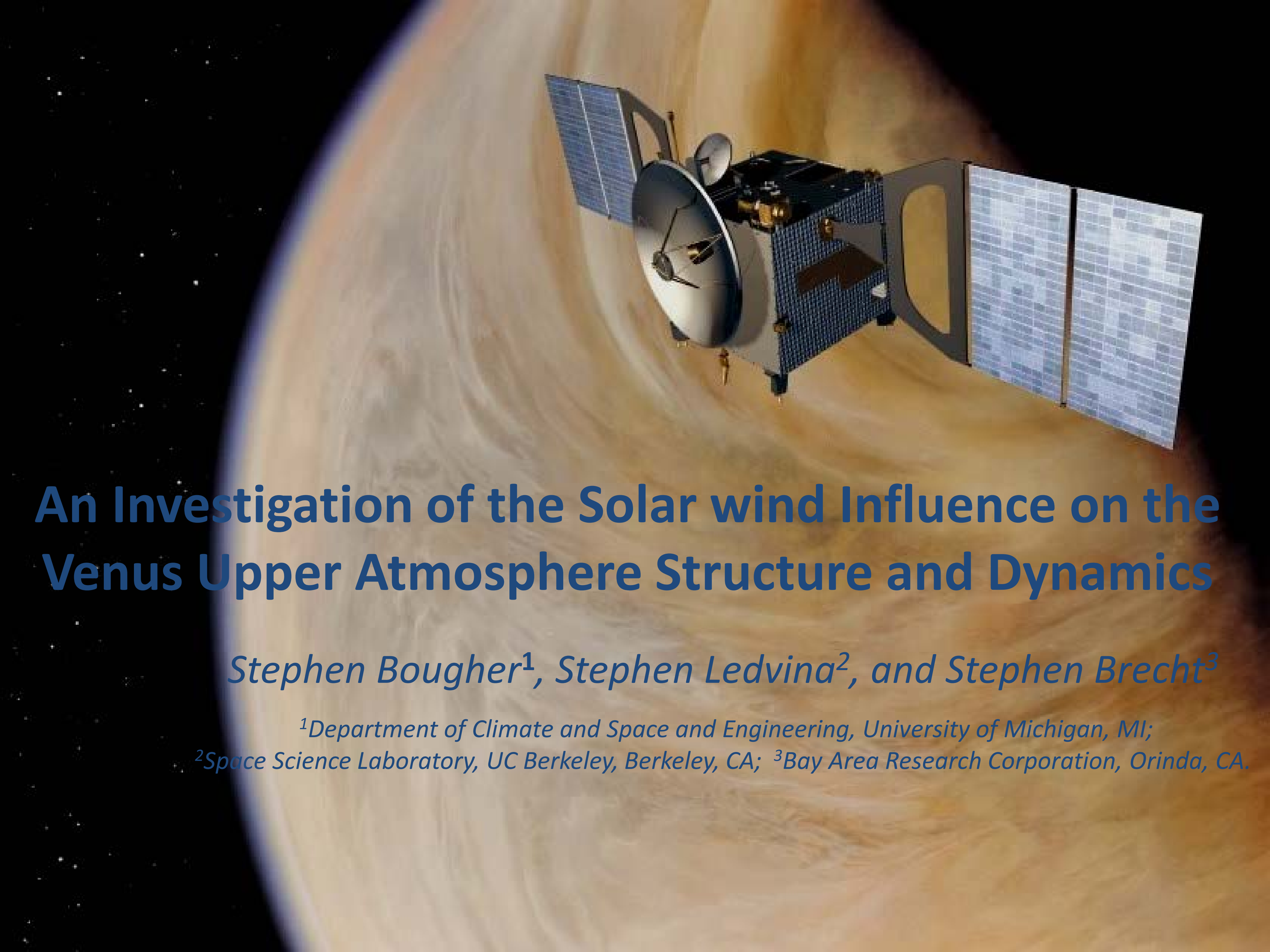

An Investigation of the Solar wind Influence on the Venus Upper Atmosphere Structure and Dynamics

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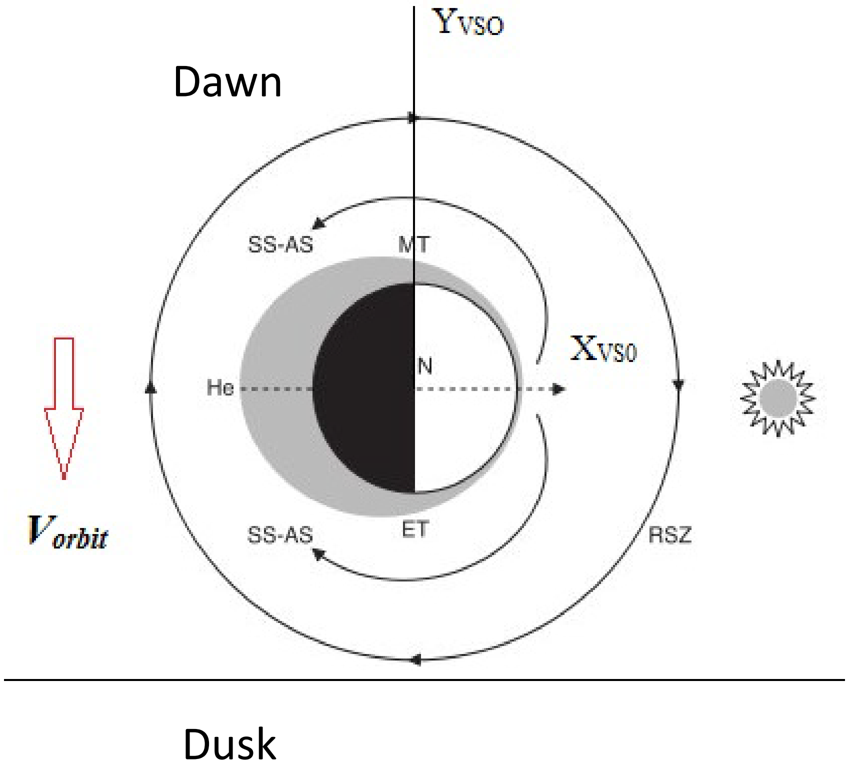
Outline

- Primary research goal
- Motivation of project (VEx ion measurements)
- Neutral wind constraints from PVO and VEx
- HALFSHEL and VTGCM coupled modeling
- Coupling: Qion results and Mion setup
- Conclusions and future plans

