NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Space-based Cloud & Precipitation Observing Systems in the 2020-2040 Period (to Support NWP)

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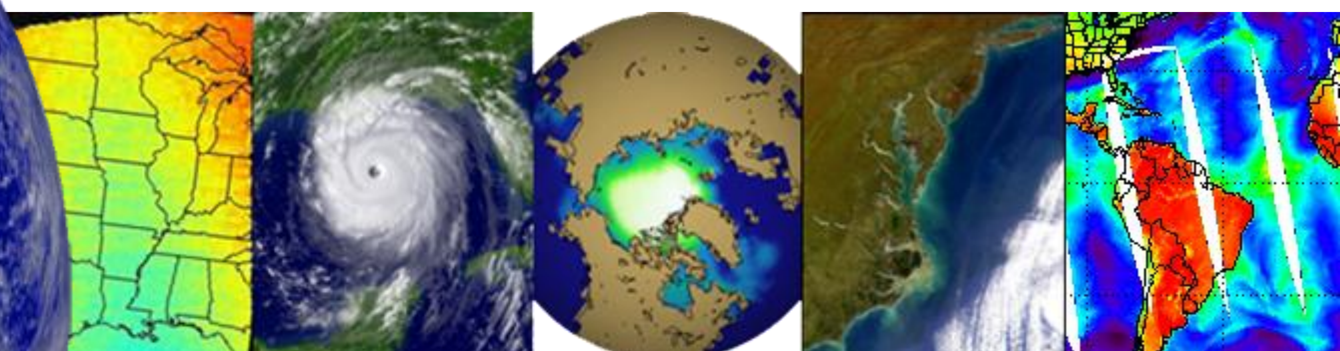

Sources and Credits

Sources Used in this presentation:

- CGMS Website
- Individual Space Agencies Websites (NOAA, EUMETSAT, JAXA, NASA, ESA, Etc)
- WMO OSCAR
- AMS, AGU, ITSC and IPWG conferences' presentations
- NASA Earth Science Technology Office (ESTO) Website
- Multiple Private companies websites

The following persons contributed to this presentation

- SATO,Yoshiaki (JMA)
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Agenda

1 **Introduction**

Major Objective. Background information.

2 **Scope**

What type of Space measurements and missions are we focusing on in this review?

3 **Evolution of the Earth-Obs. Space Constellation**

WMO/CGMS/CEOS coordination. Consortium of Space agencies and associated Partners. Focus on NWP needs.

4 **Trends, Opportunities and Challenges**

With a potential to impact the future evolution of the Global Observing Systems. In the 2030-2040 Timeframe.

5 **Thoughts on Global Observing System of the Future**

WIGOS 2040 Vision. Commercial Sector. Agile. Partnership. Optimizing the Constellation Architecture of the future.

6 **Conclusions**

Bright Future on all fronts. Double edge of NWP as driver for Future Observing Systems.

Main Objective

Disclaimers:

- This presentation is not meant to be a comprehensive presentation about every mission planned in the 2020-2040 timeframe. Instead it is meant to….

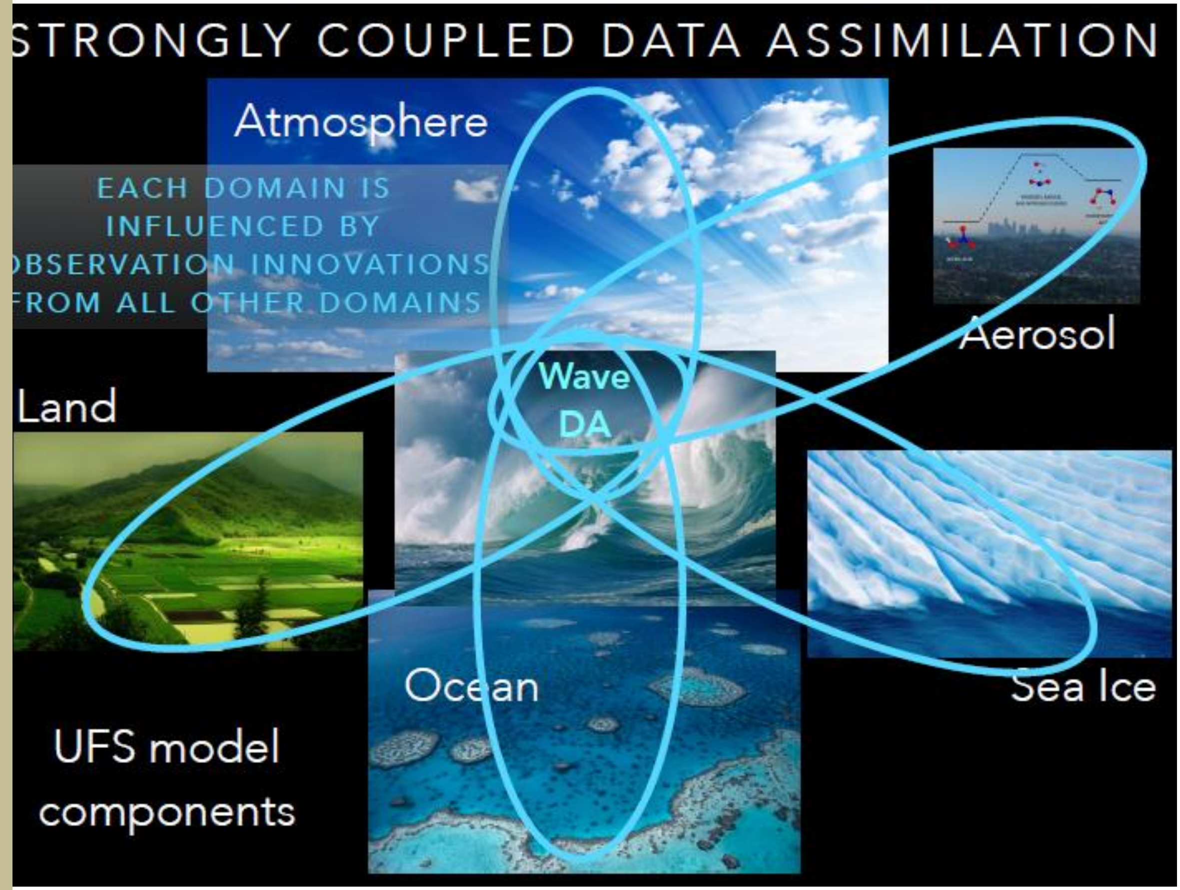
- Provide insight, for those interested in assimilating cloud and precip impacted observations, into the planning of relevant missions by the major Space Agencies, and…

- Provide hints and make educated predictions about the characteristics of future sensors and constellations (planned or not even planned yet), based on foreseen evolutions of various technologies

- No information here should be construed as actual plans for post-POR

Trends in NWP & Environmental Monitoring: An integrated, Coupled Earth System (Monitoring & Modeling)

- Coupled Data Assimilation of future: For all Sensors and in All conditions. IoT-based obs will be part of the mix
- Trends toward Higher Spatial/Vertical/Temporal resolutions
- Data Assimilation of the future will likely ‘analyze’ all geophysical parameters including Hydrometeors
- The data assimilation of the future will have Dual use (NowCasting and NWP), becoming a Data Fusion Tool.
- Data fusion of the future will be the main ‘entry-gate’ for satellite data to produce ‘Earth System’ analyses.
- Remote Sensing & NowCasting will likely gradually merge in the 2030-2040 Timeframe
- Will allow tremendous opportunities for ‘added-value’ information.



Trends In Using Satellite Atmospheric Data for Operational Environmental Prediction (NOAA Models Example)

Operational Model Evolution

Assimilation Observations Maturity at Model IOC

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Linking Satellite Observations to NWP

Linking Satellite-based measurements to NWP :

Satellite data is usually sensitive to:

- Atmosphere (Temperature, moisture, aerosols, trace gases,…)

-Surface (ice, snow, biosphere, land, ocean)

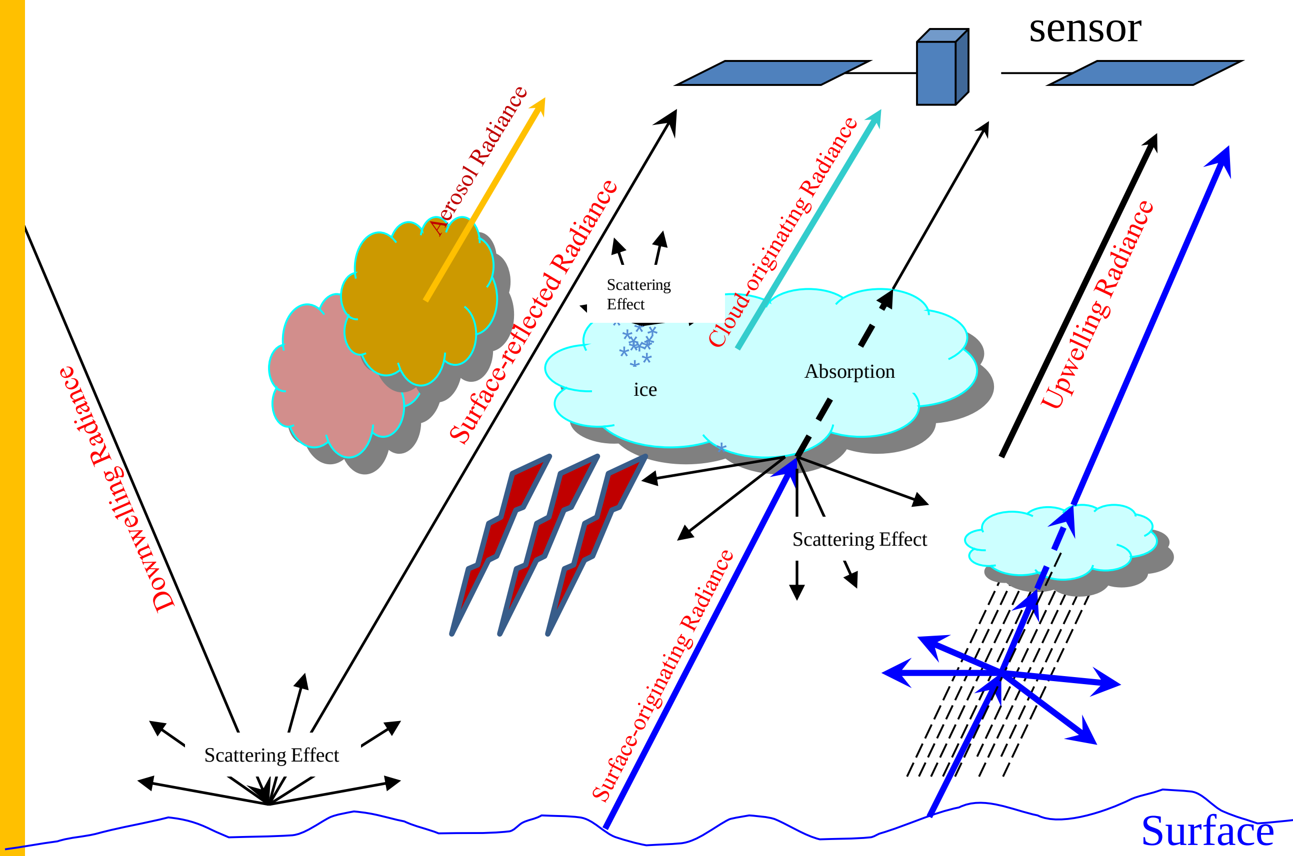
-Hydrometeors (cloud, rain, suspended ice)

NWP has traditionally focused on space-based sounding of T and Q but :

- Those measurements are also (sometimes) impacted by surface, hydrometeors, aerosols, etc

-NWP models are evolving to become coupled Earth System models therefore needing those 'noise' signals that used to be filtered out

-Hydrometeors are a prime example and the focus of this workshop (cloud, precip)



Cloud and Precip data are important. So are also the other NWP-relevant variables, under cloudy/precipitating conditions

Scope

- **Forward Looking. We will <u>not</u> try to cover existing sensors (assumed to be already known). Such as the JPSS series, the Metop series or the FY series**
- **We will mainly focus on future sensors, especially those expected in the Late 2020s, 2030s and 2040s. With an expected relevance to NWP**
- **The focus will be on two types of observations:**
  - Direct measurements of Cloud and Precipitations, both liquid and frozen state
  - NWP relevant measurements (such as T, Q, W) measured under cloudy or precipitation conditions
- **The type of satellite measurements that is the focus of the presentation includes:**
  - Microwave
  - Infrared
  - Active and passive
  - Regular missions and new ones (regular, smallsats, cubesats, etc)
  - Etc.

Across the presentation, judgement calls wil be made on which missions/sensors to highlight, driven by the expectation of their usefulness for NWP

Coming up in the late 2020-2040 Timeframe

- **Missions coming up in the next two decades could be divided into:**
  - Planned Missions **extensions**: continuations of JPSS, GOES, Metop, FY3/4, etc
  - Planned or being Investigated **New** Missions: TROPICS, CIMR, EarthCare, ..
  - Not planned Missions but indications that they will be an **emerging capability** of GOS

- **[2020-2030] Planned missions extensions will essentially sustain current cloud & precip. capabilities**
  - With occasional improved characteristics and the particular case of EPS-SG with many new capabilities.

- **[2020-2030] Planned new missions have novel/new capabilities**
  - Embedded in either operational or research missions.

