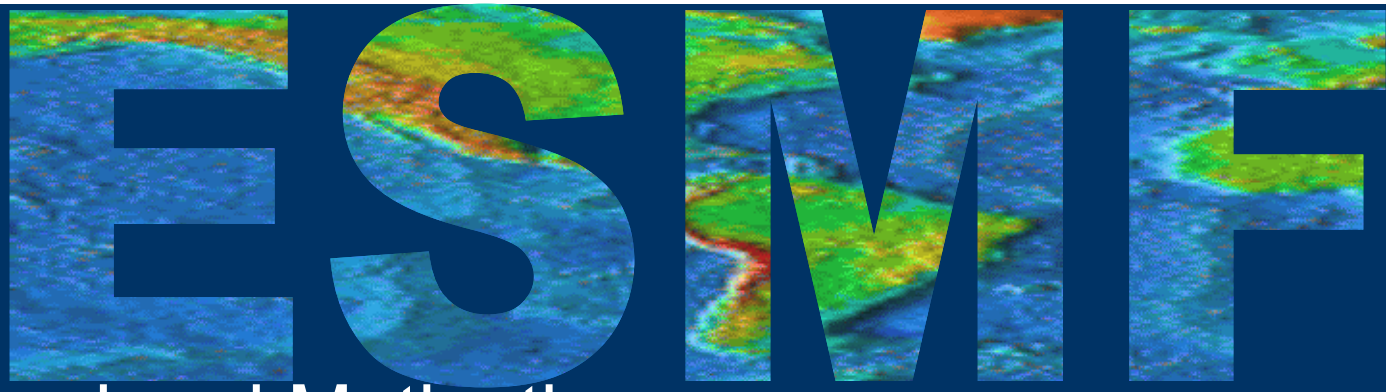


- **Code, documentation, input data**
  - Available via the Web
  - Step-by-step instructions on how to reproduce experiments
- **Experiments to span several time scales:**
  - NWP, mid-range forecast experiments
  - Coupled seasonal forecasts
  - Interannual/decadal variability
  - Centennial simulations

Coupled Configurations



	MODEL	MODEL	SCIENCE IMPACT
1	GFDL FMS B-grid atm	MITgcm ocean	Global biogeochemistry (CO2, O2), SI timescales.
2	GFDL FMS MOM4	NCEP forecast	NCEP seasonal forecasting system.
3	NSIPP ocean	LANL CICE	Sea ice model for SI, allows extension of SI system to centennial time scales.
4	NSIPP atm	DAO analysis	Assimilated initial state for SI.
5	DAO analysis	NCEP model	Intercomparison of systems for NASA/NOAA joint center for satellite data assimilation.
6	DAO CAM-fv	NCEP analysis	Intercomparison of systems for NASA/NOAA joint center for satellite data assimilation.
7	NCAR CAM Eul	MITgcm ocean	Improved climate predictive capability: climate sensitivity to large component interchange, optimized initial conditions.
8	NCEP WRF	MOM4 or POM	Development of hurricane prediction capability.