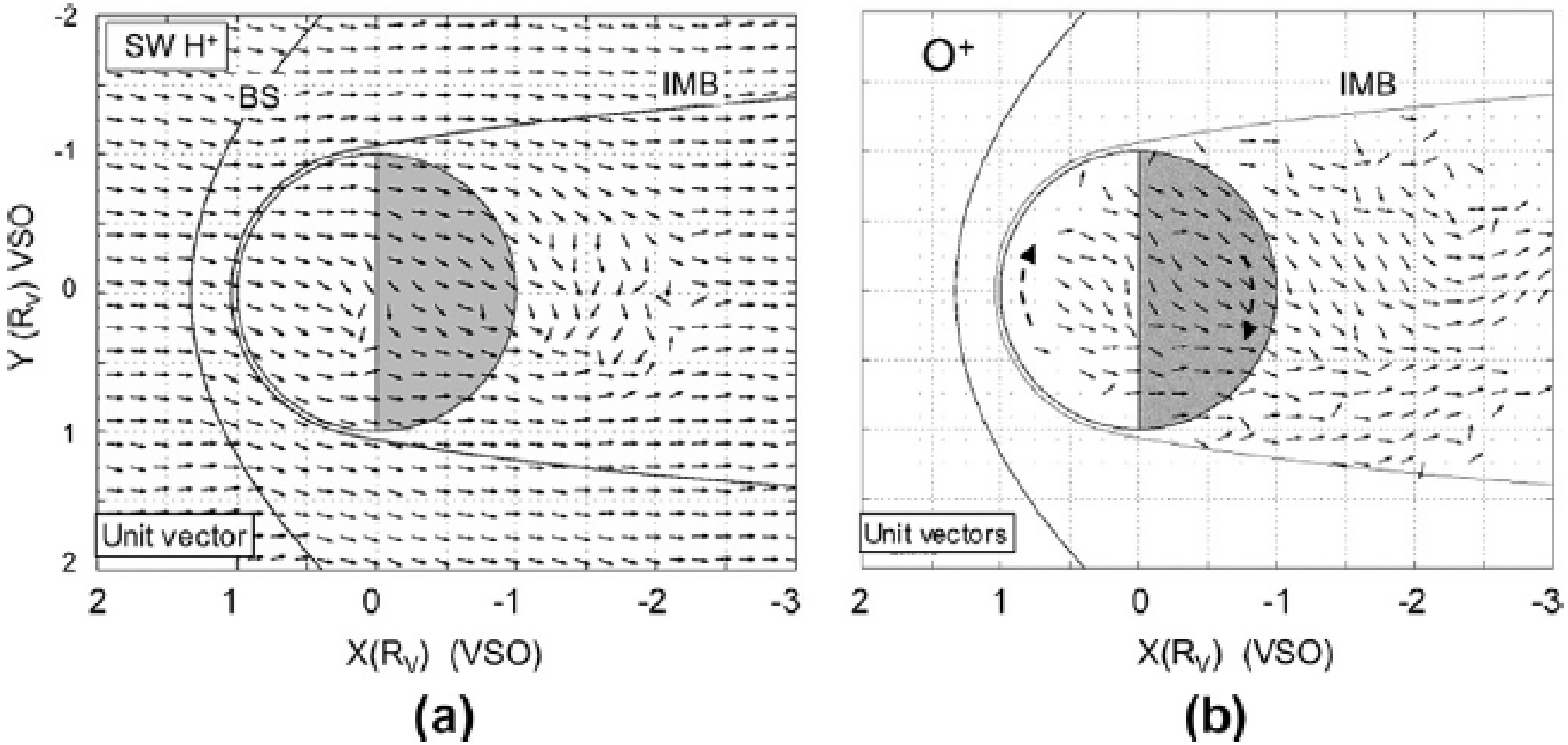
Primary Research Goal

To test the hypothesis that the Super Rotating Zonal flow (RSZ) of the neutral upper atmosphere is driven by solar wind interaction and the planets orbital motion. See old paradigm for Venus mean UATM circulation.



Schubert et al., 2007

Ion Flow from ASPERA-4



Solar wind (SW) H+ unit flow vectors (a) and ionospheric O+ flow vectors (b) projected in the XY (VSO) coordinate system. **Notice the persistent shift of flow vectors towards +Y for both SW H+ and ionospheric O+, on the nightside**. Dashed arrow marks the direction of the Venus atmosphere superrotation. From *Lundin et al.,* [2011].

