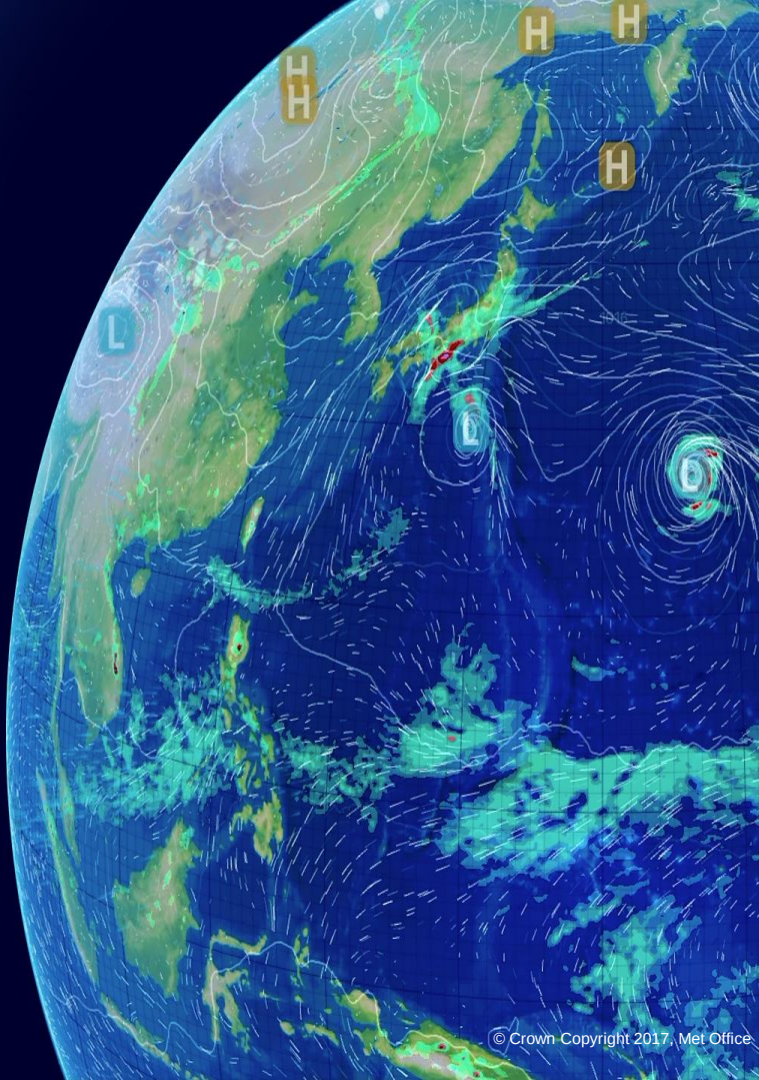
Evolution of global observing systems

John Eyre

ECMWF Seminar; Sept 2018



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Evolution of global observing systems

"… behind every weather, water and climate condition forecast, every disaster mitigated, and every prediction debated, are the observational data"

(WMO RA-V, 15th Session, May 2010, General summary)

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Evolution of global observing systems

- WIGOS Rolling Review of Requirements
  - WMO Vision for global observing systems in 2025
  - WIGOS Vision 2040
- Comparison of Vision with space agency plans
- Sharing observations
- Conclusions

WIGOS = WMO Integrated Global Observing System

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Evolution

or

Design ?

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The WIGOS Rolling Review of Requirements (RRR) process

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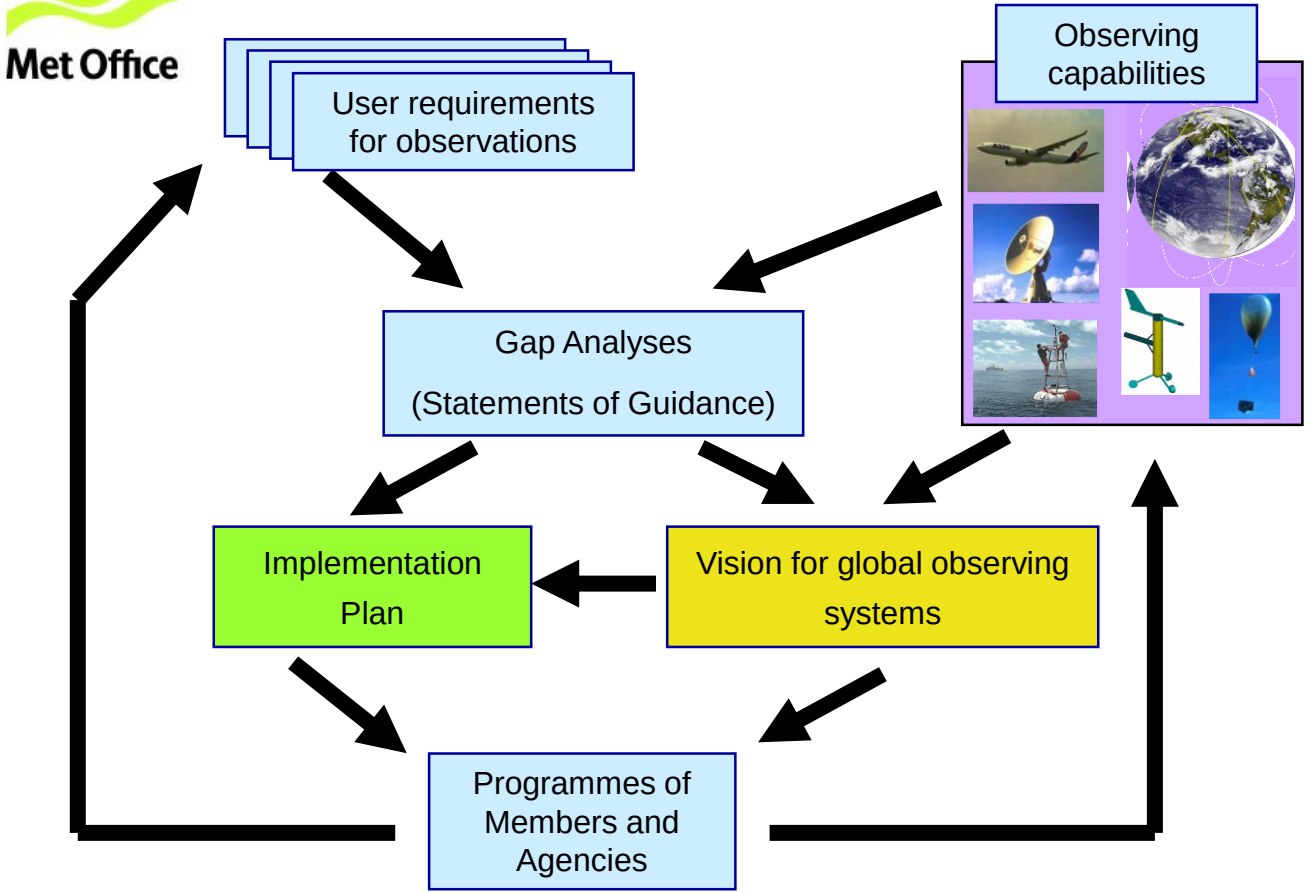
The WIGOS **RRR** process:
Rolling Review of Requirements



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RRR process: Application Areas

Global NWP
High-resolution NWP
Nowcasting
Sub-seasonal to Longer-range Forecasting
Aeronautical Meteorology
Forecasting Atmospheric Composition
Monitoring Atmospheric Composition
Atmospheric Composition info → services in urban and populated areas
Ocean Applications (Met-Ocean Forecasts and Services)
Agricultural Meteorology
Hydrology
Climate Monitoring (GCOS) - now including GFCS requirements
Climate Science
Space Weather

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RRR process: documentation

OSCAR (Observing Systems Capability Analysis and Review Tool)

User requirements:

http://www.wmo-sat.info/oscar/requirements

Space-based capabilities:

http://www.wmo-sat.info/oscar/spacecapabilities

Surface-based observing (under development):

https://oscar.wmo.int/OSCAR/index.html#/

Gap Analyses (Statements of Guidance, SoGs)

http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html#SOG

Vision:

http://www.wmo.int/pages/prog/www/OSY/gos-vision.html

Implementation Plan:

http://www.wmo.int/pages/prog/www/OSY/gos-vision.html#egos-ip

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WMO “Vision for global observing systems in 2025”

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Vision for the GOS in 2025

"challenging but achievable"

- General themes and issues
  - Response to user needs
  - Integration
  - Expansion
  - Automation
  - Consistency and homogeneity
- **Space-based component**
- **Surface-based component**
- System-specific trends and issues

