WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS
COMMISSION FOR AERONAUTICAL METEOROLOGY

INTER-PROGRAMME COORDINATION TEAM ON SPACE WEATHER

FOURTH SESSION

GENEVA, 25-28 NOVEMBER 2013

ICTSW-4/Doc. 12(2) REV1
(5.XII. 2013)

ITEM: 12

Original: ENGLISH

TRAINING AND OUTREACH MATTERS
Review of draft CIMO Guide

(Submitted by the Secretariat)

Summary and Purpose of Document

The Guide to Meteorological Instruments and Methods of Observation ("CIMO Guide") , is an official WMO Publication (WMO-No. 8) serving as a reference to all WMO Members for surface-based or space-based observations. As concerns space-based observation, the CIMO Guide aims to introduce the fundamental principles and the main features of space-based remote sensing, raise the technical awareness of WMO Members, help them to understand the advantages and limitations of space-based observation, and prepare them to use these capabilities as an increasingly important source of observation data and products.

In 2012/2013, an entirely new volume of the CIMO Guide has been drafted for satellite observations. This 160-page document includes 7 chapters that can be downloaded from: ftp://ftp.wmo.int/dept/sat/documents/cimo/. It will be submitted to the CIMO Guide Editorial Board in November 2013 and will then be provided to all WMO Members for comments with a view of final adoption of the text at the next CIMO session (2014).

The sections of this document that are specifically addressing space weather are contained in the Appendix, for consideration by the ICTSW.

ACTION PROPOSED

The Inter-Programme Coordination Team is invited to review the material in Appendix and report any corrections to the Secretariat.

APPENDIX Draft CIMO Guide Update: Extract from Chapters 3, 4, 5 and annex.

Draft CIMO Guide update
Extract from Chapter 3 (Instruments)

3.2.17 Solar activity monitors

Solar activity is monitored either by remote sensing or *in situ* in the solar wind, from deep space and earth's orbit. Several measurement approaches are possible:

- Electromagnetic radiation: measured by radiometers or spectrometers for γ-rays (< 0.001 nm), X-ray (0.001- 10 nm), EUV (10-120 nm) , UV (120-380 nm), VIS (380-780 nm) and longer wavelengths including radio-waves (> 1 m).
- Energetic particles (electrons, protons, α-particles, ions, cosmic rays, neutrons): the energy range is generally broken down into high-energy, medium-energy and low-energy, the boundaries of the ranges depending on the type of charged particle. Measurements can be integrated over the full energy range, or over partial ranges; or spectroscopy within a range may be performed.
- Magnetic and electric fields, directly measured in the solar wind, and inferred in the photosphere, either from the measurements in the solar wind or by spectroscopy of VIS solar images to exploit the Zeeman effect, or perform Doppler analysis or exploit multi-polarisation.
- Measurements can be performed by integrating over the full solar disk, or imaging the solar disk, or imaging only the corona by occulting the disk (coronagraph).
- One specific observation is the solar irradiance, either total or spectrally resolved (see section 3.2.9).

An example of instrument package for solar activity monitoring from the L1 Lagrange libration point, SOHO, is described in Table 3.40.

3.2.18 Space environment monitors

Space environment monitoring at platform level provide information used for overall Space weather conditions monitoring and predictions, as well as for platform safety. The instrumentation generally includes:

- charged particle detectors, designed for specific ranges of energy, either integrated or spectrally resolved;
- magnetometers and electrometers.

An example of instrument package for in-situ space environment monitoring, GGAK-M, is described in Table 3.41.

3.2.19 Magnetometers and electric field sensors

Magnetic and electric fields in the magnetosphere, can be measured *in situ*, as the satellite moves along the orbit. If the orbit is highly eccentric, it crosses the magnetosphere at different altitudes, thus providing 3D profiles. Gradients of the fields are better observed when more satellites are flown together in coordinated orbits. Usual instruments are:

- magnetometers, either scalar or vectorial
- electron fluxometers to compute the electric field.