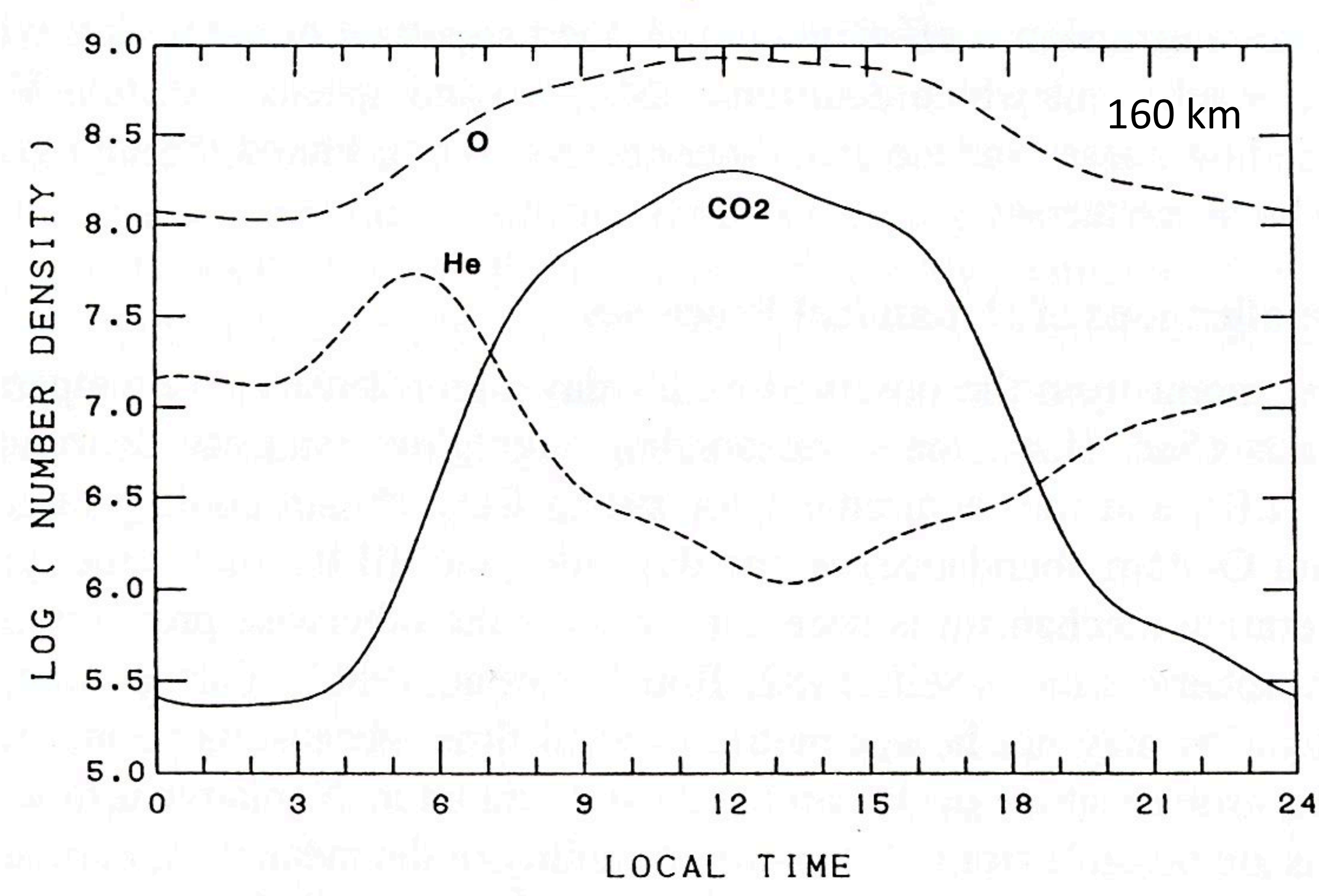
Motivation and Brief History

- *Lundin et al.* [2011] hypothesis based on VEx/ASPERA-4 observations. The O^+ wind flows in the direction of the RSZ winds. The moving O^+ ions then transfer their energy and momentum to the neutral upper atmosphere via ion-neutral collisions driving the RSZ winds. **What altitudes are impacted?**

- *Lundin et al.,* [2013], expanded on the 2011 study using ASPERA-4 data from 690 VEX orbits during two campaigns: July 2006-June 2007 (tail traversals) and July 2008-June 2010 (all orbits). O^+ is the dominant momentum flux below 600 km. **Dusk to dawn O+ ion flow confirmed.**

- *Lundin et al.,* [2014] examined the VEX neutral particle imager (NPI) observations.. O ENA flux derived constitutes a wind of a few km/s moving down to 200 km altitude. **The momentum flux of the combined ion and ENA (1-10 km/s) flow ultimately needs to be addressed. Focus on ion momentum deposition first.**

PVO Constraint: Venus Helium Bulge

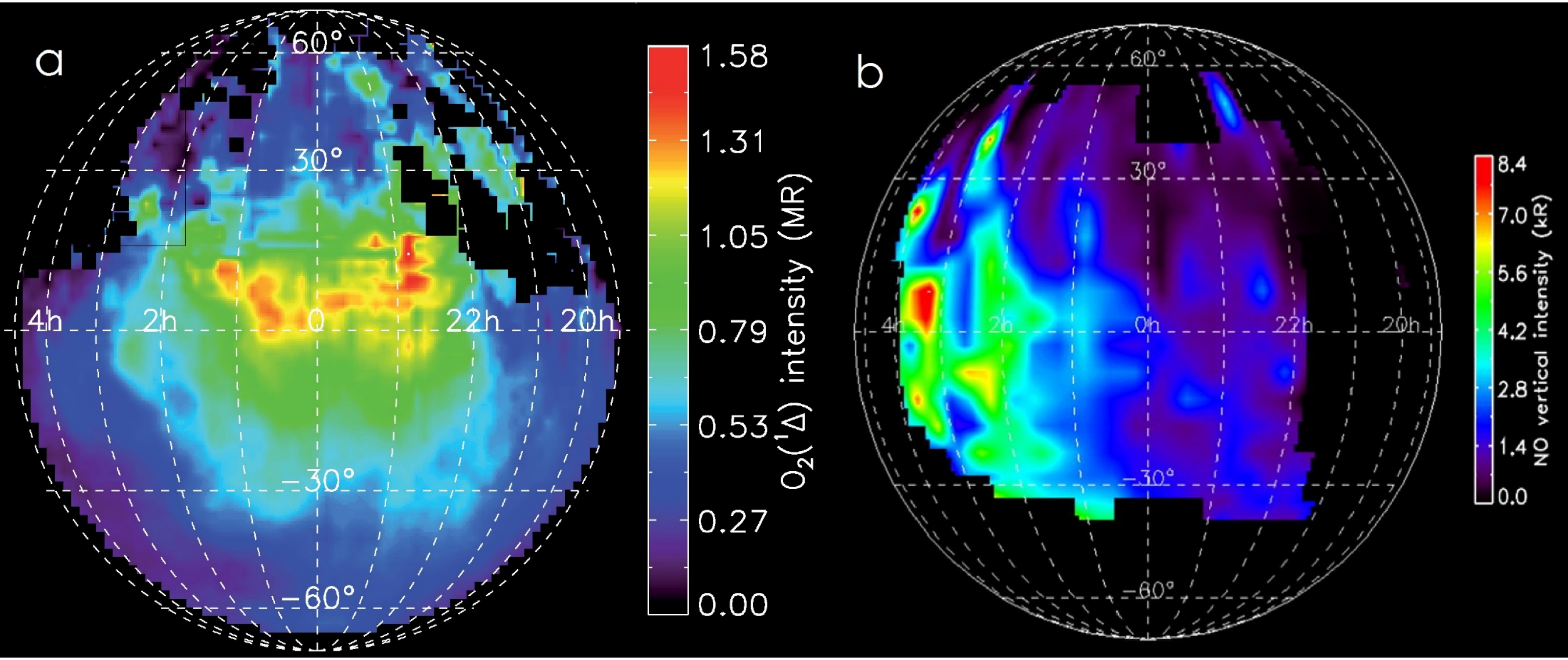


Brinton et al. (1981) and Mengel et al. (1989)

