E-region strong neutral wind shear and its effect on F-region plasma bubbles

IRRI-3

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Abstracts

Vertical wind shears predominantly form sporadic E layers. Es-layer instability is one of the major sources of large-scale wave structures, which is essential for equatorial plasma bubbles to onset and develop. In this study, we explored the potential role of large E-region shears in the formation and structuring of plasma bubbles. By integrating observation-based artificial shears into GITM simulations and utilizing its neutral outputs for SAMI3, we analyzed the effects of shears. The configuration, location, and direction of these shears are crucial for efficiently amplifying or suppressing upwelling and the development of Equatorial Plasma Bubbles (EPBs).

Introduction

❑ MIGHTI Observations

- Large shears (vertical gradients in horizontal winds), with horizontal scales exceeding 2000 km and durations of approximately 1-2 hours, are commonly observed in MIGHTI data

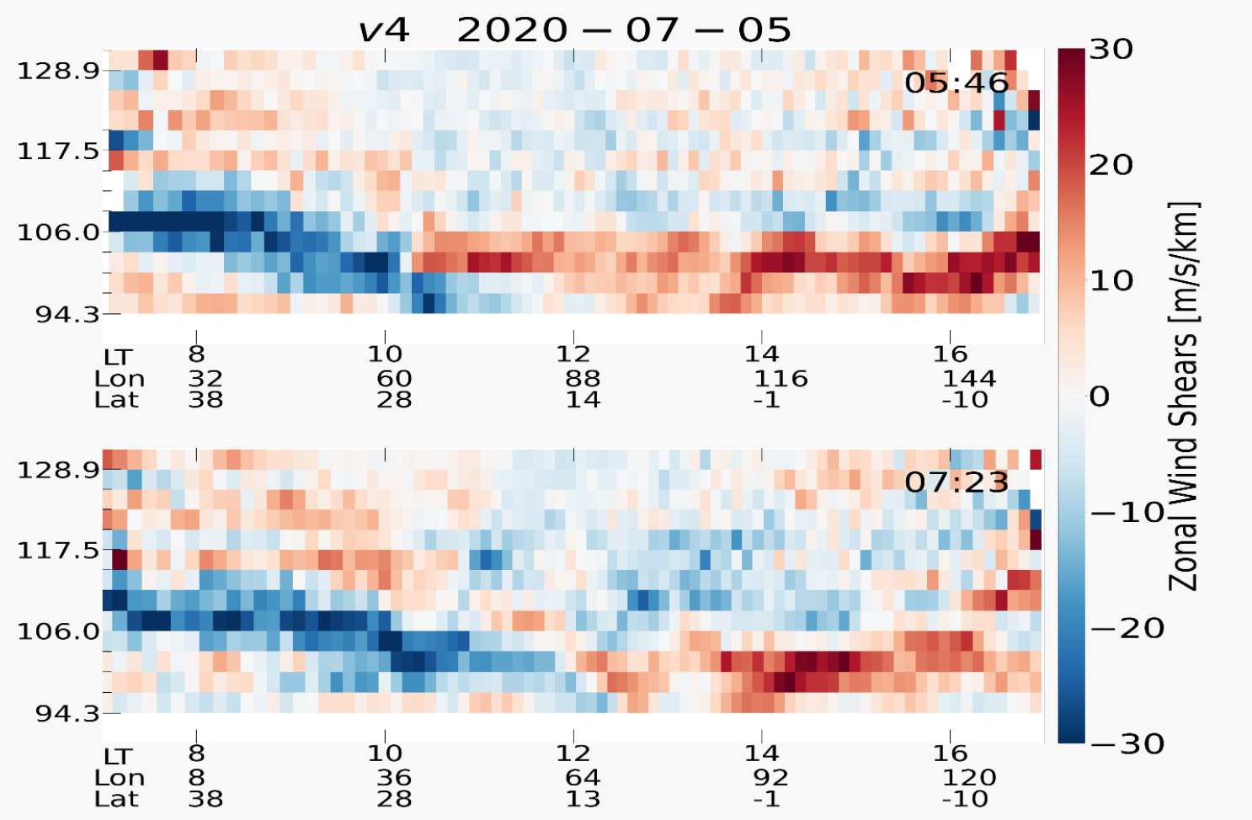


Fig 1. Observations of zonal wind shears on two orbits by ICON MIGHTI on July 5, 2020.

❑ Shears effect on E-F region (SAMI3 simulation)

- Localized wind shears lasting one hour can induce approximately 10% conjugate variations in electron density and drift variations of around 10 m/s.

