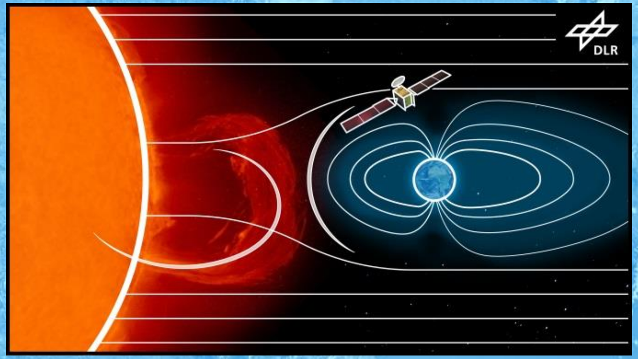


CONSEQUENCES OF TRANSIENT SOLAR EVENTS FOR OUR TECHNOLOGICAL INFRASTRUCTURE AND OBSERVATIONAL REQUIREMENTS TO MITIGATE THEIR IMPACT

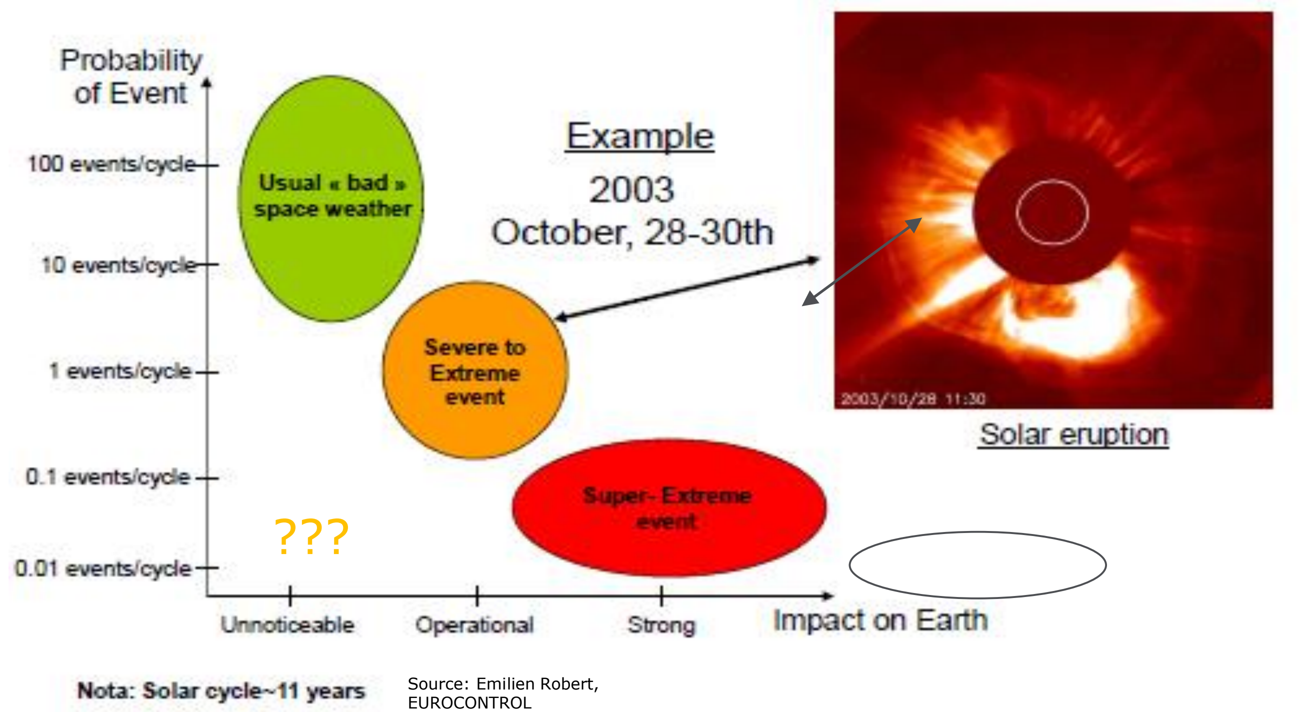
Jens Berdermann , Daniela Banys

German Aerospace Center

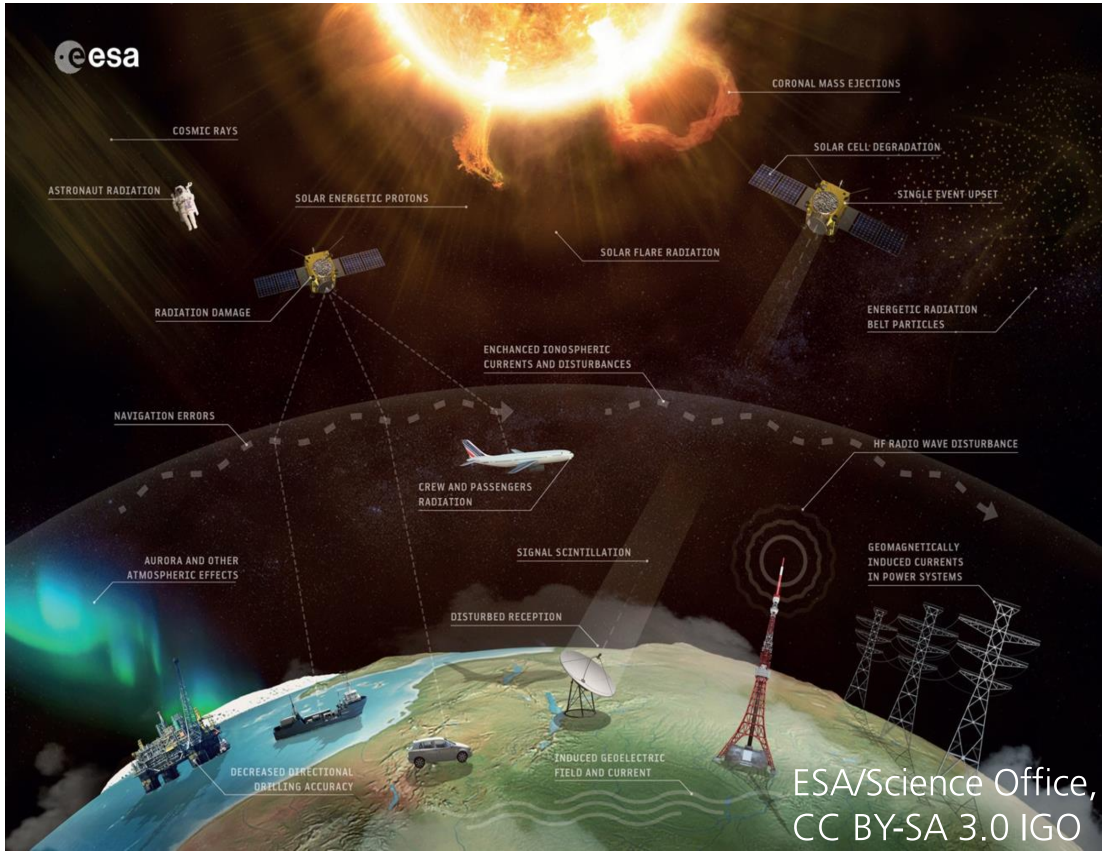
Institute for Solar-Terrestrial Physics

DLR

Probability of the occurence of solar treansient events



Source: Emilien Robert, EUROCONTROL



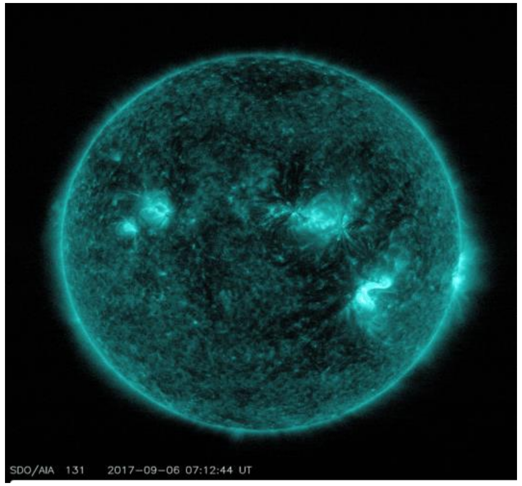
In the following we will discuss the following transient events with effects on critical infrastructure

