WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

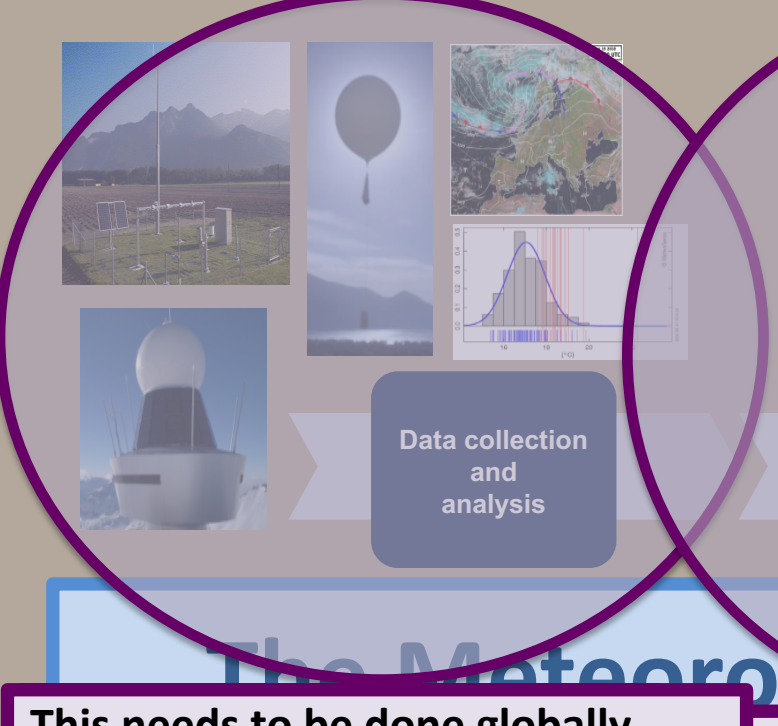
Considerations for future space-based microwave observations

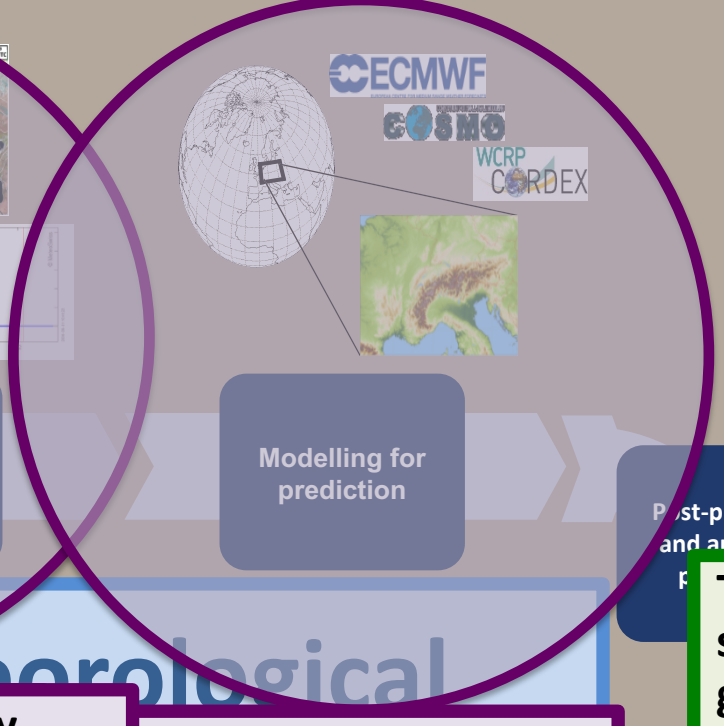
Ken Holmlund

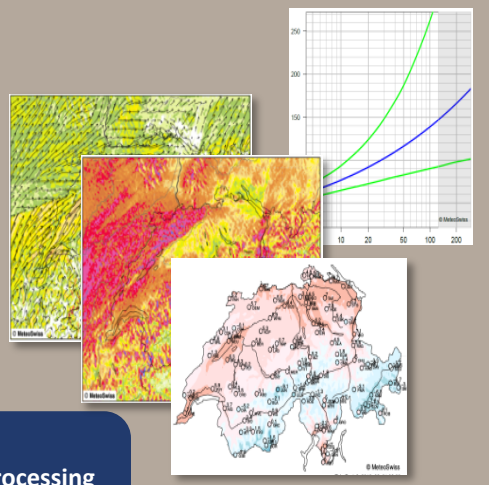
Head of Space Systems and Utilization

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale







Data collection and analysis

Modelling for prediction

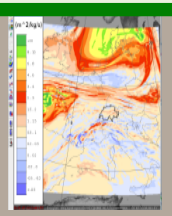
Post-processing and automatic

This is where value and socioeconomic benefits are generated; done nationally, typically by NMHS

