NOAA Strategies for Space Weather Ground-based Observing

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NATIONAL WEATHER SERVICE

AGENDA

- Why surface-based observing?
- NOAA use of surface observations
  - Global Oscillation Network Group (GONG) + ngGONG
- USAF use of surface observations
- External Drivers
- Options for future focus

NOAA's strategy for surface observing?

- NESDIS has the clear mission imperative to meet space-based observing requirements for NOAA's other line offices (e.g., NWS, NOS)
  - NESDIS manages NOAA Commercial Data Program (satellite only)
- There is no central NOAA lead for surface-based observations
  - All NOAA line offices must address their own requirements
- For space wx, NWS is only line office addressing ground based observations
  - NWS partners with NSF/NSO: Global Oscillation Network Group (GONG)
- NWS/SWPC also exploits data from other agencies; examples include:
  - USGS magnetometers
  - USAF solar observatory data

NSW-SAP 2.2.5 report on the benefits of a ground-based system:

Planning for a Collaborative Ground-Based Solar Observing Network

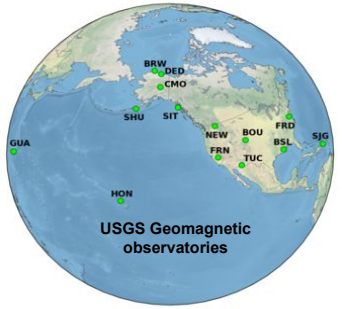
National Space Weather Strategy and Action Plan 2.2.5

"Ground-based observatories have the advantages over instruments in space of **overall lower-cost**, **serviceability**, and **upgradability**. While a ground-based network requires multiple sites to achieve continuous observations of the Sun, this also provides **operational redundancy** and avoids observational gaps due to eclipses or maneuvers. The main disadvantages are the wavelength restrictions and variable conditions of the Earth's atmosphere. However, the observation types considered here are all observable from the ground. Resolution-limiting atmospheric distortions are the unfortunate tradeoff for the accessibility of the ground, but they can be mitigated with elevated platforms and/or adaptive optics."

Ground-based Observations

Magnetometers

- Critical input to SWPC's geomagnetic storm warnings and alerts
- Quantity and distribution of USGS magnetometers inadequate for ops

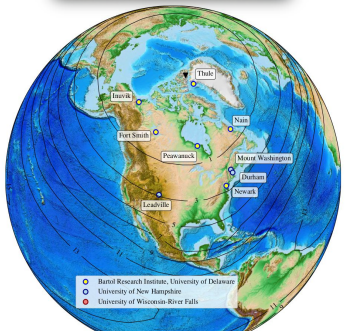


Neutron Monitors

- Critical input to SWPC's radiation storm products for aviation support
- Network dedicated to research and funded by NSF
- SWORM providing options for a path forward for funding and sustaining neutron monitors

GNSS Scintillation and Ionosondes

- Critical ground truth to support decision making at the forecast office
- Many stations were funded by NSF but do not have real-time capabilities

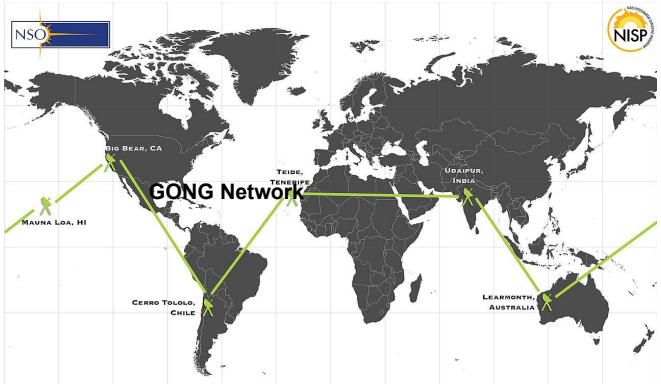


*** Note - GONG is the only ground-based space weather observing system supported by NWS. NESDIS provides space-based observations.**

Ground-based Observations

GONG* Operational Hardening/Replacement

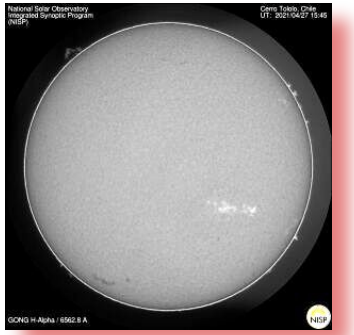
- Critical input to WSA-Enlil for solar wind and CME arrival, as well as filament eruption
- NOAA supporting operations and maintenance of the six GONG observatories
- NOAA provides operational, real-time processing of data
- GONG is 20+ years old and unsustainable - ngGONG

