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STEERING GROUP ON RADIO FREQUENCY COORDINATION (SG-RFC)

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RADIO-FREQUENCY SPECTRUM FOR SPACE WEATHER ACTIVITIES

1. Introduction

The sixteenth Meteorological Congress (Cg-16) has recognized the potential socio-economic impact of space weather events that affect for instance international air navigation, spacecraft operations, power grid operations, radio-communications and GNSS localization and time signals. This is of specific relevance to WMO as meteorological operations are relying to a large extent on satellite observations and radio-communications, and GNSS time signals. Furthermore, there is an expectation from WMO Members that meteorological and space weather support to aviation can be ultimately delivered in an integrated manner. Congress therefore agreed that support to the international coordination of space weather operations should be one of the areas of activities of the WMO Space Programme (See: http://www.wmo.int/pages/prog/sat/spaceweather-intro_en.php) This activity is being pursued through the Inter-Programme Coordination Team on Space Weather (ICTSW) which reports to both the Commission for Basic Systems and the Commission for Aeronautical Meteorology.

The impact of space weather on the reliability of trans-ionospheric radio-communications is of high relevance to the ITU. The ITU therefore decided to study the needs of operational space weather forecasting and its usefulness for forecasting ionospheric propagation conditions (See Question ITU-R 213-3/3 provided in Annex 2).

The present paper provides initial considerations on the radio-frequency spectrum needed for ground-based space weather observations.

2. Overview of Ground-based Space Weather Observations

A review of space weather observation status and needs is provided in the "Statement of Guidance for Space Weather Observations" completed by ICTSW in May 2012. Radio-frequencies are used in particular for ground-based solar and ionosphere monitoring. Space-based observations for space weather are not addressed in the present paper.

Continuous monitoring of the Sun is necessary as solar activity is the trigger of space weather events. This has led to the deployment of a large number of ground and space-based instruments for monitoring the Sun. Ground-based radio observations of the Sun are principally performed by:

- **solar radio spectrographs** operating in a continuous frequency range in the HF to UHF, or
- **solar radio telescopes** operating in discrete bands ranging from VHF to SHF for imaging or solar radio flux monitoring.

Ground-based solar radio monitoring programmes have been operating for more than 60 years, yielding long, consistent records showing well understood patterns representing the various forms of solar activity. One of the most widely-used indices of solar magnetic activity is the 10.7 cm solar radio flux (F10.7), which is the integrated solar radio flux between 2750 and 2850 MHz. Applications fall into three main areas: the detection of flares and transient events, indication of the general level of solar magnetic activity, and proxy for solar quantities that are required for modelling terrestrial processes such as the ionosphere or upper atmospheric heating. Another application of solar radio measurements is the calibration of weather radar antennas, because the solar signal provides a commonly-available signal of known strength.

Ionospheric observations are performed by the following active or passive techniques:

a) **GNSS receiver:** Total electron content (TEC) along a given propagation path can be measured by tracking the time delay and phase shift of radio signals of a Global Navigation Satellite System by a ground receiver (so called ground based GNSS). As the satellites move over the observing site the TEC along many propagation paths can be used to reconstruct the distribution of ionospheric electron density. Complemented by a constellation of space-based radio-occultation receivers, the GNSS receiver network provides vertical profiles of electron density on a global scale.

b) **Radio absorption:** Ground-based measurements of (~MHz) radio signals from known sources above the atmosphere (usually cosmic radio sources) can be used to map the absorption by the lower ionosphere (e.g. riometers). As the Earth turns, each radio source moves across the observer, and this information can be used to map the distribution of absorbing ionisation in the lower ionosphere.

c) **Ionosonde:** An ionosonde transmits a sweep of (~MHz) radio signals into the ionosphere. Echoes are returned where the local plasma frequency equals the radio frequency. The peak frequency returned from each ionospheric layer is therefore a direct measure of the electron concentration. In contrast, the height of each layer is estimated from the time of flight of the radio signal assuming propagation through free space. Modern research ionosondes can also measure additional variables, most notably plasma velocities and the spectrum of gravity waves. Ionosondes can also detect absorption through the minimum frequency (fmin) observed on an ionogram, although lower values of fmin are limited by terrestrial radio noise and instrument sensitivity.

