Models and Observations of Ionospheric Conditions

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Abstract

The Swarm satellites will provide unprecedented precision in measuring the Earth's magnetic field in the upper atmosphere. One of the primary aims is to study the Earth's geodynamo, but at this level of measurement, it will be necessary to remove many other magnetic perturbations due to currents flowing in the oceans and the ionosphere to obtain the pure field. The ionospheric currents produce perturbations of a few nT at mid- and low-latitudes and a few hundred nT in the polar latitudes due to strong dynamic interactions between the Earth's magnetosphere and the solar wind. The in-situ measurements from Swarm will allow detailed studies of the ionosphere that can be used to calibrate upper atmosphere models. The Coupled Thermosphere-Ionosphere-Plasmasphere model is a self-consistent, fully coupled 3D numerical model that solves the Navier-Stokes equations of energy, momentum and composition from first principles. Initial studies made comparing CHAMP magnetic field measurements with the CTIP model have shown successes and short-comings of the model, which will be generic to models of this kind. These results will be presented and suggestions will be made for future improvements to the physics underlying upper atmosphere modelling. The improved models will provide more realistic ionospheric currents which will aid Space Weather prediction as well as determination of the true geodynamo field.

Summary

A study was commissioned by ESA in preparation for the Swarm mission. The Coupled Thermosphere-Ionosphere-Plasmasphere model (CTIP) was used to determine what level of ionospheric currents would be likely to be encountered by Swarm. The aim with Swarm is to remove the magnetic perturbation caused by these currents from the measured magnetic fields in order to obtain the pure geodynamo field at 400-500km altitude. Ground-truthing of the CTIP model was provided by comparing model simulations with CHAMP satellite measurements of global electron densities, and also by comparing simulations of a single location with Arecibo radar electron densities, electron temperatures and ion temperatures.

The purest geodynamo field measurements will be determined from periods when the ionospheric currents are at a minimum. The optimum times are during nighttime conditions when the ionospheric conductivity is very small and periods of low magnetic activity. The optimum locations are equatorward of 50° latitude, away from the auroral ovals which are controlled by the magnetospheric dynamo. The inertia of the neutral atmosphere in responding to geomagnetic forcing means that currents driven by neutral winds can last for a few days after a storm. It is therefore necessary to choose periods that have been geomagnetically quiet for a few days previously.

Three suitable periods were chosen for the comparison with CHAMP data. These represent 3 different solar activity levels and 3 different altitudes sounded by CHAMP during the period 2001 to 2006 as its orbit decayed from 420km to 370km. These are nighttime measurements between 18LT and 05LT where Ap < 15 for at least 4 days. There is one Northern winter example in 2001 (25 Nov 01) and two Northern Summer examples in 2003 and 2006 (05 Jul 03 and 19 May 06). The local times are 4:30LT in 2001 and about 21LT in the two later years. The data from the Arecibo radar for 27 June 2006 were chosen for the single site comparison with CTIP.

The CTIP model is a numerical model that fully couples the thermosphere with the ionosphere and plasmasphere using the principles of physics. The alternative is to use an empirical model that is constructed by fitting parameters to a large database of observations or a purely ionospheric model that is not coupled to a thermosphere. There are clear successes from the ground-truthing exercise, but also a highlighting of the limitations of global circulation models. Upper atmosphere GCMs can test the physics by providing climatological behaviour, but cannot provide an instantaneous "*real*" atmosphere. Empirical models can only give an indication of average behaviour. Pure ionospheric models can give a better absolute match with data on a short time scale but without being self-consistent with the neutral atmosphere, and less reliable on the medium and long time scales.

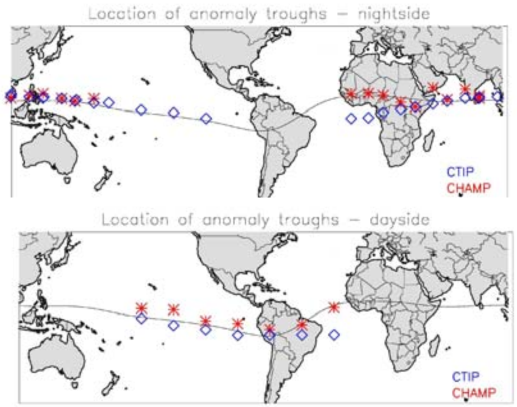
Suggested improvements for GCMs modelling currents:

(i)More realistic magnetic field models are required: IGRF versus tilted dipole

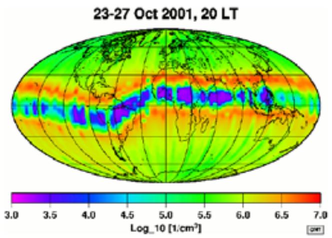
(ii)The divergence of the current must be dealt with explicitly by determining the field-aligned currents out to several thousand kilometres within the plasmasphere.

(iii)GCMs were designed to deal with big structures such as the auroral oval and equatorial electrojets rather than subtle effects from currents caused by the gravity and ion and electron pressure gradient terms. A different strategy is required here.

