Future Earth System observations: What might be important in the future

Natalia Donoho & Sid Boukabara

National Environmental Satellite, Data, and Information Service (NESDIS)

Contributions from NESDIS (Mitch Goldberg, Trisha Weir), NWS (Emily Liu, Jim Yoe), NASA (Eric Hackert, Maudood Khan, Steven Pawson, Will McCarty) and many others

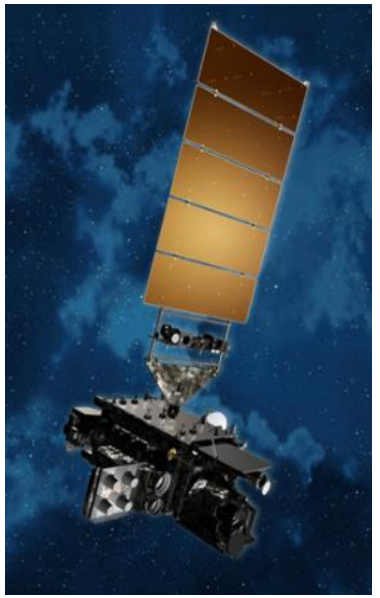
ECMWF Annual Seminar 2021

Agenda

- Introduction
  - NESDIS at glance
  - Programs of record (LEO, GEO, SWO)
  - Common Ground Services & Product Development
  - NOAA's Commercial Data Program Plans and Status
- Looking Forward
  - Major Factors Driving the Remote Sensing of the Future
  - Trends, Opportunities and Challenges
- Conclusions

NESDIS (National Environmental Satellite Data and Information Service) at a Glance

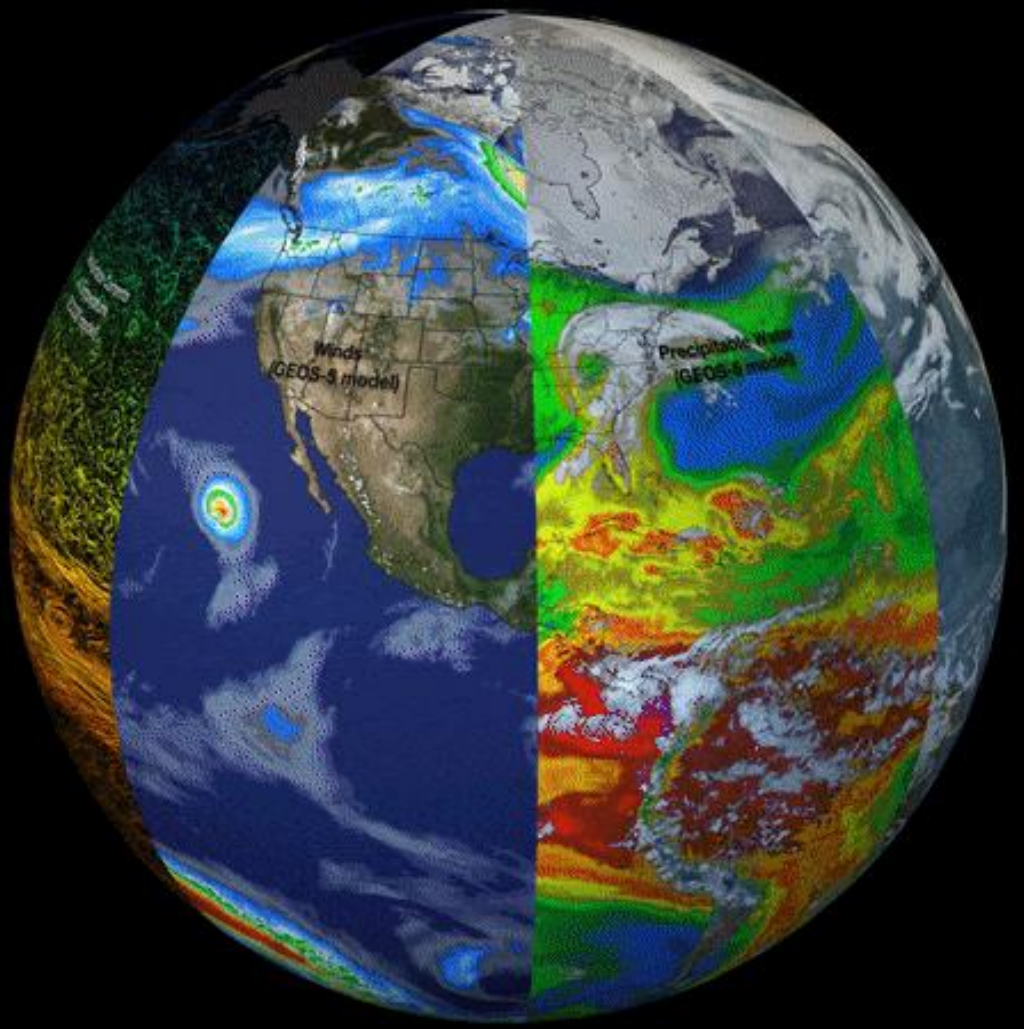
- Operates the Nation's weather satellites, 24/7
- Acquires next-generation Earth observation satellites
- Provides data and imagery for predictive environmental and atmospheric modeling
- Provides definitive assessments of the U.S. and global climate
- Maintains one of the most significant archives of environmental data on Earth



… with a global perspective

NESDIS Mission

Provide a truly integrated digital understanding of our earth environment that can evolve quickly to meet changing user expectations by leveraging our own capabilities and partnerships



NESDIS Office of Satellite and Product Operations (OSPO)

Operates the Nation's 15 environmental satellites:

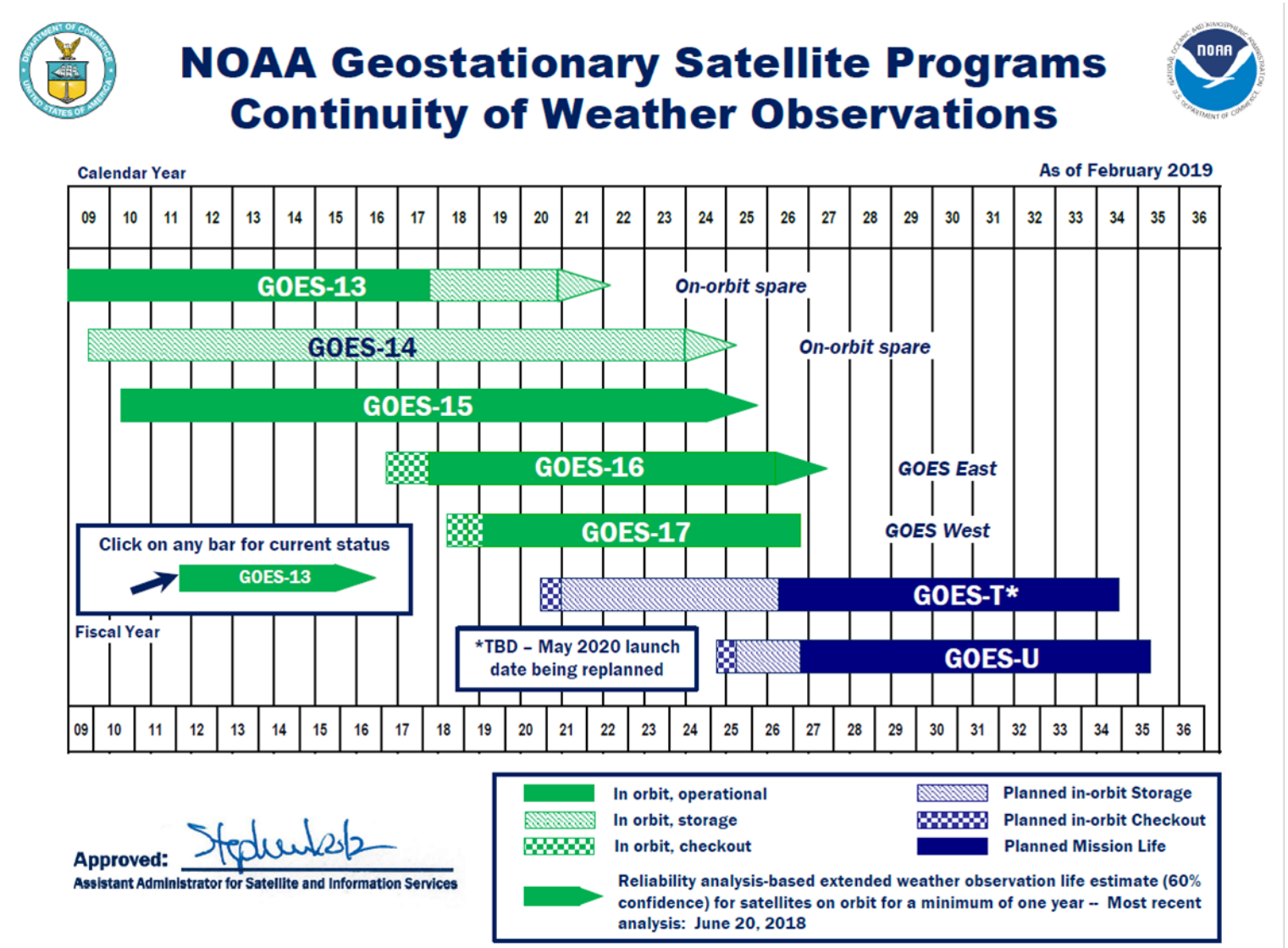
- 4 Geostationary (GOES) by NOAA
- 1 Geostationary (EWS-G) operated by NOAA
- 2 Joint Polar Satellite Systems by NOAA + NASA (NOAA-20, Suomi-NPP)
- 3 Polar-Orbiting (POES) by NOAA
- 3 Defense Meteorological Satellite program (DMSP) operated by NOAA
- Jason-3 (Ocean Surface Topography Mission) - Joint NOAA, NASA, CNES, EUMETSAT effort
- 1 DSCOVR (Deep Space Climate Observatory) by NOAA

