An ET-SAT Contribution to the Vision of WIGOS Space-based Component in 2040

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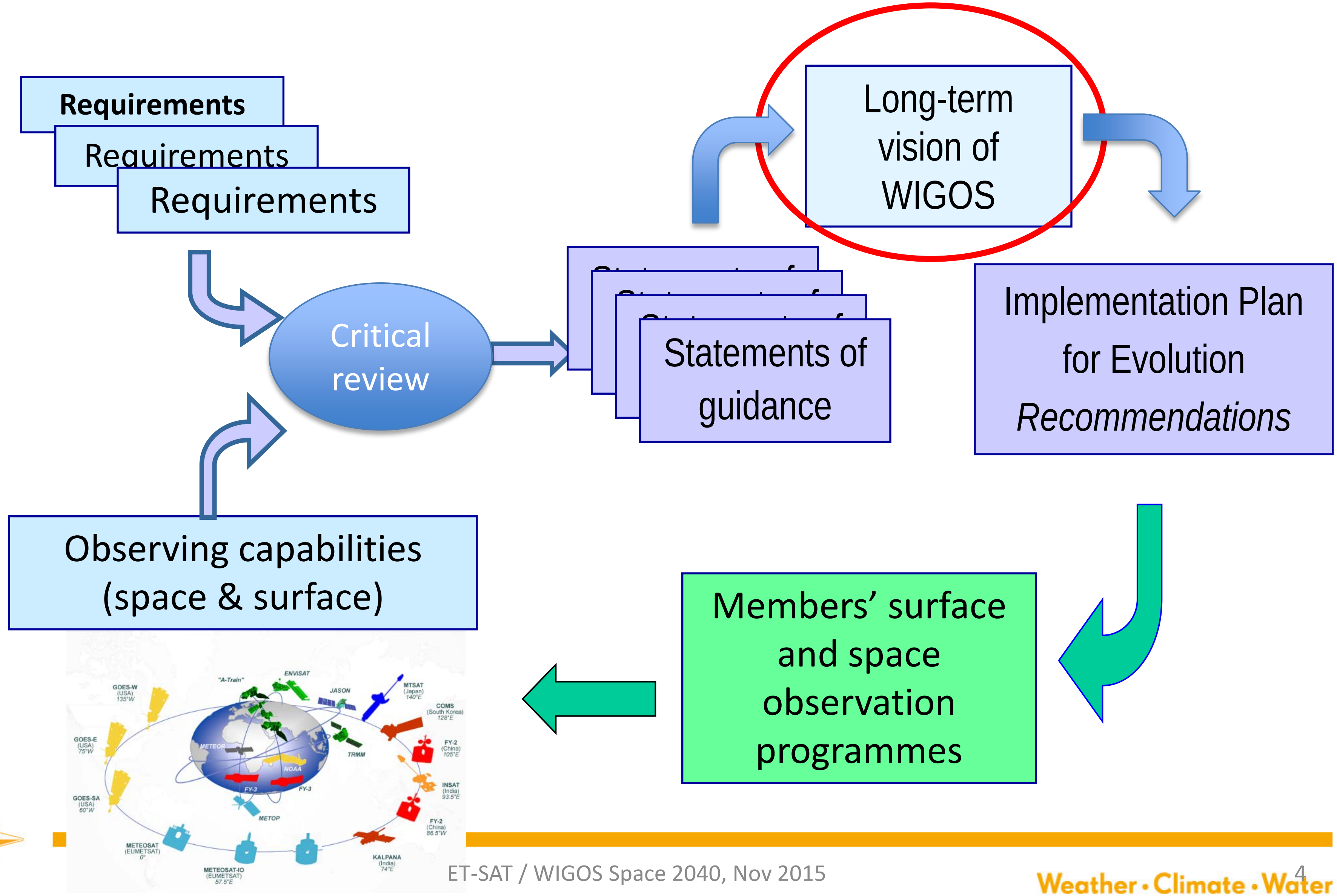
Outline

1. Background and initial assumptions
2. Evolving user needs
3. Evolving capabilities
4. Evolving providers' community
5. Elements of a Vision

Vision of WIGOS in the Rolling Review of Requirements (RRR)



Background

- The *Vision of GOS in 2025* developed in 2007-2008 needs updating
- A long-term perspective is needed to support satellite agency planning
- A *Vision of WIGOS component observing systems in 2040* is being developed in 2015-2016 as agreed by the WMO CBS-Ext.(2014)
- Is expected to ultimately replace the «Vision of the GOS in 2025»

