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# Science Mission Planning for NISAR (formerly DESDynI) with CLASP

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Abstract: The proposed DESDynI mission (Deformation, Ecosystem
Structure and Dynamics of Ice), now known as NISAR, which has reached Phase A, has utilized CLASP (Compressed Large-scale Activity Scheduling and Planning) in its mission planning phase to rapidly produce feasible, high-level science and instrument operations schedules, to test various configurations of the proposed spacecraft and instrument against developing mission objectives. This has been a key capability as this mission concept has become an international collaboration and specifications are being developed incrementally. The main instrument on NISAR would be a pair of synthetic aperture radars (SAR) with data collection rates on the order of gigabits per second making data management one of the chief constraints of the system. CLASP models data collection, data storage, and downlink while scheduling the operation of the instrument to complete science campaigns of multiple observation mappings of many wide-area targets. CLASP generates schedules to maximize observations completed. This output is used in further analyses, e.g. for power constraint checking. We discuss CLASP and its adaptations to the proposed NISAR mission in the past year, characterizations of the mission objectives, samples of different potential science campaign approaches, performance, and some results.

## I. Background

### a. Mission

The NISAR mission concept is the current incarnation of NASA's answer to National Research Council's (NRC) Decadal Survey response for previously unavailable data and insight in three earth science domains: Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) [1].

The mission concept has undergone several revisions over the years from quite drastic measures, such as the removal of a second spacecraft platform, and collaboration with an international partner, to minor such as adjustments of specific target areas.

The Indian Space Research Organization (ISRO) would partner with NASA's Jet Propulsion Laboratory (JPL) on this proposed mission, and ISRO is baselining to provide a large portion of the mission in launch, bus, infrastructure, and an S-band InSAR instrument. JPL would provide the L-band InSAR instrument, antenna, telecom, GPS and solid-state recorder.

These two InSAR instruments combined could produce data rates of upwards of 5 Gbps for intervals on order of 60 seconds, and sustained rates for global mapping of deformation objectives on order of 2 Gbps. These projected rates and duty test the bounds of today's infrastructure for moving this data from orbit to the ground.

Preliminary mission science objectives have been categorized into campaigns, by scientific discipline, regions of interest, mode of operation of the instruments, and temporal constraints on observation frequency. There are upwards of 25 such disciplines, overlapping in space time and operational modes.

The spacecraft observatory is currently baselined for a 12 day repeat cycle polar orbit, sun-synchronous for dusk and dawn passes.

### b. CLASP

CLASP is a software scheduling and planning tool (Compressed Large-scale Scheduler / Planner) with an emphasis on planning against geometric constraints as well as temporal and resource constraints. Amongst the landscape of software planning tools described in [3], CLASP shares many common scheduling features, to varying extents. CLASP models resources as either depletable or, non-depletable, or both where the former is the integral of the former. CLASP also models states, however these are somewhat restricted in domain rather than completely user definable, for example spacecraft attitude, or instrument mode. While many planners allow an arbitrary hierarchy of activities, CLASP keeps a rigid structure of spacecraft and sensor definitions that result in a finite set of parameterizations of "observation" activities that are the main actors on the schedule [6].

This somewhat rigid planning schema allows more power in the domain of spatial reasoning, and applicability towards planning coverage for mapping missions. SciBox from Johns Hopkins Advanced Physics Laboratory as applied to the MESSENGER mission is described to have geometric/geographic capabilities for planning large-area mapping [4] [5], though it too still emphasizes a broad toolkit of generic spacecraft planning capabilities written from the ground up in JAVA. Both feature modules to compute observation opportunities from science campaigns and constraints, as well as mechanisms to optimize the schedule of observations. Unlike SciBox, CLASP leverages several existing libraries of code and applications such as SPICE for ephemeris calculations and Google Earth for visual rendering. While SciBox is a toolkit requiring development for use, CLASP can generate useful simualtions out of the box, though complex models will also require adaptation.

Given a set of spacecraft, spacecraft trajectories, instruments, instrument modes, mode compatibilities/dominance, datarates, data storage parameters, downlink schedules and rates, and finally sets of geometric target campaigns with desired temporal constraints including windows of opportunity and repetitions, with each target assigned a scoring weight, CLASP aims to produce a schedule of observations from the set of spacecraft and instruments such as to maximize the accumulative score of satisfied target campaigns.

There are a number of scheduling algorithms CLASP can utilize to generate the schedule, but its chief approach is to utilize the Squeaky Wheel Optimization algorithm, coupled with a simple greedy sweep forward in time and priority order. Solutions are iterated over some finite number of attempts to find a maximum score while adjusting target priorities internally between iterations.

