

Space Weather Roundtable, June 1-2, 2023



GDC Relevance to NOAA

National Environmental Satellite,
Data, and Information Service

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NOAA use of GDC observations

- Atmospheric drag on spacecraft in LEO from measurements by GDC – note the Office of Space Commerce within NOAA is charged with providing basic SSA data and STM services to commercial space operators especially due to the proliferation of commercial constellations.
- Radio propagation for communications, navigations, and surveillance – note radio occultation from GDC's polar orbits complement COSMIC-2 low latitude orbits - assessing impacts to GPS system among others.
- Assessment of geomagnetic disturbances in LEO will enable space weather predictions of ground level technological events, e.g. GICs in the power grid among others.
- Assessing the radiation environment of LEO impacting spacecraft systems and human exposure.
- GDC has a real-time beacon and is working with both research and operations to optimize transmission content and latency.



GDC observations vs NOAA requirements

- GDC re-engineered the downlink from a daily scientific download to a space based near real-time broadcast via a commercial receiving network for partial observations needed for NOAA's space weather notification system.
- GDC has a real-time beacon and is working with both research and operations to optimize transmission content and latency; management has appointed a Deputy Project Scientist to specifically address space weather issues and GDC capabilities.
- NOAA requirements from missions like COSMIC-2 were cross referenced to GDC capabilities such as observations of magnetic field, neutral wind characteristics, I-T characteristics, total electron content and energetic particle populations and precipitation.
- From the IRB (Sept. 2022): GDC observations of I-T conditions will lead to “improvements in I-T models that are foundational to Space Situational Awareness and Space Weather prediction.



GDC Capabilities vs NOAA requirements

GDC Instrument Suite

Magnetometer (NEMESIS)

Radio Occultation (PROFILE)

Atmosphere and Ionosphere (MoSAIC)

Auroral Precipitation Experiment (CAPE)

**Atmospheric Electrodynamics probe for
THERmal plasma (AETHER); Thermal Plasma
Sensor (TPS)**

Radiation Environment Monitor (REM)

NOAA Observation Requirements

Magnetic Fields

TEC, NmF2, hmF2

Neutral Winds, I-T characteristics

**Auroral Precipitation – particles, energy deposition,
and auroral boundaries**

Electric fields

Energetic particles

NOAA/NESDIS advice needed from Decadal Survey

- Concepts and plans for enhancements of capabilities
- Improved understanding of needed latency of notifications to customers; e.g. L1 observation products to electric power industry is nominally one hour or less
- Advice on operational platform systems in order to address critical observational gaps or potential gaps
- Advice on other agency tech demos on NOAA platforms
- Advice on research, tech demos from other agencies to advance understanding of Sun-Earth interactions and the cause and effect of space weather events
- Develop ways to assess and communicate the value proposition for space weather operational observations
- Advice on how to further develop applications and models that fully exploit observational data
- Advice on how operational observations can be used as part of the research infrastructure



