The interhemispheric version of the TRANSCAR ionosphere model

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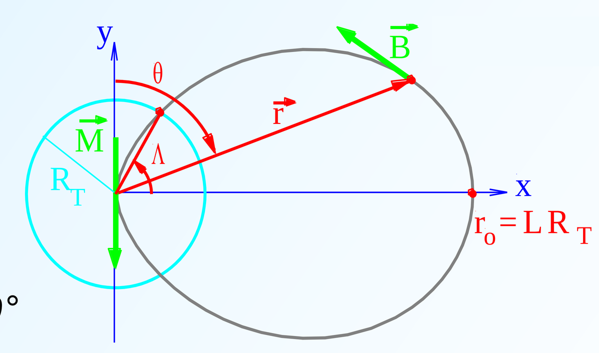
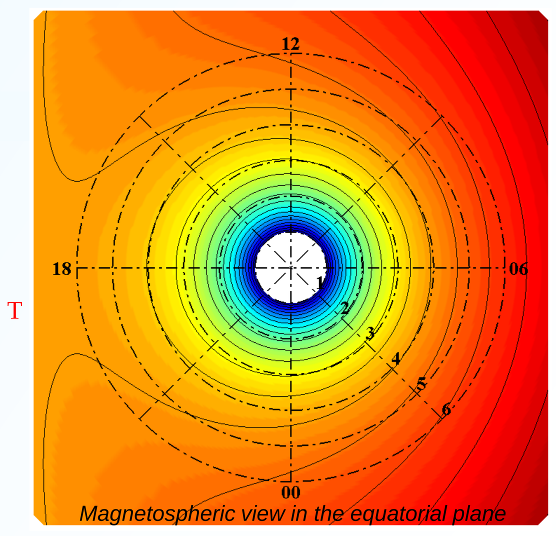
Abstract *– In order to study the impact of coupling between hemispheres on the dynamics of the ionospheric and magnetospheric plasma, a new interhemispheric ionospheric model has been developed with a dipolar geomagnetic field geometry. This new model is based on a multi-fluid approach for ions and thermal electrons and a kinetic approach for suprathermal electrons, already used in the TRANSCAR model (Blelly et al., 2005). However, substantial developments have been made, in order to cover high altitudes, low- and mid- latitudes with a single model. These developments are described below.*

Model principle: *2 interacting ionospheres*

• *Model geometry : all latitudes and altitudes coverage*

- Dipolar magnetic field lines, characterised by a reference point along the line:
  - *in geographic coordinates (Glat, Glon, alt)
  - *in magnetic coordinates (Mlat, Mlon, alt)
  - *in invariant coordinates (L, MLT, alt)
- Integration of gravity and inertial forces (centrifugal and Coriolis)
- Integration of plasma *corotation / convection* with the *Schulz (2007)* model for *Mlat < 50°* or of plasma convection only with the *Senior (1991)* model for *Mlat > 50°*
- In progress: simulation of the opening/closure of a flux tube (entry/exit of the polar cap under convection effect)





→ strong variability along a magnetic field line of:

- forces : gravity, inertial
- illumination
- interhemispheric effects: seasonal, diurnal

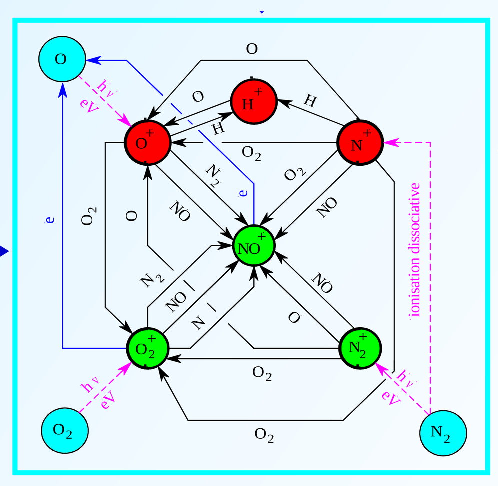
→ strong variability between different flux tubes (variable L):

- under corotation / convection effect (e.g.: at stagnation point)

• *Physicochemical model : TRANSCAR principle but with a 16-moment approach*

SUN
EUV Flux
Solar flux imposed by the F10.7 index

ATMOSPHERE
MSIS 90 model
O_2 - N_2 – O – H – N
NO
+ neutral winds (HWM90)



