Equatorial and low latitude ionosphere and equatorial spread F

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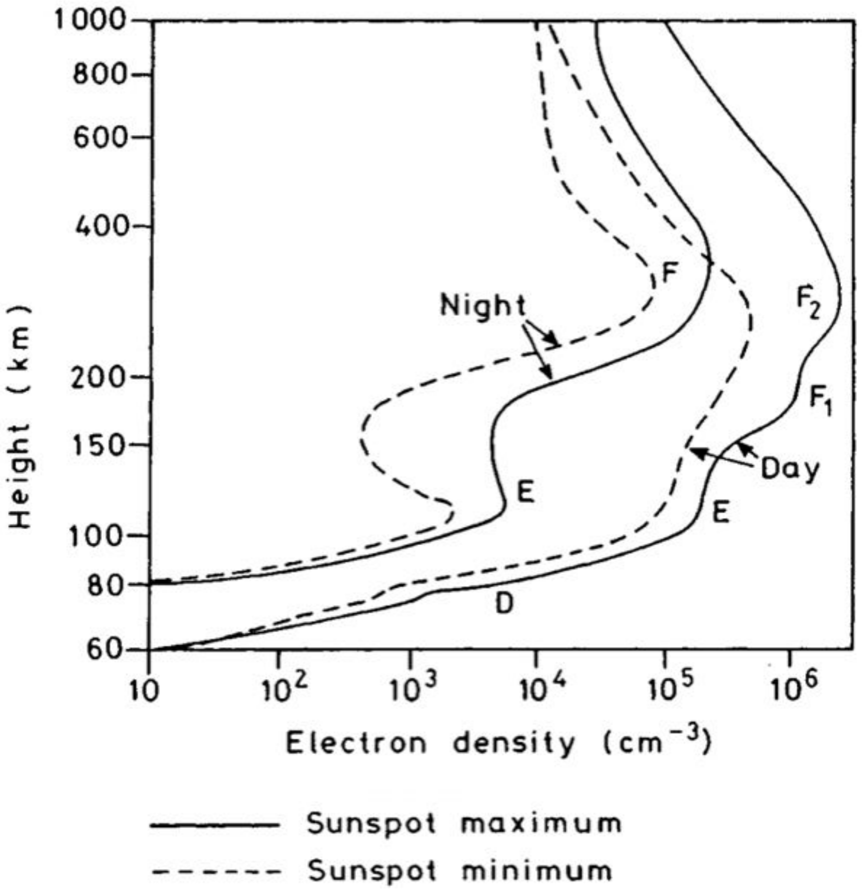
2023/04/19

Outline

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

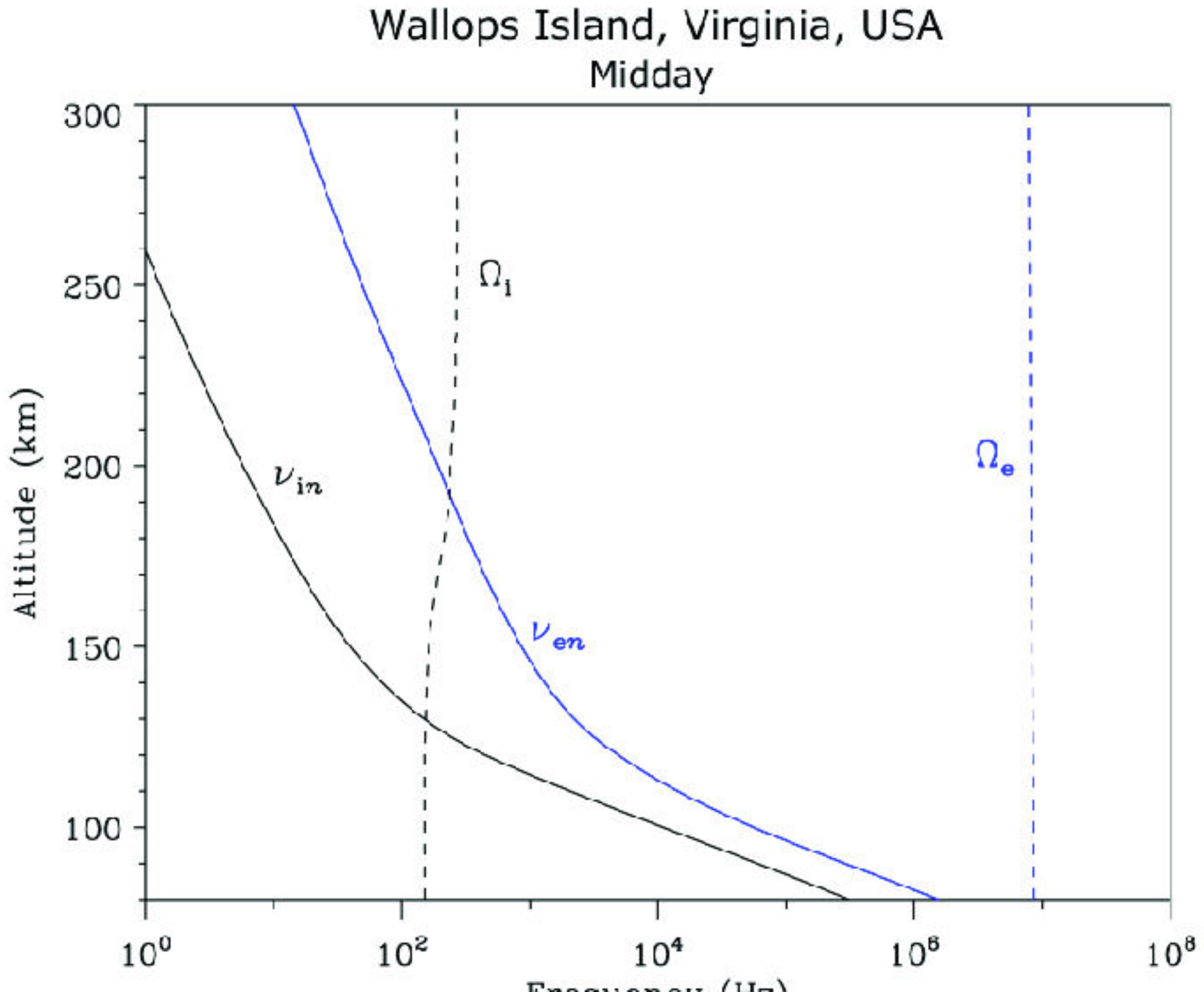
The low-latitude ionosphere



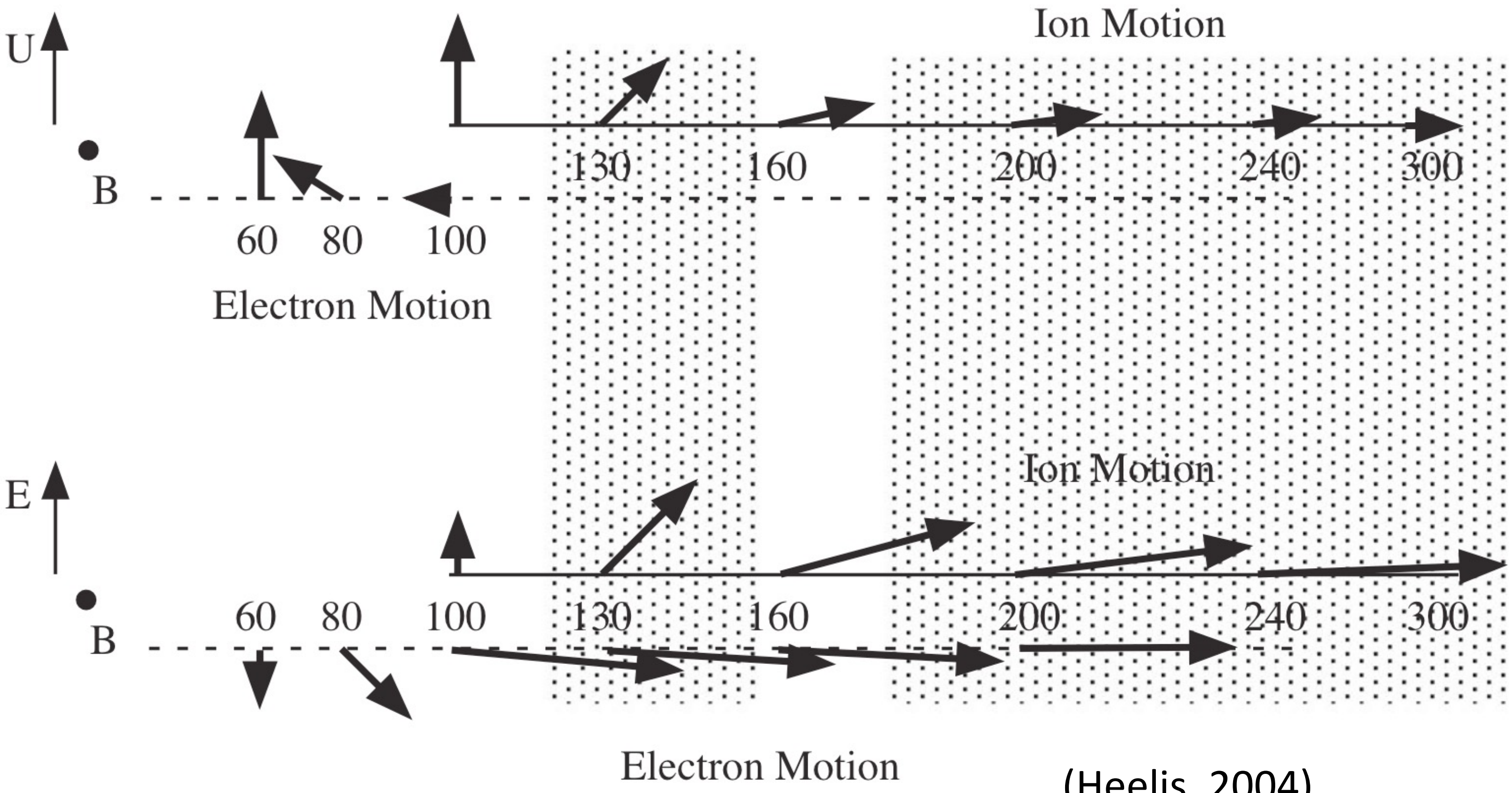
F2: O+

E, F1: NO+, O_2+

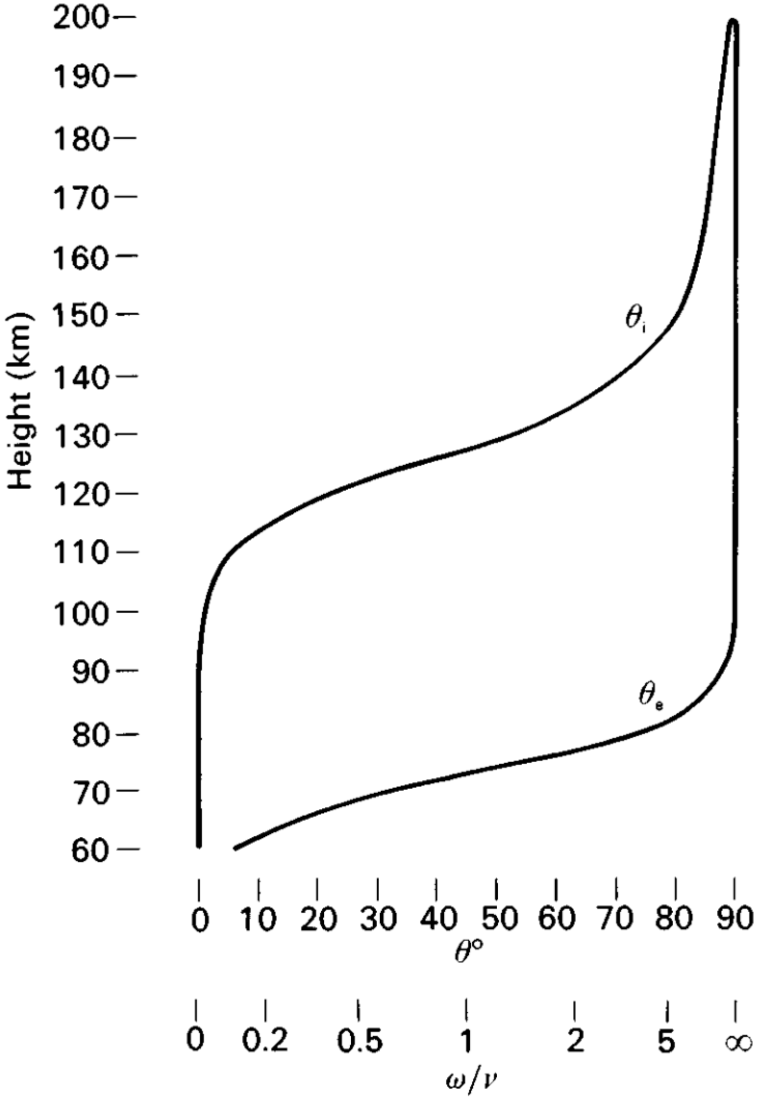
Ion/electron-neutral collision frequency vs gyrofrequency