An example of instrument package for 3D observation of the magnetosphere exploiting four satellites, CLUSTER, is described in Table 3.42**.**

Table 3.40 - Example of solar activity monitoring package: SOHO instrumentation

SOHO instrumentation	Instrumentation of SOHO
Satellite	SOHO.
Mission	Sun monitoring from the L_1 Lagrange point.
Main features	Package of the following instruments: • Solar atmosphere remote sensing instrument package: - SUMER (Solar UV Measurement of Emitted Radiation) - CDS (Coronal Diagnostic Spectrometer) - EIT (Extreme UV Imaging Telescope) - UVCS (UV Coronagraph and Spectrometer) - LASCO (Large Angle Spectrometer Coronagraph) - SWAN (Solar Wind Anisotropies) • Solar wind “in situ particle” instrument package - CELIAS (Charge, Element, Isotope Analysis) - COSTEP (Suprathermal & Energetic Particle Analyzer) - ERNE (Energetic and Relativistic Nuclei and Electron experiment) • Helio-seismology instrument package (study of the Sun's interior) - GOLF (Global Oscillations at Low Frequencies) - VIRGO (Variability of Solar Irradiance) - MDI (Michelson Doppler Imager).
Scanning technique	Sun pointing.
Coverage/cycle	Continuous from the L_1 Lagrange point.
Resources (of the satellite)	Mass: 1850 kg - Power: 1.5 kW - Data rate: 200 kbps.

Table 3.41 - Example of space environment monitoring package: GGAK-M on Meteor-M

GGAK-M	Geophysical Monitoring System Complex
Satellites	Meteor-M N1, Meteor-M N2, Meteor-M N2-1, Meteor-M N2-2.
Mission	Space environment monitoring at platform level.
Main features	Package of instruments: • MSGI-MKA (Spectrometer for Geoactive Measurements) - Electron fluxes in the energy range of 0.1-15 keV (high-sensitivity channel) - Ion (proton) fluxes in the energy range of 0.1-15 keV (high-sensitivity channel) - Electron fluxes in the energy range of 0.1-15 keV (low-sensitivity channel) - Monitoring of integral electron fluxes with a threshold energy of 40 keV. • KGI-4C (Radiation Monitoring System) - Total proton flux threshold energy of: 5, 15, 25, 30 and 40 MeV - Total electron flux threshold energy of: 0.17, 0.7, 1.7, 2.0 and 3.2 MeV - Proton fluxes with threshold energies of: 25 and 90 MeV.
Resources	Mass: 17 kg - Power: 13.6 W - Data rate: 16 kbps.

Table 3.42 - Example of magnetosphere monitoring package: CLUSTER instrumentation

CLUSTER instrumentation	Instrumentation of CLUSTER
Satellites	CLUSTER A, B, C and D (four satellites co-flying in coordinated orbits).
Mission	Monitoring of the 3-D magnetosphere.
Main features	Package of the following instruments: • FGM (Fluxgate Magnetometer) • STAFF (Spatio-Temporal Analysis of Field Fluctuations) • EFW (Electric Fields and Waves) • WHISPER (Waves of High Frequency and Sounder for Probing of Density by Relaxation) • WBD (Wide Band Data) • DWP (Digital Wave Processor) • EDI (Electron Drift Instrument) • CIS (Cluster Ion Spectrometry) experiment) • PEACE (Plasma Electron and Current Analyzer)

	• RAPID (Research with Adaptive Particle Imaging Detectors) • ASPOC (Active Spacecraft Potential Control).
Scanning technique	4 satellites travelling cross the Magnetosphere in highly-elliptical orbits.
Coverage/cycle	Continuous, *in situ* along the orbit.
Resources (of one satellite)	Mass: 1200 kg - Power: 224 W - Data rate: 16.9 kbps.

Draft CIMO Guide update
Extract from Chapter 4 (Programmes)

4.6 Missions for Space weather

Although the term “space weather” is relatively recent, the relevant activities started with the advent of the space era, if not before, because space weather has a strong impact on the safety of satellites in orbit and of man in space. Awareness and prediction of the space environment has now become a prerequisite for the long-term sustainability of space activities. In addition there is increasing awareness of the impact of space weather on facilities on the Earth.

Space weather stems from the interaction of the solar wind (charged particles) and the Earth’s magnetosphere. The solar wind modulations compress and shape the magnetosphere, and this effect propagates lower to the thermosphere and ionosphere. Telecommunications and even power grids, pipelines and other conducting networks on the Earth’s surface are affected (e.g., by *geomagnetically induced currents* (GIC)). Rapid magnetic changes on the ground, that occur during *geomagnetic storms* and are associated with space weather, can also be important for activities such as geophysical mapping and hydrocarbon production. Correlations have been discovered between *travelling ionospheric disturbances* and atmospheric gravity waves in the thermosphere.

Monitoring space weather implies two aspects: to monitor the solar winds and understand its modulation source (solar activity), and to monitor the effects within the magnetosphere and down to the Earth’s surface.

