Space Weather Impacts on Radio Propagation

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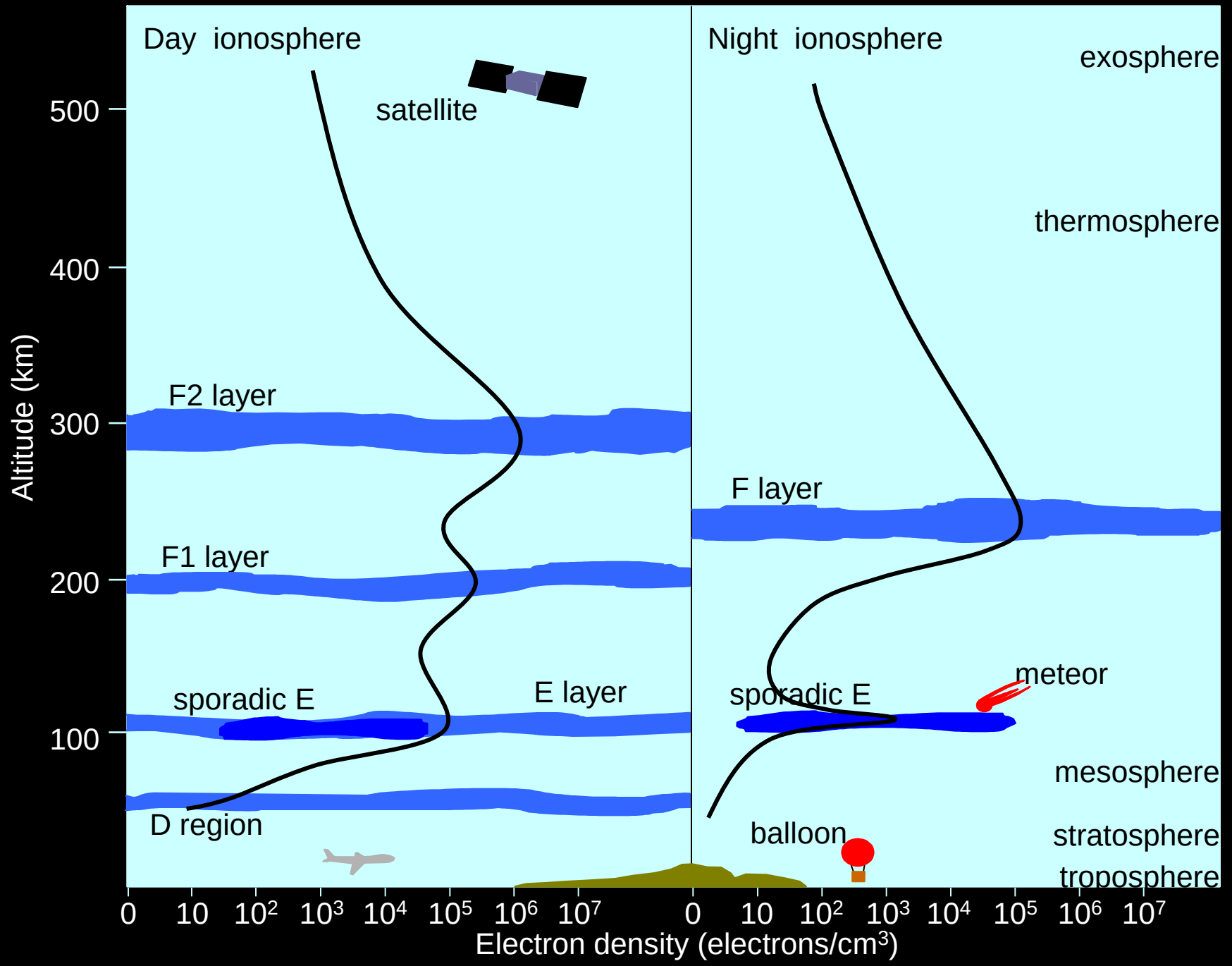
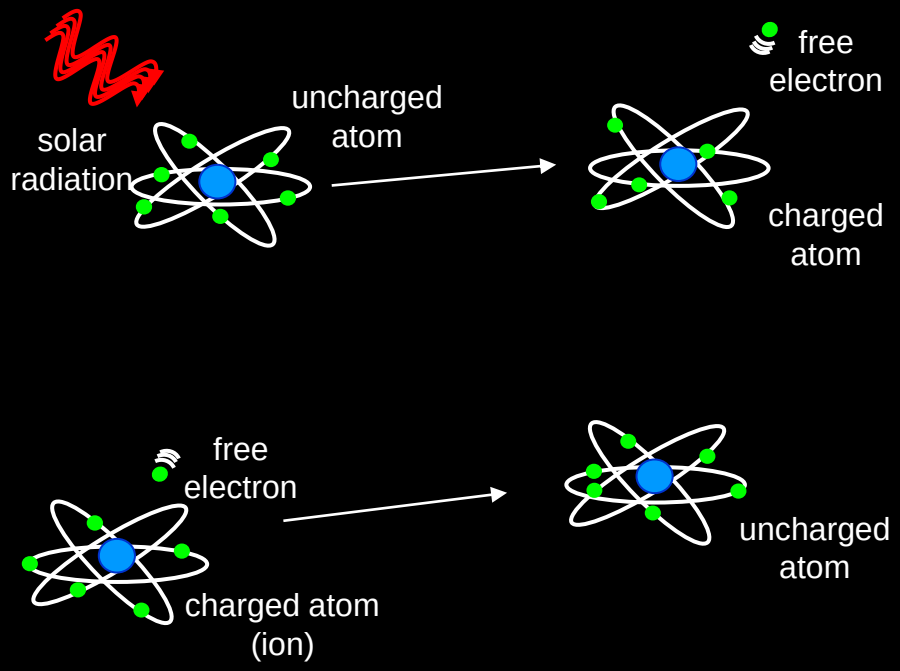
Objectives

- Understanding of how the ionosphere aids HF radio communication
- How space weather causes variability in the ionosphere and how that impacts HF communication
- How to forecast HF relevant space weather and how to minimise their impacts to HF users
- How space weather impacts GPS positioning

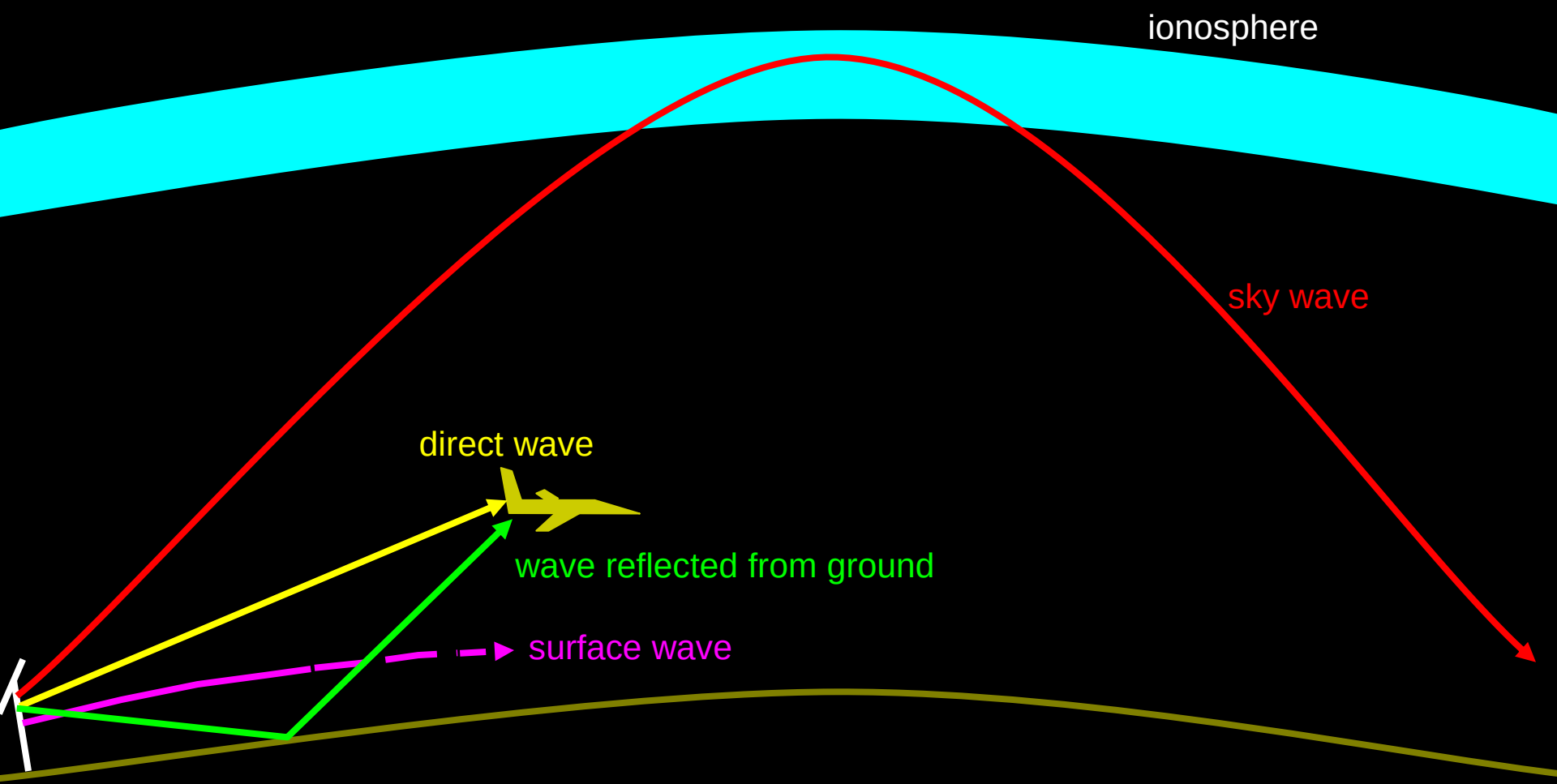

Day ionosphere
Night ionosphere
exosphere
satellite
thermosphere
F2 layer
F layer
F1 layer
meteor
sporadic E
E layer
sporadic E
mesosphere
D region
balloon
stratosphere
troposphere
Altitude (km)
500
400
300
200
100
0
10
10²
10³
10⁴
10⁵
10⁶
10⁷
Electron density (electrons/cm³)

Formation of the Ionosphere

- EUV radiation from the solar corona the main driver of ionization
- Recombination rate as a function of altitude depends on thermospheric chemistry
- Equilibrium between production and loss determines peak density and heights of ionospheric layers
- This is a simplified view, since electron transport plays an important role



Propagation of HF radio waves



HF Applications

- Compared with VHF/UHF and Satellite communications, HF is an older technology, but still plays an important role in aviation, maritime, for remote regions and defence.

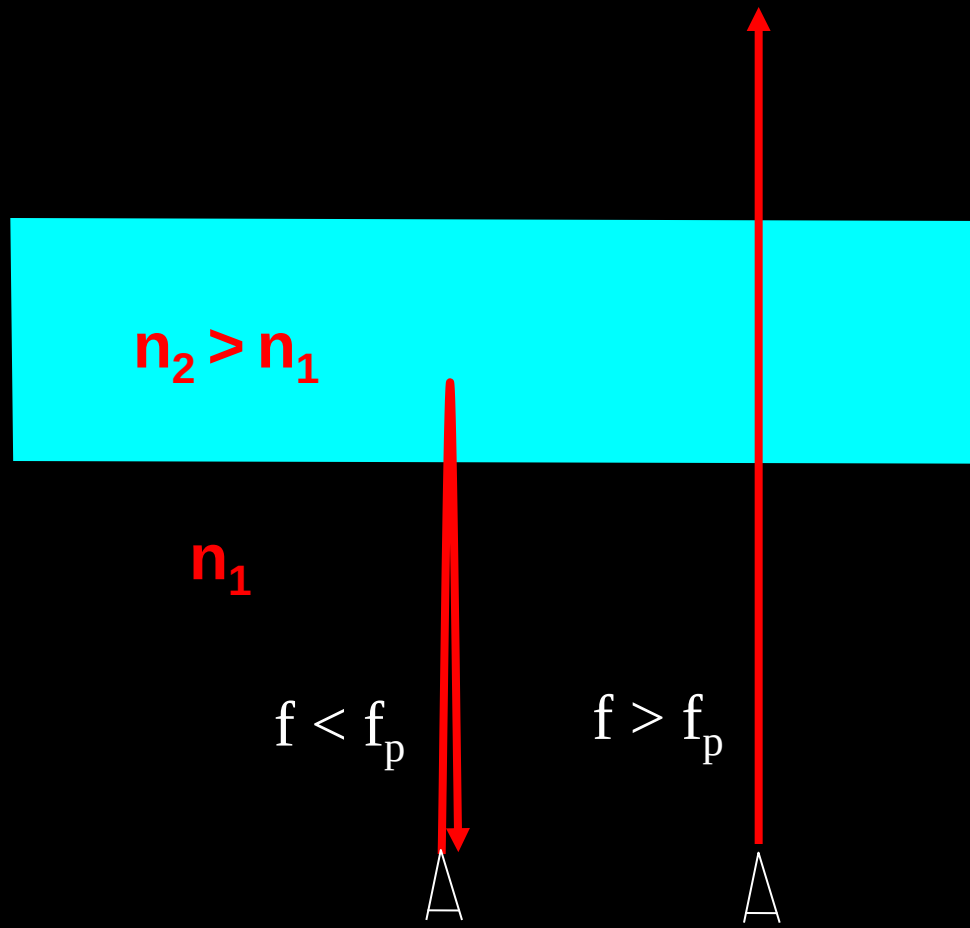
- The key advantage of HF over VHF/UHF is that line of sight is not required. Networks of repeater stations are used to allow over the horizon VHF/UHF communication, however this infrastructure is not present in all regions (particularly over oceans and poles).