Plasma motions in the ionosphere



(Heelis, 2004)



Current and conductivity

$$\mathbf{j} = N_i e(\mathbf{V}_i - \mathbf{V}_e) = \tilde{\sigma}\,\frac{\mathbf{F}}{e} = \sigma_0\,\frac{\mathbf{F}^{\parallel}}{e} + \sigma_P\,\frac{\mathbf{F}^{\perp}}{e}$$

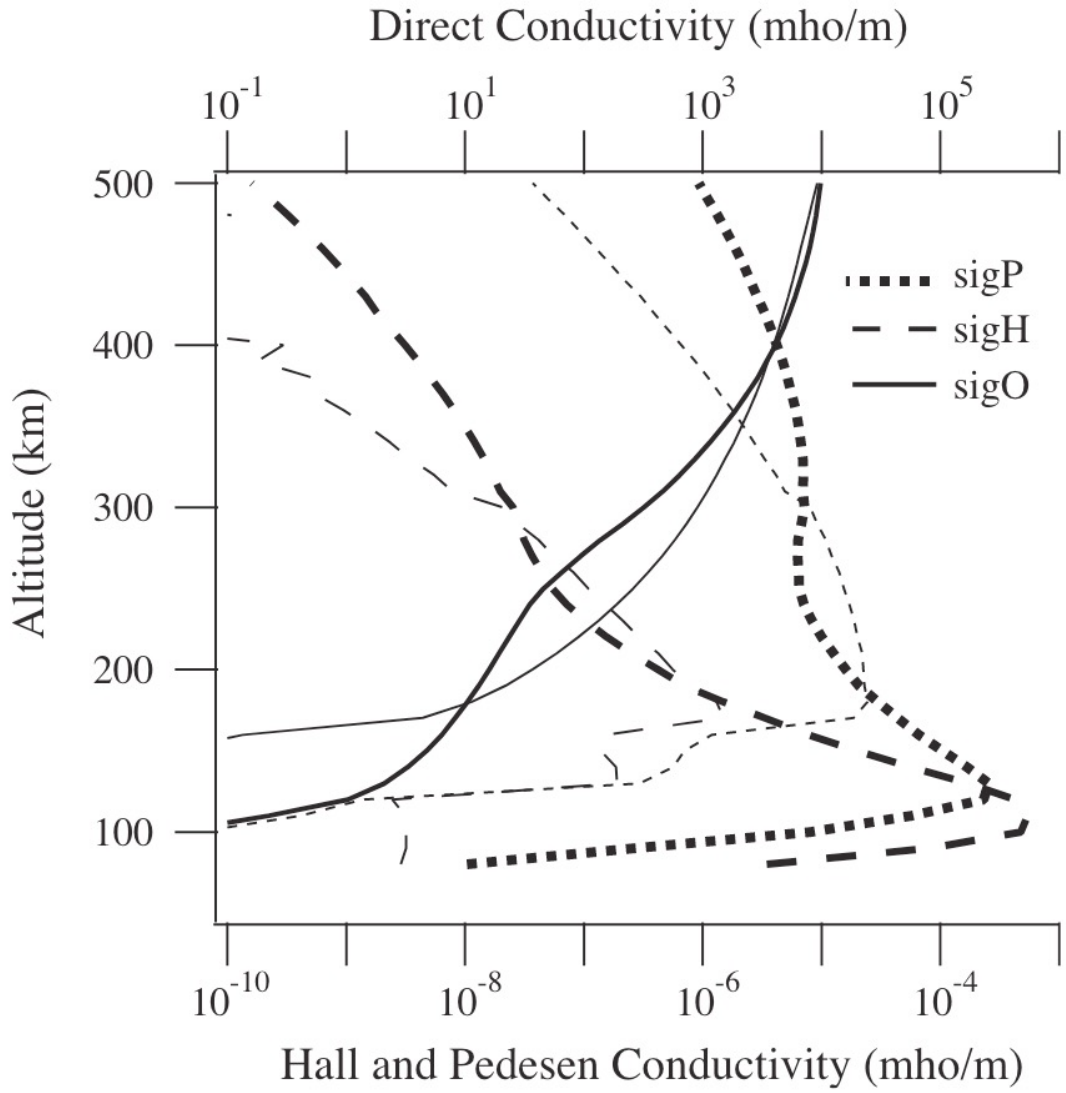
$$-\,\sigma_H\,\frac{\mathbf{F}^{\perp}\times\mathbf{b}}{e}.$$

$$\sigma_0 = \frac{Ne^2}{m_e\upsilon_e} + \frac{Ne^2}{m_i\upsilon_i} \approx \frac{Ne^2}{m_e\upsilon_e},$$

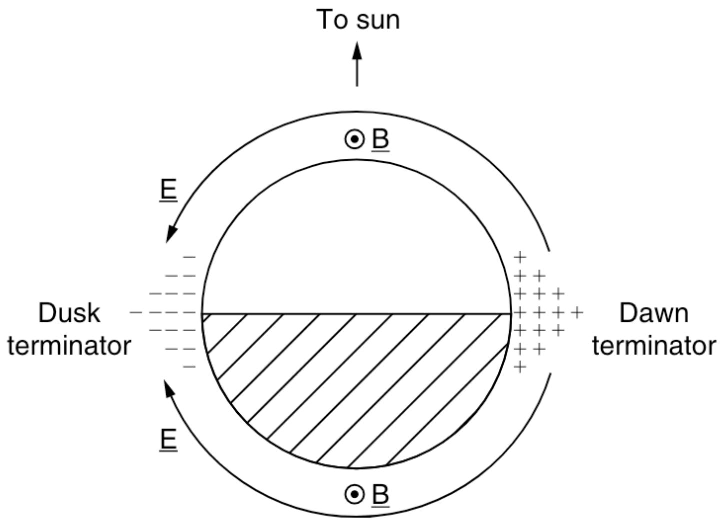
$$\sigma_p = Ne^2\left[\frac{1}{m_e}\,\frac{\upsilon_e}{(\upsilon_e^2+\Omega_e^2)} + \frac{1}{m_i}\,\frac{\upsilon_i}{(\upsilon_i^2+\Omega_i^2)}\right],$$

$$\approx \frac{Ne^2}{m_i}\,\frac{\upsilon_i}{(\upsilon_i^2+\Omega_i^2)},$$

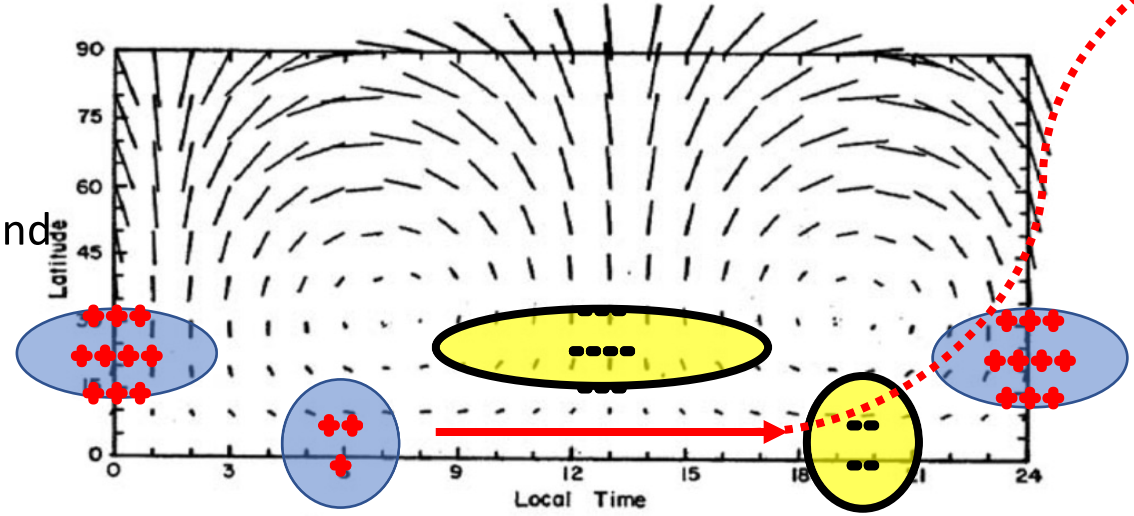
$$\sigma_H = Ne^2\left[\frac{1}{m_e}\,\frac{\Omega_e}{(\upsilon_e^2+\Omega_e^2)} - \frac{1}{m_i}\,\frac{\Omega_i}{(\upsilon_i^2+\Omega_i^2)}\right].$$

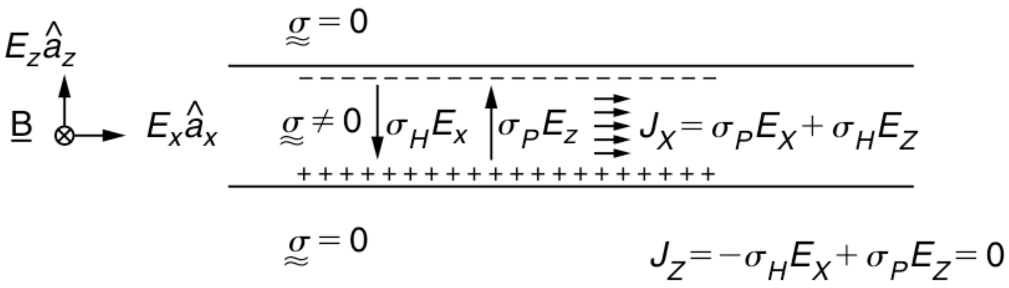


E region dynamo



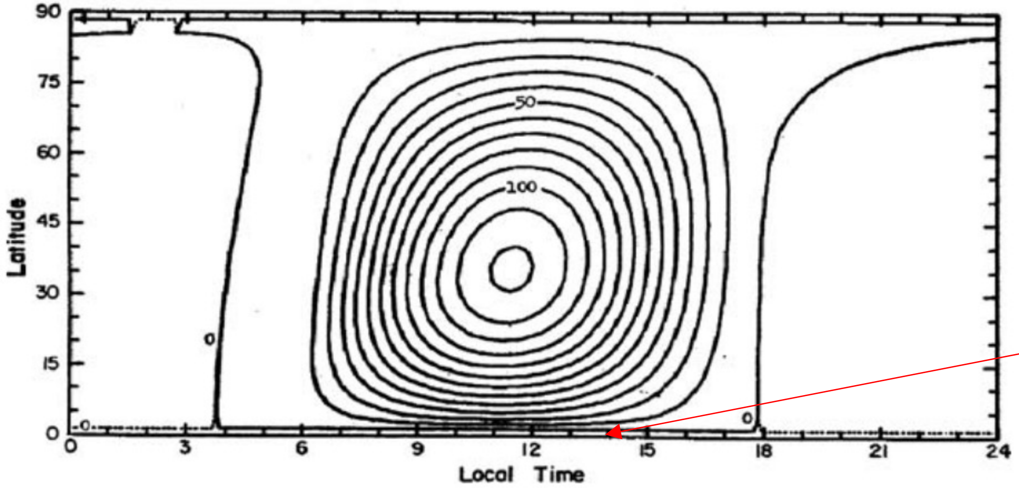
Neutral wind





The equatorial electrojet in a slab geometry.