d) **Incoherent Scatter Radar:** Incoherent Scatter Radars (ISRs) transmit powerful VHF or UHF (typically hundreds of MHz) radio pulses into the ionosphere and use the backscatter from electrons whose motion is controlled by the dynamics of the much slower and heavier ion population to determine the distribution of ionisation. While the height of ionospheric layers can be determined very accurately with ISRs, cross-calibration with ionosondes or the use of specific features in the ISR spectra are required to calibrate the electron concentration, which is inferred from the backscattered power. Careful fitting of the ISR spectrum can generate a host of parameters including line-of-sight velocities, electron and ion temperatures, and ion composition. Estimates of the horizontal distribution of ionisation can be obtained by moving the radar dish or by altering the phase of an antenna array. Vector velocities can be calculated by combining data from different antennas or from different beam directions. These research data are not yet available in real time.

e) Coherent radar: Coherent radars broadcast ~MHz radio pulses and receive coherent echoes from local plasma instabilities in the ionosphere. In this way, the returned power and line-of-sight velocity can be determined. Vector velocities can be calculated by combining data from two or more radar stations.

f) **Ionospheric scintillation receivers**, measure the random fluctuations of intensity and phase of radio waves resulting of variations in the refractive index of the ionosphere. Scintillation is typically observed in GPS signals operating at 1.58 and 1.23 GHz and is relevant for all trans-ionospheric transmissions.

3. Summary of frequencies used for Space Weather Activities

The tables in Annex 1 summarize the outcome of a preliminary survey of frequencies used by several ICTSW members in support of space weather operations. This list is an indication, not an exhaustive inventory.

As concerns the bands listed in Table IV of Annex 1, that are used for passive observation of the Sun, the status of frequency allocations is highly dependent on the region and the countries concerned. However, the following allocations can be noted, from the Table of Frequency allocations of Art. 5 of the Radio Regulations:

- 322 – 328.6 MHz - Fixed service, mobile service and radio astronomy.
- 608 – 614 MHz is allocated to radio astronomy on a primary or secondary basis depending on the Regions and countries,
- 1 400 – 1 427 MHz – Earth exploration-satellite (passive), radio astronomy, space research (passive)
- 1 660 – 1 660.5MHz – Mobile satellite service (Earth-to-space), radio astronomy
- 1 660.5 – 1 668 MHz – Radio astronomy, space research (passive), fixed (secondary), mobile except aeronautical mobile (secondary)
- 1 668 – 1 668.4 MHz – Mobile satellite (Earth–to-space), radio astronomy, space research (passive), fixed (secondary), mobile except aeronautical mobile (secondary)
- 1 668.4 – 1 670 MHz – Fixed service, meteorological aids, mobile except aeronautical mobile, mobile satellite (Earth-to-space), radio astronomy
- 2 700 – 2 800 MHz – Aeronautical radionavigation (ground-based radars and associated airborne transponders, meteorological aids (ground-based radars), radiolocation (secondary)
- 4 990 – 5 000 MHz – Fixed, mobile except aeronautical mobile, radio astronomy, space research (passive) (secondary)
- 8 215 – 8 400 MHz – Aeronautical mobile (ground-to-air), Earth exploration-satellite (space-to-Earth), fixed, fixed satellite (Earth-to-space), mobile except aeronautical mobile
- 10.6 – 10.68 GHz – Earth exploration-satellite (passive), fixed, mobile except aeronautical mobile, radio astronomy, space research (passive), radiolocation (secondary)
- 10.68 – 10.7 GHz – Earth exploration-satellite (passive), radio astronomy, space research (passive)

4. Discussion

There are differences from country to country in the frequency needs, the status of frequency allocations for space weather (e.g. under the Radio Astronomy service), the local protective measures and the actual exposure to interference. Within the allocated bands, requirements for local protection should be addressed with the national authorities. There might be a need, however, to strengthen the status of international frequency allocations for space weather in specific bands of primary importance for space weather operations worldwide.

