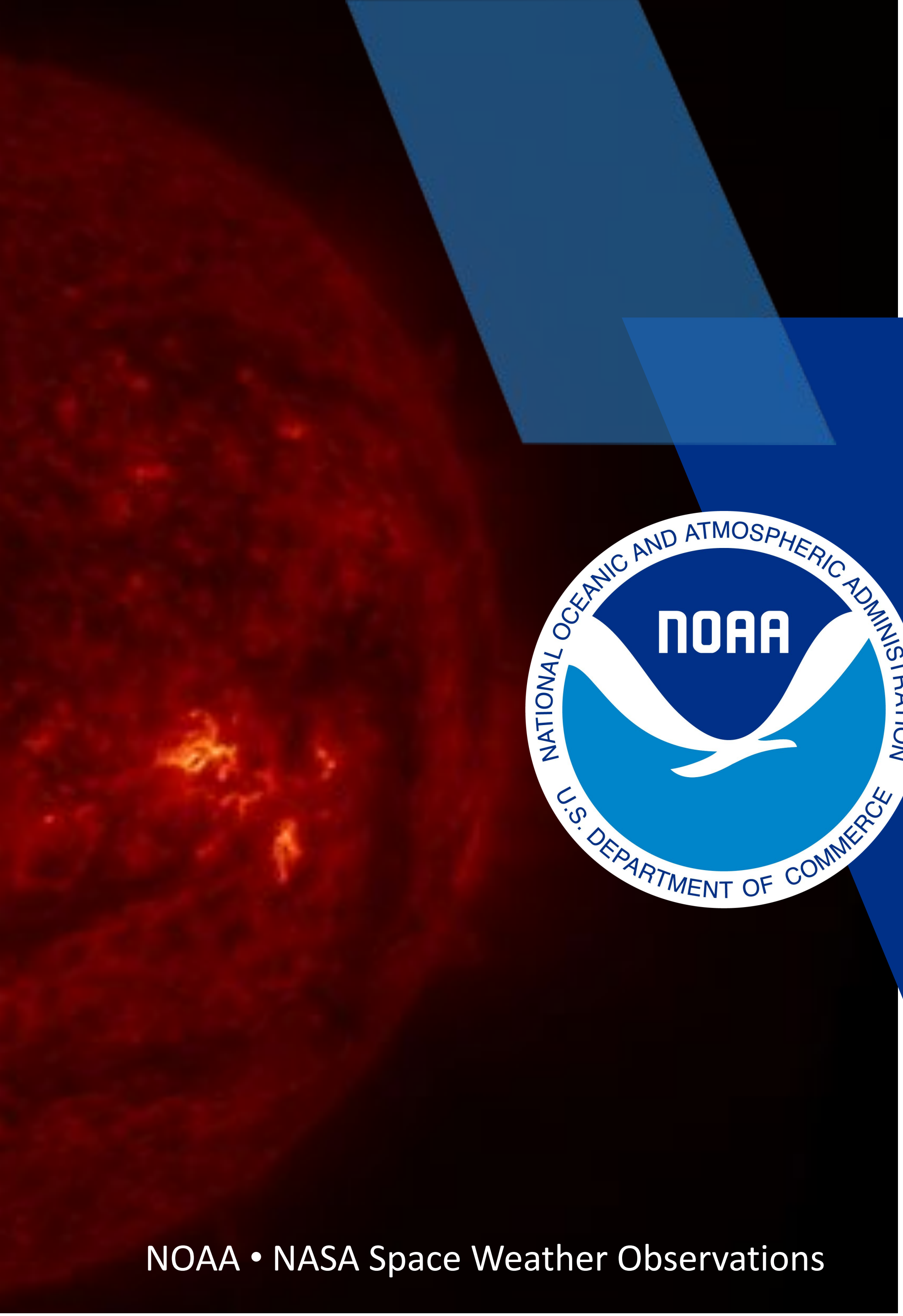


# Integrating NOAA's Real-Time Data into Space Weather Models

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# Introduction

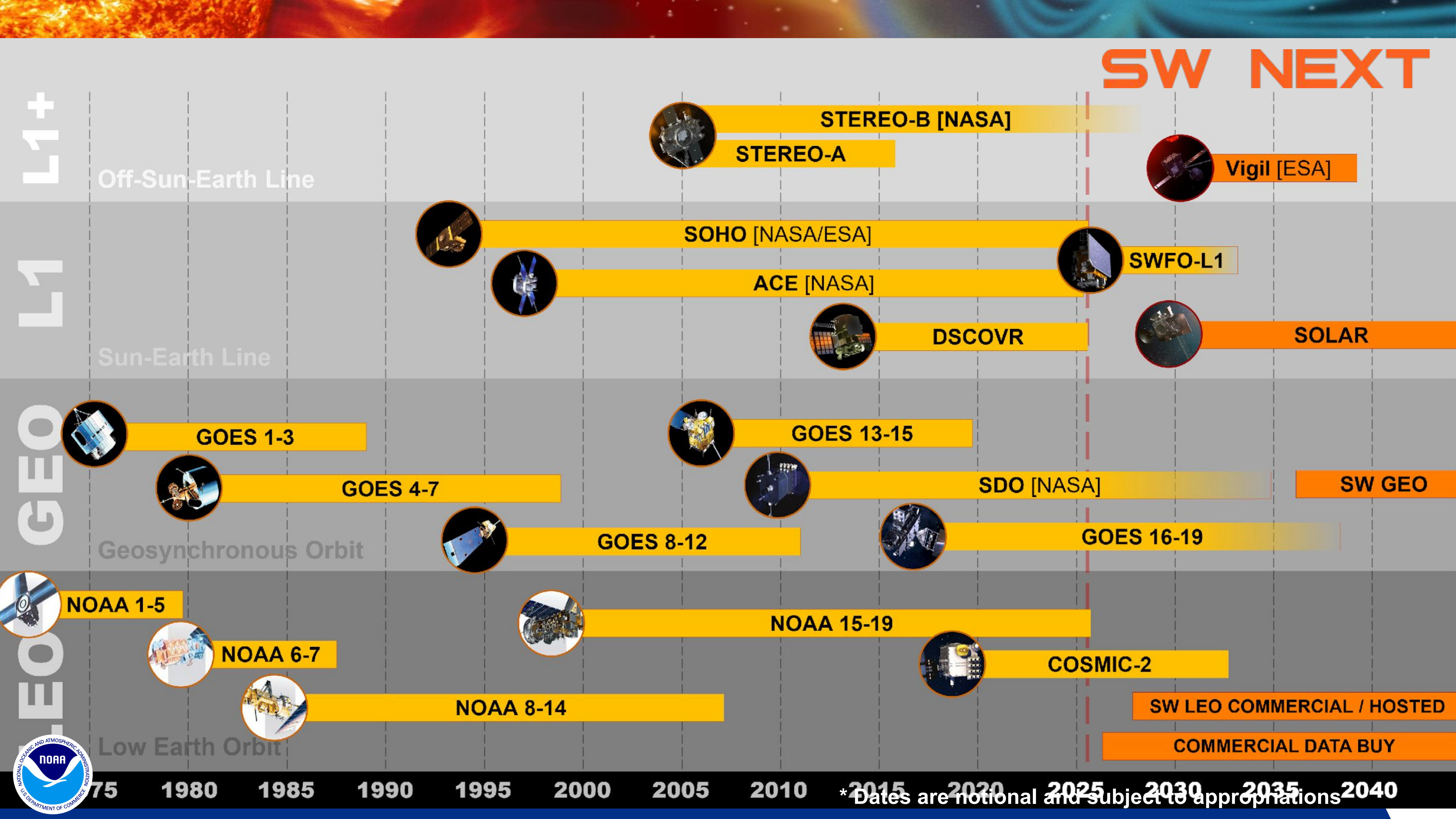
- Space weather refers to the variable conditions on the Sun and in space that can influence technological systems and endanger life or health.
- NOAA is mandated to sustain and advance critical operational space weather observations and to ensure efficient space weather knowledge transfer and information exchange.
- To sustain and advance space weather observations, NOAA is implementing its Space Weather Next Program.
- The program reflects NOAA's strategic priority in space weather

# Space Weather is a National Priority

- Space **Weather is one of the six critical societal challenges** in NOAA's Weather, Water, and Climate Strategy for building a Weather and Climate Ready Nation.
- **NOAA's Role in Space Weather Operations**
  - Provide operational space weather monitoring, forecasting, and long-term data archiving and access for civil applications
  - Maintain observation assets needed for space weather forecasting, prediction, and warnings
  - Develop requirements for emerging space weather forecasting technologies and science

# SWO Strategic Plan for Space Weather

- **Continuity of Observations:** SWO aims to continuously monitor solar events like solar flares, coronal mass ejections (CMEs), and solar wind to predict and understand their potential impact on Earth's space environment.
- **Enhanced Space Weather Observations:** By deploying advanced space weather instruments aboard satellites, NOAA seeks to improve the accuracy and timeliness of SWPC's space weather forecast products.
- **Collaboration with Partner Agencies and the Commercial Sector:** NOAA collaborates with NASA, the Department of Defense, and international space agencies and the commercial sector to enhance space weather observation and data sharing.