Current

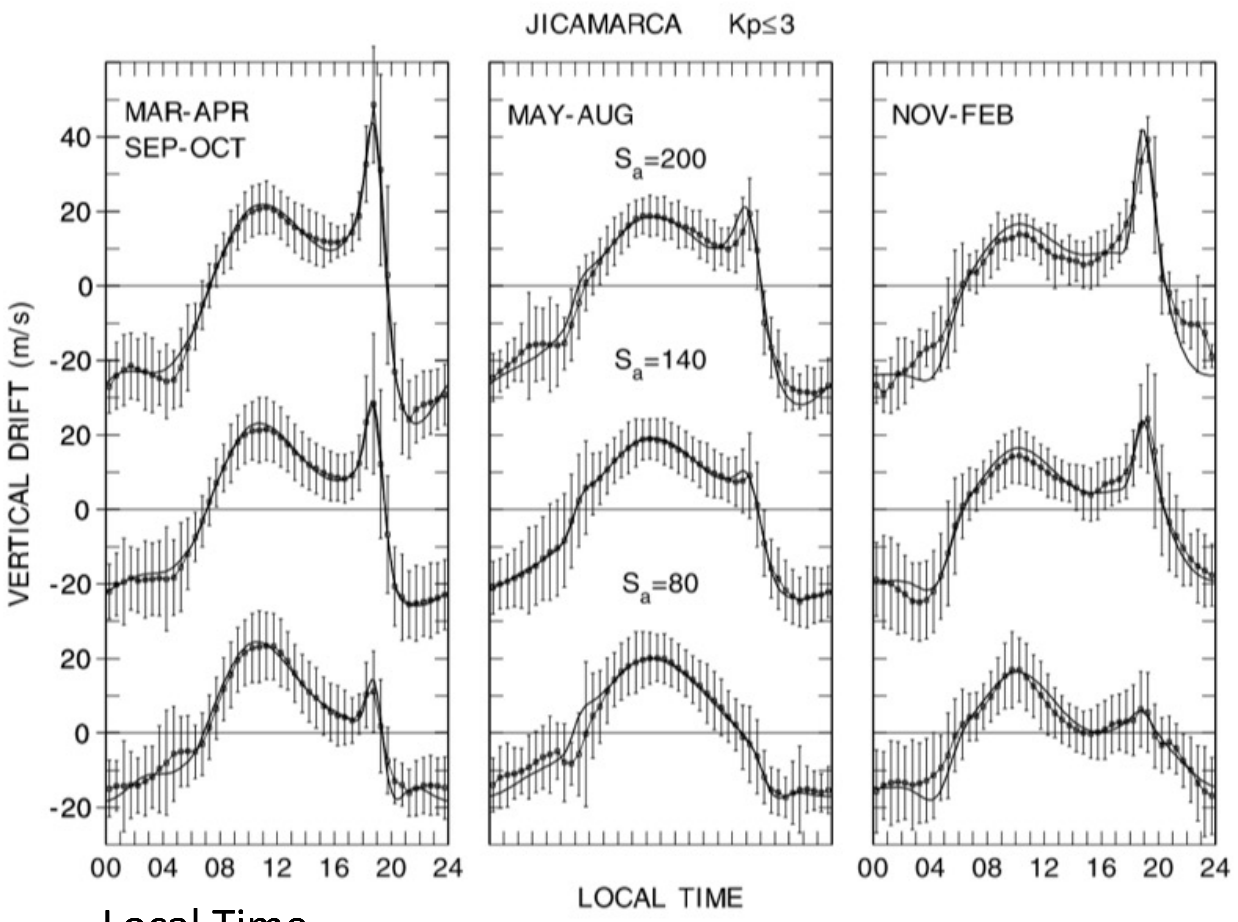


Equatorial electrojet

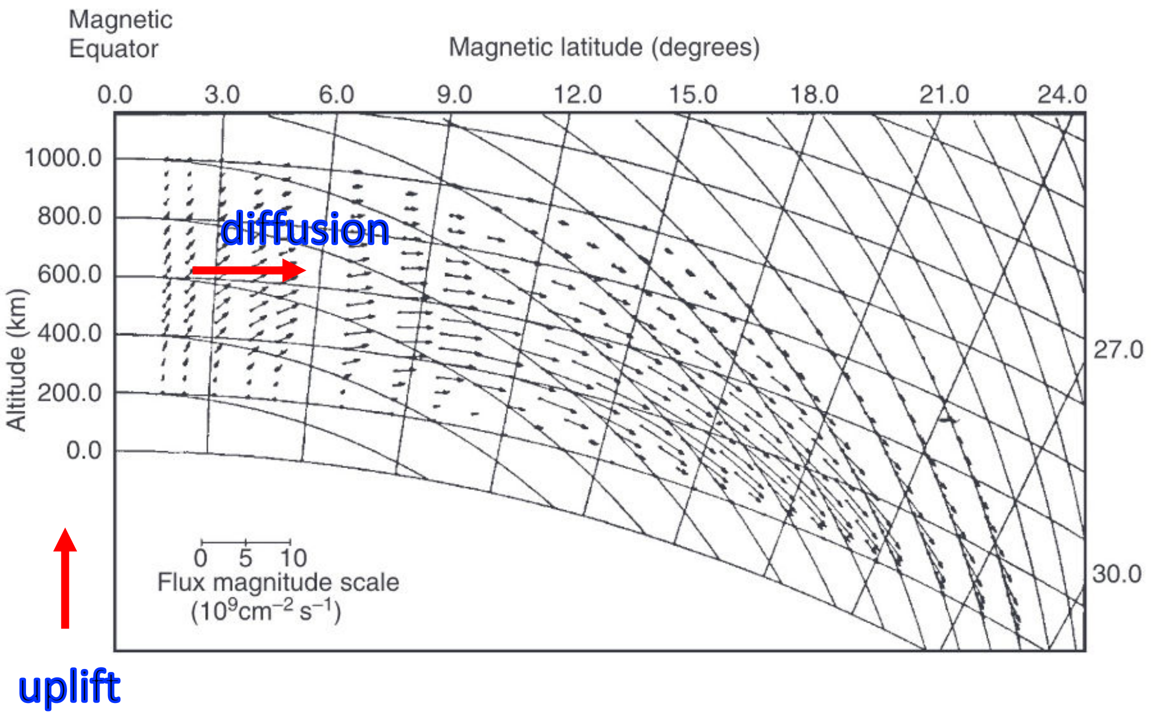
Observed by ground-based magnetometer at the equator.

(Tarpley, 1970)

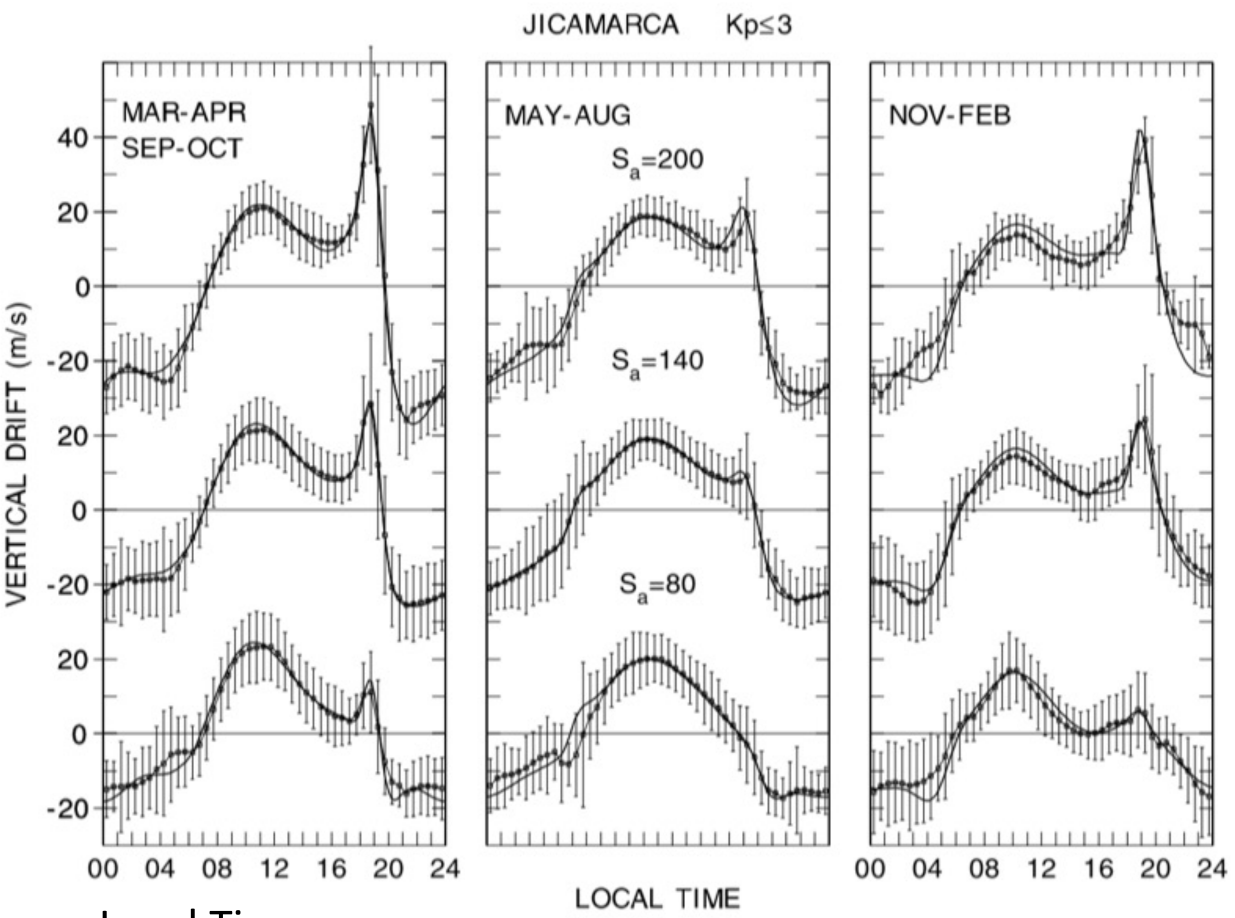
Vertical drifts and equatorial ionization anomaly



