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WORLD METEOROLOGICAL ORGANIZATION

FOUR-YEAR PLAN FOR WMO SPACE WEATHER ACTIVITIES

DRAFT 0.2

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1 INTRODUCTION

1.1 Purpose of this document

This document summarizes the needs for space weather services and recommends a set of activities to be undertaken within WMO to achieve a breakthrough in the capabilities to meet these needs.

1.2 Definition of space weather

[Definition used in WMO –TD No.1482 / SP-5, April 2008]
Space Weather encompasses the conditions and processes occurring in space, including on the sun, in the magnetosphere, ionosphere and thermosphere, which have the potential to affect the near-Earth environment.

[Definition used in the EGOS-IP, 2012]
Space Weather refers to the physical processes occurring in the space environment, driven by the Sun and Earth's upper atmosphere, and ultimately affecting human activities on Earth and in space. In addition to the continuous ultra-violet (UV), visible and infra-red (IR) radiation which provides radiative forcing to our weather and climate at the top of the atmosphere and maintains the ionosphere, the Sun emits a continuous flow of solar wind plasma which carries the Sun's embedded magnetic field, and releases energy in an eruptive mode, as flares of electromagnetic radiation (radio waves, IR, visible, UV, X-rays), energetic particles (electron, protons, and heavy ions), and high speed plasma through coronal mass ejections. The solar wind and the eruptive disturbances (i.e. solar storms) propagate out into interplanetary space and impact interplanetary space and Earth's environment.

1.3 Background

WMO started to pay attention to Space Weather in 2007 in response to a request from several members of the International Space Environment Service (ISES)[1] communicated by the Director of ISES. The potential benefits of involving WMO in international coordination of space weather operational services were analyzed in a report published in 2008 [2].

On this basis, the WMO Executive Council (EC-60) recognized the importance of space weather as it affects core meteorological infrastructure such as meteorological satellites and telecommunications; it also noted the potential synergy that could develop through integration of space weather observations, data, products and services with relevant meteorological observations, data, products and services. The EC therefore requested the Commission for Basic Systems (CBS) and the Commission for Aeronautical Meteorology (CAeM) "*to develop plans for WMO activities in Space Weather, identifying objectives, activities, resources, deliverables and expected outcomes, in close cooperation with ISES and relevant bodies of COPUOS[3], ICAO[4], IMO[5] and ITU[6]. The Council further invited the two technical commissions to submit proposals to the Council, in advance of next Congress, for appropriate inclusion into the future WMO Strategic Plan with respect to formal WMO involvement in Space Weather."*

[1] International Space Environment Service: http://www.ises-spaceweather.org/
[2] The potential role of WMO in Space Weather, WMO, SP-5, TD-1482, 2008
[3] Committee on the Peaceful Uses of Outer Space (United Nations)
[4] International Civil Aviation Organization (United Nations)
[5] International Maritime Organization (United Nations)
[6] International Telecommunications Union (United Nations)

The Terms of Reference of the Inter-Programme Coordination Team on Space Weather (ICTSW)[7] were approved by the CBS in 2009, and the team was established and initiated its activities in 2010 under the auspices of both the CBS and the CAeM.

In 2011, the sixteenth WMO Congress recognized space weather coordination as one of the activities of the WMO Space Programme[8]. The Congress encouraged Members to provide extra-budgetary financial and staff resources to support space weather coordination activity, given the severe impact of space weather on observation and telecommunication infrastructure and on aviation safety, as well as the potential synergy between space weather warnings and meteorological service delivery. Congress noted that a coordinated effort by Members was needed to address the observing and service requirements to protect against the global hazards of space weather. Congress further *"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 education and training, and work with the WMO Regional Associations to implement a coordinated strategy for Space Weather."*[9]

In 2014, the Council welcomed the progress done by ICTSW in collaboration with ICAO. Bearing in mind that space weather services were supporting several application areas including, but not limited to the aeronautical sector, the Executive Council highlighted the need of a coordinated approach among WMO Members. It requested the ICTSW "*to develop a detailed four-year plan of activities, taking into account the evolving service-oriented nature of space weather services, to inform the WMO planning processes, to address user needs, to articulate the activities of space weather providers with the applicable WMO programme areas, and to increase the awareness of Members in this area*". The Council requested this work be carried out in consultation and coordination with CAeM and inform the Executive Council Working Group on Strategic and Operational Planning (EC WG/SOP) so that plans, activities, and supporting expert groups are in consistency with wider WMO and ICAO efforts.

The present document is prepared in response to these requests.

2 VISION OF WMO SPACE WEATHER ACTIVITIES

2.1 Societal needs and trends of space weather services

The demand for space weather services is increasing as the dependence on technologies impacted by space weather continues to grow. For example, a dramatic increase in the use of polar airline routes exposed to space weather events has generated requirements for global space weather information to air traffic navigation.

The expanded uses of satellite-based navigation and timing and the optimization of radio-communications require monitoring and forecasting of ionospheric disturbances. The pressure on reliability and optimization of electric power grid operations also increase exposure to space weather events that cause geomagnetically induced currents (GIC) with potentially disastrous impact.

Industries and governments are becoming more engaged in assessing the risks and developing mitigation strategies. Emergency management agencies are developing procedures to manage the risks of severe space weather events as part of their overall risk management approach.