SW NEXT
L1+
Off-Sun-Earth Line
STEREO-B [NASA]
STEREO-A
Vigil [ESA]
L1
Sun-Earth Line
SOHO [NASA/ESA]
SWFO-L1
ACE [NASA]
DSCOVR
SOLAR
GEO
Geosynchronous Orbit
GOES 1-3
GOES 4-7
GOES 8-12
GOES 13-15
SDO [NASA]
SW GEO
GOES 16-19
LEO
Low Earth Orbit
NOAA 1-5
NOAA 6-7
NOAA 8-14
NOAA 15-19
COSMIC-2
SW LEO COMMERCIAL / HOSTED
COMMERCIAL DATA BUY
75
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
*Dates are notional and subject to appropriations

# Space Weather Observations (SWO) Portfolio

## Space Weather Follow On (SWFO)

- Two program elements
  - SWFO-L1 mission and GOES-U coronagraph
- GOES-U launched on June 25, 2024
- All space weather instruments providing science data
- All SWFO-L1 instruments delivered and integrated on the spacecraft
- SWFO-L1 launching as a rideshare with NASA IMAP no earlier than Sept. 23, 2025

## Space Weather Next (SW Next)

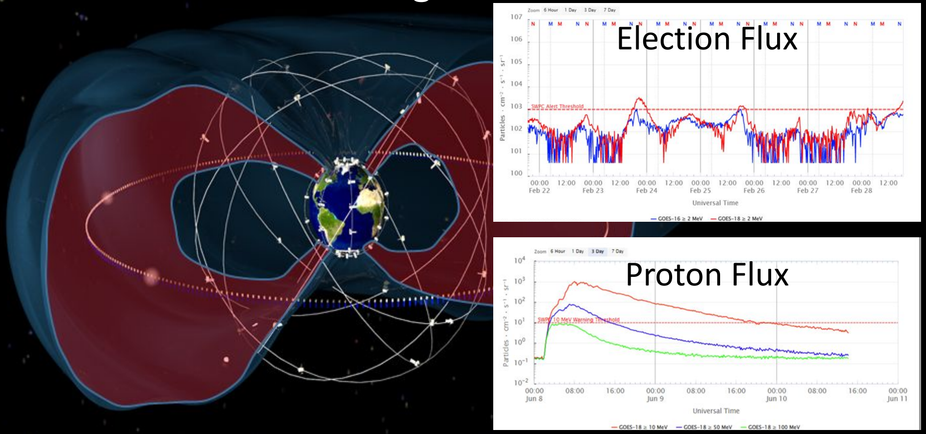
- Expands NOAA's space weather data products by developing capabilities for L1, L5, GEO, HEO, and LEO
- SOLAR Series received KDP-B approval on December 17, 2024
  - The SOLAR Series consists of two independently launched spacecraft (SOLAR-A and SOLAR-B) targeting launch of SOLAR-A in 2029 and SOLAR-B in 2032
  - Instrument and spacecraft awards completed

# SW Next GEO is in Pre-Formulation to provide continuity for critical measurements and transition new capabilities to operations

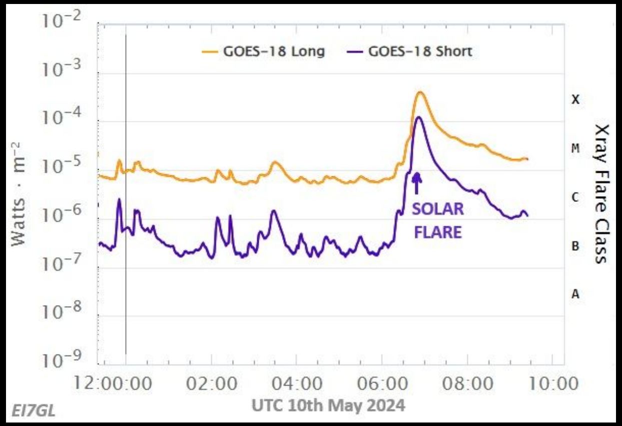
## Pre-formulation activities:

- Instrument studies to assess technology readiness
- Spacecraft RFI released
- Analysis of alternatives to assess requirements and develop mission concept

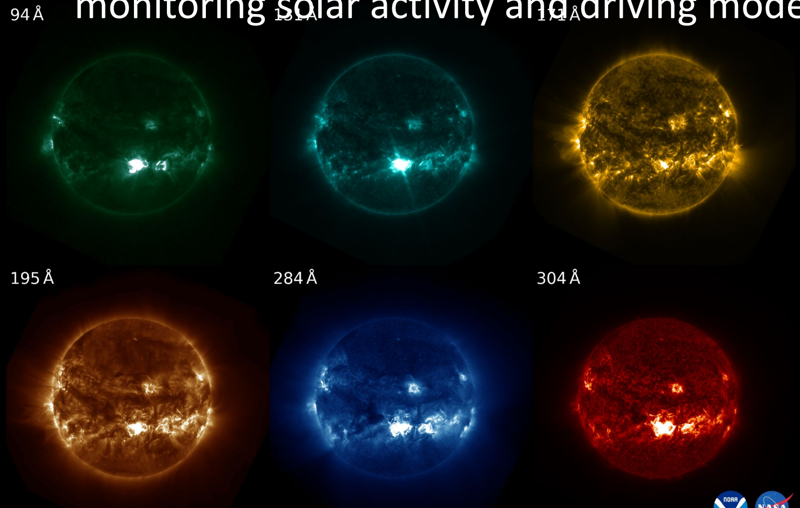
In situ energetic particles and magnetic fields for characterizing radiation environment




