Contents

1 SCIENTIFIC/TECHNICAL/MANAGEMENT 1-1
1.1 Background 1-2
1.2 Objectives and Expected Significance 1-4
1.2.1 Objectives 1-4
1.2.2 Expected Significance 1-4
1.3 Technical Approach and Methodology 1-4
1.3.1 Interoperability Track 1-5
1.3.2 Integration Track 1-8
1.4 Perceived Impact to State of Knowledge 1-9
1.5 Relevance to Element Programs and Objectives in the NRA 1-10
1.6 Work Plan 1-10
1.6.1 Key Milestones 1-11
1.6.2 Activities Contingent on Pending CMAC Proposal 1-12
1.6.3 Management Structure 1-13
1.6.4 Contributions of Principal Investigator and Key Personnel 1-13
1.6.5 Risk Management 1-14
1.6.6 Management of Source Code and Information 1-14
1.7 Acronyms 1-15
2 REFERENCES AND CITATIONS 2-1
3 BIOGRAPHICAL SKETCH 3-1
3.1 Principal Investigator 3-1
3.2 Co-Investigator(s) 3-3
3.3 Collaborator(s) 3-2
4 TABLE OF PERSONNEL AND WORK EFFORT 4-3
5 CURRENT AND PENDING SUPPORT 5-4
6 BUDGET JUSTIFICATION: NARRATIVE AND DETAILS 6-8
6.1 University of Colorado Budget Narrative and Details 6-8
6.2 NASA Goddard Space Flight Center Budget Narrative and Details 6-10
6.3 JPL Budget Narrative and Details 6-13
7 FACILITIES AND EQUIPMENT 7-15
7.1 University of Colorado 7-15
7.2 NASA Goddard Space Flight Center 7-15
7.3 JPL 7-15

1 Scientific/Technical/Management

Multi-component, coupled models are essential tools for the study of the Earth as a complex, interconnected system, the prediction of its future states, and planning for mitigation and adaptation in response to climate change. Component interoperability has become increasingly important in the development and use of such modeling systems. Interoperability allows for the independent development of components by specialists, which can then be shared across centers to promote knowledge transfer and resource efficiency. Components can be more easily tested and evaluated when modular, clear interfaces allow for controlled experimentation.

Coupled models at NASA centers are not yet interoperable. The GEOS-5 modeling effort at NASA GSFC (Molod et al. 2012) and the ModelE team at NASA GISS (Schmidt et al. 2014) are engaged in independent, though complementary research efforts. The ModelE team focuses on problems in climate research and projections, while the GEOS-5 effort emphasizes seasonal and inter-annual prediction, combining their prognostic model with advanced data assimilation schemes to improve chemistry and aerosol forecasts and produce reanalysis datasets. While there have been successful technology transfers, including the adoption in ModelE of the finite volume atmospheric dynamical core developed at GSFC, and the adoption of the ModelE MATRIX aerosol code by GSFC, such transfers have been time-consuming and *ad hoc*. This prevents the teams from leveraging each other's work; for example, GISS developers cannot easily test the behavior of their atmospheric physics with a data assimilation package for predictions at shorter time scales. The exchange of components is hindered by the absence of a shared framework. GEOS-5 uses the Earth System Modeling Framework (ESMF; Hill et al. 2004) extensively, with a set of additional rules and templates developed at GSFC called the Modeling Analysis and Prediction (MAP) Layer[1]. ModelE has begun to incorporate ESMF as well, under previous funding from NASA CMAC (NASA NNX12AP51G; PI: DeLuca; $700,000; 9/1/12-2/28/15), but so far only atmosphere and mixed layer ocean components have been wrapped. Rather than MAPL, ModelE uses a similar set of ESMF-based rules and templates called the National Unified Operational Prediction Capability (NUOPC) Layer (Theurich, 2014). The NUOPC Layer has been implemented in a number of federal and community codes, including the Community Earth System Model (CESM), Navy global and regional models, the HYbrid Coordinate Ocean Model, and the NOAA Environmental Modeling System (NEMS).

We propose to improve the interoperability of the components of GEOS-5 and ModelE, and to further increase the interoperability of these models with other agency and community codes. To do this, ModelE will be further modularized, and the MAPL and NUOPC Layers reconciled. While scientific compatibility of components cannot be guaranteed, we will aim for technical interoperability – no manual code changes required to have the components execute in both systems. This will establish a foundation for future coordination of NASA Earth system modeling activities across NASA centers and the broader community.

Plans for interfacing MAPL and NUOPC will be developed in the context of desired future capabilities for model infrastructure at NASA, including support for extremely high resolution, scalable model configurations on emerging computer architectures. Two demonstrations of capability using GEOS-5 and ModelE are planned (with a third contingency, described in the work plan). The first will leverage work completed in ModelE under the CMAC award, which involved modularization of an ocean biology component. This will be wrapped as an ESMF

[1] See https://modelingguru.nasa.gov/servlet/JiveServlet/download/1118-9-1053/MAPL_Intro.pdf

component and instrumented to run in both ModelE and GEOS-5. The second demonstration will wrap the ModelE atmosphere, then the ModelE physics, as an ESMF component and test these within the GEOS-5 environment, including its data assimilation capability. Given that ModelE and GEOS-5 share the same dynamical core, the ESMF compliant atmospheric model and physics component will enable extensive data assimilation capabilities developed at GMAO in a model configuration that is equivalent to the standard ModelE currently run at GISS. This will give GISS near real time forecasting capabilities, and allow ModelE to participate multi-model ensembles in support of NASA field campaigns. Moreover, post-campaign mini-reanalyzes based on ModelE physics will allow a more in-depth utilization of in-situ and remotely sensed measurements collected during the campaign for diagnosing and improving physical parameterizations in the model.

A parallel proposal track will focus on updating the MAPL software for current ESMF capabilities (and vice versa) and distributing and supporting MAPL capabilities through the ESMF team. The goal of this activity is to bring MAPL approaches into the ESMF mainstream, and to present the NUOPC and MAPL rules and templates to the broader community in a unified manner.

1.1 Background

This work will build upon previous awards, collaborations, and achievements. ESMF, initiated in 2002 under a set of three NASA Cooperative Agreements, is the main technology through which interoperability of modeling components is being implemented in the U.S. The ESMF framework is high performance software for building and coupling Earth system models. It defines a set of data structures (e.g. gridded and coupler components, representations for physical fields, import and export states for passing fields between components) and an overall methodology for creating coupled modeling systems. However, it does not prescribe many aspects of model behavior, including how components organize initialization sequences, satisfy their input requirements, or execute run sequences. This flexibility enabled multiple organizations to adopt the ESMF software, but limited the interoperability of ESMF components.

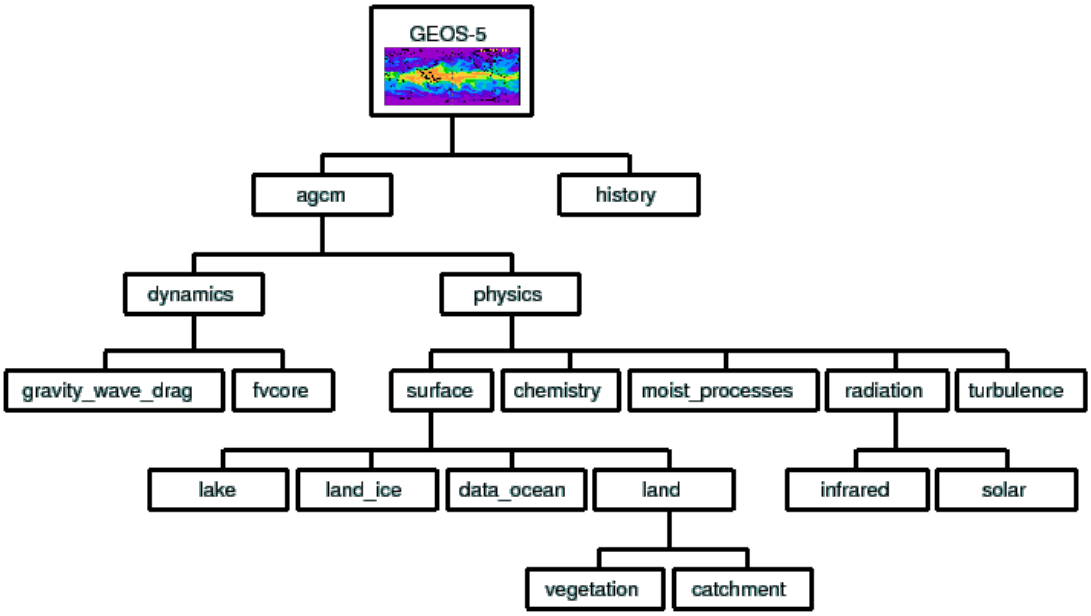


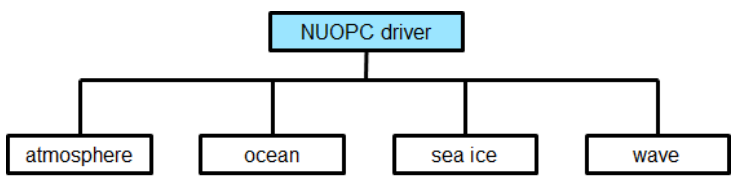
Figure 1 The GEOS-5 hierarchical architecture, based on ESMF and the MAPL interoperability layer.

To achieve practical interoperability, additional rules about how components behave needed to be imposed, and this need motivated the development of "usability" layers for ESMF.

Scientists at NASA GSFC developed an ESMF usability layer in the process of implementing the GEOS-5 model. In GEOS-5, ESMF component interfaces wrap large scale components (e.g. atmosphere, ocean), their subcomponents (e.g. gravity wave drag), and computational elements such as I/O, with the components falling into a natural hierarchy (Figure 1). This development was funded under the NASA Modeling Analysis and Prediction (MAP) program and is called the MAP Layer, or MAPL. MAPL has been used mainly and extensively within GSFC on the GEOS-5 atmospheric GCM. MAPL is also present in the GOCART aerosol component used operationally at NCEP for dust forecasting (Ginoux et al. 2001). While GOCART internally relies on MAPL infrastructure, currently its coupling to the NOAA Global Forecast System does not exercise any MAPL functionality.

As ESMF matured, several of the key classes used from MAPL were transitioned into ESMF, including configuration parameters (Config, 2004) and observational data streams (Location Streams or LocStreams, 2008). The ESMF team completely reworked its data structures and representation of grids, introducing a flexible and fast parallel finite element mesh framework as its computational engine. The range of grids supported, flexibility of data structures and machine representation, and available functionality in ESMF began to extend beyond that in MAPL.

Starting in 2010, modeling leads from Navy and NOAA operational weather prediction centers and a set of research partners initiated a project called the National Unified Operational Prediction Capability, or NUOPC[2]. The NUOPC team developed a usability layer based on the updated data structures and design of ESMF.



ESPS Models:

- ModelE
- Navy COAMPS
- Navy NavGEM
- Community Earth System Model
- HYCOM and MOM5 oceans
- NOAA Environmental Modeling System

Figure 2 The NUOPC effort has focused on standardizing major model components across multiple modeling systems, collectively called the Earth System Prediction Suite or ESPS.

