Longitudinal Variability of Equatorial Electrodynamics

E. Yizengaw\textsuperscript{1}, J. Retterer\textsuperscript{1}, B. Carter\textsuperscript{1}, K. Groves\textsuperscript{1}, and R. Caton\textsuperscript{2}

\textsuperscript{1}Institute for Scientific Research, Boston College
\textsuperscript{2}AFRL, Kirtland AFB, NM, USA

Special Thanks: M. Magoun, M. Moldwin, E. Zesta, C. Valladares, and AMBER, SCINDA, & C/NOFS teams
Outline

- AMBER instrument deployment status!
- The longitudinal dependence of EEJ/drift, ionospheric density and irregularity structures!
- Post midnight irregularities and its longitudinal dependences!
- Does the magnetospheric origin ULF wave cause ionospheric density modulation?
Status of AMBER network expansions

AMBER (African Meridian B-field Education and Research)

Team members: E. Yizengaw (PI, BC), M. Moldwin (Co-I, UM), E. Zesta (NASA), M. Magoun (BC)

Detail Information About AMBER can be found here: https://www2.bc.edu/~kassie/AMBER.html
Instrument & its Setup at the site

Sensitivity: 0.01 nT
Resolution: 0.5 sec
How to estimate drift from Mags. measurements?

Magnetometer at off the equator

\[ B_{\text{Obs}} = B_{\text{main}} + B_{\text{SQ}} + B_{\text{FAC}} + B_{\text{RC}} + B_{\text{MP}} \]

Magnetometer at the equator

\[ B_{\text{Obs}} = B_{\text{main}} + B_{\text{SQ}} + B_{\text{FAC}} + B_{\text{RC}} + B_{\text{EJ}} + B_{\text{MP}} \]

EEJ, which is generated by Hall and Pederson conductivities at the vicinity of geomagnetic equator (±3°), is proportional to vertical drifts.
Longitudinal variability of EEJ & drift

EEJ from SWARM-A, B, & C in January-February 2014 from 10:00 to 11:00 LT
Does ESF have the same longitudinal dependence?

Bubbles from GPS TEC (2009-2012)

- TEC depletion (bubbles) in 2009–2011
- 76.9°E
- 69.2°E
- 56.1°E
- 7.6°E
- 38.8°E

Scintillation from UHF data (2010-2014)

- Statistical night side bubbles Longitudinal Dependence (2010–2014)
  - Pacific: Lon = −157.4°E
  - Africa: Lon = −17.45°E
  - America: Lon = −77.15°E
  - Africa: Lon = 36.81°E
  - America: Lon = −56.07°E
  - Asia: Lon = 100.8°E
  - America: Lon = −44.21°E
  - Asia: Lon = 167.5°E

Seemala and Valladares, 2011
Post-midnight irregularities and its longitudinal dependences
Is the ionosphere calm during post-midnight?

How about long term observation?
dN = In the root-mean-square value of the relative density deviation from the mean density calculated as an envelop of ambient density, which is averaged every minute (∼400 km spatially).

To minimize additional factors (altitude variation) that cause the deviation (dN) to vary, we normalized dN by local epoch density (N), and obtained dN/N. We then use dN/N as proxy for bubble occurrence.
Does Mag data useful for post-midnight bubbles?
Does the magnetospheric origin ULF wave cause ionospheric density modulation?
ULF wave generation mechanisms

- The periodic SW dynamic pressure oscillations slowly alter the size of the magnetospheric cavity, causing the generation of poloidal ULF wave.

- The change in SW azimuthal flow direction (usually accompanying shocks) can excite Kelvin-Helmholtz (KH) instabilities at the magnetopause, which in turn causes the generation of Toroidal mode ULF wave.

