Ionospheric perturbations induced by interplanetary and solar forcing

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The ionospheric E and F regions





Dipolar geomagnetic field, assuming there is no interaction with solar wind





A more realistic image of the geomagnetic field lines, (due to the interaction with the interplanetary magnetic field, IMF, carried by the solar wind).

At high latitudes (auroral and polar) $I > 75^{\circ}$

Geomagnetic coordinate system

Solar influence

- The diurnal and seasonal variation of ionospheric density at all levels (E and F region).

- Solar cycle variations have been observed in long term analysis of ionosphere (e.g. Devasia et al, 2006 – equatorial Es layers)

- Solar effects (long-term and short-term variations) propagate via solar wind and interplanetary magnetic field (IMF), mirroring in variations of magnetospheric electric fields, affecting the ionospheric plasma.

Electric field

At high latitudes the electric field: mapping of the magnetospheric electric field created by the solar wind-magnetosphere interaction.

If an electric field exists, than lines of electric potentials exist, also, and they form the so-called convection pattern.





The convection pattern and the associated electric field depend strongly on the **orientation and strength of the interplanetary magnetic field** (IMF). Large scale electric fields are transversal, the geomagnetic field lines are highly conductive and short out any large scale parallel electric fields.

The cross–polar cap potential is one of the most important parameters quantifying the coupling between the solar wind/IMF and the magnetosphere.

However, the cross–polar cap potential has a larger variability that would be predicted from observations of the solar wind parameters: IMF and velocity, i.e. interplanetary electric field (Bristow et al, 2004)

Electric potential contours for different IMF orientations in the yz plane (GSM coordinates), from APL model [Ruohoniemi and Greenwald, 1996]



Ruohoniemi and Greenwald (1996)

Iono1: Sporadic E (Es) layers

- are thin horizontal plasma layers whose density is higher than the background density (with at least one order of magnitude);
- have vertical widths of I-5 km;
- ➤ occur at 95 125 km;
- > have lifetimes of tens of minutes (20-180 min and more);
- > are composed mainly of metallic ions (atomic ions, they have a higher lifetime than the molecular ions that form the ionospheric plasma at E region heights).

THEORIES OF E_s FORMATION

- The wind shear theory [Whitehead (1961)], generally accepted to explain most of the properties of Es layers at mid latitudes.
- The directional effect of the electric field [Nygren et al.(1984), Kirkwodd and von Zahn (1991)] the formation and some properties of Es layers at high latitudes;

Transversal motion

and longitudinal motion



Formation of an Es layer



The growth of the layer was calculated by integrating the continuity equation, assuming no production or loss...





...which shows that appropriate electric fields can form Es layers very close to the center of the polar cap, where the geomagnetic field lines are *almost* vertical.

Nygren et al (2006)

Polar cap stations

Es layers \Leftrightarrow Electric field mechanism \Leftrightarrow IMF direction and strength

Es layers : ionosonde observations (experimental)

Thule (Greenland, 77.5 N, 290 E, **85.4 CGM**) : 1998 – 1999 central polar cap Longyearbyen (Svalbard, 78 N, 16 E, **75.2 CGM**) : 1999 – 2000 boundary of the polar cap

IMF components: WIND satellite (experimental)

Ionospheric electric field: (*model*) calculated from IMF data using the APL model

Distributions of Es occurrence at Longyearbyen and Thule as a function of the clock angle of the IMF in the ByBz plane





Iono2: The F region trough

The ionospheric trough is a plasma density depletion observed at F region heights at geographic latitudes around 55°–75°, longitudinally elongated, with widths in the latitudinal direction of 5-10°.

Eiscat observation



Tomographic reconstruction

Simple(st) sketch of night trough formation



Trough formation mechanisms

CONVECTION PATTERN

 stagnation regions: balance between westward convection flow and eastward corotation
horizontal transport of high density plasmas in the vicinity of low

density plasmas (for both day and night troughs).

LOCAL PROCESSES *

□ field aligned plasma upflow, produced by large horizontal winds, electron heating or sub-auroral ion drifts

□ Joule heating resulting in the upwelling of the neutral atmosphere,

bringing more molecular ions (which recombine faster) in the F region

AURORAL PRECIPITATION

poleward wall coincides with the equatorward boundary of precipitation (sometimes, mostly for premidnight trough, less for morning/day trough)

12 hr

Ε

Link between trough occurrence and IMF



By seems to play a more important role than Bz in the occurrence of troughs during quiet times, with negative values clearly favouring the trough

WHY?

The link between **trough occurrence**, **geomagnetic activity and Bz** can be partly explained by the increased possibility of a high Kp during negative Bz.

Convection patterns are governed by IMF



Location of troughs for southward IMFs

The edges of the observed troughs in CGMLat and MLT for [Bz-, By-] and [Bz-, By+]

Shown are also contours of electric potential given by the LIMIE convection model

O: Kp> 4 X : Kp < 3



Location of troughs for northward IMFs (EQUINOX)

The edges of the observed troughs in CGMLat and MLT for [Bz+, By-] and [Bz+, By+]

Shown are also contours of electric potential given by the LIMIE convection model

O: Kp> 4 X : Kp < 3

A close relationship between patterns of equinox trough and plasma convection given by the convection model of Papitashvili and Rich (2002), i. e. with IMF intensity and direction, is seen especially for the equatorward wall.



