

# SPACE WEATHER INTRODUCTORY COURSE



Collaboration of



**Solar-Terrestrial Centre of Excellence**



**Koninklijke luchtmacht**



**Koninklijk Nederlands  
Meteorologisch Instituut**  
*Ministerie van Infrastructuur en Milieu*



## **SWIC – Summary Day 3 + SWx of the day**

Jan Janssens

# SWIC Summary Day 3 - Contents

- SWx effects
- SWx products
- SWx in the thermosphere-ionosphere
  - Eelco Doornbos
- Solar radio bursts – effects on aviation
  - Christophe Marqué
- SWx of the day

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# Summary SWx effects (1/2)

- **Solar flares**



- NOAA scale (R)
- From EUV & X-ray radiation
  - Solar flare effect
    - “magnetic crochet”
    - => Effects from ICMEs
- Shortwave fadeout
  - “Radio Blackout”
  - => PECASUS
- From radio emission
  - GNSS disturbances
  - Radar disturbances

- **Proton events**



- NOAA scale (S)
- Polar Cap Absorption (PCA)
  - => PECASUS
- Radiation
  - Astronauts, Polar flights
  - => PECASUS
- Satellites
  - Star trackers
  - Single Event Effects (SEE)
  - Solar arrays
- Ground Level Enhancement (GLE)



# Summary SWx effects (2/2)

- **ICMEs**



- NOAA scale (G)
- From magnetic field
  - Satellites
    - Magnetopause crossings
  - High-Precision industry
  - GCR: Forbush decrease
- From particles
  - Satellites
    - Drag
    - Charging effects
      - » Electrostatic Discharges (ESD)
    - Satellite-based Comms/Nav applications (GNSS)
      - » => PECASUS
  - HF Communication (aviation)
    - => PECASUS
  - Geomagnetically Induced Currents (GIC)
  - Aurora

- **Coronal Holes**



- NOAA scale (G)
  - Impacts similar but less severe than with (strong) ICMEs
  - Especially during the declining phase of Solar Cycle
  - SNAP (Spring - Autumn +)
- Satellites
  - Deep di-electric charging



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# STCE website

## <https://www.stce.be/>



## Solar-Terrestrial Centre of Excellence

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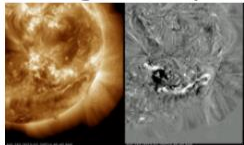
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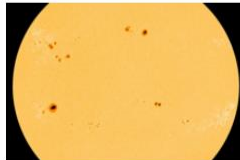
### A stunning filament eruption



On 20 January, a large filament in the southwest solar quadrant erupted producing some spectacular images.

view

### New milestones for SC25



Solar activity continued to be elevated, with both the sunspot number and the solar radio flux reaching their highest values so far this solar cycle.

view

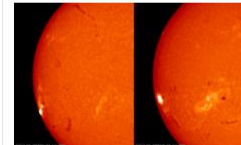
### Triple X



The Sun produced a 3rd X-class flare in just 5 days. This page features the ongoing series of X-class flares and other solar activity. [UPDATED 1.](#)

view

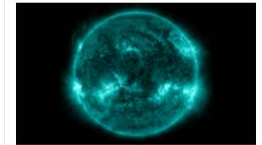
### X-class flares are back!



A side-by-side comparison of and more details on the X-class flares from 6 and 9 January.

view

### X1.9 flare from NOAA 3184



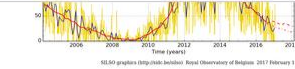
Compact and complex sunspot group NOAA 3184 produced a X1.9 flare on 9 January.

view





<https://www.stce.be/>



One of the highlights of the Open Doors is always a visit to the Solar Dome. A small introductory presentation is first given in the corridor of the SIDC. Skilled observers and space weather forecasters explain in laymen terminology what sunspots are, how they are observed, why these observations are so important, and how solar eruptions affect us and our technology. Then, the small groups of 10-15 people are guided stairs towards the top of the solar dome. There, the various solar telescopes are shown and their specific applications are discussed. Weather permitting, the visitors can also make solar observations using a projected solar image from the white light solar telescope. During and after the visit, there is plenty of opportunity to ask questions to the guides.

✔ Read more



# SIDC website

## <https://www.sidc.be/>

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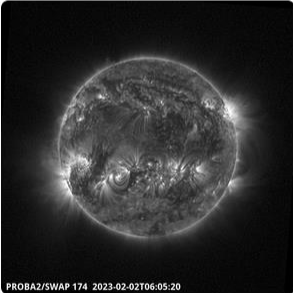
🌟 [Royal Observatory of Belgium](#)

## Solar Influences Data Analysis Center

Home Observations ▾ Services ▾ Research Activities ▾

### Observations

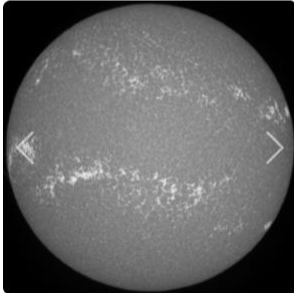
#### Space Based Imaging



PROBA2/SWAP 174 2023-02-02T06:05:20

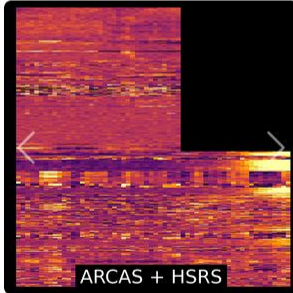
More data: [SWAP](#), [EUI](#)

#### Ground Based Imaging



More: [H-α](#), [WL](#), [Ca-IIK](#), [Drawings](#)

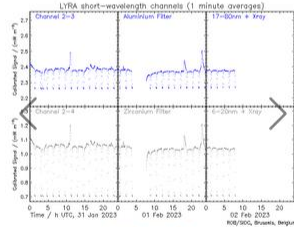
#### Ground Based Radio



ARCAS + HSRS

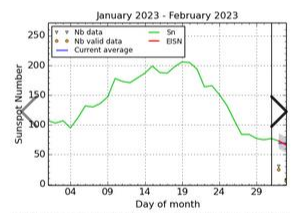
More: [ARCAS+HSRS](#), [CALLISTO](#)

#### Space Based Timelines



More data: [LYRA](#), [TSI](#)

#### WDC Sunspot Index



More data: [SILSO](#)

## Space Weather Services

Detections

Latest Alerts

Forecasts

Solar Activity

Solar Wind



# SIDC website

## <https://www.sidc.be/>

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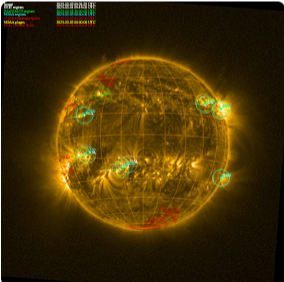
### Solardemon

**2023-02-02 04:45 B5 flare**

### CACTus

**2023-01-15 03:48 480km/s**

### Solar Map



#### Presto 2023-02-01

There was a weak shock in the L1 solar wind data at 15:40 UTC. The solar wind speed jumped from 348 to 369 km/s, the magnetic field went from 4 to 6 nT after the shock, and reached 11 nT later. The driver of the shock is probably the high speed solar wind stream expected for today, more information will be given as data becomes available.

Flare: **C-class flares (≥50%)**

Protons: **Quiet**

Geomagnetic: **Active conditions (A≥20 or K=4)**

All quiet: **False**

Provisional SSN:

#### URSigram 2023-02-02

There are six active regions visible on the solar disc, all of them with simple alpha or beta magnetic field configuration. Solar flaring activity was at low levels over the past 24 hours, with several C-class flares detected. The strongest one was a C5.8 flare from NOAA AR 3204, peaking at 22:48 UTC on 1 February. This active region is rotating out of view over the west limb. Further C class

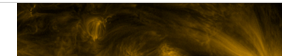
#### URSigram 2023-02-02

There was a weak forward shock in the L1 solar wind data at 15:40 UTC on 1 February. The solar wind speed jumped from 348 to 369 km/s, the magnetic field went from 4 to 6 nT after the shock, and reached 11 nT later (with Bz briefly down to -10 nT). The driver of the shock was probably the mild high speed solar wind stream expected to arrive, reaching solar wind speeds about 100 km/s faster than before

## Publications

[First Perihelion of EUI on Solar Orbiter](#)

