Conceptual Development of the DESDynI Mission

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Abstract—The high value of Radar and Lidar data for understanding climate change and earth dynamics led to the prioritization of the Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI) mission as Tier One in the last National Academy of Sciences' Earth Science Decadal Survey. A mission concept that matched those desired objectives underwent pre-Project development and passed several layers of review in late 2010 and early 2011 with the target of a 2017 launch. However, cuts in the proposed FY2012 budget forced a reset of the Radar mission and eliminated the Lidar sciencecraft. The proposed DESDynI-Radar mission may now fulfill a more limited set of objectives with a more modest budget on a longer development timescale. A multitude of options have been studied with varying levels of cost, risk and science value. Flight and Ground system implementations have a direct bearing on many of these factors and will also be addressed. The methodology and status of evaluating these options will be discussed. A key distinguishing characteristic of the projected DESDynI-Radar measurement would be large scale coverage and frequent revisit at fine resolution. This would be enabled via a new Radar technique called SweepSAR. Efforts to develop and field test SweepSAR will also be discussed, as well as other technology developments underway that are associated with this mission.

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1. INTRODUCTION

The proposed Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI) mission was endorsed in 2007 by the National Academy of Sciences as a Tier 1 mission essential for the study of earth science in the following

decade. The mission successfully passed the Pre-Phase-A Mission Concept Review (MCR) gate and was a few weeks from Phase A start when the FY'12 budget proposal from the Office of Management and Budget eliminated the Lidar sciencecraft and recommended a descope in the Radar sciencecraft budget. Studies since then have focused on evaluating options for DESDynI-Radar that would be more affordable.

At the core of the proposed DESDynI-Radar (DESDynI-R) would be a highly capable L-band Synthetic Aperture Radar (SAR) system. This SAR would ride on a dedicated, high power, precisely pointed platform capable of high downlink rates. DESDynI-R would fly in a highly repeatable orbit with short revisit times. These frequent observations would be combined via interferometric processing to detect changes in various physical properties. By stacking these observations over at least three years, measurement errors are beaten down and very small changes become detectable. Polarimetric capability is being considered for the radar.

In order to meet the OMB directive of creating a more affordable version of DESDynI-R, JPL and NASA have been seeking domestic and international partners who would benefit from being able to keep DESDynI-R's key capabilities (short repeat, large coverage) intact. Options range from data processing assistance from other U.S. agencies to a contributed spacecraft bus and/or launch vehicle from a foreign partner. These options result in different costs to NASA, and therefore require different levels of funding, which under current budget assumptions, could result in launch dates ranging from 2017 to 2020.

2. SCIENCE OBJECTIVES

Earth's land surface is constantly changing and interacting with its interior and atmosphere. In response to interior forces, plate tectonics deform the surface, causing earthquakes, volcanoes, mountain building, and erosion, including landslides. These events shape the Earth's surface, and can be violent and damaging. Human and natural forces are rapidly modifying the global distribution and structure of terrestrial ecosystems on which all of life depends, causing steep reductions in species diversity, endangering sustainability, altering the global carbon cycle

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and affecting climate. Changes in ice sheets, sea ice, and glaciers are key indicators of these climate effects and are undergoing dramatic changes. Increasing rates of land ice melt is the primary contributor to eustatic sea level rise.

DESDynI was a mission concept recommended by the National Academy of Sciences in 2007 [1] to address these changes. After several years of technical studies conducted by NASA, a robust mission concept has emerged that could observe these changes over the life of the mission, contributing significantly to our understanding of processes and controlling mechanisms in each discipline.

The primary mission objectives proposed for DESDynI are to: 1) Determine the likelihood of earthquakes, volcanic eruptions, and landslides through deformation monitoring; 2) Characterize the global distribution and changes of vegetation aboveground biomass and ecosystem structure related to the global carbon cycle, climate and biodiversity; and 3) Predict the response of ice masses to climate change and impact on sea level. In addition, DESDynI would provide observations that would greatly improve our monitoring of groundwater, hydrocarbon, and sequestered CO2 reservoirs. DESDynI would be the first mission to systematically and globally study the solid Earth, the ice masses, and ecosystems, all of which, despite numerous capable international systems in orbit, are too sparsely sampled to address many important global scale problems in geohazards, carbon and climate. These objectives were described in detail in [2].