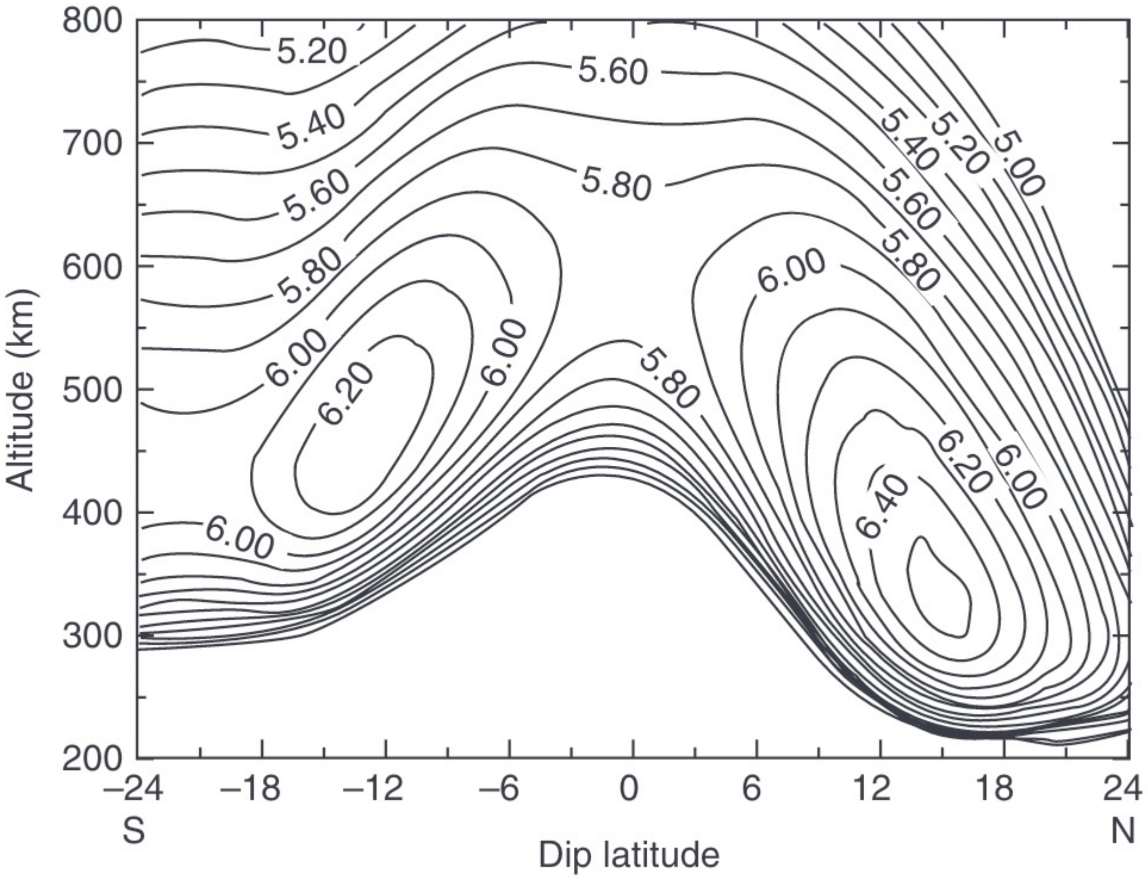
Local Time



Vertical drifts and equatorial ionization anomaly



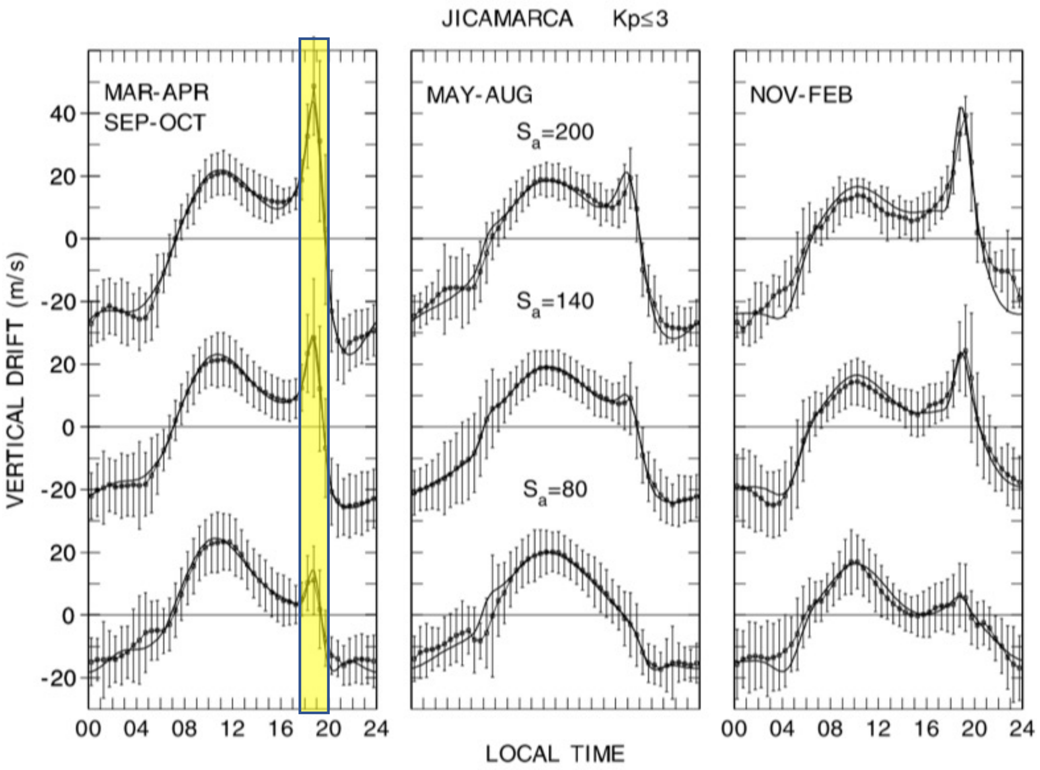
Local Time

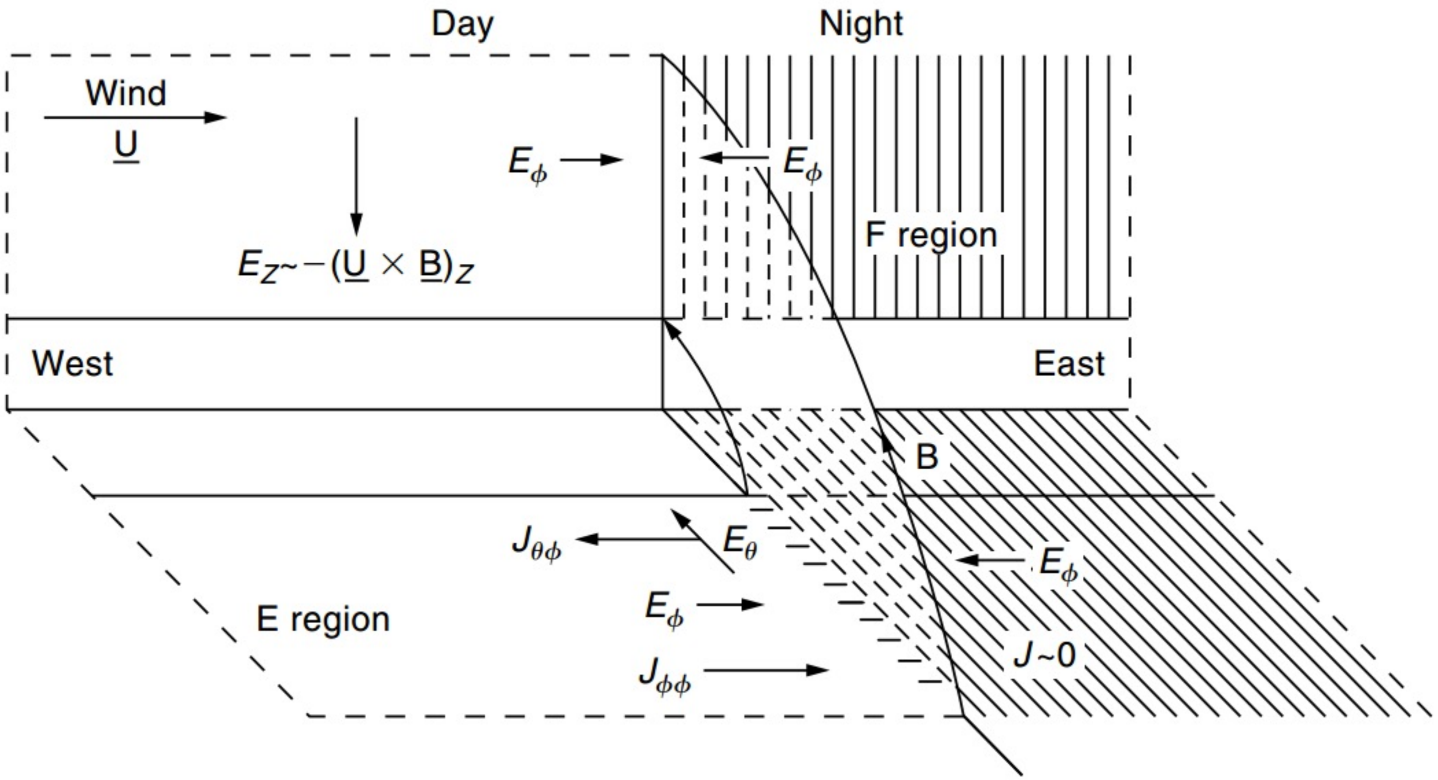


EIA

Vertical drifts and F region dynamo

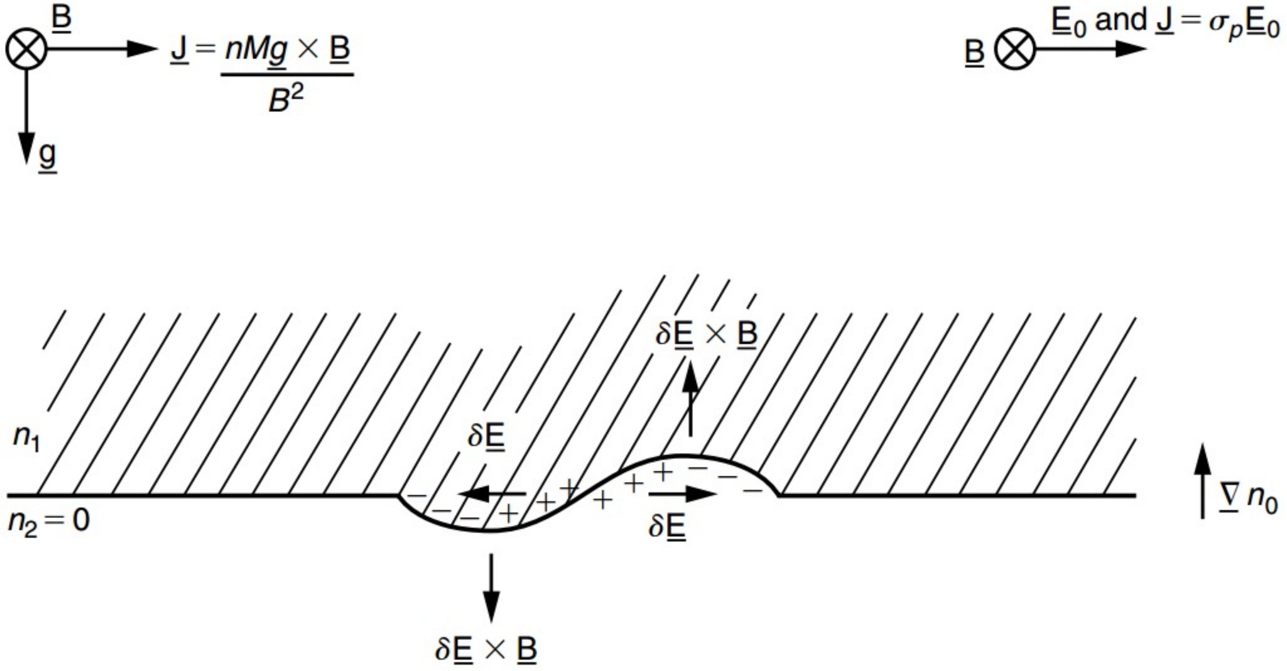
$$\mathbf{E} = \frac{\Sigma_F^p}{\Sigma_E^p + \Sigma_F^p}(\mathbf{U}_F \times \mathbf{B}).$$



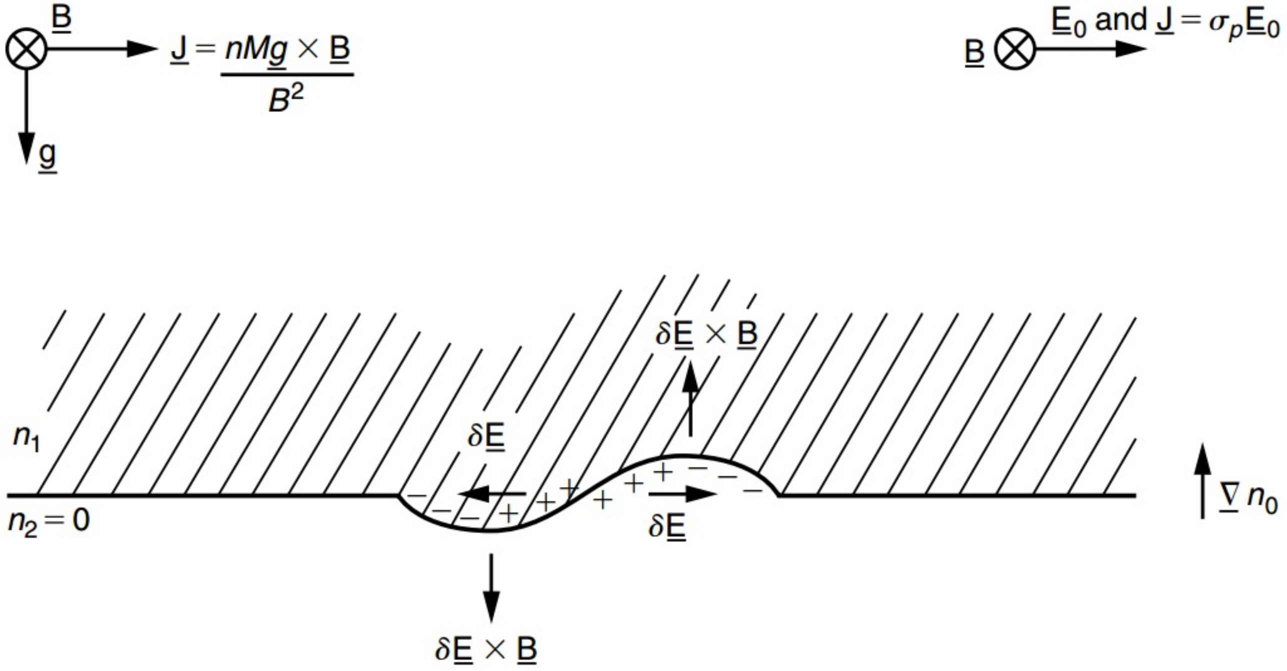


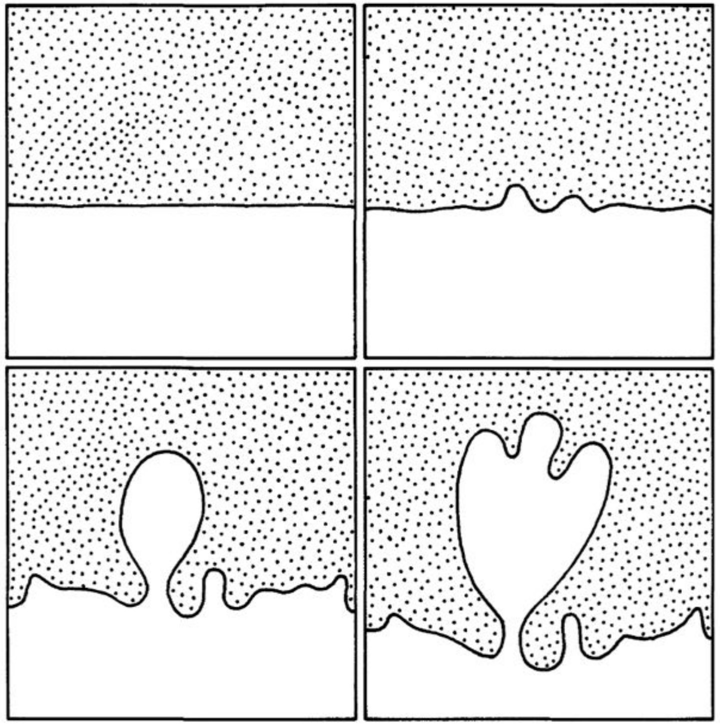
Pre-reversal enhancement (PRE)