Like MAPL, the NUOPC Layer introduced additional constraints and generic components to increase interoperability. It includes coupling conventions and generic representations of modeling system elements - drivers, models, connectors, and mediators. NUOPC drivers and models can be understood in the usual way; connectors handle simple data transformations and transfers, and mediators implement field merges and custom coupling code. In some cases, the generic components may be used without modification; in others, user code is added at clear specialization points. Calls to NUOPC methods mainly relate to component creation and

[2] http://www.nws.noaa.gov/nuopc/

sequencing, and may be mixed with calls to ESMF time management, grid remapping, and other methods.

Unlike MAPL, a hierarchical representation of components was not a first consideration in its design. The NUOPC Layer and its adoption efforts focused on a set of major components: atmosphere, ocean, wave, and sea ice, as shown in Figure 2. The NUOPC Layer is being implemented in a number of community and federal models, and the collection of NUOPC-compliant components is collectively being called the Earth System Prediction Suite (Theurich et al. 2015).

1.2 Objectives and Expected Significance

There are two types of objectives proposed. The first type has to do with creating interoperability between MAPL and NUOPC components, and the second concerns the integration of MAPL with ESMF and its distribution and support by the ESMF core team.

1.2.1 Objectives

Interoperability objectives:

OBJ1. Enable MAPL and NUOPC components and sub-components to be interoperable (i.e., be capable of executing without manual code changes in either package).

OBJ2. Advance modularization and ESMF adoption in ModelE.

OBJ3. Demonstrate interoperability of MAPL and NUOPC using examples from GEOS-5 and ModelE.

Integration objectives:

OBJ4. Merge several ESMF and MAPL capabilities to leverage features and updates in both, including observational data stream methods and grid remapping.

OBJ5. Complete migration of MAPL to the ESMF distribution, including documentation review, addition of unit and system regression tests, and integration with the build.

We anticipate that these two types of objectives will be realized as two concurrent activity tracks.

1.2.2 Expected Significance

Merging the MAPL and NUOPC conventions for implementing ESMF will enable NASA GISS and GSFC to share model components more easily, and will encourage greater knowledge sharing and collaboration between the centers.

Successful completion of the proposed work will bring NASA ModelE and GEOS-5 into a broader pool of interoperable, ESMF-based systems that includes CESM, HYCOM, Navy global and regional models, MOM5, and the NOAA NEMS model. This pool of coupled models and components is referred to as the Earth System Prediction Suite (ESPS). This suite is a direct response to National Academy and other reports that have called for common modeling infrastructure to improve U.S. modeling capabilities (NRC 1998, NRC 2001, NRC 2012, Rood et al. 2000). Bringing MAPL's conventions for hierarchical component construction into the mainstream ESMF distribution will provide a path for the wider community to exchange components at finer granularity than the ESPS currently addresses.

We expect that enabling MAPL and GEOS-5 to leverage additional classes in ESMF will improve the infrastructure capabilities available to NASA modelers, specifically in the area of high performance grid remapping.

1.3 Technical Approach and Methodology

The two tracks – interoperability and integration – outlined in the Objectives section are described in more detail here. For the interoperability track, we first review the relationship between MAPL and the NUOPC Layer, in terms of the scope and behavior of each software package. Plans for further analysis and the proposed implementation are described next, followed

by the approach to validation. Two demonstrations will show the new capabilities in practice. On the integration track, we describe the elements of MAPL that will be updated with current capabilities from ESMF, and areas in ESMF that are likely to be improved with additional features from the MAPL implementation. The plan for modifying the software distribution of MAPL so that it is bundled with ESMF is outlined. This is a significant part of the effort since the external user supporting organization for MAPL will become the University of Colorado team, and for broad distribution with ESMF the software will require additional testing, documentation, and support.

1.3.1 Interoperability Track

We plan to ensure interoperability in two directions: using MAPL components in NUOPC systems, and using NUOPC components in MAPL systems. The intent is to automate the process to the extent possible, so that future conversions can be done quickly and easily.

Interoperability of MAPL and NUOPC components (OBJ1) An analysis of the similarities and differences in the MAPL and NUOPC software was performed by the NUOPC development lead (Gerhard Theurich) and MAPL development leads (Max Suarez, Arlindo da Silva) during fall 2013. The main finding was that the systems are fundamentally similar in structure and capabilities, and are highly compatible. The feature that most contributes to this compatibility is that neither NUOPC or MAPL introduce new component data types - both are based on gridded and coupler components that are native ESMF data types (ESMF_GridComp and ESMF_CplComp). To generate NUOPC- compliant ESMF components, NUOPC itself is not required. They could be generated by MAPL. The same is true of MAPL-compliant components.

There are differences in the level of componentization between GEOS-5 and the coupled models that are being implemented with the NUOPC Layer. The initial focus of the NUOPC project is establishing conventions for a limited set of large-scale model components (atmosphere, ocean, ice, wave). These NUOPC target applications can be considered coarse-grained component systems. In GEOS-5, which is more fine-grained, ESMF wrappers extend to a large number of nested sub-components. These represent processes including atmospheric dynamics, radiation, convection, chemistry, and microphysics. The two kinds of target applications – coarse and fine grained - can be implemented using either MAPL or NUOPC. However, there are ways in which NUOPC and MAPL are specialized for their target applications.

In NUOPC, initialize, run, and finalize sequences are parameterized so that drivers – parent components that direct a set of child components - are generic. Here, generic means that the same driver can be used without modification for many different coupled models. Custom coupling code is located in a mediator component. In NUOPC, the mediator can be on a separate set of processors than the model components whose interactions it describes. Some modeling systems, such as CESM, view the flexibility to have the mediator on a separate processor set as a requirement.

In MAPL, driver code is not necessarily separated into a specialized component. Both driver code and mediator code may be included in-line in a model component parent which effectively serves as such a driver. A limitation of this approach is that the mediator must be on the same set of processes as the components that it couples. However, relative to NUOPC, the MAPL approach reduces the number of components and phases that must be created for complex sequences, and makes it easier to have computations interspersed with the driver code.

Someone using the NUOPC software could replicate the MAPL approach of intertwining driver, mediator, and model code by not creating separate mediator and driver components. An additional query call would need to be written for NUOPC that would enable a parent model

component to get state information about its children. This would allow the parent model component to write driver and mediator sequences as is done in MAPL.

The intrinsically hierarchical model of MAPL also allows for matching of imports and exports across a layered network of subcomponents. Export fields are swept up the hierarchy, so that a parent aggregates all of its children's exports. Unsatisfied imports are also swept up the hierarchy to see if they can be matched with an export field at a higher level, or ultimately imported from an external data file. Such flexibility allows for easy replacement of active components by data-driven, passive components. NUOPC does not yet have such functions but could support them.

We have considered three approaches to implementing the necessary changes: 1) changing the MAPL and NUOPC source code so that the components that they produce satisfy the requirements of both usability layers; 2) implementing static source code translation in order to translate one type of component into the other; and 3) implementing a wrapper or run-time translator that converts the data structures and behaviors of one type of component to the other during execution. To the extent possible, we will try to modify MAPL and NUOPC component methods so that they produce compatible components and additional tools or procedures are not required. However, this has limits because of the large existing user bases and established requirements for compliance in both usability layers. A first step will be to prototype solutions. There is already a simple NUOPC Layer prototype that shows how this software handles nested components. We will extend the prototype to show MAPL-like behaviors, including the sweep of export fields up the hierarchy and the sweep of unsatisfied import fields down the hierarchy. A second step will be to introduce a level of indirection into MAPL so that the component creation and related methods in MAPL can call either the original GSFC implementation or an underlying NUOPC implementation. This would be tested in a more advanced prototype drawn from a multi-component GEOS-5 configuration. This step would establish whether the behaviors of MAPL could be replicated or approximated with the NUOPC Layer, and whether the performance and memory footprints were comparable. It is effectively an implementation of the run-time translator approach. We expect several iterations of the prototype at this stage exploring and refining behavior. Ideally, we would want NUOPC to be able to replicate all MAPL behaviors with no penalty in performance, memory, or code complexity, with any changes to the definitions of NUOPC compliance backward compatible. The last steps would require an assessment of how far from this ideal case the prototypes were able to get, how much change each team would be willing to tolerate, and whether static source code transformations or other approaches are needed for the final solution. Activities related to NUOPC, MAPL and static code transformation through the Cupid Integrated Development Environment are proposed in a pending CMAC proposal (see Section 1.4), and if that funding is awarded the Cupid work may have bearing on the solutions here.

A key question is how to verify results. Several tools are available to facilitate development and compliance verification of NUOPC-compliant components and coupled models. These include the command line-based NUOPC Compliance Checker and Component Explorer, both described in the *NUOPC Layer Reference* (Theurich, 2014). There are no equivalent tools on the MAPL side.

The NUOPC Compliance Checker is an analysis tool that intercepts component actions during the execution of a modeling application and assesses whether they conform to standard NUOPC Layer behaviors. It is linked by default to every application that uses ESMF and can be activated by setting an environment variable. When deactivated, it imposes no performance penalty. The Compliance Checker produces a compliance report that includes, for each component in an application, information such as checks for presence of the required initialize, run, and finalize

phases, correct timekeeping, how fields are passed between components, and the presence of required component and field metadata.

The Component Explorer is a run-time tool that analyzes a *single* model component by acting as its driver. The tool offers a way of evaluating the behavior of the component outside of a coupled modeling application. It steps systematically through the phases defined by the component and performs checks such as whether required makefile fragments are provided, whether a NUOPC driver can link to the component, and whether error messages are generated if the required inputs are not supplied. For additional information, the Compliance Checker can be turned on while the Component Explorer is running. A test of NUOPC compliance is running the candidate component in the Component Explorer and ensuring that it generates no warnings from the Compliance Checker when it is turned on.

To validate our approach, components that were originally developed under MAPL will be tested using NUOPC compliance checking. If possible, we will work to merge the definitions of compliance so that its definition also covers MAPL. However, if that is not possible, we will verify that components that were originally developed under NUOPC can operate in MAPL through their successful execution in GEOS-5.

Advancing ESMF adoption in ModelE (OBJ2) Under a previous NASA CMAC award, the ModelE atmosphere and mixed layer ocean were wrapped as NUOPC-compliant components. Current work under a NASA MAP award (NASA NNX11AL82G; PI: DeLuca; $1,259K) is extending this to GISS ocean components. These components are being operated in a development system driven by a NUOPC driver and coupled using a mediator. The tasks here will be to continue modularization of the model. In particular, we will test ModelE with the NUOPC version of HYCOM that is being used in Navy, CESM, and NCEP codes. A goal of ESPS is to support this kind of exchange without code change. Next steps will extend ESMF components to the ice sheet model, to the atmospheric model physics, and to sea ice.

Demonstrations (OBJ3) Two demonstrations of interoperability are planned.

