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SPACE WEATHER OBSERVATION CAPABILITIES
Required space weather variables and applicable layers in "OSCAR"

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Recalling the Rolling Requirements Review process, this document introduces the Observing System Capability Analysis and Review tool (OSCAR) which contains a repository of observation requirements, an inventory of instruments and an assessment of the variables that the instruments have the potential to measure.

In order to account for the observing capabilities recorded in OSCAR, a number of new variables have been created to supplement the initial set of variables.

Furthermore, a revised set of "applicable layers" is proposed to qualify the requirements. Finally, the definitions and units of initial variables have been revised in a few cases to ensure consistency.

ACTION PROPOSED

The ICTSW is invited to review:

- the suggested system of layers and coverage for space weather variables introduced in the Appendix;
- the suggested revisions to the list of Space Weather variables, their definitions, comments, units and applicable layers.

Appendix: Discussion of the layers applicable to space weather requirements.

DISCUSSION

1. INTRODUCTION

1.1 OSCAR

In order to support the planning, evaluation, and gap analysis of future observing capabilities following the Rolling Requirements Review process, WMO is maintaining the Observing System Capability Analysis and Review tool (OSCAR), which is available on line (www.wmo.int/oscar) . OSCAR includes three components:

- *OSCAR/Requirements* is a repository of the observation requirements defined by representative expert groups of various application areas. The requirements of the "Space Weather" area (http://www.wmo-sat.info/oscar/applicationareas/view/25) are maintained by ICTSW.

- *OSCAR/Satellite capabilities* contains an inventory of space-based instruments, satellites and programmes of relevance for WMO activities. It currently contains references of more than 800 instruments, including 266 instruments for space weather, the other being designed mainly for atmosphere, ocean or land observation. In addition to the inventory, OSCAR contains an assessment of the potential relevance of each instrument for measuring given variables.

- *OSCAR/Surface capabilities* is still under construction. Similarly, it will contain an inventory and evaluation of the surface-based observation capabilities.

1.2 Scope of the document

This document introduces a revision of the "layers" used in OSCAR to characterize the range of applicability of the space weather requirements, it reports on the addition of new variables needed to account for the capabilities of space weather instruments, and proposes some further review of the definitions of these variables.

2. CHANGES TO THE SPACE WEATHER VARIABLES AND "LAYERS"

2.1 Layers applicable to space weather observation requirements

In OSCAR, the concept of "layer" is used to specify a particular spatial region where a requirement is applicable.

The layers currently defined for Space Weather are: Heliosphere, Sun , L4/L5 (solar wind), L1 (solar wind), Magnetosphere, GEO orbit, MEO orbit, LEO orbit, Ionosphere, High Thermosphere, Low Thermosphere, or "Non available" (1D or 2D variables). Some of them (Low Thermosphere, High Thermosphere, Ionosphere) are atmospheric layers; others (GEO, LEO, MEO) are orbit types; L1, L4/L5 are particular locations in space; the solar wind is a medium or a phenomenon rather than a region. The list of layers is far from being homogeneous, and some of the "layers" are overlapping, which is not well understood. The overall concept of "layer" in OSCAR for space weather should therefore be refined or at least clarified.

A revision of the outer space "layers" applicable to the space weather requirements in OSCAR is discussed in the Appendix This takes into account the need to streamline the currently defined layers, and takes advantage of the concept of "horizontal coverage" introduced in the latest version of OSCAR. The proposal is summarized in Tables 1 and 2.

Table 1: Proposed set of layers characterizing the vertical range of applicability of a requirement (for requirements depending on the vertical location).

OUTER SPACE LAYERS DEFINED FOR SPACE WATHER REQUIREMENTS	
Sun	At the Sun surface
Earth-Sun	Earth-Sun interspace (from the GEO altitude to the Sun)
GEO	At geosynchronous altitude (35,800 km)
MEO	Medium Earth Orbit altitude range from 2000 to 35,000 km
LEO	Low Earth Orbit altitude range (400-2000 km)
Ionos	Ionosphere. Electrically charged region from about 100 to 600 km

ATMOSPHERIC LAYERS USED FOR SPACE WEATHER REQUIREMENTS	
HiThermo	High-Thermosphere about 200-600 km (*)
LoThermo	Low Thermosphere about 100-200 km (*)
Near surface	At the Earth's surface
N/A (2D)	Not applicable. Two-dimensional field, no dependence on altitude
N/A	Not applicable. Variable with no dependence on altitude

(*) High/Low Thermosphere layers have been moved from the "Outer space" domain to the "Atmosphere" domain.

Table 2: Proposed set of "Types of coverage" characterizing specific area of applicability of a requirement (for requirements depending on specific locations).