Solar X-ray Irradiance for flare detection



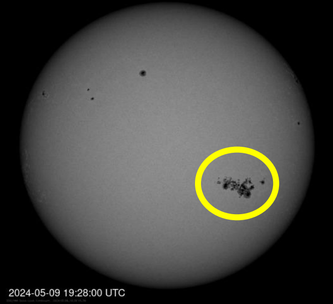

Solar EUV Imagery and Irradiance for monitoring solar activity and driving models



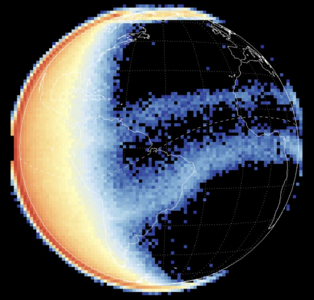

GOES-19/SUVI 3 Oct 2024

Capability enhancements under consideration

Photospheric Magnetograph Imagery NASA SDO/HMI



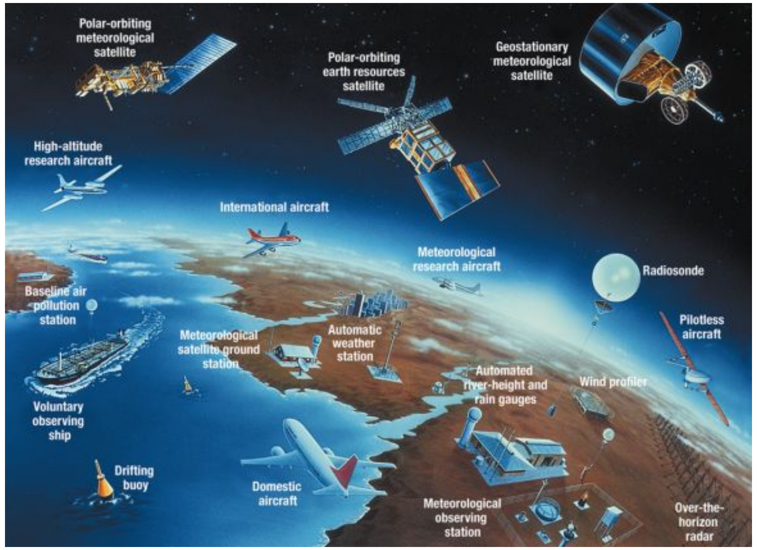

Thermospheric O/N2 Ratio NASA GOLD

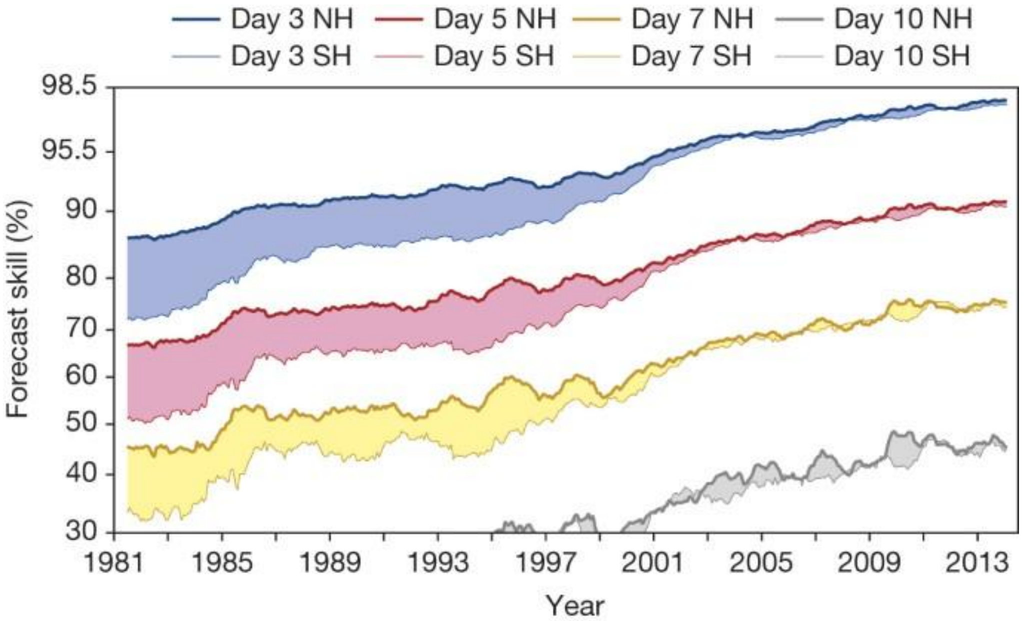


# Utilization of Satellite Measurements in Space Weather Data Assimilation

Numerical weather prediction is supported by a robust observing system consisting of NOAA remote sensing and in situ observations as well as contributions from international partners and commercial data. Assimilation of these observations improves forecast skill by correcting errors in the model state, constraining the dynamics of the model, and correcting biases.

**Assimilation of space weather observations has to potential to improve models of the near-Earth space environment.**



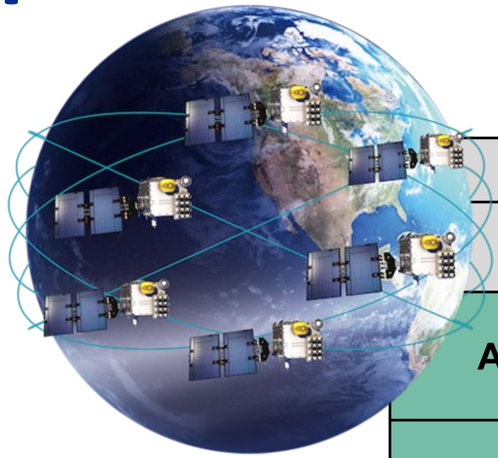




