Atmospheric Physics

Lecture 11

Sahraei
Physics Department
Razi university

http://www.razi.ac.ir/sahraei

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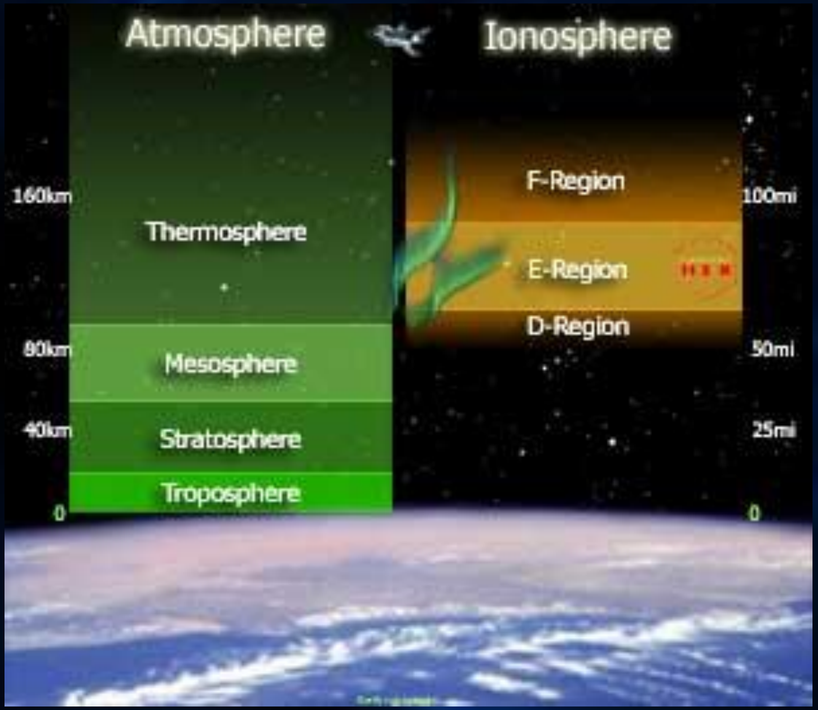
What is the Ionosphere?

- The atmosphere above ~70km that is partially ionized by ultraviolet radiation from the sun
- This region of partially ionized gas extends upwards to high altitudes where it merges with the magnetosphere
- Discovered in the early 1900s in connection with long distance radio transmissions
- Scientists postulated, and later proved, that long distance radio communication was possible due to reflection off of an ionized region in the atmosphere



Overview of the Ionosphere

Structure of ionosphere continuously changing

Varies with day/night, seasons, latitude and solar activity

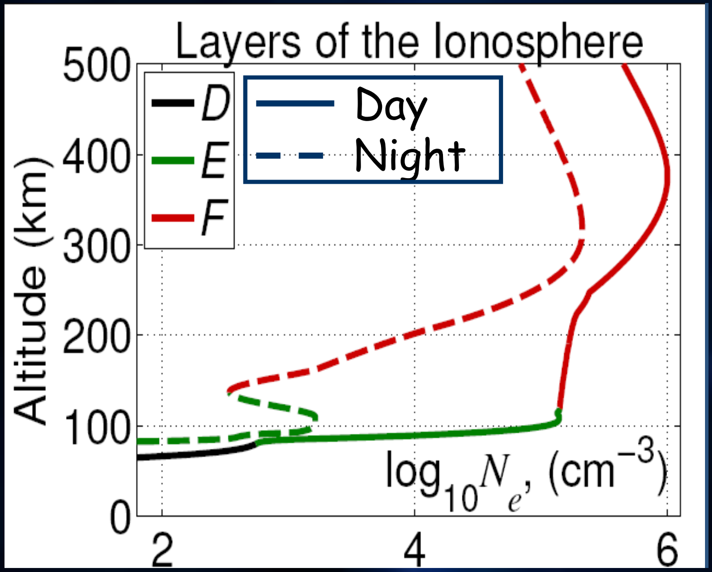
Essential features are usually identifiable

Ionosphere divided into layers, according to electron density and altitude

D Layer (or D Region)

E Layer

F Layer



Several reasons for distinct layers

Solar spectrum energy deposited at various altitudes depending on absorption of atmosphere

Physics of recombination depends on density of atmosphere (which changes with altitude)

Composition of atmosphere changes with height

Ionospheric Layers

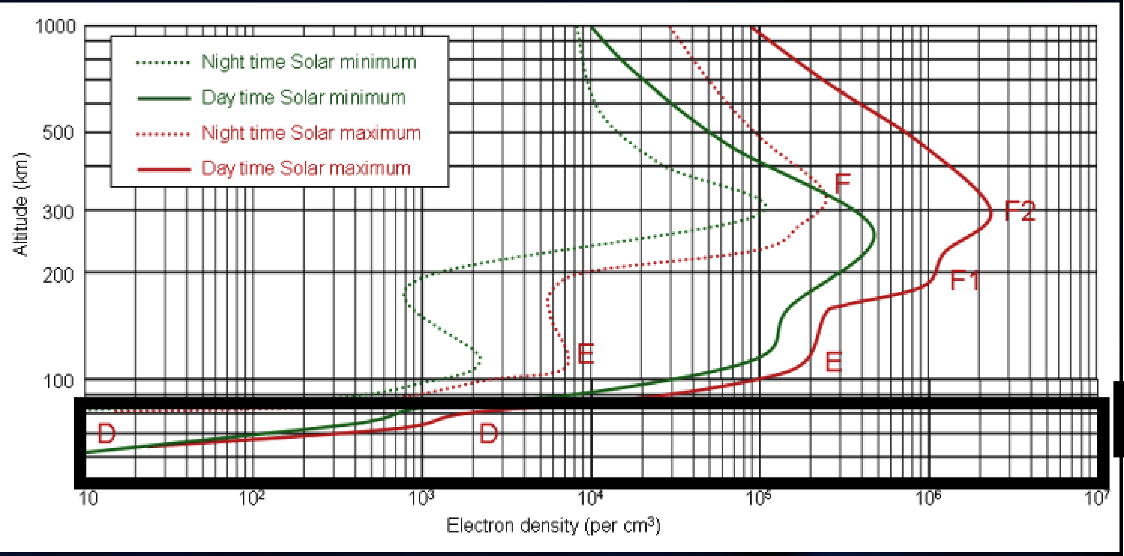
D region (50-90 km)