VEx Constraints: Nightglow Emissions

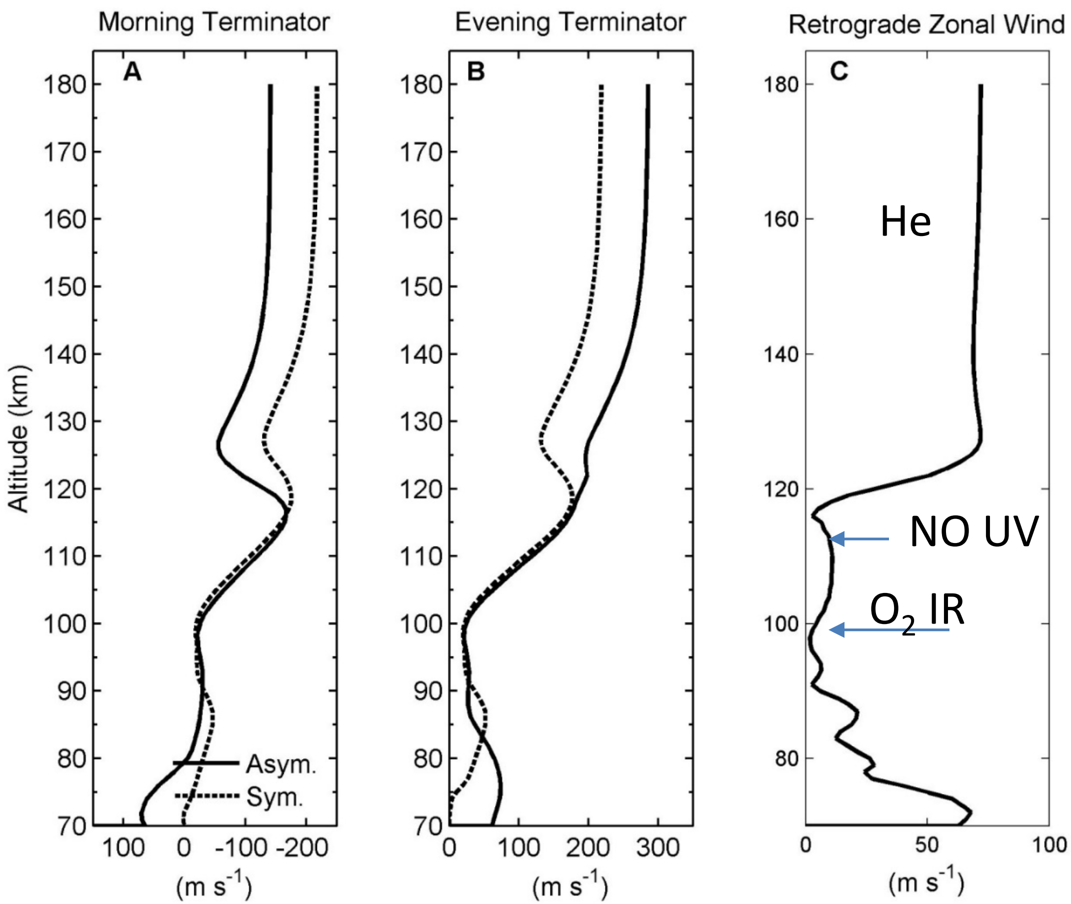
O2 IR

NO UV



Maps of the statistical distribution of the O_2 and NO nightglow intensity. The difference between the bright spot location of O_2 and NO emission suggests two different dominant wind regimes at 99 and 115 km. See Brecht et al., (2011); Soret et al., (2012a); Stiepen et al., (2013); Gerard et al., (2017).

VTGCM Terminator Winds



Brecht et al, (2011)

RSZ Wind Mechanisms

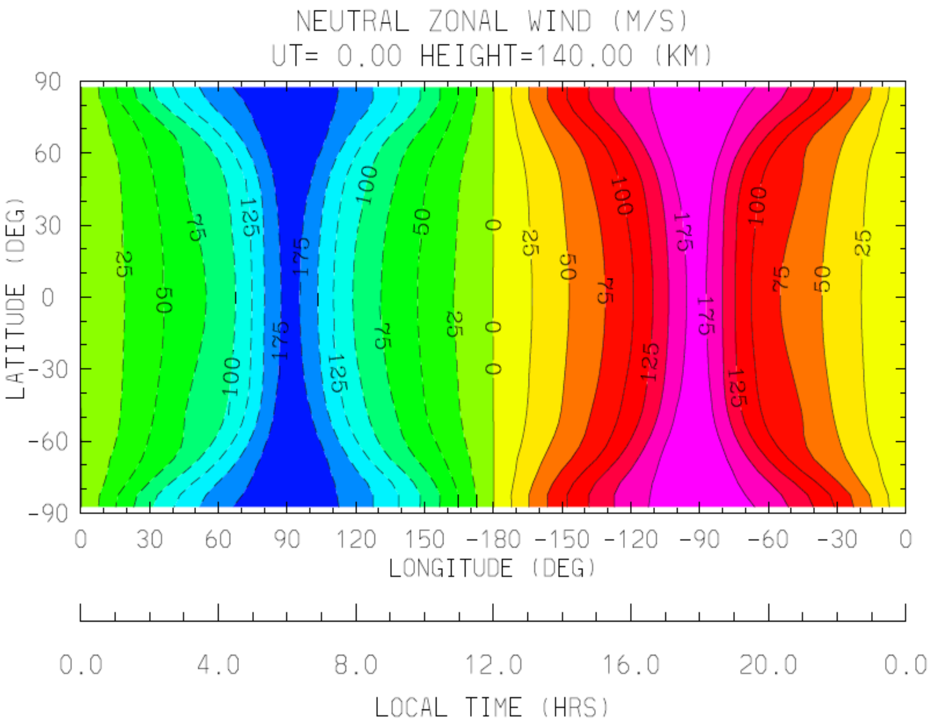
- **Gravity wave momentum deposition (LATM->UATM)**
  * Initial AD theory applied (dusk vs dawn): Alexander et al. (1992)
  * Several GW models applied over ~25 years with only partial success (e.g. Zhang et al. 1996; Hoshino et al. 2013; Zalucha et al. 2013; Brecht et al. 2019)

- **Ion-neutral collisions & energy-momentum transfer (SW-> UATM)**
  * 3-D kinetic model utilized to produce ion momentum and energy deposition rates from descending ion fluxes over the planet
  * Coupling of 3-D kinetic (SW interaction) & 3-D fluid (thermosphere) models needed for full transfer(s) to be addressed