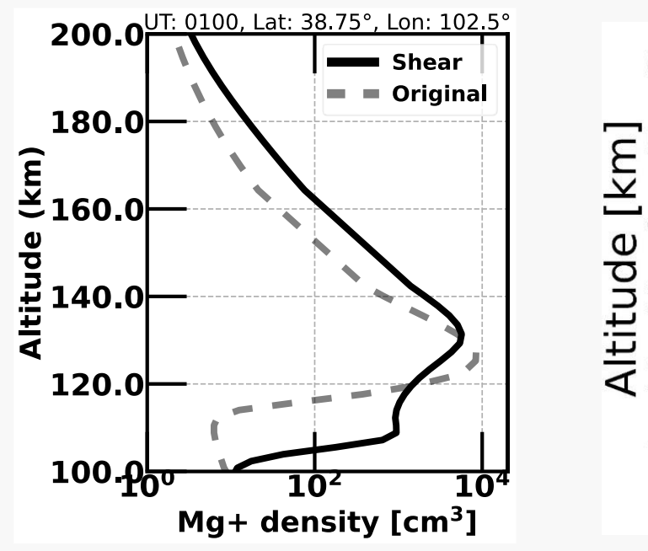


Fig 2. Mg+ density with/without zonal wind shears at ~100 km altitudes.

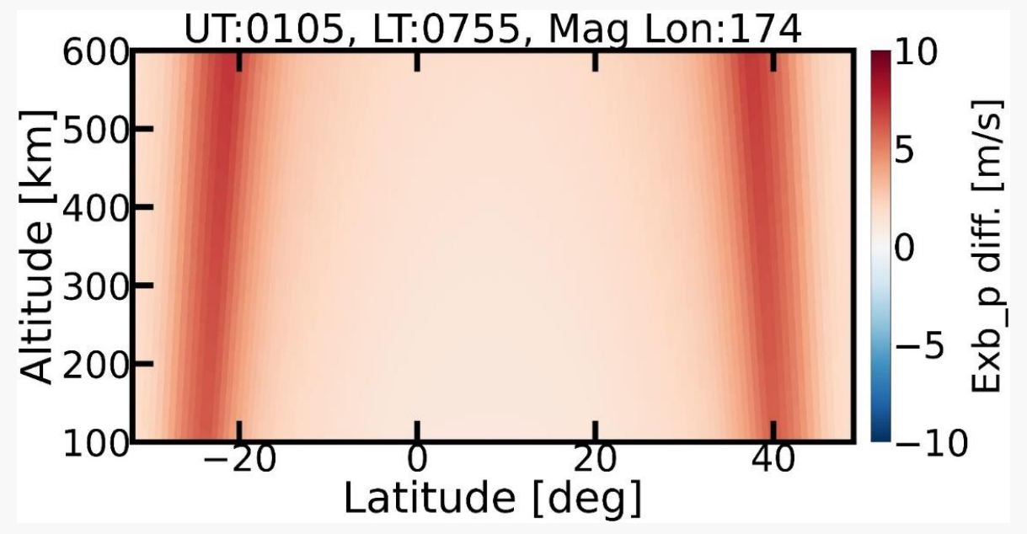


Fig 3. Difference in vertical ion drift between Conditions With and Without Shears.

[Adapted from Minjing Li, presented at the 2023 AGU Fall Meeting]

❑ Motivations

- the Impact of Vertical Gradients in Horizontal Winds on Plasma Bubble Development.

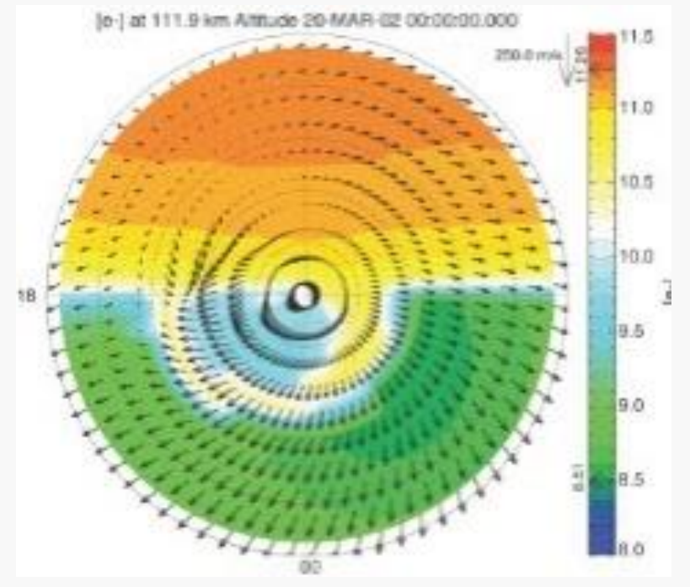
Methodology

GITM

- Coupled thermosphere-ionosphere model without hydrostatic equilibrium assumptions
- 7 neutral and ion species