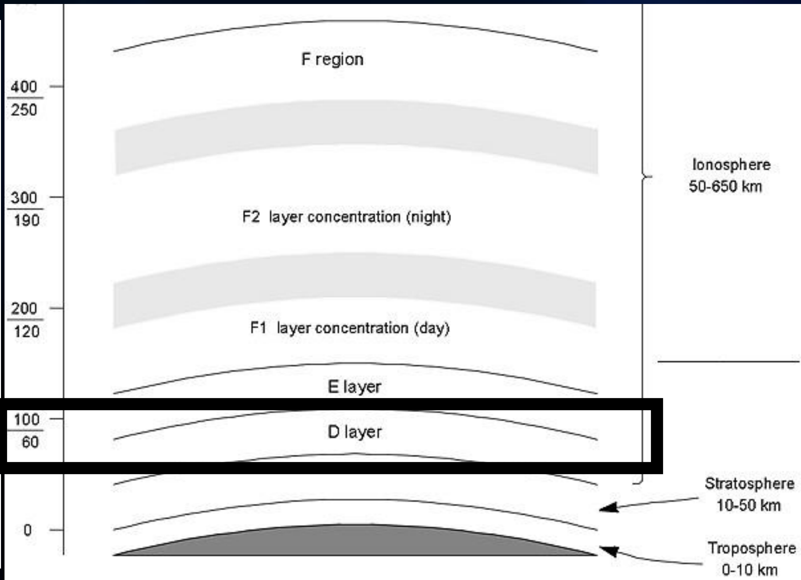
Lowest region, produced by Lyman series alpha radiation (λ = 121.6 nm) ionizing Nitric Oxide (NO)

Very weakly ionized

Electron densities of $10^8 - 10^{10}$ e^-/m^3 during the day

At night, when there is little incident radiation (except for cosmic rays), the D layer mostly disappears except at very high latitudes

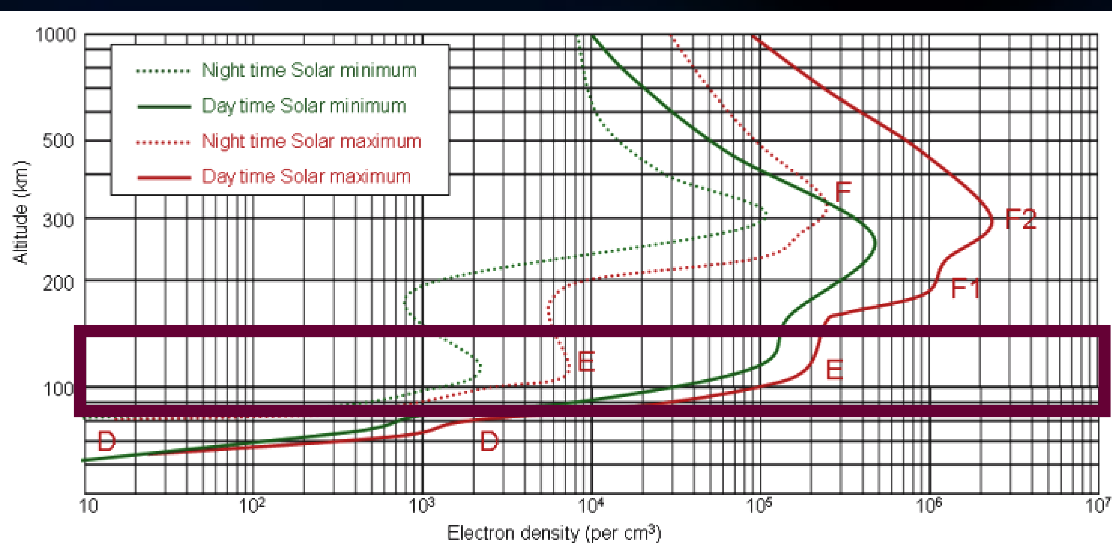


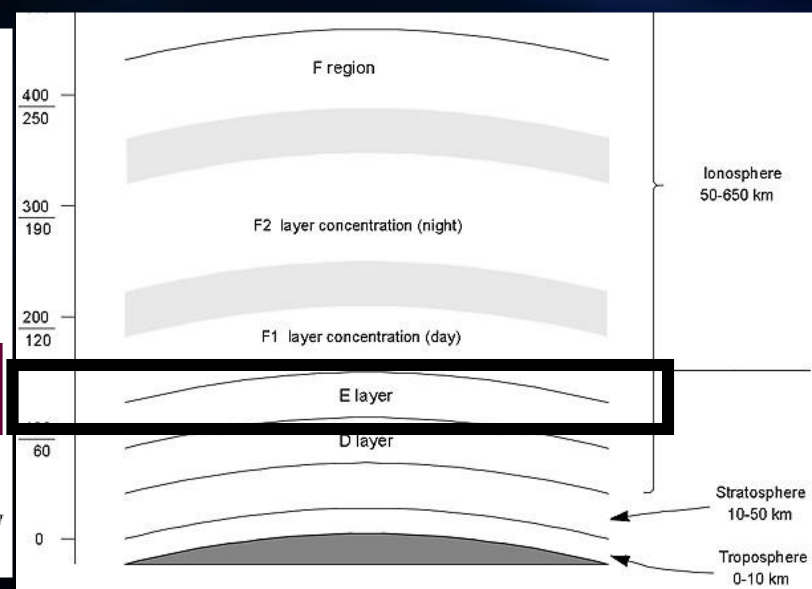


Ionospheric Layers

E Region (90-140 km)

