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1. Summary

In this Project Plan we describe the nature, organization, goals, activities, funding structure, and evaluation of the Earth System Modeling Framework (ESMF) project from 2019-2024. This is an update to previous Project Plans, which have been in place since 2010. It is distinguished from the ESMF Strategic Plan in that it focuses on principles of operation rather than strategy. It includes terms of reference for all project bodies and designated positions. The Plan is intended to serve as a vehicle for coordination and as a reference for collaborators, sponsors, customers, and others with an interest in ESMF.

The ESMF website is mentioned frequently as a source of information; it is https://earthsystemcog.org/projects/esmf/. For brevity we expand only acronyms likely to be unfamiliar, and provide a full listing in Appendix C.

2. Introduction

The ESMF collaboration [1, 2, 15] is a national effort to produce shareable software for climate, weather, and related applications. ESMF increases the interoperability, reuse, ease of use, and performance portability of models by introducing standard component interfaces and software infrastructure for common modeling functions. It includes tools for building applications from multiple science components, for data decomposition and communication on parallel computers, and for functions such as calculation of interpolation weights, time management and message logging.

Development and deployment of the ESMF is a far-reaching endeavor that requires the coordination and contributions of many participants, both technical and scientific, from novice code developer to program director, to be successful. Staff from modeling centers supported by DoD, DoE, NASA, NOAA, NCAR, and NSF, as well as numerous universities, have contributed requirements, feedback, and software to ESMF.

The initial ESMF development cycle began in 2002 as a three-year project funded by NASA with additional support from the NSF. The second cycle, which began in 2005, was a five year multi-agency effort that broadened participation to include sponsorship and major application projects from NOAA and the Department of Defense.

ESMF development over the period from 2002 to 2018 is summarized in Figure 1. It shows the major releases of ESMF during this period. The most recent releases, starting with version 6, introduce a reference implementation of the National Unified Operational Prediction Capability (NUOPC) Interoperability Layer [15], a multi-agency agreement to standardize coupling protocols beyond basic ESMF interfaces. They also include enhancements to the grid representation, regridding functions, memory and performance optimizations, and many other improvements.
Figure 1
ESMF releases from 2002-2020. The chart shows the timescales of the eight major releases and the major capabilities that each represents.

This Project Plan addresses the next five years of the ESMF effort, from 2020 to 2025. This Plan is intended as a living document, responsive to the many factors in technology, science, and society that can influence ESMF. Nonetheless, we expect the basic project structure described to persist. It is based on, and extends, organizational bodies and strategies that have proven effective in ESMF to date.

The ESMF Core Team was originally established in 2002 at the National Center for Atmospheric Research (NCAR). In 2010, the team moved to NOAA’s Earth System Research Laboratory (ESRL), and over the period 2018-2019 the team transitioned back to NCAR. Moves of the Core Team are only undertaken when necessary, and are approved by the ESMF governance.

The project status is that ESMF is well-established and mature. Project participants and sponsors include NOAA, NASA, DoD, and NCAR, and these partnerships are expected to continue. Widespread adoption of ESMF has led to a core framework with key data structures in place and with robust, well-tested operations on those data structures. The NUOPC Interoperability Layer has been adopted in major modeling systems at NOAA, DoD, and NCAR, and, gradually, is being tested and incorporated into NASA codes. Most NUOPC Layer applications couple at the level of major Earth system components, e.g., atmosphere, ocean, sea ice, land, and wave. Other kinds of components and subcomponents are also using the NUOPC Layer, such as atmospheric chemistry, radiation, and hydrology. These applications are helping to identify new requirements for ESMF and the NUOPC Interoperability Layer and are also helping to identify important areas for optimization.

New development work includes the adoption of ESMF and the NUOPC Layer into additional components. Existing systems built using ESMF are being refined, validated, and optimized. ESMF is also being integrated with emerging community infrastructures, such as the Joint Effort
for Data assimilation Integration (JEDI)\(^1\), with the goal of maintaining unified, optimized overall system architectures.

3. Definitions

Like many undertakings, ESMF can be viewed as both a project (or set of projects) and a product. As a community infrastructure effort, ESMF is also recognized as a convention or standard. As the ESMF effort matured and experienced widespread adoption, the need emerged for conventions, templates, and usage constraints designed to achieve increased interoperability for a set of ESMF components. These are collected into “usability layers.” In this section we clarify what is meant by each of these terms.

3.1. ESMF as a Standard Interface

ESMF was conceived as an infrastructure standardization effort. As such, the project aims to produce a specification for an application programming interface (API) that is stable, consistent, and recognized as a common convention or standard. In theory, the API could be implemented by more than one group, or the underlying implementation might change substantially over time. Some successful examples of standardization projects that have adopted this approach in the high performance computing arena are MPI [5] and VSIPL [6].

In practice, except for a couple of implementations of the ESMF time manager library, there is only one group that is implementing the ESMF software - a funded Core Team. The code that this group produces is referred to here as the reference implementation. It has proven difficult to specify the API prior to or separate from the reference implementation, since requirements are often established by iterating on working code with users. As a result, the interface has evolved considerably over the course of development. A major standardization effort was realized in ESMF version 5 resulting in a highly stable API and a commitment to backward compatibility. Since that version, the ESMF core team has enforced a high level of consistency across the framework code.

3.2. ESMF as Product and Project

The ESMF Product is defined as ESMF and related (e.g. NUOPC Layer) application interfaces, reference implementation and documentation; associated maintenance and testing; support and training; and a web-based collaboration environment that allows ESMF staff, sponsors, and customers to archive and exchange information. It does not include the full set of applications that have adopted or will adopt ESMF.

