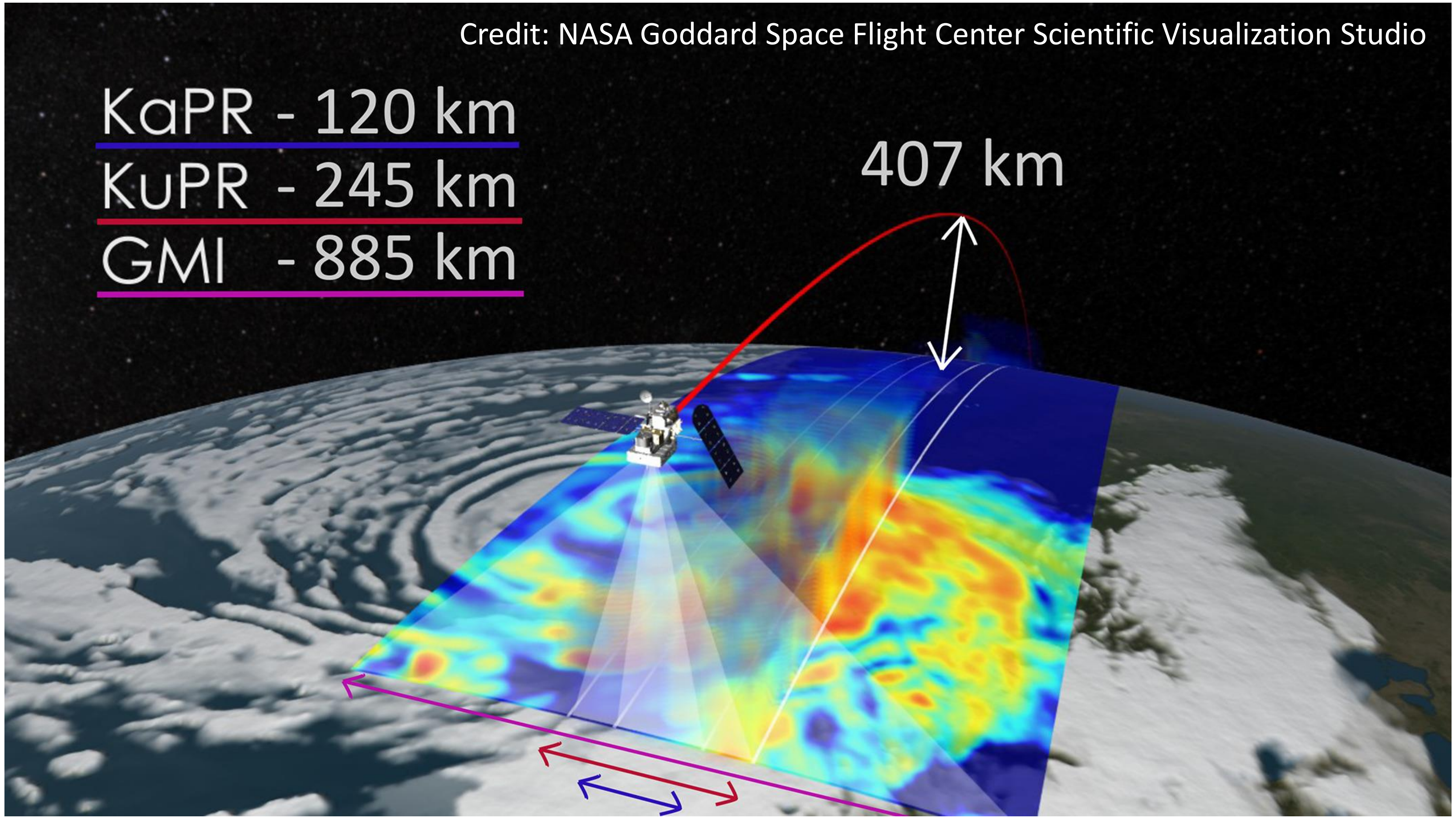


The GPM-CO measuring over a mid-latitude storm.

GPHS-426

Climatology and *Remote Sensing*

RS Lecture 4

18 January 2024

Remote Sensing (4 X 2-hour classes)

Lecturer: Yizhe Zhan

- Principles of satellite remote sensing (Wed 13 Dec 2023)
- Meteorological satellites (Tues 19 Dec 2023)
- Passive remote sensing instruments (Thurs 11 Jan 2024)
- **Active remote sensing instruments (Thurs 18 Jan 2024)**

For course material and hands-on session,

https://github.com/yzhan-met/GPHS-426_RS.git

For reach out for questions, my EDU email is yizhe@illinois.edu.

Outline

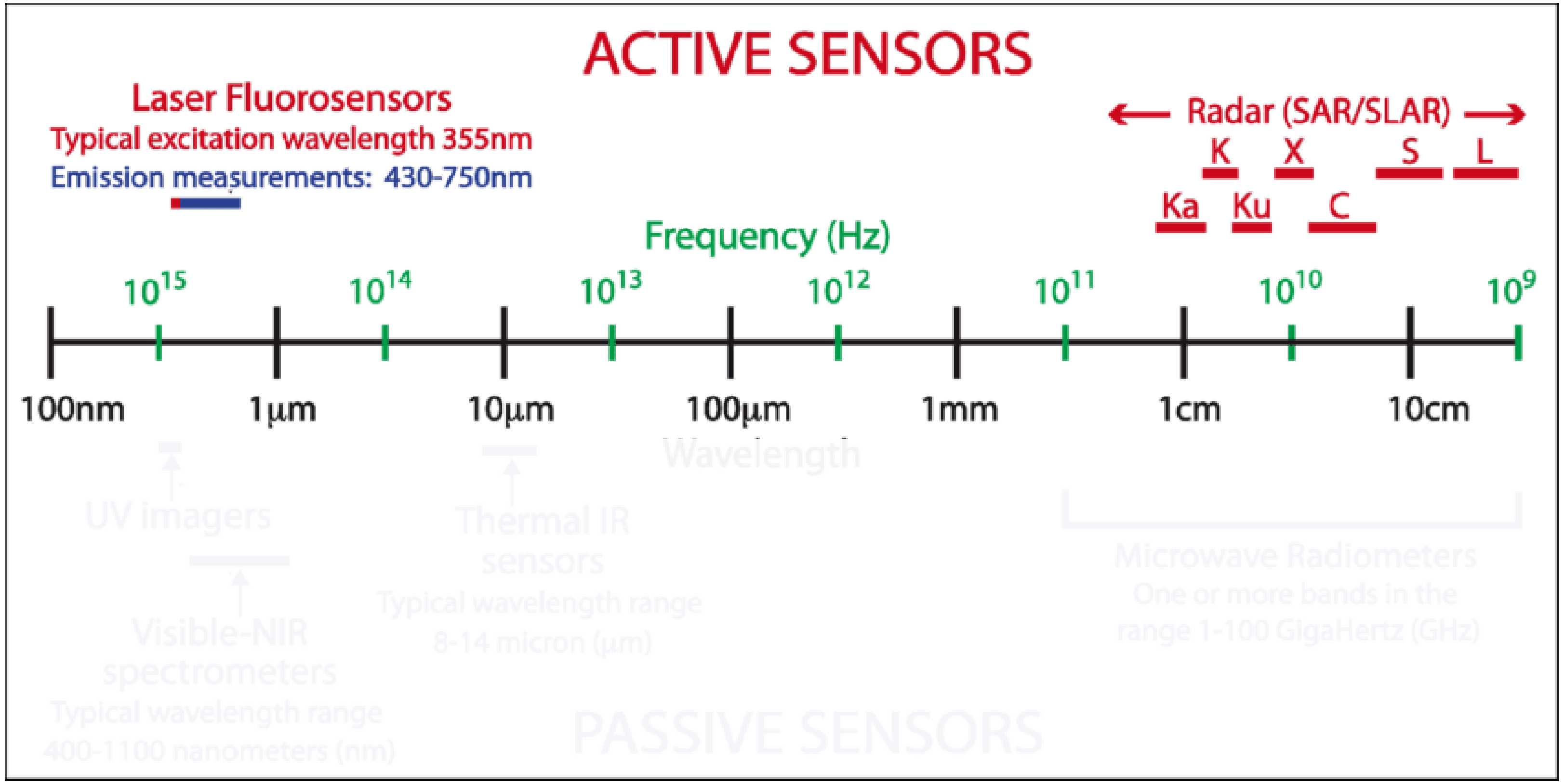
1. Active sensing instruments and products

