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Tutorial Lecture

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Winds and Composition in the Thermosphere
Winds & Composition in the Thermosphere

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Mostly about large-scale structure in the mid-latitude E & F layers

1. General Principles
2. Wind systems
3. Composition Effects — Quiet Days
4. — Storms
5. More general principles
FIRST PHYSICAL THEORY OF THE IONC SPHERE?

Re Mr Marconi’s Results in Day and Night Wireless Telegraphy

Cliver Lodge [1902]: "The observed effect, which if confirmed is very interesting, seems to me to be due to the conductivity ... of air, under the influence of ultra-violet solar radiation."

"No doubt electrons must be given off from matter ... in the solar beams; and the presence of these will convert the atmosphere into a feeble conductor."
THE KEY YEARS

1931  Regular Ionospheric Sounding began at Slough

1931  Chapman’s Theory of Ionized Layers

1931  Chapman’s Theory of Airglow

1931  Chapman-Ferraro: Solar Particles & the Earth’s magnetic field — First idea of Magnetosphere?

1932  Appleton-Hartree Magneto-Ionic Equn

1932  Start of Kp Geomagnetic Index

1933  Slough Swept-Frequency Ionograms
NEW UNDERSTANDING OF THE IONOSPHERE

GLOBAL CIRCULATION in the upper atmosphere—driven by SUN and MAGNETOSPHERE/SOLAR WIND

Chemical changes → F layer seasonal effects [D layer]
Temp. variations → winds/waves → F layer effects
Auroral heating → winds → F layer storms [D layer]
Electrodynamics → equatorial E & F layers

MAGNETOSPHERE — links with ionosphere and IMF

New focus on the high latitude ionosphere:
[polar caps, auroral zone, "troughs"]

Ideas:

"Vertical structure ↔ solar radiations"
"Latitude structure ↔ geomagnetic field"
"Ionosphere as part of interactive solar-terrestrial system"
IONOSPHERIC CONSERVATION EQUATIONS

Continuity equation [mass]:

\{Density change\} = \{Production\} - \{Loss\} - \{Transport\}

Equation of motion [momentum]:

\{Acceleration\} = \{Force\} - \{Drag\} - \{Transport\}

Heat equation [energy]:

\{Temp change\} = \{Heating\} - \{Cooling\} - \{Conduction\}

Plus:

Equation of state [perfect gas equation]
F2 layer continuity equation

\[ \frac{\partial N}{\partial t} = q - \beta N - \text{div}(NV) \]
\[ = q - \beta N - \nabla \cdot \text{grad} N - N \text{ div} V \]

"Diffusion controls height of peak"

"Main effect of vertical drift is to move the plasma to a different \( \frac{q}{\beta} \)"

"Vertical drift \( \ll \) Horiz Winds"

\[ q \propto [O] \]
\[ \beta \propto [N_2, \text{O}_2] \]

\[ \frac{q}{\beta} \sim \frac{I.[O]}{K.[N_2]} \]

* Electromagnetic Drifts weakly divergent

\[ \text{div} \frac{E \times B}{B^2} \sim 0 \]

Linear loss coeff. "\( \beta N \)"

Non-linear loss coeff. "\( \alpha N^2 \)"

Variations of ion chemistry:
Molec\(^+\)/Atomic\(^+\) Ratio
Thermal Expansion

Barometric Motion

1D

\[ Z = \frac{h - h_0}{H} = \int_{h_0}^{h} \frac{dh}{H} \leq \frac{RT}{Mg} \]

If compos is fixed at lower boundary \( h_0 \), then it remains fixed at any fixed \( Z \).

Can be changed by:

- Vertical circulation (divergence) "up" cooling, "down" warming
- Change of mixing at turbopause?
- Gravity waves???
300 km Wind & Temperature Map

MSIS 83: MARCH

$S_{1c-7} = 150$

$A_p = 4$

Latitude

Local time (hrs)

Wind & Temperature Map

Is there a mean W->E wind?

Winds: due to:
- Solar Heating ("Thermal tide"?)
- Magnetoospheric Heating (joule heating, particle)
- Gravity waves, tides from below
Fig. 1 Schematic diagram of the mean thermospheric circulation during equinox. The upper panel shows the circulation during quiet geomagnetic conditions, the middle panel is for average conditions, and the bottom panel is for geomagnetic storms.

Fig. 2 Schematic diagram of the mean thermospheric circulation during solstice. The upper panel shows the circulation during quiet geomagnetic conditions, the middle panel is for average conditions, and the bottom panel is for geomagnetic storms.
Composition Changes & Vertical Winds

O/N₂ ratio is decreased by upwelling of air.

