Parameterizing Gravity Waves and Understanding their Impacts on Venus' Upper Atmosphere

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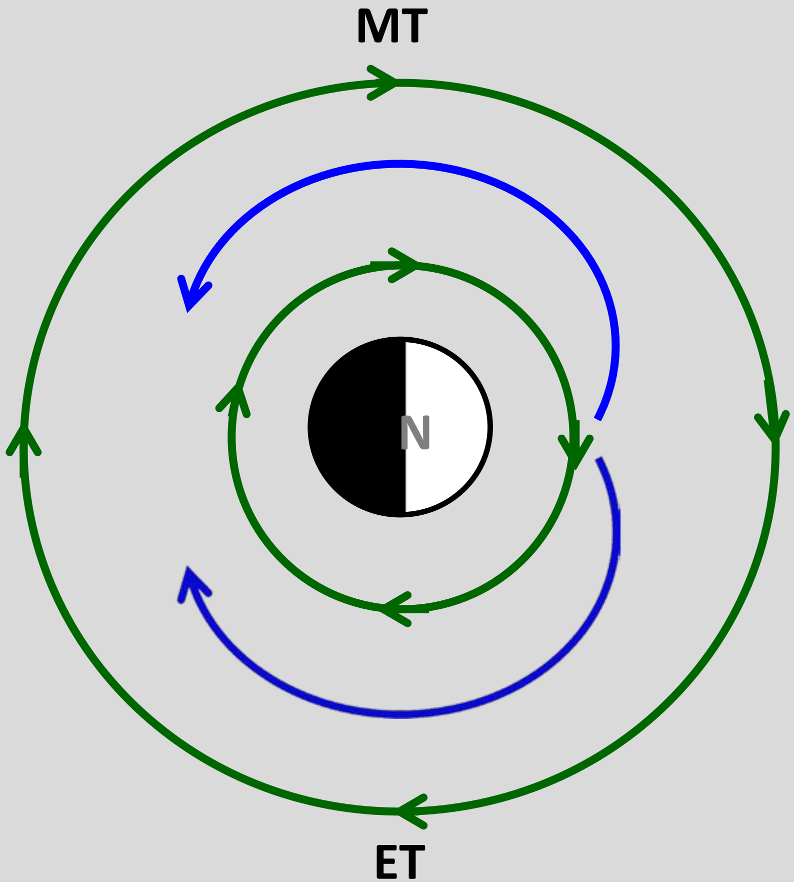
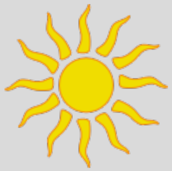
Simplistic North Pole View of Venus' Zonal Circulation



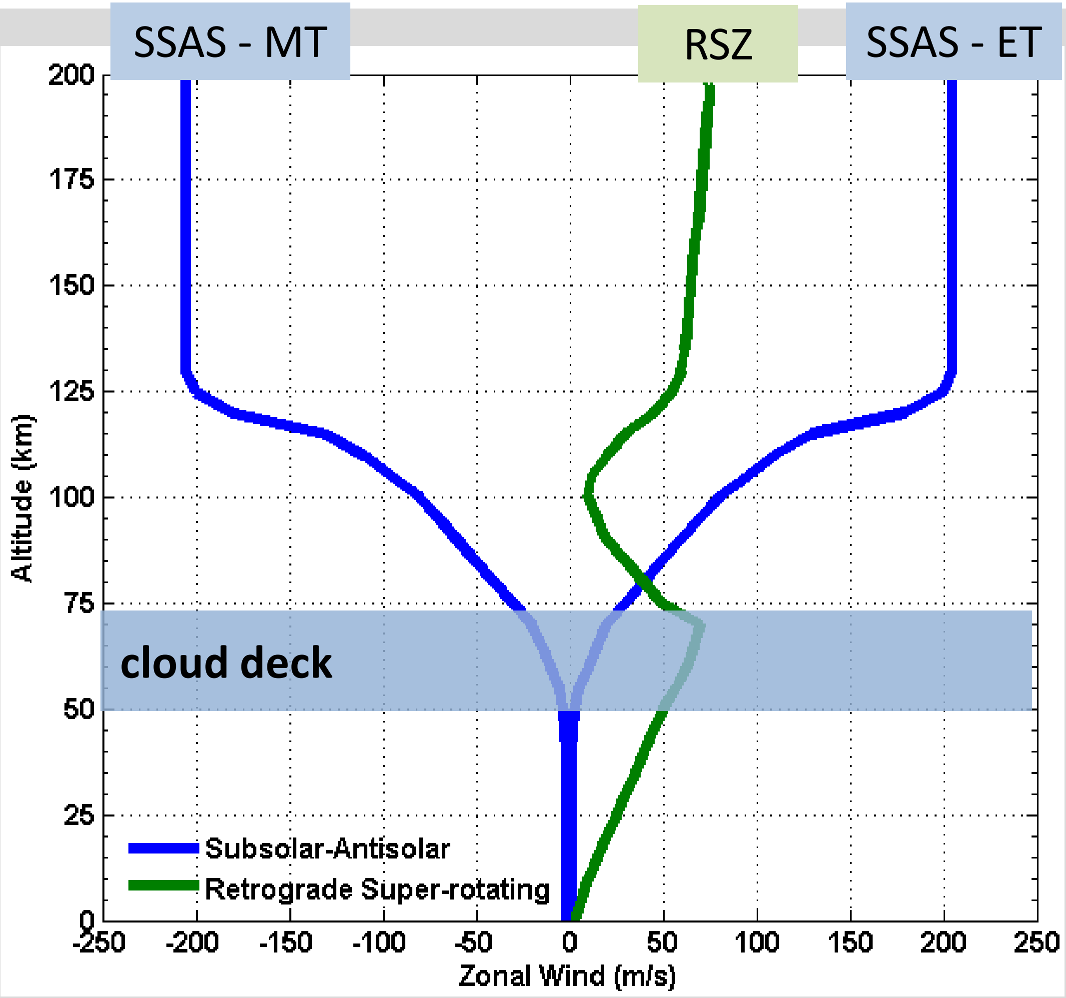
- MT = morning terminator
- ET = evening terminator



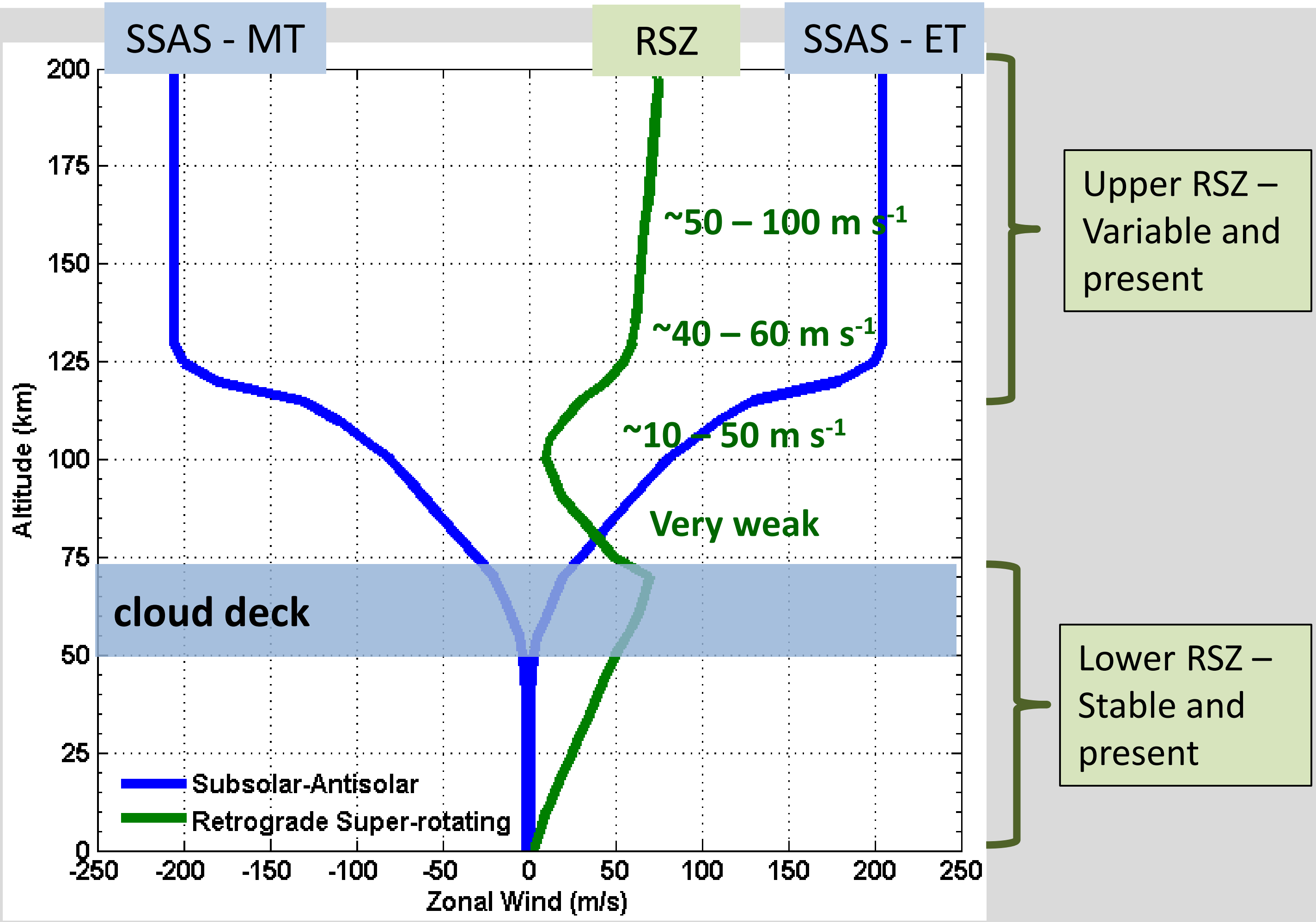
- **SS-AS** = stable subsolar to antisolar circulation cell driven by NIR and EUV heating
- **RSZ** = retrograde super-rotating zonal flow that seems to vary greatly over time