Reflection of HF Skywave

- Refractive index of ionosphere is a function of electron density

$$n = \frac{1}{\sqrt{1 - \frac{f_p{}^2(\rho_e)}{f^2}}}$$

- For $f < f_p$, radio waves are reflected, $f > f_p$ waves will escape



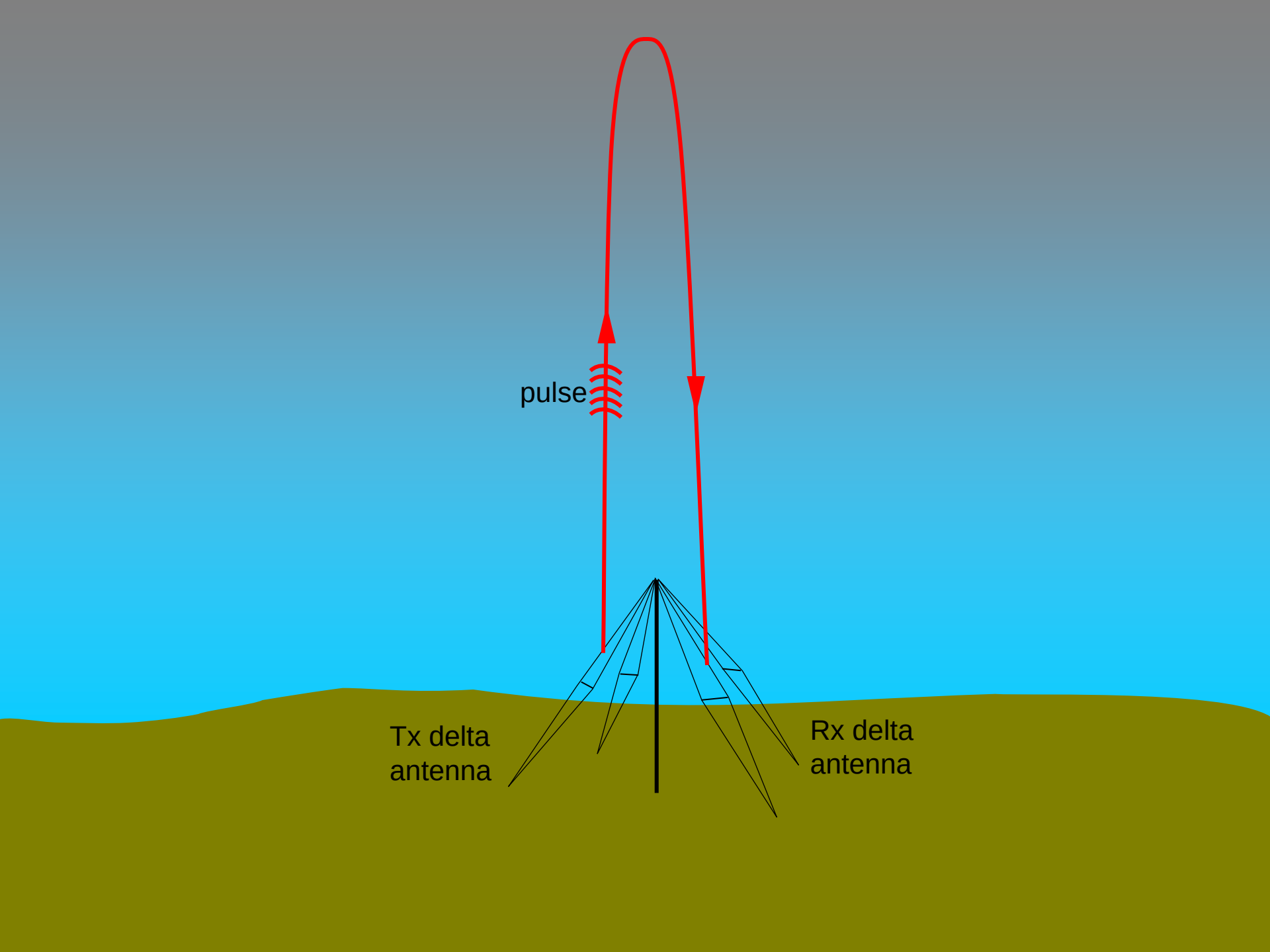
Why is Space Weather relevant to HF radio?

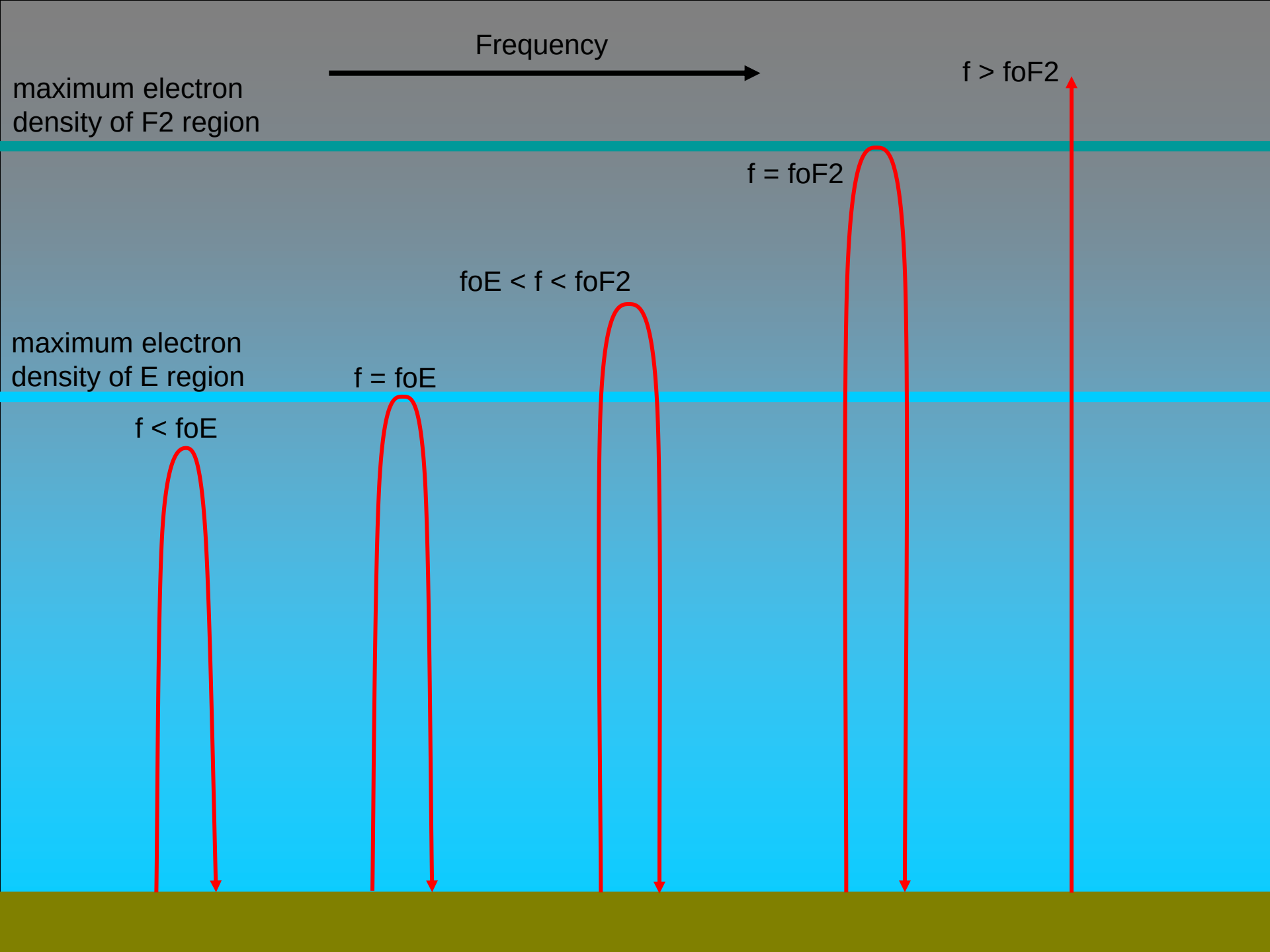
- The useable frequencies for HF communication depends on ionospheric conditions.
- Two way communication requires both users agree on frequency to use in advance
- Ionospheric conditions, and therefore useable frequencies, vary due to space weather, so space weather forecasts on long and short term timescales are required for frequency planning and management.

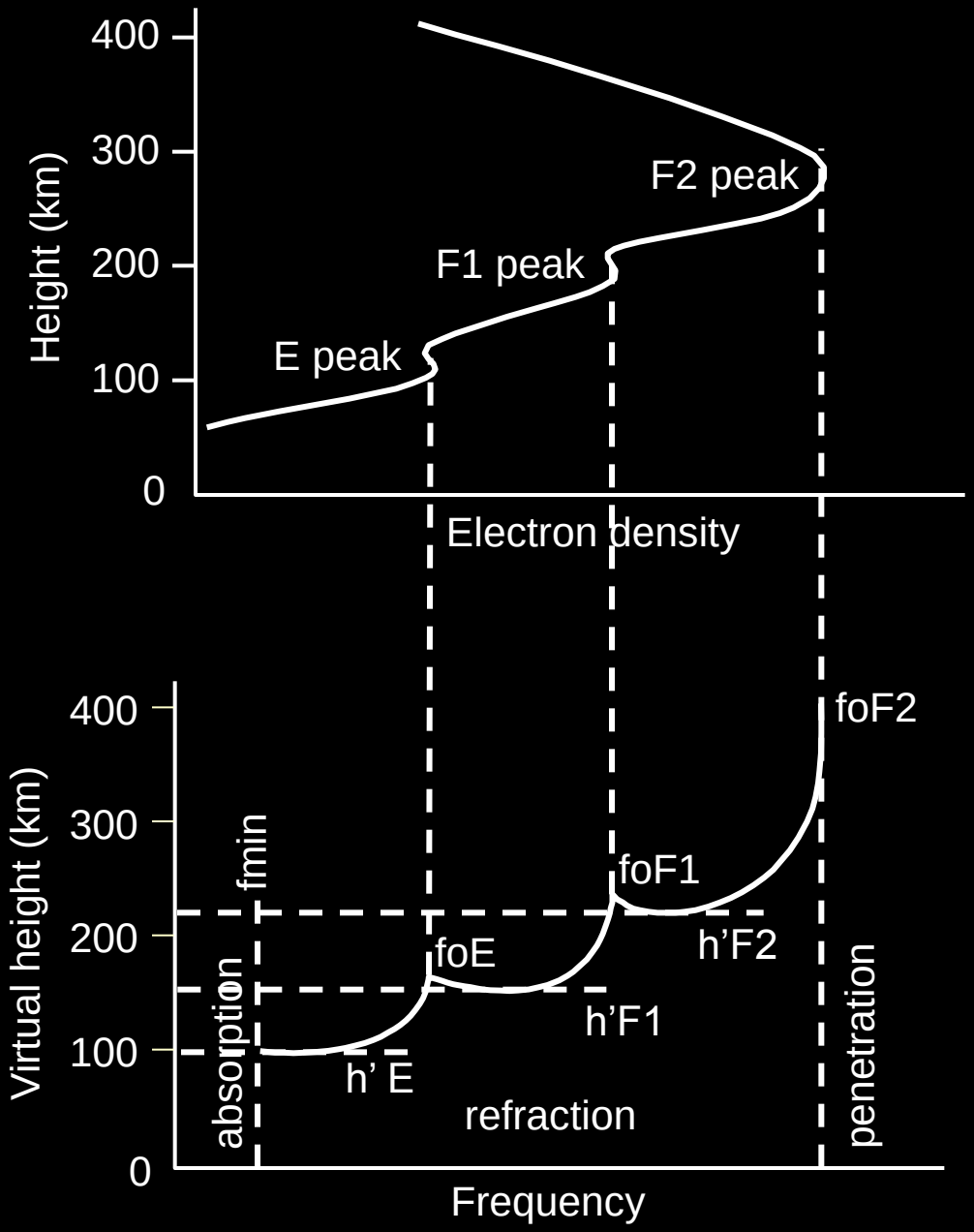
Ionosondes

- Important instrument for characterising the (bottomside) ionosphere.
- Transmits HF radio pulses over a wide frequency range and records time until echo received (if at all).

