GDC STDT
Final Report

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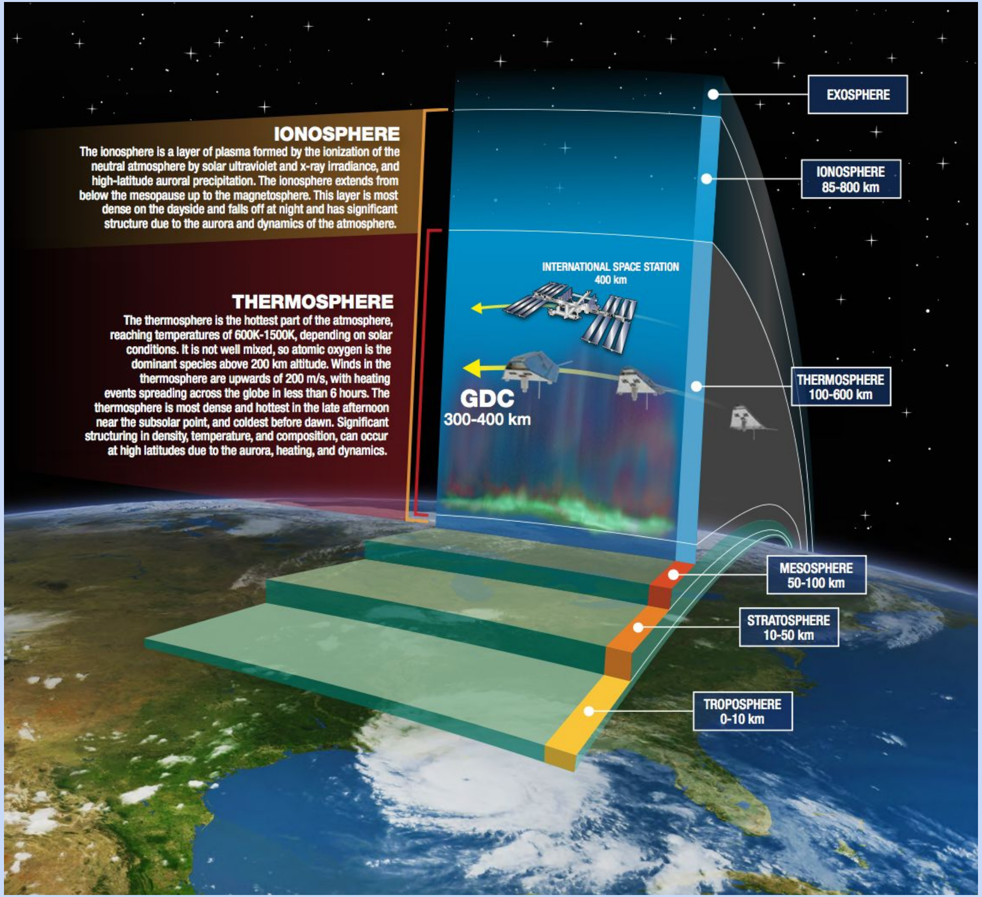
Overview

- GDC Goals, Objectives, and Prioritization
- GDC Potential Implementations and Constraints
- GDC Contributions to National Interests
- Summary & Recommendations