1. A ModelE demonstration will employ an ocean biology component that is most naturally positioned as a subcomponent of an ocean model component. This ocean component was recently modularized as part of a NASA CMAC award. The ocean biology component had straddled the divide between ocean and atmosphere, due, for example, to carbon gas exchange and to links between radiation and chlorophyll. An objective of creating a separate ocean biology component with a distinct interface was to enable it to communicate with the multiple ocean options in ModelE. These include the HYbrid Coordinate Ocean Model (HYCOM), the Russell ocean model (Russell et al. 1995, 2000, Liu et al. 2002) and the upcoming GISS Ocean 2 (GO2). The CMAC activity produced a distinct ocean biology component with a prototype ESMF interface. The goal here will be to build on that work, and define a component interface for an ESMF-based ocean biology subcomponent that can be run in either the GEOS-5 or ModelE architecture with the goal of no manual code changes. This will demonstrate the achievement of OBJ1 and OBJ2.
2. A second demonstration will involve wrapping first the ModelE atmosphere, then the atmospheric physics package, as an ESMF component and integrating it in the GEOS-5 atmospheric data assimilation system. The primary goal is to provide an instance of the GEOS-5 atmospheric GCM where all physics parameterizations derive from ModelE, and yet retain the same dynamical core currently shared between GEOS-5 and ModelE. The advantage of this formulation is that it preserves all the data assimilation interfaces in GEOS-5, directly enabling mature data assimilation algorithms used at GMAO for near real time forecasting and the production of historical reanalyzes (e.g., MERRA, Rienecker et al. 2011.) For this proposal we will

produce a mini-reanalysis for the SEAC4RS field campaign (August-July 2013)[3], including aerosol microphysics from the MATRIX package (Bauer et al. 2008), compare it to an existing GEOS-5 based mini-reanalysis and evaluate it using field campaign data. Such an exercise will demonstrate the power of interoperability for enabling detailed process studies in a data assimilation constrained environment.

1.3.2 Integration Track

The MAPL and NUOPC teams will continue to seek opportunities to leverage capabilities across the codes. NASA GSFC code libraries are already leveraged in the ESMF code to represent observational data streams (the Location Stream class) and for configuration software that offers more flexibility than Fortran namelists (the Config class). MAPL relies on data types and functions of ESMF code throughout. A new opportunity to leverage code may include accessing ESMF interpolation weight generation functions within MAPL.

Merging ESMF and MAPL Capabilities (OBJ4) The three functional areas that we will focus on when merging ESMF and MAPL capabilities are 1) observational data streams (Location Streams or LocStreams), 2) exchange grids (XGrids), an approach to conservative regridding, and grid remapping functions.

LocStreams are used to represent the locations of a set of data points, and are a central data structure in MAPL and GEOS-5. An early version of the class is also available in ESMF, migrated over from the original GSFC implementation through the efforts of NASA developers working in partnership with the ESMF team. In the data assimilation world, LocStreams can be thought of as a set of observations. Their locations are generally described using Cartesian (x, y, z), or (lat, lon, height) coordinates. There is no assumption of any regularity in the positions of the points, and no connection information is stored. To make the concept more general, the locations for each data point are represented using a construct called *keys*. Keys can include other descriptors besides location, including a second set of coordinates. Common operations involving LocStreams are similar to those involving grids. In data assimilation, for example, there is an immediate need to redistribute data between fields defined on LocStreams, perform halo region exchanges, and gather or scatter fields defined on a LocStream from/to a root processor.

Exchange grids are an approach to conservative grid remapping developed at GFDL[4]. The exchange grid is constructed by taking the union of the cell vertices in the “parent” grids to be remapped. Each exchange grid cell is associated with one cell on each parent grid, and fractional areas with respect to the parent grid cells. Data being transferred from one parent grid to the other is first interpolated onto the exchange grid using one set of fractional areas; and then onto the receiving grid using the other set of fractional areas. Exchange grids offer other conveniences, including a means to resolve coastlines. When there are masks defined by land, ocean, and sea ice components, and these and the atmosphere model may be on different grids, the exchange grid represents the total available information about location and ownership of grid cells and through component precedence rules (e.g., unclaimed cells are ocean cells) can reconcile cells that may be owned by multiple components, or no components.

In MAPL, exchange grids and conservative grid remapping are implemented using LocStreams, and operations are executed through LocStream methods. The approach requires the off-line pixilation of some grids to get their cell areas. Another MAPL class, called

[3] http://gmao.gsfc.nasa.gov/projects/SEAC4RS/
[4] http://www.gfdl.noaa.gov/~vb/pdf/xgridpaper.pdf

Horizontal Transforms (HorzTransforms), includes non-conservative grid remapping methods. However, it is not a general capability, and supports only specialized transforms for particular pairwise grid remapping, such as between cubed sphere and lat-lon grids.

ESMF implements exchange grids differently, as a separate class based on a 3D mesh. This 3D mesh is the core data structure in the parallel finite element framework that is the central engine for grid remapping in ESMF. All field discretizations - observational data streams, logically rectangular grids, and meshes - are converted into the common representation before remapping. This approach results in a high performance capability that can handle virtually all grid pairings, without requiring the off-line pixilation step.

Merging these capabilities into a shared underlying layer is possible but challenging, since care must be taken to preserve the accuracy of specialized MAPL HorzTransforms and the performance and flexibility of ESMF grid remapping. In addition, the process should be non-disruptive to development efforts at NASA.

The first step will be to update MAPL so that it uses the most current ESMF version. Next we will create an additional level of indirection, and enable the MAPL method interfaces to call either the original implementation of LocStreams or the ESMF version of LocStreams, We will work through the LocStream methods incrementally with the goal of enabling all calls to LocStreams within MAPL to go through the ESMF implementations of LocStreams and exchange grids. For critical operations including conservative remapping, the two implementations will need to be evaluated side by side for performance, memory footprint, and accuracy in the GEOS-5 code. This process is likely to require changes to behavior and additions of functionality to the LocStream implementation on the ESMF side. At the end of the process, it may be possible to remove the original LocStream class from MAPL and use the ESMF interfaces within MAPL and GEOS-5 instead.

A next step will be to investigate whether ESMF non-conservative grid remapping methods are sufficiently accurate to replace some or all of the MAPL HorzTransforms. If not, we will explore whether the algorithms could be introduced into ESMF. Ideally, these methods could also be removed from MAPL and called as ESMF methods.

MAPL in the ESMF distribution (OBJ5) A version of MAPL was introduced into the ESMF software distribution, and integrated into the build system and regression tests under a current MAP award (NASA NNX11AL82G; PI: DeLuca; $1,259K). Additional work is required to fully support the software as part of ESMF. Tasks include completing unit and system tests covering the MAPL functionality, and reviewing and completing MAPL documentation. This task will be ongoing throughout the project, and will focus initially on component constructs and other classes that are not likely to be merged with ESMF.

1.4 Perceived Impact to State of Knowledge

NASA initiated the ESMF project because a critical mass of community leaders felt that having a software framework would enable NASA centers and the broader modeling community to work more effectively together, share system components among organizations, and better address questions that are at the heart of NASA's programs: Can we understand and predict changes in the Earth system using models combined with NASA data? Can we begin to apply those understanding and predictions to formulate and improve approaches to mitigation and adaptation? The solutions to questions of such global scale must be addressed with a foundation of organizational partnerships. NASA had the programmatic foresight to see that a prerequisite to creating these partnerships is creating standards-based modeling and data systems using technical infrastructure such as ESMF. The modelers at GSFC used ESMF to construct GEOS-5, a modeling system that has been used to simulate climate variability on a wide range of time scales, from synoptic time scales to multi-century climate change. This proposal builds on that original investment, a subsequent MAP award that introduced MAPL into ESMF and advanced

ESMF I/O, grid remapping, and other capabilities. More recently, it builds on the CMAC award that funded the incorporation of ESMF into ModelE.

The proposed work would bring the individual advances of previous awards into a broader and more synergistic context. Closer partnership between the ModelE and GEOS-5 modeling teams would create opportunities for both organizations to advance their capabilities. There have been productive exchanges between the organizations in the past; a notable example is the ModelE adoption of the finite volume dynamical core developed at Goddard GSFC. With the current proposal, we are setting up infrastructure that will enable these centers to exchange both major components and sub-components. Using the framework rather than merging the systems allows for independent but coordinated development. In addition to providing data assimilation capabilities to ModelE, GEOS-5 configuration based on ModelE physics may provide a very useful contribution to GMAO's hybrid ensemble/variational data assimilation system: ensemble members based on an entirely different physical parameterization. It would also allow GISS and GMAO to more closely collaborate on forecasting and post-mission data analysis of NASA field campaigns.

1.5 Relevance to Element Programs and Objectives in the NRA

The proposed work directly addresses the three elements described in section 1.3.2 of the solicitation, the research theme *Earth System Modeling Framework for MAP-supported modeling efforts*. Specifically, the proposal addresses these elements, shown in italics, as follows:

- *Efforts to continue incorporation of MAPL within the base ESMF implementation, including documentation of MAPL software, development of tests to confirm correct operation on all computational platforms on which ESMF runs, and unification of the NUOPC and MAPL usability layers.*
  The main result of this work will be the interoperability of MAPL and NUOPC based components. It includes finishing the process of bundling the MAPL software with the ESMF distribution, by adding the necessary regression tests and improving documentation (once it is clear what MAPL interfaces will remain after an integration process).
- *Development of the base ESMF implementation to expand its utility in ways that are demonstrably advantageous to MAP-supported ESMs.*
  The merger of underlying ESMF and MAPL capabilities (LocStream, exchange grid, grid remapping), and the subsequent evaluation of the results, will result in more flexible and high performance grid remapping options for GEOS-5. It will also result in updates and features implemented in MAPL being migrated back to the ESMF distribution.
- *Efforts to enhance the ESMF compliance of MAP-supported ESMs.*
  The proposed work includes further modularizing ModelE and wrapping additional components (sea ice, ice sheet, atmospheric physics) as ESMF components and sub-components.

1.6 Work Plan

Development will be undertaken following the community-based, distributed practices established by the ESMF project and described in the *ESMF Developer's Guide*.[5] A key element of the infrastructure development strategy is exhaustive testing (the ESMF/NUOPC test suite numbers 6500+ unit and system tests) and nightly regression tests on about 30 platform and

[5] http://www.earthsystemmodeling.org/documents/dev_guide/

compiler/library combinations. Development priorities are set by a multi-agency ESMF Change Review Board (CRB) that coordinates resources for code releases and milestone deliveries. Day-to-day interactions among developers and modeling group partners are coordinated via email, telecons and tools for sharing desktop views. Infrastructure code is publicly downloadable under an open source license. New additions to the ESMF infrastructure software will be vetted for compatible license terms.

