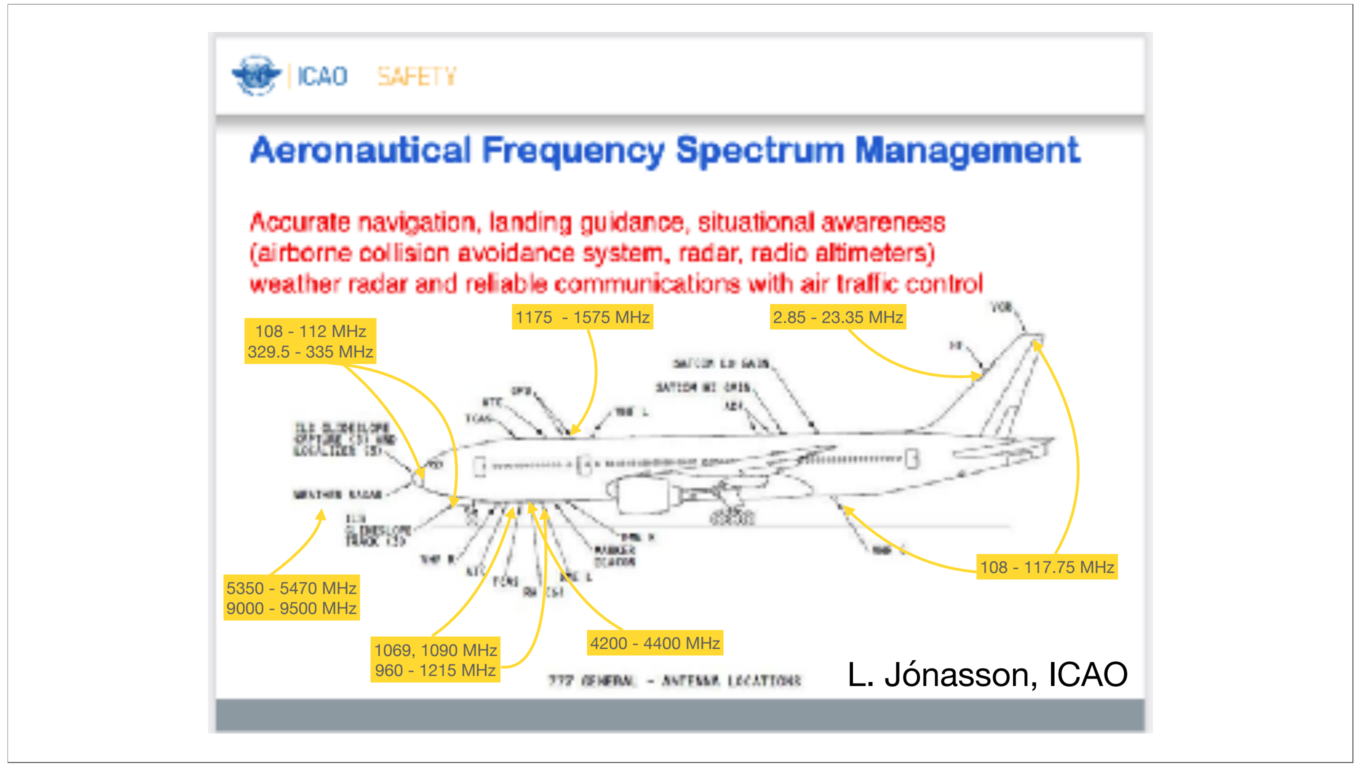
Solar radio bursts impacts on aviation

Christophe Marqué



ILS: Instrument Landing System (108 - 112 MHz, 329.5 - 335 MHz)
TCAS : Traffic Collision Avoidance System (1090 MHz)
DME: Distance Measuring Equipment (960 - 1215 MHz)
RA: Radar Altimeter (4200 - 4400 MHz)
GNSS: 1175 - 1575 MHz
VHF .. VOR VHF Omnidirectionnal range (108 - 117.75 MHz), short range positioning (with ground based network)
ATC 1030, 1090 MHz
SATCOM data + voice between plane ATC, airline communication outside coverage, eg. Inmarsat 1626 - 1660, 1525-1559 MHz


THE CONVERSATION
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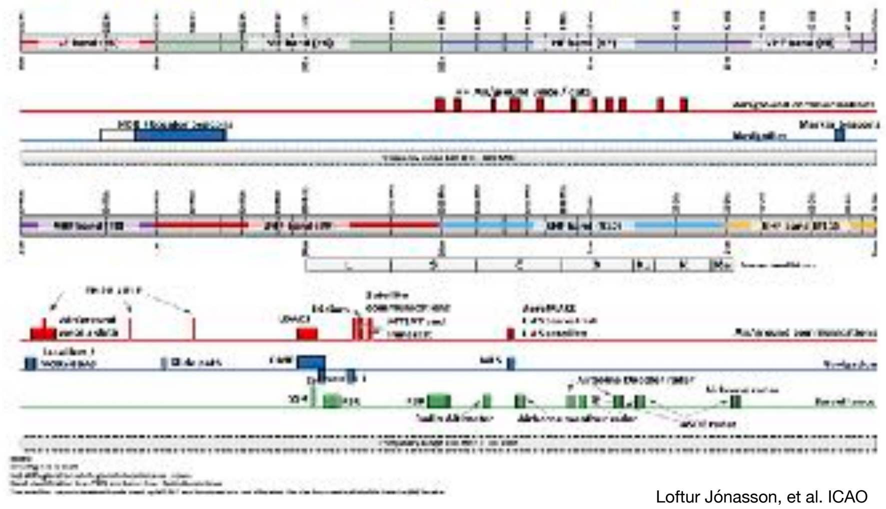
How 5G puts airplanes at risk – an electrical engineer explains
New high-speed cellphone services have raised concerns of interference with aircraft operations, particularly as aircraft are landing at airports. The Federal Aviation Administration has assured Americans that most commercial aircraft are safe, and AT&T and Verizon have agreed to hold off on installing their new cellphone antennas near airports for six months. But the problem has not been

