# Development of a Vision of WIGOS Space-based Component in 2040

**WIGOS = WMO Integrated Global Observing System**

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# Background & Main drivers for updating the 2025 Vision

WMO OMM

- Current ***Vision of the Global Observing System (GOS/WWW) in 2025*** needs updating & longer perspective, address broader & new emerging global societal needs and user requirements, and technology advances
  - Global Framework for Climate Services (GFCS). Atmospheric composition, air pollution, cryosphere, hydrology, space weather, etc
- WMO Commission for Basic System (CBS) in 2014 called for a ***Vision of WIGOS in 2040,*** being developed in 2015-2016., **References:**
  - ET-SAT-9 (12-14 Nov. 2014) Final Report (Chair: *Jack Kaye (NASA), )* with participation of space anegcies and satellite operators
  - WMO Strategic Plan 2016-2019, ***Synthesis Report of the UN SG on the post-2015 sustainable development agenda***
  - NASA *Earth Science Vision 2030, ESA & other space agency reports*
  - *Dr. Kathryn* Sullivan: AMS 2015 Annual Meeting Presidential Forum Keynote: **Anticipating Meteorology in 2040**

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

1. From Global Societal Needs in 2040, to anticipated observational **requirements** in 2040 covering all WMO thematic areas (weather, climate, water & environment) user driven approach !

3. From advances in technology 2040 **dimension**, to compare with the requirements! – technology driven approach !

**Requirements**

Requirements

Requirements

Critical review

Statements of

Statements of

Statements of

**Statements of Guidance**

Long-term vision of WIGOS

Implementation Plan for Evolution *Recommendations*

Observing capabilities (space & surface)


Members' programmes (including space agencies)

# 1. Anticipating Meteorology in 2040

# World is changing !

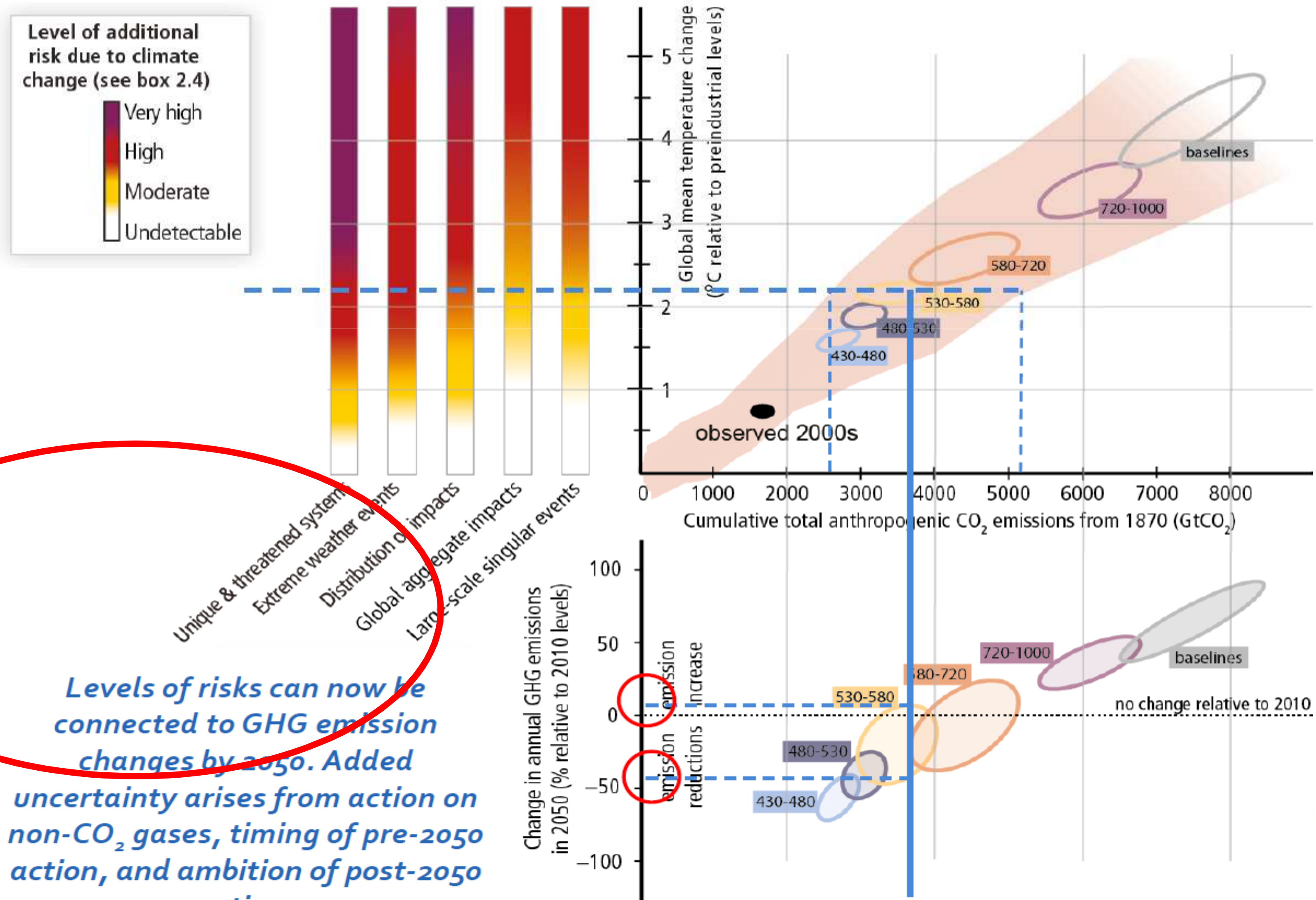
- Global population above 9 billion in 2050
- 700 million living in extreme poverty
- More than 50% live in urban areas, 72% by 2050
- 23 Megacities today, 37 by 2050
- 232 million of international migrants
- 780 million have no access to clean water
- 1.3-billion lack electricity
- 7 million premature death due to air pollution

# Outlook of future in 2040: challenges of WMO Members for meeting anticipation Services Requirements in 2040

- The planet will be warmer, leading to more extreme weather & climate events. With the population increase from 7B to 9B, with growing settlements in costal regions & megacities – increase of vunerability
  - **Average tropical cyclone intensity (maximum wind speed & rainfall) is *likely* to increase**
  - **Substantial warming in temperature extremes: monthly heat extremes (heat waves) in summer is projected to quadruple by 2040.**
  - **The frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe.** This is particularly the case in the high latitudes and tropical regions, and in winter in the northern mid-latitudes.
  - **The droughts will intensify in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration.**
  - The water-food-energy nexus to society will loom as a major global challenge in 2040!