## II. Approach

Over the last year, the NISAR/DESDynI mission concept has investigated several trade-studies for which we've run upwards of 30 separate CLASP simulations. During this time, several parameters have remained constant, such as it's now proposed as a single spacecraft mission, on a 12 day orbit, with two SAR instruments. However, over this time, of particular interest have been sizing the solid-state-recorder(s) (SSR) anywhere from 3 Tb to 12 Tb, and the impact of varying data downlink rates from 12 Tb/day to 24 Tb/day. Each of these variations is a simple adjustment to a single input parameter of the simulation at run-time. The SSR has been modeled as a single homogeneous recorder, and the downlink has been typically simulated by a periodic, perfect downlink schedule. However we have also investigated, for example, introducing a "realistic" downlink schedule as dictated by the proposed spacecraft orbit, its telecom antenna's field-of-view and the receiving stations/satellites. In this case we introduce a text-based schedule file to CLASP to replace the generated periodic downlink schedule.

There has also been considerable variation of the science campaigns and their choice of instrument modes. CLASP uses KML (Keyhole Markup Language) to specify geometric regions (as well as several of its output products) of target campaigns, so as to be inter-compatible with other software programs, such as Google Earth. Parameterization of each campaign, such as temporal constraints and preferred mode are encoded within the KML description field, leaving it as valid KML/XML. For each campaign, and any variations it might have seasonally, we keep a separate KML file in our code repository. At runtime, we stitch all relevant campaign kml files, now approaching 27 campaigns, into a single input KML file to CLASP. One additional KML file is added to that stitching to define the mission and instruments overall.

This last input would contain for example the instrument mode hierarchy information – which modes of instrument operation subsume others and could provide opportunities for simultaneous and serendipitous data acquisition for multiple campaigns. While previous CLASP simulations for the DESDynI concept maintained a relatively straightforward mode hierarchy and typically a monotonically increasing datarate up the hierarchy, the increase in science campaigns and increase in modes has led to an increasingly complex hierarchy of compatibility. We have made extensive use of abstract modes – modes that operationally map to a single instrument-operation-mode, but for planning purposes have differing compatibilities. This allows for example individual campaigns within a set of science campaigns with very similar requirements to have exceptions in either their initial "preferred" mode, or the ultimate-dominating mode for synergy. In the most recent simulations, while there are 10 instrument modes for combined S and L band instruments, we implement 29 total modes to complete the desired hierarchy.

For performance reasons, we have made a couple simplifications of the mission encoding. Firstly we have partitioned the 3 year mission into quarterly segments to keep the simulation manageable with standard computing power (12 GB RAM). This actually has an advantage in using portions of one segment of schedule repeated throughout the mission, especially for the repeat-pass-interferometry targets. When confronted with trade-studies or updates to parameters, we typically simulate on the densest season with respect to science campaigns: Quarter 3, Northern Hemisphere Summer.

We have also elected to model both proposed instruments and all of their modes as a single "sensor" in CLASP. While CLASP can simulate multiple sensors, each sensor generates its swath over the earth over an entire repeat cycle, resulting in many polygons. Although this would not cost so much for the addition of one sensor for the L and S band instruments individually, there would be little to gain, as operationally the instruments must be managed collectively (they would share timing resources). The real downside in this trade is that we can encode only a single swath in terms of width, near and far-range look angles, while in fact these parameters vary a certain degree with the radar modes (up to ~10%). We chose the most conservative swath-width and allow CLASP to overschedule targets with subsequent overlap.

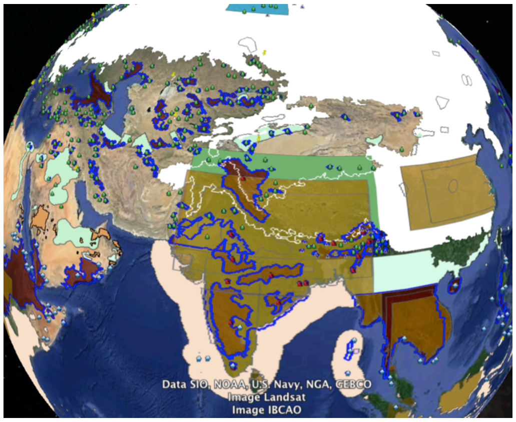

**Figure 1**. A screenshot of a subset of science campaigns geographically painted by Google Earth, centered over the Indian subcontinent.