Bauer et al. (2015)

# COSMIC-2 Space Weather Data Products

## FORMOSAT-7/COSMIC-2

- Achieved full operational capability on October 12, 2021



TEC data:
https://data.cosmic.ucar.edu/gnss-ro/cosmic2/nrt/level1b/

EDP data:
https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/spaceWeather/level2/

Scintillation/IVM data:
https://data.cosmic.ucar.edu/gnss-ro/cosmic2/rapid/

| COSMIC-2 Space Weather Products | | |
|---|---|---|
| **Product Name** | | **Instrument** |
| **Absolute TEC** | **GPS** | TGRS |
| | **GLO** | TGRS |
| **Electron Density Profiles** | | TGRS |
| **Scintillation Amplitude Index (S4)** | | TGRS |
| **Scintillation Phase Index ($\sigma_\varphi$)** | | TGRS |
| **Scintillation High-Rate Data** | | TGRS |
| **Plasma In-situ Density** | | IVM |
| **Plasma Drift** | | IVM |
| **Plasma Composition and Temp** | | IVM |

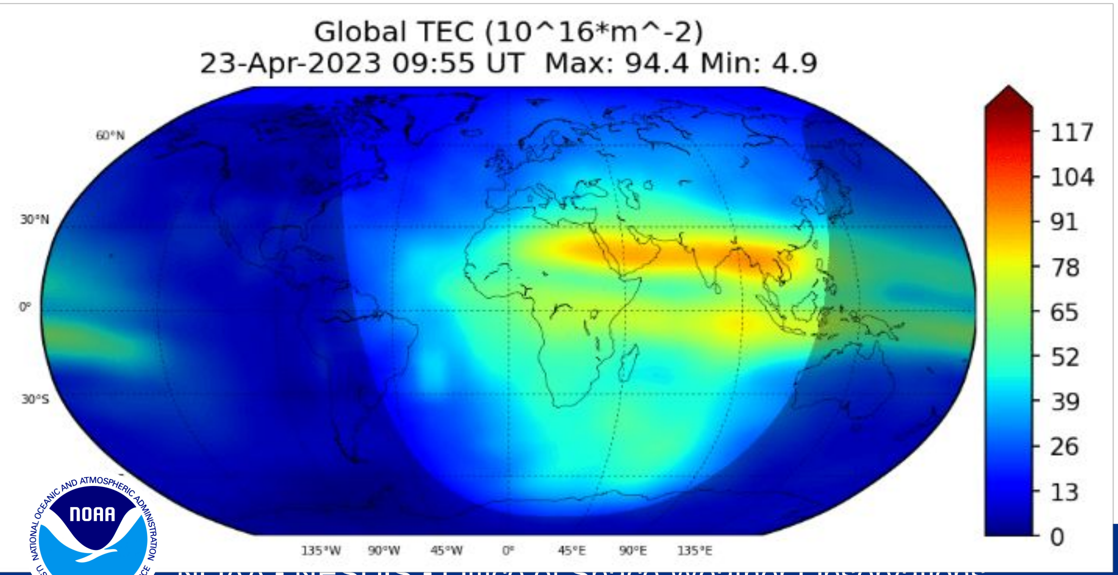
Operational products are absolute TEC and plasma in-situ density.
Products shaded in green have been verified and released.

