Ionospheric Weather and Climate

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Space Weather Impacts Course, 2023-12-04

RMI

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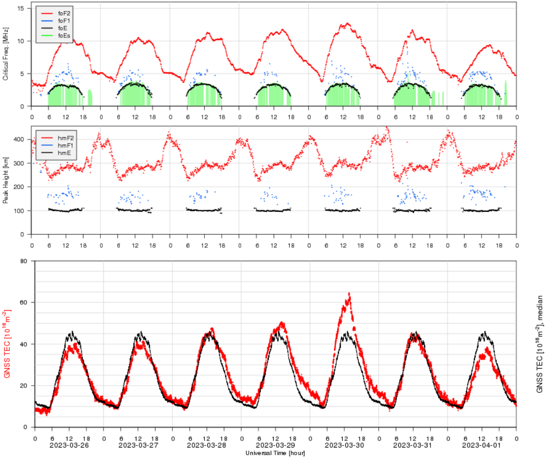
Outline

1. Mid-latitude climatology
   - Diurnal variations
   - Seasonal variation
   - Solar cycle variations
   - Variability on other time scales
2. Low-latitude climatology
   - Diurnal behaviour of the equatorial ionisation anomaly
   - Non-migrating tides
3. High-latitude climatology
   - Polar cap

Mid-latitude climatology

Diurnal variations



Peak densities and heights of the layers, and total electron content. Main features: foF_2 and $vTEC$ are maximal during day, minimal at night; hmF_2 is highest in the morning hours; E and F_1 layers seen only during the day.

The lower layers

The E and F_1 layers are almost entirely driven by direct photoionization, and thus easily modelled.

The E layer peak density is very well modelled by

$$foE = 3.3\sqrt[4]{(1 + 0.008 \cdot R)\cos\chi}$$

(R = sunspot number, χ = solar zenith angle).

The F_1 layer density, if present, is reasonably well modelled as:

$$foF_1 = 4.25\sqrt[4]{(1 + 0015 \cdot R)\cos\chi}$$

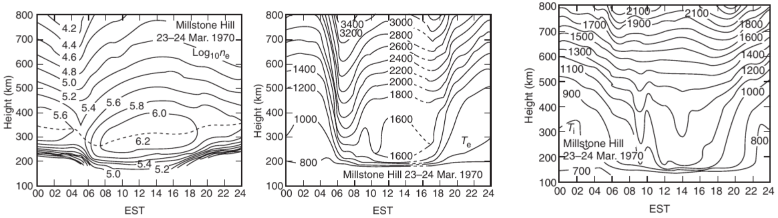
Both layers are well described by the Chapman profile:

$$N_e(h, \chi) \propto \exp\left\{\frac{1}{2}\left[1 - \frac{h - h_m}{H_s} - \exp\left(-\frac{h - h_m}{H_s}\right)\sec\chi\right]\right\}$$

Everything below F_2 peak is (almost entirely) driven by direct irradiation.

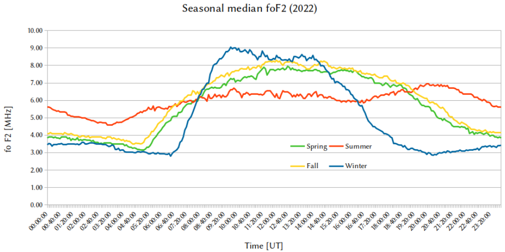
Diurnal variation of F_2-layer

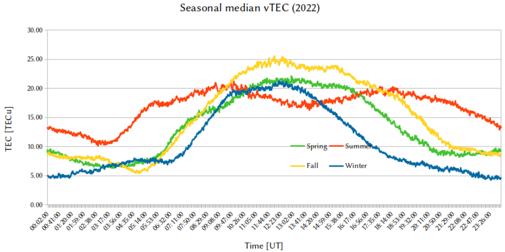
Since the F_2 layer is driven primarily by plasma motion rather than photoionisation, it presents more complicated diurnal patterns.



- Sharpest increase in density and temperatures at sunrise.
- Layer persists through the night, because of interhemispheric plasma transport.
- Altitude of the F_2 peak varies strongly between day and night (for Dourbes, 250 km during day, around 400 km at night).

Seasonal variations



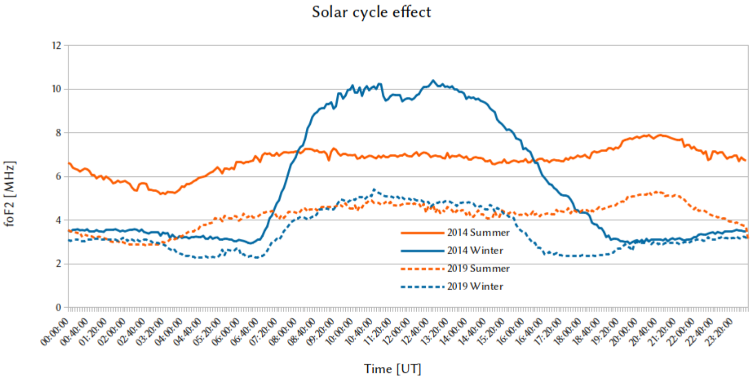


More complicated than expected from photoionisation alone!

