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# Scientific/Technical/Management

## Introduction

Over the last two decades, NASA has built the Earth Observing System (EOS) which is comprised of a series of coordinated polar-orbiting satellites designed to provide global, near simultaneous, multi-instrument observations of the Earth’s atmosphere, ocean, and land systems. The fusion of the multiple instrument observations not only provides details of the vertical structure, high horizontal resolutions, and multivariate characterizations, but also allows for much more comprehensive insight than any one individual instrument can provide alone. Additionally, the emergence of high-quality reanalysis datasets is instrumental in providing the large-scale dynamic and thermodynamic context of climate systems.

The Decadal Survey and the latest Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) stressed the need for the comprehensive and innovative evaluation of climate models with the synergistic use of the global observations. It is highly anticipated that the next IPCC report AR5 scheduled for publication in late 2013 will reemphasize the need. Despite the widely acknowledged value of the satellite observations for model evaluations, the synergistic use of the datasets is not widespread because the datasets are heterogeneous, scattered, domain specific, and innately different from model outputs. Data from different instruments and reanalysis systems have different spatial and temporal sampling characteristics (e.g., footprint geometry and resolution, swath/pointing schemes, sampling frequency) and the different formats and structures of the retrieval/assimilated products (e.g., file granularity and format, data organization). At the same time, the datasets are scattered in different data archive centers. More challengingly, the observational datasets are intrinsically different from model outputs so that many steps of data preparation and analysis are needed to bring the two close to be comparable.

Recognizing these difficulties, NASA has recently launched a pilot project called Obs4MIPs to prepare NASA satellite observational datasets that would be directly comparable to model outputs and to facilitate the wide use of the datasets for model evaluations by archiving the specially prepared observational datasets in the same location as model outputs using the Earth System Grid. Obs4MIPs now provide over 10 parameters covering a wide range of cloud, radiation, precipitation, thermodynamic, and dynamic parameters. The Obs4MIPs datasets greatly facilitate the synergistic use of the global satellite observations for model-to-observation comparisons and analyses. An analysis tool that can accompany the Obs4MIPs datasets to support the model-data comparisons and analysis would further increase the benefit of the Obs4MIPs datasets to the modeling and model analysis community.

Model-to-observation comparisons and analyses are critical to identify model biases, understand the causes of the biases, and to ultimately improve climate model performance for climate sensitivity studies and predictions. While the comparison between model and observation is essential, it is often done incorrectly because observational data and model outputs are naturally different in many ways (some are obvious but some are subtle). Therefore, it is important to develop a system that can control the access to the observational data sources that are properly prepared and quality controlled for the model-to-observation comparisons and analyses (i.e. Obs4MIPs datasets or something equivalent).

Satellite observations have been broadly used in model-data comparisons and model evaluation studies in the past. These studies normally involve the comparison of a single parameter at a time using a global time and space average. This traditional approach can evaluate model performance and identify model systematic biases but cannot diagnose the model problem. The model diagnosis process requires physics-based, multi-variable comparisons with conditionally sampled climate regimes and phenomena. A model evaluation tool should have the diagnostic analysis capabilities to associate any systematic model biases with model deficiencies in physical process representations and to direct the model improvements.

Apart from data analysis, a large portion of research time is spent on searching previously analyzed results and regenerating the same results when they fail to find the results. This lamentable practice is because scientists create massive amount of processed datasets for their exploratory multi-dimensional studies but they have few tools to help them keep track of the processing history of their processed datasets. Current practical solutions for scientists to keep track of the processing history are their organized notebooks, filenames long and descriptive enough to remind them the processing history of the data in the files, and hierarchical file structures to organize the processed data. A tool that can keep track of processing history during analysis calls, represent the summary of the processing history in a human readable way, and enable provenance-based search capabilities can greatly improve the productivity of the scientists using the analysis tool.

## Objectives and Expected Significance

***We propose to develop a provenance-empowered information system that enables multi-aspect, physics-based, and phenomenon-oriented model performance evaluations and diagnoses through the comprehensive, synergistic, and quality-controlled use of multiple observational data, reanalysis data, and model outputs.*** We will build **Climate Model Diagnostic Analyzer (CMDA)** that will provide a computationally efficient way to simultaneously process multi-source observation and model datasets for model diagnosis, generate a document to describe the processing history of resulting datasets and plots, and provide an easy way to search the processed datasets and plots based on the processing history. CMDA will support all the Obs4MIPs datasets and all the CMIP5 model decadal hindcast experiment outputs as input data for analyses.

We will leverage the existing information technologies and scientific tools that we developed in our current/prior NASA ROSES CMAC, ACCESS, COUND, MAP, MEaSURE, and AIST projects. We will utilize the open-source Web-service technology, Parallel Python, and Provenance Collection technology to achieve the goal. We will make CMDA complementary to other climate model analysis tools currently available to the community (e.g. PCMDI’s CDAT, NCAR’s CCMVal) by focusing on the missing capabilities such as co-location, conditional sampling, correlation analysis, probability distribution function, and cluster analysis of multiple-instrument datasets. In addition, CMDA will have the capability to create a processing history document for processed datasets and to search processed datasets with the processing history. The proposed work is a response to the subtopic of this NRA: “*Tools that improve and expand the accessibility and usability of NASA’s Earth science observational data for the modeling and model analysis communities*.”

The target users of CMDA are modeling and model analysis communities who are engaged in the following programmatic entities: the World Climate Research Program, World Weather Research Program (WWRP), Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS), Climate Variability and Predictability (CLIVAR) research program, Working Group on Numerical Experimentation (WGNE), and the Working Group on Coupled Modeling (WGCM) for IPCC’s 5th Assessment Report. The Co-I Dr. Jiang and Collaborator D. Teixeira are actively involved in these modeling and model analysis programmatic entities, and are familiar with the governance of the entities through their participation and leading roles. With the connections, we will engage the modeling and model analysis community to the proposed project, and promote the community awareness of CMDA and the growth of the CMAC user community.

The Earth science focus area of the proposed work is in understanding and evaluating clouds, convection and their radiative processes represented in numerical weather and climate models. We have identified two scientific applications that will be used as a demonstration of the scientific use of CMDR: (1) Evaluating representations of atmospheric moist process in the global models and (2) Evaluating representations of atmospheric radiation process in the global models. Details of the scientific applications are described in Section 1.3.8.

A number of national and international weather and climate programmatic efforts are calling for enhanced use and application of the observational datasets to maximize the investment put into these observational systems and also to leverage them to the greatest extent possible for improving our weather and climate simulation and prediction capabilities. The proposed tool CMDA will improve and expand the accessibility and usability of NASA’s Earth science observational data for the modeling and model analysis community. CMDA will increase the productivity of their research efforts by providing a comprehensive analysis tool to do model-observation comparisons, model performance verification and validation, and model diagnosis with a capability to keep track of the multi-source data analysis history. CMDA will empower scientists with capabilities to identify model biases, understand the causes of the biases, and to ultimately improve climate model performance for climate sensitivity studies and predictions. These increased research productivities of the modeling and model analysis communities will in turn increase the science return of the NASA Earth observational systems.

In addition, the proposed work will help elevate the NASA’s Obs4MIPs effort, a multi-instrument level coordinated effort to facilitate the use of NASA observational datasets for model evaluations, into a new and high level. The Obs4MIPs effort has become increasingly more visible and recognized as valuable assets by the domestic and international modeling and model analysis communities (e.g., the World Climate Research Program). By supporting a diagnostic model analysis using the Obs4MIPs datasets and CMIP5 model outputs side by side, CMDA will demonstrate the utility of satellite observations in evaluating climate models on a much broader scope and deeper level than existing efforts. The capabilities provided by CMDA will be a significant boost to the NASA observations including the Obs4MIP effort and constitutes an important contribution to the IPCC’s climate assessment activities.

## Technical Approach and Methodology

### Existing Capabilities for CMDA

Over the last several years, we have developed model analysis and data processing tools for several research projects including

* NASA ROSES CMAC project entitled “Parallel Web-Service Climate Model Diagnostic Analyzer” and led by Dr. Lee (PI of this proposal),
* NASA ROSES COUND project entitled “Evaluating CMIP5 models with satellite observations: cloud-climate feedbacks” and led by Dr. Lee (PI of this proposal),
* NASA ROSES COUND project entitled “Utilizing NASA A-Train datasets for IPCC AR5 climate model evaluation” and led by Dr. Jiang (Co-I of this proposal),
* NASA ROSES ACCESS project entitled “Tracking production legacy of multi-sensor merged climate data records” and contributed by Dr. Pan (Co-I of this proposal).
* NASA ROSES MAP project entitled “Cloud transitions in the tropics and sub-tropics: improving the representation of shallow cumulus convection in coupled systems” and led by Dr. Teixeira (collaborator of this proposal),
* NASA ROSES MAP project entitled “Judicious application of satellite observations to evaluate and improve cloud ice and liquid water representations in conventional and muti-scale weather and climate models” and contributed by Dr. Lee (PI) and Dr. Pan (Co-I),
* NASA ROSES AIST project entitled “Online services for correction of atmosphere in radar” and contributed by Dr. Pan (Co-I of this proposal).

The existing tools cover a large scope of data processing capabilities, data provenance technologies, parallel computing technologies, and web service technologies. Some of the capabilities and technologies are developed separately and not linked together for a single information system. We will build upon the existing capabilities and technologies to develop the proposed system CMDA. The existing capabilities accumulated from the prior/current projects that will be leveraged for CMDA are

* Model-data comparison in the common spatial grids and time series;
* Multivariate conditional sampling and correlation for model diagnosis;
* Single or joint variable probability density function analysis;
* Web service technologies to translate research analysis tools to web services;
* Web-browser interface for calling the web services;
* Provenance collection and representation technologies.

### New Capabilities for CMDA

The new capabilities that will be added or enhanced in the proposed system are

* Interconnectivity of individual analysis web services
* Provenance collection capability
* Provenance representation capability
* Provenance-based data search capability
* Scalable job distribution capability

The individual analysis web services are implemented but the interconnectivity of the web services for multi-step analyses is not enabled yet and thus constitutes an important new capability in the proposed system. While the provenance technologies are developed as independent technologies for other applications in our prior project, incorporating them into the proposed CMDA system is a new capability. Individual analysis web services are currently optimized for the use of parallel computing resources but the distribution of multiple simultaneous service calls by multiple users is not optimized in the current system. The proposed system will have a scalable job distribution system to handle the multiple simultaneous calls in a load-balanced way to optimize the use of computing resources.

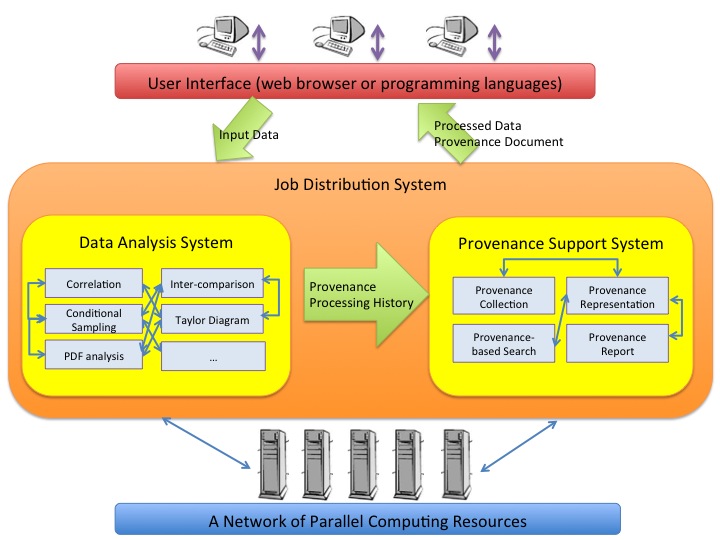
### Data supported by CMDA

The observational datasets to be supported by CMDA are the Obs4MIPs-project generated satellite observation datasets, which are specially prepared for the evaluation of climate models and model predictions. The Obs4MIPs datasets include atmosphere temperature and specific humidity retrieved from AIRS and MLS, sea surface temperature from AMSR-E, long-wave and short-wave radiation from CERES, total cloud fraction from MODIS, precipitation from TRMM, surface wind from QuickSCAT, and cloud, radiation, and atmospheric quantities from DOE’s ARM. More datasets are being prepared and expected to be available in the near future. We will include more datasets as they are available from the Obs4MIPs site.

The model outputs to be supported by CMDA are Coupled Model Intercomparison Project Phase 5 (CMIP5) global circulation models (GCMs) outputs. For the IPCC 5th Assessment Report (AR5) scheduled for publication in late 2013, over 20 climate modeling groups from around the world have joined to design a new set of coordinated climate model experiments, which comprise CMIP5. The CMIP5 model outputs are a valuable and representative asset to assess the capability and limitation of the current climate models. Among the CMIP5 model outputs, decadal hindcast experiment outputs are most relevant for comparisons with observations and model diagnostic studies. Therefore, we will include the decadal hindcast experiment outputs, which are individually prepared for different variables according to CMIP5 output specification.