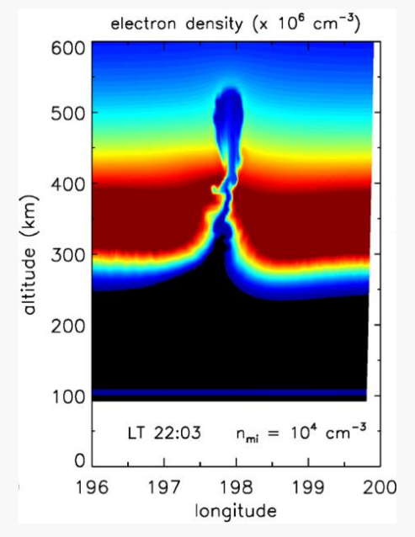
SAMI3 Metal Version

- Ionosphere model
- NRLMSISE (neutral densities), HWM14 (neutral wind)
- 9 ion species (include Fe+, Mg+)

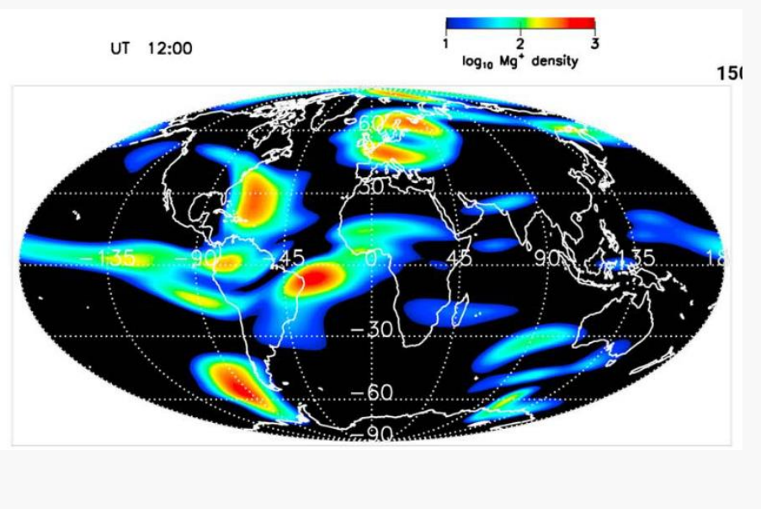


Ridley et al., 2006

7 neutral species densities, winds, temperature



Huba et al., 2020



Huba et al., 2019

Zonal/Meridional Shear setup

- Begin: 0000/0100/0200UT, 2hr duration.
- Location: centered at 87.5^oW glon & 21.25^oS glat, at 120/150 km altitude.
- The horizontal structure is inclined at $0^o/45^o$.