To address these objectives, the DESDynI project team has worked with the community to create a number of specific measurement requirements that define the mission capability. These requirements can be summarized as follows:

- For Solid Earth deformation, DESDynI is proposed to accurately measure 1) interseismic motion in two dimensions, over the areas of the globe known to be deforming at greater than 1 mm/yr rate; 2) several hundred targeted phenomena of interest such as volcanoes, coseismic and postseismic events, and landslides over the life of the mission, primarily in the same areas as the interseismically deforming zones, but also extended to other regions. These requirements lead to a global mapping system requiring rapid sampling using repeat-pass radar interferometry, the only known method to be able to deliver such measurements. Repeat-pass interferometry requires that all the images being combined are taken from a similar point relative to the target. Thus, the orbital position must be repeatable, not just to keep the target within the scene, but to allow coherent interference.
- For Ecosystem Structure, DESDynI is proposed to accurately estimate above ground woody biomass over the globe, at 100 m – 1000 m spatial scales, and over a wide variety of biomes and biomass densities. Polarimetric radar measurements would be used to measure biomass and biomass change.
- For Dynamics of Ice, DESDynI is proposed to accurately measure ice sheet, glacier, and sea-ice vector velocities comprehensively over the life of the mission. To meet these requirements again the radar interferometry, as well as speckle- and feature-tracking, would used for measuring velocities.

Clearly, DESDynI would have many demands on its measurement systems. The radar would operate in an orbit optimized to meet the kinds of sampling strategies required for the science: wide-swath fast-repeat interferometry with widely-spaced ground tracks.

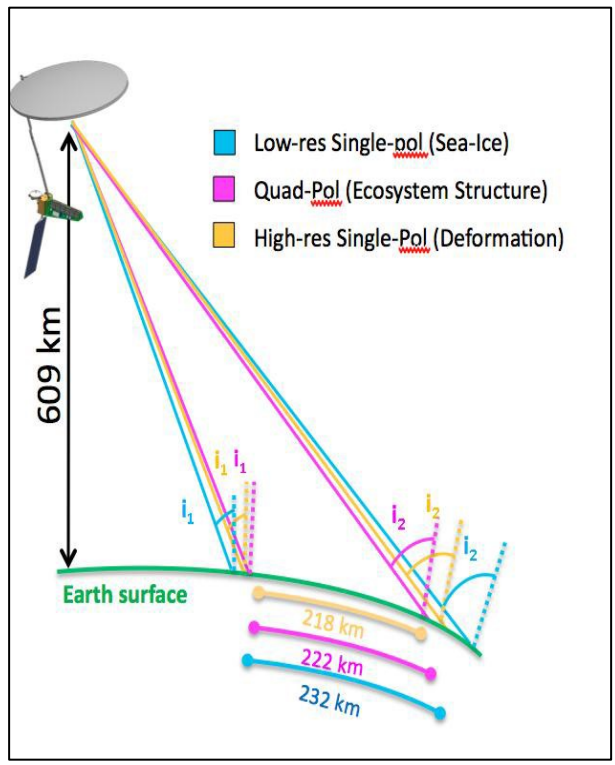

Figure 1. Proposed DESDynI Radar imaging scenario and swath widths. Using the SweepSAR method, full swath could be imaged at full resolution. Note: figure not to scale.

Other L-band radars are planned for operation by other nations, but none are designed to handle the data volumes and rates to allow for these measurements at the global scale with systematic, repeated observations. The frequent and long-term coverage that would be afforded by DESDynI (and enabled by the wide-swath of the SweepSAR technique) would allow for the collection of the impacts of many infrequent events (earthquakes, volcanic eruptions, landslides, glacier variations), low speed processes (glacial recession, interseismic motion) and globally dispersed measurements (biomass change).

3. MISSION DESIGN

The mission and trajectory design plays a critical role in the overall mission. In addition to helping to meet the science objectives, it also affects how the mission would be operated and how the data would be collected.

Orbit Selection

The accuracy of the science measurements is tied to the orbit repeat interval, with each science discipline preferring a different value. For phenomena related to deformation or cryospheric science, where changes can occur quickly, a shorter orbit repeat interval is desired. For study of phenomena that vary on seasonal-like time scales, such as the case for ecosystem structure, a much longer time interval is desired. For DESDynI, orbit studies have focused on intervals between 8 and 24 days, with a 13-day repeat interval considered an acceptable baseline to all science communities.

Within a selected orbit repeat interval, options exist at different altitudes, with the preferred range to be approximately 600 km to 800 km. This range is bounded on the lower end by limitations on the ability to achieve an adequate swath width and on the upper end by the radar signal-to-noise ratio.

One factor to consider in the mission and trajectory design, when evaluating altitudes is the effect of atmospheric drag on our ability to maintain the spacecraft within a specific corridor. This small, diamond-shaped corridor, measuring 500 meters in the cross track direction and 650 meters in the radial direction, would permit use of a simpler data processing system to create the interferograms that are needed by the DESDynI science community. At the lower altitudes, the effect of the atmosphere is much greater, resulting in a need to perform maneuvers daily. At the higher altitudes, the atmosphere does not affect the spacecraft as much, so maneuvers would be less frequent.

Another option to consider when it comes to determining orbit altitude is the performance capability of the various launch vehicles. In order to comply with NASA Orbital Debris requirements on disposal of the upper stage, the smaller class of launch vehicles, such as the Taurus or Minotaur, would need to inject the spacecraft into an orbit lower than what would be desired for science. It would then be the responsibility of the spacecraft to carry additional propellant to achieve the science orbit. For the larger class of launch vehicles, this is less of a constraint, as there would be adequate propellant remaining to deorbit the upper stage.