(7 pages)

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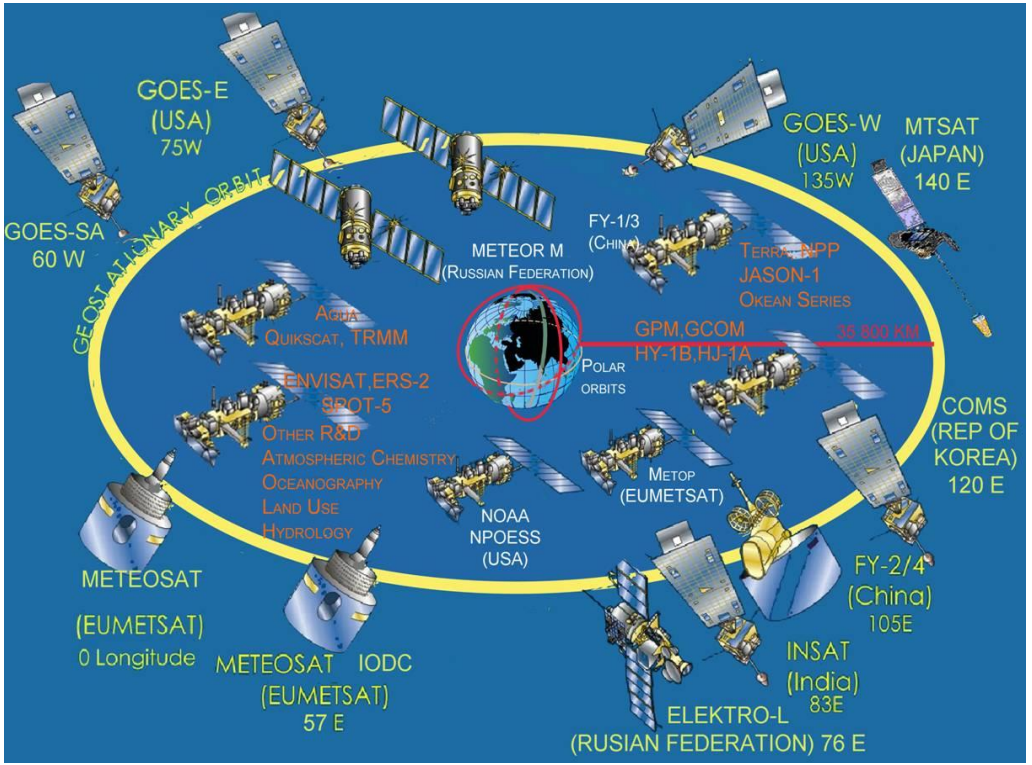
Vision 2025 - space-based component



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Vision 2025 - space-based component

- a high-level design

- Operational geostationary satellites
- Operational polar-orbiting sun-synchronous satellites
- Additional operational missions in appropriate orbits
- Operational pathfinders and technology demonstrators
- Polar and geo platforms/instruments for space weather

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Vision 2025 - space-based component

Operational geostationary satellites

– at least 6 – each with:

- **Infra-red/visible multi-spectral imager**
- **Infra-red hyper-spectral sounder**
- Lightning imager

Operational polar-orbiting sun-synchronous satellites

- in 3 orbital planes – each with:

- **Infra-red/visible multi-spectral imager**
- **Microwave sounder**
- **Infra-red hyper-spectral sounder**

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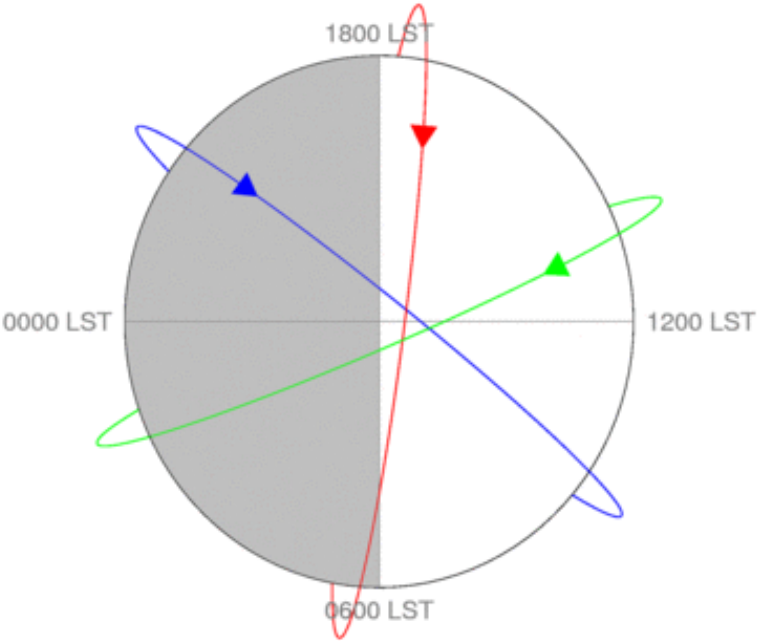
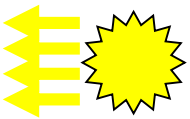
Vision for operational LEO satellites





- recommended baseline, with in-orbit redundancy

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Vision 2025 - space-based component

Met Office

Additional **operational** missions in appropriate orbits:

- **Microwave imagers,** at least 3
- **Scatterometers,** at least 2
- **Radio occultation constellation,** at least 8
- Altimeter constellation
- Infra-red dual-view imager – sea surface temperature
- Advanced visible/NIR imagers – ocean colour, vegetation
- Visible/infra-red imager constellation – land-surface
- Precipitation radars
- Broad-band visible/IR radiometers + total solar – radiation budget
- Atmospheric composition instruments, including UV LEO and GEO
- Synthetic aperture radar – waves, floods, sea-ice, …

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Vision 2025 - space-based component

Operational pathfinders and technology demonstrators:

- **Doppler wind lidar**
- **Low-frequency microwave radiometer** – salinity, soil moisture
- Microwave imager/sounder on geos - precipitation
- Advanced imagers on geos
- **Imagers on satellites in high-inclination, elliptical orbits**
- Gravimetric sensors – water: lakes, rivers, ground

Polar and geo platforms/instruments for space weather

- for solar imagery, particle detection, electron density

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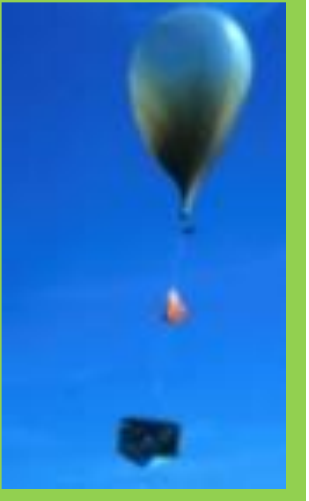
Vision 2025 - surface-based component

- a list of technologies



Vision 2025 - surface-based component

- Land – upper-air
  - Upper-air synoptic and reference stations
  - Remote sensing upper-air profiling remote stations
  - Aircraft
  - Atmospheric composition stations
  - GNSS receiver stations

- Land – surface
  - Surface synoptic and climate reference stations
  - Atmospheric composition stations
  - Lightning detection system stations
  - Application specific stations (road weather, airport/heliport weather stations, agromet stations, urban meteorology, etc.