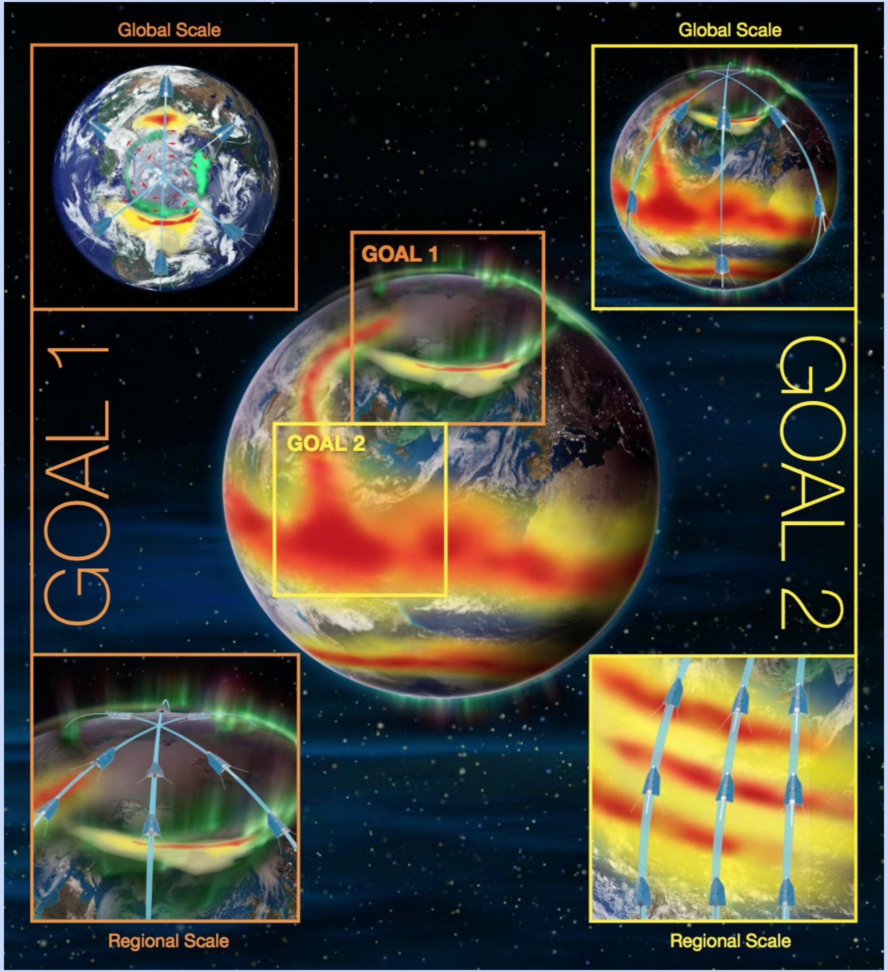
Motivation

- The Geospace Dynamics Constellation (GDC) mission is the next Living With a Star mission recommended by the 2013 Decadal Survey
- GDC will help the Heliophysics community address compelling problems pertaining to our upper atmosphere.
- GDC's high-level goal is to explore the upper atmospheric reaction to energy input, which drives significant space weather:
  - Drag uncertainties
  - Communication disruptions
  - GPS position errors
- The Science and Technology Definition Team was formed to refine the science goals and objectives for GDC from the Decadal Survey recommendation
- The STDT addressed options and considerations to inform NASA's selection of a mission architecture

Geospace Dynamics Constellation Goals

1. Understand how the high latitude ionosphere-thermosphere system responds to variable solar wind/magnetosphere forcing.

2. Understand how internal processes in the global ionosphere-thermosphere system redistribute mass, momentum, and energy.



Goal 1 Objectives

Understand how the high latitude ionosphere- thermosphere system responds to variable solar wind/magnetosphere forcing

1. Determine how high-latitude plasma convection and auroral precipitation drive thermospheric neutral winds
2. Determine how localized, coherent plasma density features arise and evolve
3. Determine how neutral winds, auroral precipitation, and collisional heating drive high-latitude neutral density structures
4. Determine how atmospheric tides and gravity waves influence the IT response to magnetospheric inputs

Goal 2 Objectives

Understand how internal processes in the global ionosphere-thermosphere system redistribute mass, momentum, and energy

1. Determine the relative importance of penetration electric fields and disturbance winds in driving plasma density variations at mid- and low-latitudes during geomagnetic storms
2. Identify the processes that create and dissipate propagating structures within the ionosphere and thermosphere during active and storm conditions
3. Determine the connections between winds and neutral density/composition variations at mid- and low-latitudes during geomagnetic storms
4. Characterize the spatial and temporal variability in IT parameters that results from the transfer of momentum and energy from atmospheric tides and gravity waves
5. Quantify the roles of radiative cooling and neutral winds in dissipating thermospheric energy
6. Determine how hemispheric asymmetries in the Earth's magnetic field, seasonal variations, and magnetospheric input affect the IT system