22 reactions + collisions

Fluide transport equations 16 moment
O_2^+ - N_2^+ - NO^+ O^+ - H^+ - N^+
e^- thermal

ionisation

Kinetic transport equations
suprathermal e-

Time-dependent model with bi-maxwellian functions

- **For light ions:** N_i, $\mathbf{v_i}^{//}$, $T_i^{//}$ and $T_i^{\perp}$, $\mathbf{Q_i}^{//}$ and $\mathbf{Q_i}^{\perp}$ described by the transport equations
- **For molecular ions:** N_i described by the continuity equation; $\mathbf{v_i}$ and T_i averaged over all the ions and $\mathbf{Q_i}$ neglected
- **For electrons:** N_e and $\mathbf{v_e}$ resulting from electroneutrality and zero field aligned current assumptions; $T_e^{//}$ and $T_e^{\perp}$, $\mathbf{Q_e}^{//}$ and $\mathbf{Q_e}^{\perp}$ solved with transport equations

Dynamical coupling between fluid and kinetic models

Fluid model supplies N_e and T_e to the kinetic model and kinetic model supplies ionisation rates and suprathermal e- thermalization (↔ thermal e- heating) to the fluid model to calculate N_e and T_e

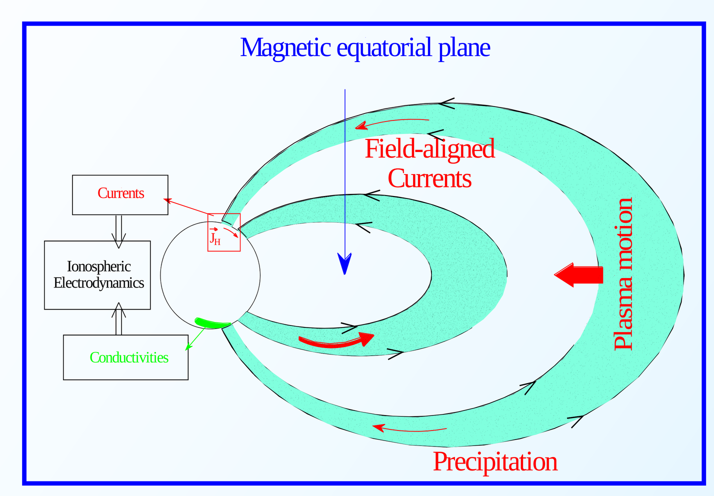
Static model

Vertical transport of electrons with consideration of:

- **sources** :primary electrons (precipitating or photoelectrons) and secondary electrons
- **losses** : collisions with neutral species and thermal electrons

• *Other developments (finalisation phase)*

- Integration of the magnetic mirror effect
- Integration of particle precipitation « everywhere » along the magnetic field line
- Coupling wit the IMM electrodynamics model (IRAP-LPP)
- Model extension to low altitudes (ionospheric Region D): TARANIS mission preparation