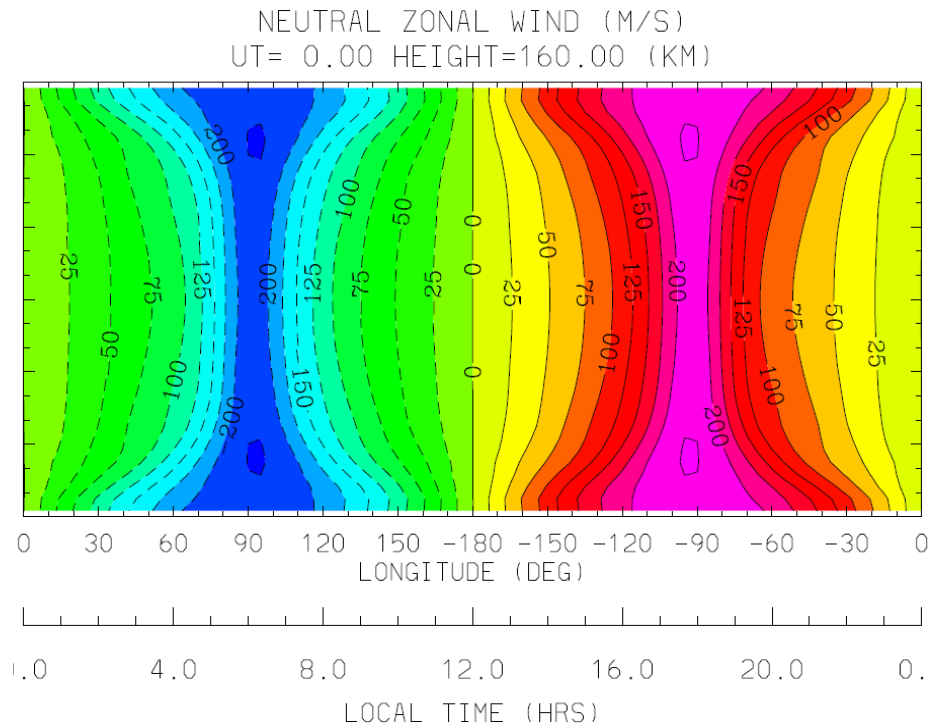
HALFSHEL and VTGCM Codes

Feature	HALFSHEL	VTGCM
Type of Model (3-D)*	Hybrid plasma code: ion dynamics (Kinetic ions, fluid electrons)	Fluid meso-thermosphere model (T, U, V, W) finite difference code
Grid	Plasma cell size is 60 km. Neutral grid cell size is ~5 km (radial) by 5x5°(horiz) for chemistry package	Horizontal (5 x 5°) Vertical (~70-250 km) 0.5 H res.
Species*	H+, O+, O_2+ (ions) O, CO, N_2, CO_2 (from VTGCM)	O, CO, N_2, CO_2 (major) N(4S), N(2D), NO, SO, SO_2 (minor) O+, O_2+, CO_2+, NO+, N_2+ (ions)
Inputs	Upstream SW conditions: Vsw ~ 400 km/s; Nsw~10/cc IMF: (5.5, 5.0, 5.0) in Rv	Top: Solar EUV-UV fluxes (VEx) LBCs: T,U,V,Z via V-GCMs; species fluxes or VMRs via KINETICS code
Special modules	Time dependent ion-neutral photo-chemistry; Complex collisional models	CO_2 15-µm cooling (NLTE); Static IR heating (~2-4.3 µm) from Roldan et al (2000) & Crisp (1986)
Other*	Qion and Mion (to VTGCM): Ion heating and ion momentum deposition (from ion fluxes)	Nightglow emissions: NO (UV), O_2 (IR), and OH (IR)

VTGCM: VEx Baseline Simulation
Uzonal at 140 km and 160 km

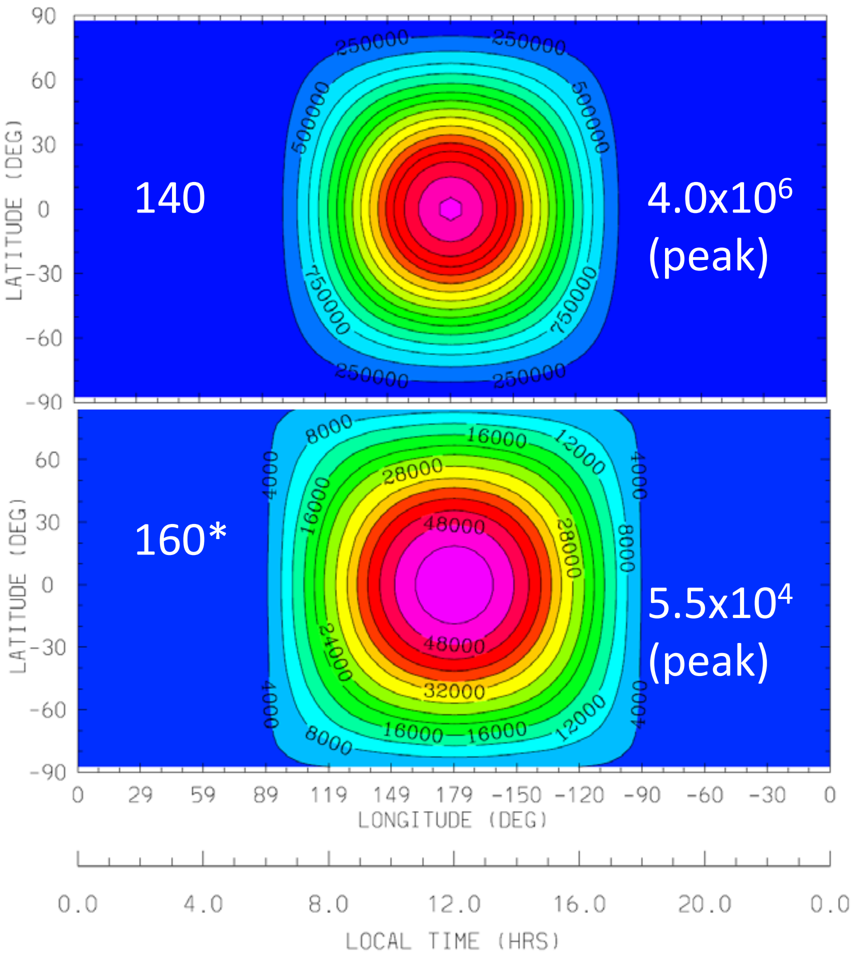


Uzonal = -192 m/s to +192 m/s (MT & ET)
(SS-AS only)

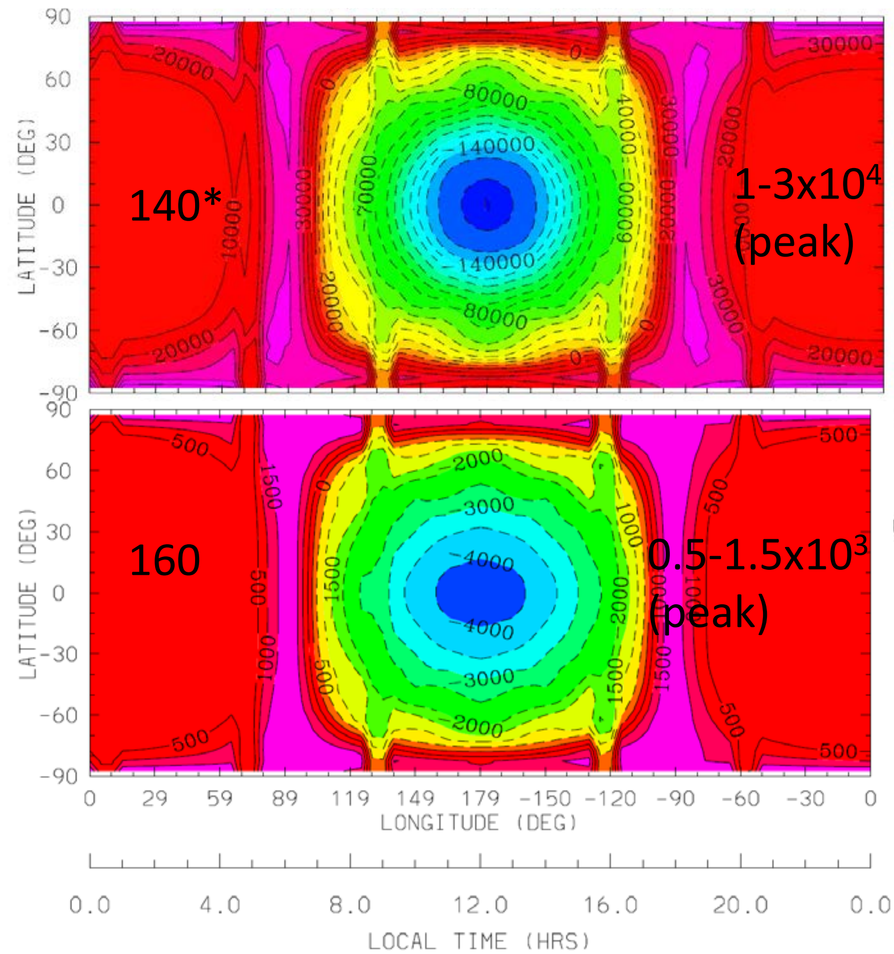


Uzonal = -225 m/s to +225 m/s (MT & ET)
(SS-AS only)