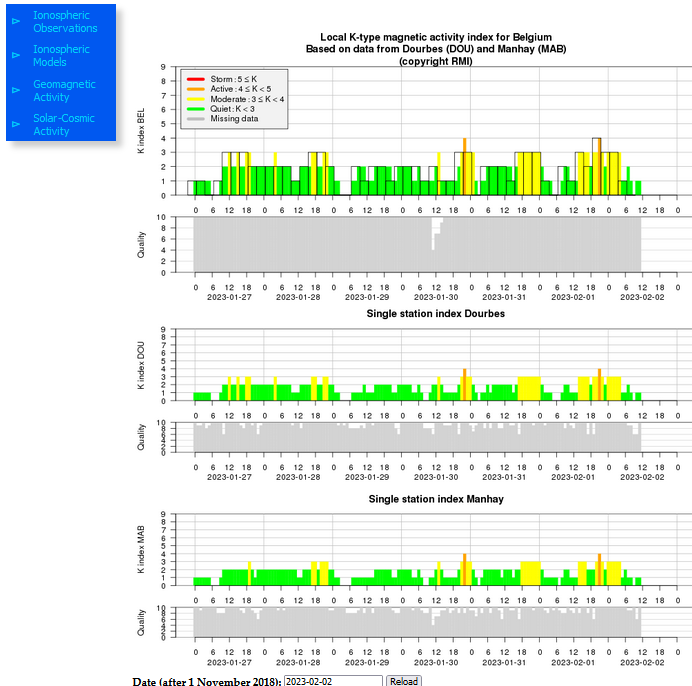
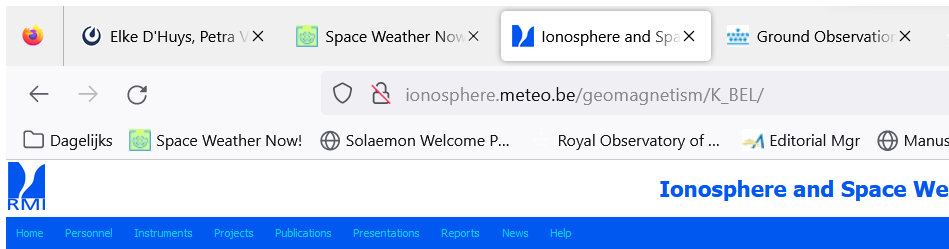
## News



# Dourbes

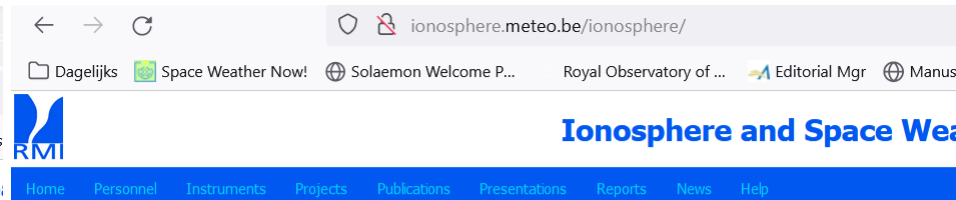
## Geomagnetic

[http://ionosphere.meteo.be/geomagnetism/K\\_BEL/](http://ionosphere.meteo.be/geomagnetism/K_BEL/)

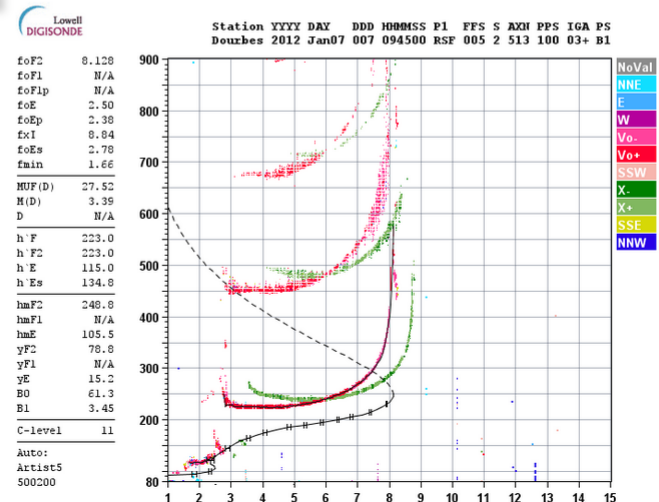


## Ionosphere

<http://ionosphere.meteo.be/ionosphere/>



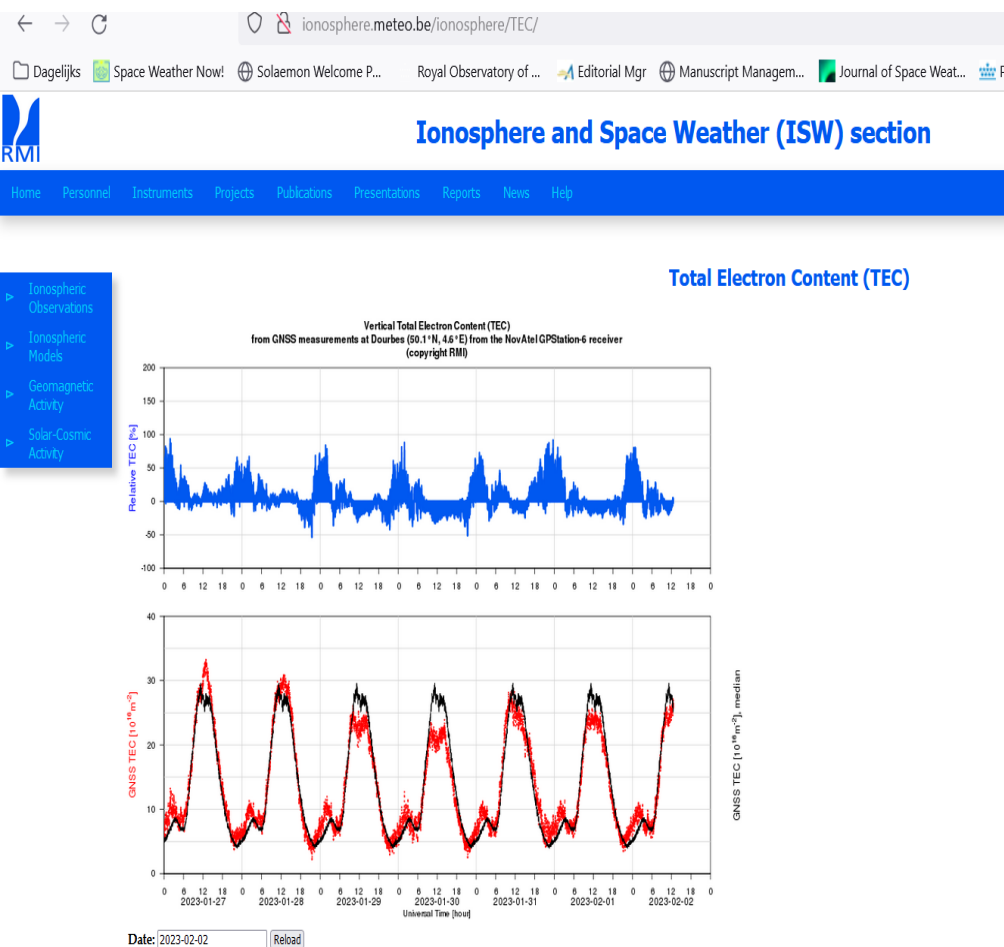
Permanent monitoring of the ionospheric condition/activity is crucial for understanding the complex nature of the ionosphere and for developing (local) operational services that can help the users in their efforts to mitigate eventual ionosphere/space weather impacts. Vertical Incidence Sounding (VIS) remains one of the most accurate and important ionosphere-monitoring techniques recorded for each of the transmitted frequencies. Thus, the resulting ionogram is an instantaneous record of the ionosphere of echoes reflected from the ionosphere. In a typical ionogram, the frequency range covers the interval 1–20 MHz and the



# GNSS

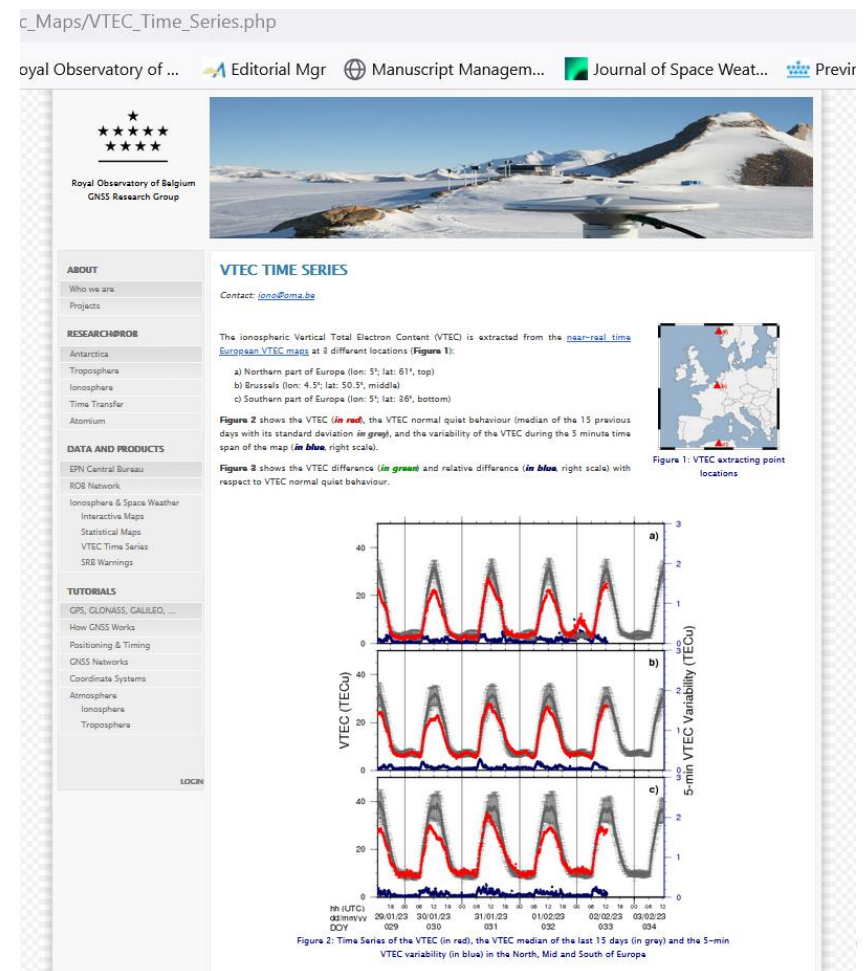
## Dourbes (RMI)

