Revisiting the "thermospheric spoon" mechanism of the thermosphere and ionosphere semiannual oscillation

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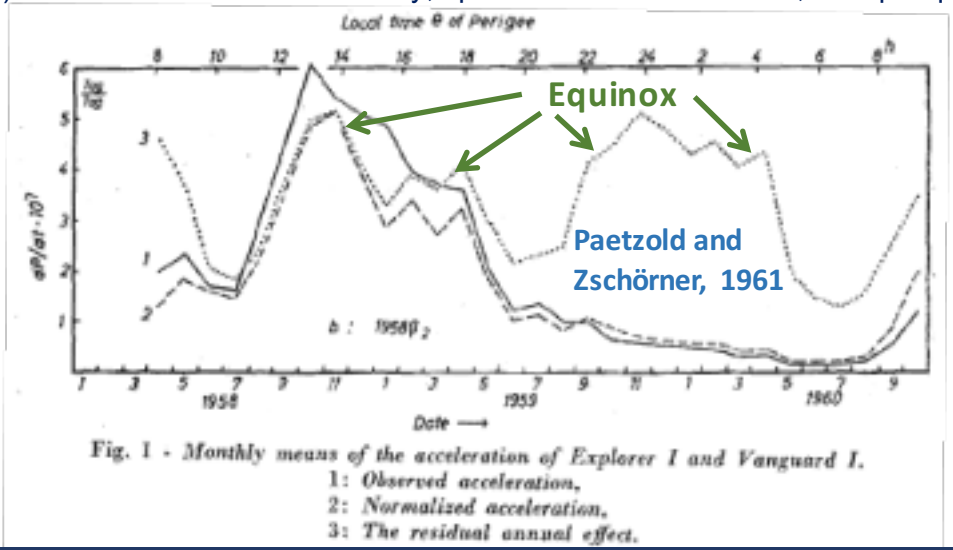
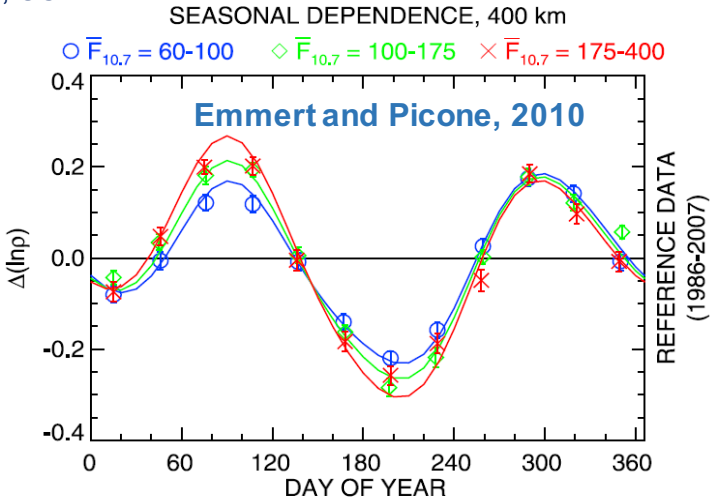


Fig. 1 - *Monthly means of the acceleration of Explorer I and Vanguard I.*
1: *Observed acceleration,*
2: *Normalized acceleration,*
3: *The residual annual effect.*



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Results shown herein are from JGR Space Physics paper:
Origins of the thermosphere-ionosphere semiannual oscillation: Reformulating the "thermospheric spoon" mechanism,
https://doi.org/10.1002/2017JA024861