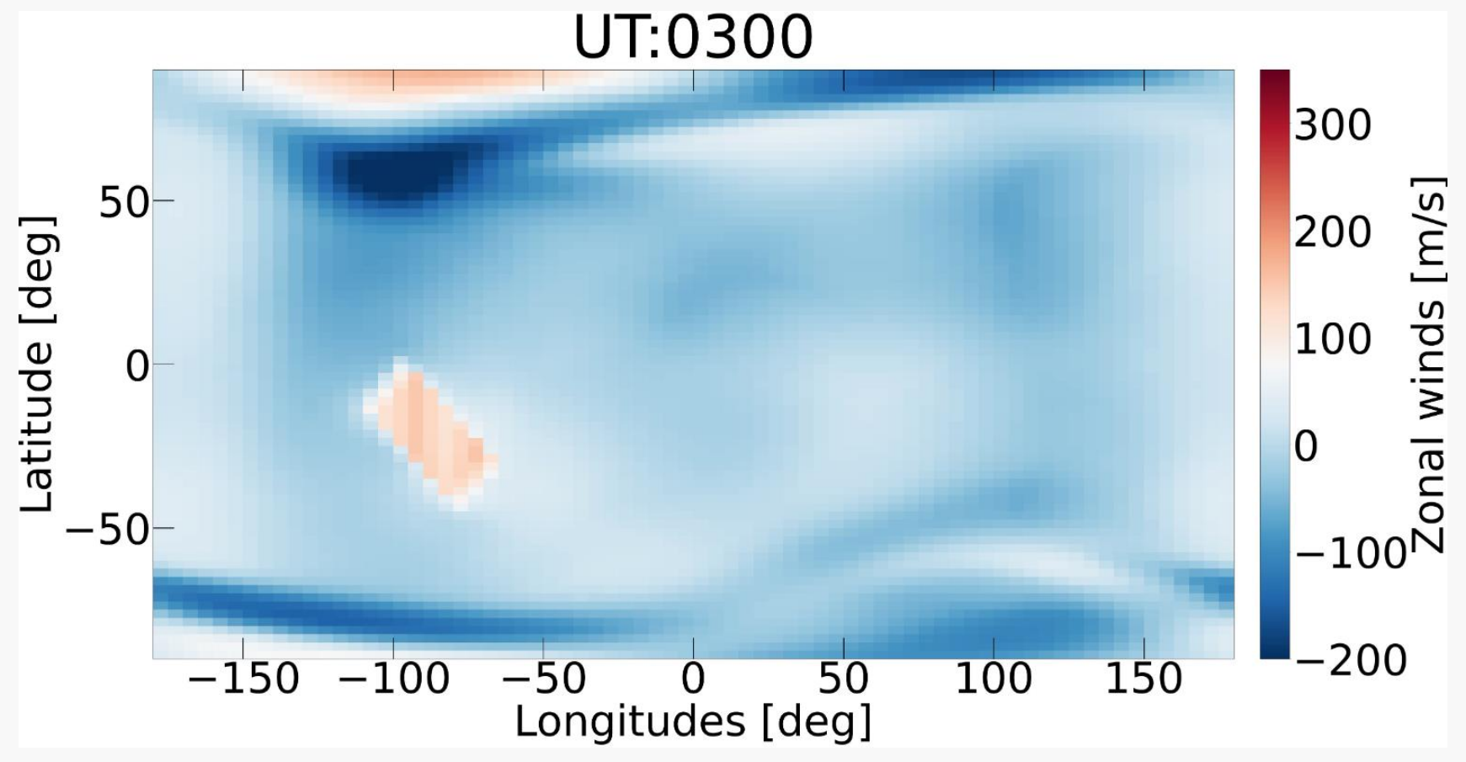


Fig 4. Zonal winds at 120 km altitude showing regions just below zero-cross wind shears, inclined at 45°.