For instance, while many of the frequencies used for solar observations lie in bands allocated, at least in some regions, to Radio Astronomy, it is not the case of the 2750-2850 MHz and the 8275-8375 MHz frequency bands. In particular, the former is providing the 10.7 cm solar radio flux, which is used by several solar observatories around the world as an internationally agreed solar activity index since more than sixty years. It is of utmost importance to preserve continuous observations in this data series at those solar observatories.

There is an allocation to the Radio Astronomy Service in the neighbouring 2650-2700 MHz band, but the 2 750-2 850 MHz band is part of the 2 700 - 2 900 MHz band allocated on a primary basis to the aeronautical radio-navigation service, meteorological ground based radars, and on a secondary basis to the radiolocation service. This band is now under consideration within ITU as an option to identify additional spectrum for the mobile service (IMT), and will be addressed by WRC-15 under agenda item 1.1. On this particular item, the WMO position opposing to the allocation of the 2700-2900 MHz band to IMT would also serve the needs of the “10.7 cm” solar flux monitoring.

5. Proposed Action (by SG-RFC)

SG-RFC is invited to note the outcome of a preliminary survey of the use of radio-frequencies for ground-based observations of the Sun and the ionosphere in support of space weather activities.

SG-RFC is invited to bear in mind the operational use of the radio-frequency spectrum for space weather when discussing the WMO position for WRC15 and beyond.

6. Draft Text for Inclusion in the SG-RFC Meeting Reports

SG-RFC noted the important use of radio-frequencies for ground-based observations of the Sun and the ionosphere in support of space weather activities. It invited the ICTSW to keep under review the current and planned use of the radio-frequency spectrum for space weather and to keep the SG-RFC informed accordingly. The session agreed to work out an approach with ICTSW towards securing the continued use of frequencies that are essential for operational space weather forecasting.

ANNEX 1: OVERVIEW OF MAIN RADIO-FREQUENCIES USED FOR SPACE WEATHER OBSERVATIONS

Note: The tables below summarize the outcome of a preliminary survey responded by several ICTSW members. They are thought to be a representative indication of the main frequencies used for space weather but do not pretend to be exhaustive.

I. Active ionospheric observations					
Frequency range	Application	T/R	Country	Location	Comments
1-20 MHz	Digital Ionospheric Sounder	T/R	Belgium	Bourbes	http://ionosphere.meteo.be
1-30 MHz	Ionosphere sounder (Ionosonde)	T/R	China 6 CMA sites:	Xinjiang Atushi Fujian Xiamen Shanxi Changan Guangxi Hengxian Qinghai Dulan Hubei Wuhan	Protection: -no radio emission within 1km in these frequencies - no high voltage power line within 100m
1-30 MHz	Ionosphere sounder (Ionosonde)	T/R	Japan	Wakkanai, Japan Kokubunji, Japan Yamagawa, Japan Okinawa, Japan Chiang Mai, Thailand Chumphon, Thailand, Kototabang, Indonesia Bac Lieu, Vietnam Cebu, Philippines Syowa, Antarctic	We have operated ionosondes at four sites in Japan, five sites in the Southeast Asia, and one site in the Antarctic. http://wdc.nict.go.jp/IONO/
1-30 MHz	Ionosonde	T/R	Rep.Korea	RRA Jeju	
2 $\pm$ 0.02 MHz	Middle frequency radar	T/R	China	Shanxi Wuzai	protection
3-30 MHz	Vertical ionosondes (VIS)	T/R	Australia		TX licence and quiet Rx Risk of interference with remote sources http://www.ips.gov.au/HF_Systems/1/3
3 to 100 MHz (?)	Oblique ionosphere sounding (OIS)	T/R	Australia		Extends to “Lower VHF”.
9-16 MHz (TBC)	Ionospheric research radars	T/R	SUPERDARN	Canada,	Super Dual Auroral Radar Network (SUPERDARN) including 20

			consortium of 10 countries.	USA, Iceland, Finland, Japan, Australia, NewZealand, Antarctica	radars in the Northern Hemisphere and 11 in the Southern Hemisphere. (http://vt.superdarn.org/)
9-16 MHz	HF Coherent radar for measuring Doppler velocity in the ionosphere	T/R	Japan	King Salmon, AK, USA	Our HF radar belongs to SuperDARN consortium. Detailed information can be seen in http://vt.superdarn.org/
200-240 MHs	European Incoherent Scatter Radar (EISCAT)	T/R	Norway	Tromso	
500 MHz	European Incoherent Scatter Radar (EISCAT)	T/R	Norway	Svalbard	
449-450 MHz	Advanced Modular Incoherent Scatter Radar (AMISR)	T/R	Canada	Poker Flat	http://amisr.com/amisr/about/amisr-overview/
430-450 MHz	Advanced Modular Incoherent Scatter Radar (AMISR)	T/R	Canada	Resolute Bay	http://amisr.com/amisr/about/amisr-overview/