# The challenges for WMO Members for the anticipation of Met Services in 2040

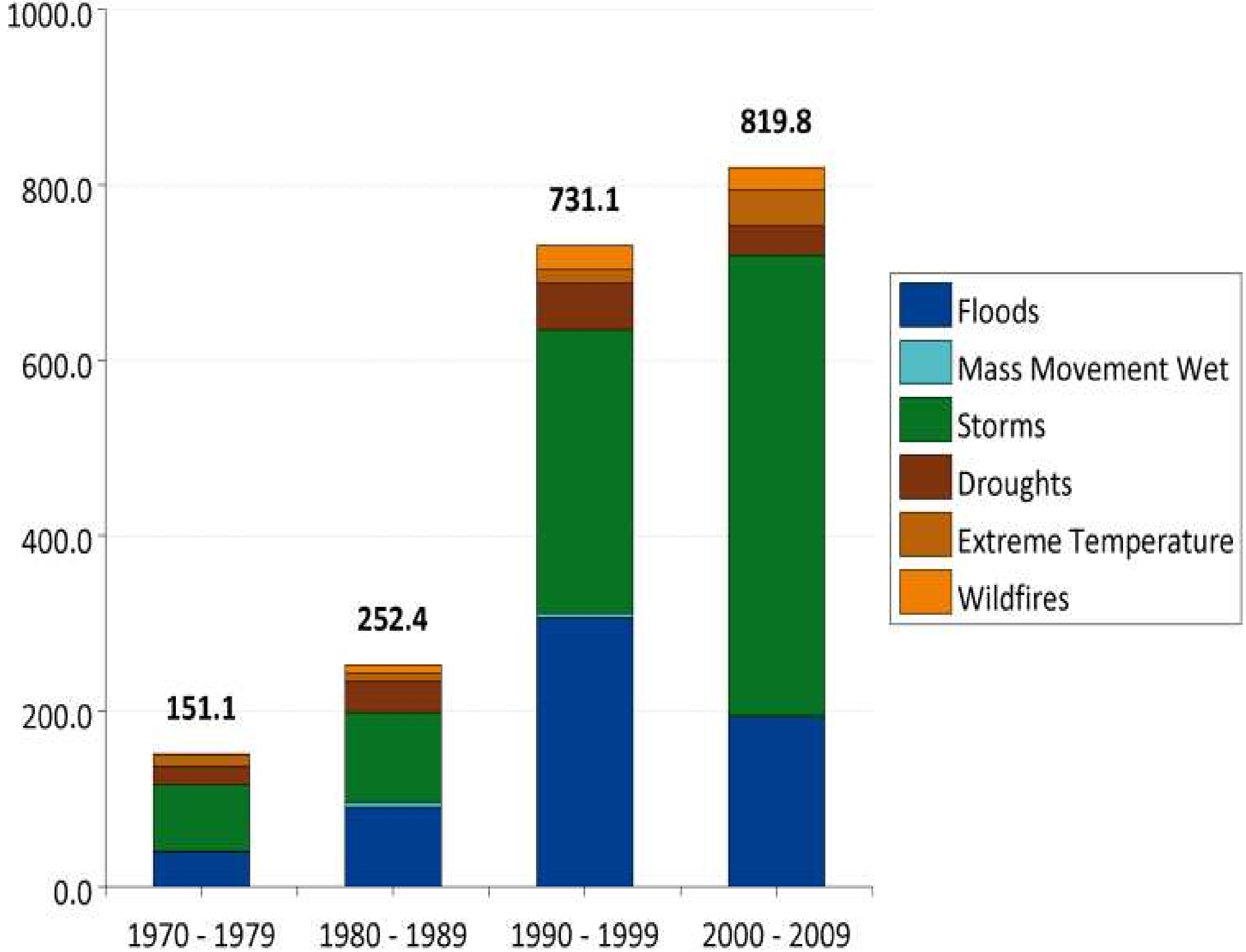
WMO OMM




*Levels of risks can now be connected to GHG emission changes by 2050. Added uncertainty arises from action on non-$CO_2$ gases, timing of pre-2050 action, and ambition of post-2050*

NMHS

## *The global total economic losses by decade and by hazard type in USD billions adjusted to 2011 (during the period 1970-2009 (Source: WMO and CRED, 2013) – what about 2040 ?*



# WMO STRATEGIC PLAN

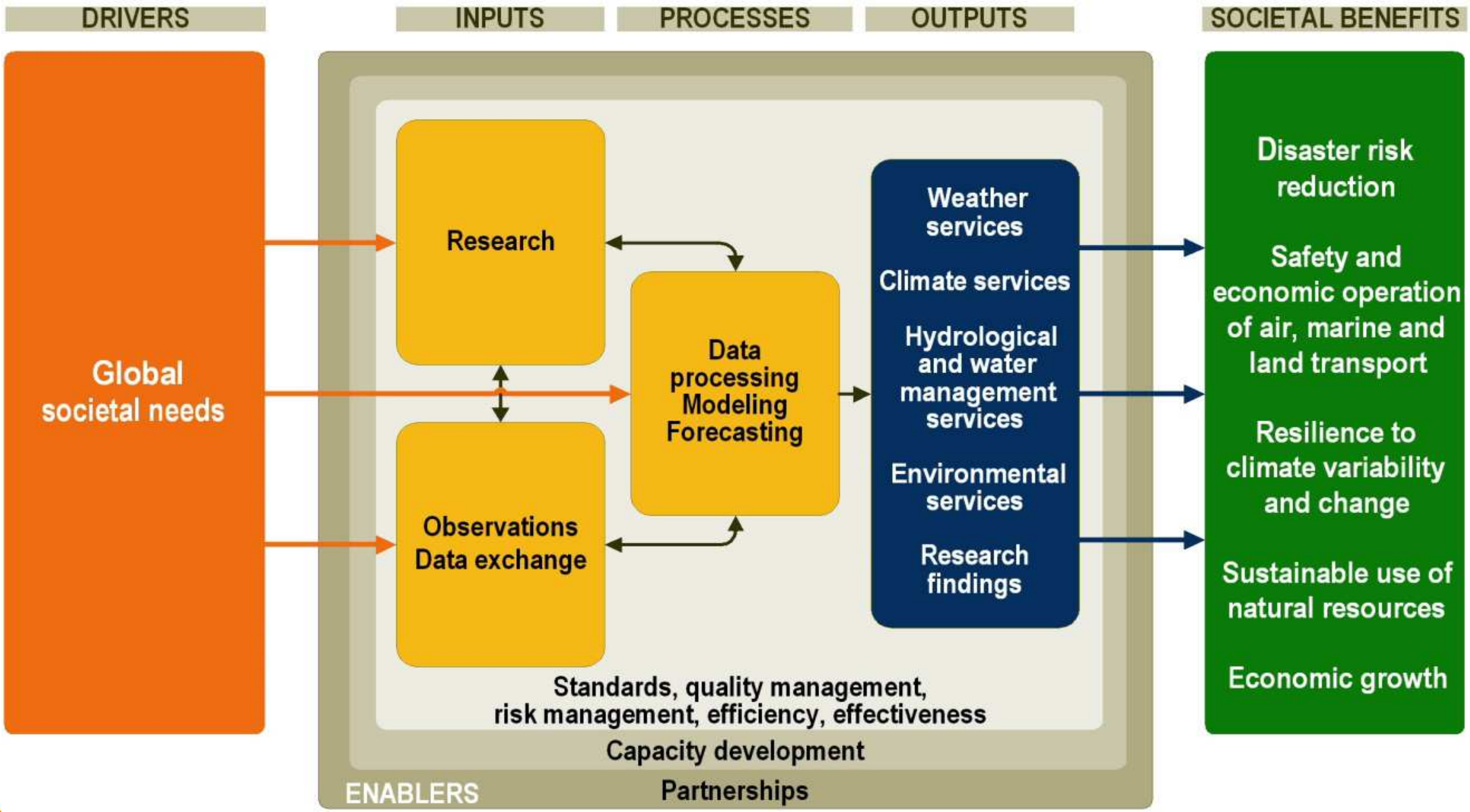
## FROM Global Societal Needs to Service Requirements

- Improved protection of life and property to reduce disaster risks
- Ensure sustainable resilient livelihoods, food security, access to water & energy, healthy lives, economic growth & combat climate change
- Sustainable use of natural resources and improved environmental quality

- By mitigating the impacts of extreme weather, climate, water & environmental events with more accuracy/timely forecasts & warning;
- By providing weather, climate, water & related environmental information services to support decision-makings;
- **by designing weather, climate, water and related environmental services to manage meteo-natural resources at all time-scales**

**NMHSs will morph from the current largely weather business into an weather/climate/environmental intelligence enterprise by 2040**