ESMF target applications typically have life spans on the order of decades - large geophysical codes are too difficult to develop, tune, and validate to make frequent fundamental changes. The ESMF Product must be maintained on a comparable time scale in order to support these codes, and requires continuity in staff and management in order to do so effectively.\(^2\) This means that

\(^1\) See for example: [https://ams.confex.com/ams/97Annual/webprogram/Paper315326.html](https://ams.confex.com/ams/97Annual/webprogram/Paper315326.html)

\(^2\) The paper *Future Directions for the ESMF* [3] provides a more detailed rationale for continued maintenance and persistent management.
the notion of an **ESMF Project** must exist beyond the confines of a three to five year funding cycle.

During ESMF’s first NASA-funded phase, the definition of the ESMF Project was relatively clear; its scope was defined by a set of three interlinked NASA Cooperative Agreements, and its goals were laid out as a set of milestones [6]. NASA provided most of the funds for development of a reference implementation by a team located at NCAR, and funds for deployment of the framework in fifteen applications, among them GFDL models [7], new NASA GMAO models and data assimilation systems, and the NCEP forecast system [8].

However, since 2005, ESMF has had multiple sponsors, each with their own milestones, reporting requirements, and mission. The activities of core framework development and the deployment activity are distinct. We term activities in which ESMF is integrated into applications, **Application Integration Projects**. Examples include integration of ESMF and the NUOPC Layer into NOAA’s Unified Forecast System (UFS), NCAR’s Community Earth System Model (CESM), and Navy regional and global codes, and the extensive use of ESMF in NASA Goddard Earth Observing System (GEOS) model. In addition to Application Integration Projects, there is community interest in providing software additions to the ESMF reference implementation. These additions may include extensions to the ESMF functionality or application domain, advanced user interfaces, optimization, porting, or other contributions. We refer to projects of this nature as **Development Projects**.

A centralized core framework development team is funded by multiple agencies, and Application Integration Projects and Development Projects contribute funds to the core effort for development, assimilation of contributions, testing, and support staff. See Section 6 for further details on this strategy.

Within this context, we define the ESMF Project as **the body responsible for developing and managing the ESMF Product**. It receives funding from multiple sponsors. It has two main parts, a **Working Project** that handles day-to-day operations and an **Executive Management** (see Section 4.2 for a full description of the ESMF organization). It includes a support and outreach function, but does not include all of the applications that are integrating ESMF. Connections between specific applications and ESMF are established through participation of application stakeholders in the appropriate ESMF organizational bodies, and vice versa.

### 3.3. Usability Layers

While the flexibility of ESMF has encouraged a broad user base, it makes it difficult to achieve interoperability without the disambiguation provided by additional metadata and usage conventions. There are currently two “usability layers” on top of ESMF that provide generic implementations of components, constrain the use of ESMF, and provide additional protocols and specialized use of metadata.

The NUOPC Interoperability Layer was proposed and defined by a multi-agency consortium under the National Earth System Prediction Capability (ESPC) Common Model Architecture (CMA) committee. The first major implementation was available in ESMF v6 and the API has stabilized significantly with the ESMF v7 release. The NUOPC Interoperability Layer is now the recommended way of implementing ESMF-based coupled modeling applications and it has been adopted by most agencies and major modeling centers in the US, including Navy global and regional systems, the NOAA community UFS, the CESM, and parts of NASA’s GEOS and...
Model E modeling systems. The NUOPC Interoperability Layer is included with the main ESMF distribution.

The Modeling, Analysis and Prediction Program Layer (MAPL) was developed at NASA Goddard and is used in the GEOS modeling system and related components. It introduces a specific, hierarchical architecture and the generic components and conventions to support it.

Under support from NASA, significant efforts have been made to unify the MAPL and NUOPC layers and to provide paths for interoperability between the two. Specifically, the NUOPC Layer was extended to support the same kind of hierarchical architecture and associated protocols as MAPL, a step to ensure that NUOPC is capable of handling all requirements and behaviors of MAPL. In addition, a wrapper has been developed that sits on top of a MAPL component and converts it into a NUOPC-compliant component. Efforts to unify and increase interoperability of these two usability layers are ongoing.

4. Goals and Strategies

The overriding goals of the ESMF are to

1. increase the scientific productivity of researchers in the Earth system domain by enabling them to use and reuse common modeling infrastructure; and
2. promote new scientific opportunities through community building and increased interoperability of codes.

The first goal is achieved mainly through the delivery of the ESMF Product. It offers the coupling tools, data structures, and utilities that modelers require. They can build models quickly, reuse existing software rather than reinventing it, and exchange and introduce new modeling components in a systematic way.

The second is achieved mainly through the ongoing activities of the ESMF Project. The collaboration required by ESMF, the standards-building activities, and the community outreach that the Project continually engages in are breaking down barriers in the modeling community and enabling new collaborations to be forged.

4.1. Key Organizational Strategies

The ESMF organization reflects the diversity of its customers and the ambition of its goals, and it is complex. However, there are a number of key strategies that underlie its structure, and help to explain the choices made. These are:

1. Recognition that the key relationship in the ESMF Project is between the ESMF Product and the scientific customer, and that the practical goal of the ESMF effort is to enhance the capabilities of a limited set of working research and operational codes. This recognition encourages the formulation of appropriate test and validation strategies, milestones, and success metrics.
2. A close and continuous relationship between the developers of the software and users of the software, encompassing requirements management, interface specification, short- and long-term reviews, and evaluation. A close relationship ensures that the product delivered is the product needed.
3. *A core development and support team under direct line management.* We have found that a dedicated Core Team promotes responsive, high quality development and support, and provides necessary assimilation services for code contributions from other sources.

4. *A set of dispersed, science-knowledgeable advocates working with each other, the development team, and application groups to organize outreach efforts, to develop training materials, and to encourage adoption of the framework.* One of the best ways to promote ESMF adoption is to have scientists advocate the product to their peers.

5. *Clear, consensually decided upon mechanisms for setting implementation priorities and for making technical decisions.* These mechanisms are required in order to avoid perceptions of unfairness, and to keep development moving along a focused and timely path.

