WEATHER CLIMATE WATER

WMO activities in support of international coordination and cooperation on Space Weather

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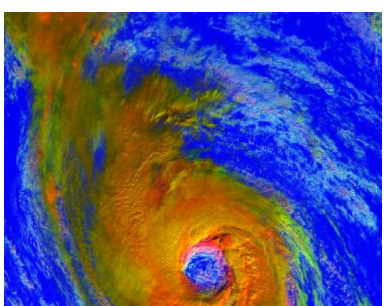
WMO Space Programme

WORLD METEOROLOGICAL ORGANIZATION

World Meteorological Organization

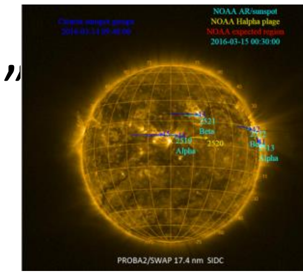
- Specialized agency of the United Nations
  for meteorology (weather and climate),
  operational hydrology
  and related geophysical sciences.

- 191 Members (States and Territories)
- Based in Geneva, Switzerland



Key Decisions of WMO Members

- 2011: "a coordinated effort by Members is needed to protect against the global hazards of Space Weather"
- 2015: " to engage in international coordination of operational space weather monitoring and forecasting with a view to support the protection of life, property and critical infrastructures and the impacted economic activities."



- Enable Members to establish operational space weather services
- Sharing observation data and products, and best practices
- Ensuring interoperability and standardization
- Coordinating a response to ICAO requirements

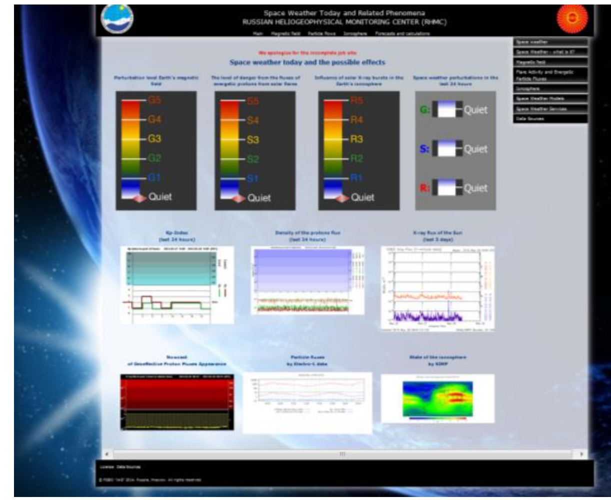
Priority

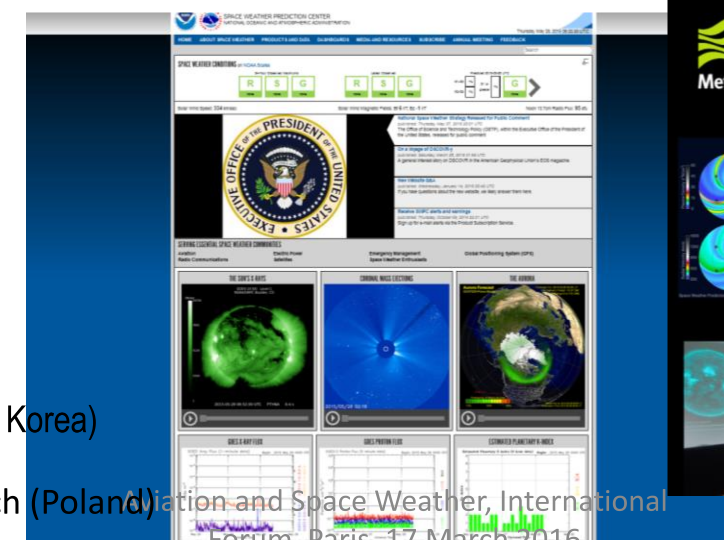
Inter-Programme Coordination Team on Space Weather