- ET-SAT contributes to this effort for space-based component
- Mutual feedback with the long-term plans or strategies of its Members
- Called for a WIGOS Space 2040 workshop to dialogue on user needs
- Initial draft has been submitted to CGMS-43 for comments
- This contribution will be reviewed with the findings of the workshop

Initial Assumptions

- The current structure of the space-based observing system is a solid foundation underpinning the success story of the «World Weather Watch» and essential to WIGOS

  (Ref: Manual on WIGOS and CGMS baseline)

  – Geostationary constellation
  – 3-orbit sun-synchronous constellation for sounding and imagery
  – Complementary missions on appropriate orbits
  – Near-real time data availability
- Questions were raised with reference to the current system
  – What should be added ?
  – What is at risk and should be reinforced ?
  – What should be improved (performance, coverage) ?
  – What could be performed differently in the future ?
  – What are the major challenges?

Main drivers for the 2040 Vision

- Evolving and emerging user requirements
  - Increased resolution (spatial, temporal, spectral..)
  - Consistent, comprehensive data records
  - Atmospheric composition, cryosphere, hydrology, space weather … were hardly addressed
- Recent/anticipated advances in technology enabling new capabilities
  - Sensor technology
  - Orbital concepts
  - Satellite programme concepts (small satellites, constellations)
  - Data system architecture
- Changes in the providers' community
  - More space faring nations
  - Imperative cost/benefit justification
  - Public/private initiatives

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Evaluation of the current Vision for 2025

- Captures most of the needs of WMO Application Areas as reflected in the Statements of Guidance
  - including «new» features such as 3-orbit hyperspectral sounding, altimetry, scatterometry, GNSS-RO, rain radar, lightning detection, etc.
- But requirements may still remain unfulfilled by 2025
  - General need of higher resolution (spatial, temporal, radiometric) reinforced by the progress of integrated modelling
  - Need better coverage by GNSS Radio-Occultation,
  - Need global coverage plan for GEO hyperspectral IR
- Some missions listed only at «pathfinder» stage
  - Low-frequency MW for salinity/soil moisture
  - Doppler lidar for 3D wind & aerosol
  - HEO imagery for sea ice, polar winds and volcano watch
  - Gravity field

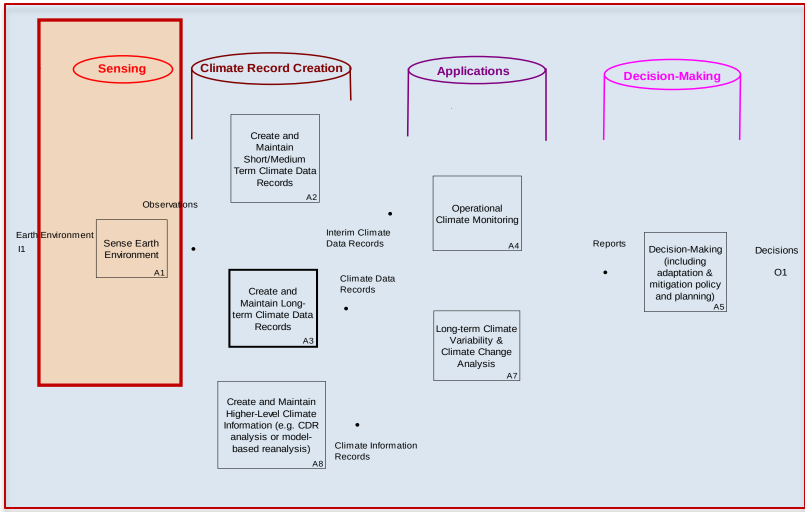
GEO Hyperspectral IR plan

Emerging needs not captured in SOG and Vision

For example:

- Atmospheric composition: including **Limb sounding** for upper troposhere and stratosphere/mesosphere
- Hydrology and cryosphere: **Lidar altimetry**
- Cloud phase detection for NWP: **Sub-mm imagery**
- Aerosol and radiation budget: **Multi-angle, multi-polarization radiometry**
- Surface pressure ? **Potential use of NIR spectrometry ?**
- Solar wind/solar eruptions: **heliospheric imagery** (at L5 point) **and in-situ energetic particle flux** (at L1)

Specific needs related to Climate Monitoring from Space



The «climate view» of the Vision should match the Architecture for Climate Monitoring from Space (CEOS-CGMS-WMO) and identify :

- Sensing capabilities responding to GCOS IP and WCRP Grand Challenges
- with performances (e.g. **stability**) required to monitor climate
- Gap analysis and planning coordination for **continuity**
- **Comparability** of new sensors with heritage datasets
- **Consistency** and **traceability** through reference standards and inter-calibration procedures
- **Generation** of FCDRs and **preservation** of original data