Geostationary (GEO) Portfolio

Broaden Your Perspective

9 Feb 2020: Himawari-8, GOES-17, GOES-16, Meteosat-11 (CIMSS/SSEC)

NOAA GEO Plans



Evolution from GOES-R to GeoXO – 1
Growing needs require new observations

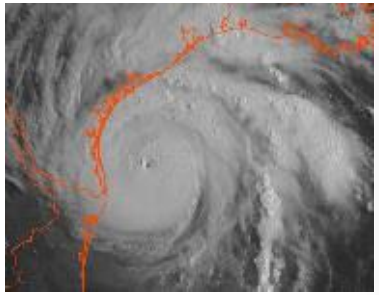
GOES-R provides Visible/Infrared Imagery and **Lightning** data:

- Essential for short-range forecasting, issuing severe weather watches and warnings, and monitoring hazardous environmental conditions including tropical storms, severe storms, damaging winds, snow, ice, flooding, fog, fires, smoke, and volcanic ash

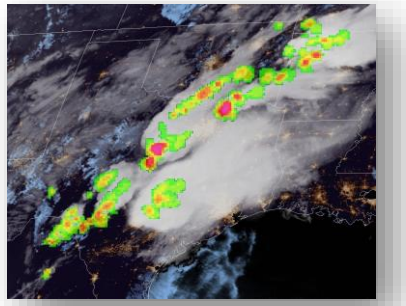
GeoXO will continue and improve Imagery and Lightning data and add new observations:

- **Hyperspectral IR Sounder** for numerical weather prediction and local nowcasting
- **Ocean Color Instrument** for monitoring dynamic coast/ocean features, ecosystem change, water quality, and hazards
- **Atmospheric Composition Instrument** for monitoring air quality and the linkage between air quality, weather, and climate

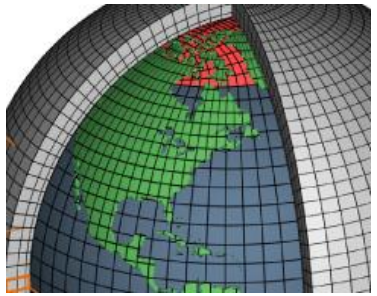
Vis/Near-IR Imagery



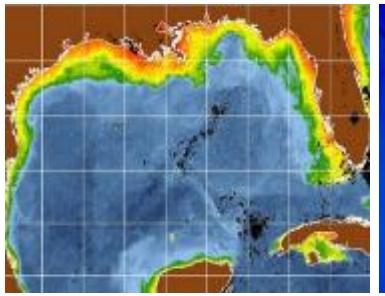
Lightning Mapping



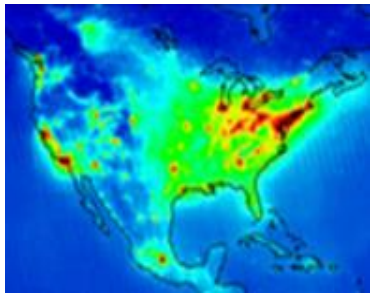
IR Sounding



Ocean Color



Atmo. Composition



GeoXO User Engagement in 2020-2021

NOAA is going directly into the user community to fully understand their current and evolving needs. We do this through a variety of means, as demonstrated with our 2020-2021 GeoXO User Engagement effort.

User Needs Virtual Workshops

- Topics of **Fire** (178 attendees), **Weather** (233), **Agriculture** (152), **Health** (207), **Oceans** (142)
- Federal: NASA, USGS, and 20 other federal agencies
- State/Local: 26 States, multiple cities, and several counties and tribal areas
- International: WMO, Canada, Mexico, EUMETSAT, Caribbean/South American orgs
- Industry: more than 70 companies and advocacy groups from weather, transportation, communications, media, aerospace, natural resource and energy sectors
- Academia: more than 60 universities

Community Meeting on NOAA Satellites

- 1013 participants representing 33 countries
- >250 organizations including Federal Agencies, international meteorological organizations, academia, and industry
- NASA, JAXA, ESA, EUMETSAT, JMA, KARI, Copernicus

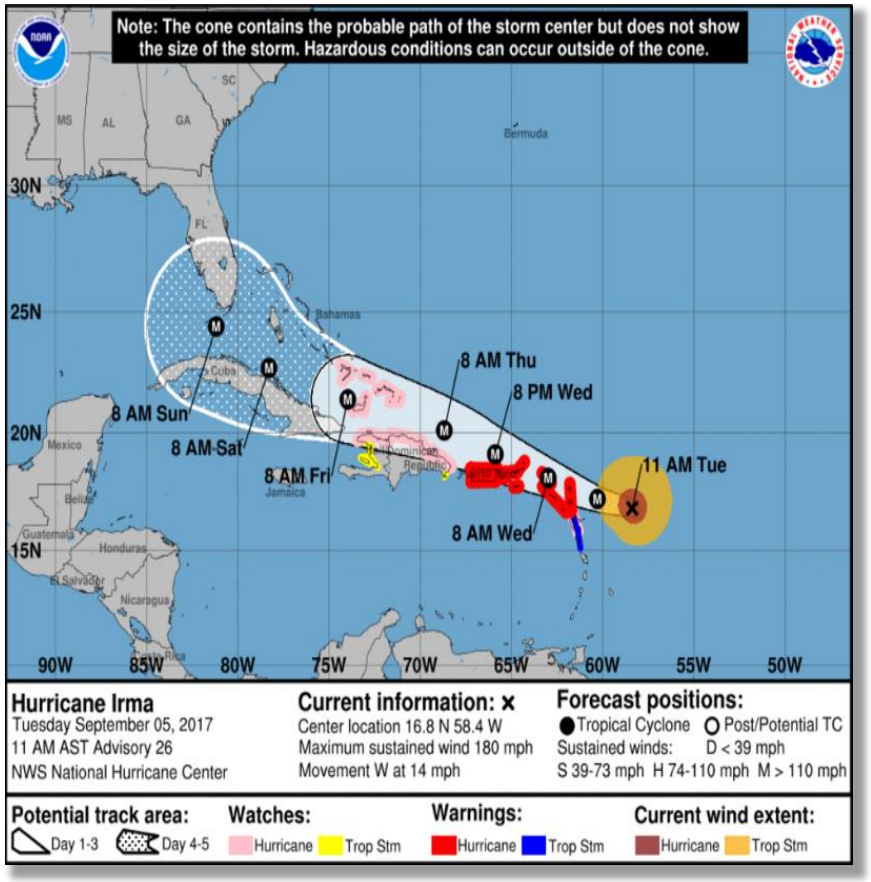
Listening Sessions, Panels, and Presentations

- National Weather Association
- American Meteorological Society
- American Geophysical Union

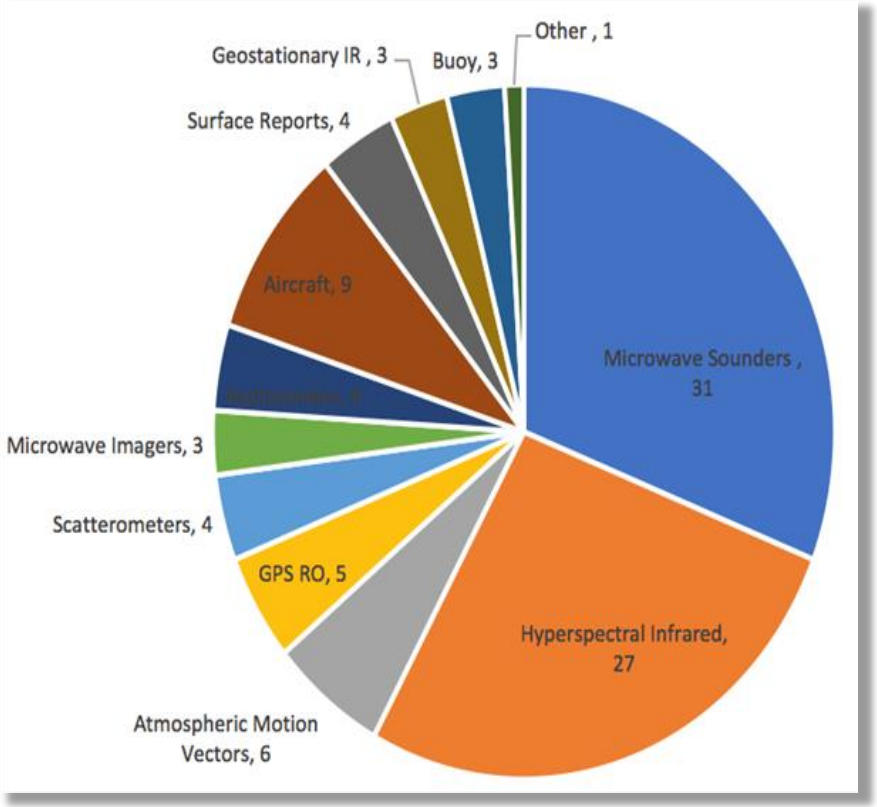
Low Earth Orbit (LEO) Portfolio

Satellites are critical for the Weather Forecast Enterprise

85% of all data used in forecast models are from polar-orbiting satellites and attribute to nearly 60% of the reduction in forecast error.