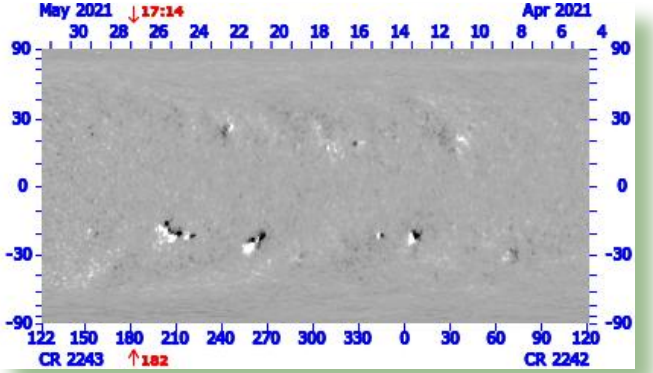


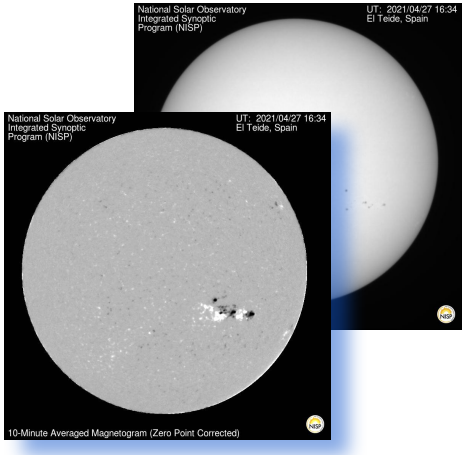
**** Note - GONG is the only ground-based space weather observing system supported by NWS. NESDIS provides space-based observations.***

GONG 101

- GONG **Hα observations**
- GONG **677nm observations**
- **Magnetogram** data
- **Synoptic maps**
- WSA-Enlil model receives GONG maps directly from SWPC



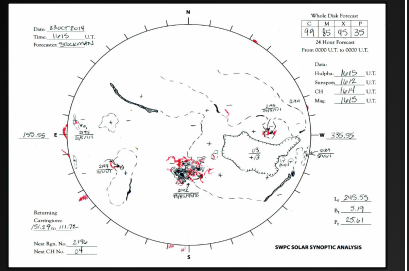




SWPC Use Cases for GONG Data

May 2023

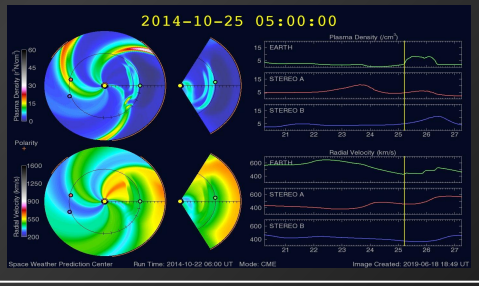
synoptic drawings



filament eruption detection/ confirmation

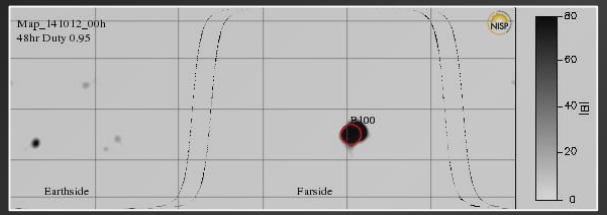
situational awareness & backup for synoptic drawings