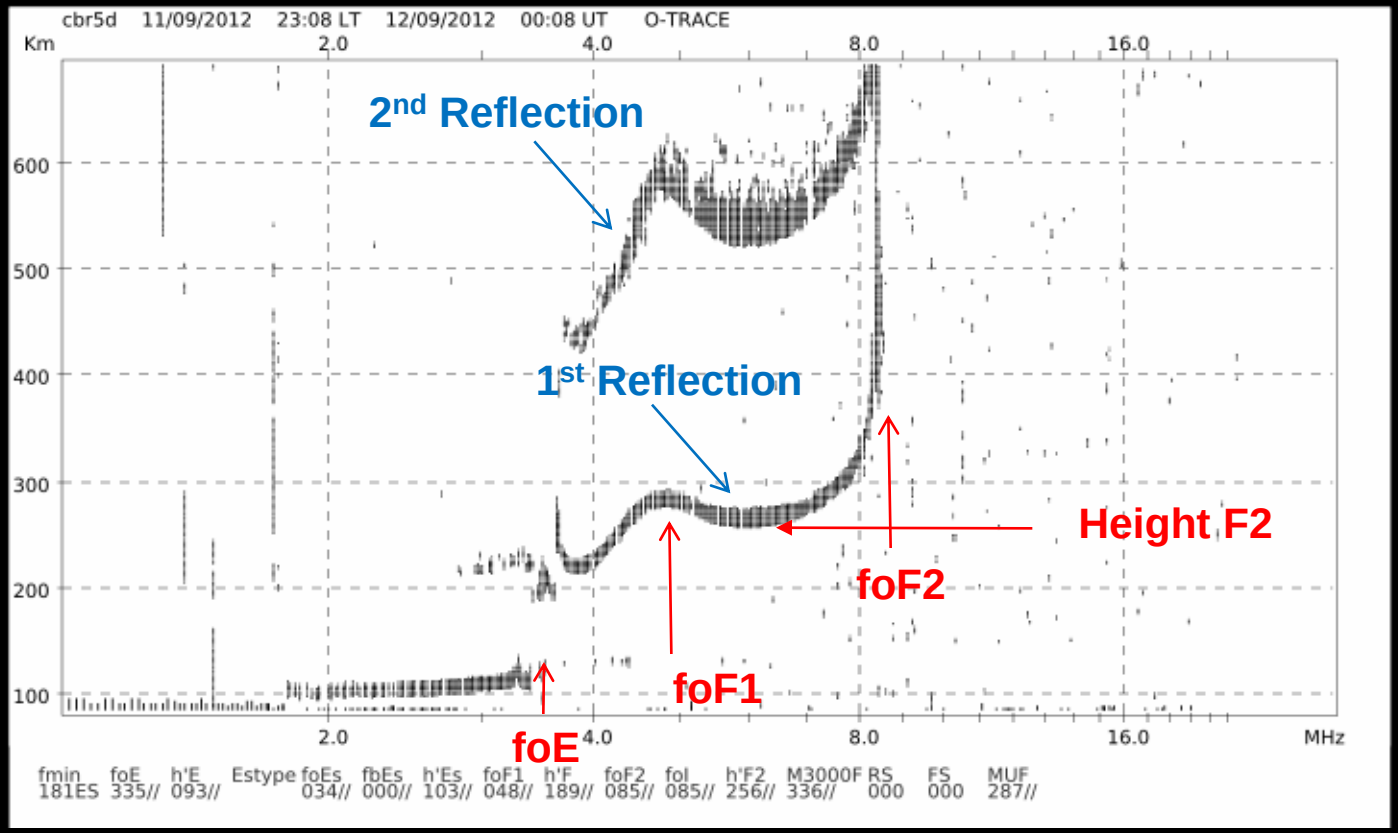
IPS Ionosonde at Casey, Antartica


pulse
Tx delta
antenna
Rx delta
antenna


Frequency
maximum electron density of F2 region
f > foF2
f = foF2
foE < f < foF2
maximum electron density of E region
f = foE
f < foE


400
300
200
100
0
Height (km)
F2 peak
F1 peak
E peak
Electron density
400
300
200
100
0
Virtual height (km)
fmin
foF2
foF1
foE
h'F2
h'F1
h' E
absorption
refraction
penetration
Frequency

