W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N
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COMMISSION FOR BASIC SYSTEMS

COMMISSION FOR AERONAUTICAL METEOROLOGY

INTER-PROGRAMME COORDINATION TEAM ON SPACE WEATHER

FIRST SESSION

BOULDER, CO, USA

29 APRIL 2011

FINAL REPORT

WMO General Regulations

Regulation 42

Recommendations of working groups shall have no status within the Organization until they have been approved by the responsible constituent body. In the case of joint working groups the recommendations must be concurred with by the presidents of the constituent bodies concerned before being submitted to the designated constituent body.

Regulation 43

In the case of a recommendation made by a working group between sessions of the responsible constituent body, either in a session of a working group or by correspondence, the president of the body may, as an exceptional measure, approve the recommendation of behalf of the constituent body when the matter is, in his opinion, urgent and does not appear to imply new obligations for Members. He may then submit this recommendation for adoption by the Executive Council or to the President of the Organization for action in accordance with Regulation 9(5).

EXECUTIVE SUMMARY

The first “face-to-face” meeting of the Inter-Programme Coordination Team on Space Weather (ICTSW) was held on 29 April 2011 in Boulder, Colorado, United States of America (USA), with delegates from Belgium, Canada, China, Japan, Republic of Korea, Russian Federation, United Kingdom, USA, European Space Agency, International Civil Aviation Organization (ICAO), International Space Environment Service, and the WMO Secretariat.

The major outcomes of the meeting were:

- Endorsement of the first issue of the Space Weather observing requirements and associated definitions of variables, subject to minor refinements, and discussion of the next steps in the Rolling Requirements Review (RRR) process in order to provide guidance towards sustaining and improving Space Weather observations ;
- Information on the WMO Information System (WIS) and preliminary discussion on the potential use of WIS to support to the management of Space Weather data and products and leverage their availability worldwide;
- Information on the ICAO process to define Space Weather service requirements and discussion of a roadmap for future collaboration with ICAO to establish a globally coordinated operational support to aviation;
- Discussion of a draft statement on Space Weather to be brought to the attention of the forthcoming WMO Congress.

The presentations given at the meeting and all the working documents were posted on:
http://www.wmo.int/pages/prog/sat/meetings/ICTSW-1.html

REPORT

1. OPENING OF THE MEETING

The first "face-to-face" meeting of the Inter-Programme Coordination Team on Space Weather (ICTSW) was opened in the Millennium Hotel, in Boulder, Colorado, USA on Friday 29 April at 13:30. The meeting was chaired by Dr Terry Onsager, host of the meeting and Co-Chair of the ICTSW. The Chairman welcomed the participants (See Appendix I) and invited them to introduce themselves since the team had only worked so far by teleconferences. Mr Lafeuille then welcomed the participants on behalf of the Secretary-General of WMO.

The primary objectives of the meeting were recalled:

- To endorse the first issue of the Space Weather observing requirements and associated definitions of variables and define the next steps in the Rolling Requirements Review (RRR) process;
- To analyze the relevance of the WMO Information System (WIS) as a potential support to the management, exchange and dissemination of Space Weather data and products;
- To discuss a roadmap for future collaboration with the International Civil Aviation Organization (ICAO).

The agenda was adopted as contained in Appendix II, with the understanding that the discussion of collaboration with ICAO would precede the discussion of WIS. In addition, it was agreed that, under Item 7 of the agenda, consideration would be given to a proposed statement on space weather that was to be discussed at a side meeting at the forthcoming WMO Congress.

2. BRIEF UPDATE ON THE ICTSW STATUS

The Chairman recalled the Terms of Reference and initial Work Plan of the team. Later on, Mr J. Lafeuille briefly presented the role of the ICTSW in the overall WMO framework.

3. SPACE WEATHER OBSERVING REQUIREMENTS

3.1 Conclusion on the definitions and requirements

ICTSW members were invited to finalize the first version of Space Weather observing requirements with their associated definitions of variables. It was clarified that the requirements can be kept under review and updated if necessary in the following years, in order to take into account the evolution of needs and technical capabilities.

The team considered that the current status of requirements captured well the discussions pursued over the past months and were properly identifying the key physical variables to be observed and their definitions. Several points needed, however, to be further refined:

- The concept of layer should be clarified;
- The "horizontal" and "vertical" resolution did not seem to be the most appropriate to characterize spatial resolution of ionospheric variables in a meaningful way;
- Several values of temporal resolution and timeliness were challenged.