WSA-Enlil model

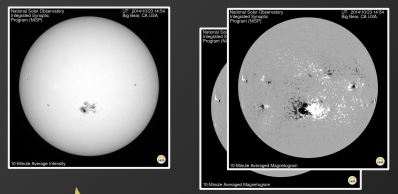


Hα images & time-lapses

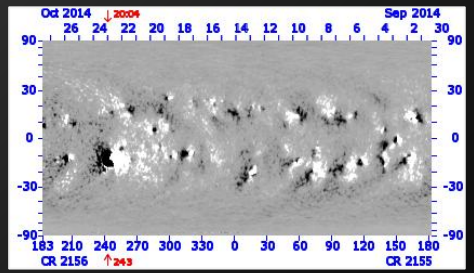
farside maps

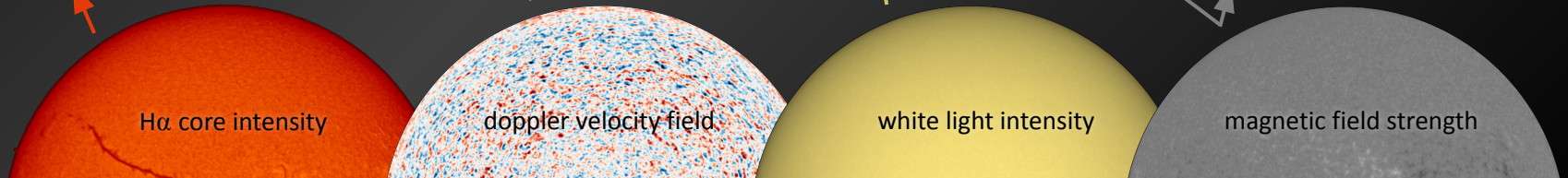


10-min averages

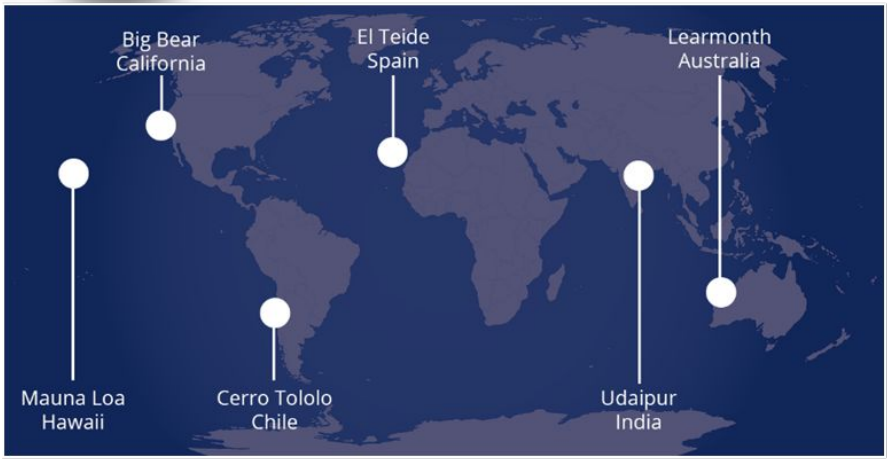


hourly synoptic maps





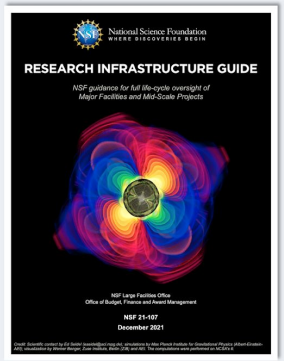
Future of GONG



- GONG is aging and becoming outdated (about 27 years in operations)
- GONG refurbishment will extend lifetime by 5-7 years (2028-2030)
- After 2030, GONG will be on "life support" – number of components will not last pass next 10 years (e.g., mechanical: turret motors, bearings; optical: protective windows, mirrors; electronics – circuit boards).
- NSO is already resorting to buying parts on eBay to keep GONG operational.

ngGONG: Basic Concept

ngGONG Proposal Development & Resubmission



Research Infrastructure Guide (RIG)
(formerly: LFM, MFG)

External Funding Required to Proceed Into Design Stage (i.e., Successful Proposal)

We Are Here

Expected GONG End of Life (EOL)

5 Project Stages

Development 10+ Years | Design 3-5 Years | Construction 4-10 Years | Operations 20-40 Years | Divestment 1-5 Years

3 Design Phases

Decision #2: **Scope of the Proposal?**

Conceptual Design Phase | Preliminary Design Phase | Final Design Phase

Conceptual Design Phase (CoDP)
~1.5 years, ~$4.98M

CoDP + Preliminary Design Phase (PDP)
~2.5 years, ~$9.98M

PDP + Final Design Phase (FDP) = Previous (Unselected) Proposal
~3.5 years, ~$17.62M

- More than an “updated GONG”
- Serves both Research & Operational Space Weather requirements
- Improved sensitivity (x10)
- Improved resolution (x2)
- Multi-Height (>2)
- Full vector magnetograms
- Improved magnetic zeropoint

ngGONG: What's Needed?