- Produced by X-ray and far ultraviolet radiation ionizing molecular oxygen (O_2)
- Daylight maximum electron density of about 10^{11} e^-/m^3
  - Occurs at ~100km
- At night the E layer begins to disappear due to lack of incident radiation
  - This results in the height of maximum density increasing





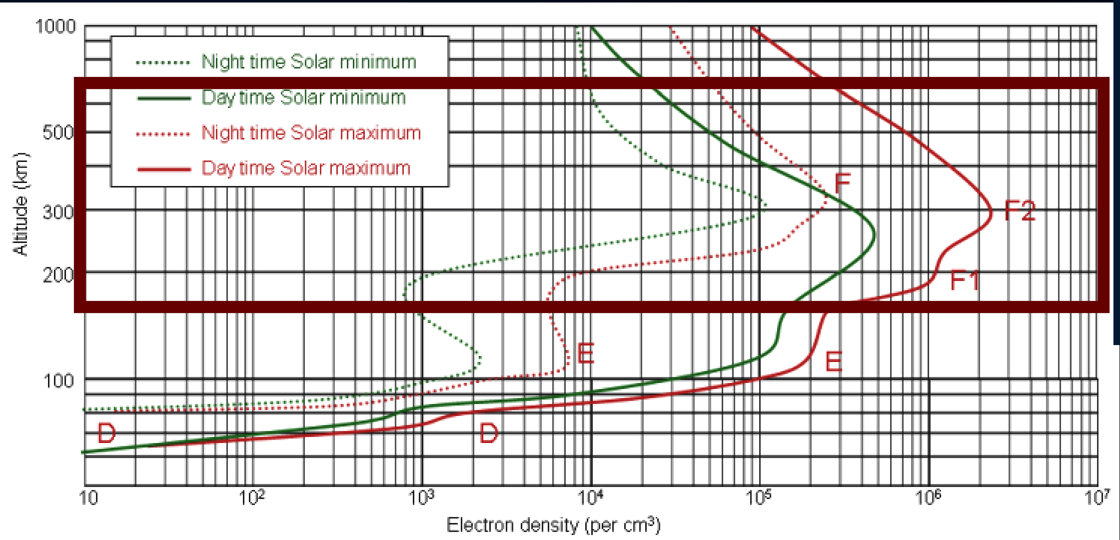
Ionospheric Layers

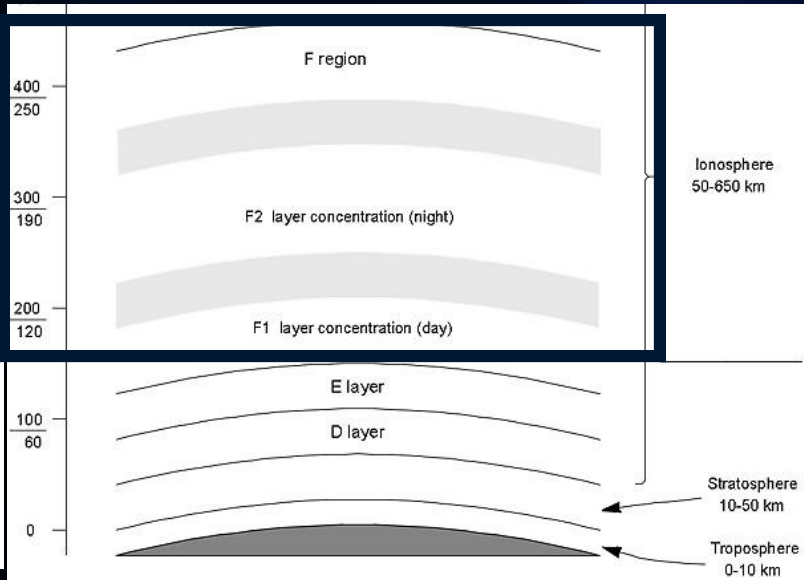
F1 Layer (140-200km)

- Electron density ~$3*10^{11}$ e^-/m^3
- Caused by ionization of atomic Oxygen (O) by extreme ultraviolet radiation (10-100nm)

F2 Layer (>200km)

- Usually has highest electron density (~$2*10^{12}$ e^-/m^3)
- Consists primarily of ionized atomic Oxygen (O^+) and Nitrogen (N^+)

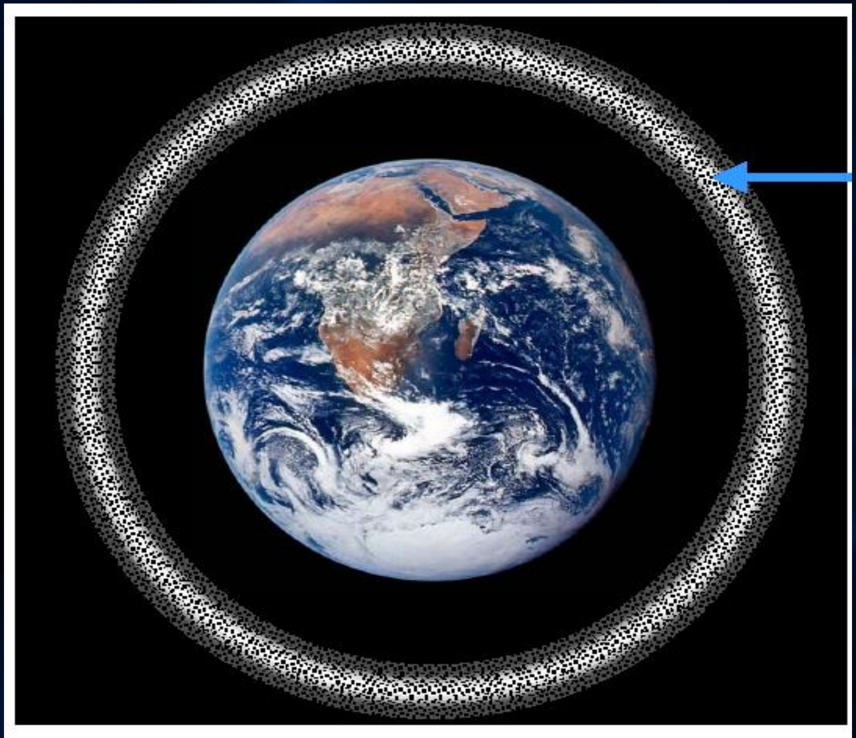




Ionosphere

The ionosphere is the part of the atmosphere that is ionized by solar radiation affects the transmission of radio waves .