IMM model synopsis

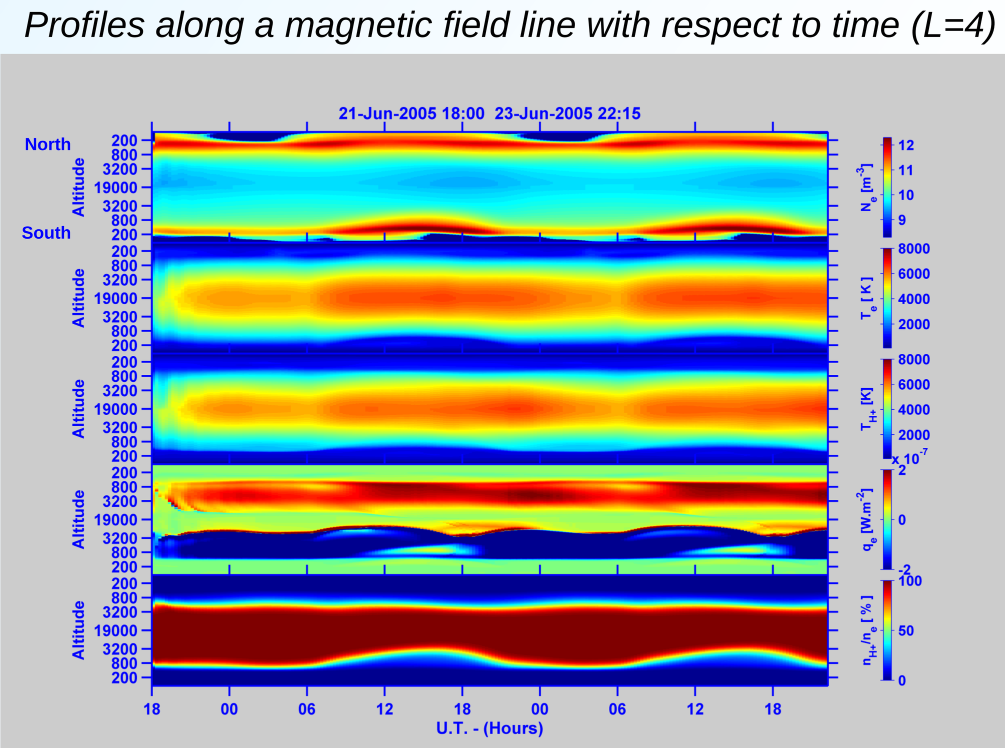
• *Future developments*

- Interhemispheric TRANSCAR developed to be module independent, each module can be easily replaced:
  - → dipolar magnetic field model will be replaced by an off-centre model or by the IGRF model
  - → empirical convection model will be replaced by SuperDARN global convection maps depending on IMF conditions and time-varying

First results of the model in the plasmasphere and conjugated ionospheres: 1.25 < L < 6

- Study: runs of 20 flux tubes during a solstice period (summer in the Northern hemisphere) with the same initial magnetic local time (18:00 MLT), but with variable L from 1.25 to 6 (with a 0.25 step)

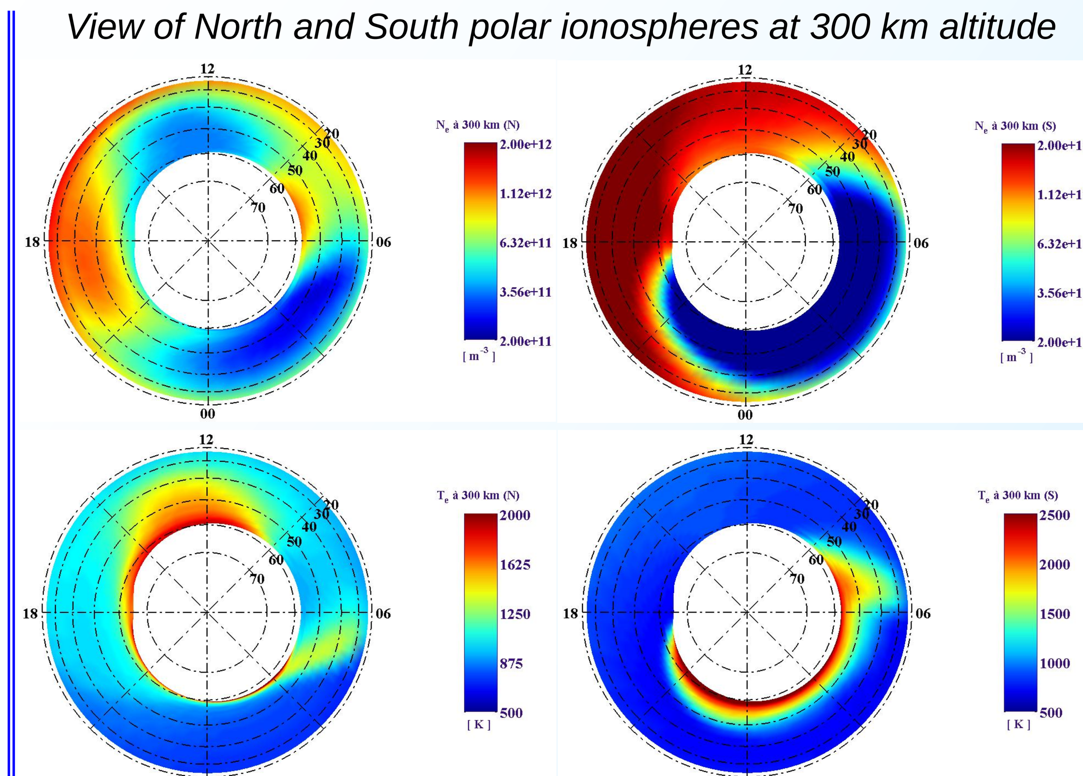
Profiles along a magnetic field line with respect to time (L=4)



Temporal evolution during solstice of N_e , T_e , Q_e , T_{H+} , z_50:

- Strong asymmetry between hemispheres
- Strong dawn-dusk asymmetry
- Electron density N_e: denser in the nightside ionosphere in the summer hemisphere (North) than in the winter hemisphere (South)
- Electron and proton temperatures T_e and T_{H+}: maximum at apex (where density is low)
- T_e and T_{H+} profiles: similar at high altitudes
- Electron heat flux Q_e: essentially directed downward in both hemispheres (due to maximum of T_e at Apex)
- In the nightside: z_50 (altitude where $N_{H+}/N_e = 0.5$) at lower altitude in the winter hemisphere (South) than in the summer hemisphere (North)
- In the dayside: z_50 increases in the winter hemisphere (South) by diffusion process

View of North and South polar ionospheres at 300 km altitude



Interhemispheric asymmetries:

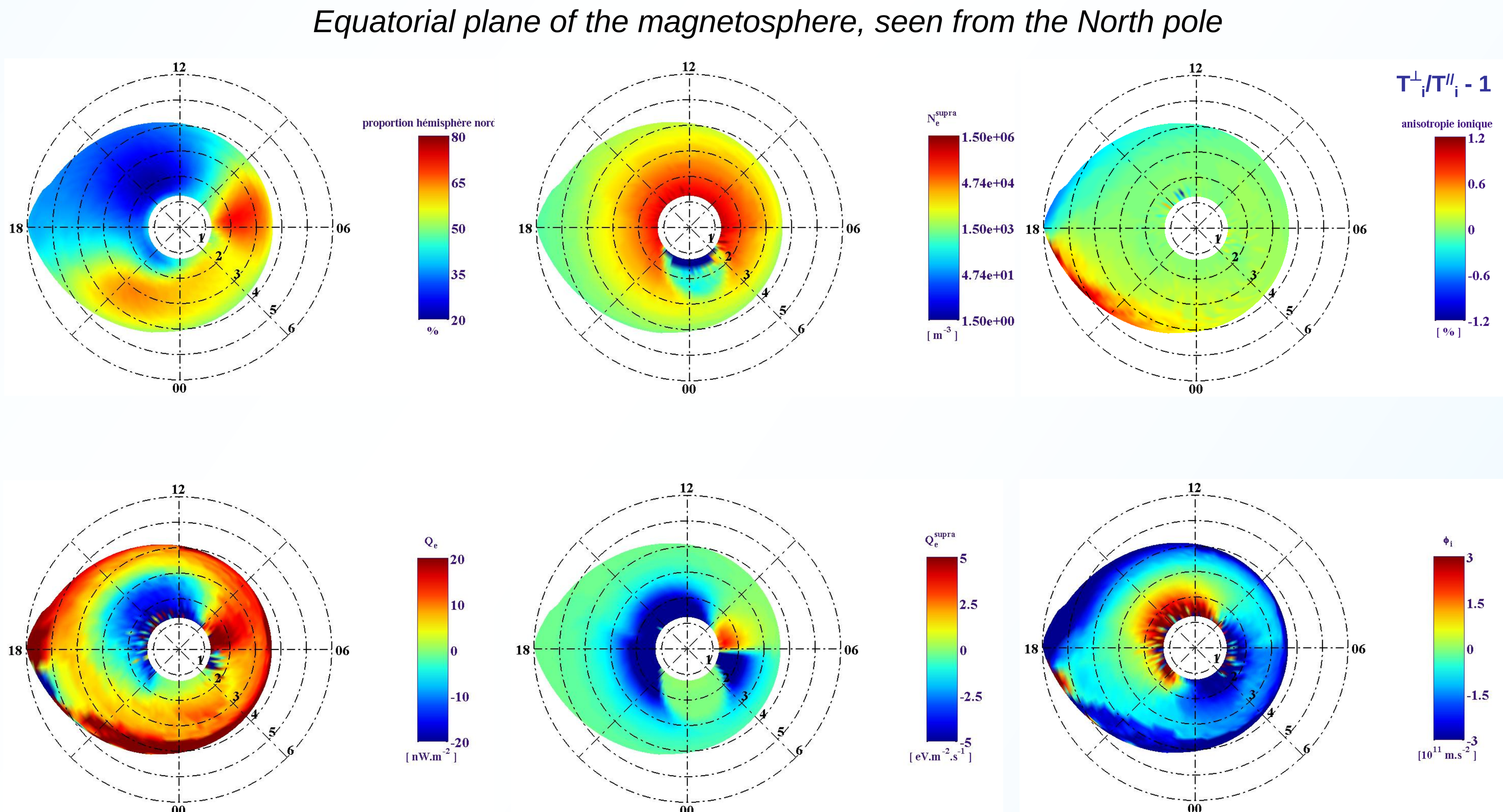
Summer hemisphere (North):