1. **ngGONG is needed in order to:**
   a. Sustain current capabilities (eg, inputs for WSA-Enlil, flare/filament monitoring, farside)
   b. Provide improved data (eg, vector field, better zeropoint, improved polar fields)
   c. Drive future R&D (eg, chromospheric fields, multi-height fields, the B-z problem)
2. **A high-level solution to the current funding roadblock**
3. **Beginning the design phase ASAP ****

***** NOAA SAB/EISWG report (Apr 27, 2023) recommends NOAA partner with NSF to support the design phase for ngGONG***

ngGONG: EISWG Recommendation to NOAA SAB

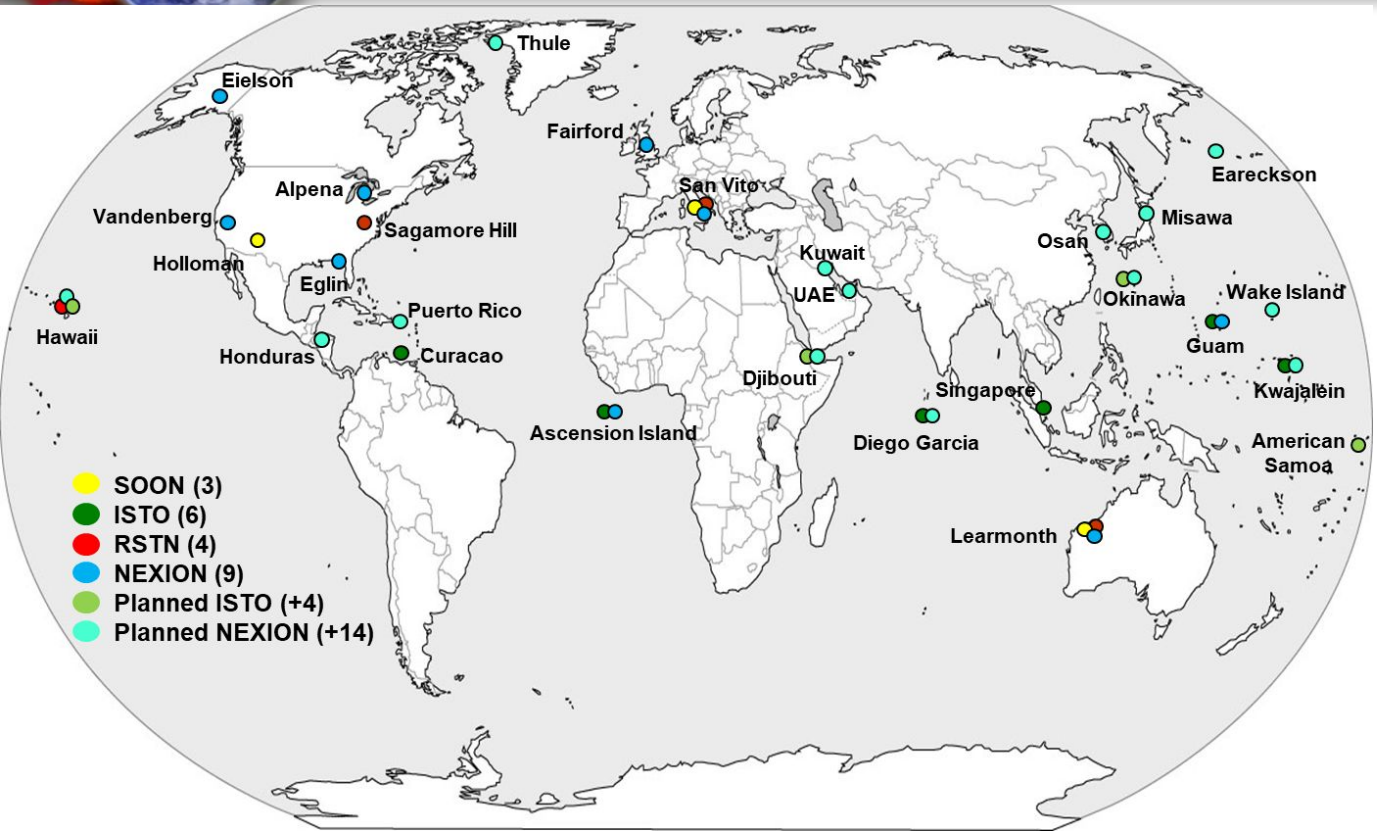
Recommendation: GONG provides a vital data source for space weather operations, and it is nearing end of life. The ngGONG project is the most straightforward replacement. It will maintain present operational capabilities, and provide observations for future requirements. The time window to complete ngGONG prior to the demise of GONG is closing. We recommend that NOAA/NWS financially support the design phase for ngGONG, to ensure the initiation of the project.