ICAO RECONNECTINGTHEWORLD

Vol. I – Overview of spectrum for aviation



Loftur Jónasson, et al. ICAO

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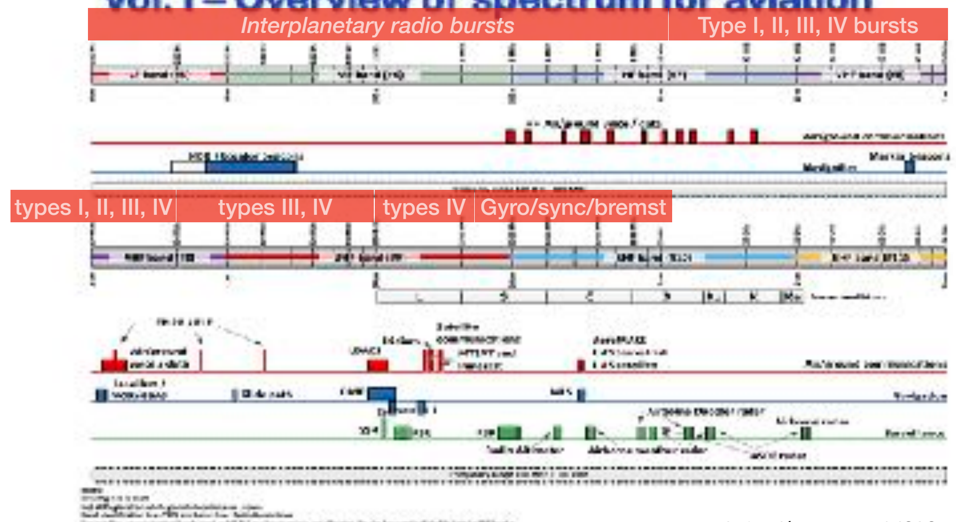
RECONNECTINGTHEWORLD

Vol. I – Overview of spectrum for aviation



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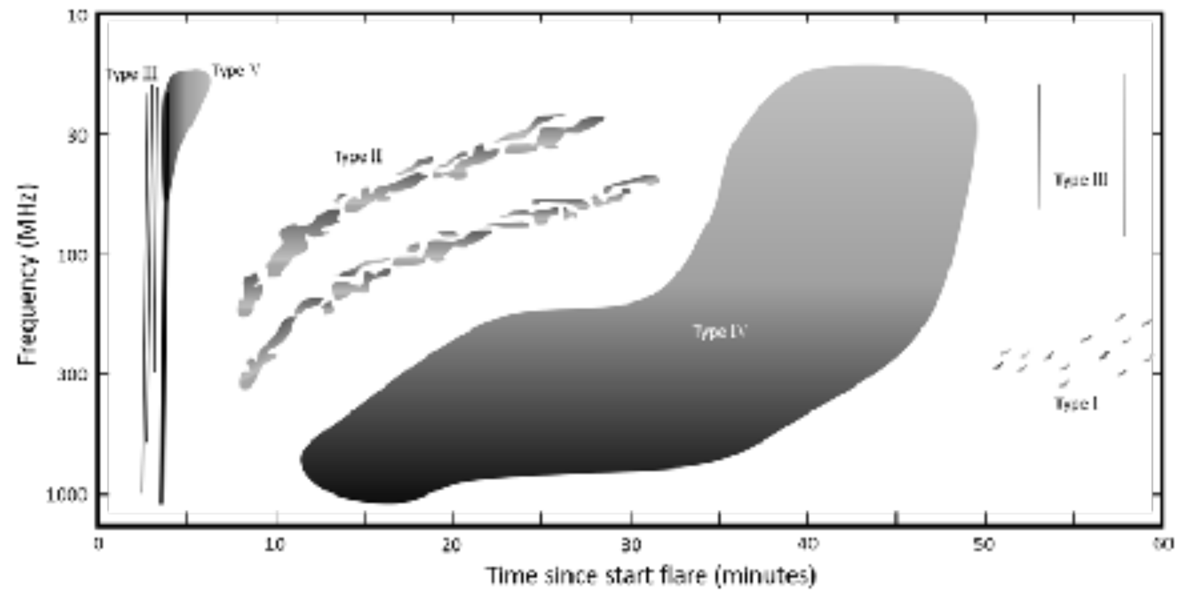
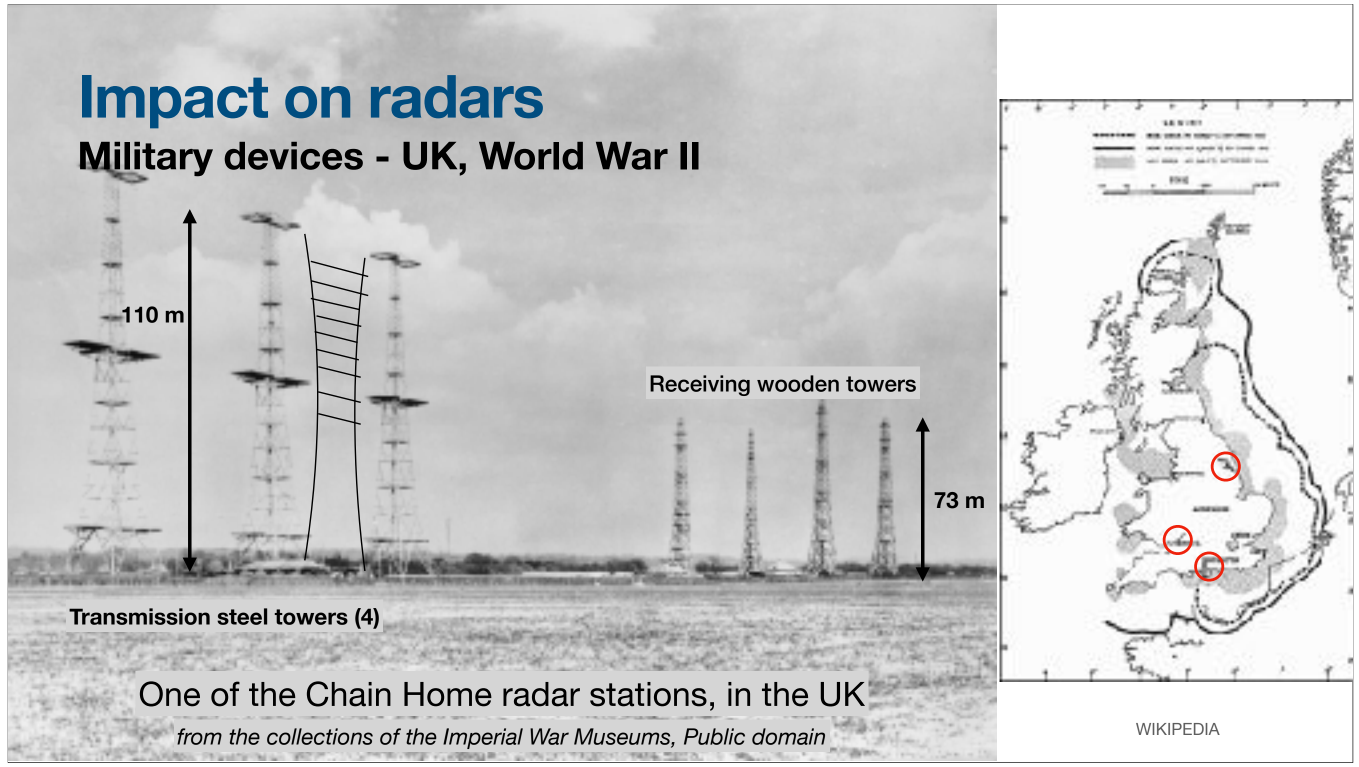