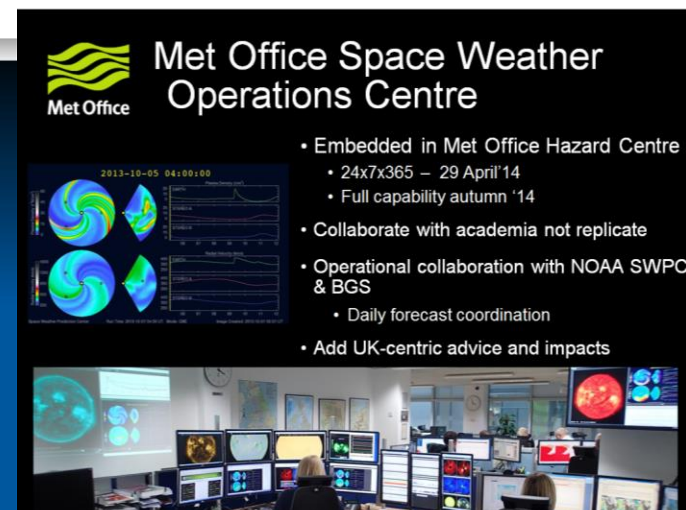
- Established in 2010
- Experts from 26 states and 7 International Organizations
- Co-chairs Dr T. Onsager (NOAA) and Dr X. Zhang (CMA)

Existing Space Weather Forecast Centres (1)

- Bureau of Meteorology(Australia)
- CMA(China)
- CSWFC (Canada)
- Institute of Applied Geophysics (Russia)
- Solar Influences Data Analysis Center, ROB (Belgium)
- NOAA (USA)
- Met Office (UK)
- INPE (Brazil)
- NICT (Japan)
- DLR (Germany)
- Radio Research Agency (R. Korea)
- Center for Space Research (Poland)







Existing Space Weather Forecast Centres (2)

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- CMA(China)
- CSWFC (Canada)
- Institute of Applied Geophysics (Russia)
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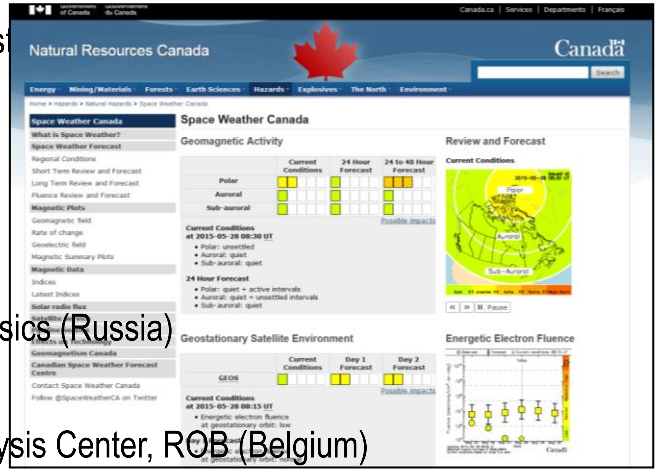