6. *Maintenance of an openly accessible web-based collaboration environment that provides comprehensive and pertinent information, including training information, metrics, task lists, documents, regression test results, links to common repositories, and more.* The communication infrastructure together with a network of informal cross-collaborator communications are the lifeblood of the project.

### 4.2. Overview of the ESMF Organization

The persistent ESMF organizational structure incorporates the elements above. We introduce the concept of a **Working Project**, defined as the team of customers and developers who collaborate day-to-day to build the ESMF Product. The Working Project consists of three parts:

1. a line-managed **Core Team** responsible for implementing the ESMF software, including unit and system testing, maintenance, support, and oversight of a web-based collaboration environment;
2. a **Content Standards Committee (CSC)**, introduced in 2010, responsible for developing metadata, usage, and other conventions to enhance interoperability through standardization and a NUOPC Interoperability Layer for operational centers;
3. a **Model Component Liaison (MCL) Committee**, introduced in 2017, a subcommittee of the CSC, charged with ensuring the readiness and reliability of components that have NUOPC interfaces;
4. a group of active users called the **Joint Specification Team (JST)** that interact with the Core Team and broader community, providing requirements, feedback, and a standards track; and
5. a **Change Review Board (CRB)** that integrates and prioritizes the requirements from multiple users and sponsors.

The Working Project is funded, guided and evaluated by its **Executive Management**. The Executive Management of ESMF is comprised of two bodies. These are:

1. an **Executive Board** charged with scientific and technical leadership; and
2. an **Interagency Working Group (IAWG)** that coordinates funding and assesses progress against programmatic goals.

Both the ESMF Executive Management and the Working Project interact with the Earth system modeling and related communities, including the computer science community and the vendor community. Figure 4 shows the ESMF Project and its interactions with outside communities.

*The ESMF organization is how the ESMF Project coordinates across milestones, missions, reporting requirements and agencies.* Coordination across the ESMF must be addressed by the
entire Project structure, so that sponsors can coordinate with other sponsors, hands-on staff can communicate with their peers, and prioritization of multi-agency requirements can be mediated at the appropriate level. Also, the coordination must be dynamic and ongoing; it cannot be accomplished through infrequent events. Interactions occur at a range of different time scales, from days to years. In this document we focus on defining the mechanisms through which coordination will take place and how decisions will be made, rather than what those decisions will be.

The remainder of this section defines in greater detail the elements and associated roles within the ESMF Working Project and Executive Management, the broader community that ESMF serves, and the interactions amongst all of these. Figure 2 shows a diagram of the ESMF organization, and the timescales at which different bodies operate.

![Diagram of ESMF organization](image)

**Executive Management**
- Interagency Working Group
  - Stakeholder liaison
  - Programmatic assessment & feedback
- Executive Board
  - Strategic direction
  - Organizational changes
  - Board appointments

**Working Project**
- Change Review Board
  - Development priorities
  - Release review & approval
- Joint Specification Team
  - User support requests & requirements
  - Design, code and other reviews
  - External code contributions
- Core Team
  - Software project management
  - Development of ESMF/NUOPC
  - Testing & maintenance
  - Distribution & user support
- NUOPC Content Standards and Model Component Liaison Committees
  - Conventions for physical constants, documentation, metadata, component readiness and reliability
- Potential standardization tasks
- Implementation schedule
- Resource constraints

**Figure 2**
The ESMF is comprised of a Working Project and Executive Management. Typical timescales of interaction are noted in the red ovals.

### 4.3. The Working Project

We refer to the organizational structure that is responsible for implementing the ESMF Product day-to-day as the Working Project. The Working Project is a balance between three bodies: a Joint Specification Team, a Core Team, and a Change Review Board. In simplest terms, the Core Team is responsible for implementing the software, the Joint Specification Team is responsible for communicating functional requirements and design preferences, and the Change Review Board is responsible for determining cross-agency priorities for software development and for
creating development schedules. In 2010, the Working Project was extended to include the NUOPC Content Standards Committee (CSC), charged with developing usage and other conventions to improve interoperability. In 2019, the Model Component Liaison Committee (MCL) was explicitly added to the Working Project due to the strategic importance of ensuring readiness, accessibility, and reliability of model components using NUOPC interfaces. The Working Project has established paths of interaction with the Earth science user community, vendors, the computer science community, and ESMF Executive Management.

The Working Project is accountable to the Interagency Working Group for satisfying programmatic goals, and to the Executive Board for satisfying functional requirements. It receives direction from both of these bodies.

4.3.1. The Core Team

The Core Team is the part of the ESMF project responsible for implementing the framework software and maintaining the collaboration environment. The Core Team is the main point of contact for users and is responsible for archiving and resolving support requests, feature requests, and bug reports. In 2010, the ESMF Core Team became responsible for implementing the NUOPC Interoperability Layer based on the ESMF architecture. The Core Team also participates in the coordination of development between the NUOPC Layer and NASA’s MAPL.

The Core Team receives framework requirements and design input from the Joint Specification Team (JST). It receives implementation priorities from the Change Review Board (CRB), and direction from the Executive Board and the Interagency Working Group (IAWG).

The Core Team is not responsible for prioritizing development tasks; that is the role of the Change Review Board. However, the Core Team Manager is an ex officio member of the Change Review Board, and can offer integrated effort, risk, and dependency assessments that may factor into the prioritization process.

The Core Team will receive guidance from the National ESPC Content Standards Committee (CSC) on changes to the NUOPC Interoperability Layer and other relevant topics. Similarly, the Core Team will receive guidance from the Model Component Liaison (MCL) Committee on implementation of NUOPC Layer caps, repository strategies, and other items. At least one person from the Core Team will be on the CSC and the MCL Committees. The Core Team should be able to meet with and advise people from the operational centers and development laboratories as necessary.

Members of the Core Team perform various functions, including software development, support, testing, and maintenance of the collaboration environment. Senior Core Team members typically have ownership of a major function, such as testing, or a major part of the framework, such as grids/regridding, and provide leadership in these areas. Core Team members may be responsible for overlapping roles, such as development and support.