# WMO STRATEGIC PLAN -Global Societal Needs

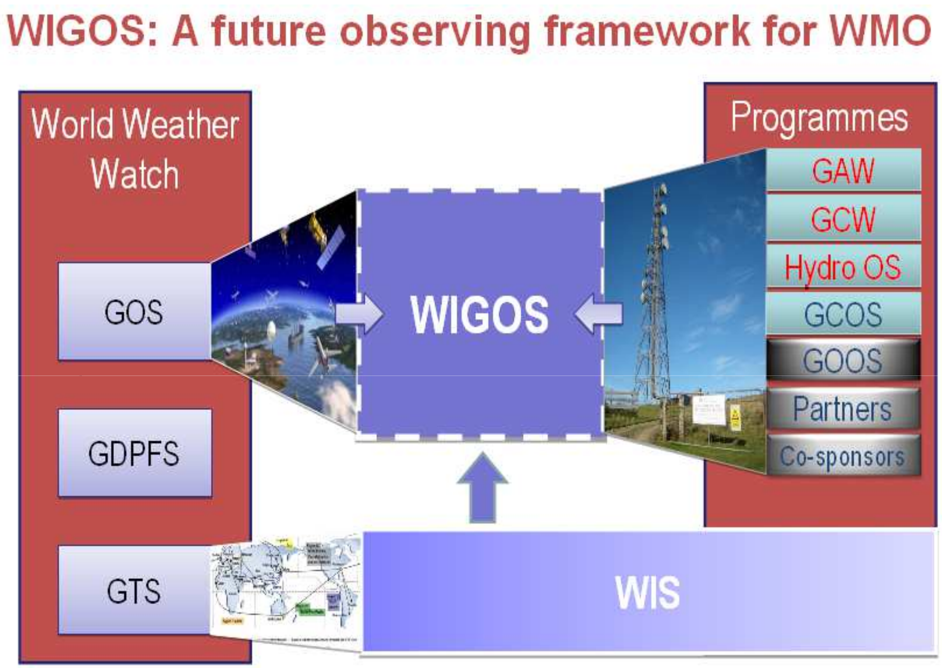


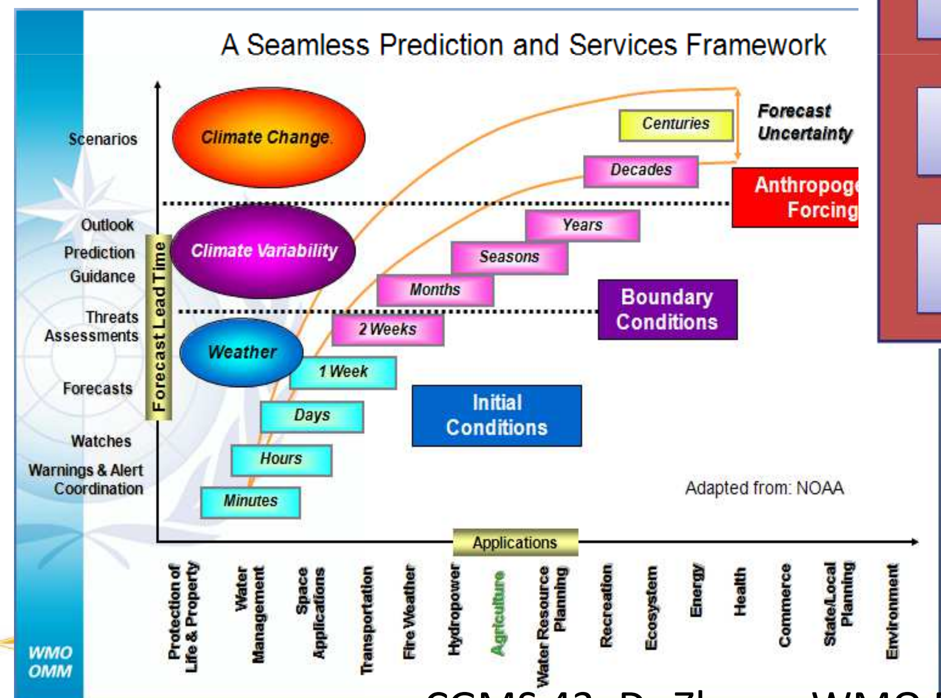
# 2. Anticipating Space Observation Requirements in 2040 –WMO perspective

# Sixteenth World Meteorological Congress (2011) decided to Implement WIGOS

WMO INTEGRATED GLOBAL OBSERVING SYSTEM

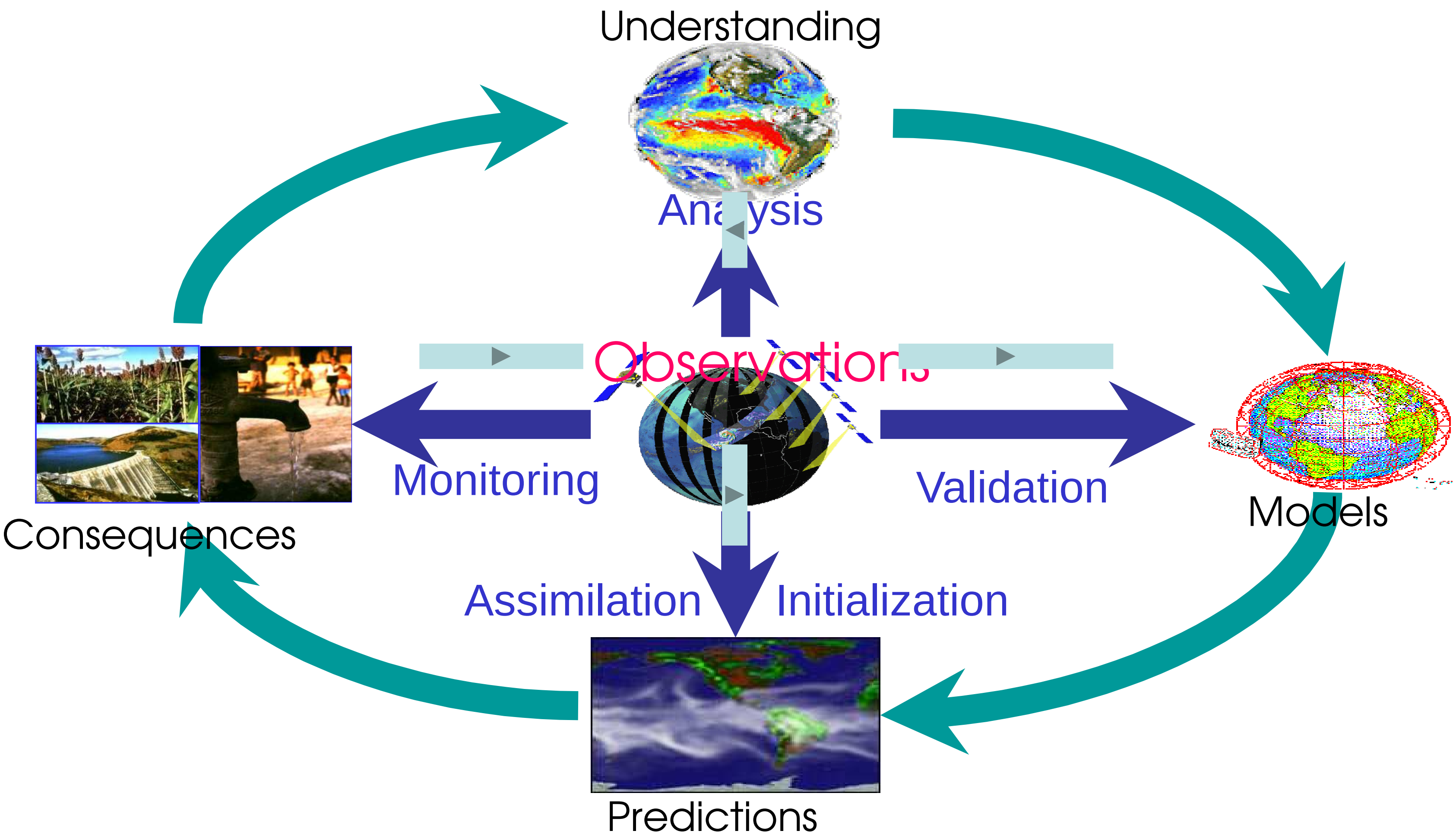
The whole is more than the sum of the parts—Aristotle




**WIGOS-Space** needs to meet weather, climate, water and related environmental services requirements

# For each domain (weather, climate, water & environment), space observations shall meet full spectrum requirements

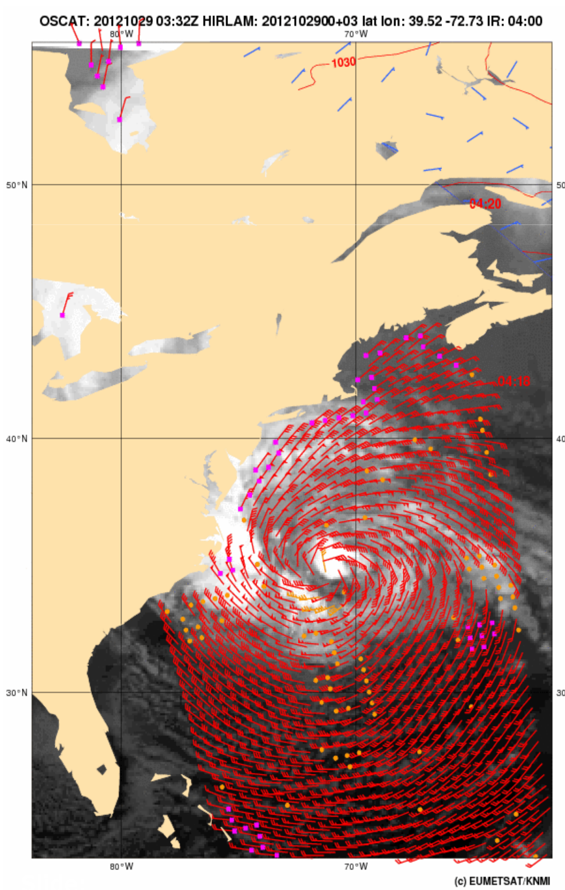



The enhanced space observations will motivate advances in monitoring, prediction and understanding