Prioritization of Objectives

- It is understood that NASA must have some flexibility in the mission design and that all Objectives may not be able to be met, therefore, we have prioritized the objectives
- Core:
  - **Objective 1.1**: Determine how high-latitude plasma convection and auroral precipitation drive thermospheric neutral winds.
    - Neutral winds have so few measurements, are so important in controlling the dynamics of the thermosphere and ionosphere, and so little information is known about them; this is the most important contribution to the science that GDC can make.
    - In addition, in order to close this Objective, many other forcing terms need to be measured: ion drag, pressure gradient, coriolis, and viscosity. Other measurements are required and gradients need to be taken.

Prioritization, Continued

- Core Comprehensive:
  - **Objectives 1.2** (plasma structures), **1.3** (neutral structures), **2.1** (penetration e-fields), **2.2** (propagating structures), **2.3** (composition)
    - These are all extremely important processes and help to address the core objective
    - All of these objectives should be addressed if possible
- Core Enhancing:
  - **Objectives 1.4** (lower atmospheric influence), **2.4** (variability driven by lower atmosphere), **2.5** (radiative cooling), **2.6** (hemispheric asymmetries)
    - These are all very important processes and help to augment the science returned from the core and core comprehensive objectives
    - There is a strong desire to address these objectives if possible

Modeling Study

- The STDT conducted a modeling study in order to help NASA bound option space. This study address three key architecture questions:
    - What is the optimum number of satellites within an orbit plane?
    - What is the optimum number of orbit planes?
    - What is the magnitude of temporal and spatial gradients that need to be resolved?
- CCMC conducted runs with different models for March 2015 storm
- For global scales, 1-2 spacecraft per plane is not good, 3-6 is sweet spot, beyond 6 is diminishing
- For global scales, 1-3 orbit planes is not great, 4-6 is sweet spot, beyond 6 is diminishing
- For smaller scales (e.g. cusp), need remeasurement times of 10 minutes or less
    - i.e., should have a series of satellites that pass through the same latitudinal band within 10 minutes of the previous satellite.
    - Can accomplish with 2+ satellites spaced <40° apart in an orbital plane

Spatial Constraints

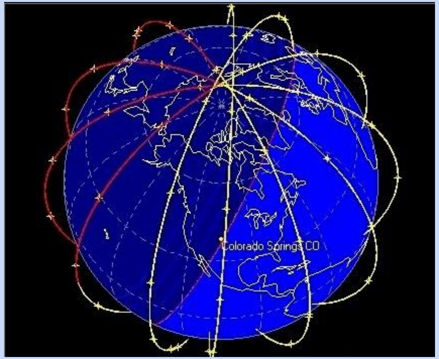
- Scales definitions:
  - **Local Scales**: < 2 hours of local time, remeasurement of <~10 minutes
  - **Regional Scales**: 2-9 hours of local time, remeasurement of ~6-20 minutes
  - **Global Scales**: >9 hours of local time, remeasurement of >20 minutes
- Inclination:
  - Needs to reach into the polar cap
  - Needs to precess to different local times in each season
  - Around 80° is optimum, allowing sampling of aurora and 180° precession in 90 days
- Altitude:
  - Measurements from 300-400 km strongly desired for most objectives
    - F-region is peaking below this (~250 km) due to very low solar activity
    - Base altitude is determined by mass density and reboosting capability of the spacecraft
  - Some core enhancing objectives require measurements between ~50 km - ~150 km