Adapted from Schubert et al. 2007

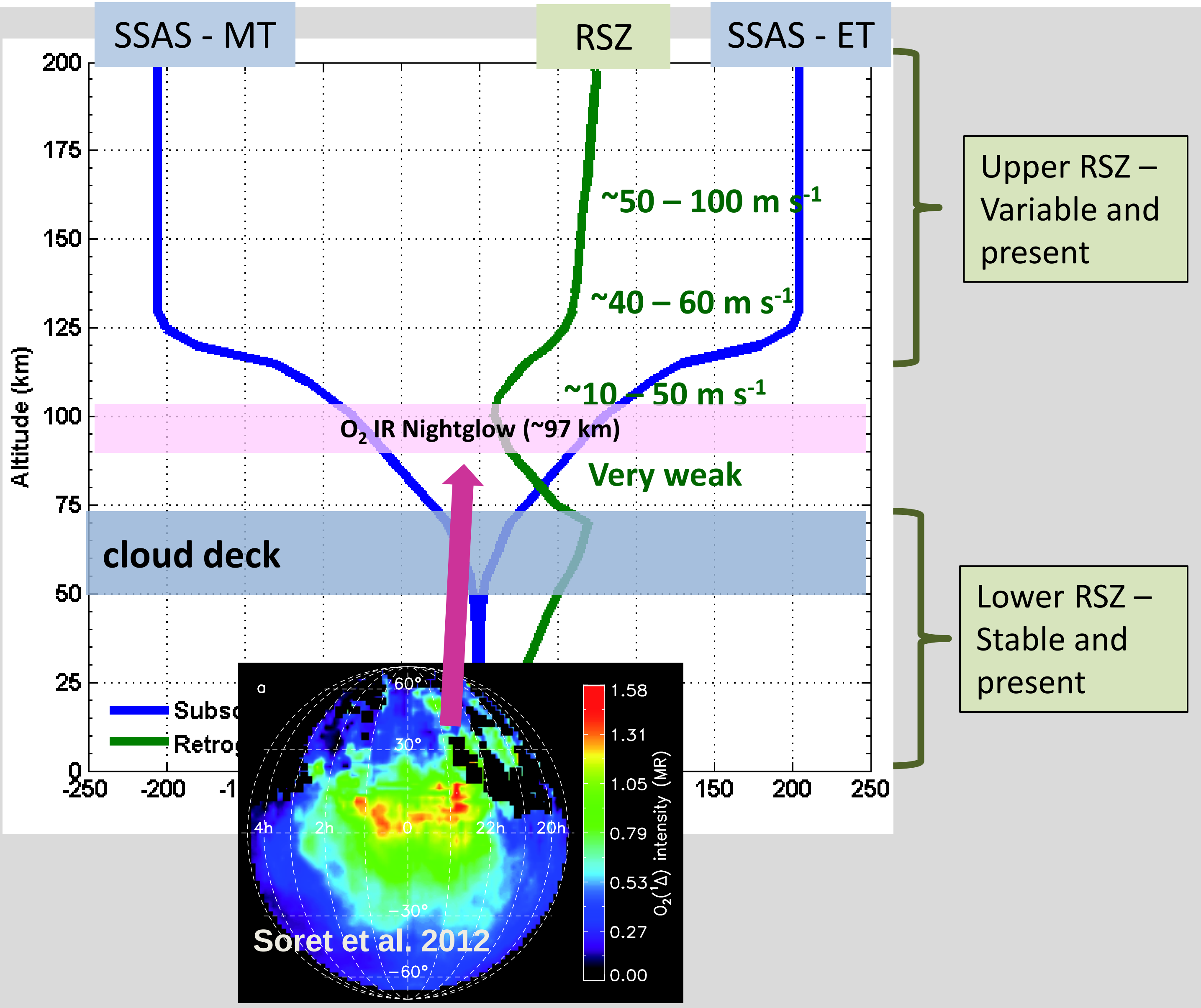
Simplistic Vertical View of Venus' Zonal Circulation



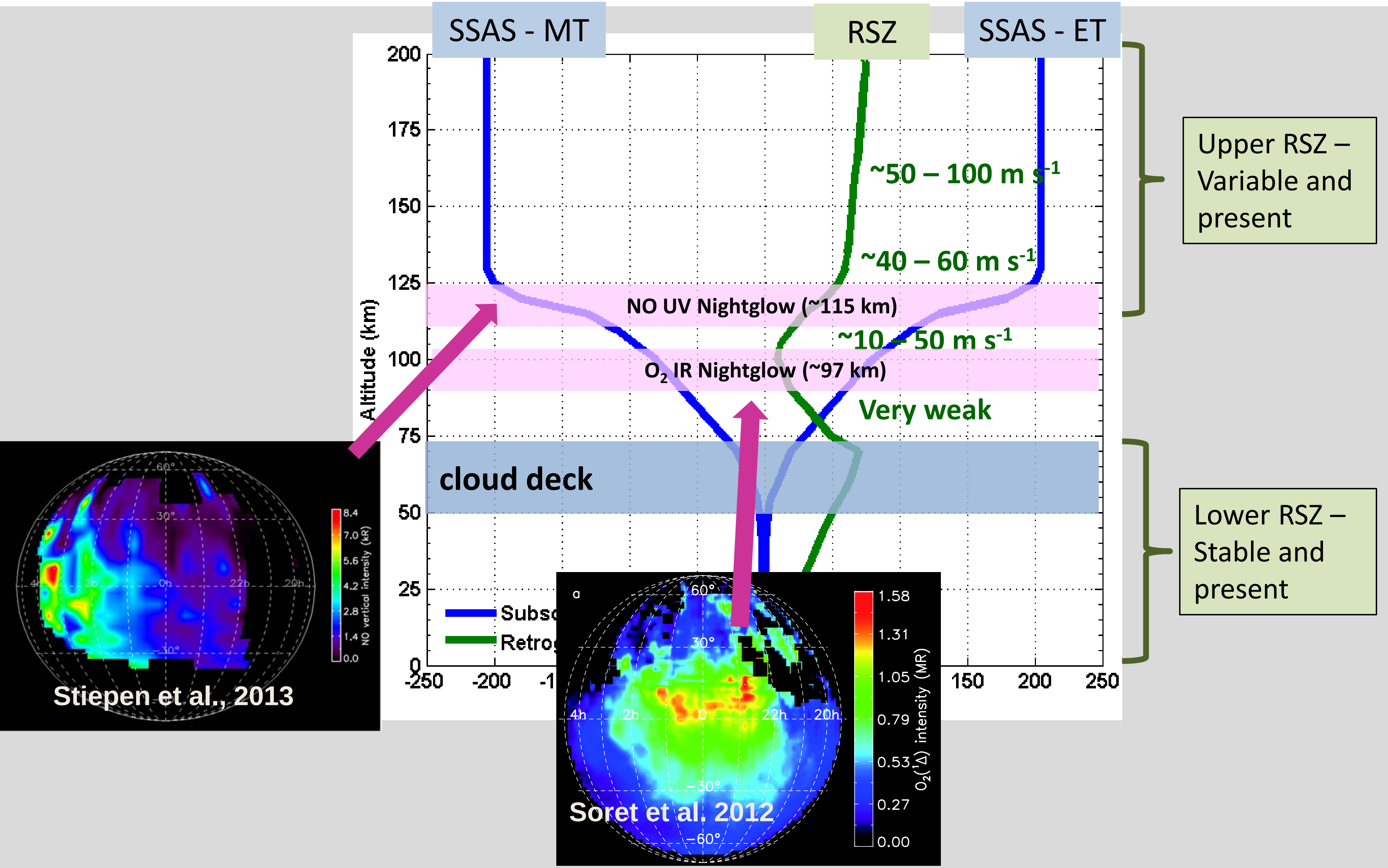
Simplistic Vertical View of Venus' Zonal Circulation