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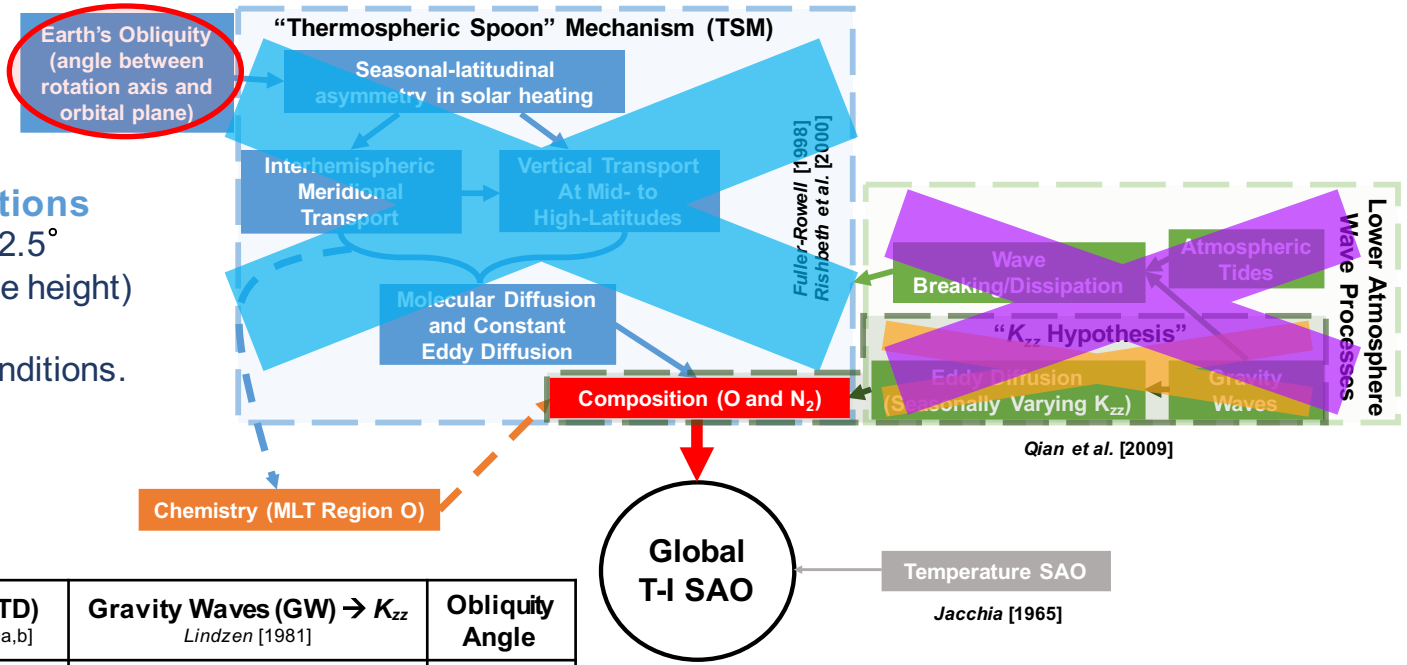
Numerical experiments performed using the NCAR TIME-GCM

NCAR TIME-GCM[1] Simulations

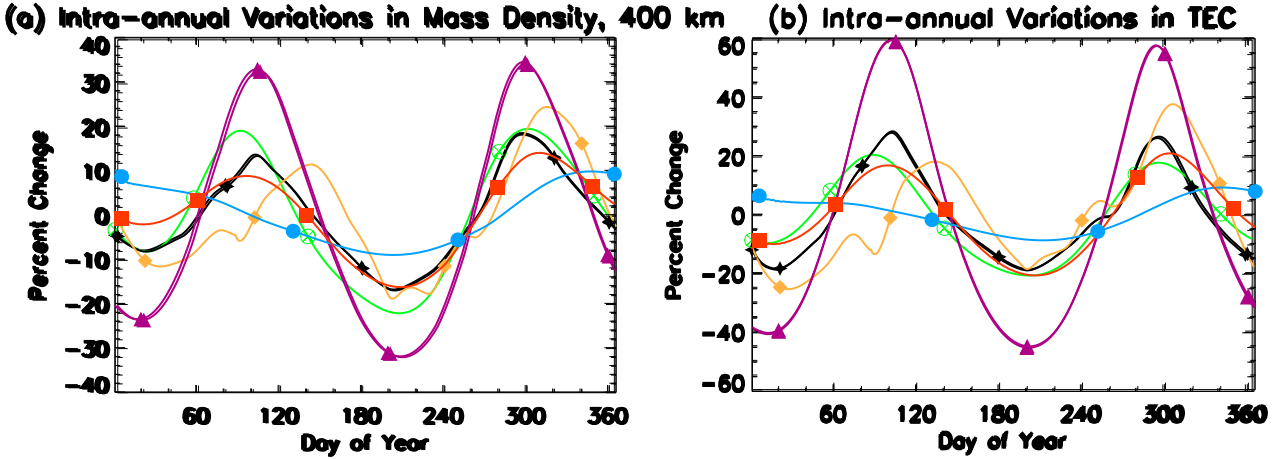
- Double resolution (2.5° x 2.5° lon x lat, 4 points per scale height)
- $F_{10.7}$ = 110 sfu
- Geomagnetically quiet conditions.