This needs to be done globally

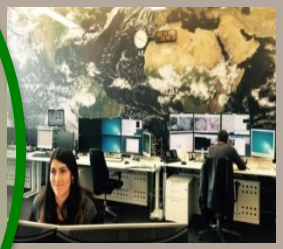
This needs to be done globally

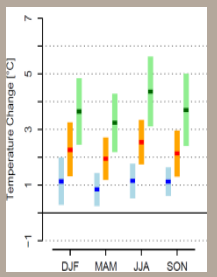
Forecast interpretation and decision



Understanding and use of forecasts

Dissemination of products and services to users





Basic WMO infrastructure underpinning all weather and climate-related actitivies; this can ONLY be implemented globally

WMO (2014) , No.1129 (courtesy Ch. Appenzeller)

DATA POLICY AND EXCHANGE

International data exchange is a major purpose of WMO, WMO Convention, Art. 2b

ANNEX 1 TO RESOLUTION 40 (Cg-XII)

DATA AND PRODUCTS TO BE EXCHANGED WITHOUT CHARGE AND WITH NO CONDITIONS ON USE

Purpose

The purpose of this listing of meteorological and related data and products is to identify a minimum set of data and products which are es
and which Members
with no conditions on
data and products w
Programmes include,
and as many data as p
state of the atmosphe
200 km in the horizon

(8) Those data and products from operational meteorological satellites that are agreed between WMO and satellite operators. (These should include data and products necessary for operations regarding severe weather warnings and tropical cyclone warnings).

Contents

(1) Six-hourly surface synoptic data from RBSNs, e.g. data in SYNOP, BUFR or other general purpose WMO Code;

(2) All available *in situ* observations from the marine environment, e.g. data in SHIP, BUOY, BATHY, TESAC codes, etc.;

orts, e.g. data in AMDAR,

per air sounding networks,
, TEMP SHIP, PILOT SHIP

twork of stations recom-
ssociations as necessary to
ation of climate, e.g. data in
nd CLIMAT SHIP/CLIMAT

TEMP SHIP codes, etc.;

(6) Products distributed by WMCs and RSMCs to meet their WMO obligations;

(7) Severe weather warnings and advisories for the protection of life and property targeted upon end-users;

(8) Those data and products from operational meteorological satellites that are agreed between WMO and satellite operators. (These should include data and products necessary for operations regarding severe weather warnings and tropical cyclone warnings).

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A New Data Policy is Required

- Single, overarching data policy resolution; existing Res. 40 used as 'strawman'
  - Modernized language and context;
  - Emphasis on earth system monitoring and prediction;
  - A unified concept
    - New elements with respect to Res. 40, 25 and 60:
      - (weather, hydrology, climate)
    - Built-in cycle for reviewing and updating as requirements change;
    - Call for subsequent implementation activities (regulatory material, capacity development);
    - Request for systems and procedures to review of compliance.

Structure of draft data policy resolution

(Annex to draft Recommendation 3.1(4)/1)

Started at Congress-18, June 2019, Res. 55, 56; launch of data policy review;

I. Preamble

- *(Noting …, Considering …, Acknowledging …,)*

II. Action section *("Congress decides to …,")*

- **Policy statement;**
- **Practice to be adopted;**
- Requests to Technical Commissions, Regional Associations, Secretary General, …

III. Annexes

1. Discipline and Domain-specific Practice for *Core* and *Recommended* Data (weather, climate, hydrology, ocean, atmospheric composition, cryosphere, space weather);
2. Guidelines to Members on Application of WMO Data Policy
3. Guidelines on the Application of Data Policy in Public-Private Engagement
4. Terms and Definitions

Key changes from Resolution 40

Resolution 40 (1995)

1. Covers weather data only;
2. Two main categories of data:
- *Essential* (*shall* be exchanged);
- *Additional* (*should* be exchanged);
3. Specific "*essential*" datasets listed directly in Annex I to the resolution (with some reference also to RBSN);
4. "*Free and unrestricted*" exchange (term not defined in the Resolution);
5. Covers exchange of data between NMHSs

Draft recommendation 3.1(4)/1

1. Covers all WMO Earth system data: weather, climate, hydrology, ...
2. Two main categories of data:
- *Core* (*shall* be exchanged);
- *Recommended;* (*should* be exchanged);
3. Specifics on *core* and *recommended* data referred to Technical Regulations, primarily Manuals on WIGOS, GDPFS;
4. "*Free and unrestricted*" exchange (term defined directly in the Resolution, literal interpretation);
5. Addressed to Members, but covers exchange of data between all partners, inclucing private sector, academia, etc.