# Challenges of space observing capability for meeting severe **Weather** forecast Requirements in 2040 - DRR

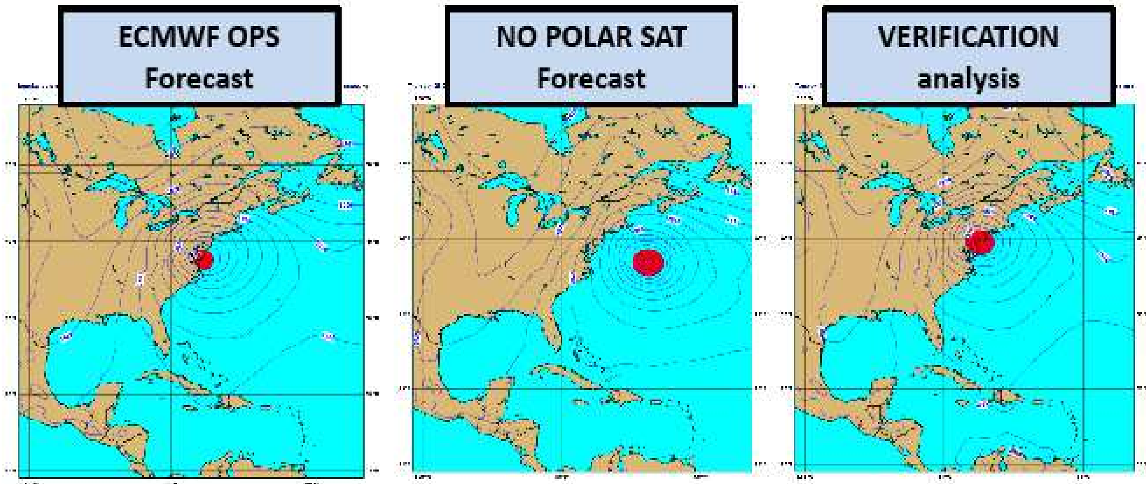
## Hurricane Forecast & Monitoring Challenges

**Global Polar-orbiting Satellites constellational is critical forecasts**




### Forecasts of Hurricane Sandy without polar satellites

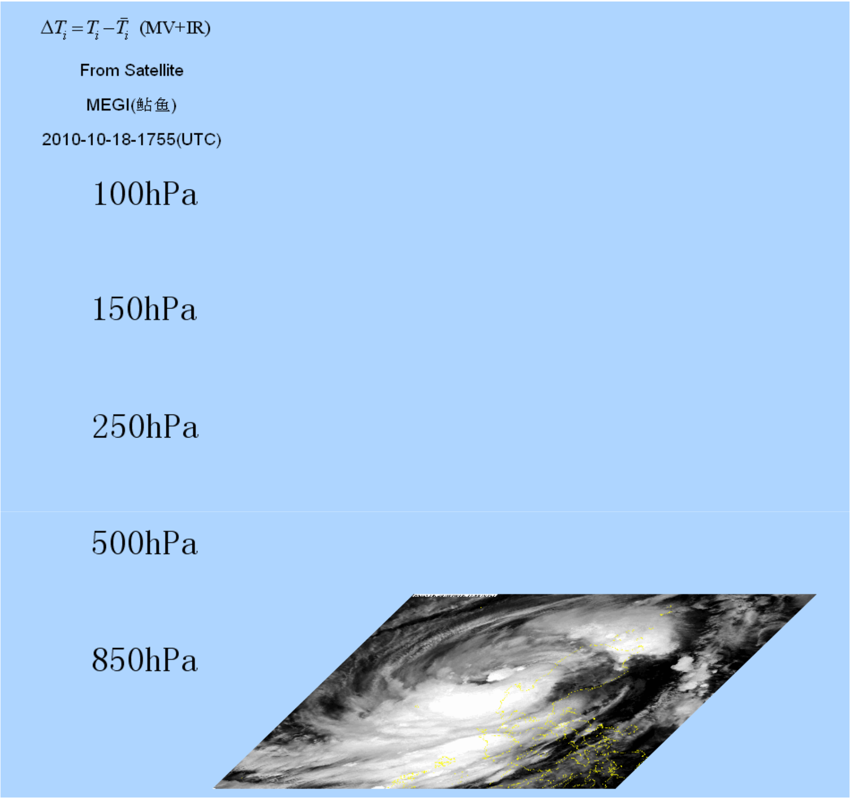
ECMWF forecasts of Mean Sea Level Pressure, **5 days in advance** of the 30th October 2012 for the landfall of Hurricane Sandy. Forecasts from an assimilation system with no polar satellites fail to predict the landfall of the storm on the US east coast.

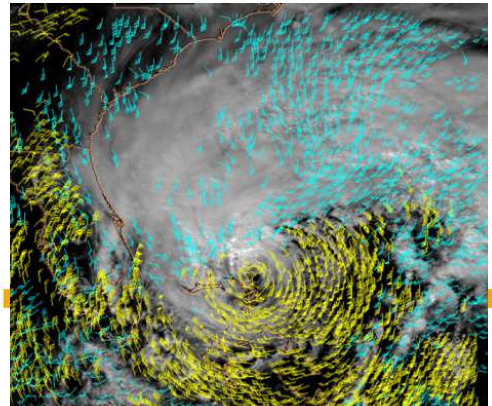


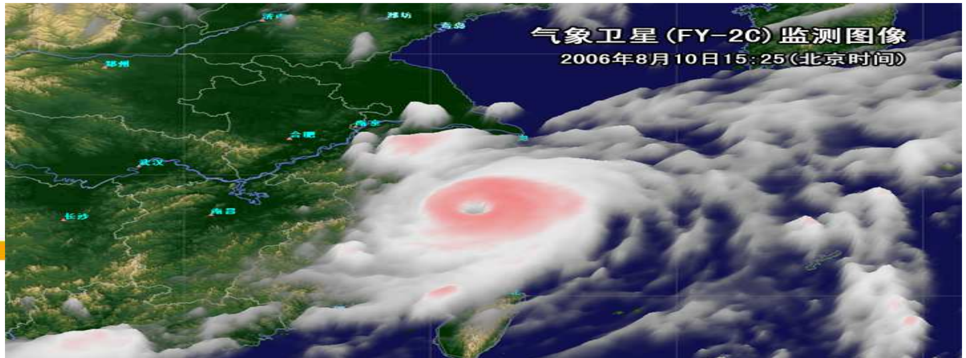

5 day forecast: Base time 2012-10-25-00z Valid Time: 2012-10-30-00z

# TC monitoring and warning Challenges

- **Biggest forecast challenge is rapid intensity change**
- Limited skill at even analyzing TC structure
- Frequent Monitoring the intensity and change is Critical to timing and placement of watches/warnings
- Can we anticipate new GEO or LEO MV instruments to observe the internal structure of TC intensity, in addition to VIS/IR ?