Scatterometer
- Example instrument: ASCAT
- Example product: SSW

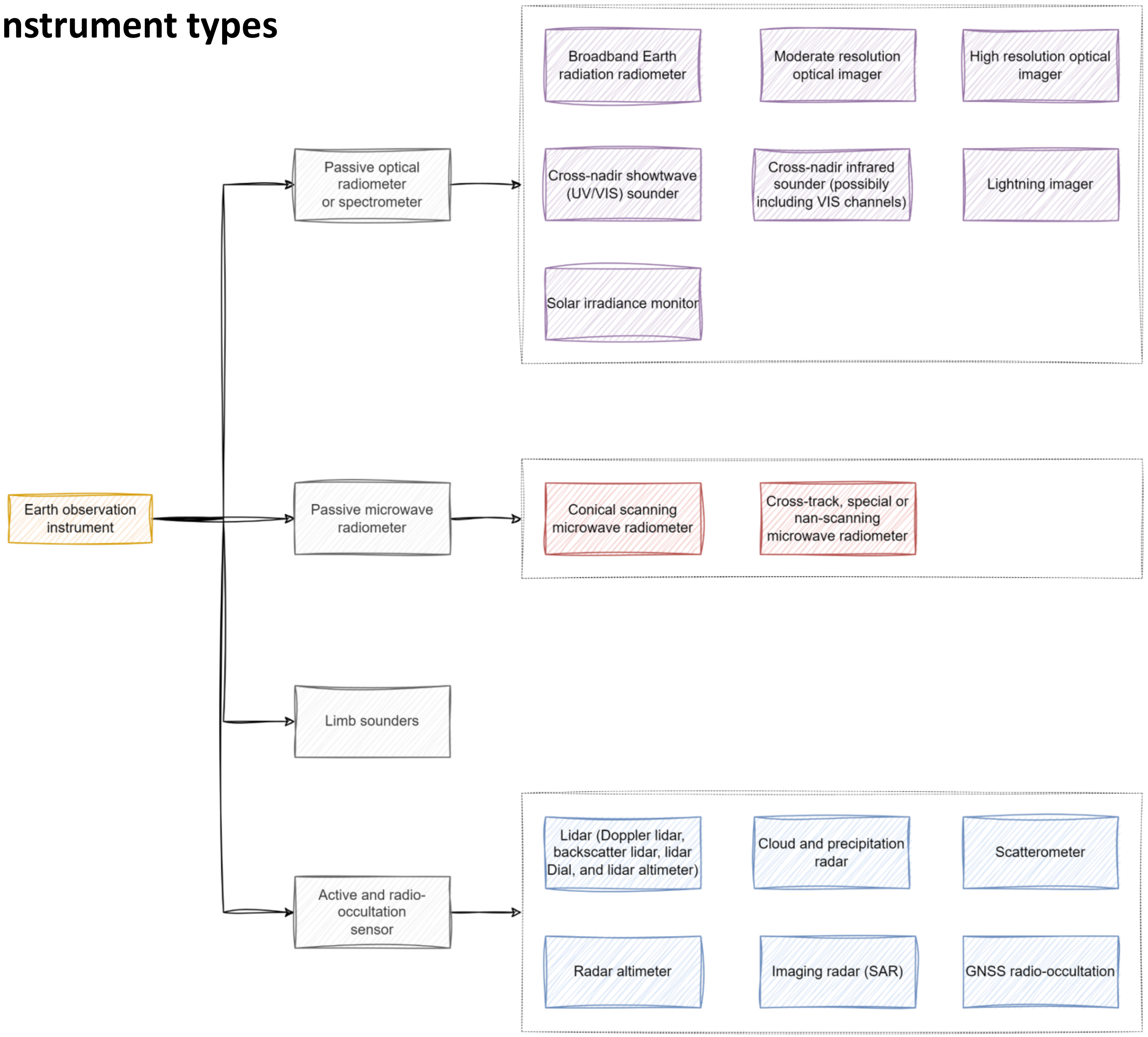
GNSS Radio Occultation
- Example instrument: TGRS
- Example product: temperature sounding

2. Future satellite programs

Remote sensing instruments (sensors)



Earth observation instrument types



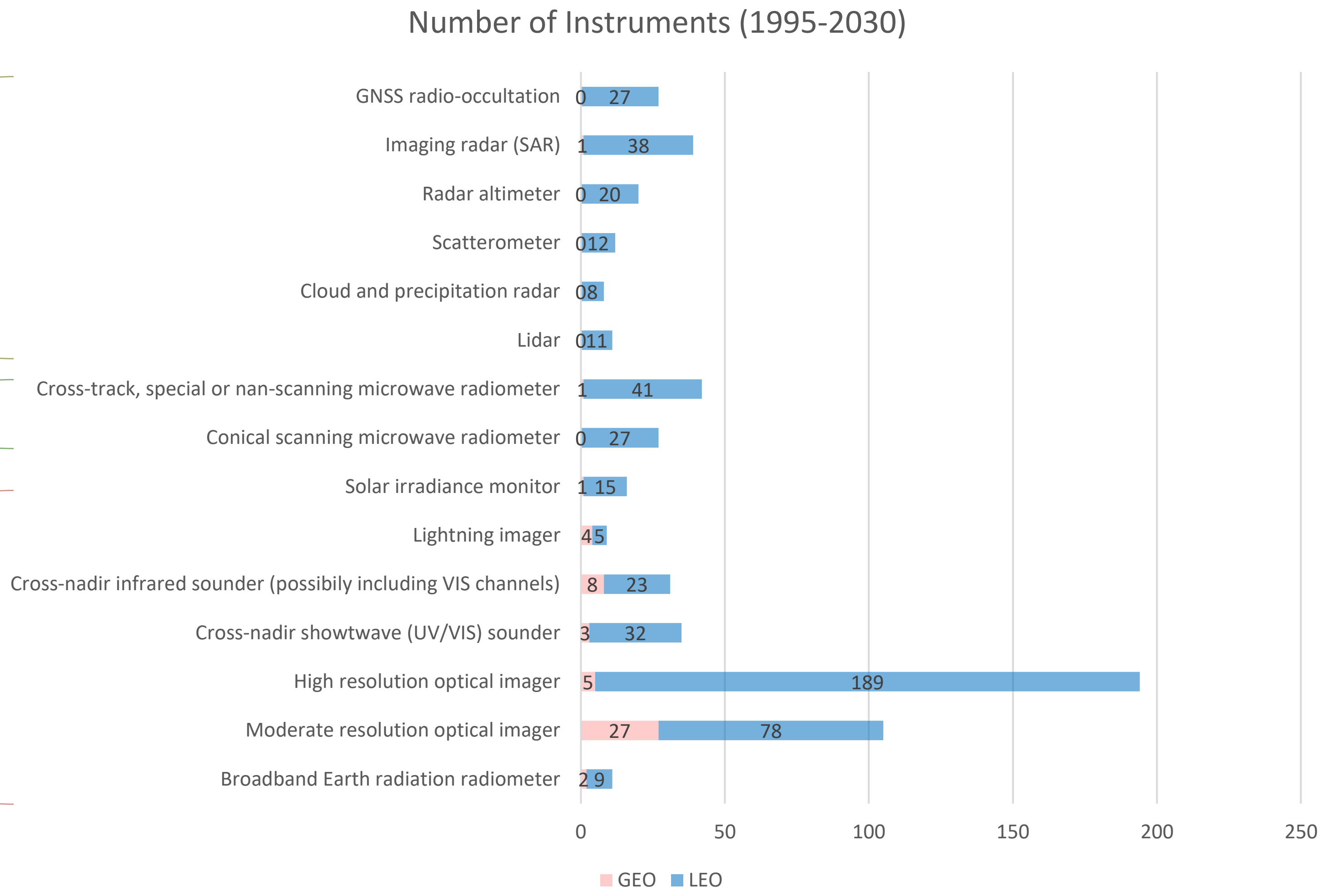
Data source: OSCAR

Earth observation instrument types (with examples)

Active and radio-occultation sensor

Passive microwave radiometer

Passive optical radiometer or spectrometer



Sentinel-6A: GNSS-RO
Sentinel-1A: SAR-C
Sentinel-3A: SRAL
Metop-C: ASCAT
CloudSat: CPR
CALIPSO: CALIOP
DMSP-F15: SSM/I
NOAA-17: AMSU-B
SORCE: TMI
GOES-17: GLM
Aqua: AIRS
Aura: OMI
Terra: ASTER
Himawari-9: AHI
Terra: CERES

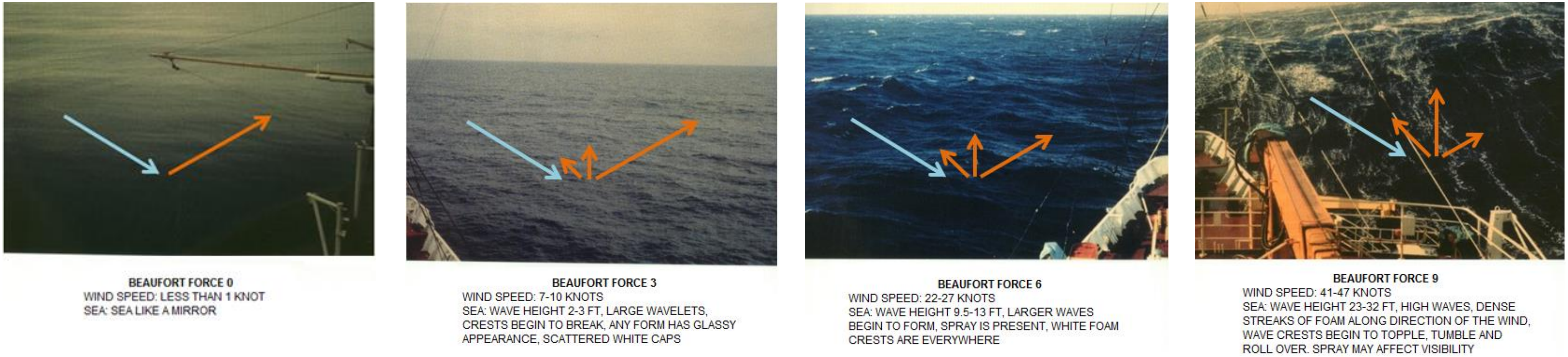
Data source: OSCAR

Scatterometer

Scatterometers are active remote sensing instruments for deriving wind direction and speed from the roughness of the sea. They transmit electromagnetic pulses and detect the backscattered signals.

Bragg scattering is a scattering mechanism that occurs when electromagnetic radiation and water waves interact with similar wave lengths. The Bragg scattering explains the effects of the reflection of electromagnetic waves on periodic structures whose distances are in the order of the wavelength.

Bragg scattering is dependent on the incident angle. Angles between 30° and 60° are often used to provide the largest sensitivity to changes in wind speed.



Bragg scattering in different Beaufort classes and therefore different states of the sea. Blue arrows show the incoming radar beam, red arrows the scattered radiation. (Credit: EUMETRAIN)

Scatterometer

Scatterometers measure the backscattered signal (radar cross section) by the ripples and waves. A Geophysical Model Function (GMF) is then used to retrieve surface wind from the roughness of the sea.