Field Line Resonances

Poloidal \textit{Pc5} \& Toroidal \textit{Pc5}

Wave occurrence rates [Agapitov \& Cheremnykh, 2013]

The ULF wave fields drive perturbations in the ionosphere, like FLR on radio sounders at low [Menket \textit{et al.}, GRL, 2007] and high latitudes [Mthembuet \textit{et al.}, AG, 2009], electric field oscillations [Cosgrove \textit{et al.}, AG, 2010], GPS TEC modulation [Yizengaw \textit{et al.}, 2013; Pilipenko \textit{et al.}, JGR, 2014], generation of kilometer scale waves in the ionosphere [Cosgrove \textit{et al.}, AG, 2010], etc.
TEC modulation by ULF waves

Pilipenko et al., JGR, 2014
ULF wave related EEJ fluctuation

Yizengaw et al., JASTP, 2013
ULF waves in the Pc5 range are very much intense enough to generate fluctuation in the ion temperature.

For example; any typical Pc5 wave of $f = 3\text{mHz}$ at $\Delta\beta=0.1\text{mHz}$ $\rightarrow \Delta Ti=300\text{K}$, may cause $\Delta N/N \sim 0.8\%$ fluctuation (Pilipenko et al., JGR, 2014).
Longitude independence of ULF wave
Summary with lots of open questions!

- The magnitude & direction of the vertical drift (both dayside and evening sector) show significant longitudinal differences, stronger in the American and Asian than African sectors, what cause this longitudinal differences? Is it due to tides or something else?

- Both ground- and space-based observations show clear longitudinal and seasonal variability of bubbles/irregularities structures, stronger in the African sector, which is opposite to the vertical drift longitudinal variability trend. If not the drift that cause the longitudinal bubbles distribution difference, then what could it be? Would it be the neutral winds that cause the long lasting bubbles in Africa?

- Both ground- and space-based observations show clear longitudinal and seasonal variability of the discrete post-midnight bubbles, stronger in the African sectors. The question is what cause such strong discrete post-midnight bubbles?

- It has been unambiguously proven that the Pc5 ULF waves can penetrate to the our atmosphere and drive perturbations in the ionosphere, modulating the magnetic and electric fields and density. The question is, can ULF wave produce strong density fluctuation that may cause at least HF propagation?
Seven Years ago

This Now!

Thank you!
What cause these quiet time post-midnight bubbles? Is there RT instability during this local time?

PBMOD run RT instability growth rate

What cause the vertical drift velocity to be reversed at this local time sector and during quiet periods?

Sporadic E-layer presence! If so what is the primary mechanism for the formation of Es layer?

♣ Charged dust particles due to strong gusty winds,
♣ meteors that can cause ionization, and polarized electric field associated with the MSTID

Yizengaw et al., GRL, 2013
Equatorial Electrojet (EEJ) formation

- The solar-driven neutral wind results in a current system and then an east-west polarization E-field in the E-region.
- At the magnetic dip equator, the resulting upward $E \times B$ drift moves negative charge at the top and a positive at the bottom of the E-region.
- The resulting E-field prevents electrons to be drifted further upward, instead, they are propelled westward by the eastward E-field. This forms an eastward electric current flow within $\pm 3.0^\circ$ of the magnetic equator, which is called the Equatorial Electrojet (EEJ).
ULF wave and density irregularity correlation

Time series of Doppler frequency variation at three different altitudes, observed by 54.95 MHz coherent backscatter radar!

(Reddy et al., AG, 1994)
What cause the enhancement of Rayleigh-Taylor instability growth rate?

\[
\gamma = \frac{\Sigma_F}{\Sigma_F + \Sigma_E} \left( V_{dr} - U_\perp - \frac{g}{v_{\text{eff}}} \right) \frac{1}{N_e} \frac{dN_e}{dh}
\]

\( \Sigma_F \ & \Sigma_E \):- F- and E-region Pederson conductivities

\( V_{dr} \):- Vertical drift

\( U_\perp \):- Perpendicular neutral wind component

\( g \):- Gravity

\( v_{\text{eff}} \):- Collision frequency

\( N_e \):- Electron density

\( \frac{dN_e}{dh} \):- Density gradient!
If not the drift, then what could it be? Would it be the neutral winds that cause the long lasting bubbles in Africa? If it is the neutral wind, why the orientation and magnitude of the wind in the African sector is unique compared to other longitudes?

- Equator ward meridional wind decrease conductivity and increase RTI growth rate

- Pole ward meridional wind increase conductivity and decrease RTI growth rate

_Huba and Krall, GRL, 2013_