TIME-GCM Simulation	Tidal LBCs (TD) *Zhang et al.* [2010a,b]	Gravity Waves (GW) → K_{zz} *Lindzen* [1981]	Obliquity Angle
Standard, Full Tilt	✔	✔	**23.5°**

[1] National Center for Atmospheric Research (NCAR) Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM)

IAVs in Globally Averaged Mass Density and TEC



TIME-GCM Simulation/ Observed Climatology	Mass Density at 400 km		TEC	
	Amplitude (%)	Phase (days)	Amplitude (%)	Phase (days)
Observed Climatology*	15.5	108	15.8	102
Standard, Full Tilt	12.8	114	19.7	106
w/o GW, Full Tilt	15.3	131	21.3	123
w/o GW+TD, Full Tilt	29.4	113	47.9	106
w/o GW+TD, Half Tilt	9.5	116	16.2	111
w/o GW+TD, No Tilt	1.5	142	2.4	133

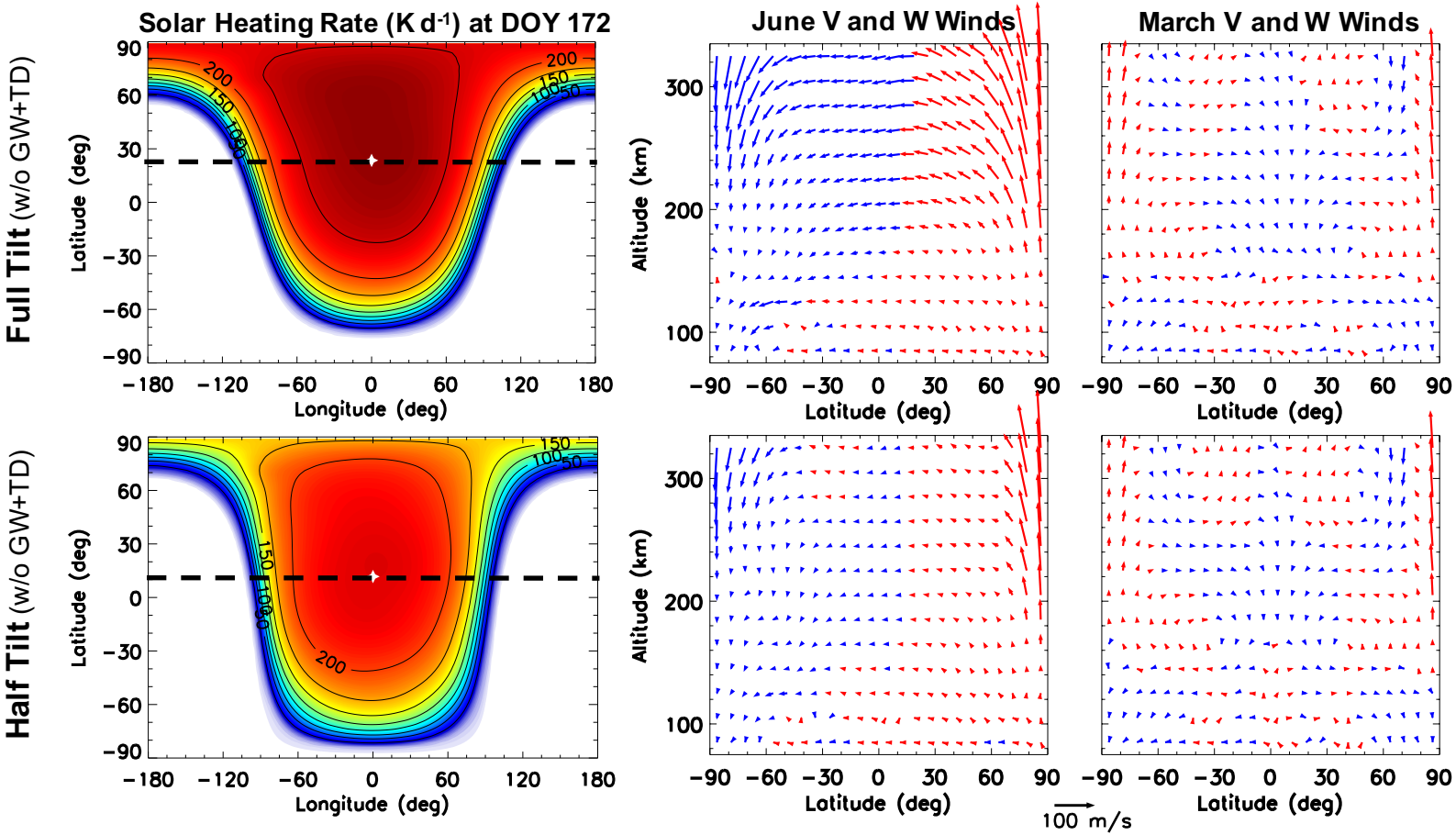
*from *Emmert et al.* [2015,2017]

No GWs →
K_{zz} is seasonally-invariant →
T-I SAO is still present

No Waves but Half Tilt →
TSM weaker →
T-I SAO weaker

No Waves and Tilt →
No TSM →
Very Small T-I SAO

Earth's obliquity drives strong interhemispheric flows at solstice



In summary:

Stronger temp/press. gradients →

Stronger interhemispheric transport (or TSM) →

stronger T-I SAO

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Seasonal Variations in the Vertical Transport of O and N_2

Thermospheric Spoon Mechanism (steady-state balance)
advective transport ≈ molecular diffusion

Individual Species Continuity Equation (*Liu*, 2013)

$$\rho \frac{\partial}{\partial t}\left(\frac{\rho_i}{\rho}\right) = -\nabla \cdot (\rho_i \overrightarrow{V_{D_i}}) + P_i - L_i - \rho \overrightarrow{V} \cdot \nabla\left(\frac{\rho_i}{\rho}\right)$$

~~Molecular Diffusion~~
~~Eddy Diffusion~~
→ K_{zz} is seasonally-invariant

~~Chemistry~~
→ Comparatively Slow (above 100 km)