Given a radar beam with wavelength λ and polarization (ρ), the backscattered and normalized radiation (σ_o) depends on wind vector $\boldsymbol{v}$, the relative azimuth angle ϕ between instrument and wind direction, and the incidence angle θ.

$$\sigma_o(\boldsymbol{v}, \theta, \phi) = \frac{\text{received } power}{\text{transmitted } power}$$

$$\sigma_o(model) = \mathrm{GMF}(v, \theta, \phi, \mathrm{\rho}, \lambda)$$

A GMF predicts modeled backscatter measurements given a local wind field. In practice, a set of backscatter values is observed, from which the best estimate of the surface wind vector is estimated by minimizing a cost function,

$$\mathrm{MLE}(\boldsymbol{v}) = \sum_{\boldsymbol{i=1}}^{\boldsymbol{N}} \left(\frac{z_i^m - z_i^o}{k_p \left[\sum_{i=1}^{N} {z_i^o}^2\right]^{0.5}}\right)$$

where k_p is the normalization factor gives an estimate for the relative accuracy of the observation, given by Stoffelen and Anderson (1997a).

For example, for ASCAT, from triplets of observed backscatter measurements, inversion of a GMF allows for the estimation of the 10-m wind vector.

Scatterometer

Two types of scatterometers – C-band and Ku-band

	C-band	Ku-band
Frequency	5.255 GHz	13.4 GHz
Wavelength	5 cm	2 cm
Limitations	less detection in the higher wind range (> 60 kt), sea ice, coastal coverage - Land contamination	sensitive to rain, coastal coverage - Land contamination
Scatterometer	ASCAT-A and ASCAT-B	QuickScat/RapidSCAT/HY2A
Polarization	VV-pol	Dual-polarization
Sampling	12.5 – 25 km	25 – 50 km
Geometry	Static	Rotating antenna
Swath	Double (about 550 km each)	Single

Scatterometer – short history

C-band Ku-band scatterometer

Skylab (NASA)

1973 (exp)

SEASAT (NASA)

1978 (3 mon)

ERS-1 (ESA)

1991 – 2000

ERS-2 (ESA)

1995 – 2011

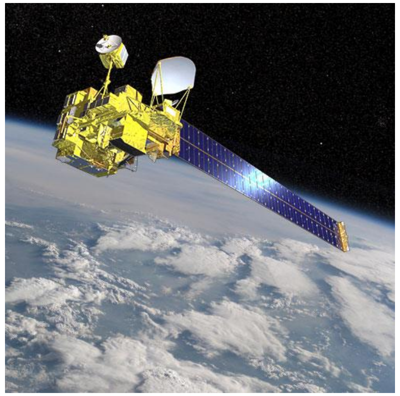
ADEOS-1 (NASDA/NASA)

1996 – 1997

Quickscat (NASA)

1999 – 2009

ADEOS-2 (NASDA/NASA)



2002 – 2003

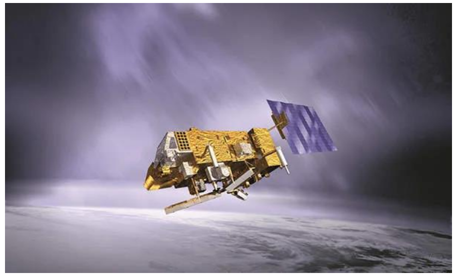
METOP-A (EUMETSAT)

2006 – 2021

Oceansat-2 (ISRO)

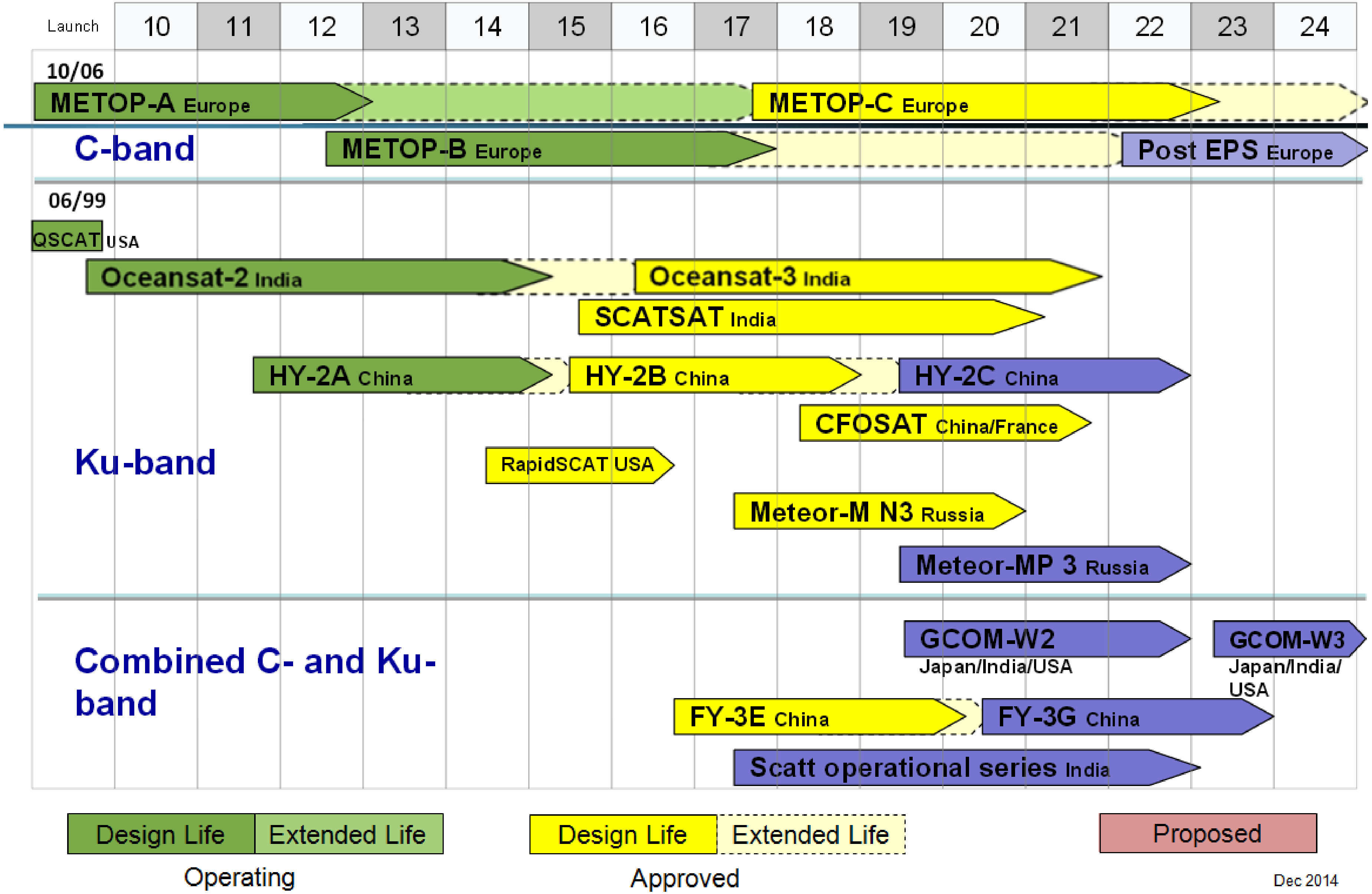
2009 – 2023

METOP-B (EUMETSAT)



2012 – now

Scatterometer – short history (continue)

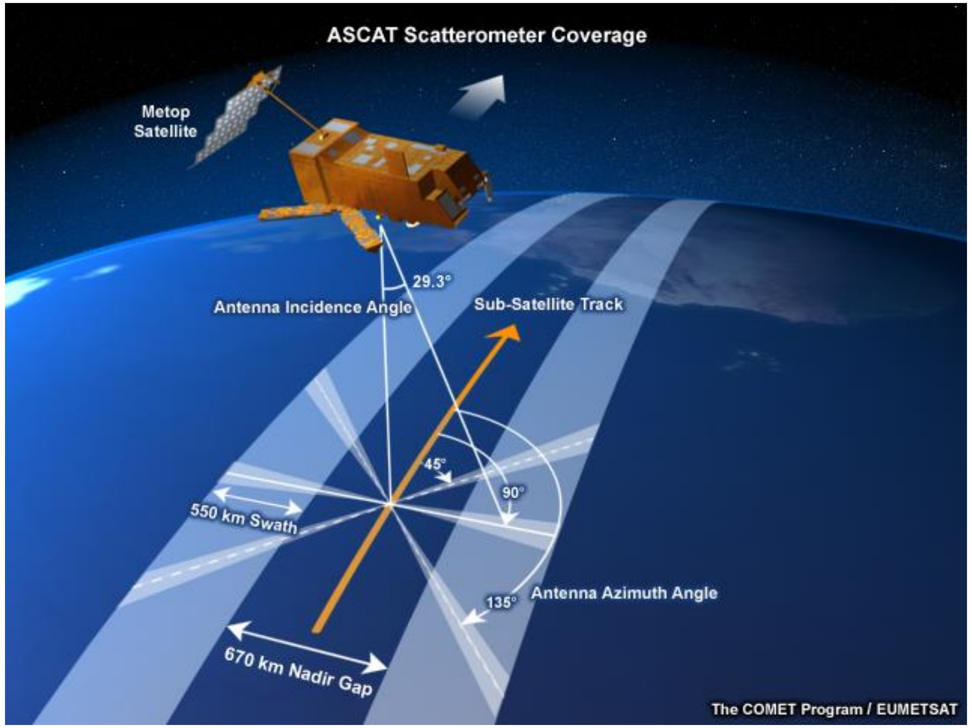


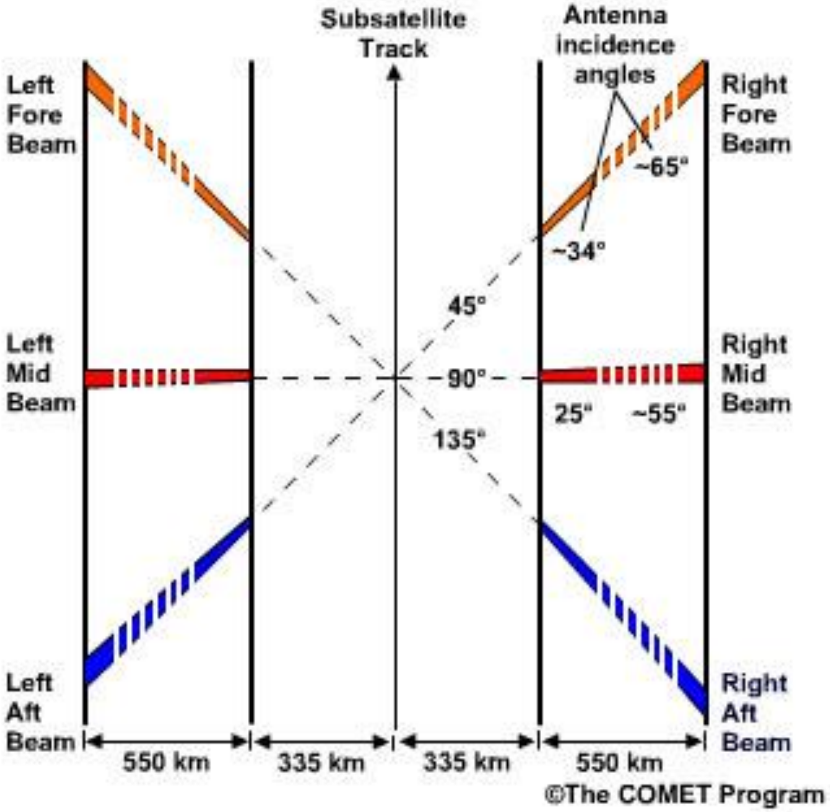
Scatterometer – ASCAT

ASCAT is a **fan beam scatterometer** – a radar with vertically polarized antennas (2 sets x 3). This configuration allows for each point of the surface is seen and measured by the scatterometer three times.

