

# TOOLS TO SUPPORT THE REUSE OF SOFTWARE ASSETS FOR THE NASA EARTH SCIENCE DECADAL SURVEY MISSIONS

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## Introduction

The future Earth science missions at the National Aeronautics and Space Administration (NASA) promise to provide an explosion of data and a platform for science that previously was unachievable using existing hardware, software, and assets. Instrument resolution is increasing, as is the ability of software and hardware to deal with data volumes that will easily grow to the 10–100 petabyte range in the next five years [1]. Over the past twenty years, NASA has invested in software to support all phases of the Earth science mission pipeline. These investments include

components and architectures that support science data processing at Science Investigator-led Processing Systems (SIPS), data archival and dissemination at the Distributed Active Archive Centers (DAACs), and ad-hoc data analyses and custom product generation using DAAC-provided data [2]. This general flow is shown in Fig. 1.

For example, the Moderate Resolution Imaging Spectroradiometer (MODIS) Data

Processing System (MODAPS) has evolved over time to support higher data processing rates and the production of data products for additional Earth-observing instruments by enhancing its architecture [3]. In addition, several recent efforts [4] to standardize process management and control for both the Orbiting Carbon Observatory (OCO) missions, as well as the NPOESS Preparatory Project (NPP) joint NASA–NOAA–DOD missions, have also demonstrated the utility in the reuse of software assets.

However, to date the aforementioned efforts

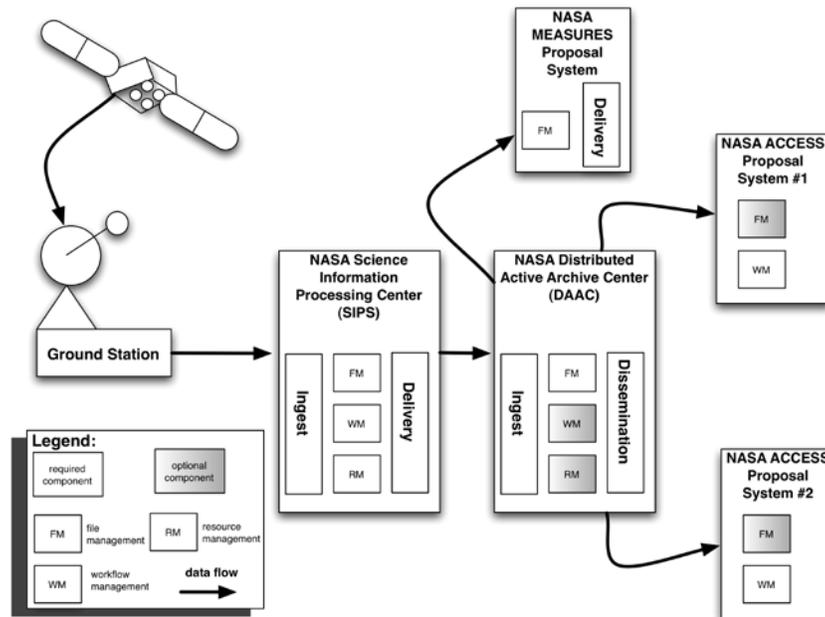


Fig 1. The NASA Earth Science Context. Data is taken by and sent to ground stations, which move the data to SIPS. DAACs are responsible for long-term archiving of the information, and dissemination. Ad-hoc analyses occur in the ACCESS and MEASURES programs.

are the exception and not the norm. Many Earth

Table 1. Summary of Reuse Readiness Levels (RRLs)

Level	Summary
RRL 1	Limited reusability; the software is not recommended for reuse.
RRL 2	Initial reusability; software reuse is not practical.
RRL 3	Basic reusability; the software might be reusable by skilled users at substantial effort, cost, and risk.
RRL 4	Reuse is possible; the software might be reused by most users with some effort, cost, and risk.
RRL 5	Reuse is practical; the software could be reused by most users with reasonable cost and risk.
RRL 6	Software is reusable; the software can be reused by most users although there may be some cost and risk.
RRL 7	Software is highly reusable; the software can be reused by most users with minimum cost and risk.
RRL 8	Demonstrated local reusability; the software has been reused by multiple users.
RRL 9	Demonstrated extensive reusability; the software is being reused by many classes of users over a wide range of systems.