Development activities include the design, implementation, maintenance and documentation of the reference implementation. Details of the ESMF development process are described in the ESMF Developer’s Guide [10].

Testing activities include unit and system testing of the software on a variety of platforms. Areas covered include functionality testing, regression testing, performance testing, use test cases, and
portability testing. The testing lead tracks bug reports and is responsible for verifying bug fixes. Details of the ESMF testing process are described in the *ESMF Developer’s Guide* [10] and on the *Test and Validation* page of the ESMF website.

User support activities include moderating the ESMF support mailing list, resolving and tracking support requests, creating training materials in conjunction with members of the Joint Specification Team, and providing in-person and online training classes.

The Core Team also manages the collaboration environment to ensure access by the community to project resources, such as the software itself and its documentation, and to ensure open and reliable channels of communication, such as user support questions and access to training materials.

There is also a non-trivial administrative function association with the ESMF project. ESMF administrative tasks include organizing project meetings and sprints, managing Board appointments, and coordinating and serving as secretary at meetings of Executive Management.

*MEMBERS and MEETINGS* The Core Team consists of software developers, testers, administrative staff, user support and training staff, web developers, and the Core Team Manager. The Core Team manager is responsible for staffing. Development meetings and ticket review meetings (for support requests, feature requests, and bug reports) are held weekly.

*CHARGE and REPORTING*

- Collect, archive, and track requirements.
- Implement requirements in software for the framework and NUOPC Interoperability Layer.
- Assimilate non-Core development activities.
- Perform maintenance and bug fixes.
- Track bugs, feature requests, and support requests.
- Unit and system test.
- Provide user documentation, design documentation, and a Developer’s Guide.
- Provide user support and training.
- Liaise with vendors.
- Liaise with other projects (shared responsibility with other ESMF bodies).
- Develop and maintain the ESMF collaboration environment.

The Core Team reports to the Executive Board and receives priorities from the Change Review Board.

### 4.3.2. The Joint Specification Team

The Joint Specification Team (JST) is a group of active users that interact with the Core Team and the broader community, providing requirements and feedback for the ESMF software interface (metadata and other standards are handled by the Content Standards Committee). Membership is open and communication is mainly through telecons and the ESMF JST and support email lists.

Since the JST is comprised mainly of Earth science application developers who have experience using ESMF, it is the body best equipped to review and refine the ESMF Application
Programming Interface (API). JST members may provide interface specifications along with requirements, or may review interfaces after prototypes have been developed by the Core Team. The balance between the JST and Core Team is fundamental to the ESMF organizational structure; it places an important aspect of ESMF development in the hands of users, thereby promoting community ownership. Since ESMF and the NUOPC Layer are now mature products, weekly design calls between the JST and Core Team now rarely occur, and the main communication mechanism is through user support and user training.

MEMBERS and MEETINGS The JST is comprised of members of the ESMF user community, meeting jointly with members of the Core Team. Teleconferences are announced on the JST mailing list and may originate with the Core Team or the user community. Membership is open.

CHARGE and REPORTING

- Generate functional requirements.
- Confirm implemented requirements.
- Participate in design and code reviews.
- Provide general feedback.
- Submit support requests, feature requests, and bug reports.
- Provide code contributions.
- Promote and develop the ESMF API as an interface standard.
- Liaise with other projects (shared responsibility with other ESMF bodies).

The Joint Specification Team is a coordinating function and does not report out.

4.3.3. The Change Review Board

The Change Review Board prioritizes tasks and prepares a Core Team development schedule, and plans, authorizes, and reviews the content of ESMF releases. It provides guidance on priorities to the Content Standards Committee and Model Component Liaison Committee and ensures coordination of this body and the Core Team.

CRB members meet on a semi-annual basis to review and revise development priorities, and prepare a development and release schedule for the Core Team. Proposals for new requirements or changes to existing requirements, and the concomitant development of new functionality, or changes to existing functionality, are communicated to the CRB from the JST via the ESMF support mailing list. The Board reviews all updates to requirements and prioritizes the implementation of new requests among the outstanding development tasks on the Core Team schedule. Prioritization takes into account the immediate needs of the agencies funding ESMF development. The release schedule prepared by the CRB specifies development tasks on a per-release basis for releases about a year into the future. The CRB reviews releases for conformance to planned contents prior to release.

The CRB also receives potential standardization tasks from the Content Standards Committee and Model Component Liaison Committee and prioritizes them in accordance with strategic objectives, JST application priorities and Core Team activities.

The CRB is led by a chair that ensures that the CRB meets on a regular schedule and provides development priorities to the Core Team in a clear, public, and timely manner. The chair is selected by the Executive Board.
MEMBERS and MEETINGS  The CRB is populated with application developers representing agency and institutional stakeholders in the ESMF project. The CRB chair leads and mediates CRB meetings. A typical CRB member controls the scientific and technical development of a set of ESMF-compliant applications. The Core Team Manager and the Content Standards Committee Chair are members of the CRB. The Core Team Manager advises the CRB on the capabilities of the Core Team and the scheduling of development activities.

Members are appointed by the Executive Board and serve renewable one-year terms. CRB discussions are mediated by the CRB chair. The CRB meets semi-annually and sends minutes and implementation schedules to the Executive Board for review.

CHARGE and REPORTING
- Review and authorize changes to the reference implementation maintained by the Core Team.
- Review potential standardization tasks and provide development priorities to the Content Standards Committee and Model Component Liaison Committee.
- Coordinate the activities of the Core Team with the Content Standards Committee and Model Component Liaison Committee.
- Update the development and release schedules, and submit them to the Executive Board for review.
- Review and approve the content of ESMF releases to assure that development tasks are completed prior to release.

The CRB reports to the Executive Board.