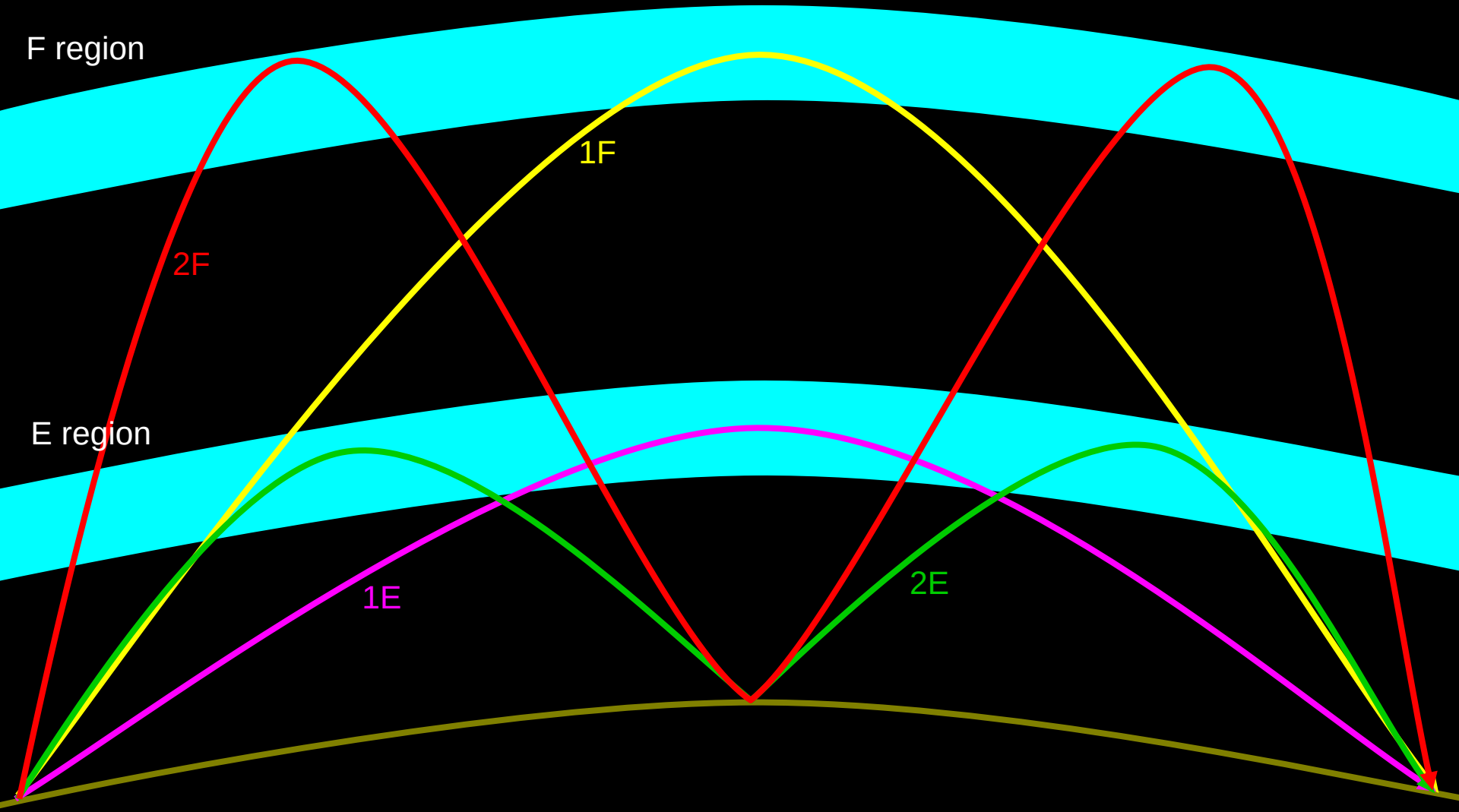
Typical Ionogram



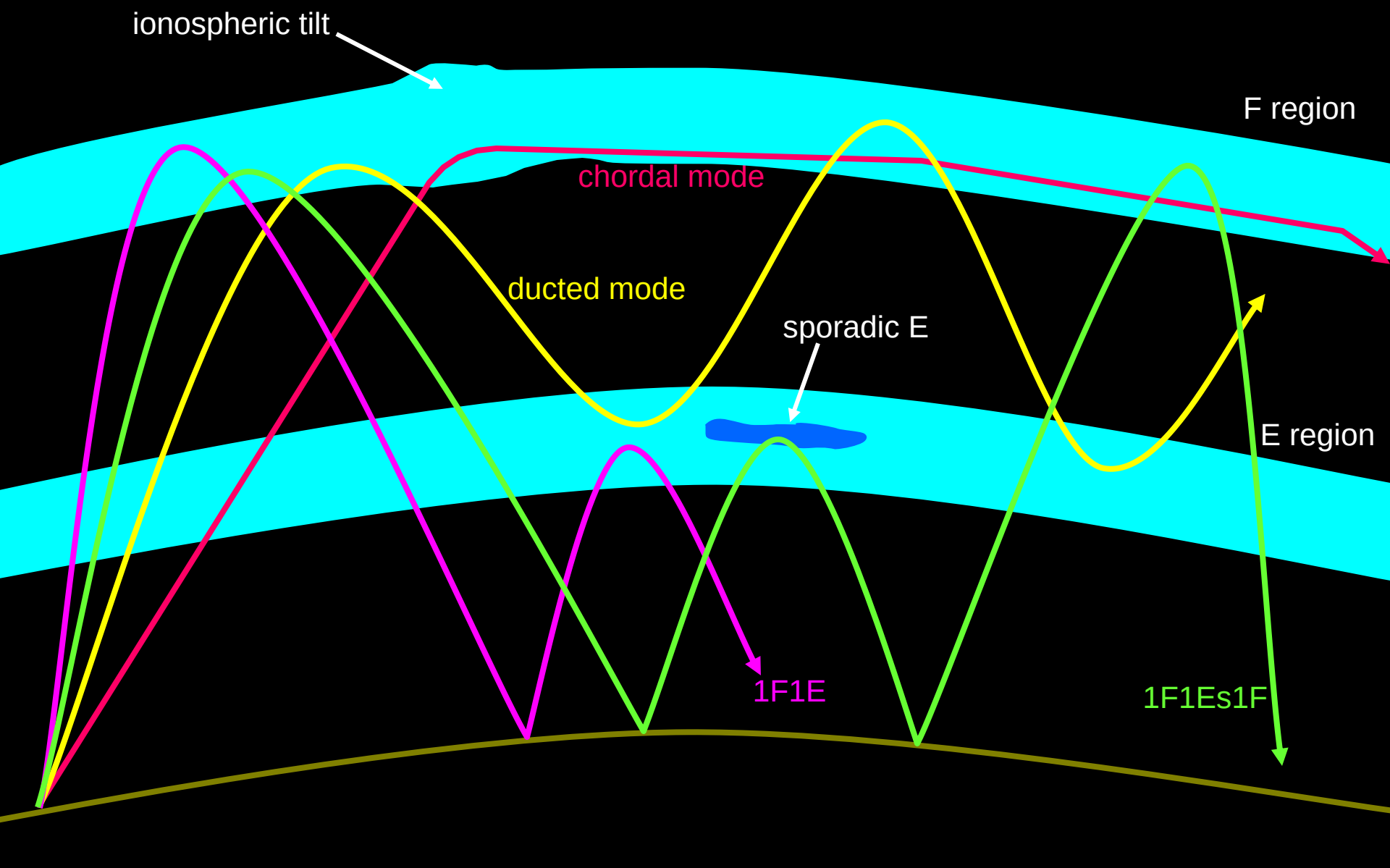
Virtual Height

Frequency

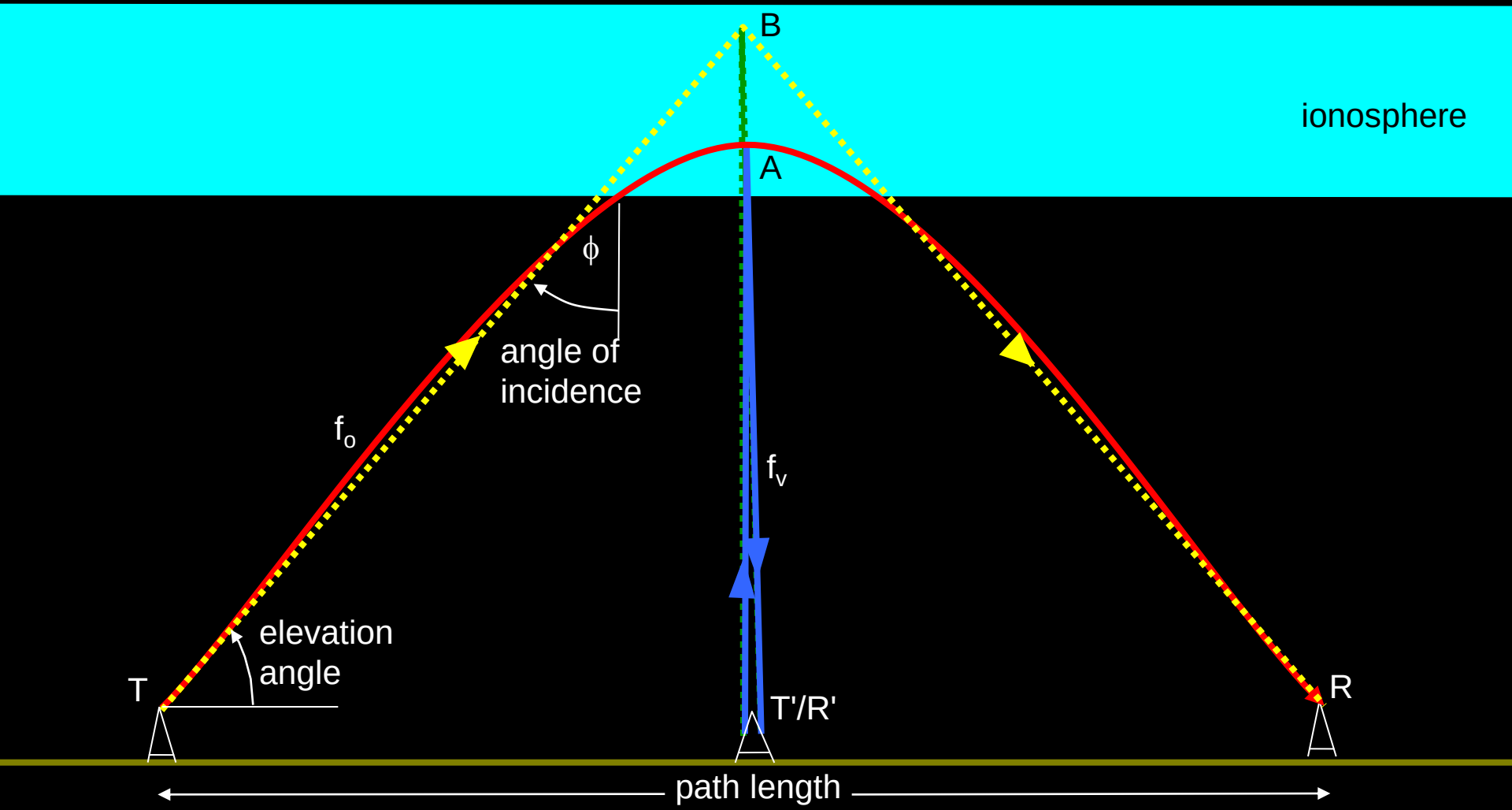
Propagation modes - simple modes



Propagation modes - complex modes



Relationship between vertical and oblique propagation



Why do we care about the Maximum Useable Frequency (MUF)?

- If high frequencies are in danger of escaping the ionosphere and not reflecting to receiver, why not just always use low frequencies to be safe?

Low Frequencies are Absorbed

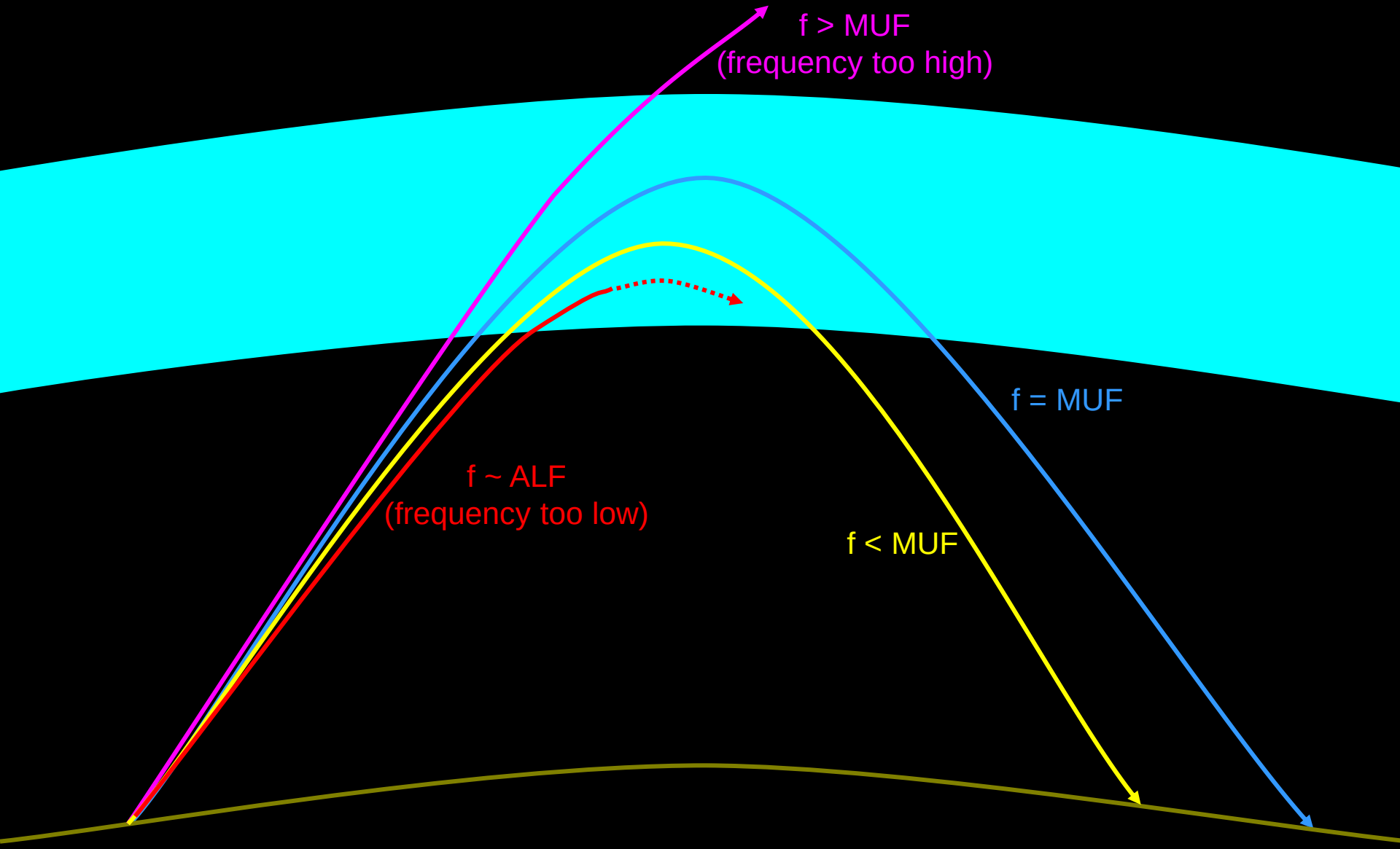
- Any radio wave not propagating through a vacuum suffers absorption loss.

$$\text{Absorption} \sim \frac{1}{(\text{frequency})^2}$$

- Absorption is higher in high density region (lower altitude), so we want to minimise the time spent at low altitude.

- Frequencies below absorption limiting frequency (ALF) cannot be used.

Frequency limits of HF sky waves

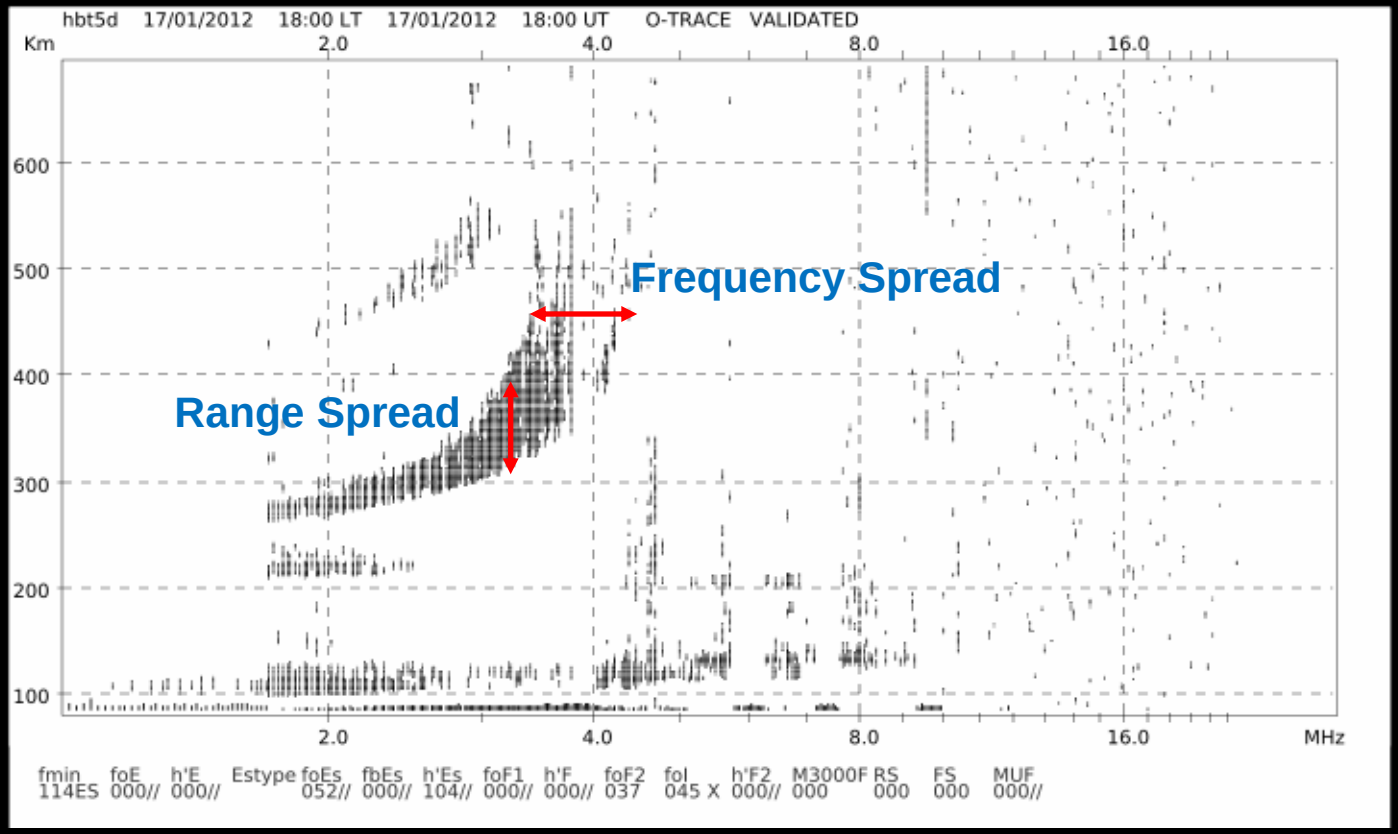


Ionospheric Disturbance

- Space weather events such as X-ray flares, CMEs and CIRs can cause significant ionospheric disturbances

- There are also several types of disturbance that can commonly occur outside of large space weather events