4.6.1 Solar activity monitoring

Space missions to understand solar physics have been performed since the early days of the space era either from deep space orbits or from Earth orbits.

Two “sentinels” of solar winds, the joint NASA/ESA mission SOHO (Solar and Heliographic Observatory) and the NASA mission ACE (Advanced Composition Explorer), were launched in 1995 and 1998, respectively. SOHO and ACE have been placed in the L_1 Lagrangian point [at 1% of the Earth-Sun distance upstream of the Earth]. From that vantage point the two satellites measure solar wind and the associated magnetic field approximately one hour before they reach the Earth. In 2006 in collaboration with several European scientific institutes, NASA launched STEREO (Solar-TErrestrial RElations Observatory), two satellites moving in the Earth’s orbit around the Sun, viewing the Sun from changing positions to get a stereoscopic view of the dynamics of coronal mass ejection and, at the same time, to measure the local features, at the satellite position, of the solar wind.

Several missions in Earth orbit are also carrying instruments dedicated to continuous monitoring of solar activity. Table 4.9 lists satellites that monitor solar activity from positions in deep space or in Earth’s orbit. In addition, some geostationary meteorological satellites (GOES or FY-4 series) contribute or will contribute to solar monitoring.

Table 4.9 - Missions specific to solar activity monitoring

Acronym	Full name	Responsible	Orbit
ACE	Advanced Composition Explorer	NASA	L_1 Lagrange point
Aditya-1	Aditya-1	ISRO	LEO, Sun-synchronous
DSCOVR	Deep Space Climate Observatory	NOAA, NASA	L_1 Lagrange point
Hinode	Hinode (former name: SOLAR-B)	JAXA	LEO, Sun-synchronous
IRIS	Interface Region Imaging Spectrograph	NASA	LEO, sunsynchronous
Picard	Picard	CNES	LEO, Sun-synchronous
PROBA 1 & 2	Project for On-Board Autonomy - 1 and 2	ESA	LEO, Sun-synchronous
Resurs DK & P	Resurs-DK and Resurs-P	Roscosmos	LEO, high-inclination
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager	NASA	LEO, low-inclination
SDO	Solar Dynamics Observatory	NASA	Geosynchronous, low inclination
SOHO	Solar and Heliographic Observatory	ESA, NASA	L_1 Lagrange point
Solar Orbiter	Solar Orbiter	ESA, NASA	Solar orbit
Solar Probe Plus	Solar Probe Plus	NASA	Solar orbit
STEREO (2 sats)	Solar-TErrestrial RElations Observatory	NASA	Ecliptic plane
TIMED	Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics mission	NASA	LEO, high-inclination
WIND	WIND	NASA	L_1 Lagrange point

4.6.2 Magnetosphere and ionosphere monitoring

Closer to the Earth (see Fig. 4.8 and Fig. 4.9), the thermosphere and the ionosphere are the layers where space weather is more turbulent. The ionosphere is affected by waves, storms and *travelling disturbances*. Through the interaction with magnetic storms, energetic particles and electrical currents can occur, which affect radio propagation. Mapping electron density in the ionospheric "E-region" enables inference of *ionospheric conductivity and currents*. When associated with magnetic field data, this information enables discriminating the internal component of the magnetic field (due to the solid Earth) from external components. Small-scale irregularities and eddies of the ionosphere can cause scattering of radio waves (*scintillations*), which affects the reliability of radio links crossing the ionosphere.

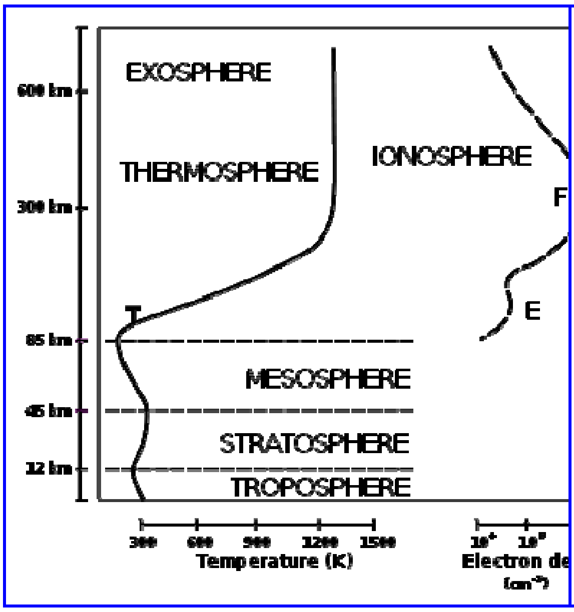

Fig. 4.8 - Atmospheric stratification below and above the Mesopause.