4.3.4. The Content Standards Committee

The Content Standards Committee (CSC) is the primary committee responsible for evolving and expanding interoperability standards for the NUOPC partners. The CSC will have responsibility for selecting or developing conventions for metadata, documentation, physical constants and other areas that require mutually agreed on values and formats. The CSC will not be responsible for the design of software or software interfaces. However, its work will need to be coordinated with the ESMF Core Team, since software development will be required to support implementation of many of the conventions. It is expected that the CSC will work in close collaboration with the ESMF Core Team. The Core Team will provide input to the CSC on standards from an implementation perspective, and ensure that the NUOPC software supports them. For this reason, there should be some individuals who are members of both committees. NUOPC will act through the CSC to provide a list of potential tasks to the CRB, along with input on priorities, for final prioritization and coordination with the tasks on the ESMF development team schedule. The CSC may communicate through teleconferences, emails, or meetings with the JST when broader input into standardization decisions is desired. The CSC and Core Team will receive priorities from the ESMF Change Review Board. The Change Review Board will be responsible for ensuring that the CSC and Core Team activities are synchronized.

The chair of the Content Standards Committee will also be a member of the ESMF Change Review Board. The CSC committee will be composed of members from the NUOPC participating operational centers, from U.S. government agencies with a stake in NUOPC development (such as NSF, Air Force, Navy, NOAA, NASA, DoE, and FAA), ESMF, other leading infrastructure projects, and academic organizations.

The CSC will meet as required to complete definition of the initial NUOPC standards and then at
least quarterly thereafter, by teleconference and/or internet with periodic face-to-face meetings.

**MEMBERS and MEETINGS** The CSC consists of members from the NUOPC operational centers, their development organizations, NASA and NCAR and other interested organizations and individuals. The CSC meets on a monthly basis during the initial NUOPC standards implementation and will meet quarterly thereafter.

### 4.3.5. Model Component Liaison Committee

The Model Component Liaison (MCL) Committee is a subcommittee of the CSC charged with advancing the readiness and reliability of components that have standard NUOPC Layer interfaces. With the increased use of community models, the use of standard interfaces, and increased demand for coupled modeling systems, there is a need to enable modelers to find, request access, run and verify, integrate, and update model components from a variety of sources.

The MCL committee develops common guidelines for model component and NUOPC cap repositories, documentation, and testing, and works with component development teams to implement them. Coordination of NUOPC cap development is important since centers have begun sharing caps as well as components and ideally a single, unified NUOPC cap is maintained for each component (where possible) and available to the community through the component’s authoritative repository. The committee meetings provide a forum for model development leads and code maintainers to coordinate on best practices and strive for a level of consistency among all components that offer NUOPC interfaces.

**MEMBERS and MEETINGS** The MCL consists of development leads and/or code managers of model components that offer (or seek to offer) a NUOPC interface as well as members of the ESMF Core Team. Membership is expected to grow as new components are added with NUOPC interfaces. The MCL has monthly teleconferences.

### 4.3.6. Working Project Management

Working Project management is responsible for the day-to-day oversight of ESMF development and support. Different styles of management are appropriate for different Working Project functions. We have found that direct line management of the Core Team allows for rapid development. The line management relationship has an immediacy missing from, for instance, that of a PI trying to direct a project member who he or she does not supervise and who may be located at another institution.

The Change Review Board requires mediation among peers. The CRB chair, who is theoretically in a neutral position with respect to multi-agency development priorities, negotiates prioritization decisions with CRB members.

The JST extends across multiple institutions and has relatively diffuse goals; members can organize and coordinate activities, but cannot line manage across group or institutional bounds.

#### 4.3.6.1. Core Team Manager

The Core Team manager is responsible for directing ESMF development. It is a full-time position.
CHARGE and REPORTING

- Supervise and direct the activities of members of the Core Team.
- Perform Core Team administrative functions as required by NCAR management and contractual obligations.
- Direct the development and maintenance of the collaboration environment, and assure that it satisfies the needs of project members, sponsors, and customers.
- Provide technical direction for the reference implementation.
- Assure that the support team is responding effectively to customer needs.
- Take responsibility for ensuring that adequate testing of the reference implementation is performed and that releases proceed in a satisfactory and timely fashion.
- Serve as a member of the CRB, and work with other members of the Board to set the development schedule.
- Assure that development proceeds along implementation schedules set by the CRB.
- Represent the Core Team to other project bodies and the outside community, including vendors.
- Mediate with other project bodies and the outside community on issues regarding core team activities such as support, training, and collaboration environment. The Core Team Manager does not, however, mediate with other project bodies regarding development priorities outside of the CRB.
- Work with the Schedule and plan Interagency Working Group activities.

The Core Team Manager reports to the Executive Board.

4.3.6.2. Content Standards Committee Chair(s) and Model Component Liaison Committee Chair(s)

The Chair(s) of these committees organize and lead standards-related activities.

CHARGE and REPORTING

- Promote standards that improve interoperability, accessibility, and ease of maintenance, and organize reviews and meetings to that end.
- The Chair(s) of these committees will be members of the ESMF Change Review Board.

4.4. Executive Management

The main ESMF management bodies are an Interagency Working Group, which determines funding levels, and an Executive Board, which provides overall scientific and technical guidance.

4.4.1. The Interagency Working Group

The IAWG provides a forum for ESMF stakeholder agencies to interact on a regular basis regarding the vision, goals, and progress of the ESMF effort as they relate to each agency’s mission and plans. Agency representatives work with the ESMF Executive Board to articulate ESMF goals and formulate metrics that reflect programmatic requirements. Members of the IAWG annually assess the success of the ESMF in satisfying these requirements. Insofar as it is possible, members of the IAWG coordinate funding and funding opportunities so that the Working Project has adequate and appropriate resources to meet requirements. The IAWG receives reports from the Executive Board on the status of ESMF development, adoption, and collaborations, and offers guidance as warranted. Members of the IAWG coordinate the
messages carried back to higher level agency management regarding ESMF progress and value.

The IAWG has the authority to convene an ad-hoc Review Committee, as needed, to review the ESMF project for conformance with standards and best practices in the broader community, and assess progress towards project goals.