# COSMIC-2 Data Assimilation in NOAA GloTEC Model

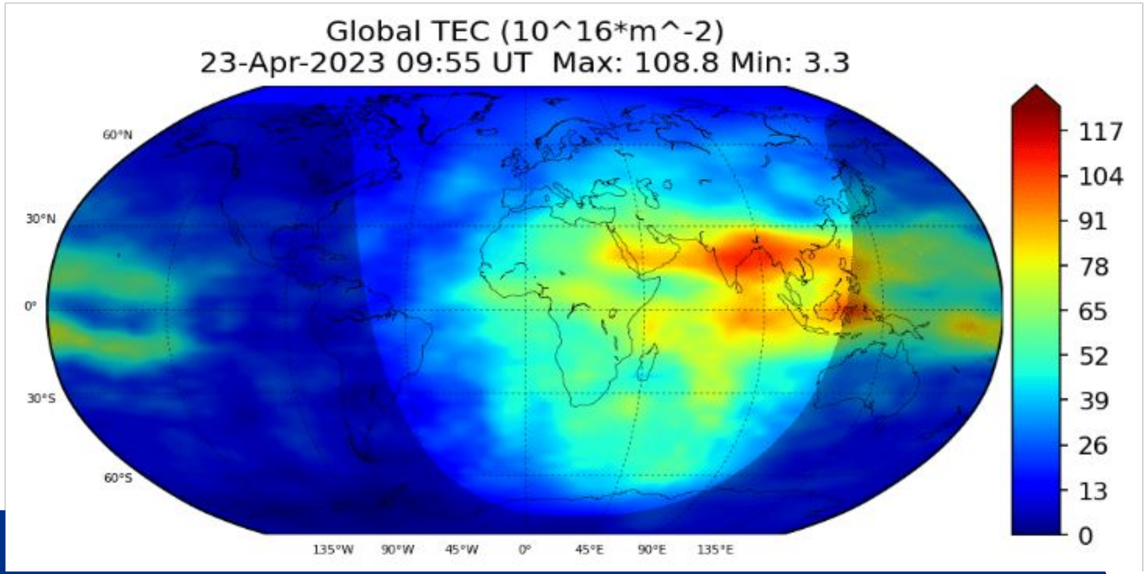
## COSMIC-2 real-time TEC measurements are used in GloTEC

- GloTEC can ingest STEC from GNSS-RO or even from GNSS-R observations.
- The background model is IRI 2016 driven with real-time F10.7
- Products include specifications for: **VTEC**, **NmF2**, **hmF2**, **MUF3000**, and **ionosphere profiles** that can be used for situational awareness, model validation, and evaluation of new data streams.
- Exploring methods to ingest RO data and other cosmic-2 measurements into an operational physics-based WAM-IPE model. This development would possibly improve MUF specification.

A) Ground-stations only




B) Combined ground-stations and RO



# Starlink Constellation Orbit Averaged Neutral Density

Owner/Operator: SpaceX

Country of Origin: United States

Application: Internet service

Website: www.starlink.com

Spacecraft type: Small satellite

Launch Mass: v0.9: ~227 kg
v1.0: ~260 kg
v1.5: ~306 kg
v2m: ~800 kg

Equipment: Ku-, Ka, & E-band phased array antennas
Laser transponders
Hall-effect thrusters

Regime: LEO
mid- & high-inclination

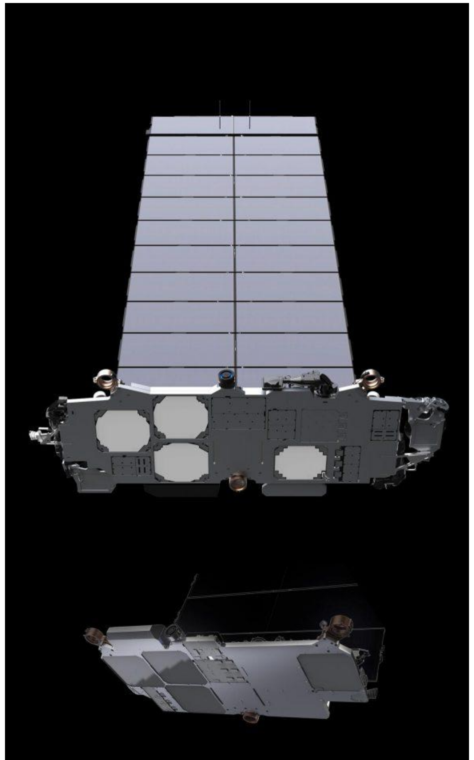
Status 8,165 satellites on-orbit (as of 8/25/2025)
Active since 2019