science data system components and architectural patterns are reconstructed for each mission. There have been a number of reasons for this practice including: (1) the distributed scientific expertise of NASA, (2) the desire to have that expertise co-located with the data as it is processed and delivered for wide dissemination, (3) procurement practices, where contract and equipment resources are stove-piped into separate contracts and programs, and (4) each scientific community purports a unique set of requirements for data processing and data products, that may not easily lend itself to justify reuse.

The paradigm of NASA missions is changing, primarily due to the upcoming missions identified in the National Research Council's Earth Science and Applications from Space decadal survey [5] (as well as other future "decadal-like" missions). It is even more imperative that NASA look to reduce costs, increase software productivity, explore areas for consolidation of homogeneous services, and ultimately promote and facilitate a culture of reusing successful software assets and patterns across its missions.

Software reuse can help inform the successful design of future NASA missions in a number of different ways, in particular through: (1) identification and selection of existing, proven Earth science software components (or software components applicable in Earth science data systems) whose reuse saves development costs and time, (2) application of existing architectural styles and patterns [6] that induce specific quality attributes (reliability, scalability, etc.) in the resultant software, and (3) identification of new assets developed for missions which are of broader applicability, and themselves should be disseminated to the community.

Reusable software artifacts are not limited to just code. These assets may include algorithms and models, architectures and design patterns, systems modules and scripts, technical documentation and test results, and use metrics as well as other artifacts produced during the software development life cycle.

The NASA Earth Science Data Systems (ESDS) Software Reuse Working Group (SRWG) is chartered with the investigation, production, and dissemination of information related to the reuse of NASA Earth science software assets. One major current objective is to engage the NASA decadal missions in areas relevant to software reuse.

In this paper we report on the current status of these activities. First, we provide some background on the SRWG in general and then discuss the group's flagship recommendation, the NASA Reuse Readiness Levels (RRLs). We continue by describing areas in which mission software may be reused in the context of NASA decadal missions. We conclude the paper with pointers to future directions.

### Working Group Background

The NASA Earth Science Data Systems (ESDS) Software Reuse Working Group is chartered with the promotion and identification of software assets targeted for reuse in NASA's Earth Science Data System pipeline [7]. The group is focused on architectures and technologies that facilitate software reuse. In particular, we are investigating software components and architectures developed to enable cloud and grid computing capabilities, as well as cyberinfrastructure for using mission and scientific data.

The flagship product of the group to date is a focused set of NASA Reuse Readiness Levels (RRLs), which have been released and are now

Topic (descriptions below)	Score(1-9)		Weight(0-100)
Portability: The software is moderately portable	5	X	100
Extensibility: Consideration for future extensibility designed into system, extensibility approach somewhat defined	5	X	100
Documentation: User manual available	5	X	100
Support: Informal user community available	5	X	100
Packaging: Software is easily configurable for different environments	5	X	100
IP Issues: Agreement and approval on authorship, attribution, and intellectual property issues has been obtained from stakeholders.	5	X	100
Standards Compliance: All components follow a universal standard, but only partially validated	5	X	100
Verification and Testing: Software application demonstrated in a laboratory environment	5	X	100
Modularity: Partial segregation of generic and specific functionality	5	X	100
<b>Overall RRL: 5.0</b>			
<p>RRL 5: Reuse is practical; the software could be reused by most users with reasonable cost and risk.</p> <p>Software is moderately portable, modular, extendable, and configurable, has low-fidelity standards compliance, a user manual, and has been tested in a lab. A user community exists, but may be a small community of experts. Authorship and rights are not specified.</p>			
<b>Description of RRL levels</b>			
click on any RRL topic to see the descriptions.			