The team discussed the distinction between two sub-applications: "Space weather warning" with very stringent requirements for temporal resolution and timeliness, and "Space weather monitoring" for which delayed observations may still be helpful.

It was agreed that a small group led by A. Hilgers would work out a revised proposal for the applicable "layers" and the approach to spatial resolution by 12 May, in order to finalize the first version of Space Weather Observing Requirements in time for submission to the Expert-Team on

Evolution of the Global Observing System (ET-EGOS).

- **Action 1.1: The group led by A. Hilgers to provide final recommendations for modifications to the Space Weather Observing Requirements, and to distribute these recommendations to the team by 12 May.**

- **Action 1.2: The ICTSW to resolve any outstanding issue by 20 May and T. Onsager to submit the requirements to ET-EGOS in advance of the ET-EGOS-6 meeting.**

The list of Space Weather variables is contained in Appendix III. The finalized version of the requirements is available as part of the on line WMO Observing Requirements Database (www.wmo-sat.info/db/) under "Space Weather" Application Area.

(Note: Following the conclusion of the meeting, the findings of the group have led to characterizing the spatial resolution of particle flux density variables by a "number of measuring points" along an Earth orbit, which was then translated into the database as a measure of arc in degrees, e.g. 45 degrees corresponding to 8 measurement points.)

3.2 Update on the WMO Rolling Review of Requirements (RRR) process

A presentation was given by J. Lafeuille on the Rolling Review of Requirements (RRR) process (www.wmo.int/pages/prog/www/OSY/GOS-RRR.html). It was highlighted that the identification of requirements was a first step. In parallel, an evaluation of the actual and planned observing capabilities should be performed. Comparing the capabilities to the requirements would then provide a basis for identifying gaps, risks, priorities, and express recommendations for the evolution of observing systems in order to best meet the requirements. Based on the experience of applying the RRR process to meteorological and climate areas, he proposed the following approach:

- To complete an initial inventory of instruments, satellite and surface-based
- To define an instrument typology
- To draw a first Gap Analysis based on (key) instrument types
- To draft a first « Statement of guidance » based on this Gap Analysis
- To evaluate measurement performances by instrument types
- To refine the Gap Analysis for (key) measured variables
- To refine the « Statement of guidance » accordingly

J. Lafeuille indicated that the WMO Space Programme was maintaining a record of Earth Observation space-based capabilities referred to as the "Dossier on the Global Observing system", which included some 300 satellite missions and 400 instruments (http://www.wmo.int/pages/prog/sat/gos-dossier_en.php). Although this Dossier was mainly focused on meteorological and climate observations it also included references of more than 30 satellite missions supporting space weather; space weather aspects were going to be expanded in the next version, which could be a starting point for the space-based part of the inventory of capabilities.

The team welcomed this approach and noted that important elements had already been collected concerning the inventory of observing capabilities. It agreed to define a roadmap to complete the RRR process and took the following actions:

- **Action 1.3: WMO Secretariat to share the initial inventory of space-based observing capabilities in support of Space Weather, as contained in the latest issue of the "Dossier", by end of October 2011**

- **Action 1.4: ICTSW Members to document their space weather observing capabilities, either surface-based or space-based, by end of November 2011**

- **Action 1.5: ICTSW co-chairs, with the support of all team members, to develop a draft Statement of Guidance by the end of 2011.**

4. WMO INFORMATION SYSTEM (WIS) AND SPACE WEATHER

4.1 Introduction to WIS, implications and potential benefits of using WIS for Space Weather data and products

Don Middleton introduced the WMO Information System (WIS), its general concept, structure, standards and recommended practices, and suggested potential implications and benefits of using the WIS to support Space Weather data management, exchange, and distribution. It was indicated that the WIS functionalities were gradually implemented and were expected to be fully operational worldwide by 2015, but that the first WIS centres were being implemented in 2011 already. Given that the majority of the ICTSW members had no prior familiarity with WMO, the WIS presentation was an opportunity to obtain an initial introduction to the WMO structure for handling and sharing information in a globally coordinated fashion.

D. Middleton highlighted the possibility for Space Weather centres to be recognized either as “Data Collection or Production Centre” (DCPC) or as “National Centre” (NC) in the WIS environment, which would allow them to make Space Weather data or products searchable and accessible worldwide through an operational, globally interoperable catalogue system. DCPCs are centres committed to providing data and products in accordance with internationally agreed requirements. It was clarified that WIS centres could use in principle any internationally agreed format (e.g. BUFR, GRID, netCDF, etc) and a range of communication media to meet the various timeliness constraints. An essential requirement to ensure interoperability of WIS centres is however to be able to produce searchable metadata and synchronize them with the global catalogues, in accordance with relevant ISO standards (ISO 19115, ISO 19139 and ISO 23950) and their WIS implementation guidelines.