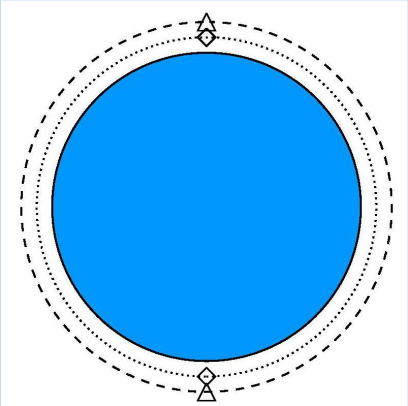
Implementation Architectures

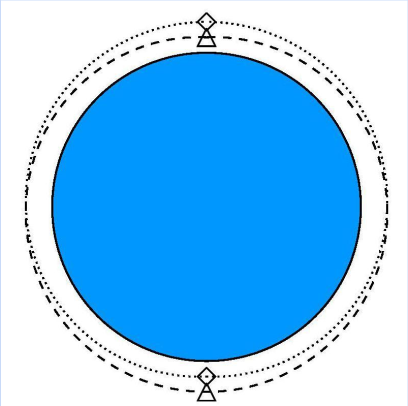
STDT could not specify a mission architecture, due to constraints on process. But, report specifies a variety of options to consider:

1. N x M: Having M different localtime planes with N satellites in each plane
2. With CubeSats: Having M motherships with N “sacrificial” CubeSats
3. High-Low Circular: Having satellites at two different altitudes
4. Over-Under: Having slightly elliptical orbits offset by 180°

Can mix these if desired! Report includes constraints and trade studies for various aspects of architectures, and all information to easily find total flight dynamics effort required.



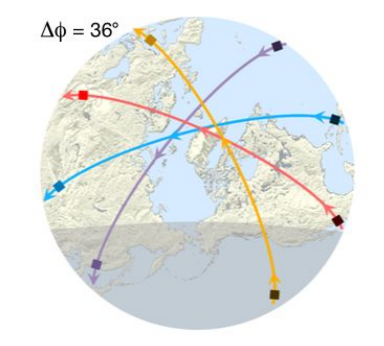




Key Point for Implementation

- In order to close GDC science objectives, a phased mission is needed
  - Satellites clustered together to measure local and regional scales
  - Satellites spread out to measure global scales
- Methods of implementation:
  - Campaigns where the constellation becomes “fixed” for some time, then transitions to the other - *similar to recent Phases implemented on the MMS mission*
    - Measure regional scales, then global scales, then back to regional scales, etc.
  - Constellation constantly evolves so there are a variety of scales
    - Differential precession, via small inclination differences (<1° changes), permits this with minimal delta-V requirements and does not take away from measurements

Example: NxM



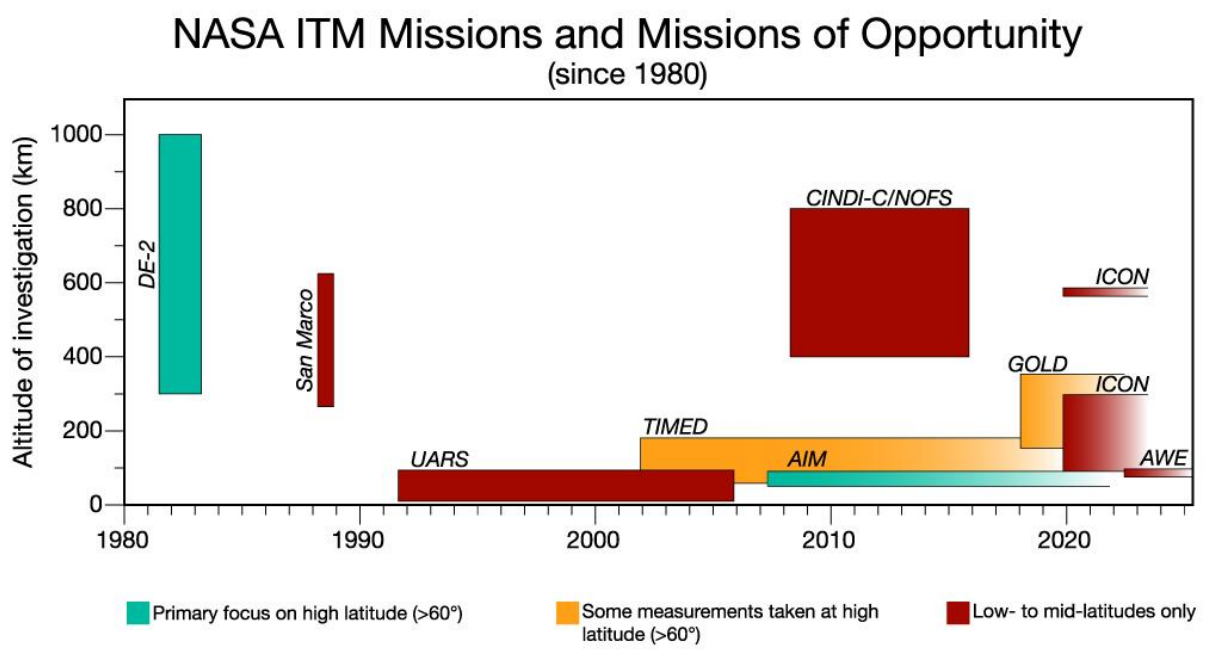
	Based on Nominal Measurement Coverage Requirements										
		Goal 1				Goal 2					
	Sats x planes (total)	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	2.6
Closure w/support	2x4 (8)										
	1x4 (4)										
Complete closure	3x4 (12)										
	4x2 (8)										
	2x2 (4)										
	1x8 (8)										
	1x3 (3)										
Closure w/support	3x3 (9)										