Observation type attributed to forecast error reduction



Highly Diverse LEO Observations

Foundational Products: Satellite Radiances and Satellite Imagery

NESDIS Level Requirements – Geophysical Products

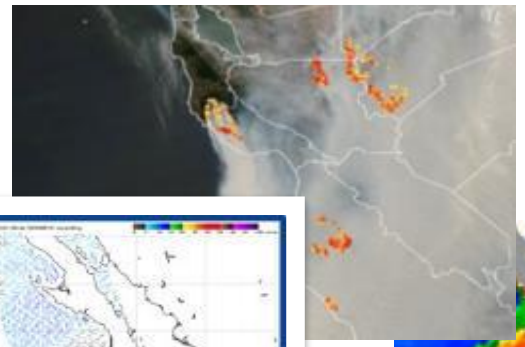
Atmosphere	Cryosphere	Land	Ocean, Fresh Water & Coasts

Analytical

Climate & Weather

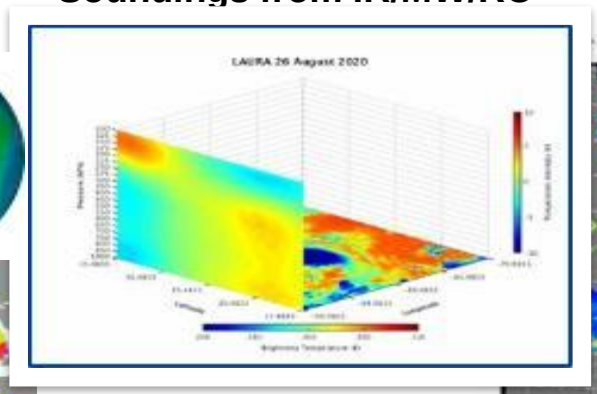
Ocean, Fresh Water & Coasts

Multipurpose VIS/NIR/IR Imagery

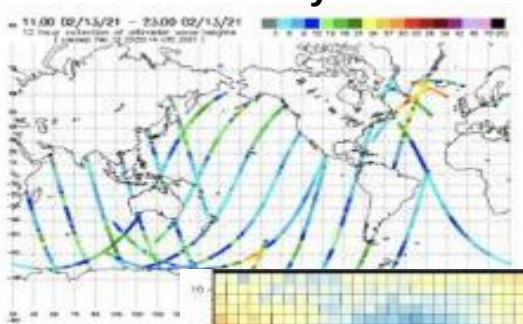


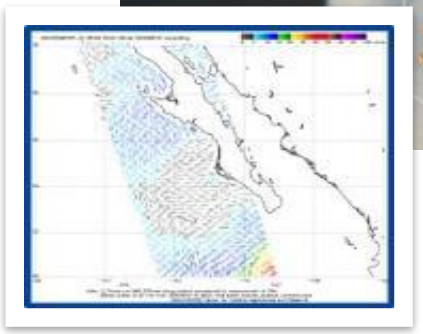
UV Imagery

Soundings from IR/MW/RO

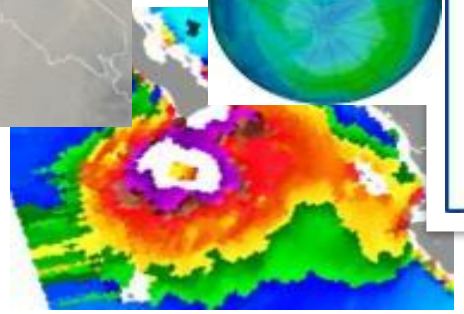


Altimetry

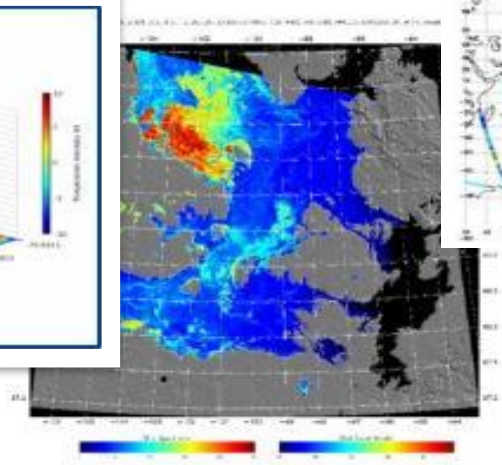




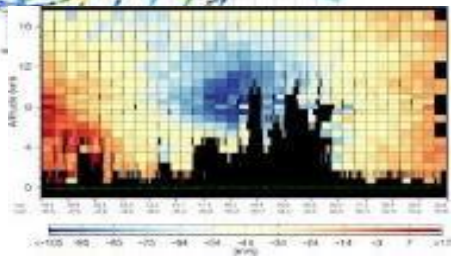
Scatterometry



MW Imagery

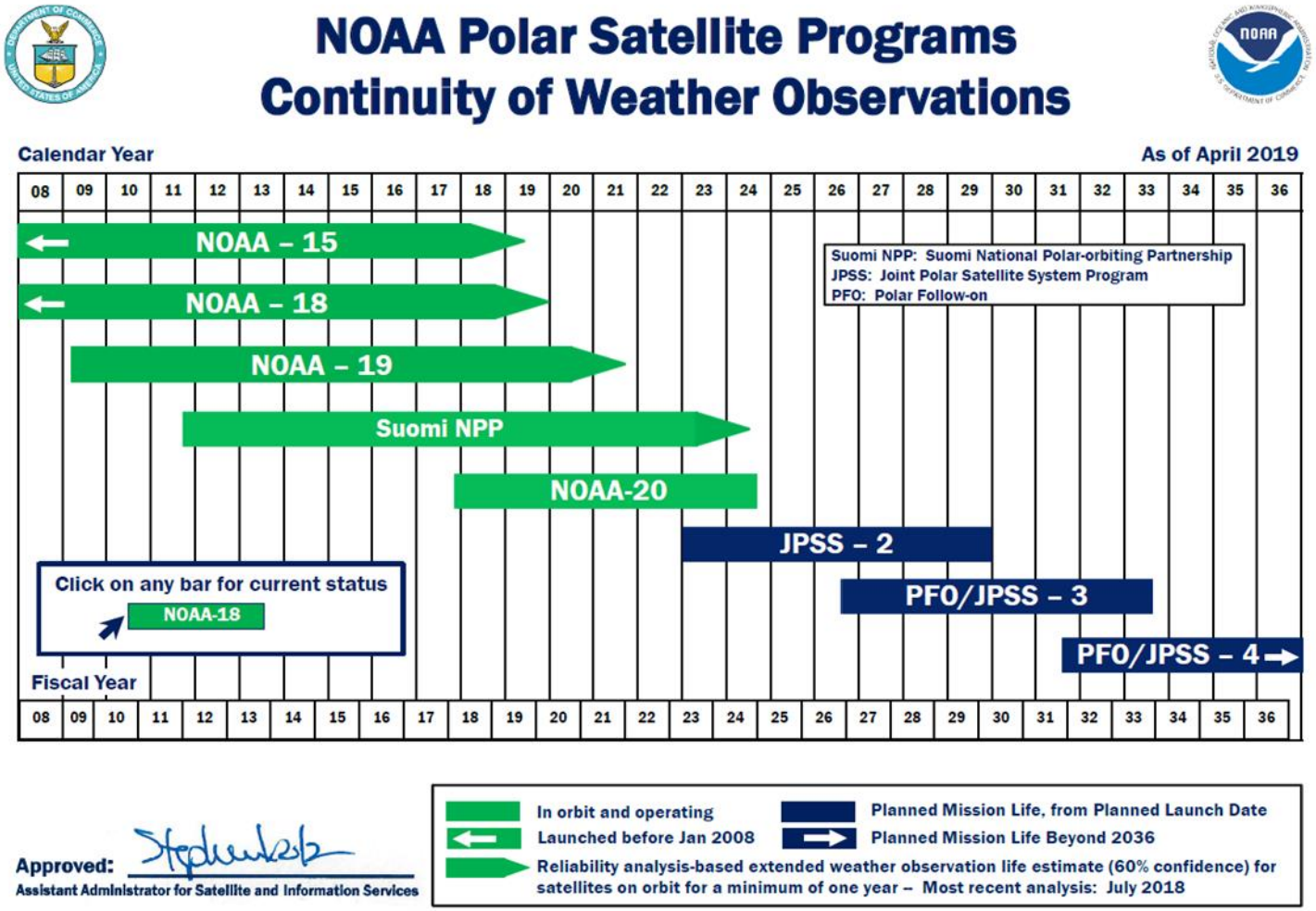


RADAR Imagery



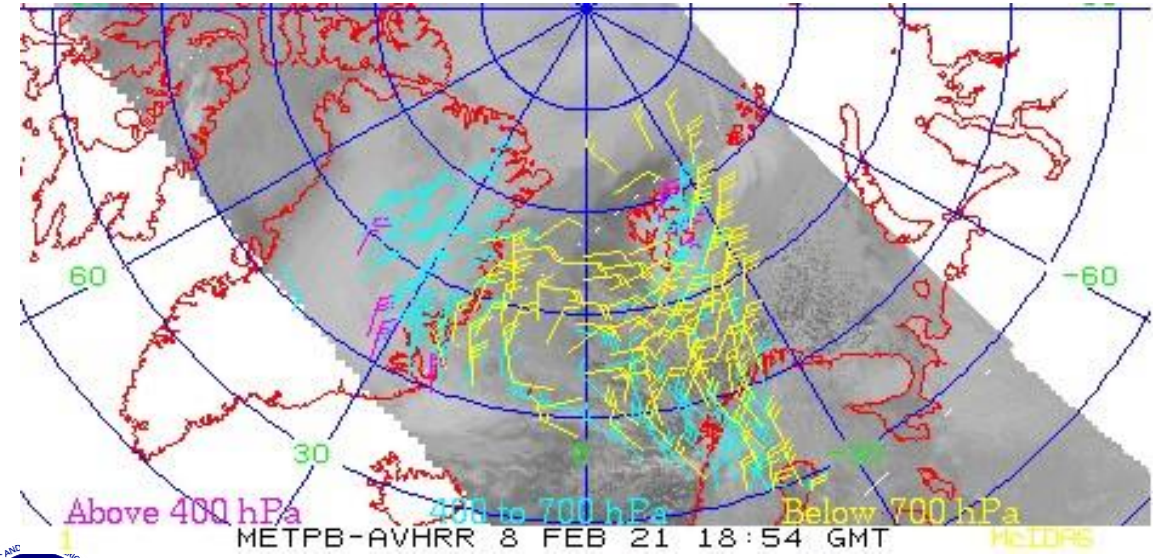
LIDAR

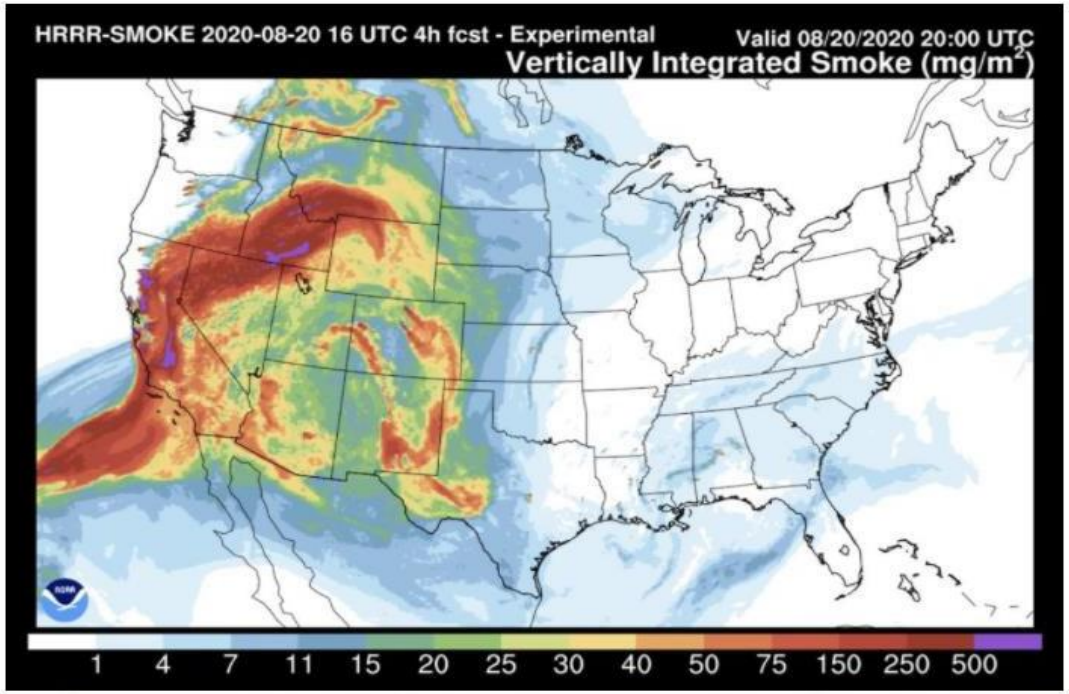
NOAA LEO Plans



NESDIS LEO Approach: Mission Concepts to Augment Global Measurement Capability

- Launch satellites more frequently to **enhance refresh and augment global observations collected from earth observation satellites,** beginning in mid-2020s
- Replenish **critical sounding data**
- NESDIS completed its LEO SounderSat Milestone-0 Review March 10, 2021





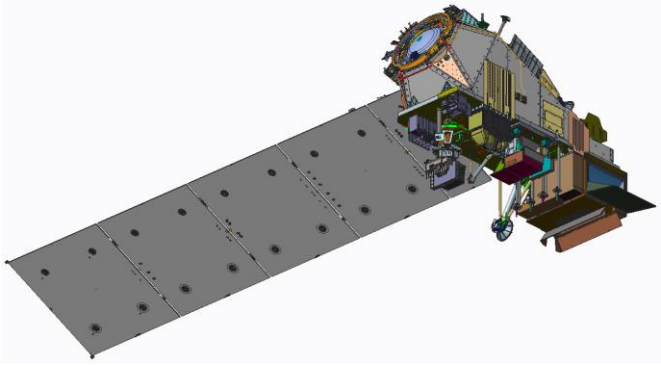
Vertically integrated smoke plot showing HRRR-Smoke forecast on August 20, 2020 valid at 20:00 UTC. The High Resolution Rapid Refresh Smoke model uses a suite of fire products from JPSS satellites.

- Capture **3D winds, ocean surface vector winds, precipitation data**, and **low-light imagery**
- **Hybrid approach**: data from NOAA satellites, strategic partners, and commercial providers

Near Term Focus in LEO is on Innovation

In FY 2022, LEO will:

- Complete a Commercial Ground Services Demonstration (JPSS)
- Continue the detailed concept development of the SounderSat Project and the LEO program, including:
  - Milestone 1 for the LEO Program
  - The Mission Concept Review for the SounderSat project
  - The Mission Concept Review for the LEO program

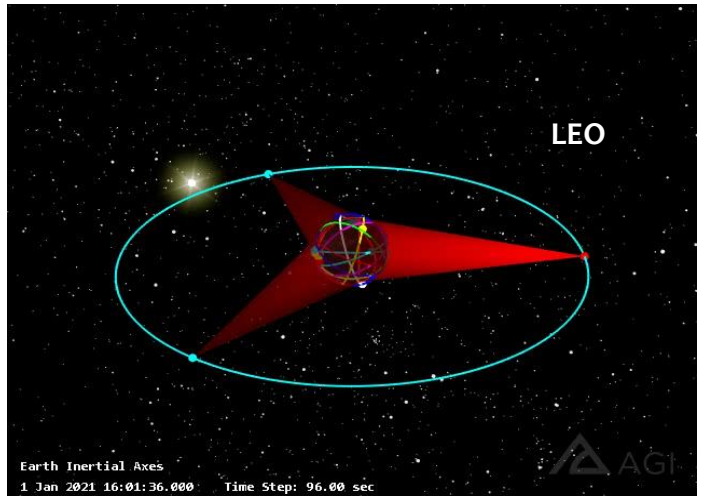


Space Weather (SWO) Portfolio

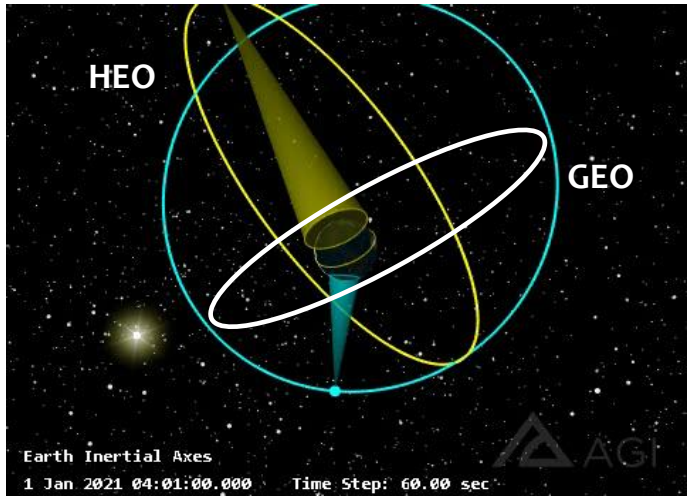
Space Weather Observations Program

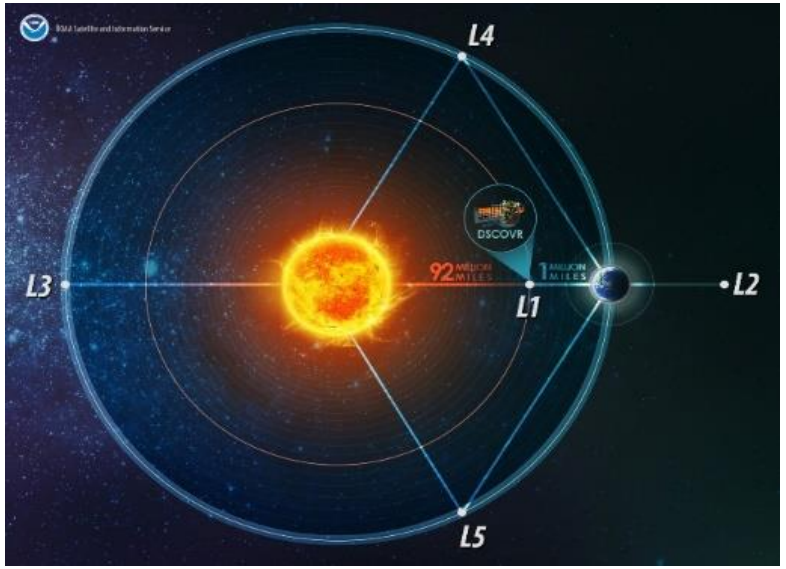
The Space Weather Program will need a comprehensive observational capability for several orbital regimes.

Thermospheric and ionospheric objectives will require in situ measurements from LEO as well as imaging capabilities from GEO.



For the magnetosphere, in situ measurements from GEO and HEO can combined with auroral imaging.





Coronal and photospheric imagery from L1 and L5 can be used for stereoscopic analysis. In situ plasma/field data will drive heliospheric models.

NOAA's Next-Gen Earth Observation Strategy

Integrated, Adaptable, and Affordable: Orbits, Instruments & Systems

LEO

Miniaturized instruments on small, lower cost, and proliferated satellites and partner data improving forecasts through better and additional data. Better precipitation forecasts, wave height predictions, ocean currents, and more.

GEO

Continuous real-time observations supporting warnings and watches of severe weather and hour-by-hour changes. High-inclination orbits to observe northern latitude & polar regions.

Space Weather

Reliably monitoring coronal mass ejections from L1, GEO, and LEO can protect the nation's valuable, vulnerable infrastructure. New capabilities at L5 and high earth orbit can provide additional insight and improve forecasts.

Common Ground Services

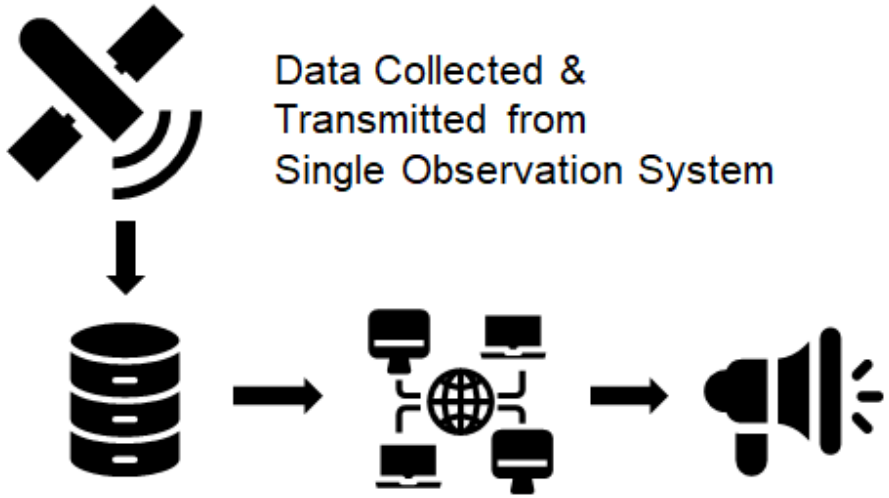
Secure ingest of data in different formats from different partners requires a flexible, scalable platform. Common Services approach integrates cloud, AI, and machine-learning capabilities to verify, calibrate, and fuse data into new and better products and services.