Environmental Information Services Working Group (EISWG) Statement on GONG and its Successor Data Source for Space Weather Operations

Submitted to the NOAA Science Advisory Board (SAB) for approval and action (The EISWG is a Standing Working Group of the SAB)

https://sab.noaa.gov/wp-content/uploads/EISWG_GONG_report_April-11-2023.pdf

USAF Ground-based Observations



** Courtesy of HQ USAF/A3W, Lt Col Omar Nava*

- SOON: Solar Optical Observing Network
- ISTO: Ionospheric Scintillation & Total Electron Content (TEC) Observatory
- RSTN: Radio Solar Telescope Network
- NEXION: Next-Generation Ionosonde Network

External drivers: SWORM NWS-SAP Goal 2.2 Preservation of Critical Observations

2.2.5 Report submitted to SWORM for future ground solar observing networks (e.g. ngGONG) have been advanced within the Department of Commerce (DOC, both NOAA/NESDIS and NOAA/NWS), the Department of Defense (DOD), and the National Science Foundation (NSF). In recognition of the broader need, the ***National Space Weather Strategy & Action Plan (NSW-SAP) via SWORM directed the DOC and DOD to coordinate with NSF to deliver a plan for a collaborative ground-based solar observing network that meets their combined operational observing requirements***. Proposals have been submitted for coordination and funding for a design phase; critical for further advancement.

The distinction between partnerships of customer agencies USAF, NOAA/NESDIS and NOAA/NWS and observations from the NSF Facilities' GONG could develop a strategy for going forward with ngGONG.

External drivers: PROSWIFT Act

"Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow" (PROSWIFT) Act of 2020

60601: (a) Findings: "(C) Space-based and **ground-based observations** provide crucial data necessary to understand, forecast, and prepare for space weather phenomena.

60603: Sustaining and advancing critical space weather observations: "(f) SUSTAINING **GROUND-BASED** OBSERVATIONAL CAPABILITY.— The Director of the National Science Foundation, the Director of the US Geological Survey, the Secretary of the Air Force,and, as practicable in support of the Air Force, the Secretary of the Navy, shall each—

"(1) maintain and improve **ground-based observations** of the Sun, as necessary and advisable, to help meet the needs identified in the survey under section 60601(d)(3); and

"(2) continue to provide **space weather data through ground-based facilities**, including radars, lidars, magnetometers, neutron monitors, radio receivers, aurora and airglow imagers, spectrometers, interferometers, and solar observatories.

External drivers: PROSWIFT Act

"Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow" (PROSWIFT) Act of 2020

60607: Pilot program for obtaining commercial sector space weather data

"(a) ESTABLISHMENT.—Not later than 12 months after the date of enactment of the PROSWIFT Act, the Administrator of the National Oceanic and Atmospheric Administration may establish a pilot program under which the Administrator will offer to enter into contracts with one or more entities in the **commercial space weather sector** for the provision to the Administrator of space weather data generated by such an entity that meets the standards and specifications published under subsection (b).

"(b) DATA STANDARD AND SPECIFICATIONS.—Not later than 18 months after the date of enactment of the PROSWIFT Act, the Administrator of the National Oceanic and Atmospheric Administration, in consultation with the Secretary of Defense, may publish standards and specifications for **ground-based**, ocean-based, airbased, and space-based commercial space weather data and metadata.