The ionospheric Rayleigh-Taylor instability

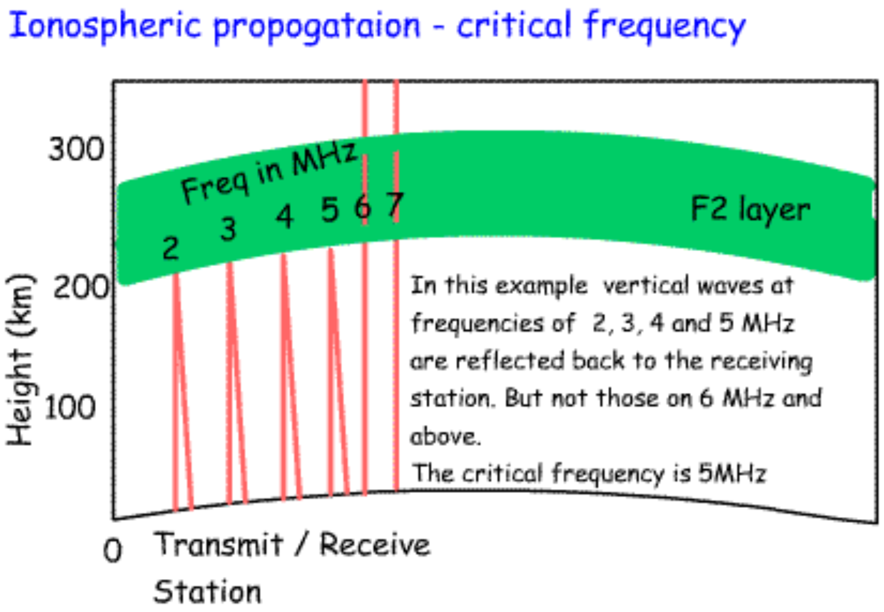


The ionospheric Rayleigh-Taylor instability

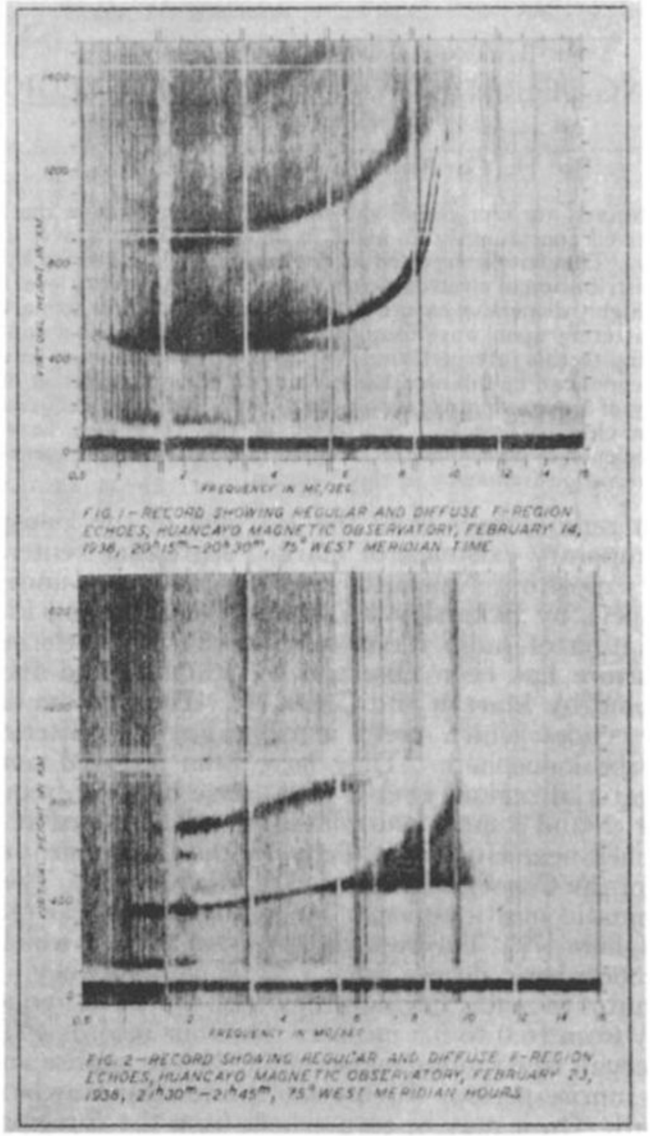




Equatorial spread F: ionosonde and ionogram



$$f_c \approx 9\sqrt{N_{max}}$$



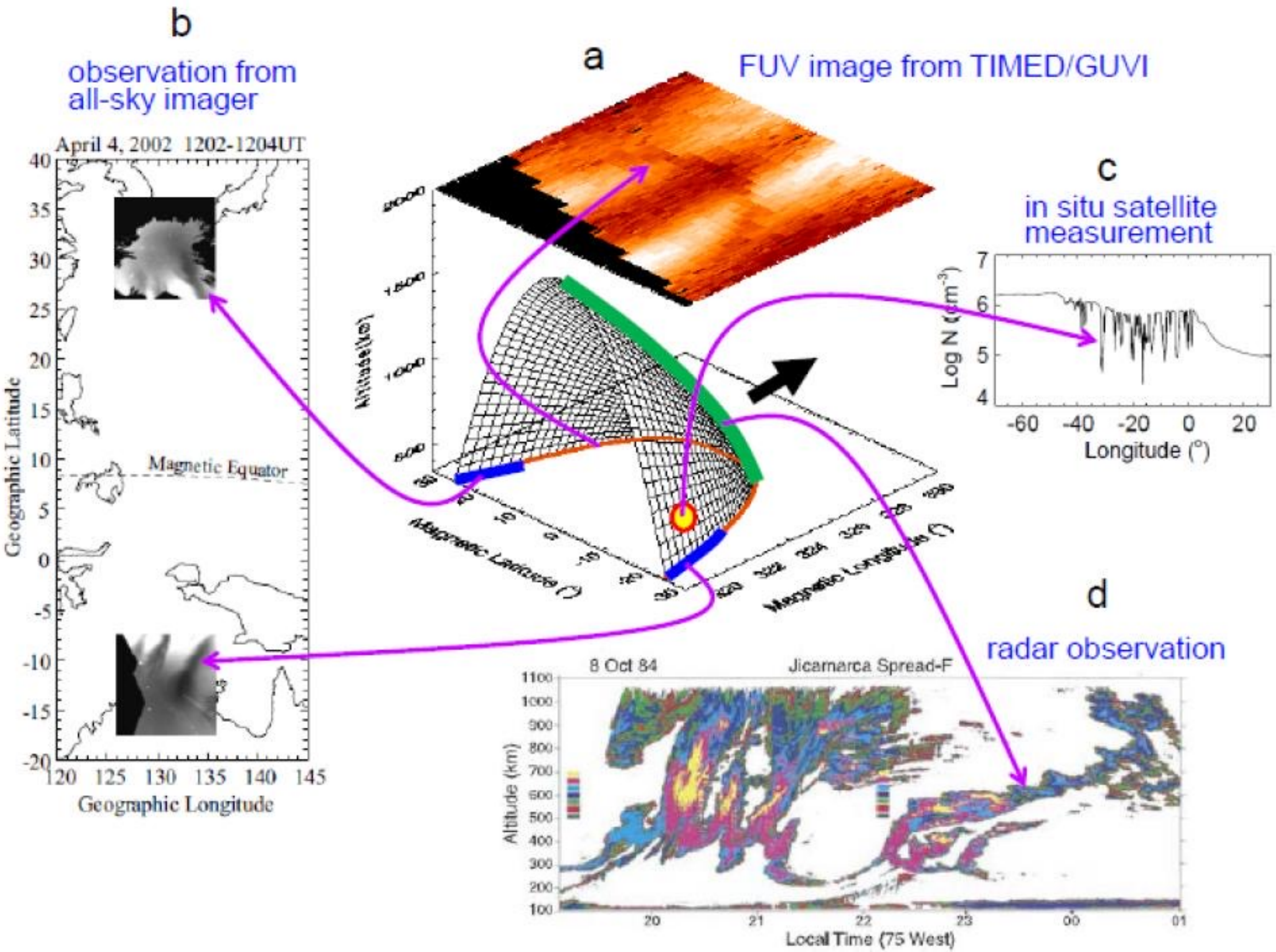
Range spread

Frequency spread

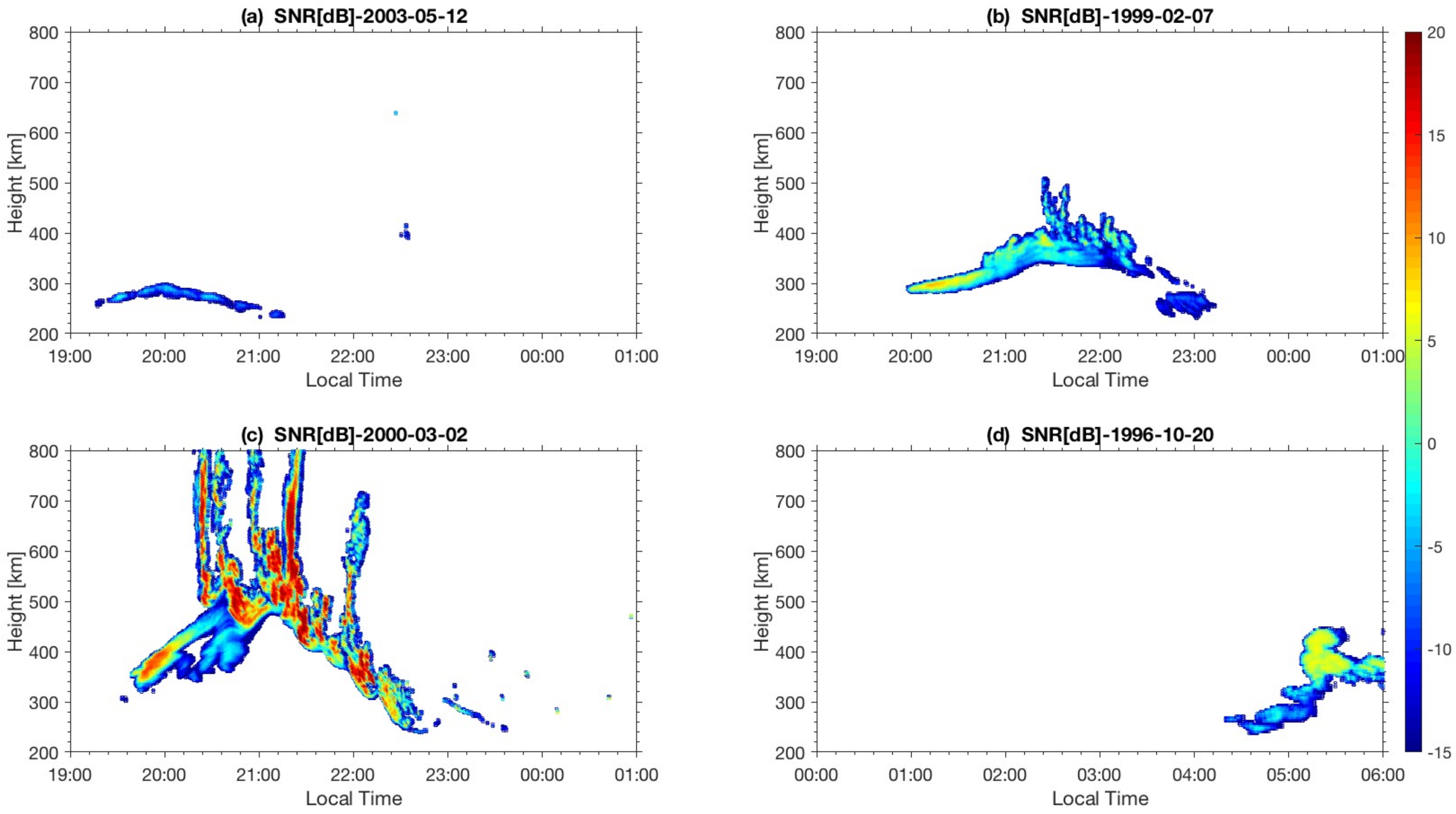
(Booker & Wells, 1938)