https://www.stce.be/educational/classification

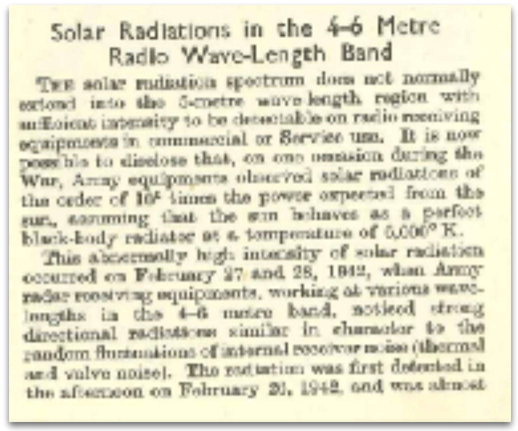
Surveillance radars



Detected in Hull, Bristol, Southampton
Transmission power 0.1 - 1 MW
55 MHz

Impact on radars

Military devices - UK, World War II

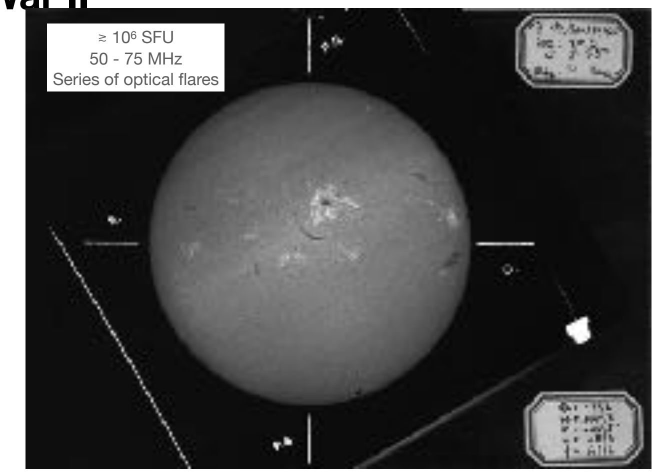


Solar Radiations in the 4–6 Metre Radio Wave-Length Band

THE solar radiation spectrum does not normally extend into the 5-metre wave-length region with sufficient intensity to be detectable on radio receiving equipments in commercial or Service use. It is now possible to disclose that, on one occasion during the War, Army equipments observed solar radiations of the order of 10^5 times the power expected from the sun, assuming that the sun behaves as a perfect black-body radiator at a temperature of 6,000° K.

This abnormally high intensity of solar radiation occurred on February 27 and 28, 1942, when Army radar receiving equipments, working at various wave-lengths in the 4–6 metre band, noticed strong directional radiations similar in character to the random fluctuations of internal receiver noise (thermal and valve noise). The radiation was first detected in the afternoon on February 27, 1942, and was almost

Hey, 1946

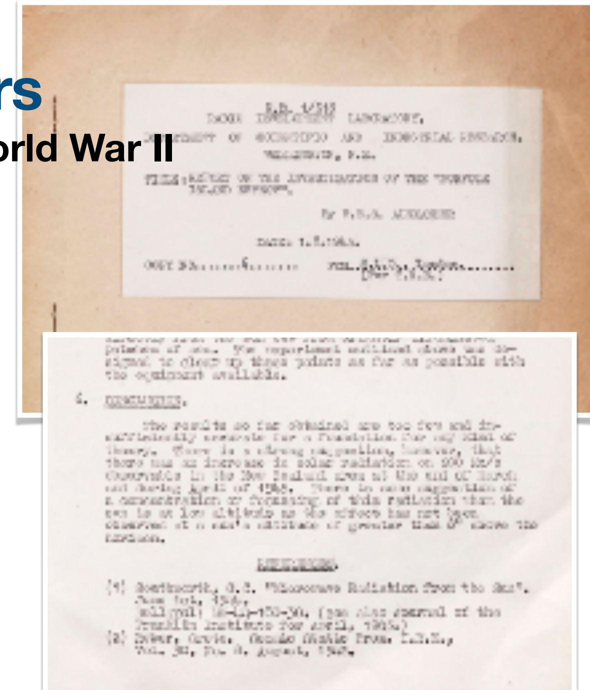


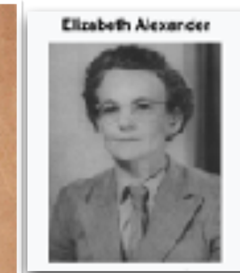
source: https://observations-solaires.obspm.fr/

Impact on radars

Military radars - NZ, World War II

- In March - April1945, Royal New Zealand Air Force radar station on the Norfolk Island picked up increase level of noise at Sun rise and Sun set at 200 MHz
- The head of the ORS of Radio Development Lab., Elisabeth Alexander investigated it, with new measurements and linked it to the Sun itself





Likely the radar picked up intense noise storm emission from sunspot groups

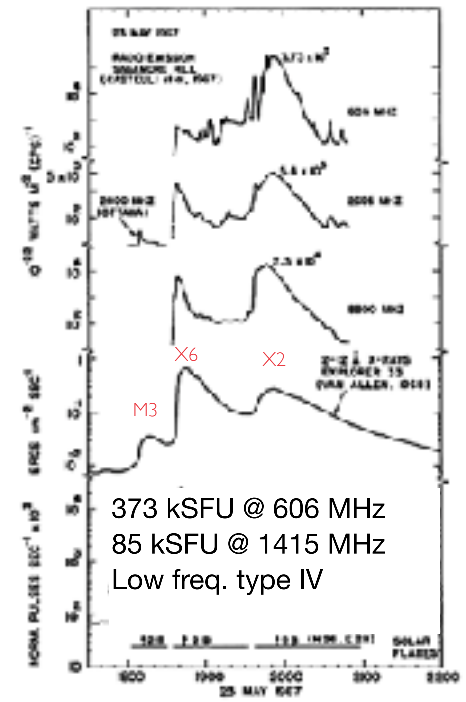
Elizabeth Alexander was the head of the Operational Research Section of the Radio Development Laboratory in New Zealand.