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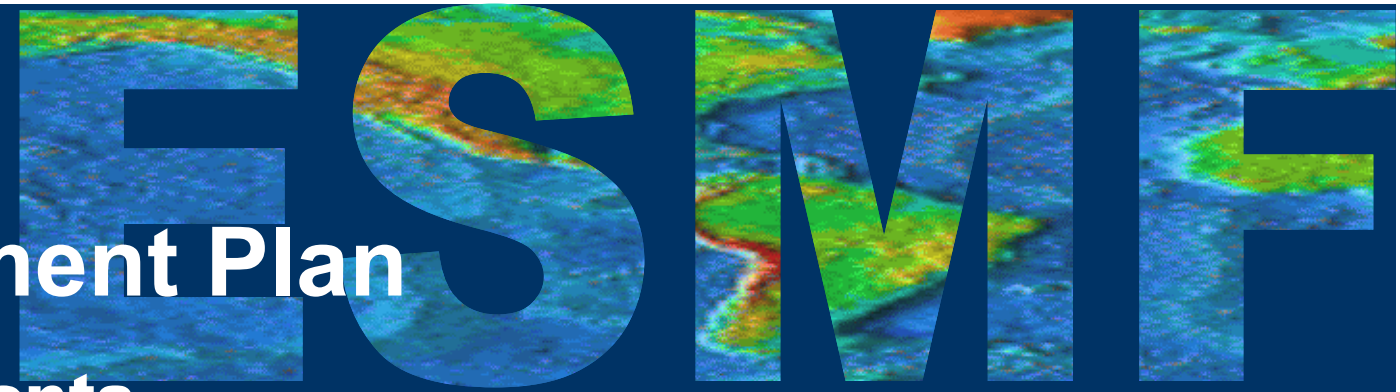
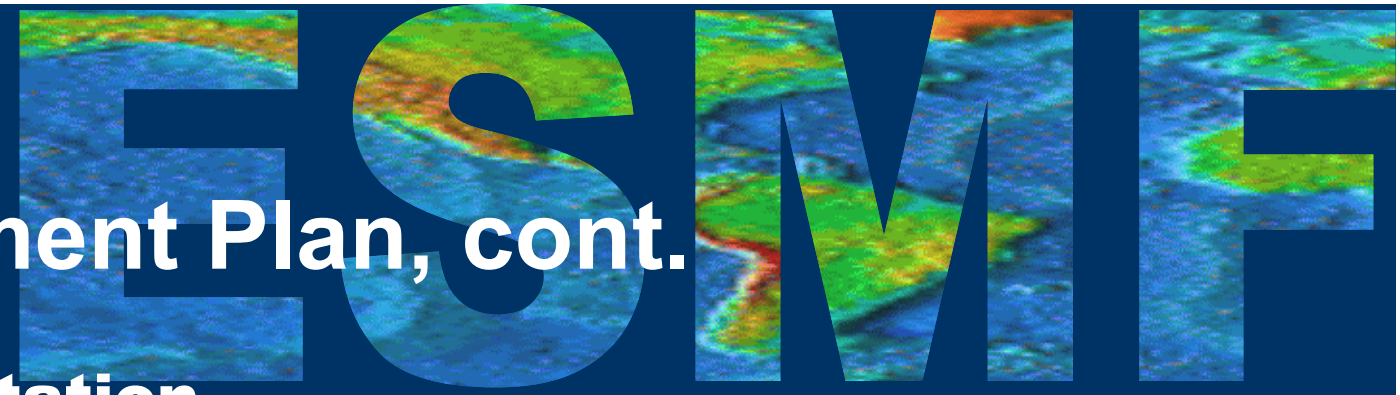


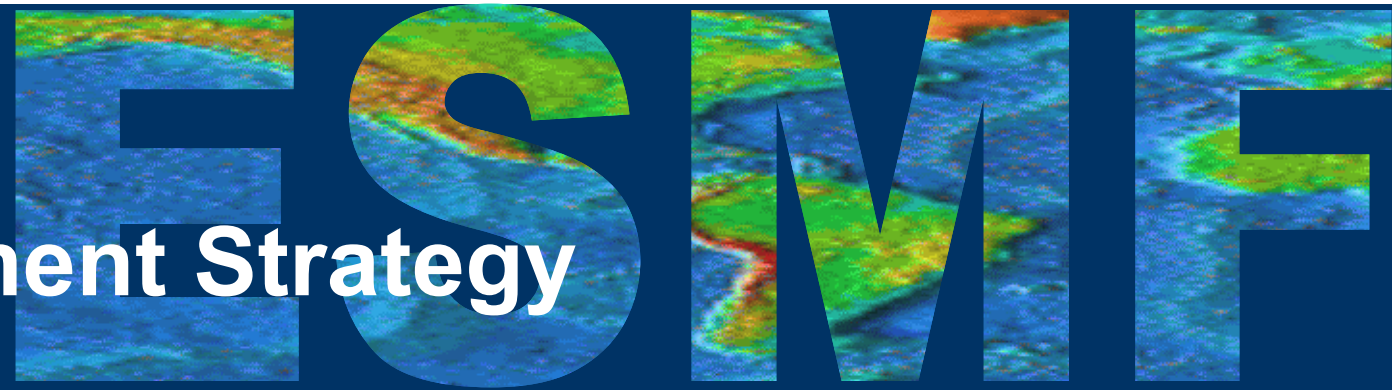
Development Plan

- **Requirements**
  - Will involve intensive interaction between Core ESMF team and a dispersed set of collaborating scientists and software engineers
  - High-level results presented in General Requirements Document; detailed requirements documents for specific components prepared later
- **Design**
  - Design study includes examination of FMS, GEMS, MCT, and other existing Earth science frameworks
  - Results presented in Architecture Report, detailed design documents for specific components prepared later

Development Plan, cont.