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Vision 2025 - surface-based component

- Land – hydrology
  - Hydrological reference stations
  - National hydrological network stations
  - Ground water stations

- Land – weather radar
  - Weather radar station

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Vision 2025 - surface-based component

- Ocean – upper air
  - Automated Shipboard Aerological Platform (ASAP) ships
- Ocean – surface
  - HF coastal radars
  - Synoptic sea stations (ocean, island, coastal and fixed platform)
  - Ships
  - Buoys – moored and drifting
  - Ice buoys
  - Tide stations
- Ocean – sub-surface
  - Profiling floats
  - Ice tethered platforms
  - Ships of opportunity

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Vision 2025 - surface-based component

- R&D and Operational pathfinders – examples
  - UAVs
  - Gondolas
  - GRUAN stations
  - Aircraft
  - Instrumented marine animals
  - Ocean gliders

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Vision 2025 - surface-based component

- For each instrument type – list of variables observed
- System specific trends and issues
  - “The surface-based GOS will provide: …”
  - Radiosonde networks …
  - Aircraft observing systems …
  - Land-surface observations systems …
  - Surface marine observations …
  - Ocean sub-surface observing technology …
  - Remote-Sensing observing systems …
  - Lightning detection systems …
  - Surface-based observations of atmospheric composition …
  - … Nowcasting and very short-range forecasting …

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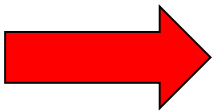
“Vision 2025”

Vision for global observing systems in 2025

(approved 2009)



Implementation Plan for the Evolution of Global Observing Systems: “EGOS-IP 2025” (approved 2013)

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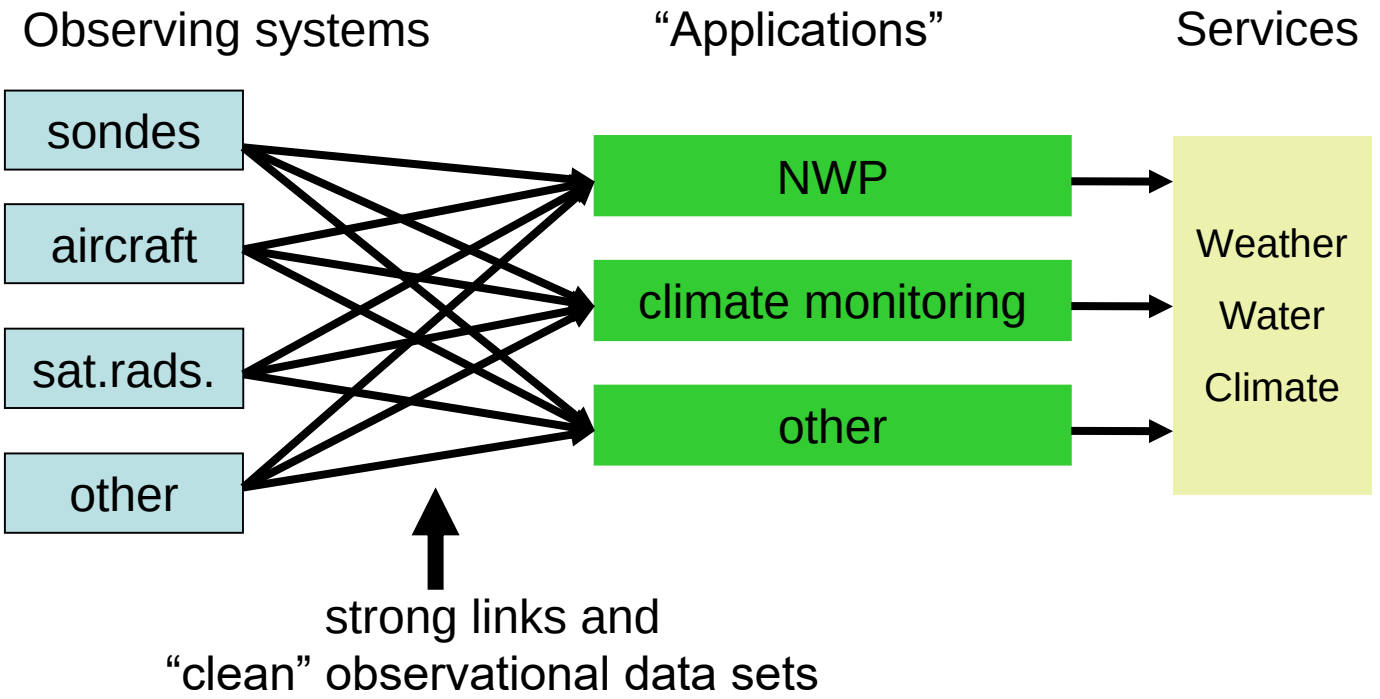
WIGOS - what will it deliver?



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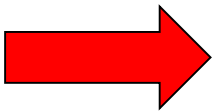
“Vision 2025”

Vision for global observing systems in 2025

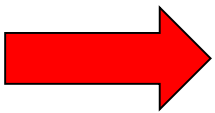
(approved 2009)



Implementation Plan for the Evolution of Global Observing Systems: “EGOS-IP 2025” (approved 2013)

“Vision for WIGOS in 2040”

(to be approved 2019)



Implementation Plan for WIGOS

(to be approved 2023)

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Vision 2040 - space-based component What's new? (1)

- Concepts
  - Backbone system, with specific orbit configuration and measurement approach
  - Backbone system, with open orbit configuration and flexibility to optimize the measurement approach
  - Operational pathfinders and technology demonstrators
  - Additional opportunities – WMO Members + 3rd parties – government, academic, commercial

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Vision 2040 - space-based component What's new? (2)

- Geo ring – including UV/VIS/NIR sounders
- LEO constellation – including MW imagers, scatterometers, night-time vis. imagers
- Other LEOs – more detail, including:
  - MW imager for surface temperature
  - MW temperature sounding for upper stratosphere and mesosphere
  - Atmospheric composition – more specific, including limb sounding
  - Precipitation **and cloud** radar
  - GNSS-R
  - Lidars: wind, aerosol, sea-ice thickness
  - Multi-angle, multi-polarisation imagery (aerosol and radiation)
  - Space weather – much more detail

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Vision 2040 - surface-based component
What's new?

- Upper-air – drone-based obs
- Near-surface land – carbon obs – above ground and soil
- Autonomous ocean surface vehicles
- Autonomous underwater vehicles
- Observations from platforms at submarine telecoms cables
- Cryosphere – more detail
- Space weather – more detail

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Comparison of “Vision 2025” with space agencies’ plans

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Comparing “Vision” and capabilities

Sources of information:

OSCAR/Space: http://www.wmo-sat.info/oscar/spacecapabilities

- programmes
- satellites
- instruments
- capability review – assessment of instruments by type
- gap analysis by variable

WMO satellite status list:
http://www.wmo.int/pages/prog/sat/satellitestatus.php

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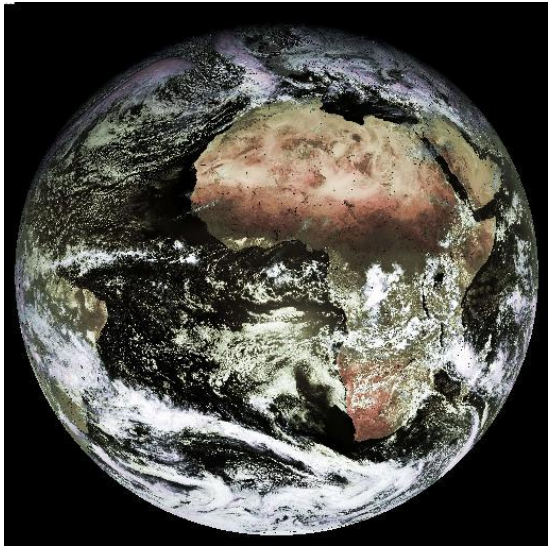
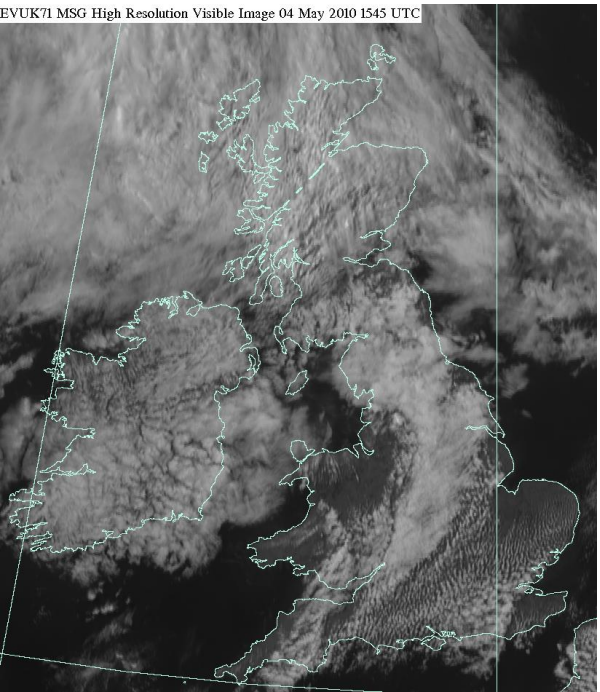
Operational geostationary satellites





Objectives

- weather in motion - nowcasting
- cloud cover and cloud height
- winds (from moving clouds)
- other cloud properties
- aerosols
- vegetation, snow, fire
- sea/land surface temperature