Phase 1 Several of the activities proposed can proceed in parallel. On the interoperability track, developing an interoperability path for MAPL/NUOPC will start with additional analysis and the joint creation of a preliminary design document and development roadmap. This will include a testing and verification strategy that includes compliance checking of the resulting components. While this is going on, the ModelE team will proceed with improving the modularity of ModelE and wrapping the ocean biology component with ESMF in preparation for the related demonstration. The University of Colorado team will initiate a NUOPC-based prototype of nested components similar to the MAPL implementation in order to better understand how MAPL and NUOPC implementations can align. On the integration track, JPL and GSFC staff will work together to update MAPL and GEOS-5 to the latest ESMF release. They will also introduce a level of indirection into the MAPL code so that its current functionality is retained and usable while capabilities merged over from ESMF can be incrementally introduced and evaluated. Key milestones at the end of this first phase are the unification of the Location Stream implementation between ESMF and MAPL, and a first prototype of an interoperable MAPL and NUOPC component, verified using the NUOPC compliance checking tools and execution in GEOS-5.

Phase 2 is more demonstration and product focused. The collaboration will be working to pull together multiple threads of the work – the more modular ModelE, merged underlying libraries in MAPL and ESMF, and the component-level MAPL/NUOPC interoperability prototype – to deliver the ocean biology component crossover demonstration and the demonstration of the GISS atmosphere and atmospheric physics in GEOS-5. The collaboration should have a good idea at this point which capabilities from MAPL, ESMF and NUOPC will be merged and which need to be retained as separate interfaces. This will guide the final integration of MAPL into the ESMF distribution. The addition of documentation and tests will be ongoing throughout the project, but the preparation of the final product for the broader ESMF user base, which will require stepping up documentation and testing, will be deferred until the approaches implemented on the interoperability and integration tracks have demonstrated their viability.

1.6.1 Key Milestones

The milestones listed below are derived from the proposal objectives. The milestones that involve development on the ESMF code base, including NUOPC and MAPL, will be coordinated with the ESMF CRB to ensure that they are addressed following this schedule.

The estimated start date is in FY16-1Q.

- FY16-Q3: Design document, implementation plan, and tests identified for MAPL/NUOPC unification.
- FY16-Q4: MAPL/GEOS-5 upgraded to ESMF v7.
- FY17-Q1: Proof-of-concept unification of MAPL/NUOPC infrastructures including merge of MAPL component and NUOPC component concepts (includes NUOPC nested prototype)
- FY17-Q3: Unified MAPL/NUOPC layer integrated into GEOS-5 - prototype.
- FY17-Q4: Unified Location Stream and exchange grid data structures in ESMF and MAPL.
- FY18-Q1: Demonstrate modified GEOS-5 coupled with external component through NUOPC (GISS atmosphere component)

- FY18-Q3: Completion of interoperable ocean biology component demonstration.
- FY19-Q1: Completion of GISS atmospheric physics component with GSFC data assimilation demonstration.
- FY19-Q3: Delivery of ESMF source code release with combined MAPL and NUOPC support.

1.6.2 Activities Contingent on Pending CMAC Proposal

A proposal submitted to the 2015 NASA CMAC solicitation by PI Rocky Dunlap of the ESMF team includes activities focused on the unification of the NUOPC Layer and MAPL. It overlaps with tasks in this proposal that are necessary to both activities. This section describes anticipated changes to the work plan if that CMAC proposal is funded.

The main focus of the new Dunlap proposal is the continued development of the Cupid Integrated Development Environment (IDE), a graphical interface for analysis, development and training of NUOPC-based codes. Cupid is a plug-in for the popular Eclipse[6] tool, and it allows users to view an outline of the components in the application, their initialize, run, and finalize phases, and their NUOPC compliance status; to see the outline side-by-side with a code editor; to compile and run jobs, to obtain contextual guidance while NUOPC code is being edited; and to generate code needed for NUOPC compliance automatically. Cupid development was previously supported by CMAC funding (under ROSES 2011), in the same project that introduced the NUOPC Layer into ModelE. The new CMAC proposal aims to increase the technical readiness level of the Cupid software, add features, and add new support for GEOS-5. In order to add Cupid support for GEOS-5, additional unification of the MAPL and NUOPC Layers is necessary and was included in the CMAC proposal tasks. The specific objective is to "unify overlapping parts of the MAPL and NUOPC infrastructure layers resulting in a GEOS-5 capable of coupling to NUOPC-based components and applications." The overlapping tasks are related to OBJ1 in this ROSES proposal and the following milestones are needed and included in both proposals:

- FY16-Q1: Design document, implementation plan, and tests identified for MAPL/NUOPC unification.
- FY16-Q2: MAPL/GEOS-5 upgraded to ESMF v7.
- FY16-Q3: Proof-of-concept unification of MAPL/NUOPC infrastructures including merge of MAPL component and NUOPC component concepts.
- FY17-Q1: Unified MAPL/NUOPC layer integrated into GEOS-5 – prototype.
- FY17-Q3: Demonstrate modified GEOS-5 coupled with external component through NUOPC.

The milestone dates are shifted by several months relative to the dates in this proposal due to the earlier start date in the CMAC proposal. These tasks do not cover the integration of underlying MAPL and NUOPC classes described in OBJ4 and OBJ5.

If the CMAC proposal is funded and there are additional resources for performing this set of overlapping milestones, we propose to add an additional demonstration: testing GEOS-5 data assimilation using the GISS model driver and the fully coupled ModelE system. This enables GISS staff to test the new data assimilation capability in the context of the coupled modeling system that they know and understand. We anticipate that the additional modularity and ESMF interfaces introduced into ModelE will facilitate the task. However, there are many uncertainties

[6] https://eclipse.org/

in this task due to the complexity of the fully coupled GISS model and the complexity of GEOS-5 data assimilation, and this demonstration is significantly more difficult than the others that are proposed. The milestone added is:

– FY19-Q3: Demonstrate fully coupled ModelE operating with GSFC data assimilation.

Proposed Timeline of Activities

	Year 1 (2016)				Year 2 (2017)				Year 3 (2018)				Year 4 (2019)			
Task	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
	Phase 1								***Phase 2***							
Design and impl. plan for MAPL/NUOPC	X	X	X													
MAPL and GEOS-5 updated for current ESMF	X	X	X	X												
Proof of concept MAPL/NUOPC comp. prototype			X	X	X	X										
MAPL/NUOPC proto. tested in GEOS-5					X	X	X									
Unified LocStream impl. in ESMF and MAPL	X	X	X	X	X	X	X	X								
Demo GISS atm. comp. in GEOS-5							X	X	X							
Ocean biology comp. demo								X	X	X	X					
GISS atm. physics in GEOS-5 demo										X	X	X	X			
ESMF release with full MAPL support									X	X	X	X	X	X	X	
Coupled ModelE with GSFC DA (contingent)									X	X	X	X	X	X	X	X

1.6.3 Management Structure

Cecelia DeLuca of the University of Colorado is the PI of the proposed investigation. She is responsible for the quality and direction of the proposed research and the proper use of awarded funds. She is also responsible for all technical, management, and budget issues and is the final authority for this task. The Co-Is report to and take direction from the PI and will provide all the management data needed to ensure that the PI can effectively manage the entire task. PI and Co-Is will communicate during quarterly or as needed team telecons. The PI will communicate with the technical team on telecons scheduled biweekly or more frequently as needed.

1.6.4 Contributions of Principal Investigator and Key Personnel

Principal Investigator

– **Cecelia DeLuca** of University of Colorado, PI, is the manager of the ESMF Core Team. She oversees the technical development of the framework, serves as an administrative lead, represents the Core Team to other project and external bodies, and ensures that the development team executes the priorities set by the ESMF Change Review Board (CRB).

DeLuca participates as an *ex officio* member of the CRB and ESMF Executive Board. Her team will lead development of the MAPL/NUOPC component interoperability implementation.

Key Personnel

- **Dr. Arlindo da Silva** is the NASA Goddard Institutional PI of the proposed investigation. Dr. da Silva was one of the PIs of the original ESMF proposal and has served in the ESMF Executive Board since its inception in 2000. Dr. da Silva currently leads the aerosol modeling and data assimilation efforts at NASA's Global Modeling and Assimilation Office (GMAO), and manages its Software Infrastructure Team. He will dedicate 5% of his time to this project and will be assisted by a part-time senior software engineer. Dr. da Silva's activities will be leveraged using GMAO Core funds, at no cost to this proposal. The GSFC Institutional PI is responsible for the execution of the NASA/GSFC portion proposed activity, the quality of products delivered, and the proper use of all funds awarded to GSFC. In particular, the GSFC team will provide technical support and testing of the demonstrations, and will assist in the MAPL/NUOPC unification activities.
- **Co-I Dr. Gavin Schmidt** is the director of the Goddard Institute for Space Studies and one of lead developers of ModelE. He will serve as a point of contact for ModelE and will help to coordinate and provide technical guidance.
- **Dr. Peggy Li** of JPL, Co-I, will coordinate updates to MAPL with capabilities from current versions of ESMF, including functionality related to observational data streams, exchange grids, and grid remapping. In addition, she will migrate capabilities from MAPL specialized for and necessary to GEOS-5 to ESMF. Dr Li will assist with transfer of support for MAPL from GSFC to the University of Colorado, and tasks necessary for distribution of MAPL as part of the ESMF software.

Collaborator

- **Dr. Rocky Dunlap** of University of Colorado, collaborator, is a member of the ESMF Core Team and the technical lead for the Cupid IDE. He will advise on coordination with that project and will coordinate tasks with this effort should both efforts be funded.

1.6.5 Risk Management

A central risk is that the unified MAPL/NUOPC approach is not integrated into the modeling codes, especially GEOS-5 which has extensive existing infrastructure. To mitigate the risk, the approach taken must be non-disruptive to science and any changes must be carefully tested before being integrated into the production modeling system. We plan to mitigate risk by following an incremental approach that enables the GEOS-5 team to switch between the original and new implementations, using the familiar MAPL interfaces. Using this approach, the new implementation can be tested and compared *in situ*. This approach has proven successful and non-disruptive in previous projects; for example, a completely new implementation of the finite element mesh library in ESMF was tested in this fashion without disrupting active development going on throughout the ESMF code base and with partner modeling applications.

1.6.6 Management of Source Code and Information

ESMF and NUOPC code is distributed under the NCSA open source license and maintains a development repository that is publicly viewable. The ESMF team is committed to providing as much information about the project as feasible in an open, accessible way. The Earth System

CoG wiki-based collaboration environment[7] has proved useful in organizing information for other ESMF development efforts and a project space will be created on it for this work.

1.7 Acronyms

CESM	Community Earth System Model
CMAC	Computational Modeling Algorithms and Cyberinfrastructure
COAMPS	Coupled Ocean Atmosphere Mesoscale Prediction System
ESMF	Earth System Modeling Framework
GEOS-5	Goddard Earth Observing System, Version 5
GFDL	Geophysical Fluid Dynamics Laboratory
GISS	Goddard Institute for Space Studies
GMAO	Global Modeling and Assimilation Office
GSFC	Goddard Space Flight Center
HYCOM	HYbrid Coordinate Ocean Model
IDE	Integrated Development Environment
JPL	Jet Propulsion Laboratory
MAPL	Modeling Analysis and Prediction Layer
MOM5	Modular Ocean Model 5
MPI	Message Passing Interface
NavGEM	Navy Global Environmental Model
NCEP	National Centers for Environmental Prediction
NEMS	NOAA Environmental Modeling System
NUOPC	National Unified Operational Prediction Capability

[7] https://www.earthsystemcog.org/projects/cog/

2 References and Citations

Bauer, S.E., D. Wright, D. Koch, E.R. Lewis, R. McGraw, L.-S. Chang, S.E. Schwartz, and R. Ruedy, 2008: MATRIX (Multiconfiguration Aerosol TRacker of mIXing state): An aerosol microphysical module for global atmospheric models. Atmos. Chem. Phys., 8, 6603-6035, doi:10.5194/acp-8-6003-2008.