Science Planning

Beyond the orbital mechanics and science implications of the orbit repeat interval, there is also the impact on the planning and observation strategy. One of the proposed objectives of DESDynI would be to provide global coverage of the earth's land and ice surfaces within the selected orbit repeat interval. In the case of a shorter repeat interval, this would translate into a greater percentage of the earth needing to be covered on any given day. This would result in a larger daily data volume, when compared to a day from a longer repeat interval, where less of the earth would be observed.

TDRSS would be the most desirable downlink architecture for DESDynI because it offers a wide range of options for improved data volume capability. DESDynI could choose between a higher data rate design combined with some minimal amount of TDRSS coverage time and a moderate data rate design with increased coverage time. However, because TDRSS is a shared resource, there are limitations to the amount of coverage time that could be requested.

One combination of TDRSS parameters that would allow us to achieve the proposed DESDynI science objectives with a high-level of confidence assumes a 300Mbps data rate and 45 minutes of coverage per orbit. This would result in a daily data volume capability of approximately 12 Terabits per day.

4. SAR INSTRUMENT

SAR System Requirements & Design

The DESDynI SAR Instrument is still in the planning phase, with the radar design efforts focused in two main areas:

(1) Flowing the science requirements into instrument design parameters, and optimizing the instrument concept to minimize cost while satisfying the most science

(2) Developing the instrument architecture to provide the optimal performance at the lowest cost, and identifying and developing any long-lead components to mitigate technology risk

Early trade studies concluded that using a "SweepSAR" scan-on receive technique, implemented using an array-fed reflector antenna geometry, allowed for the most cost-effective achievement of the key science requirements [1]:

(1) wide swath to provide global coverage with a short repeat period

(2) sensitivity (-25dB NES_0) and ambiguities (-15 to -20 dB) that take advantage of the large reflector

(3) stability and calibratability taking advantage of the small compact feed array to house all active components

SAR Instrument Characteristics

The DESDynI radar would operate at L-band (1.2 GHz, 24 cm wavelength), in a sun-synchronous orbit with an exact

repeat period of between 8 to 12 days, from an altitude of 587 to 761 km, in order to accommodate the various partnerships under consideration. (The exact orbit and repeat period, and the required swath, would be defined when partnership agreements are forged, and the project enters the formulation phase.) From this range of altitudes and repeat periods, the maximal swath width at the equator required to achieve global coverage is approximately 230 to 350 km, which would normally necessitate ScanSAR operation to achieve acceptable performance over such a wide swath. To meet DESDynI's proposed science requirements, it is necessary to image the entire swath without sacrificing resolution as with ScanSAR. Hence DESDynI would operate in the new mode called SweepSAR [2,3].

SweepSAR, implemented as proposed for DESDynI, would achieve its wide swath while meeting tight ambiguity and thermal noise requirements through the use of a reflector and array feed (Fig. 1). By transmitting on all elements in the feed (about 2 to 3.25 m in length) the reflector (9 to 13.5 m in diameter) would be illuminated by a narrow beam, thus providing broad illumination of the ground. On receive, a subset of the receive modules would be activated, providing a broad beam illumination of the reflector and thus a narrow receive beam on the ground. By using processing that effectively rapidly switches the active receive modules in a sweeping fashion, the receive beam would track the echo as it propagates across the illuminated transmit area. Active beam forming techniques would be used to enhance performance, and keep the data rate to the minimum required to image the desired swath width.

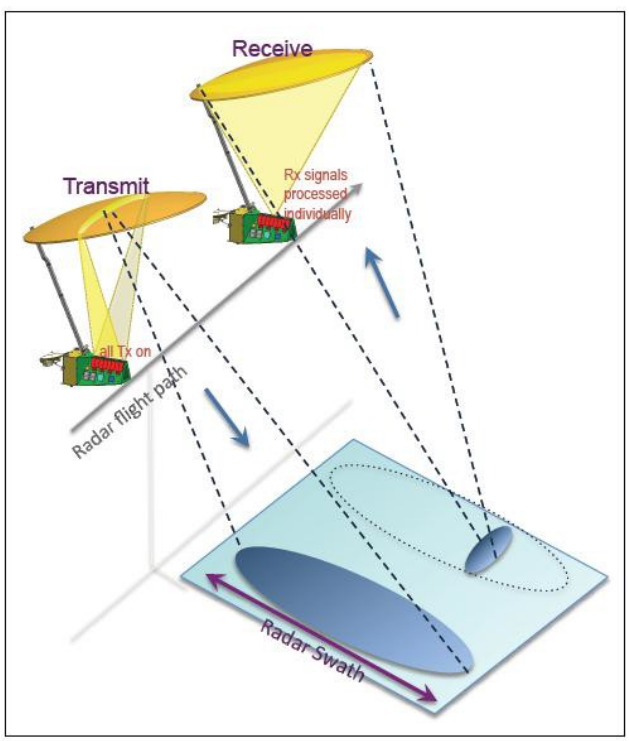

Figure 2. Proposed DESDynI Radar imaging using the SweepSAR technique. Note: figure not to scale.