Impact on radars

Military devices - Cold war

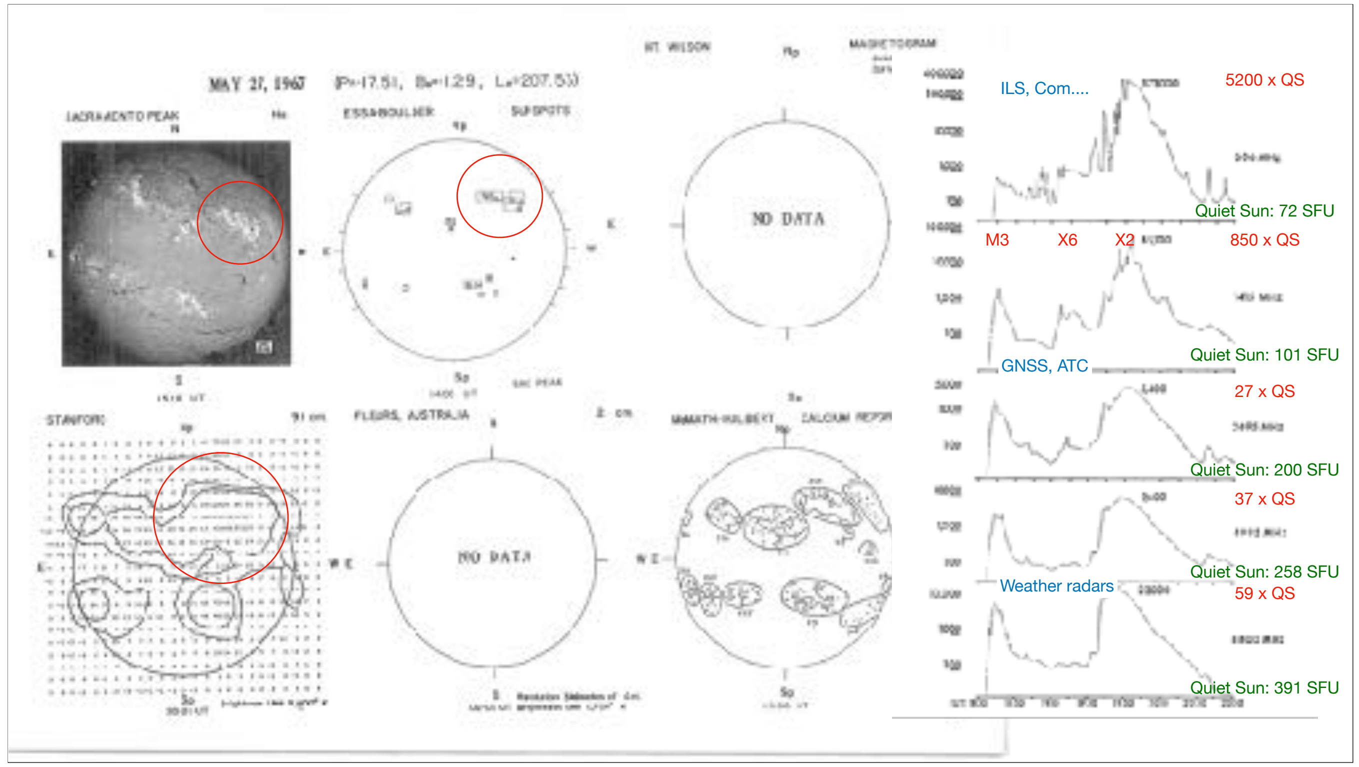
Jamming of Ballistic Missile Early Warning System (BMEWS) radars at 440 MHz

"Cold War military commanders viewed full scale jamming of surveillance sensors as a potential act of war. (...) the online memorial tributes to Col C. K. Anderson, (...) clearly credit him and his NORAD solar forecasting staff (...) with providing the information that eventually calmed nerves and allowed aircraft engines to cool as they returned to normal alert stance."



Knipp et al. 2016

Picture of Alaskan station - other stations: Colorado, Greenland, Yorkshire, Trinidad, New Jersey
https://en.wikipedia.org/wiki/Ballistic_Missile_Early_Warning_System

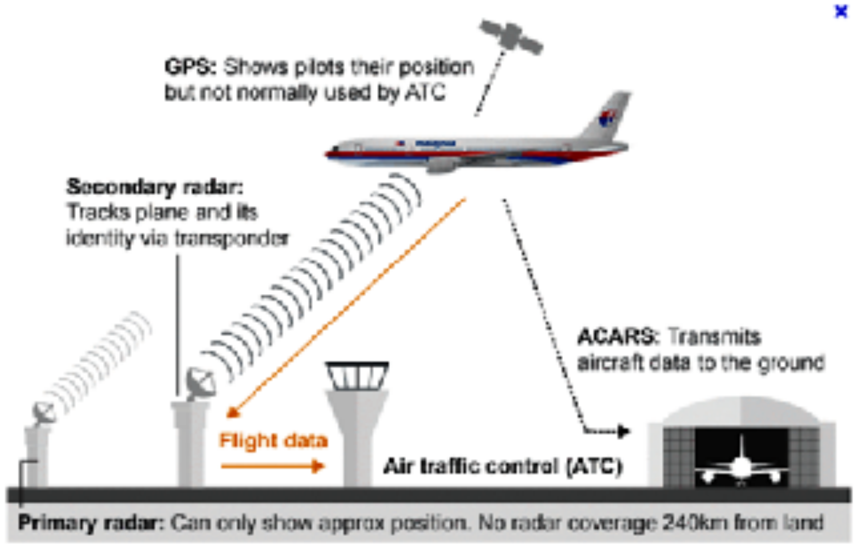


MAY 27, 1967
ESSAB/OULIER
SUNSPOTS
MT. WILSON
MAGNETOGRAM
NO DATA
STANFORD
FLEURS, AUSTRALIA
NO DATA
ILS, Com....
5200 x QS
Quiet Sun: 72 SFU
M3
X6
X2
850 x QS
GNSS, ATC
Quiet Sun: 101 SFU
27 x QS
Quiet Sun: 200 SFU
37 x QS
Quiet Sun: 258 SFU
Weather radars
59 x QS
Quiet Sun: 391 SFU