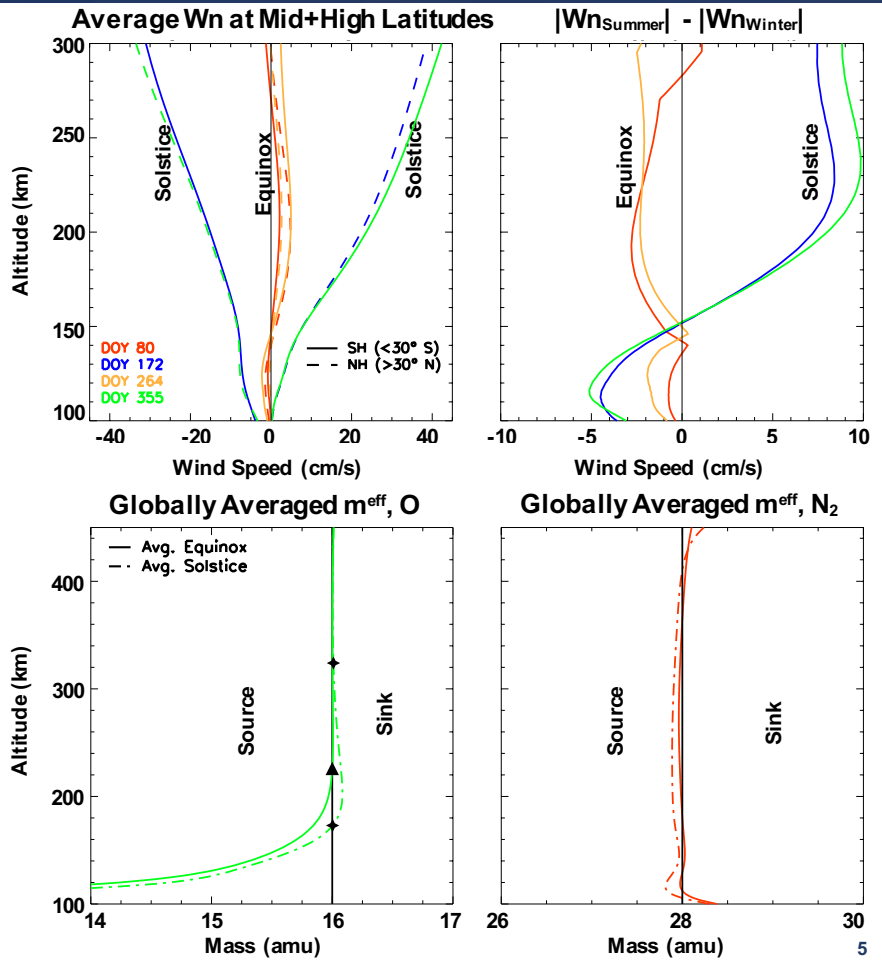
Advection

- Stronger vertical winds at solstice
- Net vertical motion at solstice:
  sink of O, source of N_2 ⟶ T-I SAO