- **[2020-2040] Emerging capabilities are speculative (not in the plan per se)**
  - Based on technological trends, commercial sector emergence, etc.
  - Connecting the dots between different areas
  - What is listed in this section is not to be considered as firm plans but rather as an educated guess

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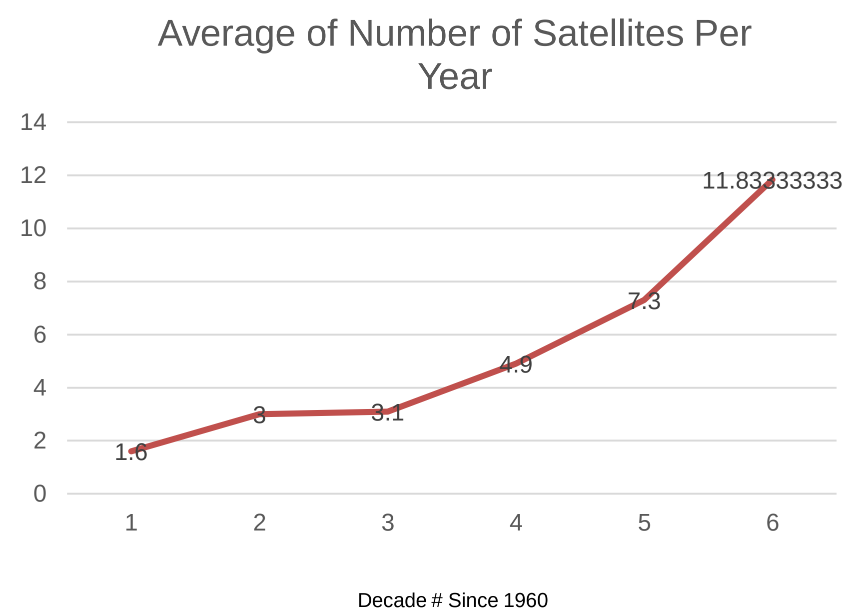
GOS Trend: Increase in Space-Faring Nations

	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.*

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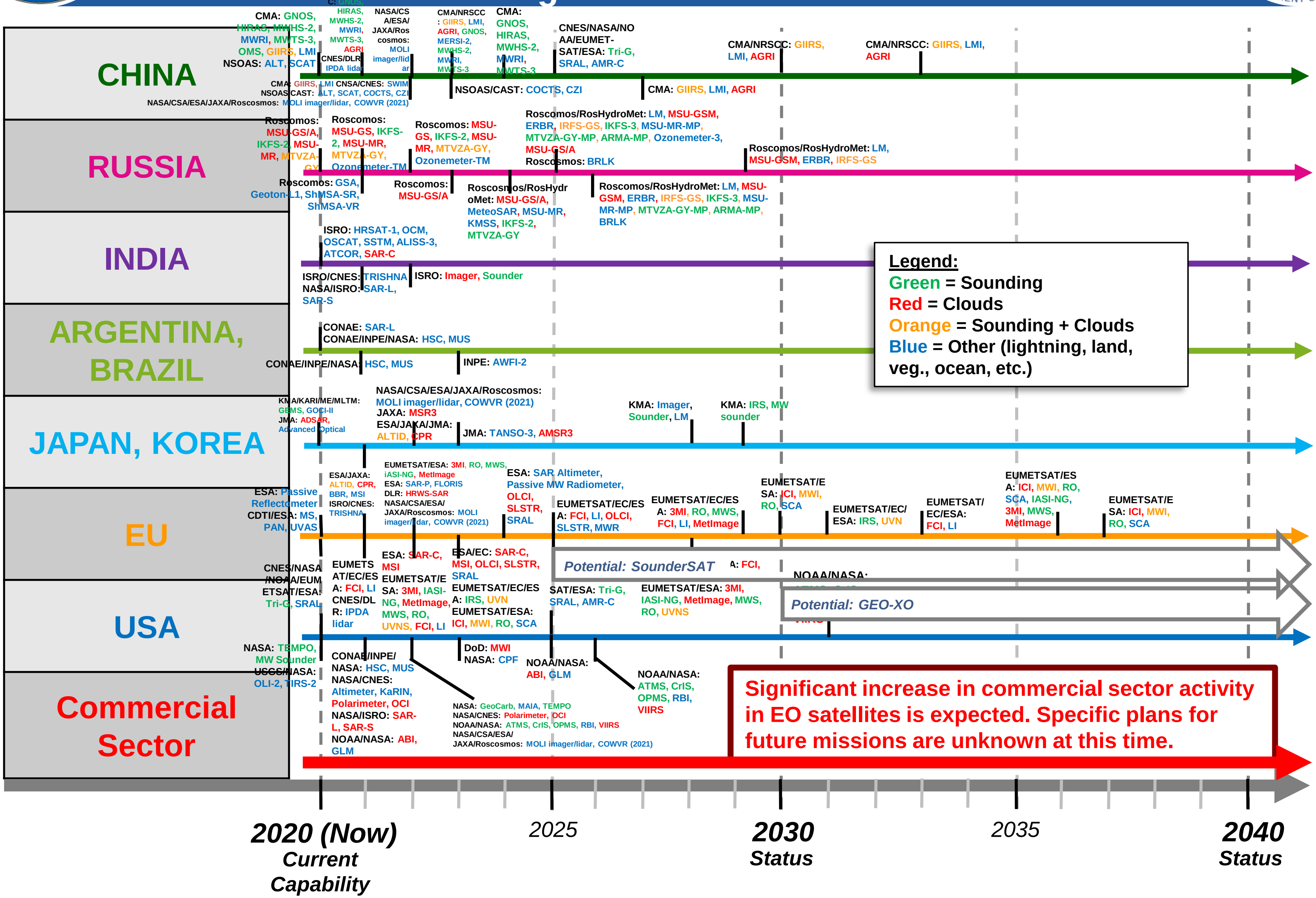
GOS Evolution : Big Picture

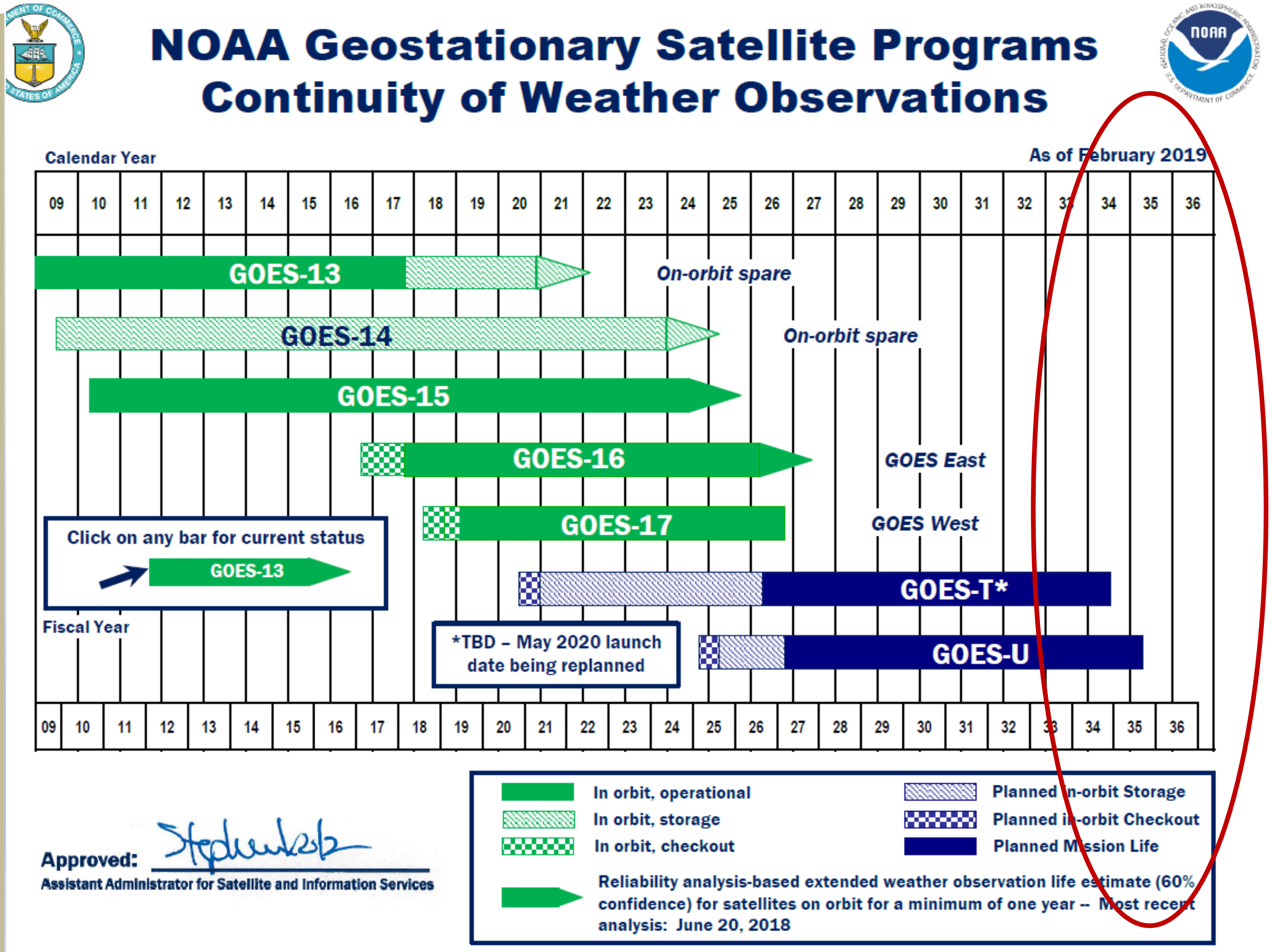
Sounding & Cloud Measurement



NOAA GEO Plans

Current/planned Geo extension missions data will continue to offer the following for cloud and precip:

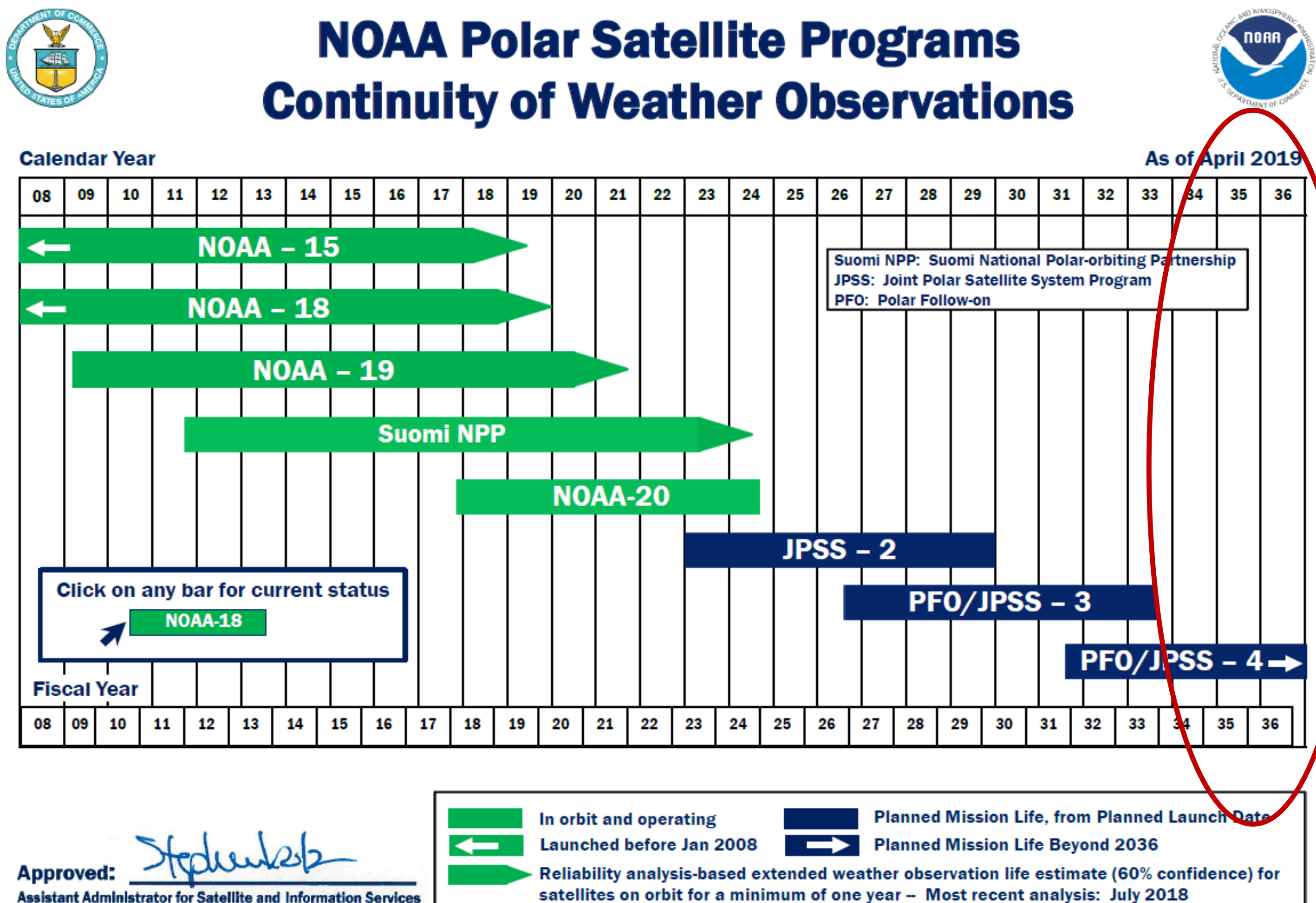
- Cloud and Moisture Imagery & (radiances)
- Cloud products (Optical Depth, Particle Size, Top Height, Phase, Pressure & Temperature
- Legacy Moisture Profile in rainy/cloudy situations
- Legacy Vertical Temperature Profile in rainy/cloudy situations
- Rainfall Rate/QPE
- Lightning
- ABI and GLM sensors