Air traffic radars

Civil aviation

Primary radars : 2800 MHz
Secondary radars: 1030 & 1090 MHz



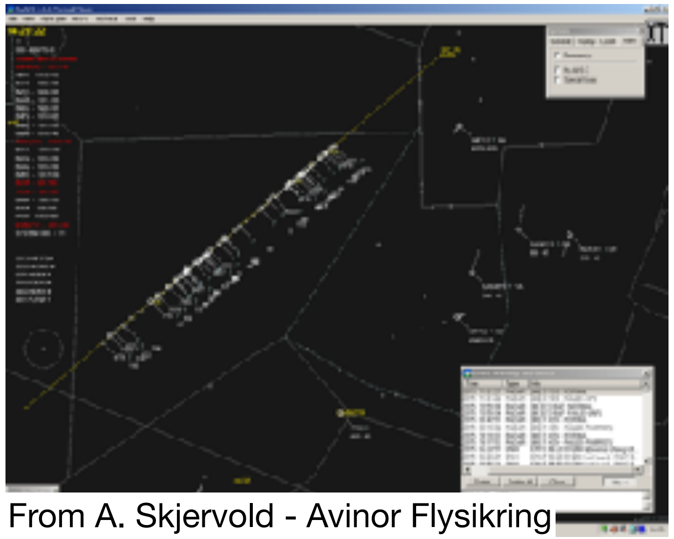
Source: BBC

November 4 2015
A media storm

- ATC radars in Sweden suffered severe disturbances between 14:20 UT and 16:00 UT
- Incoming flights were deviated, no departures allowed
- Geomagnetic storm was initially considered as the source of disturbances (media)

A European wide disruption

- Sweden: ATC radars suffered severe disturbances
  14:20 UT - 16:00 UT
- Sweden: Partial closure of air space for an hour
- Minor disturbances in Norway, Belgium



From A. Skjervold - Avinor Flysikring

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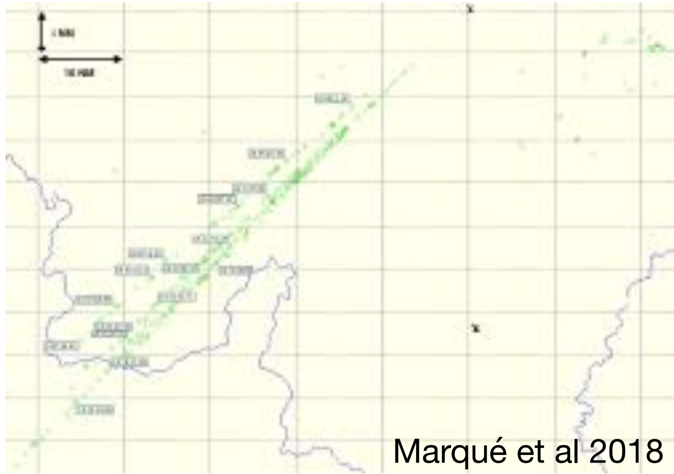
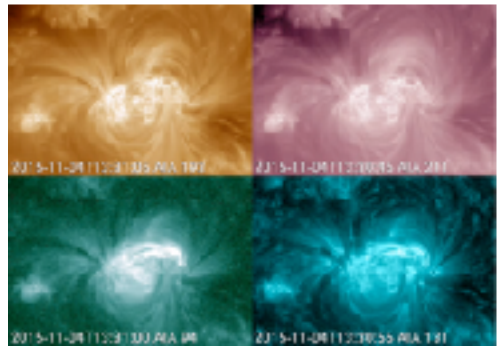
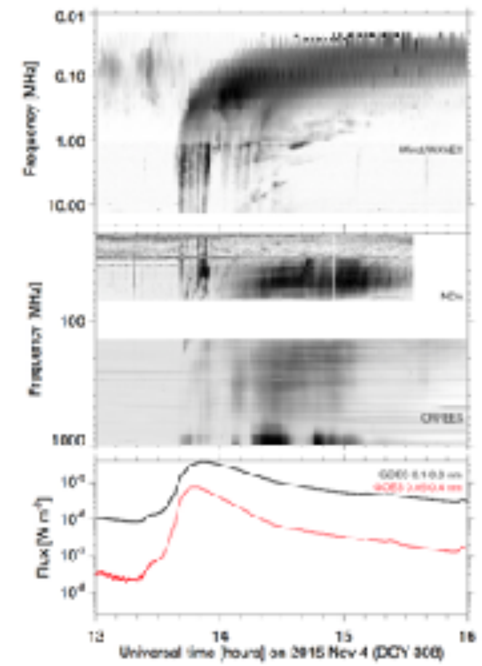


Marqué et al 2018

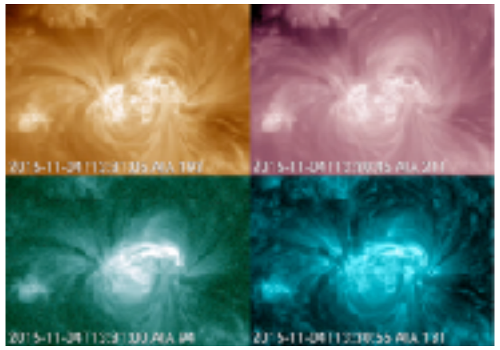
Solar event

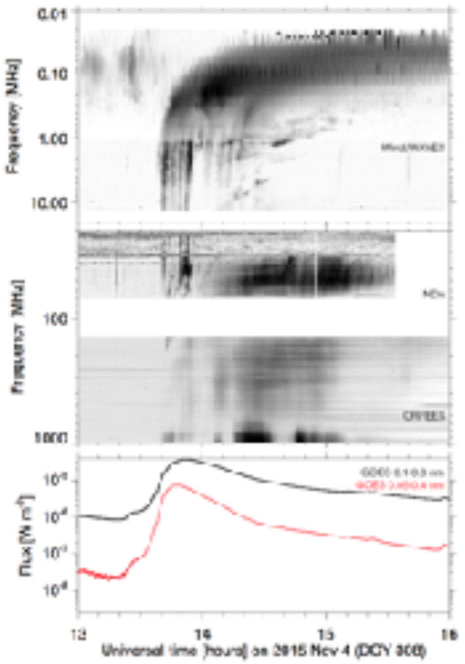




M3.7 flare peaking @1352 UT
NOAA AR 2243

Solar event





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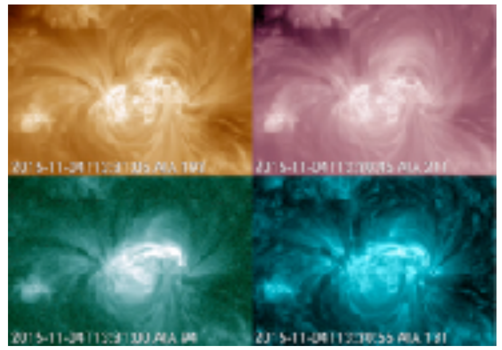