4.2 Discussion on the use of WIS

In the light of the WIS presentation, the ICTSW discussed the relevance of using the WIS to support international exchange of some Space Weather data and products. The team considered the different components of the WIS system, and discussed ways in which the current organizations involved in Space Weather might either become WIS components of or interface with the components being established. Following the discussion there remained a lack of clarity among the team as to how the various space weather organizations might best fit within the WIS structure.

It was agreed that further discussion would be needed among the Space Weather service providing organizations to better understand the WIS system and to determine how WIS can be utilized to enhance the exchange of space weather information, including e.g. real time observations with very high timeliness requirements.

- **Action 1.6: ICTSW Members to review current formats and operational data exchange procedures and delivery mechanisms, evaluate the feasibility and benefits of using WIS framework, and identify observations and products that would benefit of being registered in WIS, by March, 2012.**

5. COLLABORATION WITH ICAO

Following recent contact between ICAO representatives and WMO, Mark Gunzelman gave a presentation on the development of a “Concept of Operations for International Space Weather Information for Global Aviation” on behalf of the ICAO International Airways Volcano Watch Operations Group (IAVWOPS). He described the process being followed to define the service requirements to address aviation space weather needs, and he welcomed the ICTSW participation in reviewing and commenting on the draft Concept of Operations. The ICTSW was informed that ICAO was planning to formalize its service requirements for Space Weather, once agreed, in the form of a Standard and Recommended Practice (SARP) that will be contained in Annex III of the ICAO Convention. The ICAO Convention is the fundamental treaty defining ICAO activities and the obligations of its Contracting States. Annex III of the convention contains the detailed regulatory description of “Meteorological Services for International Air Navigation”, which are the services coordinated by WMO in response to ICAO; it is defined in consultation between ICAO and WMO. In order to include the Space Weather SARP as either a "Change" or an "Addition" to Annex III, ICAO would require prior endorsement by its Decadal Decisional Meeting at the end of 2014, which is a joint meeting with the WMO Commission for Aeronautical Meteorology (CAeM), and seek final approval by the ICAO General Assembly in November 2016. It is therefore essential that ICTSW be engaged in the finalization of this SARP in 2012 and 2013 so that WMO be prepared to respond to ICAO on this extension of meteorological services to aviation. This process is similar to the one followed by ICAO and WMO several years ago to implement volcanic ash detection by the Volcanic Ash Advisory Centres (VAAC), which is now an integral part of Annex III.

The team recognized the important link between the Concept of Operations being developed by ICAO and the mandate of the ICTSW to define observing requirements and to support the coordination of products and services. Collaboration with ICAO on the ConOps and the subsequent definition of Space Weather SARP was seen as a unique opportunity to help Space Weather services to evolve towards an operational, globally coordinated, service to aviation.

The team agreed to review and comment on the space weather requirement when released and to coordinate with ICAO on supporting the airline requirements.

- **Action 1.7: WMO Secretariat to circulate to ICTSW the draft CONOPS for International Space Weather Information in Support of Aviation, by end of October 2011, for review.**

- **Action 1.8: ICTSW Members to review the draft CONOPS for International Space Weather Information in support of Aviation and provide comments to the team by March 2012.**

The team would then consider the most appropriate way to forward consolidated comments to ICAO by June 2012.

6. OUTCOME OF RECENT WORKSHOPS

The ICTSW was reminded of several workshops on Space Weather that had been organized recently, but no time was available to discuss this item.

7. ANY OTHER BUSINESS

Preparation of a statement to the WMO Congress

The team was informed that the World Meteorological Congress, which is the supreme governing body of the organization, that meets once every four years with representation of all Member States and Territories, would have its sixteenth meeting in May 2011. This forthcoming Congress would have the opportunity to decide on the future framework of WMO's involvement in Space Weather. Furthermore, a "Side event" on Space Weather would be organized in Geneva prior to Congress deliberations on Space Weather. The team agreed that such a side event would be an excellent opportunity to raise the attention of WMO Congress delegations on the importance of Space Weather for society and its relevance for WMO. It also welcomed the suggestion that a statement to the Congress be developed by the participants to the side event. The elements of such a statement were discussed by the team. ICTSW members were encouraged to ensure that their respective national delegations to the WMO Congress were aware of these initiatives and invited to participate.