Observation of ESF

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

Electron density gradient

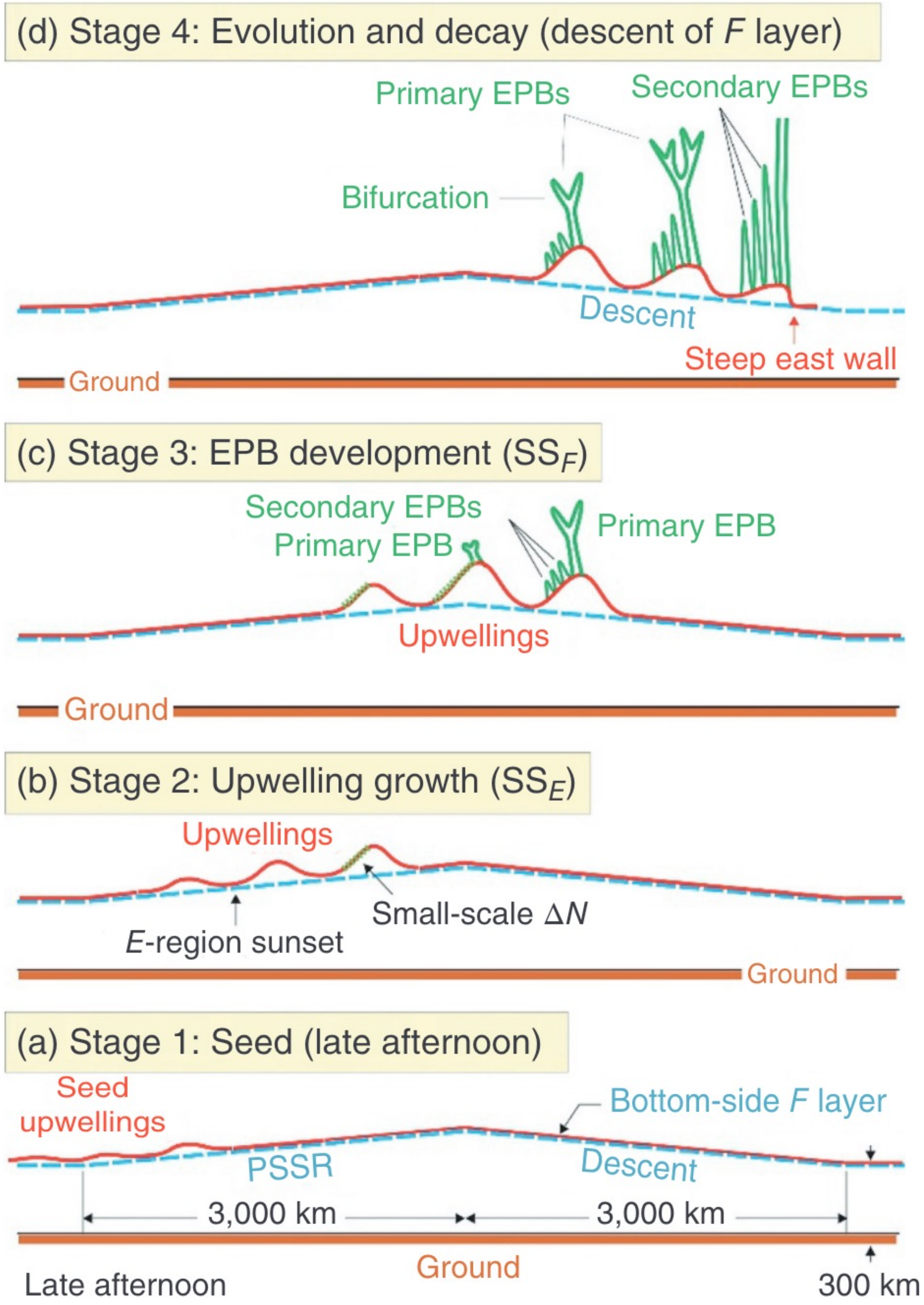
$$\gamma_{GRT} = \frac{\Sigma_P^F}{\Sigma_P^E + \Sigma_P^F}\left(V_P - U_L^P + \frac{g_e}{\nu_{eff}}\right)K^F - R$$

Recombination

(Sultan, 1996)

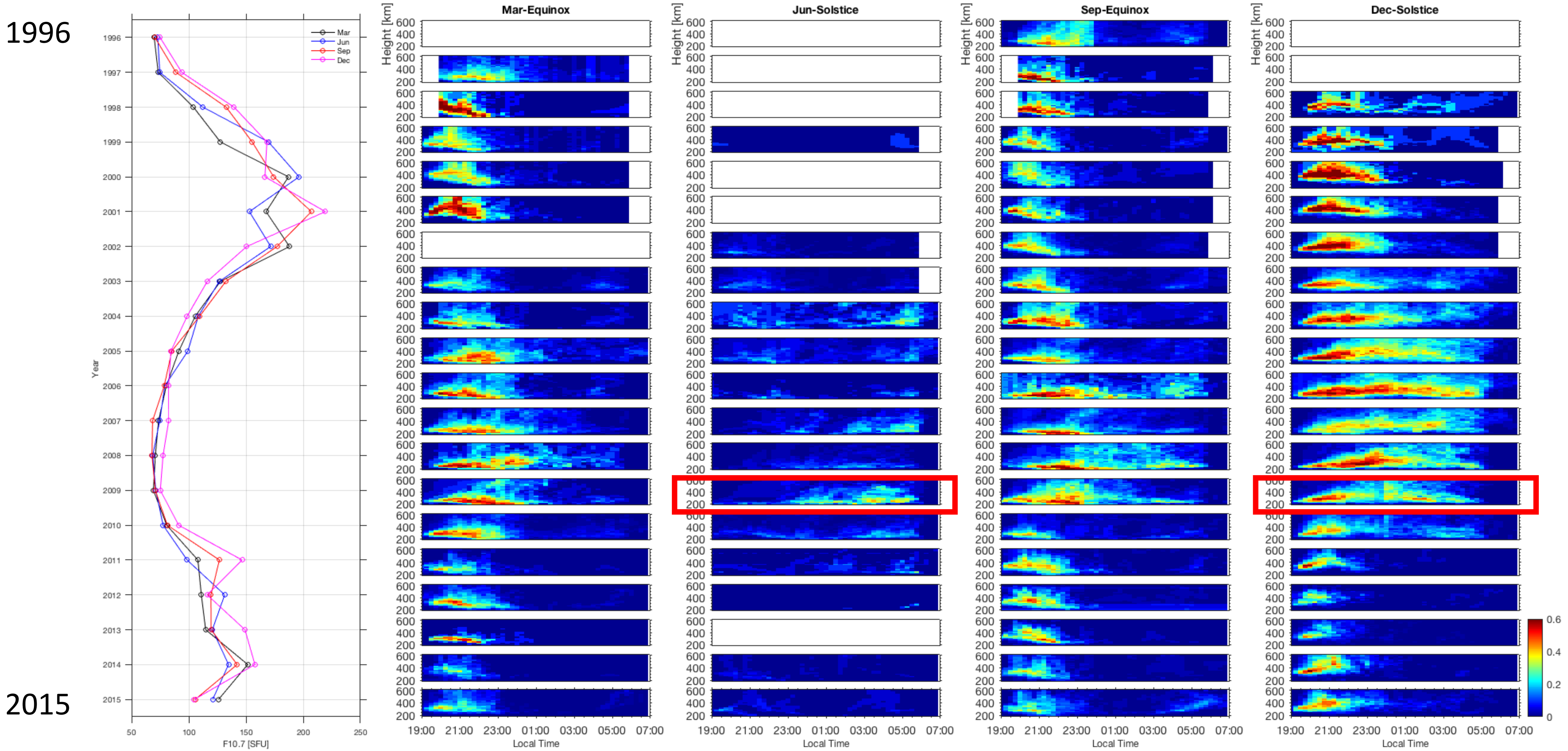
Ion-neutral collision frequency

vertical drift meridional wind



(Tsunoda, 2021)