Implementation Findings

- Science goals and objectives can be addressed using a constellation mission with demonstrated technologies.
- Multi-year (3-year minimum) mission is required to address different seasons and scales to be measured.
- Science objectives are enhanced by non-spacecraft related support:
  - Data assimilation will tie together measurements so global dynamics can be tracked
  - Modeling and lab calibration will allow unobservable quantities (e.g., collision frequencies, auroral deposition) to be determined
  - Ground-based observations will provide supplementary data, enhancing science return
- Non-traditional mission concepts such as using CubeSats to augment main measurements may offer significant advantages and should be strongly considered. Distributed measurements (even if limited in states) are important for determining dynamics.

Non-Overlap with Other NASA Missions

- TIMED: Some overlap with Objectives 2.4 and 2.5, but TIMED doesn’t have measurement capabilities nor inclination nor constellation
- GOLD: Overlap with Objective 2.3, but GOLD is missing very large amounts of correlative measurements and doesn’t measure high latitudes
- ICON: Some overlap with Objectives 2.2 and 2.4, but ICON does not measure at high latitudes
- AWE: Some overlap with Objective 2.4, but is missing large amounts of correlative measurements and doesn’t measure high latitudes
- SDO: Provides EUV measurements if still in operation



GDC Contributions to National Interests

- NASA Office of Inspector General’s 2019 report of Heliophysics mission portfolio:
    - Recommendation 2: Complete implementation of 2015 NSWAP tasks in accordance with SWORM subcommittee deadlines
        - GDC will help address this by improving our understanding of the IT system, where most space weather occurs, and providing global measurements of system
    - Recommendation 4: Establish a formal mechanism to increase collaboration with DoD and the commercial space industry regarding heliophysics research and space weather modeling and forecasting efforts
        - GDC will assist in three areas:
            - Electron density gradients for communications
            - Thermospheric density variations for orbit prediction
            - Auroral precipitation for satellite anomalies and human radiation exposure
        - Interest in these by Navy and Air Force

Summary

- Goals fully support Decadal Survey science focus and are of primary need to the Heliophysics community
- Objectives are highly focused and closable
    - Prioritized to allow for flexibility in implementation
- Implementation
    - Options are provided, allowing NASA's pre-formulation to finalize the best strategy
- GDC goals and objectives match with other national interests and can be of value to other agencies

Recommendations

- Support GDC as the next Heliophysics mission
- Accept the prioritization of objectives, with neutral winds being a fundamental physical parameter that must be measured
- Emphasize the need for ground-based observations, lab calibration activities, modeling resources and new technology development alongside the main GDC effort
- Implementation: Recommend that there are 3+ satellites per orbit plane and 4+ orbit planes if at all possible to close all objectives
    - CubeSats (or small satellites in general) can be used to augment primary measurements and allow measurements to certain physical parameters at significantly more locations
- NASA should include GDC in cross-agency collaborations due to strong synergies in science, measurements, and space weather goals

Questions?