Fig 2. The Reuse Readiness Level Web Calculator. Users input an associated weight and score for each of the RRL topic area levels and an RRL is computed and displayed as a weighted average of those calculations. The associated RRL description is shown in yellow at the bottom of the calculator.

available for use [8]. The RRLs, similar to the NASA Technology Readiness Levels (TRLs) for technology, are a nine-level guide that can be used to rank and compute the reusability of a software asset [9]. A summary of the RRLs, taken from [8], is shown in Table 1.

Besides the RRLs, the Software Reuse Working Group (SRWG) is also working on the development of case study documents describing efforts to leverage the RRLs in the assessment of two areas of NASA mission software: (1) the methodology and suitability of existing NASA software assets for inclusion in a mission, and (2) the identification, curation, and dissemination of software assets that are being developed as part of a NASA mission that can be included in future missions. In addition, the SRWG is working on a recommendation for the packaging of reusable software assets to facilitate distribution, covering an information model for software packaging, and a classification/comparison of the state of the art in software packaging techniques.

Both of the aforementioned documents are considered works-in-progress, and both of the documents include input from current NASA decadal missions, including the Soil Moisture Active & Passive (SMAP) mission and the Ice, Cloud, and land Elevation Satellite 2 (ICESat-2)

mission. We also are actively working with other Tier-1 NASA decadal missions including the Orbiting Carbon Observatory-2 mission, and the Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI) mission to best determine how and where reusable software assets could be leveraged. We plan to support the upcoming Tier-2 missions as they begin to ramp up as well. In the next section we will provide greater detail about the NASA Reuse Readiness Levels (RRLs) and their applicability to NASA decadal missions.

## Reuse Readiness Levels

The NASA Reuse Readiness Levels (RRLs) have been developed for use as a measure to evaluate the potential reusability of software. The RRLs can be used to assess software that is being developed or to assess software assets that are being considered for adoption. Software can be evaluated either by using the RRLs in a simple manner to obtain a rough assessment of the software or by using the RRLs more extensively to obtain a precise assessment, which would include an assessment of the software in terms of nine topic areas.

Using the RRLs in a simple manner, the software under evaluation is compared to the brief summary descriptions of the RRLs to determine a value, from 1 to 9, that reflects the level of the potential reusability of the software. The RRLs can be used in this way to attain a quick assessment, which lacks precision, but may be appropriate for attaining efficient assessments when comparing many competing software candidates or when only a rough estimate of the potential reusability of a software product is required.

Alternatively, extensive use of the RRLs can be applied by using a 9x9 grid to evaluate the software against each of the topic areas to determine the level of maturity that the software has attained for each of the nine topic areas. Using the RRLs in this extensive manner can be more time consuming, but enables assessment of each topic area to identify areas where additional development may be required to meet the needs of a particular software project. Prior to using the RRLs in this manner, the software requirements of the project should be identified for each topic area so that the level of effort necessary to improve the software to an acceptable level for each topic area can be determined.

A calculator is being developed for use with the RRLs (a web-based prototype of this calculator is shown in Fig. 2). Using the RRL

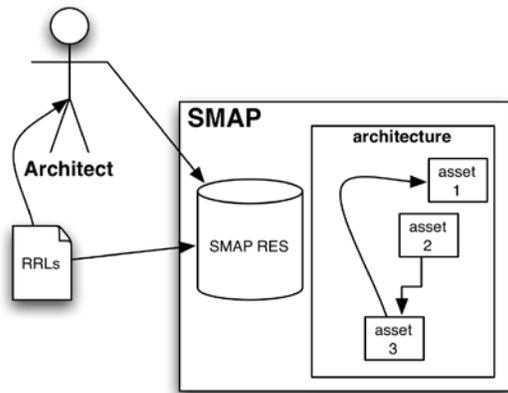


Fig 3. Using the SRWG RRLs and RES to design and implement NASA decadal missions.

calculator, weights can be established for each topic area, depending on the importance of a particular topic area to meet the requirements of a particular software project, and an average overall RRL value can be calculated from assessments of topic area levels. A more advanced version of the RRL calculator, which may offer more features and/or guidance on assessing software assets, is under consideration. The SRWG has also received a copy of a Microsoft Excel-based calculator tool, developed by modifying an existing TRL calculator [10], from a member of the software reuse community. We are examining this tool to ensure that it correctly captures the information contained in the current release of the RRL document.