Backups

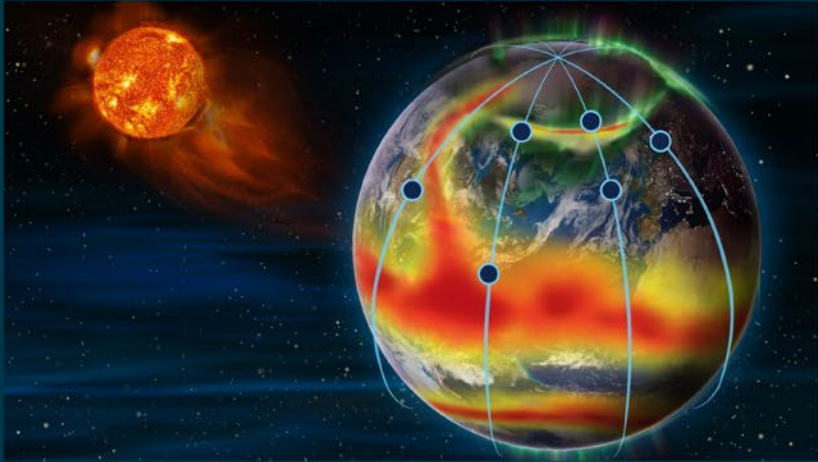


GDC vs. COSMIC-2

GDC-NOAArequirements_v2								
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A17								
A	B	C	D	E	F	G	H	I
1	Observation	Geographic Coverage	Vertical Range	Spatial Resolution	Measurement Accuracy	Sampling Interval	Instrument/Monitor	requirements from: Service Area Observational User Requirements Document, 2017
2	Auroral Boundary: LEO	LEO					CAPE	
3	Deposition: LEO	LEO					CAPE	
4	Electric Field: LEO	LEO					TPS, AETHER	
5	Energetic Ions: LEO	LEO					REM	
6	Geomagnetic Field: LEO	LEO		2 nT		10 / sec	NEMISIS	
7	Electrons: Medium and High Energy, LEO	LEO					REM	
8	Ions: Medium and High Energy, LEO	LEO					REM	
9	Ionospheric Electron Density Profiles	LEO			3000 / day		PROFILE	
10	Neutral Density	LEO			10% 1 / 2 sec		MoSAIC	
11	Thermospheric Neutral Winds	LEO		4.5 m/s (3.5 m/s vertical)	1 / 2 sec		MoSAIC	
12	Aurorae: Supra-Thermal through Auroral Energy Particles, Electrons	LEO			10% 1 / sec		CAPE	
13	Aurorae: Supra-Thermal through Auroral Energy Particles, Ions	LEO			10% 1 / sec		CAPE	
14	Thermosphere Temperature	LEO			2% 1 / 2 sec		MoSAIC	
15	Thermospheric Neutral Composition	LEO			1% 1 / 2 sec		MoSAIC	
16	Slant Total Electron Content of the Ionosphere	LEO			3000 / day		PROFILE	
17								
18								
19								
20	Thermal Plasma Density			25/cm^3 or 2%	2 / sec		TPS	
21	Ion Drift Vector			18 m/s	1 / sec		TPS	
22								
23								

GDC-NOAArequirements_v2					
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D17					
A	B	C	D	E	F
1	Data Type	Threshold	Objective	PROFILE	Expected performance
2	Total Electron Content - TEC*				
3	3-2.1. Measurement Range [TECU*]	3 to 1,000	1 to 1,000		
4	3-2.2. Measurement Uncertainty [RMS]				
5	a. Relative [TECU]	0.3	0.001		
6	b. Absolute [TECU]	3	1		
7	3-2.3. Number of LimbTEC profiles per day**	12,000	30,000	3000	
8	3-2.4. Zenith hemisphere TEC tracks/day (each TEC arc is expected to be in two tracks corresponding to fore and aft POD antennas)**	12,000	30,000		
9	3-2.5. Average Latency [mins.] for Hi/Lo Incl. Orbits	45 / 30	5-May		
10	3-2.6. TEC sample rate [seconds]	1	1		
11	a. Occulting satellites	10	1		
12	b. Zenith hemisphere satellites	10	1		
13	Electron Density Profiles - EDP				
14	3-2.7. Measurement Range [electrons-m ⁻³]	3x10 ¹⁰ to 10 ¹³	10 ¹⁰ to 10 ¹³	10 ¹⁰ to 10 ¹³	
15	3-2.8. Measurement Uncertainty*** [RMS]	Less than the greater of 20% or 10 ¹¹	Less than the greater of 3x10 ¹⁰ or 10%		
16	a. Electron Density, N _e [electrons-m ⁻³]	20%	5		
17	b. N _e at F ₂ layer peak, N _{max} F ₂ [percentage]	20		10	
18	c. Height at F ₂ layer peak, H _{max} F ₂ [km]	20		10 km	
19	3-2.9. Number of Profiles per day**	12,000	30,000	3000	
20	3-2.10. Vertical Data Resolution [km]				
21	a. Altitude Range 60-100 km	1	1	N/A	
22	b. Altitude Range 100-800 km	2	1	2 km	
23	3-2.11. Average Latency [mins.] for Hi/Lo Incl. Orbits	45 / 30	5-May		
24	Scintillation Amplitude Index - S ₄				
25	3-2.12. Minimum Sampling Rate [Hz]****	50	200	50	
26	3-2.13. On-Board Calculation Time Interval [seconds]****	10	10		
27	3-2.14. Calculation Cadence [seconds]	10	1		
28	3-2.15. Measurement Range [dimensionless]	0.1 to 1.5	0.1 to 1.5		
29	3-2.16. Measurement Uncertainty [RMS]	0.1	0.1		
30					
31					