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"Free and unrestricted exchange"

- **What does it mean?**
  - Per Annex 4**:** *"Free and unrestricted means available for use, re-use and sharing without charge and with no conditions on use[1]";*
- **Background**
  - Programs and systems such as WIGOS, WIS, GCW, GAW, S-GDPFS, which include both users and data providers outside the NMHSs, cannot be implemented via a "closed" data exchange;
  - Socioeconomic benefits of open data exchange fully demonstrated in many studies; only way to ensure maximum benefit to all Members, including protection of life and property;
  - Emergence of global NWP as core underpinning capability has demonstrated the critical need for fully global exchange of both observations and model output;
  - Research and operational communities are inextricably linked; two-way data exchange is essential;
  - Private sector now major data user and data provider; clear rules needed in order for both public and private sectors to thrive and benefit mutually;

[1]*Requests for attribution not considered a condition; attribution recommended*

Expected benefits of new WMO Unified Data Policy

- Vastly improved weather, climate and related Earth system monitoring and prediction data products due to strengthened observational data exchange;
- Significantly improved access to high quality modelling and prediction data for all WMO Members, in particular developing countries;
- Broad scope of data exchange enables private sector added value activities, while protecting key public interests;
- Streamlining WMO data policy by including all relevant Earth system domains and disciplines; aligned with WMO strategic drive toward Earth system monitoring and predictions
- Future-proofing via clear distinction between respective roles of data policy and regulatory material; updating expected to take place primarily in the latter;

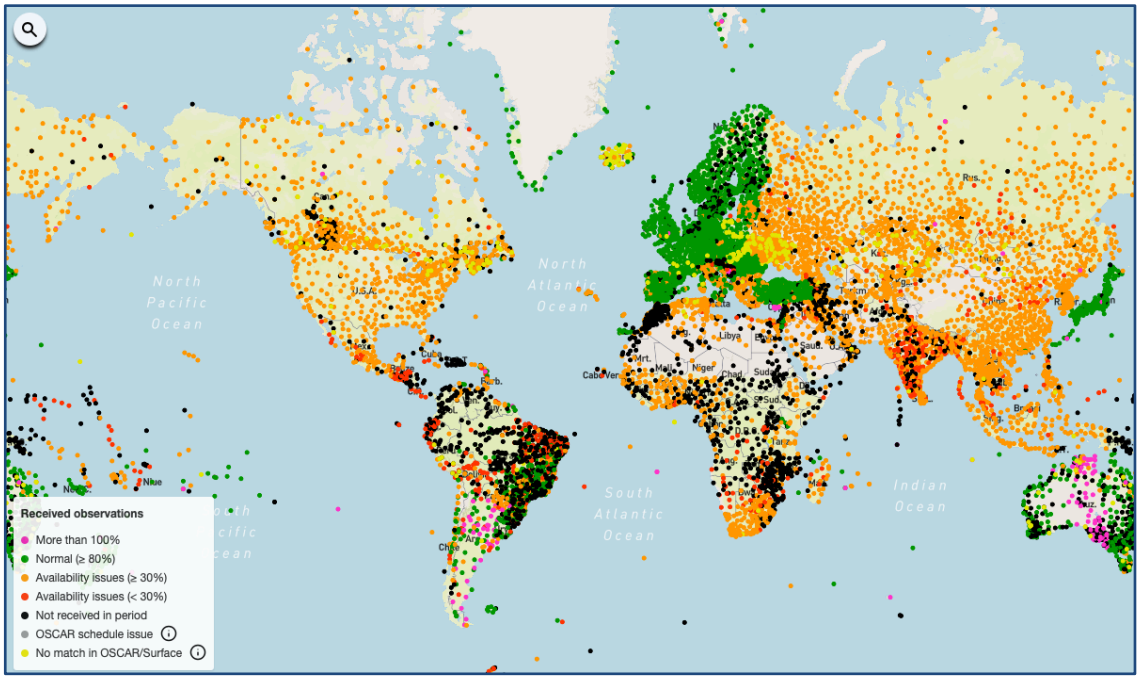
Implications for Members of WMO Unified Data Policy

- **The WMO Unified Data Policy will not in and of itself lead to any immediate new obligations to exchange large volumes of data; this will happen as Technical Regulations are amended and updated, subject to approval by future Congress sessions;**
  - However, the groups of users with whom data are exchanged will be broadened significantly;
- Safeguard for Members (“Acknowledging” in draft Congress resolution):

  7) The right of governments, having done their utmost to implement the decisions of Congress, to, based on their national laws and policies, choose the manner by, and the extent to which, they make data available domestically or for international exchange, while still understanding that without reciprocity, international data exchange cannot be sustained,

Resolution 34 (Cg-18)-GBON

In response to the gaps in observational data coverage shown by the WIGOS Data Quality Monitoring System, Congress-18 adopted the GBON Concept as provided in the annex to the resolution;



Surface pressure observations received by global NWP Centers on Apr 27 2021, 12Z)
(source: WIGOS Data Quality Monitoring System)

In addition, Congress requested INFCOM to draft relevant provisions of the Manual on the WMO Integrated Global Observing System (WMO-No. 1160) regarding the implementation of the GBON, which will clarify international requirements for the exchange of observations and respective obligations of the Members in this regard, and to submit these to EC-72 (deferred to EC-73 due to COVID) for approval;

The Systematic Observations Financing Facility (SOFF)

Why is it needed?