### Overall Architecture of CMDA

The overall archi-tecture and user interface design of CMDA are illustrated schematically in Figure 1. The architecture of CMDA consists of three main functional blocks: (1) data processing system, (2) provenance support system, and (3) job distribution system. The data processing system is composed of several processing units, indi-vidually wrapped with Web Service interfaces and powered by the Cloud technology to interconnect multi-step service calls with high network communication efficiency. The provenance support system is composed of processing history collection system, processing history representation system, and processing-history based data search system. They will be also wrapped with web service interfaces. The job distribution system will handle the scalable distributions of simultaneous job calls to utilize the computing resources optimally and to reduce the user waiting time for the return of the requested process results. CMDA will utilize the network of parallel computing resources in executing the web services behind the scene.



**Figure 1. Schematic illustration of the architecture and user interface of the proposed CMDA.**

The user interface design of CMDA is tuned to meet the needs of the target users, which are the modeling and model analysis community. CMDA will have both a programming-language (Pyton, Matlab, IDL) interface and a web-browser interface. Climate model analyses are by nature exploratory which requires multiple runs with different input configurations. A programming-language interface is effective for scripting multiple runs and batching the runs. On the other hand, a web-browser interface is useful for instantaneous use without the hassle of local installation and compatibility issues. This flexible dual-interface design will not only lower the learning curve and the adoption barrier of the tool, but also increase the productivity during the period of intense usage. This will make CMDA optimal for an education tool for the JPL’s Climate Science Center Summer School, which plans to use the current version of CMDA for this summer in August 2013.

### Data Processing System of CMDA with Interconnectivity

The data processing system of CMDA has been partly developed under the current ROSES CMAC program. The existing system contains many individual processing units that are made to be separate web services. The new capability to be added in the data processing system is the interconnectivity between the individual processing units. This new capability will allow users to perform a multi-step analysis by calling multiple analysis web services in sequence with proper exchange of input and output arguments and data between the web services.

Let us assume we have a 3D variable that a user wants to first apply a mean value calculation over the vertical dimension to bring it down to a 2D variable, and then conduct some two-dimensional time series analysis over the new 2D variable. In this scenario, our client will need to call two of our services in the order as in the following:

new\_2D\_var = <http://ws.jpl.nasa.gov/services/threeDimMeans?input1=in1&input2=in2>

time\_series\_result = http://ws.jpl.nasa.gov/services/twoDimTimeSeries?data=new\_2D\_var&input3=in3

The “equals” sign (i.e., “=”) in the above represents a web service call. This can be done from various clients, such as a python program, a shell script using curl, a web browser, or a web page running JavaScript programs. The URI (uniform resource identifier) on the right hand side of the equation is said to be in RESTful style, where the scoping information is carried in the URI and the method information is conveyed by HTTP (GET in this case). Examples of scoping information are input arguments such as spatial and temporal range, variable name, and a season of choice.

Notice that in this example two web services are “chained” with the intermediate data, namely “new\_2D\_var,” as the connection, meaning the output of the first service call becomes the input of the second. In a “normal” setting, the client file system becomes the means for intermediate data transfer. That is, the client first saves the variable array to its disk as a file after the first service call, and then uploads the file to the second server as input data for the second service call. A more efficient approach would be to have only the URI of the intermediate data, but not the data itself, be passed back and forth between the client and servers, and let the two servers negotiate between themselves how to transfer the data itself. In this way, the cost saving in data communication can be significant because the two web services usually are deployed with the network link between them much stronger than the connection from the clients, which may be wireless, even when the two servers belong to two different institutions. We will implement the URI-based interconnectivity and communication between web services.

In general, the two CMDA web services can be deployed to two different hardware servers, with no shared file system. To provide an efficient solution to allow users to perform multi-step analyses by calling multiple web services in a sequence across a LAN (local area network), a WAN (wide area network), or a mixed setting, we propose to use the Cloud technology to facilitate a direct and seamless connection among our web services. One possibility would be the Amazon AWS, but the cost of data movement on AWS is the main reason for us to look into open source Cloud solutions that are based on our local on-site storage. We propose to use ownCloud 5, which is an open source, Dropbox like cloud system with a rich set of functionalities and large user base. With ownCloud 5, a client can “drop” a file to a directory for another client to pick up and use. The files on the client are automatically synced with the server. According to the founder of ownCloud, there are more than 800,000 active users of ownCloud as of February of 2013.

The ownCloud 5 is a PHP web application running on Apache on Linux (also on Windows). This PHP application manages every aspect of ownCloud 5, namely user management, plug-in, and file sharing and storage. This is done through a database that is connected to the PHP app and serves the users and maintains control of data. The ownCloud 5 uses a built-in storage abstraction layer to leverage any storage protocol that can be mounted on the server, such as NSF, GFS2, FTP, and WebDAV. It can also mount external cloud storages such as Google Drive and Dropbox, or REST API-based storages. For a system admin, connecting ownCloud 5 to back-end storage is simply mounting on-site storage on the server. One can even create more than one storage location for an ownCloud 5 instance and use LDAP or Active Directory servers to dynamically assign a storage path to each user. The ownCloud 5 integrates into currently prevailing file systems with features in security, monitoring, governance, back-up, activity logging. The users can store files in standard file system formats on most file systems. More importantly, the storage is physically located in our data center, allowing full data protection, secure access, and backups.

The ownCloud 5 can be deployed to physical, virtual, or private cloud servers. This is good news because our CMDA web services are deployed to a VMWare virtual machine. For server side configuration, the ownCloud 5 provides a web portal as a central location for administrative control and configuration of the system and file and folder access, and for managing settings and administrative tasks such as migration and backup. Functionalities can be extended and customized through a set of APIs provided by the ownCloud 5.

In summary, we propose to interconnect multi-step service calls in CMDA using the URI-based communication and the Cloud technology, namely ownCloud 5, to improve network communication efficiency and simple and scalable application-level implementation.

### Provenance Support System of CMDA

Another new capability to be added to CMDA is to keep track of processing history and to search results based on the processing history. A recent advance in provenance collection and representation technologies makes this capability easy to add to an existing information system with complex data processing history. The Provenance Working Group in W3C has been formed to define a language for exchanging provenance information among applications, making these provenance technologies more standardized. Following the standards set by the working group, we will make CMDA more transparent and infusible to other Earth science data information systems that would use similar provenance technologies. The benefit to the users of CMDA is very tangible. The users will have an easy-to-read processing history document attached to each dataset and plot that they create using CMDA and will be able to search their processed datasets and plots using key words in the data processing methods that they used. They will significantly ease the burden of keeping track of many files and plots that they generate during their exploratory studies.

Scientists often run into a situation where “they have a baked cake, but they don’t have the recipe.” They use our web services to analyze data, but after a while, they tend to lose track of what they did to obtain those results that they saved on their disk drives. If the results are passed on to them by their colleges, it is even harder to know exactly what algorithms and parameters were applied. Ad hoc ways, such as long, descriptive file names are often being used to attack the problem, but these are not automatic and hence a burden on the scientists. We propose to use the technology and system of provenance as the means to automatically collect the “recipe information” as the “cake” is being “baked.” Moreover, our tools will have the “recipe information” indexed and searchable.

The provenance of some data file (or, “artifact” in provenance terminology) is simply its history. Examples of the history information include: URIs (or, locations) of input and output data, upstream data source used to produce the output, source code (if open source) or executable used to produce the output, code version, ATBD (algorithm theoretical basis document) used, parameters (e.g., lat-lon bounding box, time window) used for each and every data processing step, and the user of the web service who produced the output.

The provenance mathematical model includes three roles, namely, Artifact, Process, and Agent, and their causality relationship (that is, who is the effect caused by what). In the world of data analysis, an Artifact is a data product, a Process is the execution of a data processing program, and an Agent is a human user or an institution.

There are five causality relationships in the abstract provenance model: used, wasGeneratedBy, wasControlledBy, wasTriggeredBy, and wasDerivedFrom. For example, when we say a Process “used” an Artifact, we mean some data are the input to a program. When we say an Artifact “wasGeneratedBy” a Process, we mean the data are the output from a program. When we say an Artifact “wasDerivedFrom” an Artifact, we mean some data is the upstream source of another data. And when we say a Process “wasControlledBy” an Agent, we mean a user ran a program. It is perceivable that these roles and their relationships are sufficient to describe the history of any data product or analysis result that our web services produce.

Graphically and in a machine usable way, the causality relationships can be conveniently represented as triples (subject, predicate, and object) in RDF (Resource Description Framework), a semantic web standard model for data interchange. In the example of “a 2D plot was generated by a 2D Map Program”, “a 2D plot” is a “subject”, “wasGeneratedBy” is a predicate, and “a 2D Map Program” is an “object”.

In order for the provenance information from our data analysis web services to be collected and ingested into a searchable, browsable, and citable provenance database, we will leverage the provenance web services developed at JPL for the ACCESS-09 funded project “Tracking Production Legacy of a Multi-sensor Merged Climate Data Record (PI: Hook Hua).” The Co-I Dr. Pan was a core developer of the provenance web services (refer to as JPL Provenance System from here on). Figure 2 illustrates the architecture of the system. Using the proven technologies and existing system, we will implement the provenance support system in CMDA with the following steps:

1. Instrument our analysis web service code to generate a provenance log to collect provenance data for each session associated with a client request. The following lines are examples of instrument code:

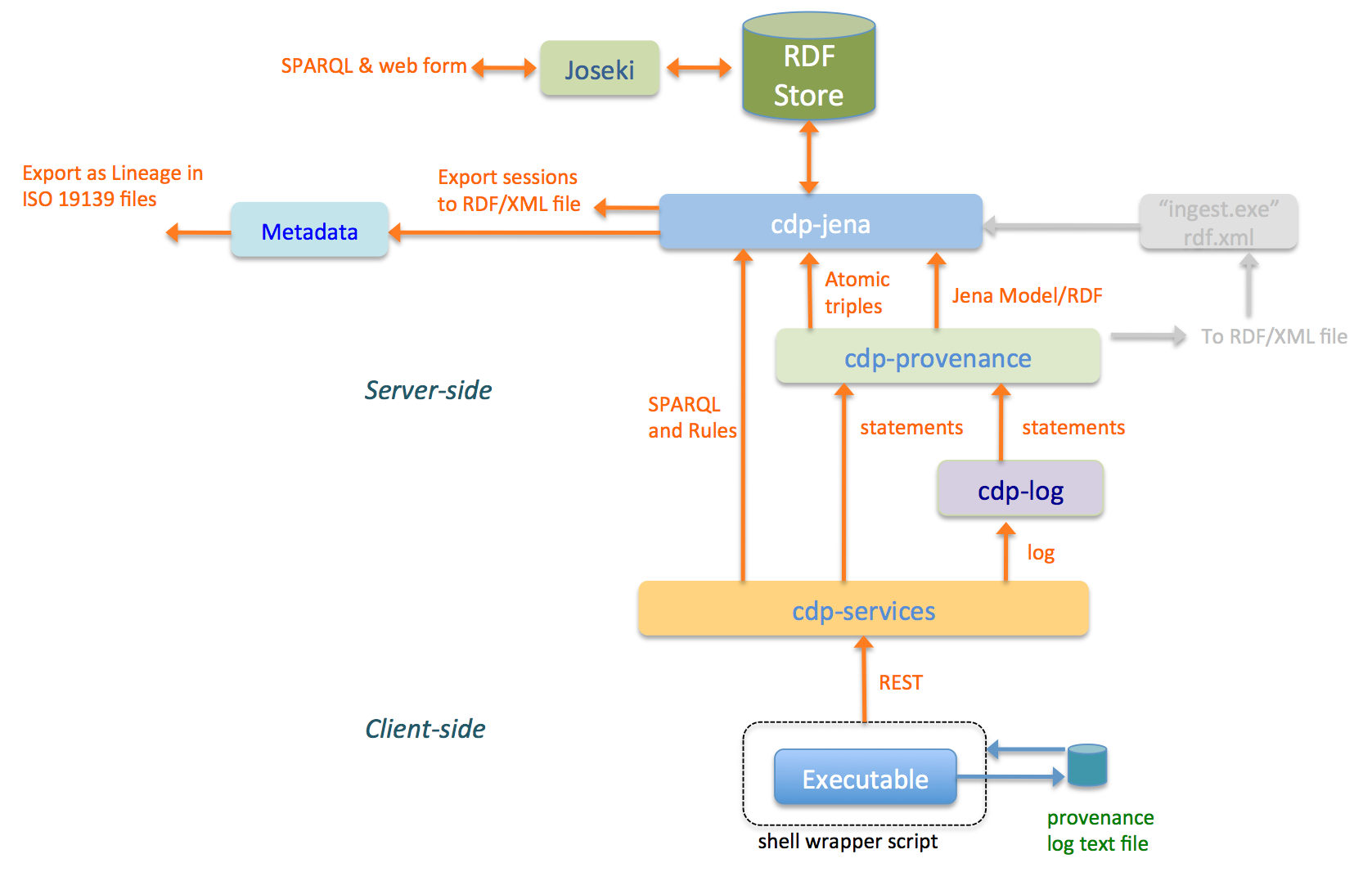
processStart(‘2DVarMapService’, ‘/home/cmac/service/twoDimMap.py’, ‘v2.1’)

processUsedArtifacts(‘data:CMIP5’,[‘/home/cmac/data/ts\_Amon\_HadGEM2-A\_amip\_ 197809-200811.nc’], ‘input’)

processUsedArtifacts(‘parameters:GEO:TEMP’,[‘-30:30, -10:25’, ‘Winter’], ‘input’)

processGeneratedArtifacts(‘image’, [‘/home/cmac/result/nasa\_amsre\_tos\_199001\_201212\_Annual.jpeg’], ‘output’)

processEnd(‘2DVarMapService’)