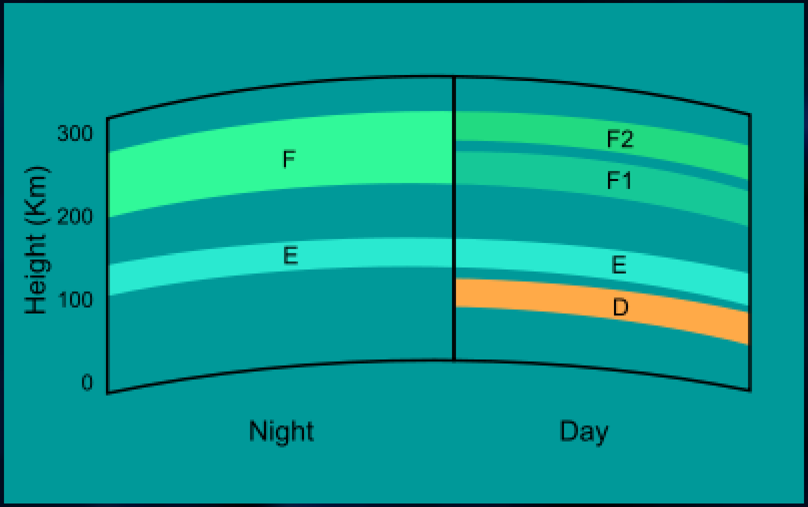
It extends from a height of 70 kilometers to 400 kilometers above the surface.



The electrical structure of the atmosphere is not uniform and is arranged into three layers, D, E, and F.

Since the production of charged particles requires solar radiation, the thickness of each layer, particularly the D and E layers,changes from night to day.

The layers weaken and disappear at night and reappear during the day.



D Layer

The D layer is not very interesting. During the daylight hours it serves to absorb most energy below about 7 MHz. During the night hours, it totally disappears.

It quickly reaches full ionization soon after sun-up, and almost immediately loses its energy after the sun goes down.

It does nothing in the way of reflecting signals as far as science knows.

D Layer Properties

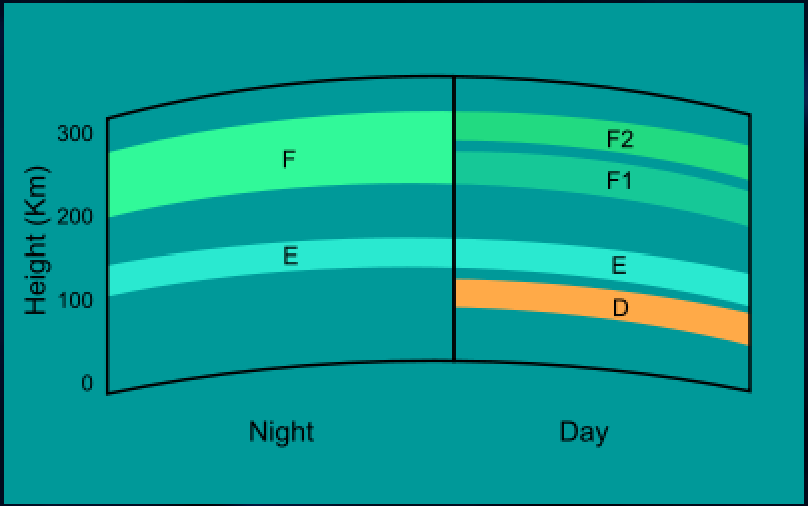
70-90 kms (Parts of Stratosphere, Mesosphere and Thermosphere)

Temperature – about 190 K

Ionization Properties –

Usually about 1000 electron/cm^3

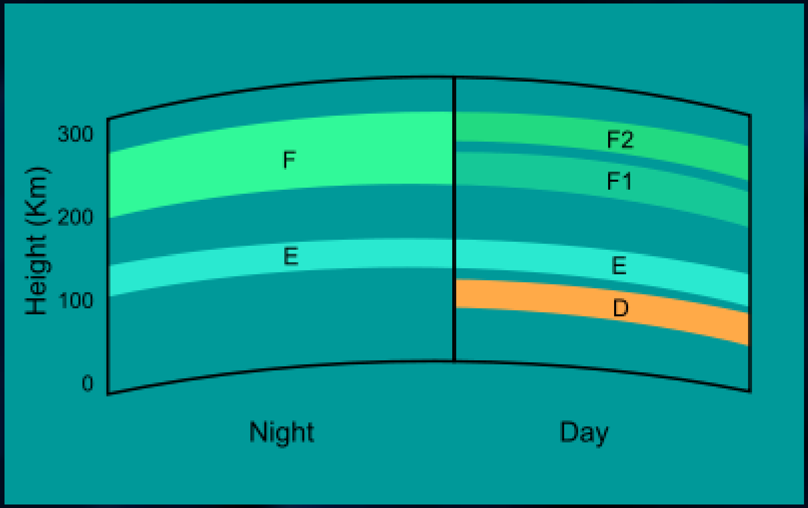
Ions present : O^+, N_2^+, O_2^+, NO^+



E Layer

Above the D layer is the E-region extending from 90 km to 150 km. The peak in the E region during day time is seen near 110 km.