SAR Operational Modes

There are essentially three primary modes of operation needed to meet the proposed DESDynI science objectives:

(1) Single-Polarization Split-Spectrum mode, with 20 MHz bandwidth at one end of the allocated 80 MHz radar band, and 5 MHz at the other end, is defined for repeat-pass radar interferometric observations used for surface deformation measurements. The split band of operation would be used to solve for ionosphere-induced errors in the interferometric phase [4]. In addition, the radar would be required to fly an exact repeat orbit, to within a few hundred meters, in order to reduce the effects of geometric and volumetric decorrelation.

(2) For ecosystem science, the primary mode of data collection would be a specialized 20 MHz Quad-Polarization mode covering the range of incidence angles from 30° to 45°. This mode is really two dual-polarization modes, HH/HV at one end of the 80 MHz band and VV/VH at the other end, transmitted and received simultaneously. Acquisition in this mode would allow low pulse repetition rates and manageable ambiguities, at the expense of not acquiring the full scattering matrix in a traditional quad-polarimetric mode.

(3) For low-resolution imaging of sea-ice for the purpose of feature tracking, a 5 MHz bandwidth Low-Resolution Single-Pol mode is defined to keep the data volume down. The spacecraft could be rotated to either the left or right-looking direction to observe both poles, and it is anticipated that this would be done seasonally.

Data collections for all modes could occur on both ascending and descending orbits. Other modes, such as wide-bandwidth 80 MHz single-pol or full quad-pol, would be used for specialized targets of interest.

The SAR instrument would take advantage of mature heritage designs to the extent possible, and use existing commercially available components to implement the SweepSAR technique with an array-fed reflector design. No new technology development is needed – only engineering to adapt currently available technology's capability.

SAR Technology

Reflector, Boom, and Feed/Electronics Structure—The instrument mechanical elements would all use mature technologies. The low-mass deployable mesh reflector, along with its accompanying deployment boom, is available from two manufacturers, both with extensively flight-proven heritage systems in the 6 to 15 meter diameter range. The feed/electronics structure would be constructed using thermally-stable composite panels available from several

industry providers having flight hardware development experience. The large passive mesh reflector and compact feed implementation would solve the problem of the traditional unwieldy complex antenna – a conventional rigid-panel phased-array, typically ~12m long by 2m wide for L-Band ScanSAR, would have to be ~12m long by 12m wide to function for SweepSAR, no doubt prohibitively expensive. An independent study by Aerospace Corp concluded that "the array-fed reflector design is predicted to be lower cost than the conventional planar-array design (with its ScanSAR disadvantage) by a factor of 1.7 to 2.4" [5].

Feed RF Aperture—The SAR antenna feed aperture would be implemented using a simple dual-polarization microstrip patch array, as was used for the SeaSat, SIR-A,B,C, and Shuttle Radar Topography Mission (SRTM) SARs. The feed array has been modeled using High Frequency Structure Simulator (HFSS), and integrated with a Grasp model of the reflector, to provide antenna patterns for use by the radar performance estimation modeling [6]. The number of patches in the array to support the range of designs under consideration would be between 6 and 12 in elevation by 2 in azimuth.

Transmit/Receive Modules—The transmit/receive module design would use high-efficiency ~100W power amplifiers to minimize the number of modules, thereby minimizing fabrication, assembly and test recurring cost. A high-efficiency power amplifier using commercially-available GaN devices is currently under development [7]. The ~100W peak RF power level is higher than typical for a conventional spaceborne phased-array T/R module, but is not so high as to require any extreme measures for multipaction breakdown mitigation. The DESDynI SAR T/R module would take advantage of heritage components used in the Aquarius Scatterometer 200W front-end for transmit/receive diplexing and receiver protection. The transmit/receive module architecture also takes advantage of the digitizer on each receive channel, necessitated by SweepSAR technique's receive digital beamforming, to do on-board digital calibration. The transmit channel amplitude and phase, receive channel gain and phase, and channel-to-channel timing skew would be measured and corrected digitally, to a much higher degree of accuracy than is typically possible using conventional temperature monitoring and pre-flight look-up tables [8]. The thermal control of the T/R module would use a simple passive radiator designed in as part of the electronics packaging to minimize the thermal path resistance [7], along with simple thermostatically controlled supplemental film heaters.