**Figure 2. The architecture of the provenance web services developed at JPL for the ACCESS-09 funded project “Tracking Production Legacy of a Multi-sensor Merged Climate Data Record.”**

These lines are inserted into our CMDA service code wherever applicable. For example, the first line (processStart()) is inserted where the program twoDimMap.py is starting, the second line (processUsedArtifacts()) is inserted to where input data is fed to the program, the third line (processUsedArtifacts()) is inserted to where input parameters are taken, the fourth line (processGeneratedArtifacts()) is inserted to where the output image is generated by the program, and finally the fifth line (processEnd()) is put where the service is ending for the current session;

1. Call the analysis web services to upload their provenance log created in step (1);
2. The analysis service triggers the provenance service to convert the log into triples (the semantic web representation of the same information);
3. The provenance service triggers the “jena” service to put the triples into a semantic web database called RDF Store. Jena is Apache’s Java framework for building semantic web apps;
4. The RDF Store can be queried using SPARQL (RDF Query Language) via Joseki (a SPARQL server). The provenance metadata is ingested into a relational database (Apache Solr) after being applied domain rules and classified. This enables faceted navigation of the provenance data. For example, one can constrain two facets, a user name and a time range, to find out all the data products that this user has created during the time period. Once a data product is found, one can further browse its pedigree to find out what source data products were involved in making it, what parameters were used, who created it at what time, what algorithm in which version of the code was used to generate the data, etc.

In the above steps (1) and (2), we will revisit the CMDA analysis application code, decide what level of details we want to collect as provenance on behalf of our clients, and insert code to generate provenance log. In step (5), we will decide where to store the provenance and how our clients should use it. The possible choices are one or more of the following: (A) Use the entire existing JPL provenance system, including its RDF Store and Solr database. The advantage is that the users get to faceted browse all analysis results and their pedigree charts; (B) Shuffle the provenance associated with a result file into its metadata section. The format can be more human readable like the log file, or more computer readable like the triples. If the metadata area is not the best location for provenance, we can create a separate text file with the same metadata, and have these metadata files be distributed and co-located along with the actual analysis results. This option requires some coding efforts; and (C) Develop a light-weight desktop browser, reusing the code that is already developed for the JPL provenance system, that gives the users the ability to search and browse their own analysis results in their local environment. The advantage of this option is that the privacy of algorithms and approaches is respected before they are openly published.

### Scalable Job Distribution System of CMDA

Currently, CMDA individual analysis web services are optimized for the use of parallel computing resources but the distribution of multiple simultaneous service calls by multiple users is not optimized. CMDA will be used as an education tool for the Summer School organized annually by the JPL Center for Climate Science (details in Section 1.3.9). A heavy and interactive use of CMDA is expected during the Summer School. And, as the user base of CMDA grows, many simultaneous web service calls will overload the web server if scalable job distribution is not supported. Therefore, a scalable job distribution capability will be a critical enhancement over the current version of CMDA. There are many ways to achieve load balancing for web pages and web services.

We realize there is no “one-size-fits-all” solution and hence propose to apply three different approaches to our CMDA web services and determine the best approach for CMDA. For fast development and testing, the initial implementation of these approaches will be done quickly to check their performance. After the performance is compared, we will determine the best approach and implement only the best one thoroughly.

**DNS Load Balancing:** The first approach uses “DNS load balancing.” The key idea is to deploy multiple identical services at different IPs and route service requests from the clients evenly to those services. To do this, we need in our DNS (Domain Name System) service multiple “Address Record” to be associated to the single host name that the clients see. An Address Record points a domain or subdomain to an IP address. For example, 137.78.73.106 is the normal IP of the CMAC web server (cmacws.jpl.nasa.gov), but we can have multiple IPs, e.g., 137.78.73.106, 137.78.73.107, 137.78.73.108, each being a server hosting identical services, all associated to this server. When the clients access our customized DNS server, a list of all the Adress Records are returned, but the order of the list varies for each request, so the clients can get services from any one of these IPs. This brings us some level of load balancing and fault tolerance. The algorithms used to determine the order of the A record list are usually round robin or geographically specific.

The DNS approach to load balancing is easy to implement, but this approach has it inherent drawbacks. Two examples are, the task distribution is not based on current load status of the servers, and the client side IP address caching and reuse may defeat the purpose. Examples of open-source DNS servers providing load balancing and high availability are HAProxy, BIND, and lbnamed.

**Proxy Technology:** The second approach uses “proxy technology.” The basic idea is for a proxy server to make requests to actual back-end servers behind the scenes on behalf of the client. The client only knows the existence of the proxy server but not the multiple back-end servers behind it. Conversely, there is a “reverse proxy” technology from the standpoint of the actual back-end servers, because all they know about is that they are providing services to the proxy server and they have no knowledge of the real client out there.

An example of the open-source, proxy based software package is called the Zen Load Balancer. In the following, we use the steps to configure Zen Load Balancer to demonstrate how the proxy technology works to achieve load balancing: (1) Install Zen Load Balancer from a VirtualBox image. The guest OS is Debian (a free Linux distribution similar to Ubuntu); (2) Create a virtual IP for the physical IP of the above installation; (3) Create a farm, assigning the above virtual IP address and a port number (e.g., 80) to it. Add the IP addresses of the back-end servers to the farm. Now the requests sent to the URL will be forwarded to the back-end servers; (4) Create a cluster using two farms, one serving as the master and the other backup. This enables “failover,” meaning if the master farm is down for any reason, the backup will be automatically turned into the new master and start serving after a very brief break.

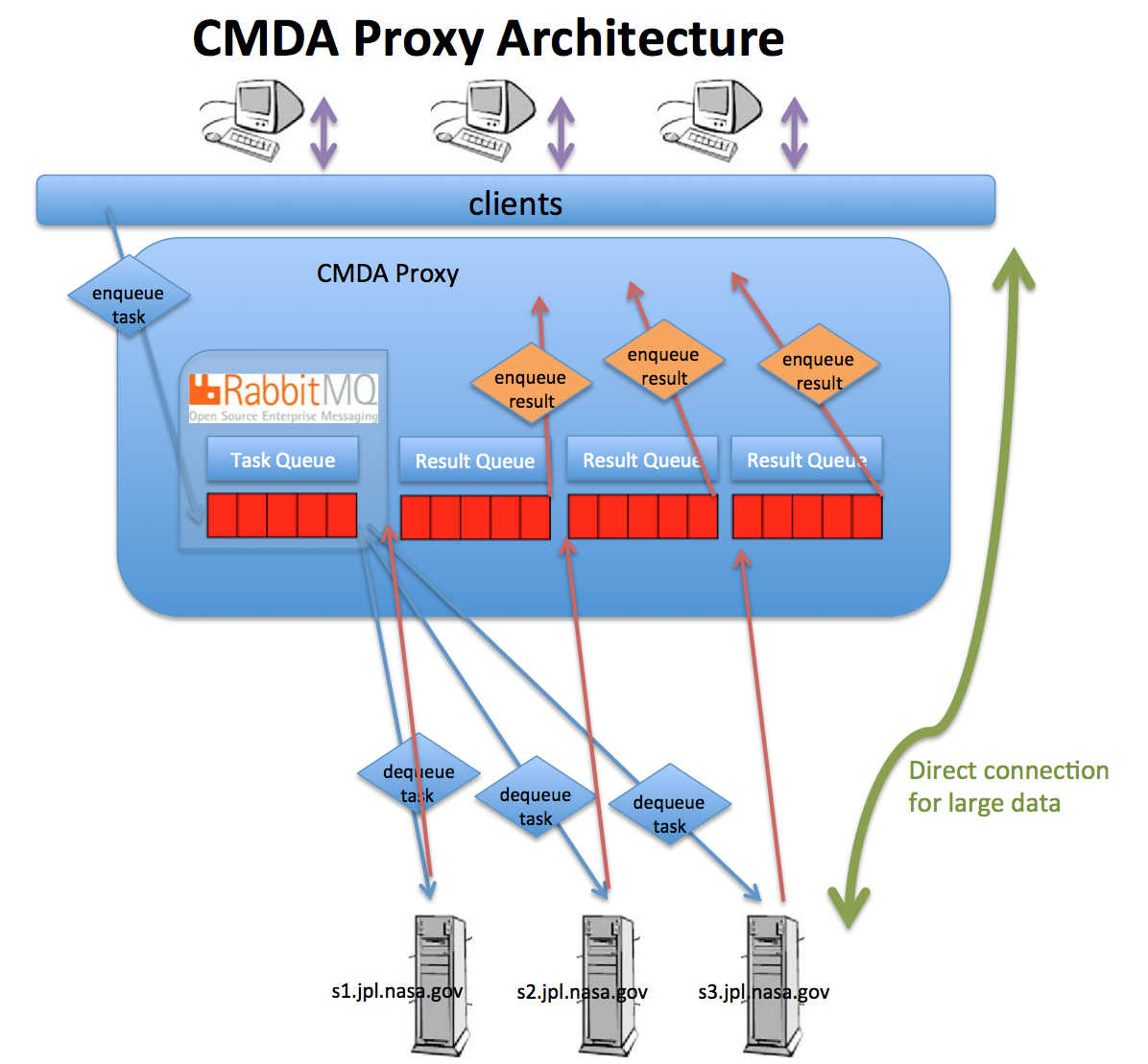
Zen Load Balancer works with a reverse proxy technology. It forwards the connection to the back-end servers, changing the client IP with the farm’s virtual IP. Therefore, the back-end servers do not know the IP of the client, and all communications between the client and the back-end servers go through the proxy, which can become a bottleneck for performance.

Another open-source proxy solution is by using Apache along with the modules mod\_proxy and mod\_proxy\_balancer. It provides simple load balancing. The hardware configuration consists of a server to be used as the load balancer and two or more servers hosting the web services. The configuration of the load balancer is through Apache’s Virtual Host configuration. In the <Proxy> tag, one can name the “balancer,” i.e., the URL that the clients will see, and add as many as “BalanceMember”s as desired, which are the back-end servers. The simplest balancing algorithm that can be set is “byrequest,” which means Round Robin.

The above two open-source solutions each have an inherent drawback. The DNS solution depends on how different kind of clients handle (cache, reuse, etc.) multiple IPs, and a Round Robin distribution does not guarantee balanced load. Some solution, such as lbnamed, improved by polling load information, but what is polled, i.e., load averages, total users, console users, and boot time, is only a rough estimation of the actual load on a server. The proxy solution is not scalable in handling client-server communication simply because all data between all the clients and the back-end servers go through the proxy server.

**Pull and Queue based Proxy:** The third approach involves developing our own balancer proxy based on the pull strategy built on top of a queuing mechanism. Figure 3 depicts the concept design of the CMDA job distribution system. Inside the system, there are queues (“first in first out” mechanism) to link the “producers” and “consumers.” The “Task Queue” is where the back-end servers compete for new tasks received from the clients and enqueued by the proxy. The results from each and every back-end server are sent back to the proxy into the queues corresponding to the individual back-end servers. In this way, the proxy is able to return the results to their corresponding clients.

There are two advantages in this design that will overcome the two drawbacks of the two open-source solutions mentioned above: (1) The back-end servers “pull” to get new tasks from the Task Queue. This ensures true load balancing because idling servers are the first to dequeue the Task Queue to get new tasks if any; and (2) Only meta-data is communicated through the queues. For example, if a back-end server produces a large binary data file or image, only the URIs of these large results are enqueued into its result queue. These URIs point directly to the IP of the back-end server, so the requesting client can directly get the large results from the server, by-passing the proxy altogether. This makes the design scalable.



**Figure 3. The architecture design of the CMDA Scalable Job Distribution System.**

For the queuing mechanism we propose to use RabbitMQ, an open-source message broker software package that implements the Advanced Message Queuing Protocol (AMQP). The Co-I Dr. Pan has used this to construct software pipelines for a JPL project named MIRO.