- **Implementation**
  - Implementation study will determine implementation language, language interoperability strategy, programming model
  - Examine viability of supporting software tools, e.g. CCA, Cactus
  - Results presented in Implementation Report
- **Best Practices**
  - Early distribution of Software Developer's Guide will encourage consistent standards, conventions and practices throughout the project

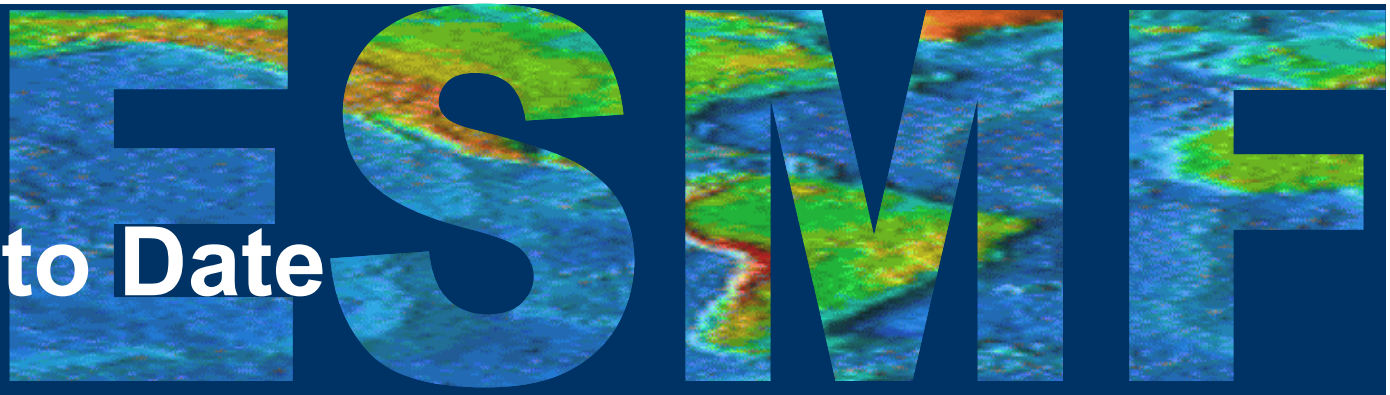


Development Strategy

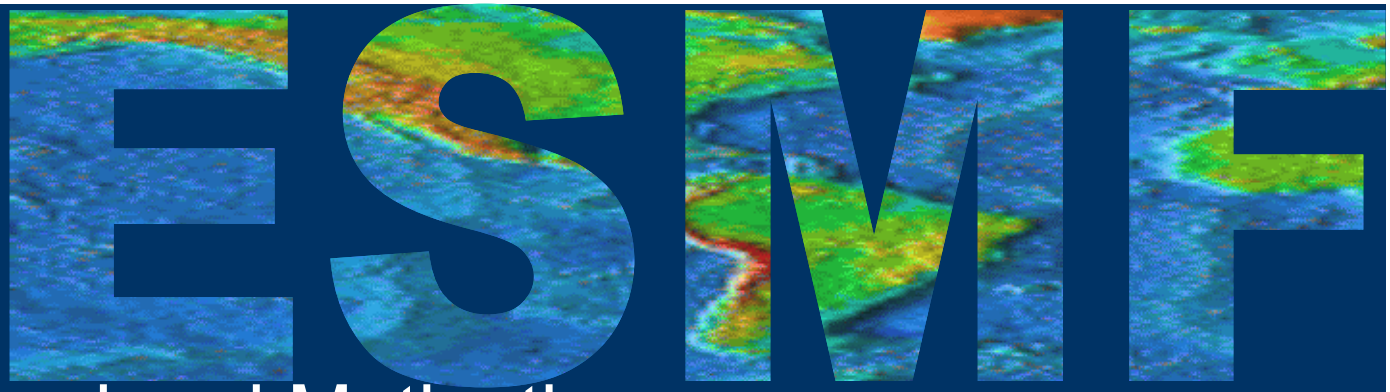
Collaborative, organized, efficient

- Modular, object-oriented software design
- Open, collaborative web development environment based on SourceForge
- Communication via teleconferences, mailing lists and ESMF website
- Reviews for requirements, design, code and documentation
- ProTeX, LaTeX and Latex2html tools to support integrated and easy to maintain documentation
- Defect tracking
- Web-based CVS source code control

Progress to Date



- Web-based development environment established on SourceForge, tutorial session for project participants
- Prototype utilities being used by CAM, CLM, NASA DAO (fvCAM)
- Broad requirements collection in progress using commercial approach: attention to traceability, verifiability, evolution (each requirement has attributes of priority, source, status, verification, notes)