Mid-latitude seasonal anomaly: foF_2 in winter larger than in summer.

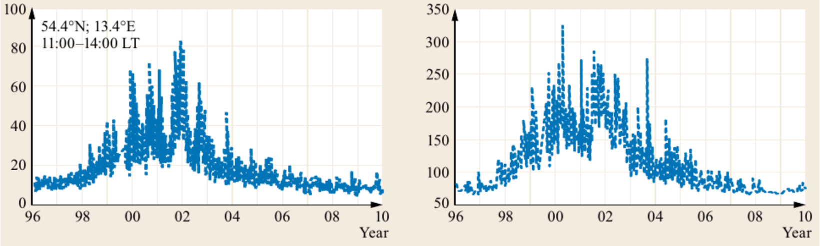
This is due to chemistry: more O, less N_2 in winter means more photoionisation, less recombination.

Solar cycle effects: F_2 peak



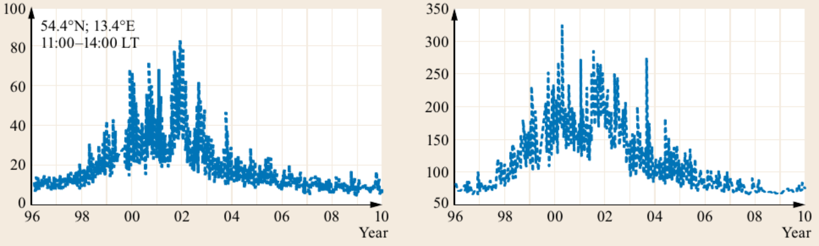
Solar cycle causes general electron density increase and emphasises seasonal anomaly (note: cycle 24 was a weak one).

Solar cycle effects: *TEC*



VTEC follows $F_{10.7}$ closely, also at shorter time scales (less than a year).
Also: some changes in the shape of the electron distribution.

Solar cycle effects: *TEC*



VTEC follows $F_{10.7}$ closely, also at shorter time scales (less than a year).
Also: some changes in the shape of the electron distribution.

More importantly: (stronger) solar maximum means more solar events like flares and CMEs.

Other time-scales

There are some other time scales on which regular variations in the ionosphere can be seen.

- Diurnal and semi-diurnal tides (of gravitational and thermal origin). In the lower ionosphere, mostly the semi-diurnal mode, in higher ionosphere the diurnal mode.
- On longer time-scales: the relative strengths of solar cycles and (even longer) variations in the geomagnetic field affect the large scale morphology of the ionosphere.
- Variability on shorter time scales due to various disturbances.

Summary

1. The mid-latitude ionosphere exhibits regular variations on various time-scales: (semi-) diurnal, seasonal, solar cycle, and longer.
2. Lower layers are driven directly by photoionisation, and are easily modelled.
3. F_2 layer is formed by plasma drifts, and exists at night as well but at higher altitude.
4. Because of seasonal thermospheric composition changes, higher ion content in winter than summer.

The end this section.

Questions so far?

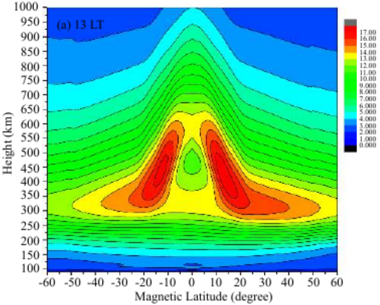
Low-latitude climatology

Diurnal behaviour of the EIA

During the day, the fountain effect produces high plasma density at high altitudes.

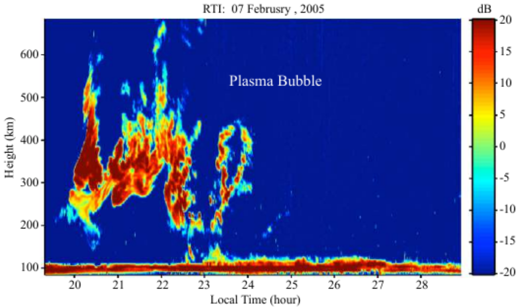
After sunset, recombination is quickest at lower altitude. This causes extreme gradients of plasma density with height.

