Structure of the mid-latitude ionosphere

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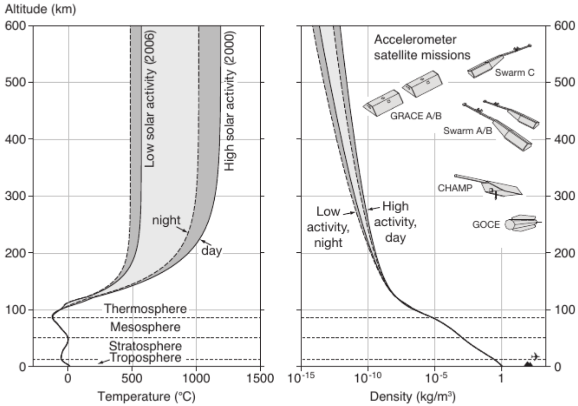
Role of the ionosphere and space weather in military communications

Outline

Thermospheric chemistry

The thermosphere

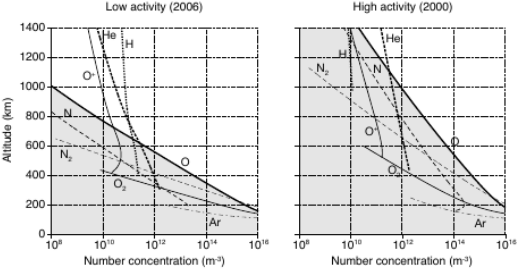
The thermosphere is the name for the atmosphere above 80 km, up to about 600 km. Above that is the exosphere.



Temperature, density, composition all change with varying irradiation by the sun.

Thermospheric composition

The thermosphere contains mostly atomic gases (produced by photodissociation) rather than molecular ones (O_2, N_2, CO_2,...). Largest components are O, H, and He.



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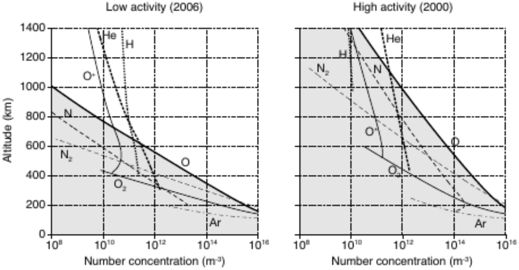


Question:

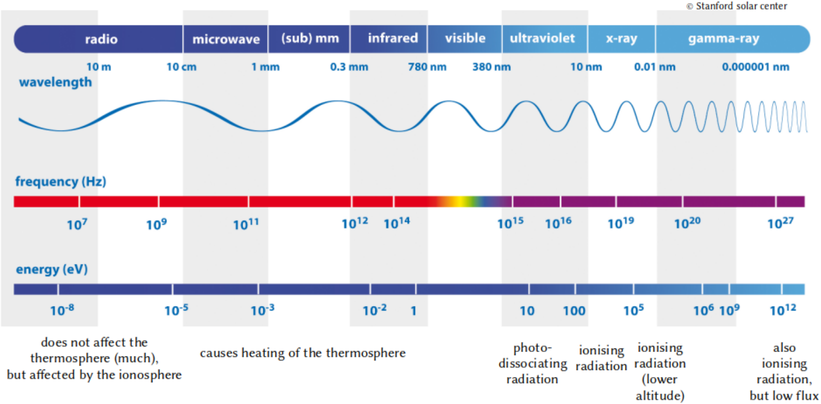
The lower atmosphere is mostly N_2, why is there so little N in the thermosphere?

Atomic O is most important in the lower ionosphere, H above the "upper transition height," the actual altitude of which varies a lot.