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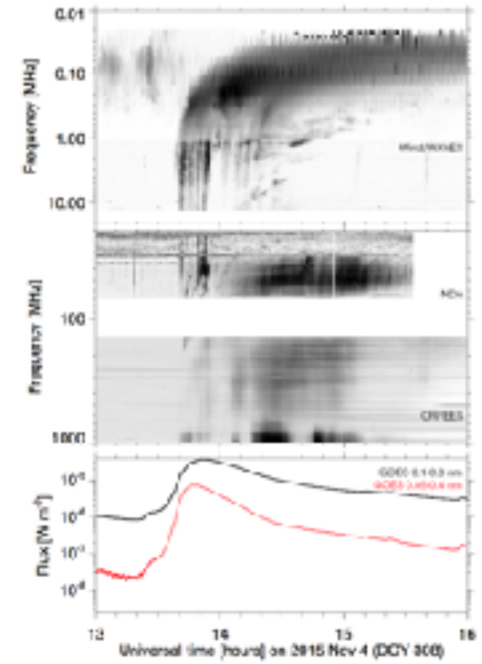
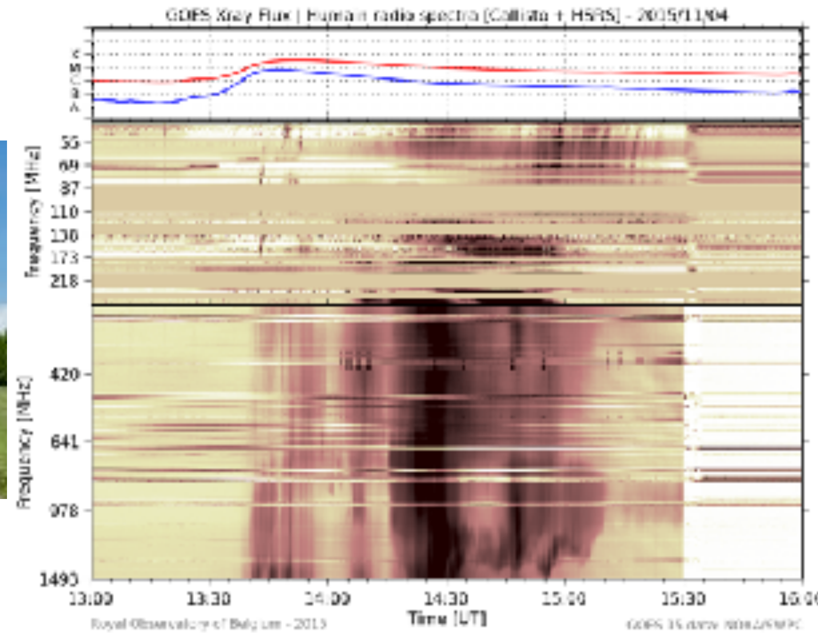
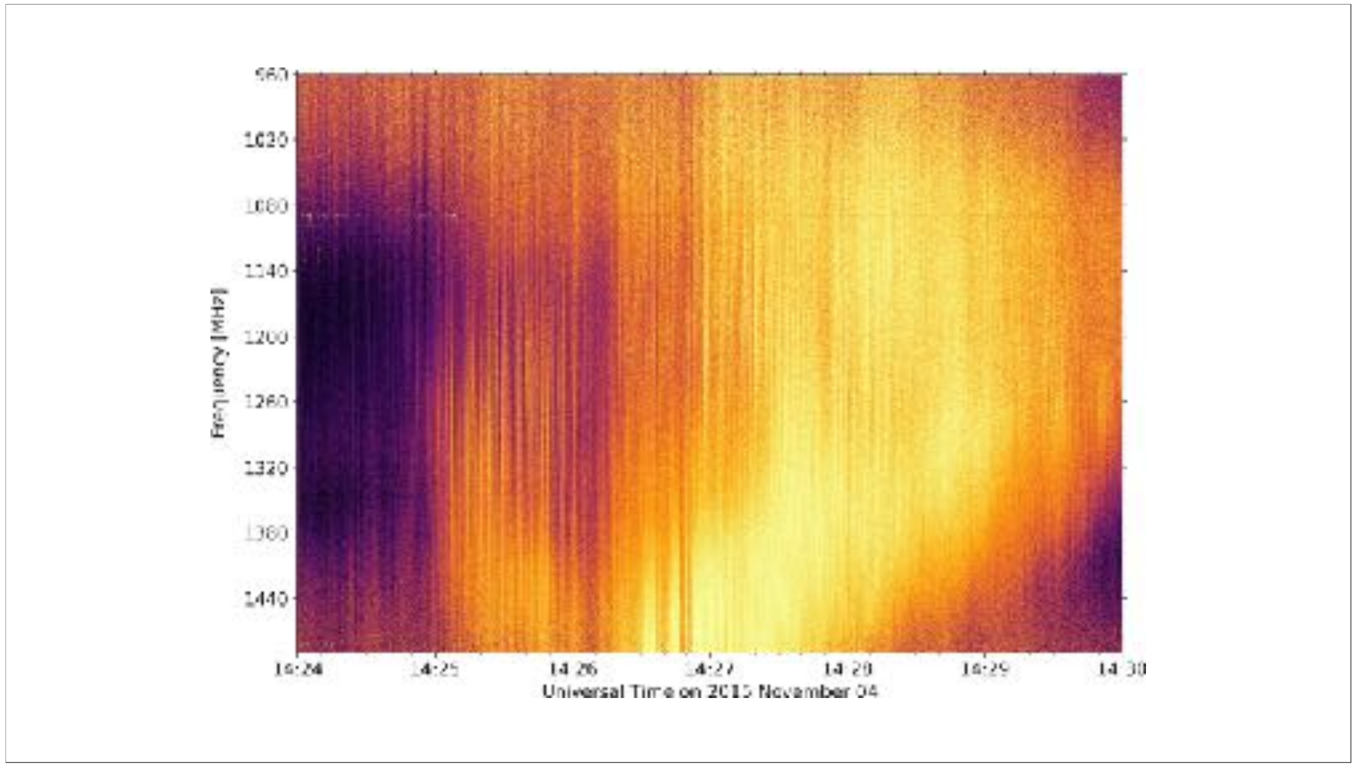