WMO Convention and Paris Agreement implicitly assume that observations is solely a national responsibility

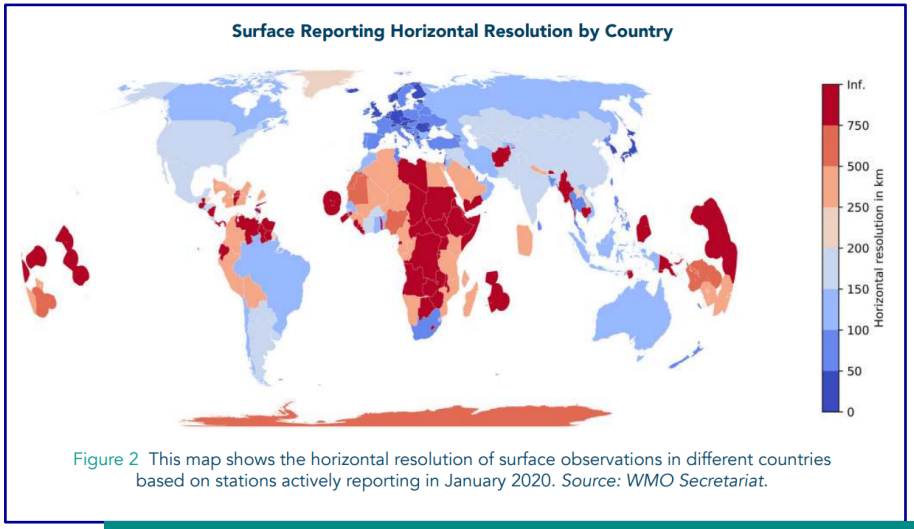
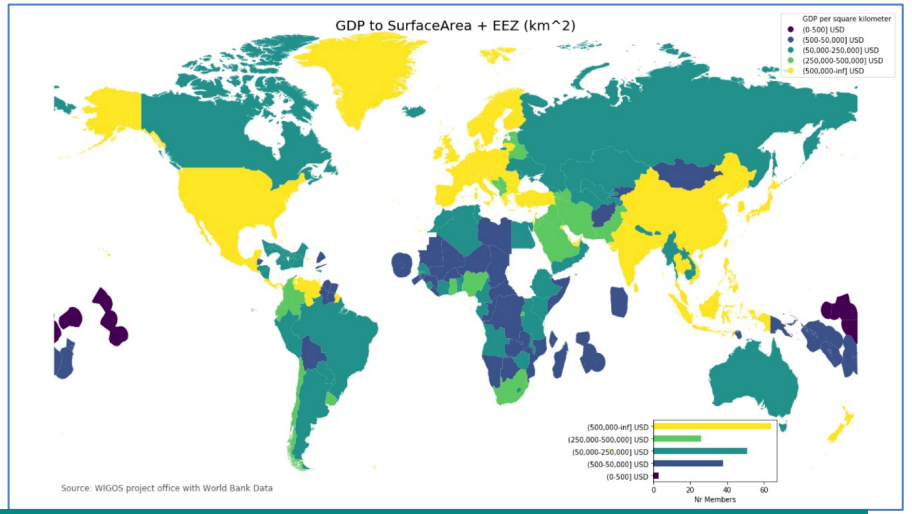


Figure 2 This map shows the horizontal resolution of surface observations in different countries based on stations actively reporting in January 2020. *Source: WMO Secretariat.*



- ***Ability to observe** (left panel): Observing systems in countries depicted in red fail to meet minimum observations requirements for weather and climate analysis and prediction*
- ***Ability to pay** (right panel): Affordability of observing responsibility (GDP/km2 of surface area) of countries in yellow up to ten million times higher than for countries in dark blue*

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EC-73 3.4(1)/1

{The Executive Council …}

Requests INFCOM to **develop an initial list of Earth system data to be exchanged as core** and recommended data under the new policy, and to provide this list to WMO Congress along with the draft WMO Unified Policy for the International Exchange of Earth System Data;

Requests further INFCOM to, in consultation with the Commission for Weather, Climate, Water and Related Environmental Services and Applications (SERCOM) and other relevant WMO bodies, **develop a process to maintain and update** the list of Earth system data to be exchanged as core and recommended data under the data policy, according to the further development of WMO regulatory material;

Requests the Secretary-General to disseminate the "WMO Unified Policy for the International Exchange of Earth System Data", as well as the initial list of Earth system data to be exchanged as core and recommended data under the new policy, to Members and to WMO partners and stakeholders for their comments and suggestions;

Invites Members to communicate the "WMO Unified Policy for the International Exchange of Earth System Data" with stakeholders, including those in the private sector, at national level to foster a mutual understanding of the policy and to ensure its implementation.