NOAA LEO Plans

Current/planned LEO extension missions data will continue to offer the following for cloud and precip:

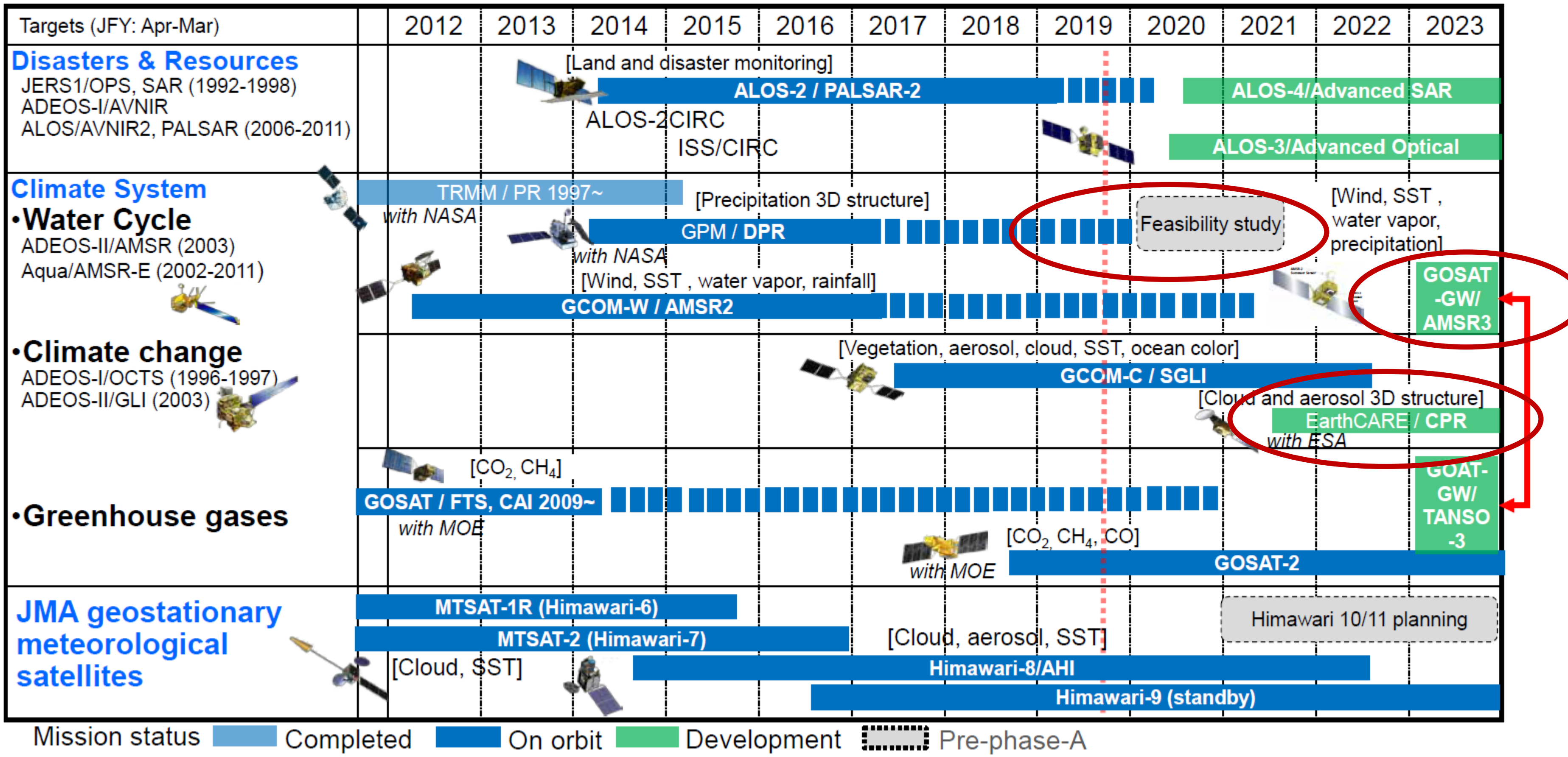
- Cloud and Precip. (radiances)
- Cloud and rain products
- Moisture Profile in rainy/cloudy situations
- Temperature Profile in rainy/cloudy situations
- Both MW and IR-based measurements
- ATMS, CrIS, VIIRS Sensors
- Different spatial and vertical resolutions



A trend to watch: 3D-wind profiles using constellations of MW/IR sounders, therefore in cloudy/rainy conditions

Japan's Plans (JMA/JAXA)

Japanese Earth Observation Satellites



Credit: JMA and JAXA presentations at CGMS 2019.
Hitoshi Tsuruma

China’s CMA/NSMC Plans

FY3 Series (Leo): MWRI Microwave Imager is playing a critical role of gap filling microwave imaging data.

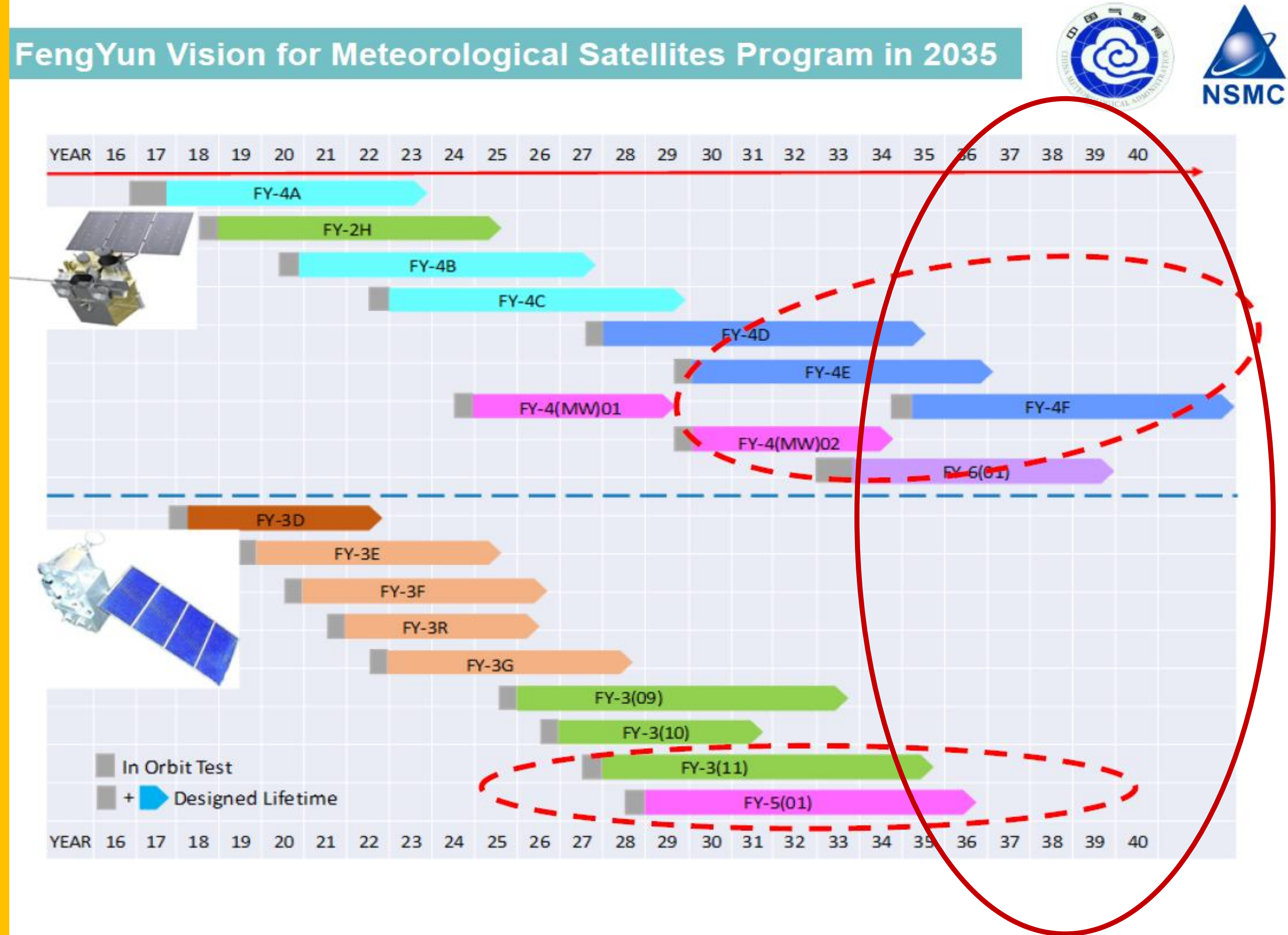
HIRAS Hyperspectral Atmospheric Sounder

MWTS (Micro-Wave Temperature Sounder)

MWHS (Micro-Wave Humidity Sounder)

FY4 Series (Geo): GIIRS Hyperspectral IR sounder

LMI Lightning Mapper Imager



Courtesy of Peng Zhang (CMA)

EUMETSAT / ESA Plans

Metop-SG series

Will include both continuation and 'New' capabilities.

- ICI
- MWI
- MWS
- IASI-NG

MTG Series

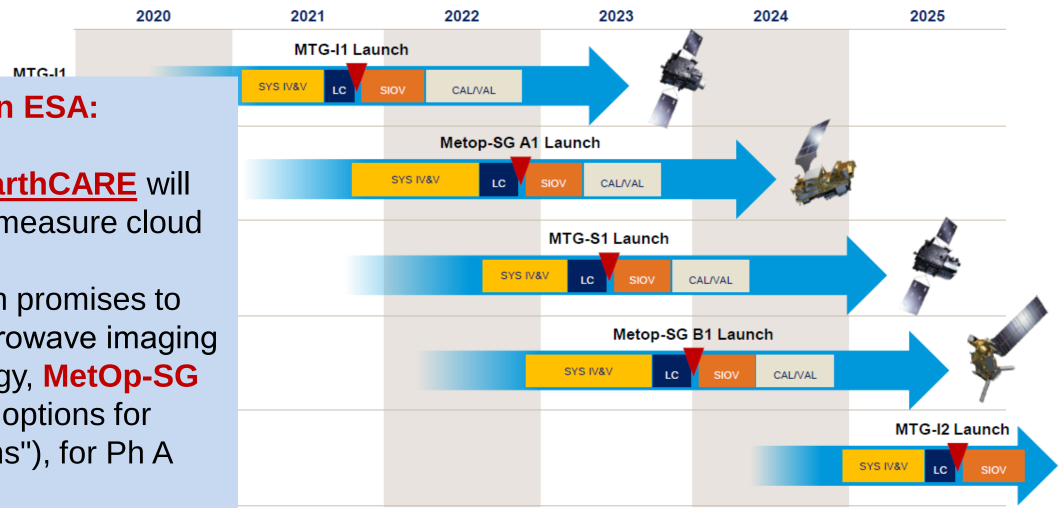
IRS Hyperspectral Atmospheric Sounder

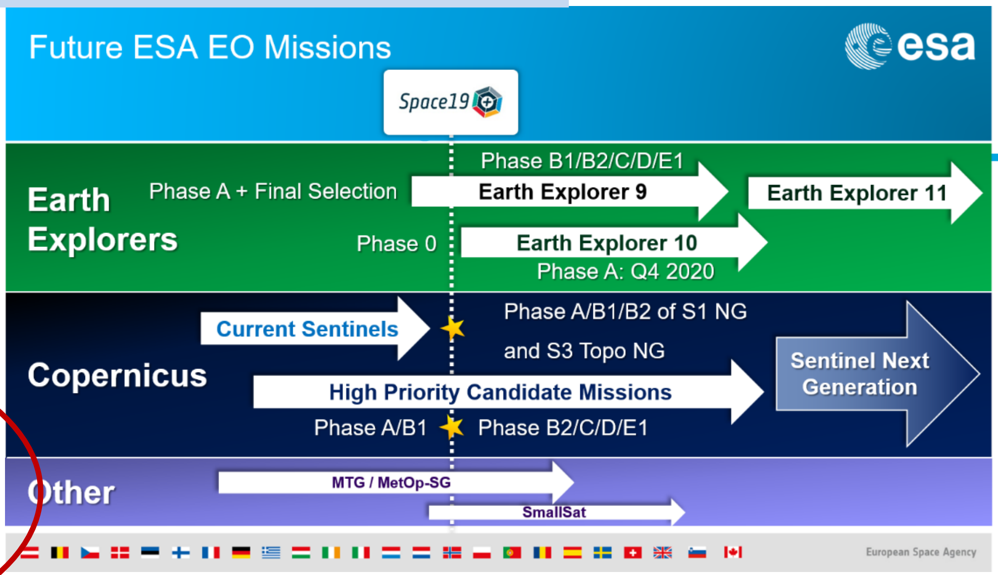
- IRS

See Christophe's presentation on EUMETSAT/ESA for details!

Four main program lines in ESA:

1) In the Earth Explorers, EarthCARE will be a major mission that will measure cloud and precip
2) Copernicus CIMR mission promises to be a 'game changer' for Microwave imaging
3) w EUMETSAT/Meteorology, MetOp-SG
4) ESA presently evaluating options for small sats ("SCOUT missions"), for Ph A study.





EUMETSAT CGMS

Credit: Eumetsat presentation at CGMS 2019.