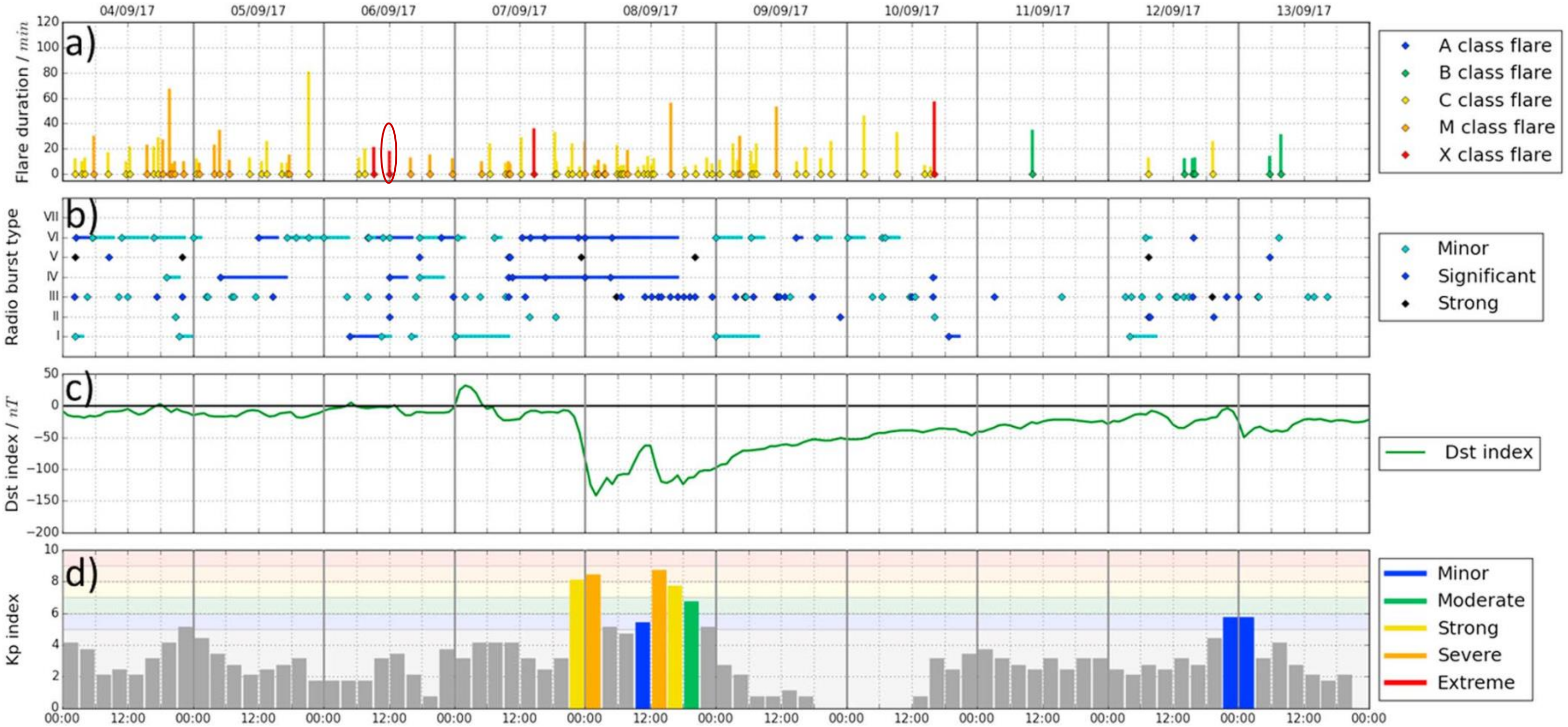
- Flares
- Radio Bursts
- Coronal mass ejections

Space Weather Impact on GNSS – Solar Flare

Space Weather Event 06/09/2017 (Solar Flare X9.3, Ranking 14)

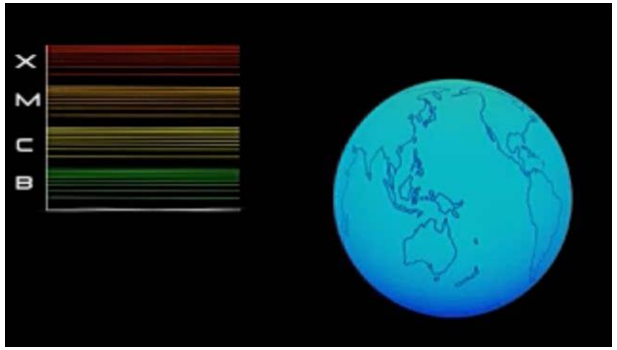
Catania group 46 (NOAA active region 2673) region: a complex structure causing SW transients for days

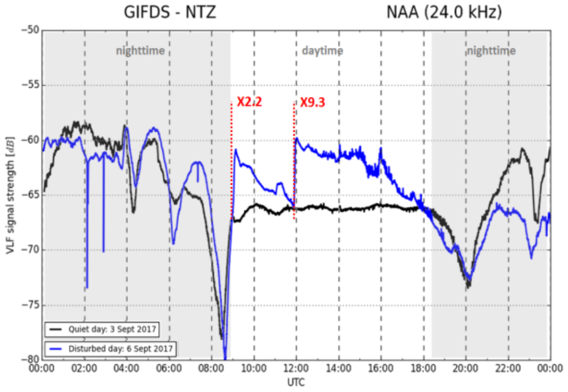


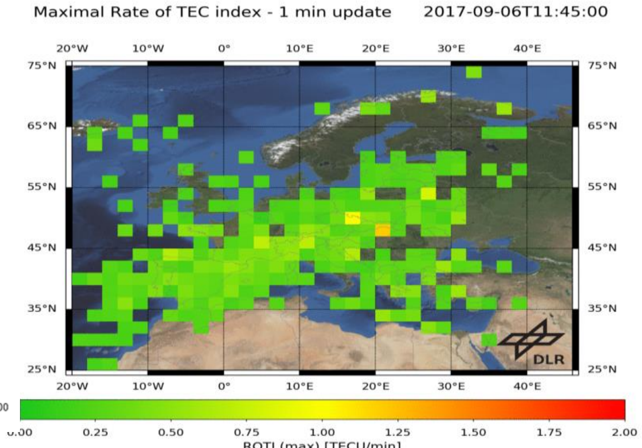


Classification in X-ray region:

A - class:	$< 10^{-7}$ Wm^{-2}
B - class:	$10^{-7} - 10^{-6}$ Wm^{-2}
C - class:	$10^{-6} - 10^{-5}$ Wm^{-2}
M - class:	$10^{-5} - 10^{-4}$ Wm^{-2}
X - class:	$> 10^{-4}$ Wm^{-2}



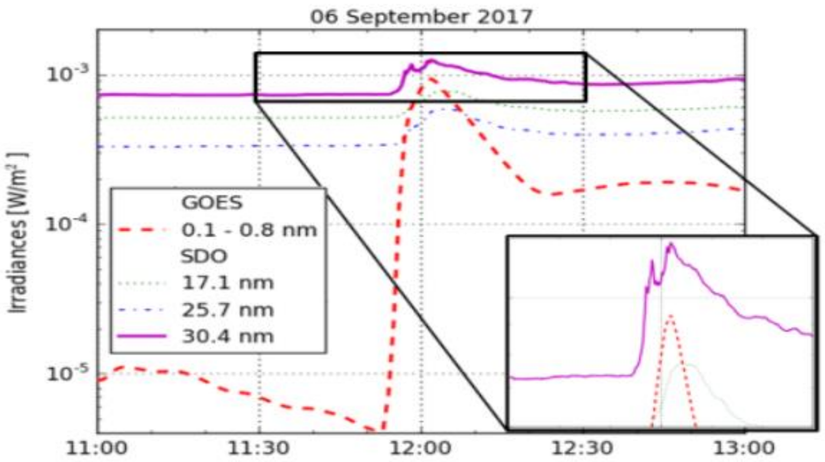




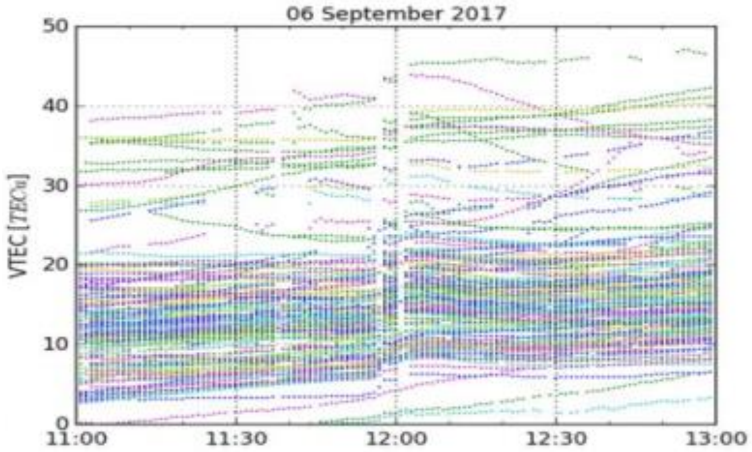
Space Weather Impact on GNSS – Solar Flare

Source: X9.3 Solar Flare on 6th September 2017
Region: Earth Day Side
Duration: Minutes
Impact: Solar flares with a strong EUV component around 30 nm can seriously affect GNSS positioning services used in e.g. aviation , maritime navigation. All the GNSS satellite systems in view were affected in a similar way, including GPS, GLONASS and Galileo.