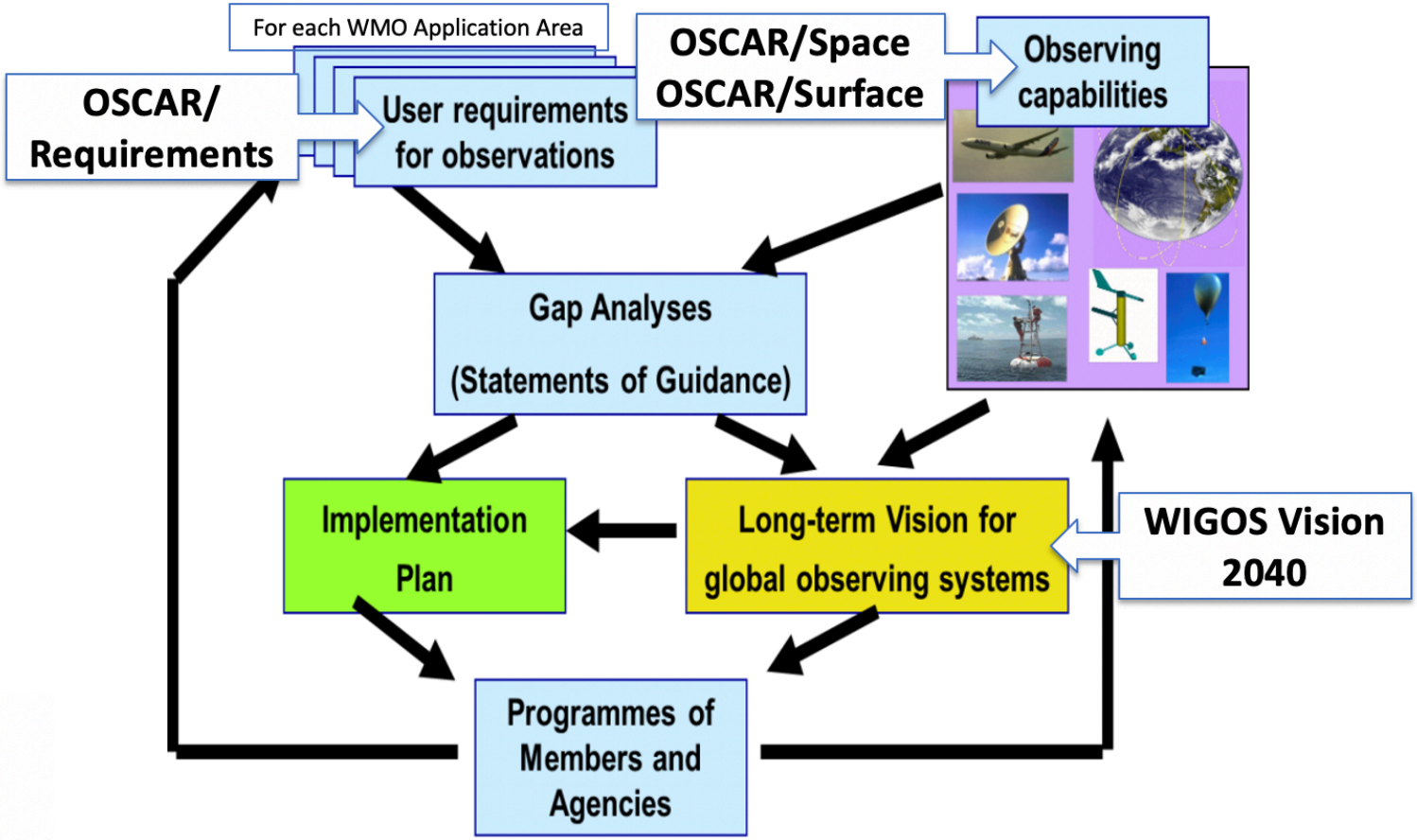
Recommends to the Congress the consideration of the WMO Unified Policy for the International Exchange of Earth System Data through the draft resolution provided in the annex annex to this Recommendation.

=> Ext Congress October 2021

WMO Unified Data Policy webpage

Design and Evolution of WIGOS

- Earth System modelling is key
- Driven by the Rolling Review of Requirements (RRR) process