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Major Factors Driving the Remote Sensing of the Future

International Drivers

- 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
- The Data Sharing Principle Conundrum
- International Partnerships for a Global Observing Systems (CGMS, CEOS, GEOSS)

National Drivers

- Increasing Public Demand for Environmental Intelligence
- Growing Pressure to Reduce Government Expenditures
- Emergence of private Sector in Earth-Observing Satellite but also in Environmental Prediction
- Data volume explosion, User needs (Big Data)
- Emergence of new areas of high interest (water, arctic,..)
- Spectrum Interference Challenges (in the Microwave)

Users Needs Evolution

- Evolution of the Weather Forecasting (NWP) & Environmental Monitoring Enterprise
- Convergence of NowCasting and Remote Sensing: Satellite Data Fusion & Assimilation
- Coupled Earth System of the Future and increasing resolutions
- Users Needs evolution

Architecture Drivers

- Technological and Innovative advances of Sensors, Payload Hosting solutions
- Impact studies, OSSEs, FSOI, etc to perform value assessments
- Growth of Citizen Science, IoT for Environmental Monitoring
- Trend toward the Cloud-based Computing Solutions
- Need to justify Costs, Demonstrate ROI and Value of Obs. Systems
- Evolution toward Use-Driven Requirements (esp. NWP)

→ **Evolution of GOS**

These drivers are forcing agencies to think carefully about the best way to optimize the potential added value of next-generation observing systems. What NWP needs currently and what NWP will need in the future should be articulated

WMO WIGOS 2040: Trends & Vision

(Extracts Relevant to Cloud/Precip and NWP)

- **Vision**: (1) backbone with specified orbital configuration and measurement, (2) backbone with flexible orbits and new measurements, and (3) Operational pathfinders
- **Progress** in sensing technology will lead to higher signal sensitivity of sensors, leading to higher spatial, temporal, spectral and/or radiometric resolution.
- **Hyperspectral** will be used not only in IR but also in the UV, VIS, NIR and MW
- **Radio-occultation** technique will be generalized, using additional frequencies to maximize the sensitivity to atmospheric variables (incl. cloud/precip)
- **Commercial sector**. ….public/private partnerships, new business models
- **Number of space-faring nations** will lead to growing opportunities for a wider distribution of the space-based observation effort among WMO Members.
- **Sub-orbital** flights of balloons or unmanned aerial vehicles will also contribute.
- **Smaller sats** with shorter life cycles, more limited scope, more experimental payloads, and with faster, more flexible decision processes

Major Space Industry and technology Trends
(With Potential to Impact GOS)

Remote Sensors	Current Trends
Passive Microwave **(Sounders, Imagers & Limb sounders)**	- Higher spectral and spatial sampling - ***Microwave sensors on Geo*** - ***Mounting on Small satellites***
Passive IR/VIS/UV **(IR and Hyperspectral IR)**	- Combining hyperspectral and high spatial resolution - ***Hyperspectral IR on Geo*** - ***Small sats*** - Visible and night time visible on Geo
Active Microwave **(scatterom., altimeter, radar, SAR).**	- Wider swaths - ***Multiple frequencies*** - Multiple polarizations - ***Finer spatial resolution***
Occultation **(Radio, solar, etc)**	- Higher density coverage - Additional frequencies, polarimetric measurements - ***Higher sensitivities to cloud and precip*** - ***Commercial data***

- Lower space access costs
- Trend toward cheaper, focused Observing systems (Smallsats, Cubesats, Microsatellites and Chipsats)
- Near-Space Global Observing System
- Trend toward Commercialization of Satellite Data & Privatization of Satellites
- New Global GOS international partners will allow better spatial coverage (denser orbital configuration)
- Convergence of meteorological and commercial needs for Earth global coverage (Google Loon project, Polar Communication & Weather PCW mission, etc) could lead to better coordination (similar to TAMDAR for airlines data sharing strategy)

A Peek into Future Microwave Sensors

Table 4.4. Emerging technology roll-up for microwave radiometers

Technology Area	Measurement	State-of-the-Art	Notional Requirements
High frequency Microwave Component technology	Clouds and precipitation, Atmospheric Composition, Humidity and Temperature	183-GHz 500K Tsys; 100mW LO; η=10% W-band detectors	900-GHz 500K Tsys; 100mW LO; η=40% >G-band detectors WG Filters >300 GHz
Integrated Systems	RZSM; Precipitation; Air-Sea-Flux; Altimetry	Separate instrument systems	Combined higher level of integration, aperture sharing, common FPAs
Large Aperture	RZSM; Precipitation; Land Surface	6m+ class deployable from rocket faring; 0.7m deployable from 1.5U f > 40-GHz for comm.	Performance to ~600 GHz at 2m diameter deployable from 2.5U; 10m class to W-band;
Uniform and stable calibration for small radiometers; SI-traceable calibration	Temperature profile; Precipitation; Water vapor Ocean surface Clouds	Individual radiometer calibration assessments; cross calibration analysis required with other radiometers	Uniform calibration between fleet sensors; N>>10 radiometers all traced to SI-standard

New technology applicable to microwave radiometers designed for future Earth science measurements assessed with TRL~3 or higher, also includes techniques to extend polarimetric measurements to W-band and higher frequencies, improvements implementing digital receiver back-end electronics including realization of ultra-wideband radiometers with RFI mitigation technology.

Future Sensors will have …

- Higher Frequencies
- Better SNRs
- SI traceable calibration
- RFI mitigation integrated
- Polarimetric measurements expanded to higher freqs
- Ultra spectral sampling

Source: NASA/ESTO 2016 Microwave Technologies Review and Strategy

Technology Trends: 2030-2040 Timeframe

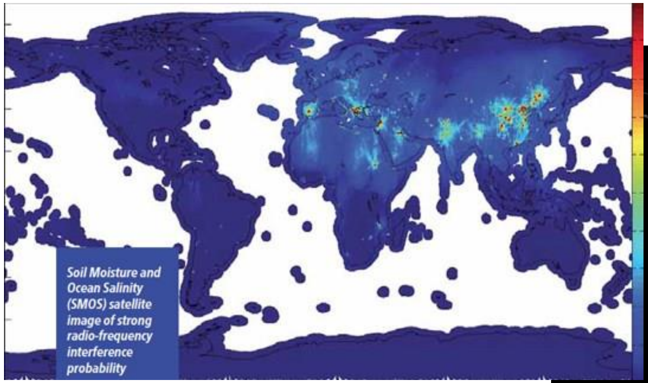
Positives	Challenges/Silver Linings
Payload Hosting (similar model to TAMDAR/AMDAR model?).	Spectrum interference (5G). Take advantage of 5G in Planetary Boundary Layer (PBL).
Noise Reduction and increase in quality (resolutions, # channels , etc)	Quality vs Quantity. Example of SmallSats (noise reduction).
Diversity of Sources (countries, commercial sector, etc.) and sensors	Commercial sector and the risk to free data policy.
SmallSat/Cubesats/etc	Importance of merging and cross calibrations of satellites /Emergence of SI-traceable calibration sensors to serve as anchors
Near-Space platforms and IoT (complementary with traditional space- and ground-based GOS)	
Polarization including for RO sensors: for convective cloud and precipitation	
Robustness of GOS	

RFI Challenge in the Microwave

- Radio Frequency Interference (RFI) is spreading more and more upward in the microwave spectrum: **If unchecked could lead to searching for alternative frequencies and/or loss of capability to measure certain geophysical parameters**

1.4GHz (case of SMOS, SMAP)

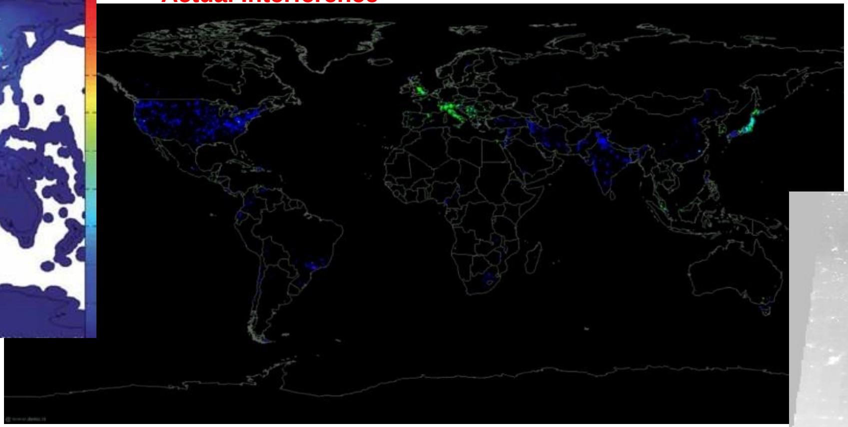
Actual Interference



Source: International Telecommunications Union

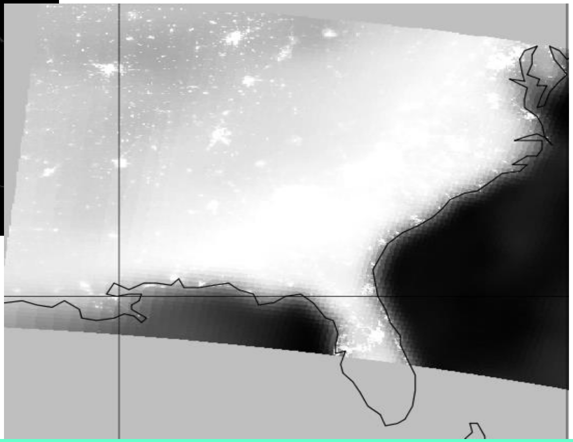
6-7 GHz and 10 GHz (case of AMSR)

Actual Interference



23.8 GHz (case of ATMS)

Simulated Interference-5G at -20dBW/200MHz

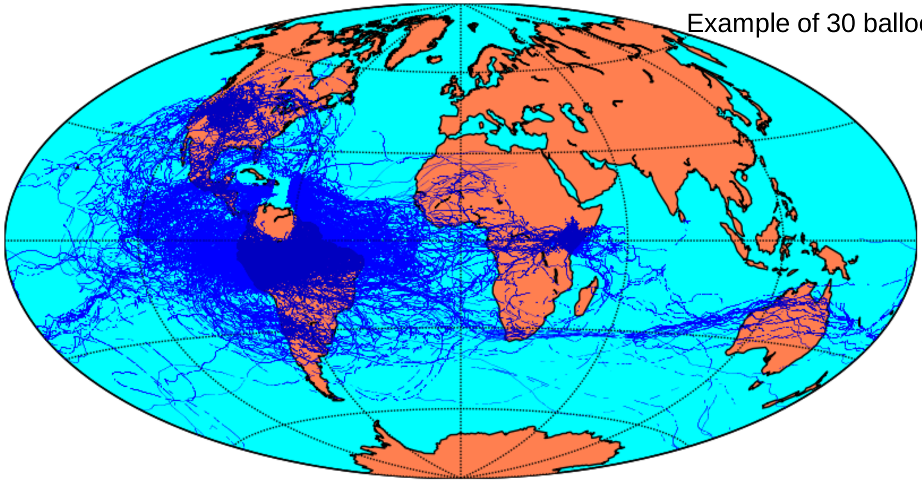


RFI could have signifiant impacts on channels currently used for cloud and precip and/or lower troposphere sensing in active conditions. Likely impacts: Shift to higher MW frequencies for cloud and precip sensing, Loss of sensitivity to large amounts.

Non-Governmental Sector Potential for Space Observations. Case of Near-Space Platforms

- Between now and 2040:
  - New Possibilities for env. data
  - New Players in the industry
  - New Challenges
  - Many Opportunities
  - Driven by Industry needs (not necessarily by Governments' needs)
  - IoT for cloud/precip already a reality (telecom towers, traffic cameras, etc)
- Challenge: Use of Big data in NWP.
- NWP should benefit from and make use of these opportunities.
- NWP should evolve (agility, efficiency, adaptability, comprehensiveness,..) to face challenge of Big data

Example of 30 balloons



FB and Google in heated competition to provide internet connectivity in under-covered areas (typically also under-represented in terms of environmental measurement).