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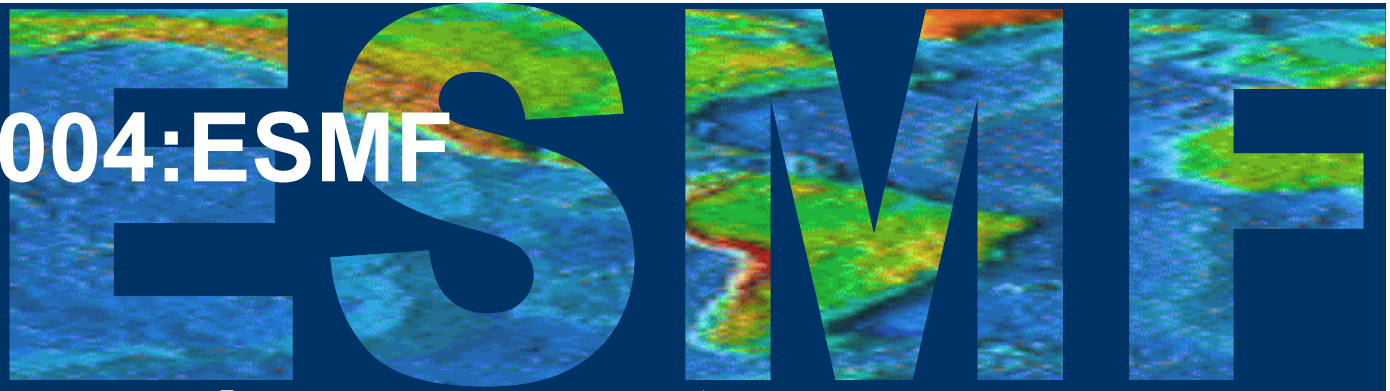
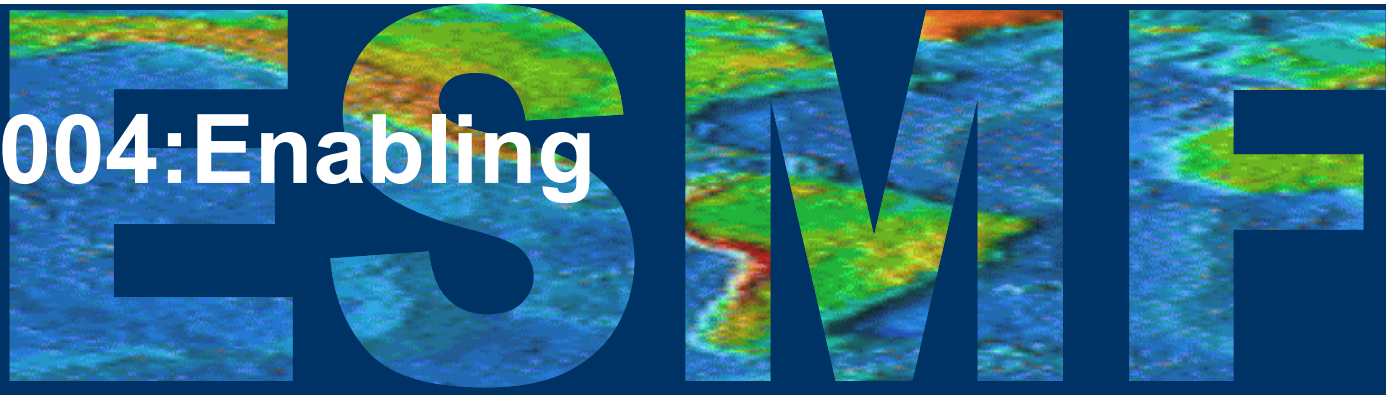


- **Maintenance and management**
  - NCAR commitment to maintain and support core ESMF software
  - NCAR commitment to develop ESMF, with focus and level contingent on outside funding
  - Persistence of ESMF Executive Committee and Advisory Board
- **Technical evolution**
  - Functional extension:
    - Support for advanced data assimilation algorithms: error covariance operators, infrastructure for generic variational algorithms, etc.
    - additional grids, new domains
  - Earth System Modeling Environment, including web/GUI interface, databases of components and experiments, links to GRID services

Beyond 2004:Enabling Science



ESMF will facilitate improved accuracy of prediction at all timescales

- NWP / Tropical cyclones
- Seasonal / ENSO forecasts
- Interannual and decadal / Air-sea gas exchange variability
- Centennial / Climate - IPCC simulations

ESMF will enable new coupling scenarios

Earth's surface to Sun's surface, combined geophysics and societal dynamics, …