Ginoux, P., M. Chin, I. Tegen, J. Prospero, B. Holben, O. Dubovik, and S.-J. Lin, Sources and global distributions of dust aerosols simulated with the GOCART model, J. Geophys. Res., 106,20,255-20,273, 2001: Goddard Space Flight Center, 1997: The GEOS-3 Data Assimilation System. *DAO Office Note 97-06, Office Note Series on Global Modeling and Data Assimilation*.

Hill, C., C. DeLuca, V. Balaji, M. Suarez, and A. da Silva, 2004: Architecture of the Earth System Modeling Framework. *IEEE Comput. Sci. Eng.*, **6**(1), 18-28.

Liu, J., G. A. Schmidt, D. G. Martinson, D. Rind, G. L. Russell and X. Yuan, 2003: Sensitivity of sea ice to physical parameterizations in the GISS global climate model. J. Geophys. Res. 108, no. C2, 3053, doi:10.1029/2001JC001167.

Molod, A., L. Takacs, M. Suarez, J. Bacmeister, I.-S. Song, and A. Eichmann, 2012: The GEOS-5 Atmospheric General Circulation Model: Mean Climate and Development from MERRA to Fortuna. Technical Report Series on Global Modeling and Data Assimilation, **28**, 124 pp.

National Research Council, 1998: Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities. *The National Academies Press*, Washington, DC.

National Research Council, 2001: Improving the Effectiveness of U.S. Climate Modeling. *The National Academies Press*, Washington, DC.

National Research Council, 2012: A National Strategy for Advancing Climate Modeling. *The National Academies Press*, Washington, DC.

Rienecker, M., M. J. Suarez, R. Gelaro, R. Todling, J. Bacmeister, E. Liu, M. G. Bosilovich, S. D. Schubert, L. Takacs, Gi-K. Kim, S. Bloom, J. Chen, D. Collins, A. Conaty, A. da Silva, W. Gu, R. D. Koster, R. Lucchesi, A. Molod, T. Owens, S. Pawson, P. Pegion, C. R. Redder, F. R. Robertson5 A. G. Ruddick, M. Sienkiewicz, and J. Woollen, 2011: MERRA – NASA's Modern-Era Retrospective Analysis for Research and Applications. *J. Climate, **24**, 3624-3648. DOI: 10.1175/JCLI-D-11-00015.1*.

Rood, R. B., J. L. Anderson, D. C. Bader, M. L. Blackmon, T. F. Hogan, P. K. Esborg, 2000: High-End Climate Science: Development of Modeling and Related Computing Capabilities. Technical Report to the Office of Science and Technology Policy.

Russell, G.L., J. R. Miller, D. H. Rind, 1995: A coupled atmosphere-ocean model for transient climate change. Atmos. Ocean 33 , 683-730.

Schmidt, G.A., M. Kelley, L. Nazarenko, R. Ruedy, G.L. Russell, I. Aleinov, M. Bauer, S.E. Bauer, M.K. Bhat, R. Bleck, V. Canuto, Y.-H. Chen, Y. Cheng, T.L. Clune, A. Del Genio, R. de Fainchtein, G. Faluvegi, J.E. Hansen, R.J. Healy, N.Y. Kiang, D. Koch, A.A. Lacis, A.N. LeGrande, J. Lerner, K.K. Lo, E.E. Matthews, S. Menon, R.L. Miller, V. Oinas, A.O. Oloso, J.P. Perlwitz, M.J. Puma, W.M. Putman, D. Rind, A. Romanou, M. Sato, D.T. Shindell, S. Sun, R.A. Syed, N. Tausnev, K. Tsigaridis, N. Unger, A. Voulgarakis, M.-S. Yao, and J. Zhang, 2014: Configuration and assessment of the GISS ModelE2 contributions to the CMIP5 archive. *J. Adv. Model. Earth Syst.*, **6**, no. 1, 141-184, doi:10.1002/2013MS000265.

Theurich, G., 2014: NUOPC Layer Reference, ESMF v7.0.0*. Available online at: https://www.earthsystemcog.org/projects/nuopc/refmans

Theurich, G. and co-authors, 2015: The Earth System Prediction Suite: Toward a Coordinated U.S. Modeling Capability. *Submitted to Bull. Amer. Meteor. Soc.*

Use or disclosure of information contained on this sheet is subject to the restriction on the cover page of this proposal.

3 Biographical Sketch

3.1 Principal Investigator

Cecelia DeLuca

University of Colorado/CIRES
cecelia.deluca@noaa.gov
303-497-3604

NOAA Earth System Research Laboratory
325 Broadway
Boulder, CO 80305

Education

A.L.B. 1992 Liberal Arts/Social Sciences, Harvard University, Cambridge, MA
M.S. 1994 General Engineering, Boston University, Boston, MA
M.S. 1996 Meteorology, Massachusetts Institute of Technology, Cambridge, MA

Positions

2009-present Manager, NOAA Environmental Software Infrastructure and Interoperability Group
NOAA Cooperative Institute for Research in the Environmental Sciences
University of Colorado
2006-2009 Section Head, Earth System Modeling Infrastructure
National Center for Atmospheric Research
1999-2006 Software Engineer/Group Head, Earth System Modeling Framework
National Center for Atmospheric Research
1996-1999 Software Engineer
MIT Lincoln Laboratory

Relevant Experience

15+ years of experience in software product conception, resource acquisition, product delivery, and user support for national and international Earth science modeling, data, and metadata infrastructure projects.

- Co-founder and development team manager of the Earth System Modeling Framework (ESMF), the leading U.S. modeling framework in the weather and climate domain; used by research and operational groups at NASA, the Navy and the National Weather Service (2002-present)
- Manager of technical development for a portfolio of additional software projects and programs, including the National Unified Operational Prediction Capability Layer, a set of ESMF-based conventions and code templates used by U.S. weather prediction centers and their research partners; Cupid, an integrated development environment for ESMF; and ESMPy, a widely used Python grid remapping package.
- Co-founder and development team manager of the Earth System CoG project, a project hosting and collaboration environment with data services provided by the international Earth System Grid Federation (2009-present)
- Co-PI on the Earth System Documentation (ES-DOC) project, an international consortium that develops model metadata schemata and tools (questionnaires, displays,

Use or disclosure of information contained on this sheet is subject to the restriction on the cover page of this proposal.

etc.) for a variety of efforts including the 5th Coupled Model Intercomparison Project (2012-present)

Selection of Peer Reviewed Publications

1. Lawrence, B. N., V. Balaji, P. Bentley, S. Callaghan, C. DeLuca, S. Denvil, G. Devine, M. Elkington, R.W. Ford, E. Guilyardi, M. Lautenschlager, M. Morgan, M-P. Moine, S. Murphy, C. Pascoe, H. Ramthun, P. Slavin, L. Steenman-Clark, F. Toussaint, A. Treshansky, S. Valcke, 2012: Describing Earth System Simulations with the Metafor CIM, *Geoscientific Model Development*, **5**(6), 1493-1500.
2. Valcke, S., Balaji, V., Craig, A., DeLuca, C., Dunlap, R., Ford, R. W., Jacob, R., Larson, J., O'Kuinghttons, R., Riley, G. D., and Vertenstein, M., 2012: Coupling technologies for Earth System Modelling, *Geosci. Model Dev*., **5**, 1589-1596.
3. DeLuca, C., G. Theurich, and V. Balaji, 2012: The Earth System Modeling Framework. *Earth System Modelling-Volume 3*, 43–54.
4. Turuncoglu, U.U., N. Dalfes, S. Murphy, C. DeLuca, 2012: Toward self-describing and workflow integrated Earth system models: A coupled atmosphere-ocean modeling system application. *Environmental Modeling & Software*, **39**, 247-262.
5. Voinov, A.A., C. DeLuca, R.R. Hood, S. Peckham, C.R. Sherwood, J.P.M. Syvitski, 2010: A Community Approach to Earth Systems Modeling. *Eos, Transactions American Geophysical Union*, **91**(13), 117–118, doi:http://dx.doi.org/10.1029/2010EO130001.
6. Dunlap, R., L. Mark, S. Rugaber, V. Balaji, J. Chastang, L. Cinquini, C. DeLuca, D. Middleton and S. Murphy, 2008: Earth System Curator: Metadata Infrastructure for Climate Modeling. *Earth Science Informatics*, **1**(3-4), 131-149.
7. Collins, N., G. Theurich, C. DeLuca, M. Suarez, A. Trayanov, P. Li, W. Yang, C. Hill, 2005: Design and Implementation of Components in the Earth System Modeling Framework, *International Journal of High Performance Computing Applications*, **19**(3), 341-350.
8. Hill, C. C. DeLuca, V. Balaji, M. Suarez, A. da Silva, 2004: The Architecture of the Earth System Modeling Framework, *Computing in Science and Engineering*, **6**(1), 18-28.
10. Dickinson, R.E., S.E. Zebiak, J.L. Anderson, M.L. Blackmon, C. DeLuca, T.F. Hogan, M. Iredell, M. Ji, R. Rood, M.J. Suarez and K.E. Taylor, 2002: How Can We Advance Our Weather and Climate Models as a Community? *Bulletin of the American Meteorological Society*, **83**(3), 431-434.

Use or disclosure of information contained on this sheet is subject to the restriction on the cover page of this proposal.

3.2 Co-Investigator(s)

Arlindo M. da Silva

Global Modeling and Assimilation Office
NASA Goddard Space Flight Center
Greenbelt, MD

CO-INVESTIGATOR
ARLINDO.DASILVA@NASA.GOV
(301) 614-6174

Education

- Ph.D. in Meteorology, 1989, Massachusetts Institute of Technology
- MS in Physics, 1984, Catholic University of Rio de Janeiro, Brazil
- BS in Physics, 1982, Catholic University of Rio de Janeiro (PUC/RJ), Brazil

Professional Work History

- 1994-present: Research Meteorologist, Global Modeling and Assimilation Office (formerly DAO), NASA/Goddard Space Flight Center
- 1994: USRA Visiting Fellow, Data Assimilation Office, NASA/GSFC
- 1990-93: Assistant Professor, Department of Geosciences, University of Wisconsin-Milwaukee.
- 1989-90: Visiting Scientist, Program in Atmospheric and Oceanic Sciences, Princeton University.
- 1984-89: Research Assistant, MIT

Professional Affiliations, Committees & Working Groups

- Member, American Geophysical Union
- Member American Meteorological Society (former President of Milwaukee Chapter)
- Member, Earth System Modeling Framework (ESMF) Executive Board
- CALIPSO Science Team
- GEO-CAPE Global OSSE Working Group (co-Chair)

Professional Awards

- NASA Group Achievement Award: TC4, ARCTAS, GLOPAC
- NASA Group Achievement Award: STS-127 Columbia Investigation
- NASA GSFC Center Awards: 1996, 1997, 2000, 2001, 2003
- *Carl-Gustav Rossby Award* for PhD Thesis, MIT, 1989.