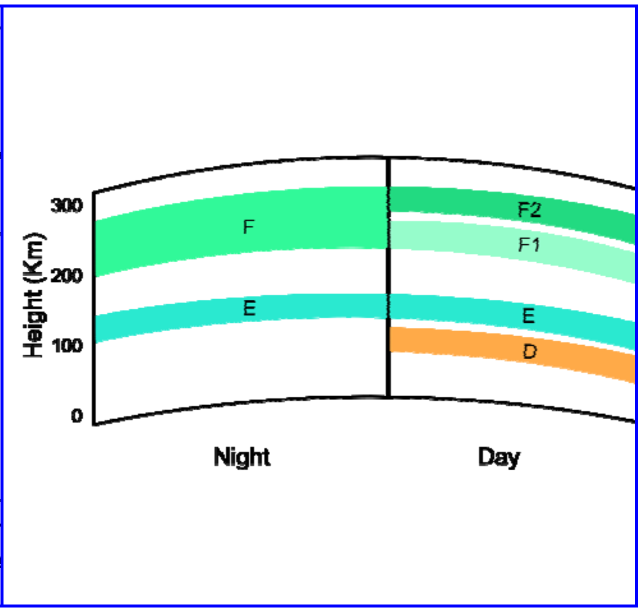

Fig. 4.9 - Layers of denser electronic content. The densest layer is F2, present day and night.

4.6.2.1 Observation of the Magnetosphere

Missions dedicated to Magnetosphere have a long-standing heritage. Two significant current examples are THEMIS and MMS.

THEMIS (Time History of Events and Macroscale Interactions during Substorms) is a NASA mission launched in 2007. It consists of a constellation of five small satellites in highly eccentric orbits, crossing the magnetosphere at several altitudes (see Fig. 4.10) corresponding to periods ranging from 0.8 to 4 days.

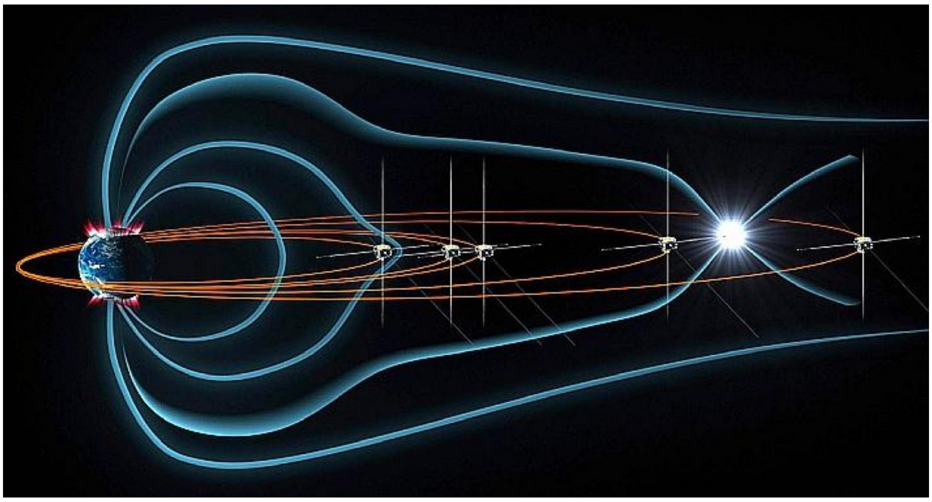

Fig. 4.10 - The orbits of the five THEMIS satellites in the magnetosphere.
The white flash represents an energy released substorm.

THEMIS measures the magnetic field, electric fields and charged particles in order to address the physical processes in near-Earth space that initiate the violent eruptions of the aurora that occur during substorms in the Earth's magnetosphere. A number of ground stations are part of the system, to detect auroras and to measure the surface magnetic field.

The Magnetospheric Multiscale mission (MMS) developed by NASA is based on a constellation of four satellites with highly eccentric orbits spread across the magnetosphere, similarly to THEMIS (see Fig. 4.11). Plasma analyzers, energetic particle detectors, magnetometers, and electric field instruments are used to study the microphysics of *magnetic reconnection*, the ultimate driver of space weather. Table 4.10 lists a number of missions specifically addressing the magnetosphere.