- Strong ionospheric heating (increase of T_e) at Sunrise and Sunset, and diffusion to lower latitudes
- Diurnal cooling due to ions production caused by increase of N_e by solar ionisation: thermalization
- Increase of N_e after Sunrise and decrease of N_e at Sunset: N_e-T_e antiphase
- Maximum of N_e at 18:00 MLT: layer ascent caused by corotation/convection (matter is not consumed anymore)

Winter hemisphere (South):

- Very localised ionospheric heating (very short period of solar illumination between 06:00 and 08:00 MLT) and quick thermalization
- At high latitudes in the nightside: energy transfer from the summer hemisphere (North) to the winter hemisphere (South)
- Maximum of N_e at 18:00MLT (like in the summer hemisphere)

Equatorial plane of the magnetosphere, seen from the North pole



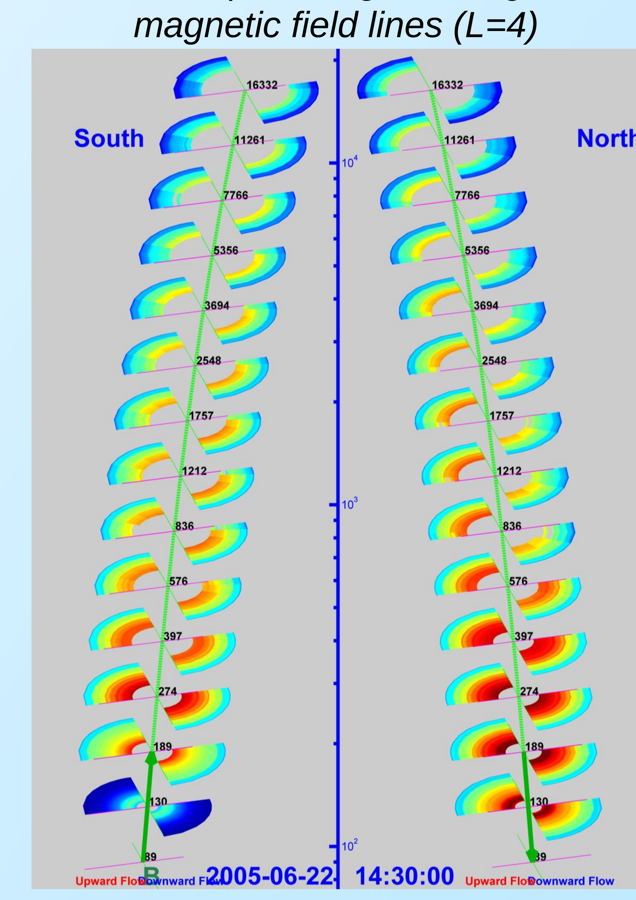
L and local time (LT) variations:

- TEC, integrated along the magnetic field line, is dominant in the nightside and dawnside of the summer hemisphere (North)
- TEC, integrated along the magnetic field line, is dominant in the dayside and the duskside of the winter hemisphere (South)
- Suprathermal electron density N_{es} decreases with increasing L, but remains relatively uniform with LT. Presence of a shadow cone in the nightside.
- For L > 3, around the stagnation point: development of ion temperature anisotropies $T^{\perp}_i/T^{//}_i$ (due to the 16-moment resolution)

Interhemispheric exchanges:

- For L < 3: electron heat flux Q_e directed towards the summer hemisphere (North) in the dawnside and towards the winter hemisphere (South) in the duskside
- For L < 3: ion flux Φ_i directed towards the winter hemisphere (South) in the nightside and towards the summer hemisphere (North) in the dayside
- For L > 3, around the stagnation point: strong ion flux Φ_i and strong electron heat flux Q_e
- For L < 3: strong oscillations of Q_e and Φ_i, probably due to matter production
- For L < 3: suprathermal electrons heat flux Q_{es} is correlated with Q_e. Again presence of a shadow cone in the nightside

Electron pitch-angles along the magnetic field lines (L=4)



- Dayside observations: net flux of electrons from the summer hemisphere (North) to the winter hemisphere (South)

Scientific perspectives

- Fine structure study at Sunrise and Sunset, in order to study the interhemispheric exchanges (energy flux and matter flux), with respect to season, L parameter, solar activity...
- Comparison of the model results with incoherent radar data (Millstone Hill, EISCAT), and satellite data (Demeter, Akebono, Cluster)

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