On-Board Digital Signal Processing—The SweepSAR beamforming, digital calibration, programmable filtering, and azimuth pre-summing and block floating-point quantization data reduction algorithms would all be implemented using the commercially-available rad-hard Xilinx Virtex-5 FPGAs. Flight quality parts were released by Xilinx last July, and are available for procurement. The SAR DSP architecture includes distributed per-channel processing as well as centralized one-per-polarization processing to best take advantage of the V5's resources and capabilities, while minimizing the parts quantities and board complexity in order to keep costs down. The design currently under development would include four receive channels, each with a 12-bit analog-to-digital converter, per first-stage (distributed) processor, with each first-stage processor implemented using a single V5 FPGA. The centralized second-stage processors, one for each of the two polarizations, would each include two V5 FPGAs to handle the data reduction. The on-board processing algorithms are currently being developed and demonstrated using a testbed based on a generic "iBoard" [9] development platform.

Back-End Electronics—The SAR back-end electronics functions would all be implemented using heritage designs from recent previously-developed L-band radars, Aquarius and SMAP (currently in the formulation phase).

SweepSAR Airborne Demonstration

The SweepSAR airborne demonstration used an array-fed reflector (Ka-band) with eight digital receiver channels to emulate the proposed DESDynI SweepSAR measurement technique using scaled geometry and timing [10]. The airborne radar system was flown on the NASA DC-8 in July 2011, and collected data over 12 flight lines, including corner reflectors deployed in radar dark areas at Edwards AFB, and urban areas over Palmdale. SweepSAR beamforming was simulated in non-real-time processing of the collected data after the flights. An image from this demonstration is shown in Figure 3.

Figure 3. SweepSAR Airborne Demo beam-formed corner reflector image.

The dataset from the eight receive channels would be used in the future for play back into the DESDynI SAR DSP testbed to demonstrate the real-time processing algorithms.

5. FLIGHT SYSTEM

The proposed DESDynI Flight system would be comprised of the spacecraft bus and the L-Band Radar payload. The objective of the flight system team would be to ensure the spacecraft bus design interfaces with the radar design appropriately and would be able meet the mission requirements.

It is the accommodation of this radar payload that poses a number of challenges to the flight system design, most of which go beyond the physical accommodation of the radar feed and reflector. There are also a number of issues related to the data generation capability of this instrument. These data would place significant demands on the data transfer, storage, downlink, and ultimately the processing subsystems.

Spacecraft Overview

As expected, the L-band radar payload would be different from what has flown previously, but at first glance, a lot of the traits of the spacecraft bus design would closely match those of other earth orbiting missions. The spacecraft would be a three-axis stabilized system, dependent on items such as reaction wheels, Inertial Measurement Units (IMUs), and star trackers to maintain attitude control and torque rods to manage momentum accumulation. A standard RAD750 computer would manage the command and control function on the spacecraft. Tracking, Telemetry and Command (TT&C) data would all be sent via S-band. The total mass of the fully fueled flight system would be approximately 2 metric tons, with orbital average power requirements on the order of 2 kilowatts. All of this could be packaged to fit within either an Intermediate class launch vehicle (i.e., Atlas V, Delta IV, Falcon9), or smaller launch vehicles such as the Delta II, Taurus or Minotaur series launch vehicles.

Physical Accommodation Challenges

The biggest challenge affecting the physical configuration of the flight system design is the need to overcome gravity gradient torques. By having large, non-equivalent masses distributed several meters apart, the gravity gradient torques could be fairly significant. In order to overcome this configuration-induced torque, several options were examined. One option considered was to use a large balance mass (on the order of 300kg) to counteract the mass of the reflector. In this configuration, the gravity gradient torque was effectively canceled out. However, designing a system to deploy a 300kg mass was deemed too costly. A more elegant solution, and one that is part of the proposed design today, would be to use the solar array as the counteracting mass. By deploying the array in the direction of nadir, and having a two-axis gimbal, an equally effective system for cancelling out the gravity gradient torque would be realized.

The other significant challenge with flying such a large reflector is finding a suitable arrangement for the various sensors needed to operate spacecraft. These include the star trackers, sun sensors, and GPS antennas. A further complication affecting the placement of these sensors is the desire to fly the spacecraft with the instrument pointed to either the left or right of the groundtrack. By adding the capability to yaw the spacecraft 180 degrees, observation of the both the North and South Polar regions would be permitted, but would eliminate the possibility of having of a dedicated side of the spacecraft with a near-constant view of deep space, which is commonly preferred for these types of sensors.

In order to overcome this issue, and the blockage from the deployed reflector, additional sensors would be needed. In the case of sun sensors, a total of one to two dozen sun sensors would be needed to provide near-4pi steradian coverage (Complete 4pi steradian coverage is not achievable, in the reflector concept envisioned for DESDynI). To improve GPS reception, a third antenna was added to the top of the boom, to augment the performance of the two that are installed on the zenith deck of the spacecraft. Though the third antenna has a near optimal view to the GPS constellation, it is subject to the dynamics of the boom, and therefore additional antennas would be needed on the spacecraft bus to achieve the Precision Orbit Determination (POD) accuracy required by DESDynI.

Data Handling Challenges

Beyond the physical accommodation challenges, there are also issues related to the data coming from the radar. A lot of these issues demand a reexamination of the design choices that are typically used on Earth Science missions.