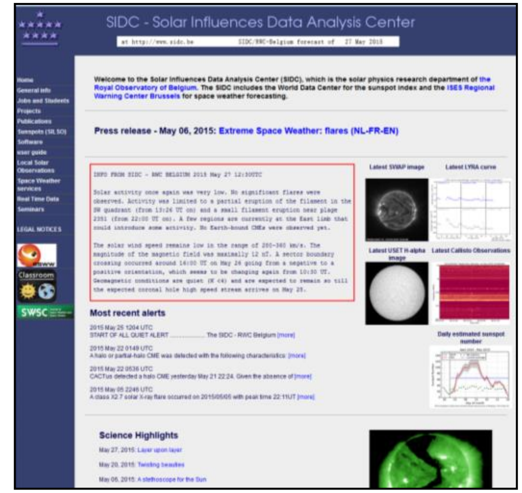

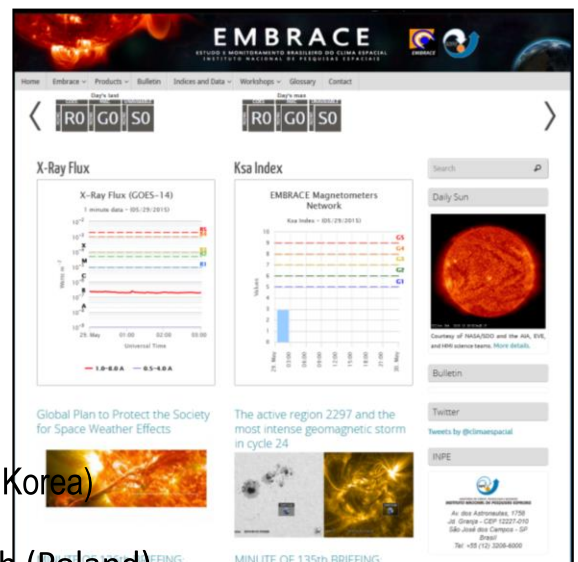

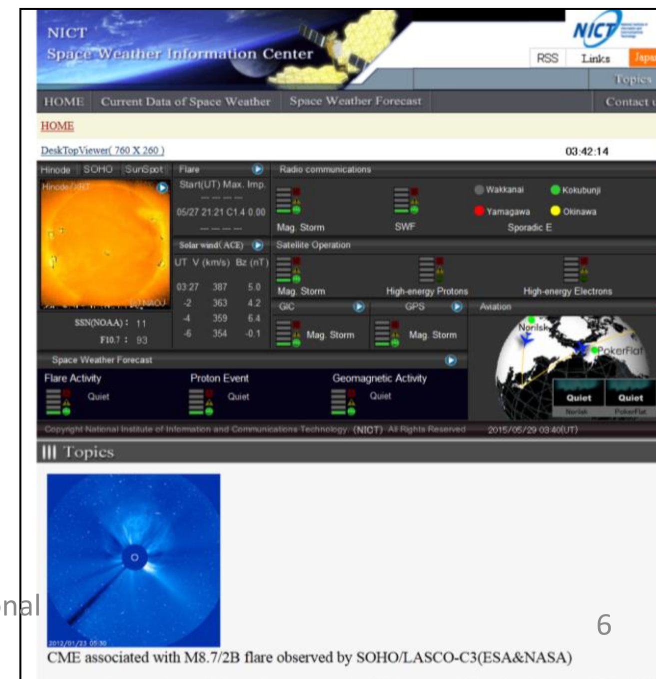

Existing Space Weather Forecast Centres (3)

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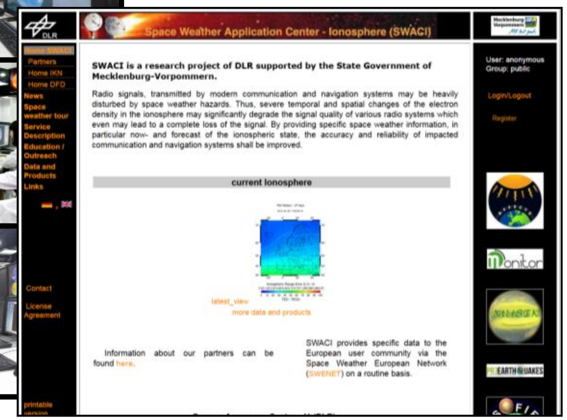
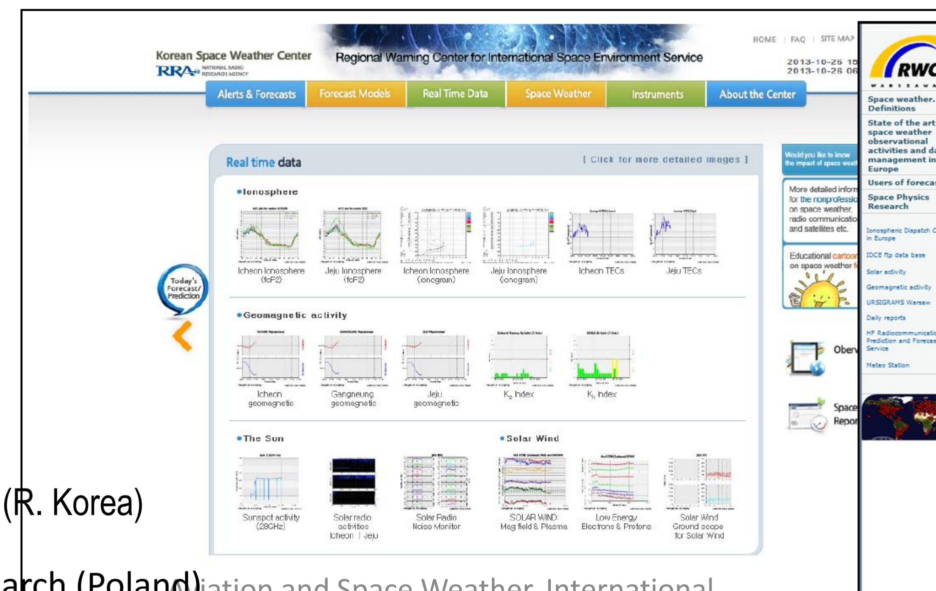
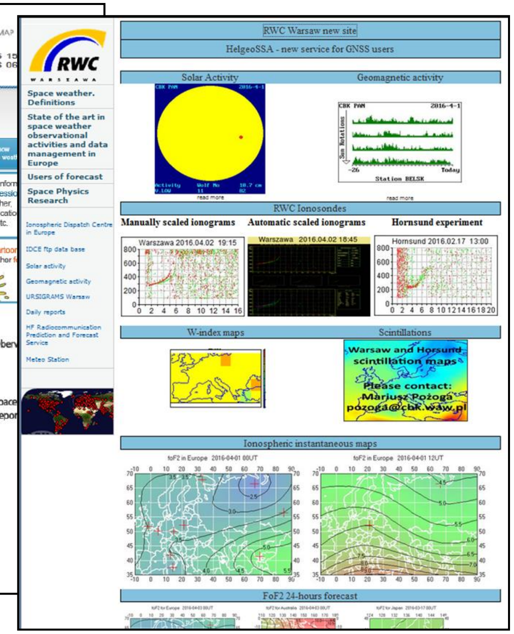