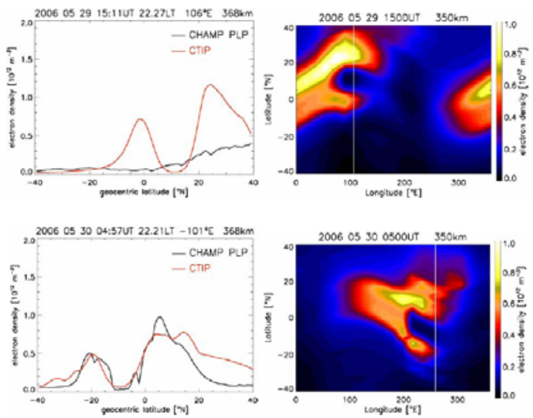
(iv) The CHAMP satellites were above the maximum height boundary of the CTIP thermosphere at solar minimum, and so extrapolation was necessary, using the assumption that high viscosity causes minimal height variation in the neutral winds. Recent derived winds from CHAMP compared with ground-based FPI measurements indicate that this assumption needs revisiting.



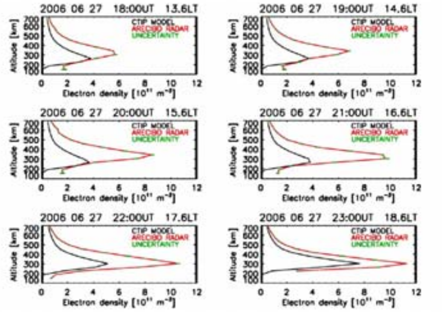
Comparison of the location of the electron density trough at the magnetic equator measured by the CHAMP satellite with CTIP reveals the importance of the magnetic field model used by the GCM. CTIP uses a simple tilted dipole magnetic field.



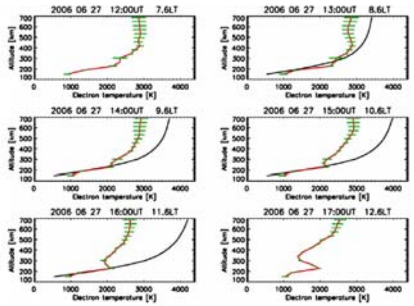
CHAMP observation of the electron density in the post-sunset sector (Lühr et al., 2003)



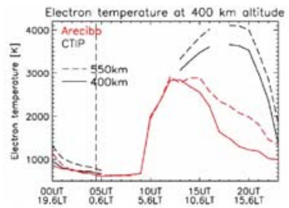
The left hand plots show a comparison of the CHAMP PLP electron density measurements with CTIP for 2 sample dates: 29 and 30 May 2006. The right hand plots show latitude-longitude electron density distributions at 350km with a white line indicating the path of CHAMP on each date.



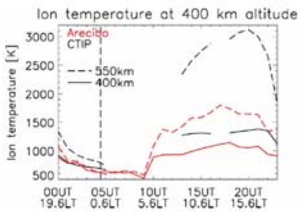
Comparison of electron density profiles observed by the Arecibo radar on 27 Jun 2006 with CTIP. The green bars estimate the uncertainty of the Arecibo measurements.



Comparison of electron temperature profiles observed by the Arecibo radar on 27 Jun 2006 with CTIP. The green bars estimate the uncertainty of the Arecibo measurements.



The temporal evolution of the electron temperature measured by the Arecibo radar on 27 Jun 2006 compared with CTIP for two altitudes: 400km and 550km. The dashed line is local midnight.



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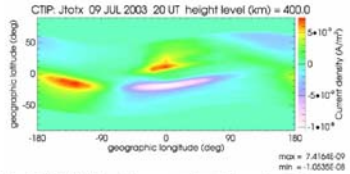
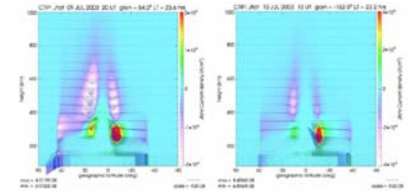
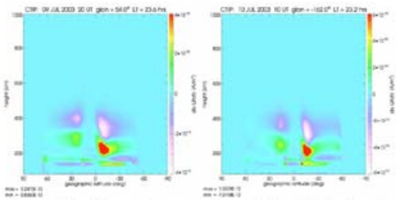


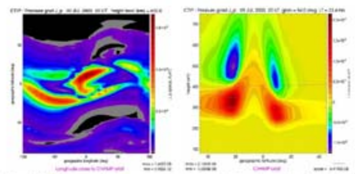
CTIP simulation of the global distribution of the southward-component of the total current at 400km at 20UT on 09 Jul 2003



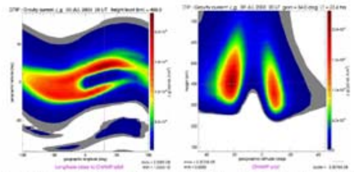
Latitude-height distribution of the CTIP simulation of the total current vector near the CHAMP orbit at 20UT on 09 Jul 2003 and 10UT on 10 Jul 2003.



Latitude-height distribution of the CTIP simulation of the divergence of the current near the CHAMP orbit at 20UT on 09 Jul 2003 and 10UT on 10 Jul 2003.



CTIP simulation of the pressure gradient driven currents for 20UT on 09 Jul 2003. Left hand plot shows longitude-latitude and right shows latitude-height distributions along the meridian closest to the CHAMP orbit, indicated by a magenta line.



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