Electromagnetic radiation

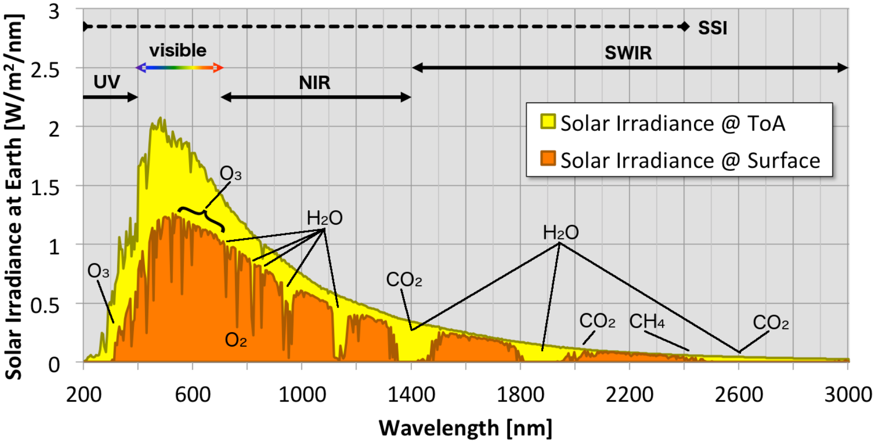
The electromagnetic spectrum

Different parts of the EM spectrum are relevant, for different reasons.



Note: besides EM-radiation, ionisation is also produced by high-energy particles (especially in polar region).

Solar spectrum

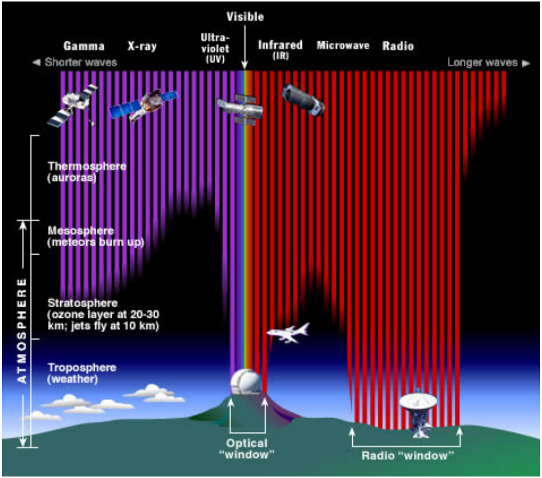


The flux of solar radiation drops of quickly at higher energies (= higher frequencies = shorter wavelengths).

Electromagnetic radiation penetration depth

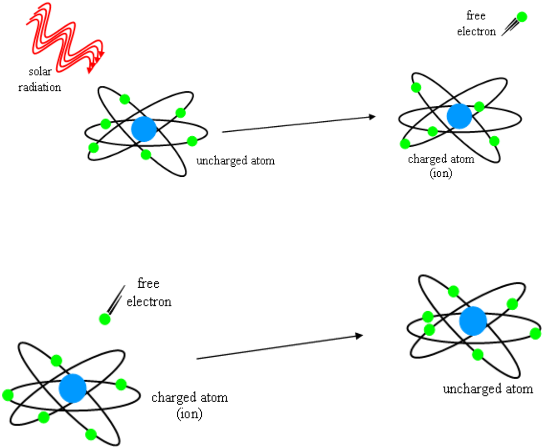
Different wavelengths penetrate the atmosphere to different altitudes.

For the ionising frequencies: higher energy means penetration to lower altitudes.



Ionisation & recombination mechanisms

Ionisation and recombination



- The thermospheric gas can be ionised, mainly by the EUV components of the solar spectrum.
- Ionisation is only partial (more complete ionisation in plasmasphere).
- X-rays penetrate to lower altitude, but usually less flux than EUV.
- Particles (from the sun or cosmic-rays) can also cause ionisation.

Ionisation and recombination

The primary production of ionisation reaction: $O + \hbar\nu \longrightarrow O^+ + e^-$, where the photon is EUV or X-ray.