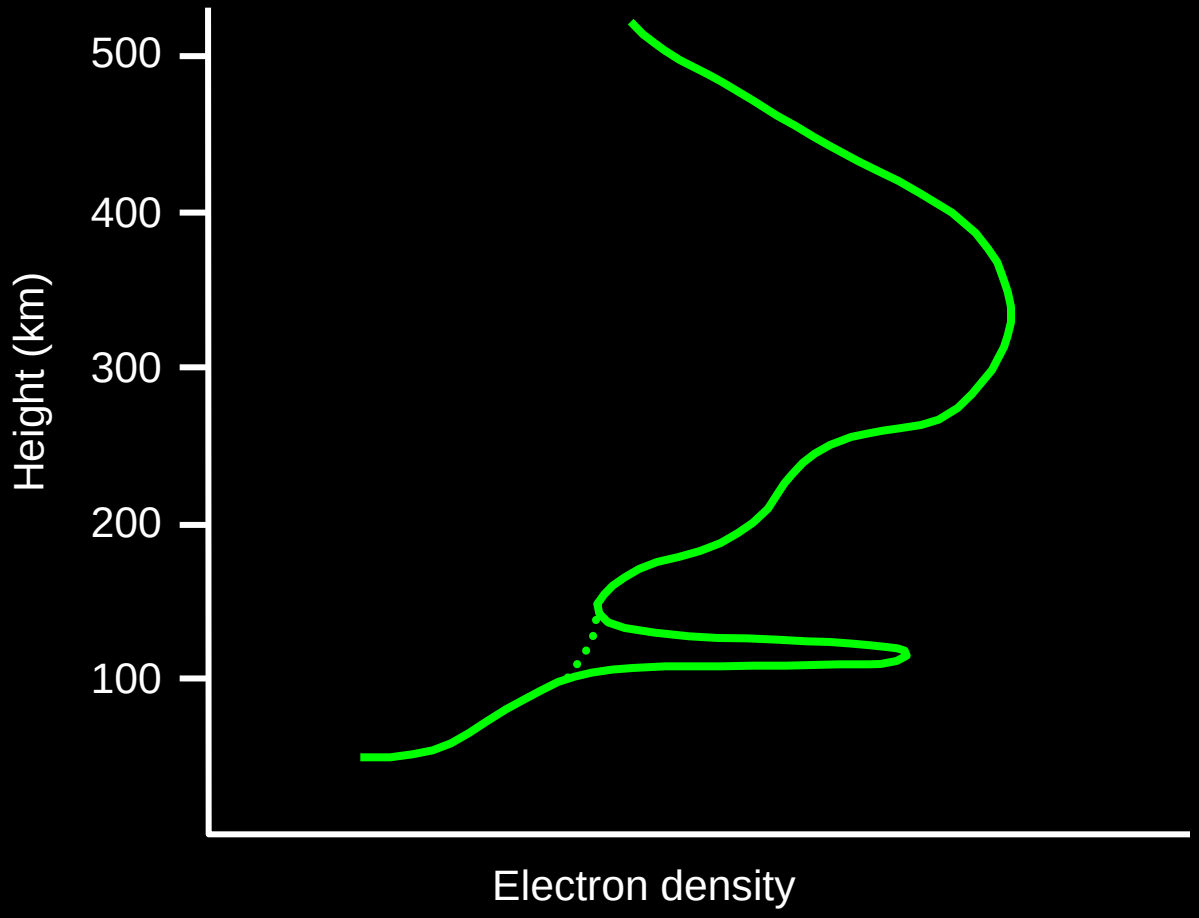
Spread F


hbt5d 17/01/2012 18:00 LT 17/01/2012 18:00 UT O-TRACE VALIDATED
Km
2.0
4.0
8.0
16.0
600
500
400
300
200
100
Frequency Spread
Range Spread
MHz
fmin foE h'E Estype foEs fbEs h'Es foF1 h'F foF2 foI h'F2 M3000F RS FS MUF
114ES 000// 000// 052// 000// 104// 000// 000// 037 045 X 000// 000 000 000 000//

Spread F

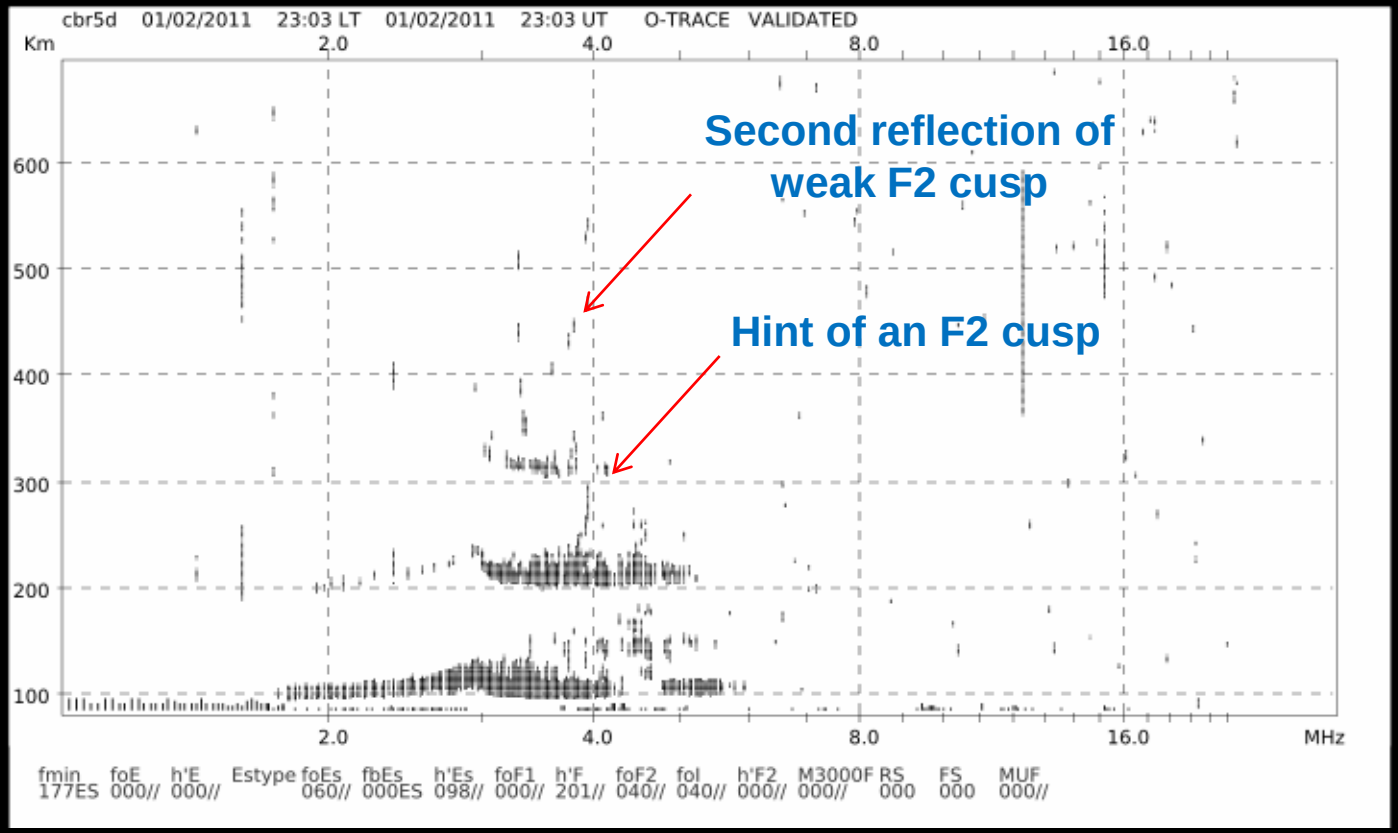
- Spread F is more prevalent at equatorial (lower than 20°) and higher (greater than 40°) geomagnetic latitudes;
- At equatorial latitudes, spread F is more likely at night, at the equinoxes and in summer.
- At higher latitudes, spread F is more prevalent at night and the equinoxes;
- Spread F is more likely when MUFs decrease;
- Spread F can cause high flutter fading rates in HF communications and disruptions to satellite communications and navigation from trans-ionospheric scintillation.

Sporadic E

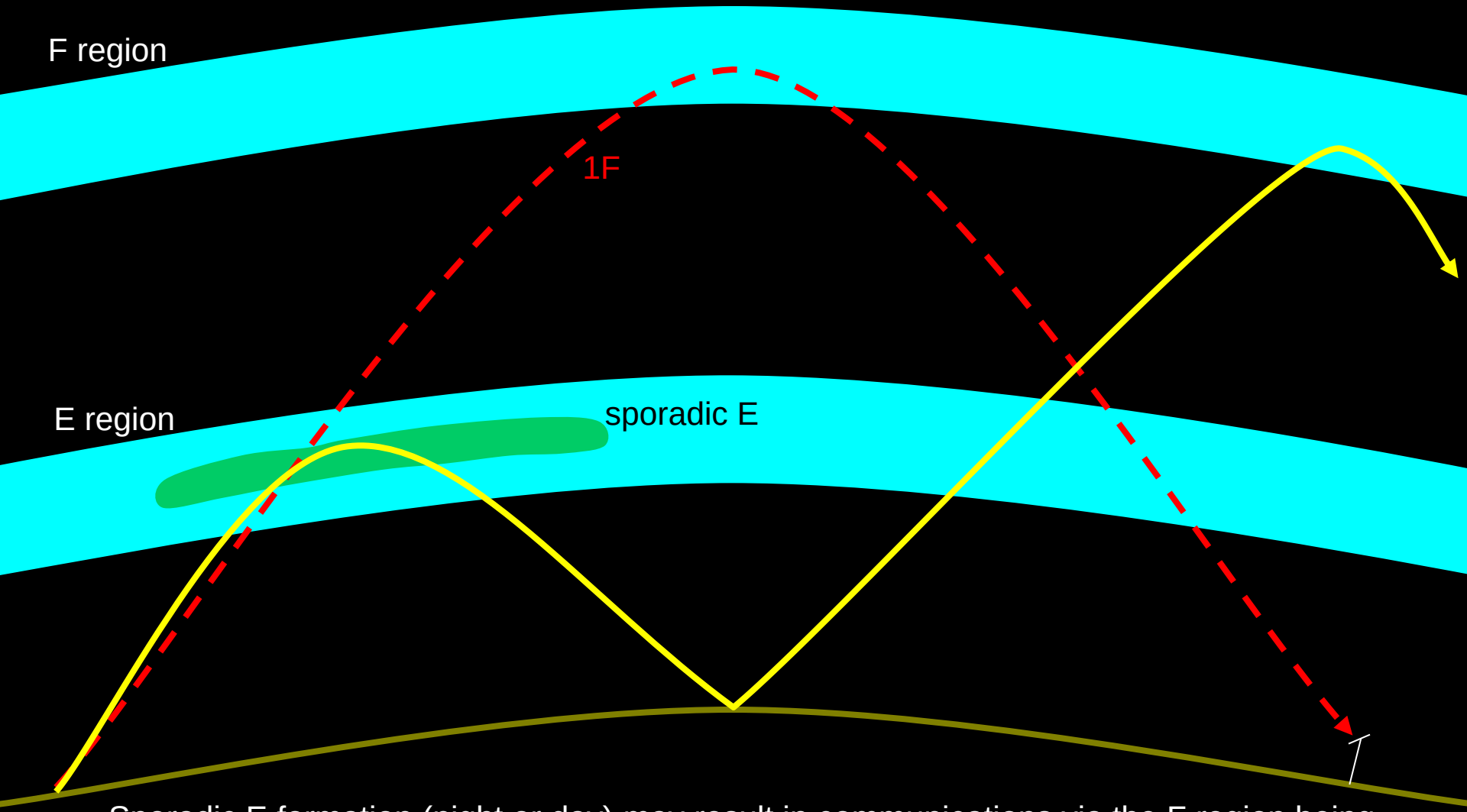


The electron density of sporadic E can sometimes be as great or greater than the electron density of the F2 region

Blanketing Sporadic E



Fading - Sporadic E



Sporadic E formation (night or day) may result in communications via the F region being interrupted if the sporadic E electron density is high enough to reflect the radio wave.

foF2 Variation

- foF2 varies with
  - Location
  - Time of day
  - Season
  - Solar Cycle

Time of Day Variation

- Ionospheric density depends on balance of electron production and loss, with electron transport playing an important role.

- At nightime, no ionosing flux so electron density and hence foF2 decreases

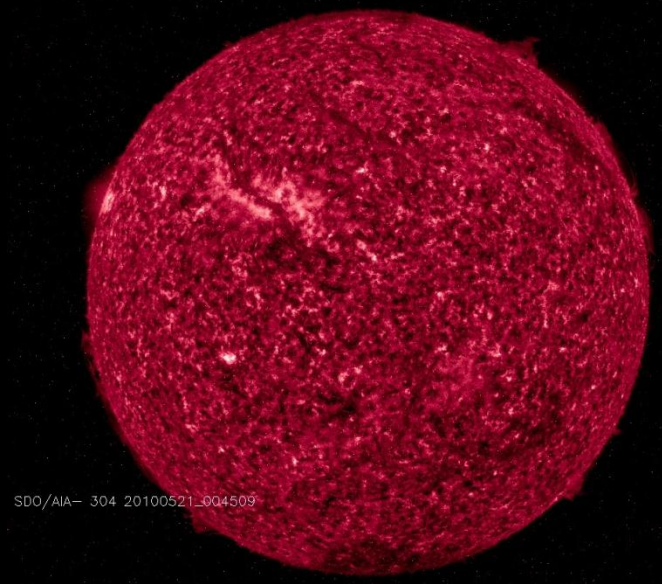
Seasonal Variation

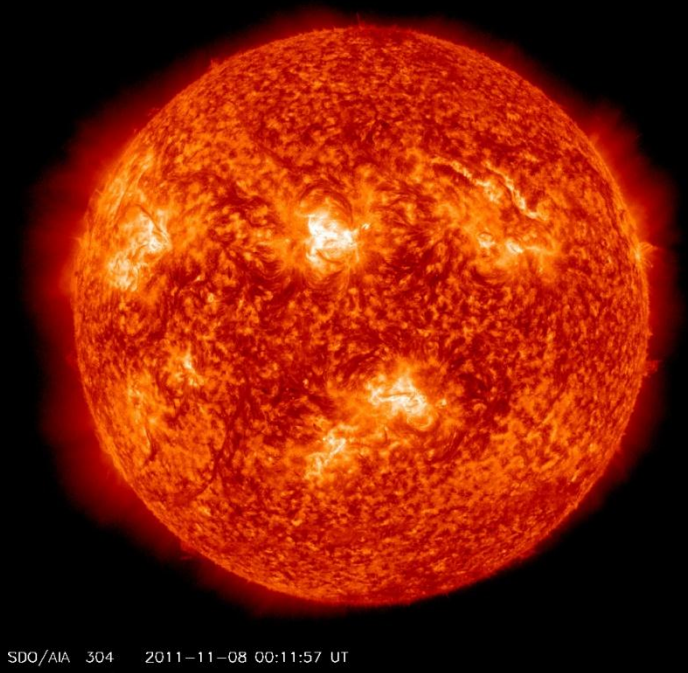
- Would you expect foF2 to be higher in summer or winter?