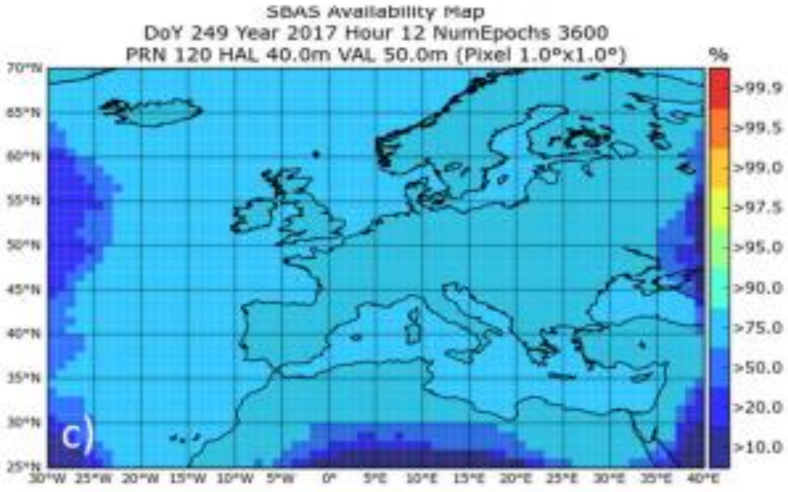
Berdermann, J., Kriegel, M., Banys, D., Heymann, F., Hoque, M. M., Wilken, V., et al. (2018). ***Ionospheric response to the X9.3 Flare on 6 September 2017 and its implication for navigation services over Europe****. Space Weather, 16. https://doi.org/10.1029/2018SW001933*