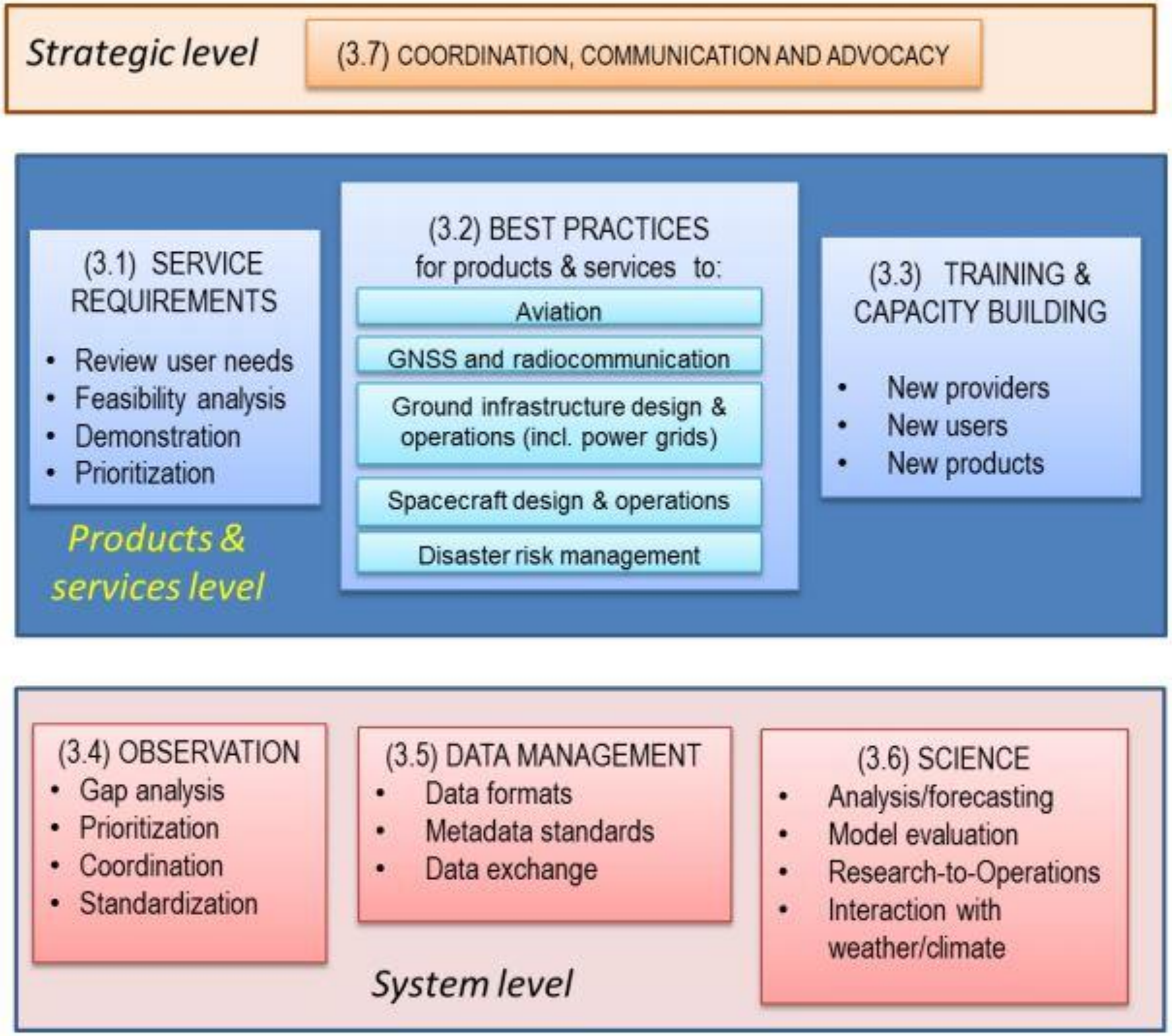


Future plans:

WMO FOUR-YEAR PLAN FOR SPACE WEATHER (2016-2019)

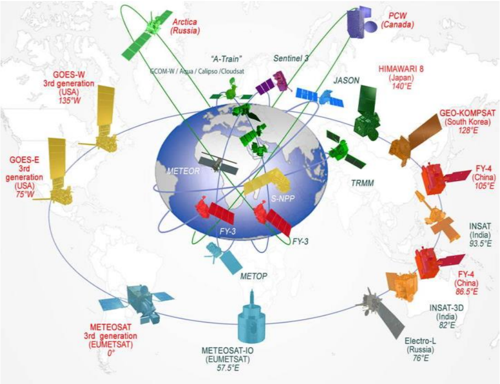
Four-Year Plan in Support of International Coordination of Operational Space Weather Monitoring and Forecasting

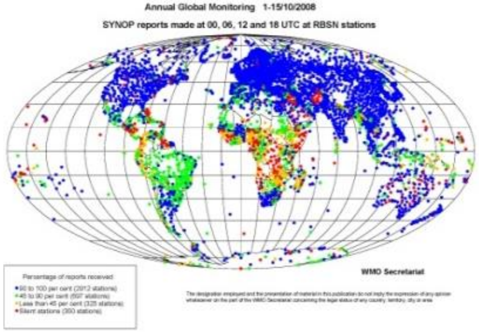
(Submitted to Exec Council in June 2016 for approval, per request from WMO Congress)



Systems Level Activities

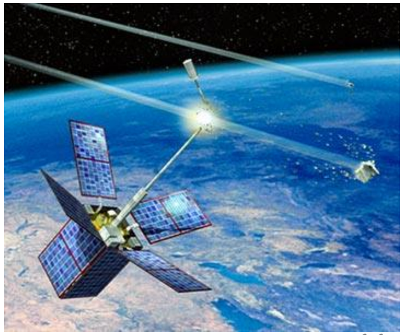
- Coordinate observational assets and plans to ensure continuity and interoperability of space weather observations
- Take advantage of integration of meteorological and space weather observations where relevant
- Support information exchange through the WMO Information System (WIS) framework, standards, practices, policies
- Dialogue with meteorological/climate community on modeling and verification