Common Services & Product Development

A New Paradigm in Data Science and Information Services

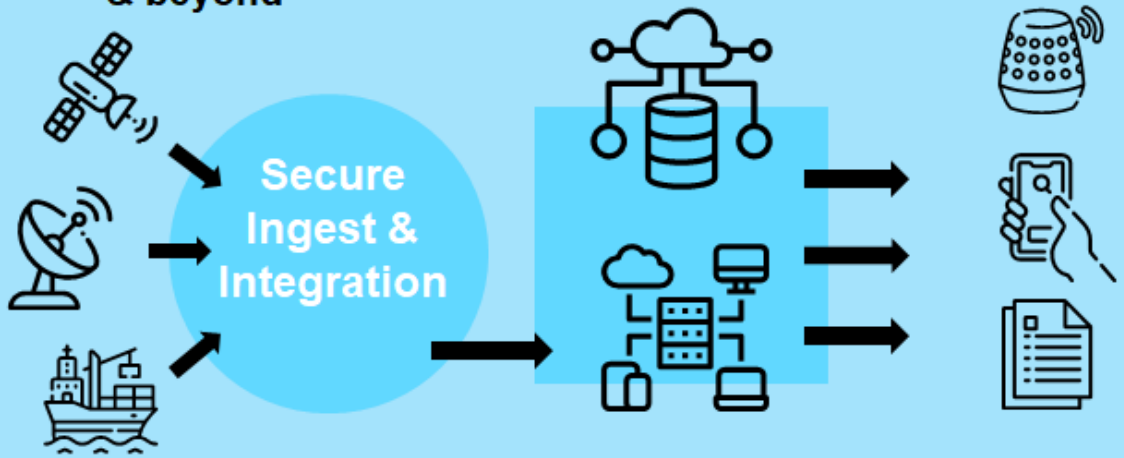
TODAY'S GROUND SERVICE

- Single system data services
- Limited computing power



TOMORROW'S GROUND SERVICE

- Secure ingest for all data types
- Powered by AI, data science
- Super-computing capability through cloud transition & beyond



NOAA's Commercial Data Program Plans and Status

Operational Radio Occultation Data Purchase, Delivery Order (DO)-1:

- GeoOptics & Spire Global were awarded Radio Occultation (RO) Indefinite Delivery, Indefinite Quantity (IDIQ) contracts in the fall of 2020
- Contract Period of Performance is Nov 2020 - Nov 2022
    - Approach: a series of Delivery Orders to leverage competition in the market and adjust NOAA requirement as capabilities are matured
    - All vendors delivered under Delivery Order 1 for 30-day testing
    - Variable delivery requirements for remaining Delivery Orders
    - Final Delivery Order may extend up to one year beyond Nov 2022

Delivery Order (DO)-1

- 500 profiles/day, delivered as both Level 0 and Level 1, for 30 days (15-Dec-2020 to 15-Jan-2021)
- NOAA and US Gov't only; day-old unrestricted
- Data flow was used to validate formats, latency, and prepare systems for operational use, as well as to support initial impact assessments.
- DO-1 resulted in a NOAA ready-for-operations capability to process data from two vendors into both neutral atmospheric and ionospheric products.

Operational Radio Occultation Data Purchase, Delivery Order (DO)-2:

- DO-2 was awarded for 1,300 profiles/day from GeoOptics for 6 months (March 17 to Sept 16, 2021). Represents an additional ~20% over current RO volume, sufficiently large to show impact.
  - US Govt only in near-real time, then delayed open sharing
  - Vendor to deliver data as both Level 0 and Level 1, while UCAR refines capability to generate products from Level 0.
  - Absolute Total Electron Content (TEC) and Electron Density Profiles (EDP) files are now being produced and distributed regularly.

- First 45-days used as the baseline evaluation period for decision to include in the operational forecast model and for Congressional Impacts Assessment Reporting.

  On May 20, 2021, NOAA began incorporating commercially purchased radio occultation data into operational numerical weather prediction models. The NWS National Centers for Environmental Prediction (NCEP) released an upgrade to the flagship Global Forecast System (GFS). This version (V16.1) includes the assimilation and processing of commercial radio occultation data in real-time.
  - Data Assimilation Impact Study is nearly complete; this information will feed into the Congressional Report due later this year.

Delivery Order (DO)-3: RFP Requirements

- Duration: 6 months
  - The contractor shall deliver Level 0 and Level 1 data
- Data Rights:
    - *Balances WMO obligations with cost and feasibility*
    - *Near-real time distribution to U.S. Government agencies, National Meteorological Centers (NMC), WMO Met Centers, and CGMS members for non-commercial use with no further distribution, then unlimited distribution after 24 hours*
- Data Quantity: The Government seeks a total of 2000 to 3000 average occultations per day to be supplied.
    - *Establishes new level for NWP ingest.*
    - *Latency of 140 minutes or less*
    - *Quality requirements stated in terms of signal-to-noise ratio*
- Data Types: No longer exclude Galileo-based data; UCAR will be prepared to process Galileo data

Delivery Order (DO)-3 Status:

- On August 13, 2021, NOAA awarded a third Delivery Order (DO-3) under its existing Indefinite Delivery Indefinite Quantity contract for radio occultation (RO) satellite weather data to Spire Federal.
  - Through this DO, NOAA is purchasing **3000 RO profiles per day** for six months beginning in September 2021
- **DO-3 Schedule:**

Event	Date
24h Sample begin	1 Sept 2021 NLT 11:00 ET (1500 UTC)
Data flow begin	16 Sept 2021 (same time as above)
Data flow end	16 March 2022 NET 1500 UTC

Data Sharing

A number of laws, policies, international agreements, and partnership principles drive NOAA's general data sharing practices. Commercial data are an entirely new subset of the satellite data we collect and share, with unique considerations:

- The NOAA Commercial Space Policy states NOAA will negotiate the least restrictive terms possible, while evaluating data sharing on a case by case basis
- The Weather Act directs NOAA to adhere to existing international agreements in use of commercial data
- **World Meteorological Organization Resolution 40 sets the standard of full and open data sharing for global meteorological data (WMO currently updating Res 40 to address commercial data considerations)**

As other USG agencies and EUMETSAT begin commercial data purchases, interagency and international coordination on the sharing of commercial data purchased by each will be critical

- Agreement to share data purchased is the first step (requires paying higher price per observation, but allows collective buying and sharing)
- Need coordination to ensure partner buy different data, to maximize the impact on the global system
- **NOAA's next opportunity to set sharing standards is with DO-3 for this IDIQ contract (under development), and then the follow on to current operational RO data contracts in late 2022**

***Note:* NOAA is involved in interagency conversations examining the potential to standardize licensing tiers and definitions across the USG.**

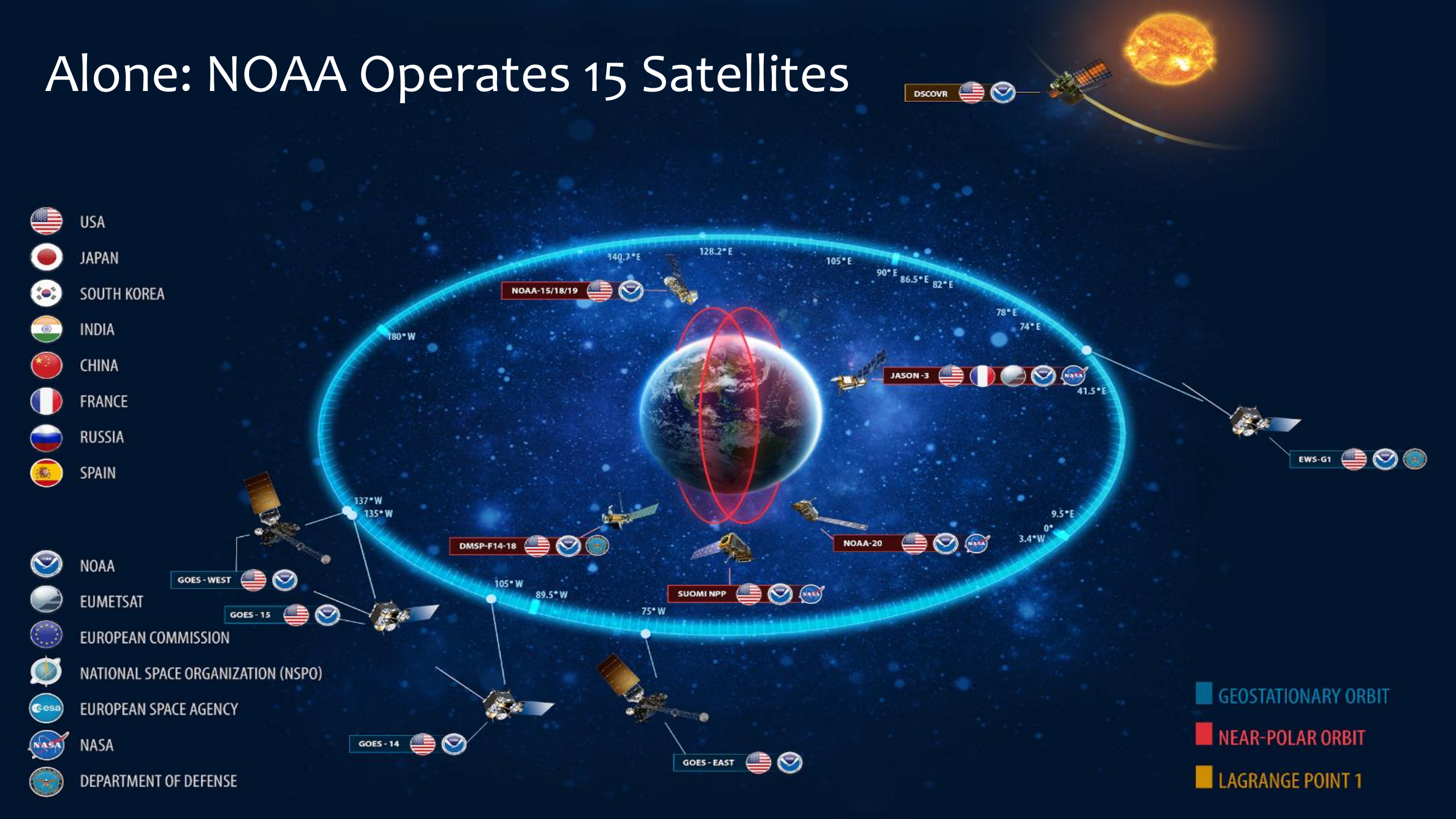
Data Sharing-2

In recent developments:

- CGMS WGII recommendations regarding RO data have further been defined:
  - WG II recommends that Agencies when pursuing data clearly define all aspects of the data, e.g., orbits and coverage, in order to optimize the benefits of the data.
  - WG II recommends that Agencies consider data buy with an option for redistributing data to global NWP centers.

Looking Forward

Alone: NOAA Operates 15 Satellites



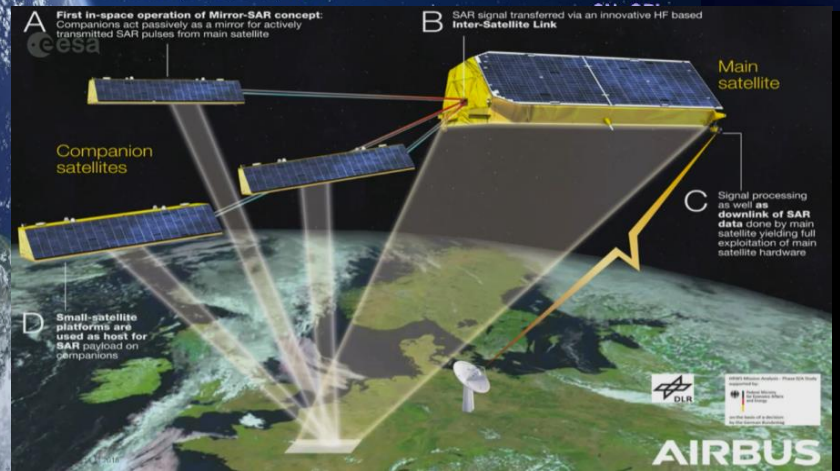
Together: We Form an International Community

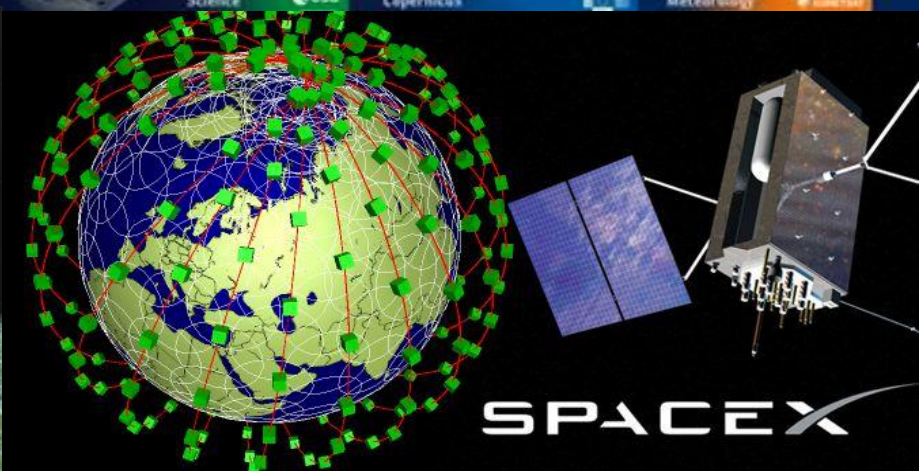
We Are In a Golden Age of Earth Observations

Plus EUMETSAT, JMA, Copernicus, and our WMO partners

Research

Commercial



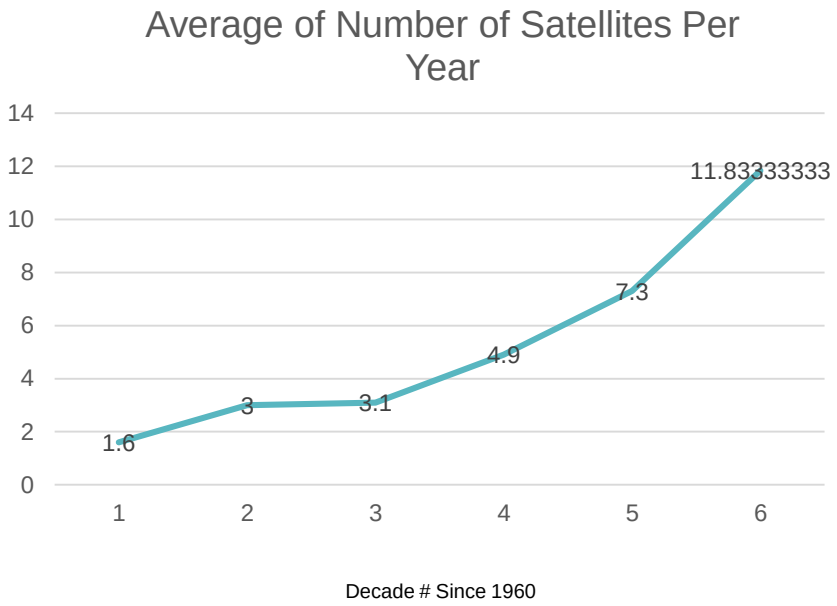


Increase in Space-Faring Nations

	1960-1970	1970-1980	1980-1990	1990-2000	2000-2010	2010-2016
US	16	26	14	14	20	13
Europe	0	1	3	7	11	9
Japan	0	1	4	4	6	4
Korea	0	0	0	1	2	5
India	0	0	4	13	10	9
China	0	0	1	3	11	16
France	0	0	1	3	4	4
Russia*	0	2	4	3	3	2
Germany	0	0	0	0	2	1
Algeria	0	0	0	0	1	3
Turkey	0	0	0	0	1	3
Brazil	0	0	0	1	2	2
Total	16	30	31	49	73	71

Source and credit: *World Meteorological Organization (WMO) Observing Systems Capability Analysis and Review (OSCAR) website. Mainly public-sector owned Earth-Observation satellites were included in these statistics*.*

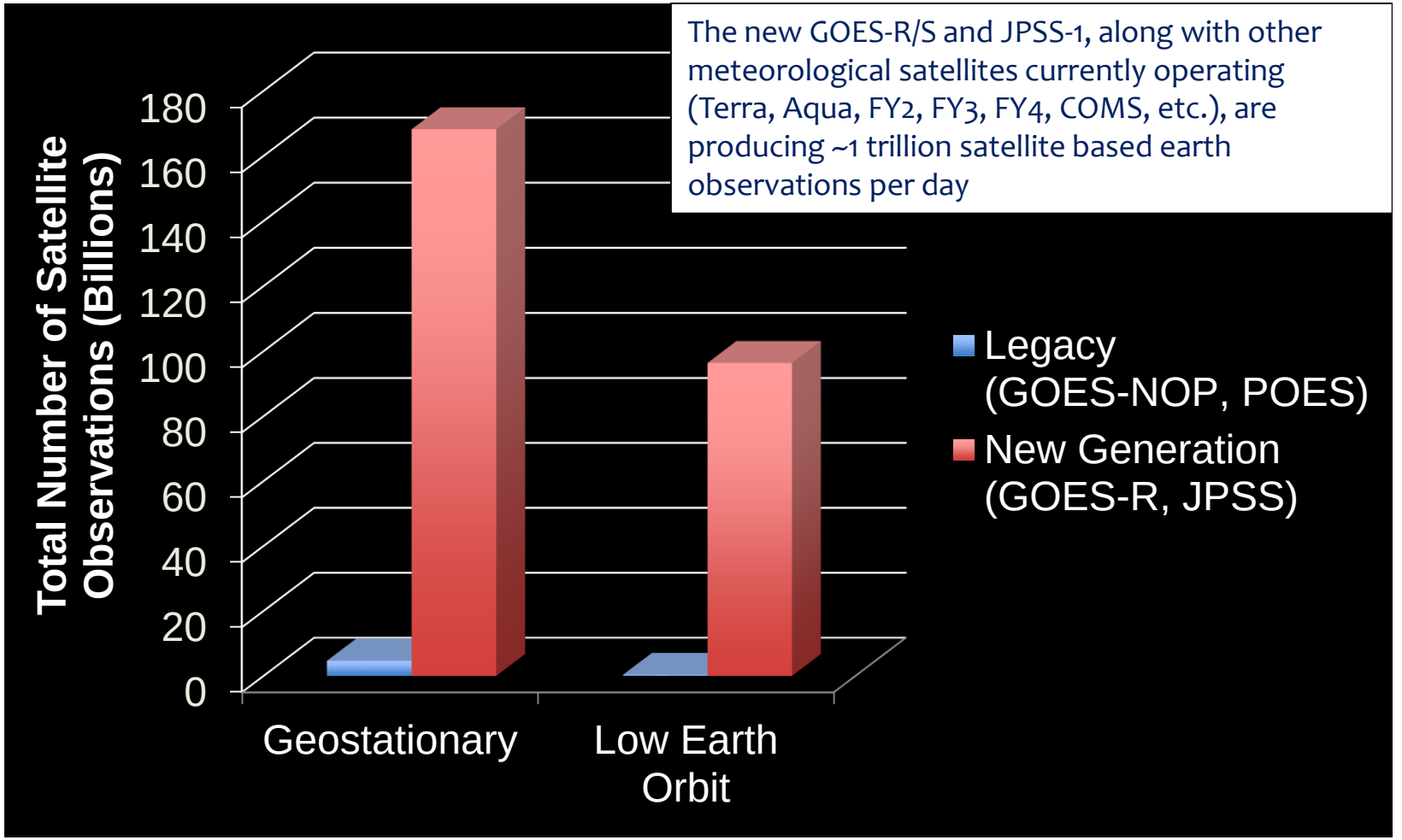
**Russia has launched a large number of short-lived satellites in the 1960's.*



We are in the Big Earth Data Era

We are already in the Big Earth data era.