<http://ionosphere.meteo.be/ionosphere/TEC/>



## Uccle (ROB)

[http://gnss.be/Atmospheric\\_Maps/ionospheric\\_maps.php](http://gnss.be/Atmospheric_Maps/ionospheric_maps.php)



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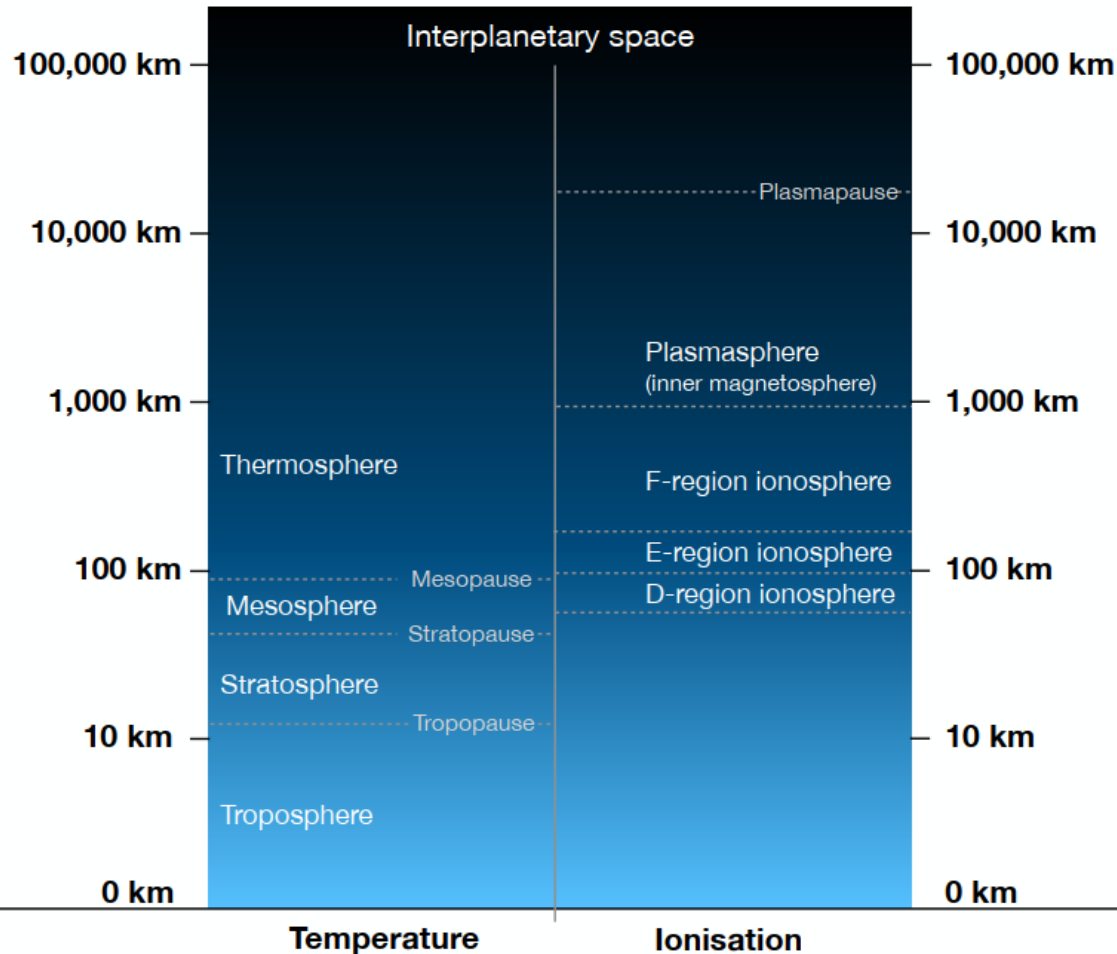
# SWx in the thermosphere-ionosphere