Most important fact of aeronomy

Ionisation of O is not easily (directly) reversible:

$$O + \hbar\nu \underset{\text{very slow}}{\overset{\text{very fast}}{\rightleftharpoons}} O^+ + e^-$$

Instead, recombination goes like this (for example):

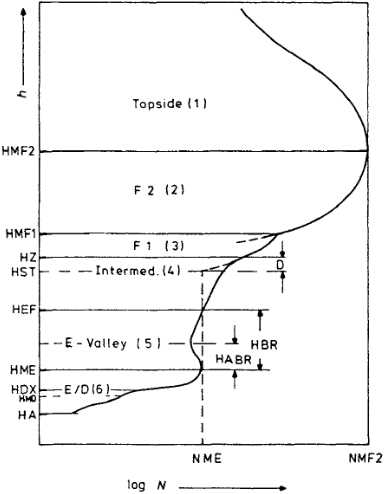
$$O^+ + N_2 + e^- \longrightarrow NO^+ + N + e^- \longrightarrow NO + N + \text{dissipate energy}$$

Thus, recombination speed is primarily determined by density of surrounding neutral gas.

Mid-latitude ionosphere structure

Typical free-electron distribution

Solar radiation affects the *thermosphere* through the *ionisation mechanism*, creating the **ionosphere**.

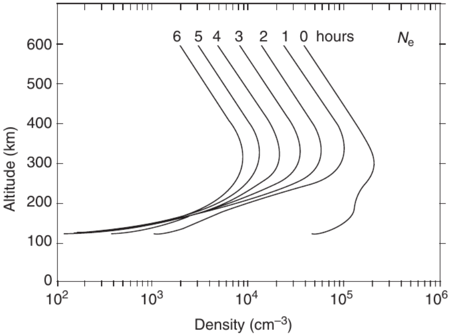


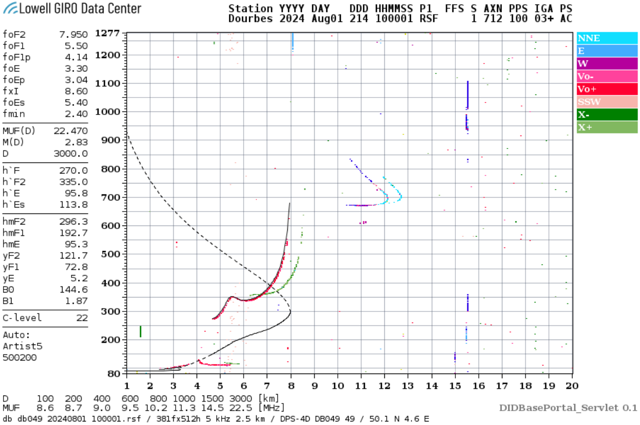
- Electron distribution at mid-latitudes (roughly 30°–60°) has a typical layered structure.
- Actually multiple main maxima, due to different ionisation/recombination equilibria.
- Main F_2-layer above 200 km, F_1-layer around 150 km E-layer around 110 km.
- Hard X-rays & energetic particles can produce an additional, lower D-layer (below 90 km).

Night-time recombination

During the night, ionisation disappears due to recombination (note the logarithmic density scale).

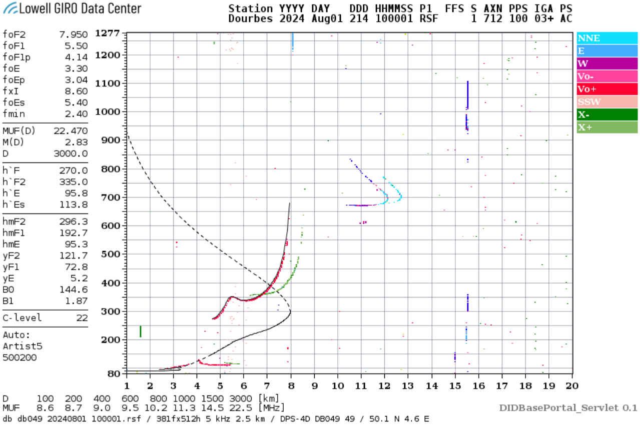
Recombination rate depends strongly on *neutral* density, thus: faster recombination at lower altitude.