Climatology of occurrence rate

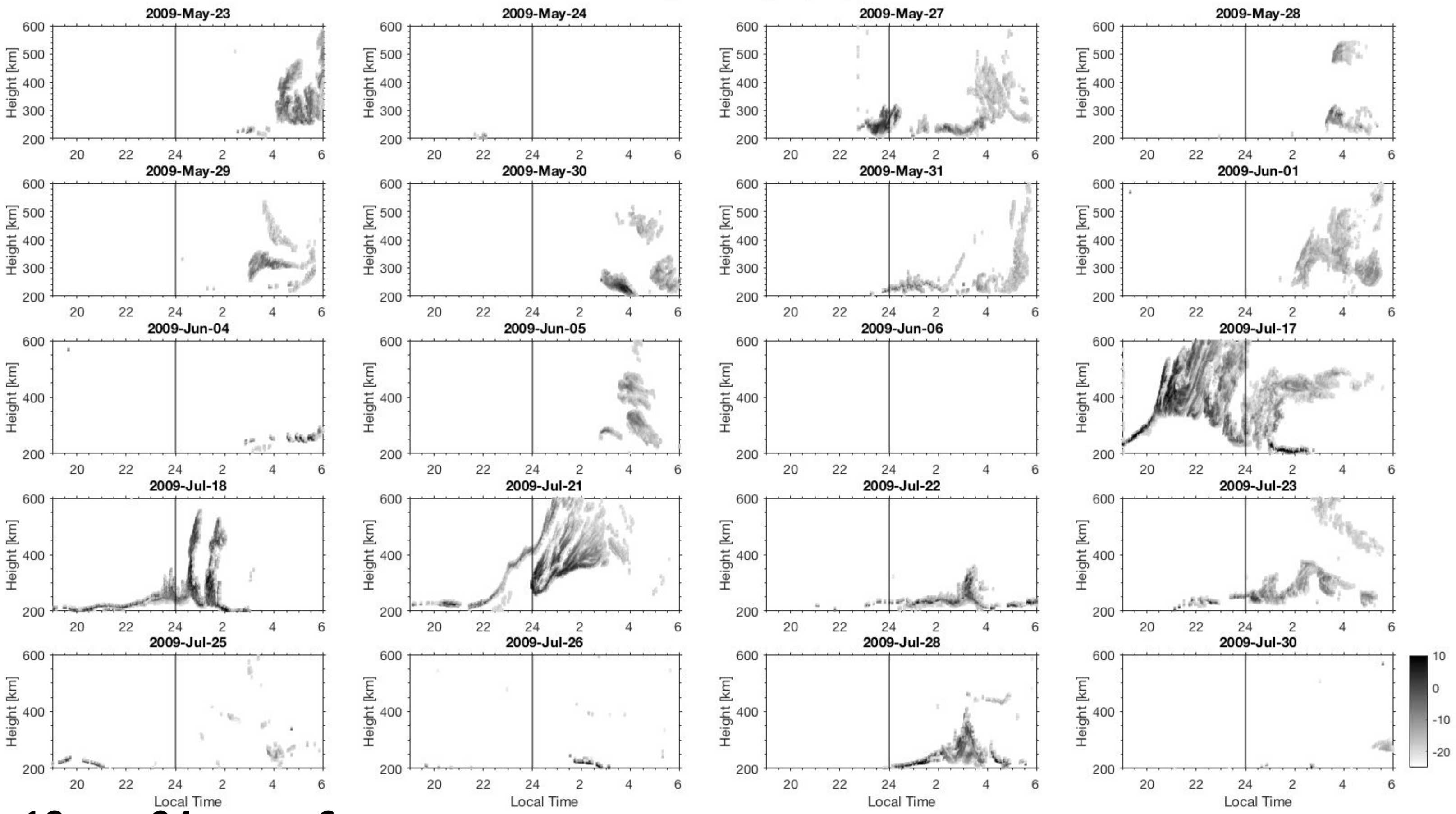


Postmidnight ESF

- June Solstice ESF: Morphology

✓ ESF occurs, predominantly, in the post-midnight sector

RTI map



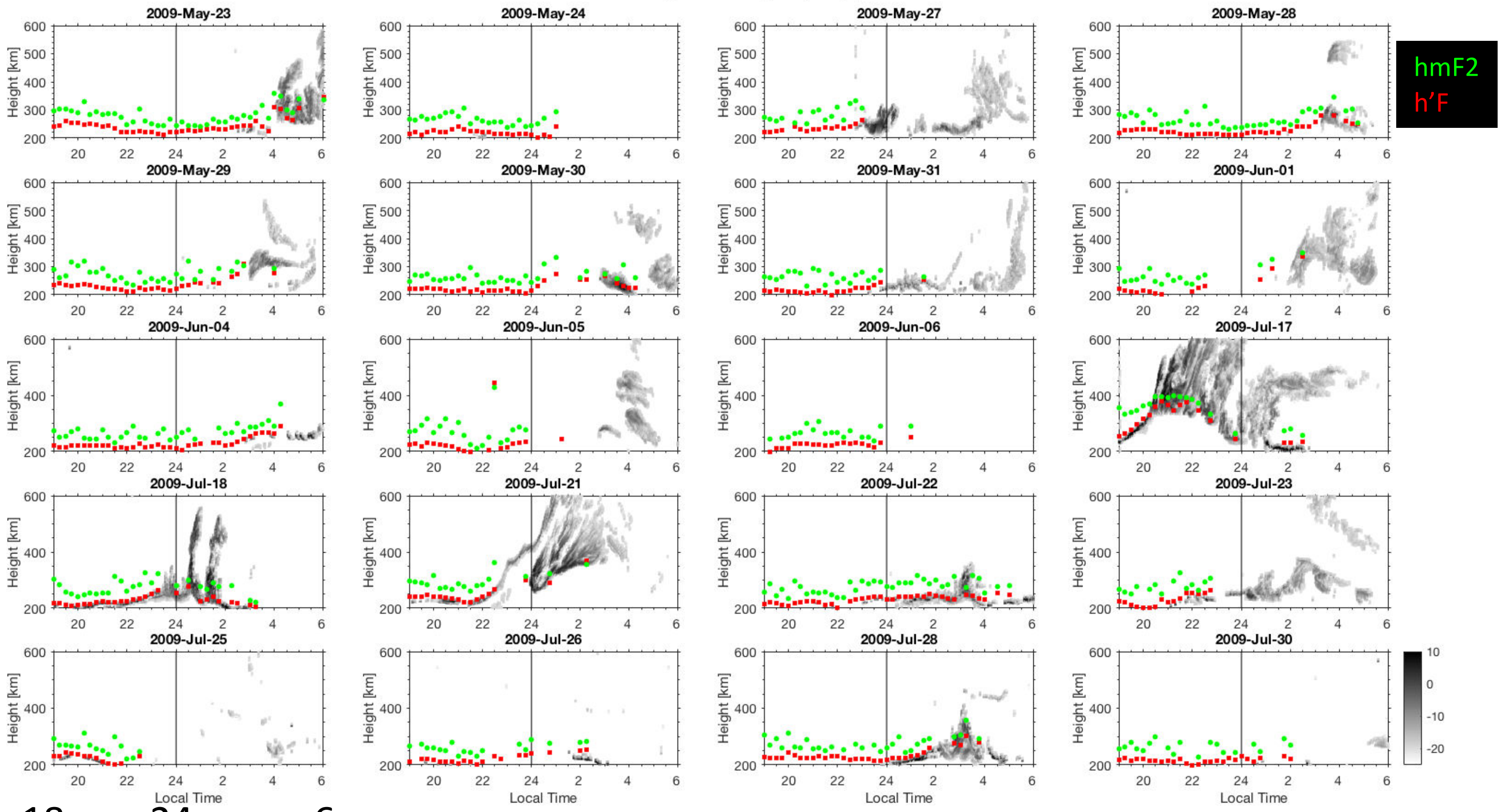
18 24 6

Local Time

- 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

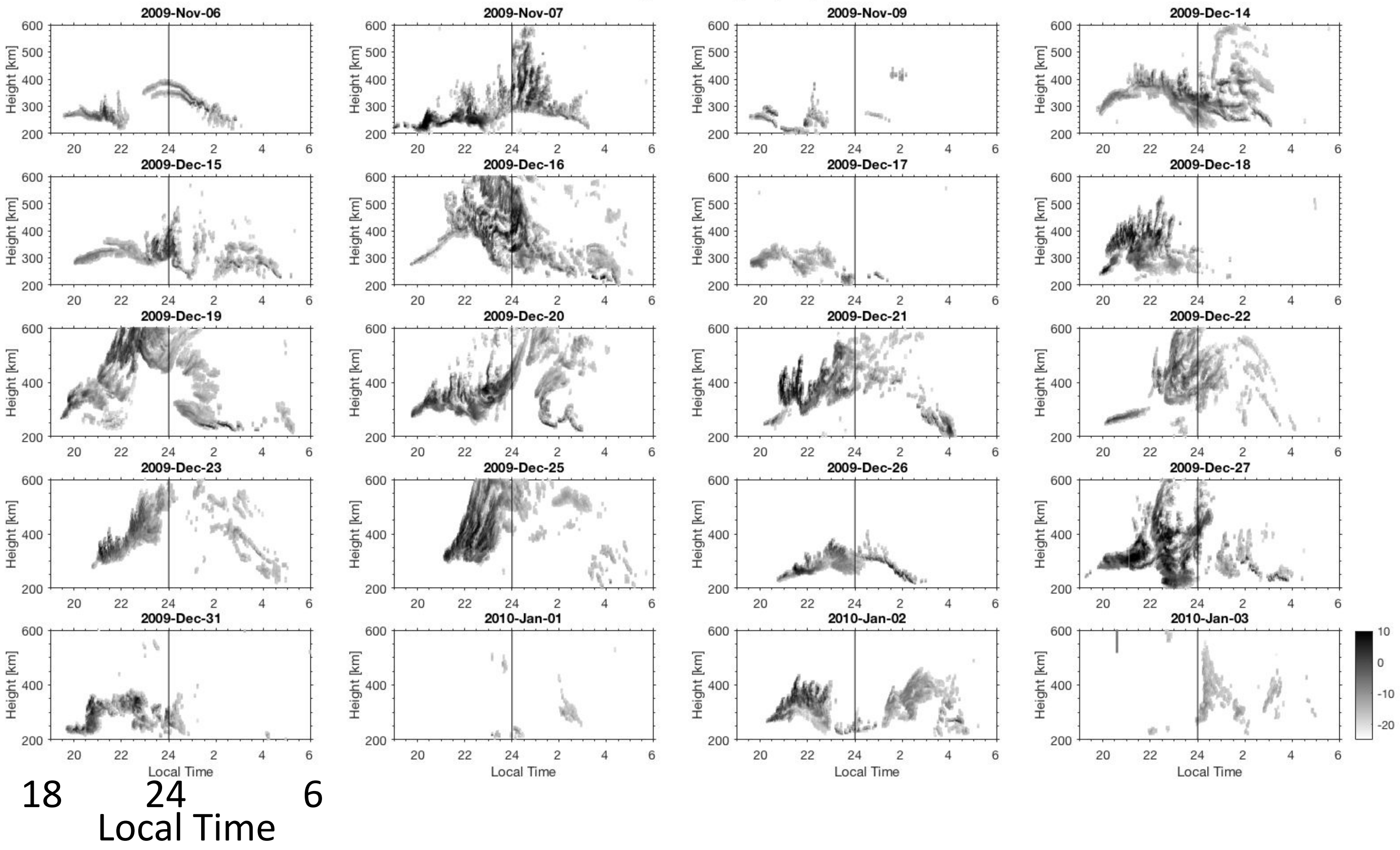


18 24 6
Local Time

- December Solstice ESF: Morphology

✓ ESF starts in the evening and extends until post-midnight hours

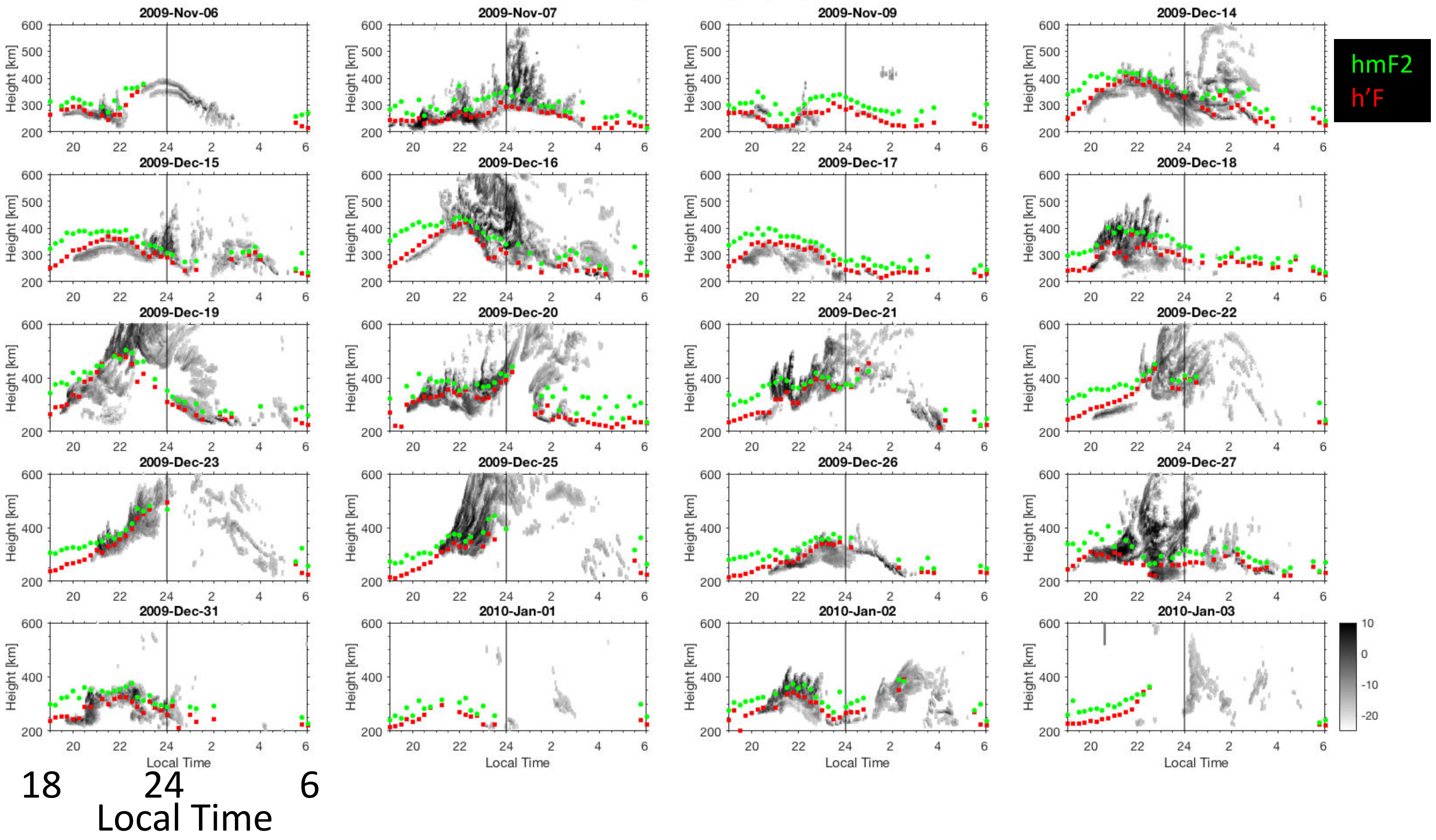
RTI map



- December Solstice ESF: *F*-region conditions

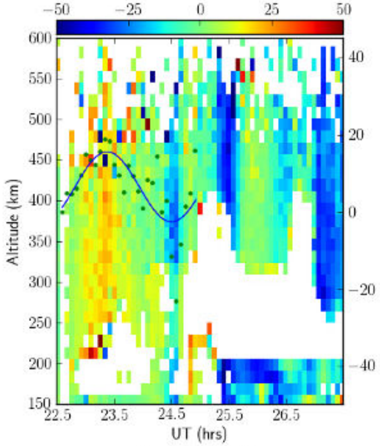
✓ Signatures of PRE or late evening upward drifts

✓ Strong uplifts produce well-developed, long-lasting ESF events

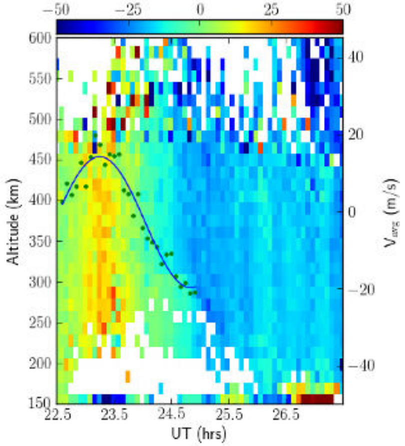


Open questions

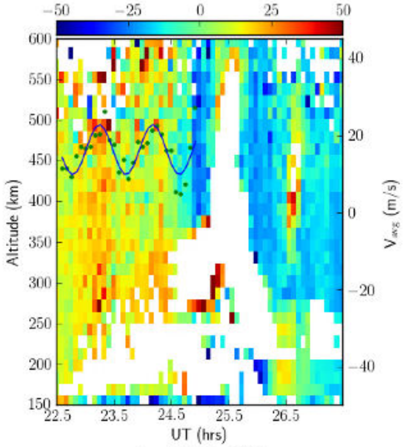
- 1. day-to-day variability
- 2. atypical ESF
- 3. prediction of occurrence