Operational geostationary satellites

	2018	→ 2025
E.Pacific	GOES-14,-15,-16,-17	GOES-T,-U
W.Atlantic		Electro-L N3
E.Atlantic	MSG: M-9,-10,-11	MTG-I1,-I2,-S1
Indian Ocean	Met-8 INSAT-3DR Kalpana-1 Electro-L N2 FY-2H INSAT-3D FY-2E,-2G FY-4A	MSG? INSAT-3DS Electro-L N5 FY-4B,-4C,-4D
W.Pacific	FY-2F1 COMS Himawari-8,-9	GEO-KOMSAT-2A,-2B Himawari-8,-9(?) Electro-L N4

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Operational geostationary satellites in 2025 (1)

satellite series	Vis/IR imager	Hyperspectral IR sounder	Lighting imager
MSG	**SEVIRI (12 ch)**	**no**	**no**
MTG	**FCI (16 ch)**	**IRS**	**LI**
GOES-R	**ABI (16 ch)**	**no**	**GLM**
Himawari	**AHI (16 ch)**	**no**	**no**
FY-4	**AGRI (14 ch)**	**GIIRS**	**LMI**
INSAT-3DS	**IMAGER (6 ch)**	**no (low-res SOUNDER)**	**no**
GEO-KOMSAT-2	**AMI (16 ch)**	**no**	**no**
Electro-L	**MSU-GS (10 ch)**	**no**	**no**

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Operational geostationary satellites in 2025 (2)

	Vis/IR imager	Hyperspectral IR sounder	Lighting imager
E.Pacific	**YES**	**?**	**YES**
W.Atlantic	**YES**	**?**	**YES**
E.Atlantic	**YES**	**YES**	**YES**
Indian Ocean	**YES**	**YES**	**YES**
W.Pacific	**YES**	**?**	**?**

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Operational geostationary satellites in 2025 (3)

Issues:

- Coverage of IR sounding and LI
- Quality of AMVs
- IR sounder maturity / back up
- Others ??

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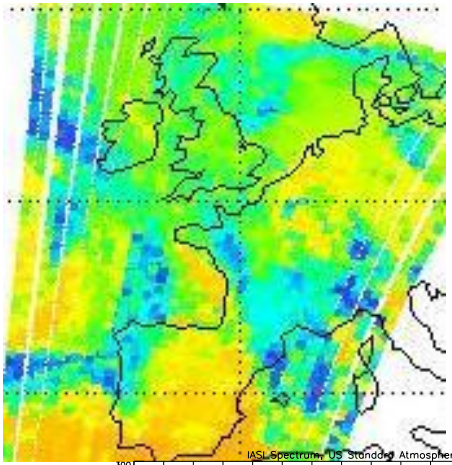
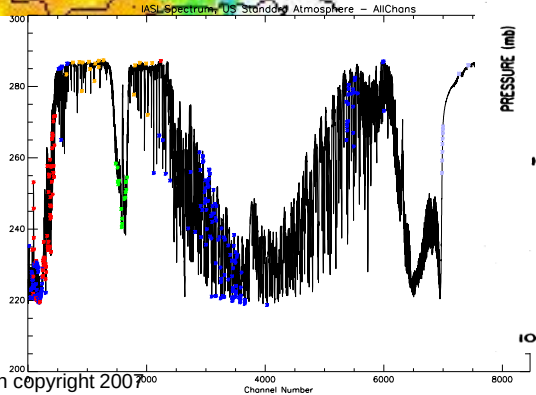
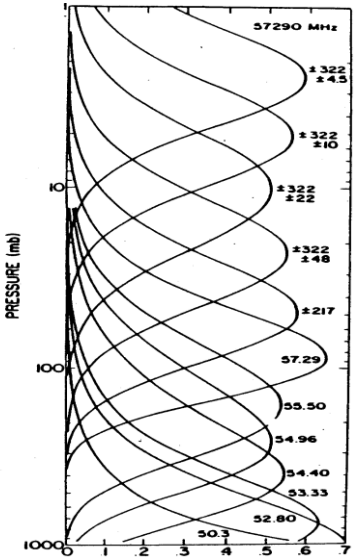
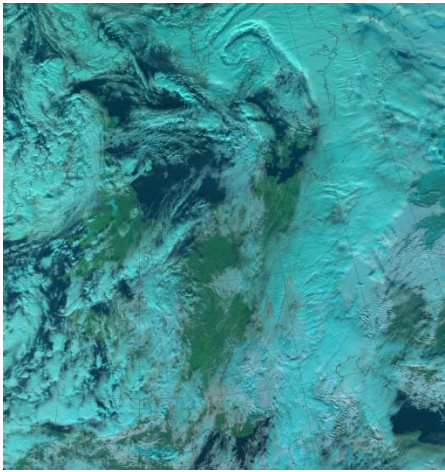
Operational polar-orbiting sun-synchronous satellites

- hyperspectral IR sounding
- MW sounding
- vis/IR imagery









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Operational polar-orbiting sun-synchronous satellites

	2018	→ 2025
Early morning (LECT ~1730)	DMSP F-17,-18 NOAA-15 NOAA-18	(DMSP F20) FY-3E,-3H
Morning (LECT ~0930)	Metop-A,-B FY-3C Meteor-M N2	Metop-C Metop-SG Meteor-M N2-2, N2-4 FY-3F
Afternoon (LECT ~1330)	NOAA-20, Suomi-NPP FY-3B,-3D	JPSS-2 FY-3G
(LECT ~1530)	NOAA-19 DMSP F-16	Meteor-M N2-3

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Operational polar-orbiting sun-synchronous satellites in 2025 (1)

satellite series	Hyperspectral IR sounder	MW sounder	Vis/IR imager
Metop-SG-A	**IASI-NG**	**MWS**	**METimage**
Metop	**IASI**	**AMSU-A, MHS**	**AVHRR**
JPSS	**CrIS**	**ATMS**	**VIIRS**
FY-3	**HIRAS**	**MWTS-3, MWHS-2**	**MERSI-2**
FY-3RM	**no**	**MWTS-3, MWHS-2**	**MERSI-2**
Meteor-M N2	**IKFS-2**	**MTVZA-GY**	**MSU-MR**
Meteor-MP	**IKFS-3**	**MTVZA-GY-MP**	**MSU-MR-MP**
DMSP	**no**	**SSMIS**	**OLS**

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Operational polar-orbiting sun-synchronous satellites in 2025 (2)

	Vis/IR imager	Hyperspectral IR sounder	MW sounder
Early morning	**YES?**	**YES?**	**YES?**
Morning	**YES**	**YES**	**YES**
Afternoon	**YES**	**YES**	**YES**

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Operational polar-orbiting sun-synchronous satellites in 2025 (3)

Issues:

- Early morning orbit: FY-3E → FY-3H?
- Continuity – vulnerability to early failure
- Operational back-up – preparations?
- Upper atmosphere sounding (UAS) channels, following SSMIS
- MW sounders – NEdT marginal
- Others??

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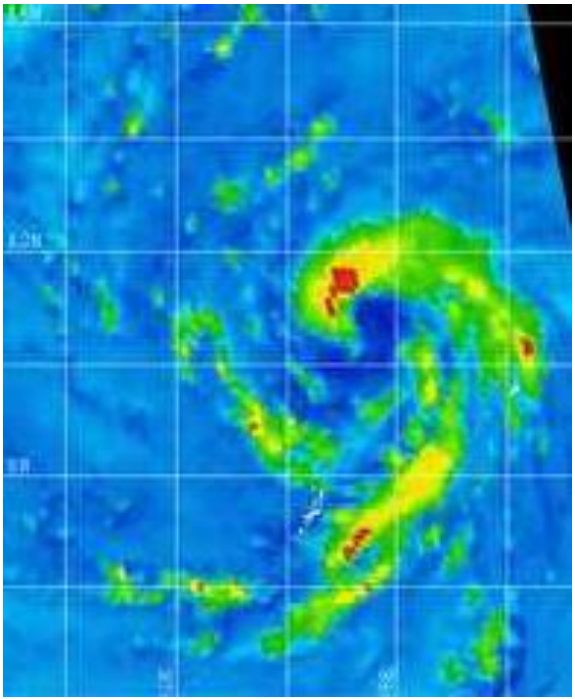
Microwave Imagery

Objectives

- cloud and precipitation
- total column water vapour
- sea-ice, snow, sea surface wind
- SST, soil moisture