Ionization is due to X-Ray (1-10 nm) and far ultraviolet (UV) solar radiation ionization of molecular oxygen (O2). This layer can only reflect radio waves having frequencies less than 10 MHz.



F Region

The F region is the very thickest region of the ionosphere, which makes the F region special.

It is the only layer of the ionosphere that is subdivided into two parts, the F1 layer and the F2 layer.

During the day the F region ionizes at different rates, due to the thickness. As a result two characteristic changes occur:

1) during the day, the region splits up and

2) at night the two layers slowly recombine.

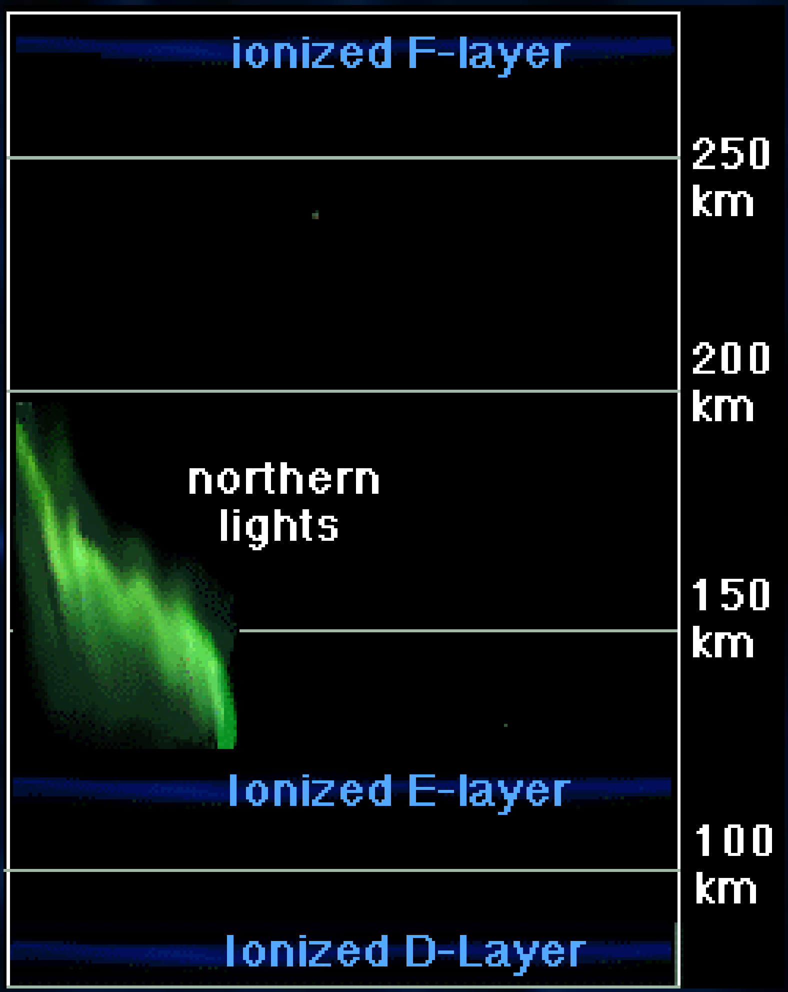
The F layer is present during both day and night.

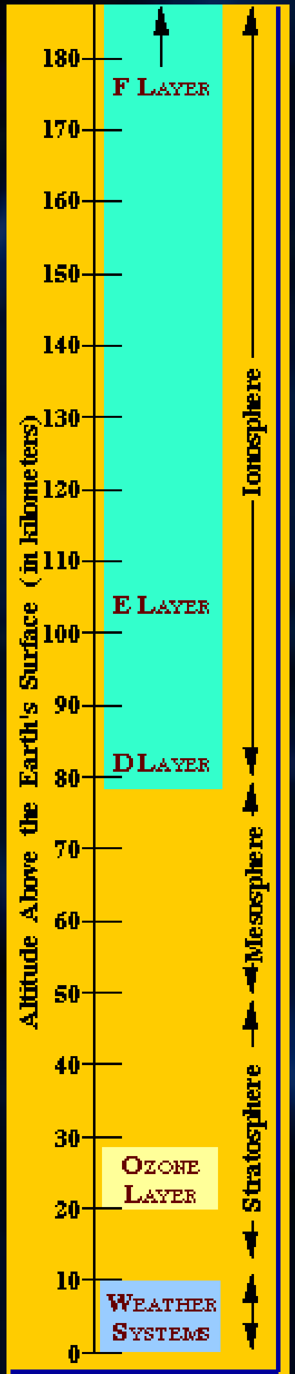
This change in height of the various electrically charged layers doesn't effect the weather, but does effect radio signals.

During the daylight hours, the F2 layer forms.

The F2 layer is on top of the F1 layer (making it situated closer to the sun).

As a result of being closer to the sun, it comes into contact with more of the UV and x ray energy. Because of this, the F2 layer becomes more ionized than the F1 layer.


ionized F-layer
250 km
200 km
northern lights
150 km
Ionized E-layer
100 km
Ionized D-Layer


Altitude Above the Earth's Surface (in kilometers)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
F Layer
E Layer
D Layer
Ozone Layer
Weather Systems
Ionosphere
Mesosphere
Stratosphere