Vertical motion \( \Rightarrow \) energy input / release

Vertical Wind

\[ W = W_B + W_D \]

"BAROMETRIC" 1-dim expansion / contraction

\[ W_B = \left( \frac{\partial h}{\partial t} \right)_p \]

(Does not change composition at a fixed pressure-level)

"DIVERGENCE" 3-dim circulation linked to horizon wind by continuity equation

\[ W_D = -\frac{1}{\rho g} \frac{Dp}{Dt} \]

Motion of air through pressure levels

To specify composition of thermosphere

\[ P = 28 \ln [O] - 16 \ln [N_2] - 12 \ln T \]

\* Independent of height if thermosphere is in diffusive equilibrium

\* \( \partial p/\partial h \leftrightarrow W_D \) "Wind induced diffusion"

\* "Horiz. variation \( \leftrightarrow \) global circulation"

\* "Think pressure-levels": \( Z = \int_0^H dh \)
A HALF-CENTURY OF SOLAR & IONOSPHERIC DATA

Willis et al. JATP 1994
IONOSPHERIC F2-LAYER MAP FOR AMERICAN SECTOR

$\text{f}_x \text{F}2 \text{ in Latitude & Local Time: Dec 1957}$
F2-LAYER ANOMALIES at MID-LATITUDES

"Winter" or "Seasonal" Greatest NmF2 in winter
"Annual" Greatest NmF2 in December
"Semiannual" Greatest NmF2 & hmF2 at equinox

PHYSICAL CAUSES

Neutral composition changes [O/N₂] ratio or MMM
Horizontal neutral-air winds Vertical ion drift: U cos I sin I
Solar zenith angle Ion production ∫q dh ∝ cos χ

NEUTRAL COMPOSITION is controlled by vertical air motion

"Upwelling" ⇒ Decreased [O/N₂] ratio, increased MMM
"Downwelling" ⇒ Increased [O/N₂] ratio, decreased MMM

Greatest downwelling at ~ 5°equatorward of dayside auroral oval

(Millward et al.)
EXPLANATION of Seasonal & Semiannual Anomaly:

Solar-driven circulation ⇒ seasonal changes of [O/N₂] ratio

Summer midlatitudes: Upwelling ⇒ Decreased [O/N₂]
Winter midlatitudes: Downwelling ⇒ Increased [O/N₂]

Greatest downwelling at about 5° equatorward of auroral oval
Horiz wind U is weak near downwelling, strong at lower latitudes

Winter at ~50° geog: sectors near magnetic poles:

Max downwelling & compo effect – close to auroral oval
Wind effect moderate: U small, I large, cos I sin I ~ 0.25
{Compo} > {zenith angle} ⇒ NmF2 (winter) > (equx) > (summer)

Winter at ~50° geog: sectors remote from magnetic poles:

Downwelling & compo effect smaller – far from auroral oval
Wind effect strong: U large, I moderate, cos I sin I ~ 0.5
{Compo} < {zenith angle} ⇒ NmF2 (winter) < NmF2 (equinox)
SUPIM NmF2

SUMMER
EQUINOX
WINTER

W = WINDS

Time (hours)

NMF2 ×10^4

Solar Min

X = 90°
Critical Frequency foF2 at Lindau 52°N
for sunspot minimum & maximum
The boxes are 1-16 MHz ↑ 00-24 LT
\[ \ln \left( \frac{N_{mF2}}{N_{mF2}^*} \right) = \tilde{N} + \tilde{N} \cdot f(t - t_\text{LT}) \]

AC/DC Analysis: Slough

JanFeb
MarApr
MayJun
JunJul
JulAug
AugSep
SepOct
OctNov

7hr Smoothed Data

Rodger Wrenn Rishbeth. JATP 1987/9
Field & Rishbeth. JASTP 1997
SUMMER  
EQUINOX  
WINTER

\[ \bar{N} \] vs. lat:
Fig. 1. Percentage changes in NmF2 (full curves) and [O/N2] ratio (dashed curves), computed from the CTIP coupled model for stormtime 0-72 hours, at nine zones of magnetic latitude as shown. Left: December solstice, geographic longitude 0° (European/African sector). Right: June solstice, geographic longitude 126° (Asian/Australian sector). Black dots show local midnight.

\[ \frac{\text{NmF2}}{\text{NmF2}_{v}} \cdot \frac{[\text{O/N2}]}{[\text{O/N2}]_{v}} = \text{AT F2 PEAK} \]

EXCEPT \text{"INITIAL PHASE"}
THINGS to THINK ABOUT . . .

* Always consider time & distance scales
  "How long does [a process] take?"  "Over what distance does it operate?"

  Vertical scales (tens of km) << Horizontal scales (100-1000 km)
  Vertical speeds (~ m s\(^{-1}\)) << Horizontal speeds (~ 100 m s\(^{-1}\))

But – Vertical motions are very important (structure, energy)

* Difficult to get absolute values of parameters from ionospheric observations
  But – modelling is often insensitive to parameters

* Better space/time resolution => new science

* Importance of routine solar-terrestrial monitoring & WDCs

* Use SI units!
HOW TO USE c.g.s. UNITS [gaussian, e.m.u., e.s.u. etc]

1. Work out numerical values, taking care with powers of 10
2. If it looks wrong, multiply by $c$
3. If it's still wrong, try $c^2$, $1/c$, $1/c^2$, ... (etc)
4. If it's still wrong, try a different animal from the c.g.s. zoo
5. Repeat as necessary ...

HOW TO USE M.K.S.A. [S I] UNITS

1. Work out numerical values, taking care with powers of 10