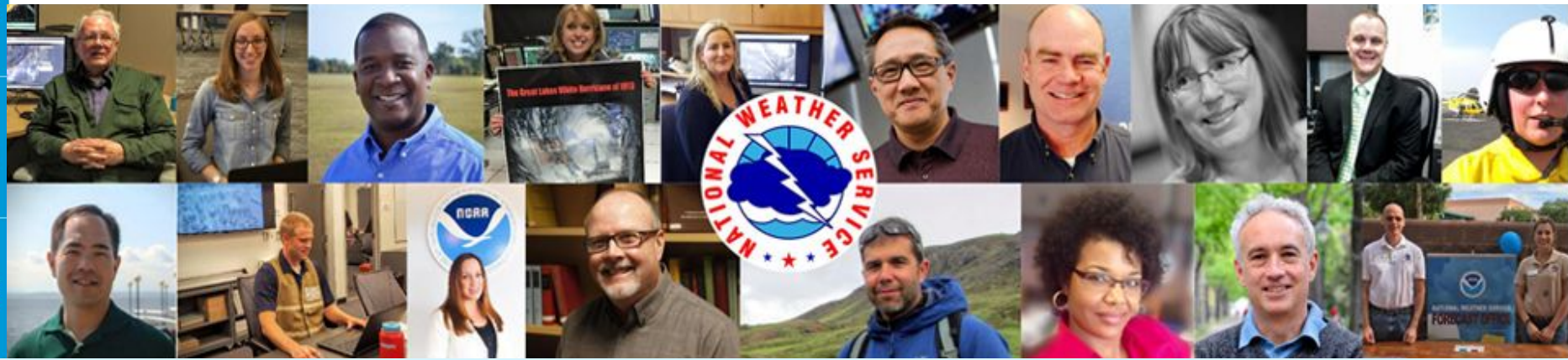
Options for the future focus

- Grow/strengthen our partnerships
  - Continue moving forward with NSF/NSO on ngGONG
  - Opportunity for synergy between ngGONG and USAF/USSF modernization?
  - Opportunities with international partners?
- Better exploit commercial data sources
- Bottom line: ground-based observing remains a key component of our space weather observing strategy; we need to resource it appropriately and continue to pursue improvements with our federal and international partners

Thank you!

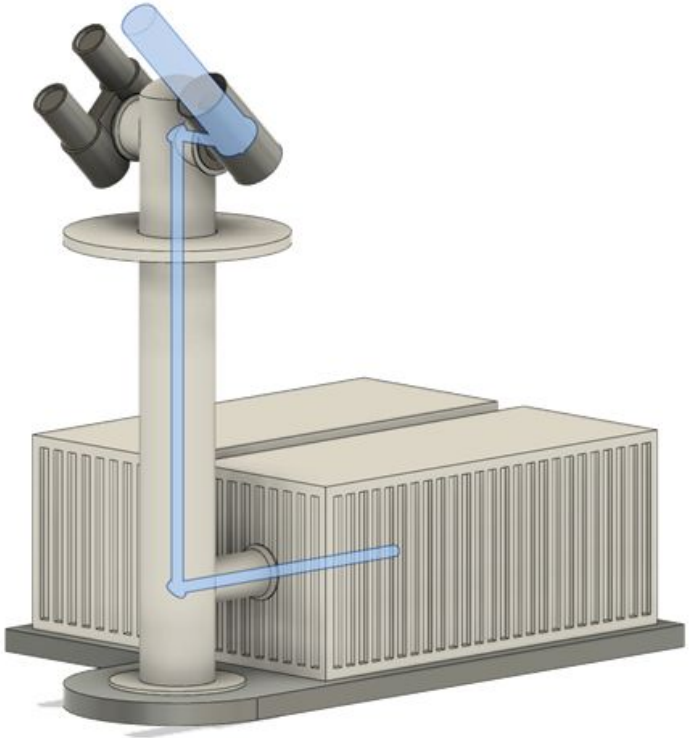
If you'd like to follow up on any item, feel free to contact me via:

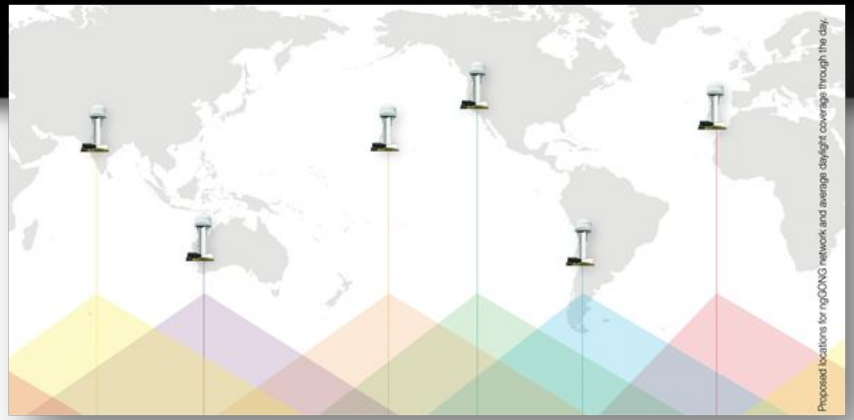
- NOAA/NWS email: michael.farrar@noaa.gov
- LinkedIn: linkedin.com/in/MikeFarrar-Wx
- Twitter: @MikeFarrar_Wx