*Eelco Doornbos (KNMI)*





## Classification and nomenclature of the terrestrial atmosphere



Based on G.W. Pröls, Physics of the Earth's Space Environment, Figure 2.13

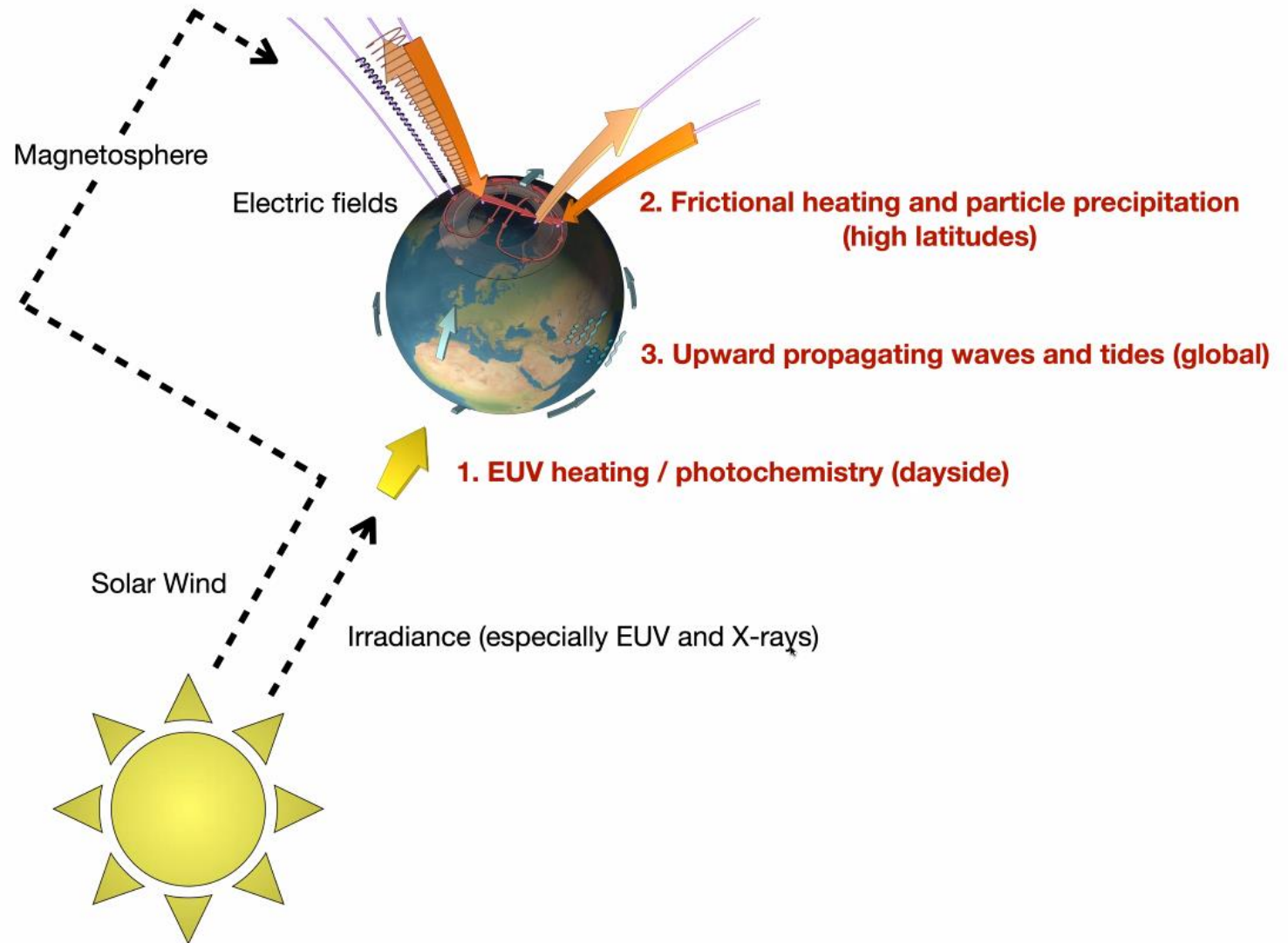




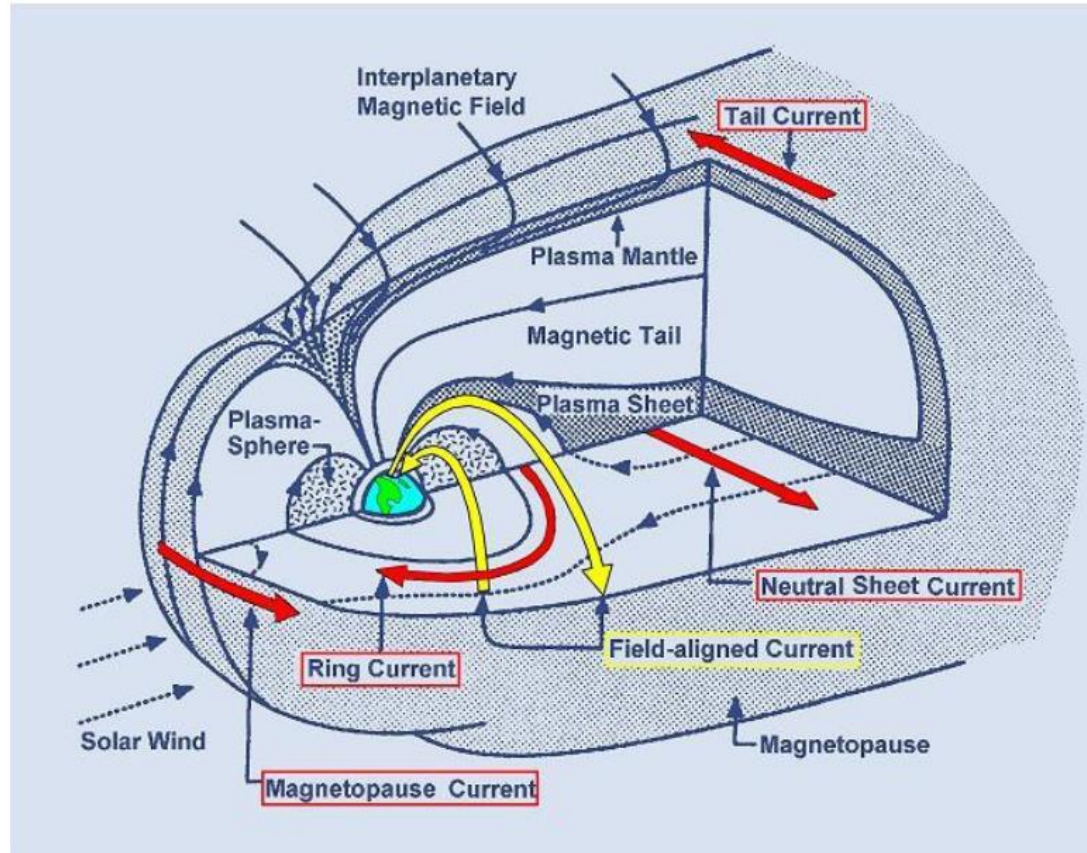
# Ionospheric regions

- D-region (~80-100 km): rapid ionisation during X-ray flares leading to absorption of HF radio signals
- E-region (~100-150 km): systems of currents of charged particles from the magnetosphere close here at high latitudes, leading to impacts in power grids due to geomagnetically induced currents
- F-region (>150 km, peak at ~250-500 km): highest electron densities, scintillation of radio signals in regions of steep gradients

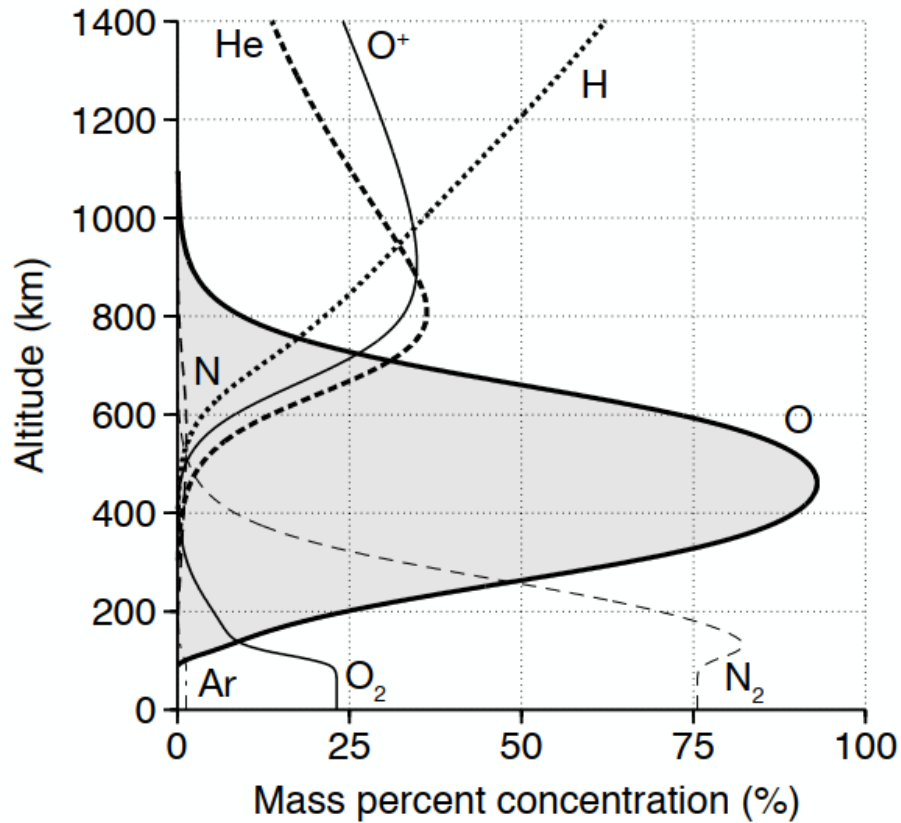




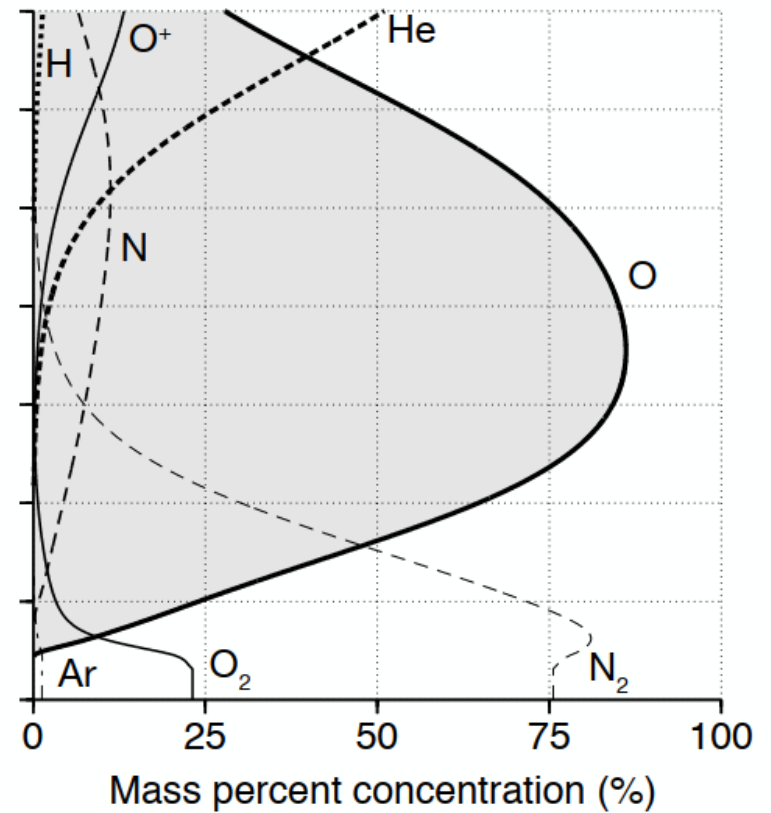
# Magnetospheric currents



Low activity (2006)



High activity (2000)