Selected Recent Publications

Randles, C. A., P. R. Colarco, and A. **da Silva**, 2013: Direct and semi-direct aerosol effects in the NASA GEOS-5 AGCM: aerosol-climate interactions due to prognostic versus prescribed aerosols, J. Geophys. Res. Atmos., 118, 149–169, doi:10.1029/2012JD018388.

Gorkavyi, N., D.F. Rault, P.A. Newman, A.M. **da Silva** and A.E. Dudorov, 2013: New stratospheric dust belt due to the Chelyabinsk bolide. *Geophys. Res. Lett.*, ***40****, 1-6, doi:10.1002/grl.50788.*

Kishcha, P., A.M. **da Silva ,**B. Starobinets, and P. Alpert, 2013: Air pollution over Northwest Bay of Bengal in the early post-monsoon season: Evaluating the NASA MERRAero assimilated datasets. *J. Geophys. Res.* **119,** doi:10.1002/ 2013JD020328**.**

Reale, O., K.-M. Lau, A. da Silva and T. Masui, 2014: Impact of assimilated and interactive aerosol on Tropical Cyclogenesis. *Geophys. Res. Lett., 41, doi:10.1002/2014GL059918.*

Use or disclosure of information contained on this sheet is subject to the restriction on the cover page of this proposal.

Peggy Li
Jet Propulsion Laboratory
4800 Oak Grove Dr., Pasadena 91109
E-mail: peggy.li@jpl.nasa.gov

EDUCATION

Ph.D. in Computer Science, California Institute of Technology, 1986
M.S. in Electrical Engineering, National Taiwan University, 1979
B.S. in Electrical Engineering, National Taiwan University, 1976

EXPERIENCE

6/1999 --- Present	Technologist, Instrument Software and Science Data Systems Section, JPL
1/1996 --- 6/1999	Technical Group Supervisor, Automation and Scheduling Technology Group, Applications Development Section, JPL
8/1989 ---12/1995	Computer Scientist, Advanced Parallel Processing Project, JPL
5/1986 --- 5/1989	Project Leader, Symult Systems Corp.

RESEARCH ACTIVITIES

Dr. Li has led several R&D tasks in the parallel and distributed computing area since she joined JPL in 1989, including the development of a distributed discrete event simulation framework, a remote interactive visualization and analysis (RIVA) system for the planetary data visualization, and a parallel volume rendering system (ParVox) for NASA's Earth and Space Technology project. She is currently the lead architect and designer for the OurOcean portal that serves near real-time ocean data from NASA satellites, in-situ observations and the ocean model output for the California coastal regions and JPL Tropical Cyclone portal for hurricane modeling and monitoring. Her research interests are in distributed computing, scientific visualization and simulation and modeling.

SELECTED PUBLICATIONS

Li, P., et. al, "Our Ocean Portal for Operational Oceanography", 2010 AGU Ocean Science Meeting, February 2010.

Li, P., et. al, "NASA GRIP-3D Visualization of Near Real-time Satellite Observations for Hurricane Field Campaign Using Google Earth API", 2009 AGU Fall Meeting, December 2009.

Li, P., et. al, "Prototype of an Integrated Hurricane Information System for Research: Design and Implementation of the Database and Web Portal", 2007 AGU Fall Meeting, December 2007.

Li, P., et. al, "OurOcean – An Integrated Solution to Ocean Modeling and Forecasting", Proceedings of 2006 Oceans Conference, Boston, September 2006.

Nghiem, S. V., Y. Chao, G. Newmann, P. Li, D.K. Perovich, and T. Street, "Depletion of Perennial Sea Ice in the East Arctic Ocean", Geophys. Res. Lett., 33, L17501, 2006.

Li, P., "Visualization of Earthquake Simulation Datasets", *2004 NASA Earth Science Technologies Conference*, San Francisco, 2004.

Li, P, "Supercomputing Visualization for Earth Science Datasets", *Proceedings of 2002 NASA Earth Science Technology Conference*, June, 2002.

Wang, P. and Li, P., "Parallel Computation and Visualization of Three-dimensional, Time-dependent, Thermal Convective Flows", *Lecture Notes in Computer Science*, 1998.

Chao, Y., Li, P., Wang, P., Katz, D, Cheng, N., and Whitman, S., "Ocean Modeling and Visualization on Massively Parallel Computers," *Industrial Strength Parallel Computing*: *Programming Massively Parallel Processing Systems*, Morgan Kaufmanns, 1998.

Li, P., Whitman, S., Mendoza, R., Tsiao, J. "ParVox – A Parallel Volume Rendering System for Distributed Visualization", *1977 Proc. of IEEE Symp. on Parallel Rendering*, pp.7-14, 1997

Use or disclosure of information contained on this sheet is subject to the restriction on the cover page of this proposal.

Gavin A. Schmidt

NASA/Goddard Institute for Space Studies, Code 611,
2880 Broadway, New York, NY 10025
Email: Gavin.A.Schmidt@nasa.gov Tel: (212) 678-5627

Education

BA (Hons), 1987, Oxford University, UK (Mathematics)
Ph.D., 1994, University College London, UK (Applied Mathematics)

Employment

2014 – present	Director, **NASA Goddard Institute for Space Studies**
2004 – 2014	Physical Scientist, **NASA Goddard Institute for Space Studies**
2004 – present	Adjunct Sr. Research Scientist, **Center for Climate Systems Research, Columbia University**
2002 – 2004	Research Scientist, **CCSR, Columbia University**
1998 – 2002	Associate Research Scientist, **CCSR, Columbia University**
1996 – 1998	NOAA Postdoctoral Fellow in Climate and Global Change
1994 – 1996	Postdoctoral Fellow, **McGill University, Montreal**

Current Professional Activities

Chair, AGU Climate Communications Prize committee: 2014 –
Associate Editor: J. Climate

Outreach

American Museum of Natural History, NY Academy of Sciences, College de France, RealClimate.Org, CNN, ABC, Comedy Central, NY Times, Wash. Post, USA Today, New Scientist, and other media.
"Climate Change: Picturing the Science" G. Schmidt and J. Wolfe, W. W. Norton, New York, 2009.
AGU Climate Communication Prize winner, 2011

Select Recent Publications

Schmidt, G.A., et al., 2014: Configuration and assessment of the GISS ModelE2 contributions to the CMIP5 archive. *J. Adv. Model. Earth Syst.*, **6**, no. 1, 141-184, doi:10.1002/2013MS000265.

Schmidt, G.A., D.T. Shindell, and K. Tsigaridis, 2014: Reconciling warming trends. *Nature Geosci.*, **7**, no. 3, 158-160, doi:10.1038/ngeo2105.

Miller, R.L., G.A. Schmidt, et al., 2014: CMIP5 historical simulations (1850-2012) with GISS ModelE2. *J. Adv. Model. Earth Syst.*, **6**, no. 2, 441-477, doi:10.1002/2013MS000266.

Schmidt, G.A., et al., 2014: Using paleo-climate comparisons to constrain future projections in CMIP5. *Clim. Past*, **10**, 221-250, doi:10.5194/cp-10-221-2014.

Shindell, D.T., et al., 2013: Interactive ozone and methane chemistry in GISS-E2 historical and future climate simulations. *Atmos. Chem. Phys.*, **13**, 2653-2689, doi:10.5194/acp-13-2653-2013.

Sun, M., J. Li, C. Yang, G.A. Schmidt, M. Bambacus, R. Cahalan, Q. Huang, C. Xu, E.U. Noble, and Z. Li, 2012: A web-based geovisual analytical system for climate studies. *Future Internet*, **4**, 1069-1085, doi:10.3390/fi4041069.

Schmidt, G.A., R. Ruedy, R.L. Miller, and A.A. Lacis, 2010: The attribution of the present-day total greenhouse effect. *J. Geophys. Res.*, **115**, D20106

3.3 Collaborator(s)

Ralph S. Dunlap

Professional Research Associate, University of Colorado/NOAA

RELEVANT EXPERIENCE:

Dr. Ralph S. Dunlap is a professional research associate at the Cooperative Institute for Research in Environmental Science, University of Colorado and is a research lead for the NOAA Environmental Software Infrastructure and Interoperability (NESII) group, which develops the Earth System Modeling Framework (ESMF) and other software infrastructure in support of geoscience modeling. Dr. Dunlap is an early career scientist, having recently completed a Ph.D. on software reuse of modeling infrastructure, including automatic code generation of ESMF-based couplers. Dr. Dunlap is currently the lead architect and developer of the Cupid Integrated Development Environment and has over five years of experience building software engineering tools for numerical modelers. He is Co-I on the NSF-sponsored Earth System Bridge project, which is building software components to connect modeling frameworks. Dr. Dunlap has served on the organizing committee of a series of scientific workshops on Coupling Technologies for Earth System Models, which brings together researchers and practitioners to collaborate on design and implementation of modeling infrastructure.

EDUCATION:

- Ph.D. in Computer Science, 2013, Georgia Institute of Technology
  Dissertation: Effective Reuse of Coupling Technologies for Earth System Models
- M.S. in Computer Science, 2013, Georgia Institute of Technology
- B.S. in Computer Science, 2003, Georgia Institute of Technology

PROFESSIONAL EXPERIENCE:

- University of Colorado / NOAA, 2014-present - Professional Research Associate
- Georgia Institute of Technology, 2013-2014 - Research Scientists II
- National Center for Atmospheric Research (NCAR), 2008 – Software Engineer

SELECTED REFEREED PUBLICATIONS

[1] **Dunlap, R.**, Vertenstein, M., Valcke, S., & Craig, T. (2014). Second Workshop on Coupling Technologies for Earth System Models. Bulletin of the American Meteorological Society, 95(2), ES34-ES38.

[2] S. Valcke, V. Balaji, A. Craig, C. Deluca, **R. Dunlap**, R.W. Ford, R. Jacob, J. Larson, R. O'Kuinghttons, G.D. Riley, and M. Vertenstein. Coupling Technologies for Earth System Modeling. Geoscientific Model Development, 2012.

[3] Spencer Rugaber, **R. Dunlap**, Leo Mark, Sameer Ansari. Managing Software Complexity and Variability in Coupled Climate Models. IEEE Software 28(6): 43-48, 2011. DOI 10.1109/MS.2011.114.

[4] **R. Dunlap**, Spencer Rugaber, Leo Mark. A Feature Model of Coupling Technologies for Earth System Models. Computers and Geosciences, 2011. DOI 10.1016/j.cageo.2011.10.002.