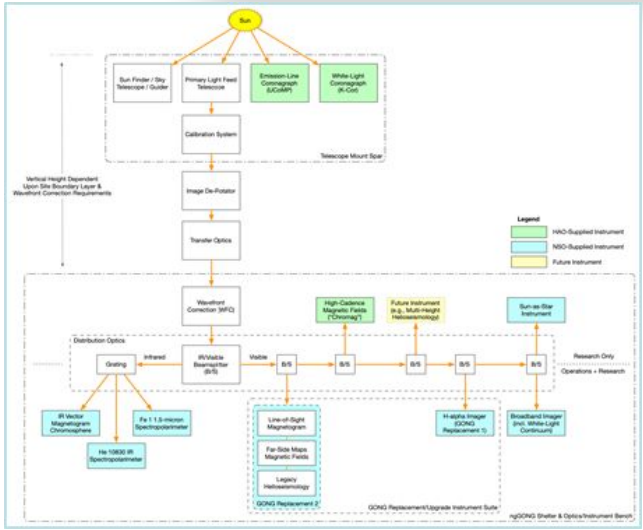


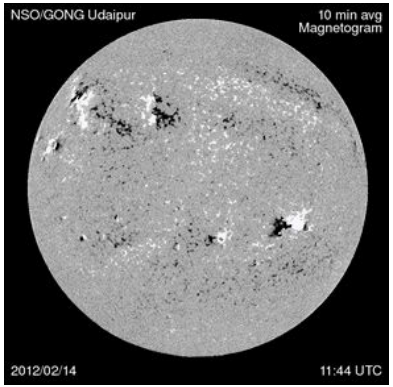
BACKUP SLIDES

ngGONG Concept









Development and Application of OSE/OSSEs

OSE: Observing System Experiment **OSSE**: Observing System Simulation Experiment

Why OSE/OSSEs are needed:

- Investment in observing systems (ground and space based) will increasingly depend on quantitative assessments of data value in operational products
- The Weather Act (2017) (for meteorology) requires OSSEs for high-cost data satellites
- A similar requirement has not yet been enacted for space weather, but we should be prepared

Challenge: OSE/OSSEs and the tools to conduct them (data assimilation models) are essential for space weather, but not a priority for basic research. Therefore, the required effort will need to be supported separately from traditional research funding sources.

Recent OSE/OSSEs and Related Activities

Four OSSE studies funded by NOAA/NESDIS in 2021-2022

- Ionospheric Electron Density
- Thermospheric (neutral) density
- Radiation belt electron (magnetospheric particle) flux

OSE/OSSE studies funded by other organizations with potential positive impacts to NOAA space weather observing program

- Mission and instrument optimization studies conducted or planned by NASA, APL, and other academic institutions

NOAA/NESDIS Supported OSSE Studies (1 of 2)

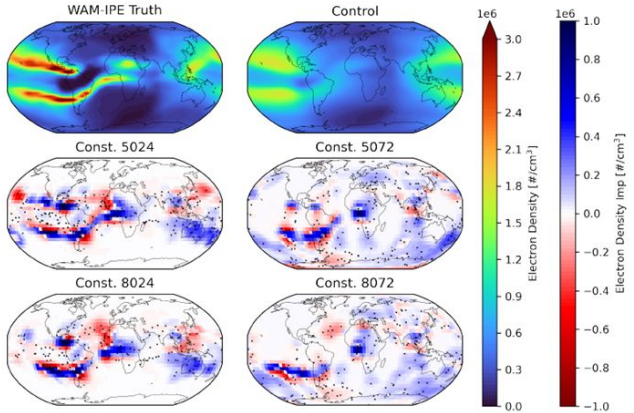
Impact of Neutral Density Coverage from Satellite Accelerometers on an Assimilation System

- PI: Dr. E. Sutton: CU Boulder, SWx TREC
- Results: Identified orbit altitudes for density data assimilation and accuracy improvement