Location of troughs for southward (right) and northward (left) IMFs (WINTER)



Location of troughs for southward (right) and northward (left) IMFs (SUMMER)



Convection pattern/velocity/density

Convection pattern (LiMIE model with IMF values Bx =1 nT, By =7 nT and Bz = 1 nT, contour interval: 1.5 kV)



Zonal ion velocity at 345 km

Agreement (resonable) between observed zonal velocity and modelled convection pattern Electron density at 345 km

Trough coincides with modelled westward convection, carrying lowdensity plasma from the night side.

CONCLUSIONS (2)

- Winter: More troughs are observed on the dawn side during positive Bz, when the convection pattern is very distorted so that the negative cell extends in the dawn sector.
- Summer is clearly different form the other seasons. Troughs form at high latitudes and IMF effect is observed, except for an increase during negative Bz.
- The results indicate that plasma flow has a major role in trough generation in all seasons except summer. It also shows that the dependence of the trough occurrence with IMF is complex and depends on season and time of day.
- However, the connection between the trough occurrence to the convection patterns, thus to the IMF orientation, seems quite clear.

CONCLUSIONS (3)

> There is a relationship between the F region trough, geomagnetic activity and IMF:

- ✤ Troughs occur during high geomagnetic activity mostly when Bz is negative
- Troughs occur during low geomagnetic level when Bz is positive AND are clearly favoured bypositive By.
- The relationship between troughs and IMF is most likely the result of the shape of convection cells for different IMFs, leading to horizontal plasma flows that bring plasma of different origins close to each other.
- Convection pattern governed by interplanetary environment plays a major role in the formation mechanism of regular troughs (i.e. non-local)

Trough and plasmapause

TOP IONOSPHERE (850 km) **DMSP** satellites (F15, F13) (trajectory above tomgraphy chain)





700 600

500

/km

Altitude

F REGION IONOSPHERE

Satellite tomography results, Finnish chain, 15-20 E (courtesy to Tero Raita, Sodankyla Geophysical Observatory, Finland)



EISCAT Data **UHF** radar (69.59°N, 19.23°E 66.73° mlat, 102.18° mlon)



Tromsö UHF

Έ

29 Sep 2005 1907 UT

Data sources and models

PLASMAPAUSE calculation from plasmaspheric model *

Analytic

- plasmasphere (with or without plasmaspheric wind)
- polar wind
- auroral regions

Inputs: VDF of the particles, number density, flux, bulk velocity, temperature (parallel, perp, tot), heat flux



INTERPLANETARY MAGNETIC FIELD: By, Bz

(WIND, ACE, IMP8...)

POLAR CAP AND AURORAL CONVECTION MODEL ** (LIMIE).



* Pierrard and Stegen, J. Geophys. Res,, 2008

** Papitashvili et al, J. Geophys. Res., 1994

Correspondence between trough and
plasmapause28 September 2005



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Pierrard and Voiculescu (2011)





Trough observation 18:05 UT (20:30 MLT)

λ=59°

Electron density [10¹¹ m⁻³

No trough – PP coincidence

Possible reasons: > PP - model result

Tomographic observation: TIDs carrying ionospheric plasma inside the trough region?



Trough observation 18:05 UT (20:30 MLT)

DMSP (33 E) 17:30 UT (21:00 MLT)

Trough is seen both in the F region and the top ionosphere

TIDs at the south?

-high Te ? (PP signature)-westwd drift (SAID?)



Trough observation 17:50 UT (21:20 MLT)

DMSP (45 E) 16:51 UT (20:14 MLT)

λ=63°

No coincidence between trough and PP



Trough observation 17:01 UT (19.30 MLT) **DMSP (28 E)** 17:50 UT 20:15 MLT

 $\lambda = 61$ °

PP would correspond to eqwd wall in the absence of the plasma bulge

Real PP (if high Te – signature of PP)

CONCLUSIONS (4)

Plasmapause CAN be related to "regular" troughs

- When the projection of the modeled PP into the ionosphere does not coincide with trough (wall) other ionospheric (TID, advective plasma transport, etc) or magnetospheric processes might be at work
- PP model might not correctly reproduce the relatively small scale ionospheric features shaping the trough
- Coincident in situ identification of plasmapause is needed (IMAGE, CLUSTER)



Subauroral ion drifts and ionospheric troughs

SAID is localized near the equatorial edge of the ion precipitation.

SAID has formed as a result of downward currents in the ionosphere are generated by precipitating ions which have to close with upward current associated with precipitating energetic electrons via horizontal currents circulating in the ionospheric trough.

Abnormal subauroral ion drifts



Voiculescu and Roth (2008)

Abnormal subauroral ion drifts



Voiculescu and Roth (2008)

Suggested explanation

- the counterpart of that proposed by Lemaire et al. (1997) and De Keyser et al. (1998) for the formation of SAIDs,. requiring a particular configuration of the inner magnetosphere (this could be the reason for which ASAIDs are not frequently observed).

In the case of ASAIDs an earthward field developing in the equatorial plane is required. In the thermoelectric field hypothesis hot plasma must be closer to the earth than cold plasma. Such a situation occurs when:



hot ring current ions and the *cold plasmatrough* overlap, generating a thermoeletric field due to gyroradius effects (*opposite to the SAID generation*)

OR

Plasmasheet ions penetrate very *close* to the plasmasphere so that they form a *shoulder* between plasmasphere and plasmatrough.