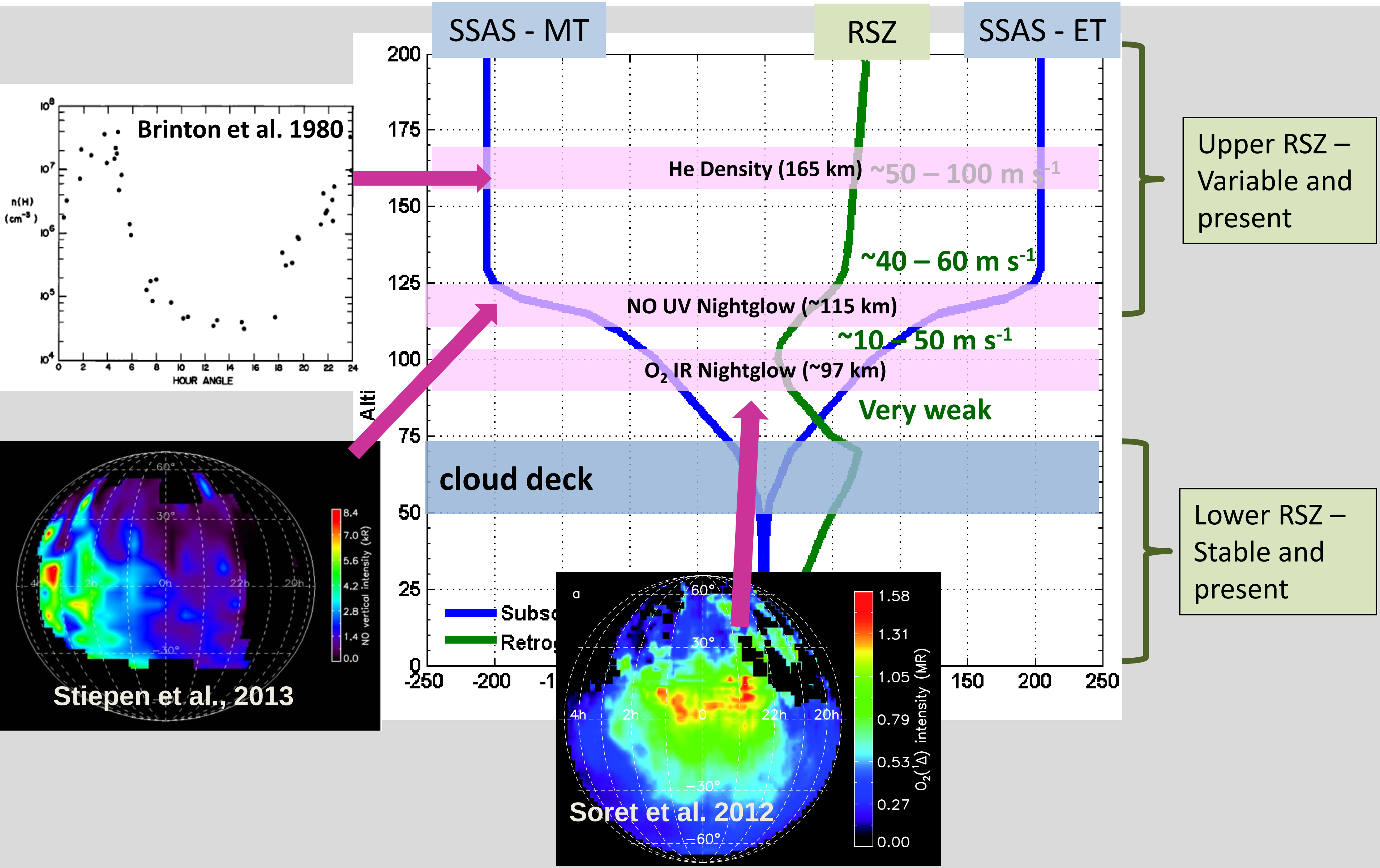
Simplistic Vertical View of Venus' Zonal Circulation



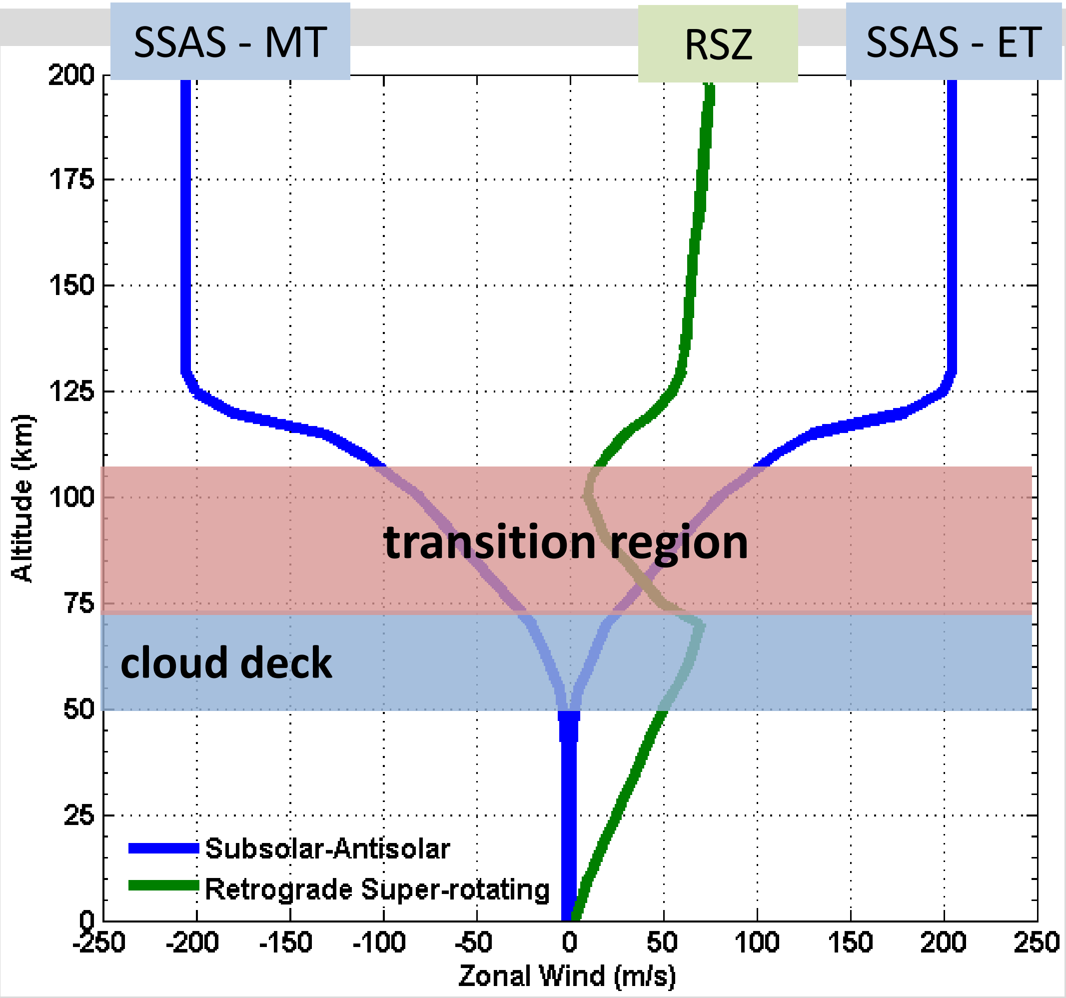
Simplistic Vertical View of Venus' Zonal Circulation



Simplistic Vertical View of Venus' Zonal Circulation



Simplistic Vertical View of Venus' Zonal Circulation



Circulation questions gravity waves may contribute towards:

- What drives the upper RSZ and it's variability?
- What contributes to the SSAS variability?
- What contributes to the variability within the transition region?
  - i.e. How does the lower RSZ, upper RSZ, and SSAS interact to create this transition region?

Wave Observations

- Wave Parameters are being discerned through:
  - **Temperature Profiles**
    - e.g. Seiff et al., 1980; Counselman et al., 1980; Kliore and Patel, 1980; Kolosov et al., 1980; Hinson and Jenkins, 1995; Tellmann et al., 2012
  - **Thermal Imaging**
    - e.g. Peralta et al., 2008; Fukuhara et al., 2017; Kouyama et al., 2017
  - **Cloud Imaging**
    - e.g. Belton et al., 1976; Rossow et al., 1980; Markiewicz et al., 2007; Titov et al., 2012; Piccialli et al., 2014; Bertaux et al., 2016
  - **Non-LTE CO_2 Emissions**
    - e.g. Garcia et al. 2009
  - **Density Perturbations**
    - e.g. Niemann et al., 1980, Kasprzak et al., 1988
  - **O_2 IR nightglow**
    - e.g. Altieri et al., 2014

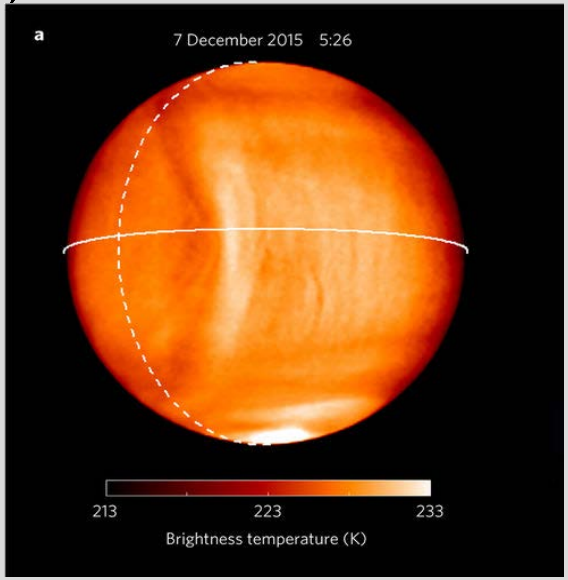


Image from LIR by Akatsuki. (*Nature Geoscience*, 2017. DOI: 10.1038/NGEO2873)