This Big Earth data challenge will be exacerbated by the trend toward flotillas of Smallsats, IoT, commercial data, ridesharing, etc.



Major Factors Driving the Remote Sensing of the Future in NOAA

- Affordability of space access and New International Space-faring nations
- *International Vision of Satellite Remote Sensing Capabilities:* WMO WIGOS 2040 and CGMS Plans/Actions
- Emerging new opportunities (sensors, satellites) from international partners
- International Partnerships for a Global Observing Systems and the Data Sharing Principle Conundrum

International Drivers

Space Architecture Drivers

Remote Sensing Technique Trends

Evolution of NOAA's Satellite Remote Sensing

Major Factors Driving the Remote Sensing of the Future in NOAA

National Drivers

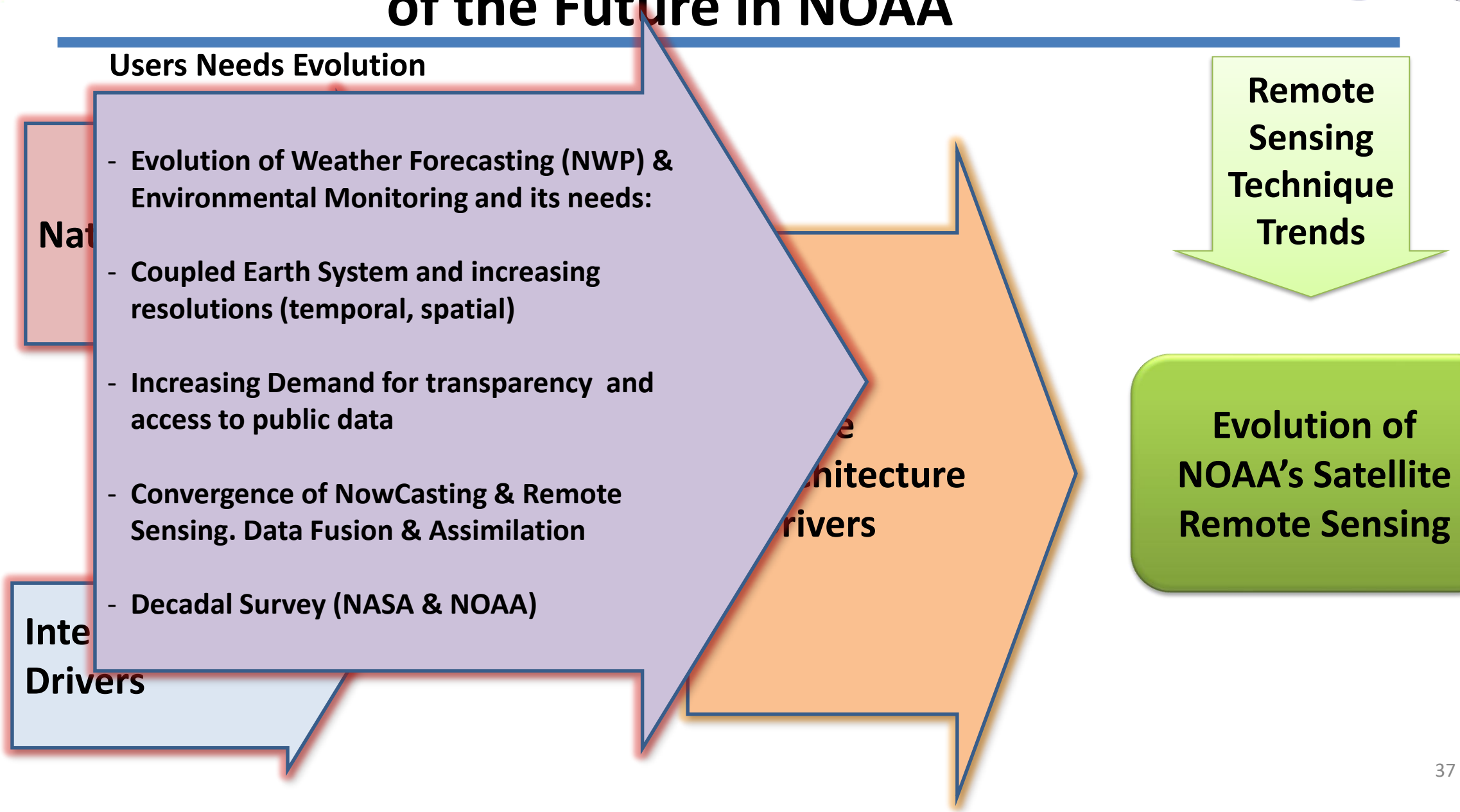
- Increasing Public Demand for Environmental data (for all applications)
- Pressure to Reduce Govt Expenditures
- Emergence of private Sector in Earth-Observation & Environmental Prediction
- Data volume explosion (Big Data)
- New areas of high interest (water, Arctic,..)
- Spectrum Interference (in the Microwave)
- Congressional weather Acts, Exec. Orders