### Scientific Use of CMDA

We have identified two scientific applications that will be used as a demonstration of the scientific use of CMDR in the context of climate model evaluation.

**(1) Evaluating representations of atmospheric moist process in the global models**

We will apply CMDA to evaluate the moist process parameterizations of the CMIP5 GCMs. The fidelity of climate and weather models depends critically on the representation of clouds and precipitation. It is very evident that large disagreement exists in clouds and precipitation represented in GCMs, and many of the uncertainties mainly originate from inadequate representations of atmospheric moist processes, such as moist convection, precipitation formation processes, sub-grid scale dynamics, hydrometeor contents, microphysics, and the associated radiation fluxes. The processes governing convection and precipitation formation involve a wide range of temporal and spatial scales. It is therefore a great challenge to accurately represent these interactions in atmospheric models, as some of the key processes cannot be explicitly resolved at the current resolution of global models. Parameterizations need to be carefully developed and extensively evaluated to account for the sub-grid processes. The synergistic use of the global observations across multiple sensors with proper co-location and merging can provide comprehensive and detailed information for evaluating the moist process representations in GCMs.

**(2) Evaluating representations of atmospheric radiation processes in the global models**

We will apply CMDA to co-locate and conditionally sample global satellite observation datasets (i.e. Obs4MIPs datasets) and CMIP5 model outputs for the evaluation of the radiation fields in the models. Representing atmospheric radiation interactions remains a pressing challenge to reduce and quantify uncertainties associated with present climate and climate change projections [Randall et al., 1991; 2007; Stephens et al., 2005]. Conventional GCMs (e.g., CMIP3/CMIP5 models) exhibit persistent systematic biases such as the overestimation of downward shortwave, underestimation of downward longwave at the land and ocean surfaces, and outgoing longwave at the top of the atmosphere in the precipitating and convectively active regions (e.g., ITCZ, Warm pool). These biases might impose strong impacts on surface wind stress, SSTs, sea surface height, land surface air temperatures, soil moisture/temperatures, soil evaporation as well as on the atmospheric and oceanic circulations in the present climate and climate projection. Co-located and conditionally sampled satellite retrievals from multiple sensors and platforms will be a rich dataset to provide a global-scale distribution and long-term variability of these highly coupled parameters and to trace the impact of the model biases in the radiative process on the other climate parameters.

### Educational Use of CMDA

The Center for Climate Sciences (CCS) in JPL is planning to use the current version of CMDA as an educational tool for its summer school to be hosted in August 2013. The summer school annually brings together about 30 graduate students and postdocs from around the world to engage with premier climate scientists from JPL and elsewhere. Functional and user interface requirements for the educational tool have been defined according to its curriculum and expected use. We plan to continue this educational and outreach use of CMDA in the ACCESS award period. We will utilize this opportunity to promote the community awareness of CMDA and cultivate its user base.

As an example of the planned use of CMDA in summer school exercises, the students will be asked to use the monthly mean CMIP5 model outputs and Obs4MIPs datasets to compute and plot the zonal mean total cloud fractions and report model systematic biases if exist. The students will be also asked to consider the observational uncertainty and limitation and their effect on the comparison with model outputs. Another example is to study the relationship and correlation between cloud water content and precipitation rate or SST in the context of dynamic and aerosol conditions. The data analysis web services in CMDA provide capabilities needed for such analyses and visualizations.

The user interface for the education tool will be a web browser based interface so that the initial learning curve is minimal, the compatibility with any operating systems of student machines is met, and no local installation of libraries or programs is needed. These advantages are found to be very critical from the previous experience of the summer school where an IDL based tool was used and its use was challenged by compatibility issues and steep learning curves. The web-browser based interface with web services providing analysis engines solves all of the problems encountered by the previous tool.

### Tool/Technology Life Cycle and Operations Concept

We will take the following multiple complementary approaches to achieve an effective total life-cycle development and sustainable operations:

* **Proven Technologies**: We will leverage only proven technologies and open source packages to minimize the development cost. The proposed work is based on the proven technologies such as the Web Service technology, the Cloud technology, the Provenance technology, and the Job Distribution technology.
* **Earth Science Projects**: The proposal team members are involved in several NASA Earth Science Research Programs including MEaSUREs, MAP, COUND, and CMAC (details in Section 5). We will collaborate with the other projects to leverage the scientific and technological experiences and to cross-promote the products (either science, datasets, or tools) of the projects.
* **Educational Use**: We will use CMAC as an education tool for the JPL CCS Summer School (details in Section 1.3.9). The actual use of the tool during the proposed work period will significantly strengthen the usefulness of CMAC. We will use this outreach opportunity to promote the tool in the community. User feedbacks we will receive from the Summer School students will guide directions to polish the tool to be more useful for the community.
* **Open-source Deployment**: We will create an open source project for CMAC early in the ACCESS award period with the current version of CMAC in order to engage the open source community to use and maintain the capabilities of CMAC. We will release a new version of CMAC each time when key milestone scheduled for the proposed work are met. We will follow best practices for code documentation in order to make the open source project successful.
* **Modeling and Model Analysis Community**: The Co-I Dr. Jiang and Collaborator Dr. Teixeira are actively involved in many modeling and model analysis programmatic entities (details in Section 4). With the connections, we will engage the modeling and model analysis community to the proposed project, and promote the community awareness of CMDA and the growth of the CMAC user community.

## Perceived Impact to State of Knowledge

Information systems that facilitate individual NASA data product discovery and processing services are becoming more available (e.g. GCMD, ECHO, ESG, Giovanni). However, information systems that support the comprehensive processing of multi-source data products and the synergistic use of multiple-instrument measurements for model evaluations and diagnoses are limited in availability and insufficient in capability. Most of the existing climate data analysis tools that are available for a community use (e.g. PCMDI’s CDAT, NCAR’s CCMVal) focus on model output analyses and visualization and lack the capability to process multi-instrument observational data in combination with model outputs (e.g. co-locate and conditionally sample multiple-instrument data to one another, and use them to evaluate and diagnose model performance). As expected, there exist many in-house research tools for such analyses but they are not designed for a community use. Those tools are highly domain specific, thus not general enough for applying to other investigations, and are characterized by low software quality and limited reuse and sharing.

The proposed system CMDA will provide the modeling and model analysis community with capabilities they need for model-data intercomparisons and model diagnostic analyses. CMDA will enable multi-source dataset processing and model performance diagnostic analysis based on multi-variate, physics-based, phenomenon-oriented comparisons and analyses using satellite observational datasets and reanalyses. The proposed system will be complementary to those climate model analysis tools currently available to the community such as CDAT and CCMVal. CMDA is becoming a community tool as it will be used as an educational tool for the summer school organized by JPL CCS this summer. With the excellent outreach opportunity, it will produce immediate and tangible benefits to the young generation of the modeling and model analysis community.

Scientifically, the multi-variate model-to-data comparisons and analyses are critical in understanding the causes of model errors and biases and improving climate model performance for climate sensitivity studies and predictions. A simple one-parameter comparison with a traditional model analysis tool can illustrate the symptomatic biases and errors in models but cannot trace back to the cause of the biases errors. For example, a study of the instantaneous interaction and relationship between physical variables in the context of its environmental condition using the conditional sampling method will be needed to gain new insight into possible errors in model physics and parameterizations. CMDA will provide capabilities to conduct such a study.

Technologically, CMDA will demonstrate the first implementation of an information system that utilizes parallel, distributed web services with interconnectivity, provides provenance capabilities, and deliver a scalable job distribution. The individual technologies exist but the technical challenges will be to incorporate them into one system with efficient connections and communications. Approaches we will take to implement these components into a single system will represent a blueprint for future Earth science information systems that will have these multifaceted capabilities.

The new capabilities to be added to CMDA will have very tangible benefits to users. We recognize that multi-sensor, multi-parameter, and multi-variable analyses are difficult; multi- source datasets are rarely designed to work together, science analyses are usually very “free form,” exploratory with many “what if” scenarios, and processing algorithms are complex and ever changing. The data analysis system with interconnectivity will enable a multi-step analysis involving sequential multiple web service calls without manual interruption for file and input and output exchanges. The provenance support system will significantly ease the burden of keeping track of the processing history of many datasets and plots that the users generate during their exploratory studies by producing provenance that is human readable, searchable, browsable, and citable. The scalable job distribution system will provide a reliable and optimal use of the computational resources that are seemingly never sufficient for all the computational needs for the users.

## Relevance to Element Programs and Objectives in the NRA

The proposed work responds to one focus area of this 2013 ACCESS NRA – ***Tools that improve and expand the accessibility and usability of NASA’s Earth Science observational data for the modeling and model analysis communities***. The proposed system will provide a flexible and efficient computational means to perform multi-variate model-to-data comparisons and analyses, to understand the causes of model errors and biases, to improve climate model performance for climate sensitivity studies and predictions. Furthermore, it will provide (1) the capability of interconnecting individual analysis web service, (2) the capability to trace and search processed datasets through data processing history, and (3) the capability of scalable job distribution to optimize the use of computational resources. The multifaceted capabilities will greatly increase users’ ability and efficiency to harvest the scientific content of the Earth science observational data and reanalysis datasets.

## Work Plan

In Year 1, we will first develop the scalable job distribution system of CMDA and test and benchmark its performance in the scalability. This task is scheduled first in order to make CMDA reliable for its education use for the JPL CCS Summer School scheduled in August 2014. Next, we will enhance the existing data analysis system of CMDA by adding the interconnectivity capabilities provided by the Cloud technology. We will experiment several server/client configurations to achieve optimal network communication efficiency and at the same time simple application-level implementation, which will allow the extension and update of the tool in the future easy. We will also create an open source project for CMDA early in Year 1 and release the latest version of CMDA to the open source community at the end of Year 1.

In Year 2, we will develop the provenance support system of CMDA. The first task for the provenance support system is to instrument the existing analysis web service code to generate a provenance log. Next, we will adapt and apply the existing provenance system (developed for the ACCESS-2009 project: PI Hook Hua) to the proposed tool CMDA. We will adapt a provenance representation service that convert the provenance log into triples and convert the triples into a semantic web database, and adapt a provenance search system that enables faceted navigation and search of provenance data. We will release the latest version of CMDA source code to the open source community toward the end of Year 2. We will also document the technical approaches we took to develop CMDA and publish in a peer-reviewed journal and present the result to the Earth science information system development community.

During the two-year work period, we will demonstrate the education use of CMDA in two summer schools organized by JPL CCS. CCS will provide separate funding to develop a curriculum and to customize the user interface and functionality of CMDA for the education use. The work for the summer school and the proposed work will be coordinated so that the key milestones and capabilities for the proposed ACCESS work are aligned with those for the CCS summer school work. The scalable job distribution system will be demonstrated in the first summer school of the two. The data analysis system enhanced with interconnectivity will be demonstrated in the second summer school. Because the provenance support system will be complete toward the end of the ACCESS award period, its capability will be demonstrated in the next summer school after the work period.

**The Co-I Dr. Pan will participate in the Technology Infusion Working Group (TIWG), which is one of Earth Science Data System Working Groups (ESDSWG). Dr. Pan will bring his expertise in the state-of-art web service, distributed computing, and provenance technologies to TIWG and contribute to TIWG’s activities in defining processes to infuse new technologies into the evolving Earth science data systems.**

### Key Milestones



**Figure 4. Work schedule of the proposed work with key milestones**

Five key milestones are planned for the proposed work:

1. Implementation of scalable job distribution system;
2. Implementation of data analysis system with interconnectivity;
3. Implementation of provenance support system;
4. Implementation of fully integrated CMDA;
5. Demonstration of education use of CMDA.

Figure 4 shows the workflow to achieve the key milestones (shown as diamonds).

### Management Structure and Team Member Contributions

**Management Plan:** Dr. Seungwon Lee, the PI of the proposed investigation, is responsible for the quality and direction of the proposed research and the proper use of all awarded funds. She is also responsible for all technical, management, and budget issues and is the final authority for this task. The Co-Is will provide all the contributions needed to ensure that she can effectively manage the entire task. The proposal team will host a weekly meeting to discuss task progress and coordination. The proposal team has been working together for several years and has developed an efficient working relationship from the current/prior NASA research grants.

**Dr. Seungwon Lee** of JPL, PI, will supervise the work described in this proposal. She has primary responsibility for defining the application scope of the proposed system and the requirements of its capabilities by seeking inputs from the targeted research community. By leveraging her combined experience of both the information technology development and the Earth science investigations, Dr. Lee will facilitate effective interactions between the Earth scientists of the proposal team (Dr. Jiang and Dr. Teixeira) and the information technologists of the team (Dr. Pan and Dr. Zhai).