Venus Thermospheric General Circulation Model (VTGCM)

(e.g. Bougher et al., 1988; Brecht et al., 2011)

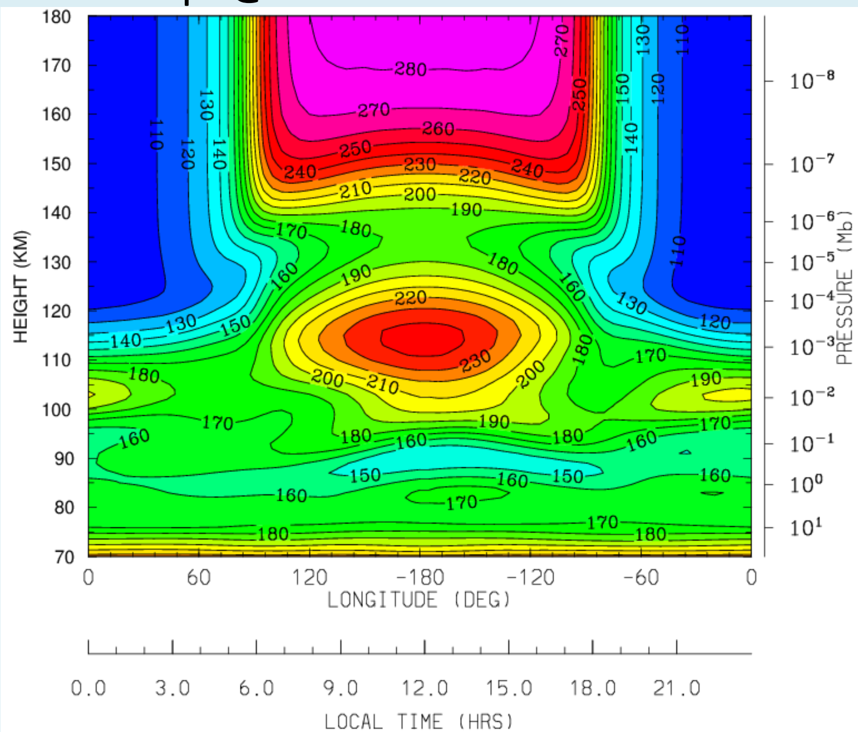
- Altitude range: ~70 - 250(200) km (night)
- Horizontal: 5° x 5° latitude vs longitude
- Vertical resolution: 69-log pressures levels.
- Major Fields: T, U, V, W, O, CO, N_2, CO_2, Z.
- Minor Species: N(4S), N(2D), NO, O_2, SO, SO_2
- PCE ions: CO_2^+, O_2^+, N_2^+, NO^+, O^+, Ne
- O, CO, O_2, $N(^4S)$, $N(^2D)$, NO, SOx sources/losses explicitly calculated.
- O_2 IR, NO UV, OH IR nightglow calculated.
- F10.7 ~70 or 130 at Earth.
- Q-Efficiency (EUV,UV) = 20,22% (Fox, 1988)
- CO_2 15-µm cooling scheme from Bougher et al., (1986) using Roldan et al., (2000) exact cooling profiles (at reference T and O-abundances).
- Rayleigh Friction (prescribed based upon observations)
  - Symmetric (RF-SSAS) subsolar to antisolar [Always on for the cases in this talk]
  - Asymmetric (RF-RSZ) retrograde super-rotation zonal flow
- Oxford Venus GCM (OXVGCM) – T,U,V,Z output implemented at VTGCM lower boundary
- Kzz Day (Night) Max

- ~1.0 x 10^6 cm^2/sec (~4.0 x 10^7 cm^2/sec)
- $A_o = 8.4 \times 10^{11}$ ($A_o = 1.4 \times 10^{13}$)

VTGCM with RF-RSZ off:

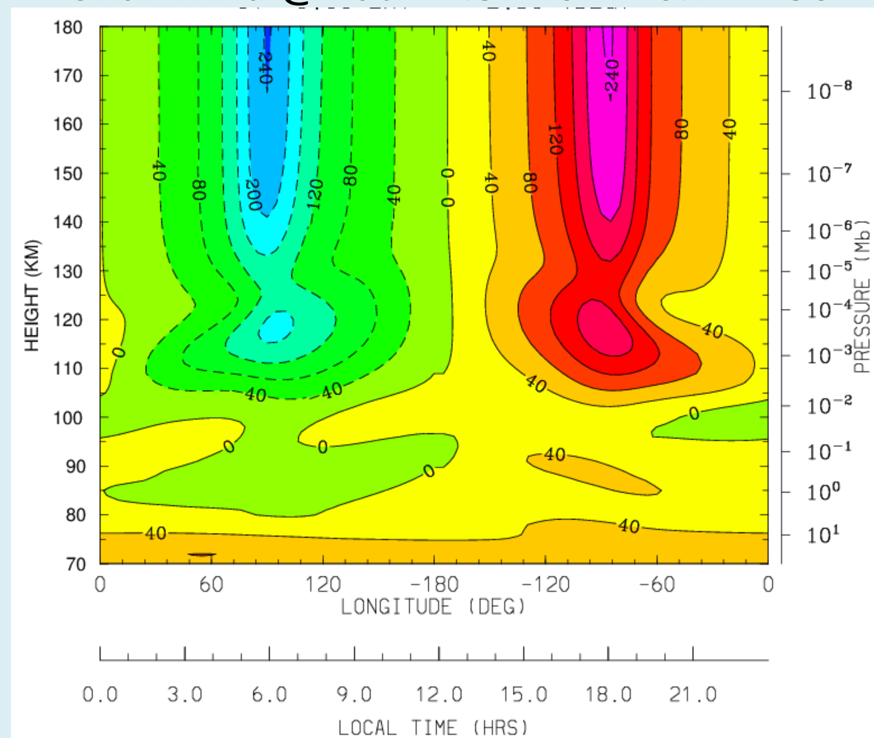
Temperature (K) and Neutral Zonal Winds (m/s)

Temp. @ Lat = 2.5N for F10.7 = 130



Max. = 285 K   Min. = 100 K

Zonal Wind @ Lat = 2.5N for F10.7 = 130

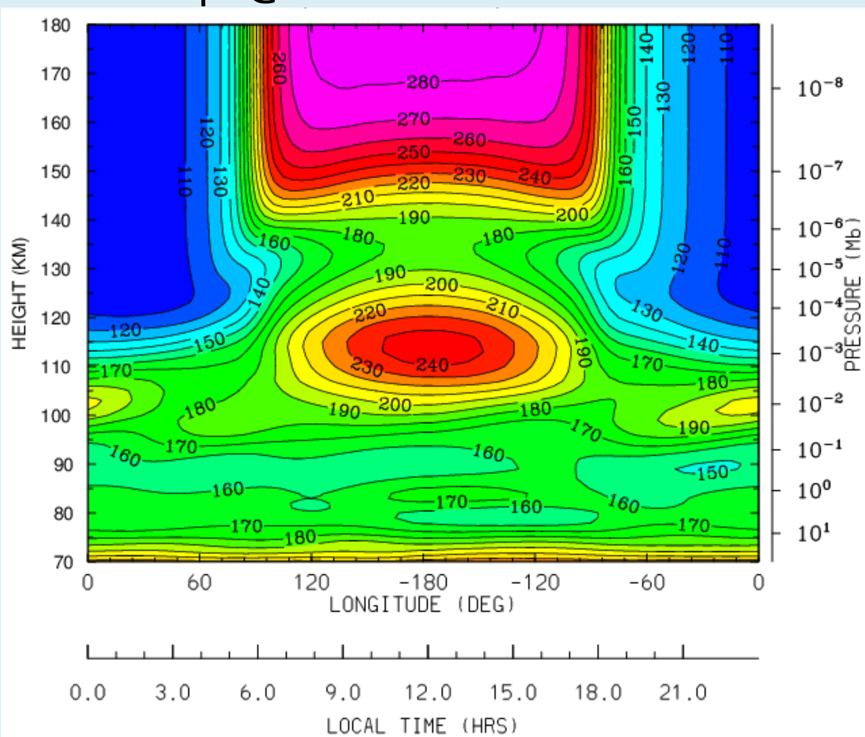


Min. = -244 m/s   Max. = 244 m/s

VTGCM with RF-RSZ:

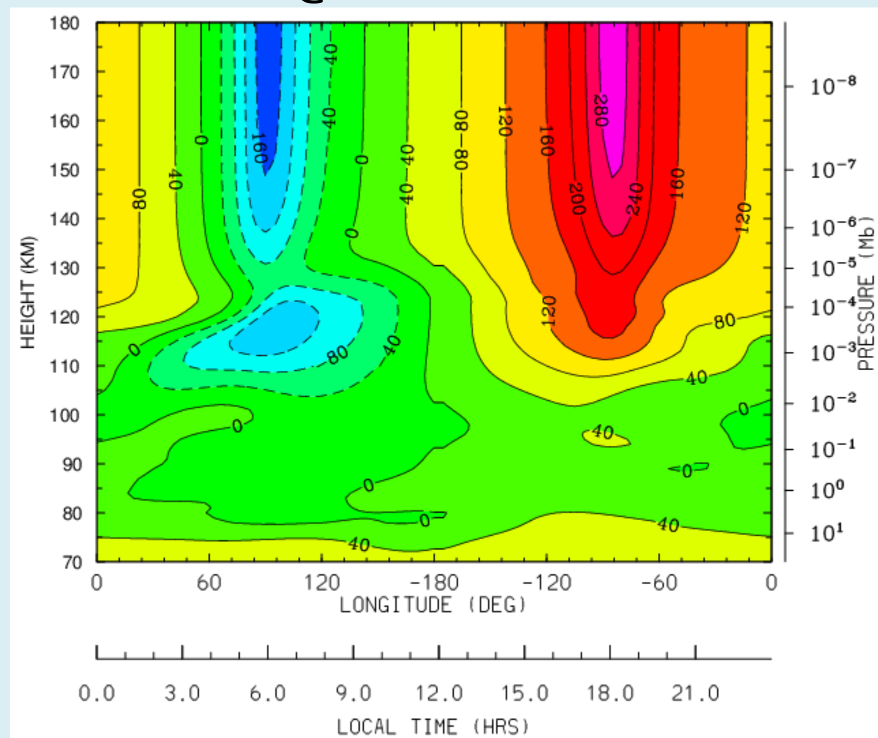
Temperature (K) and Neutral Zonal Winds (m/s)

Temp. @ Lat = 2.5N for F10.7 = 130



Max. = 286 K Min. = 100 K

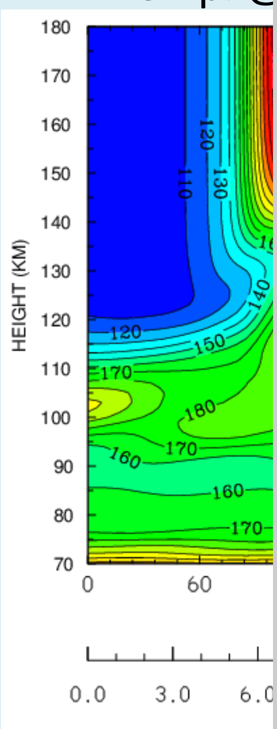
Zonal Wind @ Lat = 2.5N for F10.7 = 130

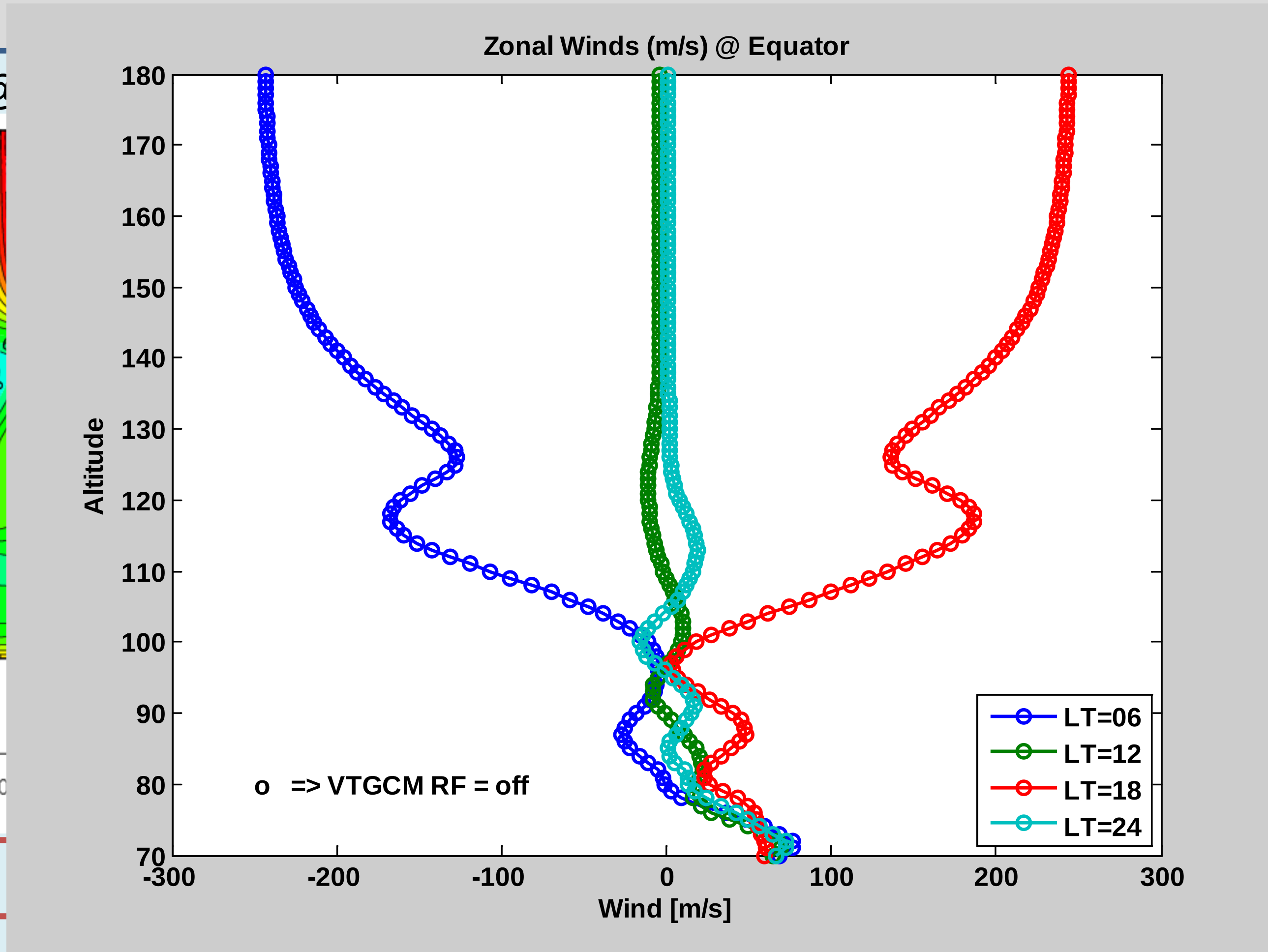


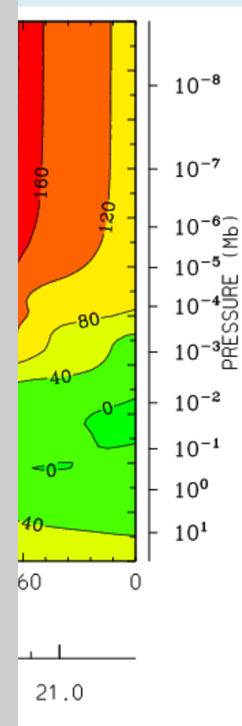
Min. = -179 m/s Max. = 303 m/s

VTGCM with RF-RSZ:
Temperature (K) and Neutral Zonal Winds (m/s)