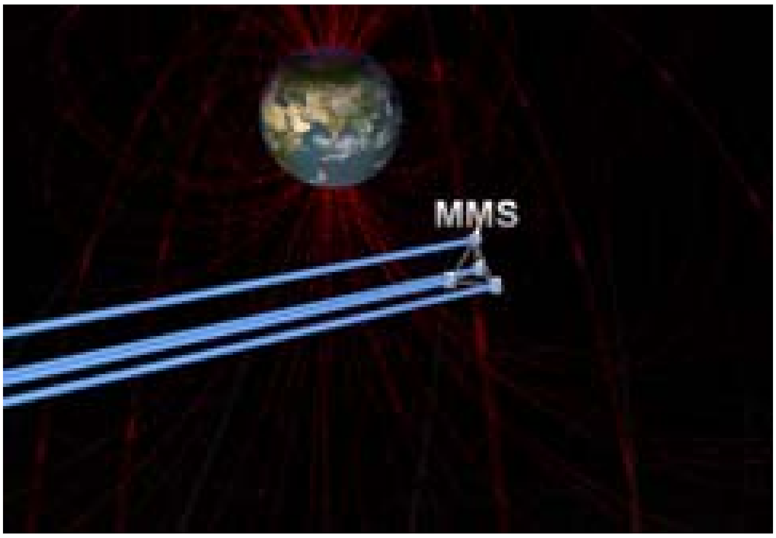

Fig. 4.11 - The four MMS satellites flying in formation. Tetrehedral pattern
to capture the 3-D structure of the encountered reconnection sites.

Table 4.10 - Non-exhaustive list of missions orbiting inside the Magnetosphere

Acronym	Full name	Responsible	Orbit
Arctica-M	Arctica-M	RosHydroMet	Molniya orbit
ARTHEMIS	Acceleration, Reconnection, Turbulence, and Electrodynamics of the Moon's Interaction with the Sun	NASA	Lunar orbit
C/NOFS	Communication/Navigation Outage Forecasting System	DoD, NASA	LEO, low inclination
CASSIOPE	CASSIOPE	CSA	Highly elliptic, high inclination, relatively low altitude
CLUSTER (4 sats)	CLUSTER	ESA, NASA	Highly elliptic, polar inclination, tetrehedral formation flight
GEOTAIL	GEOTAIL	JAXA, NASA	Extremely elliptic, low inclination, crossing the Moon orbit
IBEX	Interstellar Boundary Explorer	NASA	Highly elliptic, low inclination
Ionozond (5 sats)	Ionozond	Roscosmos	4 sats in sunsynchronous orbit, one in drifting orbit
MMS (4 sats)	Magnetospheric MultiScale mission	NASA	Highly elliptic, low inclination, tetrehedral formation flight
THEMIS (5 sats)	Time History of Events and Macroscale Interactions during Substorms	NASA	Highly elleptic, low inclination, apogees at 5 different altitudes
TWINS (2 sats)	Two Wide-angle Imaging Neutral-atom Spectrometers	NASA, USAF	Molniya orbit
VAP (2 sats)	Van Allen Probe (formerly RBSP, Radiation Belt Storm Probes Mission)	NASA	Highly elliptic, low inclination, crossing the radiation belts

In section 4.5.2 a number of missions in lower orbit have been described that also carry instruments relevant to the magnetosphere:

- Ørsted: FVM (Fluxgate vector magnetometer) and OVM (Scalar Overhauser magnetometer);
- SAC-C: MMC/ Ørsted-2 (Magnetic Mapping Payload / Ørsted-2);
- CHAMP: MIAS (Magnetometer Instrument Assembly System);
- SWARM: ASM (Absolute Scalar Magnetometer), VFM (Vector Field Magnetometer) and EFI (Electric Field Instrument).

4.6.2.2 Observation of the Ionosphere

With the advent of radio occultation sounding, the profile of the electron density across the ionosphere has become the best measurable geophysical variable associated with space weather.

The signal from navigation satellites (GPS, GLONASS, Compass, Galileo) is affected by the rotation of the electric field and the delay induced by the ionosphere. In order to correct for this effect, at least two frequencies are used (now shifting to three): ~ 1180 GHz, ~ 1580 GHz and, possibly, ~ 1250 GHz. By differentiating the two (or three) signals, information is obtained on:

- the ionospheric Total Electron Content (TEC)
- the electron density profile.