**Dr. Lei Pan** of JPL, Co-I, will be the lead architect and developer of the proposed information system. He is the information technology expert in the proposal team. He has designed the architecture of the existing CMDA, and developed and implemented it. He has extensive experience in numerical methods, large-scale software for computer-aided engineering, high performance computing applications, distributed parallel programming methodologies, and Web Service technologies. He will be responsible for the architecture, design and development of CMDA.

**Dr. Chengxing Zhai** of JPL, Co-I will be the lead developer of the data analysis system of CMDA. He has developed many model analysis tools for observational data processing, model-data intercomparisons, which are the building blocks of the data analysis system of CMDA. He will work together with Dr. Pan to implement the interconnectivity of the data analysis system and the instrumentation of the data analysis system for provenance generation.

**Dr. Jonathan Jiang** of JPL, Co-I, will lead the effort of applying the developed CMDA to scientific investigations, validating results, and demonstrating scientific values of CMDA. He is the lead scientist of the proposal team. He has led and contributed to several important publications in using satellite datasets for model evaluations and model-data comparisons [e.g. Jiang et al. 2004, 2010; Li et al. 2005a, 2005b, 2007; Su et al. 2006b, 2010b; Waliser et al. 2009]. He will leverage the expertise gained from the research projects to maximize the scientific usefulness of CMDA for our target users. He is also the instructor of the JPL CCS summer school who will use CMDA as an educational tool to demonstrate the use of satellite data for climate studies and model-data intercomparisons. He will provide the scientific inputs to customize CMDA for the summer school use.

**Dr. Joao Teixeira** of JPL, Collaborator, will serve as the main liaison between this proposal team and the climate modeling and model analysis community. He has extensive research experience in climate model parameterization of the atmospheric boundary layer and evaluation of the climate model parameterization. He is the deputy director of JPL Center for Climate Science (CCS). He also holds a leading role in several international weather and climate programmatic entities including Process Studies and Model Improvement Panel in US CLIVAR, GCSS/WGNE Pacific Cross-Section Intercomparison Working Group for WCRP, and GEWEX Cloud System Study Scientific Steering Committee. With the leadership roles, he will cultivate a close interaction between the proposal team and the climate modeling and model analysis community and promote the community awareness of CMDA and the growth of the CMDA user community.

## Data Sharing

The proposal team has reviewed the Earth Science Data Information Policy and the Data Rights and Related Issues documents referenced in the NRA. The team agrees to, and will abide by, the provisions of this policy. The plan for dissemination and distribution of the tools and technologies to be developed under this proposal has been described in Section 1.2.10 Tool/Technology Life Cycle and Operations Concept, and conforms to this Policy.

# References and Citations (no page limit)

All references and citations given in the *Scientific/Technical/Management Section* must be provided using easily understood, standard abbreviations for journals and complete names for books. It is highly preferred but not required that these references include the full title of the cited paper or report.

From *Guidebook*, p. 2-9.

Include only the references cited in this proposal.

Type reference here; use “Reference\_RS12” style. Type text here Type text here Type text here Type text here Type text here Type text here Type text here Type text here.

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# Acronyms

GEWEX Global Energy and Water Exchange Project

# Biographical Sketches

## Principal Investigator

**Dr. Seungwon Lee**

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**EDUCATION**

Ph. D. Physics Ohio State University 2002

M.S. Physics Ohio State University 2001

B.A. Physics Seoul National University 1995

**RELEVANT EXPERIENCE**

Dr. Lee has over 15 years of experience of research and technology development in computational physics, dynamic systems, statistical data analysis, optimization algorithms, information systems, and high performance computing systems for science and engineering applications. She is a PI of the NASA ROSES COUND project for evaluating CMIP5 models for cloud-climate feedbacks, and a PI of the NASA ROSES CMAC project for developing a web-service based climate model analyzer. She is a Co-I of the NASA US-Rosetta for MIRO instrument forward and retrieval model development. She led several research projects as a PI under the JPL internal Research and Technology Development program, which did innovative research on Earth science data summarization with advanced clustering algorithms, evolutionary optimization methods for spectral retrieval problems and trajectory design, parallel computing for Satellite Orbit Analysis Program. She served as a Co-I of a NEWS-data web services project (led by Mr. Hook Hua) under the NASA ROSES ACCESS program and a Co-I of EPISODE project (led by Dr. Jeffrey Jewell) under the NASA ROSES AISR program and. She also contributed to other NASA research projects including the development of a co-location tool for A-Train data and ECMWF outputs, the characterization of cloud properties using NASA’s observational data, development of cloud-related parameterizations for climate models, the development of a statistical method to quantify the relationships between passive radiometer and active radar measurements for hurricane studies, the development of radiative transfer models for water-level populations of cometary coma for the Microwave Instrument for Rosetta Orbiter, and the development of quantification of trace chemicals with a gas chromatograph and mass spectrometer system for Vehicle Cabin Atmosphere Monitor. She is the first author or co-author of over 40 refereed publications.

**PROFESSIONAL EXPERIENCE**

**2003 – present:** Researcher – High Capability Computing and Modeling Group

Science and Technology Directorate, Jet Propulsion Laboratory, Pasadena CA

**2002 – 2003**: Postdoctoral Fellow, Department of Chemistry

University of California, Berkeley CA

**SELECTED PUBLICATIONS**

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## Co-Investigators

**Dr. Lei Pan**

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**RELEVANT EXPERIENCE**

Over 20 years of experience of research and technology development in numerical methods, large-scale software for computer-aided engineering, high performance computing applications, distributed parallel programming methodologies, Web Service technologies, and applying provenance in the semantic web. He had been with The MSC Software Corp., CA for 6 years and led several projects that built software components for MSC.Patran and MSC.Nastran. He led or participated JPL R&TD projects aimed at porting legacy software packages, such as ROI PAC, IMOS, and GEOS-Chem, to modern cluster computers. He is the original developer of the concept and methodology of Navigational Programming. He architected the ATrain co-location tool, and developed its core algorithm – the linear nearest neighbor search. He is a core developer of the RESTful web services for correcting atmosphere effects in radar, a 3-year NASA ROSES AIST project, a core developer of a 2-year ACCESS Provenance project, and an architect and core developer of a 2-year CMAC project, which serves as the basis of this work.

**EDUCATION**

• Ph.D., Information & Computer Sciences, University of California, Irvine (UCI), 2005

• M.S., Information & Computer Science, University of California, Irvine (UCI), 2002

• M.S., Mechanical Engineering, Rensselaer Polytechnic Institute (RPI), Troy NY, 1996

• M.S., Mechanical Engineering, Zhejiang University (ZJU), Hangzhou China, 1989

• B.S., Mechanics, Peking University (PKU), Beijing China, 1987

**PROFESSIONAL EXPERIENCE**

2005 – present: Senior Member of Technical Staff, Jet Propulsion Laboratory

2003 – 2005: Member of Technical Staff, Jet Propulsion Laboratory

1996 – 2002: Senior Software Engineer, The MSC Software Corp., Santa Ana, CA

1992 – 93: Chief Public Relations Rep., Hangzhou Int’l Public Relations Inc., Hangzhou, China

1990 – 1992: Software Engineer, National Institute of Project Planning, Hangzhou, China

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H. Hua, B. Wilson, G. Manipon, L. Pan, and E. Fetzer, "Improving the Understanding of Provenance and Reproducibility of a Multi-Sensor Merged Climate Data Record," Abstract, IPAW 2012 - 4th International Provenance and Annotation Workshop, Santa Barbara, CA, June 19-21, 2012.

L. Pan, J. Xue, M. B. Dillencourt, and L. F. Bic, “Toward automatic data distribution for migrating computations,” International Conference on Parallel Processing (ICPP 07), Xian, China, Sept., 2007.

L. Pan, M. K. Lai, M. B. Dillencourt, and L. F. Bic, “Mobile pipelines: Parallelizing left-looking algorithms using navigational programming,” in Proceedings, 12th Int’l Conference on High Performance Computing - HiPC 2005, ser. Lecture Notes in Computer Science, Dec. 2005.

L. Pan, W. Zhang, A. Asuncion, M. K. Lai, M. B. Dillencourt, and L. Bic, “Incremental parallelization using navigational programming: A case study,” in Proceedings of the 2005 Int’l Conference on Parallel Processing (ICPP 2005), Oslo, Norway, June 2005, pp. 611–620.

L. Pan, M. K. Lai, K. Noguchi, J. J. Huseynov, L. Bic, and M. B. Dillencourt, “Distributed parallel computing using navigational programming.” Int’l Journal of Parallel Programming, vol. 32, no. 1, pp. 1–37, 2004.

**Dr. Jonathan H. Jiang**

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Phone: 818-354-7135 Jet Propulsion Laboratory  
Fax: 818-393-5065 Pasadena, CA 91109

**Education**

* Ph.D. in Atmospheric Physics, York University (1996)
* M.Sc. in Astrophysics, York University (1991)
* B.Sc., in Astrophysics, Beijing Normal University (1985)

**Professional Experience**

* **Research Scientist** (2004-), Jet Propulsion Laboratory, California Institute of Technology, U.S.A.

Major responsibilities include:

* Funded Research Projects:
* NASA Aura Science Team: Principal Investigator (2011-)
* NASA COUND Program: Principal Investigator (2011-)
* NASA MAP Program: Principal Investigator (2013-)
* NASA CloudSat/CALIPSO Science Team: Co-Investigator (2009-)
* NASA ACMAP: Co-Investigator/Principal Investigator (2002-2010)
* NASA IDS Program: Co-Investigator/Principal Investigator (2007-2010)
* Aura MLS project: Lead, MLS upper tropospheric measurements summary/inspection (2005-)
* **Scientist** (2001-2003), Jet Propulsion Laboratory, California Institute of Technology, U.S.A.

Major responsibilities: MLS cloud forward model development, cloud retrieval using satellite obs.

* **Caltech Postdoctoral Scholar** (1999-2000), California Institute of Technology, USA
* **Research Associate** (1998-1999), Université du Québec à Montréal, Canada
* **Postdoctoral Research Fellow** (1996-97), McGill University, Canada

**Selected Awards**

* **NASA Exceptional Achievement Medal** *for pioneering a new approach to quantifying the impact of air*

*pollution on clouds and climate, through combing observations from multiple NASA satellites (2010)*

* **NASA TC4 Team Achievement Award** *for outstanding contribution to NASA TC4 field experiment (2008)*
* **NASA Group Achievement Awards** *for contribution to Aura Microwave Limb Sounder Project (2005, 2006)*
* **NASA Space Act Award** *for significant contribution to MLS cloud forward model and level 2 software (2005)*

**Scientific Publications** **(89 peer-reviewed scientific publications to date; 2283 citations; H-Index 29)**

* Su, H., **J.H. Jiang**, Tropical Clouds and Circulation Changes During the 2006-07 and 2009-10 El Niños, *J. Climate*, 26, 2, doi:10.1175/JCLI-D-1200 152.1, 2013.
* **Jiang, J.H.**, et al., Evaluation of Cloud and Water Vapor Simulations in CMIP5 Climate Models Using NASA A-Train Satellite Observations, *J. Geophys. Res*. 117, 10.1029/2011JD017237, 2012.
* **Jiang, J.H.**, et al., Influence of convection and aerosol pollution on ice cloud particle effective radius, *Atmos. Chem. Phys.* 11, 457-463, doi:10.5194/acp-11-457-2011, 2011.
* **Jiang, J.H.** et al., Five-year Observations of Upper Tropospheric Water Vapor and Cloud Ice from MLS and Comparisons with GEOS-5 analyses, *J. Geophys. Res.* 115, doi:10.1029/2009JD013256, 2010.
* L'Ecuyer, T., **J.H. Jiang**, Touring the atmosphere aboard the A-Train, *Phys. Today,* 63, 7, 36-41, 2010.
* **Jiang, J.H.**, et al. Aerosol-CO relationship and aerosol effect on Ice cloud particle size: Analyses from Aura MLS and Aqua MODIS observations, *J. Geophys. Res.* 114, doi: 10.1029/2009JD012421, 2009.
* **Jiang, J.H.**, et al., Clean and polluted clouds: relationships among pollution, ice cloud and precipitation in South America, *Geophys. Res. Lett.,* 35, doi:10.1029/2008GL034631, 2008.
* **Jiang, J.H.**, et al., Connecting surface emissions, convective uplifting, and long-range transport of carbon monoxide in the upper-troposphere: New observations from the Aura MLS, *Geophys. Res. Lett*. 34, doi:10.1029/2007GL030638, 2007.

**Dr. Chengxing Zhai**

Jet Propulsion Laboratory, California Institute of Technology,

4800 Oak Grove Dr, Pasadena, CA 91109, U.S.A.

Phone: (818) 393-0758 Email: Chengxing.Zhai@jpl.nasa.gov

**Education**

**B.S.**,Physics, Peking University, China, 1989

**M.S.**,Physics, University of Washington, 1991

**Ph.D.**, Physics, University of Washington, 1994

**Work Experience**

2004-present: Technologist, Jet Propulsion Laboratory, California Institute of Technology, CA

2000–2004: Software Engineer, Jet Propulsion Laboratory, California Institute of Technology, CA

1999-2000: Software Engineer, Hughes Space and Communications Company, El Segundo, CA.