Tools such as the RRL calculator enable a structured evaluation of reusable assets as software producers and consumers measure applicability and compatibility for their particular project. We are exploring the integration of the RRL calculator with our Reuse Enablement System (RES) [11], a software portal used to track and disseminate information about reusable software assets. The RES system is currently being deployed by the Soil Moisture Active & Passive (SMAP) mission as a proof of concept as shown in Fig. 3. In the following section, we will describe the relationship of RRLs and associated software reuse tools to that of the NASA decadal missions.

### Reuse of Mission Software

The reuse of software offers opportunities for the new decadal survey missions and future space missions to reduce costs and improve the quality of the software that is either produced by or used from previous efforts. Likewise, software

reuse offers opportunities to obtain similar benefits when processing and reprocessing data obtained from such missions. Recipients of the NASA ESDS Software Reuse Working Group Peer-Recognition Software Reuse Award [12] have demonstrated the contribution of new reusable assets and the utilization of existing reusable assets in systems development for NASA missions; for example, the National Polar-orbiting Operational Environmental Satellite System Preparatory Project's Science Data Segment reused a variety of system components to reduce development effort and help ensure reliability [13], as did the Orbiting Carbon Observatory's (OCO) Ground Data System [4].

In conjunction with the ICESat-2 mission effort, procedures and templates also are being developed to use the RRLs to assess the current state of readiness when assessing software from previous missions for potential reuse in future missions. Using such tools can help to improve the usability of software created during previous missions. Such tools also can be used to assess the potential reusability of software that is being developed for new missions to improve its potential for reusability in other future missions. The SRWG plans to work with the ICESat-2 team as needed to help them assess some of the existing software assets from the original ICESat mission that they plan to reuse.

In addition, using tools, such as calculators (as shown in Fig. 2), templates, and procedures, in conjunction with the RRLs, to assess the reusability of software, can identify aspects of the RRLs that may be considered for possible improvement. ICESat-2's experience will enable a use case study to help the SRWG improve the RRLs and how they are used to perform software reusability assessments. Likewise, testing the use of such tools for assessing the potential reuse of software also will contribute to their refinement and inspire the development of additional tools for assessing reusability [14, 15, 16] and can foster the consumer's confidence that the asset has been assessed as to its level of robustness and readiness for operational use.

### Conclusions

Considering the data processing needs of the new decadal survey missions, the reuse of software from previous missions offers an opportunity to leverage the investments made in previous missions. The RRLs have been developed by the ESDS SRWG to assess the readiness of software for potential reuse. Using

the RRLs in conjunction with other tools, such as the RRL calculator, templates, procedures, and lessons learned, can improve capabilities for reusing software in new missions and for realizing the benefits of software reuse.

In addition to reusing software and system artifacts from previous missions in the new missions, software reuse offers an opportunity for the decadal survey missions to develop software that can be used in other future missions. Planning for the potential reuse of new software can complement the efforts of reusing previously developed software. Adopting a systematic approach to software reuse can contribute to the improvement of software development practices and to the potential reuse of software and other system artifacts in the future [15].

The use of tools to assess the reusability of software and to register and describe software for potential reuse offers benefits for organizations that develop software for potential reuse and for those that reuse existing software. The use of such tools for the decadal survey missions can assist in the preparation of software that was developed for use in previous missions for possible reuse in future missions. In addition, these tools also can help to prepare software that is being developed for the new missions for use in future missions.

Software assets considered as candidates for potential reuse can be registered and described in a RES where they can be found and analyzed by developers for inclusion in future systems. Refining such tools and developing additional tools to support the reuse of software can contribute to the capabilities available for both software producers and software adopters.

It is important for current missions to recognize that the systems and components they are currently developing may have the potential to be reused by future missions. Therefore, any steps they can take to make such assets more reusable will help encourage a more systematic reuse process, one that can continue to improve future missions through the realization of the benefits of software reuse.

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