# The GFCS initial priority areas

Challenges & opportunities for new partnership to address new observational requirements via user communities

Agriculture

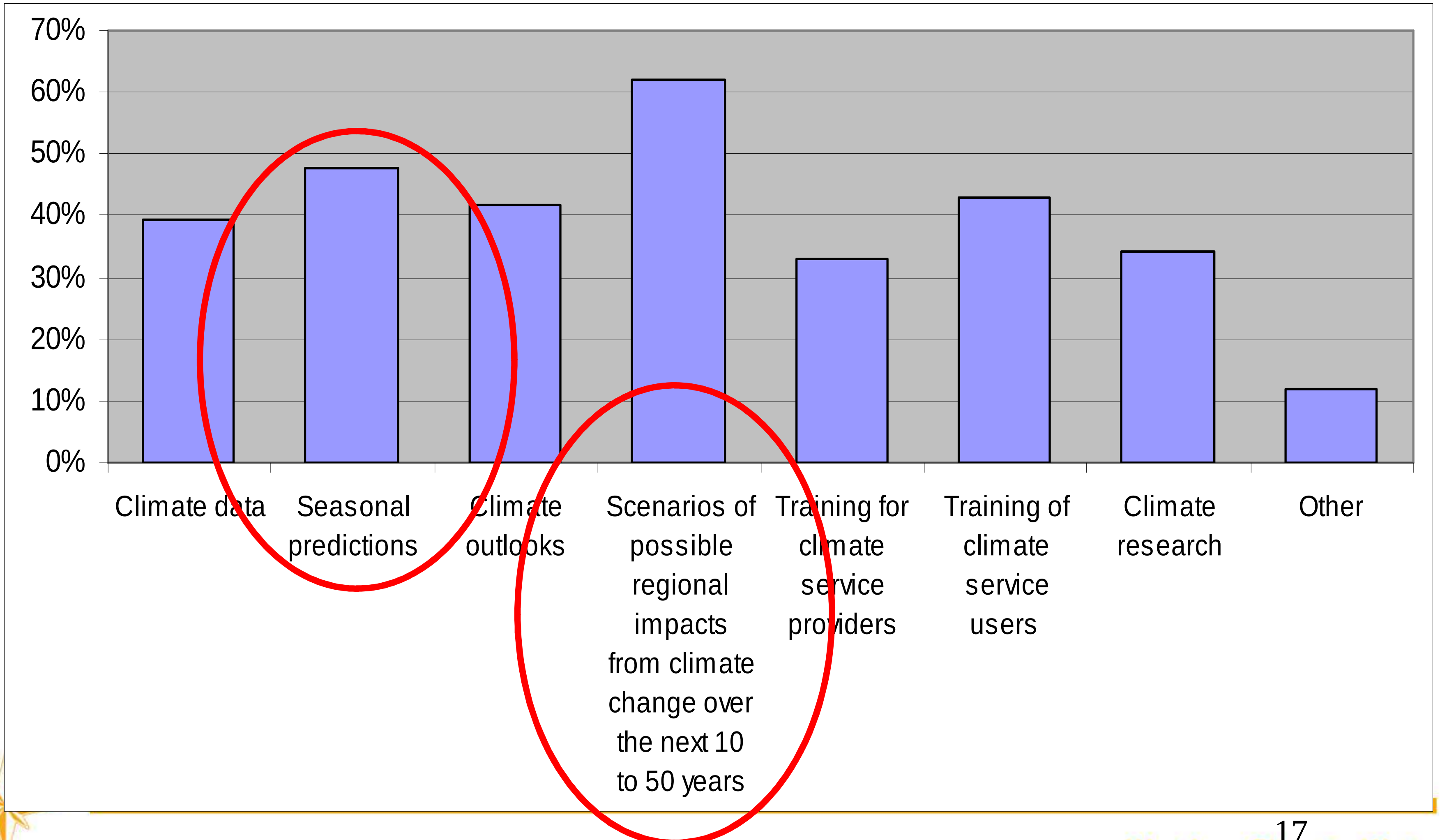
Water

Health

Disaster Risk Reduction

# Questionnaire:

Which climate services do you need but are currently unable to obtain ?



# WIGOS 2040 – Key observing requirements for climate-1
# Climate System Approach vs. Disciplinary Approach

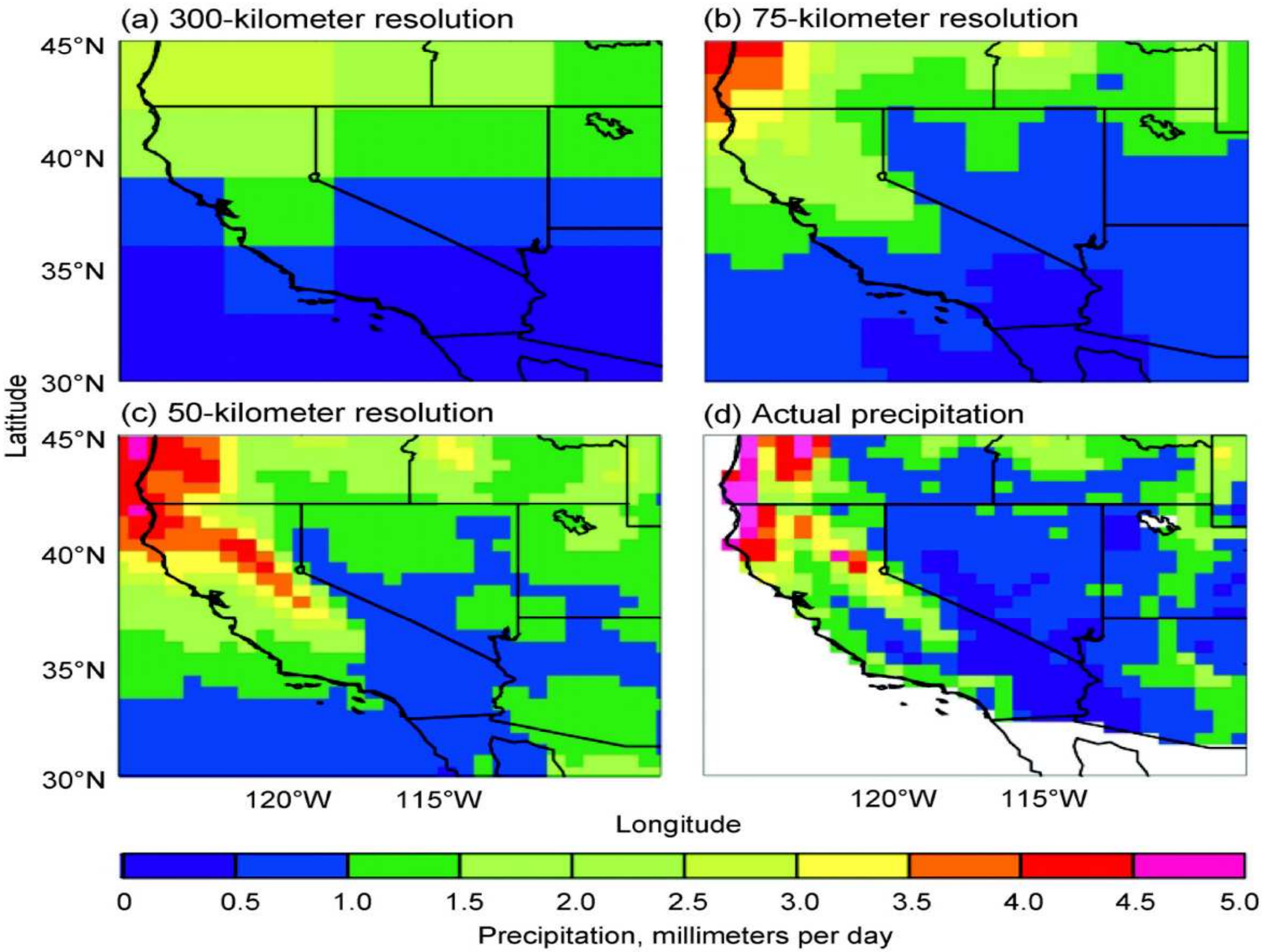
**Current**

- Disciplinary approach observations (operational observation of atmosphere+ R&D observations for other spheres, i.e., hydrosphere, cryosphere, lithosphere, and biosphere)

**In 2040**

- Sustained observations of the whole climate system (5 spheres), such that the changes in any component system can be traced to measure the total impact
- New technology for observing **water in all its phases (vapor, liquid & solid)**

# Need high resolution rainfall climate observations to validate climate models



# WIGOS 2040 – Key observing requirements for climate-2
# Improving Measurement precision and long-term consistency

## Current

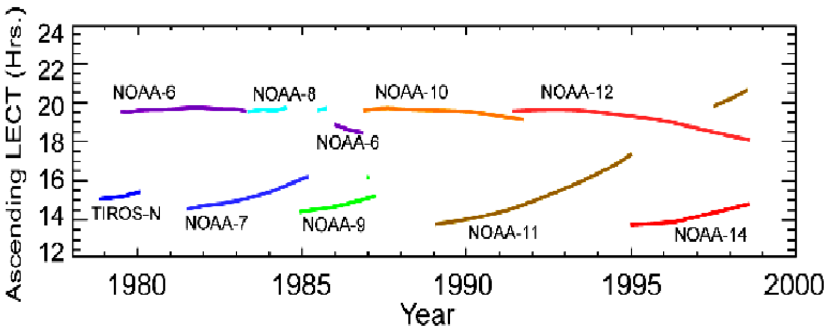
- Trade-off solution with spatial, spectral, temporal resolutions & radiometric precision.
- Great efforts for developing a calibrated data set long after the observations are taken (MSU, for example).
- Initial success of Global Space-based Inter-calibration System (GSICS) for major operational satellite sensors.