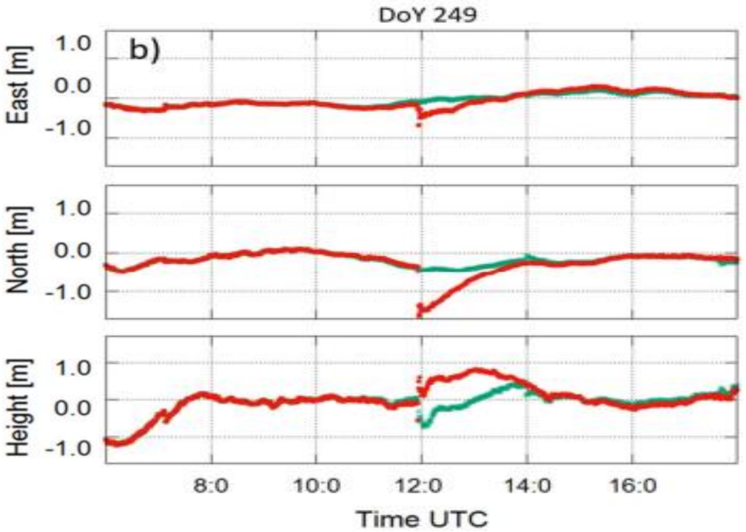
Loss of Lock



EGNOS

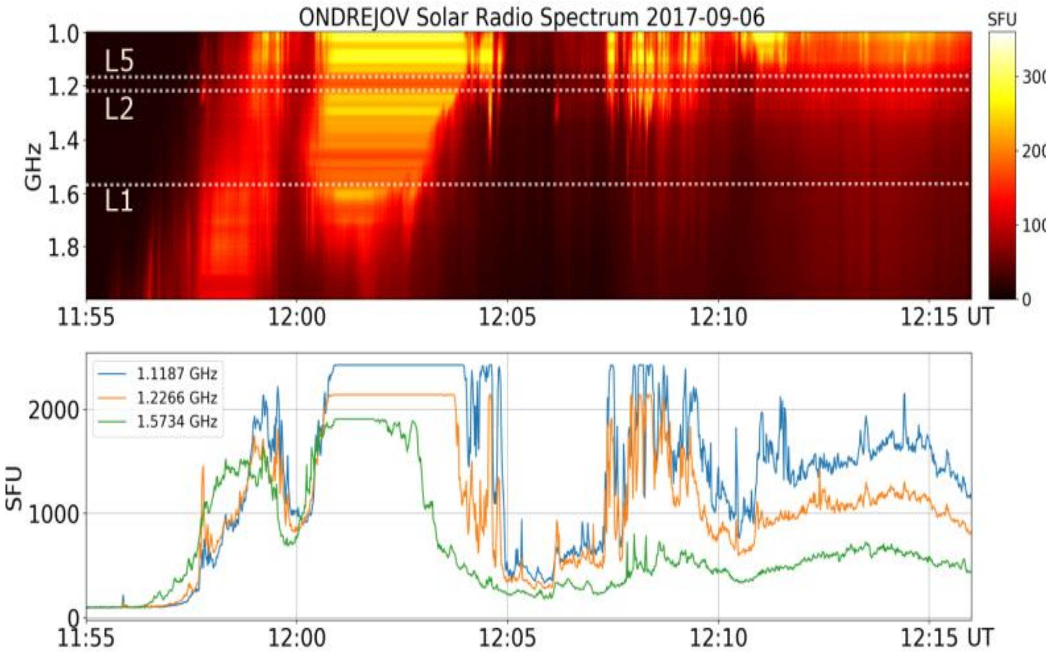


Precise Point Positioning

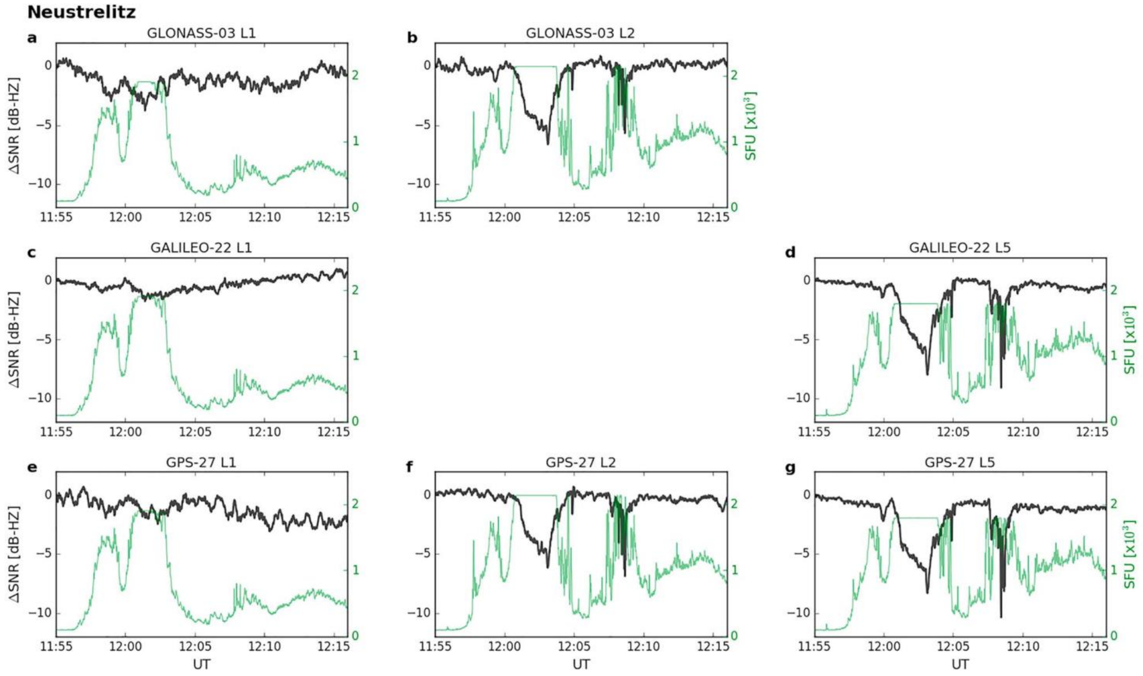


Space Weather Impact on GNSS – Radio Burst

Solar radio observation on the 6 September 2017



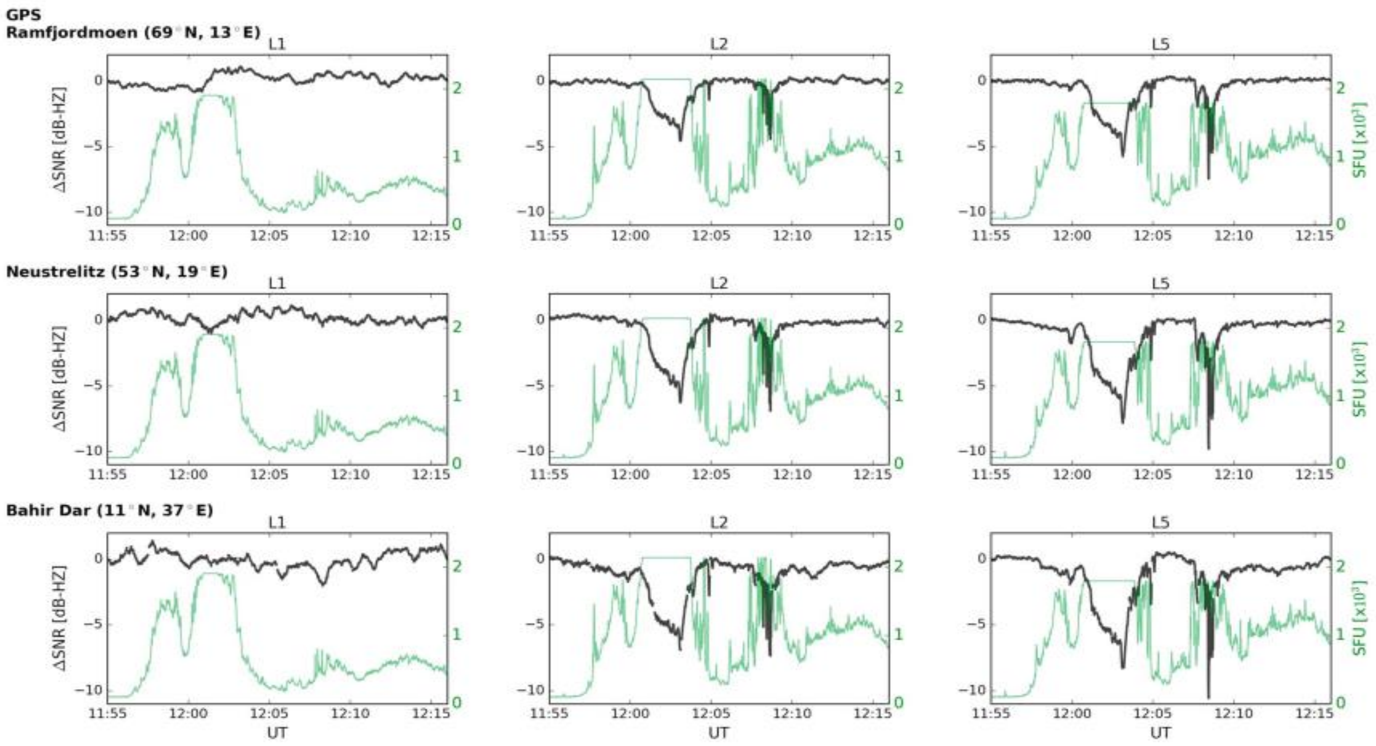
Ondrejov solar radio spectrum in the 1.0- to 2.0-GHz range (top). Ondrejov solar radio flux intensity near the GPS frequencies (bottom)



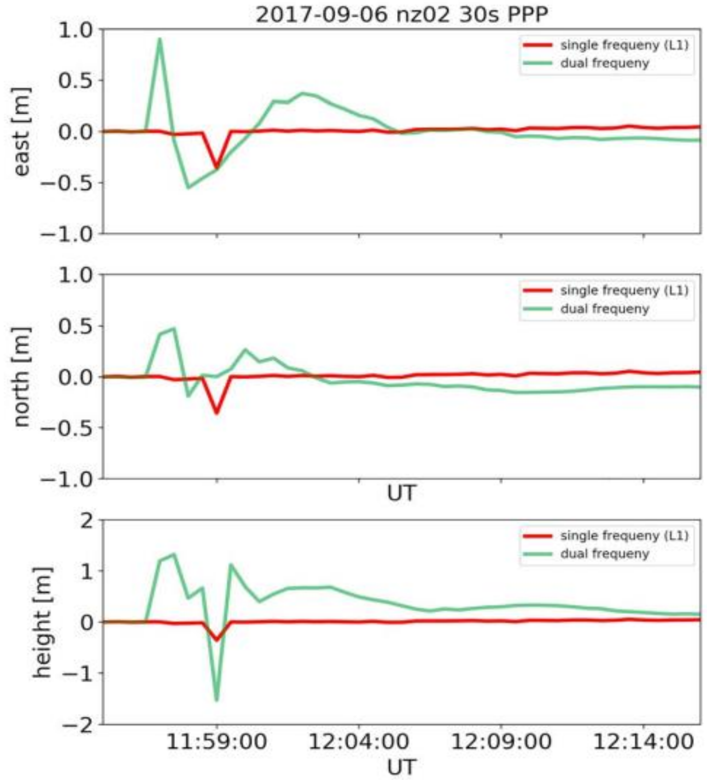
Signal to noise ratio for different GNSS frequencies and systems measured at the Neustrelitz EVNet station.

*Sato, H. , Jakowski, N. , Berdermann , J. , Jiricka, K., Heßelbarth, A. , Banyś, D. , Wilken V. (2018), **Solar Radio Burst Events on 6 September 2017 and Its Impact on GNSS Signal Frequencies**. Space Weather, 16. https://doi.org/10.1029/2018SW001933*

Space Weather Impact on GNSS – Radio Burst



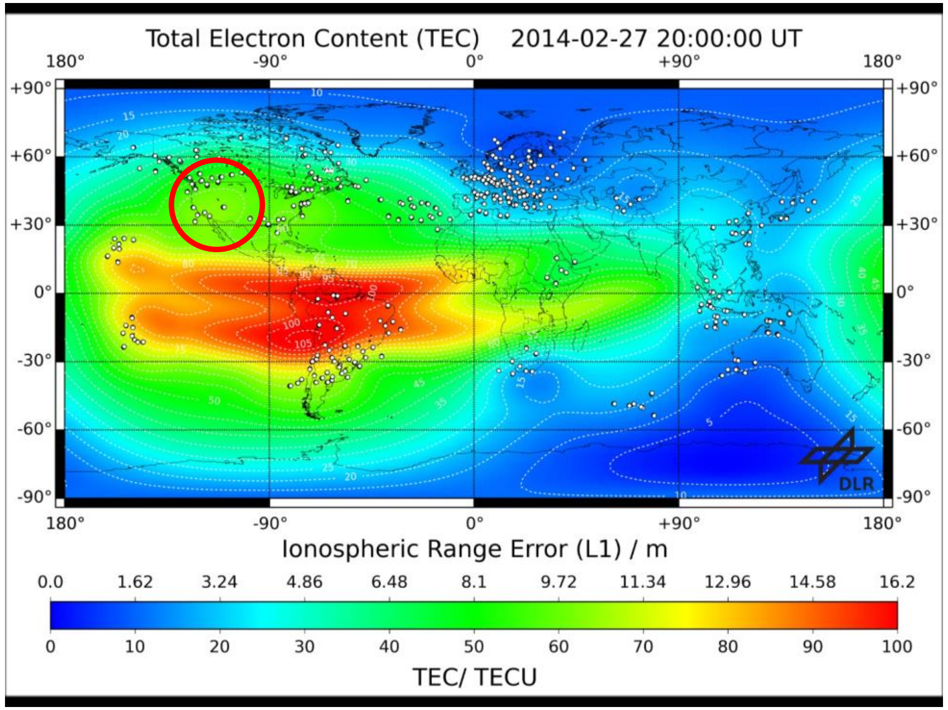
Precise Point Positioning

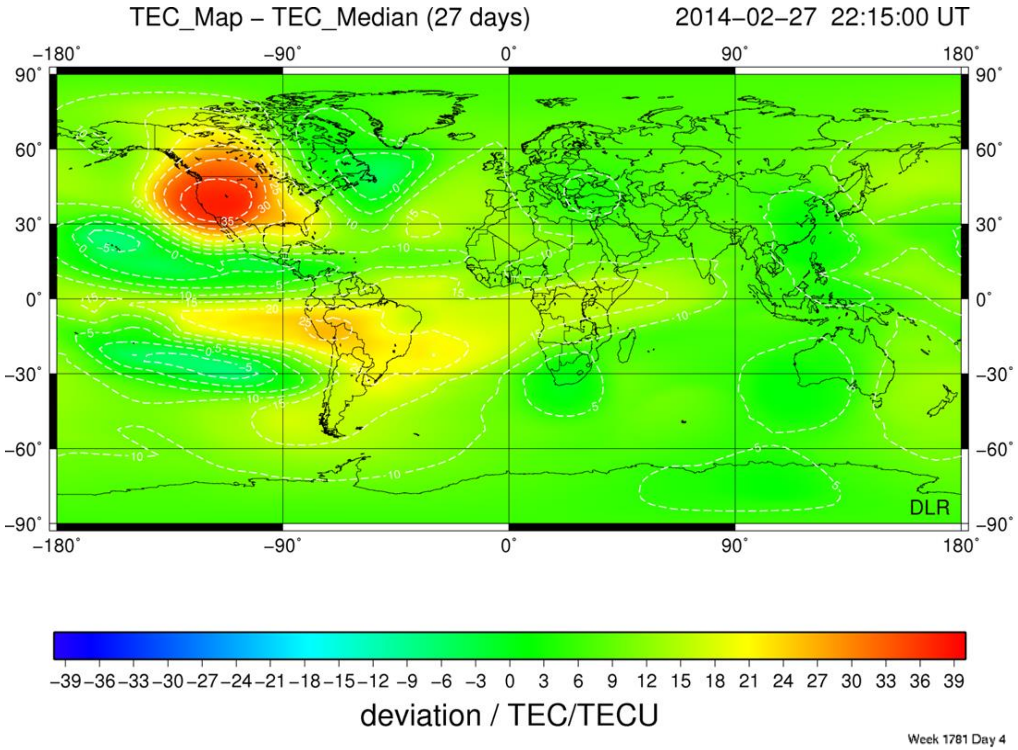


Source: Solar Radio Burst on 6th September 2017
Region: Earth Day Side
Duration: Minutes
Impact: The solar radio pulsation caused larger SNR reduction for GPS L2/L5 and GALILEO L5 frequencies. All the GNSS satellite systems in view were affected in a similar way, including GPS, GLONASS and Galileo.