Space Architecture Drivers

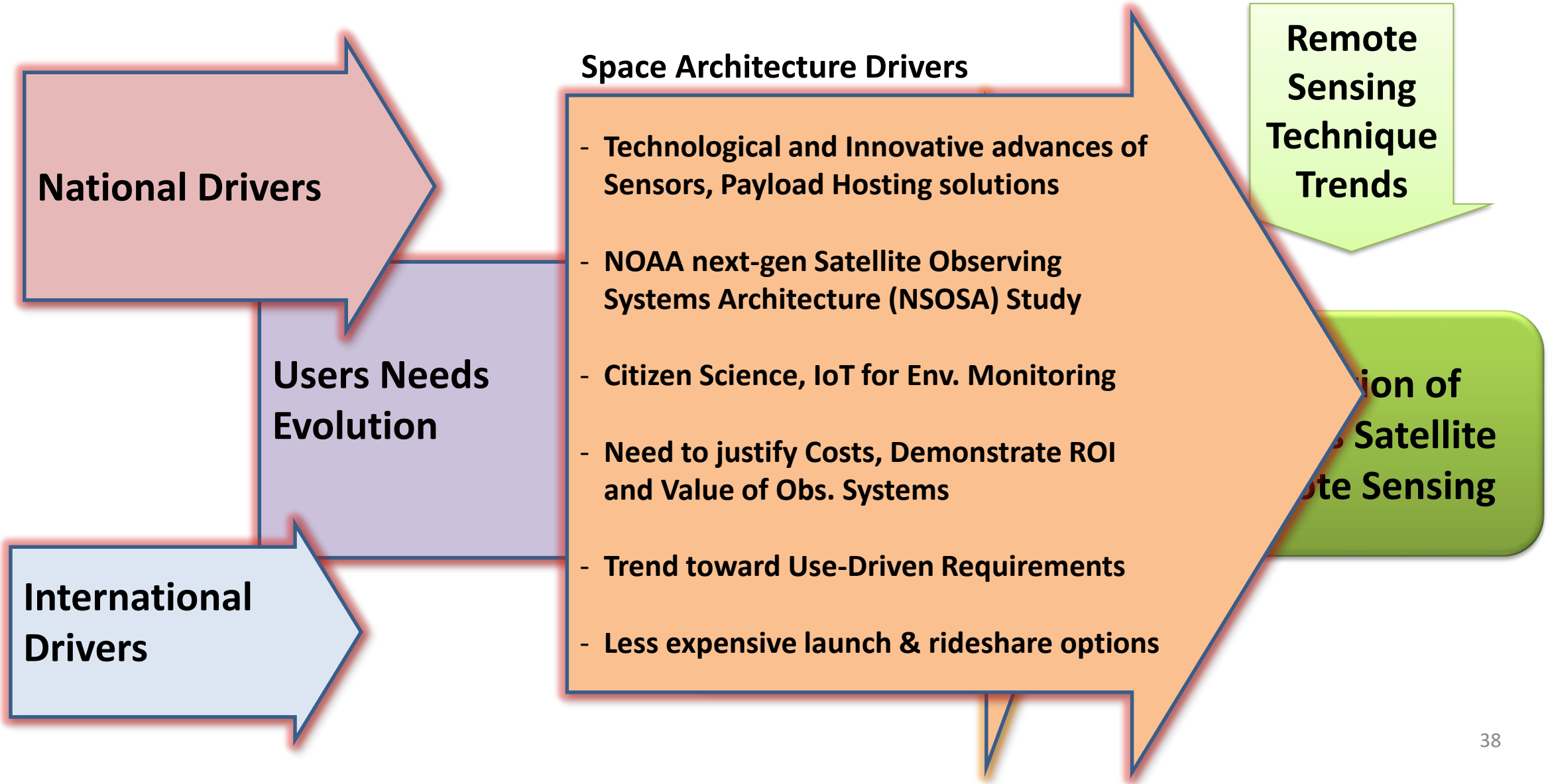
Remote Sensing Technique Trends

Evolution of NOAA's Satellite Remote Sensing

Major Factors Driving the Remote Sensing of the Future in NOAA



Major Factors Driving the Remote Sensing of the Future in NOAA



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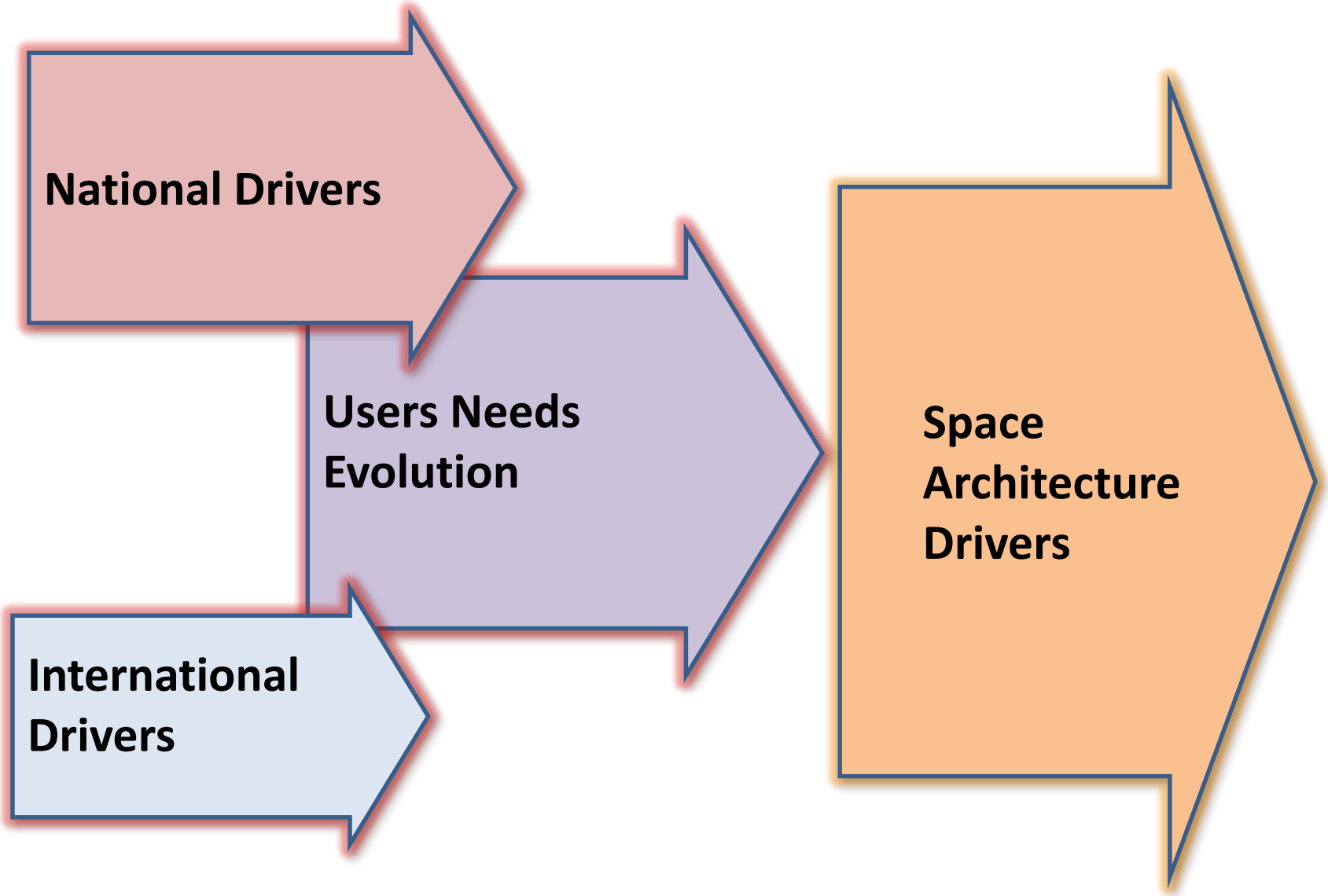


Trends in Global Earth Observation Systems

(Toward the Ability to Comprehensively sense the environment all the time, everywhere)

GOS Trends and Driving Factors:

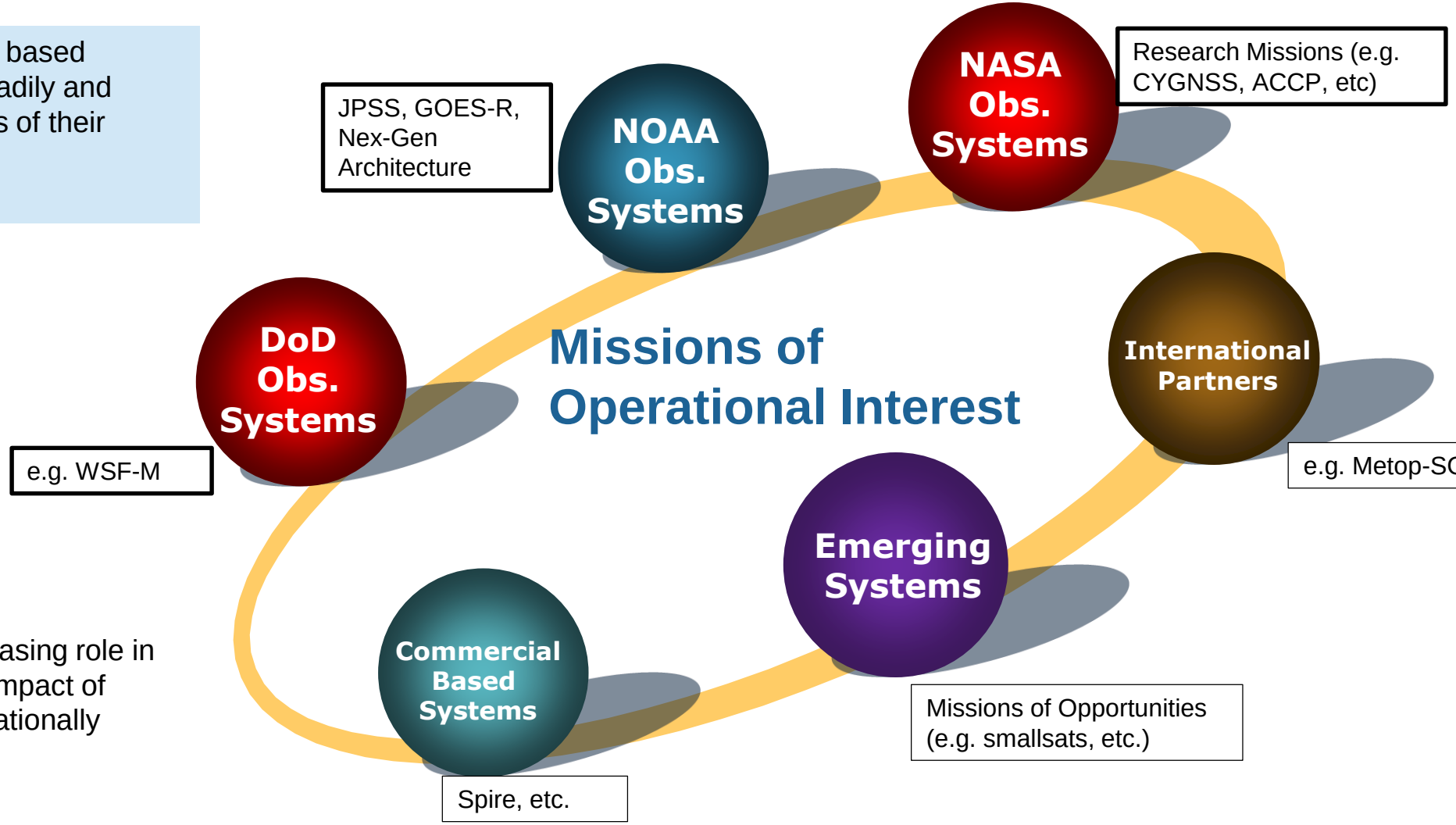
- New and Emerging Actors in Global Observing System
- New & enhanced Sensors (higher resolutions, higher SNR, etc.)
- New technology (smallsats, cubesats..)
- Emergence of potential new Payload hosting platforms (commercial, Near-Space platforms, rideshare, etc.)
- Increase in volume and diversity of data
- Commercialization of satellite data and new business models
- Spectrum challenges in the MW
- Risk due to Space Debris
- New sensing Technology : Hyperspectral MW, Wind Lidar, Polarimetric RO, Reflectometry, etc

Space agencies are making long-term plans. Similar to the Earth System model (ESM) approach (on the modeling and requirements side), the EOSC design and evolution is approached in a similar comprehensive, coordinated fashion (on the Observation side).

The Future of Exploiting Observing Systems

(Operational, Research, Commercial, International Partners)

In the future, data from new space based observing systems will be more readily and systematically ingested, regardless of their operational status



Remote Sensing will play an increasing role in the assessment of the value and impact of Satellite data to be exploited operationally (complement to OSSE)

Conclusions

- NESDIS is expanding partnerships to explore and initiate new space and ground capabilities:
  - GeoXO: Phase A studies of instruments.
  - LEO Program and Sounder Mission: Milestone-0 review completed March 10, 2021. Mission Concept Review in 2022
  - Collaboration with NASA, DOD, and Industry on Technology & Data Exploitation
  - Commercial RO Data Purchase: Operational use in NCEP Models in 2021
  - Ground Study: Developing our next-gen ground system. Design Cycle 1 completed in 2021
- The Earth-Observing Satellite Constellation (EOSC) is the Satellite-Observations equivalent of the Earth System Model
- EOSC is a global asset providing widespread benefits across many applications and with various societal benefits, including the protection of life and property.
- EOSC is a remarkable international success story that depended on effective collaboration and coordination of international partners and free and open exchange of critical environmental data.

Conclusions-2

- EOSC is a complementary, robust, complex and evolving system that observes the Earth's system components: atmosphere, oceans, land, space weather.
- EOSC is rapidly evolving with many factors driving it (technology, emerging data providers, commercial sector, new capabilities, etc.)

Thank you!

In case we don't have time for questions: please don't hesitate to reach me at:
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