II. Passive and GNSS ionospheric observations					
Frequency range	Application	T/R	Country	Location	Comments
38.2 MHz	Ionosphere D-Region absorber	R	China	Heilongjiang Mohe Heilongjiang Jia Musi Beijing Lingsan Hainan Tunchan	Protection: -no radio emission within 1km in these frequencies - no high voltage power line within 100m
1100-1600 MHz	GNSS receivers	R	Australia		See the GNSS frequencies: http://www.positim.com/gnss_freqs.jpg
1100 to 1600 MHz mainly 1.22-1.57 GHz	GNSS ionospheric monitoring	R	Belgium	ROB, Brussels for an European network	http://gnss.be
1100 to 1600 MHz mainly 1.22-1.57 GHz	GNSS ionospheric monitoring	R	Japan	More than 1200 stations in Japan	GNSS-TEC maps have been produced using a dense GNSS receiver network, GEONET, operated by GSI, Japan. http://seg-web.nict.go.jp/GPS/GEONET/
1227 MHz 1575 MHz	Ionospheric scintillation receiver	R	Rep. Korea	Daejon, Gangneung, Gwangju, Icheon, Jeju	
1227.6 MHz 1246.0 MHz 1575.42 MHz 1603.0 MHz 2491.75 MHz	Ionospheric scintillation receiver	R	China	Guangdong Maoming Guangdong Guangzhou Fujian Xiamen Guangdong Shaoguan Hubei Wuhan	Protection: - no mobile phone base station within 1km - no high voltage power line within 100m

III. Solar Observations (Spectrographs)

Frequency range	Application	T/R	Country	Location	Comments
10-80 MHz	Decameter Array (including HF spectrograph)	R	France	Nançay (47°N, 2°E)	Used for astronomic and solar corona observations http://secchirh.obspm.fr/instruments.php
18-1800 MHz	Solar Radio Spectrograph	R	Australia	Culgoora observatory (Narrabri)	Need quiet environment within at least 30 km, preferably 200-300 km. Risk of interference with aircrafts, ground repeaters, or remote ground sources in case of temperature inversion over sea. http://www.ips.gov.au/Solar/2/2
25-180 MHz	Solar Radio Spectrograph	R	Australia	Learmonth	Same comment as Culgoora http://www.ips.gov.au/Solar/3/2
25-2500 MHZ	Solar Radio Spectrograph (HIRAS)	R	Japan	NICT Hiraiso Observatory	Solar radio burst and solar flare monitoring
30-500 MHz	Solar Radio Spectrograph	R	Rep.Korea	RRA KSWC Jeju	http://www.spaceweather.go.kr/observation/ground/spectrum
30-2500 MHz	Solar Radio Spectrograph	R	Rep.Korea	RRA KSWC Icheon	
45-450 MHz	e-Callisto spectrograph	R	Belgium	Humain	Monitoring solar flares and CMEs http://sidc.oma.be/humain/
20-650 MHz	Solar Radio Spectrograph (ARTEMIS)	R	Greece	Thermopyle (38.47°N, 22.41°E)	http://secchirh.obspm.fr/instruments.php
70 MHz -9.0 GHz	Solar radio spectrograph	R	Japan	Yamagawa radio observation facility	Solar radio burst and solar flare monitoring In test phase. Routine operation will start in 2016.
130-1000 MHz	Solar Radio Spectrograph (ORFEES)	R	France	Nançay	
300-3000 MHz	Solar Radio Spectrograph	R	Belgium	Humain	In commissioning http://sidc.be/humain