Temp. @ … 10.7 = 130





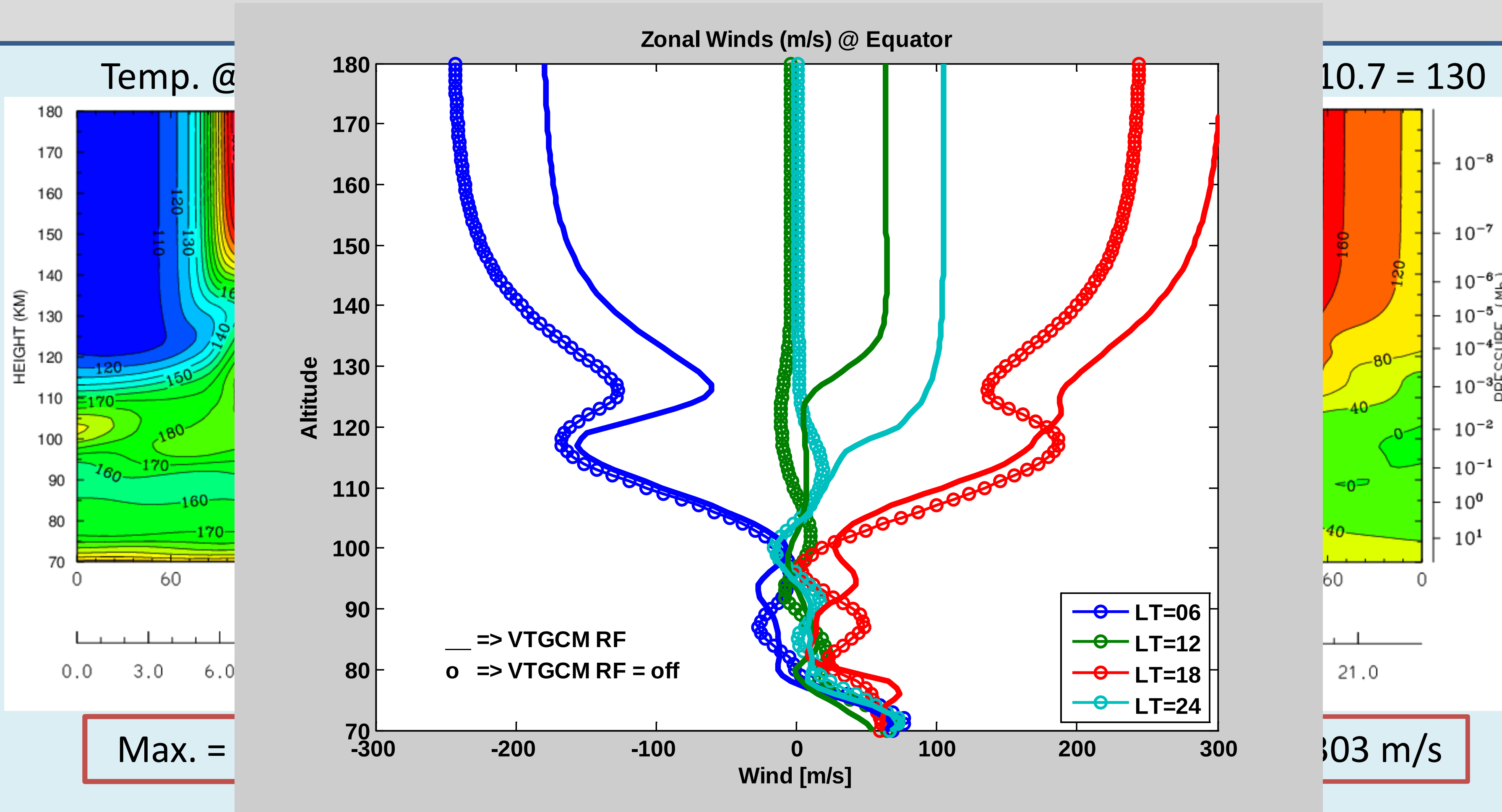


Max. = … 303 m/s

VTGCM with RF-RSZ:

Temperature (K) and Neutral Zonal Winds (m/s)

Temp. @ … 10.7 = 130



Max. = … 303 m/s

Past VTGCM GW Work

- **Zhang and Bougher; (JGR) 1996**
  - **Parameterization:** Fritts and Lu (1993)
  - **Results:** GW scheme did provide deceleration of the SSAS winds and produced variability in the O_2 IR nightglow emission.

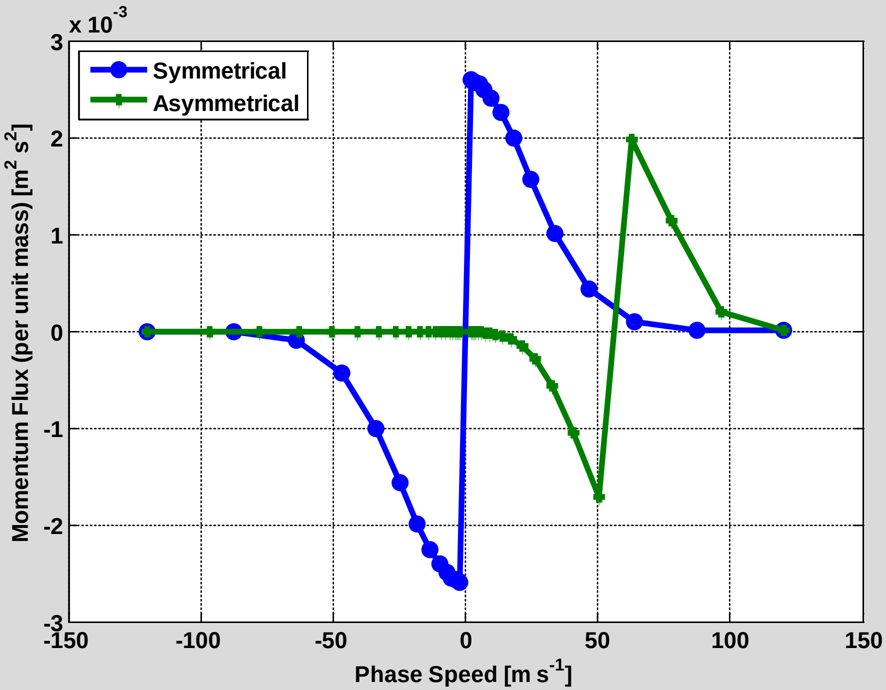
- **Zalucha, Brecht, Rafkin, Bougher, and Alexander; (JGR: Planets) 2013**
  - **Parameterization :** Alexander and Dunkerton (1999)
  - **Results:** GW were able to modify the winds in the jet flanks, but is peripheral to the main goal of decelerating the winds in the jet core. Due to:
    - (1) waves became unstable leading to breaking in the strong shear zones below ~115 km
    - (2) waves were reflected (due to **total internal reflection**) and did not propagate into the jet core regions in the thermosphere where drag is needed the most.

Current VTGCM GW Work

- **Implementing a different GW parameterization that systematically accounts for the realistic dissipation, including breaking and saturation, for the thermosphere.**
  - **Parameterization:** Yiğit et al., 2008
  - **Description:**
    - Spectral non-linear parameterization.
    - Gauss source spectrum.
    - Accounts for dissipation of vertically propagating GWs due to molecular viscosity, thermal conduction, non-linear breaking/saturation, ion drag (off), radiative damping (off), and eddy viscosity (off).
    - Waves are allowed to be saturated at multiple heights and are not completely removed at a single breaking level.
    - Does NOT account for total internal reflection.
    - Currently only connected to the momentum equation (energy equation connection is future work).

Wave Characteristics

Parameter	Value
Horizontal wavelength [km]	100, 300, 400, 500
Max momentum flux (per unit mass) [$m^2 s^{-2}$]	2E-5, 2E-4, 1E-3, 1.5E-3, 2.6E-3, 3E-3
Max Phase Speed (@ cloud top) [m/s]	60, 80, 85, 90 ,100, 120
Number of harmonics	28, 38, 40, 50, 60
Half-width of the Gaussian momentum flux distribution [m s^{-1}]	24, 35, 40, 50, 60, 70



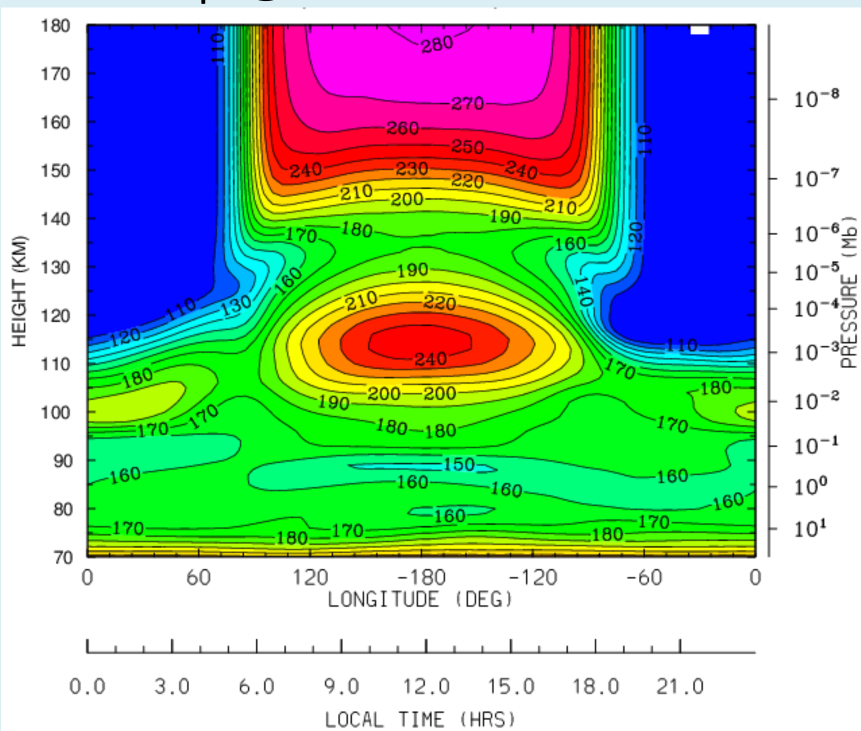
Momentum flux spectrum at the source level (~70 km).