1997–1999: Software Engineer, Raytheon System Company, El Segundo, CA

**Relevant Experience**

Dr. Zhai has 20 years of experience in modeling, data processing and analysis, and algorithm development. He is specialized in estimation, statistical analysis, spectral analysis, signal processing and detection, retrieval algorithm development, and instrument calibration technology. In the past three years, he has been working on evaluating the CMIP5 General Circulation Models (GCMs) performance in simulating current climate using A-train satellite observations and analyzing model processes relevant to climate sensitivity. He has performed independent quality checks on the NASA data and technical notes for the obs4MIPs project, and thus he is intimately familiar with the requirements. He is currently a Co-I of project, Parallel Web-Service Climate Model Diagnostic Analyzer, funded by NASA ROSES/CMAC program.

**Recent Honors and Awards**

* NASA Group Achievement Award for demonstrating micro-arc-second astrometry capability using SIM Spectral Calibration Development Unit, 2011.
* NASA Group Achievement Award for studying exoplanet system detection using astrometry and radial velocity 2010.
* JPL Ranger Award for supporting SIM project, 2008.

**Selected Recent Peer-Reviewed Publications**

* 1. Su, H., J.H. Jiang, **C. Zhai**, et al., Diagnosis of Regime-dependent Cloud Simulation Errors in CMIP5 Models Using A-Train Satellite Observations, J. Geophys. Res., doi:10.1029/2012JD018575, 2013.
  2. Jiang, J.H., H. Su., **C. Zhai**, A. Del Genio, et al. Evaluation of Cloud and Water Vapor Simulations in CMIP5 Climate Models Using NASA “A-Train” Satellite Observations, J. Geosphys. Res., 118, doi:10,1029/ 2011JD017237, 2012.
  3. Jiang, J.H., H. Su, **C. Zhai**, S.T. Massie, M.R. Schoeberl, P.R. Colarco, S. Platnick, Y. Gu, and K.-N. Liou, Influence of convection and aerosol pollution on ice cloud particle effective radius, *Atmos. Chem. Phys*., 11, 457-463, 2011.
  4. **Zhai, C**., M. Shao, G. Goullioud, and B. Nemati, Micro-pixel accuracy centroid displacement estimation and detector calibration, Proc. R. Soc. A 8, vol. 467 no. 2136 3550-3569 arXiv:1102.2248v2, 2011.
  5. Small, J., J.H. Jiang, H. Su, and **C. Zhai**, Relationship between aerosol and cloud fraction over Australia, Geophys. Res. Lett. 38, L23802, doi:10.1029/ 2011GL049404, 2011.

## Collaborator

**Dr. João Teixeira**

Jet Propulsion Laboratory

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[teixeira@jpl.nasa.gov](mailto:teixeira@jpl.nasa.gov)

626-395-6720

**EDUCATION**

Ph.D., Meteorology, *University of Lisbon*, Lisbon, Portugal, 2000.

Licentiate, Geophysical Sciences, *University of Lisbon*, Lisbon, Portugal, 1992

**RESEARCH AND PROFESSIONAL EXPERIENCE**

2010-present Deputy Director, JPL Center for Climate Sciences, Pasadena, CA

2011-present AIRS Science Team Leader, JPL, Pasadena, CA

2010-present Supervisor, Climate Physics Group, Jet Propulsion Laboratory, Pasadena, CA

2008-present Research, Principal Scientist, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

2005-2007 Senior Scientist, NATO Undersea Research Centre, La Spezia, Italy

2000-2005 UCAR Scientist, Naval Research Laboratory, Monterey, CA

1993-1999 Scientist, European Centre for Medium-Range Weather Forecasts, UK

**PROFESSIONAL ACTIVITIES**

Chair, ONR Science Team “Unified Parameterizations for Seasonal Prediction,” 2011-present

Member, Scientific Steering Committee, US CLIVAR, 2010-2012

Co-chair, Process Studies and Model Improvement Panel, US CLIVAR, 2010-2012

Lead Principal Investigator, NOAA Climate Process Modeling Team, 2010-present

Member, Process Studies and Model Improvement Panel, US CLIVAR, 2009-2010

Member, JIFRESSE Executive Committee, 2008-present

Chair, GCSS Pacific Cross-Section Intercomparison (GPCI) working group, 2005-2012

Member, GEWEX Cloud System Study (GCSS) Scientific Steering Committee, 2004-2010

**SELECTED RECENT PUBLICATIONS**

Teixeira and 37 co-authors, Tropical and sub-tropical cloud transitions in weather and climate prediction models: The GCSS/WGNE Pacific Cross-section Intercomparison (GPCI), *J. Clim.*, **24**, 5223-5256.

Teixeira, J., B. Stevens, C. S. Bretherton, R. Cederwall, J. D. Doyle, J. C. Golaz, A. A. M. Holtslag, S. A. Klein, J. K. Lundquist, D. A. Randall, A. P. Siebesma, & P. M. M. Soares, The parameterization of the atmospheric boundary layer: a view from just above the inversion, *Bull. Amer .Meteor. Soc.*, **89**, 453-458, 2008.

Teixeira, J., & C. A. Reynolds, Stochastic nature of physical parameterizations in ensemble prediction: a stochastic convection approach, *Mon. Weath. Rev.*, **136,** 483-496, 2008.

Teixeira, J., P. May, M. Flatau, & T. F. Hogan, On the sensitivity of the SST from a global ocean-atmosphere coupled system to the parameterization of boundary layer clouds, *J. Mar. Sys.*, **69**, 29–36, 2008.

Teixeira, J., C. Reynolds, & K. Judd, Time-step sensitivity of non-linear atmospheric models: numerical convergence, truncation error growth and ensemble design. *J. Atmos. Sci.*, **64**, 175-189, 2007.

# Current and Pending Support

## Current Awards

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| PI: Dr. Seungwon Lee Current Support | | | | |
| PI Name | Award/Project Title | Program Info | Period & Total Budget | Commitment (Work Year) |
| Seungwon Lee | Evaluating CMIP5 models with satellite observations: cloud-climate feedbacks | NASA ROSES COUND program  Dr. Tsengdar J. Lee  Tsengdar.J.Lee@nasa.gov | 9/1/2011-8/31/2013  $420K | 0.20 |
| Seungwon Lee | Parallel Web-Service Climate Model Diagnostic Analyzer | NASA ROSES CMAC program  Dr. Tsengdar J. Lee  Tsengdar.J.Lee@nasa.gov | 10/1/2012-09/30/2014  $616K | 0.20 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Co-I: Dr. Jonathan Jiang Current Support | | | | |
| PI Name | Award/Project Title | Program Info | Period & Total Budget | Commitment (Work Year) |
| Jonathan Jiang | Utilizing Aura MLS and A-Train datasets to analyze and evaluate IPCC AR5 models in the upper troposphere | NASA Aura Science Team  Dr. Kenneth W. Jucks  Kenneth.W.Jucks@nasa.gov | 04/2011-03/2014  $500K | 0.15 |
| Jonathan Jiang | Utilizing NASA A-Train datasets for IPCC AR5 climate model evaluation | NASA ROSES COUND program  Dr. Tsengdar J. Lee  Tsengdar.J.Lee@nasa.gov | 10/1/2011-09/2013  $470K | 0.15 |
| Hui Su | Investigating the Influence of Asian Aerosol Pollution on Water Vapor Transport from Troposphere to Stratosphere | NASA Aura Science Team  Dr. Kenneth W. Jucks  Kenneth.W.Jucks@nasa.gov | 06/2011-05/2014  $692K | 0.10 |
| Hui Su | Using NEWS Water and Energy Cycle Products to investigate processes that control cloud feedback. | NASA ROSES NEWS program  Dr. Jared Entin  Jared.K.Entin@nasa.gov | 07/2011-08/2013  $259K | 0.10 |
| Rong Fu | Exploring the impacts of climate variations and land use on interannual changes of CO in the tropical tropopause layer using multi-year Aura and A-Train measurements | NASA Aura Science Team  Dr. Kenneth W. Jucks  [Kenneth.W.Jucks@nasa.gov](mailto:Kenneth.W.Jucks@nasa.gov) | 06/2011-05/2014  $542K | 0.05 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Co-I: Dr. Lei Pan Current Support | | | | |
| PI Name | Award/Project Title | Program Info | Period & Total Budget | Commitment (Work Year) |
| Seungwon Lee | Parallel Web-Service Climate Model Diagnostic Analyzer | NASA ROSES CMAC program  Dr. Tsengdar J. Lee  Tsengdar.J.Lee@nasa.gov | 10/1/2012-09/30/2014  $616K | 0.50 |

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| --- | --- | --- | --- | --- |
| Co-I: Dr. Chengxing Zhai Current Support | | | | |
| PI Name | Award/Project Title | Program Info | Period & Total Budget | Commitment (Work Year) |
| Seungwon Lee | Parallel Web-Service Climate Model Diagnostic Analyzer | NASA ROSES CMAC program  Dr. Tsengdar J. Lee  Tsengdar.J.Lee@nasa.gov | 10/1/2012-09/30/2014  $616K | 0.20 |

## Pending Awards

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| PI: Dr. Seungwon Lee Pending Support | | | | |
| Proposer Name | Award/Project Title | Program Info | Period & Total Budget | Commitment (Work Year) |
| Jui-Lin F. Li | Characterizing and Understanding Cloud-Radiation-Dynamics using CloudSat/CALIPSO and other A-Train observations as well as Reanalysis for Model  Improvement  SECTION VI **- Team Members** | NASA ROSES CloudSat And CALIPSO Science Team Recompete | 01/01/2013-12/31/2015  $473K | 0.20 |
| Brian Mapes | A cloud-systems view of A-train nadir data: morphometrics, global impacts, and interactions in regional and local circulations | NASA ROSES  CloudSat And CALIPSO Science Team Recompete | 01/01/2013-12/31/2015  $600K | 0.10 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Co-I: Dr. Jonathan Jiang Pending Support | | | | |
| Proposer Name | Award/Project Title | Program Info | Period & Total Budget | Commitment (Work Year) |
| Hui Su | Aerosol effects on upper tropospheric ice clouds | NASA ROSES CloudSat/CALIPSO Science Team | 09/2013-08/2016 | 0.10 |

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| --- | --- | --- | --- | --- |
| Co-I: Dr. Chengxing Zhai Pending Support | | | | |
| Proposer Name | Award/Project Title | Program Info | Period & Total Budget | Commitment (Work Year) |
| Gautam Vasisht | Advanced wave front control with Palomar’s Project | NASA ROSES APRA program  Dr. Hashima Hasan  hhasan@nasa.gov | 01/01/2013-09/30/2015  $751K | 0.15 |
| Mike Shao | Enabling exo-earth direct imaging using concurrent astrometry | NASA ROSES  TDEM  Dr. Hashima Hasan  [hhasan@nasa.gov](mailto:hhasan@nasa.gov) | 01/01/2013-09/30/2015  $774K | 0.10 |

Co-I Dr. Lei Pan Pending Awards: None

# Budget Justification (partially page limited)

In the evaluation of proposals submitted under ROSES-2010, SMD will be showing all of the budget data to peer reviewers (i.e., SMD is *not* redacting budgets). Proposers should include all relevant details in the budget justification. Proposers should *not* upload a separate second “total budget” document, but a detailed budget should be included at the end of the proposal document. Proposals submitted in response to this ROSES NRA should follow the directions for the budget section of the proposal given in Section 2.3.10 of the *NASA Guidebook for Proposers*. There are no additional requirements for ROSES proposals from non-NASA proposers.

From *ROSES NRA*, p. 13.

Each proposal shall provide a budget justification for each year of the proposed effort and shall be supported by appropriate narrative material and budget details in compliance with the following instructions.

Failure to adequately provide detailed cost data will require NASA Procurement Personnel to contact the proposing organization for the required information. This will result in a delay of the award. All Proposers are required to submit a thoroughly detailed cost breakdown. NASA Procurement Personnel must be able to determine that all proposed costs are allowable and reasonable. A detailed budget will facilitate this cost analysis. Reference Section A, Appendix A of the *Grant and Cooperative Agreement Handbook* located at the following URL: http://prod.nais.nasa.gov/pub/pub\_library/grcover.htm.

From *Guidebook*, p. 2-11.

Type your text here; use “Body\_RS12” style.

## Budget Narrative

The Budget Narrative should clearly state the type of award instrument the Recipient anticipates receiving if selected for award (i.e., contract, grant or cooperative agreement). NASA will, however, make the final decision on the award instrument used (reference D.1.2).