Effective Mass measures departures from diffusive equilibrium

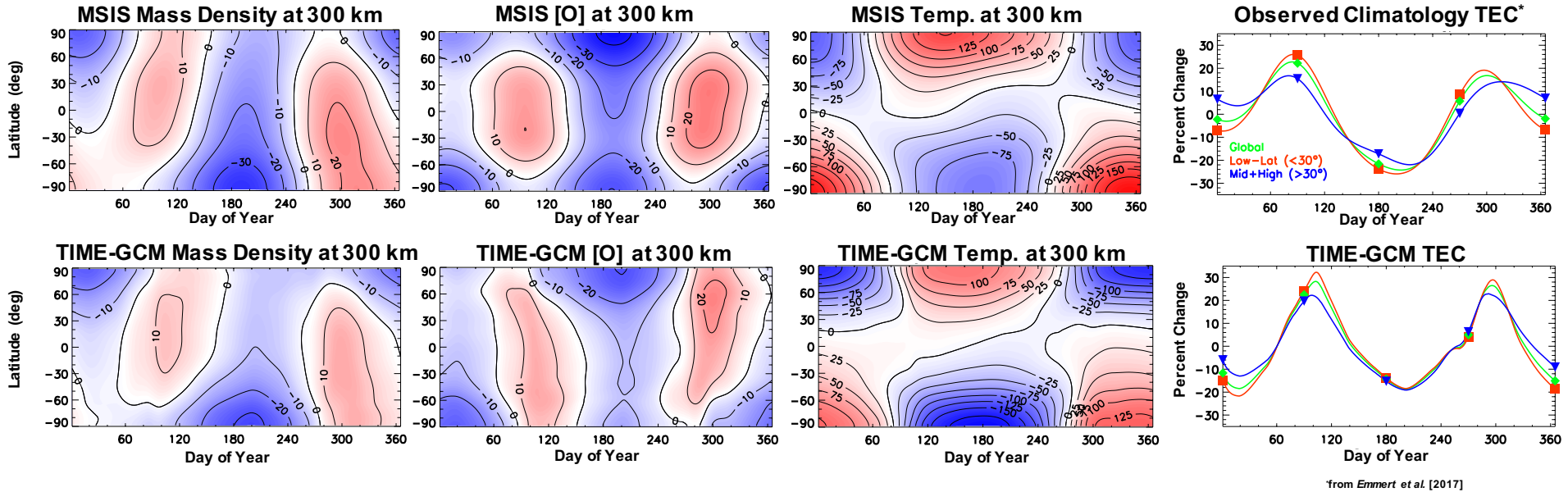
Equinox
- Source of O extends higher

Solstice
- Clear O sink between ~170 and 300 km
- Larger source of N_2 (relative to equinox)



Validating spatial patterns of IAVs from the "standard" TIME-GCM

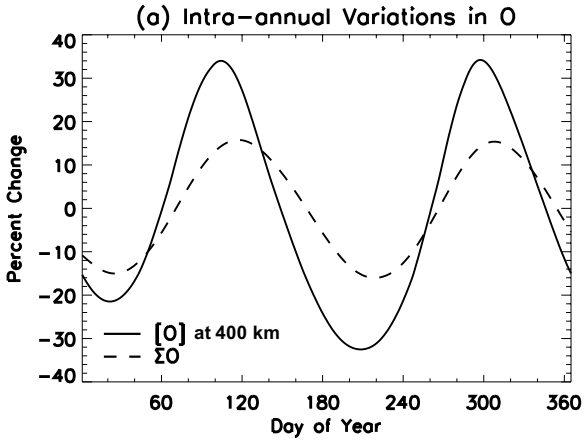
IAVs simulated in the T-I from the "standard" TIME-GCM compare well with NRLMSISE-00 and *Emmert et al.* [2017]