Results

Effects of Zonal/Meridional Wind shears at 120/150 km

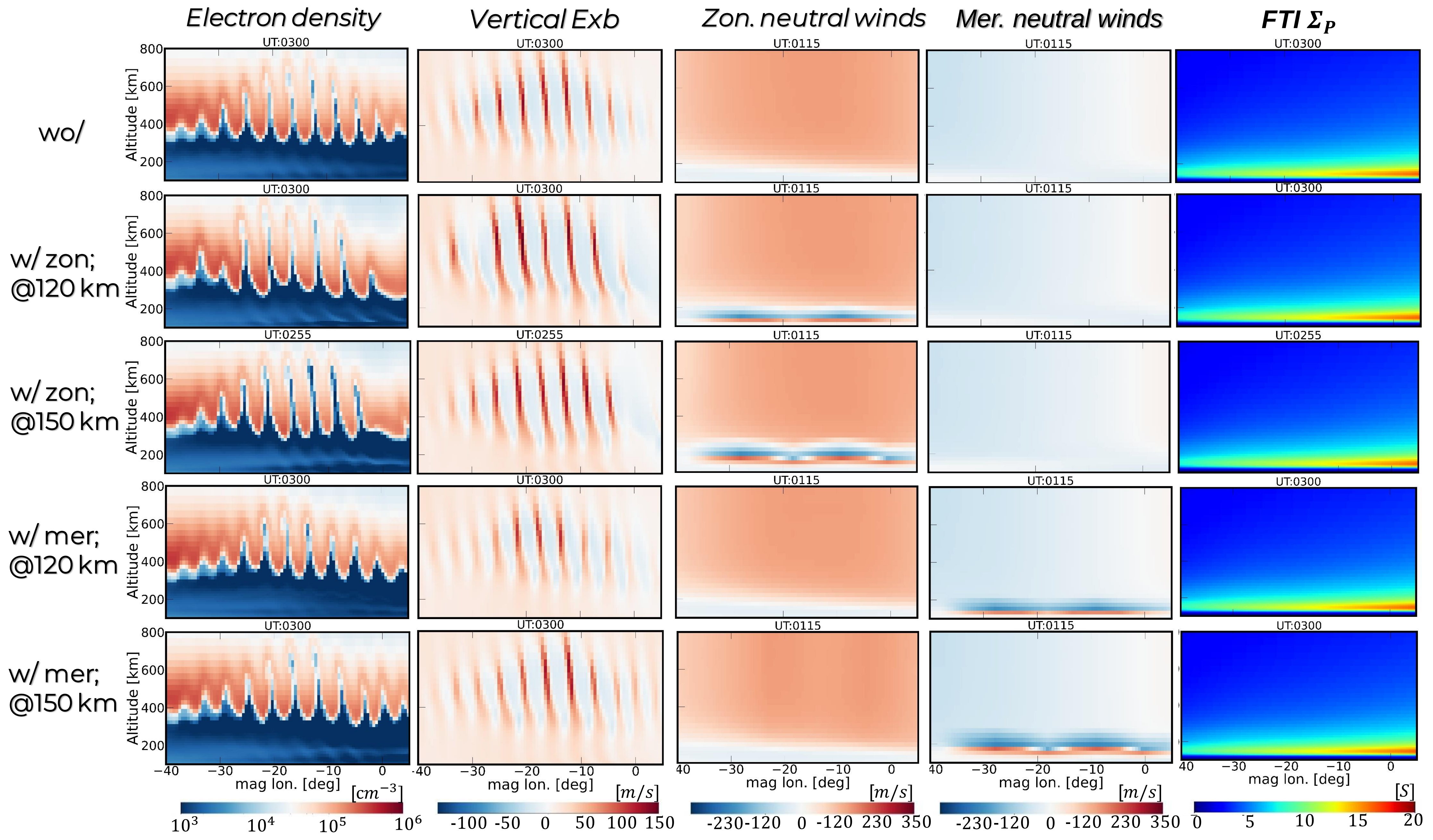
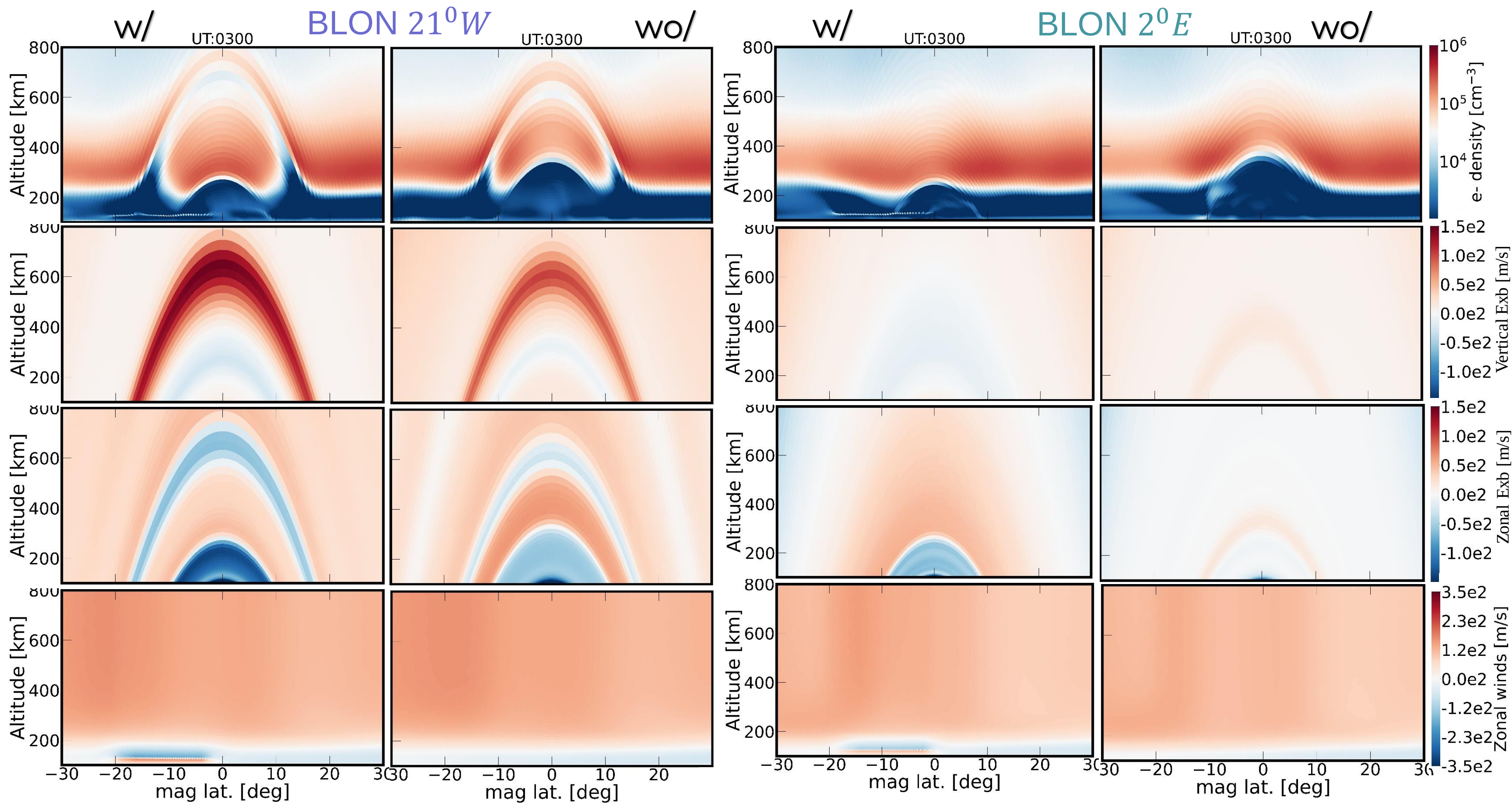


Fig 5. From left to right: electron density, vertical ExB drift, Zonal Neutral Winds, Meridional Winds, and flux tube integrated Pedersen conductance. Each row represents w/wo Zonal/Meridional Wind shears at 120/150 km.