It is noted that the TEC, although integrated along-view, is measured for changing tangent heights, therefore it is possible to reconstruct the vertical profile by tomography. Several *radio occultation payloads* are being flown, both on multi-purpose satellites and dedicated facilities (e.g., the COSMIC constellation).

Radar altimeters also provide TEC observations by exploiting two frequencies, generally ~ 13.5 GHz and ~ 5.3 GHz. The coverage is only at nadir and tomography is not possible; however, since altimetry missions are often orbited at high altitude (e.g., 1,336 km for JASON), the measurement includes the lower part of the *plasmasphere* (the layer above the thermosphere, from ~ 1,000 to ~ 40,000 km altitude).

Direct measurement of TEC can also be performed by phase delay analysis of the two or three frequencies transmitted by a GNSS satellite and received by a LEO satellite. In this case TEC is observed along the path from the GNSS satellite (orbit altitude ~ 20,000 km) to the LEO satellite (orbit altitude ~ 800 km), thus in the medium plasmasphere. The number of available GNSS satellites is rather large: ~ 24 each for GPS and GLONASS systems, ~ 30 for Galileo, ~ 35 for Compass, for a total close to 110, with a fair global distribution.

4.6.2.3 Space environment observation from operational meteorological satellites

The constellations of operational meteorological satellites substantially contribute to space weather monitoring. In many cases the focus is on charged particles, in connection to the need for monitoring risky events for the onboard electronics and other sub-systems sensitive to corpuscular radiation. In many cases, magnetic and electric fields are also measured. In some cases, solar activity is also monitored, however the orbits of meteorological satellites are not optimal for space weather monitoring: for instance (see back Fig. 4.9), the 90 to 300 km height range cannot be covered and Sun-synchronous orbits with fixed LST do not cover the daily cycle, thus introducing a sampling bias. Nonetheless, the high number of satellites and their long-term continuity constitute a valuable contribution.

Table 4.11 presents the information available from operational meteorological satellites related to space weather. Radio occultation payloads (see section 4.2.2) are omitted.

Table 4.11 - Operational meteorological missions carrying instruments relevant for Space weather

Satellite series	Payload for *in situ* space environment monitoring
GOES 11 to 15	SEM: Space Environment Monitoring, suite of instruments for charged particles, solar X ray and magnetic field SXI: Solar X-ray Imager
GOES R, S, T, U	SEISS: Space Environment In-Situ Suite for charged particles in solar wind and cosmic rays EXIS: Extreme Ultraviolet Sensor / X-Ray Sensor Irradiance Sensors SUVI: Solar Ultraviolet Imager MAG: Magnetometer
Electro-L	GGAK-E: Heliogeophysical Measurements System for charged particles of the solar wind and of cosmic rays.
Electro-M	GGAK-E/M: Heliogeophysical Measurements System for charged particles of the solar wind and of cosmic rays.
FY-2	SEM: Space Environment Monitor for charged particles of the solar wind
FY-4	SEM: Space Environment Monitor for charged particles of the solar wind SXEUV: Solar X-EUV imaging telescope for incoming X-rays and Extreme UV from the Sun
NOAA 15 to 19	SEM/2: Space Environment Monitoring / 2, for medium energy and total energy proton detection
MetOp A, B	
JPSS	SEM-N: Space Environment Monitoring for NPOESS, including a spectrometer for Precipitating Electrons and Ions, a spectrometer for medium-energy particles, and omni-directional detectors for high-energy particles
DMSP F16 to S20	SSIES: Special Sensor Ion and Electron Scintillation Monitor SSJ5: Special Sensor Precipitating Electron and Ion Spectrometer SSM: Special Sensor Magnetometer SSULI: Special Sensor Ultraviolet Limb Imager SSUSI: Special Sensor Ultraviolet Spectrographic Imager.
Meteor-M	GGAK-M: Geophysical Monitoring System Complex, split in - MSGI-MKA: Spectrometer for Geoactive Measurements - KGI-4C: Radiation Monitoring System
Meteor-MP	- GGAK-MP: Geophysical Monitoring System Complex, improved after GGAK-M
FY-3 A, B	SEM: Space Environment Monitor for charged particles of the solar wind
FY-3 C to G	SES: Space Environment Suite, including: - SEM: Space Environment Monitor, same as on FY-3A and FY-3B - WAI: Wide-field Auroral Imager - IPM: Ionospheric PhotoMeter

Draft CIMO Guide update
Extract from Chapter 5 (Products)

5.9 Space Weather

This theme comprises variables that characterise the Space Weather. The variables relevant to this theme are classified below into three categories:

- solar processes (Table 5.8);
- Sun-Earth inter-space, dominated by the solar wind (Table 5.9);
- Near-Earth: magnetosphere and ionosphere (Table 5.10).