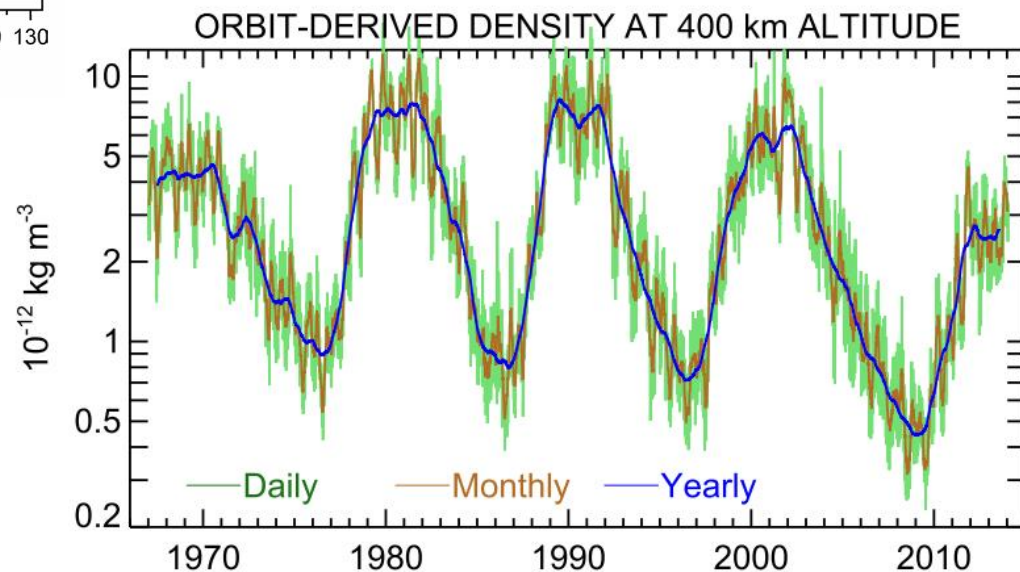
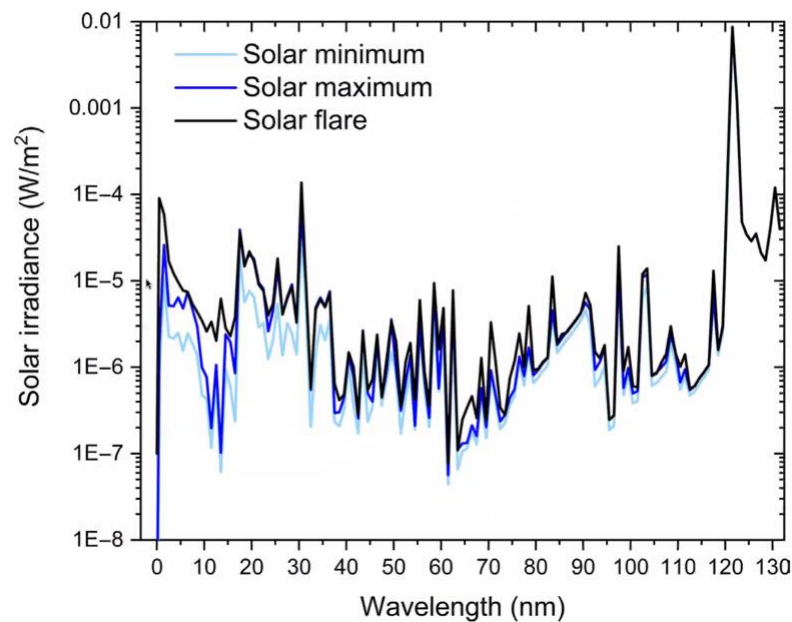
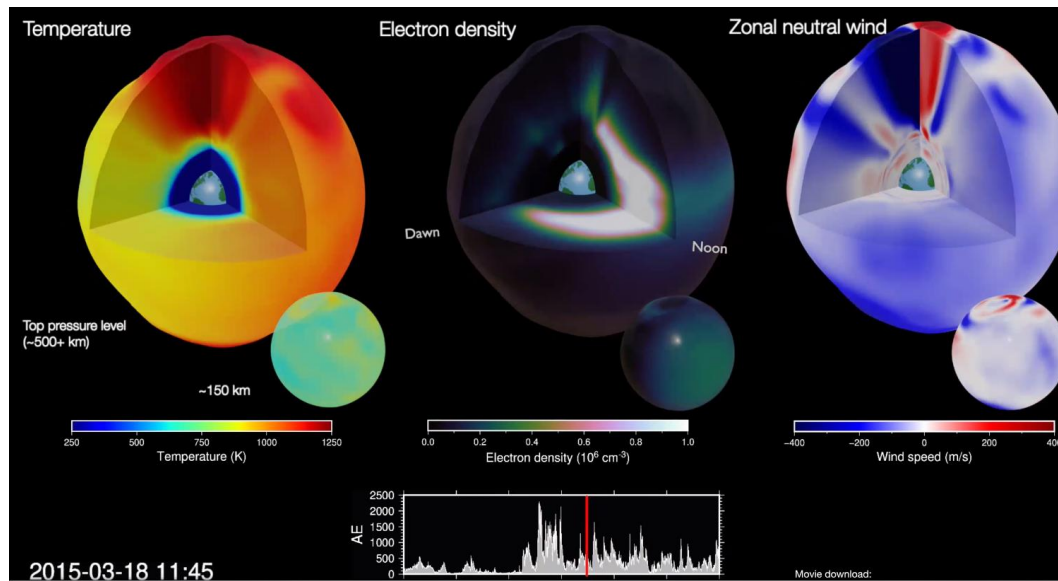
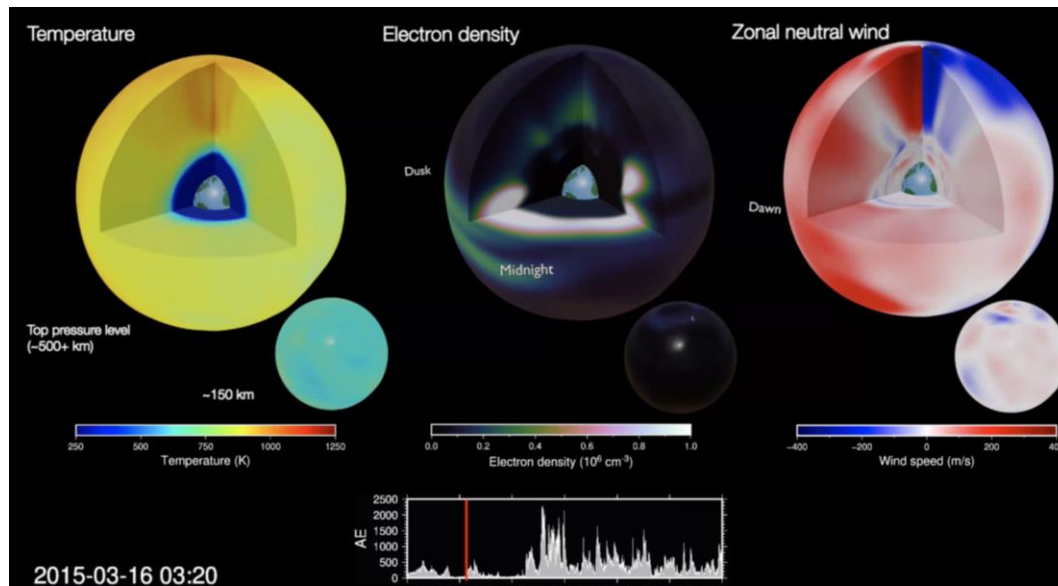
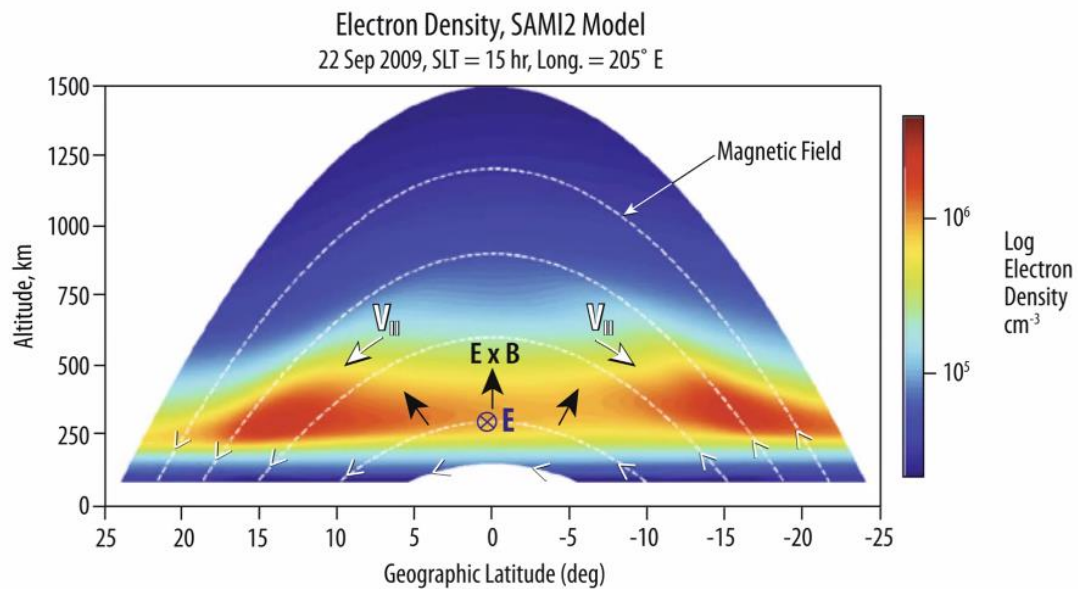
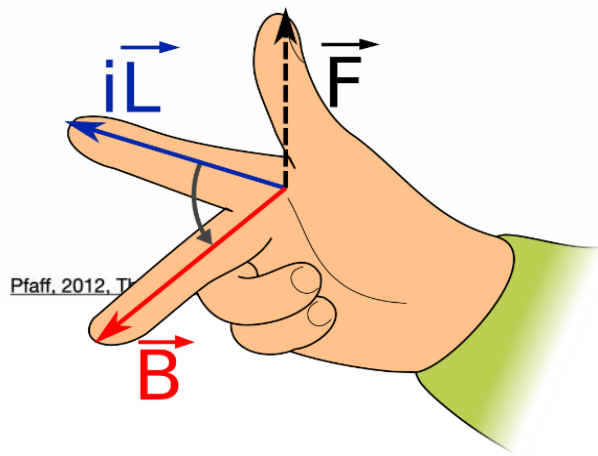
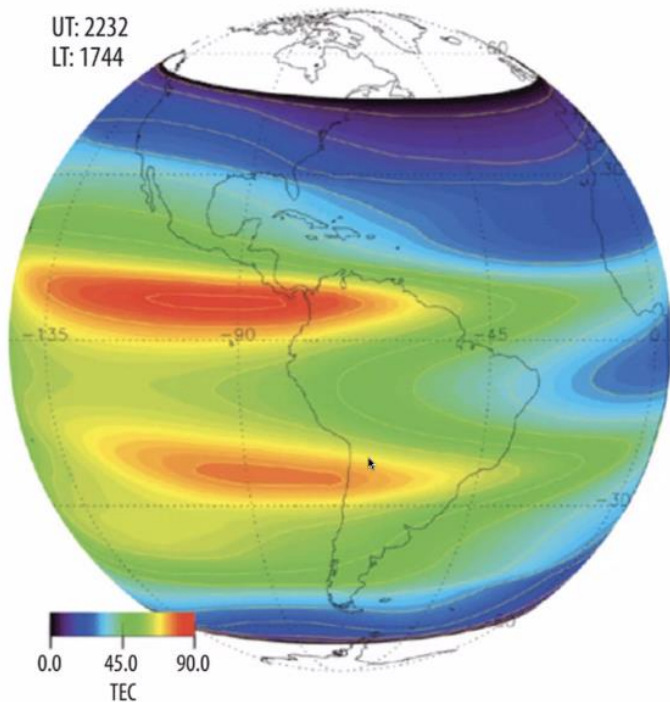