OUTER SPACE "COVERAGE"	
Global	(Default coverage)
Corona	Solar corona
L4-L5	Lagrange points, on the orbit of the Earth at 150,000,000 km of both Sun and Earth
L1	Lagrange libration point, 1,500,000 km towards the Sun
Magnet	Magnetosphere, region extending from about 100 km to more than 100,000 km on the Earth's side opposite to the Sun.
Sun-side	Sun lit side of he Earth
Shadow	Shadow side of the Earth
Polar	Polar areas, not protected by the Earth's magnetic field

2.2 List of variables

Among the 267 space weather instruments recorded in OSCAR, many are measuring variables that go beyond the initial list of variables identified in the Space Weather requirements. New variables had to be entered in order to be able to reflect these new capabilities. For example, the original list included "electron flux density energy spectrum" but not "electron flux density", thereby preventing to properly record the performance of instruments that are integrating the flux density over the energy spectrum.

This discrepancy between measured and required variables might be indication that many of the capabilities are research oriented and are measuring more than what the operational users are requiring and using on a routine basis. This is however not a guarantee that all operational needs are fulfilled.

Table 3 lists the initial set of variables and the new variables suggested for addition.

Table 3: Initial and suggested new variables

Initial set of space weather variables	Variables suggested for addition
Ionospheric Total Electron Content (TEC) Electron density profile foEs, foF2, h'F, hmF2, h'P (spread F) Ionospheric scintillation Ionospheric radio absorption Ionospheric plasma velocity	
Aurora	
Radiation Dose Rate	Electrostatic charge
Electric field Vector magnetic field (Geomagnetic field) Interplanetary magnetic field	Radio-waves
Electron flux density energy spectrum	Electron flux density energy spectrum image Electron flux density Electron flux density image
Proton flux density energy spectrum	Proton flux density
Heavy ion flux density energy and mass spectrum	Heavy ion flux density energy and mass spectrum image Heavy ion flux density Heavy ion flux density image Nuclei flux density energy and mass spectrum Nuclei flux density energy and mass spectrum image Nuclei flux density Nuclei flux density image
Cosmic ray neutron flux density	Cosmic-ray flux density Cosmic-ray flux density energy and mass spectrum Neutron flux density energy spectrum Neutron flux density Alpha-particle flux density energy spectrum Alpha-particle flux density
Solar wind density Solar wind velocity Solar wind temperature	
Solar radio emission f10.7	
Solar EUV flux Solar EUV image	Solar EUV flux energy spectrum Solar EUV flux energy spectrum image
Solar X-ray flux Solar X-ray image	Solar X-ray flux energy spectrum Solar X-ray flux energy spectrum image
Heliospheric image Solar Ca II-K image Solar H-alpha image Solar white light image	Solar VIS flux, Solar VIS image Solar VIS flux energy spectrum Solar VIS flux energy spectrum image Solar UV flux energy spectrum Solar UV flux energy spectrum image Solar UV flux, Solar UV image Solar Lyman-alpha flux, Solar Lyman-alpha image Solar gamma-ray flux energy spectrum Solar gamma-ray flux
Wide-angle solar corona Image	

Solar magnetic field	Solar electric field Solar velocity fields
	NIR flux, NIR image SWIR flux, SWIR image VIS flux energy spectrum VIS flux energy spectrum image VIS flux, VIS image UV flux energy spectrum UV flux energy spectrum image UV flux, UV image EUV flux energy spectrum EUV flux energy spectrum image EUV flux, EUV image X-ray flux, X-ray image X-ray flux energy spectrum X-ray flux energy spectrum image Gamma-ray flux Gamma-ray flux energy spectrum

Note: when looking at the "Space Weather" application area (http://www.wmo-sat.info/oscar/applicationareas/view/25) only a limited number of variables are visible, because OSCAR only displays the variables for which a requirement is recorded. For the full set, see http://www.wmo-sat.info/oscar/variables and, in the Filter window, select the themes *Ionospheric disturbances*, *Space energetic particles* and *Solar and interplanetary*.

2.3 Definitions of variables

In some cases, the definitions of the variables, the associated comment, the units defined for this variable, or the applicable “layers” have been revised. Particular attention should be paid to the consistency between the dimension of the variable and the measuring units.

In particular, it is suggested to clarify the definitions of radiative flux and particle flux density, to ensure consistency with the units used: [W. m^{-2}], [particles · cm^{-2}. s^{-1}. sr^{-1}] respectively.

3. CONCLUSION: PROPOSED ACTION

ICTSW is invited to:

- Review the proposed set of layers and “types of coverage” to characterize the area of applicability of space weather requirements (as explained in Appendix);

- Review the list of variables and advise on its completeness and relevance, removing unnecessary redundancy;

- Review, for each variable, the definition, comment, measuring unit, and applicable layers.

Discussion of the layers applicable to space weather requirements

Why do we have "layers" in OSCAR ?