See https://community.wmo.int/rolling-review-requirements-process

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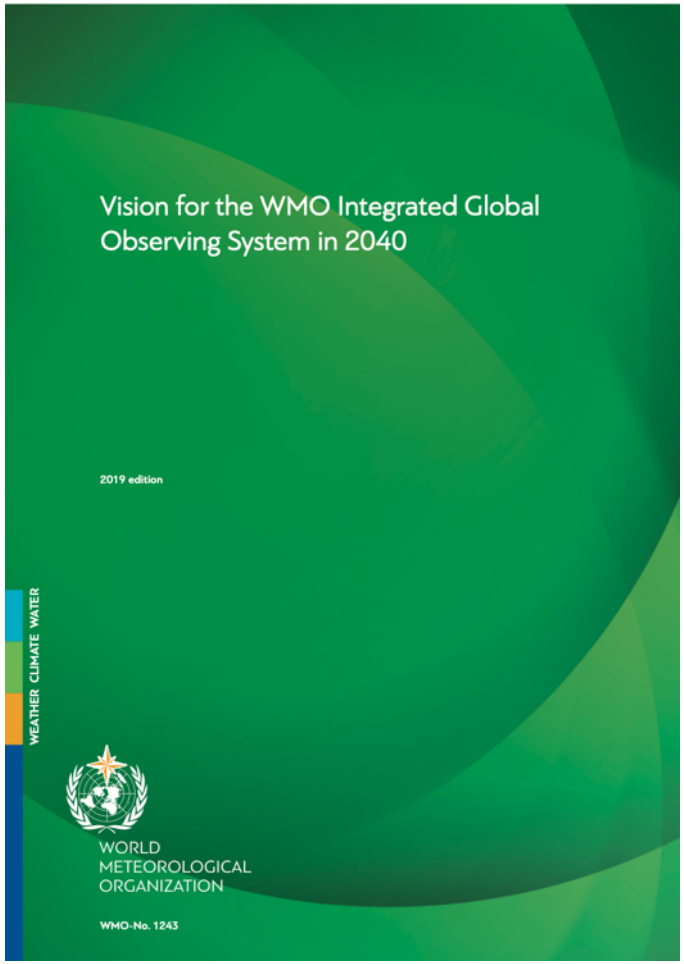
WIGOS 2040 Space Component



- Describes the space- and surface based observing networks we desire to operate by 2040
- The space-based component consists of four subcomponents:
  1. Backbone system with specified orbital configuration and measurement approaches
  2. Backbone system with open orbit configuration and flexibility to optimize the implementation
  3. Operational pathfinders, and technology and science demonstrators
  4. Additional capabilities (e.g. contributions by commercial operators)

See https://community.wmo.int/vision2040

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Trends and issues

- User requirements:
  - Higher resolution observations and better temporal and spatial sampling/coverage;
  - Improved data quality and consistent characterization of uncertainty;
- Technology
  - Sensors
  - Spectral coverage
  - **In-orbit traceability/reference measurements**
- Orbits/temporal coverage
  - LEO, GEO, HEO
  - **Constellations, including cube-sats**
- Sustainability
  - Ground and space
  - Frequency protection

Description of the space-based observing system components

as given in the WIGOS Vision 2040 (WMO-No. 1243)

The proposed space-based component consists of **four main subcomponents.**

Rather than giving strict stipulations for each subcomponent, a balance has been struck between providing enough specificity to describe a **robust and resilient system** and accommodating potential **new capabilities** arising from unanticipated opportunities.

The division of the observing capabilities into four subcomponents does not imply sequential priorities, that is, it is not expected that all Subcomponent 1 systems will necessarily be realized before elements of other subcomponents are addressed.

The main distinction between the various subcomponents is the current level of consensus about the optimal measurement approach, especially the demonstrated maturity of that approach: there is stronger consensus for the capabilities included in Subcomponent 1 compared to those in Subcomponent 2, and so forth. It is likely that the boundaries between the groups will shift over time, for instance, some capabilities currently listed in Subcomponent 2 could transfer to Subcomponent 1.

Description of the space-based observing system components

Subcomponent 1: Backbone system with specified orbital configuration and measurement approaches:

- This subcomponent shall provide the basis for Members' commitments and should respond to their vital data needs,
- It shall build on the current CGMS baseline (CGMS Baseline — Sustained contributions to the Global Observing System)
- Sun-synchronous core constellation satellites in three orbital planes (morning, afternoon, early morning)
  - MW sounding + Imagery:
- Sun-synchronous satellites at three additional equatorial crossing times for improved robustness and improved time sampling, particularly for monitoring precipitation
  - MW imagery for SST+MSU/SSU
  - MW sounding and imagery in inclined orbits

Subcomponent 2: Backbone system with open orbit configuration and flexibility to optimize implementation:

- This subcomponent shall be the basis for the open contributions of WMO Members and shall respond to target data goals
- Backbone system with open orbit configuration and flexibility to optimize the implementation
  - Constellation of high-temporal frequency MW sounding

Description of the space-based observing system components

Subcomponent 3: Operational pathfinders and technology and science demonstrators:

- This subcomponent shall respond to research and development needs
- Hyperspectral MW

Subcomponent 4: Additional capabilities:

- This subcomponent shall include additional contributions by WMO Members, as well as from the academic and private sectors.