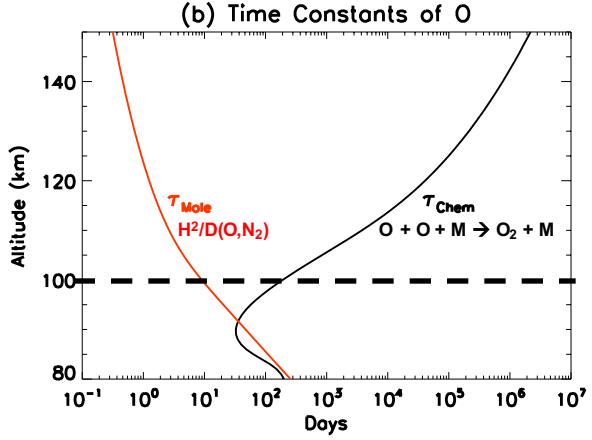


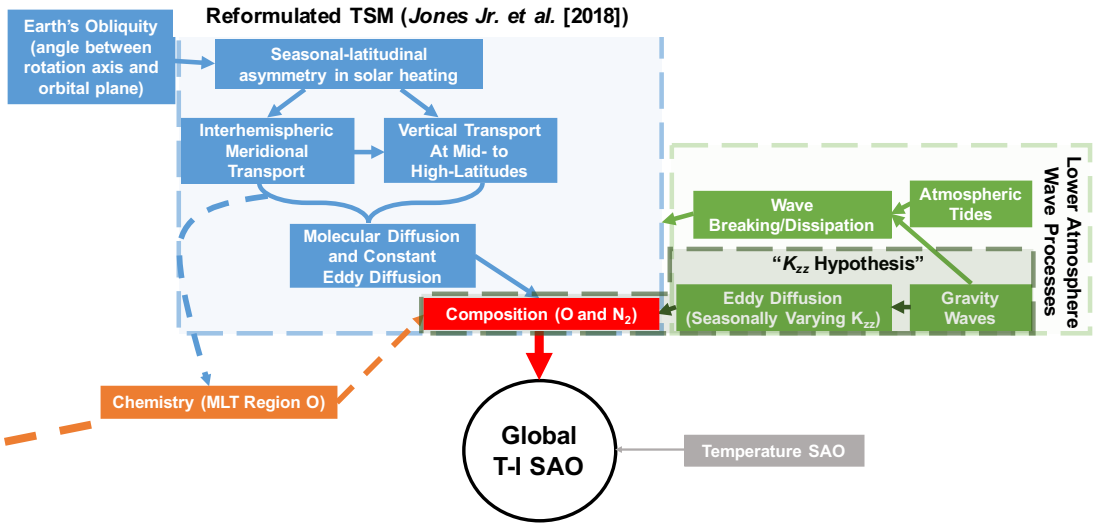
*from *Emmert et al.* [2017]

Phases of IAVs in mass density and [O] are approx. constant with latitude and altitude above 200 km in the TIME-GCM

Chemical Effects on the Global T-I SAO



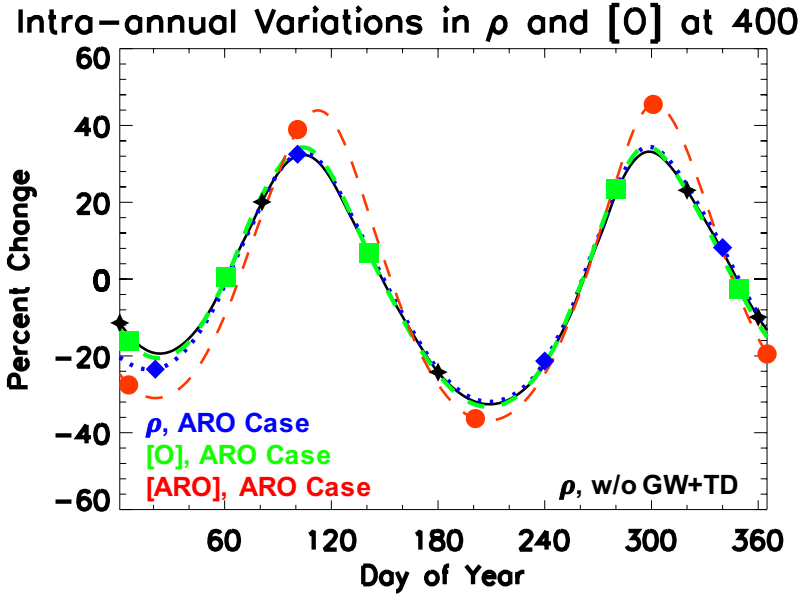




IAVs in ∑O are not flat throughout the year → chemistry contributing to T-I SAO

O chemical life times shorter than molecular diffusion in MLT → Chemistry in MLT as important as dynamics