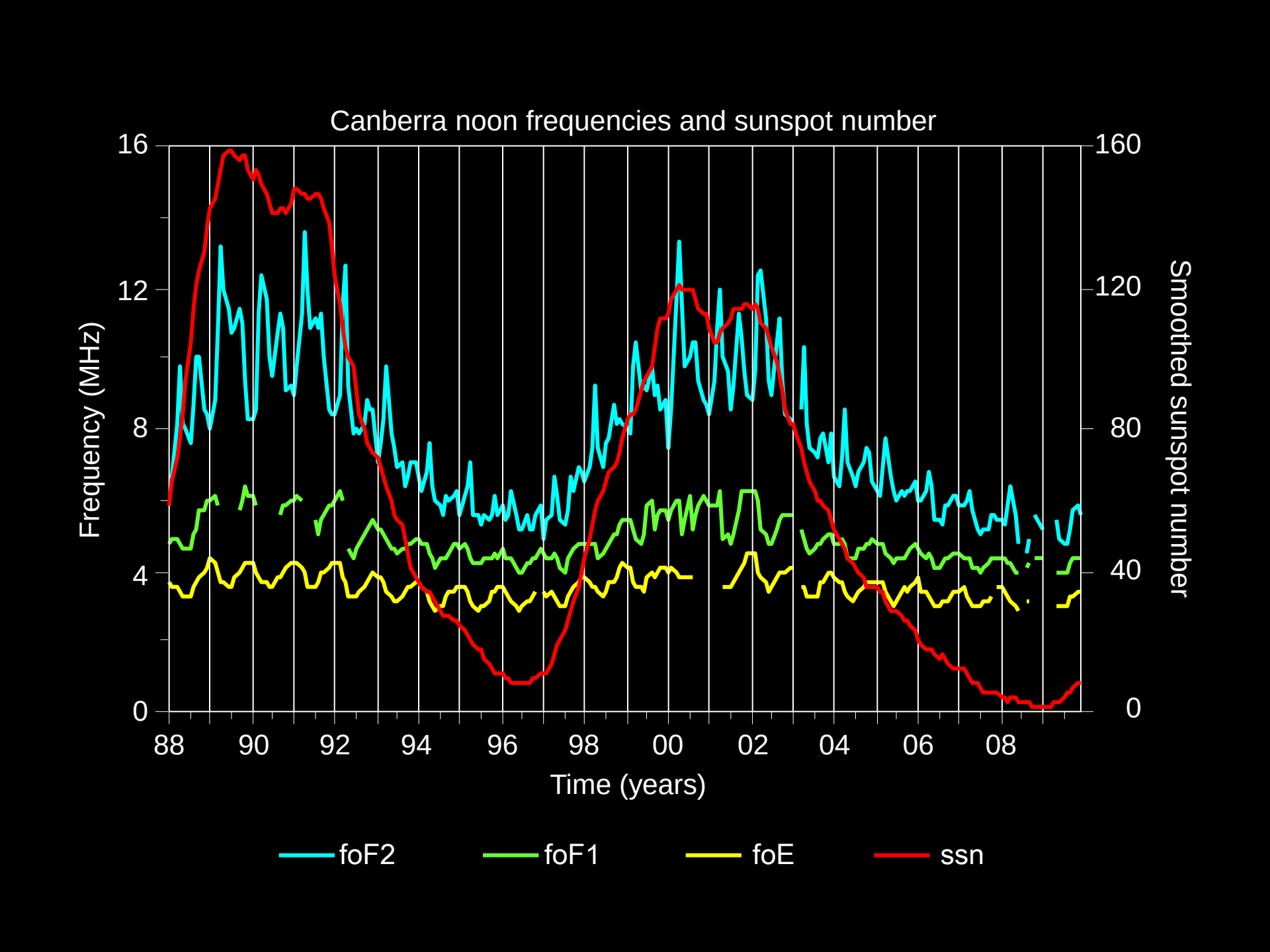
Seasonal Variation

- Would you expect foF2 to be higher in summer or winter?
- Ionoising flux is higher during summer, so we might expect higher foF2. However, theromospheric chemistry changes also occur changing re-combination rate and transport processes are different. The details are complex.
- Daytime winter foF2 can be higher than summer
- Nighttime winter foF2 is lower than summer

Solar Cycle foF2 Variation



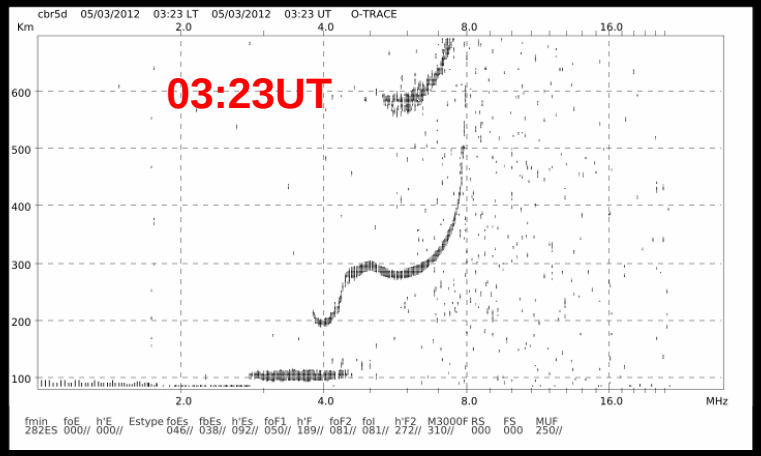


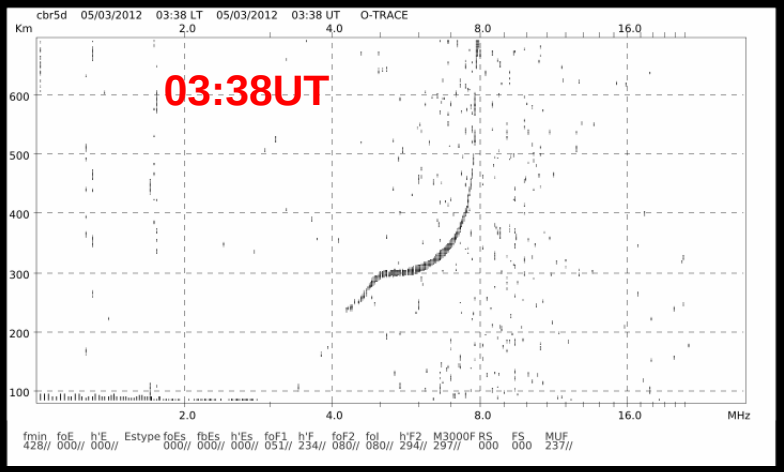

Canberra noon frequencies and sunspot number
Frequency (MHz)
Smoothed sunspot number
Time (years)
0
4
8
12
16
0
40
80
120
160
88
90
92
94
96
98
00
02
04
06
08
foF2
foF1
foE
ssn

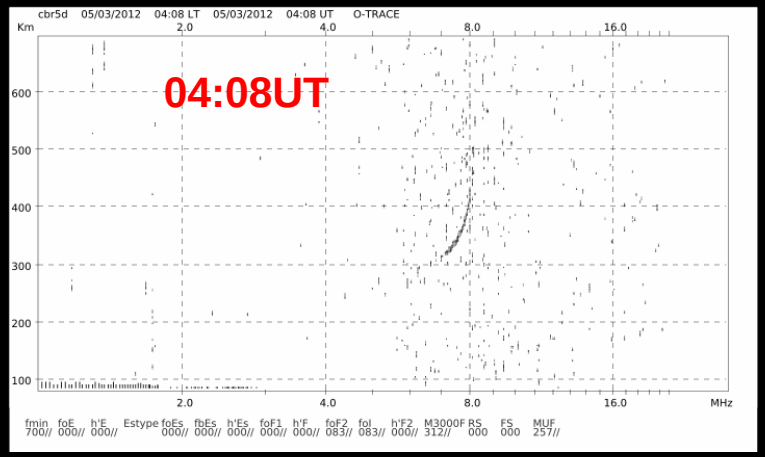
Space Weather Effects

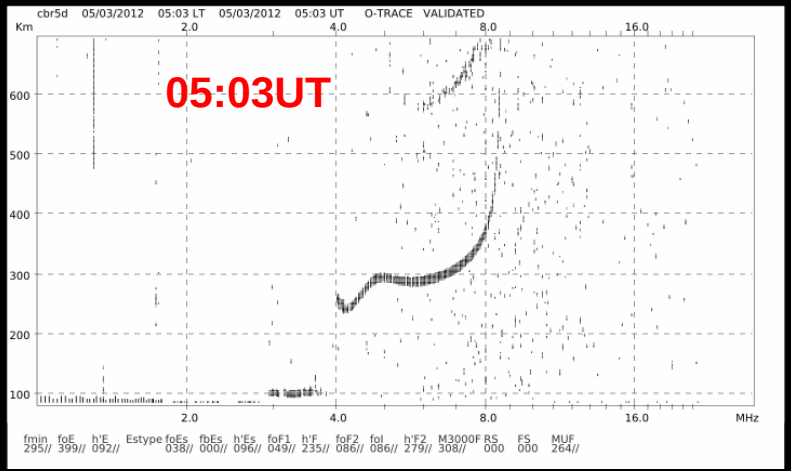
- X-ray flares
- Geomagnetic Storms
- These often but not always have a common cause (i.e. a large flare with associated CME) but the effects are different