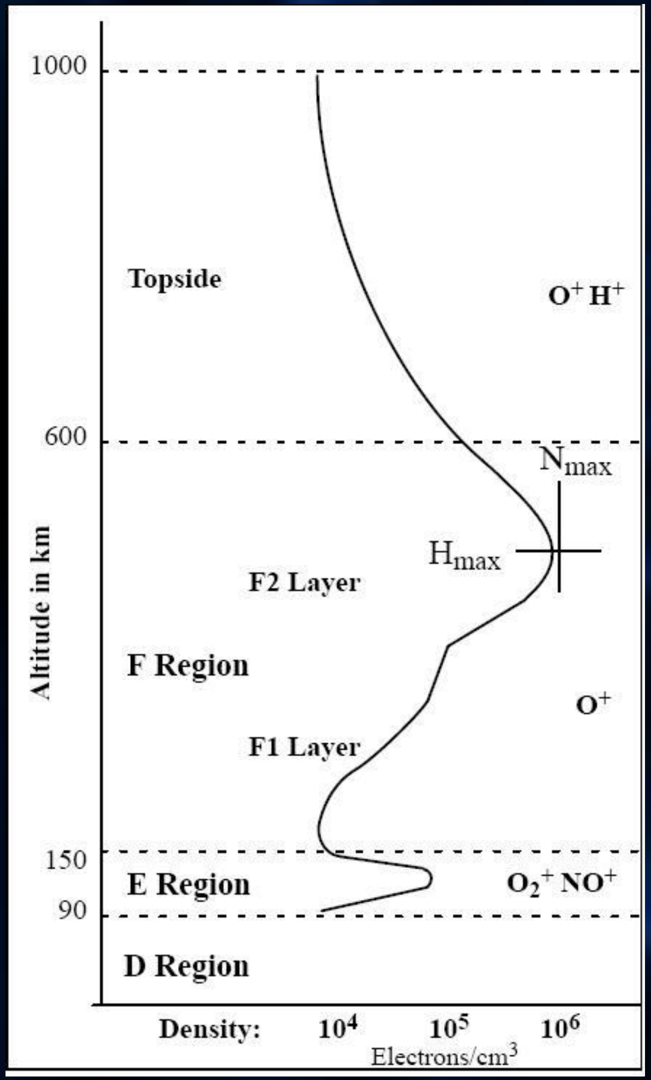
Ionosphere – Regions

Different Regions of the Ionosphere

D (70 - 90 kms, ionized by X-rays 0.1-1 nm)

E (90 - 150 kms, ionized by EUV 80-103 nm and X-rays 1-20 nm)

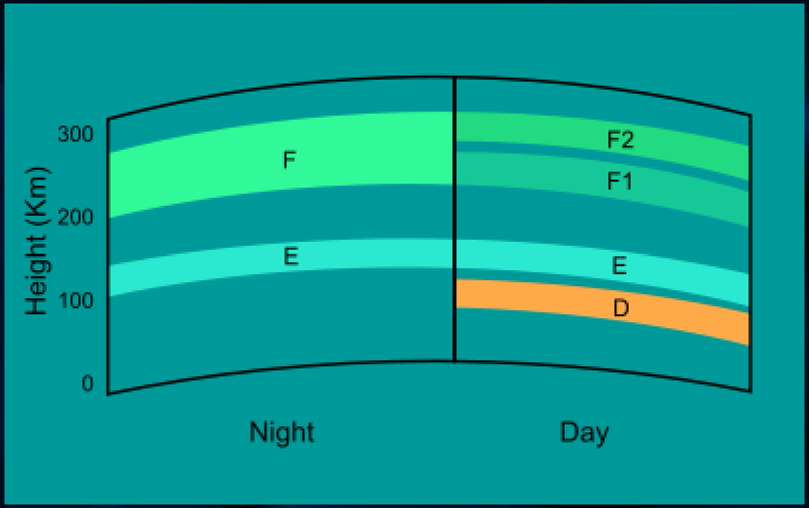
F (forms F1)and F2 layers during the day) (ionized by EUV 20-80 nm)



F1 region

The nominal height of the F1-layer peak is 200 km.

Its density is estimated at $2.5x10^5$ electrons/cm^3 at noon but it can be seven times higher (2 millions electrons/cm^3) depending on the ultraviolet amount it receives from the sun. This layer vanishes at night.