Requirements in OSCAR are related to the observation of, generally, 4D variables: V(x,y,z,t). A requirement characterizes the expected accuracy of observations of these variables, hence in principle:

$$\text{Requirement } (V) = \{ \Delta V, \Delta x, \Delta y, \Delta z, \Delta t \}$$

In the case of weather, climate, land and ocean observations, the spatial domain under consideration is a very thin shell at the surface of the globe. There are 3 orders of magnitude difference between its horizontal and vertical dimensions. Horizontally, x and y vary between [0, 40,000 km] while vertically z varies typically between [-10, 40 km] . We can assume that the required accuracy is the same along x and y ($\Delta y = \Delta x$) but this is not true for Δz which must be defined as a distinct value. In practice we also record the required data latency (δt) although it is more a system requirement. Climate applications then requested to also record the "Stability per decade" of the uncertainty (ΔVd). Schematically, requirements would thus be defined as:

$$\text{Requirement } (V) = \{ \Delta V, \Delta Vd, \Delta x, \Delta z, \Delta t, \delta t \}$$

Because the sensitivity of any variable is often not constant in space, the requirements are not necessarily uniform. OSCAR therefore enables to modulate the requirements according to the location in space, either vertically or horizontally.

- Vertically : concept of "layer".

  A "layer" in OSCAR is a vertical range where a given requirement is applicable. In order to facilitate harmonization, a set of possible layers is defined within each domain (Ocean, land, atmosphere, outer space) for example, "Low troposphere" or "Upper ocean". For each variable V(x,y,z,t) we can define a subset of meaningful layers, which are contained in the variation interval of z for V(x,y,z,t) and where a requirement is potentially applicable.

  If V is not a function of z, for instance if it is simply V(x,y,t) or V(t), the requirement also does not depend on z . Then there is no issue, and no point in defining a layer.

- Horizontally: concept of "coverage", which is a recent development in OSCAR.

  The "coverage" defines horizontal regions where a given requirement is applicable. By default it is the whole globe but it can be restricted to e.g. oceanic areas, land surface, polar regions, "local measurements", specific WMO Regions, etc. In order to facilitate harmonization, a set of possible types of horizontal coverage is defined for each domain.

  Finally, the requirements in OSCAR are defined schematically as follows:

  $$\text{Requirement } (V, L, C) = \{ \Delta V, \Delta Vd, \Delta x, \Delta z, \Delta t, \delta t \}$$
  Applicable to variable V(x,y,z,t)
  when z is within layer [L]
  and (x,y) within Coverage [C]

Applicable layers and coverage for space weather observation requirements

The Space Weather application area is dealing with different scales in space and time, and is not bound to the geocentric vertical and horizontal dimensions. The current list of "layers" used for space weather is not homogeneous and does not meet the common sense. It should however be possible to streamline it to accommodate space weather requirements in extending the concepts of layers and of coverage as follows:

- The "layer" would characterize the Earth-Sun distance when a requirement depends on such distance;
- The "coverage" would characterize portions of space in other dimensions, when the requirement applies selectively to certain portions of space.

- *Variables related to observations of the Sun* are generally not 3D variables but rather 1D (Solar Radio Emission, Solar flux in various bandwidths) or 2D (Solar images in various bandwidths, Solar velocity fields or Solar magnetic fields). As requirements for these variables are not dependent on z there is no reason to define a layer. The Corona is a particular region of interest, which can be identified as a specific "Coverage".

- *For Space Energetic Particles (SEP)* there are currently requirements in LEO, MEO, GEO and near the surface (for cosmic rays). These requirements are different because of the different impacts. SEP observations may be required also at L1, L4/L5 or more generally (for modelling purpose) in the broader Earth-Sun region. This would imply the following layers: LEO, MEO, GEO, near surface, and Earth-Sun. "Near-surface" is an existing layer from the Atmosphere domain in OSCAR. "Earth-Sun" would be a new layer, defined for example from the GEO altitude to the distance of the Sun. A requirement for SEP observation specifically at L1 (or L4/L5) could still be assigned to the Earth-Sun layer if we specify L1 (or L4/L5) as the "Coverage".

- *For solar wind variables* (e.g. solar wind temperature, velocity and density) the requirements are currently specified for L1 only, although the solar wind is thought to affect the whole Earth-Sun domain. Solar wind observation requirements could be similarly assigned to the "Earth-Sun" layer, with L1 specified as the required "coverage".

- *Ionospheric variables* are obviously relevant to the whole ionosphere and the related requirements can be simply applied to the whole ionosphere unless these requirements are significantly depending on altitude, in which case the ionosphere can be split into more layers.

- The magnetosphere was defined as a layer by ICTSW, but it is not used by any requirement at present. The shape of the magnetosphere is not well reflected as a vertical "layer", however it could now be described as a particular "coverage" within the "Earth-Sun layer.

- More generally, additional types of "Coverage" could be defined to account for the particular distribution in space of space weather phenomena, e.g.: sun-lit side of the Earth, shadow-side of the Earth, polar regions.

- The existing layer "Heliosphere" is useless since basically it includes the whole space we are dealing with. It would make sense if a requirement was defined with certain values in the heliosphere and other values outside of the heliosphere, but it is not the case in OSCAR as we are not considering deep space astronomy requirements.

In summary, the following changes are proposed:

- remove “Heliosphere”, “Sun”, “Magnetosphere”, “L1”, “L4/L5”
- create an “Earth-Sun” layer
- define specific types of coverage: Corona, L1, L4/L5, Magnetosphere, Sun-side, Shadow, polar area.

The resulting list of layers and coverage types for space weather requirements is indicated in the tables below.

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