Table 5.8 - Satellite observations relevant to solar processes monitoring

Variable	Deatils	Physical unit
Solar gamma-rays, X-rays, EUV. UV, VIS	Integrated flux density	watt·m^{-2}
	Flux density energy spectrum	watt·m^{-2}·nm^{-1}
	Flux density image	erg·cm^{-2}·arcsec^{-1}·s^{-1}
Solar Ca II-K image	K-line of Ca-II (393.4 nm)	erg·cm^{-2}·arcsec^{-1}·s^{-1}
Solar H-alpha image	Hydrogen-alpha transition (656.3 nm)	erg·cm^{-2}·arcsec^{-1}·s^{-1}
Solar Lyman-alpha image	Hydrogen Lyman-alpha transition (121.6 nm)	erg·cm^{-2}·arcsec^{-1}·s^{-1}
Solar Lyman-alpha flux	Hydrogen Lyman-alpha transition (121.6 nm)	watt·m^{-2}
Solar magnetic field	Magnetic field at the solar surface (photosphere)	gauss
Solar radio emission	Integrated radio flux over the solar disk	watt·m^{-2}
Solar velocity fields	Image of 3D velocity of particles in the photosphere	m·s^{-1}·arcsec^{-1}
Solar electric field	Image of the electric field in the photosphere	mV·m^{-1}·arcsec^{-1}
Solar corona image	Image of the corona surrounding the Sun	erg·cm^{-2}·arcsec^{-1}·s^{-1}

Table 5.9 - Satellite observations relevant to Sun-Earth inter-space and solar wind

Variable	Details	Physical unit
Electrons, Protons, Neutrons, Alpha-particles	Integrated flux density	particles·cm^{-2}· s^{-1}· sr^{-1}
	Flux density energy spectrum	particles·cm^{-2}· s^{-1}· sr^{-1}·eV^{-1}
	Flux density image	particles·cm^{-2}· s^{-1}· sr^{-1}·arcsec^{-1}
Heavy ions [$2(\text{He}) < Z \leq 26(\text{Fe})$], Cosmic-rays	Integrated flux density	particles·cm^{-2}· s^{-1}· sr^{-1}
	Flux density energy spectrum	particles·cm^{-2}· s^{-1}· sr^{-1}·(MeV/nucleon)$^{-1}$
	Flux density image	particles·cm^{-2}· s^{-1}· sr^{-1}·arcsec^{-1}
Gamma-rays, X-rays, EUV, UV, VIS, NIR, SWIR	Integrated flux density	watt·m^{-2}
	Flux density energy spectrum	watt·m^{-2}·nm^{-1}
	Flux density image	erg·cm^{-2}·arcsec^{-1}·s^{-1}
Radio-waves	Integrated flux density	watt·m^{-2}
Heliospheric image	Image of the Sun-Earth inter-space	erg·cm^{-2}·arcsec^{-1}·s^{-1}
Interplanetary magnetic field	Magnetic field in the solar wind	nT
Solar wind density	Density of the solar wind plasma	particles·cm^{-3}
Solar wind temperature	Temperature of solar wind protons	K
Solar wind velocity	Velocity of the solar wind plasma	km·s^{-1}

Table 5.10 - Satellite observations specific to magnetosphere and ionosphere

Variable	Details	Physical unit
Ionospheric plasma velocity	Velocity of bulk plasma or electrons, a function of altitude	km·s^{-1}
Ionospheric Scintillation	Random fluctuations of radio waves and refractive index	dimensionless
Ionospheric Total Electron Content (TEC)	Number of electrons between two points.	TECU
Electron density	3D field of the electron density in the ionosphere	electrons·m^{-3}
Magnetic field	Magnetic field in the Earth environment (magnetosphere)	nT
Electric field	Magnitude and direction of the Earth's electric field	mV·m
Electrostatic charge	Accumulated electric charge on a satellite platform	pA·cm^{-2}
Radiation Dose Rate	3D field of the dose rate of energetic particles	mSievert·h^{-1}

The following sections give details on a few selected variables, relevant to the ionosphere and magnetosphere.