X-ray Flares and sudden ionospheric disturbance







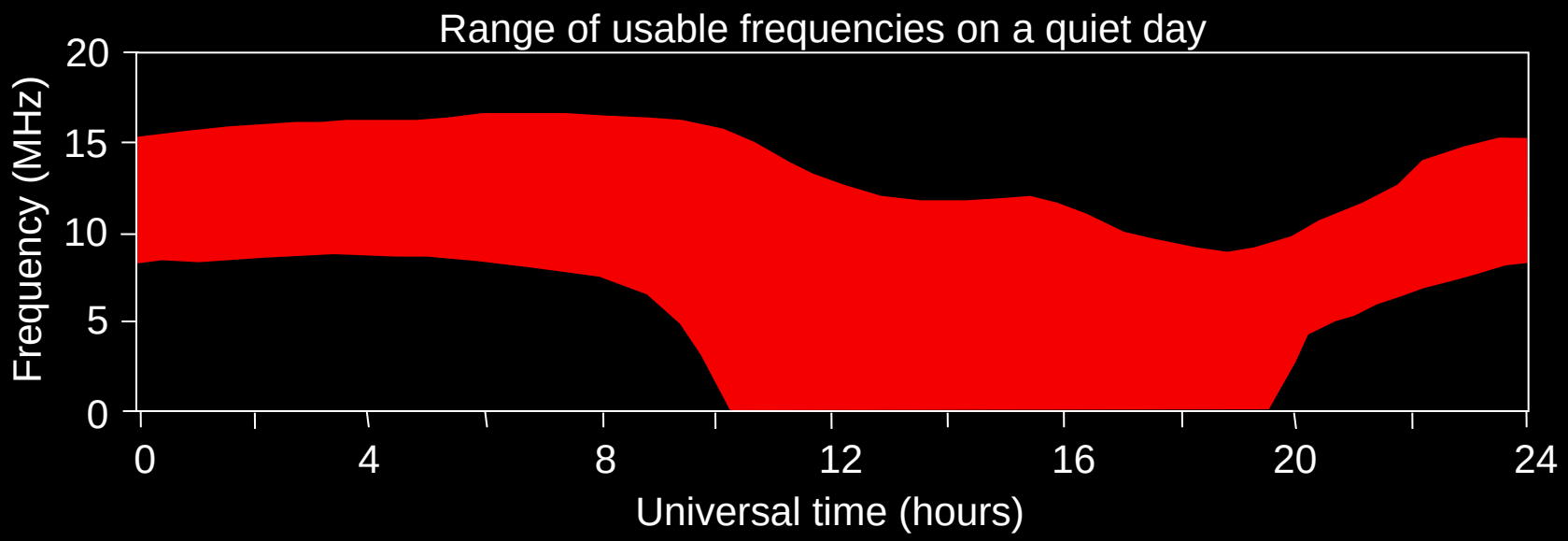


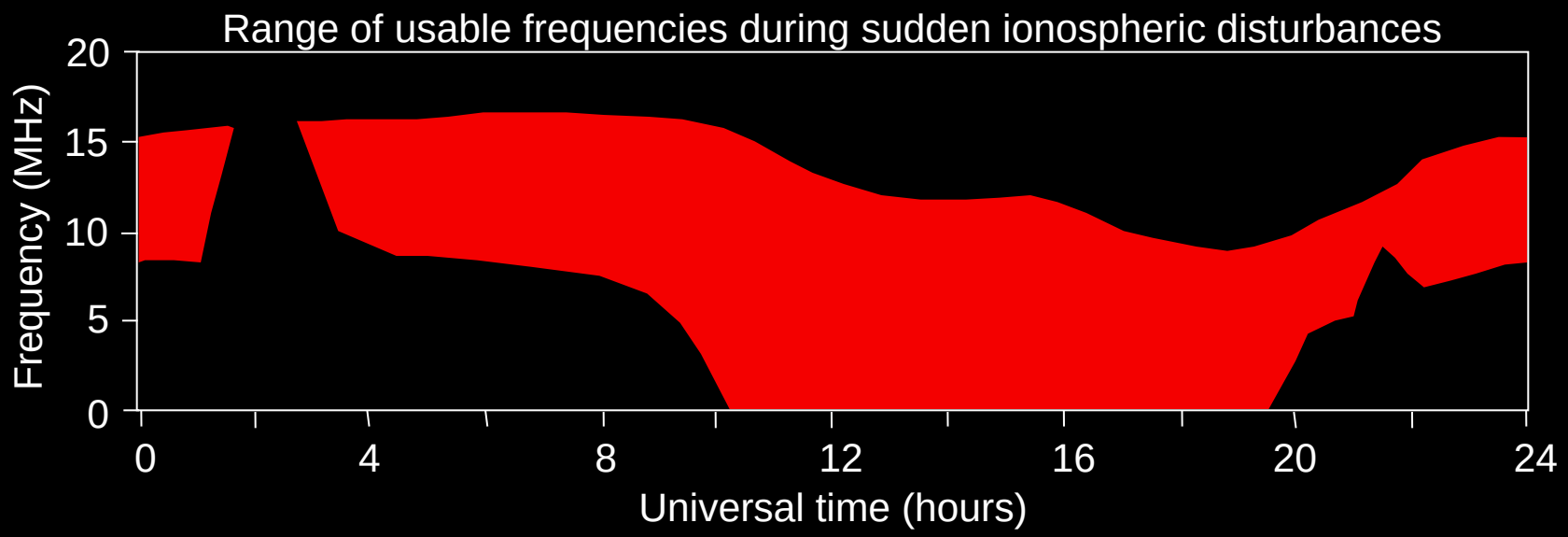
Why do X-ray flares cause fadeouts?

- Huge increase in X-ray intensity produces significant ionisation at much lower altitudes than normal, in the D layer (~ 80-100Km)

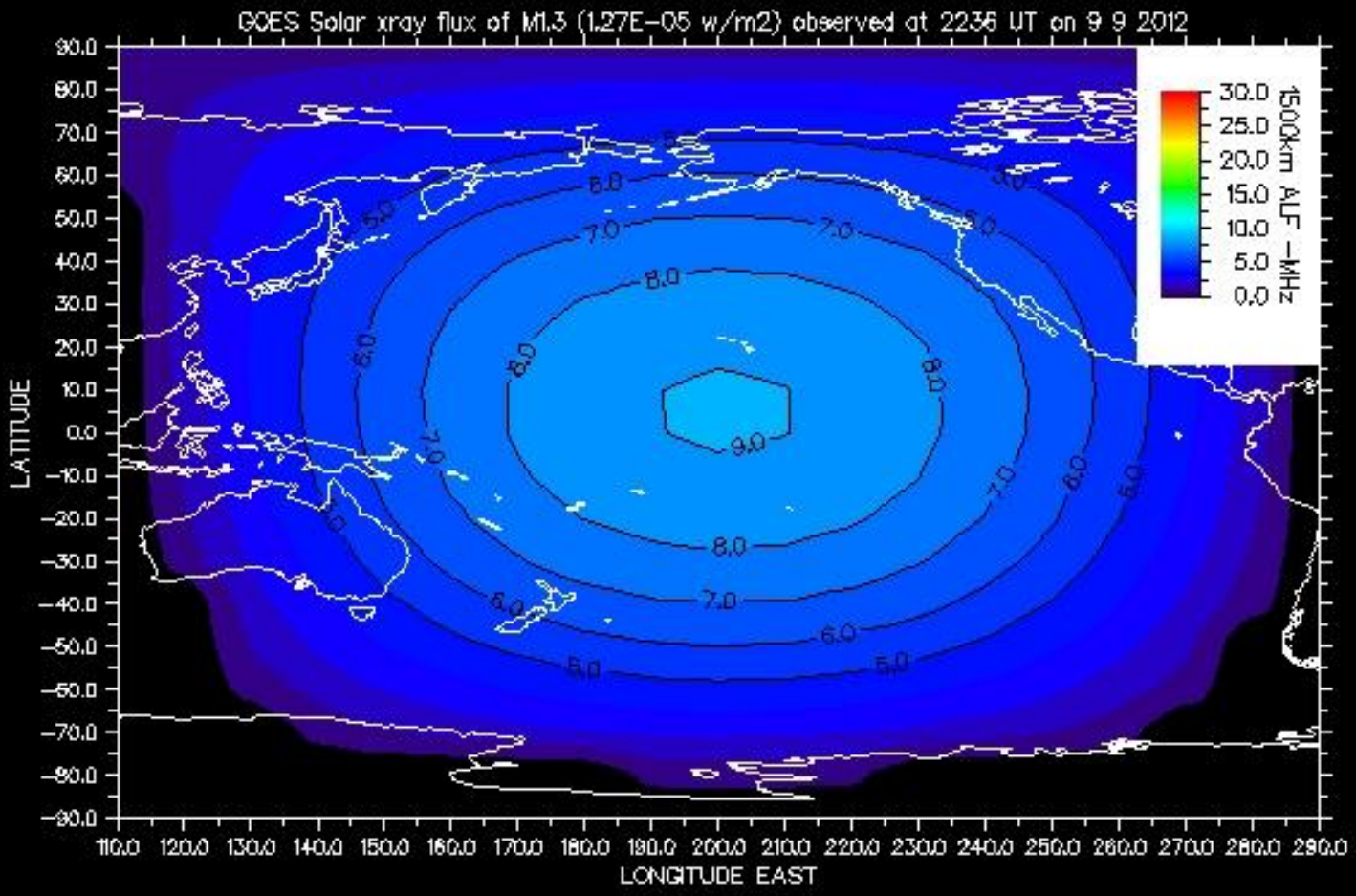
- The gas density is much higher in the D-region, so propagating radio signals suffer from greater collisional loss.

Flare effects on HF frequency band





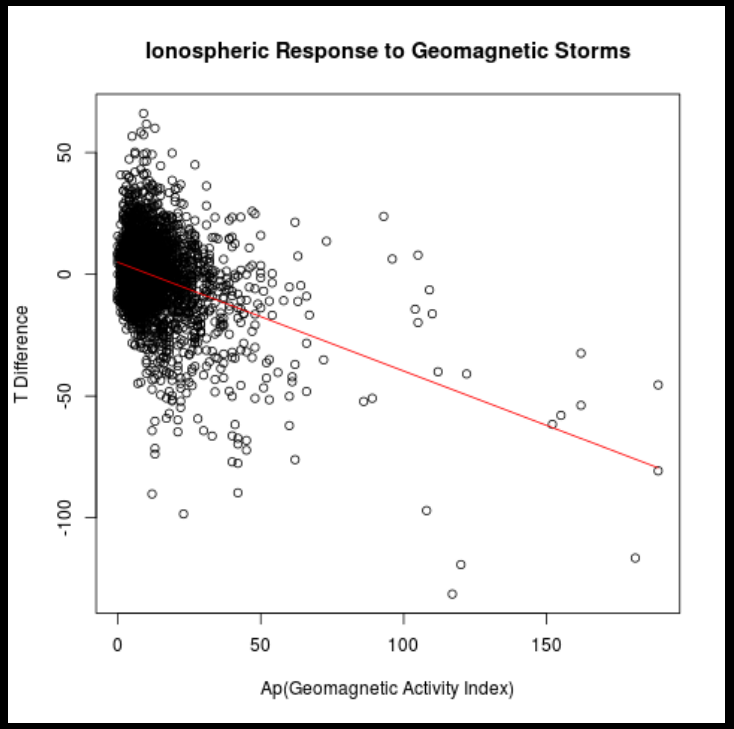
Fadeout Map

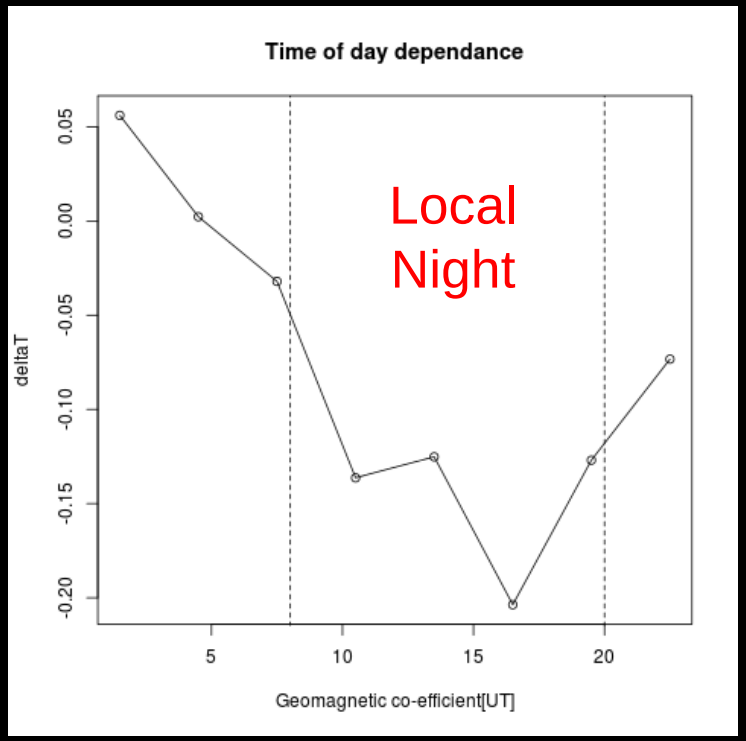

GOES Solar xray flux of M1.3 (1.27E-05 w/m2) observed at 2236 UT on 9 9 2012
1500km ALF -MHz
30.0
25.0
20.0
15.0
10.0
5.0
0.0
LATITUDE
LONGITUDE EAST

Geomagnetic Storms

- Large geomagnetic storms can have a significant impact on the ionosphere
- The more poleward the location, the more significant the effects.
- The local time of day of the geomagnetic activity plays an important role in the ionospheric response.

Geomagnetic Activity and foF2 Depressions





Hands on

- Put all data, README.txt and *.jar files in the same directory.
- For Windoze/Mac, double click wdc_cid.jar, for *NIX type java –jar wdc_cid.jar
- Change date to d:31, m:05, y:03 (i.e. 31st of May 2003).
- Large list of stations in menu, you have data for stations Darwin, Brisbane and Hobart.
- Some questions to investigate
  - Look at Brisbane and Darwin between 02-03UT. What event do you observe? Do you see this at Hobart? Why?
  - Look at Hobart. Do you see any Spread F or Sporadic E? If so when?
  - Try scaling some foF2 values at the same time each hour over the day. How does it vary? What time do you think is local sunrise and sunset at each location?

HF Prediction, modelling and forecasting service

- IPS uses the T-index, which uses decades of ionospheric maps to determine the mean expected conditions given the location, time of day, season and T index

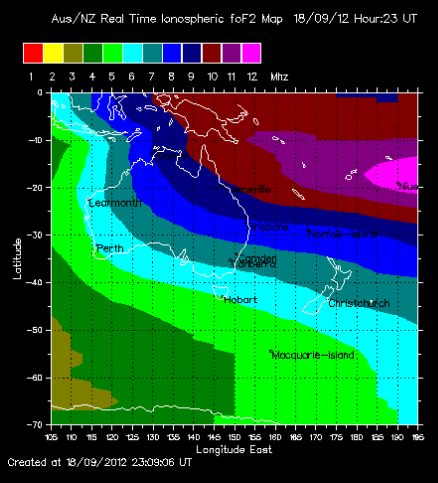
- Forecast monthly T index, based on sun-spot number predictions. This allows long term frequency management for customers.

- The T-index is used by our HF circuit prediction tool, ASAPS (Advanced Stand Alone Prediction Tool) to predict the best HF frequencies for a given circuit.