Advantages of Near-Space Platforms (in Stratosphere):

- Higher Spatial Resolution
- Cost-Effective
- Flexible payload hosting
- Flexible navigation (Stationary or not)
- Does not necessarily require space-grade components (so cheaper)
- X-Loon approached WMO: willingness to share data

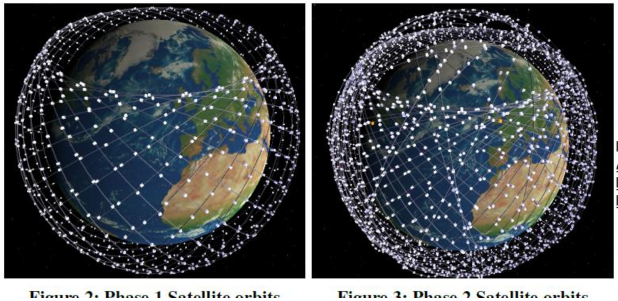
Disadvantages of Near-Space Platforms :

- Stability needs improvement
- Maturity of payload hosting not established
- Contamination extent to be studied
- Uncertainty about spatial coverage control

Potential for PayLoad-Hosting by Missions of Opportunity

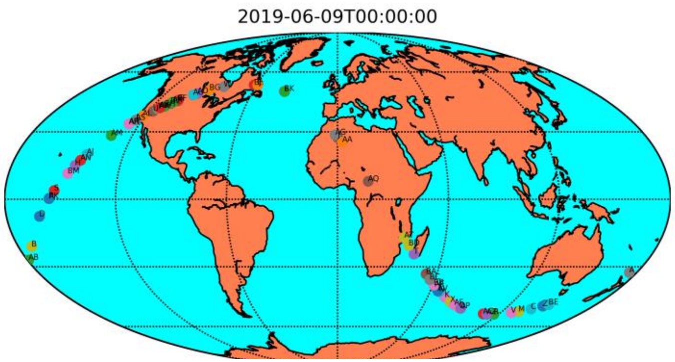
(Example of Simulating Space-X Starink and Assessing Impact on NOAA systems)

- **Example: Starlink** is a satellite constellation planned by SpaceX, to implement a new space-based Internet communication system
- **Goal: All the time, everywhere! (similar to NWP ideal)**
- Group satellites pass over the Earth at the same orbit
- Phase 1: 1600 satellites at 550 kms altitude
- First 240 operational satellites were launched
- Significant potential for hosting Earth-Observations
- Can this offer the next TAMDAR-on-steroids? (where sensors were put on planes 4 NWP)



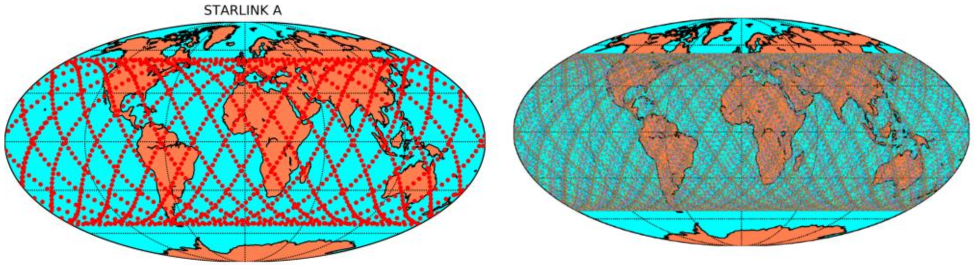
Mark Handley, University College London:

Perigee: 526.3 km
Apogee: 530.8 km
Inclination: 53.0 °
Period: 95.1 minutes



Potential Advantages of Leveraging Missions of Opportunity for Earth Observations:

- Potential Significant Higher Spatial and Temporal Resolutions (7 mins in tropcs with 24 orbits/4 satellites)
- Potential Significant Cost-Effectiveness
- Unprecedented flexibility
- Effort is on ongoing to assess impact on NOAA systems using OSSE experiments



Very high spatial and temporal resolution. Opportunities for observational system

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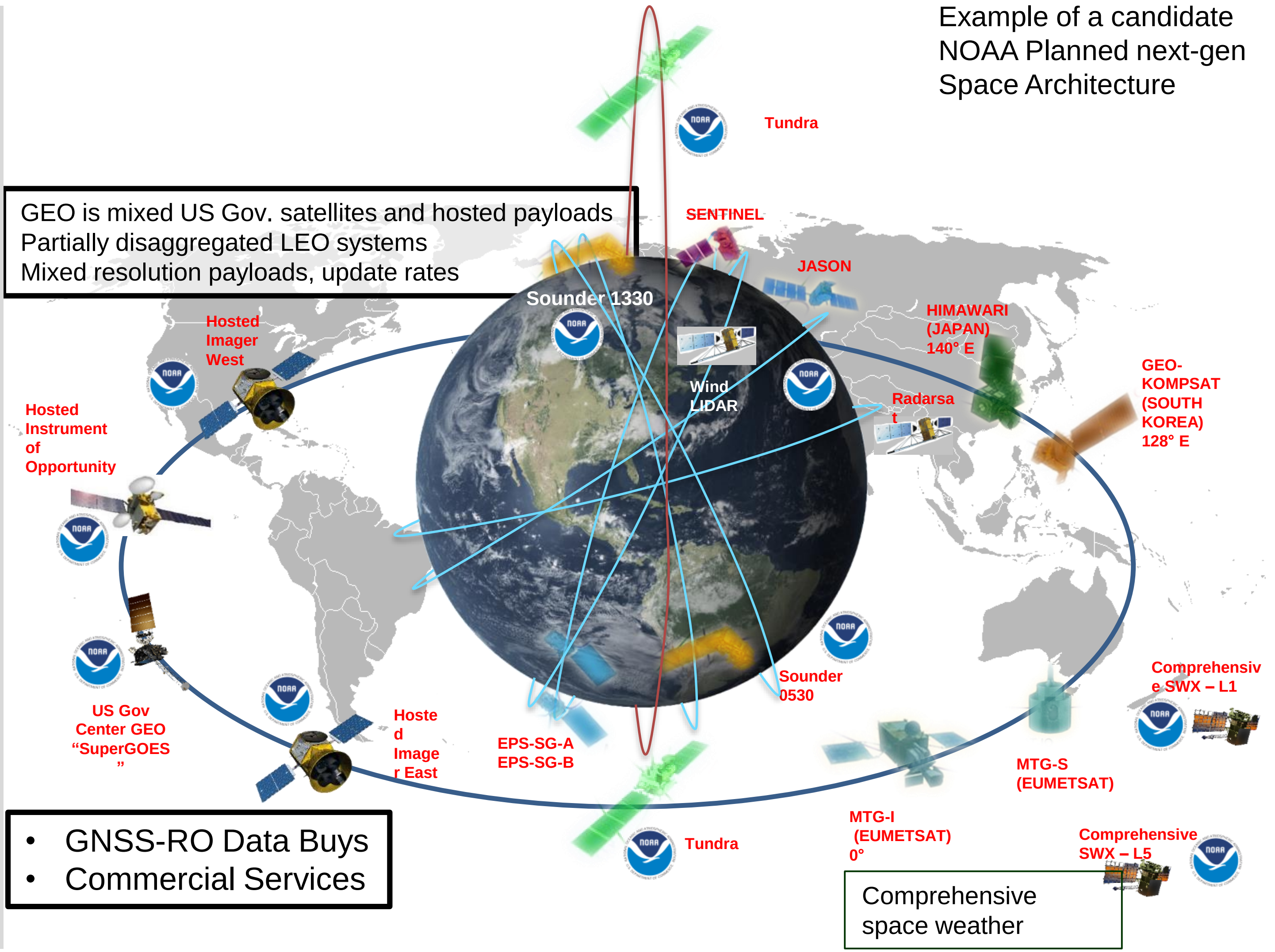
GOS in 2040 Timeframe:
Likely a Hybrid and Disaggregated Architecture

- Examples of existing /planned small satellites (incl. from NASA):
  - TEMPEST
  - TROPICS
  - MicroMAS
  - EON-MW
  - CYGNSS
  - CIRAS
  - PAZ/ROHP
- Crucial role of partnerships for ride share, sensors, data buys
- Commercial Services for Radio Occultation and Other Sensors
- Strategic role for remote Sensing & NWP: How to maximize ROI of satellites with short lifespans. Requires:
  - Accelerating the end-to-end exploitation chain of satellite data:
  - Calibration including Monitoring
  - Validation
  - Algorithm development and product generation
  - Data assimilation and usage in NWP systems



Special Note on NASA's ACCP

- Overarching goal of ACCP is to jointly measure aerosol-cloud-precipitation properties to improve understanding of the processing of water and aerosols (Braun 2019)

- Program of record of ACCP : GPM mission, DPR, GCOM-W, EarthCare, GOSAT

- Part of the recommended directions in the most recent NASA Decadal Survey (2017)

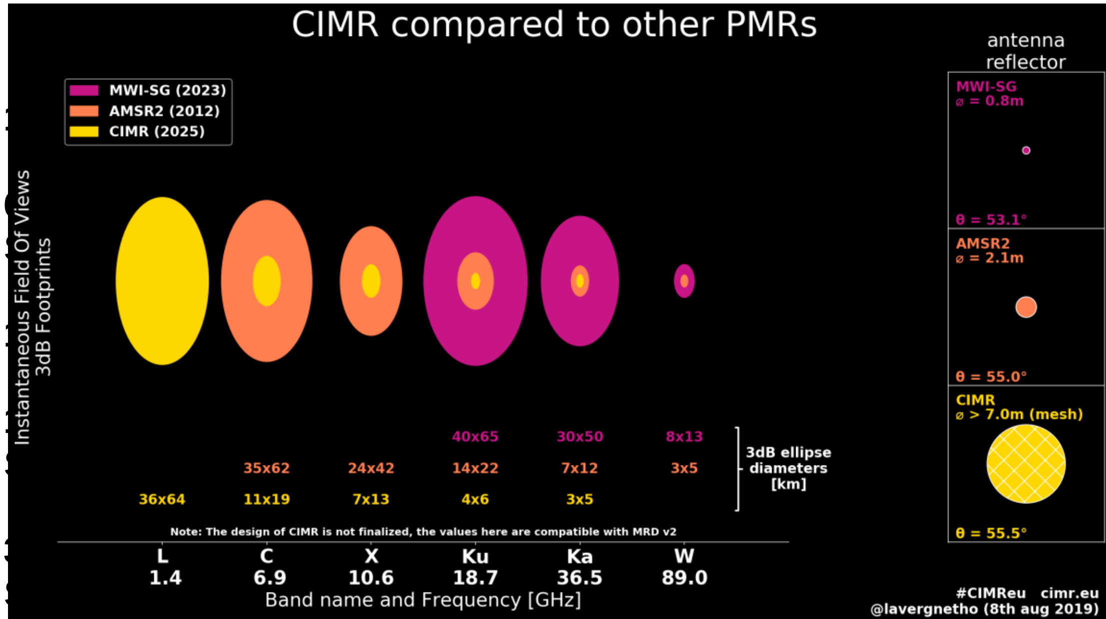
- The study will conclude in 2021 with the recommendation of a few optimal observing systems based on a semi-quantitative Value Framework approach (Seidel 2019)

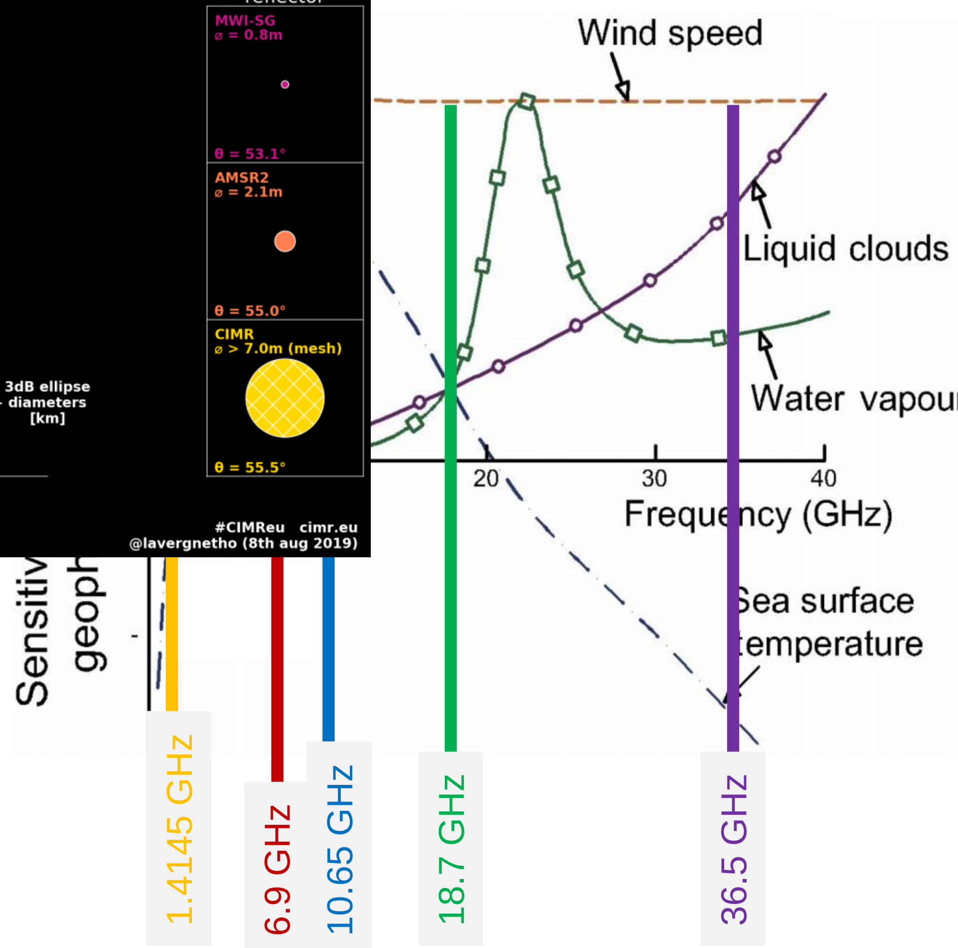
- **Sensors considered (Braun 2019, personal comm.):**
  - Precip and cloud Profiling Radar(s) –Active-,
  - Microwave radiometer(s) -Passive-
  - Atmospheric Lidar –Active-,
  - Spectrometer –Passive-
  - Polarimeter –Passive-
- **Platforms considered: Cubesat, smallsat, medium size**
- Constellation: Single platform, constellation or hybrid
- Part of the ACCP applications is 'Improved Numerical Weather Prediction'
- **Launch is 2029 at the earliest.**

Special Note on DoD's WSF-M MWI

- Only publicly available data can be shared:
    - **WSF-M** (**Weather System Follow-on - Microwave**) is the next-generation operational environmental satellite system, Weather System Follow-on – Microwave (WSF-M), for the Department of Defense (DoD).
    - WSF-M is designed to mitigate high priority DoD Space-Based Environmental Monitoring gaps: ocean surface vector winds, tropical cyclone intensity
    - Builds on GPM GMI technology
    - Program of Record: **GPM, DMSP SSMIS, ATMS and WindSAT**
    - **Expected to be completed in 2023**

Special Note on Copernicus CIMR





SIC = Sea Ice Concentration, SST = Sea Surface Temperature, SIT = Sea Ice thickness, SSS= Sea Surface Salinity, WS = Wind speed, TWV = Total Water Vapour, TCWV = **Total Cloud-liquid Water Vapour**, SD = Snow Depth, SM = Soil Moisture, SWE = Snow Water Equivalent, SID = Sea Ice Drift, **PCP=precipitation**

***Gabarro et al*, 2017**

Agenda

1 **Introduction**
Contributions. Credits. Background information.