Each beam provides measurements of radar backscatter on a 12.5 km and/or 25 km grid, in such a way that each swath is divided into 41 (41*12.5) or 21 (21*25) so-called Wind Vector Cells (WVCs).

The ASCAT fan beam instrument operates at a frequency of 5.255 GHz (C-band). This makes it generally insensitive to rain, but C-band radars have limitations when it comes to extreme wind speeds larger than 60 knots.

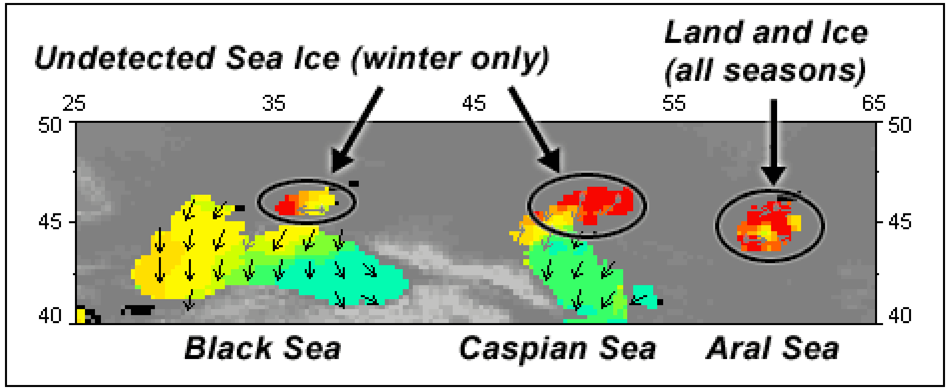


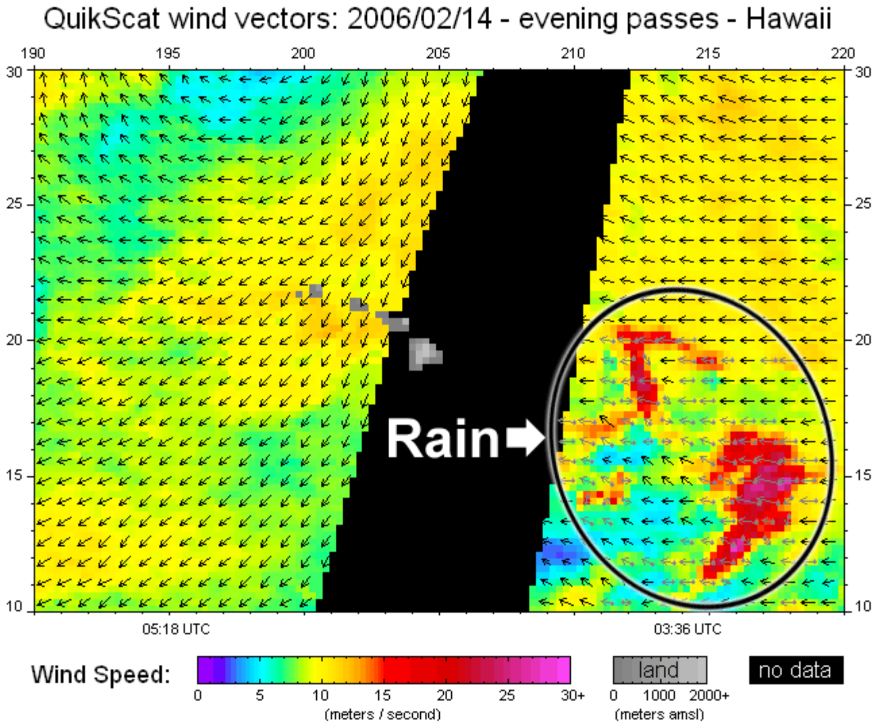


Scatterometer – Limitations

In general, the quality of scatterometer winds is quite good. But there are some situations where the data can be compromised:

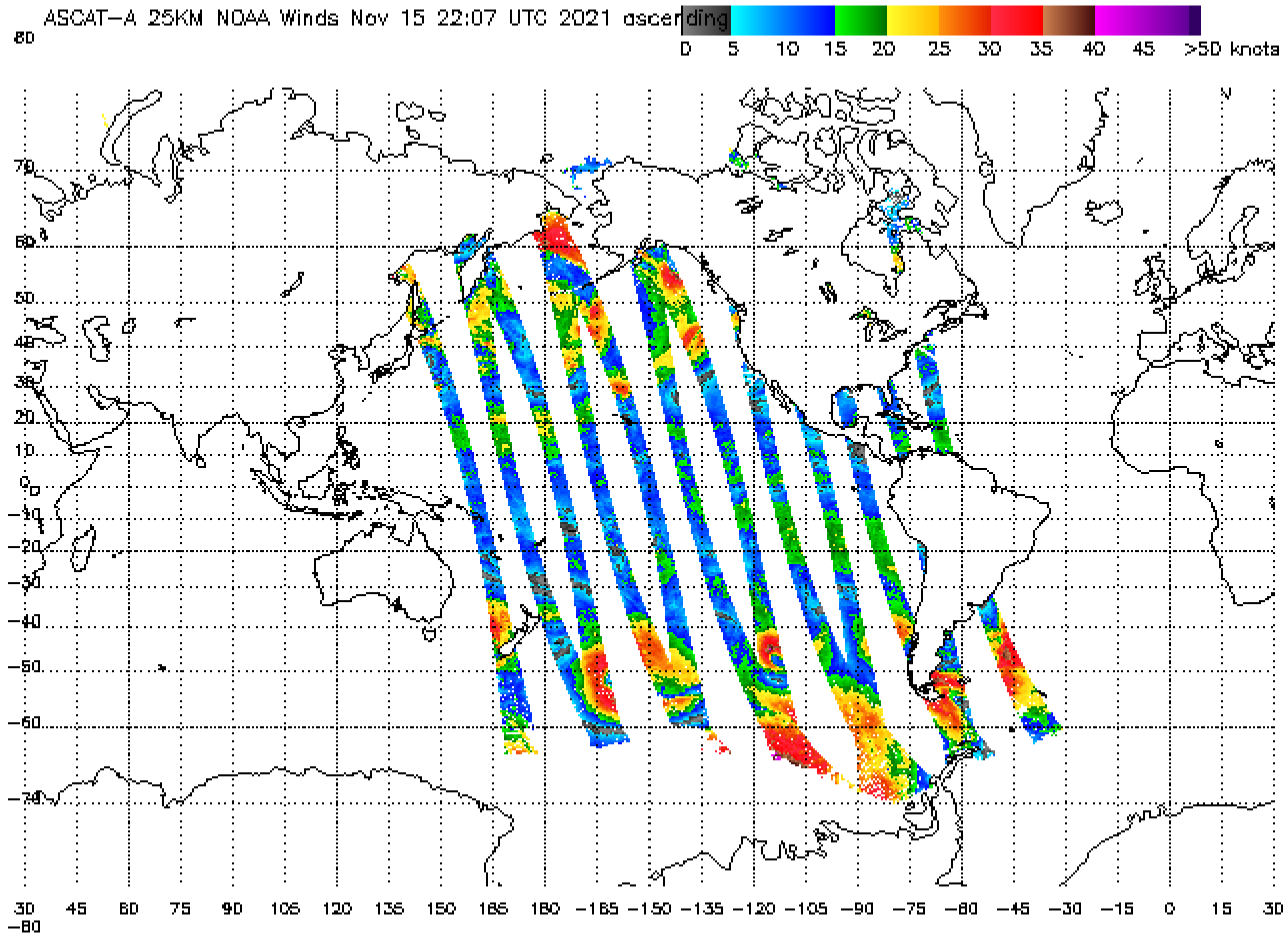
- sea ice and land contamination
- large spatial wind variability (for example in the vicinity of fronts and low pressure centers, e.g. downbursts)
- rain - especially in Ku-band systems
- higher wind speeds (>60 knots) - especially in C-band systems