Space weather services are regularly used today in some countries by the commercial airlines, the satellite industry, drilling and surveying operations, and users of satellite-based navigation systems. It is anticipated that this demand will considerably expand with a

[7] See: http://www.wmo.int/pages/prog/sat/spaceweather-ictsw_en.php
[8] WMO Space Programme description.
[9] Report from the 16th WMO Congress, 16 May-3 June 2011, WMO N° 1077

broader awareness of the impact of space weather events and a greater maturity of space weather product and services.

2.2 International context of space weather activities

On the international scene, the International Space Environment Service (ISES) is a collaborative network of space weather service-providing organizations around the globe. Its aim is to improve, to coordinate, and to deliver operational space weather services. ISES has been the primary organization engaged in the international coordination of space weather services since 1962. ISES members share data and forecasts and provide space weather services to users in their regions. ISES provides a broad range of services, including: forecasts, warnings, and alerts of solar, magnetospheric, and ionospheric conditions; space environment data; customer-focused event analyses; and long-range predictions of the solar cycle. ISES currently includes 16 Regional Warning Centers, four Associate Warning Centers, and one Collaborative Expert Center. ISES is a Network Member of the International Council for Science World Data System (ICSU-WDS) and collaborates closely with WMO.

The International Civil Aviation Organization (ICAO) has developed a draft Concept of Operations and is developing requirements for operational space weather services, in consultation with WMO, with a view to include such services in a future amendment of Annex 3 of the ICAO Convention. The Conjoint WMO/CAeM-Met Divisional meeting held in July 2014 has confirmed this plan, while considering that several issues required further consideration, including the definition of the roles, requirements, capabilities and overall number of global and regional forecasting centres, as well as their designation process, governance, cost recovery principles, competency standards and duration of mandate.

The Committee on Space Research (COSPAR) of the International Council for Science (ICSU) is developing a roadmap to identify the main scientific and observational challenges for understanding space weather processes and supporting the development of space weather services.

Within the Committee on Peaceful Uses of the Outer Space (COPUOS) of the United Nations General Assembly, the need was expressed to strengthen international coordination of efforts to monitor the space environment to support the long-term sustainability of space assets and activities.

The Coordination Group for Meteorological Satellites (CGMS) has started to address space weather space-based observation needs and included objectives in this regard into its multi-year High-Level Priority Plan upon a proposal from WMO. The CGMS is a technical coordination body focusing primarily on weather and climate satellite programmes in response to WMO requirements. It is anticipated that it will extend its role to address a significant part of the space weather observation needs from space.

2.3 Need of improved international coordination

Improving the provision of space weather services worldwide requires international coordination and cooperation, in order to create a shared satellite-based observing system, to secure the availability and interoperability of critical global and regional observations, and to ensure the global consistency of the end products.

In particular, observations must be performed according to agreed standards, in an interoperable way, and shared in agreed formats with standardized metadata to enable their efficient use. Members must reach consensus on the highest priority observations and ensure that globally cost-effective solutions are achieved and that gaps are avoided on critical observations.

Alerts and warnings must be communicated effectively. They should contain standardized information to ensure consistent messages during extreme events and enable post-event verification and evaluation.

Space weather services to aviation must be standardized, coordinated, evaluated and delivered along procedures to be agreed among ICAO and WMO.

Training must be available to allow interested WMO Members to utilize existing information in a meaningful way, build their own service capabilities, and to support user uptake of new product and services.

The ISES is a valuable starting point for such an operational coordination but this effort needs to be leveraged to the truly global and intergovernmental level. This is why ISES invited WMO, in 2007 already, to support international coordination of space weather. An operational coordination as foreseen by WMO, in partnership with ISES, is the missing link between the important international initiatives mentioned above, on one hand, and the fulfilment of user needs, on the other hand.

2.4 Relevance of space weather for WMO

Although space weather monitoring and forecasting is not explicitly in the scope of WMO as “the specialized United Nations agency for meteorology, operational hydrology and related geophysical sciences”, it can be considered among the “related geophysical sciences” in several respects.

As the upper boundary of Numerical Weather Prediction models tends to raise above the mesosphere a good understanding of the conditions (density, temperature and wind) in the thermosphere becomes more and more relevant to NWP. The dynamics of the lower atmosphere has a significant impact on the ionosphere, through planetary and gravity waves. Whole atmosphere models encompassing the thermosphere and coupled with ionosphere models are now available at an experimental stage.

Space Weather on one hand and terrestrial weather/climate on the other hand are both driven by the energy emitted by the Sun, though sensitive to different aspects in terms of spectrum, and timescales. Besides this common dependence on solar radiated power, increased UV radiation or energetic particles stemming from high solar activity have an impact on Ozone precursors and Ozone concentration, which are Essential Climate Variables. Several authors have established a correlation between various indicators of solar activity and the resulting weather/climate observed in the stratosphere, troposphere or at the surface. Such statistical evidence show at least the interest of further research to better understand these processes.

Space weather affects satellites –today the backbone of weather and climate observation, radio-communications, and GNSS systems - which are increasingly used in meteorological operations for atmospheric sounding.

A direct convergence of interests between the meteorological and space weather communities appears in the use of observing capabilities: most of the meteorological operational satellites are carrying space weather sensors, either for monitoring satellite health or for observation of the Sun, the solar wind, or the radiation and particle environment. Many of the GNSS systems are used by both meteorological and ionosphere monitoring communities, either by radio-occultation or ground-based receivers, to retrieve Total Electron Content or water vapour content and temperature, respectively.

Finally, as illustrated by the case of aviation, there is a requirement from certain user application sectors for the delivery of integrated services including weather and space weather forecast. This integration of services is in line with the multi-hazard approach which is recommended for Disaster Risk Reduction in the Hyogo Framework for Action[10].