- Zonal wind shear can promote bubble growth within the shear region and suppress bubble formation at the edges (approximately 0-5 degrees east longitude).
- Meridional wind shears have minimal effects, as zonal winds are primary E-region driver.
- The altitude of zonal or meridional shear has minimal impact on the bubble structure



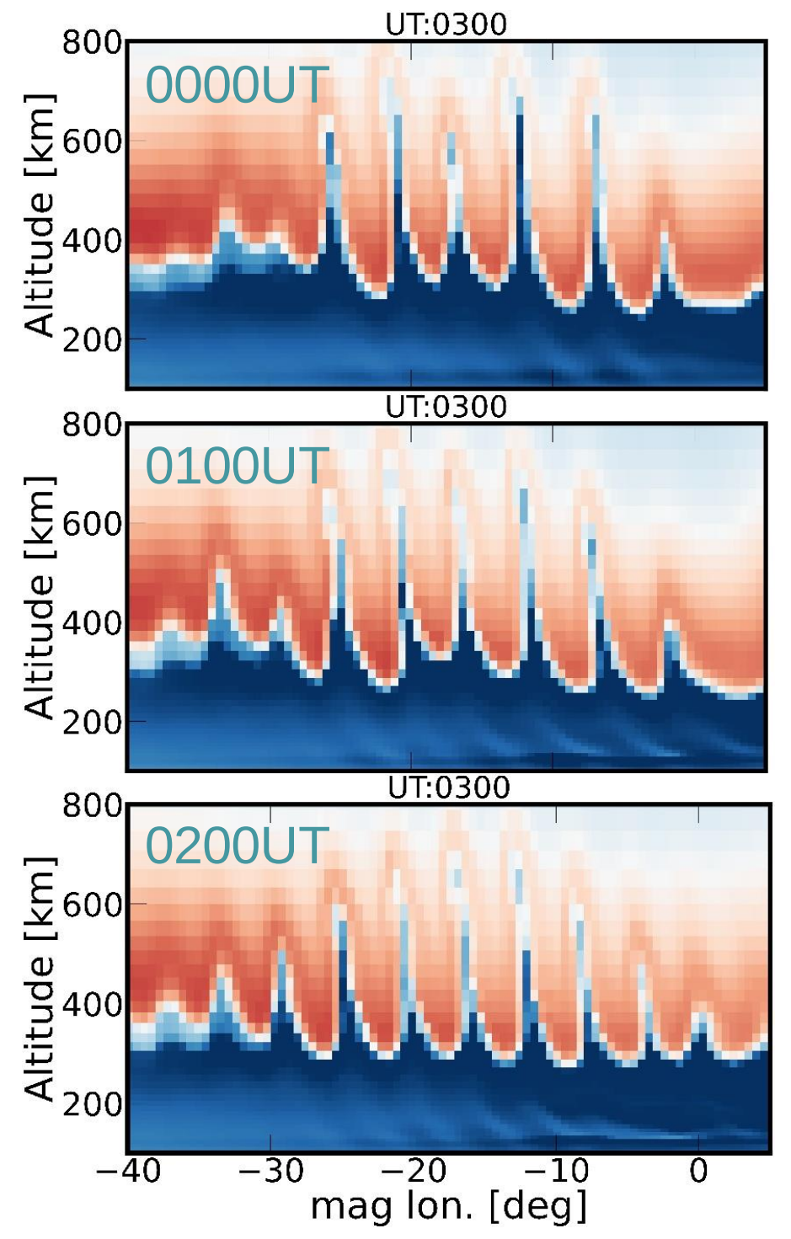
- At 21°W, vertical ExB drift decreases and zonal ExB drift decreases, while the opposite changes occurs at 2°E. These variations could be attributed to adjustments in the electric field, maintaining a curl-free state near the edges of the shear zone

Fig 6. The left two columns compare results with or without zonal wind shears at 21°W longitude, at 120 km (case of the second row in Fig. 5). The right two columns are at 2°E longitude.