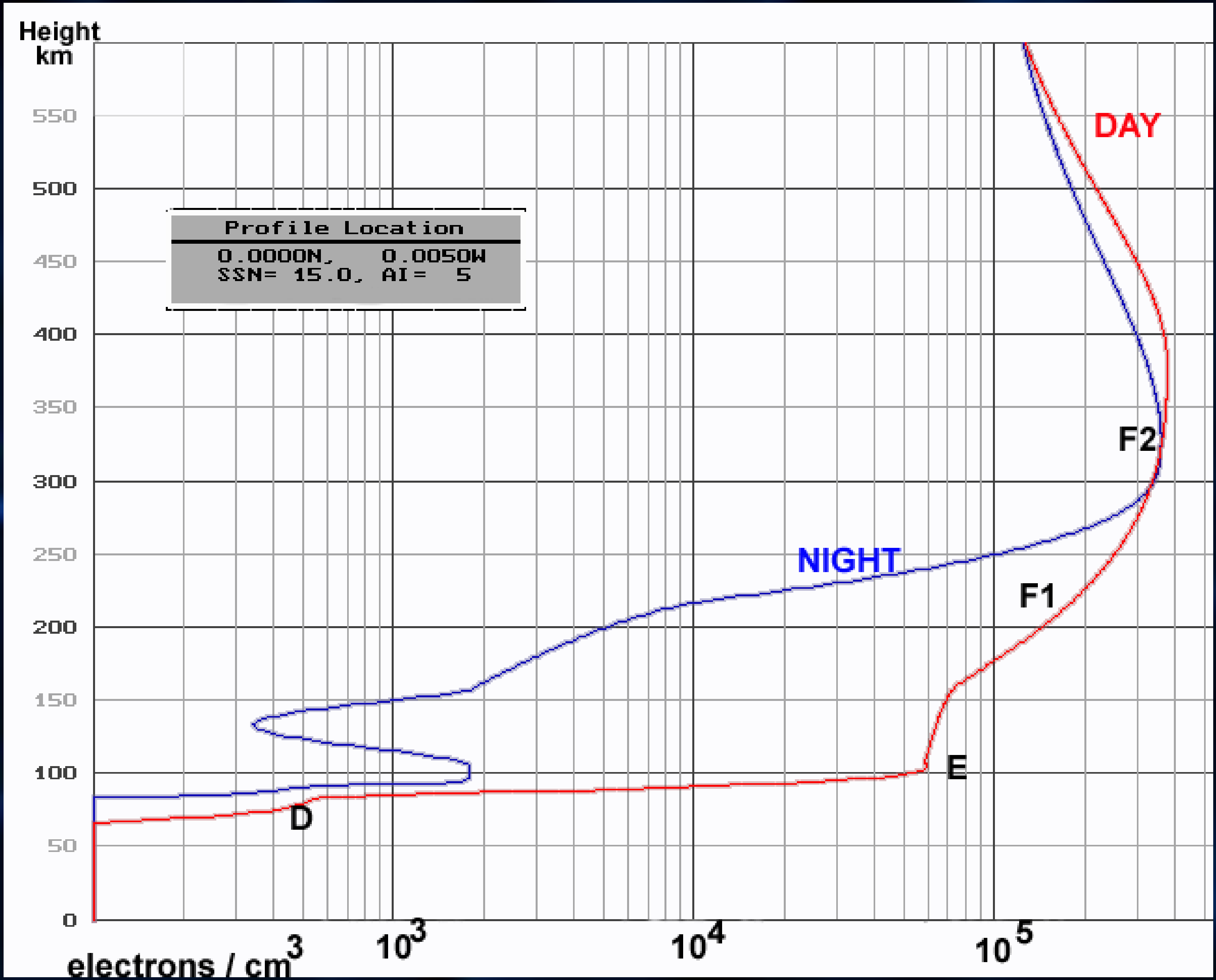
F2 region

The nominal height of the F2-layer peak is 300 km.

Its density is estimated at 10^6 electrons/cm^3 at noon, and ten times less at midnight.

It is thus the denser ionospheric layer.

However, its height and electron density are highly variable due to large daily, seasonal, and sunspot-cycle variation that, combined, produce a general erratic behaviour.


Height
km
550
500
450
400
350
300
250
200
150
100
50
0
Profile Location
0.0000N, 0.0050W
SSN= 15.0, AI= 5
DAY
F2
NIGHT
F1
E
D
electrons / cm3
10
3
10
4
10
5

The ionosphere vertical density pattern shows a strong diurnal variation and a solar cycle variation.

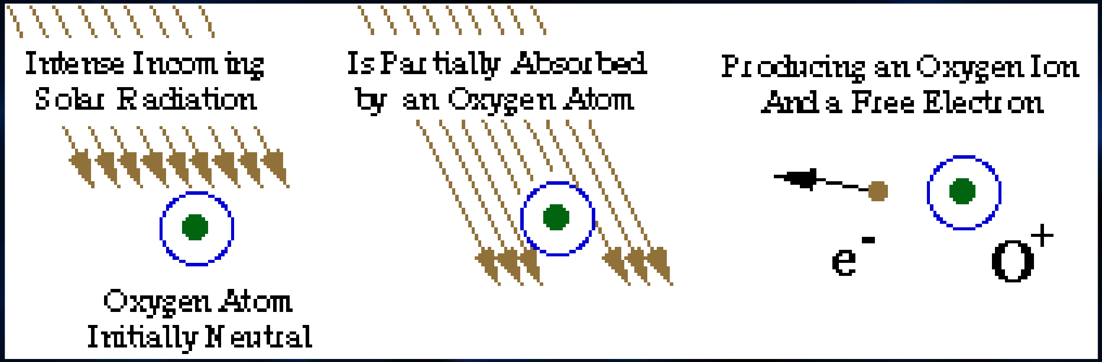
Identification of ionospheric layers is related to inflection points in the vertical density profile.

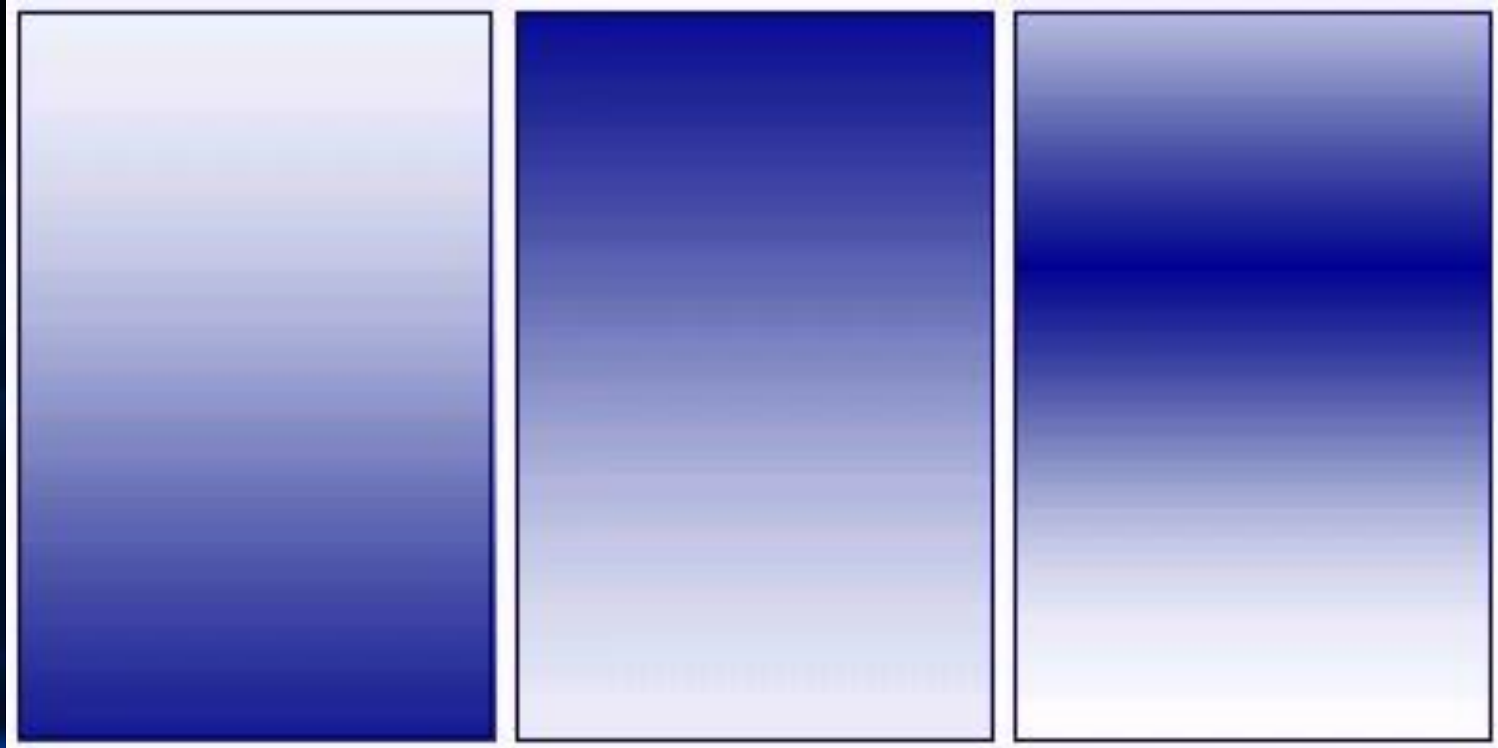
Primary Ionospheric Regions			
Region	Altitude	Peak	Density
D	60-90 km	90 km	$10^8 – 10^{10}$ m^{-3}
E	90-140 km	110 km	Several x 10^{11} m^{-3}
F1	140-200 km	200 km	Several 10^{11}-10^{12} m^{-3}
F2	200-500 km	300 km	Several x 10^{12} m^{-3}
Topside	above F2		