[5] **R.Dunlap**, Leo Mark, Spencer Rugaber, V. Balaji, Julien Chastang, Luca Cinquini, Cecelia DeLuca, Don Middleton, and Sylvia Murphy. Earth System Curator: Metadata Infrastructure for Climate Modeling. Earth Science Informatics 1(3-4): 131-149, 2008. DOI 10.1007/s12145-008-0016-1.

4 Table of Personnel and Work Effort

Title: Extending Interoperability of ESMF-Based Models at NASA
Non-NASA PI Name: Cecelia DeLuca , University of Colorado
GSFC Co-I Name: ARLINDO DA SILVA

Submitted in response to NNH15ZDA001N-MAP, Modeling, Analysis, and Prediction

Summary of Personnel and Work Effort

The following table reflects the level of support required of all personnel necessary to perform the proposed investigation, regardless of whether these individuals require funding from this proposal.

Name and/or Position Title	Role	Institution	PY 1 FTEs	PY 2 FTEs	PY 3 FTEs	PY 4 FTEs	Total
NASA-Funded Work Effort							
Cecelia DeLuca	PI	Univ. of Colorado	0.05	0.05	0.05	0.05	0.20
Peggy Li	Co-I	NASA JPL	0.35	0.35	0.34	0.32	1.36
Support Scientist (TRINNOVIM)	Support	Columbia University	0.40	0.40	0.40	0.40	1.60
Senior Software Engineer	Support	SAIC	0.80	0.80	0.80	0.80	3.20
Senior Software Engineer	Support	University of Colorado	0.82	0.80	0.78	0.76	3.16
Subtotal:			2.42	2.40	2.37	2.33	9.52
Work Effort for Which No Funding is Requested							
Arlindo da Silva	Co-I	NASA GSFC Code 6101.1	0.05	0.05	0.05	0.05	0.20
Gavin Schmidt	Co-I	NASA GISS Code 611	0.05	0.05	0.05	0.05	0.20
Subtotal:			0.10	0.10	0.10	0.10	0.40
Total:			**2.52**	**2.50**	**2.47**	**2.43**	**9.92**

The proposed work level is appropriate to perform the investigation on the basis of previous experience integrating ESMF into NASA applications.

5 Current and Pending Support

Cecelia DeLuca

Current Support

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency/ Point of Contact telephone and email	Period of Performance/ Total Budget	Commitment (Person-Months per Year)
Cecelia DeLuca	ESMF Development in Support of NASA Applications	NASA/MAP	7/7/11 – 7/6/16 $1,259,000	.10
Cecelia DeLuca	NOAA Environmental Software Infrastructure and Interoperability Project	NOAA CPO/NESII	6/1/14-7/31/15 $937,000	.05
Cecelia DeLuca	NOAA Environmental Software Infrastructure and Interoperability Project – R2O	NOAA NWS/NUOPC	5/1/15-4/30/16 $600,000	.05
Lee Allison	EarthCube Test Enterprise Governance: An Agile Approach	NSF EarthCube	9/15/13-8/31/15 $30,000	.05
Ben Kirtman	An Integration and Evaluation Framework for ESPC Coupled Models	ONR BAA 13-011	12/1/13-11/30/16 $120,000	.05
Scott Peckham	Earth System Bridge: Spanning Scientific Communities with Interoperable Modeling Frameworks	NSF EarthCube	9/15/13-8/31/15 $316,242	.05
Cecelia DeLuca	CoG Support for the High Impact Weather Prediction Project	HIWPP	10/1/13-9/30/15 $24,170	.02
Cecelia DeLuca	Asynchronous I/O Components for Coupled Earth Systems	HPCMP PETTT	9/1/14-8/31/15 $83,377	.02

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency/ Point of Contact telephone and email	Period of Performance/ Total Budget	Commitment (Person-Months per Year)
Cecelia DeLuca	Modeling and Data Infrastructure in Support of NOAA's Global Models	NOAA Climate Program Office FY15	8/1/15-7/31/18 $2,827,482	.30

Pending Support - None

Arlindo da Silva

Current Support

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency	Period of Performance/ Total Budget	Commitment (Person-Months per Year)
Xiaohong Liu	Developing and Evaluating an Advanced Aerosol Module in GEOS-5 for Data Assimilation and Climate Studies	NASA/MAP	FY2014-FY2017 $250K/year	0.10
P. Minnis	Using Near-Real Time Satellite Retrieved Cloud and Surface Properties to Validate and Improve GEOS-5 Analyses and Forecasts	NASA/MAP	FY2013-FY2016 $100K/year	0.10
P. Colarco	Diagnosing uncertainty in the aerosol direct radiative effect with the NASA GEOS-5 model and NASA satellite observations	NASA/ACMAP	FY2014-FY2016 $200K/year	0.10
M. Rienecker	Global Modeling and Assimilation Office with Chemistry Climate Model and Global Modeling Initiative Core Activities	NASA HQ	FY2014-FY2018 $10M/year	0.5

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency	Period of Performance/ Total Budget	Commitment (Person-Months per Year)
Sarah Lu (NCEP)	Improving Cloud Microphysics and their Interactions with Aerosols in the NCEP Global Models	NOAA/CTB	FY2014-FY2015 $89K	0.05

Pending Support

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency	Period of Performance/ Total Budget	Commitment (Person-Months per Year)
Rocky Dunlap (University of Colorado)	Cupid: An Integrated Development Environment for Earth System Models	NASA CMAC	FY2016-FY2017 $155K/year	0.08

Peggy Li

Current Support

Name of Principal Investigator on Award	Award/Project Title	Program Name/Sponsoring Agency	Period of Performance/ Budget	Commitment (Person-Months per Year)
Cecelia Deluca (University of Colorado)	ESMF Development Support of NASA Applications	NASA MAP	8/2011-8/2016	.5
Svetla Hristova-Veleva	Fusion of Hurricane Models and Observations	NASA AIST	6/2012-5/2016 $1.2M	.16
Fred Bingham (UNCW)	SPURS-IS	NASA Physical Oceanography Program	2/2015-2/2018	.16
Zhijin Li	Multi-Scale Modeling and Data Assimilation for SPURS2	NASA Physical Oceanography Program	2/2015-2/2018	.08

Pending Support - None

Gavin Schmidt

Current Support

Name of Principal Investigator on Award	Award/Project Title	Program Name/Sponsoring Agency	Period of Performance/ Budget	Commitment (Person-Months per Year)
Cecelia DeLuca (University of Colorado)	ESMF Development Support of NASA Applications	NASA MAP	8/2011-8/2016	.5
Gavin Schmidt	Development and Vision for the GISS ModelE	NASA MAP	7/2013-7/2017	10.0

Pending Support

Name of Principal Investigator on Award	Award/Project Title	Program Name/Sponsoring Agency	Period of Performance/ Budget	Commitment (Person-Months per Year)
Rocky Dunlap (University of Colorado)	Cupid: An Integrated Development Environment for Earth System Models	NASA CMAC	FY2016-FY2017 $155K/year	0.08
Gavin Schmidt	Consistent simulations of the radiative and particulate impacts of solar activity on climate	NASA LWS	FY2016-FY2018 $195K/year	0.6
Gavin Schmidt	Implementation of a new ocean component into the GEOS5 data assimilation framework	NASA MAP	FY2016-FY2019 $241K/yr	0.6

6 Budget Justification: Narrative and Details

6.1 University of Colorado Budget Narrative and Details

SALARIES

- Cecelia DeLuca, manager of the NOAA Environmental Software Infrastructure and Interoperability Project, will serve as the PI of this proposal at University of Colorado. Requested support is 5% time.
- One Professional Research Assistants (PRAs) at 82% time, reduced 2% per year over the four years of the project, at 12 months per year, is requested for software development. Salaries are inflated at 3% annually. These increases are effective October 1 of every year.

FRINGE BENEFIT
The fringe benefit rate is applied at 35.8% of salary.

TRAVEL
Two trips per year over the last three years of the project are requested for travel to conferences to present work, and for any meetings required for coordination.
Travel is calculated the first year assuming:
Domestic round-trip airfare: $350 per flight
Meals and lodging for a 4 night stay at $275/day: $1100
Registration: $465
Ground transportation: $100
Total is $2015 per trip.
Travel costs are increased 2.2% each year, for a total of $12,632.

OTHER DIRECT COSTS
IT supplies are requested at $500 per year, inflated at 2.2% per year. Software expenses (e.g. compiler licenses) are requested at $800 the first year, inflated at 2.2% per year. A laptop purchase the first year is requested at $3000.

INDIRECT COSTS
The off-campus indirect cost rate of 26% is determined for the period 7/1/13 to 6/30/18 by a negotiated agreement, dated 9/10/14, between the University of Colorado and the U.S. Department of Health and Human Services.

OTHER APPLICABLE COSTS

Dr. Peggy Li, JPL (Government Bypass) is a Co-I, and will lead the implementation of merged underlying libraries in ESMF and MAPL.

Dr. Arlindo da Silva (Government Bypass) is a Co-I, and with Dr, Gavin Schmidt (Co-I) will lead the demonstrations of model interoperability.

University of Colorado Budget

CU Proposal No.

PROPOSED BUDGET DETAILS

Institution: The Regents of the University of Colorado
572 UCB
Boulder, CO 80309-0572

Title: Extending Interoperability of ESMF-Based Models at NASA

Principal Investigator: Cecelia Deluca

Duration: 12/1/15 - 11/30/19

	Year 1	Year 2	Year 3	Year 4	Total
A. Salaries and Wages					
PI: C. DeLuca					
5% time, 12 mos every year	7,592	7,819	8,054	8,296	31,761
Professional Research Asst - TBD					
82% time reduced 2% annually, 12 mos.	91,856	92,304	92,697	93,029	369,886
Total Salaries and Wages	99,448	100,123	100,751	101,325	401,647
B. Fringe Benefits					
Research Faculty: 35.8% of salary	35,602	35,844	36,069	36,274	143,789
Total S/W and Fringe Benefits	135,050	135,967	136,820	137,599	545,436
C. Permanent Equipment - none	0	0	0	0	0
D. Travel					
Domestic:					
Project personnel travel to attend scientific conferences					
RT Coach Airfare: $350					
Meals & Lodging: $275/day x 4 days					
Registration and abstracts: $465					
Ground Transportation: $100					
Two trips per year, years 2-4 @ $2,015	0	4,119	4,210	4,303	12,632
E. Other Direct Costs					
1. IT Supplies:	500	511	522	533	2,066
2 Laptop for personnel $3000/each	3,000	0	0	0	3,000
3 Software	800	818	836	854	3,308
Total Other Direct Costs	4,300	1,329	1,358	1,387	8,374
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Total**
F. Total Direct Costs	139,350	141,415	142,388	143,289	566,442
G. Indirect Costs					
Off Campus Research: 26% of MTDC;					
Predetermined for the period					
7/1/13-6/30/18, provisional thereafter.					
Per HHS agreement dated 9/10/14.	36,231	36,768	37,021	37,255	147,275
H. Total UCB Costs	175,581	178,183	179,409	180,544	713,717
Total amount requested:	**$713,717**				
I. Total Distribution from NASA					
(NASA Goddard	182,335	187,805	193,439	199,242	762,821
JPL	140,010	139,790	139,940	140,030	559,770
J. Total amount requested from NASA	**$ 2,036,308**				

6.2 NASA Goddard Space Flight Center Budget Narrative and Details

Notice of Restriction on Use and Disclosure of Proposal Information
The information (data) contained in this section of the proposal constitutes information that is financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, that in the event a contract (or other agreement) is awarded on the basis of this proposal, the Government shall have the right to use and disclose this information (data) to the extent provided in the contract (or other agreement).

