Equatorial Electrodynamics

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Introduction

The Earth’s equatorial/low latitude ionosphere is host to the most complex phenomena in the Earth’s upper atmosphere driven by neutral atmospheric and electrodynamics processes and disturbed by plasma irregularities with a large range of scale sizes.

The quiet-time electrodynamics is driven by several solar cycle and season dependent local and lower atmospheric processes including solar and lunar tides, planetary and gravity waves, and are also affects by el nino, earthquakes, tsunamis, lightning and by high latitude sudden stratospheric warmings.

The storm-time electrodynamics is affected by solar wind/magnetosphere/high latitude ionospheric processes including solar coronal mass ejections, high speed streams associated with corotating interaction regions, substorms, solar wind density, velocity and dynamic pressure changes, solar flares, and Joule heating.
Ground-based and satellite (AE-E, DE-2, DMSP, ROCSAT-1, C/NOFS, CHAMP, and Swarm) data determined the climatology signatures of low latitude electrodynamic processes.
Quiet Time Low Latitude Ionospheric Electrodynamics: Outstanding Questions

• Short-term variability (time scales less than about a month) of equatorial electric fields and currents.
• Altitudinal variability equatorial plasma drifts in the lower ionosphere, their relationship to local and lower altitude neutral wind and waves, and effects on plasma irregularities.
• Topside electrodynamic processes including the processes controlling the peak altitudes of equatorial plasma depletions.
• Relative effects of vertical plasma drift and TIDs on postmidnight equatorial plasma irregularities.
• Gravity wave effects on quiet-time equatorial plasma drifts
• Equatorial and higher latitude electrodynamic coupling effects

Current ionospheric databases are too limited for meaningful answers to these questions in spite of the availability of very recent simulations studies and powerful new data analysis tools.
The quiet-time variability of equatorial plasma drifts is strongly height dependent.
The quiet-time drift variability of equatorial plasma drifts season, solar cycle and perhaps also longitude dependent.

Jicamarca

This large day-to-day variability is due to changes in tidal forcing, effects of planetary waves, irregular winds in the dynamo region, and changes in the dynamic conditions at the base of the thermosphere.
Evening prereversal velocity enhancements
Geomagnetic activity effects
Equatorial prompt penetration and disturbance dynamo ExB plasma drift perturbations

Short-lived (time constant of up to a few hours) perturbations are due to the prompt penetration of solar wind driven high latitude electric fields into the low latitude ionosphere.

Longer lasting perturbations are due to ionospheric disturbance dynamo electric fields driven by enhanced energy deposition into the high latitude ionosphere.

Over Jicamarca 40 m/s = 1 mV/m
Storm-time plasma drift effect on the radar backscatter power (proportional to the electron density)
Geomagnetic Activity Effects: Outstanding Questions

• Storm-time, seasonal, solar cycle and longitudinal (UT) dependence of prompt penetration and disturbance dynamo electric fields.
• Altitudinal dependence of disturbance dynamo electric fields and their relationship to storm time winds.
• Effects solar wind and magnetospheric parameters (e.g., solar wind density, and speed, IMF By, plasmasheet ion density, magnetic field line stretching and dipolarization, substorms) on the lifetime and magnitude of prompt penetration electric fields and
• Height dependent relationship between storm-time winds and plasma drifts.
Solution of the Vasyliunas Equation
Mathematical Formulation of Linear Convection Models

\[ E(\theta, \phi, t) = \int_{-\infty}^{t} G(\theta, \phi, \tau) \Phi_0(t - \tau) d\tau \]  \hspace{1cm} (1)

E = ionospheric electric field

\( \Phi_0 \) = Potential distribution along the polar cap/auroral zone boundary

\( G \) = Green’s function (physical content of the model)

Integrating (1) by parts:

\[ E(\theta, \phi, t) = [G(\theta, \phi, \tau) \Phi_0(t - \tau)]_{-\infty}^{\infty} + \int_{-\infty}^{\infty} G_0(\theta, \phi, \tau) \frac{d\Phi(t - \tau)}{dt} d\tau \]

where

\[ G_0 = \int_{-\infty}^{t} G(\theta, \phi, \tau) d\tau \]

\( G_0 \) = response of the system to a step function \( H(t) \)

\[ H(t) = \begin{cases} 1 & t \geq 0 \\ 0 & t < 0 \end{cases} \]
Assuming no source at $-\infty$ and $G_0 = 0$ for $\tau < 0$, then

$$E(\theta, \phi, t) = \int_{-a}^{\infty} G_0(\theta, \phi, \tau) \frac{d\Phi(t - \tau)}{dt} d\tau$$

Assuming

$$\Phi_0(t) = \sum_{i=1}^{N} \Delta \Phi_i H(t - t_i)$$

$$\dot{\Phi}_0(t) = \sum_{i=1}^{N} \Delta \Phi_i \delta(t - t_i)$$

$$E(\theta, \phi, t) = \sum_{i=1}^{N} \Delta \Phi_i G_0(\theta, \phi, t - t_i)$$
Storm-time Electrodynamics

ICON, COSMIC, Swarm, and complementary ground-based measurements should provide, for the first time, large databases needed for the effective use of powerful multivariate data analysis (e.g., Principal Component and Canonical Correlation analysis) for the study of quiet-time low and upper atmospheric, and of recently developed solar wind drivers and transfer functions for storm-time solar wind/magnetosphere effects on the low latitude ionosphere.

The current solar wind drivers and transfer functions [e.g., Newell et al., 2007, 2008; McPherron et al., 2013; Bala and Reiff, 2012, 2013; Borovsky, 2013, 2014] can account for the main processes responsible for solar wind-magnetosphere coupling and for the variance of several geophysical parameters (e.g., $AE$, $AU$, $AL$, $Kp$, and auroral power, MBI) with significantly improved accuracy.

These transfer functions have already been used for solar wind-magnetosphere-ionosphere coupling studies [e.g., Tsyganenko and Andreeva, 2015], and in studies of storm-time ionosphere coupling using CHAMP and ROCSAT-1 satellite data [Xiong et al., 2015, 2016].
Summary

The major difficulty for major progress in the study of low latitude electrodynam
processes is the very limited current database of GLOBAL ionospheric electric field
and altitude dependent wind measurements.

ICON, COSMIC, and Swarm and ground-based measurements and complementary
numerical simulations have the potential to lead to major improvements on the
understanding and development of much improved predictive models of the complex
electrodynamical processes in the low latitude ionosphere.