## In 2040

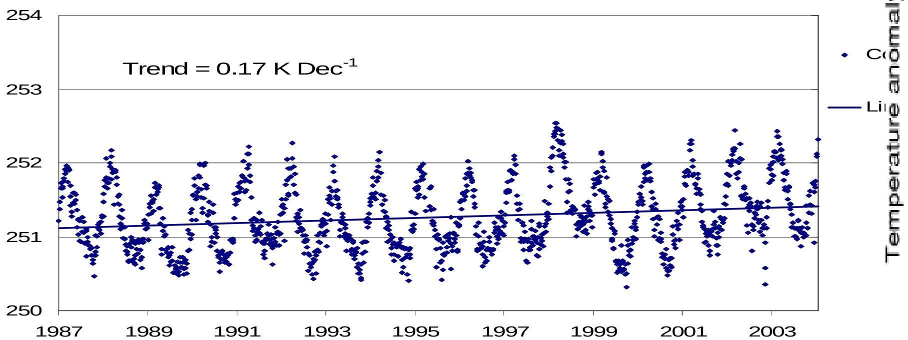
- The strategic focus for improving measurement precision while also enhancing spatial, spectral, and temporal resolution.
- Plan for good calibration of multi-satellite measurements
- Full engagement of all space observations with GSICS as the foundation for long-term consistency data records

# The architecture shall ensure long-term quality assured climate observations with integration of space and surface observations

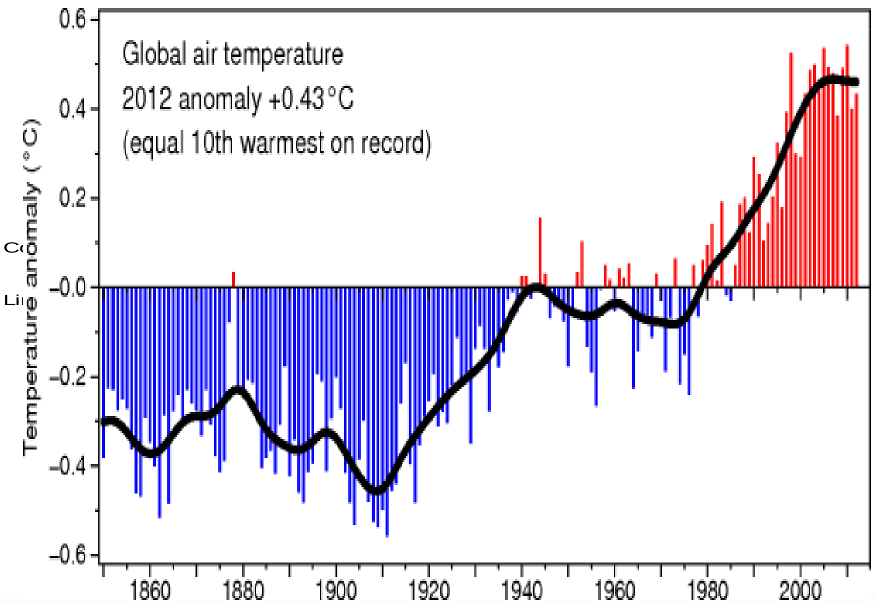
Figure 5




Local equatorial crossing time for NOAA satellites show the long-term drift (from Wentz, 2002).

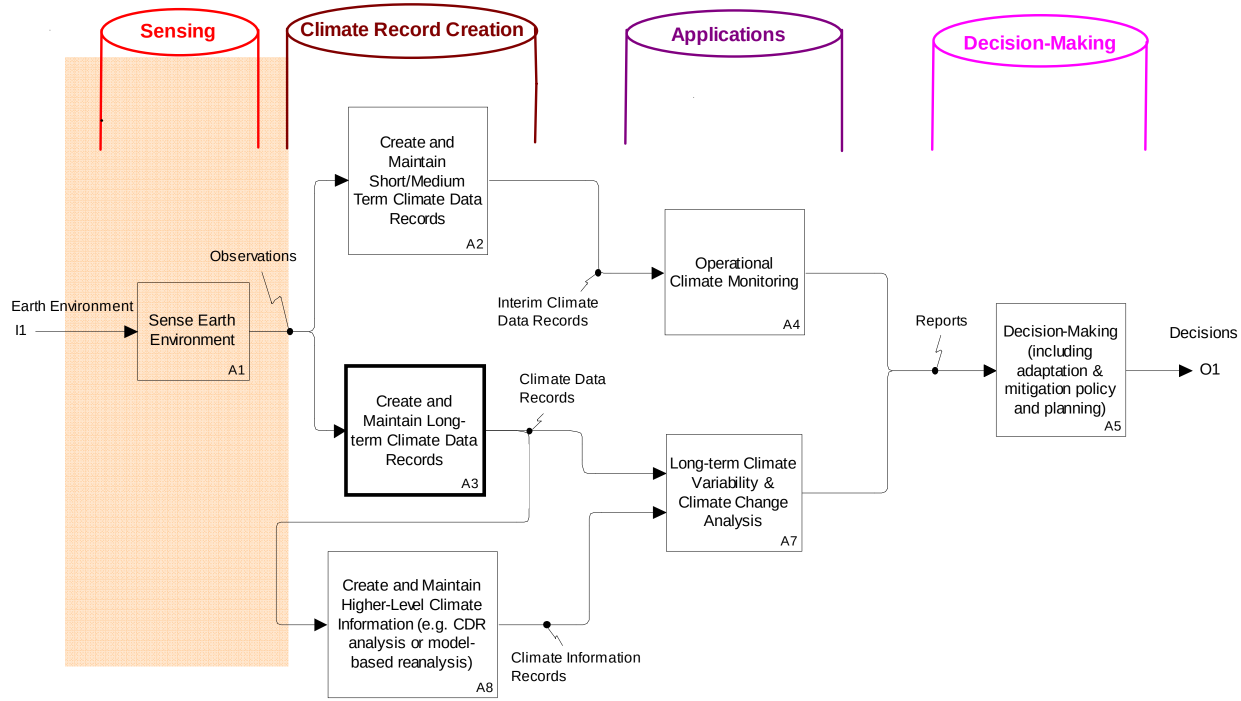



## Longest surface T instruments measurements (>240 years) Against 30 years average (1961-1990) WMO Centiennial stations



# Needs from Architecture for Climate Monitoring

- The ECV inventory reviews the *actual* use of existing or planned data records




- The capability to record such data is determined at least one decade ahead by the **sensing level** (satellite, sensors) design
- **Elements and processes** driving the space segment must be defined to avoid future gaps in the *potential* to observe ECVs