Fig. 1. 1967–2013 global average thermospheric mass density at an altitude of 400 km, derived from orbit data (Emmert, 2009, 2015) and plotted on a log scale. Shown are daily values (green), monthly running averages (orange), and yearly running averages (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



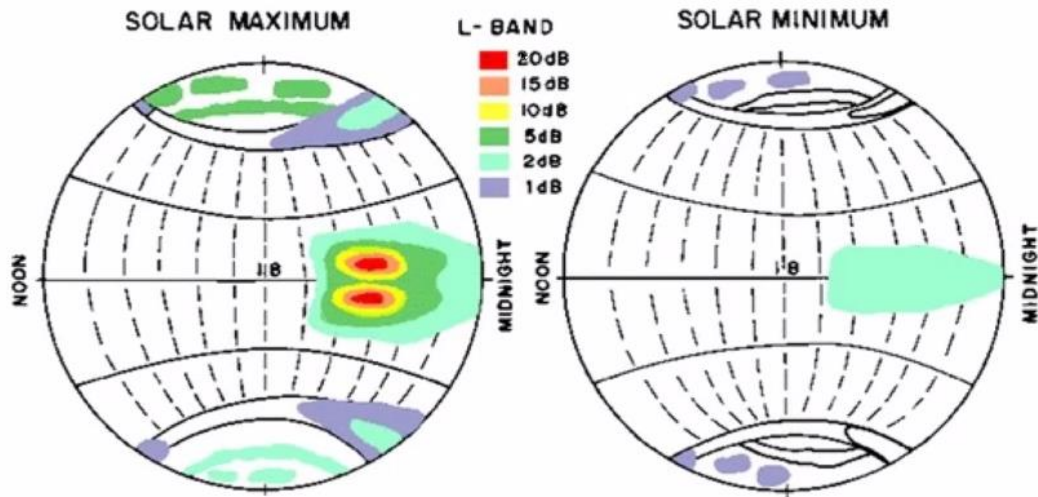




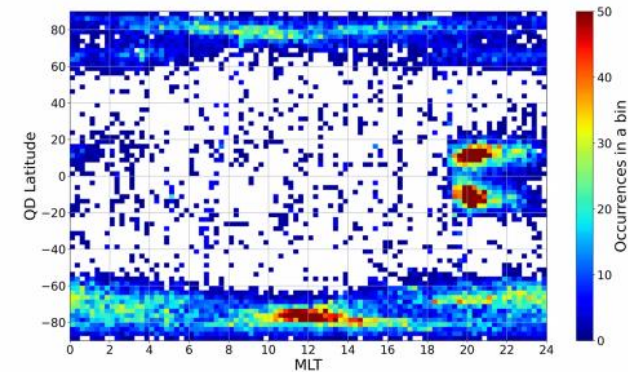
**Fig. 19** SAMI2 model calculations versus latitude and altitude of the plasma density for 1500 SLT at 205° East. The upward  $E \times B$  drift at the magnetic equator is driven by the eastward electric field, and there is subsequent flow downward along the magnetic field lines



# Ionospheric scintillation



Global variation of amplitude scintillation fades at L band (after Basu et al. 1988a, b, colored by A.W. Wernik)

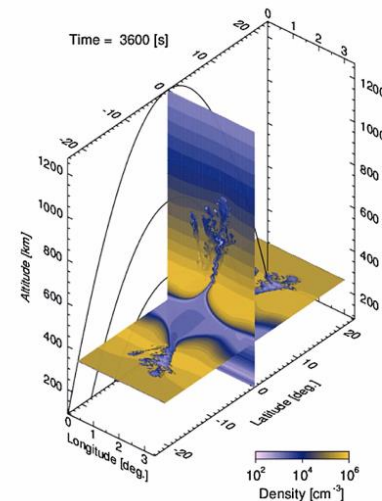
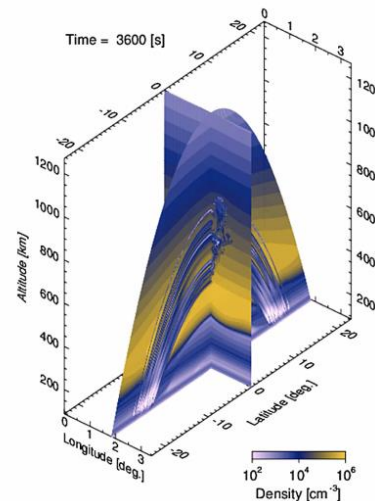
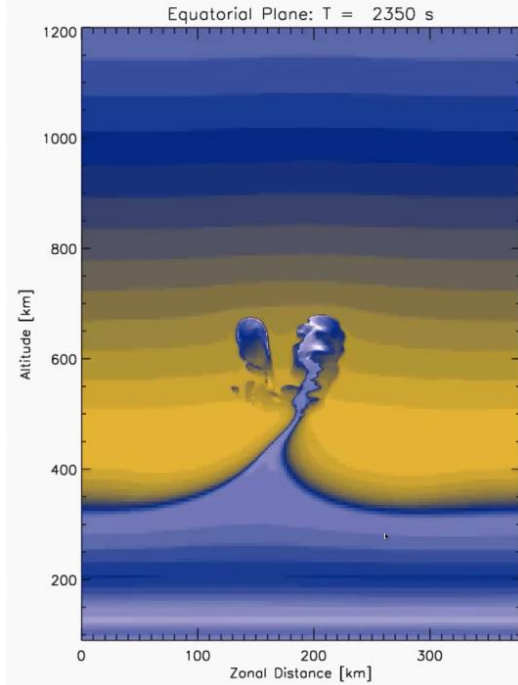


Distribution of GPS Loss of Lock events affecting Swarm A, B and C from Dec 2013-Dec 2020.