MEMBERS and MEETINGS  The IAWG consists of program executives from federal agencies that have a stake in the progress of the ESMF. The Working Group may invite other members to join. The Working Group may optionally designate a Chairperson to coordinate the timing and location of meetings, reviews, and meeting agendas. The IAWG meets yearly, or as directed by the Chairperson. An executive secretary will be responsible for meeting minutes, reports, schedules, and the Chairperson’s business.

CHARGE and REPORTING

- Communicate agency objectives and constraints to the Executive Board and confer with the Board to ensure that they are reflected in ESMF goals and vision;
- Review and concur on ESMF programmatic metrics proposed by the Executive Board, and changes to those metrics as may be necessary from time to time.
- Assess progress against programmatic metrics on an annual basis, and communicate results and recommendations to the Executive Board. Convene a Review Committee as needed.
- Coordinate reporting of ESMF reviews, accomplishments, status and plans, and agency impacts back to the member agencies.
- Report on agency perspectives and issues with respect to ESMF and discuss them with other members of the IAWG.
- Advise the Executive Board on funding issues and opportunities that may be relevant to continued progress, and, insofar as it is possible, work to coordinate funding and funding opportunities so that the Working Project has adequate and appropriate resources to meet requirements.
- Ensure all stakeholders are represented on the IAWG.
- Nominate agency representatives to serve on the ESMF Executive Board, and confirm the slate of members selected by Executive Board standing members. The Executive Board should be comprised of both agency representatives and members of the broader community.

4.4.2. The Executive Board

The Executive Board is the primary management body of the ESMF. It sets the goals, scope, and strategic direction of the Project as a whole, and provides technical and scientific guidance on practical matters as they arise.

The Executive Board is charged with ensuring that the ESMF organization works effectively. It is responsible for developing and approving changes to the Project Plan, which includes terms of reference for ESMF Project bodies and positions. The Executive Board is responsible for ensuring that the Project Plan is implemented, and it has the authority to make changes to the ESMF organization in order to do so. The Executive Board is the body that represents the ESMF Project to the IAWG.

The Executive Board also selects members of the Change Review Board. Appointments to management and coordination positions, including the Program Coordinator and Core Team Manager, must be confirmed by the Executive Board.
**MEMBERS and MEETINGS** The ESMF Executive Board consists of leads from ESMF collaborating institutions, and adequately reflect the funding agencies. It should include NUOPC agency representatives and members of the broader community. Candidates are nominated by members of the IAWG and a slate of members is selected by the standing members of the Executive Board. The slate is confirmed by the IAWG. Members serve renewable three year terms. The Executive Board Chairperson is selected by member consensus and serves a renewable three year term. The CRB Chairperson and Core Team Manager are *ex officio* members of the Executive Board. The Executive Board meets twice yearly, or as directed by the Chairperson. An executive secretary will be responsible for meeting minutes, reports, schedules, and the Chairperson’s business, and ensuring that the CRB reports are reviewed and acknowledged.

**CHARGE and REPORTING**

- Set the goals, scope, organizational structure and processes, functional metrics, and future directions of the ESMF Project. Approve any major organizational changes or moves of the Project.
- Represent the ESMF Project to the IAWG, and interact with the IAWG on any issues of interest or concern to that body.
- Propose programmatic metrics for review and acceptance by the IAWG.
- Provide information on the progress of the ESMF Project to the IAWG, the policy community, the Earth science community, and others.
- Promote the ESMF Project within the national and international Earth science and related communities.
- Periodically develop and approve updated versions of the ESMF Project Plan, and approve changes to the Project Plan.
- Track progress and ensure adherence to the ESMF Project Plan and direct any necessary corrective activities.
- Review development schedules from the Change Review Board.
- Approve new ESMF Project bodies and positions.
- If necessary, terminate ESMF Project bodies or positions, or remove individuals from specific roles within the Project.
- Select members of the Change Review Board.
- Confirm management and coordination positions, including the Core Team Manager, the Program Coordinator, and the JST Coordinators.

The Executive Board receives updates from the Change Review Board, JST, Content Standards Committee, and Core Team. The Executive Board represents the ESMF Project to the IAWG.

### 4.5. Interactions with Vendors

The HPC environment changes rapidly, and, as with the switch from vector to microprocessor based computer architectures, the changes can have profound effects on the way codes are structured. ESMF initiated the Industry Partners Forum (IPF) at SuperComputing 2003 in order to give vendor representatives, ESMF developers, and project leads a forum for interaction. It was discontinued when it was found that it was more productive to establish vendor relationships one-on-one. Vendor interactions are now coordinated and tracked through the Core Team.

### 5. Processes
Here we describe a number of routine events that generate flows of activity through the ESMF organization. This section defines what the appropriate contacts and paths are for these events. It also shows how the structure described in Section 3.2 can operate with reasonable efficiency for a large, complicated community effort! However, the section does not include an exhaustive description of ESMF development processes and conventions. These details are provided in the *ESMF Developer’s Guide* [10].

### 5.1. Points of Contact

#### 5.1.1. Support Requests

Support requests should be sent to esmf_support@ucar.edu.

#### 5.1.2. New Requirements

At this point in the ESMF project, most new requirements enter through user support requests.

#### 5.1.3. New Users

Many new users encounter the ESMF website before any other contact, so it is important that documentation and code access information is easy to find. The ESMF website is located at: [https://earthsystemcog.org/projects/esmf/](https://earthsystemcog.org/projects/esmf/). Since new users are often looking for introductory material about how ESMF works, the home page contains a link to the training schedule and materials. Another initial means of contact is the support mailing list, as people have questions about installing or porting the framework.

#### 5.1.4. New Code Contributions

We define two types of contributions, *drop* and *assimilated*. Drop contributions can be placed at any time in a contributions repository accessible from the ESMF website. These contributions are unmonitored, publicly available, and unsupported by the ESMF Core Team. The only prerequisite is that the contributor must register with the service that provides the contributions repository, which can be done by contacting esmf_support@ucar.edu.