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Microwave imagers - 2018

satellites	instrument	channels (GHz)
DMSP F15	**SSM/I**	19-85
DMSP F16,F17,F18, F19	**SSMIS**	19-183, incl.50-60
TRMM	**TMI**	10-85
Coriolis	**Windsat**	6.8-37
GCOM-W1	**AMSR-2**	6.9-89
FY-3B,-3C,-3D	**MWRI**	10-89
Megha-Tropiques	**MADRAS**	18-157
GPM Core	**GMI**	10-183
Meteor-M N2	**MTVZA-GY**	10-183, incl.50-60
HY-2A,-2B	**MWI**	6.6-37

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Microwave imagers - 2025

satellite series	instrument	channels (GHz)	
DMSP	**SSMIS**	19-183, incl.50-60	
GCOM-W ?	**AMSR-2**	6.9-89	→ 2025 ?
GPM-Core ?	**GMI**	10-183	→2018+
HY-2	**MWI**	6.6-37	→ 2028
FY-3, FY-3RM	**MWRI**	10-89	→ 2028
Metop-SG-B	**MWI**	18-183, incl.50-54,118	2022→
Metop-SG-B	**ICI**	183-664	2022→
DWSS	**MIS**	6.3-183, incl.50-60	??
Meteor-M	**MTVZA-GY**	10-183, incl.50-60	→2028
Meteor-MP	**MTVZA-GY-MP**	6.9-183, incl.50-60	2021-2030

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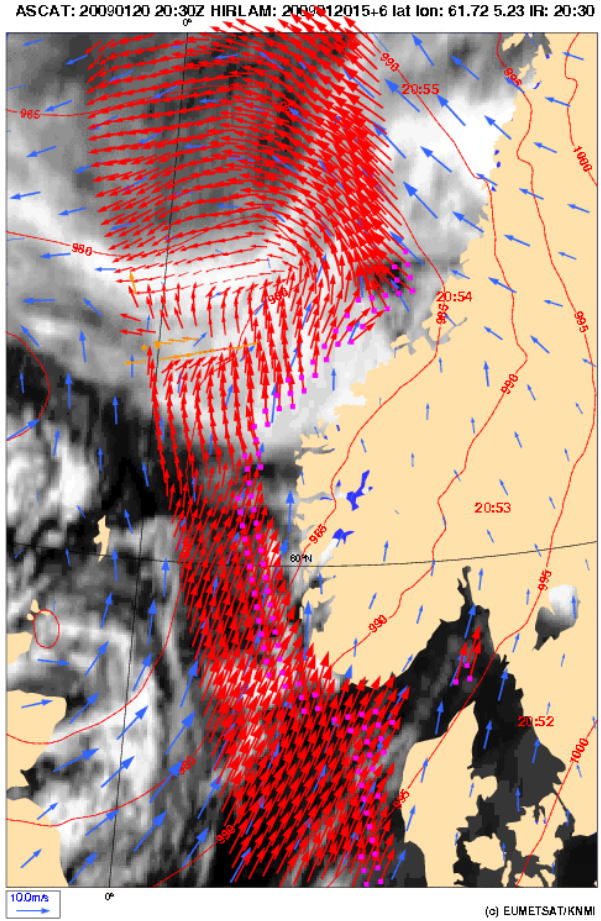
Scatterometry

Objectives

- ocean surface wind speed and direction
- soil moisture
- snow equivalent water
- sea-ice type



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Scatterometers - 2018

satellites	instrument	
Metop-A,-B	**ASCAT**	C-band
ScatSat-1	**OSCAT**	Ku-band
ISS RapidScat	**RapidScat**	Ku-band
HY-2A	**SCAT**	Ku-band

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Scatterometers - 2025

satellite series	instrument		
Metop	**ASCAT**	C-band	→2024+?
Metop-SG-B	**SCA**	C-band	2022→
FY-3E,-3H	**WindRad**	C+Ku-band	2019-29
HY-2	**SCAT**	Ku-band	→ 2027+
Meteor-M N3	**SCAT**	Ku-band	2021-26
ScatSat-1	**OSCAT**	Ku-band	2016-21
CFOSAT, -FO?	**SCAT**	Ku-band	2018-27?
OceanSat-3,-3A	**OSCAT**	Ku-band	2019-24

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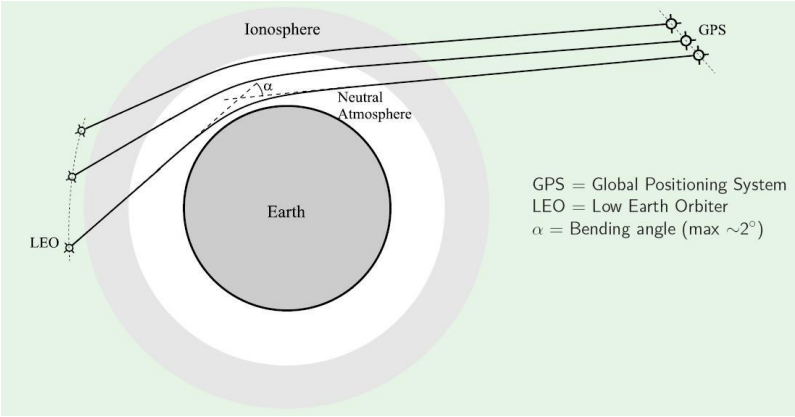
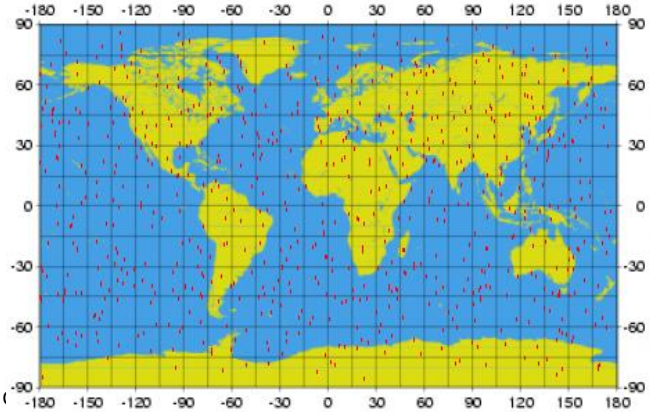
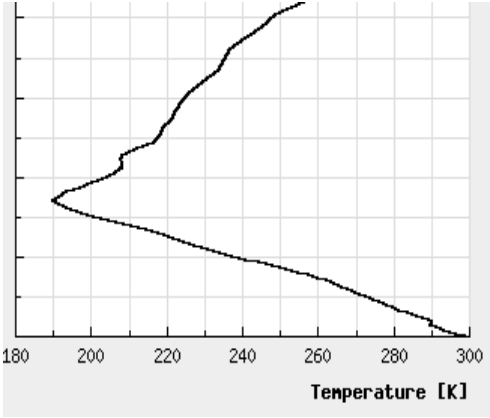
Radio occultation

Objectives

- refractivity profiles at high vertical resolution
  - temperature / humidity profiles
- ionospheric electron content







Radio occultation – 2018

Total:

9 receivers

~1800 occultations per day

(Nov 2015)

satellites	instrument	
COSMIC	**IGOR**	~1 satellites
Metop-A and -B	**GRAS**	
GRACE-A or -B	**Blackjack**	
TerraSAR-X	**IGOR**	
Tandem-X	**IGOR**	
FY-3C	**GNOS**	
Oceansat-2	**ROSA**	
Megha-tropiques	**ROSA**	
KOMPSAT-5	**AOPOD**	

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Radio occultation - 2025

WMO EGOS-IP says:

“ at least 10000 occultations per day”

satellite series	instrument		
COSMIC-2A	**Tri-G**	6 sats	2018-25?
Metop-C	**GRAS**		→ 2026+?
Metop-SG	**RO**	2 sats	2021-30+
FY-3	**GNOS**		→ 2029+?
Meteor-M N3	**Radiomet**		2020-25
Meteor-MP	**ARMA-MP**		2021-30
JASON-CS	**Tri-G**	2 sats	2020-30+
SEOSAR/Paz	**ROHPP**		2018-23
GRACE-FO	**Tri-G**	2 sats	2018-23
Commercial ?	**?**	?	?