# 3. Anticipated Advances in technology to meet requirements. – technology driven !

# Technology advances for sensors

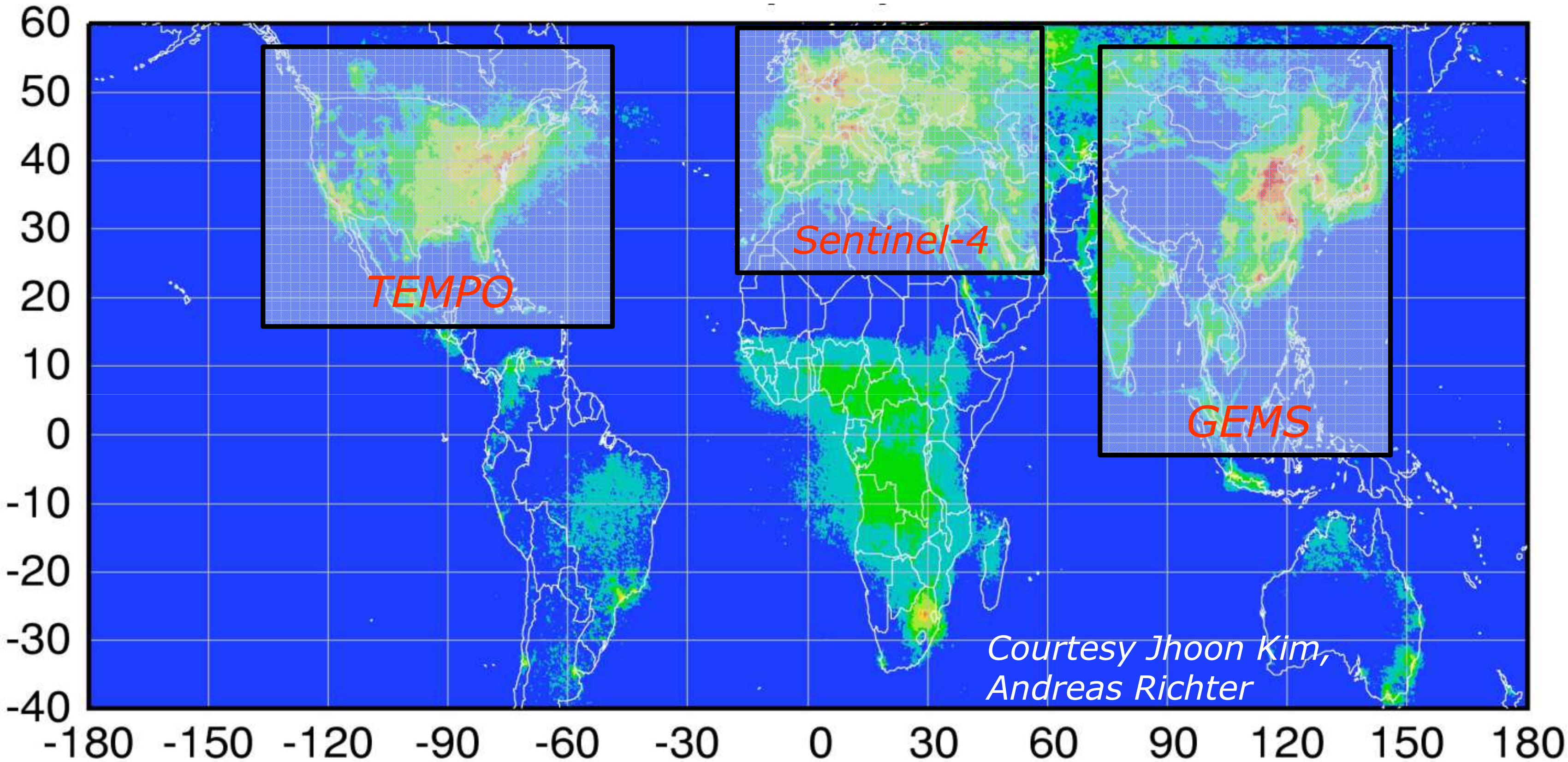
- Better sensors, geometric/radiometric resolution
- Spectrum better exploited: UV, Far IR, MW
- Hyperspectral sensors in UV, VIS, NIR, IR, MW
- Combinations of active/passive (including bi-static)
- Better use of polarimetric measurements (incl. with SAR)
- Diversified implementation of GNSS RO
  - additional frequencies, large constellations
  - ionospheric scintillation
  - Direct and reflected signals..

➢ Note: radiofrequency spectrum protection issues

# Technology advances for satellite systems

- More satellite providers, allowing more diverse orbits
  - HEO-GEO-MEO-LEO (inclined or sun-sync) and lower platforms
- Backbone system
  - Geostationary ring
  - LEO sun-synchronous in 3 planes (am/pm/earlymorning)
  - Sun-Synch. Satellites at various ECT for better time sampling
  - Missions on inclined orbits (altimetry, precipitation & soil moisture missions)
  - HEO missions for improved Arctic coverage
  - **How the successful R/D missions be added to the baseline 2040 ?**
- In-orbit measurement reference standards for calibration, traceability
  - would leverage the value of the whole constellation of satellites
- Other, novel concepts
  - Nanosatellites ready to serve as gap fillers for contingency
  - Use of the International Space Station for demonstration missions,….

# The Space Architecture shall Integrate operational and R&D satellites building synergies for enhanced climate observing capabilities: Example: Geostationary pollution monitoring




Spatial coverage of funded spectrometers 2018-2020

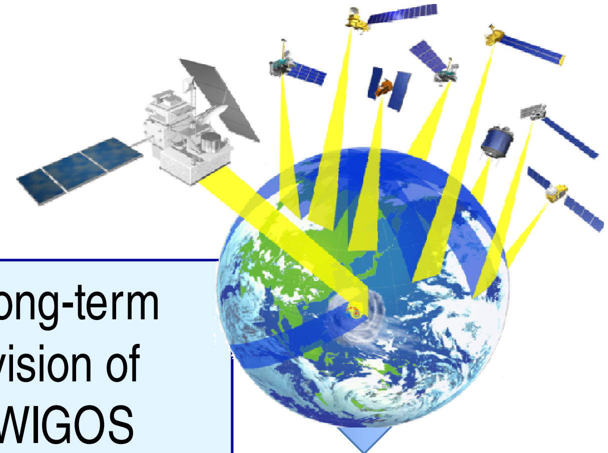
Policy-relevant science and environmental services enabled by common observations

# Changes in the providers' community

- Continued need of international commitments by government-designated entities towards global optimization and interoperability
  - Governments shall ensure that «backbone» system provides essential data freely in a WMO-coordinated framework
- New business models possibly involving commercial initiatives
  - Opportunity to *supplement* the public «backbone system»
  - Issues requiring careful consideration:
    - Transparency/traceability, data availability, global coordination
    - Risk to undermine the funding efforts of the backbone system
  - Models could be investigated to enhance participation of WMO Members in the space effort (e.g. CLS-ARGOS, or DMC-constellation)

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

## WIGOS Vision in 2040 – Key challenges
## Can we Go beyond coordination to start International Planning ?



**Requirements**

Requirements

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Critical review

Observing capabilities (space & surface)


Statements of Guidance

Long-term vision of WIGOS

Implementation Plan for Evolution *Recommendations*

Members' programmes (including space agencies)

# Need interaction with applications

- Difficulty to anticipate the user needs 25 years ahead
- Users unaware of potential future capabilities
- Space agencies need to better understand the user needs
- Direct interaction needed to stimulate a prospective view
- Dialogue is planned at a «**WIGOS Space 2040 workshop**»
  - **Geneva, 18-20 November 2015 (important dialogue)**
  - **Leads or representatives of the major user communities and space agencies involved in the Vision development**
  - **A panel of representative users of WMO applications (NWP, NWC, GAW, GCW, Ocean, Hydrology..)**
  - **With invitation to all important & interested agencies**

# Acknowledgements

- This presentation is based on the conclusions of ET-SAT-9 on 12-14 November 2014 with participation of:

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  *Riko Oki (JAXA)*
  *Sid Boukabara (NOAA)*
  *Yasushi Izumikawa (JMA)*

# Thank you for your attention!

Your feedback is welcome

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# Backup slides

# Main drivers for updating the 2025 Vision

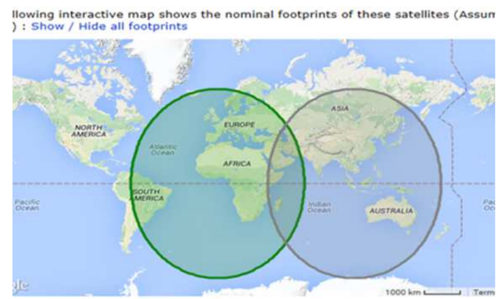
- WMO strategic Plan address broader & new emerging global societal needs and user requirements not captured in the Vision-2025
  - Global Framework for Climate Services (GFCS). Atmospheric composition, cryosphere, hydrology, space weather were hardly addressed
- Advances in technology
  - Sensor technology
  - Orbital concepts, including Small satellites, constellations
  - Data processing, infomation and assimilation technology
  - Data circulation scheme
- Changes in the providers' community
  - More space faring nations
  - Need cost/benefit justification
  - Public/private initiatives