The first hurdle that needed to be addressed was the transfer of the data from the radar to the spacecraft. Typically, payloads send their data to the spacecraft using either an RS-422 or LVDS interface. However, these interfaces peak at data rates of 10 Mbps and 400 Mbps, respectively. For this radar, when operating in the fully polarimetric mode (quad polarization), the data rate can be as high as 1.6 Gbps per polarization channel. In order to handle such a high data rate using one of the standard interfaces, several data lines operating in parallel would be required. Again, this was being prohibitively costly, since both the spacecraft and radar payload would need to manage each of those individual data links independently. Another option being actively pursued is the serial-deserializer (SERDES) interface, which can handle data rates as high as 2.5 Gbps. Using just a couple of these interfaces, the bandwidth available would more than adequately span the range of radar capability being considered.

In addition to the high data transfer rate, there is also the challenge of storing and downlinking these data. Depending on which class of science requirements is envisioned for this mission, the onboard data storage requirements could vary

significantly. In order to achieve the more advanced science objectives, an onboard storage system capable of 4 Terabits would be needed. If a more modest level of science objectives is chosen, then a sub-Terabit amount of storage would be adequate. The other aspect of sizing the data storage system is the telecommunications link that would be used to send data to the Earth. Here again, DESDynI needs to evaluate alternative design options from what is commonly used in an earth science mission.

Typically, science missions use the NASA Near-Earth Network (NEN) to communicate with the ground and to receive their downlink. With most ground stations located at the higher northern latitudes, a spacecraft in LEO can expect to overfly a ground station nearly once every orbit and have a downlink session lasting between 7 and 15 minutes. Combined with the existing capabilities of these stations to receive data at rates up to 150 Mbps, the maximum data volume return per orbit is limited to less than 150 Gigabits. Though upgrades are planned to increase the data rate capability to 300 Mbps, the short downlink durations still limit the data volume to less than 250 Gbits

With this level of data volume, the DESDynI Radar would only be permitted to operate for about 5-7 minutes per orbit on average. This would limit the scope of global coverage for the mission. Various other alternatives were considered, such as the use of commercial ground stations or an optical communication system. Both these options would offer much higher data rates, but once again, cost was a constraining factor and these options were not pursued further.

The most appealing option available to DESDynI is the use of the NASA Tracking and Data Relay Satellite System (TDRSS). In addition to providing near continuous downlink opportunities, it permits the use of much higher data rates. By taking advantage of the 650MHz Ka-Band channel that exists on the second generation TDRSS (F8, 9, 10), DESDynI could transmit data at a rate as high as 1.2 Gbps.

The other benefit of using TDRSS is the arrival point of data on the Earth is within the continental United States (White Sands, New Mexico). This is advantageous over the NEN sites at places like Svalbard, Norway or Poker Flats, Alaska, because the bandwidth available to transfer data to JPL and the science community is significantly larger.

6. SCIENCE DATA SYSTEM

The main function of the Science Data System (SDS) is to receive level 0 radar data and ancillary data to produce a set of science data products that would meet the objectives of the three DESDynI science disciplines—solid earth, cryosphere, and ecosystem structure.

Key Challenges

Under this proposal, the DESDynI SDS design is driven by the sheer amount of data received from the spacecraft and radar instrument. The DESDynI radar is expected to collect 12 Tbits of radar signal data each day. This data would be downlinked via TDRSS at 300 Mbps Ka-band for a 45 minute downlink period per orbit to the science data center. However, this is not necessarily the upper limit of the data return. The DESDynI study could return up to 40 Tbits of radar data each day if the on board telecom system upgrade to 1Gbps Ka band downlink is carried out. In addition to processing extremely large data volumes, another SDS design challenge is the major effort to improve automation in order to reduce operations cost.

Implementation Strategy

Due to the challenges posed by the DESDynI study, the design of the hardware, the catalog system, and the processing system was carefully examined. During the mission concept development phase, a few key studies were made. The first key study was the hardware design study. Because of the expandable requirements levied by the study and the potential number of requirements that would need reprocessing, a question arose: which type of storage space and operating computing environment would best fit DESDynI's needs? The options of cloud computing, renting hardware, and buying hardware were carefully evaluated. However due to funding uncertainties, a temporary conclusion was made: purchase a small set of hardware to use as a testbed for initial algorithm development and as a potential future hardware platform. This strategy will not only support immediate algorithm and software development, but also reduce risk of potential future hardware obsolescence.

The second key study was to identify which potential heritage cataloging and processing system DESDynI should use. During the DESDynI study period, the Soil Moisture Active Passive (SMAP) mission had already been developing its SDS for quite some time. SMAP has inherited the design from the heritage JPL Process and Control System which was also used by the Orbiting Carbon Observatory (OCO), NPP Sounder PEATE, Atmospheric CO2 Observations from Space (ACOS), and OCO-2 projects. The Science Processing and Data Management (SPDM) subsystem is the brain of the operations environment of the SMAP SDS. The SPDM provides the function that allows for automation of the science data processing so that the computer system can operate 24 hours a day, seven days a week, relieving the operators of this time consuming task. The SPDM would automatically ingest external files to the SDS staging area, then prepare and move ingested files from the staging area to the local storage. A work flow manager and resource manager under the SPDM would then move, track, monitor and dispatch the input files to various computer nodes for different level processes, meta data generation, cataloging, and data

distribution. A high level view of the SDS is shown in Figure 4.