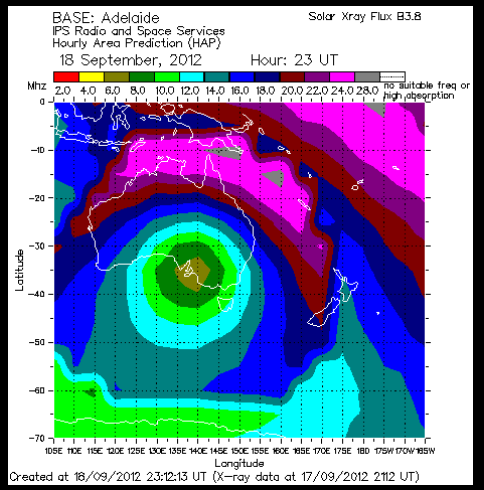
HF Circuit Prediction

Monthly T index

foF2 map

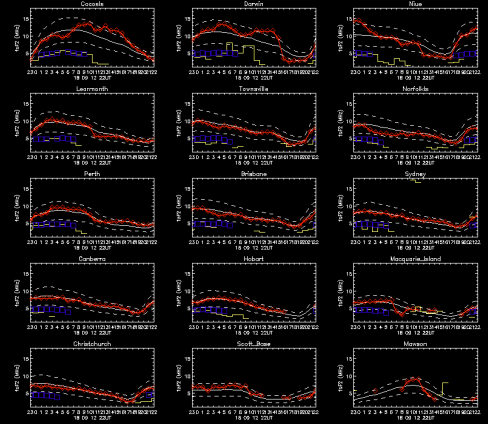


Optimal Frequencies

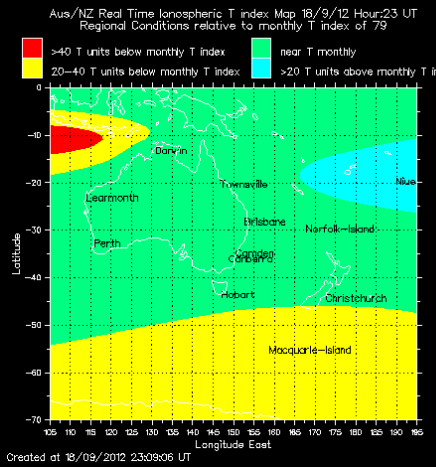


Nowcast Corrections

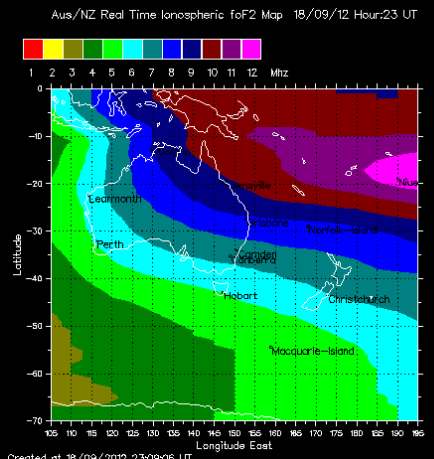
Real time foF2 from Ionosondes



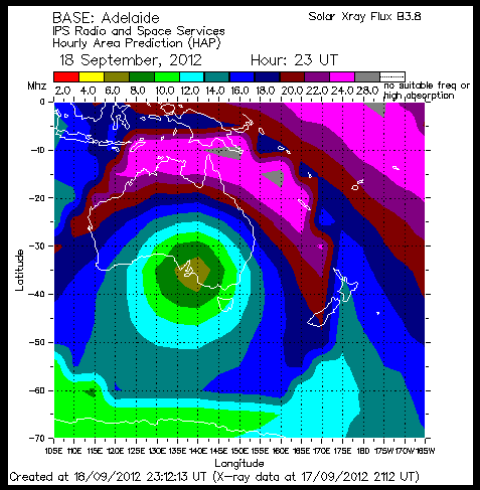
T index difference map



foF2 map



Optimal Frequencies



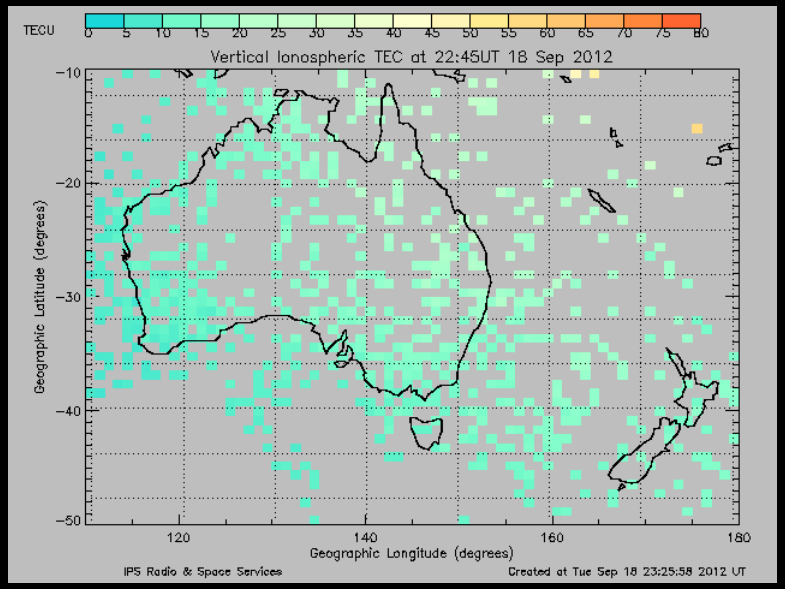
3-day Forecast

- Forecasts are generally more useful than nowcasts (if they are correct!)

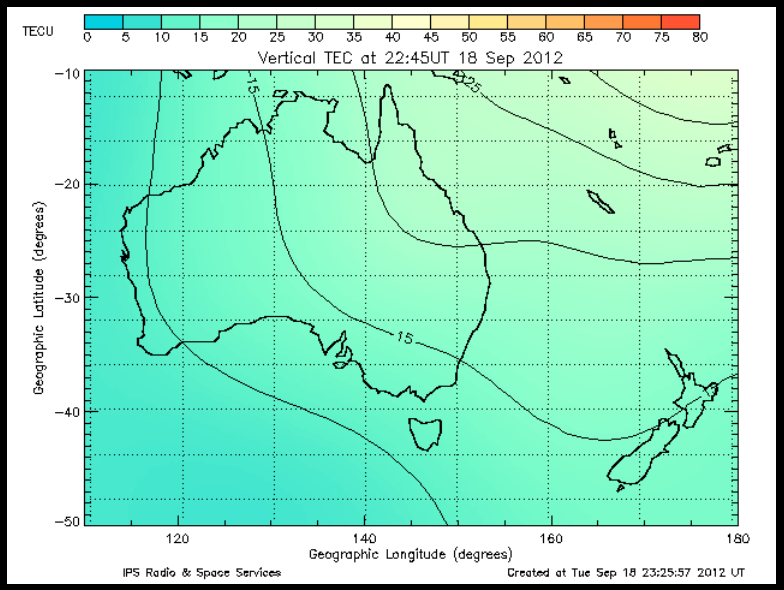
- IPS issues forecasts for 3 days ahead each day at 2330UT

GPS TEC Real Time Map

Ionospheric Pierce Points (IPPs)

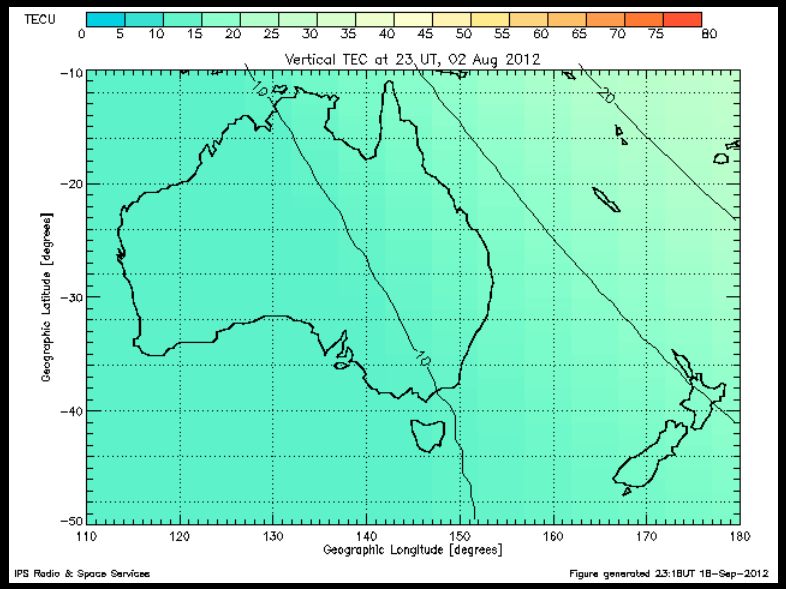


TEC map composed of a linear sum of basis functions

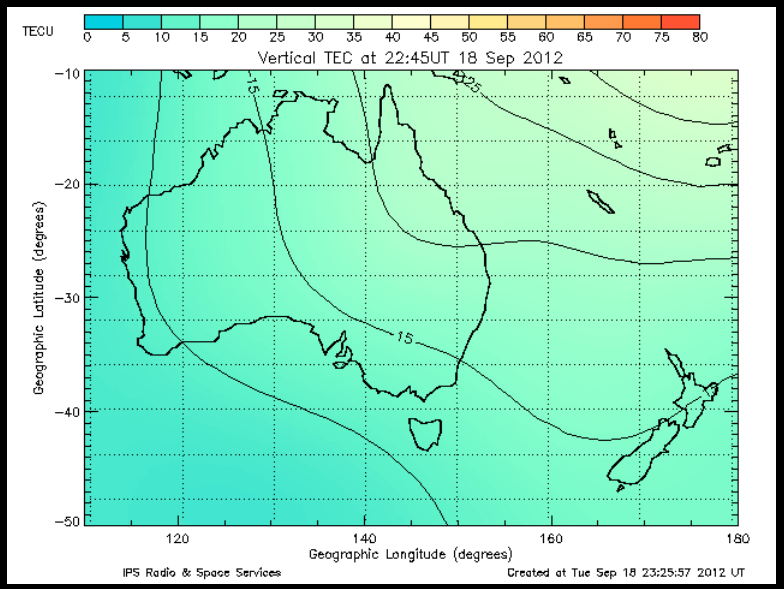


GPS TEC Real Time Map

GPS Broadcast TEC model

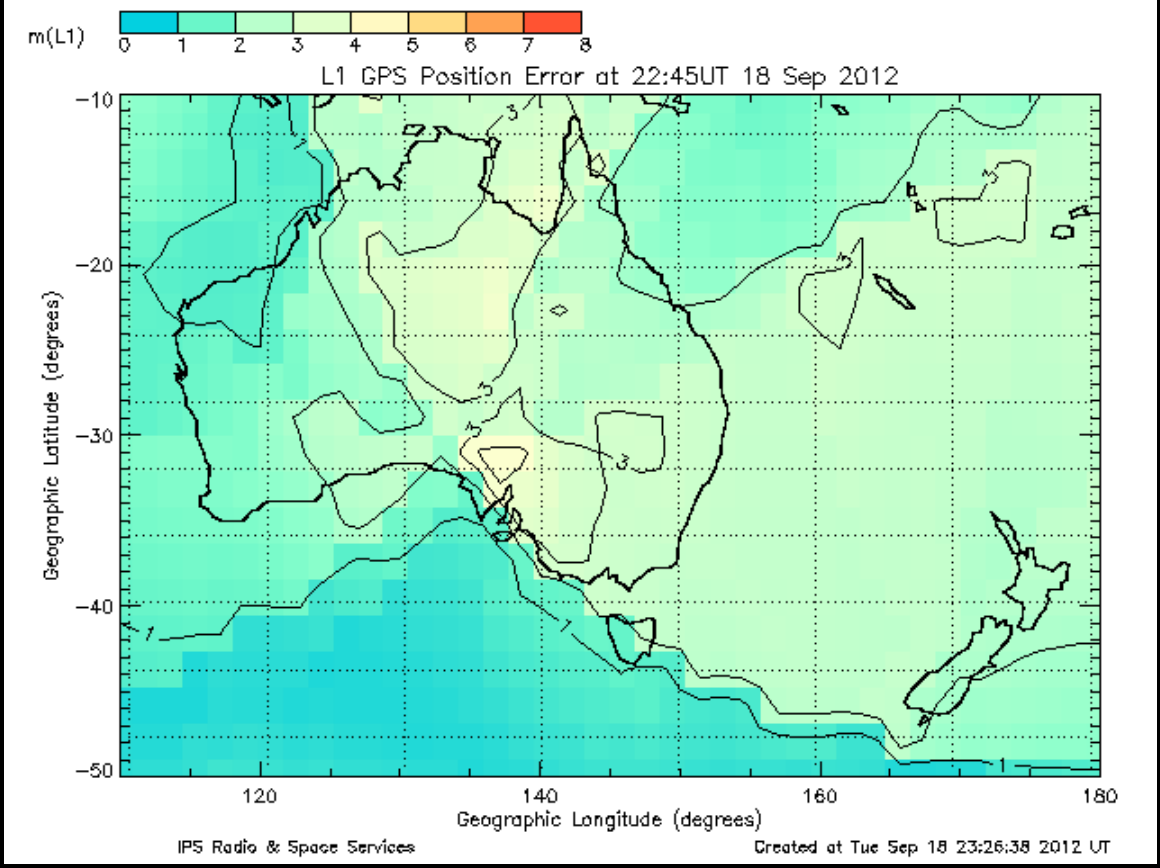


Real time TEC map



GPS TEC Real Time Map

Real time estimate of the contribution of the ionosphere to single frequency GPS positioning error.



Ground Based Augmentation Systems