How is the Ionosphere Formed?

Incoming solar radiation is incident on a gas atom (or molecule).

In the process, part of this radiation is absorbed by the atom and a free electron and a positively charged ion are produced. (Cosmic rays and solar wind particles also play a role in this process but their effect is minor compared with that due to the sun's electromagnetic radiation.)





Air density decreasing with altitude

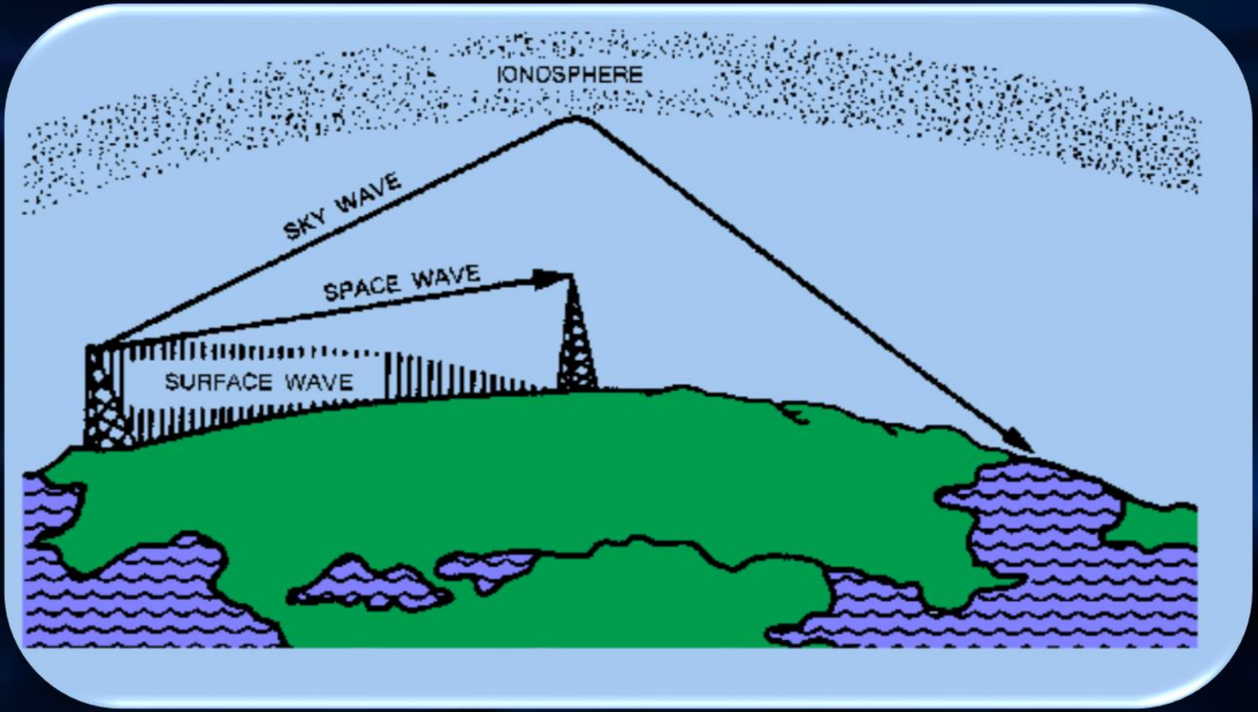
Amount of EUV increasing with altitude

Ionosphere density maximum at some altitude

Why ionospheric layers form at some altitudes ? This is the resulting of two opposing phenomena : on one part, the decreasing of the density of the neutral atmosphere as altitude increases (left), and on another part the increasing of the amount of EUV as altitude increase (center) create at some altitude an increasing of the density of ionosphere (right); a layer forms.

Transmission of VLF through the Ionosphere

Radio waves reflected by the Ionosphere – acts like a mirror (because ions present in the Ionosphere)



Transmission of VLF through the Ionosphere

The waves are refracted by the differently ionized layers in the ionosphere – the combination of this refractive effects results in the reflection of the radio waves