- **Action 1.9: ICTSW Members to consider the text proposed for the space weather side event at the upcoming WMO Congress and submit comments to the co-chairs by 6 May.**

- **Action 1.10: ICTSW Members to ensure that their national delegates are aware of the space weather activities and agenda items at the upcoming WMO Congress, to draw their attention to the proposed side-event statement and encourage their participation in WMO Congress deliberation on this topic.**

(Note: The final Space Weather Statement resulting from the Congress Side Event is contained in Appendix IV.)

8. CONCLUSION

The chairman summarized the conclusions of the meeting in noting that:

- the first set of Observing Requirements were close to be finalized,
- a way forward was considered to review the capabilities,
- the team had a first exposure to the WIS,
- service requirements were being developed by ICAO in consultation with the team, and
- the WMO Congress would have deliberations on the importance of Space Weather.

While all these efforts were still in progress, they were promising and already showed the importance of ICTSW's work.

It was agreed that the presentations given at the meeting would be posted like the working documents on: http://www.wmo.int/pages/prog/sat/meetings/ICTSW-1.html

The date and place for its future meeting were not finalized.

The Chairman and the WMO Secretariat thanked the members for their participation. The meeting was adjourned at 18:00.

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PROVISIONAL AGENDA

1. **OPENING OF THE MEETING**
   - **1.1** Introduction and welcome
   - **1.2** Adoption of the agenda
   - **1.3** Working arrangements for the session

2. **BRIEF UPDATE ON THE ICTSW STATUS**
   - **2.1** Membership
   - **2.2** Terms of Reference
   - **2.3** Work plan
   - **2.4** ICTSW in the context of WMO

3. **SPACE WEATHER OBSERVING REQUIREMENTS**
   - **3.1** Conclusion on the definitions and requirements
   - **3.2** Update on the WMO Rolling Review of Requirements (RRR) process

4. **WMO INFORMATION SYSTEM (WIS) AND SPACE WEATHER**
   - **4.1** Introduction to WIS, implications and potential benefits of using WIS for Space Weather data and products
   - **4.2** Discussion on the use of WIS

5. **COLLABORATION WITH ICAO**

6. **OUTCOME OF RECENT WORKSHOPS**

7. **ANY OTHER BUSINESS**

8. **CONCLUSION**

VARIABLES CONSIDERED FOR THE OBSERVING REQUIREMENTS

(See: www.wmo-sat.info/db/ and select the Application Area "Space Weather" for more information and for the requirements)

Variable	Unit	Accuracy unit	Definition
Cosmic ray neutron flux density	$(h)^{-1}$	%	Flux of neutrons on the surface of Earth due to collisions in the atmosphere of cosmic rays impacting Earth atmosphere from the Sun and outer space.
Electron flux density energy spectrum	$(cm^2\ s\ sr)^{-1}$ or $(cm^2\ s\ sr\ eV)^{-1}$	%	Flux density energy spectrum of low-, medium-, and high-energy protons from the magnetosphere, the radiation belts or the interplanetary medium.
Heavy ion flux density energy and mass spectrum	$(cm^2\ s\ sr\ MeV/nuc)^{-1}$	%	Flux density energy and mass spectrum of heavy ions ranging from Helium to Iron.
Proton flux density energy spectrum Vector magnetic field	$(cm^2\ s\ sr)^{-1}$ or $(cm^2\ s\ sr\ eV)^{-1}$ nanoTesla (nT)	% nanoTesla (nT)	Flux density energy spectrum of low-, medium-, and high-energy protons from the magnetosphere, the radiation belts or the interplanetary medium. Magnitude and direction of the magnetic field on the surface of Earth and within the magnetosphere (i.e., in low-Earth orbit and in geosynchronous orbit).
Electron Density Profile	Electrons/m^3	Electrons/ m^3	Vertical profile of the electron density in the ionosphere
foEs	MHz	MHz	The highest ordinary-wave frequency reflected back from a sporadic E layer and observed by an ionosonde.
foF2	MHz	MHz	Critical frequency of the F2 layer of the ionosphere.
h´F	km	km	Virtual height of the bottom of the ionospheric F-layer.
hmF2	km	km	Altitude of the peak density in the ionospheric F2 layer.
Ionospheric plasma velocity	km/sec	km/sec	Velocity of bulk plasma or electrons (depending on measurement technique) as a function of altitude in the ionosphere.
Ionospheric Radio Absorption	dB	dB	Attenuation of a radio wave passing through the lower ionosphere.
Ionospheric Scintillation (S4 and Sigma_Phi)	dimensionles s	%	Random fluctuations of radio waves resulting of variations in the refractive index of the ionosphere, characterized by the coefficient of variation of intensity (S4) and phase (Sigma_Phi) indices. [Coefficient of variation = standard deviation divided by mean] - dimensionless
Ionospheric Total Electron Content (TEC)	electrons/m^2 practical unit: TECU = 10^{16} electrons/m^2	TECU	Number of electrons in between two points.
Spread F (h´P)	km	km	Vertical thickness of highly structured ion density in the F-region of the ionosphere.
f10.7	Watts/(m^2 Hz)	Watts/(m^2 Hz)	Integrated radio flux over the solar disk at 10.7 cm wavelength
Heliospheric image	ergs/(cm^2 arcsec s)	%	Image of the interplanetary space between the Sun and Earth
Interplanetary magnetic field	nanoTesla (nT)	nanoTesla (nT)	Vector magnetic field in the solar wind.
Solar CaII-K image	ergs/(cm^2 arcsec s)	%	Image of the Sun in the K-line of Ca-II
Solar EUV flux	Watts/m^2	%	Integrated EUV flux over the solar disk
Solar EUV image	ergs/(cm^2 arcsec s)	%	Images of the Sun in the Extreme Ultra-Violet (EUV) wavelengths.

