Ionosphere-Thermosphere

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• PART I: Local I/T processes (relevance for Homework Assignments)
• PART II: Terrestrial I/T system (relevance for Laboratory Tasks)

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Material adopted from the following authors.

- HSS lecture notes prepared by Professor Tim Fuller-Rowell (volume 1 HSS text book)

Neutral Atmospheres

• All ionospheres exist in an atmosphere.
• The thermosphere-ionosphere forms the neutral to plasma interface between planets with atmospheres and space.
• The composition of the ionosphere is governed by the atmosphere and the ionizing radiation.
• The atmospheric dynamics influences the ionosphere.
The Terrestrial Thermospheric composition: the basis for the ionosphere
Lower atmosphere has turbulent mixing which leads to constant composition.

Above the turbopause the neutral species are in their own hydrostatic equilibrium.
In the terrestrial upper atmosphere atomic oxygen is produced.

Atomic oxygen is associated with its own chemistry reactions.
MARS, it also has an atmosphere!

Atomic oxygen is also present, as is a lot of carbon dioxide.
Ionospheres

- Ionospheres exist in a neutral gas.
- The relative plasma to neutral density is variable.
- The daytime plasma is produced by solar EUV soft X-ray ionization.
- The ionosphere is electrically coupled to the magnetosphere.
- The terrestrial ionospheres natural coordinate system is the Earth’s magnetic field.
O+ F2 Layer

Above the peak it is in diffusive equilibrium with its plasma scale height.

Below the peak chemistry dominates, but molecular composition creates a large range of chemical reactions and temperature dependencies.
Nomenclature and simple mathematical functions for the ionosphere.
A natural coordinate for the atmosphere is the pressure level!
MARS has an ionosphere!

The ionosphere is dominated by the molecular ion $O_2^+$, that on the Earth would be called the E-region.
Photoionization

• The Solar EUV irradiance is key.
• Only recently has the short wavelength component become routinely observable.
• Proxy indices are less than satisfactory!
• NASA: satellites TIMED(SEE) and SDO(EVE) have provided high resolution spectral and now temporal information about EUV irradiance variability.
Solar EUV and Soft X-Ray Flux

- Photodissociation
- Photoionization; ion-electron pair production
- Excited species; chemistry
- Airglow
- Transport processes (e.g. molecular diffusion, thermal conduction)
- Neutral gas heating
- Ion heating
- Electron heating
- Photoelectron escape flux
- Secondary & tertiary ionization
- Incoming particle flux
- Energy loss to the mesosphere
Solar Zenith angle geometry

Atmosphere

Planetary surface
Daytime thermal profiles for the thermosphere and ionosphere at Millstone Hill, MA.
A midlatitude location: left panel 14:22 LT, right panel 02:22 LT at equinox in 1970.
Auroral Ionization

• The magnetosphere generates ionization via energetic particles, usually electrons.
• These particles are energized in the magnetosphere and create ionization and heating in the thermosphere-ionosphere.
• Auroral displays are the manifestation of this process.
• Ionospheric conductivity is a dynamic “resistor” in the M-I electro-dynamics (MHD).
The altitude of ionization depends upon the energy of the auroral particles.
The auroral electrons precipitation leads to heating and density increases in the ionosphere
Electric Fields and Winds

- In the F-region the electric field and neutral winds can induce plasma drifts to raise and lower the F-Layer.
- This modifies the plasma diffusion balance and hence density and profile shape.
- The ionosphere also corotates.
- At all latitude E X B can transport plasma perpendicular to the magnetic field line.
The Earths magnetic field is a poor dipole!

But many models still use a dipole representation!
Equatorward wind at mid latitudes with inclined magnetic field pushes plasma upward along the magnetic field direction to regions of different neutral composition.

An Eastward Electric field together with the magnetic field creates an upward plasma drift.
The low latitude day time ionosphere is dominated by transport caused by the Eastward electric field. This results in plasma redistribution and the formation of the Appleton Anomaly (equatorial anomaly).
The Appleton anomalies also known as the Equatorial anomalies.

The F-region densities are shown as Log10 Ne (cm**-3)
Schematic polar plot of the electric field called a 2-cell pattern.

The F-region plasma E X B drift trajectory directions are shown by the arrows.
Observed ionospheric plasma drift velocities, overlaid with a corresponding 2-cell electric field pattern
The effect of the E X B induced electric field (or wind) on the ionospheric density and profile.
O+ F2-layer is the dominant ionospheric layer under quiet geomagnetic conditions.

However, during very disturbed geomagnetic conditions, the rapid conversion of O+ into NO+ leads to an E/F1 layer becoming dominant.
PART-II

• Morphology of the ionosphere is a systems level problem.
• Many physics processes operate together as a system.
• Historically studies attempted to understand these processes individually and then “assimilate” their net effects....... NOT A GOOD APPROACH!
Auroral Precipitation
Joule Dissipation
Solar EUV
Plasmaspheric Downflow
Starlight & Scattered Radiation
Meteors
UV Radiation
X-rays
Very Energetic Particle Precipitation

F1 - Region
E - Region
Lower Thermosphere

D-Region
Mesosphere

Tides and Gravity Waves
Even simple E X B is complex because there are two separate sources of E

The ionosphere co-rotates, implying an E field, and then the magnetosphere’s E field maps into the ionsphere and an atmospheric dynamo generated yet another E field.
The F-region plasma as seen in a geographic local time from executes very complicated trajectories!

This means that a ground based observatory at high latitudes is not monitoring the same plasma flux tube continually, and hence the observer is not seeing the plasma evolution!
Thermospheric wind field are altitude dependent and responsive to Changes in magnetospheric energy input, STORMS.
Joule heating: \( J = (E + V \times B) \)

Large temperature and circulation changes in the upper thermosphere
Energy Flow

magnetospheric energy
500 - 1000 GW

- particle precipitation <20%
  - heat, ionization, airglow e.g. auroral illumination

- electromagnetic energy >80%
  - Joule heating $J \cdot (E + U \times B)$ >80%
    - heat, pressure gradients, winds, etc.
  - kinetic energy $U \cdot (J \times B)$ <20%
    - Ion drag drives neutral winds

- kinetic energy <20%
  - Ion drag drives neutral winds
Ion-neutral collisions in upper thermosphere frequent enough to drive high velocity neutral wind

Neutral Winds and Temperature: 300 km altitude

Maximum wind speed observed by DE-2
\[ \sim 1400 \text{ m/s} \]

ExB ion drift and NmF2
At mid-latitudes: can be high correlation between composition changes and ion density

Increase in $N_2$

Ionospheric depletion

Modeling

Observations
US-TEC – SWPC
IRI plus data

“positive phase”
and tongue of ionization

“negative phase”
Plasma “bulge” and Storm Enhanced Density

May 30, 2003 01:00 UT TEC [10,100], TECu

- SEDs
- Bulge
- Enhanced Eq Anomaly
- TEC Hole

Geodetic Latitude

Longitude
Neutral density response to flares
(Sutton and Forbes)

CHAMP satellite data
Pedersen and Hall Conductivity

![Graph showing Pedersen and Hall Conductivity vs. altitude and ion number density.](image-url)
And there is lots more!