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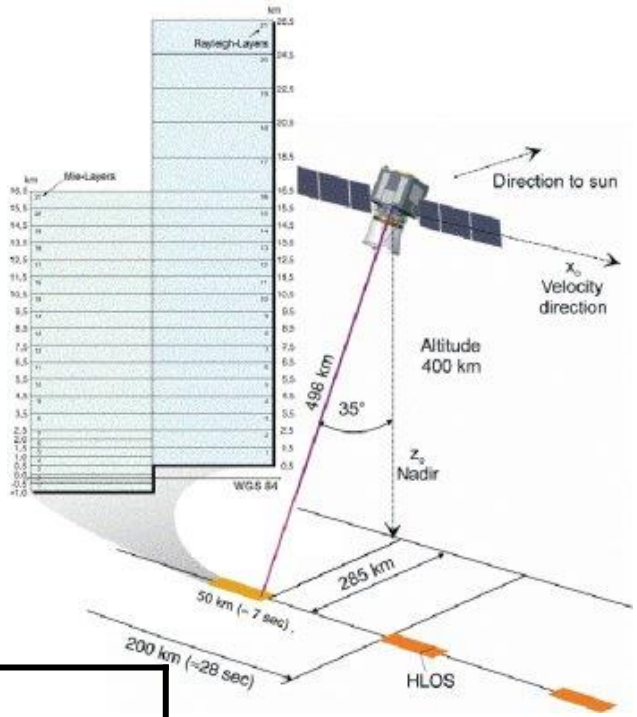
Doppler wind lidar

Objectives

- wind profiles (line-of-sight)
- profiles of cloud and aerosol
- aerosol properties
- boundary layer height



satellites	instrument	
ADM-Aeolus	**ALADIN**	2018-21
3D-Winds	**3D-Winds lidar**	???

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Low frequency microwave – ~1.4 GHz

Objectives

- soil moisture
- sea surface salinity
- sea surface wind (high wind speed)
- sea ice thickness (thin ice)

satellites	instrument	
SMOS	**MIRAS**	2009-18+
SAC-D	**Aquarius**	2011-15
SMAP	**SMAP**	2015-18+

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Cloud and precipitation radar

satellites	instrument	frequency (GHz)	
TRMM	**PR**	13.8	1997-2015
Cloudsat	**CPR**	94	2006-18+
GPM-Core	**DPR**	13.6 + 35.6	2014-18+
EarthCARE	**CPR**	94	2021-24
FY-3RM-1, -2	**Ku/Ka-PR**	? 12-18 + 26-40 ?	2020-28

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Imagers on satellites in high-inclination elliptical orbits

satellites	instrument		
Arctica-M N	**MSU-GS/A**	10 channels	2019-30
PCW-1, -2	**ISR**	21 channels	2022-29

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Additional operational missions and operational pathfinders in 2025

SUMMARY

MW imagers	**7+**	needed for GPM concept
Scatterometers	**4+**	
RO	**15+**	EGOS-IP calls for >10,000 occs. per day
DWL	**?**	
Low-freq. MW	**?**	
Cloud+precip radar	**1**	FY-3RM/KuKaPR
Imagers in HEO	**2?**	Arctica

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Other applications

- Focus here has been on operational NWP
- Most technologies covered are also important for other applications
- … but other technologies also needed for:
  - Atmosphere: atmospheric composition
  - Ocean: SST, SSH, ice thickness, ocean colour
  - Land surface
  - Earth Radiation Budget
  - Space Weather
- Similar analysis needed for these applications
- Generally, more gaps for other applications

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Sharing observations

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Observing Network Design Principles for WIGOS

1. Serving many Application Areas
2. Meeting user requirements
3. Meeting national, regional and global requirements
4. Designing appropriately spaced networks
5. Designing cost-effective networks
6. Achieving homogeneity in observational data
7. Designing through a tiered approach
8. Designing reliable and stable networks
9. Making observational data available
10. Providing information so that the observations can be interpreted
11. Achieving sustainable networks
12. Managing change

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Some issues

- Data availability!

- Keys gaps remains:
  - some for operational meteorology
  - more for climate monitoring and other applications
  - several vulnerabilities to early failure

- Role of NWP centres in helping space agencies

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Conclusions

- Space agencies' plans provide a good response to the "WMO Vision for 2025"
  - ... with some gaps for operational meteorology
  - ... and more gaps for climate monitoring and other applications
- Surface observations remain crucial – many important requirements for NWP and related applications cannot be met from space
- Continued efforts needed to make observational data available for our community

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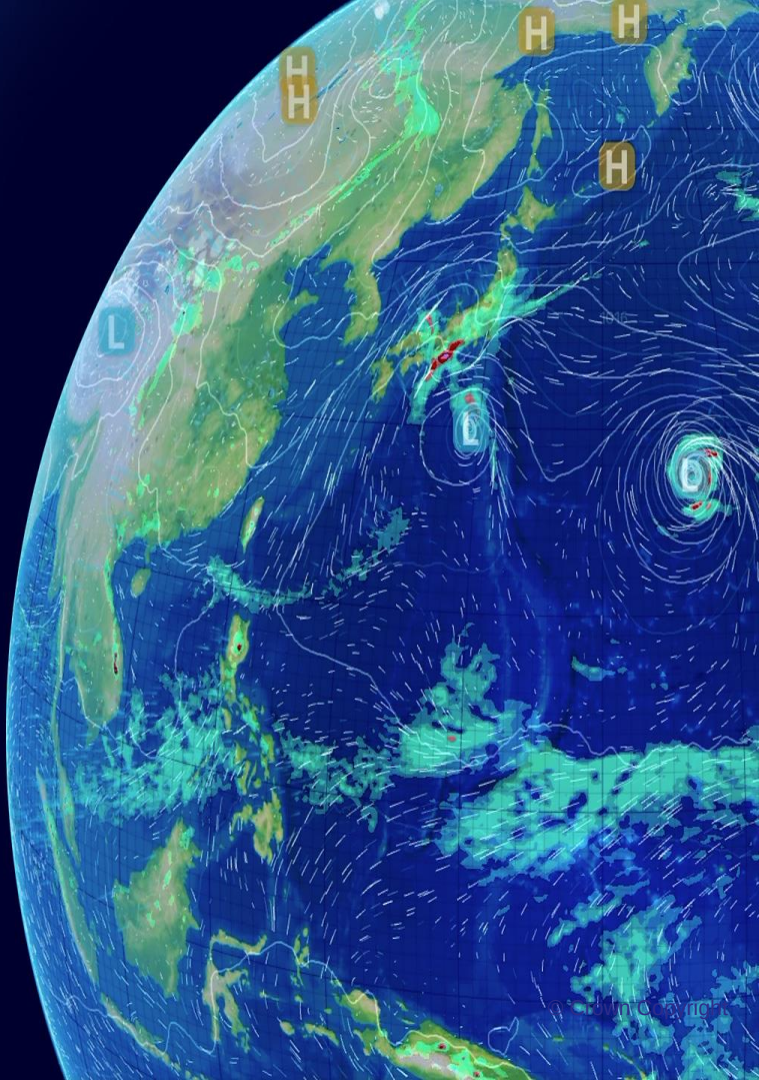
Met Office

Thank you!

Questions?



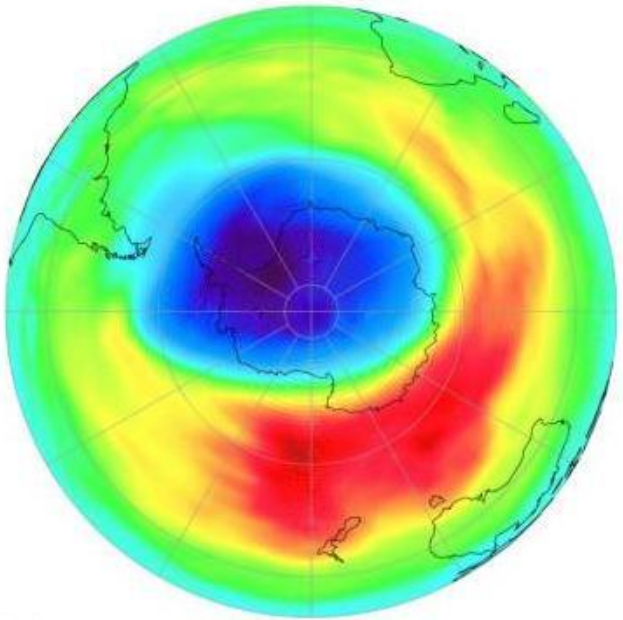
www.metoffice.gov.uk
2017, Met Office

Nadir-viewing UV-SWIR spectrometry
UVNS (Sentinel-5 on Metop-SG)

Heritage: GOME-2 (Metop)

Objectives

- ozone profile and column
- columns of SO_2, NO_2, H_2O, CO, CH_4
- aerosol optical depth
- columns of BrO, HCHO, OCHCHO
- column of CO_2



Implementation:

- EU's GMES Sentinel-5

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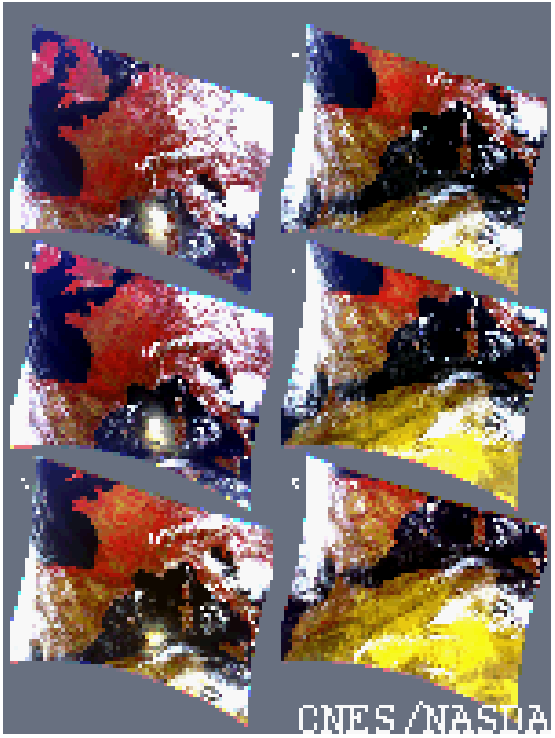
Multi-viewing multi-channel multi-polarisation imaging 3MI (on Metop-SG)

Heritage: POLDER (ADEOS)

Objectives

- aerosol – optical thickness, particle size, type, height, absorption
- cloud phase, height, optical depth
- surface albedo, ocean colour



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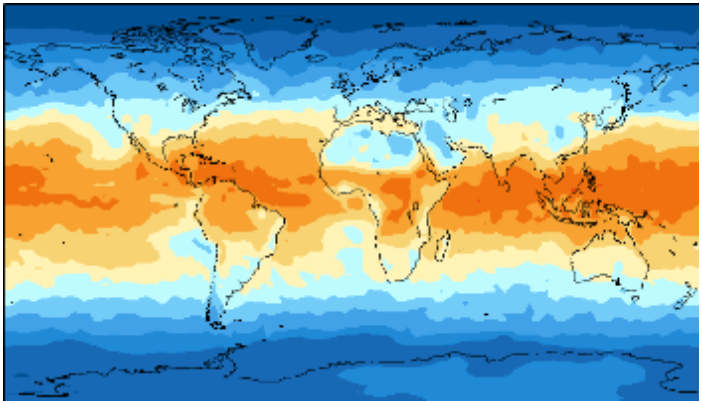
Radiant budget instrument
CERES, RBI

Heritage: ERB

Objectives

- outgoing longwave and shortwave radiant energy at top of atmosphere



Implementation

- NOAA-20
- JPSS
- FY-3

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Total solar irradiance monitor
TSIS, SIM, SIM-2

Heritage: SORCE

Objectives

- incoming solar radiation top of atmosphere

Implementation

- ISS
- CSIM
- FY-3

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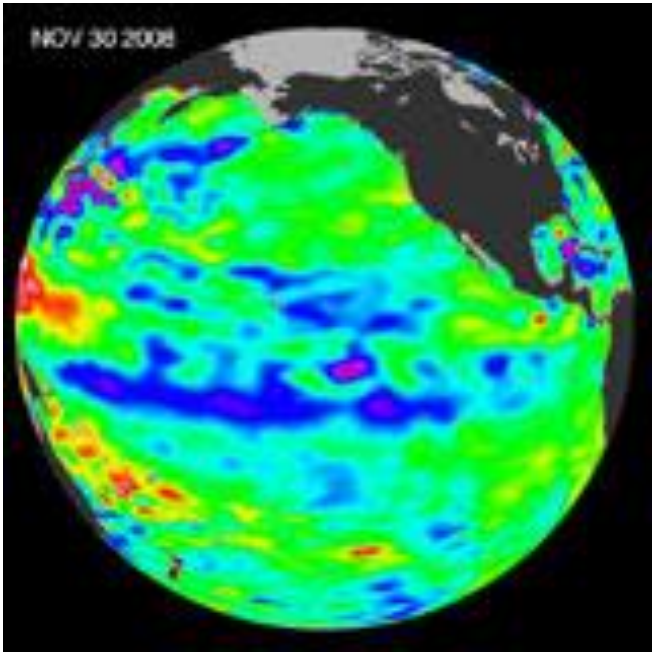
Altimetry
ALT

Objectives

- ocean topography
  - ocean currents, sea level, …
- sea state
- sea/land-ice topography



Implementation:

- Jason, Jason-CS
- Sentinel-3
- FY-2
- CFOSAT
- SWOT

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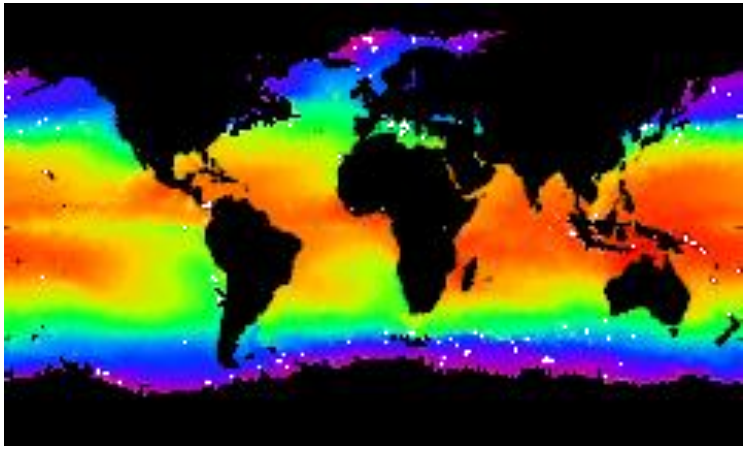
Dual-view radiometry
DVR

Objectives

- sea surface temperature (climate quality)
- land surface temperature
- vegetation index, cloud imagery, aerosols

Implementation:

- ERS-1 and -2: ATSR
- ENVISAT: AATSR
- Sentinel-3: SLSTR



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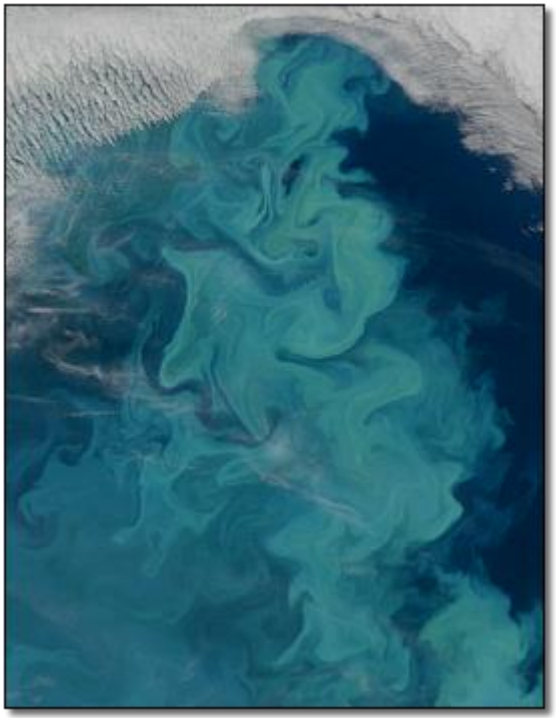
Ocean colour imagery
OCI

Objectives

- chlorophyll , yellow substance, water sediment, algal blooms
- vegetation index, cloud imagery, aerosols
- total column water vapour over land



Implementation:

- SeaWIFS, MERIS
- OLCI on Sentinel-3
- HY-2

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Implementation of the Vision

- Vision
  - a realistic aspiration and target for 2025
  - endorsed by WMO/CBS in 2009

- Implementation Plan
  - … for the Evolution of Global Observing Systems, EGOS-IP
  - responds to the Vision
  - provides guidance for Members and partner consortia
  - proposes roles for fulfilling the new Vision
  - sets out “road-map” for achieving it
  - ~120 pages, 115 Actions
  - endorsed by WMO/CBS in 2012