The DESDynI Project would process all radar data to Level 0a (decommutated raw data), Level 0b (reformatted and conditioned raw data), and Level 1 (single-look complex images). The project would be able to produce calibrated and validated geo- and biophysical products for each of the science disciplines. For the study of earthquakes, volcanoes, and other crustal processes, a key data product would be geocoded two- and three-dimensional surface deformation models accurate on the order of millimeters per year. For glaciology, the project would be able to produce two-and three-dimensional models of glacier and ice sheet velocities accurate to order 1 m/yr. For ecosystem structure, key products would include polarimetric decomposition maps, forest cover, biomass, and seasonal change maps, accurate to 20%.

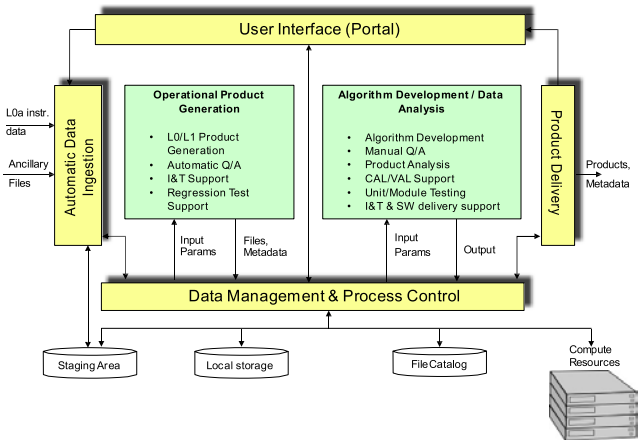

Figure 4: SDS Architecture

An innovative approach has come to the attention of the developers. Rather than simply inherit the design and create another instance of SDS for DESDynI, the developers decided to team up with the SMAP SDS and treat the DESDynI radar as another instrument of a larger SDS, under the same processing and data management of the larger SDS. This instrument would have its own processing logic, however it would use the same infrastructure and framework of design and implementation. This concept would allow for an integrated SDS design.

7. SUMMARY

The proposed DESDynI-Radar mission has the potential to provide unprecedented continuous, long term data sets that would greatly enhance science in multiple disciplines. The mission would require the use of new SAR techniques like SweepSAR to achieve the wide swath at a reasonable cost. Trades in ground and flight systems, along with partnership discussions, are generating a set of options for the science community and NASA to evaluate and consider implementing late in this decade.

Acknowledgement

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REFERENCES

[1] DESDynI MCR presentation, Jan 19-20 2011, Pasadena, CA

[2] Freeman, A., G. Krieger, P. Rosen, M. Younis, W. Johnson, S. Huber, R. Jordan, A. Moreira, SweepSAR: Beam-forming on receive using a reflector-phased array feed combination for spaceborne SAR. Proc. Radar Conference 2009, Pasadena, CA

[3] Johnson, W.T.K., P.A. Rosen, S. Hensley, and A. Freeman 2009. Radar designs for the DESDynI mission. In Proc. IEEE Radar Conference 2009

[4] Rosen, P.A., S. Hensley, C. Chen 2010. Measurement and mitigation of the ionosphere in L-band Interferometric SAR data. Proc. IEEE Radar Conference 2010, Washington DC

[5] Kantrowitz, F., D. Ksienski, M. Barrera, W. Bloss, V. Canales, P. Carian, A. Chandler, D. Chien, K. MacGowan, S. Osofsky, DESDynI Payload Electronics Risk Assessment Spacecraft Concept Comparison, Dec 17, 2010

[6] Chamberlain, N., H. Ghaemi, L. Giersch, L. Harcke, R. Hodges, J. Hoffman, W.T.K. Johnson, R. Jordan, B. Khayatian, P. Rosen, G. Sadowy, S. Shaffer, Y. Shen, L. Veilleux, P. Wu, "The DESDynI Synthetic Aperture Radar Array-Fed Reflector Antenna", 2010 IEEE International Symposium on Phased Array Systems & Technology, Boston, Oct 2010

[7] Hoffman, J., L. Del Castillo, J. Miller, M. Jenabi, G. Birur, "Advanced Thermal Packaging for High Power TR Modules," *IEEE Radar Conference*, Kansas City, May 2011

[8] Hoffman, J., E. Peral, L. Veilleux, D. Perkovic, S. Shaffer, "Digitally Calibrated TR Modules Enabling Real-time Beamforming SweepSAR Architectures for DESDynI-class Radar Instruments", 3rd Workshop on Advanced RF Sensors and Remote Sensing Instruments, ESA/ESTEC, Noordwijk, The Netherlands, 13-15 September 2011

