Equatorial and low latitude ionosphere and equatorial spread F

Weijia Zhan

2023/04/19
Outline

• The low-latitude ionosphere
• Vertical plasma drifts and the evening PRE
• The ionospheric Rayleigh-Taylor (RT) instability
• ESF
The low-latitude ionosphere

F2: O+
E, F1: NO+, O₂⁺
Ion/electron-neutral collision frequency vs gyrofrequency
Plasma motions in the ionosphere

(Heelis, 2004)
Current and conductivity

\[ j = N_i e (V_i - V_e) = \bar{\sigma} \frac{F}{e} = \sigma_0 \frac{F^\parallel}{e} + \sigma_p \frac{F^\perp}{e} \]

\[ -\sigma_H \frac{F^\perp \times b}{e}. \]

\[ \sigma_0 = \frac{Ne^2}{m_e v_e} + \frac{Ne^2}{m_i v_i} \approx \frac{Ne^2}{m_e v_e}, \]

\[ \sigma_p = Ne^2 \left[ \frac{1}{m_e} \frac{v_e}{(v_e^2 + \Omega_e^2)} + \frac{1}{m_i} \frac{v_i}{(v_i^2 + \Omega_i^2)} \right], \]

\[ \approx \frac{Ne^2}{m_i} \frac{v_i}{(v_i^2 + \Omega_i^2)}, \]

\[ \sigma_H = Ne^2 \left[ \frac{1}{m_e} \frac{\Omega_e}{(v_e^2 + \Omega_e^2)} - \frac{1}{m_i} \frac{\Omega_i}{(v_i^2 + \Omega_i^2)} \right]. \]
E region dynamo

Neutral wind

Current

Equatorial electrojet

The equatorial electrojet in a slab geometry.

Equatorial electrojet

Observed by ground-based magnetometers at the equator.

(Tarpley, 1970)
Vertical drifts and equatorial ionization anomaly
Vertical drifts and equatorial ionization anomaly
Vertical drifts and F region dynamo

\[ E = \frac{\sum_F^p}{\sum_E^p + \sum_F^p} (U_F \times B). \]

Pre-reversal enhancement (PRE)
The ionospheric Rayleigh-Taylor instability

\[ \mathbf{J} = nMg \times \mathbf{B} \quad \frac{B^2}{B^2} \]

\[ \mathbf{E}_0 \text{ and } \mathbf{J} = \sigma_\rho \mathbf{E}_0 \]

\[ n_1 \]

\[ n_2 = 0 \]

\[ \delta \mathbf{E} \times \mathbf{B} \]

\[ \delta \mathbf{E} \times \mathbf{B} \]

\[ \Sigma n_0 \]
The ionospheric Rayleigh-Taylor instability
Equatorial spread F: ionosonde and ionogram

\[ f_c \approx 9\sqrt{N_{\text{max}}} \]

(Booker & Wells, 1938)
The peak of the volumetric emission rate occurs in the bottomside $F$-region and is proportional to the product between $O^+$ and $O_2$ densities.
Types of radar equatorial spread F (ESF)
Controlling factors

Linear growth rate of generalized RT instability

\[
\gamma_{GRT} = \frac{\Sigma^E_p}{\Sigma^E_p + \Sigma^F_p} \left( V_p - U^P_L + \frac{g_e}{v_{eff}} \right) K^F - R
\]

Electron density gradient
Recombination
(Sultan, 1996)
Ion-neutral collision frequency
vertical drift
meridional wind

Controlling factors:
- Linear growth rate of generalized RT instability
- Vertical drift
- Meridional wind
- Ion-neutral collision frequency
- Electron density gradient
- Recombination

(Sultan, 1996)
(a) Stage 1: Seed (late afternoon)

(b) Stage 2: Upwelling growth (SS_e)

(c) Stage 3: EPB development (SS_F)

(d) Stage 4: Evolution and decay (descent of F layer)

(Tsunoda, 2021)
Climatology of occurrence rate
Postmidnight ESF
• *June Solstice ESF: Morphology*

✓ ESF occurs, predominantly, in the post-midnight sector
• **June Solstice ESF**: $F$-region conditions

✓ No clear signatures of PRE or midnight upward drifts

✓ ESF events are, however, often preceded by weak apparent uplifts
- **December Solstice ESF: Morphology**
  - ESF starts in the evening and extends until post-midnight hours
• **December Solstice ESF:** *F*-region conditions
  ✓ Signatures of PRE or late evening upward drifts
  ✓ Strong uplifts produce well-developed, long-lasting ESF events
Open questions

• 1. day-to-day variability
• 2. atypical ESF
• 3. prediction of occurrence
Hysell et al., 2022
Scintillation Index S4
the normalized ratio of the standard deviation of signal intensity fluctuations to the mean signal intensity:
\[
\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}
\]
ROTI

- The Rate of TEC index (ROTI) is defined as standard deviation of the rate of TEC (ROT) assuming the ionosphere as a thin layer. Hence the index provides information about temporal ionospheric irregularities.

https://impc.dlr.de/products/ionospheric-perturbations/rate-of-change-of-tec-index/one-minute-mean-roti-global