We are using the following data:

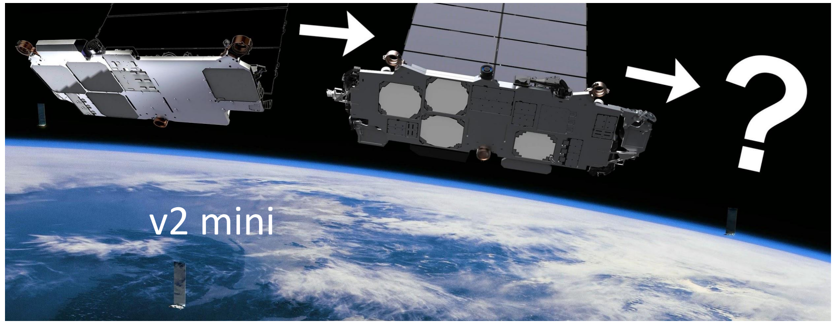
- Position & velocity ephemeris
- Attitude & panel articulation
- Estimated non-conservative accelerations
- Satellite geometry

Time Periods:

- April 2022 – April 2023:
  - v1.0: 1,525 sats
- February 2024:
  - v1.0: 1,392 sats
  - v1.5: 2,873 sats
  - v2m: 706 sats

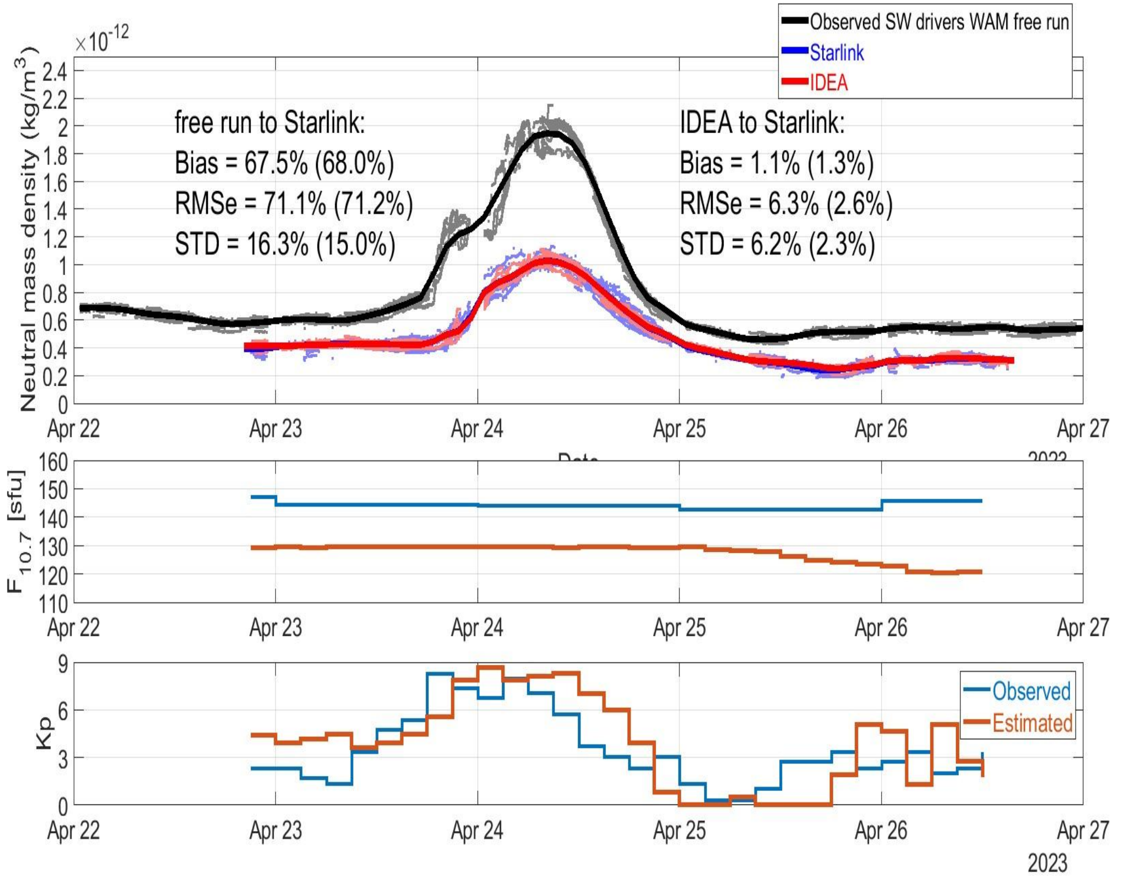


Starlink v1.X Satellite Bus



# Data Assimilation of Neutral Density Data into the NOAA WAM model

- A sample Starlink neutral density data has been tested by ingesting into Whole Atmosphere Model (WAM) using the Iterative Driver Estimation and Assimilation methodology (IDEA) (E. Sutton, 2018).
- The test has shown WAM quiet-time neutral density biases can be removed
- The orbit average data is also sufficient to follow a large part of the response to geomagnetic storms