Budget Justification: Narrative

NASA Center Funding
Procurement and Travel Only

Per October 20, 2010 guidance from NASA SMD, updated April 20, 2012, for ROSES proposals, NASA civil servant labor dollars will be redacted from NSPIRES and budget justifications. Each NASA Center will separately submit its total budget that includes its civil servant labor *for subsequent retrieval by NASA Headquarters*.

http://science.nasa.gov/researchers/sara/how-to-guide/nspires-CSlabor/

NASA Center Funding By Program Year

	PY 1 Cost	PY 2 Cost	PY 3 Cost	PY 4 Cost	Total Cost
NASA/GSFC	182,335	187,805	193,439	199,242	762,822
Total:	182,335	187,805	193,439	199,242	762,822

NASA Center Funding By Fiscal Year

	FY 2016 Cost	FY 2017 Cost	FY 2018 Cost	FY 2019 Cost	FY 2020 Cost	Total Cost
NASA/GSFC	182,335	187,805	193,439	199,242	0	762,822
Total:	182,335	187,805	193,439	199,242	0	762,822

GSFC Civil Servant Roles:

Co-I da Silva will supervise and coordinate the activities of integrating the ESMF and related activities at GMAO. He will perform these functions as part of his regular duties as lead of GMAO's Software Infrastructure Group.

Co-I Schmidt will supervise and coordinate the activities of integrating the ESMF and related activities at NASA/GISS. He will perform these functions as part of his regular duties as director of NASA/GISS.

NO FUNDS ARE BEING REQUESTED FOR NASA CIVIL SERVANTS.

GSFC On-Site Contractor Roles:

A) GMAO CODE 610.1
To perform the programming tasks needed for the project at GMAO, a Senior Programmer is needed for

9.6 months each year. The cost estimate is based on currently established loaded rates for the contract that already exists at GSFC.

B) GISS CODE 611.0
To perform the tasks at NASA/GISS a Support Scientist is needed for 4.8 months each year. The cost estimate is based on currently established loaded rates for the contract that already exists at NASA/GIS.

Other Direct Costs

Other

Other Direct Costs, SED - These costs, as discussed in NASA financial regulations, are for services to support the research effort that go beyond the standard costs considered under Center Management and Operations (Center Overhead), and are not incurred elsewhere within GSFC. Within the Sciences and Exploration Directorate these costs cover system administration for the complex information technology services required to support the proposed research activities, administrative and resource analysis support, and supplies to support the research effort.

Facilities and Administrative (F&A) Costs, GSFC
NASA CM&O (Center Management and Operations) is managed from Headquarters and is therefore excluded from this proposal.

Cost Sharing

GSFC FTEs:
Rationale for cost sharing and benefits / relationship to proposed investigation: The research being proposed by the University of Colorado is of great benefit for model development at the GMAO and NASA/GIS. The supervisory functions to be performed by Dr. Da Silva and Dr. Schmidt will be funded by both GMAO and GISS core funds.

Specific Cost Items:
Rational for cost sharing and benefits / relationship to proposed investigation:

Description of Required Facilities and Equipment

Existing Facilities and Equipment for Which Funding is Not Requested
The existing facilities and equipment needed to carry out the proposed research are available at the proposer's institution, NASA/Goddard Space Flight Center. These include: computers and software available at GMAO, GISS and NASA Center for Climate Simulation.

Budget Justification: Details

Below is the total budget for the items described in the Budget Narrative. Also below are any supporting budgets.

NOTE: For NASA ROSES proposals, NASA Civil Servant Labor is redacted per SMD guidance from NSPIRES and from budgets in Proposal Documents; NASA HQ will retrieve the full NASA budget for each NASA Center from the agreed-upon repository.

NASA Goddard Space Flight Center Budget

Solicitation: NNH15ZDA001N-MAP Modeling Analysis and Prediction
GSFC Proposer Name: ARLINDO DA SILVA
Proposal Number: 600-15-4880
Proposal Title: 600-15-4880 - Extending Interoperability of ESMF-Based Models at NASA
Total Excluding GSFC CS Labor: 762822
Proposal Start Date: 12/01/2015
Proposal End Date: 11/30/2019

			1-Dec-15 to 30-Nov-16	1-Dec-16 to 30-Nov-17	1-Dec-17 to 30-Nov-18	1-Dec-18 to 30-Nov-19	
A. Civil Servant - Key Personnel			PY 1	PY 2	PY 3	PY 4	Total
Name	ARLINDO DA SILVA	Base Sal. Rate	0	0	0	0	
Skill	Scientist-Tier 2	Person Months	0	0	0	0	0
Assigned Org	610.1	Requested Salary	0	0	0	0	0
Role	Co-I	Fringe	0	0	0	0	0
		Total Dollars	0	0	0	0	0
Name	Gavin Schmidt	Base Sal. Rate	0	0	0	0	
Skill	Scientist-Tier 4	Person Months	0	0	0	0	0
Assigned Org	611	Requested Salary	0	0	0	0	0
Role	Co-I	Fringe	0	0	0	0	0
		Total Dollars	0	0	0	0	0
B.1.b. Civil Servant - Administrative Support			PY 1	PY 2	PY 3	PY 4	Total
POC/Function	Res & Procur Supt	Base Sal. Rate	0	0	0	0	
Skill	Prof Admin-Sr	Person Months	0	0	0	0	0
Assigned Org	610.1	Requested Salary	0	0	0	0	0
Role	Support	Fringe	0	0	0	0	0
		Total Dollars	0	0	0	0	0
B.2a.1 On-Site Contractors			PY 1	PY 2	PY 3	PY 4	Total
POC/Function	Senior Software Engineer	Loaded Rate	129100	132973	136962	141071	
Skill	Programmer-Sr	Person Months	9.6	9.6	9.6	9.6	38.4
Assigned Org	610.1	Total Dollars	103280	106378	109570	112857	432085
Role	Support						
POC/Function	Support Scientist (Trinnovim)	Loaded Rate	160000	164800	169744	174836	
Skill	Scientist-Tier 3	Person Months	4.8	4.8	4.8	4.8	19.2
Assigned Org	611	Total Dollars	64000	65920	67898	69934	267752
Role	Support						
Other Direct Costs SED			15055	15507	15972	16451	62985

	PY 1 Cost	PY 2 Cost	PY 3 Cost	PY 4 Cost	Total Cost
GSFC Civil Servants Key Personnel	0	0	0	0	0
GSFC Civil Servants Other Personnel	0	0	0	0	0
Subtotal GSFC Civil Servants	0	0	0	0	0
Contractors On-Site	167280	172298	177467	182791	699837
Contractors On-Site Cooperative Agreements	0	0	0	0	0
Contractors On-Site Test & Fab Pool	0	0	0	0	0
Off-Site Subawards / Subcontracts	0	0	0	0	0
Subtotal Other Personnel	167280	172298	177467	182791	699837
Subtotal Labor Cost	167280	172298	177467	182791	699837
Subtotal Others	0	0	0	0	0
Subtotal Travel	0	0	0	0	0
Other Direct Costs SED	15055	15507	15972	16451	62985
Subtotal Other Cost	15055	15507	15972	16451	62985
Indirect CM&O	0	0	0	0	0
Grand Total Proposal Costs	182335	187805	193439	199242	762822

6.3 JPL Budget Narrative and Details

The expected performance period is four years from December 1, 2015 to November 30, 2019. The total budget for JPL is $140K per year or a total of $560K for the entire performance period.

The JPL personnel supporting this taks is Dr. Peggy Li (JPL lead Co-I, Section 389F). She will work at 0.35 FTE for the first and the second year, 0.34 FTE for the second year and 0.32 FTE for the fourth year.

Three trips are planned for this task. In the first and the third year, $1,500 is allocated each year for a 3-day trip to Boulder, Colorado for technical discussions with the team members and $2,000 is allocated in the fourth year to present the results in either the AGU fall meeting or the AMS annual meeting.

NASA Jet Propulstion Laboratory Budget

Extending Interoperability of ESMF-Based Models at NASA

ROSES A.13 MAP
Timephased Cost Estimate Sheet
Dollars (Does not include Gov't Co-I's)

	Dec 2015 - Nov 2016	Dec 2016 - Nov 2017	Dec 2017 - Nov 2018	Dec 2018 - Nov 2019	Total Program
Hours / (FTEs)					
Peggy Li	624 (0.35 FTE)	613 (0.35 FTE)	594 (0.34 FTE)	563 (0.32 FTE)	2,394 (1.36 FTE)
Total Hours:	624 (0.35 FTE)	613 (0.35 FTE)	594 (0.34 FTE)	563 (0.32 FTE)	2,394 (1.36 FTE)
Amount	$59,480	$60,910	$61,550	$60,970	$242,910
Fringe	$33,260	$33,740	$33,490	$33,890	$134,380
Category A	$0	$0	$0	$0	$0
Total Direct Compensation (includes Employee Benefits)	$92,740	$94,650	$95,040	$94,860	$377,290
Travel	$1,500	$0	$1,500	$2,000	$5,000
JPL Services	$0	$0	$0	$0	$0
Procurements					
Chargebacks	$4,170	$4,090	$3,970	$3,770	$16,000
Subcontracts	$0	$0	$0	$0	$0
Procurement RSA	$0	$0	$0	$0	$0
Purchase Orders	$0	$0	$0	$0	$0
Caltech Transfers	$0	$0	$0	$0	$0
Multi-Program Support	$7,060	$6,890	$6,460	$6,510	$26,920
Total Direct Costs	**$105,470**	**$105,630**	**$106,970**	**$107,140**	**$425,210**
Allocated Direct Charge	$18,830	$18,480	$17,220	$17,090	$71,620
General & Admin	$15,710	$15,680	$15,750	$15,800	$62,940
Reserves (Burdened)	$0	$0	$0	$0	$0
Total JPL Costs	**$140,010**	**$139,790**	**$139,940**	**$140,030**	**$559,770**
Government Co-I's Not in JPL's Costs	**$0**	**$0**	**$0**	**$0**	**$0**
Total Costs	**$140,010**	**$139,790**	**$139,940**	**$140,030**	**$559,770**

7 Facilities and Equipment

All required facilities and equipment will be available for this research.

7.1 University of Colorado

No special facilities or equipment is required.

7.2 NASA Goddard Space Flight Center

No special facilities or equipment is required.

7.3 JPL

No special facilities or equipment is required.