Bearing these elements in mind, there is a good case for using the well-established global coordination role of WMO to support the coordination of space weather observation, data exchange, analysis and forecasting, and service delivery, taking advantage of WIGOS and WIS, as decided by the Executive Council at its sixtieth session.

The Implementation Plan for the Evolution of Global Observing Systems, adopted by the WMO Executive Council in 2013 states: "*Space weather observations are required: to forecast the occurrence probability of space weather disturbances; to drive hazard alerts when disturbance thresholds are crossed; to maintain awareness of current environmental conditions; to determine climatological conditions for the design of both space-based systems (i.e., satellites and astronaut safety procedures) and ground based systems (i.e., electric power grid protection and airline traffic management); to develop and validate numerical models; and to conduct research that will enhance our understanding. A comprehensive space weather observation network must include ground based and space-borne observatories, with a combination of remote sensing and in-situ measurements*[11]."

2.5 Current assets of WMO

Several WMO Members[12] have a space weather activity within the mandate of the NMHS, either addressing the whole range of space weather activities including warnings or forecasts, or limited to certain aspects such as ionospheric or geomagnetic monitoring. Other NMHSs have a formal cooperation agreement (or Memorandum of Understanding) with national organizations dealing with space weather (e.g. space agency, observatory).

The WMO Integrated Global Observing System (WIGOS) provides an adequate framework to facilitate national inter-agency agreements which are necessary in such cases. Furthermore, the WMO Information system (WIS), being open to various institutions beyond the NMHS, enables space weather centres which are not NMHSs to become, e.g. Data Collection or Production Centres (DCPC) in the WIS structure[13].

Twenty-three WMO Members are directly involved in the Inter-Programme Coordination Team on Space Weather (ICTSW)[14]. Additional WMO Members are participating indirectly through their membership in the European Space Agency, which is a member of ICTSW.

Since its creation the ICTSW has analysed the observation requirements for space weather[15] and issued a first Statement of Guidance for Space Weather Observation[16], in the context of the WMO Rolling Review of Requirements. A Space Weather Product Portal has been developed, which has served as a prototype for a wider portal named the "Product Access Guide"[17] integrating space weather and meteorological products.

Considerable work has been done by ICTSW in support of ICAO in order to: (i) review the draft Concept of Operations for Space Weather Services to International Air Traffic Navigation; (ii) review the draft requirements and the draft Standard and Recommended

[10] Hyogo Framework for Action: http://www.unisdr.org/files/8720_summaryHFP20052015.pdf
[11] Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP)
[12] Including Argentina, Australia, China, Finland, Russian Federation, United Kingdom, United States.)
[13] For example the National Institute of Information and Communications Technology (NICT) in Japan
[14] ICTSW membership: http://www.wmo.int/pages/prog/sat/documents/ICTSW_Members.pdf
[15] Space weather observation requirements: http://www.wmo-sat.info/oscar/applicationareas/view/25
[16] Statement of Guidance: http://www.wmo.int/pages/prog/www/OSY/SOG/SoG-SW.doc
[17] Space Weather Portal: http://www.wmo-sat.info/product-access-guide/theme/space-weather

Practices (SARP); (ii) outline a possible organization of space weather services based on global and regional centres. The outcome of ICTSW reviews has been provided by WMO to the ICAO Volcano Watch Operations Group, which is in charge of space weather issues.

2.6 High-level goals

Considering, on one hand, the societal needs which are not fulfilled and, on the other hand, the strengths and capabilities of WMO, the proposed high-level goals of WMO for space weather are:

- Support the international coordination of operational space weather monitoring and forecasting to support the protection of life, property and infrastructures and the impacted economic activities;
- Provide a truly global and intergovernmental framework to enable international commitments and facilitate the establishment of a global operational framework for space weather services;
- Promote the availability and integration of space weather observations, through review of space-based and surface-based observations requirements, harmonization of sensor specifications, monitoring plans for space weather observation to analyse and fill the gaps, while optimizing the overall cost of the observing system;
- Facilitate space weather data exchange and delivery through open data sharing, internationally agreed standards, and coordinated procedures in the context of the WMO Information System (WIS);
- Developing best practices , including e.g. quality assurance guidelines, among WMO Members to improve the interoperability, accuracy and reliability of space weather warnings while optimizing the overall cost of the system;
- Improve the emergency warning procedures and global preparedness to space weather hazards in accordance with the WMO strategy on Disaster Risk Reduction;
- Harmonize the definition of end products and services, in interaction with aviation and other major application sectors;
- Support capacity building and extend to all WMO Members the benefits of space weather services which are currently available only among a limited number of Members;
- Encourage the dialogue between the research and operational space weather communities and facilitate the transfer of technical and scientific advances from research to operations;
- Encourage the dialogue and promote synergy between the space weather and the meteorological/climate communities and activities.

2.7 Guiding principles

It is proposed to pursue the goals above in accordance with the following principles.

- Build on the achievements of ICTSW and the momentum gained within this team.
- Promote data sharing and the continuous availability of essential observations.
- Build capacity by expanding best practices to the less advanced members.
- Foster multi-disciplinary collaboration, noting the diversity of organizational schemes of space weather activities which are often conducted outside the NMHS, depending on the country,
- Avoiding duplication but promote instead complementary action through partnerships with internationally recognized UN or non-UN entities: ISES, COSPAR, OOSA, ICAO, ITU, etc.…
- Leverage national or regional initiatives and programmes
- Long-term sustainability
  Scientific basis.