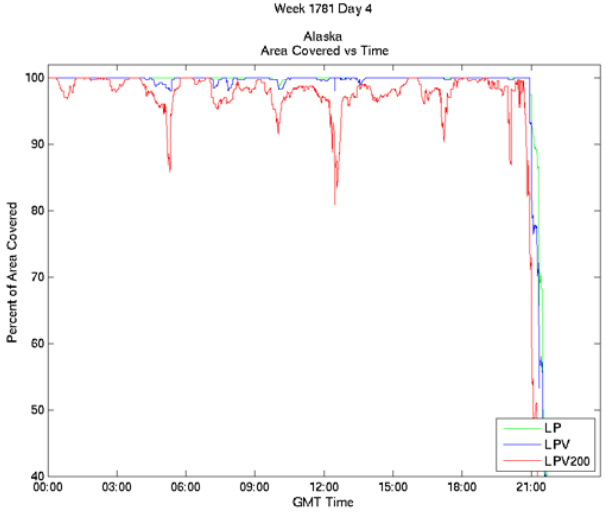
Sato, H. , Jakowski, N. , Berdermann , J. , Jiricka, K., Heßelbarth, A. , Banyś, D. , Wilken V. (2018), ***Solar Radio Burst Events on 6 September 2017 and Its Impact on GNSS Signal Frequencies****. Space Weather, 16. https://doi.org/10.1029/2018SW001933*

Space Weather Impact on GNSS – Ionospheric Storm



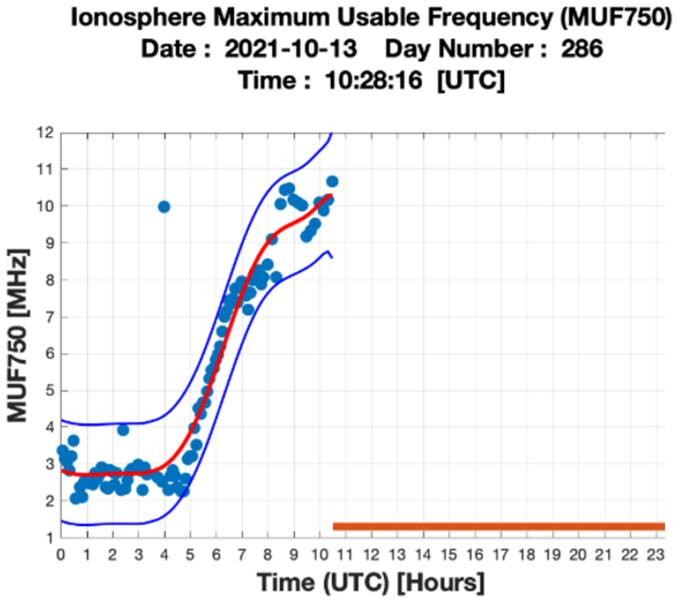


Source: Ionospheric storm on 27.02.2014
Region: North America
Duration: ca. 3h
Impact: Outages of SBAS due to storm induced Ionospheric Disturbances
No LPV availability of WAAS over Alaska on 27th February 2014.
(**L**ocalizer **P**erformance with **V**ertical Guidance)



Space Weather impact on communication

- Weakening, interference or loss of signal from RF communication
- Degraded condition of the radio wave propagation of the Air Traffic Control



The blue dots represent the MUF_{750} calculations based on observations from the digital ionosonde in Juliu

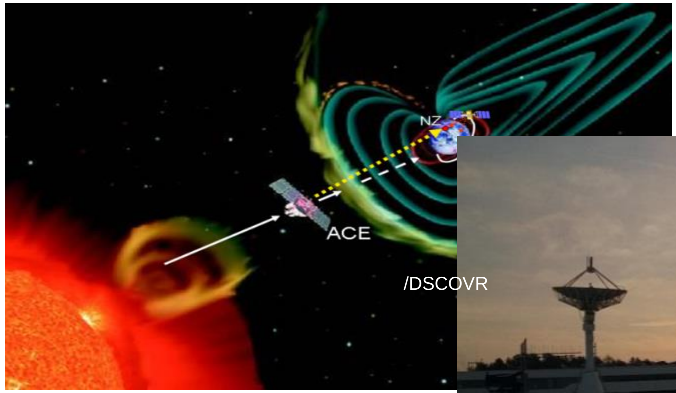
The red graph represents the running polynomial one-hour forecast estimate of MUF_{750}. The blue curves are the 90% statistical prediction intervals, and the orange intervals (if any) in the bottom of the plot show periods of no measurements.

Current Alarm State

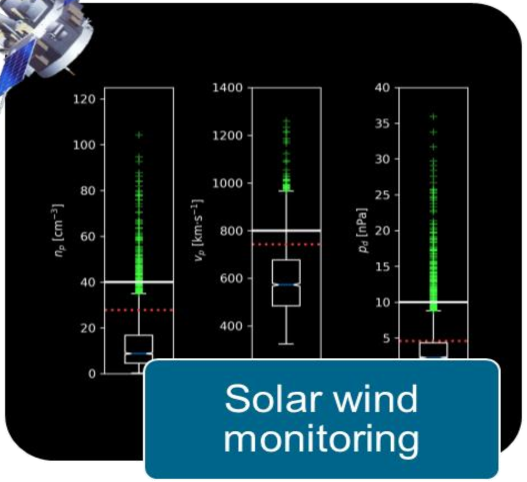
```
Message: << WARNING conditions - (Level 2) >>

Date: 2021-10-13
Day Number: 286
Time: 10:28:16 UTC

Fluctuating conditions for MUF
-> Increasing future MUF

The running estimate of MUF:          10.3 MHz
The 3-hour MUF forecast:              10.9 MHz
The MUF data spread:                   1.7 MHz (large)

The 3-hour mean of MUF:                9.4 MHz
The 3-hour standard deviation of MUF:  0.5 MHz
```

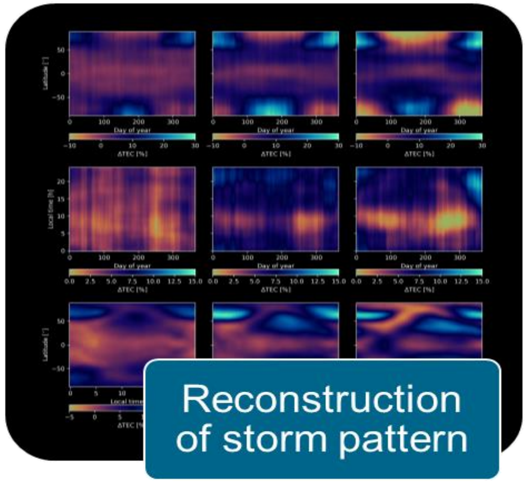
- The Maximum Usable Frequency for slip-distances of 750 km (MUF750) is the highest frequency that permits acceptable operation of a HF radio-communication service. *ESA SSA/S2P Demonstration Product MUF750km alarm (I.139) from the Ionosonde Station in Juliusruh (Leibniz Institute of Atmospheric Physics) provided via the IMPC of DLR.*

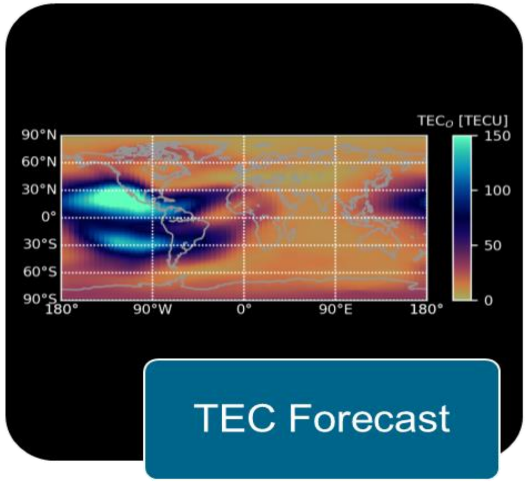
Conclusion: Reliable space weather information and forecasts at the earliest possible time are needed



DLR is a **member of the Real Time Solar Wind (RTSW) observation network** involved in the data transfer and the analysis of NASA's Advanced Composition Explorer (ACE) and the Deep Space Climate Observatory (DSCOVR) satellite