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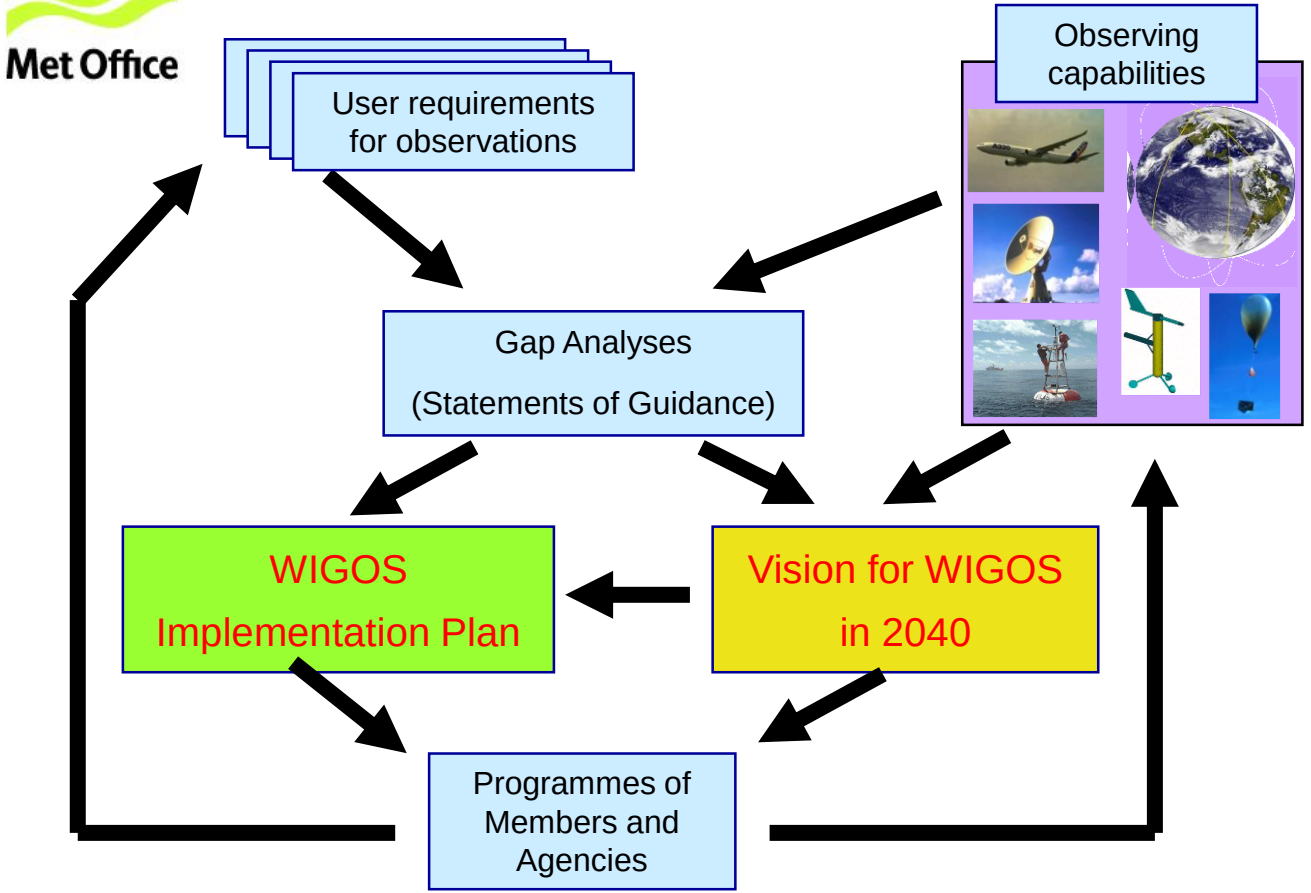
The WIGOS **RRR** process:
Rolling Review of Requirements



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Vision for WIGOS in 2040: plan for drafting, review and approval

- 2014-16 Draft Vision 2040 Space developed
- Nov 2015 Vision 2040 Space Workshop, Geneva
- 2016-17 Draft Vision 2040 Surface developed
  - input from new GCOS-IP noted
  - to be done for space-based component
- Oct 2016 Vision 2040 Surface Workshop, Geneva
- Nov 2016 Draft Visions (surface and space) → CBS
- 2017 Combined surface/space Vision drafted
- Jan 2018 Progress reviewed by ICG-WIGOS-7
- ➢ Early 2018 Combined surface/space Vision consolidated
- 2018-19 Consultation – all stakeholders
- June 2018 Endorsed by WMO/EC-70
- 2018 Endorsed by CBS-Ext
- 2019 Approved by WMO Congress-18

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WIGOS Implementation Plan (WIGOS-IP)

Expectation

- 2019 WMO Congress-18 approves Vision for WIGOS
- 2019 WMO Congress-18 requests development of WIGOS-IP
- 2023 WMO Congress-19 approves WIGOS-IP

WIGOS-IP – main inputs:

- Vision for WIGOS in 2040
- EGOS-IP / 2025
- IPs of partners: GCOS-IP, GCW-IP, etc.

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Vision 2040 - surface-based component

- Preamble
- Section 1. General trends and issues
- Section 2. The surface-based component - a table listing:
  - instrument/observations types,
  - the geophysical variables that they measure,
  - **their expected trends and evolution**
- Section 3. **Application-specific and other issues**

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Vision 2040 - surface-based component

Preamble

- High level goals to guide evolution of WIGOS
- Link to WMO Strategic Plan
- Using existing, new and emerging technologies
- Leading to better data, products and services from NHMSs
- WMO, working with partners
- Major changes → science, IT, products, training, …
- Rapid changes in implementation agents …
- … but principles of sharing observations remain
- Supersedes Vision 2025 – reflects broader scope of WIGOS; updates on observing technologies and their development
- To be combined with Vision 2040 Space

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Vision 2040 - surface-based component

Section 1. General trends and issues

- Response to user needs
- Integration
- Expansion
- Automation and technology trends
- Consistency, **continuity** and homogeneity

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Vision 2040 - surface-based component

Section 2. The surface-based component - Table

Instrument / observation type	Geophysical variables and phenomena	Evolution and trends

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Vision 2040 - surface-based component

Section 2. The surface-based component (1)

- Upper-air observations
  - Upper-air weather and climate observations
  - Aircraft-based observations
  - Remote sensing upper-air observations
  - Atmospheric composition upper-air observations
  - GNSS receiver observations
  - Lightning detection systems
  - Weather radars
  - Automated Shipboard Aerological Platform (ASAP) observations
  - **Drone-based observations**

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Vision 2040 - surface-based component

Section 2. The surface-based component (2)

- Near-surface observations over land
  - Surface weather and climate observations
  - Atmospheric composition surface observations
  - Applications-specific observations (road weather, airport/heliport weather stations, agromet stations, urban meteorology, etc.)
  - **Carbon observations: above ground and soil**

- Near-surface observations over rivers and lakes
  - Hydrological observing stations
  - Ground water observations

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Vision 2040 - surface-based component

Section 2. The surface-based component (3)

- Near-surface observations over ocean
  - Ground-based observing stations at sea (ocean, island, coastal and fixed platform/station locations)
  - Ship observations
  - Buoy observations – moored and drifting
  - Sea-level observations
  - **Autonomous ocean surface vehicles**

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Vision 2040 - surface-based component

Section 2. The surface-based component (4)

- Ocean underwater observations
  - Profiling floats
  - **Autonomous underwater vehicles (e.g. gliders)**
  - Sub-surface observations from drifting and moored buoys
  - Ships of opportunity
  - **Observations from platforms at submarine telecommunication cables**
  - Ice-tethered platform observations

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Vision 2040 - surface-based component

Section 2. The surface-based component (5)

- Cryospheric observations over sea-ice
  - Ice buoy observations
  - …
- Cryospheric observations over ice sheets and glaciers
  - Ice buoys observations
  - …
- Other cryospheric observations
  - Permafrost observations
  - …

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Vision 2040 - surface-based component

Section 2. The surface-based component (6)

- Space weather observations
  - Solar optical observations
  - Solar radio observations
  - Ionospheric observations – ionosonde
  - Ionospheric observations – riometer
  - Ionospheric observations – GNSS
  - Geomagnetic observations
  - Cosmic ray observations

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Vision 2040 - surface-based component

Section 2. The surface-based component (7)

- R&D and operational pathfinders - examples
  - Unmanned aeronautical vehicles (UAVs)
  - Aircraft-based observing systems and airborne platforms
  - Observations from gondolas
  - [Chemistry] ?
  - … Ionospheric observations – GNSS
  - More ?

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Vision 2040 - surface-based component

Section 3. Application-specific and other issues

- Retaining expertise on instrument specification and design
- Open access to observational data pre-processing info
- RFI issues
- …
- Application-specific key points
  - NWP
  - Nowcasting
  - Climate monitoring
  - …
  - [potentially all Application Areas within RRR]

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