3 ACTIVITIES

3.1 Key activities

Considering the initial work plan of the Inter-Programme Coordination Team on Space Weather (ICTSW) approved by the Commission for Basic Systems, the guidance from the Executive Council, and the request from the WMO Congress, the following breakdown of activities is proposed:

(a) Evaluating user requirements for space weather products and services, in particular in support of aviation, radio-propagation and radio-navigation, geomagnetic effects on infrastructure, spacecraft operations and overall disaster risk management;
(b) Developing best practices for generating products and delivering such services to the users;
(c) Training and building capacity, to enable the provision of services and support user uptake;
(d) Prioritizing and coordinating ground and space-based observations of key space weather phenomena and their precursors and developing best practices to ensure the quality and interoperability of these observations;
(e) Promoting and facilitating data management, standardization and exchange;
(f) Developing best practices for modelling, analysing, and forecasting space weather, and promoting transition from research to operations, forecast verification, and synergy with climate and weather modelling;
(g) Ensuring a science-based, authoritative communication on space weather conditions and representing the operational space weather community in the United Nations system.

These key activities, which are illustrated in Figure 1, are described indetail in Annex 2. A distinction is made between short-term objectives, that can be reached in 2015-2018, and longer term objectives that necessarily exceed that time frame.

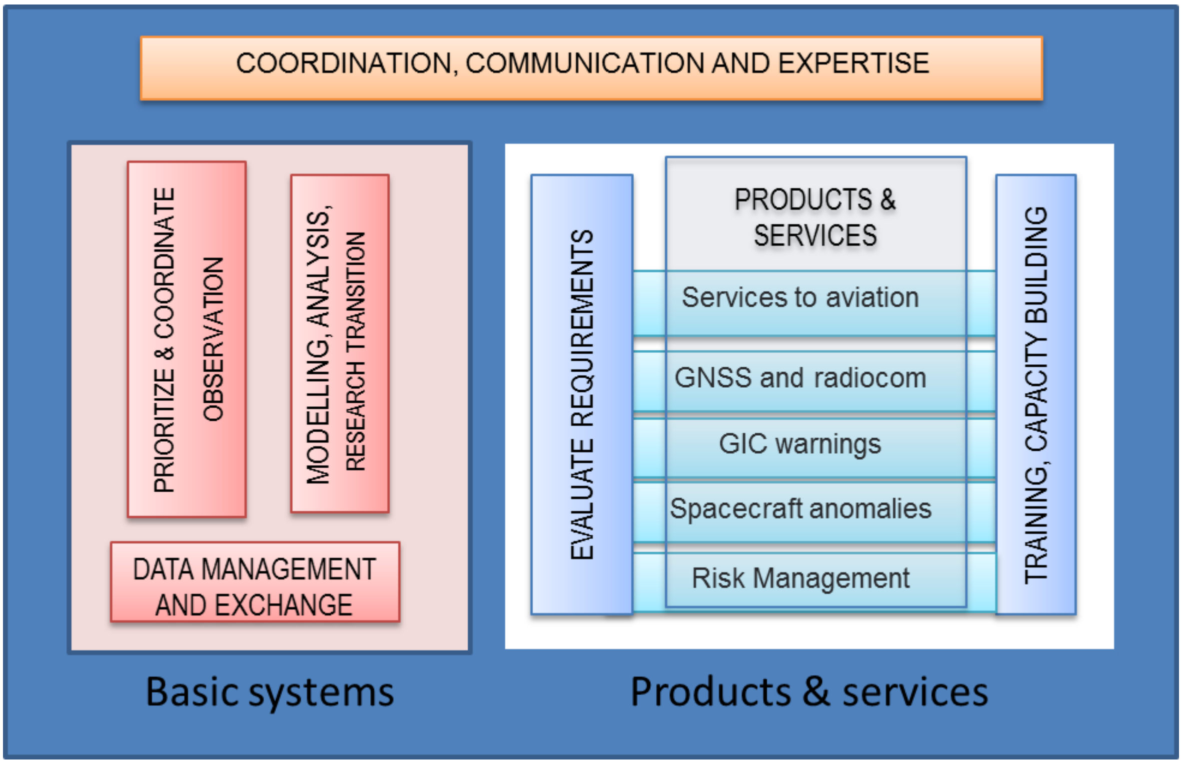

Figure 1: Schematic block diagram of the proposed key activities

3.2 Expected benefits and challenges

The requirements for space weather products and services should be analysed, in particular in the following sectors:

- Aviation, where requirements will be expressed in a regulatory framework by ICAO, and additional requirements are expressed at the commercial level by some airlines.
- Radio-communication and satellite radio-navigation;
- Infrastructures impacted by geomagnetic disturbances, including the energy sector;
- Spacecraft operations;
- Disaster Risk Reduction (DRR) management and other users.

The objective shall be to facilitate the cost-effective generation of highest-impact services. There are challenges, since users are often not aware of the space weather capabilities, or the way to make use of them. Demonstration actions are needed to support the dialogue between the users - to express well-defined requirements - and providers - to fully understand and effectively respond to these requirements.

Best practices will be developed for services meeting these needs. The goal will be to harmonize the production of end products and services, in interaction with major application sectors, to best respond to the evolving needs of key socio-economic sectors and public safety. Best practices, including e.g. quality assurance guidelines, shall be developed and promoted among WMO Members to improve the interoperability, accuracy and reliability of space weather warnings, while optimizing the overall cost of the system. In particular, the emergency warning procedures (including e.g. space weather scales) and global preparedness to space weather hazards shall be organized in accordance with the WMO strategy on Disaster Risk Reduction

Training and capacity building shall be supported, developing skills, based on science and operational practices, in the generation of space weather products and services, and the ability to interpret them. This will enable the provision of high-quality services based on best practices and agreed competencies, and the effective uptake of services for forecasting and warning purposes.