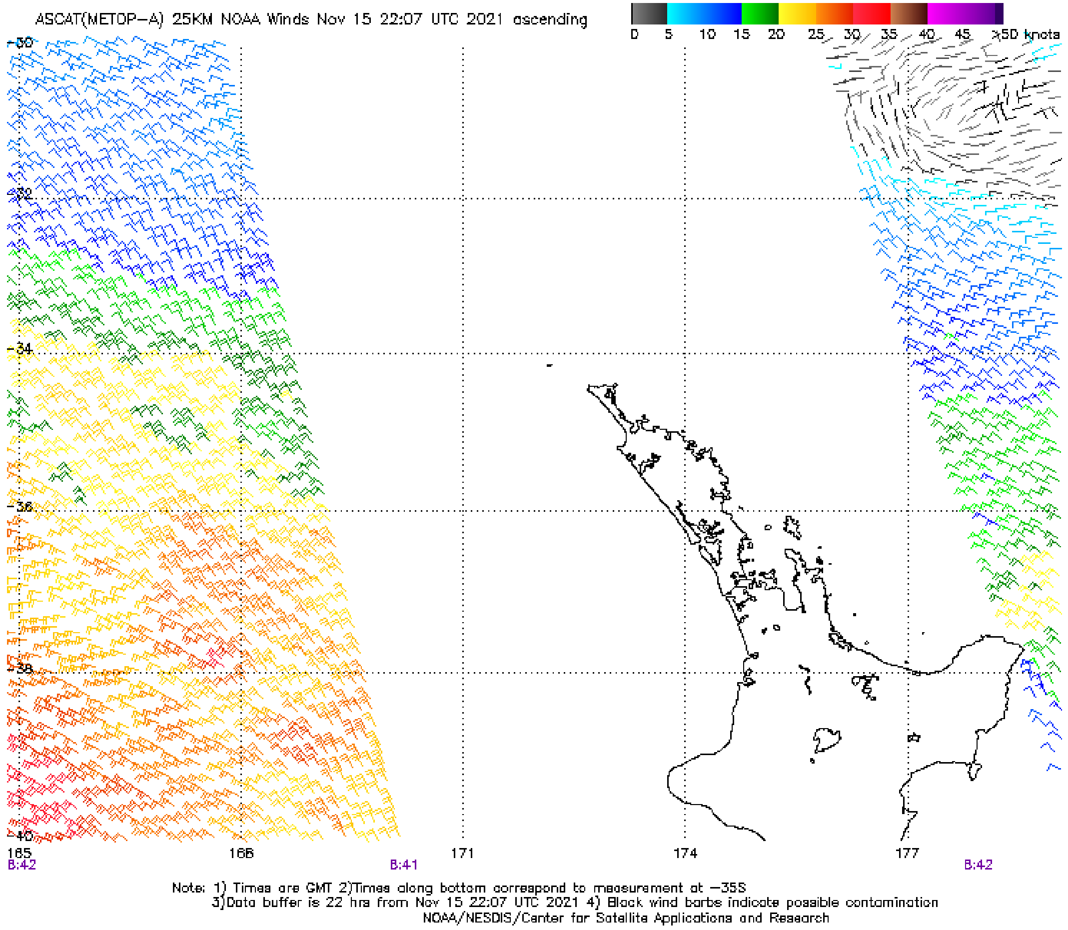




Scatterometer – Product

https://manati.star.nesdis.noaa.gov/datasets/ASCATData.php





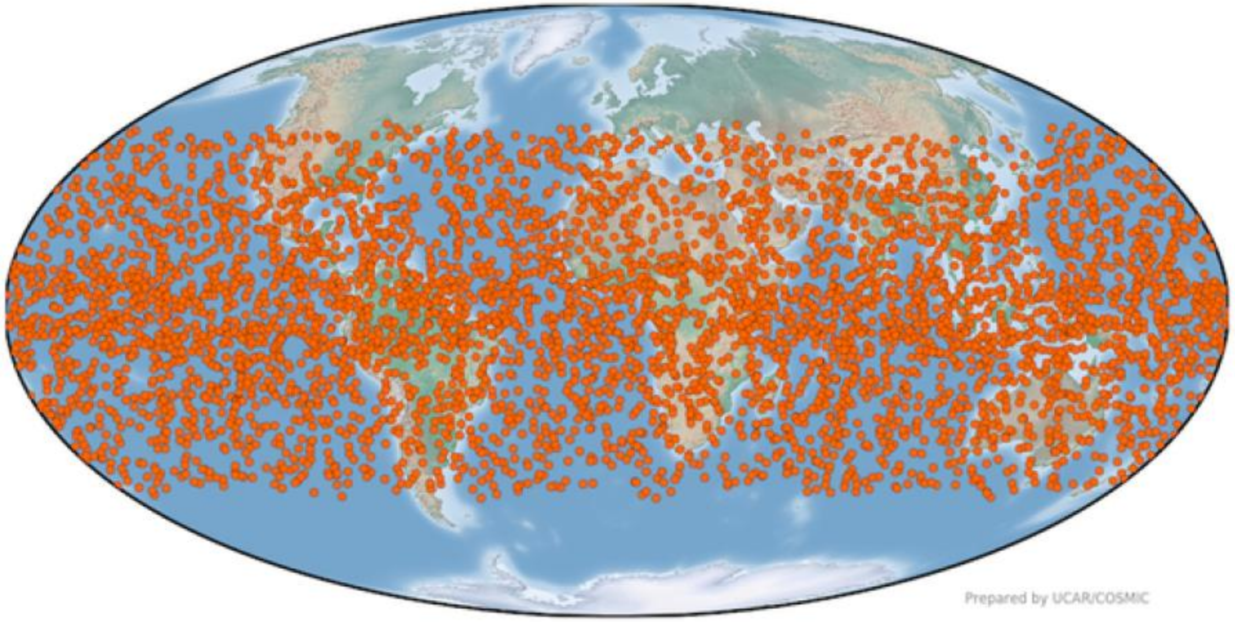
GNSS Radio Occultation

The Global Navigation Satellite System - Radio Occultation is a satellite remote sensing technique that uses GNSS (e.g., GPS) measurements received by a LEO satellite to profile the Earth's atmosphere and ionosphere with high vertical resolution and global coverage.

As radio signals from the GPS satellites (~20,200 km) pass through the atmosphere, molecules and electrons bend their paths and slow their progress. By intercepting the radio signals and measuring their bending and **signal delay** on LEO satellites (~500 km), scientists are able to retrieve profiles of bending angles, refractivity, temperature, pressure, and water vapor in the atmosphere and of electron density in the ionosphere.

Advantages of RO:

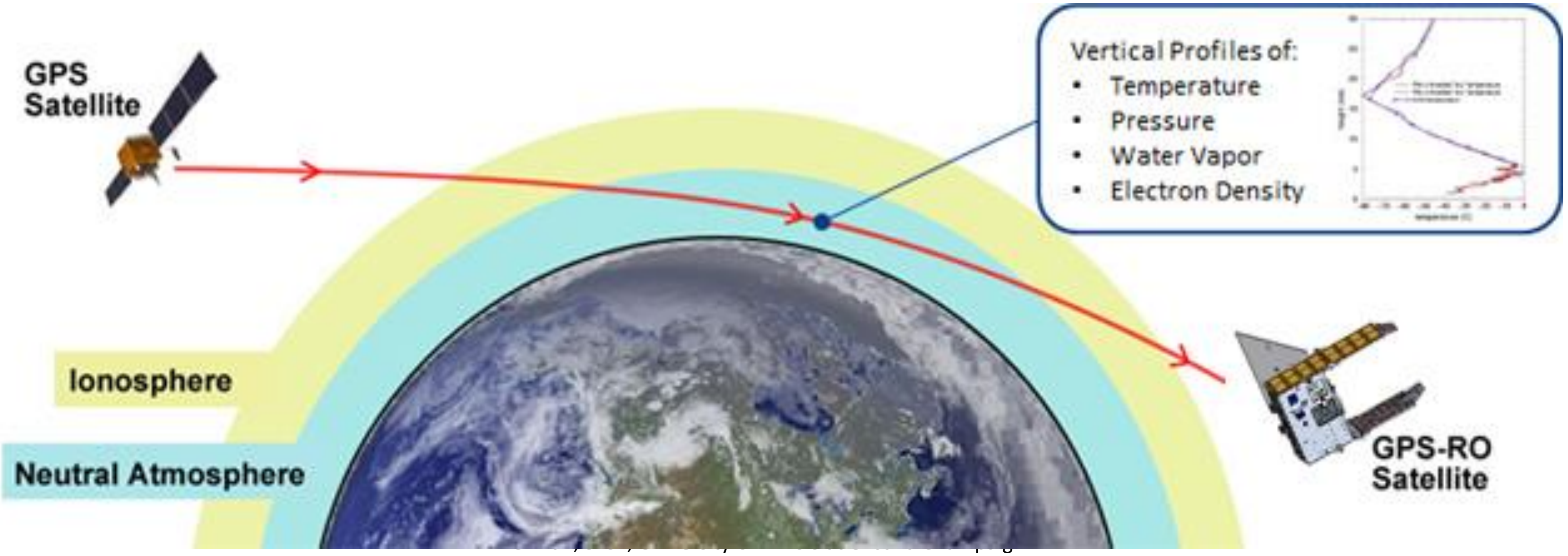
- More accurate forecasts of day-to-day weather
- More accurate hurricane forecasts at longer lead times
- More accurate predictions of heavy-precipitation events
- Improved climate monitoring and research
- Increased data collection over oceans
- Improved space weather forecasts