Service Level Activities

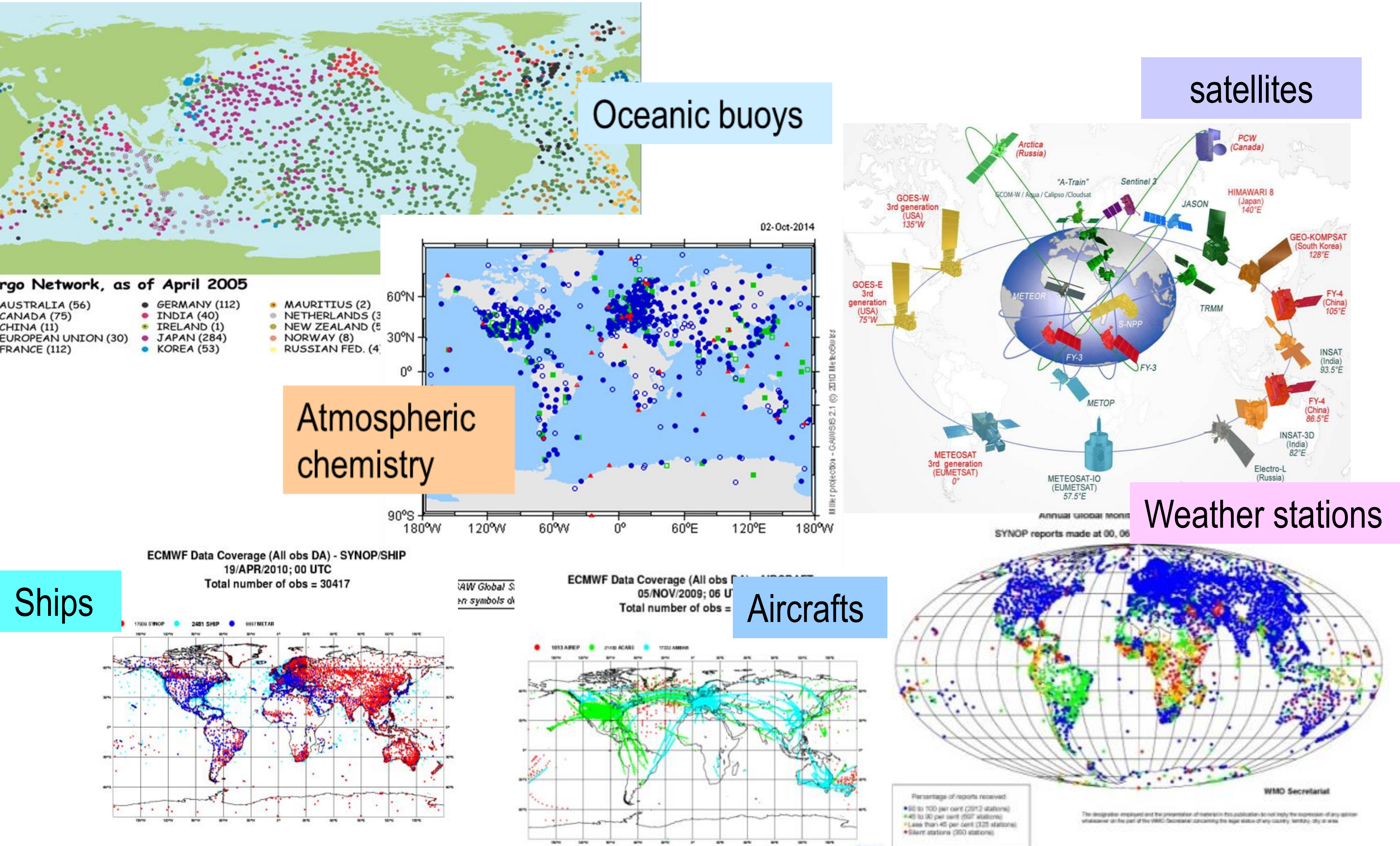
- Organize WMO Members to deliver coordinated services responding to ICAO requirements
- Prepare for extreme events in a multi-hazard Disaster Risk Reduction approach
- Analyze requirements for applications including ionospheric disturbances (radio propagation and GNSS), satellite operations, and ground infrastructure (power grids)
- Provide training on delivery and use of services



Key activity area 1:

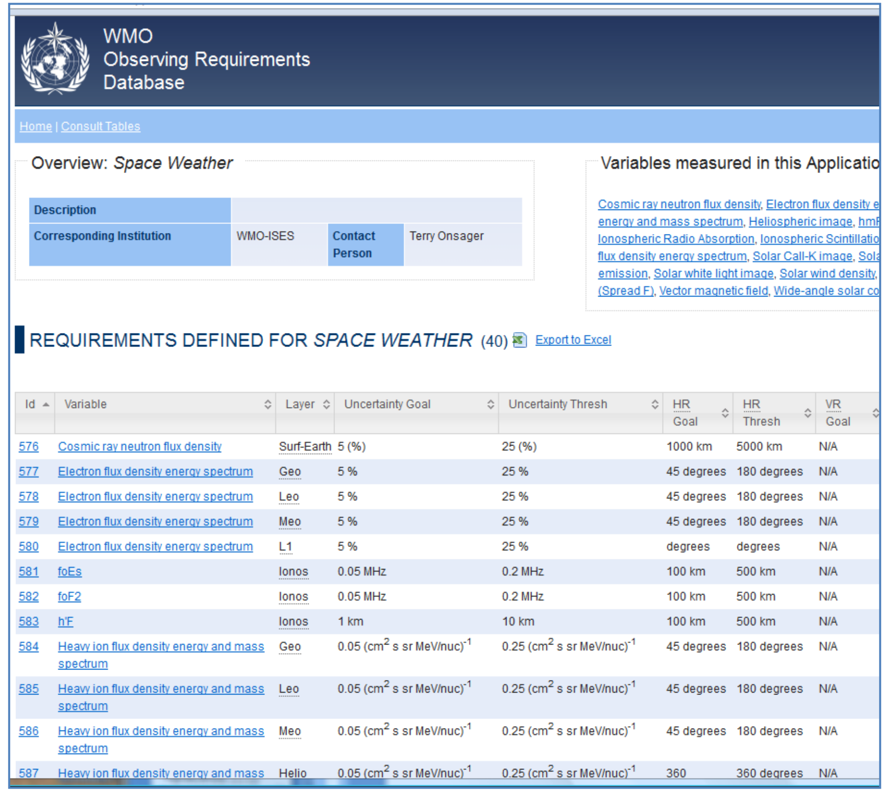
SPACE WEATHER OBSERVATION

WMO Integrated Global Observing System components



International Space Weather Observing Requirements

- Observing requirements are documented in a database and kept under review
- Addressing operational applications (alerts, warnings and forecasts) and climatology needs
- Basis for gap analysis and issuing a "Statement of Guidance" for future observations e.g.:
  - Sun and solar wind
  - Ionosphere
  - Near real time data availability