GEO Microwave:

- Note: Today there is nothing on GEO MW, which is being explored.
- Open issues are wrt to optimization of integration time, resolution, NeDT
- Benefit trade-off wrt to constellations

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Satellite data Requirements for Global NWP

Presented to CGMS-49 Plenary, May 2021
Agenda item 5: CGMS-49-WMO-WP-20

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The Position Paper Main Elements

- Background/Purpose/Future Evolution
- 10 principles that by and large are captured in the current WIGOS Manual
  - Data sharing, meta-data, user interaction, calval, timeliness/formats/tools, early access, archived data, sustainability, calibration/SI
  - Principle 10 (goes beyond WM4.1.5): Maintain space-based assets beyond the design lifetime as long as they provide value added observations on a safe and affordable basis as determined by the operating agency
  - Again these represent a user perspective and are not committing for the Space Agencies
- Recall the Space-based component of WIGOS 2040
- Three tables capturing the requirements, which is the main substance
  - Backbone, Additional, Emerging

Table 1: Backbone Satellite for global NWP

Geostationary core constellation with a minimum of five satellites providing complete Earth coverage		
Type of satellite sensors	**WIGOS Subcomponent**	**Products**
Multi-spectral VIS/IR imagery with rapid repeat cycles	**1**	Level 1: Radiance products Level 2:Atmospheric Motion Vectors (AMVs), Aerosol Optical Depth (AOD), Sea Surface Temperature (SST)
IR Hyperspectral I Sounders	**1**	Level 1: Radiance products Level 2:AMVs
Sun-synchronous core constellation satellites in three orbital planes (morning, afternoon, early morning)		
Type of satellite sensors	**WIGOS Subcomponent**	**Products**
VIS/IR imagery	**1**	Level 1: Radiance products Level 2: Aerosol Optical Depth (AOD), Atmospheric Motion Vectors (AMVs), Sea Surface Temperature (SST)
IR Hyperspectral Sounder	**1**	Level 1: Radiances
Microwave Sounder	**1**	Level 1: Radiances
Microwave Imagery	**1**	Level 1: Radiances Level 2:SST, total column water vapour, clouds, precipitation, sea ice
Scatterometer	**1**	Level 1: Backscattering cross-sections Level 2: Ocean surface vectors winds, soil moisture
Sun-synchronous satellites at three additional (any other than above) equatorial crossing times for improved robustness and improved time sampling		
Type of satellite sensors	**WIGOS Subcomponent**	**Products**
Microwave Sounder	**2**	Level 1: Radiances
Hyperspectral Infrared Sounder	**Not currently reflected in WIGOS Vision 2040**	Level 1: Radiances
Wide-swath radar altimeters and high altitude, inclined, high-precision orbit altimeters	**1**	Level 2: Sea surface height, wind and waves, ice freeboard
Global Navigation Satellite System (GNSS) radio-occultation (basic constellation)	**1**	Level 1: Bending angle Level 2: Refractivity
UV/VIS/NIR sounders, nadir and limb	**1**	Level 2: Ozone, aerosol properties
IR dual-angle view imagers	**1**	Level 2: SST

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The WIGOS Vision 2040 states hyperspectral sounding from 5 geostationary orbits “The realization of that capability has started, but only 2-3 orbital slots are currently considered to be filled in the coming decade.”

Table 2: Additional Satellite for global NWP

Data from Low-Earth orbiting satellites		
Type of satellite sensors	**WIGOS Subcomponent**	**Products**
Multiangle, multipolarization radiometers	**2**	Level 1: Radiance products Level 2: Aerosol Optical Depth (AOD)
Precipitation Radar	**1**	Level 1: Backscatter Level 2: Precipitation rate
Scatterometer	**Not currently reflected in WIGOS2040**	Level 1: Backscattering cross-sections Level 2: Ocean surface vector winds, soil moisture
Radio-occultation	**3 and 4[3]**	Level 1: Bending angle Level 2: Refractivity
SAR imagers	**1**	Level 2: Sea ice
Absolutely calibrated broadband radiometers and total solar irradiance and solar spectral irradiance radiometers	**1**	Level 1: Radiance