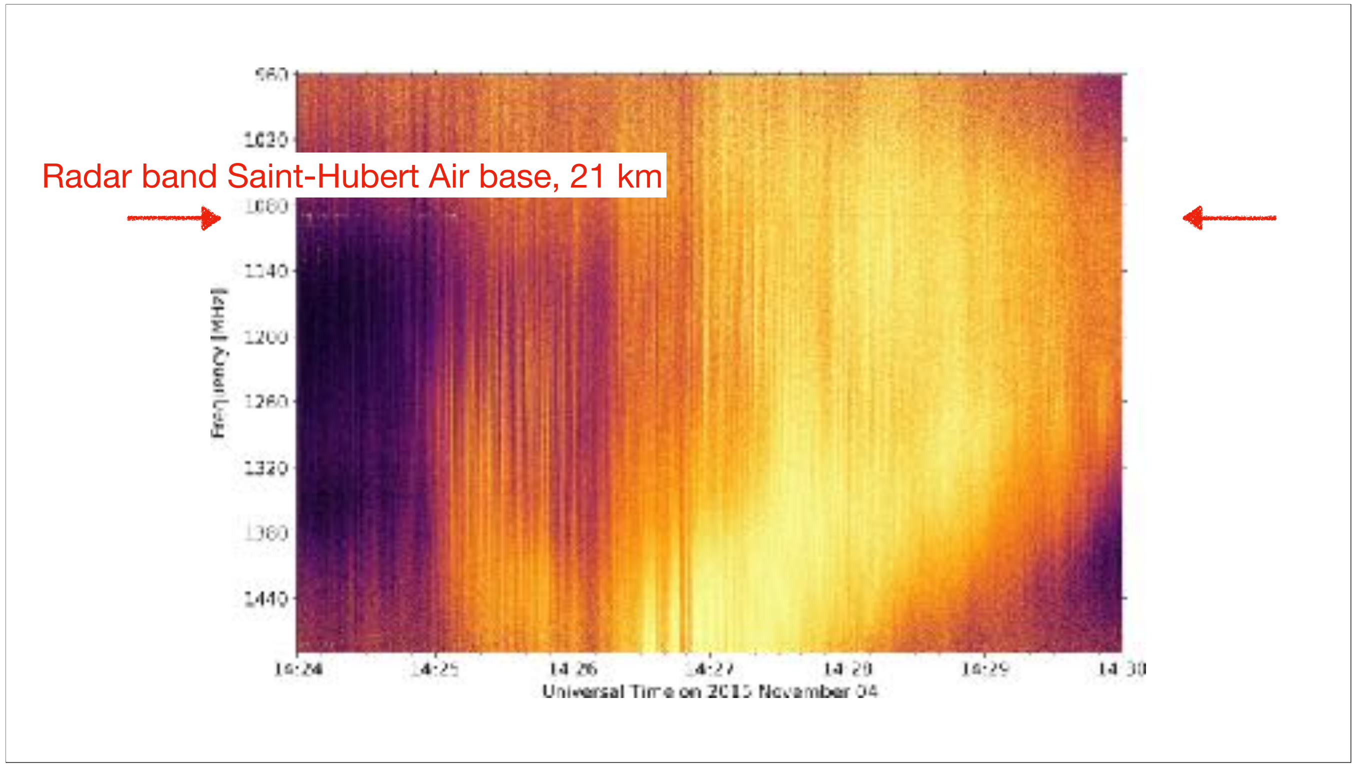
In Humain

http://sidc.be/humain





960
1020
1080
1140
1200
1260
1320
1380
1440
Frequency [MHz]
14:24
14:25
14:26
14:27
14:28
14:29
14:30
Universal Time on 2015 November 04


Radar band Saint-Hubert Air base, 21 km
Frequency [MHz]
Universal Time on 2015 November 04

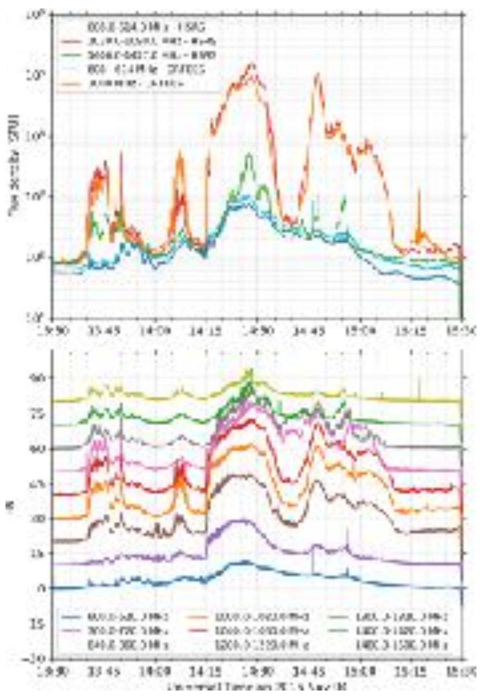
An exceptional event?

Strong magnitude

ORFEES (1000 MHz)	100 kSFU
Blein (1000 – 1250 MHz)	123 kSFU
Humain (1060 MHz)	157 kSFU

But...

610 MHz	820 - 1000 SFU
1415 – 1427 MHz	5200 - 6300 SFU



Interference threshold comparison

- The interference threshold for such radars is about **-102 dBm** ($6{,}3 \,.\, 10^{-14}$ W) at receiver input.
- The quiet sun level on that day was about 75 SFU ($75 \,.\, 10^{-22}$ $W.m^{-2}.Hz^{-1}$), which results in a power at receiver input of **-101 dBm**
- At the peak of the burst the Sun emission level was more than 100 000 SFU, which gives at least a power at receiver input of **-68 dBm**

34 dB above interference threshold (~ 2500 times that level)

TABLE 2

SINGLE FREQUENCY RADIO BURST MAXIMA 1956—PRESENT

Symbol	Observatory	Frequency (MHz)	Date	Peak Flux Units (10^{-22} W m^{-2} Hz^{-1})
A	Nagoya	1000	March 29, 1960	347000
B	Nagoya	2000	March 29, 1960	49000
C	Nagoya	3750	March 29, 1960	8250
D	Tokyo	9500	March 29, 1960	~ 25000*
E	Hollandia	545	March 29, 1960	~100000
F	Hollandia	200	March 29, 1960	20000
G	Nagoya	9400	February 23, 1956	21400†
H	Nagoya	9400	July 18, 1958	20000
I	Nagoya	9400	November 15, 1960	24000
J	Nagoya	3750	February 23, 1956	18000†
K	Nagoya	3750	April 1, 1960	14200
L	Nagoya	3750	November 15, 1960	11600
M	Nagoya	3750	September 3, 1960	13000
N	Nagoya	3750	September 15, 1960	8000
O	Nagoya	2000	November 11, 1960	5600
P	Tokyo	9500	September 1, 1961	9600
Q	Nagoya	1000	November 11, 1960	42000
R	Hollandia	545	July 14, 1959	40000
S	Hollandia	200	August 26, 1958	10000
T	Nagoya	1000	July 14, 1959	10500
U	Nagoya	1000	September 15, 1960	13800
V	Nagoya	1000	April 1, 1960	18000
W	Netherlands	200	April 1, 1960	~300000

* Estimated mean data

† See Bands (1960) p. 285.