IV. Solar Observations (Discrete frequencies)					
Frequency range	Application	T/R	Country	Location	Comments
150-450 MHz (specifically 150, 236, 327, 410 and 432 MHz)	Radio Heliograph	R	France	Nançay (47°N, 2°E)	http://secchirh.obspm.fr/instruments.php Solar 2D and 1D images at selected frequencies
245 MHz – 15.4 GHz (specifically 245, 410, 610, 1415, 2695, 4995, 8800, 15400 MHz)	Solar radio flux monitoring	R	Australia	Learmonth	http://www.ips.gov.au/Solar/3/4 Solar Electro-Optical Network (SEON)
245 MHz – 15.4 GHz (specifically 245, 410, 610, 1415, 2695, 4995, 8800, 15400 MHz)	Solar radio flux monitoring	R	USA	Sagamore Hill, Mass.	Solar Electro-Optical Network (SEON)
245 MHz – 15.4 GHz (specifically 245, 410, 610, 1415, 2695, 4995, 8800, 15400 MHz)	Solar radio flux monitoring	R	USA	Palehua, Hawaï	Solar Electro-Optical Network (SEON)
245 MHz – 15.4 GHz (specifically 245, 410, 610, 1415, 2695, 4995, 8800, 15400 MHz)	Solar radio flux monitoring	R	Italy	San Vito	Solar Electro-Optical Network (SEON)
1400-1427 MHz (*) 1660-1670 MHz (*) 2750-2850 MHz (**) 4.990-5.000 GHz (*) 8.275-8.375 GHz 10.600-10.700 GHz(*)	Solar radio flux monitoring	R	Canada	Dominion Radio Astrophysical Observatory (DRAO) near Penticton, 49.32° N 119°62° W	(*): Radio-astronomy band (**): 10.7 cm solar radio flux. This frequency lies in a band allocated by ITU to the Radiolocation Service (radar) http://www.nrc-cnrc.gc.ca/eng/solutions/facilities/drao.html
1400-1427 MHz (*) 1660-1670 MHz (*) 2750-2850 MHz (**) 4.990-5.000 GHz (*) 8.275-8.375 GHz	Solar radio flux monitoring	R	Belgium	Humain (Planned)	Similar to Canada / DRAO

10.600-10.700 GHz(*)					
2801 ±5% MHz (**) 4542 ±5% MHz 9084 ±5% MHz	Solar radio telescope	R	China	Shandong Shidao	Protection: no radio emission within 1km in these frequencies. (**) 10.7 cm solar radio flux, see above.
2.8 GHz	Solar radio flux monitoring	R	Japan	NICT Hiraiso Observatory	Monitoring 10.7 cm solar radio flux
2.8 GHz	Solar radio flux monitoring	R	Rep. Korea	RRA Icheon	Monitoring 10.7 cm solar radio flux

Annex 2: QUESTION ITU-R 213-3/3

The short-term forecasting of operational parameters for trans-ionospheric radiocommunication and radionavigation services

(1978-1990-1993-2000-2000-2009-2012)

The ITU Radiocommunication Assembly,

considering

a) that accurate, quantitative short-term forecasting of space weather related ionospheric variations a few hours or days in advance would increase the reliability of radiocommunication and radionavigation-satellite services including safety related applications;

b) that, in addition to the widespread disturbances associated with major geophysical or space weather events (including ionospheric or geomagnetic storms) that affect the total electron content (TEC), the spatial and temporal gradients of TEC and the occurrence of ionospheric scintillations, there are other hour-to-hour and day-to-day ionospheric variations (which may be local in influence);

c) that space weather data products addressing trans-ionospheric radiocommunications and radionavigation services exist,

decides that the following Questions should be studied

1 What are the needs and techniques for the short-term forecasting of operational parameters for trans-ionospheric radiocommunications and radionavigation services?

2 How useful are the established techniques of ground based and space-based space weather monitoring for short-term forecasting of trans-ionospheric propagation conditions?

3 What is the status of standardization of space weather data products for trans-ionospheric radiocommunications and radionavigation services?

further decides

1 that the results of the above studies should be included in one or more Recommendations and/or Reports;

2 that the above studies should be completed by 2015.

Category: S3