[9] He, Y., M. Ashtijou, "iBoard: A highly-capable, high-performance, Reconfigurable FPGA-based Building Block for Flight Instrument Digital Electronics", NASA/ESA Conference on Adaptive Hardware and Systems (AHS-2010), Anaheim California, June 2010

[10] Hensley, S., G Sadowy, R Chao, E Chuang, D Escoto, H Ghaemi, M Grando, A Guarnera, B Hawkins, B Heavey, B Latham, E Liao, S Lin, J Martin, T Michel, T Miller, R Muellerschoen, D Perkovic, M Quddus, P Rosen, M Sanchez- Barbetty, S Shaffer, J Shimada, I Tan, J Tanabe, K Tham, T Thrivikraman, L Veilleux, "First Results from an Airborne SweepSAR Demonstration at Ka-band", IGARSS, Vancouver, July 28 2011

BIOGRAPHIES

Howard J. Eisen *received a M.S. in Aerospace Systems and B.S. degrees in Physics and Aeronautics and Astronautics from the Massachusetts Institute of Technology.*

He has been with JPL for 24 years in a variety of mechanical engineering, systems engineering, and management roles on Mars (Pathfinder/Sojourner, MRO, MSL) and Earth orbiting (MSTI, SIR-C, Shuttle Radar Topography Mission) missions and proposals (MER, New Frontiers).

He is presently the Program Manager for the JPL Earth Radar Missions Office which includes DESDynI. He was awarded the Silver Snoopy Award for his work on STS-99/SRTM and has received three NASA Exceptional Achievement Medals..

Ben Jai *is the Mission Systems Manager of the Soil Moisture Active and Passive Project (SMAP) and is responsible for the overall ground aspect of the mission; interfacing with GSFC in space and ground antennas, data systems, and data archival and distribution organizations. In addition to his role on SMAP, Ben is also the Mission Systems Lead for DESDynI pre-project.*

Ben received his Master's degree in Computer Engineering from the University of Southern California. Since joining JPL in 1985, he has served in a number of engineering and management roles involving ground data system development, mission operations system development, and mission management at JPL. His previous assignments include the development of the Ground Data System and the Mission Operations System on many missions such as NASA Scatterometer, SeaWinds, Mars Global Surveyor, Stardust, Mars Odyssey, and Mars Surveyor Operations Projects. He has held positions as Data System Engineer, Ground Data System Manager, Mission Operations Manager, and Mission Manager.

Prior to joining SMAP, Ben led the development of mission operations and ground data systems of the Mars Reconnaissance Orbiter Project (MRO). He also led the entire MRO flight team through launch, cruise, Mars Orbit Insertion (MOI), and aerobraking to the completion of the primary science phase of the mission. He was awarded the NASA Exceptional Achievement Medal in 2007.

Paul Rosen *is currently the manager of the Radar Science and Engineering Section and Project Scientist for the DESDynI Mission at the Jet Propulsion Laboratory. His assignments at JPL have centered on scientific and engineering research and development of radar instruments and applications.*

Dr. Rosen was a team leader on the Shuttle Radar Topography Mission, for which he received NASA's Exceptional Service Medal (2001) and NASA's Exceptional Achievement Medal (2002).

Prior to JPL, Dr. Rosen spent two years at Kanazawa University, Kanazawa, Japan. He received a PhD in Electrical Engineering from Stanford University and his M.S. and B.S in Electrical Engineering from University of Pennsylvania.

Dr. Rosen is a visiting faculty member and lecturer at the Division of Geological and Planetary Sciences at Caltech, and has served on the UCLA Extension Program faculty. He was recently elected Fellow of the IEEE, and is a member of the American Geophysical Union. He has been an author on over 40 journal and book chapter publications, and over 100 conference papers.

Louise Veilleux *received a B.S.E.E from University of Maine, Orono in 1979, and a M.S.E.E from MIT in 1982. She has been with JPL for more than 25 years in the Radar Science and Engineering Section. She developed radar flight hardware for SIR-B, SIR-C, and SRTM SARs, was involved in the formulation and development of NScat, SeaWinds, and Aquarius Scatterometers, as well as the SMAP (and precursor HYDROS) and SWOT (and precursor WSOA) Earth-observing radars currently under development.*

Peter Xaypraseuth *is currently serving as the DESDynI Flight System Engineer and is responsible for overseeing the design of the spacecraft bus and the interface to the payload.*

Peter received a B.S. in Aerospace Engineering from California State Polytechnic University, Pomona in 2000. He has been with JPL for more than 12 years, with most of that time spent on the Mars Reconnaissance Orbiter mission, where he had various system engineering roles throughout Development and into Operations. He has also worked on the Dawn mission as a Systems Engineer responsible for developing contingency plans and also the GRAIL mission where he served as the lead Mission Engineer.