GDC-NOAArequirements_v2								
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D17								
A	B	C	D	E	F	G	H	I
15	Incl. Orbits							
16	Scintillation Amplitude Index - S ₄							
17	3-2.12. Minimum Sampling Rate [Hz]****	50	200	50				
18	3-2.13. On-Board Calculation Time Interval [seconds]****	10	10					
19	3-2.14. Calculation Cadence [seconds]	10	1					
20	3-2.15. Measurement Range [dimensionless]	0.1 to 1.5	0.1 to 1.5					
21	3-2.16. Measurement Uncertainty [RMS]	0.1	0.1					
22	3-2.17. Tracks Analyzed	All	All					
23	3-2.18. Average Latency [mins.] for Hi/Lo Incl. Orbits	45 / 30	5-May					
24	3-2.19. Ionospheric Occultation High Rate Data Send to Ground (60 km to S/C Altitude)****	Strongly scintillated profiles up to 10% of sensor data budget	Strongly scintillated profiles up to 20% of sensor data budget					
25	Scintillation Phase Index - σ _p							
26	3-2.20. Minimum Sampling Rate [Hz]****	50	200					
27	3-2.21. On-Board Calculation Time Interval [seconds]****	10	10					
28	3-2.22. Calculation Cadence [seconds]	10	1					
29	3-2.23. Measurement Range [radians]	0.1 to 20	0.1 to 20					
30	3-2.24. Measurement Uncertainty [RMS] [radians]	0.1	0.1					
31	3-2.25. Tracks Analyzed	All	All					
32	3-2.26. Average Latency [mins.] for Hi/Lo Incl. Orbits	45 / 30	5-May					
33	3-2.28. Ionospheric Occultation High Rate Data Send to Ground (60 km to S/C Altitude)****	Strongly scintillated profiles up to 10% of sensor data budget	Strongly scintillated profiles up to 20% of sensor data budget					
34								
35								
36								
37								



Geospace Dynamics Constellation (GDC) Independent Review Board (IRB) Report

Co-Chair - O. Figueroa
Co-Chair - M. Hagan

The GDC Mission

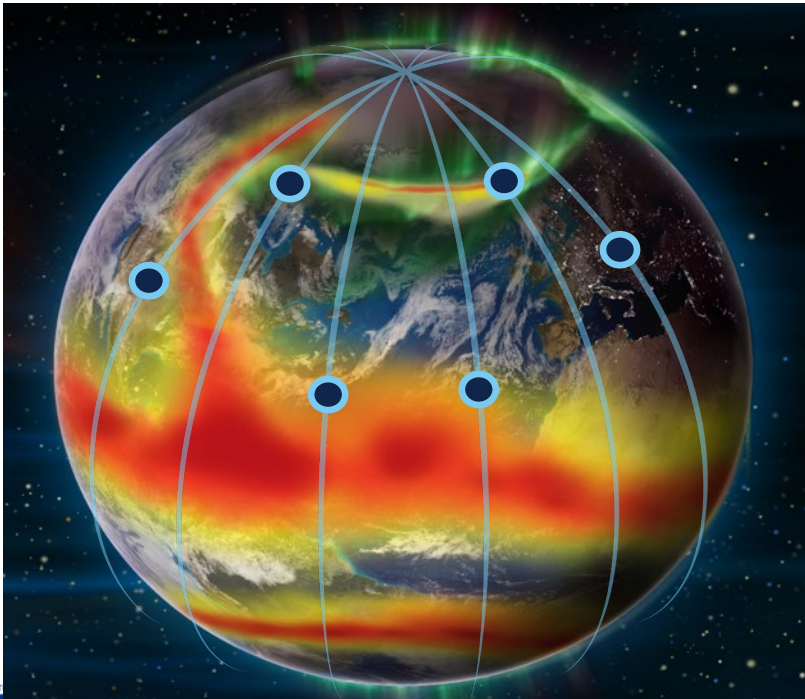
6 polar-orbiting satellites at ~375 km

6 science instruments

3 interdisciplinary science teams

1 radiation environment monitor (REM)

Precise Orbit Determination for
GNSS neutral density cross-calibration



Science Instruments:

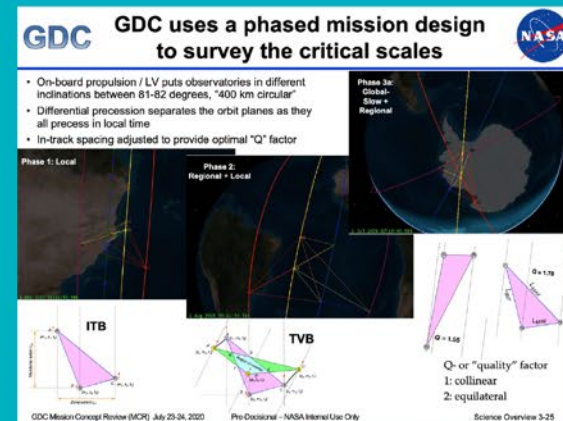
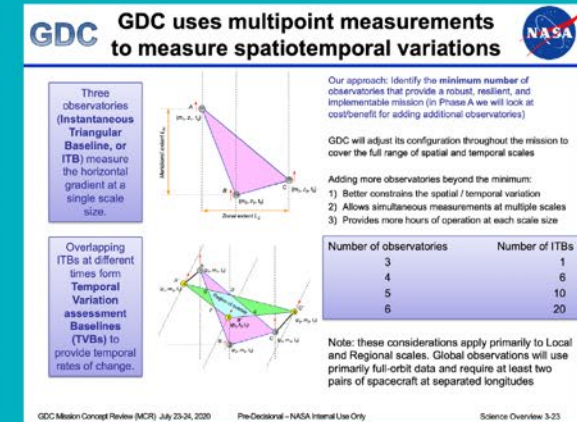
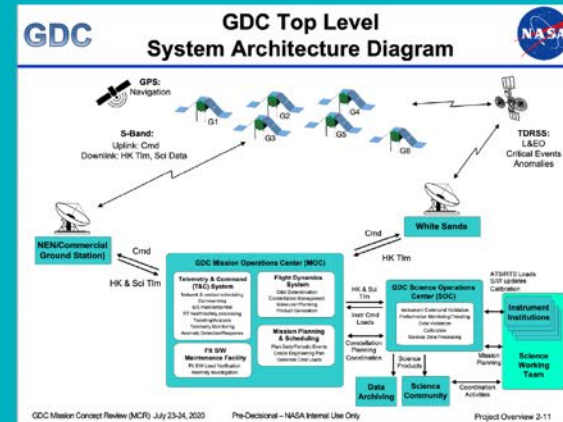
- AETHER Langmuir probe (PI Andersson, CU Boulder)
- MoSAIC ion/neutral mass spec (PI Benna, UMBC)
- CAPE auroral precipitation (PI Gershman, GSFC)
- TPS Thermal plasma (PI Anderson, UT Dallas)
- NEMESIS Magnetometer (PI Moldwin, U of Michigan)
- PROFILE GNSS-RO (PI Verkhoglyadova, JPL)

Interdisciplinary Science Teams:

- NEXUS (PI Thayer, CU Boulder): GNSS neutral density; real-time space weather experience (GOLD & IMAP)
- ADAPTIVE (PI Bishop, Aerospace Corp): model/data connection & visualization; space weather expertise
- SOPHIE (PI Deng, UT Arlington): multiscale forcing from above

GDC Architecture

- Baseline mission: Six spacecraft (6 identical sets of instruments) in different inclinations 81-82 degrees/400km orbits, differential precession separates the orbit planes as they precess in local time
 - Important to launch 6 S/C to protect the integrity of the minimum required (5) to meet science objectives in 3 years
- Threshold mission: Four spacecraft address highest priority science objectives in the STDT



GDC What are the differences between GDC's Baseline and Threshold Missions?

	Baseline	Threshold	Impacts / Notes
Objective 1.1		Full success	Some impacts to these measurements from the measurement descope (see notes below). GDC could still bring significant closure on these Objectives.
Objective 1.2		Full success	
Objective 1.3		Full success	
Objective 2.1	Full success	Not addressed	Threshold mission may provide some information here, but in a less comprehensive fashion, depending on the constellation configuration. Objective 2.1 will only be ~50% addressed, without the electron density profile measurement. Objective 2.4 will not be addressed unless the launch date is optimized for the Threshold mission.
Objective 2.2			
Objective 2.3			
Objective 2.4			
Min. # of multipoint observations required	5* (see footnote)	4	Baseline implementation is six spacecraft. Can lose any single spacecraft and achieve full success.
Mission Duration (post-HOC)	33 months	Finishes in 13 months	33 month baseline mission permits assessment of the full range of variations at all scales. The most critical variations are explored in ~13 months of Threshold.

*Baseline implementation uses 6 observatories to provide better resiliency and better constrain spatial and temporal variations. This is the absolute minimum required to realize science objectives, within a mission of smallest length.

While not a focus of the Threshold mission, GDC will gather useful data on these Objectives, allowing partial progress.

The following parameters are measured in the Baseline mission, but not in the Threshold mission:

- T_e Electron Temperature** ground-based observation → modest impact on accuracy of reaction rates, can be offset via including modeling and
- f_e Energy-angle distribution of energetic electrons** → modest impact on accuracy of energetic charged particle heating and ionization rates
- B_z Magnetic Field** → modest impact on accuracy of incoming electromagnetic energy – can use energetic particle measurements and other techniques to assess current density (upward current regions) and Joule heating rates – also can offset this somewhat by combining with ground-based measurements, modeling, and other space assets
- NmF₂, hmF₂ (peak plasma density, altitude of the peak)** → modest impact on ion drag, conductivity, Joule heating rates, and vertical plasma pressure gradient – can be reduced somewhat with the use of modeling
- Slant TEC and S4 index** (integrated column density above the constellation and presence of meter-scale plasma structuring below the constellation) – not critical for the Threshold mission

Source: GDC Mission Concept Review (MCR) July 23-24, 2020. Pre-Decisional - NASA Internal Use Only. Science Overview 3-21.