Finally, CLASP can deal with targets in either a pixelated/rasterized/gridpoint fashion or in an abstract polygonal "shard" mode. We utilize a gridpoint approach, tessellating the entire earth's surface with squares such that there are 800 squares around the equator, or roughly 50km per side squares. Every campaign target is thus remapped from a polygon to the set of intersecting squares, or more precisely, those squares whose center-points are contained within the target. This has some obvious potential for inaccuracies, for example, where a center-point may lie outside a concave polygon target. However we have found our targets and this gridpoint resolution to provide adequate accuracy, when used with comparably sized observations of 15 seconds. This is in contrast with shards which would provide practically infinite precision (limited by representation of floating-point numbers) and accuracy, but suffer with an abundance of polygons/shards in global simulations such as this where our cryospheric targets intersect with frequently overlapping swaths near the poles. These multiple intersections result in many shards, many of which have little value in producing a satisfactory schedule since there are an abundance of visibility opportunities for the target as a whole and scheduling for a few key shards will satisfy most of the rest as they are interdependent.

## III. Performance

All runs of simulation have been executed on an Intel Xeon 3GHz processor with 12 MB cache and 6000 BogoMIPS.

The system has typically had 12GB of RAM but recently was upgraded to 192 GB. With the parameters as defined, CLASP runs within 2GB of RAM. Some variations on the gridpoint spacing had been increased to 3200 around the equator and observation lengths shortened, but this proved difficult to keep in memory without swapping to disk and dramatically increasing run-time.

Each simulation is typically allowed 30 iterations to maximize the solution, usually finding 5-6 improved solutions.

Timing on this platform:

- Initial loading of model, generation of grid polygons, generation of observation “visibilities” : ~60 seconds
- Solution per iteration: ~115 seconds
- Best solution write-to-disk: ~790 seconds

Simulating other seasonal quarters with fewer science campaign demands has a considerably faster run-time per iteration, but obviously still dominated by the output generation as each improved solution is found.

## IV. Results

We provide here some artifacts of CLASP simulation runs as results gathered from various simulations throughout the year. For example, often the profile of data storage on the SSR over a seasonal/quarterly segment is checked for consistency with our expectations; see figure 2. We have several targets that require particular temporal spacing, causing periodic peaks in SSR usage, which the last few are visible in figure 2. CLASP is using an inherently a greedy scheduling algorithm, which leads to the “front loading” of the schedule, taking earliest opportunities first, and leaving margin at the end of the scheduling horizon.

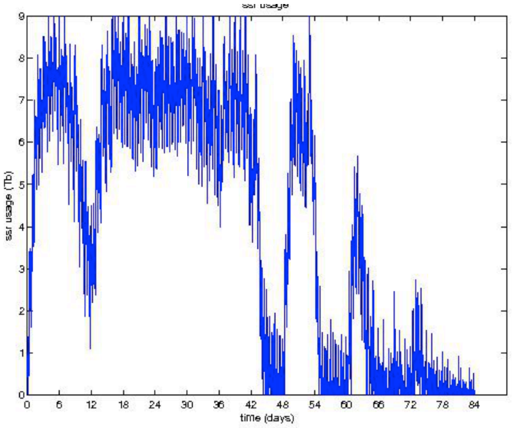

**Figure 2.** A plot of solid-state-recorder fill state over the course of a single season simulation.

The mission concept would have requirements to cover 80% of each of the science campaigns. In table 1, we tabulate satisfaction of our science campaigns in percentage of all observations and percentage of area with required number of observations. We can see that the majority of campaigns would be satisfied, though isro_subsidence has fallen below the threshold, and isro_landslide is

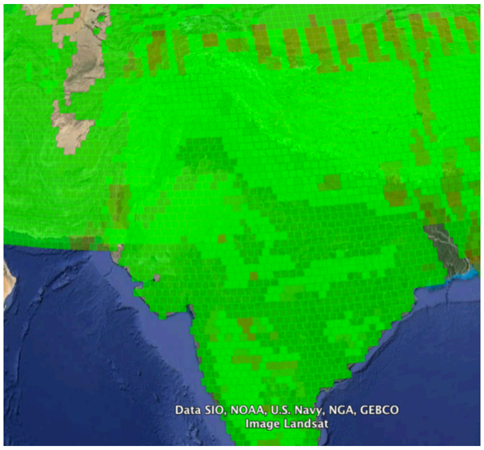

**Figure 3**. Geographic rendering of targe satisifcation. Green represents fully satisfie while red is unsatisfied and yellow, brown an orange between. There is a pattern c unfulfilled campaigns north of India here wher several campaigns overlap.