Assimilated contributions are those that the contributor has proposed or agreed will become part of the reference implementation. These contributions must satisfy ESMF conventions and quality standards in terms of interfaces, documentation, portability, error handling, and so on, and will be fully supported by the ESMF Core Team. Potential contributors are encouraged to first contact the Core Team Manager to discuss the nature and implications of the contribution. The Core Team Manager is obligated to share information about potential contributors in a timely manner with other project bodies. Code contributions may be proposed and discussed at JST teleconferences or at project and other meetings.

Following initial discussions, the contributor may choose to have the Core Team Manager or a representative on the CRB to add assimilation of the code to the proposed tasks list for the next CRB meeting. At the CRB meeting the code assimilation task will be discussed and prioritized.

#### 5.1.5. New Sponsors
Potential sponsors of ESMF-related projects are encouraged to contact the Chair of the Interagency Working Group or the Core Team Manager and attend IAWG meetings to facilitate coordination.

5.2. Software Implementation

Requests for bug fixes, maintenance (e.g., a port to a new architecture), assimilation of contributed code, implementation of new capabilities, and interface standardization all require changes to the reference implementation. The time scales associated with each type of task differs. The small bug fix might be made and sent out quickly in a patch. The new functionality must be recorded as a requirement, prioritized with respect to other requirements, time for design and implementation scheduled, and the new code distributed in a release. Interface standardization often requires lengthy discussion and coordination with other projects, which can take months or even years. In this section we describe the various development paths in ESMF. Figure 5 illustrates timescales associated with development tasks.

Figure 3
Software implementation happens at different timescales – such as fast bug fixes, scheduled development, and longer interface standardization.

5.2.1. Bug Fixes and Routine Maintenance – the Fast Path

We recognize the necessity of providing a fast path to responding to support requests, implementing bug fixes, and performing routine maintenance. A portion of most Core Team members’ time is reserved for this type of activity (typically, this is 20%).

The support process is as follows: Users with support requests write the esmf_support@ucar.edu mailing list with questions, bug reports, and requests for ports and enhancements. All requests are archived, categorized, and tracked. Support requests requiring significant time and effort (more than two FTE-weeks) are normally prioritized by the CRB. However, if a request is identified as high priority, it may be addressed within the Core Team time reserved for support activities.

5.2.2. The Development Path

Requests for significant development take longer than simple bug fixes to complete. Development tasks originate with requirements, which enter the ESMF Project via any of the
routes described in Section 5.1.2. A list of proposed development tasks is reviewed at each CRB meeting. During the meeting the items are discussed and prioritized, and may be scheduled for implementation. The Core Team confirms the feasibility of the schedule before it is finalized. Typically one can expect development tasks to take on the order of months to be scheduled, completed, tested, and released.

5.2.3. The Standardization Path

The development of an interface standard is a lengthy, collaborative process that requires meticulous attention to detail on the design side and global software changes on the implementation side. In ESMF we conduct detailed interface reviews after a capability is implemented, tested, released, and tried out by users. An initial implementation of the software and the feedback that it has received from users can inform a standards review body, which, if it is on a separate path, has sufficient deliberation time to fine-tune interfaces so that the standard API is both tailored to users’ needs and coherent. This can take months or years.

5.3. Assimilation of Contributions

Contributions from the JST and the broader community are an integral part of ESMF development. As described in Section 5.1.4, we define two types of contributions: drop contributions, which are dropped into a public repository for anyone to use, with minimal involvement by the ESMF team, and assimilated contributions, which become part of the reference implementation.

For example, in the ESMF Version 2.0, the I/O package, Configuration Attributes class, and regridding software used in ESMF were all based on outside sources: WRF [13], the GMAO package INPACK, and the LANL SCRIP software [14], respectively. These packages were all modified to a significant degree in order to satisfy ESMF requirements, with the work either done entirely by the Core Team or split between the Core Team and the contributor. It is difficult to anticipate in advance what balance will make sense for a particular contribution; different approaches are appropriate for different capabilities.

Section 5.1.4 describes the points of contact and outlines the process for introducing a new code contribution.

5.4. Software Engineering Plan

The ESMF Developer’s Guide [10] contains the processes, practices, and conventions recommended for the ESMF Core Team and for developers integrating the framework into applications. The Developer’s Guide is a living document maintained by the Core Team. The document was significantly modified at the end of the first three years of ESMF development in order to reflect the new multi-agency organizational structure and processes.

5.5. Training

ESMF maintains a training program to help new and existing users understand and learn to use ESMF and the NUOPC Interoperability Layer. Upcoming training events are announced on the
JST mailing list and are posted on the ESMF website at: https://earthsystemcog.org/projects/esmf/tutorials.

Webinars are hosted approximately 2-3 times per year and include both overview presentations and tutorials that go into depth about a particular topic. Training courses are also offered on site at sponsor labs. These training courses are coordinated ahead of time with the sponsor to ensure that the topics covered are relevant to the needs of the sponsor. On site courses may be 1-3 days and typically include a large portion of time dedicated to hands on exercises, such as running simple ESMF and NUOPC Layer applications.

6. Funding

ESMF funding for the Working Project is a combination of two parts. There is a base level of funding for the Core Team that represents a critical mass of staff necessary to deliver and support ESMF for some minimal set of customers. This base level of staffing for ESMF is about nine FTEs, including manager, tester, admin/web staff, and developers/support staff.

In addition to the base, there are funding contributions to the ESMF Core Team commensurate with the extent of Application Integration and Development Project activities. This is necessary because Application Integration and Development Projects typically require Core Team resources over and above that required for routine development and support.

7. Evaluation

The ESMF Executive Bodies evaluate the progress of the ESMF Project as part of their charge. In addition, individual sponsors may conduct their own evaluation activities. We consider two types of evaluation: a metrics-based evaluation that focuses on the ESMF Product, and a science impacts evaluation.