Regarding space weather observation, the primary goal shall be the high-level coordination of satellite-based and ground-based observing assets, developing a plan to address the long-term continuity of essential space weather satellite observations and promoting efforts to fill observation gaps in a cost-effective manner through shared capabilities. Integration or interoperability of Space Weather observations should be pursued, through harmonization of sensor specifications and improved traceability.

Space weather information exchange and delivery through the WMO Information System (WIS) shall be standardized and enhanced. A major challenge is the stringent timeliness constraints of most space weather data.

Space weather analysis, modelling and forecasting shall be supported. This entails support to the development of operational, data-assimilative, predictive models, benefiting from advanced weather and climate prediction capabilities, and community initiatives for model coupling and evaluation. Efforts shall be made to advance the understanding of space weather impacts on weather and climate processes.

Coordinated communication is necessary to achieve understanding, by all Members, of the importance of space weather services, to provide visibility to external parties on WMO space weather activities, and to inform the society on the capabilities and limitations of space weather information. This should lead to a broad support to a future Space Weather Watch.

4 ORGANIZATION AND IMPLEMENTATION

4.1 Mapping of activities with WMO strategic priorities and activities

WMO space weather activities, which are led by the WMO Space Programme, are integrated into a number of WMO Programmes and projects.

In the WIGOS perspective, space weather is fully integrated in the Rolling Review of Requirements, including the identification of space weather observation requirements, an assessment of the current gaps in our observing systems as documented in a Statement of Guidance and in the Implementation Plan for the Evolution of the Global Observing Systems.

The Steering Group on Radio Frequency Coordination (SG-RFC) has initiated consideration of frequency allocation issues for space weather observations in the microwave domain.

Regarding the WIS, a pilot project is underway to use the WIS for the exchange of space weather forecast products (geomagnetic activity, solar flares, and solar energetic particles).

Within the Aeronautical Meteorology Programme, the ICTSW has assisted the Aeronautical Meteorology Division in reviewing the ICAO Concept of Operations for space weather services to global air traffic navigation and provided guidance on the future organization of an effective operational space weather service delivery coordinated by WMO. ICAO recognizes WMO, through the ICTSW, as a source of technical advice on space weather matters. The continuing active participation of WMO will be essential as it is anticipated that Annex 3 of the ICAO Convention will make such space weather services for civil aviation mandatory.

Space weather training is under consideration by the Virtual Laboratory (VLab) for Education and Training in Satellite Meteorology, in partnership with COSPAR.

The table below summarizes the mapping of space weather activities with the seven key priorities of the draft WMO Strategic Plan 2016-2019.

Key priorities in the WMO Strategic Plan 2016-2019	**Related activity in the space weather four-year plan**
Improve the effectiveness of high quality impact-based forecasts and early warnings for extreme weather, climate and water events for disaster risk reduction	Improving global preparedness to space weather hazards
Implement climate services under the Global Framework for Climate Services (GFCS)	Investigate interactions of space weather with terrestrial climate
Implement the WMO Integrated Global Observing System (WIGOS)	Integration of space weather observations in WIGOS
Improve the ability of NMHSs to meet International Civil Aviation Organization (ICAO) requirements;	Space weather services to aviation in response to ICAO requirements
Develop operational polar weather, climate, and hydrological services	Importance of space weather effects in polar regions, including geomagnetic disturbances, ionospheric disturbances, and energetic particle impacts
Advance capacity development for NMHSs	Capacity building towards the delivery of space weather services
Improve efficiency and effectiveness of WMO constituent body activities.	Inter-commission working structure (See below)

4.2 Working structure

The range of activities require a broad spectrum of competencies from the space weather expert communities. These competencies can be schematically grouped in two areas:

- Space weather Products, Services, Applications and Requirements Evaluation
- Basic systems (Observation, Information, Models) for space weather.

For the sake of efficiency, these two broad areas should be addressed by two expert groups with focused expertise. Following the successful example of ICTSW, these groups would hold regular virtual meetings and consolidate their work once a year in a face-to-face meeting.

In addition, participation of space weather experts is necessary in existing expert teams of several technical commissions including:

- Commission for Basic Systems (CBS) for example the expert teams on Observing System Design and Evolution, Metadata and Data Representation Development;
- Commission for Instruments and Methods of Observation (CIMO);
- Commission for Aeronautical Meteorology (CAeM);
- Commission for Atmospheric Sciences (CAS);
- Commission for Climatology (CCl).

A point of contact should also be nominated in every Regional Association.

The overall coordination and management should be ensured by an Inter-Commission Coordination Group on Space Weather (ICGSW) which would replace the existing Inter-Programme Coordination Team on Space Weather. Draft Terms of Reference for these three groups are proposed in Annex.

4.3 User engagement and partnership

In order to be fully efficient, the activity of these expert teams will require increased support from the Secretariat and strong engagement of the Members. Space weather is an evolving effort and we must address how to meet Members' needs in a manner that is efficient and consistent with the WMO structure.

This strong engagement is also a condition for building solid and helpful partnerships with organizations assuming complementary roles.