2 **Scope**
What type of Space measurements and missions are we focusing on in this review?

3 **Evolution of the Earth-Obs. Space Constellation**
WMO/CGMS/CEOS coordination. Consortium of Space agencies and associated Partners. Focus on NWP needs.

4 **Trends, Opportunities and Challenges**
With a potential to impact the future evolution of the Global Observing Systems. In the 2030-2040 Timeframe.

5 **Thoughts on Global Observing System of the Future**
WIGOS 2040 Vision. Commercial Sector. Agile. Partnership. Optimizing the Constellation Architecture of the future.

6 **Conclusions**
Bright Future on all fronts. Double edge of NWP as driver for Future Observing Systems.

Attempt at Predicting the Evolution of the Space-Based Earth Observing Sensors
(with Focus on cloud/precip and NWP)

- Long term Plans of Major Space agencies extend to at least 2030s and some to 2040s. Continuity of space observations of NWP-relevant cloud and precip as well as sounding in cloudy and precip conditions, seems secure.
- At the same time, there is an increase in sources, numbers, diversity and quality (noise, resolution, temporal refresh, spectral coverage and resolution, etc) of Satellite Observations including for cloud/precip
- Emergence of new capabilities for cloud/precip: Higher spatial resolution, Better SNR, Sub-millimeter sensing, Hyperspectral Microwave sensors (hydrometror profiling, microphysics sensing, etc), Polarimetric RO, etc
- The future will likely lead a hybrid constellation with SI-traceable anchor observing systems along with a large number of other smaller satellites
- Perhaps traditional satellites will be complemented by near-space constellation of sensors-equipped balloons and by data from Commercial/Public partnerships (payload hosting, data buys, etc)
- Challenges exist (Cost sustainability, Spectrum loss, RFI, data sharing, etc), some presenting some silver lining opportunities (for NWP)

Summary

- **Our perspective for the 2030-2040 Timeframe:**
  - We are at the dawn of a golden era of satellite-based earth observation sensors, including for the observation of cloud and precip and/or a more accurate measurement of other NWP-relevant variables, in cloudy and precipitating conditions.
  - Efforts are on going (or will be initiated soon) to think about designing the Space constellation of the future: Post-JPSS, Post-GOES-R, post EPS-SG, post-FY3/4, etc
  - NWP (gradually becoming the ESP), because it is such a foundational application, is increasingly used as a driver for designing and optimizing the next-generation space architecture. This represents a double-edge sword: Potential for ignoring the needs of the future if decisions are based on OSE, FSOI, OSSE, etc using current NWP capabilities
  - **NWP community has to fine-tune its messaging to space agencies about its current and future needs. Ideally work closely on this aspect. Point in case: Cloud and Precip needs.**
  - Cloud/Precip workshop should include not only use of cloud/precip in current NWP, but also look into future needs (e.g. need for microphysical properties, need for hydrometeor profiling, added signal to distinguish cloud/precip from other NWP-relevant signals,..) to convey to Agencies
  - **Possible mechanism: closer work relationship between this group and IPWG, ICWG, Working groups for CGMS (successful example of NWP community involvement in ITWG)**

BACKUP

Sensors & Environments Capabilities

IR T/Q Sounding from LEO

Source: WMO OSCAR Gap Analysis

Instrument	NRT?	Sorting	Satellite	Orbit	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
SI-GDR		5	Meteor-P2	81.2 °																											
IKFS-2		3	Meteor-M N2-6	09:00 asc							X	X	X	X	X	X															
IKFS-2		3	Meteor-M N2	09:30 asc	X	X	X																								
SI-GDR		5	Meteor-P3	10:15 asc																											
SI-GDR		5	Meteor-P4	10:15 asc																											
CrIS	Yes	1	NOAA-20	13:25 asc	X	X	X	X	X	X	X																				
CrIS	Yes	1	SNPP	13:25 asc	X	X	X																								
AIRS	Yes	1	Aqua	13:30 asc	X	X	X																								
CrIS		1	JPSS-2	13:30 asc					X	X	X	X	X	X	X	X															
CrIS		1	JPSS-3	13:30 asc									X	X	X	X	X	X	X	X											
CrIS		1	JPSS-4	13:30 asc														X	X	X	X	X	X	X	X						
IRAS	Yes	4	FY-3B	13:38 asc	X	X	X																								
TES-nadir		1	Aura	13:45 asc																											
HIRAS	Yes	1	FY-3D	14:00 asc	X	X	X	X	X																						
HIRAS		1	FY-3G	14:00 asc					X	X	X	X	X	X																	
HIRS/2		4	NOAA-13	[illegible] asc																											
HIRS/2		4	NOAA-11	14:10 asc																											
HIRS/2		4	NOAA-7	14:30 asc																											
HIRS/2		4	NOAA-9	14:30 asc																											
HIRS/2		4	TIROS-N	14:30 asc																											
IKFS-2		3	Meteor-M N2-2	15:00 asc		X	X	X	X	X	X																				
IKFS-2		3	Meteor-M N2-1	15:09 asc																											
IKFS-2		3	Meteor-M N2-3	15:09 asc			X	X	X	X	X	X																			
IKFS-3		1	Meteor-MP N1	15:30 asc								X	X	X	X	X	X	X	X												
HIRS/4		4	NOAA-19	04:46 desc	X	X	X																								
HIRS/2		4	NOAA-12	05:10 desc																											
HIRAS		1	FY-3E	06:00 desc			X	X	X	X	X	X																			
HIRAS		1	FY-3H	06:00 desc							X	X	X	X	X	X															
HIRS/3		4	NOAA-15	06:54 desc																											
HIRS/3		4	NOAA-17	07:03 desc																											
HIRS/2		4	NOAA-6	07:30 desc																											
HIRS/2		4	NOAA-8	07:30 desc																											
HIRS/2		4	NOAA-10	07:30 desc																											
HIRS/4		4	NOAA-18	08:32 desc																											
IKFS-2		3	Meteor-M N2-4	09:00 desc				X	X	X	X	X	X																		
HIRS/3		4	NOAA-16	09:01 desc																											
IRAS		4	FY-3A	09:05 desc																											
IASI	Yes	1	Metop-A	09:30 desc	X	X	X	X																							
IASI	Yes	1	Metop-B	09:30 desc	X	X	X	X	X	X	X																				
IASI		1	Metop-C	09:30 desc		X	X	X	X	X	X	X																			
IASI-NG		1	EPS-SG-A1	09:30 desc					X	X	X	X	X	X	X	X															
IASI-NG		1	EPS-SG-A2	09:30 desc												X	X	X	X	X	X	X	X								
IASI-NG		1	EPS-SG-A3	09:30 desc																			X	X	X	X	X	X	X	X	
IKFS-3		1	Meteor-MP N2	09:30 desc									X	X	X	X	X	X	X	X											
HIRS/2		4	NOAA-14	09:30 desc																											
HIRS/4	Yes	4	Metop-A	09:30 desc	X	X	X	X																							
HIRS/4	Yes	4	Metop-B	09:30 desc	X	X	X	X	X	X	X																				
HIRAS		1	FY-3F	10:00 desc				X	X	X	X	X	X																		
IRAS	Yes	4	FY-3C	10:15 desc	X	X	X																								
IMG		1	ADEOS	10:30 desc																											

Sensors & Environments Capabilities

IR T/Q Sounding from GEO

Source: WMO OSCAR Gap Analysis

Instrument	NRT?	Sorting	Satellite	Orbit	14	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2
SOUNDER		3	GOES-9	135°W																													
SOUNDER		3	GOES-10	135°W																													
SOUNDER		3	GOES-11	135°W																													
VAS		3	GOES-4	135°W																													
VAS		3	GOES-6	135°W																													
SOUNDER	Yes	3	GOES-15	128°W	X	X	X	X	X	X	X																						
SOUNDER	Yes	3	GOES-14	105°W	X	X	X	X	X	X	X																						
SOUNDER		3	GOES-8	75°W																													
SOUNDER		3	GOES-12	75°W																													
VAS		3	GOES-5	75°W																													
VAS		3	GOES-7	75°W																													
SOUNDER	No	3	GOES-13	60°W	X	X																											
SOUNDER		3	GOES-10 (S-Ameri	60°W																													
SOUNDER		3	GOES-12 (S-Ameri	60°W																													
IRFS-GS		1	Electro-M N1	14.5°W												X	X	X	X	X	X	X	X	X	X	X							
IRS		1	MTG-S1	0°										X	X	X	X	X	X	X	X	X											
IRS		1	MTG-S2	0°																		X	X	X	X	X	X	X	X	X			
SOUNDER (INSAT)		3	INSAT-3DR	74°E			X	X	X	X	X	X	X	X	X																		
SOUNDER (INSAT)		3	INSAT-3DS	74°E									X	X	X	X	X	X	X	X													
IRFS-GS		1	Electro-M N2	76°E													X	X	X	X	X	X	X	X	X	X	X						
SOUNDER (INSAT)	Yes	3	INSAT-3D	82°E	X	X	X	X	X	X	X	X																					
GIIRS		1	FY-4C	86.5°E								X	X	X	X	X	X	X	X														
GIIRS		1	FY-4E	86.5°E														X	X	X	X	X	X	X	X								
GIIRS		1	FY-4G	86.5°E																				X	X	X	X	X	X	X	X		
GIIRS	Yes	1	FY-4A	105°E			X	X	X	X	X	X																					
GIIRS		1	FY-4B	105°E							X	X	X	X	X	X	X	X															
GIIRS		1	FY-4D	105°E										X	X	X	X	X	X	X	X												
GIIRS		1	FY-4F	105°E																	X	X	X	X	X	X	X	X					
SOUNDER		3	GOES-9 (GMS bac	155°E																													
IRFS-GS		1	Electro-M N3	165.8°E																X	X	X	X	X	X	X	X	X	X	X			

Sensors & Environments Capabilities

MW T/Q Sounding from LEO

Source: WMO OSCAR Gap Analysis

Instrument	NRT?	Sorting	Satellite	Orbit	Years marked (X)
SAPHIR		5	Megha-Tropiques	20 °	2018–2020
MWHS-2		3	FY-3RM-1	50 °	2020–2025
MWHS-2		3	FY-3RM-2	50 °	2023–2028
MWTS-3 (FY-3RM)		4	FY-3RM-1	50 °	2020–2025
MWTS-3 (FY-3RM)		4	FY-3RM-2	50 °	2023–2028
MTVZA-OK (MW)		2	SICH-1M	82.5 °	
SSMIS	No	2	DMSP-F16	06:20 asc	2018–2019
MTVZA-GY		2	Meteor-M N2-6	09:00 asc	2024–2029
MTVZA		2	Meteor-3M	09:15 asc	
MTVZA-GY		2	Meteor-M N2	09:30 asc	
ATMS	Yes	1	NOAA-20	13:25 asc	2018–2024
ATMS	Yes	1	SNPP	13:25 asc	2018–2020
ATMS		1	JPSS-2	13:30 asc	2022–2029
ATMS		1	JPSS-3	13:30 asc	2026–2033
ATMS					
AMSU-A					
HSB					
MWHS-1					
MWHS-2					
MWHS-2					
MWTS-2					
MWTS-3					
SSM/T-2					
MTVZA-GY					
MTVZA-GY					
MTVZA-GY					
MTVZA-GY-MP					
SSM/T-2					
SSM/T-2					
AMSU-A					
MHS					
SSM/T-2					
MWHS-2					
MWHS-2					
MWTS-2					
MWTS-3					
SSMIS					
SSMIS					
AMSU-A					
AMSU-B					
AMSU-A					
AMSU-B					
SSMIS	No	2	DMSP-F18	07:08 desc	2018–2020
AMSU-A	Yes	4	NOAA-18	08:32 desc	2018–2020
MHS	Yes	5	NOAA-18	08:32 desc	
MTVZA-GY		2	Meteor-M N2-4	09:00 desc	2021–2026
AMSU-A		4	NOAA-16	09:01 desc	
AMSU-B		5	NOAA-16	09:01 desc	
MWHS-1		5	FY-3A	09:05 desc	
MWS		1	EPS-SG-A1	09:30 desc	2022–2029

Instrument	NRT?	Sorting	Satellite	Orbit	Years marked (X)
MWS		1	EPS-SG-A2	09:30 desc	2029–2036
MWS		1	EPS-SG-A3	09:30 desc	2036–2043
MTVZA-GY		2	Meteor-M N1	09:30 desc	
MTVZA-GY-MP		2	Meteor-MP N2	09:30 desc	2026–2033
MWI (MetOp-SG)		3	EPS-SG-B1	09:30 desc	2023–2030
MWI (MetOp-SG)		3	EPS-SG-B2	09:30 desc	2030–2037
MWI (MetOp-SG)		3	EPS-SG-B3	09:30 desc	2037–2044
AMSU-A	Yes	4	Metop-A	09:30 desc	2018–2021
AMSU-A	Yes	4	Metop-B	09:30 desc	2018–2024
AMSU-A		4	Metop-C	09:30 desc	2018–2025
MHS	Yes	5	Metop-A	09:30 desc	2018–2021
MHS	Yes	5	Metop-B	09:30 desc	2018–2024
MHS		5	Metop-C	09:30 desc	2018–2025
MWHS-2		3	FY-3F	10:00 desc	2021–2026
MWTS-3		4	FY-3F	10:00 desc	2021–2026
MWHS-2	Yes	3	FY-3C	10:15 desc	2018–2020
MWTS-2		4	FY-3C	10:15 desc	
MTVZA-GY		2	Meteor-M N2-5	15:00 desc	2023–2028