7.1. Product Evaluation

The success of the ESMF Product can be evaluated partly through adoption, quality, usability, performance, portability, and other software metrics. It is important to establish adequacy in these areas for two reasons. First, some of the goals of ESMF are expressed directly through these metrics; for example, software reuse is expressed through adoption metrics. Second, a usable product is a prerequisite for achieving the science goals of the ESMF. A sample of product evaluation metrics follows:

**ADOPTION METRICS:**
- Number of groups running ESMF in a production (research, operational) system
- Number of groups running ESMF in any system
- Number of multi-user computers with ESMF installed as a system library
- Number of registered users or code accesses

**QUALITY METRICS:**
- Test coverage
- Number of unit and system tests
• Number of bugs reported by users; number of bugs closed

**USABILITY METRICS**
• Number of support requests; number of support requests closed
  • Availability and quality of documentation

**PERFORMANCE AND PORTABILITY METRICS**
• Number of platforms supported
  • % overhead in time to completion

In 2007 ESMF introduced a Metrics page on its website that captures many of the metrics cited above.

### 7.2. Science Impacts Evaluation

The science goals expressed in Section 4 concern increased collaboration across the community, and the freer exchange of code and ideas. The best indicator here is likely how many model components and integrated modeling systems have evaluated and adopted ESMF. In the long term, it may also be telling to look at how many science teams have formed around new applications based on ESMF components.
8. Appendix A: Glossary

**Application Integration Project** A team of developers working with one or more applications to implement and test science and other capabilities, assimilate ESMF, and optimize for performance. As appropriate, these teams may also develop and optimize application-specific capabilities within the ESMF software and assist with framework validation. There are multiple Application Integration Projects associated with ESMF, each managed by an Application Integration Project Lead or Manager.

**Application Integration Project Lead** An individual tasked with coordinating or managing the development and validation of one or more ESMF-based science applications.

**Application Programming Interface (API)** The set of method names and corresponding arguments that form the user interface to a software package.

**assimilated contribution** Code contribution that is incorporated into the ESMF reference implementation. Assimilated contributions must satisfy ESMF requirements and are supported by the Core Team.

**Change Review Board (CRB)** The interagency group that sets development priorities for the ESMF implementation being developed by the Core Team.

**Core Team** The Core Team is comprised of the development effort in NCAR CISL, plus others who can be line managed by the Core Team Manager. Core Team responsibilities include requirements management, design, implementation, testing, user support and training, and maintenance of the ESMF software and associated collaboration infrastructure, such as the ESMF website and central repository.

**Core Team Manager** Line manager of the Core Team, located in NCAR CISL.

**Development Project** Research effort external to the Core Team that contributes to development of the framework.

**drop contribution** Code contribution that is “dropped” into the ESMF contributions repository and made publicly available. Drop contributions are minimally supervised and not supported by the Core Team.

**ESMF Project** The entity that develops and manages the ESMF Product.

**ESMF Product** The ESMF Product includes the ESMF application interface, reference implementation and documentation; associated maintenance and testing, support and training; and a web-based collaboration environment that allows ESMF staff, sponsors, and customers to archive and exchange information.

**Executive Management** ESMF Executive Management provides high-level scientific and technical guidance, advocacy, and evaluation. It is comprised of the Executive Board, Interagency Working Group, and Review Committee.

**Joint Specification Team (JST)** The group of hands-on science developers who interact closely with the Core Team to define requirements, develop a viable framework implementation and
specification, and evaluate and provide feedback on the ESMF software. Multiple Application Integration Teams are represented on the JST. Application Integration Team Leads or Managers are represented on the Change Review Board.

**management overhead** Overhead (staff and resources) required for ESMF project oversight and administration.

**reference implementation** The ESMF API implementation developed by the Core Team. There may be other implementations of the API.

**Working Project Management** The level of management of the ESMF Project that provides day-to-day oversight of development and user support.
## 9. Appendix B: Schedule of Meetings

<table>
<thead>
<tr>
<th>MEETING</th>
<th>PERIOD</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive Board</td>
<td>Yearly</td>
<td>Varies</td>
</tr>
<tr>
<td>Interagency Working Group</td>
<td>Yearly, usually in conjunction with the Executive Board</td>
<td>Washington DC if possible</td>
</tr>
<tr>
<td>Change Review Board</td>
<td>Semi-annually</td>
<td>Teleconference</td>
</tr>
<tr>
<td>Core Team</td>
<td>Weekly</td>
<td>Teleconference</td>
</tr>
<tr>
<td>Core Team Ticket Review</td>
<td>Weekly</td>
<td>Teleconference</td>
</tr>
</tbody>
</table>
10. Appendix C: Acronyms

API Application Programming Interface
CESM Community Earth System Model
CISL NCAR Computing and Information Systems Laboratory
CSEG CESM Software Engineering Group
CRB Change Review Board
DARPA Defense Advanced Research Projects Agency
DoD Department of Defense
DOE Department of Energy
ESMF Earth System Modeling Framework
GFDL NOAA Geophysical Fluid Dynamics Laboratory
HPC High Performance Computing
HPCS High Productivity Computer Systems
IPF Industry Partners Forum
IAWG ESMF Interagency Working Group
JEDI Joint Effort for Data assimilation Integration
JPL NASA Jet Propulsion Laboratory
LANL Los Alamos National Laboratory
MIT Massachusetts Institute of Technology
NASA National Aeronautics and Space Administration
NCAR National Center for Atmospheric Research
NCEP NOAA National Centers for Environmental Prediction
NOAA National Oceanic and Atmospheric Administration
NSF National Science Foundation
NUOPC National Unified Operational Prediction Capability
SCRIP Spherical Coordinate Remapping and Interpolation Package
WRF Weather Research and Forecasting Model
11. References


[6] National Aeronautics and Space Administration Cooperative Agreements, number NCC5-623 (Part I), NCC5-625 (Part II), GSFC-CT-3 (Part III)