The Budget Narrative must describe the basis of estimate and rationale for each proposed component of cost, including direct labor, subcontracts/subawards, consultants, other direct costs (including travel), and facilities and equipment. The Proposer must provide adequate budget detail to support estimates. The Proposer must state the source of cost estimates (e.g., based on quote, on previous purchases for same or similar item(s), cost data obtained from internet research, etc.) including the company name and/or URL and date if known, but need not include the actual price quote or screen captures from the web. The Proposer must describe in detail the purpose of any proposed travel in relation to the grant and provide the basis of estimate, including information or assumptions on destination, number of travelers, number of days, conference fees, air fare, per diem, miscellaneous expenses, etc. If destinations are not known, the Proposer should, for estimating purposes, make reasonable assumptions about the potential destination and use historical cost data based on previous trips taken or conferences attended.

**There should be direct and obvious correlation between the items described in the Budget Narrative, those given in the Budget Details, and the figures entered in the *Proposal Cover Page*.**

From *Guidebook*, pp. 2-11 and 2-12.

The Jet Propulsion Laboratory is a Federally Funded Research and Development Center owned by NASA and operated by the California Institute of Technology. Work performed at JPL is done under a Prime Contract with NASA through task orders that are added to the contract when work is approved. This proposal, if selected, will be executed through a task order under this Prime Contract.

You should include a short summary of the work to be performed, the workforce and facilities required, and subcontracts to be issued, to set the stage for the detailed budget information that follows. Also indicate if any of the subcontracts will be to other NASA Centers, or other Government agencies.

Type your text here; use “Body\_RS12” style.

### Personnel and Work Effort (1 page max.)

A required element of the Budget Narrative is a table of Personnel and Work Effort, summarizing the work effort required to perform the proposed investigation. The table must have the names and/or titles of all personnel [includes all funded and unfunded co-Is, collaborators, postdoctoral fellows and graduate students] necessary to perform the proposed effort, regardless of whether those individuals require funding. For each individual, list the planned work commitment to be funded by NASA, per period in fractions of a work year. In addition, include planned work commitment not funded by NASA, if applicable. Where names are not known, include the position, such as postdoc or technician.

From *Guidebook*, p. 2-12.

Type your text here; use “Body\_RS12” style.

Use the following table format for your Summary of Personnel and Work Effort. (The text in the table included here is an example only.)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | Organization | Role | Work Commitment | |
| Year 1 | Year 2 |
| Dr. Lawrence Brown | JPL | Principal Investigator | .20 | .15 |
| Dr. Richard Short | JPL | Co-Investigator | .15 | .05 |
| Dr. John Smith | Oregon State University | Co-Investigator | .10 | .10 |
| Dr. Carl George | GSFC | Co-Investigator | .10 | .10 |
| Dr. Brian Greene | JPL | Post Doc | .05 | .05 |
| Dr. Joseph Clark | USGS | Co-Investigator | .05 | .05 |
| Dr. Linda Sharp | USC | Collaborator | .01 | .01 |
| TBD | JPL | Post Doc | .25 | .5 |
| TBD | JPL | Other Professional | .3 | .3 |

Include planned work commitment not funded by NASA, if applicable.

This means collaborators. Even though they will not receive funding from this proposal, you should note the approx. FTE level of effort they will contribute in their collaborator role.

### Facilities and Equipment (2 pages max.)

The final element of the Budget Narrative is a description of any required facilities and equipment. This section should describe any existing facilities and equipment that are required for the proposed investigation. It must explain the need for items costing more than $5,000 and describe the basis for estimated cost (i.e., competitive quotes were obtained, justification for sole source purchase, proposed cost based on previous purchases for same or similar item(s), cost data obtained from internet research, etc.).

Proposed costs for purchased facilities, tooling, or equipment must be entered in the Proposal Cover Page and included in the Budget Details (ref. Section 2.3.10(b)).

**There should be direct and obvious correlation between the items described in the Budget Narrative, those given in the Budget Details, and the figures entered in the *Proposal Cover Page* forms.**

From *Guidebook*, p. 2-12.

The following facilities <and/or> equipment are required and will be available for this work.

Or

No special facilities or equipment are required for this work.

Or

The following special equipment is required for this work and will be procured with funds from this award:

* Include only those facilities and/or equipment that will be required to perform the work.
* Include pictures of the equipment with a brief description if appropriate..

#### Jet Propulsion Laboratory

Type your text here; use “Body\_RS12” style.

Example: A high end UNIX workstation with 16 GB of memory and 2 TB of local disk is required for software development and testing. The memory size is determined by the xxx software requirements. The local disk is sized to hold the yyy dataset and the output from the zzz application.

The estimated cost of $5,500 is from the online catalogue price of an HP wwww workstation with the required configuration and commercial software. The cost is rounded up to allow for unanticipated price or configuration changes.

Example: JPL has local supercomputing facilities that are available for use by this project. The facilities include ….. A letter of support describing the availability of this facility for this project is included in Sect 5.

#### Company A

Type your text here; use “Body\_RS12” style.

#### Company B

Type your text here; use “Body\_RS12” style.

### Rationale and Basis of Estimate

Use the following statement:

The cost estimate for this proposal was prepared using JPL’s Pricing System and the current internally published Cost Estimation Rates and Factors dated January 2013.

The derivation of the cost estimate is a grassroots methodology based on the expert judgment from a team of experienced individuals who have performed similar work. The team provides the necessary relevant experience to develop a credible and realistic cost estimate. The cognizant individuals identify and define the products and the schedule needed to complete the tasks for each work element. Then they generate the resource estimates for labor, procurements, travel, and other direct costs for each work element. The resource estimates are aggregated and priced using JPL’s Pricing System. JPL’s process assures that lower level estimates are developed and reviewed by the performing organizations and their management who will be accountable for successfully completing the proposed work scope within their estimated cost.

It is also useful to justify the workforce requested in your proposal, including the skills mix, by referring to prior work of a like nature that was successfully completed. You want to convince the reviewer that you have properly scoped the job – i.e., you haven’t padded the budget, but you haven’t underbid it either! One of the most common weaknesses noted in peer reviews is the belief that there is too much work for the amount of labor proposed. You need to convince the reviewer that you have scoped it “just right”.

Type your text here; use “Body\_RS12” style.

Summary Cost Estimate

Copy and “paste as picture” from the CES\_by\_PY tab of your PEG roses output.xls workbook. Adjust columns *in the workbook* as necessary to make sure the table is readable. The numbers in your budget detail should match the numbers in this table, and on the NSPIRES cover pages!





## Budget Details – Year 1

In addition to the Budget Narrative, Proposers are required to include detailed budgets, including detailed subcontract/subaward budgets, in a format of their own choosing. Regardless of format chosen, the following information must be included in the Budget Details.

1. Direct Labor (salaries, wages, and fringe benefits): List the number and titles of personnel, amounts of time to be devoted to the grant (level of effort for each position), and rates of pay. The annual salary should be clearly noted for each position. Labor should be clearly broken out from fringe benefits. The fringe benefit rate/percent should be clearly noted on the budget for each labor category for ease of review.

Important Note: All Recipients are reminded that in accordance with Section 1260.10(b)(1)(ii) of the Grant and Cooperative Agreement Handbook, “NASA is required to apply the applicable negotiated rate for all grants awarded to the recipient.” If fringe benefits comprise part of the applicable negotiated rate, NASA will use this rate for all grants and cooperative agreements awarded to the recipient. Recipients shall not escalate those rates for fringe benefits. If the applicable negotiated rate excludes fringe benefits, recipients may escalate their rates for fringe benefits.

2. Other Direct Costs:

a. Subcontracts/Subawards: Attachments shall describe the work to be subcontracted/subawarded, estimated amount, recipient (if known), and the reason for subcontracting (e.g. uniquely qualified co-investigator is located at another institution from the proposing institution). Itemized budgets are required for all subcontracts/subawards, regardless of dollar value. Reference Section 1260.33, Subcontracts, and Section 1260.144, Procurement Procedures, paragraph (e) of the Grant and Cooperative Agreement Handbook for additional requirements/documentation for subcontractors.

b. Consultants: Identify consultants to be used and provide the amount of time they will spend on the project and rates of pay to include annual salary, overhead, etc.

c. Equipment: List all facilities and equipment items separately. General-purpose equipment (i.e., personal computers and/or commercial software) valued at or above $5,000 is not allowable as a direct cost unless specifically approved by the NASA Award Officer. Any requested general-purpose equipment purchase valued at or above $5,000 to be made as a direct charge under this award must include the equipment description, an explanation of how it will be used in the conduct of the research proposed, and a written certification that the equipment will be used exclusively for the proposed research activities and not for general business or administrative purposes. [Ref.: Appendix B, Part (c)(7)].

d. Supplies: Provide general categories of needed supplies, the method of acquisition, and the estimated cost.

e. Travel: Provide a detailed breakout of costs for any proposed travel. Detailed budget data shall include the following:

- Number of people and number of days

- Departure/Arrival cities

- Airfare

- Per diem

- Car rental

- Conference fees (if applicable)

- Miscellaneous Costs (i.e., car rental fuel, airport parking, tolls, etc.).

Note: Every effort should be made to accurately estimate and detail travel costs. Under Federal procurement regulations, missing or minimum data is not acceptable for budget evaluation and award purposes. If destinations are not known at time of proposal preparation, then reasonable assumptions about the potential destination and historical data for previous trips may be used but the preparer is still required to include the same amount of detail listed above. That is, use reasonable assumptions and historical data for destinations and length of stay, however, use current pricing for the applicable categories listed above. If adequate budget detail is not submitted with the proposal then this will delay your award.

f. Other: List and enter the total of direct costs not covered by 2a through 2e.

3. Facilities and Administrative (F&A) Costs: Identify F&A cost rate(s) and base(s) as approved by the cognizant Federal agency, including the effective period of the rate.

Provide the name, address, and telephone number of the Federal agency official having cognizance. If approved audited rates are not available, provide the computational basis for the indirect expense pool and the corresponding allocation base for each proposed rate.

Reference Important Note in paragraph 2.3.10(b)1. above: All budgets shall be prepared using the most current “approved” indirect rates for estimating and award purposes. Proposers shall not use unapproved “future” rates. Failure to do so will cause a delay in receiving your award as the NASA Procurement Office will then have to come back to the Proposer with a request to reduce the proposed rates to the most current “approved” rates. Proposers may charge less than the approved current rates but shall not propose more in anticipation of the rates changing in the future.

4. Other Applicable Costs: Enter total explaining the need for each item and itemized lists detailing expenses within major budget categories. Also enter here the required funding for any Co-Is who cannot be funded through the PI award, e.g. because the PI is at a non-Government organization and a Co-I is at a U.S. Government organization (see Section 2.3.10(c)(ii)(a)).

5. Subtotal-Estimated Costs: Enter the sum of items 1 through 4.

Less: Proposed Cost Sharing (if any): NSPIRES does not allow notating cost sharing on the standardized budget form. However, if cost sharing is proposed, it should be discussed in detail in the Budget Narrative. Further, if cost sharing is based on specific cost items, identify each item and amount in the Budget Detail with a full explanation provided in the Budget Narrative.

If an institution of higher education, hospital, or other non-profit organization wants to receive a grant or cooperative agreement, cost sharing is not required. The award would be made in accordance with the requirements of Subparts A and B of the Grant and Cooperative Agreement Handbook. Subparts A and B are also applicable to NASA grants and cooperative agreements awarded to commercial firms which do not involve cost sharing. This does not prohibit voluntary cost sharing. NASA may accept cost sharing from any type of organization if it is voluntarily offered. Reference 1260.123 (Cost Sharing or Matching) and Section 1260.4 (Applicability) of the Grant and Cooperative Agreement Handbook. If a commercial organization wants to receive a grant or cooperative agreement, cost sharing is required unless the commercial organization can demonstrate that it does not expect to receive substantial compensating benefits for performance of the work. If this demonstration is made, cost sharing is not required but may be offered voluntarily. Reference also the Grant and Cooperative Agreement Handbook Section D, Provision 1274.204 (Costs and Payments), paragraph (b), Cost Sharing.

Cost sharing is not required when a commercial organization receives a contract, but it may be offered voluntarily.

6. Total Estimated Costs: Enter the total amount of funding requested from the Government.

Other Budget Guidelines

In preparing the Budget Justification (both Narrative and Details), Proposers must consider the following additional important NASA procurement policies:

(i) Purchase of Personal Computers and/or Software. Note the discussion of item "2.c. Equipment" on the Instructions above regarding the proposed purchase of personal computers and/or commercial software at or above $5,000. Such items are usually considered by NASA to be general purpose equipment that must be purchased from general, organizational overhead budgets and not directly from the proposal budget unless it can be demonstrated that such items are to be used uniquely and only for the proposed research. If a proposal is selected for award, failure to adequately address the requirements of the instructions for item 2.c above (Equipment) will require that NASA contact the proposing organization for the required information. Such activity may delay the award until the purchase is justified as a direct charge for general-purpose equipment to be used exclusively for the proposed research activities.