Summary

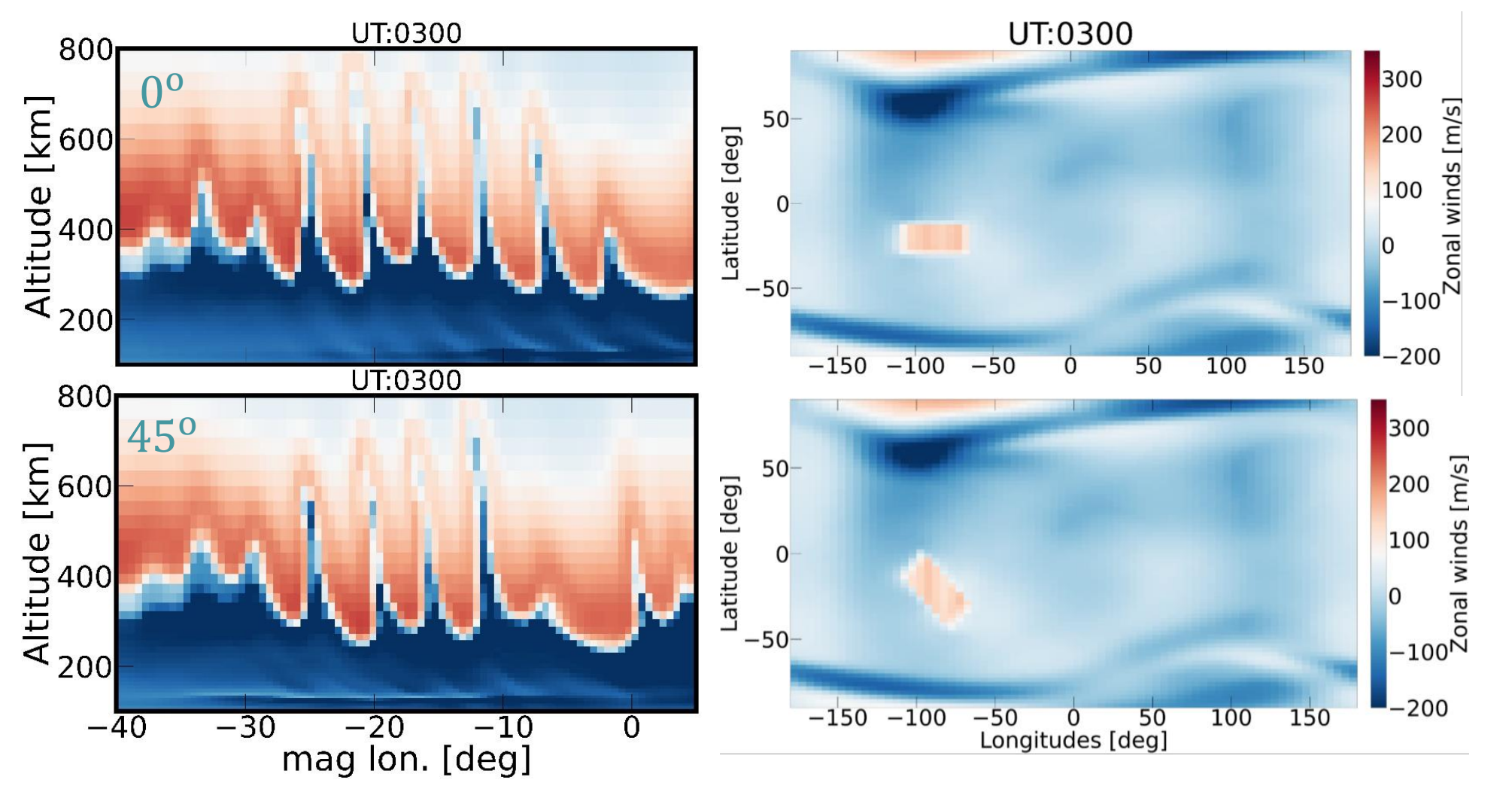
1. Zonal wind shears have a stronger influence on plasma bubbles than meridional shears, which have minimal effects, and altitude variations nearly do not alter the results.
2. The timing and geometry of shear are important changing plasma bubbles.