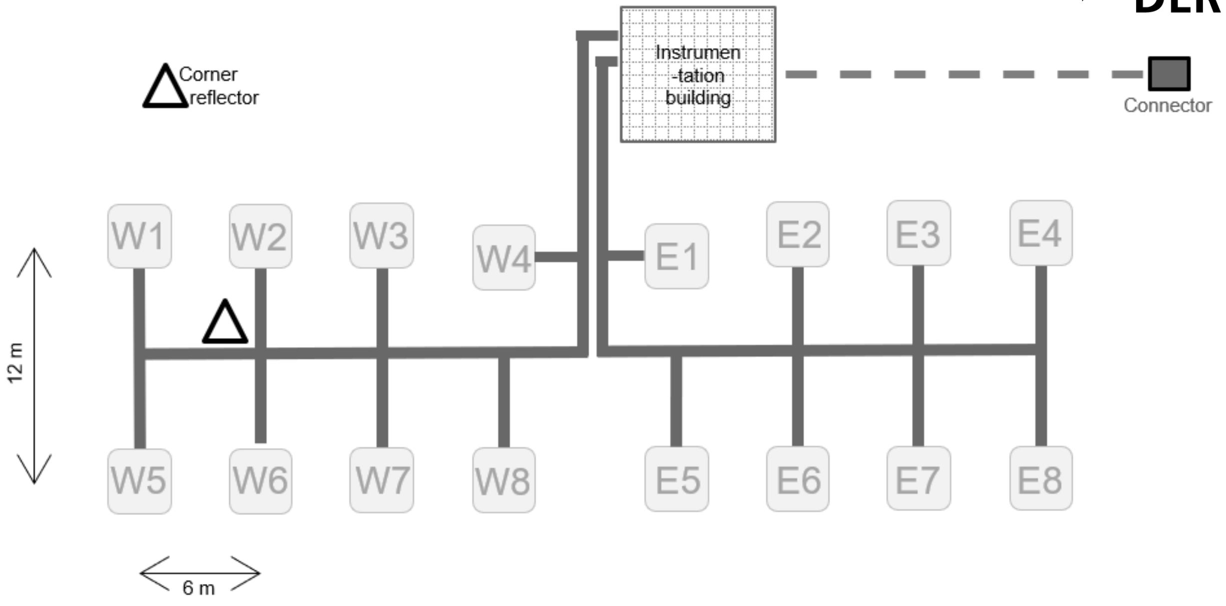




- 24h forecast with high temporal and spatial resolution
- Database of ~600 geomagnetic storm events covering 2 SCs
- Assimilation with real-time TEC data

MIRA Multi-Instrument Ionospheric Radio Array

- Measurement field for various passive instruments (10 kHz - 2 GHz)
- Verification of instruments before export as well as long-term measurements of various ionospheric and solar disturbances



Instruments

GNSS receiver + Bitgrabber, Beacon receiver, GIFDS VLF receiver, CALLISTO solar spectrometer (HF/VHF-, VHF/UHF-, L-Band)

CALLISTO HF/VHF

CALLISTO VHF/UHF

CALLISTO L-Band

GIFDS

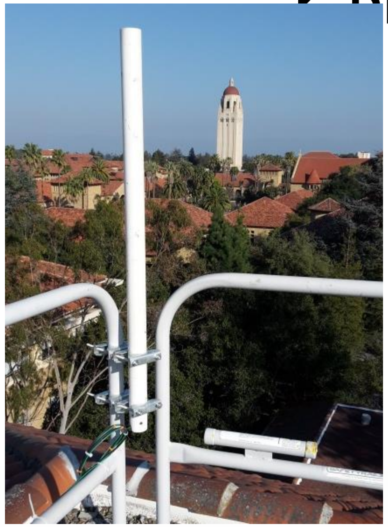
GNSS

Beacon

MIRA

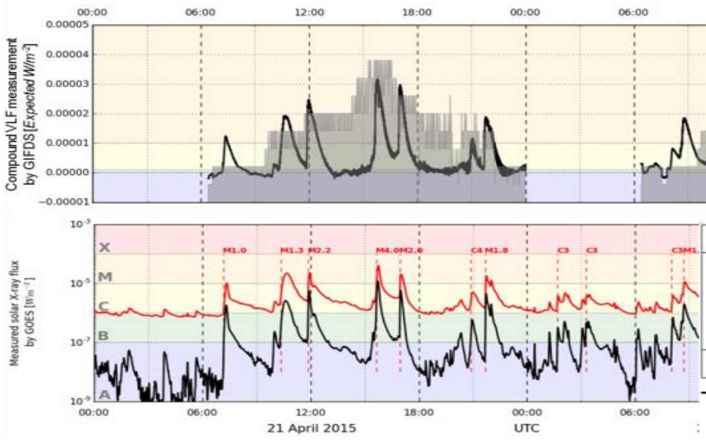
GIFDS: Global Ionospheric Flare Detection System

- Solar flares can disturb communications as well as navigation signals.
- DLR operates a network of Very Low Frequency (VLF< 100KHz) receiving stations distributed around the globe.
- GIFDS has great potential to warn users in case extreme flares with a delay of less than 1 minute



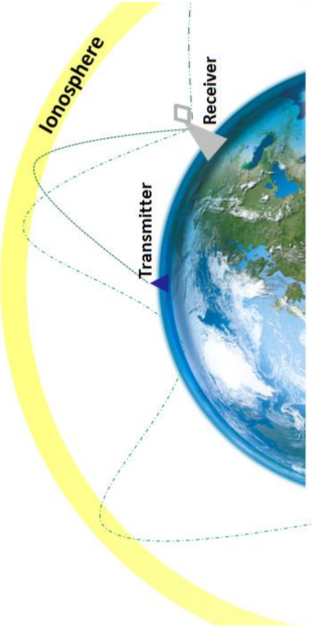
GIFDS receiving sites:

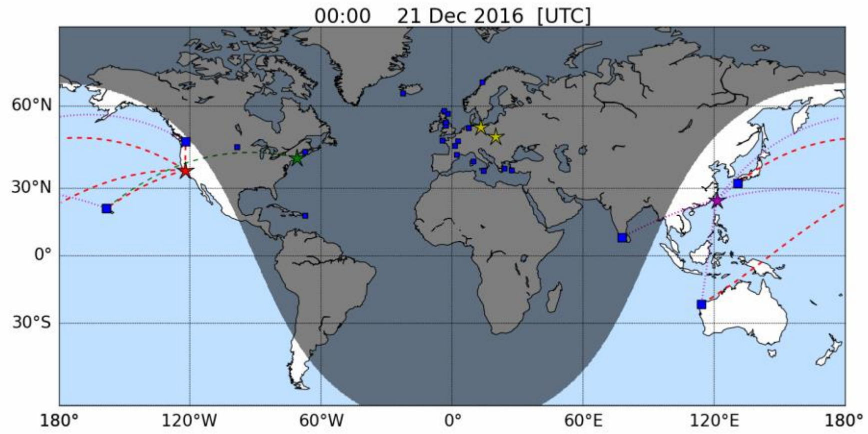
– DLR Neustrelitz, Boston College, PAN Krakow, Stanford University, NCU Taiwan, SANSA, Fortaleza



Date	GOES Time [UTC]	GOES Size	GIFDS Time [UTC]	GIFDS Size
21-04-15	07:11:00	M1.0	07:12:00	$1.2 \cdot 10^{-5}$
	10:20:00	M1.3	10:22:00	$1.9 \cdot 10^{-5}$
	11:52:00	M2.2	11:52:30	$2.4 \cdot 10^{-5}$
	15:38:00	**M4.0**	**15:38:10**	$\mathbf{3.2 \cdot 10^{-5}}$
	16:58:00	M2.0	16:58:30	$2.9 \cdot 10^{-5}$
	20:53:00	C4.9	20:56:00	$1.1 \cdot 10^{-5}$
	21:42:00	M1.8	21:43:00	$1.9 \cdot 10^{-5}$
22-04-15	08:01:00	C3.8	08:04:00	$8.1 \cdot 10^{-6}$
	08:40:00	M1.0	08:41:00	$1.8 \cdot 10^{-5}$

→ correlation coeffcient: 0.91





*D. Wenzel, N. Jakowski, J. Berdermann, Chr. Mayer, C. Valladares, B. Heber, "**Global Ionospheric Flare Detection System (GIFDS)**", : Journal of Atmospheric and Solar-Terrestrial Physics (2016), pp. 233-242 DOI information: 10.1016/j.jastp.2015.12.011.*