Growing role of numerical modeling

- Assimilation in coupled models will drive a comprehensive Earth system modeling with monitoring and predictive capabilities serving many applications
- Rapid refresh NWP cycles to support very short term forecasting and Nowcasting
- Requires improved time/space resolution and timeliness
  - Towards global 5 kmx1h resolution
- Emerging need for microphysical properties of hydrometeores
- Reinforced requirement for 3D wind and surface pressure
- Error characterization should benefit of anchor measurements to control the model bias (Role of GSICS)
- Robustness of the data chain ensuring continuity of data records for reanalysis purpose
- Allows quantitative assessments of the value of each observation to support observing system optimization

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Technology advances for sensors

- Sensors with improved geometric/radiometric performance
- Spectrum better exploited: UV, Far IR, MW
- Hyperspectral sensors in UV, VIS, NIR, IR, MW
- Combinations of active/passive
  - e.g. bi-static sensing, GNSS reflectometry
- Expanded polarimetric measurement capability (incl. SAR)
- Diverse radio-occultation techniques
  - additional frequencies (to L1=1575, L2=1227, L5=1176 MHz)
  - large constellations
  - ionospheric scintillation

Constrained by radiofrequency spectrum protection issues

Technology advances for orbital systems (1/2)

- More satellite providers, allowing a wider range of orbits
  - HEO-GEO-MEO-LEO (inclined or sun-sync) and lower platforms
  - Interoperability rather than similarity
- Measurement reference standards for calibration, traceability
  - In-orbit, at surface, Moon
  - Leveraging the value of the whole constellation of satellites
- Non-classical systems
  - Very small satellites (e.g. nanosatellites)
  - Use of the orbital platforms (like ISS) for demonstration missions
  - Near-space systems (Balloons, unmanned aerial vehicles)

Technology advances/ orbital systems (2/2)

- Consequences of covering a diversity of orbits
  - Improved sampling
  - Increased robustness, resilience,
  - Implementation challenges (technical coordination)
- Different programme concepts
  - Classical series of large satellites spanning ≈ 30-year life cycle
  - Small satellites/nanosat with limited scope, reduced cost,shorter life cycle and decision process: useful flexibility e.g. for gap-fillers or demo missions
  - And everything in-between

Technology advances/ data management

- Larger data volumes and shorter latency
- Long term data preservation
- Interoperability: metadata standardization
- Radio-frequency spectrum protection (incl. higher frequency bands)
- Direct Broadcast enhanced by «DBNet» approach
  - Collaborative, Default Tolerant Network
- Satellite data relay
- Cloud computing (storage & processing) and big data analytics
- Data exploitation platforms
- Moving data or products ?
- Security issues

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Research & Operations missions

- Operational, R&D, and Transition programmes
  - General principle : different scope and priorities, but we need both !
  - In addition, regular use of R&D missions in operations
    - To complement operational data sources
    - As preparation / evaluation before operational follow-on
  - R&D flight Opportunities aboard operational missions
  - Formation flight enabling creating synergies
- Support Research To Operations transition process where relevant
  - Technological maturity: robust/affordable/available technology
  - Operational maturity: long-term /real time continuity of service
  - User maturity: application with demonstrated benefit
  - Organisational maturity: established user-provider interaction on requirements, specifications, feedback, and funding scheme justified by benefits

International cooperation

- Data sharing : full, free and open
- Multi-agency coordination mechanisms (CGMS & CEOS)
- International partnerships
- Inter-governmental organizations
- Space-based observation still relies on a small number of Members
  - Not all WMO Members can afford a national space programme
  - Would lead to duplication of efforts
- Other models could facilitate participation of more WMO Members
  - Regional space programme (Africa, S. America)
  - Private law company with governmental stakeholders (e.g. DMC-constellation, or CLS-ARGOS)

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Need for user-provider dialogue

- Difficulty for space agencies (and for users) to anticipate the user needs 25 years ahead
- Difficulty for users to anticipate potential future capabilities
- Space agencies need to better understand the user needs
- Direct interaction needed to stimulate a prospective view
- Motivation for the WIGOS Space 2040 workshop

- The following slides are a strawman …

Approach to developing a new vision

- Rather than prescribing every component, trying to strike a balance:
  - Specific enough to provide clear guidance on system to be achieved
  - Open to opportunities and encouraging initiatives
- Promote complementary 3-tier components
  - **A detailed specified backbone system**, basis for Members' commitments, and addressing the vital data needs along the lines of the current CGMS baseline with a few additions
  - **A flexible system augmenting the backbone elements** to provide more data, basis for open contributions of WMO Members, responding to target data goals, quality interoperability standards
  - **Operational pathfinders** and technology and science demonstrators
- Data freely, accessible in timely manner with metadata, sensor characteristics, etc.
- Recommended standards for possible additional data for other operators (e.g. academic, commercial) willing to exploit technical / business / programmatic opportunities while complying with WMO technical standards