Geographic coverage provided by COSMIC-2 on October 1, 2019

GNSS Radio Occultation

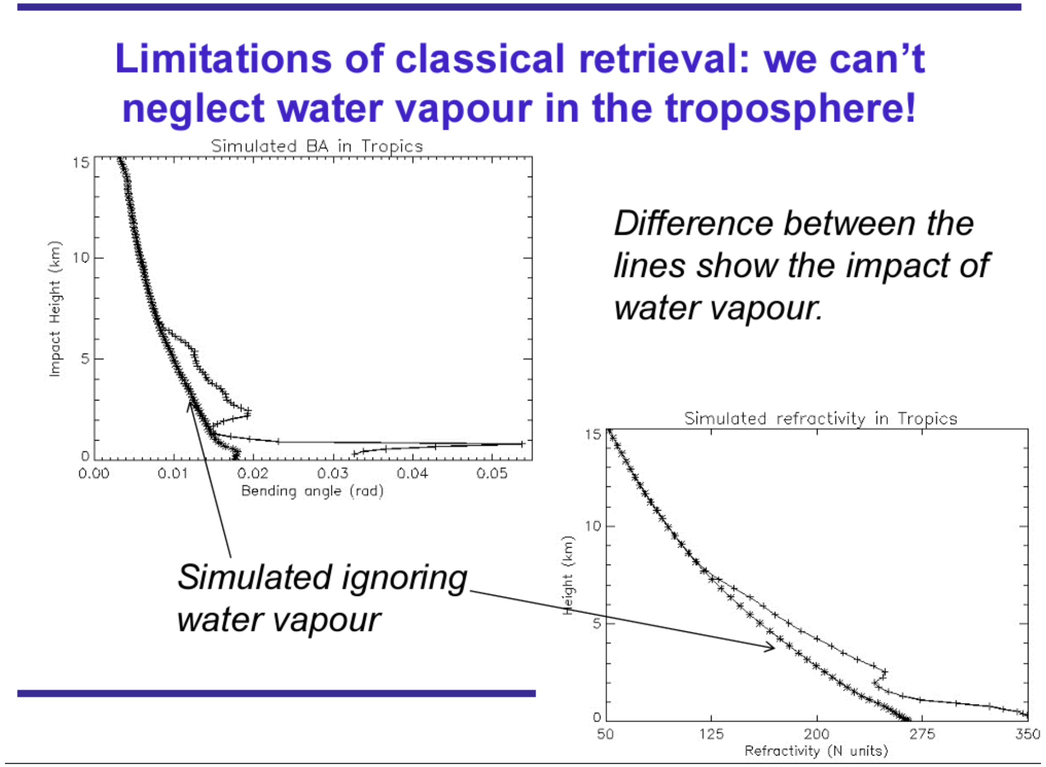
- RO is an active technique and measurements have been used to study planetary atmospheres (e.g., Mars, Venus) since the 1960’s.
- The use of RO measurements in the Earth’s atmosphere was originally proposed in 1965, but until 1996, the proof of concept “GPS/MET” experiment demonstrated useful temperature information could be derived from the GPS RO measurements.
- The GPS satellites are primarily a tool for positioning and navigation. These satellites emit radio signals at L1 (1.575 GHz) and L2 (1.227 GHz).
- Because the refractive index is not unity, the GPS signal velocity is modified in the ionosphere and neutral atmosphere. The gradients in the refractive index also “bend” the path.
- The GPS RO is then based on analysing the bending caused the neutral atmosphere along ray paths between a GPS satellite and a receiver placed on a LEO satellite.



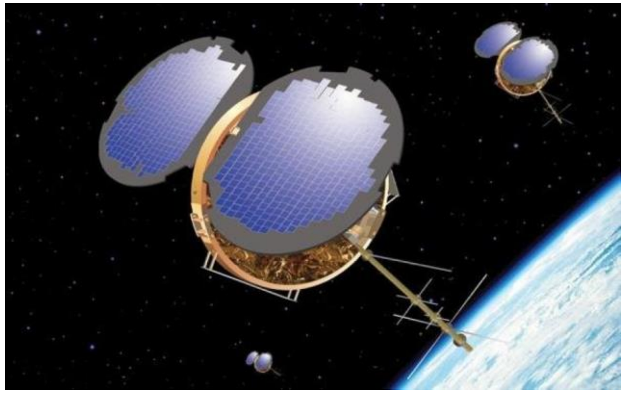
GNSS Radio Occultation

- GPS receivers do not measure bending angle directly.
- Instead, it measures a time series of phase-delays at the two GPS frequencies.
- The accumulated bending angle can be calculated from precise orbit data and the excess phase measurements.
- The bending angle profile can in turn be converted to a refractivity profile using an Abel integration.
- In dry air conditions, atmospheric temperature, pressure, and density profiles can then be retrieved using a refractivity equation, hydrostatic integral, and ideal gas law.
- In moist air conditions, we would expect a T-H ambiguity problem results from moisture's impact on refractivity. Various methods have been proposed to minimize the uncertainty (e.g., Li et al., 2019).

$$N = 77.6\,\frac{P}{T} + 3.73 \times 10^5\,\frac{e}{T^2}$$



COSMIC-1 (2006 – 2020) and COSMIC-2 (2019 – now)



FORMOSAT-3/COSMIC was launched into a circular low-Earth orbit in 2006 and retired in 2020.

The data from COSMIC-1 have contributed significantly to a wide range of scientific investigation. For example,

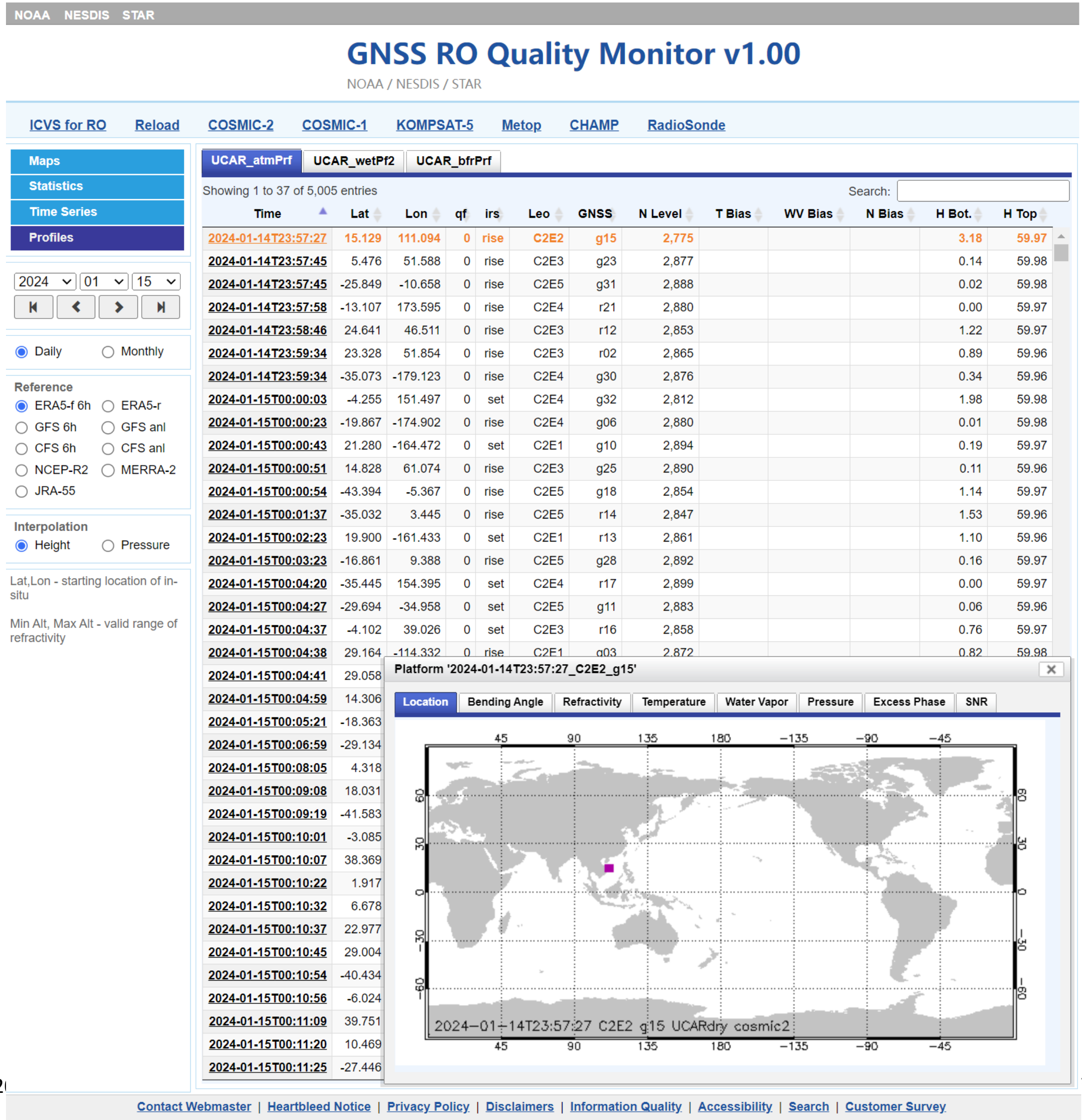
1. The data set has led to improved global weather forecasting, especially in data sparse regions including the oceans and near the poles.
2. It has established a global climate change "thermometer" which has unprecedented long-term stability.

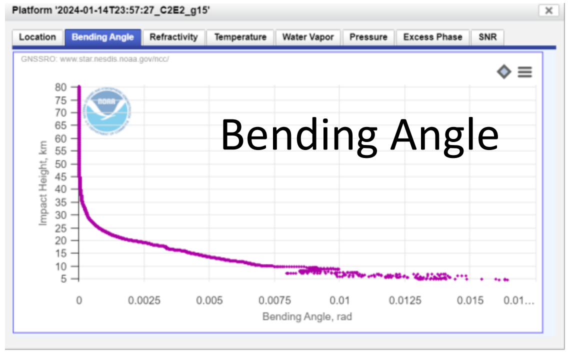
The success of COSMIC-1 leads to a follow-on GNSS-RO mission (COSMIC-2) - six COSMIC-2 satellites launched in 2019 into low-inclination orbits.

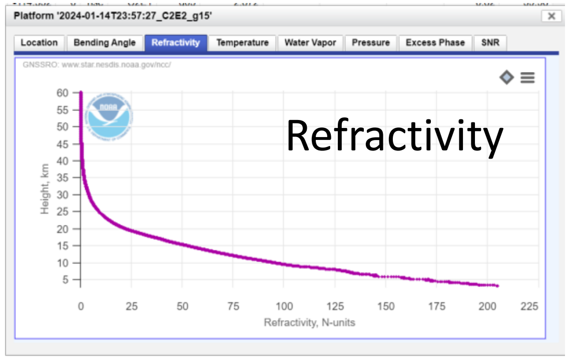
The main instrument, TGRS (Tri-GNSS Radio-occultation system), was developed by JPL and is tracking more than 4,000 high-quality profiles per day.