E, F_1 and F_2 layers all cause reflections from different altitudes.

Return of the example



E, F_1 and F_2 layers all cause reflections from different altitudes.

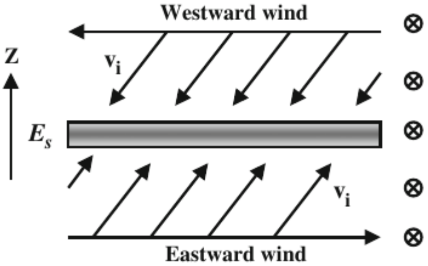
Question:

Lowest frequencies are absorbed in the D region. Why?

Sporadic layers

Sporadic *E*-layers

There is always a small amount of very long lived ions (Fe^+, Mg^+) in the lower ionosphere (mostly from meteors).

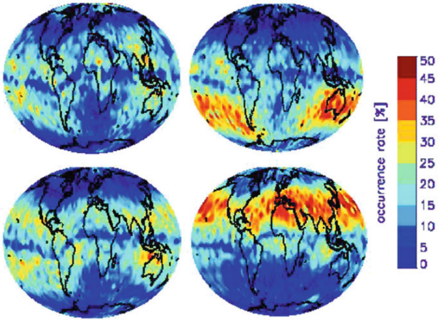


- Wind shears can trap long lived ions in very thin layers, due to Lorentz force.
- These layers are very thin in altitude, but can reach very high densities (due to very slow recombination of metallic ions).

Es layers can have significant effects on HF communications, as well as cause perturbations in trans-ionospheric radio.

Es occurrence

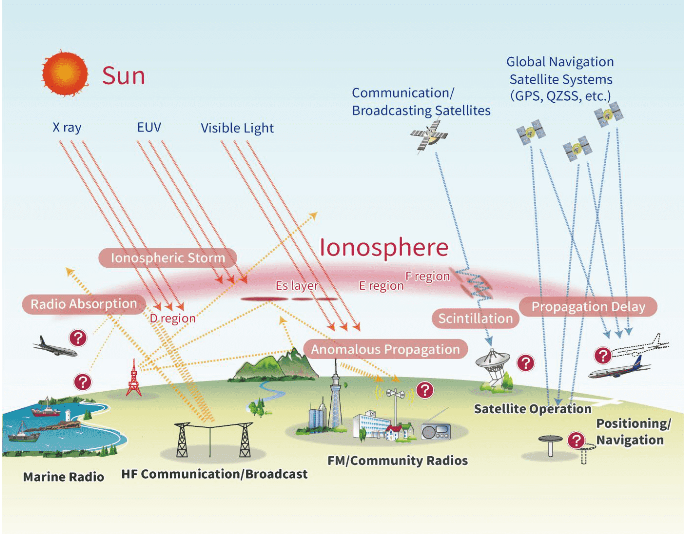
Sporadic layers are highly irregular and difficult to forecast in detail, but have clear regional & seasonal patterns.



Other mechanisms can cause similar exceptional layers in the *E* region, *e.g.*, particle precipitation during auroras.

Radio applications

Radio signals and the ionosphere



- VLH, UHF, L-band: above ω_p, so pass through (but with delays & scintillation).
- ω_p of various layers is somewhere in the HF band. Can be reflected, absorbed, or pass through.

Summary

1. The thermosphere is (partially!) ionised by solar radiation.
2. Recombination strongly depends on neutral density.
3. In the typical mid-latitude, the electron distribution comprises several layers: F_2, F_1, E, D.
4. Occasionally additional sporadic layer in E region.

Various radio bands are affected in different ways. Ionospheric layers' ω_p is typically in the HF band. Higher frequencies go through the ionosphere (but still experience perturbations); lower frequencies are reflected.

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The end!

Questions?