VTGCM: Baseline Key Thermal Terms at 140 and 160 km ($eV/cm^3/s$)

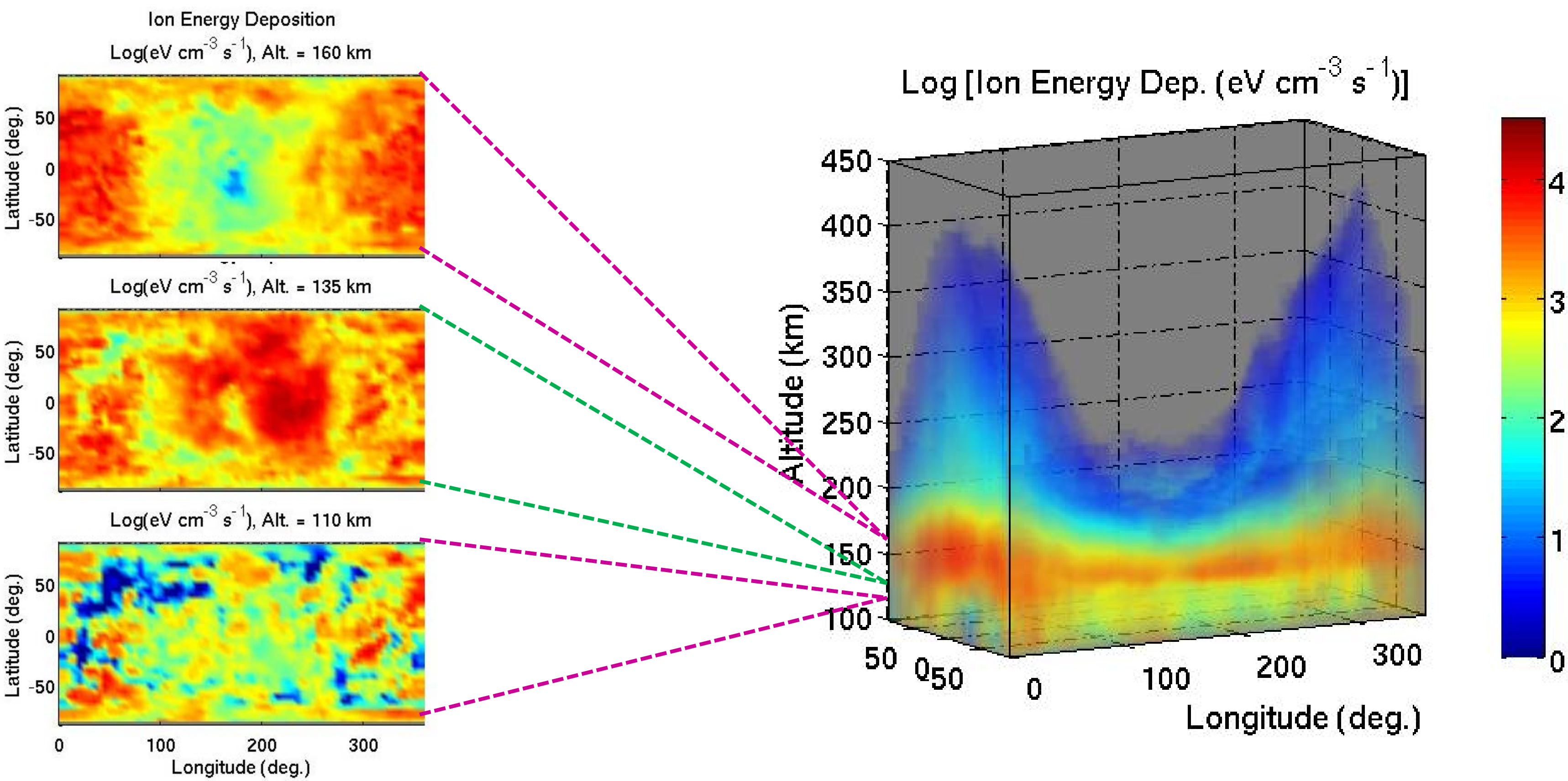


140 and 160 km (QNET = QEUV + QNIR)



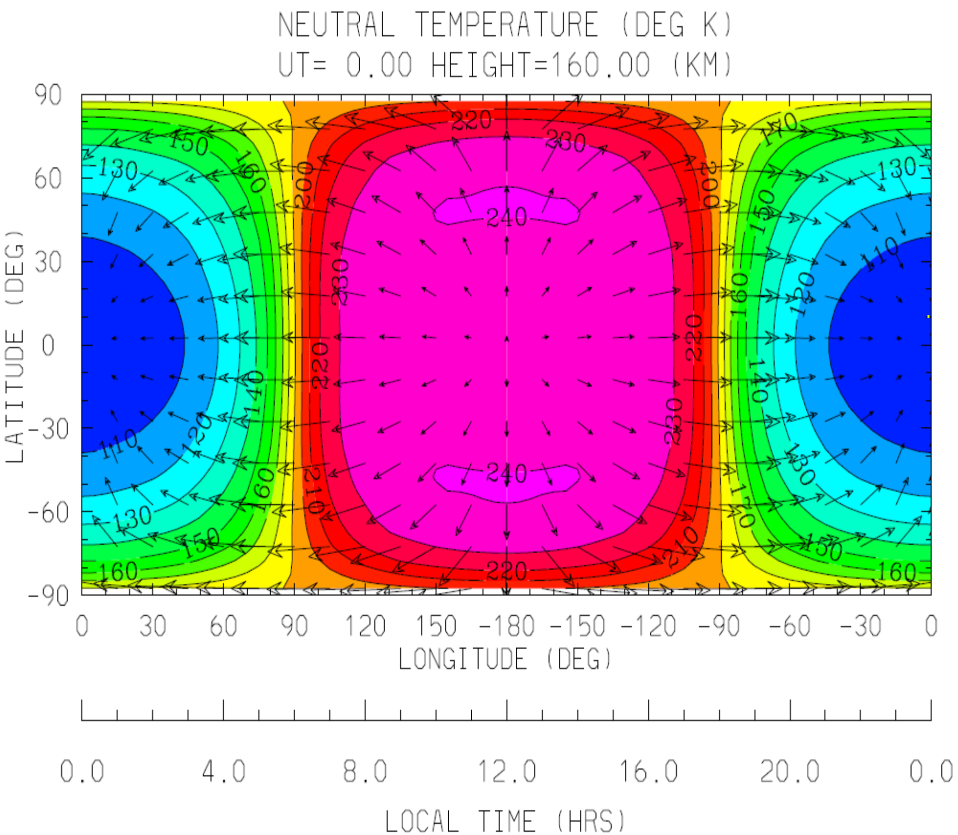
140 and 160 km (QDYN)