Pezzopane et al., 2021

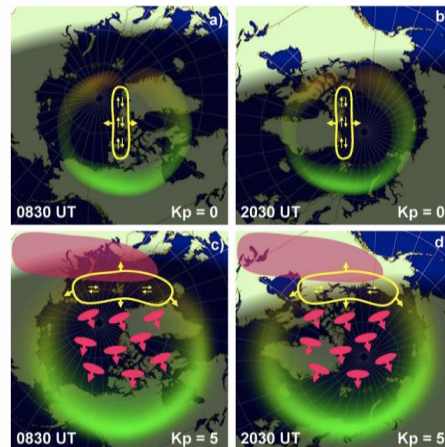


## Scintillation mechanism 2: equatorial plasma bubbles (equatorial spread-F)



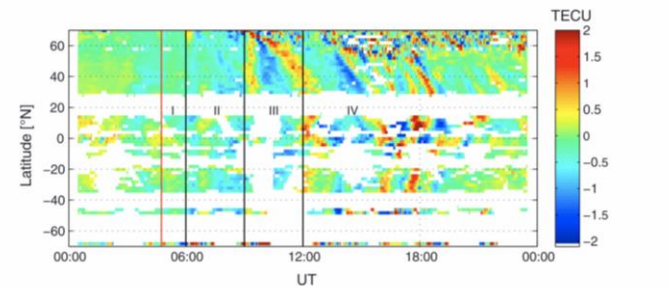
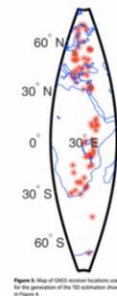
Nonlinear growth, bifurcation, and pinching of equatorial plasma bubble simulated by three-dimensional high-resolution bubble model

## Scintillation mechanism 1: Polar cap patches



A schematic illustration of active space weather regions in the polar cap ionosphere when IMF BZ is north (top row,  $K_p = 0$ ), and IMF BZ is south (bottom row,  $K_p = 5$ ). The active regions for creation of polar cap patches/plasma irregularities are shown in yellow color and move under the influence of IMF as indicated by yellow arrows. For IMF BZ north the active region is caused by flow shears near transpolar arcs in the central polar cap, and space weather problems are only expected far north of Svalbard both day (panel a, 0830 UT) and night (panel b, 2030 UT). For IMF BZ south the tongue of ionization (pink) extends into the dayside auroral oval, where magnetic reconnection chops it into polar cap patches (pink) that begin to drift across the polar cap. In the production region there are flow channels and strong flow shears that initiate the growth of ionospheric irregularities. Svalbard will be directly under the production region at daytime (panel c, 0830 UT), and at night Svalbard will see patches arriving from the polar cap (panel d, 2030 UT).

## Mechanism 3: Traveling ionospheric disturbances during a geomagnetic storm



**Figure 4.** Illustration of TID amplitudes generated from GNSS data along the European-African sector with about 30°E center longitude during the 17 March 2015 storm. The red line indicates storm onset at 04:45 UT, and the solid black lines show the shift between the different phases of storm.

# Summary

- The thermosphere-ionosphere is the upper part of the Earth's atmosphere.
- It is weakly ionised, so it consists of both neutral particles (thermosphere) and ions and electrons (ionosphere).
- The combined thermosphere-ionosphere system is strongly driven by three distinct energy sources: solar EUV irradiation (dayside), interaction with the magnetosphere (auroral latitudes) and interaction with the lower atmosphere (global).
- The impacts of these two systems are very different (thermosphere: satellite drag, ionosphere: radio signals, currents). But there are strong interactions.
- Important ionospheric impacts are related to small-scale irregularities related to strong gradients (equatorial plasma bubbles, polar cap patches and traveling disturbances).



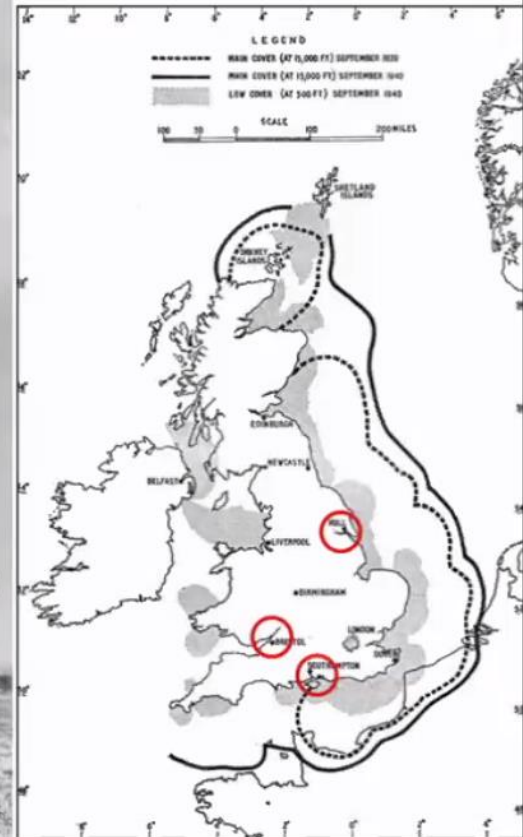
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# Impact on radars

## Military devices - UK, World War II



WIKIPEDIA





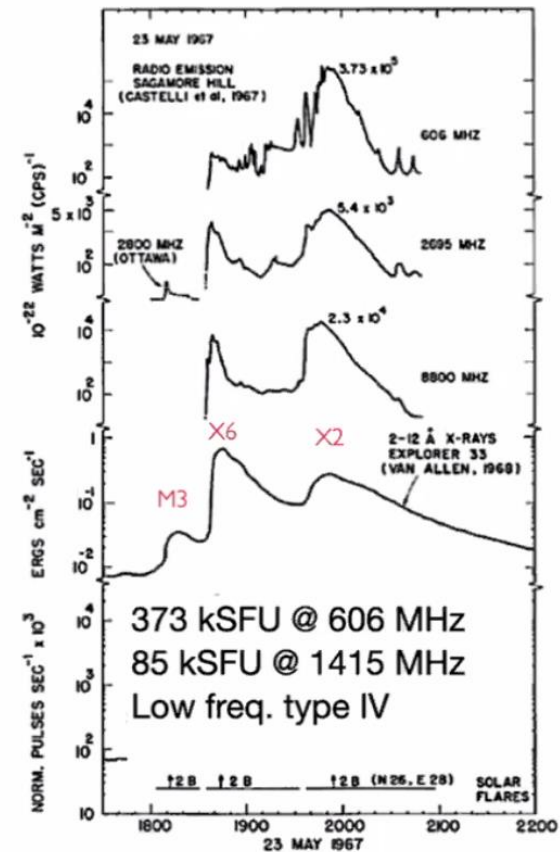
# Impact on radars

## Military devices - Cold war



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

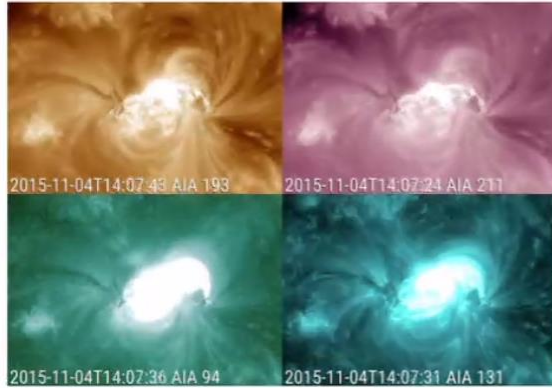
"Cold War military commanders viewed full scale jamming of surveillance sensors as a potential act of war. (...) the online memorial tributes to Col C. K. Anderson, (...) clearly credit him and his NORAD solar forecasting staff (...) with providing the information that eventually calmed nerves and allowed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