Preliminary results: Mesospheric O chemistry damps T-I SAO



w/o GW+TD Full Tilt, **ARO Case**

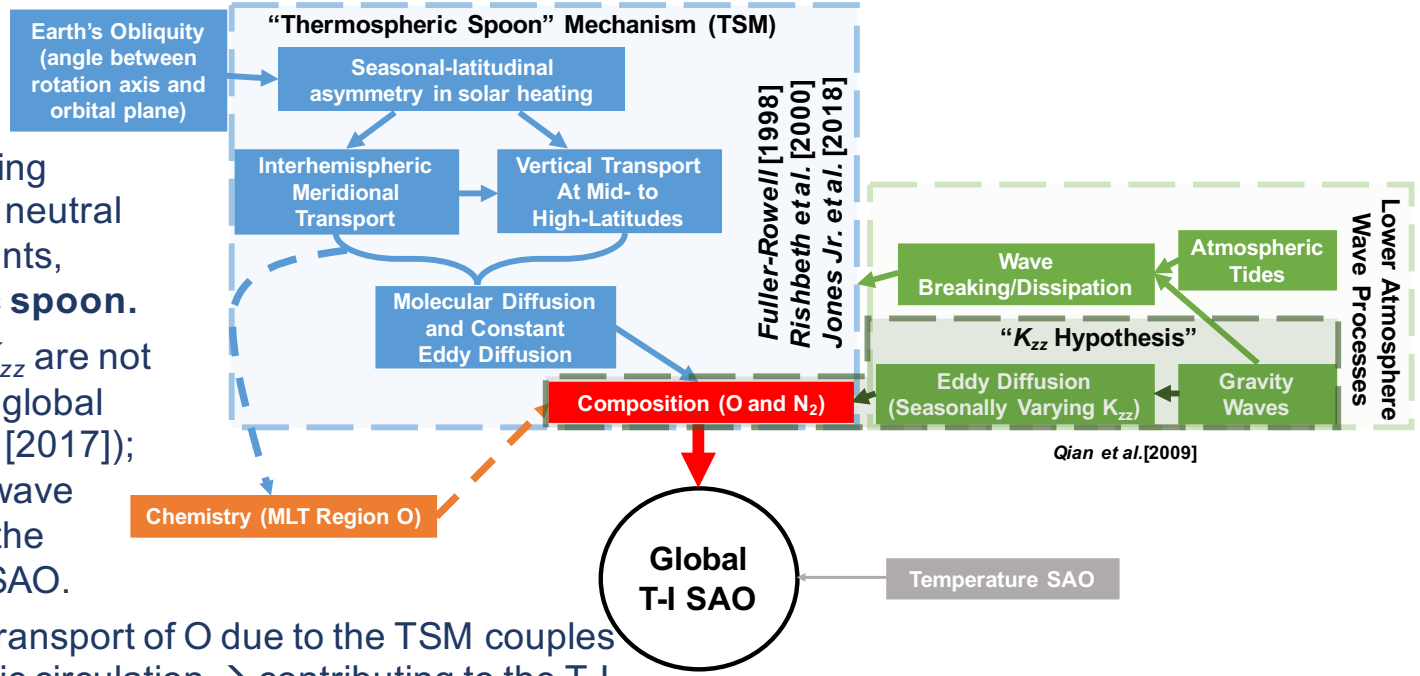
- Ar is co-opted to behave like O (e.g., same mass and diffusion)
- ARO acts like a O, but as a minor species

SAO amplitude also reduced in TIME-GCM Standard Case

	Mass Density at 400 km		[O]		[ARO]	
TIME-GCM Simulation	Amplitude (%)	Phase (days)	Amplitude (%)	Phase (days)	Amplitude (%)	Phase (days)
w/o GW+TD Full Tilt	29.4	113	30.4	112	-	-
w/o GW+TD Full Tilt, ARO Case	28.1	113	29.3	112	38.0	115

Summary

- Earth's obliquity drives the global T-I SAO through seasonally varying large-scale advection of neutral thermospheric constituents, **i.e., the thermospheric spoon.**
- Seasonal variations in K_{zz} are not the primary driver of the global T-I SAO (*Jones Jr. et al.* [2017]); rather, tidal and gravity wave dissipation act to damp the obliquity-generated T-I SAO.
- Meridional and vertical transport of O due to the TSM couples to the upper mesospheric circulation → contributing to the T-I SAO through O chemistry.



Future Work

- Quantify the relative contributions of dynamics (or the TSM) and MLT O chemistry to the global T-I SAO in upper thermospheric mass and electron density.
- Determine the dominant driver of the annual oscillation (AO) in thermospheric mass density and ionospheric electron density.

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THANK YOU!!!

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