HALFSHEL Ion Heating Rate to the VTGCM Neutral Atmosphere (eV/cm^3/s)

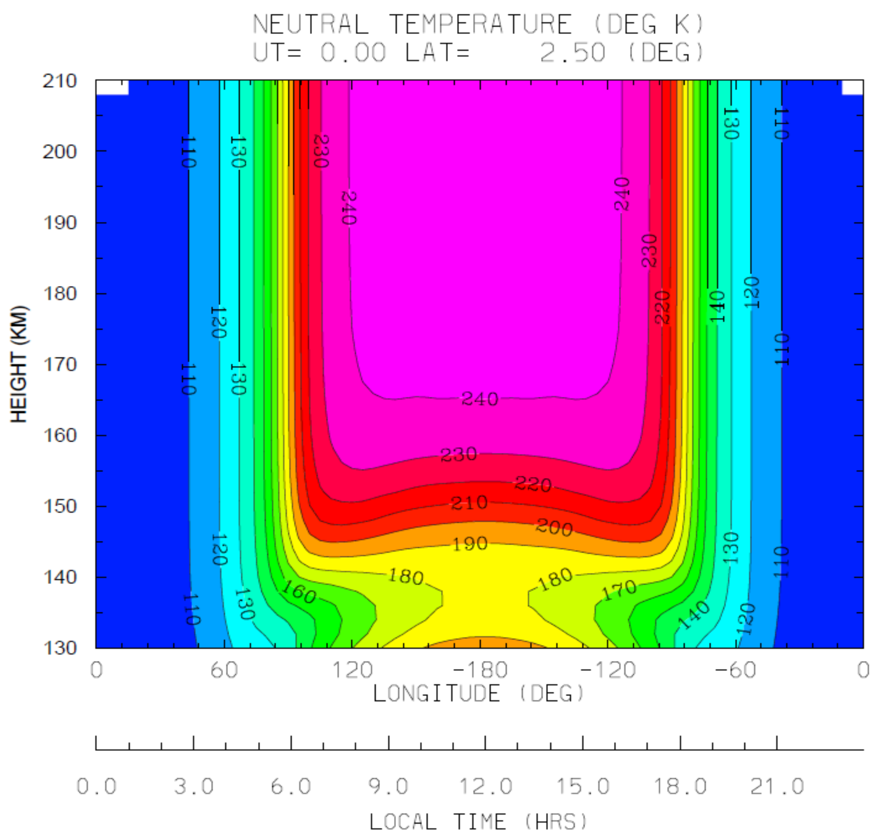


LT = 12 24 12

VTGCM: VEx Baseline Simulation Temps at 160 km and LAT = 2.5N

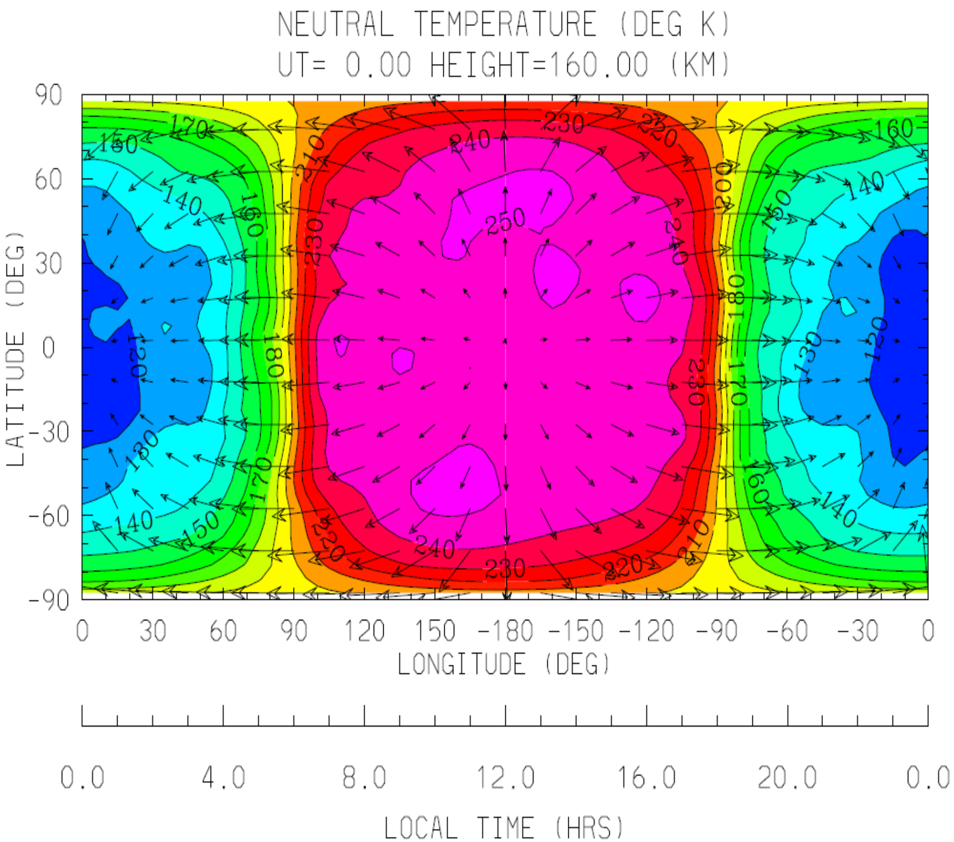


T_{160} ~ 100 to 240 K
(SS-AS only)

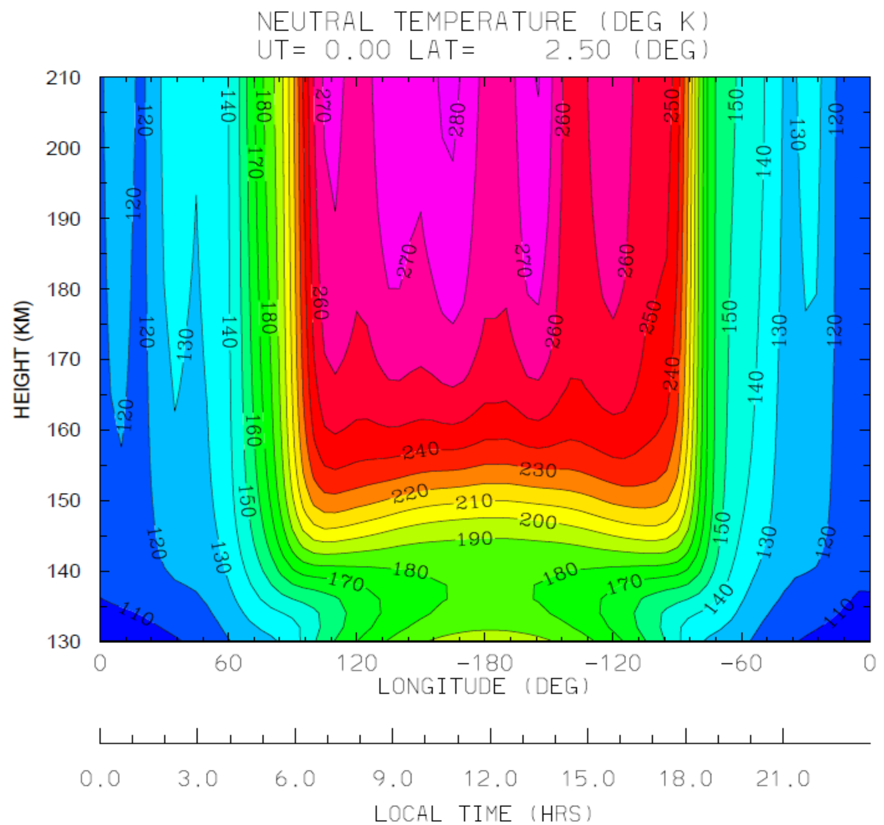


T_{max} ~ 245 K (noon); T_{min} ~ 100 K(midnite)
(SS-AS only)