Ionospheric Electron Density Profile

- PI: Dr. T. Matsuo: CU Boulder, Aerospace Eng. Sci.
- Results: Identified LEO high- and low-inclination configurations for optimizing electron density profile measurement using radio occultation data assimilated into an Ensemble Adjustment Kalman Filter (EAKF)

Scenario #	Orbit Configuration								Description
	400 km				550 km				
	12/24 LT		06/18 LT		12/24 LT		06/18 LT		
	Mid incl.	High incl.	Mid incl.	High incl.	Mid incl.	High incl.	Mid incl.	High incl.	
1									Free run (no assimilation)
2	X	X	X	X	X	X	X	X	Assimilate all data
3	X	X	X	X					400 km only
4	X	X							400 km, 12/24 LT only
5			X	X					400 km, 06/18 LT only
6	X		X						400 km, mid incl. only
7		X		X					400 km, high incl. only
8	X								single satellite: 400 km, 12/24 LT, mid incl.
9		X							single satellite: 400 km, 12/24 LT, high incl.
10			X						single satellite: 400 km, 06/18 LT, mid incl.
11				X					single satellite: 400 km, 06/18 LT, high incl.
12					X	X	X	X	550 km only
13					X	X			550 km, 12/24 LT only
14							X	X	550 km, 06/18 LT only
15					X		X		550 km, mid incl. only
16						X		X	550 km, high incl. only
17					X				single satellite: 550 km, 12/24 LT, mid incl.
18						X			single satellite: 550 km, 12/24 LT, high incl.
19							X		single satellite: 550 km, 06/18 LT, mid incl.
20								X	single satellite: 550 km, 06/18 LT, high incl.



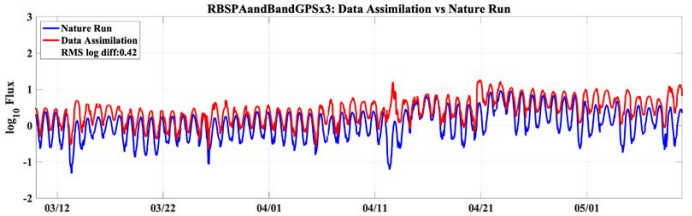
NOAA/NESDIS Supported OSSE Studies (2 of 2)

Radiation Belt Electrons (LEO, MEO, GEO measurements)

- PI: Dr. Y. Shprits: Space Sciences Innovations
- Results: Quantified importance of LEO measurements/pitch angle, timescale of model recovery during storms, etc.

Radiation Belt Electrons (GEO, GTO, MEO measurements)

- PI: Dr. A. Kellerman: UCLA/Atmospheric Sciences
- Results: Novel OSSE approach; used DART framework. Quantified value of low-altitude data (MEO, GTO) in specifying the state of the radiation belts, including at GEO.



Specification Orbit	*Rank*	*Reanalysis Data*	*Error*	*Bias*
GTO2	1	MEOaGEO	49.04	31.66
	2	MEO2c	50.88	34.04
	3	MEO2uc	50.88	34.04
	4	MEO21c	55.58	39.13
	5	MEO21uc	55.58	39.13
MEO2c	1	GTO4to5	38.51	29.15
	2	GTO2	39.08	34.52
	3	GTOTHEMIS	40.27	38.56
	4	GTOaGEO	43.85	42.42
	5	GEOc	46.85	2.40
GEO2c	1	GTOaMEO	46.37	43.75
	2	MEO21c	56.00	55.19
	3	MEO21uc	56.00	55.19
	4	MEO2c	60.84	59.65
	5	MEO2uc	60.84	59.65

AGU 2022 Special Session: SM24A - Advancing Space Weather Research and Mission Development: OSSEs, OSEs, and Related Methods

Session included OSEs/OSSEs using data assimilation (DA) and general optimization/validation studies

- Lessons from tropospheric weather OSE/OSSE studies (Cucurull)
- Ionospheric, thermospheric, and radiation belt applications (Pedatella, Sutton, Dietrich, Schiller)
- Innovative DA approaches (Elvidge, Sutton)
- LEO missions (Forsythe, Araujo de Mesquita)
- Methods and tools in iono/thermospheric and magnetospheric regimes (Yudin, Liemohn, Wiltberger, Toth, Ringuette, Fujita)