At the international level, the identified key partners are:

- ISES
- CGMS
- ICAO
- ITU
- COSPAR
- COPUOS
- European Commission
- European Space Agency (SSA Programme)

4.4 Communication and advocacy

A communication plan is necessary to face the mobilization challenges implied at various levels:

- Raising awareness of WMO Members to understand the benefit and implications of developing a new activity in the WMO framework and collecting their feedback on success and limiting factors;
- Demonstrating the emerging services to the users until a mature stage is reached;
- Publicizing the capabilities and listening to users' expectations in order to have a good understanding of users' needs, and expand the user basis;
- Reporting in relevant international fora to provide visibility on WMO's activity and stimulate international partnerships;
- Maintain a flow of information with partners to ensure that efforts are well supplementing each other;
- Show the achievements and demonstrate the benefits of acting in coordination, which allows higher reliability of space weather information available to the society, and optimization of resources required to produce this information.

4.5 Resources and benefits

This action plan is in continuity of the activity pursued with the current ICTSW, though with a significant expansion as required to move from a "demonstration stage" to an actual implementation which can allow a breakthrough with tangible benefits in several applications.

This requires greater involvement of space weather experts from Members, together with a support from the Secretariat which should include at least one full-time person. Given the strong pressure on dedicated staff resources within the Secretariat, this support could be achieved by secondment of experts by Members and consultancy on specific tasks.

The Executive Council has requested the establishment of a Trust Fund to support the WMO Space Weather activities. Indeed, financial resources are needed to cover:

- Expert Team meetings to secure the participation of highly qualified experts
- Liaison with external partners
- Communication actions
- Development or translation of training material
- Training seminars
- Consultancy or financial support to secondment of staff.

These resources should be compared to the resources that would be spent by Members in the absence of WMO. Several WMO Members are pursuing a space weather programme which entails a heavy level of expenditure (investment, operation cost or staff resources) at the national level. It may be considered that allocating a fraction of this expenditure to a WMO Trust Fund on Space Weather would be sufficient to fund the activities above with the result of a greater efficiency and reduced costs through optimization and sharing of efforts.

It is also pointed out that once space weather services have reached a mature stage they should also generate revenues (e.g. cost recovery mechanism for the services required by ICAO, possibility of commercial services developed on the basis of warnings to power grid, telecommunication or GNSS operators, etc).

4.6 Implementation roadmap

[To be drafted]
Build on the momentum acquired by ICTSW
Gradual increase of activity with growing visibility and availability of resources.
Early achievements through pilot projects, with tangible outcome, which should allow further demonstrating the benefits of coordination through WMO, and give evidence of WMO's reliability for international partnership in the area of space weather.
Milestones in the ICAO process
WMO decision milestones

5 CONCLUSIONS

The early results obtained in the sixteenth financial period (2012-2015) illustrate the broad field of activity that could benefit from WMO involvement in space weather, and demonstrate the capability of WMO to effectively facilitate a breakthrough in this area. Given the increasing demand for space weather services to aviation and other sectors, it is thus recommended that WMO engages more directly during the seventeenth Financial Period (2016-2019) and beyond at a larger scale, and on a sustainable basis, to improve global space weather capabilities.

A prerequisite is that the most advanced WMO Members in that field engage technically, through their experts, and financially, in contributing to the Trust Fund, to lead pilot projects. This should be supported by the Secretariat.

The proposed activities are consistent with the proposed strategic priorities for the seventeenth period.

6 ANNEX 1: TERMS OF REFERENCE

(To be drafted for consultation of CBS-Management Group)

6.1 Terms of Reference of the ET-SPARE (?)

Expert Team on Space weather Products, Applications and Requirements Evaluation

6.2 Terms of Reference of the ET-SWOIS (?)

Expert Team on Space weather Observation and Information Systems

6.3 Terms of Reference of the ICGSW

Inter-commission Group for Space Weather

7 ANNEX 2: DETAILED ACTIVITIES

7.1 User requirements for space weather products and services

Goals	Ensure that the most important needs for space weather services are met, in particular as regards: • Aviation, with requirements expressed in a regulatory framework by ICAO, and additional requirements by commercial airlines. • Radio-communication and satellite radio-navigation sectors; • Services to infrastructures impacted by geomagnetic disturbances, including the energy sector; • Services to spacecraft operations; • Support to Disaster Risk Reduction (DRR) and other users.
Benefits	Cost-effective generation of highest-impact services. - to express well-defined requirements - and providers - to fully understand and effectively respond to these requirements.
Challenges	Users are often not aware of the space weather capabilities, or the way to make use of them. Demonstration actions are needed to support the dialogue between the users, to define precisely their requirements, and providers, who filly understand and effectively respond to these requirements.
Assets, opportunities and potential partners	The Space Weather Product portal is a convenient home for product demonstration and early use. Build on the DRR Programme and e.g. partnership with the EU(JRC) to refine requirements and strategy for preparedness to space weather hazards. Work closely with ICAO to define the service requirements for aviation.

Short-term objectives	**Deliverable**	**Time frame**
Improve and expand the Space Weather Product Portal, with further products and related training material.	Enhanced Space Weather Product Portal	
Harmonize the definition of products and services in consultation with key user groups		
Draft an overview of the processes involved and issues to be addressed for extreme event warning, in the light of the WMOs experience on severe weather warnings.	Report on extreme event warning processes and issues	
Assist the relevant ITU Radiocommunication sector (ITU-R) Study Groups (including SG-3 on Radiopropagation) discussions regarding ionospheric disturbances monitoring and forecasting capabilities	Advice to ITU-R	
Participate on the ICAO Expert Team to establish space weather service requirements and the guidelines for service provision.	Advice to ICAO	
Long-term objectives	**Deliverable**	**Time frame**
Advise major application programmes and activities within WMO (such as the Aeronautical Meteorology Programme, Disaster Risk Reduction programme, Public Weather Services programme for services to the energy and telecommunication sectors, etc) on space weather service capabilities and the feasibility of space weather service delivery		

7.2 Best practices for product generation and service delivery

Best practices will be developed for services meeting the identified priority needs.