Sensors & Environments Capabilities

Precipitation (liquid or solid)

Source: WMO OSCAR Gap Analysis

Instrument	NRT?	Relevance	Satellite	Orbit	02	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
PR		3 - high	TRMM	35 °	X	X	X	X	X	X	X	X	X	X	X	X	X	X															
Rainradar		1 - primary	FY-3RM-1	50 °																			X	X	X	X	X	X					
Rainradar		1 - primary	FY-3RM-2	50 °																						X	X	X	X	X	X		
RainCube		4 - fair	ISS RainCube	51.6 °																	X	X	X	X									
DPR	No	1 - primary	GPM Core Observ	65 °													X	X	X	X	X	X	X										
CPR (CloudSat)		5 - marginal	CloudSat	13:30 asc					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
CPR (Earth-CARE)		5 - marginal	EarthCARE	14:00 desc																				X	X	X	X						

Sensors & Environments Capabilities

Cloud Top T

Source: WMO OSCAR Gap Analysis

Instrument	NRT?	Relevance	Satellite	Orbit
ABI	Yes	2 - very high	GOES-17	137.2°W
ABI		2 - very high	GOES-T	137°W
IMAGER (GOES 8-11		2 - very high	GOES-9	135°W
IMAGER (GOES 8-11		2 - very high	GOE	
IMAGER (GOES 8-11		2 - very high	GOE	
SOUNDER		2 - very high	GO	
SOUNDER		2 - very high	GOE	
SOUNDER		2 - very high	GOE	
VAS		2 - very high	GO	
VAS		2 - very high	GO	
VISSR		5 - marginal	GO	
VISSR		5 - marginal	GO	
VISSR		5 - marginal	SM	
IMAGER (GOES 12-1	Yes	2 - very high	GOE	
SOUNDER	Yes	2 - very high	GOE	
IMAGER (GOES 12-1	Yes	2 - very high	GOE	
SOUNDER	Yes	2 - very high	GOE	
VHRR (ATS)		5 - marginal	AT	
ABI		2 - very high	GOE	
ABI		2 - very high	GO	
IMAGER (GOES 12-1		2 - very high	GOE	
IMAGER (GOES 8-11		2 - very high	GO	
SOUNDER		2 - very high	GO	
SOUNDER		2 - very high	GOE	
VAS		2 - very high	GO	
VAS		2 - very high	GO	
MVIRI		3 - high	Meteosat	
VISSR		5 - marginal	GO	
VISSR		5 - marginal	SM	
IMAGER (GOES 12-1	Yes	2 - very high	GOE	
IMAGER (GOES 12-1		2 - very high	GOES-12	
IMAGER (GOES 8-11		2 - very high	GOES-10	
SOUNDER	No	2 - very high	GOE	
SOUNDER		2 - very high	GOES-10	
SOUNDER		2 - very high	GOES-12	
MVIRI		3 - high	Meteosa	
MSU-GS		2 - very high	Electr	
IRFS-GS		1 - primary	Electr	
MSU-GSM		2 - very high	Electr	
IRS		1 - primary	MT	
IRS		1 - primary	MT	
FCI		2 - very high	MT	
FCI		2 - very high	MT	
FCI		2 - very high	MT	
FCI		2 - very high	MT	
SEVIRI		2 - very high	Meteo	
MVIRI		3 - high	Mete	
MVIRI		3 - high	Mete	
MVIRI		3 - high	Mete	
MVIRI		3 - high	Mete	

Instrument	7	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045
ABI (GOES-17)		X	X	X	X	X	X	X	X	X	X	X	X																
ABI (GOES-T)				X	X	X	X	X	X	X	X	X	X	X	X														
IMAGER (GOES 8-11 (GOES-9)																													

Instrument	NRT?	Relevance	Satellite	Orbit
MVIRI		3 - high	Meteosat-5	0°
MVIRI		3 - high	Meteosat-6	0°
MVIRI		3 - high	Meteosat-7	0°
SEVIRI	Yes	2 - very high	Meteo	
SEVIRI		2 - very high	Meteo	
SEVIRI	Yes	2 - very high	Meteos	
SEVIRI		2 - very high	Meteosat-8	
MVIRI		3 - high	Meteosat-7	
MVIRI		3 - high	Meteosat-5	
MVIRI		3 - high	Meteosat-6	
IMAGER (INSAT)		2 - very high	INSAT-	
IMAGER (INSAT)		2 - very high	INSAT-	
SOUNDER (INSAT)		2 - very high	INSAT-	
SOUNDER (INSAT)		2 - very high	INSAT-	
VHRR (INSAT)		3 - high	INSAT	
VHRR (INSAT)		3 - high	INSAT	
VHRR (INSAT)		3 - high	INSAT	
VHRR (INSAT)		3 - high	INSAT	
VHRR (INSAT)		3 - high	Kalpa	
IRFS-GS		1 - primary	Electro	
MSU-GS	Yes	2 - very high	Electro	
MSU-GS		2 - very high	Electro	
MSU-GSM		2 - very high	Electro	
STR (Electro)		5 - marginal	Electro-	
S-VISSR (FY-2F/G/H	Yes	2 - very high	FY-2	
IMAGER (INSAT)	Yes	2 - very high	INSAT	
SOUNDER (INSAT)	Yes	2 - very high	INSAT	
MX-LWIR		2 - very high	GISA	
MX-LWIR		2 - very high	GISA	
VHRR (INSAT)		3 - high	INSAT	
GIIRS		1 - primary	FY-4	
GIIRS		1 - primary	FY-4	
GIIRS		1 - primary	FY-4	
AGRI		2 - very high	FY-4	
AGRI		2 - very high	FY-4	
AGRI		2 - very high	FY-4	
S-VISSR (FY-2C/D/E		2 - very high	FY-2	
S-VISSR (FY-2C/D/E	Yes	2 - very high	FY-2	
VHRR (INSAT)		3 - high	INSAT	
VHRR (INSAT)		3 - high	INSAT	
VHRR (INSAT)		3 - high	INSAT	
VHRR (INSAT)		3 - high	INSAT	
S-VISSR (FY-2F/G/H	Yes	2 - very high	FY-2	
GIIRS	Yes	1 - primary	FY-4	
GIIRS		1 - primary	FY-4	
GIIRS		1 - primary	FY-4	
GIIRS		1 - primary	FY-4	
AGRI	Yes	2 - very high	FY-4	
AGRI		2 - very high	FY-4	
AGRI		2 - very high	FY-4	

Instrument	NRT?	Relevance	Satellite	Orbit	7	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
AGRI		2 - very high	FY-4F	105°E														X	X	X	X	X	X	X	X							
S-VISSR (FY-2C/D/E		2 - very high	FY-2C	105°E																												
GHI		3 - high	FY-4B	105°E				X	X	X	X	X	X	X	X																	
S-VISSR (FY-2A/B)		3 - high	FY-2A	105°E																												
S-VISSR (FY-2A/B)		3 - high	FY-2B	105°E																												
S-VISSR (FY-2F/G/H	Yes	2 - very high	FY-2F	112°E	X	X	X	X																								
AMI	Yes	2 - very high	GEO-KOMPSAT-2A	128.2°E			X	X	X	X	X	X	X	X	X	X	X															
MI	Yes	2 - very high	COMS	128.2°E	X	X	X	X																								
JAMI		2 - very high	Himawari-6 (MTSA	140°E																												
VISSR (Himawari-5)		2 - very high	Himawari-5 (GMS-	140°E																												
VISSR (Himawari 1-		5 - marginal	Himawari-1 (GMS-	140°E																												
VISSR (Himawari 1-		5 - marginal	Himawari-2 (GMS-	140°E																												
VISSR (Himawari 1-		5 - marginal	Himawari-3 (GMS-	140°E																												
VISSR (Himawari 1-		5 - marginal	Himawari-4 (GMS-	140°E																												
AHI	Yes	2 - very high	Himawari-8	140.7°E	X	X	X	X	X	X	X	X	X	X	X	X	X															
AHI		2 - very high	Himawari-9	140.7°E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X													
IMAGER (MTSAT-2)	No	2 - very high	Himawari-7 (MTSA	145°E																												
IMAGER (GOES 8-11		2 - very high	GOES-9 (GMS bac	155°E																												
SOUNDER		2 - very high	GOES-9 (GMS bac	155°E																												
IRFS-GS		1 - primary	Electro-M N3	165.8°E													X	X	X	X	X	X	X	X	X	X	X					
MSU-GS		2 - very high	Electro-L N3	165.8°E				X	X	X	X	X	X	X	X	X	X															
MSU-GSM		2 - very high	Electro-M N3	165.8°E													X	X	X	X	X	X	X	X	X	X	X					
MSU-GS		2 - very high	Electro-L N4	166°E					X	X	X	X	X	X	X	X	X	X	X													
VIRS		4 - fair	TRMM	35 °																												
MERSI-2		2 - very high	FY-3RM-1	50 °				X	X	X	X	X	X																			
MERSI-2		2 - very high	FY-3RM-2	50 °							X	X	X	X	X	X																
ECOSTRESS		2 - very high	ISS ECOSTRESS	51.6 °		X	X	X	X	X	X																					
MSU-GS/A		2 - very high	Arctica-M N1	63.4 °				X	X	X	X	X	X																			
MSU-GS/A		2 - very high	Arctica-M N2	63.4 °							X	X	X	X	X	X																
MSU-GS/A		2 - very high	Arctica-M N3	63.4 °								X	X	X	X	X	X															
MSU-GS/A		2 - very high	Arctica-M N4	63.4 °									X	X	X	X	X	X														
MSU-GS/A		2 - very high	Arctica-M N5	63.4 °									X	X	X	X	X	X														
SI-GDR		3 - high	Meteor-P2	81.2 °																												
SM (Meteor-2)		4 - fair	Meteor-2-3	81.2 °																												
SM (Meteor-2)		4 - fair	Meteor-2-4	81.2 °																												
SM (Meteor-2)		4 - fair	Meteor-2-5	81.2 °																												
SM (Meteor-2)		4 - fair	Meteor-2-6	81.2 °																												
SM (Meteor-2)		4 - fair	Meteor-2-10	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-1	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-2	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-3	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-4	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-5	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-6	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-7	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-8	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-9	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-10	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-11	81.2 °																												
IR (Meteor-1)		5 - marginal	Meteor-1-12	81.2 °																												

And so on…

Russian Federation Earth-Observations Constellation Plans

Meteor-M N 2 Basic Instruments Specifications

Instrument	*Application*	*Spectral band*	*Swath-width (km)*	*Resolution (km)*
MSU-MR Low-resolution multi-channel scanning radiometer	Global and regional cloud cover mapping, ice and snow cover observation, forest fire monitoring	0,5 – 12,5μm (6 channels)	2900	1 x 1
KMSS Visible spectrum scanning imager	Earth surface monitoring for various applications (floods, soil and vegetation cover, ice cover)	0,4-0,9 μm (3+3 channels)	450/900	0,05/0,1
MTVZA-GY Imager-sounder (module for temperature and humidity sounding of the atmosphere)	Atmospheric temperature and humidity profiles, SST, sea level wind, etc.	10,6-183,3 GHz (26 channels)	1500	16 – 90
IKFS-2 Advanced IR sounder (infrared Fourier-spectrometer)	Atmospheric temperature and humidity profiles	5-15 μm	2000	35
"Severjanin-M"* X-band synthetic aperture radar	All-weather Ice coverage monitoring	9500-9700 MHz	600	0,5/1
GGAK-M Heliogeophysical measurements suite	Heliogeophysical data			
BRK SSPD Data collection system (DCS)	Data retransmission from DCPs			