Table 3: Emerging Satellite for global NWP

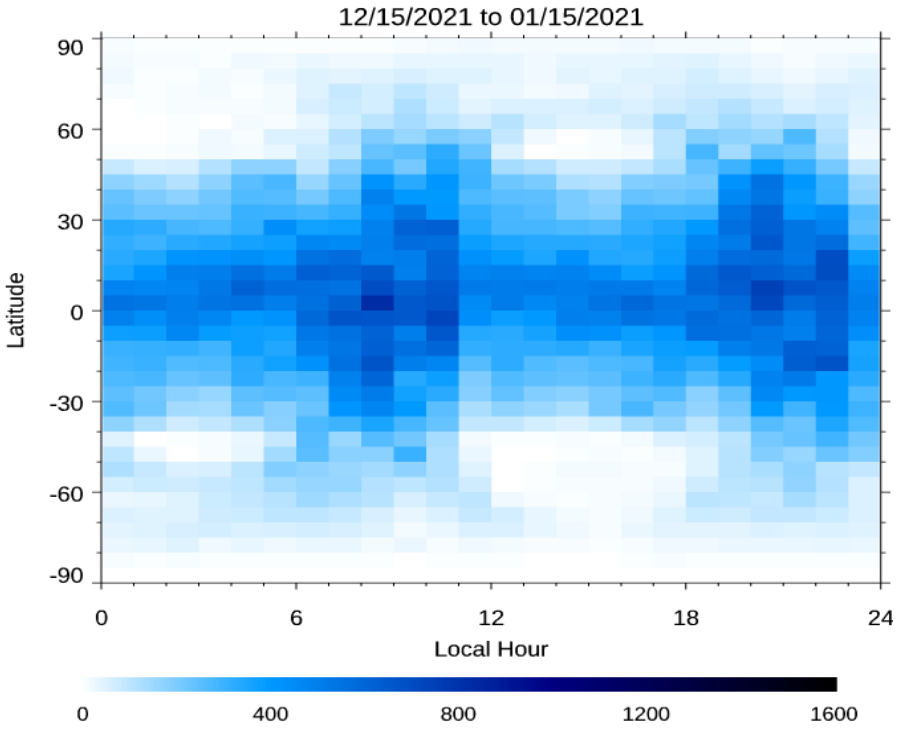
Geostationary core constellation with a minimum of five satellites providing complete Earth coverage		
Type of satellite sensors	**WIGOS Subcomponent**	**Products**
Lightning mapper	**1**	Level 2: Strike density
Data from Low-Earth orbiting satellites		
Type of satellite sensors	**WIGOS Subcomponent**	**Products**
Wind lidar	**Currently 2**	Level 1: Backscatter, extinction Level 2: Line-of-sight winds
Cloud lidar	**2**	Level 1: Backscatter, extinction
Cloud radar	**1**	Level 1: Reflectivity
Sub-mm imagery	**2**	Level 1: Radiances Level 2: Clouds

Conclusions for space-based microwave observations

- Need to address future needs
  - Spectral coverage
  - Traceable calibration
    - ISO, in-orbit reference
  - Temporal coverage
    - Precipitation (International Precipitation Working Group)
    - Optimization of all in-orbit assets (imagers and sounders)
- Need to ensure data access
  - Cube/small sat constellations quality and timeliness
  - Cube/small sat constellation data from commercial providers
  - Example and lessons learned from radio-occultation
    - User requirements/WMO data policy
    - Data purchase with license for free distribution e.g. to global NWP
    - Accurate definition of data characteristics, e.g. coverage, raw data

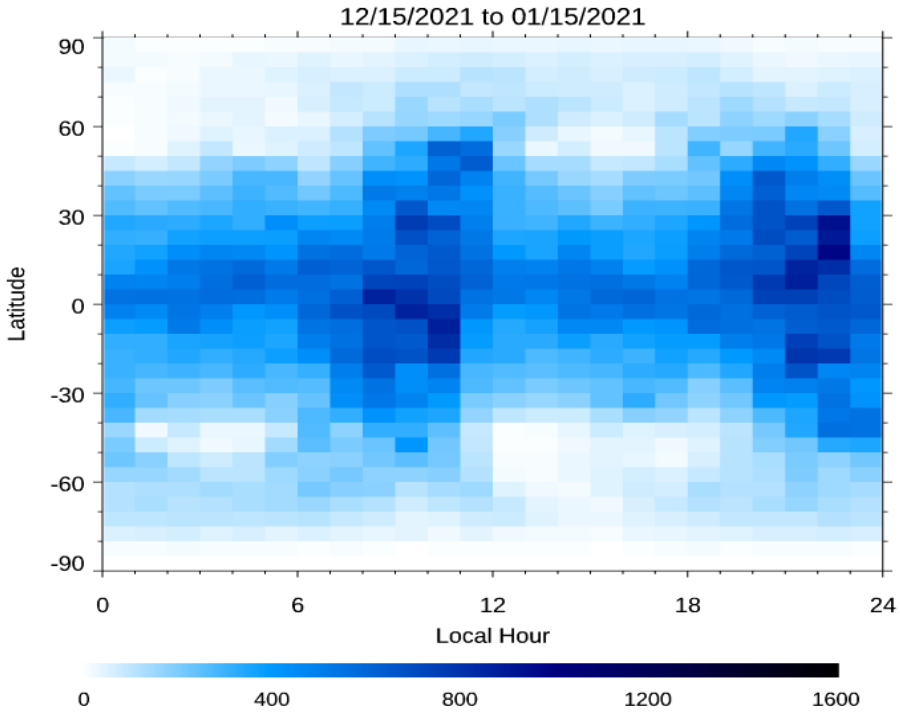
Adopted by CGMS-49

Geographic and Local Time Coverage



COSMIC-2 + 3 Metops + Kompsat-5 + PAZ

Note that this is **not** a good sampling of the diurnal cycle …



COSMIC-2 + 3 Metops + Kompsat-5 + PAZ + SPIRE + GeoOptics

Coordination Group for Meteorological Satellites

NOAA data, mid Dec 2020 – mid Jan 2021

IROWG INTERNATIONAL RADIO OCCULTATION WORKING GROUP

CGMS

Figure courtesy of IROWG and Ben Ho, NOAA

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Thank you

https://public.wmo.int/en/our-mandate/what-we-do/observations/Unified-WMO-Data-Policy-Resolution

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