Goals	Harmonize the production of end products and services, in interaction with major application sectors, to best respond to the evolving needs of key socio-economic sectors and public safety. Developing best practices , including e.g. quality assurance guidelines, among WMO Members to improve the interoperability, accuracy and reliability of space weather warnings while optimizing the overall cost of the system; Improve the emergency warning procedures (e.g. space weather scales) and global preparedness to space weather hazards in accordance with the WMO strategy on Disaster Risk Reduction
Benefits	
Challenges	
Assets, opportunities and potential partners	Partners. ISES, ICAO, ITU, EU (JRC), CGMS, ESA (SSA)

Short-term objectives	**Deliverable**	**Time frame**
Services to aviation: Coordinate with ICAO in establishing space weather services for aviation	(i) Review of ICAO Standard and Recommended Practices (SARP) and requirements. (ii) Recommendation on the concept of global and regional centres	
Services to DRR: Establish real-time communication mechanisms to share urgent information and maintain consistency of information during extreme events	Communication procedures among warning centres for extreme events	
Services to DRR: Review the existing global and regional space weather scales, and develop an international, community scale, or set of scales, to characterize the severity of space weather events in support of user decision scenarios. (See ICTSW Action 4.16)	Internationally agreed scales for the severity of space weather situations	
Services to DRR: Conduct post-event analyses to refine capabilities and document information reliability.		
Services to GIC sensitive infrastructures: Define guidelines for the specification of regional geomagnetic disturbance products to ensure future regional geomagnetic products on the WMO portal are comparable (ICTSW Action 4.14)		
Services to spacecraft operations: Collaborate with CGMS to review the procedure and format for recording spacecraft anomalies that are assumed to be caused by the space		

environment, in order to effectively document the impact of space weather on spacecraft.		
Long-term objectives	**Deliverable**	**Time frame**
Establish quality assurance guidelines based on user requirements	quality assurance guidelines warning procedures	
Draft a Guide on best practices for space weather warning centres during severe events.	Guide on severe space weather events management	
Encourage countries to include space weather risk into their national multi-hazard warning schemes		

7.3 User training and capacity building for users and providers

Goals	Develop skills in generating space weather products and services, based on science and operational practices; and ability to interpret these products and services	
Benefits	Provision of high-quality services based on best practices and agreed competencies; effective uptake of services for forecasting and warning purposes	
Challenges		
Assets, opportunities and potential partners	Partners: - COSPAR - the WMO-CGMS Virtual Laboratory (VLab) - ISWI - SCOSTEP	
Short-term objectives	**Deliverable**	**Time frame**
Provide tutorial tools and organize training sessions taking advantage of the VLab and partner organizations		
Select training material references for inclusion on the Space Weather Product Portal, and revise the structure as appropriate (ICTSW Action 4.15)		
Long-term objectives	**Deliverable**	**Time frame**
Determine the current level of services available within each Region		
Provide training and sharing of knowledge to allow the utilization of existing products and services by all Members and to encourage participation in regional service provision		
Develop a training strategy (Action 4.25)		

7.4 Ground and space-based observation of space weather variables

Goals	high-level coordination of satellite-based and ground-based observing assets, developing a plan to address the long-term continuity of essential space weather satellite observations and promoting efforts to fill observation gaps in a cost-effective manner through shared capabilities. Improved integration or interoperability of Space Weather observations through harmonization of sensor specifications, and improved traceabiity.
Benefits	Optimized observing system planning, and improved interoperability and integration of observations to maximize the return on investment.
Challenges	Diversity of organizations owning and operating the various surface-based networks, requiring national inter-agency agreements
Assets, opportunities and potential partners	Assets: requirements and Statement of Guidance developed by ICTSW; section on space weather in the EGOS-IP; WIGOS framework. Partners: INTERMAGNET for magnetic field measurements SG-RFC and ITU for frequency matters

Short-term objectives	**Deliverable**	**Time frame**
Keep under review the observation requirements in OSCAR/Requirements, and the Statement of Guidance (gap analysis)	Updated requirements Updated SOG Input to updated EGOS-IP	
Review the inventory of surface-based networks in ICTSW-4/Doc 9.1/Appendix. (ICTSW Action 4.20)	Inventory of main available networks	
Identify observing assets in each Region that can be included in global observing systems		
Prepare a template for the specification of surface-based capabilities to be added to OSCAR/Surface for space weather observations, to support the RRR process	Framework enabling surface-based capabilities evaluation and gap analysis	
Review the types of instruments used for Space Weather observations, their characteristics and assessment in OSCAR/Space (Action 4.22)	Improved analysis tool for space-based capabilities	
Review implementation status and plans of space-based observation for space weather, in OSCAR/Space, to support the RRR process	Updated capabilities in OSCAR/Space	
Improve the collection of magnetometer data with high-timeliness (in collaboration with the INTERMAGNET). This can be accomplished by: (i) deployment of magnetometers in regions with limited coverage; (ii) rapid dissemination of data from existing magnetometers within WIS; and (iii) agreement with data providers for their data to be used in space weather products. (EGOS-IP Action W7)		
Support definition of best practice for the inter-calibration of energetic particle measurements		
Long-term objectives	**Deliverable**	**Time frame**