= Values for symmetric blue cure

VTGCM with GW:

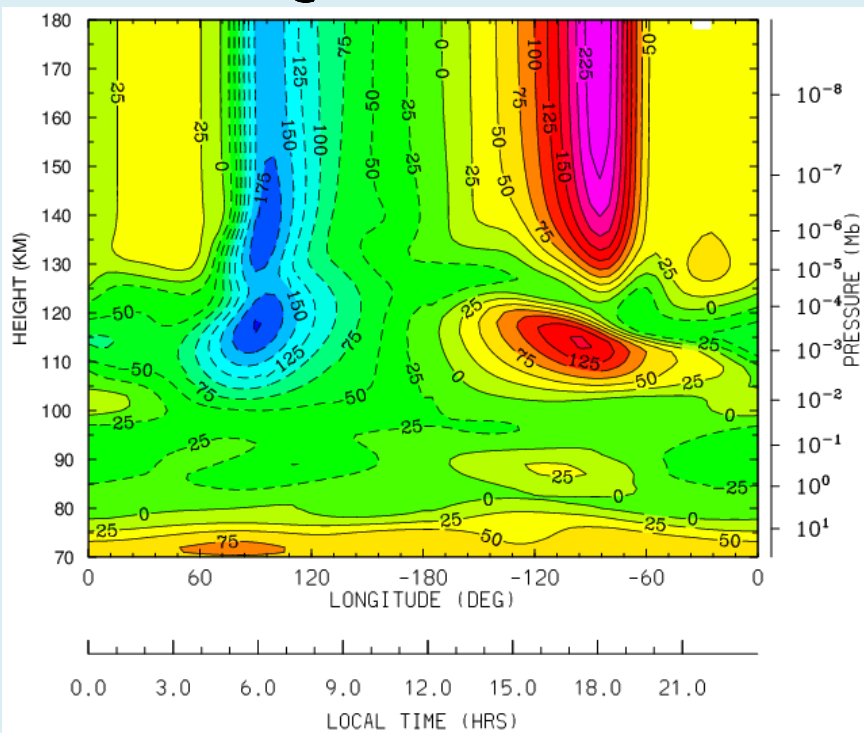
Temperature (K) and Neutral Zonal Winds (m/s)

Temp. @ Lat = 2.5N for F10.7 = 130



Max. = 281 K Min. = 100 K

Zonal Wind @ Lat = 2.5N for F10.7 = 130

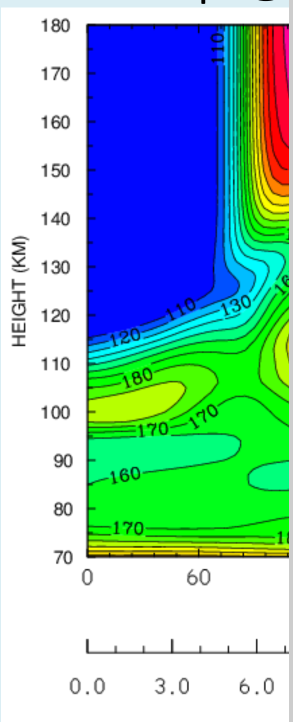


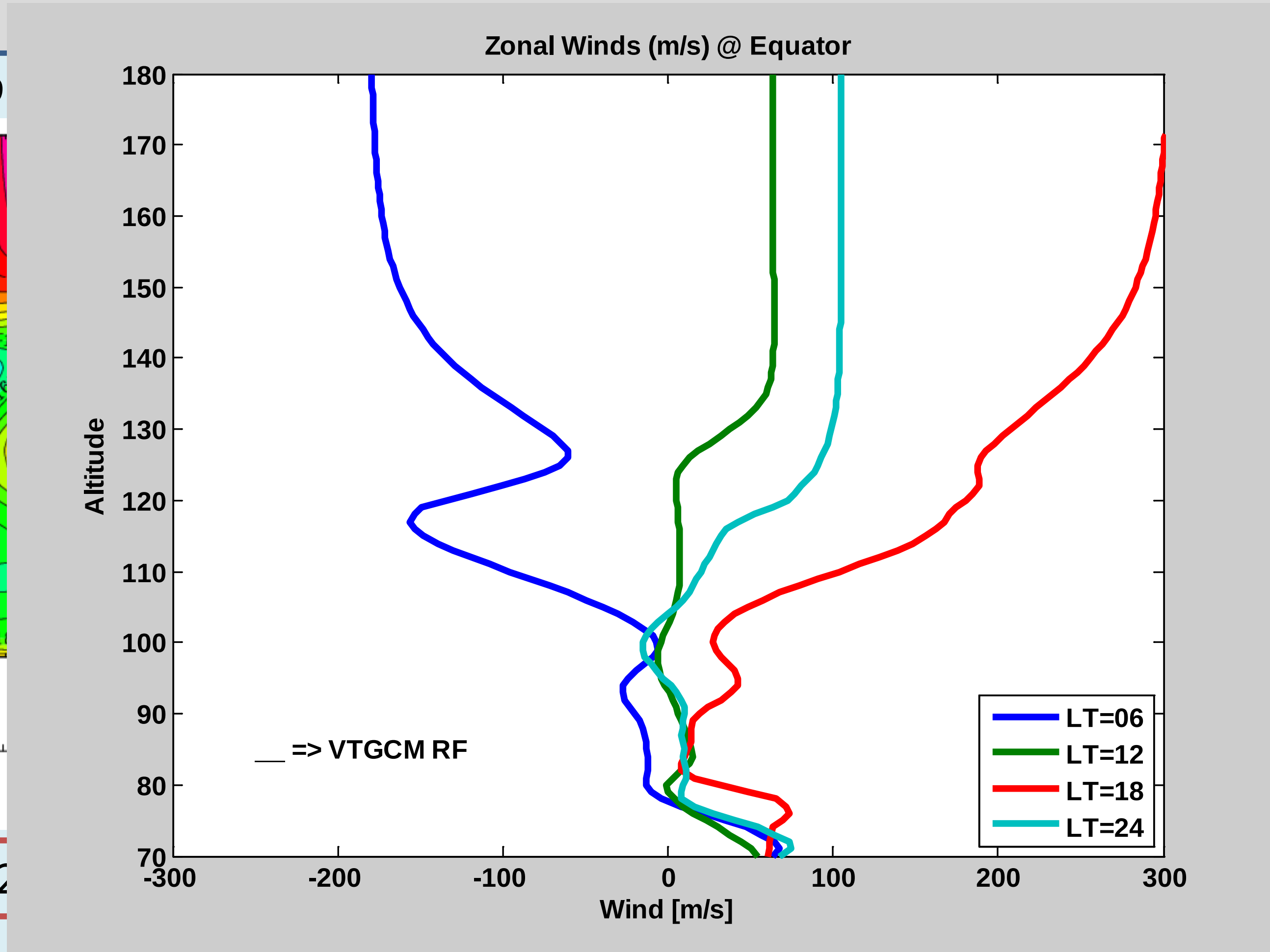
Min. = -202 m/s Max. = 248 m/s

VTGCM with GW:

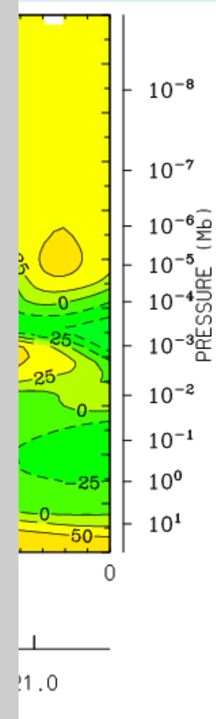
Temperature (K) and Neutral Zonal Winds (m/s)