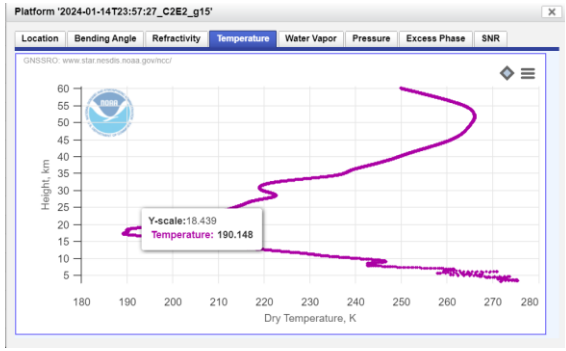
With a 24-degree inclination orbit at 720 km altitude, COSMIC-2 occultations primarily distribute from 45 N and 45 S.

GNSS RO data

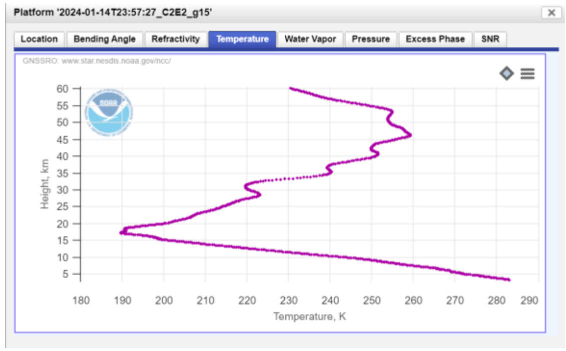




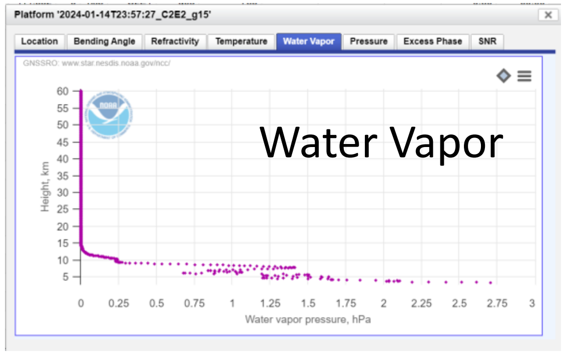




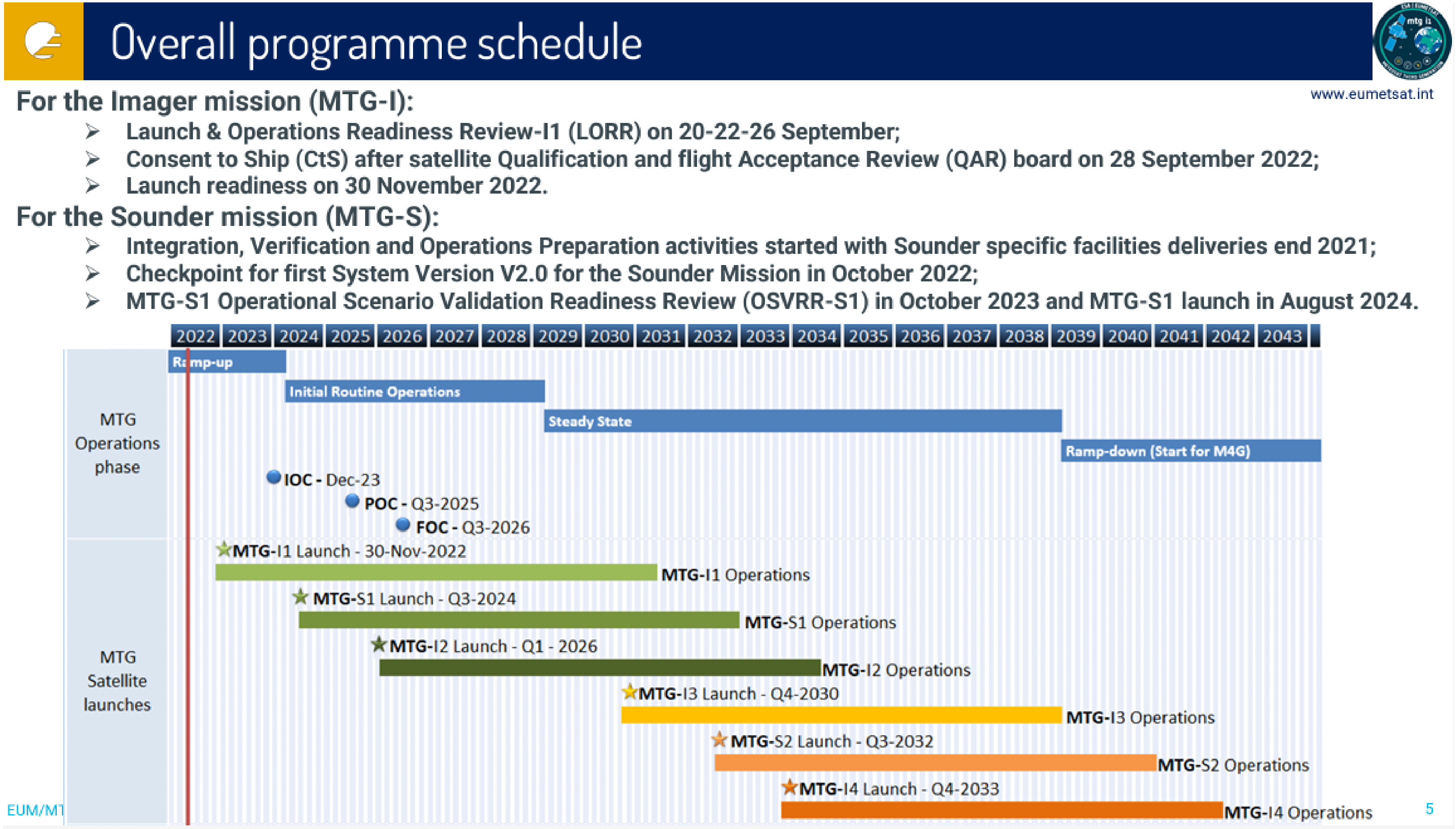
Temperature profile (dry air)