Castelli, 1968

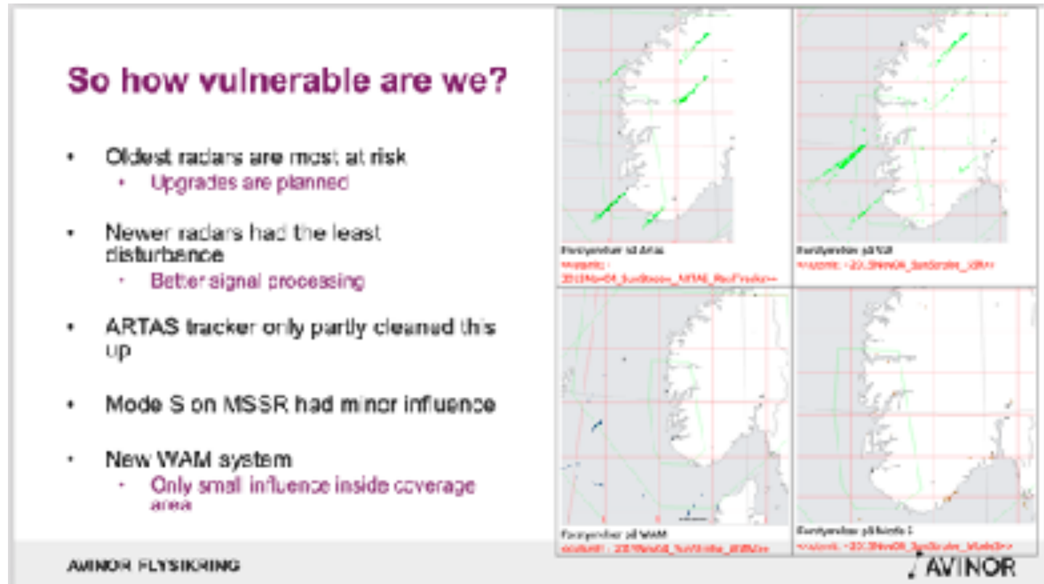
Table 3. Peak flux densities in SFU for the strongest radio bursts since 2000 (peak flux greater than 50 000 SFU at 1415 MHz) tabulated by NOAA[a] (RSTN network at 1415 MHz) and by the Nobeyama Observatory[b] (1000 and 2000 MHz)

Date	Flux at 1000 MHz	Flux at 1415 MHz	Flux at 2000 MHz
2001 April 15	N/A	58 000	N/A
2002 April 21	190 000	110 000	9000
2006 December 05	N/A	129 000[c,d]	N/A
2006 December 13	440 000	130 000[e]	302 000
2006 December 14	N/A	55 000	N/A
2011 February 15	46000	58 000	1500
2011 September 24	N/A	110 000	N/A
2012 March 05	522 000	200 000[e]	19 000

[a] ftp://ftp.swpc.noaa.gov/pub/warehouse/

[b] http://solar.nro.nao.ac.jp/norp/index.html [c] Saturation limit [d] Cliver et al. (2011) report for this event a peak flux density of ~ 10^6 SFU from OVSA observations between 1 and 1.5 GHz [e] End of observations at peak flux; probably underestimated

Our own study, 2018

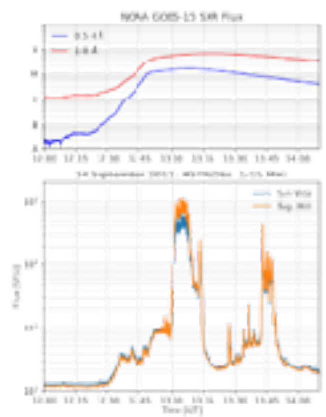


http://www.mn.uio.no/english/about/news-and-events/events/The%20Birkeland%20Anniversary/andreas-d-skjervold_150617.pdf

GNSS systems

Other services

GNSS



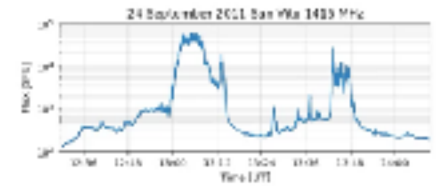
- M7.1 flare, max @ 13:20 UT
- AR 11302, Ekc, βγ

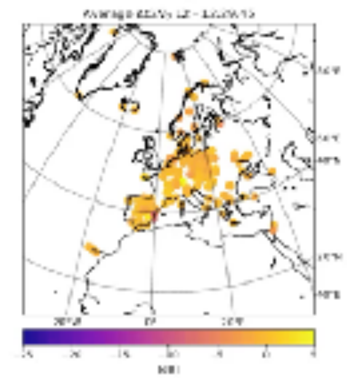
★ 110000 SFU @13:02 UT [Sag. Hill]

★ 60000 SFU [San Vito]

- Dm type IV burst (Bleien, Ondrejov)

C/N0 degradation

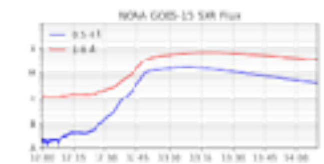


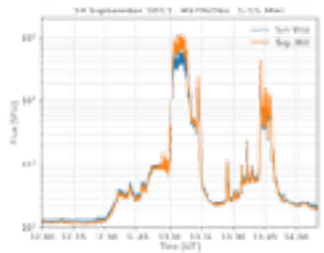


http://gnss.be/

Other services

GNSS





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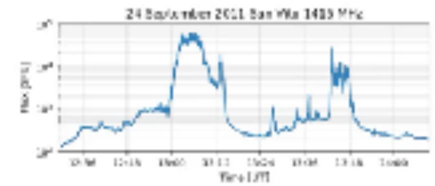

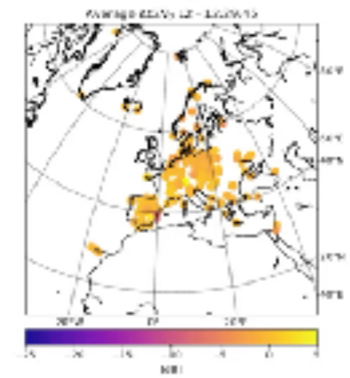

http://gnss.be/

In conclusion

- The November 4 2015 event one of the strongest radio events of cycle 24
- Impact on ATC radars depends on radar type and technologies
- Impact on ground based GNSS stations (no report from aviation industry)
- Type IV bursts can be delayed by almost an hour with respect to the X ray flare
- Flux density can vary by several order of magnitudes in narrow bands