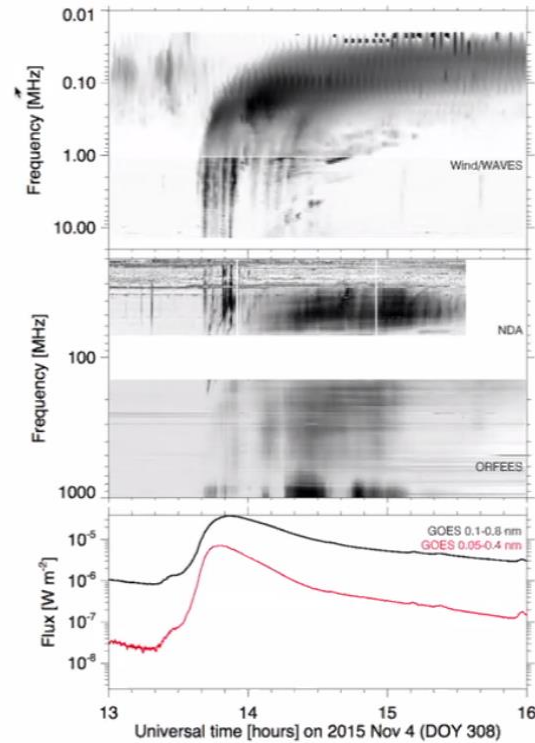
Knipp et al. 2016



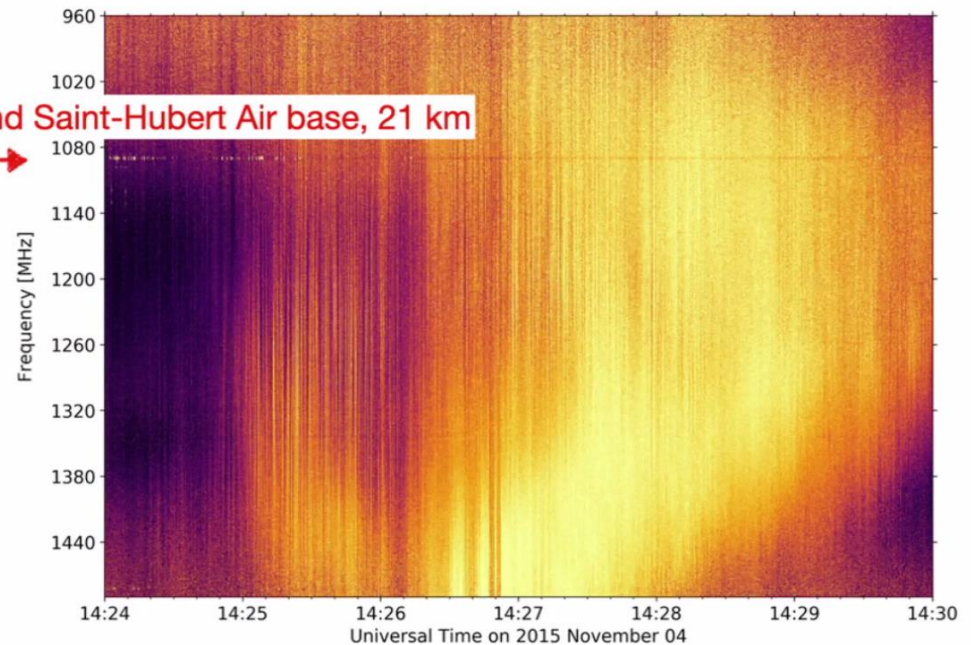
# Solar event



M3.7 flare peaking @1352 UT  
NOAA AR 2243

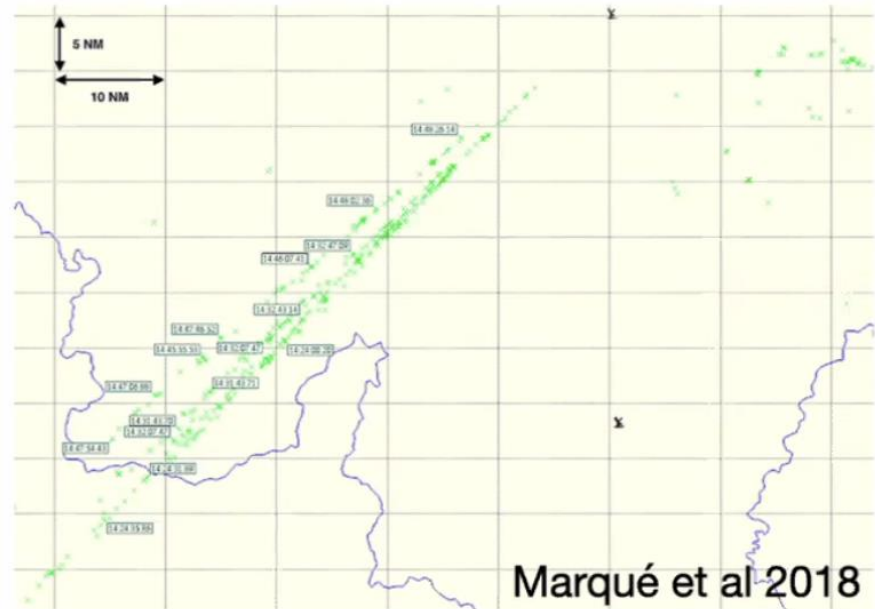


Radar band Saint-Hubert Air base, 21 km



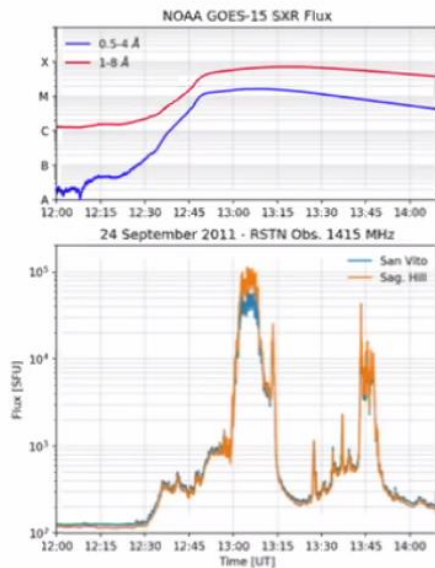
## A European wide disruption

- 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



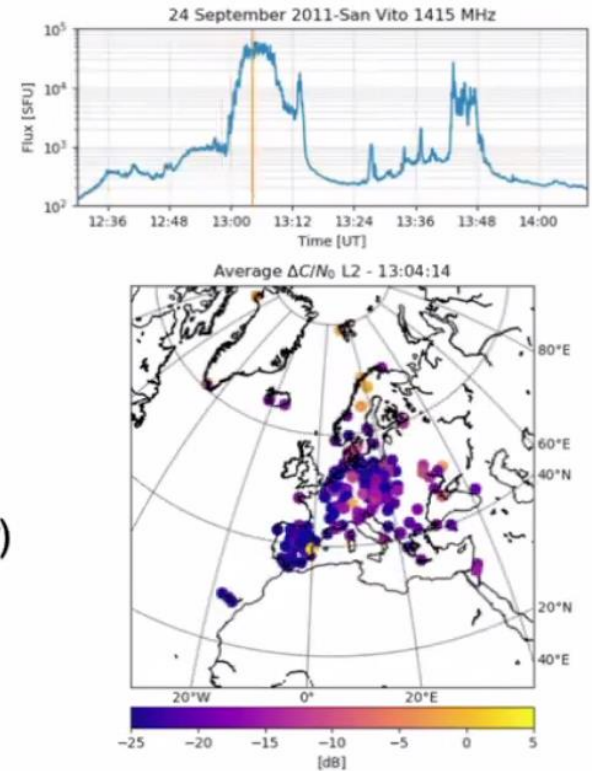
# Other services

## GNSS



- M7.1 flare, max @ 13:20 UT
- AR 11302, Ekc,  $\beta\gamma$
- ★ 110000 SFU @ 13:02 UT [Sag. Hill]
- ★ 60000 SFU [San Vito]
- Dm type IV burst (Bleien, Ondrejov)

C/N0 degradation



<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



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# SWx of the day

- SIDC URSIgram: <https://www.sidc.be/index.php>
- Solar flares:
  - GOES x-ray: <https://www.swpc.noaa.gov/products/goes-x-ray-flux>
  - Solar Demon: <https://www.sidc.be/solardemon/flares.php>
  - Humain Radio bursts: [https://www.sidc.be/humain/humain\\_spectra\\_realtime.php](https://www.sidc.be/humain/humain_spectra_realtime.php)
- GOES proton: <https://www.swpc.noaa.gov/products/goes-proton-flux>
- Sunspots:
  - SILSO: <https://www.sidc.be/silso/eisnplot>
  - SolarMonitor: <https://solarmonitor.org/index.php>
- Radio flux: <https://www.spaceweather.gc.ca/forecast-prevision/solar-solaire/solarflux/sx-5-flux-en.php>
- CMEs:
  - CACTus: <https://www.sidc.be/cactus/out/latestCMEs.html>
  - SOHO: <https://soho.nascom.nasa.gov/data/Theater/>
  - STEREO: <https://stereo-ssc.nascom.nasa.gov/cgi-bin/images>
- Solar Wind:
  - DSCOVR: <https://www.swpc.noaa.gov/products/real-time-solar-wind>
- Geomagnetism:
  - NOAA Kp: <https://www.swpc.noaa.gov/products/planetary-k-index>
  - K Dourbes (K\_BEL): [http://ionosphere.meteo.be/geomagnetism/ground\\_K\\_dourbes/](http://ionosphere.meteo.be/geomagnetism/ground_K_dourbes/)  
([http://ionosphere.meteo.be/geomagnetism/K\\_BEL/](http://ionosphere.meteo.be/geomagnetism/K_BEL/) )
  - Dst: [http://wdc.kugi.kyoto-u.ac.jp/dst\\_realtime/presentmonth/index.html](http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/presentmonth/index.html)
- GOES electrons: <https://www.swpc.noaa.gov/products/goes-electron-flux>
- GNSS (TEC, ionospheric maps): <http://gnss.be/> ; <http://ionosphere.meteo.be/ionosphere/TEC/>