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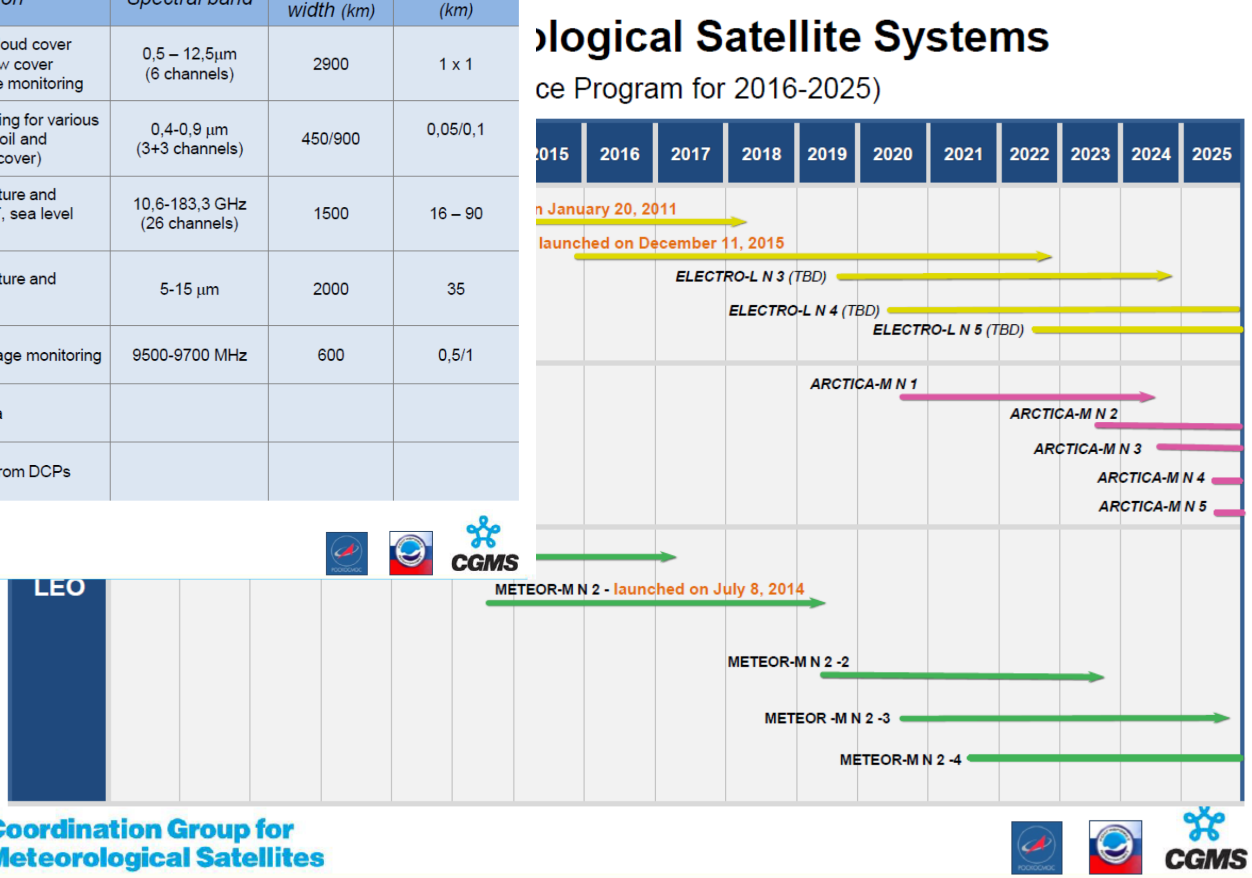
CGMS



Credit: Roscosmos/Roshydromet presentation at CGMS 2019.

India Plans (IMD and ISRO)

INSAT-3D Sounder Channels Characteristics

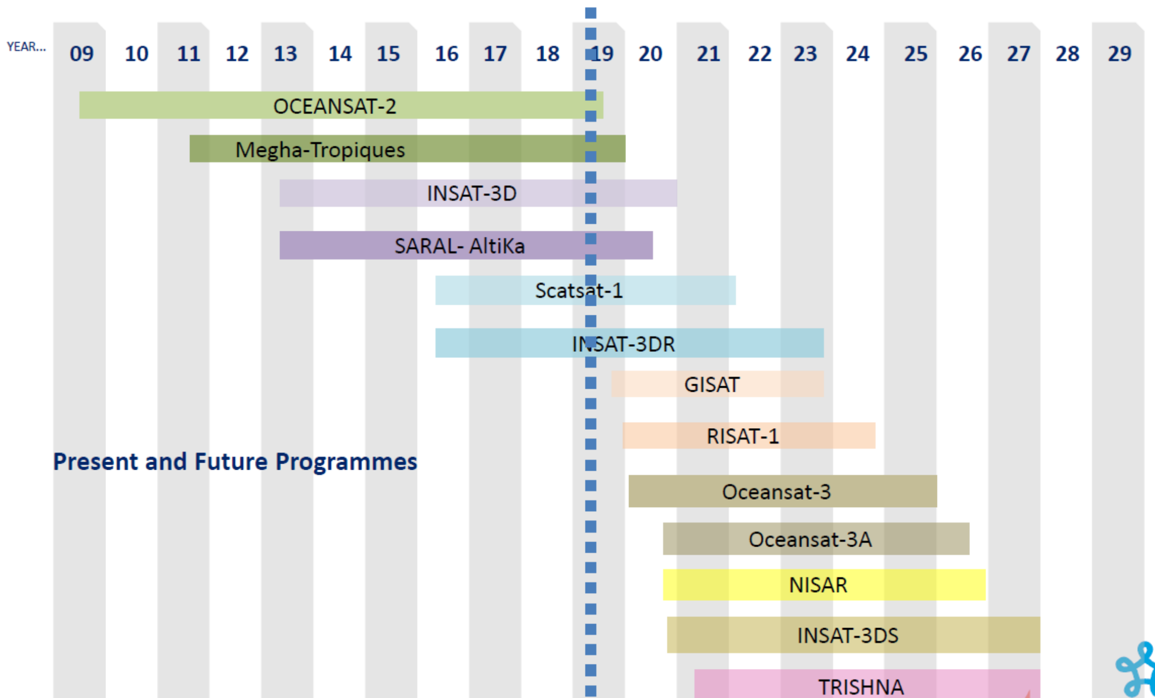
Detector	Ch. No.	λ_c (µm)	ν_c (cm^{-1})	NEΔT @300K	Principal absorbing gas	Purpose
Long wave	1	**14.67**	682	0.17	CO_2	*Stratosphere temperature*
	2	**14.32**	699	0.16	CO_2	*Tropopause temperature*
	3	**14.04**	712	0.15	CO_2	*Upper-level temperature*
	4	**13.64**	733	0.12	CO_2	*Mid-level temperature*
	5	**13.32**	751	0.12	CO_2	*Low-level temperature*

FUTURE GEO SATELLITES – INSAT-3DS

INSAT-3DS: India will launch this exclusive third meteorological satellite of this series in 2022.

Payloads	Channel	Resolution	Data Rate/Bandwidth
Imager	visible (0.52-0.77 µm)	1x1 Km	3.92725 Mbps
	.70 µm)	1x1 Km	
	0 µm)	4x4 Km	
	1 µm)	8x8 Km	
	1.3 µm)	4x4 Km	
	2.5 µm)	4x4Km	
	nel (14.71-12.02 µm)	10x10 Km	40.00 Kbps
	nnel (11.03-6.51 µm)		
	nel (4.57-3.74 µm)		
	µm)		
	5MHz		
	5MHz		

EXAMPLE - Overview - Planning of ISRO satellite systemsfor Oceans and Atmosphere



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Credit: IMD/ISRO presentation at CGMS 2019.

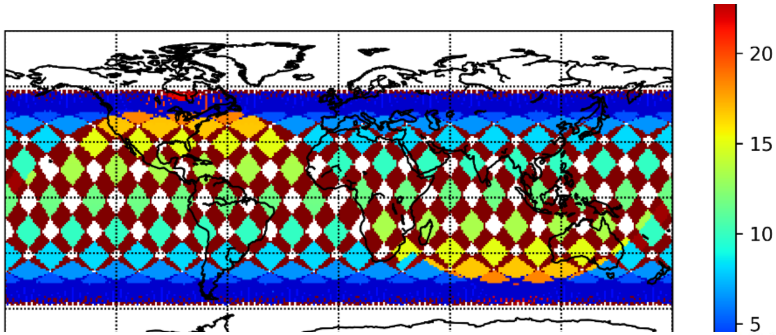
KMA Plans

- KMA will conduct feasibility study to decide the priority of GK3 payloads such as imager, sounder, and lightening mapper if possible. GK3 is planning to be launched around early 2028.
- As of the LEO, last year the KMA LEO program (MW sounder) was not approved by the decision of special feasibility test. And thus KMA will modify the LEO program including both IRS and MWS, and investigate the effect on KMA's NWP next year. The goal of KMA is to kick-off the LEO program in 2023 to be launched in around 2029.
- More concrete plan will be decided in late next year as of GK3, but LEO program still need more time for final decision.

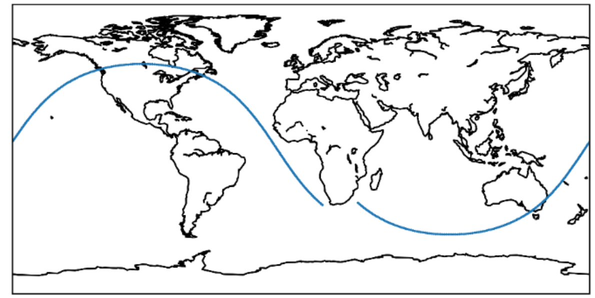
Credit: Personal Communication : Dohyeong Kim (Korean National Meteorological Satellite center)

Example of Temporal Resolution

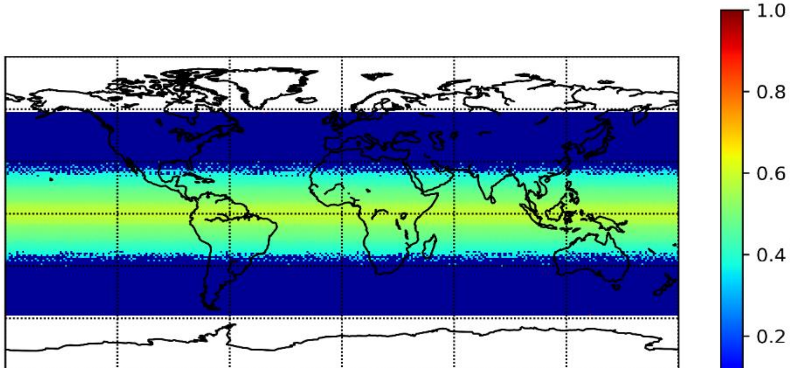
(Example based on SpaceX-type orbital configuration simulation of 1,24, :



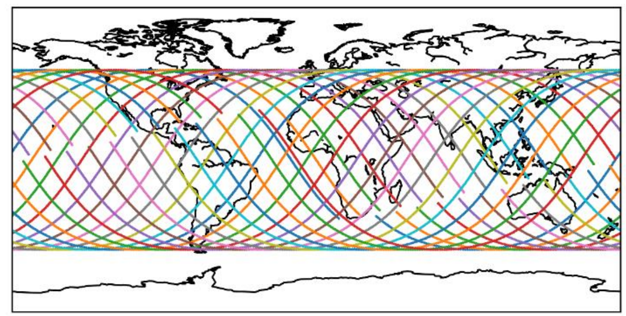
12h refresh rate in tropics



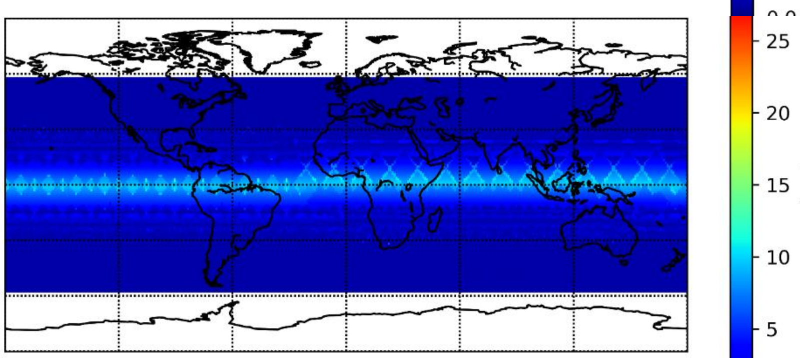
1 Orbit
1 Satellite



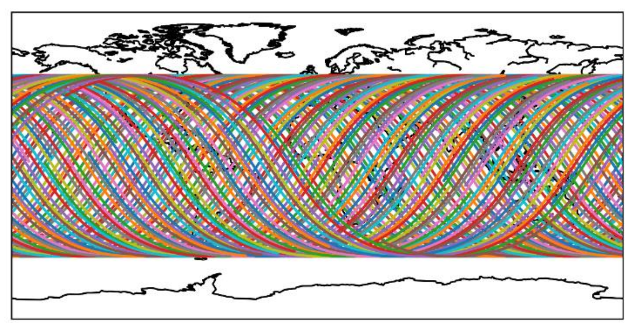
1/2h refresh rate in tropics



24 Orbits
1 Satellite



7 mins refresh rate in tropics

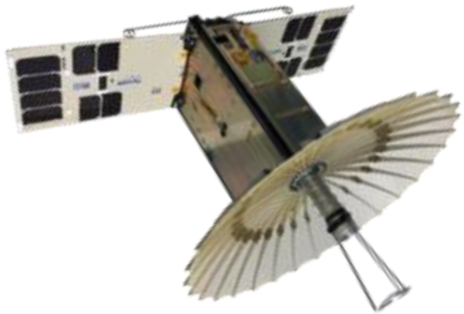


24 Orbits
4 Satellites

Refresh rate: 12/24/4= 7 minutes hour in Tropics

NASA Plans /Commercialization

Successful Recent Launches and Ops of Additional 6U CubeSats



Radar in a CubeSat (RainCube)
Jet Propulsion Laboratory

Precipitation Radar – Validate a new architecture for **Ka-band radars on CubeSat platform** and an ultra-compact deployable Ka-band antenna

Launched May 21, 2018
Deployed from ISS July 13, 2018
First Light August 27, 2018

Temporal Experiment for Storms and Tropical Systems Demonstration (TEMPEST-D)
Colorado State University

5 Frequency mm-Wave Radiometer – Technology demonstrator **measuring the transition of clouds to precipitation**

Launched May 21, 2018
Deployed from ISS July 13, 2018
First Light September 5, 2018

Coordination Group for Meteorological Satellites

Credit: NASA presentation at CGMS 2019. J. Kaye