WMO
Observing Requirements
Database

Home | Consult Tables

Overview: *Space Weather*

Description			
Corresponding Institution	WMO-ISES	Contact Person	Terry Onsager

Variables measured in this Applicatio

Cosmic ray neutron flux density, Electron flux density e
energy and mass spectrum, Heliospheric image, hmF
Ionospheric Radio Absorption, Ionospheric Scintillatio
flux density energy spectrum, Solar Call-K image, Sola
emission, Solar white light image, Solar wind density,
(Spread F), Vector magnetic field, Wide-angle solar co

REQUIREMENTS DEFINED FOR *SPACE WEATHER* (40) Export to Excel

Id	Variable	Layer	Uncertainty Goal	Uncertainty Thresh	HR Goal	HR Thresh	VR Goal
576	Cosmic ray neutron flux density	Surf-Earth	5 (%)	25 (%)	1000 km	5000 km	N/A
577	Electron flux density energy spectrum	Geo	5 %	25 %	45 degrees	180 degrees	N/A
578	Electron flux density energy spectrum	Leo	5 %	25 %	45 degrees	180 degrees	N/A
579	Electron flux density energy spectrum	Meo	5 %	25 %	45 degrees	180 degrees	N/A
580	Electron flux density energy spectrum	L1	5 %	25 %	degrees	degrees	N/A
581	foEs	Ionos	0.05 MHz	0.2 MHz	100 km	500 km	N/A
582	foF2	Ionos	0.05 MHz	0.2 MHz	100 km	500 km	N/A
583	h'F	Ionos	1 km	10 km	100 km	500 km	N/A
584	Heavy ion flux density energy and mass spectrum	Geo	0.05 $(cm^2\ s\ sr\ MeV/nuc)^{-1}$	0.25 $(cm^2\ s\ sr\ MeV/nuc)^{-1}$	45 degrees	180 degrees	N/A
585	Heavy ion flux density energy and mass spectrum	Leo	0.05 $(cm^2\ s\ sr\ MeV/nuc)^{-1}$	0.25 $(cm^2\ s\ sr\ MeV/nuc)^{-1}$	45 degrees	180 degrees	N/A
586	Heavy ion flux density energy and mass spectrum	Meo	0.05 $(cm^2\ s\ sr\ MeV/nuc)^{-1}$	0.25 $(cm^2\ s\ sr\ MeV/nuc)^{-1}$	45 degrees	180 degrees	N/A
587	Heavy ion flux density energy and mass	Helio	0.05 $(cm^2\ s\ sr\ MeV/nuc)^{-1}$	0.25 $(cm^2\ s\ sr\ MeV/nuc)^{-1}$	360	360 degrees	N/A

http://www.wmo-sat.info/oscar/applicationareas/view/25

WMO Vision for Space-based Observation in 2040 (in progress)

Tier I operational

- Solar coronagraph and radio-spectrograph, at L1
- In situ plasma, energetic particles, magnetic field (at L1 in solar wind, and GEO)
- In situ plasma, energetic particles at LEO
- GNSS radio-occultation for temperatire, humidity and electron density

Tier II operational

- Solar EUV/X-ray imager, magnetograph, EUV/X-ray irradiance, on the Earth-Sun line (e.g. L1, GEO) and off the Earth-Sun line (e.g. L5, L4)
- Solar coronagraph and heliospheric imager off the Earth-Sun line (e.g. L4, L5)
- Solar wind plasma, energetic particles & magnetic field off Earth-Sun line (e.g. L5)
- Magnetospheric energetic particles (e.g. GEO, HEO, MEO, LEO)
- Enhanced RO constellation for atmospheric/ionospheric soundings

Tier III, Pathfinders technology demo

- Solar coronal magnetic field imager, solar wind beyond L1
- Ionosphere/thermosphere spectral imager (e.g. GEO, HEO, MEO, LEO)
- Ionospheric electron and major ion density,
- Thermospheric neutral density and constituents

Key activity area 2:

SPACE WEATHER SERVICES TO INTERNATIONAL AIR NAVIGATION

Support to global air navigation

- WMO together with the International Civil Aviation Organization (ICAO) establish the regulatory framework for ***meteorological service for international air navigation*** (ICAO Annex 3 and WMO Technical Regulations, Vol.II)
- To contribute to safety, efficiency and regularity of the air transport
- Organizing/standardizing: observation, warnings, forecast, delivery, quality

Meteorological information and volcanic ash advisories

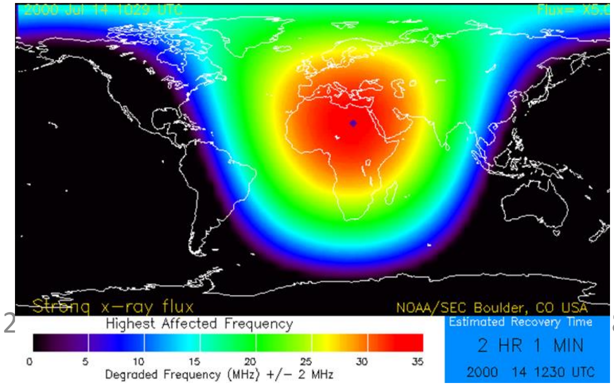
Space weather services to aviation

- Space environmental parameters have critical impact
  - Disruption of radio-communication
  - Degradation or loss of GNSS capability
  - Radiation damage to avionics
  - Ionizing radiation dose to crew/passengers

- Monitor these hazards to support decision making to minimize the risk :

  Alert, Warning, Forecast

  When ? How long ? Where ? How severe (in standard scales)?
- Multiple, cross-border users require a global, consistent service



Collaboration with ICAO on the definition of space weather services to global aviation

- Concept of Operations (CONOPS) is being refined
- Requirements are being developed

- Aiming at amendment #78 to ICAO Annex 3 to enter in force in Nov 2018

METEOROLOGY PANEL

Concept of Operations
for
Space Weather Information
in Support of
International Air Navigation
and
Consistent with the
Global Air Navigation Plan
And the
Aviation System Block Upgrades

DRAFT

2016

Version 4.0

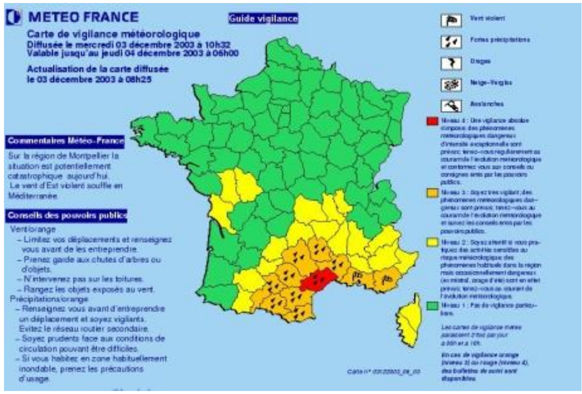
1

Key activity area 3:

DISASTER PREPAREDNESS

Disaster preparedness

- Identify SWx in national risk registers
- Multi-hazard early warning schemes
- Preparedness for cascading disasters
- Foster common best practices (hazard scales, data exchange)



NOAA Space Weather Scales

Category: Scale	Category: Descriptor	Effect (Duration of event will influence severity of effects)	Physical measure	Average Frequency (1 cycle = 11 years)
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp=8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

Scale	Descriptor	Effect	Physical measure	Average Frequency
Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 chest x-rays) is possible. Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; elevated radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 10 chest x-rays) is possible. Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in commercial jets at high latitudes may receive low-level radiation exposure (approximately 1 chest x-ray). Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: none. Satellite operations: infrequent single-event upsets possible. Other systems: small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} Based on this measure, but other physical measures are also considered.
** These events can last more than one day.

Scale	Descriptor	Effect	Physical measure	Average Frequency
Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 $(2x10^{-3})$	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 $(5x10^{-5})$	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in W·m^{-2}. Based on this measure, but other physical measures are also considered.
** Other frequencies may also be affected by these conditions.

Concluding remarks

- «Space Weather» is a science in progress but routine operational services are delivered by centres around the world, to respond to the needs of an increasingly vulnerable society
- International coordination is required to strengthen observations and data exchange, expand best practices and ensure interoperability and standardization
- Support to aviation is among the priority objectives for WMO through ICAO-WMO longstanding collaboration
- Benefits : improved services, leveraging the capability of existing centres, sharing observation/development efforts
- WMO provides collaboration framework for its Members to pursue these goals in synergy with weather/climate services

Thank you

Questions:
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WEATHER CLIMATE WATER

WORLD
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