Ensure the protection of radio-frequency bands essential for passive and active measurements for space weather, through participation in ITU work within the Radio-astronomy service and other services as relevant		
Coordinate the space weather observation requirements and network design with the weather and climate monitoring architectures		
Define recommended, harmonized sensor specifications towards ensuring interoperability of these measurements		
For interoperability and back-up purposes, to coordinate and standardize the existing ground-based solar observation data, and expand them where required, for redundancy, and to develop a common data portal or virtual observatory within the WIS. (EGOS-IP Action W2)		
To increase the spatial resolution of ground-based GNSS ionospheric observations (TEC and scintillation), either by deploying additional receivers in regions with sparse coverage (e.g. Africa), making the data from existing receivers accessible, or by utilizing different means of receiving GNSS data, such as aircraft-mounted receivers, to reduce gaps over the oceans. (EGOS-IP Action W3)		
To coordinate the use of dual-frequency radar altimeter observations by Space Weather community to improve or validate ionospheric models and for operational TEC monitoring over the oceans. (EGOS-IP Action W6)		
Develop a plan for maintaining and improving space weather observations of the plasma and energetic particle environment along the following priorities: (1) maintain long-term continuity, and if possible improve the spatial resolution, of measurements at all altitudes from LEO through GEO orbits; (2) improve the sharing of existing and planned plasma and energetic particle measurements; (3) include energetic particle sensors on HEO satellites; and (4) conduct research to incorporate the plasma and energetic particle data into numerical models to give flux estimates at all locations where our satellites are in orbit. (EGOS-IP Action W8)		
To develop and implement a coordinated plan ensuring continuity of solar measurements, solar wind and interplanetary magnetic field measurements, and heliospheric imaging, including measurements at different locations such as at the L1 Lagrange point, the Sun-Earth line upstream from the L1 point, the L5 Lagrange point, coronagraphs measurements, as well as the required global network of ground-based antennas for data reception and processing. (EGOS-IP Action W1)		

7.5 Space weather data management and exchange

Goals	Standardize and enhance space weather information exchange and delivery through the WMO Information System (WIS)
Benefits	
Challenges	Stringent timeliness constraints of most space weather data
Assets, opportunities and potential partners	Several Space Weather centres are in the process of being registered as DCPC or already registered (BOM/IPS, NICT)

Short-term objectives	**Deliverable**	**Time frame**
Identify NMHSs within each Region that can participate in the collection of data and the production and dissemination of services		
Develop a plan with all ISES RWCs and the space weather service providers within ICTSW for registering relevant space weather products to the WIS		
Ensure that ICTSW is invited to contribute to revise the WMO core metadata profile to describe space weather data in the ISO 19115 standard		
Review and complement if necessary the ISES procedures for quick operational exchange of products and bulletins among warning centres		
To foster sharing of ground-based GNSS data and GNSS Radio-Occultation among the meteorological and space weather communities, and to facilitate the near real-time access to these data through WIS. (EGOS-IP Action W5)		
To improve the timeliness of space-based GNSS measurements from LEO satellites to get near-real-time information about the 3D electron density distribution of the ionosphere/ plasmasphere system. (e.g. by use of a RARS concept or other network of satellite ground stations for rapid transmission). (EGOS-IP Action W4)		
Investigate the use of RINEX format in the WIS for integrated water vapour content from GNSS ground-based receivers, recommend that RINEX and GTEX be recognized for data exchange on the WIS (Action 4.17)		
Investigate the use of BUFR format by CMA for radio-occultation data from FY-3/GNOS		
Provide a sample of COSMIC-2 data formats for comparison with the formats used by the NWP community for radio-occultation data. (Action 4.19)		
Long-term objectives	**Deliverable**	**Time frame**

7.6 Space weather analysing, modelling and forecasting

Goals	Foster the development of operational, data-assimilative, predictive models, benefiting from advanced weather and climate prediction capabilities. Advance the understanding of space weather impacts on weather and climate processes.	
Benefits		
Challenges		
Assets, opportunities and potential partners	Space weather sessions in meteorological conferences (AMS, EMS) WCRP Stratosphere-troposphere Processes And their Role in Climate (SPARC) project	
Short-term objectives	**Deliverable**	**Time frame**
Harmonize skill scores and model verification techniques		
Encourage the development of whole atmosphere models from the surface to the top of the thermosphere		
Long-term objectives	**Deliverable**	**Time frame**
Encouraging the dialogue and linkage between the research and operational Space Weather communities		
Support workshops on space weather impacts on Essential Climate Variables		
Utilize data-assimilation models throughout the Sun-Earth system for improved numerical prediction.		

7.7 Coordination, communication and expertise

Goals	Understanding of the importance of space weather services by all Members, providing visibility to external parties on WMO space weather activities, and informing the society on the capabilities and limitations of space weather information.	
Benefits	Broad support to a future Space Weather Watch,	
Challenges		
Assets, opportunities and potential partners	COPUOS	
Short-term objectives	**Deliverable**	**Time frame**
Ensuring an agreed terminology for space weather variables, products and phenomena		
Report at COPUOS to raise awareness on the capabilities and provide visibility to this WMO effort, attracting support and partnership		
Formalize the cooperation with ISES through an appropriate exchange of letters, if not a MOU. (Action 4.24)	Exchange of letters.	
Long-term objectives	**Deliverable**	**Time frame**