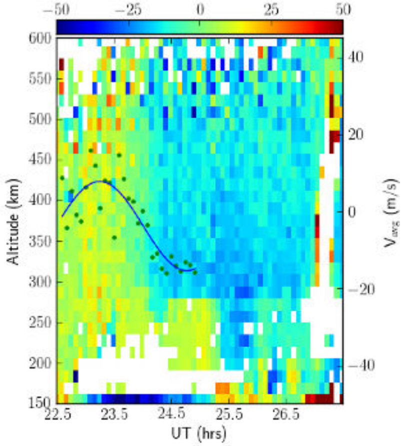
Sep. 21/22, 2021



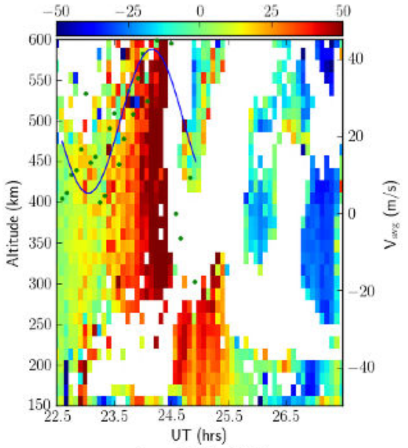
Sep. 24/25, 2021



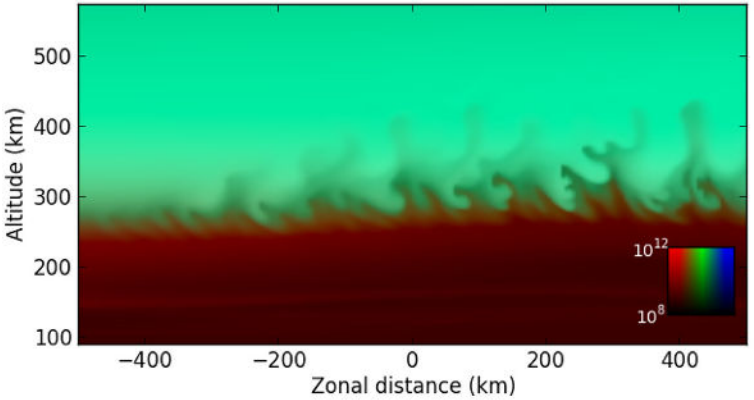
Sep. 22/23, 2021



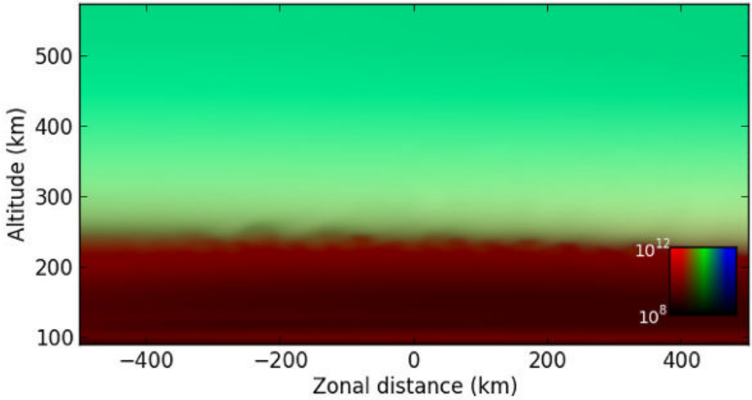
Sep. 25/26, 2021



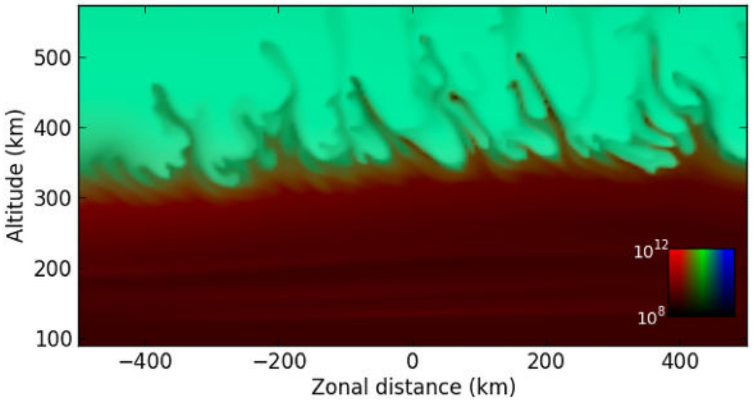
Sep. 23/24, 2021



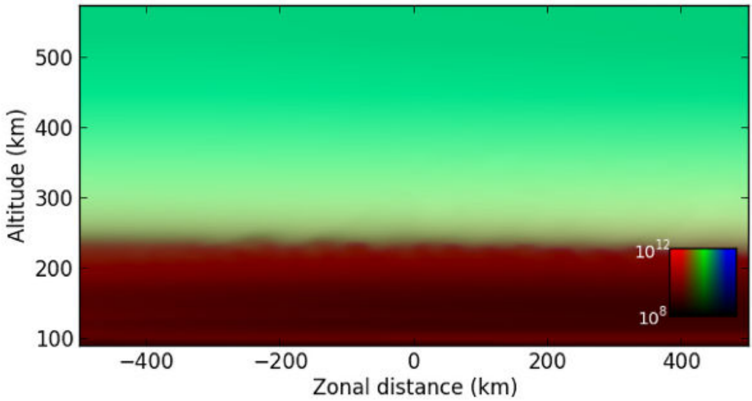
Sep. 21/22, 2021, 0100 UT



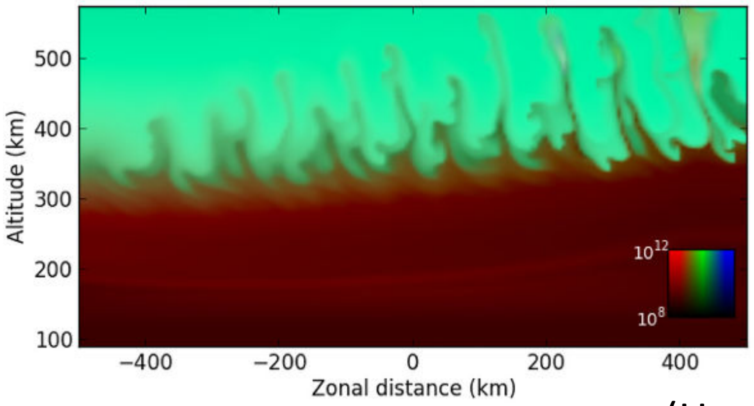
Sep. 24/25, 2021, 0100 UT



Sep. 22/23, 2021, 0100 UT



Sep. 25/26, 2021, 0100 UT

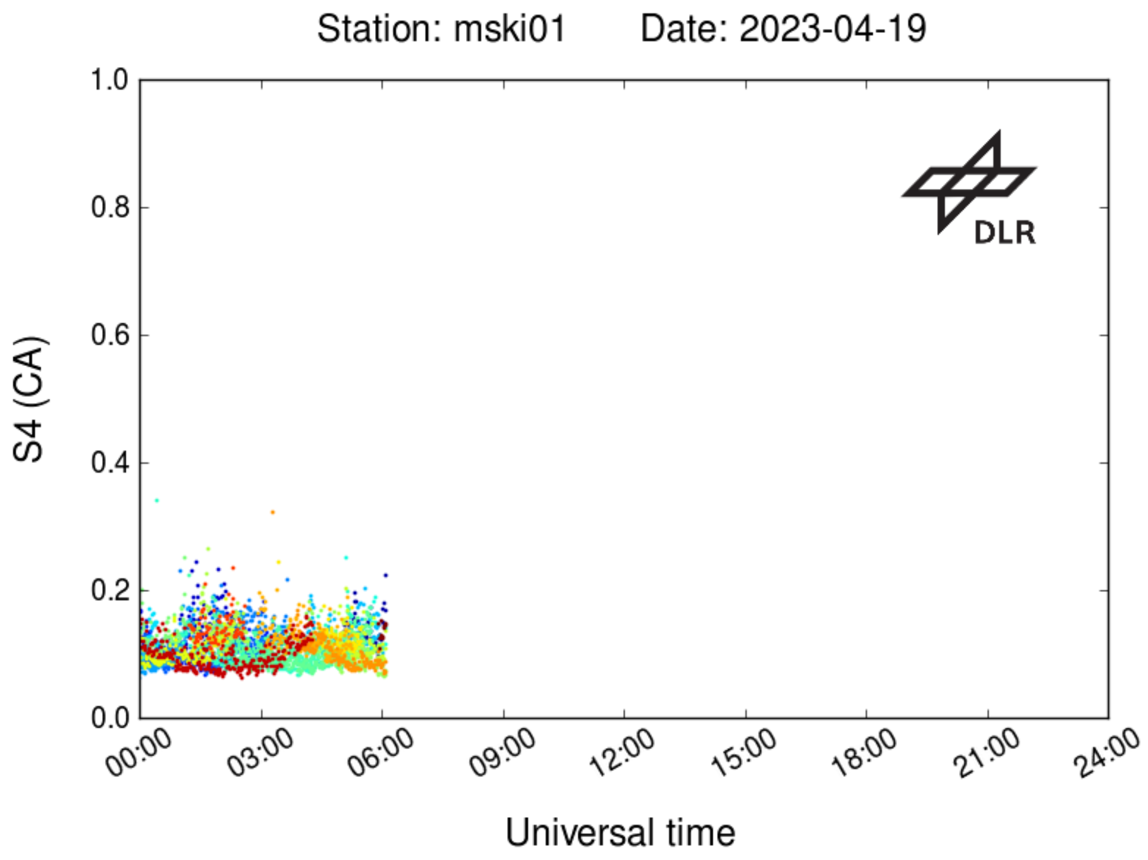


Sep. 23/24, 2021, 0030 UT

(Hysell et al., 2022)

Scintillation Index S4

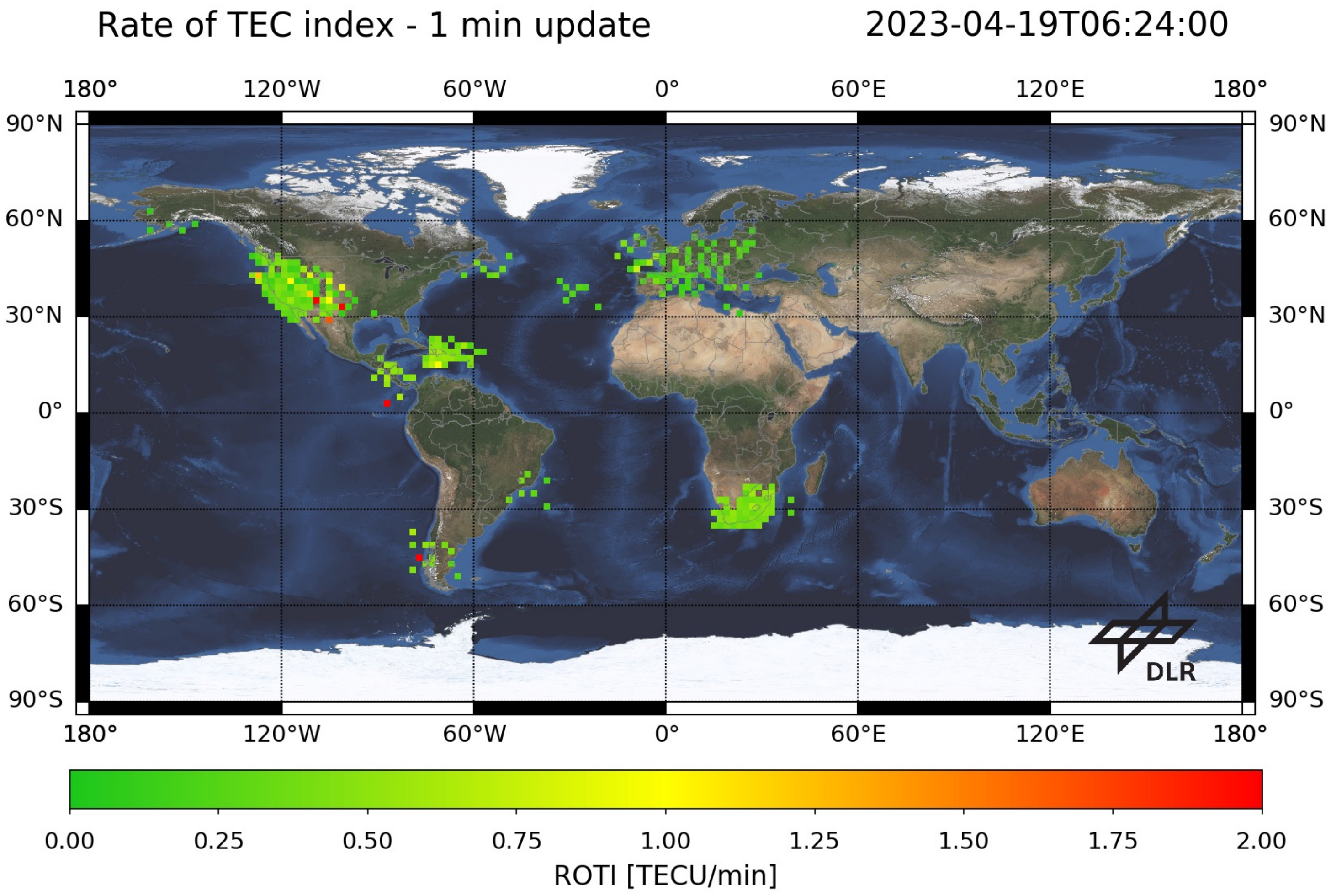
the normalized ratio of the standard deviation of signal intensity fluctuations to the mean signal intensity: $\frac{\langle I^2\rangle - \langle I\rangle^2}{\langle I\rangle^2}$



https://swe.ssa.esa.int/tio_sci#

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