VTGCM: 100% Qion (only)
Temps at 160 km and LAT = 2.5N

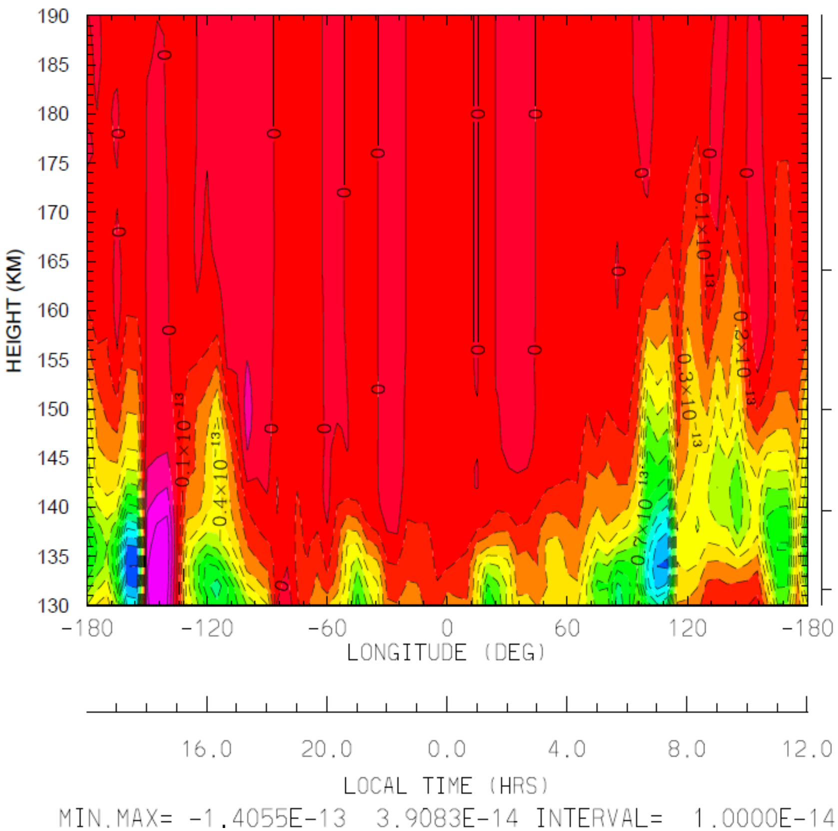


T_{160} ~ 111 to 255 K
(SS-AS only)

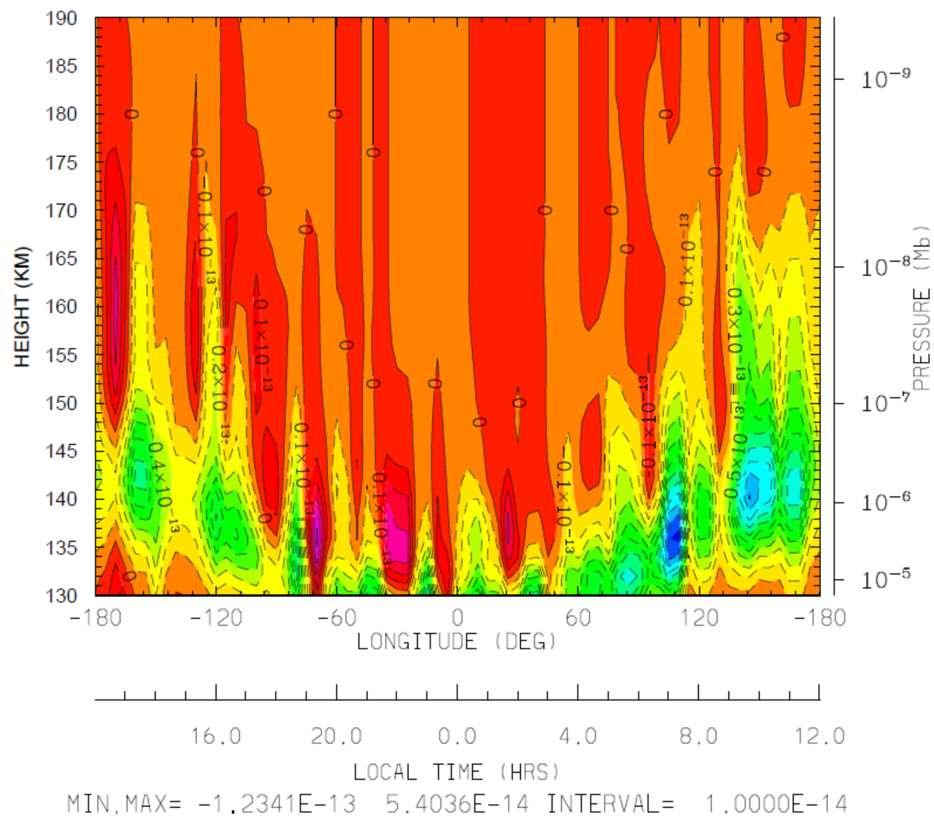


Texo (DY) ~ 270-285 K; Texo (NT)~ 105-130 K
(SS-AS only)

HALFSHEL Momentum Deposition Rate ($gm.cm/s^2$) (LAT = 2.5N)



Zonal



Meridional

VTGCM threshold: ~ 0.5-2.0 cm/s^2

Conclusions:
Qion Results & Implications for Mion Impacts

- Hybrid and fluid models can be coupled to address the ion energy & momentum hypothesis of Lundin et al (2011).
- Ion heating peaks at ~135-160 km, with higher altitude deposition on the dayside than nightside (same pressures). Ion momentum deposition should follow the same trend.
- T-enhancements are "patchy", especially on the nightside (+5-30 K). Yields patchy nightside structure overall (T, densities, winds).....
- "Patchy" momentum deposition rates should result in "vertical spikes" of momentum deposition similar to heating.
- Asymmetric energy deposition supports the hypothesis that the RSZ winds could be driven by the plasma interaction. Magnitude of momentum deposition (~135-160 km) is the key. Next step....
- Adding orbital motion will further enhance the asymmetric energy deposition in thermosphere, further driving RSZ winds.