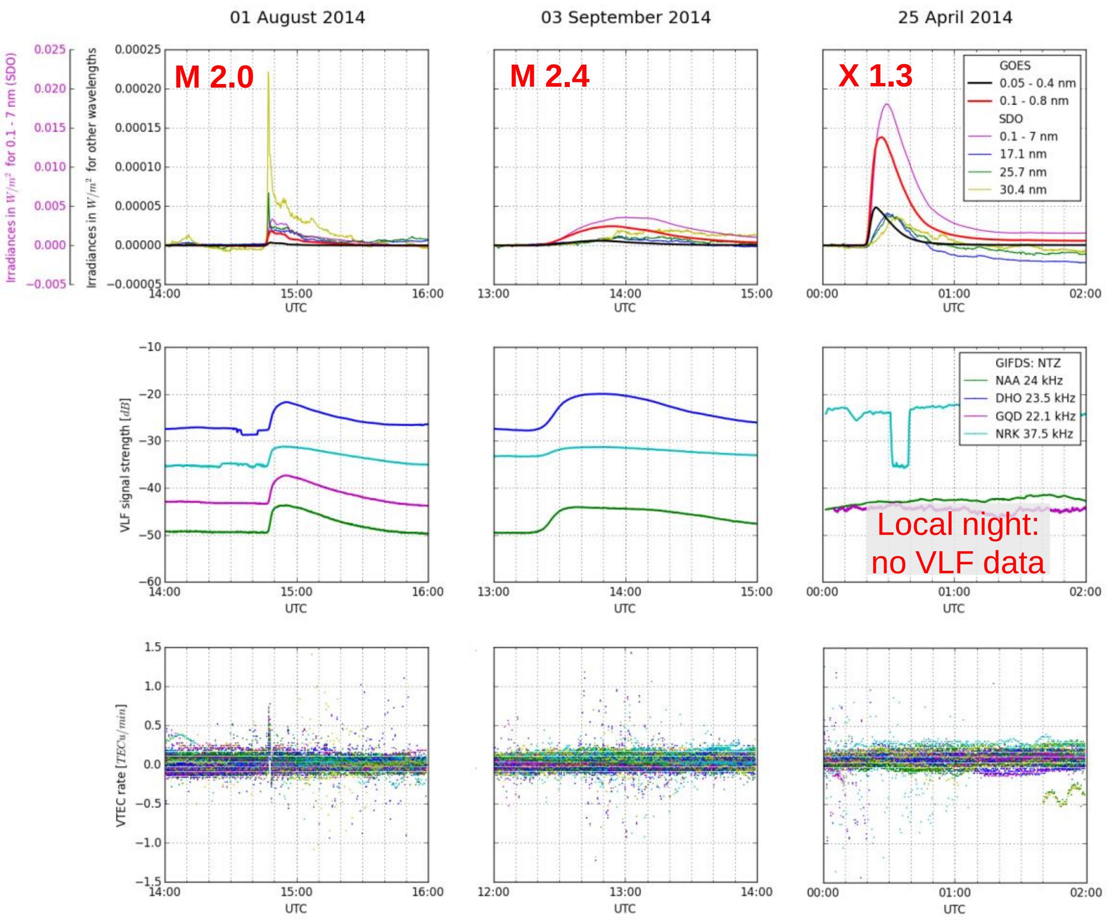
GIFDS: Global Ionospheric Flare Detection System

Solar radiation bursts at EUV and X-ray wave lengths can lead to a considerably increased plasma density in the ionosphere.

- X-ray (red) primarily affects HF
- EUV (yellow) mainly influences GNSS

X-ray scales have only limited information for GNSS users
- Even strong X-ray flare may have weak EUV component (see X 1.3 on the right)
- False alarms are possible

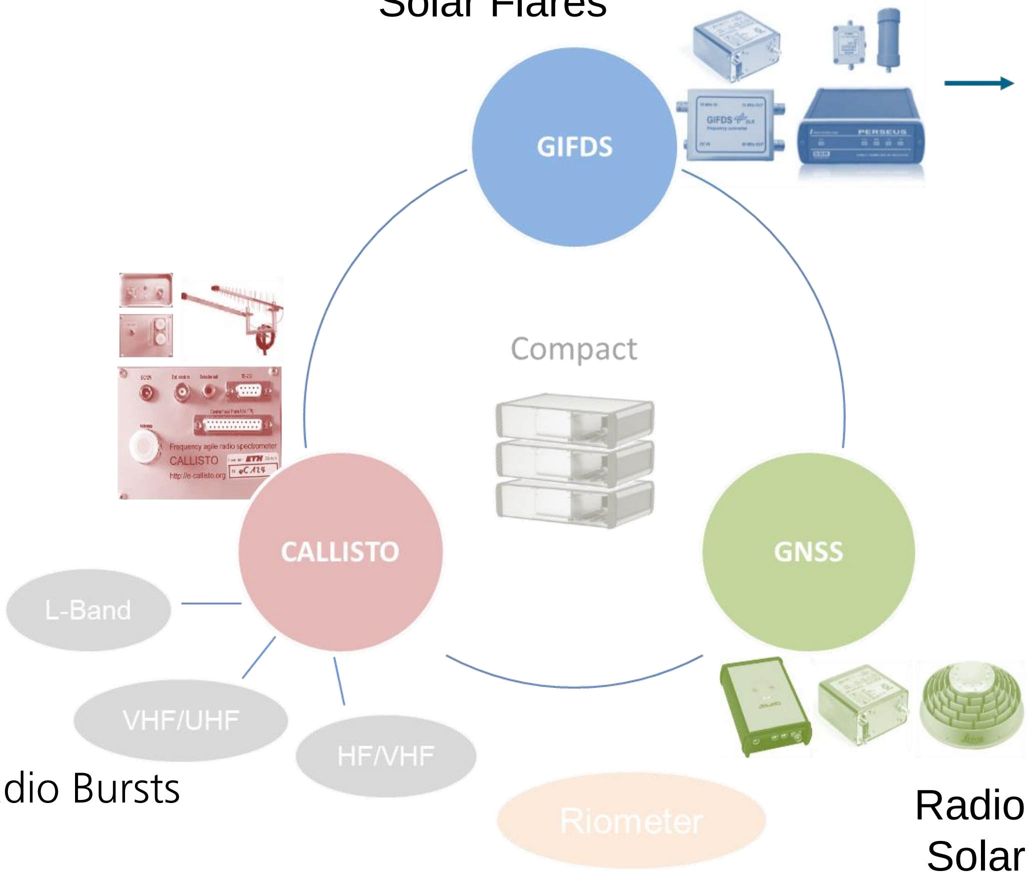
Combination of GIFDS and TEC rate information can help to derive user-specific warnings of flares

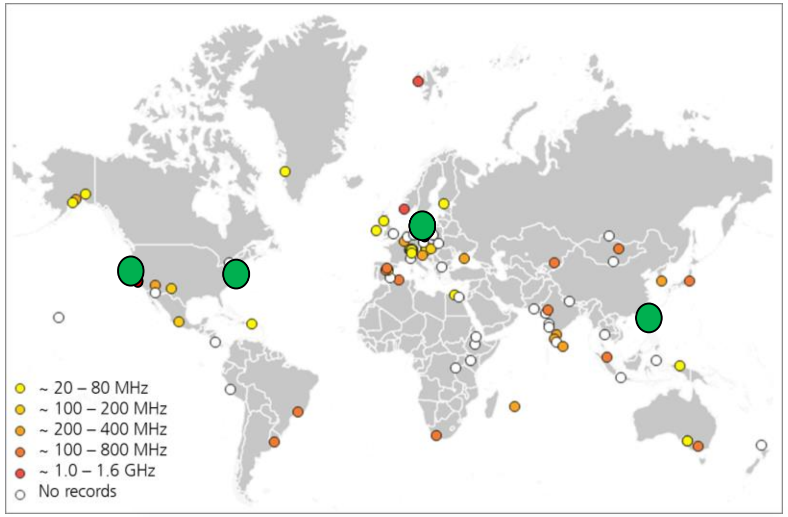


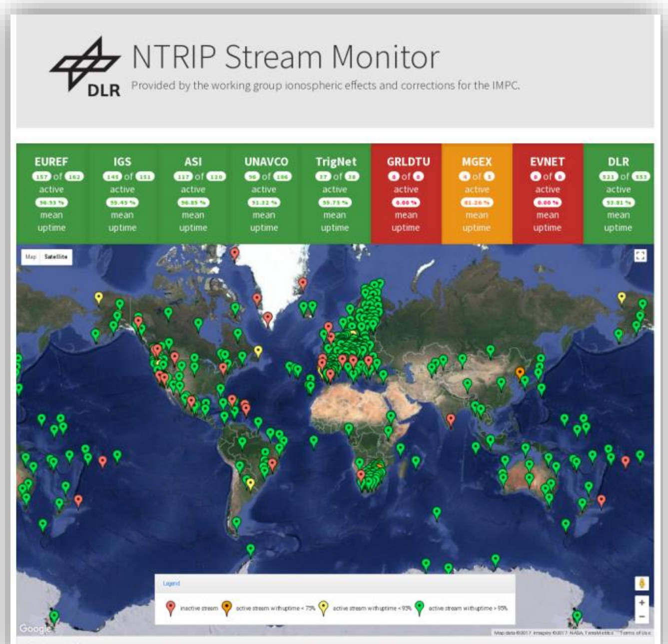
SIGN Solar-Ionospheric Global Network

Development and construction of a compact space weather station for research and real-time assessment of the space weather situation.