# Rolling Review of Requirement (RRR) process
# Current Application Areas (10)

- Weather:
  - Global NWP & High Resolution NWP
  - Nowcasting & Very Short Range Forecasting
- Climate
  - Climate Monitoring (GCOS)
  - Climate Applications & Services (GFCS)
  - Agriculture Meteorology
  - Ocean Applications
  - Seasonal & Inter-Annual Forecasting (SIAF)
- Water
  - Hydrology
- Environment
  - Atmosphere Chemistry
  - Space Weather

# User application needs recorded in existing «Statements of Guidance»

- WMO application areas have developed  Statements of Guidance summarizing their priority needs for observations
- Most of these needs **are captured in the Vision for 2025** and **are being implemented**  (3 orbit sounding, altimetry, GNSS-RO, precipitation radar, etc.)
- However some requirements still unfulfilled in current Vision
  - Need higher resolution (spatial, temporal, radiometric) than currently available/planned
  - Need for better coverage by GNSS Radio-Occultation
  - No global coverage plan  for GEO hyperspectral IR
  - Some mission concepts requiring demonstration




GEO Hyperspectral IR plan

# New user needs (not captured in current Vision)

- **Limb sounding** for atmospheric composition
- Former «pathfinders» to become operational candidates
  - **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** for underground water storage and support to altimetry
- **Lidar altimetry** for hydrology and cryosphere
- **Sub-mm imagery** for cloud phase
- **Multi-angle, multi-polarization radiometry** for aereosol and radiation budget
- **NIR spectrometry** for surface pressure
- **Solar wind** and **heliospheric imagery** at Lagrangian points L1 and L5 respectively

# Growing role of numerical modeling

- Seamless modeling from very short to longer time scales
- Requires improved time/space resolution and timeliness
  - Towards global 5kmx1h resolution
- Reinforced requirement for 3D wind and surface pressure
- Allows quantitative assessments of the value of each observation to support observing system optimization

# Technology advances/ satellite systems (2/2)

- Consequences
  - Increased robustness, resilience, and improved sampling by diversity of approaches
  - Requires user agility
  - **Interoperability** is a key requirement

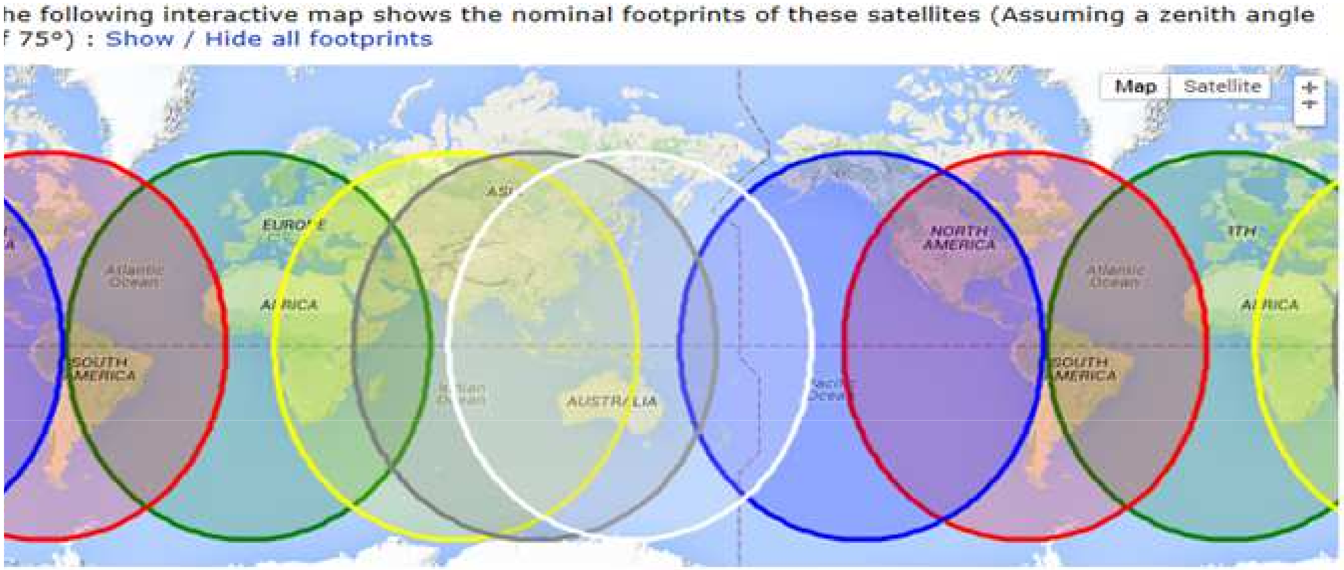
- Data circulation
  - Large data volumes and short latency
  - Security issues
  - Interoperability/standardization
  - Long term data preservation

# Three dimension anticipations leading to the WIGOS Vision 2040

1. From Global Societal Needs dimension in 2040 project to anticipation of meteorological services 2040
2. From Meteorological services 2040 dimension, project to anticipated observing requirements 2040–covering all WMO thematic areas (weather, climate, water & environment) under framework of WIGOS – user driven approach !
3. From Advances in technology 2040 dimension, to compare with the requirements. – technology driven !

# Challenges of space observing capability for meeting severe Weather monitoring Requirements in 2040 – DRR

# Direct monitoring storm/hurriance genesis, intensify & moving




- Biggest forecast challenge is rapid intensity change


- Geostationary satellites are critical with better hurricane structure data (wind, temperature and moisture data) for improving monitoring and forecasting

GEO Imagers & sounder Coverage (potential gap in 2040)

# Architecture for Climate Monitoring /sensing level

- Review/update climate observation **requirements**
- Define **reference system** that would meet the requirements
  - Enhanced «CGMS Baseline» + minimum specifications to support FCDR
- Monitor agencies' plans to assess the potential of future missions to support the required CDR
  - Measurement potential driven by sensor features, orbit coverage
  - Necessary but not sufficient for actual climate record creation
- Prospective **Gap/Risk Analysis** comparing planned missions with reference : manage gap/risk to ensure seamless continuity
- Sensor design with attention to **comparability with heritage sensors**
- Consistency and traceability of measurements through measurement references and **inter-calibration procedures**

# WIGOS 2040 – Key requirements for climate - 4
# From Observations to value-added products & Info.

## Current

- Non-optimized, non-holistic investment approach for space, ground and application segments.
- Insufficient investment in new science/technologies enabling interpretation from obs to products & information, thus the full benefits of the huge investment in the space not realized

## In 2040

- Holistic space programme investment approach (including space, ground and application segments) ensuring turning satellite observations into value-added products, information and knowledge supporting many applications
- The benefits of space observations are better realized with broader & more effective applications

# WIGOS 2040 – Key observing requirements for climate-3 Quantitative Assessments of Observation Impacts

**Current**

- Success limited to quantitative assessments of the value of observations in driving NWP models (medium range)
- The present disciplinary approach to Earth observations and modeling poorly assesses the feedbacks between diverse system components, thereby limiting the ability to make accurate predictions and guidance for obs developments

**In 2040**

- The observations from space will drive a robust seamless Earth system modeling and predictive capabilities
- It will allow for quantitative assessments of the value of each observation (including space and surface component), such that the global observing systems will be able to evolve toward an optimized suite.

WMO OMM

# Atmospheric Science entering into 21st century
# Imperative 2: Develop New Observation Capabilities

- Contemporary numerical models are sufficiently powerful that they can predict or simulate a range of phenomena such as weather, climate and climate change and air pollution episodes. However, observations of critical variables on time and space scales relevant to forecasts are essential to improving such numerical predictions.
- *Space agencies should commit to a strategy, priorities, and a program for developing new capabilities for observing critical variables, **including water in all its phases, wind, aerosols, and chemical constituents and variables related to phenomena in near-Earth space, all on spatial and temporal scales relevant to forecasts and applications**.*
- *The possibilities for obtaining such observations should be considered in studying the optimum observing systems.*