# Modeling Earth's Radiation Belts and Their Effects on Satellites

- An observing system simulation experiment (OSSE) framework is developed to examine the impact of different measurement topologies on the reconstruction of the radiation environment.
- The study investigated different spacecraft architecture configurations by assimilating simulated data into the 3D Versatile Electron Radiation Belt (VERB-3D) model (Subbotin & Shprits, 2009).
- Furthermore, the sensitivity of the reconstruction to boundary conditions, pitch angle knowledge, and energy range of simulated observations is also quantified.

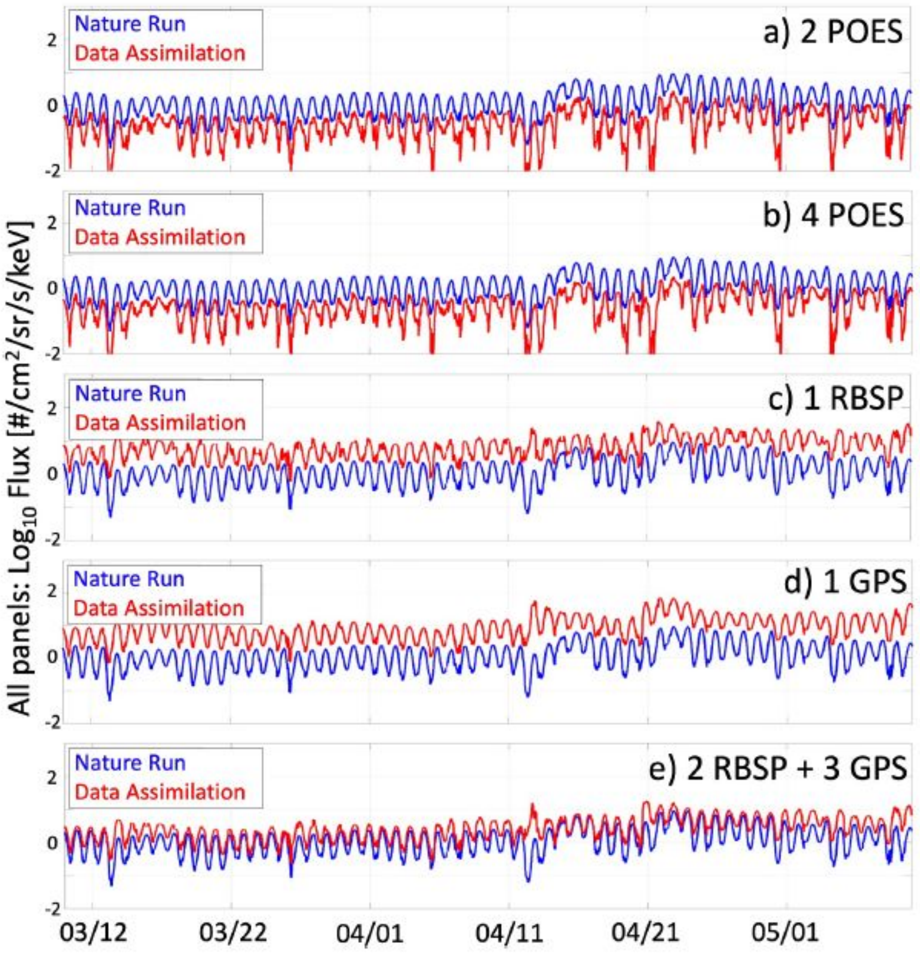



**Figure 4.** Flux comparison between GOES-like flythrough of the nature run (blue trace) and reconstruction (red trace) using (a) 2 POES spacecraft, (b) 4 POES spacecraft, (c) one RBSP spacecraft, (d) one GPS spacecraft, (e) and 2 RBSP combined with 3 GPS spacecraft.

Shprits et al. (2025)

# Concluding Remarks

- NOAA’s real-time space weather data is critical for improving the accuracy, reliability, and responsiveness of space weather models.
- Data assimilation bridges the gap between observations and physics-based models, enabling better nowcasting and forecasting of radiation belt dynamics, solar storms, and geomagnetic disturbances.
- Integration of NOAA’s observations enhances our ability to monitor and predict space weather events in near-real-time.
- Collaboration between operational agencies and model developers is essential to fully leverage NOAA’s data and improve space weather preparedness.
- Continued investment in observation-model integration will be vital for advancing space weather forecasting capabilities and mitigating space environment risks.