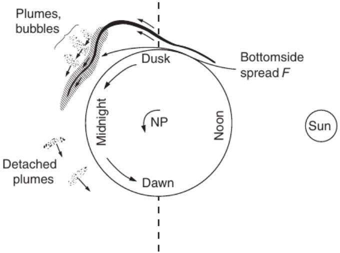
This causes the plasma to become unstable (Rayleigh-Taylor instability), leading to the formation of plasma bubbles.



Plasma bubbles

Plasma bubbles are a regular feature of the equatorial night-time ionosphere(a source of spread-*F* and scintillation).

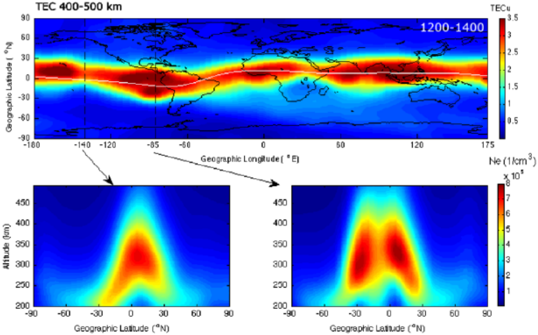




They generally form below hmF_2 and rise to over 700 km, while drifting eastward.

Non-migrating tides

There are permanent, standing planetary wave patterns called "non-migrating tides" in the ionosphere, which are most clearly visible in the EIA region.



The precise origins of these structures are not entirely known, but their effect on plasma bubble occurrences is clear.

Summary

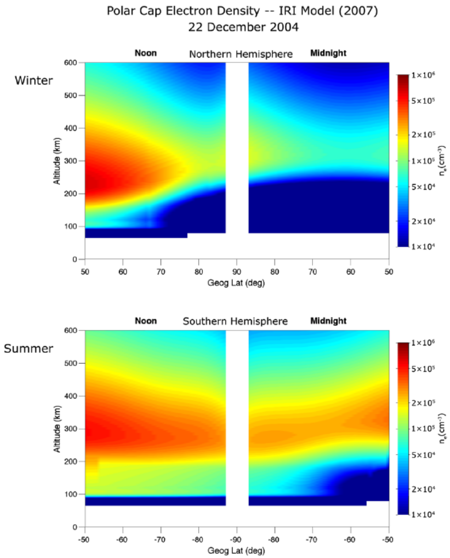
1. The most important diurnal feature of the EIA region is the development of plasma-instabilities, leading to formation of plasma bubbles.
2. There are regular longitudinal variations in the equatorial anomaly.
3. Both longitudinal structuring and solar activity levels influence the production of plasma bubbles.

The end this section.

Questions so far?

High-latitude climatology

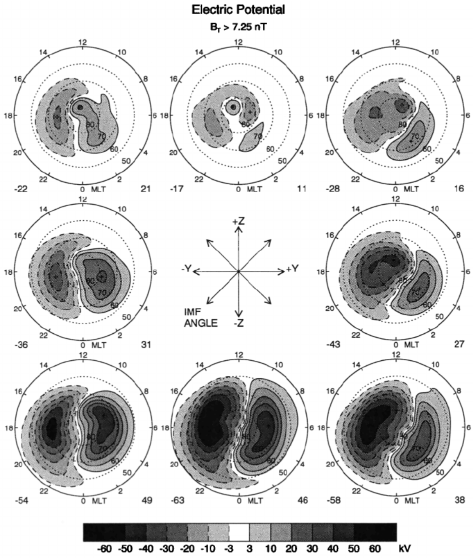
High-latitude climatology



Photoionisation in the high latitude region is mostly relevant during Sumer season. There is little diurnal variability.

However, in these regions the impact ionisation from precipitating particles is more important than photo ionisation.

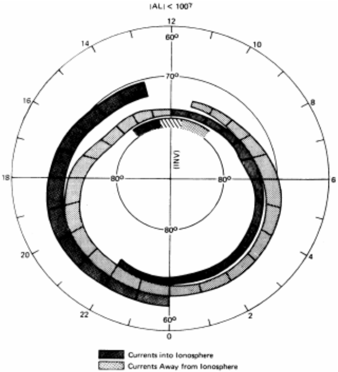
Connection to the interplanetary field



The main driver of the behaviour of the polar cap ionosphere is the interplanetary magnetic field. Both its orientation and strength affect polar cap convection patterns.

“Normal” condition of the auroral oval

The main persistent feature of the auroral oval is the large scale structure is currents from and to the magnetosheath.



This current structure produces two stream instabilities because ions and electrons are moving with different velocities.

Summary

1. The polar cap differs in two important aspects from mid- and low-latitude ionosphere:
    1. Particle impact ionisation dominates over photoionisation.
    2. The main large scale driver is the IMF, rather than solar irradiation.
2. The auroral oval is always a region of disturbances.

The end.

Questions?