(ii) Joint Proposals Involving a Mix of U.S. Government and Non-Government Organizations.

(a) Unless otherwise specified in the solicitation, if a PI from any type of public or private organization proposes to team with a Co-I from and/or use a facility at a U.S. Government organization (including NASA Centers and the Jet Propulsion Laboratory), the budget for the proposal must include all funding requested from NASA for the proposed investigation, and this must be reflected in the budget totals that appear in the budget forms (e.g., Proposal Cover Page and Budget Details). Any required budget for that Government Co-I and/or facility should be included in the proposal’s Budget Narrative and should be listed as "Other Applicable Costs" in the required Budget Details. If the proposal is selected, NASA will execute an inter- or intra-Agency transfer of funds, as appropriate, to cover the applicable costs at that Government organization.

The required cost for any Government Co-I and/or facility should be entered in the “Other” line(s) on the NSPIRES budget entry form in the “Other Direct Costs” section. This cost must be included in the total cost of the proposed work. No indirect burden should be applied to this amount. NASA will transfer funds, as appropriate, to cover applicable costs for the Government Co-I and/or facility. Reference 2.3.10(c)(iv) below – Full-Cost Accounting at NASA Centers.

(b) If a PI from a U.S. Government organization (including NASA Centers and the Jet Propulsion Laboratory) proposes to team with a Co-I from a non-Government organization, then the proposing Government organization must cover those Co-I costs through an appropriate award for which that Government PI organization is responsible. Such non-Government Co-I costs should be entered as a "Subcontract/Subaward" on the Budget Summary.

(c) If a PI from a non-U.S. organization proposes to team with a Co-I from a U.S. organization then reference part (vii) below.

(iii) Responsibility of the Proposing Organization to Place Subawards for Co-Is at Other Organizations. Other than the special cases discussed in item (ii) above, and unless specifically noted otherwise in the NRA, the proposing PI organization must subcontract the funding of all proposed Co-Is who reside at other non-Government organizations, even though this may result in a higher proposal cost because of subcontracting fees.

(iv) Full-Cost Accounting at NASA Centers. Regardless of whether functioning as a team lead or as a team member, personnel from NASA Centers must propose budgets based on full-cost accounting. Proposal budgets from NASA Centers must include all costs that will be paid out of the resulting award. Costs which will not be paid out of the resulting award, but are paid from a separate NASA budget (e.g., Center Management and Operations, CM&O) and are not based on the success of this specific award, should not be included in the proposal budget. For example, CM&O should not be included in the proposal budget while direct civil service labor, travel, service pools, and other charges to the proposed research task should be included.

(v) Unallowable Costs. The Office of Management and Budget (OMB) Circulars A-21 (<http://www.whitehouse.gov/omb/fedreg\_a-21rev>) (now codified at 2 CFR Part 220, http://www.access.gpo.gov/nara/cfr/waisidx\_07/2cfr220\_07.html), A-87 (<http://www.whitehouse.gov/omb/circulars\_a087\_2004>) (now codified at 2 CFR Part 225, http://www.access.gpo.gov/nara/cfr/waisidx\_07/2cfr225\_07.html), A-122 (http://www.whitehouse.gov/omb/circulars\_a122\_2004), (now codified at 2 CFR Part 230, http://www.access.gpo.gov/nara/cfr/waisidx\_07/2cfr230\_07.html), and the Federal Acquisition Regulation (FAR) at 48 CFR Part 31(https://www.acquisition.gov/far/05-09/html/FARTOCP31.html), identify and describe certain costs that may not be included in a proposed budget (unallowable costs). The use of appropriated funds for such purposes is unallowable and may lead to cancellation of the award and possible criminal charges. Grant recipients should be aware of cost principles applicable to their organization as set forth in the above regulations.

(vi) Prohibition of the Use of NASA Funds for Non-U.S. Research. NASA’s policy welcomes the opportunity to conduct research with non-U.S. organizations on a cooperative, no-exchange-of-funds basis. Although Co-Is or collaborators employed by non-U.S. organizations may be identified as part of a proposal submitted by a U.S. organization, NASA funding may not normally be used to support research efforts by non-U.S. organizations at any level. However, the direct purchase of supplies and/or services that do not constitute research from non-U.S. sources by U.S. award recipients is permitted. Ref. Section (l) of Appendix B. Also reference paragraph (c)(8)(iv) of Appendix B which states in part, “NASA funding may not be used for foreign research efforts at any level, whether as a collaborator or a subcontract. The direct purchase of supplies and/or services, which do not constitute research, from non-U.S. sources by U.S. award recipients is permitted.”

(vii) Proposals from non-U.S. PI organizations that propose the funding of U.S. Co-Is. A proposal submitted by a non-U.S. organization that involves U.S. Co-Is for whom NASA funding is requested must provide the budgets for those U.S. Co-Is in compliance with all applicable provisions in this Section 2.3.10. The budget should identify the U.S. Co-I organization to which funding will be awarded. In addition, compliance is required by the proposing non-U.S. organization with the provisions of Section (l) of Appendix B.

From *Guidebook*, pp. 2-12 through 2-16.

Review the full text of the Guidebook and *ROSES NRA* and then address in this section as necessary.

Organize your budget details for each year as follows (**the text included here is an example only**). Retain all of the headings; if there are no costs associated with a heading, so indicate; e.g., Equipment.

Include external Co-I budgetary information at the end of this file as long as the file doesn't exceed 10MB (including the NSPIRES cover page).

**New Cost Instructions for NASA Civil Servants Co-Is on ROSES Proposals**

(08/16/10)

Starting August 16, the NSPIRES web cover page budgets should no longer include the cost of NASA civil servant salaries. In addition, the detailed budget within the proposal should not show the cost civil servant salaries either. However, for the purpose of peer review, the proposal's narrative must clearly indicate the NASA civil servant FTEs that are being applied to the proposed investigation. The full cost of the proposed NASA civil servant salaries will be provided separately to the program officer, through a separate upload.

In the team member section where it asks if this person is participating as an employee of the US government, it also asks for the dollar amount requested. Again, do not include NASA Civil Servant’s salary, only ODCs such as travel and procurements.

**Budgets in the proposal and uploaded afterwards:** Each proposal should, as before, have in it a budget narrative that gives the time being devoted to the project by the PI and each Co-Investigator, whether or not they are NASA civil servants. However, the detailed budget pages from each organization at the end of the proposal should not include CS labor costs. Those CS labor budgets will be uploaded directly by the centers via F.1 (for ROSES 2010 at http://tinyurl.com/2crx2nn) **three working days after the proposal due date**. These budgets should be labeled with the full number of the proposal with which they are associated (e.g., 10-OSS10-0152).

Direct Labor – Year 1

* Dr. Lawrence Brown is the PI and will oversee all aspects of the proposed work. Dr. Brown will……. Time Commitment is .20 wy. ($32,100 requested salary with $16,100 fringe benefits)
* Dr. Richard Short will serve as a Co-Investigator on this effort. Dr. Short will …… Time Commitment is .15 wy. ($18,800 requested salary with $9,400 fringe benefits).
* Type your text here; use “List\_Bullet\_RS12” style.

Other Direct Costs – Year 1

Subcontracts/Subawards

* Subcontract to Oregon State University for Dr. John Smith. Dr. Smith will provide … Time Commitment is .10 wy ($20K). See **Co-Investigator Budget Details** later in this proposal.
* More subcontracts …
* More subcontracts ….
* Desktop Network Chargebacks (calculated at $6.06/hr.): All JPL computers are subject to a monthly subcontractor service charge that includes hardware, software, and technical support. ($1.7K)

Consultants

* There are no consultants required for this task – or -
* Name each consultant, the work to be performed, and the expected work years and cost.
* ….

Equipment

* There are no major equipment purchases necessary – or - .
* List and describe each equipment item, its expected cost, and the basis for the expected cost (i.e, catalogue price, vendor quote, etc.
* ….

Services

* No services are required for this task – or -
* List each service center from your PEG budget output, the work to be performed, and the expected cost
* Machine Shop: Fabrication of miscellaneous parts for experimental work. ($2K)
* Caltech IA for Post-doctoral Fellow Dr. Brian Greene. Post-doctoral fellows at Caltech are billed as a service under the JPL cost accounting system. Dr. Greene will be responsible for …. Time Commitment is .05 wy ($10K)
* …...

Supplies and Publications

* Publication and Documentation: Miscellaneous publication and documentation charges ($2K).
* Type your text here; use “List\_Bullet\_RS12” style.

Travel

Proposals must include, or otherwise address, a small travel budget for the annual ESDSWG joint meeting.

* Dr. AAA will participate in the ESDSWG and attend the annual meeting. Since the location for the annual meeting changes each year, travel has been estimated for a typical East Coast venue:
* 1 person for 4 days, from Pasadena,CA to Washington, DC
* Airfare: $780, based on current non-refundable airfare from LAX - IAD
* JPL conforms to the GSA maximum per diem and lodging rates established each year, which vary by location and season. Typical for an east coast trip is $71/$200 per day.
* Misc costs for this trip include rental car @ $50/day, transportation to/from home to LAX at ~ $75
* Estimated total cost: $2,000
* ….

Other

* Multiple Program Support (MPS) $7.9K.

Facilities and Administrative (F&A) Costs – Year 1

* Allocated Direct Costs (ADC) $18.4K.
* Applied General ADC $14.9K.

Other Applicable Costs – Year 1

* Costs (excluding salary and benefits) for Civil Servant Government Co-I, NASA/GSFC, Dr. Carl George ($50K).
* Full cost for Government Co-I, USGS, Dr. Joseph Clark ($40K)
* See **Co-Investigator Budget Details** later in this proposal

Total Estimated Costs for Year 1: $247,100.00

## Budget Details – Year 2

Direct Labor – Year 2

* Dr. Lawrence Brown is the PI and will oversee all aspects of the proposed work. Dr. Brown will……. Time Commitment is .20 wy. ($32,100 requested salary with $16,100 fringe benefits)
* Dr. Richard Short will serve as a Co-Investigator on this effort. Dr. Short will …… Time Commitment is .15 wy. ($18,800 requested salary with $9,400 fringe benefits).
* Type your text here; use “List\_Bullet\_RS12” style.

Other Direct Costs – Year 2

Subcontracts/Subawards

* Subcontract to Oregon State University for Dr. John Smith. Dr. Smith will provide … Time Commitment is .10 wy ($20K). See **Co-Investigator Budget Details** later in this proposal.
* More subcontracts …
* More subcontracts ….
* Desktop Network Chargebacks (calculated at $6.06/hr.): All JPL computers are subject to a monthly subcontractor service charge that includes hardware, software, and technical support. ($1.7K)

Consultants

* There are no consultants required for this task – or -
* Name each consultant, the work to be performed, and the expected work years and cost.
* ….

Equipment

* There are no major equipment purchases necessary – or - .
* List and describe each equipment item, its expected cost, and the basis for the expected cost (i.e, catalogue price, vendor quote, etc.
* ….

Services

* No services are required for this task – or -
* List each service center from your PEG budget output, the work to be performed, and the expected cost
* Machine Shop: Fabrication of miscellaneous parts for experimental work. ($2K)
* Caltech IA for Post-doctoral Fellow Dr. Brian Greene. Post-doctoral fellows at Caltech are billed as a service under the JPL cost accounting system. Dr. Greene will be responsible for …. Time Commitment is .05 wy ($10K)
* …...

Supplies and Publications

* Publication and Documentation: Miscellaneous publication and documentation charges ($2K).
* Type your text here; use “List\_Bullet\_RS12” style.

Travel

* Dr. AAA will participate in the ESDSWG and attend the annual meeting. Since the location for the annual meeting changes each year, travel has been estimated for a typical East Coast venue:
* 1 person for 4 days, from Pasadena,CA to Washington, DC
* Airfare: $780, based on current non-refundable airfare from LAX - IAD
* JPL conforms to the GSA maximum per diem and lodging rates established each year, which vary by location and season. Typical for an east coast trip is $71/$200 per day.
* Misc costs for this trip include rental car @ $50/day, transportation to/from home to LAX at ~ $75
* Estimated total cost: $2,000
* ….
* ….
* ….

Other

* Multiple Program Support (MPS) $7.9K.

Facilities and Administrative (F&A) Costs – Year 2

* Allocated Direct Costs (ADC) $18.4K.
* Applied General ADC $14.9K.

Other Applicable Costs – Year 2

* Costs (excluding salary and benefits) for Civil Servant Government Co-I, NASA/GSFC, Dr. Carl George ($50K).
* Full cost for Government Co-I, USGS, Dr. Joseph Clark ($40K)

See **Co-Investigator Budget Details** later in this proposal

Total Estimated Costs for Year 2: $247,100.00

## Co-Investigator <Name> Budget Details

Insert budget details for each non-JPL Co-Investigator here, with the same level of detail as the JPL budget section.

Budgets for Co-Investigators from the same institution should be presented as a single institutional budget.