I. Backbone system
Established measurement approaches (1/2)

- **Geostationary** ring providing frequent multispectral VIS/IR imagery
  - with IR hyperspectral, Lightning mapper, UV sounder
- **LEO sun-synchronous core constellation** in 3 orbit planes (am/pm/earlymorning)
  - hyperspectral IR sounder, VIS/IR imager, MW imager, MW sounder, Scatterometer
- **LEO sun-sync. at 3 additional ECT** for improved robustness and improved time sampling particularly for monitoring precipitation
- Wide-swath altimeter, and high-altitude, inclined, high-precision orbit altimeter,
- IR dual-angle view imager (for SST)
- UV sounder (nadir and limb)
- Low-frequency MW (e.g. for soil moisture and ocean salinity)
- MW upper stratospheric and mesospheric temperature sounding

I. Backbone system
Established measurement approaches (2/2)

- Precipitation radars and MW sounder and imager on inclined orbits
- Lidar (Doppler and dual/triple-frequency backscatter) for wind and aerosol
- Absolutely calibrated broadband radiometer and TSI radiometer
- GNSS radio-occultation (basic constellation)
- HEO VIS/IR/MW mission for continuous polar coverage (Arctic & Antarctica)
- Narrow-band or hyperspectral imagery (ocean colour, vegetation)
- High-resolution multispectral VIS/IR imagers (land use, vegetation, flood monitoring)
- SAR imagery for sea state and sea-ice observations
- Near IR imagery for Carbon Dioxyde and Methane

- On-orbit measurement reference standards for VIS/NIR, IR, MW absolute calibration

II. Backbone system
Emerging measurement approaches.

- Surface wind and sea state (e.g. GNSS reflectometry missions, passive MW, SAR)
- Limb sounders (UV – VIS – NIR – IR - MW)
- Lidar for aerosol/wind (Doppler) and atmospheric composition (DIAL)
- Lidar altimeters for sea-ice thickness
- Cloud phase detection, e.g. by sub-mm imagery
- Multi-angle, multi-polarization radiometers for aerosol and radiation budget
- High-resolution land or ocean observation (multi-polarization SAR, hyperspectral VIS)
- High temporal frequency MW sounding (GEO or LEO constellation)
- Surface pressure by NIR spectrometry
- Magnetometer and particle spectrometers (solar wind and magnetosphere)
- Solar and solar wind observation at L1 and energetic particle detectors on GEO

III. Operational pathfinders and technology demonstrators

- RO constellation for enhanced atmospheric/ionospheric soundings
  - Including additional frequencies optimized for atmospheric sounding
- Radar and Lidar for vegetation
- Hyperspectral MW sensors

- Nanosatellites ready to serve as gap fillers for contingency
- Use of orbiting platforms (like the International Space Station) for demonstration missions

Next steps

- This strawman is to be reviewed and detailed after analysis of the findings of the WIGOS Space 2040 workshop considering the anticipated user needs, capabilities, priorities and affordability

Thank you for your attention!

Your feedback is welcome

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Commercial providers: threat/opportunity (1/2)

- The issue is not whether industry should be involved but how: what should be the best respective roles/responsibilities ?
  - Contractor (classical case), or implementing agent of a governmental agency ?
  - Public/private partnership ? The public agency as the exclusive customer ?
  - Independent companies, with public and private users as potential customers ?
- «Commercial» satellite programmes can be an opportunity to enhance the observing system – through business reactivity – but also entail major risks which need to be addressed such as:
  - Severe limitation of data exchange against WMO practices
  - Loss of transparency/traceability of data generation process
  - Hampering global coordination of long-term plans implementing the Vision
  - Short-term attractiveness of commercial initiatives could undermine the decision process and funding of essential long-term national programmes

Commercial providers: threat/opportunity (2/2)

- Continued need of governmental **commitments** by WMO members
  - implemented by government-designated entities,
  - guaranteing global optimization, international data exchange, interoperability
- With reference to WMO Resolution 40 (Cg-XII):
  - Members shall ensure provision of «essential data» freely, which entails full governmental control on a WMO-coordinated «backbone» system
  - Commercial programmes could enhance the system with «additional data»
  - Private/public partnership may include both aspects: a freely accessible «essential» service specified by the public authority, and an «additional» service marketed by the company
- Although not co-ordinating commercial initiatives the WMO Vision can influence their provision of observations in setting priority goals, data quality and interoperability standards