| Science Campaign | Percent of all requested observations scheduled | Percent of completely satisfied target regions |
|---|---|---|
| es_veg_dp_dry | 100% | 100% |
| es_veg_dp_wet | 100% | 100% |
| es_veg_leafoff | 100% | 100% |
| es_veg_leafon | 100% | 100% |
| es_veg_qp_dry | 100% | 100% |
| es_veg_qp_wet | 100% | 100% |
| isro_ag | 97.74% | 88.34% |
| isro_ag_sub | 100% | 100% |
| isro_landslide | 95.75% | 83.87% |
| isro_ocean_apps | 99.08% | 97.66% |
| isro_sea_ice | 100% | 100% |
| isro_subsidence | 96.43% | 75% |
| isro_volcano | 100% | 100% |
| land_ice | 100% | 100% |
| nt_ag | 100% | 100% |
| nt_aquifers | 99.78% | 98.96% |
| nt_prmfrst | 100% | 100% |
| nt_wetland | 100% | 100% |
| priority_ice | 100% | 100% |
| isro_coastal_studies | 98.83% | 95.31% |
| isro_coastal_studiesp | 97.66% | 95.31% |
| se_deformation_anthropogenic | 99.84% | 99.46% |
| se_deformation_landslide | 100% | 100% |
| se_deformation_strain | 99.25% | 97.59% |
| se_deformation_volcano | 100% | 100% |
| sea_ice | 98.22% | 91.14% |
| es_veg_dp_dry | 100% | 100% |
| es_veg_dp_wet | 100% | 100% |
| es_veg_leafoff | 100% | 100% |
| es_veg_leafon | 100% | 100% |
| es_veg_qp_dry | 100% | 100% |

**Table 1**. Science campaign satisfaction of a recent simulation. For each science campaign a single gridpoint/cell/region may require several observations to satisfy the campaign: Column 2 is the percent of all individual observations satisfied, while Column 3 is the percentage of cells with all required observations satisfied.

near the threshold. We could run this simulation again with an increased scoring value on these two campaigns, however a closer look at our campaign distribution geographically (Figure 1) together with geographic rendering of science campaign satisifaction (Figure 3) shows there is a confluence in the Indian subcontinent contributing to the reduced satisfaction numbers.

For other campaigns, lack of complete coverage is a little more easily explained. For example the 'sea_ice' campaign would require 35 observations per season. This would be easily achieved at the high latitudes where swaths would overlap frequently. However as the targets progress further from the poles there simply would not be enough opportunities of observation; at the equator there would be only 14. We can see this progression in Figure 4, as the sea_ice target progresses down into the southern region of Hudson Bay.

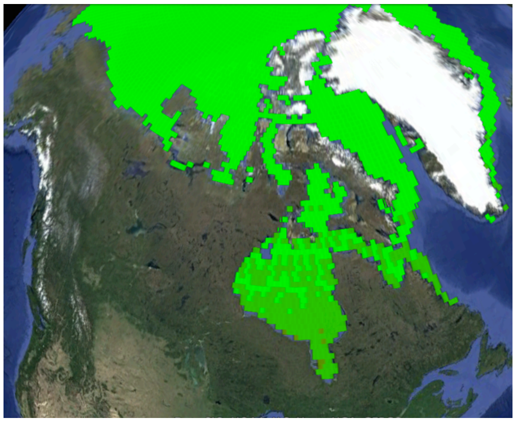

**Figure 4**. Satisfaction of 'sea_ice' campaign in Northern Hemisphere. Green is satisfied, while colors progressing towards red are less satisfied.

Finally, we often observe the simulation as a whole. While CLASP keeps a score of each solution, it is not perfectly mapped to the requirements of this mission concept. Instead we often take the science campaign satisfaction statistics and aggregate them into a single number to assess design trades. Figure 5 illustrates the merit surface we prepared for our Mission Critical Review in 2013. The free axes are the solid-state-recorder capacity and the daily data downlink volume. The merit is dependent on both of these variables, however, much more so on the downlink.

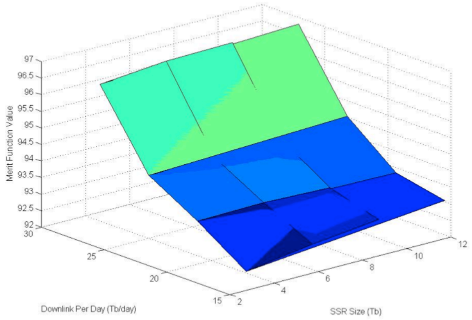

**Figure 5.** A plot of our merit surface while varying SSR capacity and total downlink bandwidth per day. Merit function is a polynomial aggregate of satisfied science campaigns, emphasizing lowest scoring campaigns.

## V. Conclusion

We've shown here a few aspects of the CLASP tool as applied to the real-world scheduling problem of the NISAR concept (formerly DESDynI). It has been invaluable in facilitating rapidly translating the effects of several variations of mission parameters, from the mission's proposed science requirements to instrument operations and fulfillment of those requirements.

While we have presented materials from actual simulations run on behalf of the mission design, we would like to note that none of this material should be construed as the mission's final design. In fact, one result of these simulations has been a resurgence in a movement to dramatically overhaul and simplify the science campaign definitions.

Acknowledgement
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## VI. References

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