Solar H-alpha image	ergs/(cm^2 arcsec s)	%	Image of the Sun in the Hydrogen-alpha transition wavelength (656.3 nm).
Solar magnetic field	Gauss	%	Vector magnetic field at the solar surface (photosphere)
Solar radio emission	Watts/(m^2 Hz)	%	Integrated radio flux over the solar disk.
Solar white light image	ergs/(cm^2 arcsec s)	%	Image of the Sun in white light
Solar wind density	cm^{-3}	%	Density of solar wind plasma
Solar wind temperature	K	%	Temperature of solar wind protons
Solar wind velocity	km/s	%	Vector velocity of solar wind plasma
Solar X-ray flux	Watts/m^2	%	Integrated X-ray flux over the solar disk
Solar X-ray image	ergs/(cm^2 arcsec s)	%	Image of the Sun in X-ray wavelengths
Wide-angle solar corona image	ergs/(cm^2 arcsec s)	%	Image of the solar corona surrounding the sun

STATEMENT FROM THE WMO SIXTEENTH CONGRESS SIDE-EVENT ON GLOBAL PREPAREDNESS FOR SPACE WEATHER HAZARDS

The participants in the Cg-XVI Side Event on Space Weather acknowledged:

- The increasing risks of Space Weather events to all WMO Members due to the increasing reliance on advanced technologies;
- The diversity of sectors impacted by Space Weather, including: navigation, communication, electric power, pipelines, satellites, and aviation, as well as the impacts on core meteorological observations;
- The actions being taken today by industries and governments to prepare for, and respond to, Space Weather storms and related indirect hazards;
- The progress already achieved in establishing ground-based and space-based observing networks;
- The progress already achieved in establishing a framework of Space Weather prediction and service centres;
- The need for coordinated near-term and far-term actions in order to plan and implement capabilities that will meet regional and global Space Weather requirements, as identified in the WMO Rolling Review of Requirements (RRR) in a sustained, comprehensive, robust, efficient and integrated fashion;
- The capacity of WMO Members to contribute to a globally coordinated system of observations and services, relying on their national R&D and operational assets, as well as on international partnerships;
- The benefits that can accrue to all WMO Members from increased WMO coordination of Space Weather activities;
- The need to raise awareness, advocate the benefits, and provide training so that WMO Members can take advantage of coordinated Space Weather activities.

The participants in the Cg-XVI Side Event on Space Weather therefore recommended:

- To develop and implement near-term and far-term action plans that will enable Members to determine needs and requirements, and to benefit from existing services;
- That WMO Members will contribute, where possible, to enhance regional and global capabilities, including observation collection and information delivery;
- To strengthen the statements included in paragraph 3.7.11 of Document 3.7 for the WMO Space Programme along the following lines: "The Congress noted that a coordinated effort by Members is needed to address the observing and service requirements to protect against the global hazards of Space Weather. It invited the WMO Space Programme, in coordination with the Inter-programme Coordination Team on Space Weather and with the support of the relevant technical commissions, to develop near-term and far-term action plans, including training and education, and work with the WMO Regional Associations to implement a coordinated strategy for Space Weather."

LIST OF ACTIONS

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