Temperature profile

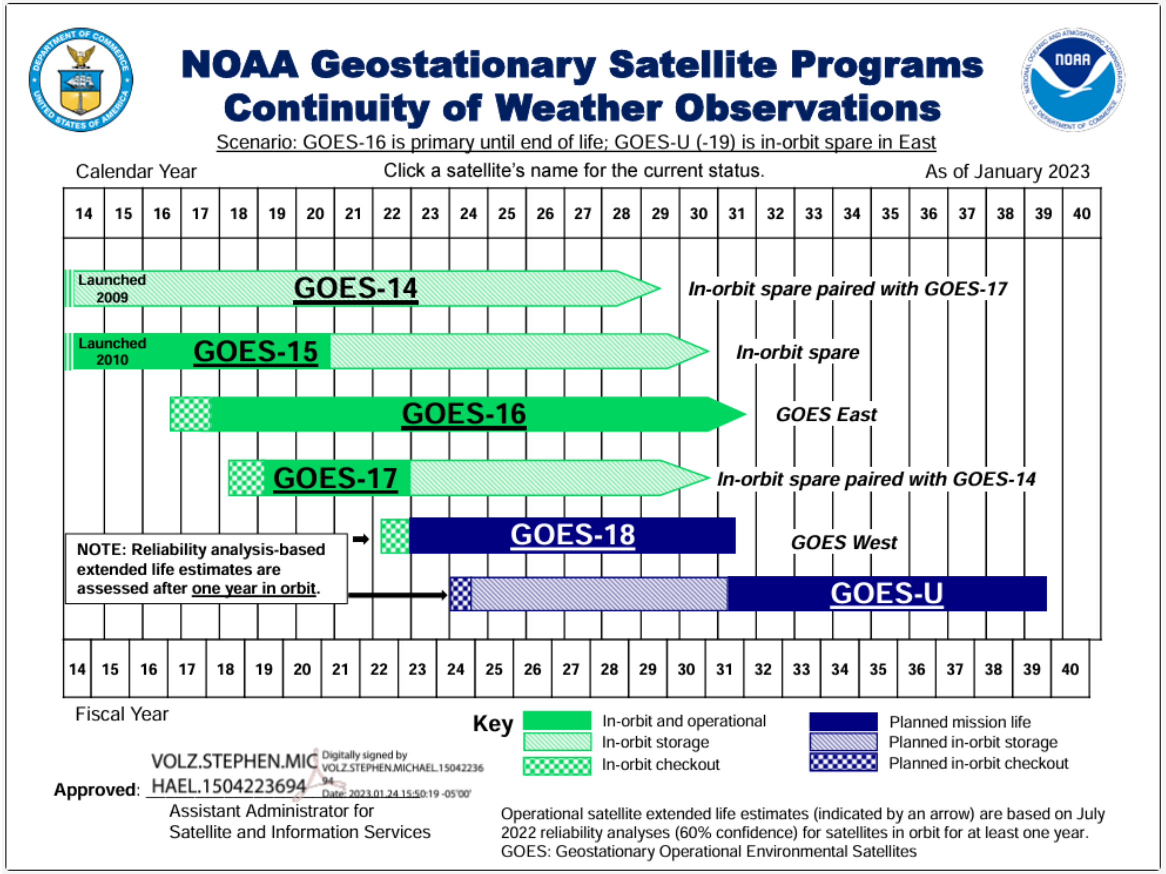


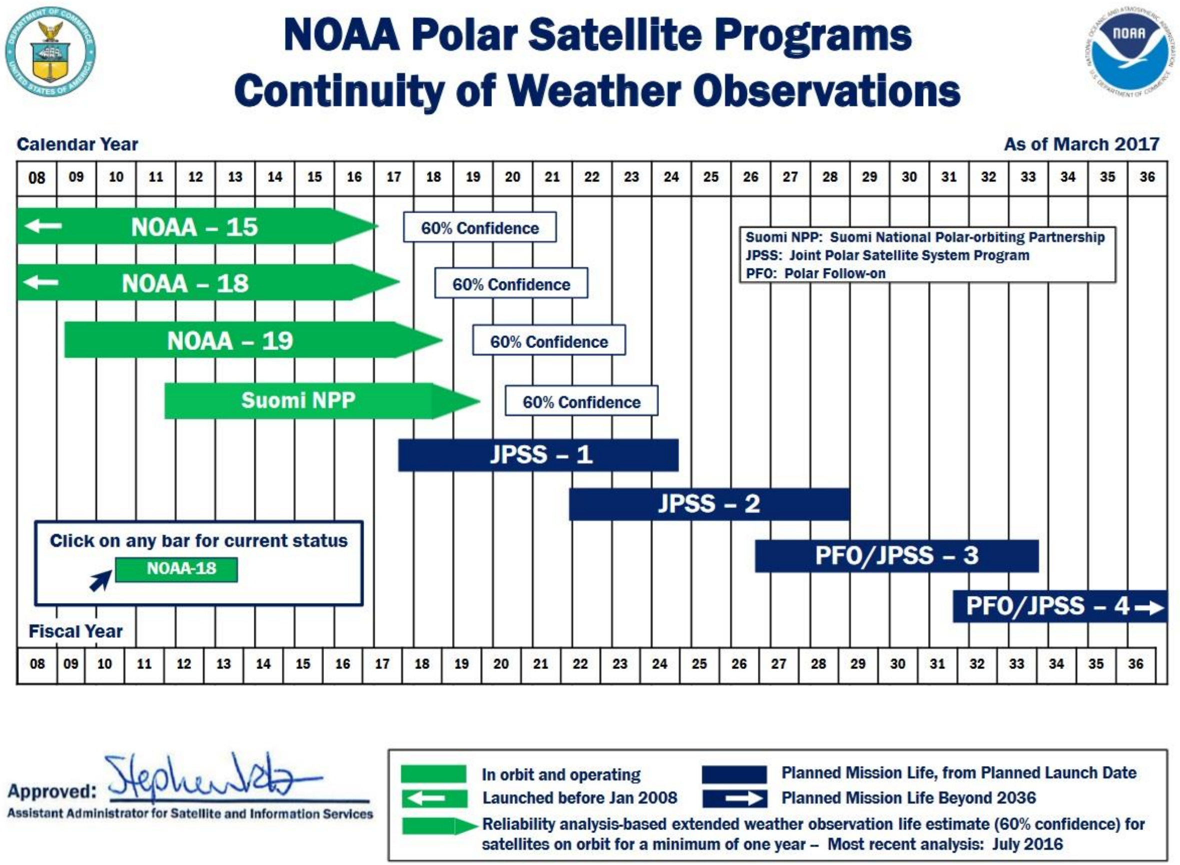
EUMETSAT



https://www.eumetsat.int/planned-launches

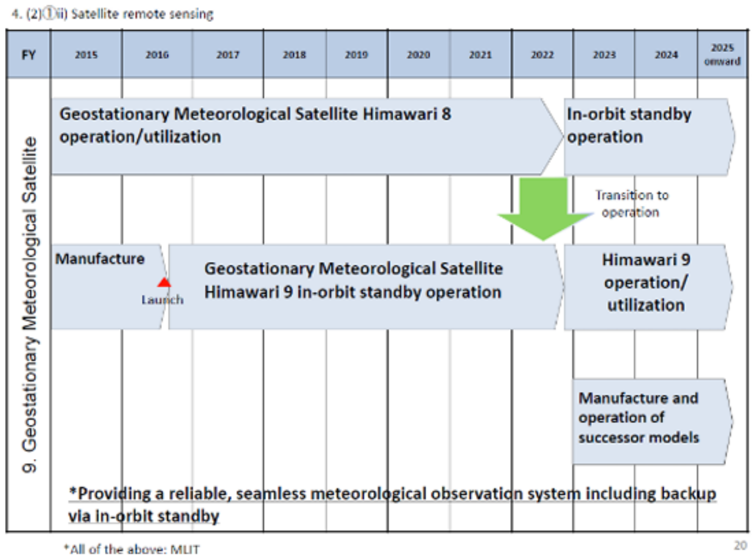
NOAA


NOAA Geostationary Satellite Programs
Continuity of Weather Observations
Scenario: GOES-16 is primary until end of life; GOES-U (-19) is in-orbit spare in East
Calendar Year
Click a satellite's name for the current status.
As of January 2023
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Launched 2009
GOES-14
In-orbit spare paired with GOES-17
Launched 2010
GOES-15
In-orbit spare
GOES-16
GOES East
GOES-17
In-orbit spare paired with GOES-14
GOES-18
GOES West
NOTE: Reliability analysis-based extended life estimates are assessed after one year in orbit.
GOES-U
Fiscal Year
Key
In-orbit and operational
In-orbit storage
In-orbit checkout
Planned mission life
Planned in-orbit storage
Planned in-orbit checkout
Approved: VOLZ.STEPHEN.MICHAEL.1504223694
Assistant Administrator for Satellite and Information Services
Operational satellite extended life estimates (indicated by an arrow) are based on July 2022 reliability analyses (60% confidence) for satellites in orbit for at least one year.
GOES: Geostationary Operational Environmental Satellites


NOAA Polar Satellite Programs
Continuity of Weather Observations
Calendar Year
As of March 2017
08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
NOAA – 15
60% Confidence
NOAA – 18
60% Confidence
NOAA – 19
60% Confidence
Suomi NPP
60% Confidence
Suomi NPP: Suomi National Polar-orbiting Partnership
JPSS: Joint Polar Satellite System Program
PFO: Polar Follow-on
JPSS – 1
JPSS – 2
PFO/JPSS – 3
PFO/JPSS – 4
Click on any bar for current status
NOAA-18
Fiscal Year
Approved:
Assistant Administrator for Satellite and Information Services
In orbit and operating
Launched before Jan 2008
Planned Mission Life, from Planned Launch Date
Planned Mission Life Beyond 2036
Reliability analysis-based extended weather observation life estimate (60% confidence) for satellites on orbit for a minimum of one year – Most recent analysis: July 2016

JMA

- 2018: JMA started considering the next GEO satellite program



[Description of Japan's geostationary meteorological satellites in the Implementation Plan revised in FY2017]

The Implementation Plan of the Basic Plan on Space Policy:

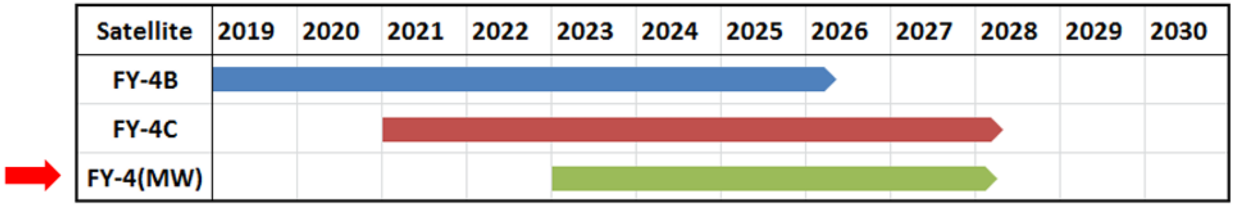
"By FY2023 Japan will start manufacturing the Geostationary Meteorological Satellites that will be the successors to Himawari-8 and -9, aiming to put them into operation in around FY2029".

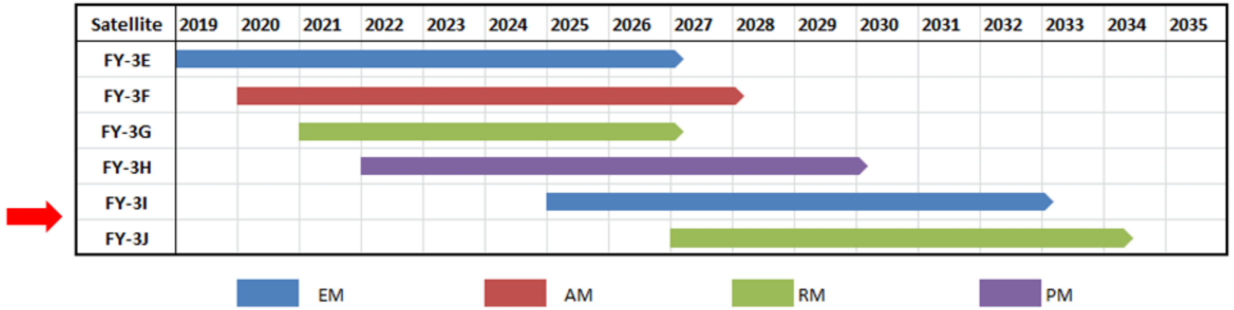
Vision for WMO Integrated Global Observing System in 2040 for GEO satellites

	Application	Satellite/Instrument
VIS/IR Imager w/ rapid repeat cycles	Cloud amount/type/top height/temperature, wind, sea/land surface temperature, precipitation, aerosols, snow cover, vegetation cover, albedo, atmospheric stability, fires, volcanic ash, sand/dust storm, convective initiation	• **NOAA: GOES-16,17/ABI** • **JMA: Himawari-8,9/AHI** • **KMA: GK-2A/AMI** • **CMA: FY-4A/AGRI** • **EUMETSAT: MTG-I1/FCI (2021)**
Hyperspectral IR Sounder	Atmospheric temperature/humidity, wind, rapidly evolving mesoscale features, sea/land surface temperature, cloud amount/top height/temperature, atmospheric composition	• **NOAA: N/A** • **JMA: N/A** • **KMA: N/A** • **CMA: FY-4A/GIIRS** • **EUMETSAT: MTG-S1/IRS (2023)**
Lightning Mapper	Lightning, location of intense convection, life cycle of convective systems	• **NOAA: GOES-16,17/GLM** • **JMA: N/A** • **KMA: N/A** • **CMA: FY-4A/LMI** • **EUMETSAT: MTG-I1/LI (2021)**
UV/VNIR Sounder	Ozone, trace gases, aerosol, humidity, cloud top height	• **NASA: TEMPO (2022)** • **JMA: N/A** • **KMA: GK-2B/GEMS (2020)** • **CMA: N/A** • **EUMETSAT: MTG-S1/UVN (2023)**

CMA

National Space Infrastructure Program for Meteorological Satellites (from 2020 to 2025) approved by the State Council





GIIRS:

First Geo. Interferometric Infrared Sounder