Solar Flares



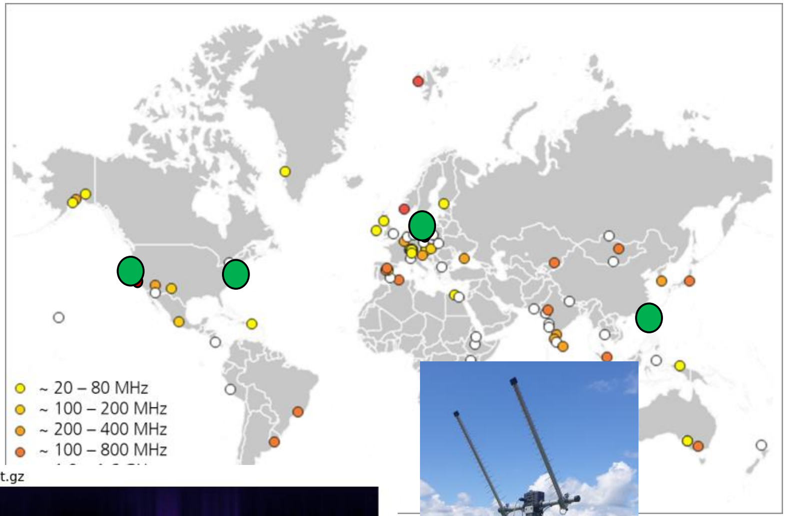




Radio Bursts

Radio Bursts, Solar Flares,
Solar Storm

SIGN Solar-Ionospheric Global Network



Objectives
Monitoring radio frequency interferences and solar radio bursts
Extension of the e-Callisto network in collaboration with ISWI

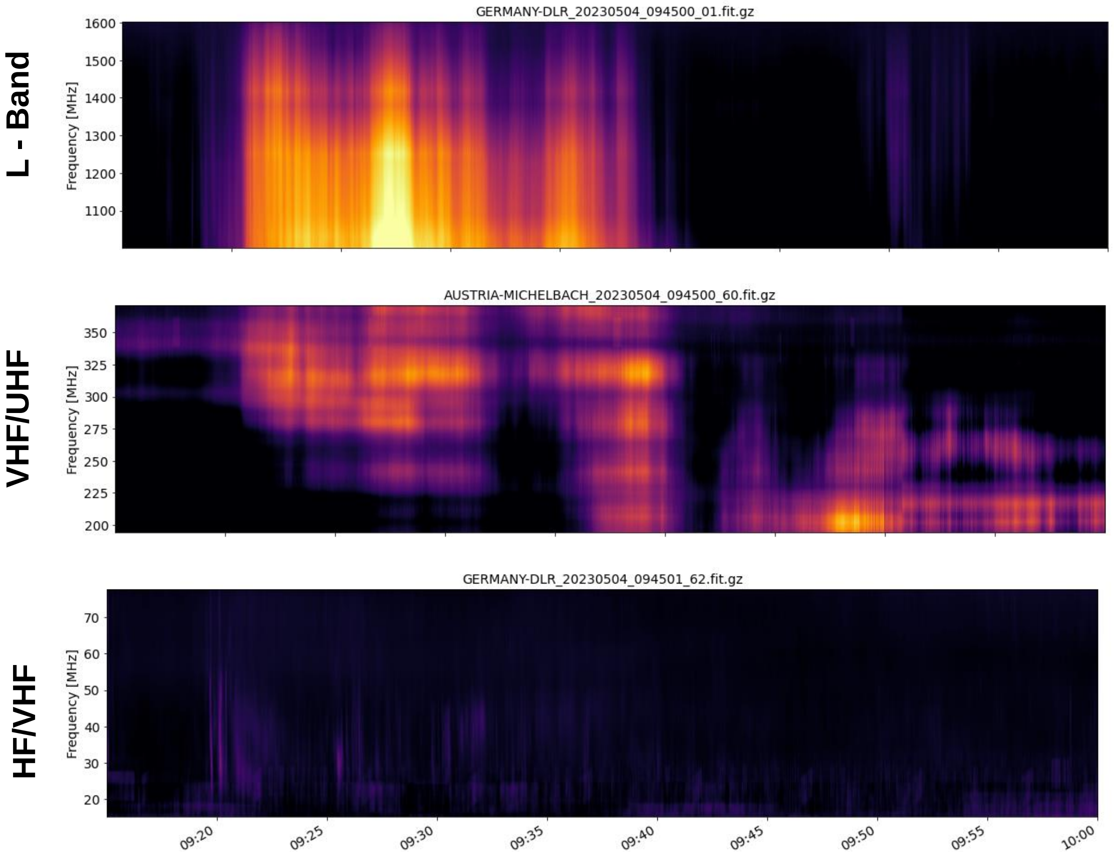
4 full CALLISTO/SIGN sites planned

L-Band spectrum: 1 – 1.6 GHz
- LPDA antenna of 1m lengthinstalled in 1.5m height

VHF/UHF spectrum: 100 – 870 MHz
- LPDA antenne of 2m length installed in 1.5m height

HF/VHF spectrum: 20 – 80 MHz
- LWA/DMA antenna of 2 m height

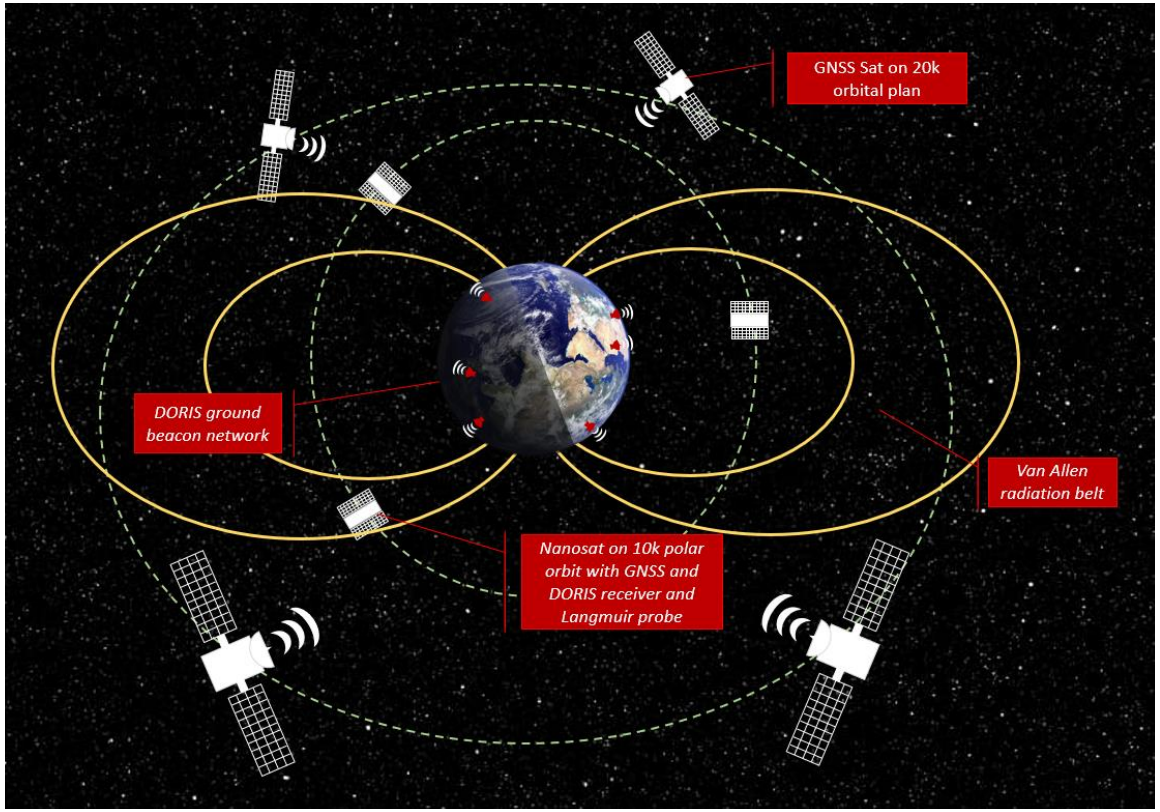
Radio bursts on 28 March 2022



Plasmasphere Monitoring for Space Weather Impact Prediction (PM4SWIP) – ESA Concept Study

- Next to important deep space missions like SWFO, IMAP (L1) or VIRGIL (L5) also LEO and MEO observations are important
- **The plasmasphere is a central source of information in respect to the geo-effectivity of solar storms** and not well investigated until now.

- **A satellite constellation of 3 CubeSats orbiting at high inclination Polar orbits of about 6,000 km altitude** is proposed for monitoring the plasmasphere
- Each CubeSat will host
  - **DORIS Beacon receiver** (400 MHz and 2 GHz)
  - **GNSS receiver**
  - **Langmuir probe** (Spherical EUV and Plasma Spectrometer – SEPS-) for in-situ electron density and EUV measurements.
- Combined GNSS and DORIS line of sight measurements and in-situ Langmuir probes measurements will be used for **monitoring plasmasphere variation and detecting the plasmapause location.**



A satellite constellation of 3 CubeSats orbiting at high inclination Polar orbits of about 6,000 km altitude

Thank you!


Artist: Dmytro Vasylyev

The DLR Institute of Solar-Terrestrial Physics provides scientific and technological foundations for timely, accurate, and reliable observations and predictions of space weather (https://impc.dlr.de/).

Contact:
Jens Berdermann
Institute for Solar-Terrestrial Physics

Jens.Berdermann@dlr.de
+49 3981 480 106