5.9.1 Ionospheric Total Electron Content (TEC)

Definition: Number of electrons along a path between two points. Observed under different viewing angles so as to generate vertical profiles by tomography. Requested in the ionosphere and plasmasphere - Physical unit: [electrons/m^2]; practical unit: TECU = 10^{16} electrons/m^2 - Uncertainty unit: [%].

Method 1: GNSS radio-occultation - Principle: Differential refraction between two frequencies (~ 1.2 and ~ 1.6 GHz) transmitted by a navigation satellite and received by a LEO satellite during the occultation phase. Path-integrated content observed at changing tangent heights so as to provide vertical profile. Applicable only in LEO.

Method 2: Radar altimetry - Principle: Differential phase delay between signals from dual-frequency radar altimeter (~ 13 GHz and ~ 3 or 5 GHz). Phase rotation measurement, primarily needed to correct the altimeter ranging measurement, is also used to infer the column-integrated TEC. Applicable only in LEO.

Method 3: GPS-LEO signal phase delay - Principle: Differential phase delay between signals from two-frequency GPS transmitters (~ 1.2 and ~ 1.6 GHz) and a receiver in LEO using GPS for navigation. In principle, any satellite equipped with a GPS navigation system is suitable. The information refers to the topside ionosphere and plasmasphere, i.e. the layer between the satellite altitude and the GPS altitude (~ 20,000 km). Applicable only in LEO.

5.9.2 Electron density

Definition: 3D field of the electron density. Requested in the ionosphere and plasmasphere - Physical unit: [electrons/m^3] - Uncertainty unit: [%].

Method 1: GNSS radio-occultation - Principle: Differential refraction between two frequencies (~ 1.2 and ~ 1.6 GHz) transmitted by a navigation satellite and received by a LEO satellite during the occultation phase. Derived by tomography of Total Electron Content (TEC). Applicable only in LEO.

5.9.3 Magnetic field

Definition: Magnitude and direction of the Earth's magnetic field. Indicative of the degree of geomagnetic disturbance within the magnetosphere, and also of the Earth's interior. Requested in the magnetosphere - Physical unit: [nT] (1 Tesla = 10^4 Gauss) - Uncertainty: [nT].

Method 1: Magnetometry - Principle: one (for scalar) or more (for vector) magnetometers for *in situ* measurement along the orbit as the satellite moves. Applicable in LEO, in GEO and in Highly Elliptical Orbits.

5.9.4 Electric field

Definition: Magnitude and direction of the Earth's electric field. Requested in the magnetosphere - Physical unit: [mV/m] - Uncertainty: [mV/m].

Method 1: Ion drift - Principle: Measurement of magnitude and direction of the incoming ion flux. The electric field is derived from the relationship between electric field, measured ion drift velocity and measured magnetic field strength. *In situ* measurement along the orbit as the satellite moves. Applicable in LEO, in GEO and in Highly Elliptical Orbits.

Draft CIMO Guide update
Annex to chapter 5 (product quality)

8. Space Weather

Ionospheric Total Electron Content (TEC)	Electron density profile	Magnetic field	Electric field

Table5.11.1 - Estimated potential quality of product “Ionospheric Total Electron Content (TEC)” (by 2020)

Layer	Orbit	Technique	Uncertainty (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Ionosphere	LEO	GNSS radio-occultation	5 %	300	3	12	12	90-800 km altitude
	LEO	Radar altimetry (non-scanning)	10 %	100	200	120	2	90-1300 km altitude
	LEO	GPS-LEO signal phase delay	20 %	300	4000	12	12	1000-20000 km altitude

Table5.11.2 - Estimated potential quality of product “Electron density” (by 2020)

Layer	Orbit	Technique	Uncertainty (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Ionosphere	LEO	GNSS radio-occultation	10 %	300	10	12	12	90-800 km altitude

Table5.11.3 - Estimated potential quality of product “Magnetic field” (by 2020)

Layer	Orbit	Technique	Uncertainty (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Magnetosphere	LEO	Magnetometry	0.3 nT	100	-	240	1	Limited to satellite orbit
	GEO	Magnetometry	1 nT	100	-	0.25	6	Limited to satellite orbit

Table5.11.4 - Estimated potential quality of product “Electric field” (by 2020)

Layer	Orbit	Technique	Uncertainty (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Magnetosphere	LEO	Ion drift	10 mV/m	100	-	240	1	Limited to satellite orbit
	GEO	Ion drift	10 mV/m	100	-	0.25	6	Limited to satellite orbit