Temp. @





0.7 = 130

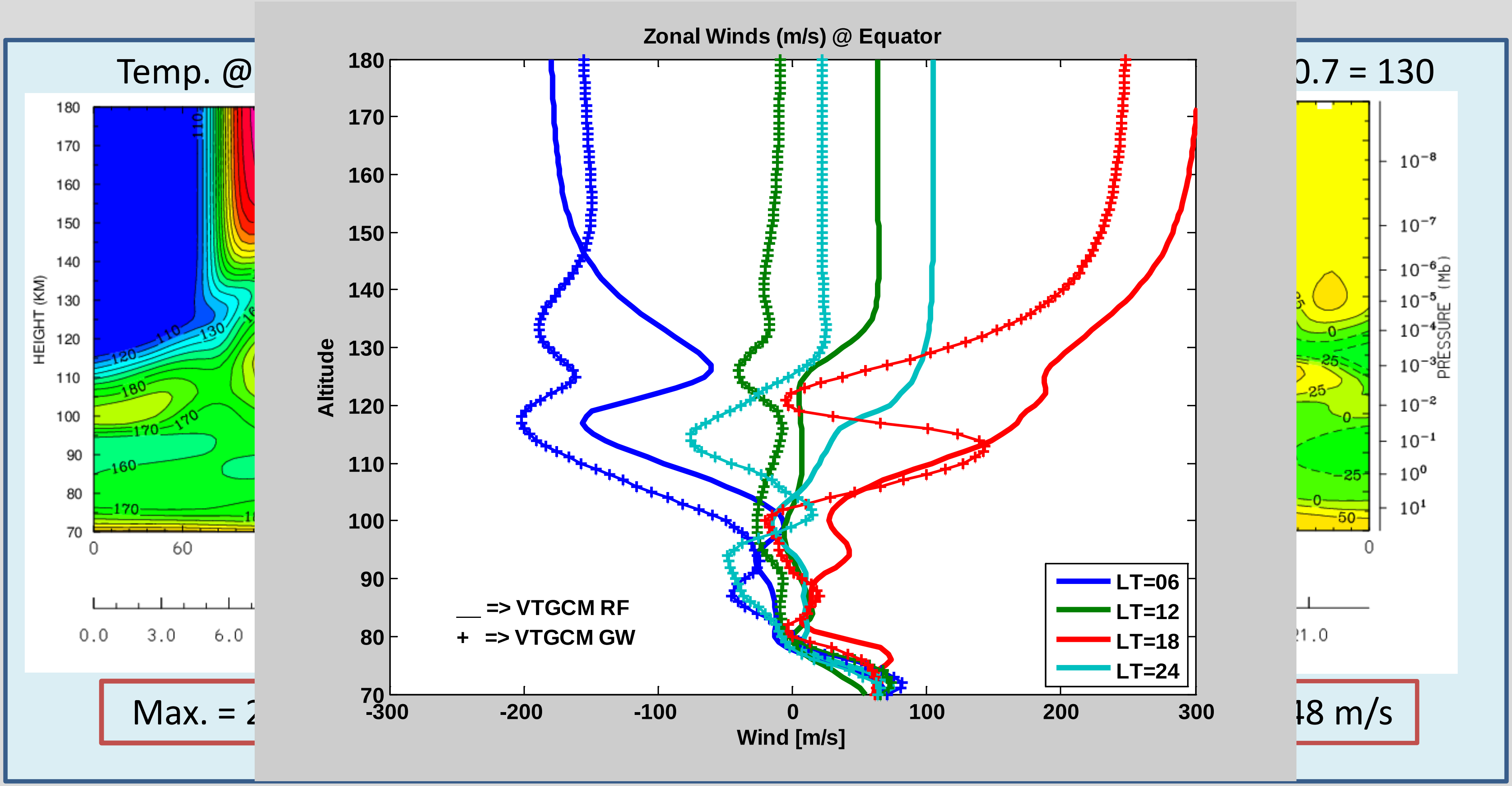


Max. = 2

48 m/s

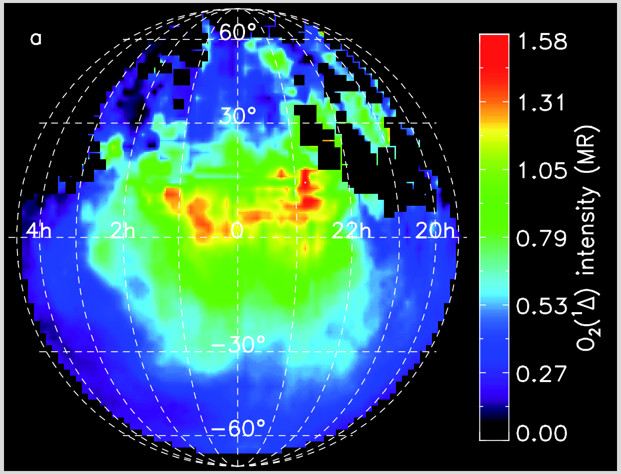
VTGCM with GW:

Temperature (K) and Neutral Zonal Winds (m/s)



O_2 IR Nightglow: Observed vs. VTGCM

•O_2 (IR) nightglow global map of vertical brightness (MR) provided by VEX VIRTIS



Mean Alt. = 97 km

Mean Local Time (LT)= ~ 2400

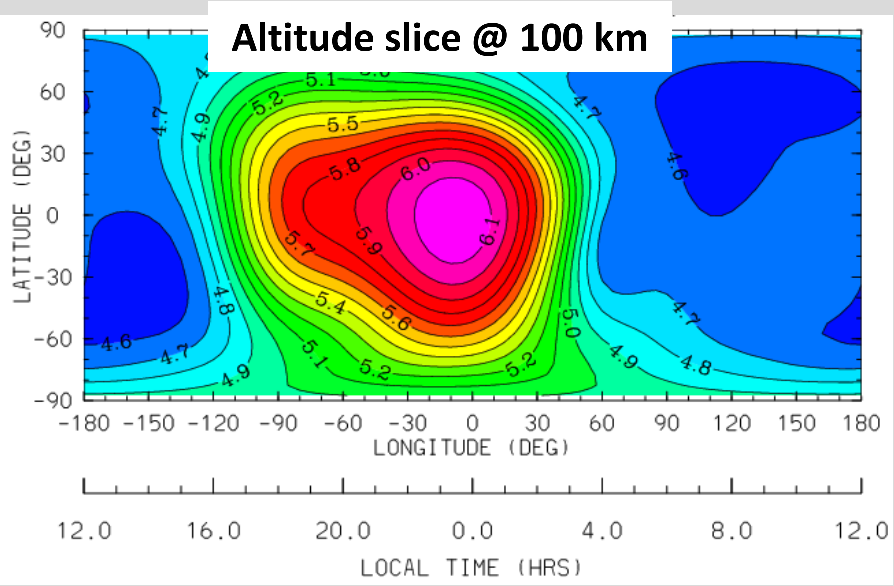
Peak Intensity = 1.6 MR

Hemi. Avg. = 0.5 MR

Mean Latitude = ~0°

(VEX observations; Soret et al. 2012)

MR = Mega Rayleigh = 10^{12} photons cm^{-2} s^{-1} in 4π sr



Peak Alt. = 100 km

Peak LT = 2300

Peak Intensity = 1.19 MR

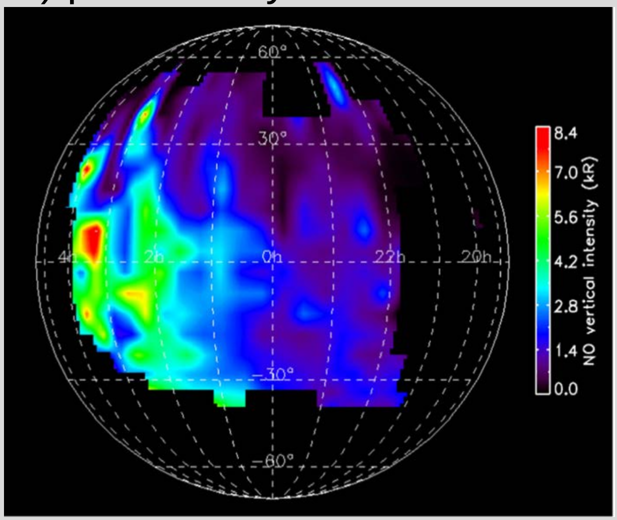
Peak Volume Emission Rate = 1.50x10^6 photons/cm^3/sec

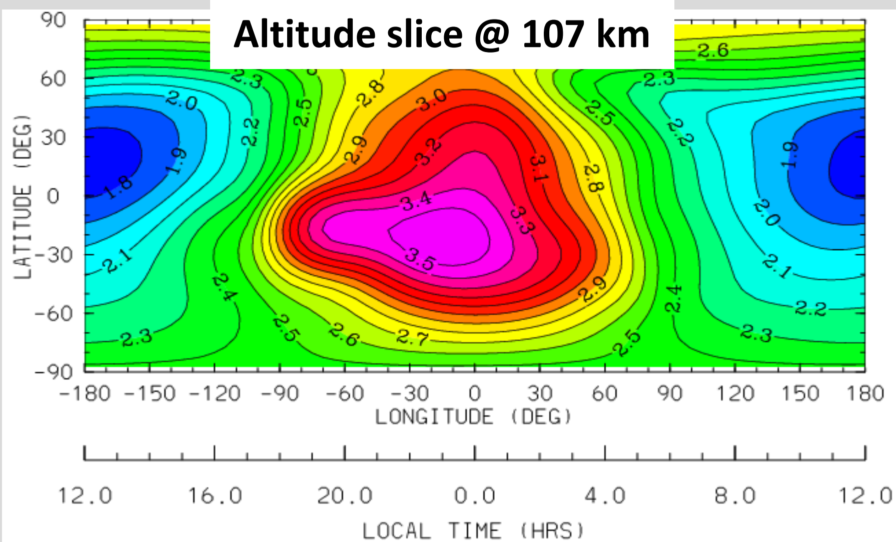
Peak Latitude = ~0°

(VTGCM Simulations)

NO UV Nightglow: Observed vs. VTGCM

- NO UV global vertical brightness map (kR) provided by VEX SPICAV





Mean Alt. = 115.5 ± 7 km

Mean Local Time (LT) = 0200

Peak Intensity = 8.4 kR

Hemi. Avg. Intensity = 1.9 kR

Mean Latitude = ~0°

(VEX observations; Stiepen et al., 2013*)*

Peak Alt. = 107 km

Peak LT = 2300

Peak Intensity = 3.02 kR

Peak VEM = 4.00 x 10^3 photons/cm^3/sec

(VTGCM Simulations)

What we are learning…

- **Yiğit parameterization is producing different results compared to previous GW work.**
  - It is capable of depositing momentum at higher altitudes.
  - However, it is also depositing momentum in the transition region, which slows the ET zonal winds too much (as shown by the nightglow results)
- **Including a "moving" lower boundary** creates more critical layers at the bottom of the model which generates a difficult region for GW to propagate through.
- **Work in progress:** Need to turn on other sections of the parameterization (i.e. eddy viscosity, ion drag, radiative damping)
- There is **not one unique set of parameter values**, but trying to find a collection of parameter values to reasonably reproduce observations.
- **Venus has a very complicated zonal circulation with an upper and lower RSZ!!!**
  - It is unclear if the RSZ has one or two different drivers.
  - Maybe GWs are not the whole story and energetics are a driver too (Ledvina, Brecht, and Bougher work in progress).

Thank You!