Shears Initiated at 0000/0100/0200 UT



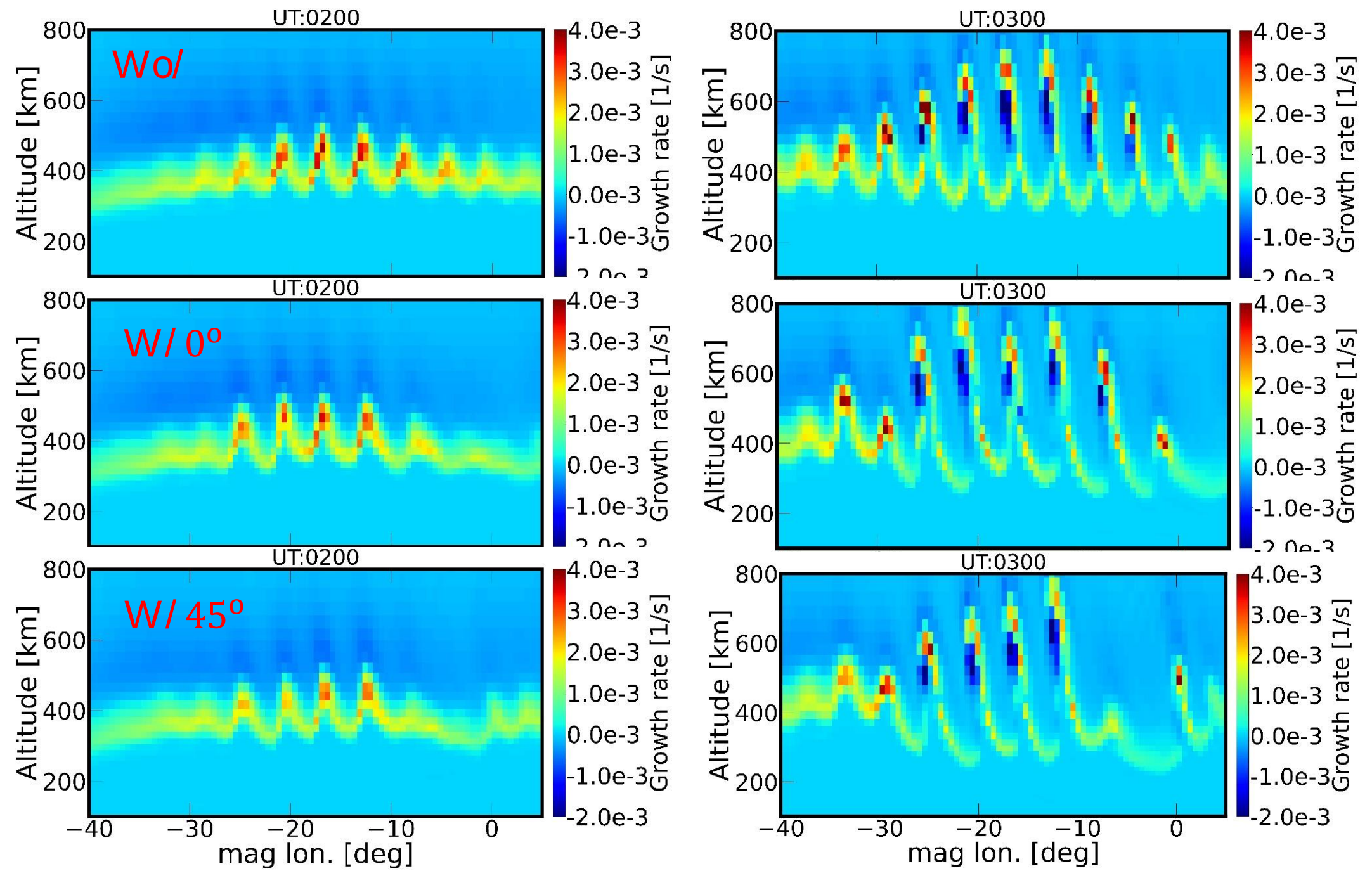
- Results initiated at 0000 and 0100 UT show similar bubble structures and altitudes, whereas simulations started at 0200 UT resemble those without shear, suggesting that shear effects should be introduced before or at the onset of bubble formation.

Shears at 0° and 45° Inclination angles



- Horizontal structure of shears have a significant impact on plasma bubble development. Specifically, shears inclined at 45^0 substantially suppress the bubble increase.

○ γ_g is one of the key determinant of growth rate changes



- Equation for calculating the growth rate

$$\mathcal{A}\omega^2 + \mathcal{B}\omega + \mathcal{C} = 0$$

where

$$\mathcal{A} = \int \sigma_{HIa} G(s)\, ds$$

$$\mathcal{B} = i \int (\sigma_P + \mathcal{L}\sigma_{HIa})\, G(s)\, ds$$

$$\mathcal{C} = \int \left(\frac{1}{L_n(1+\psi)} \left[\sigma_P \left(E_{0\phi} - \frac{B}{c} V_{np} \right) + \sigma_H \left(E_{0p} + \frac{B}{c} V_{n\phi} \right) - \sigma_{HI} g_p + g_{a\phi} \right] - \sigma_P \mathcal{L} \right) G(s)\, ds$$

Huba et al., 2022