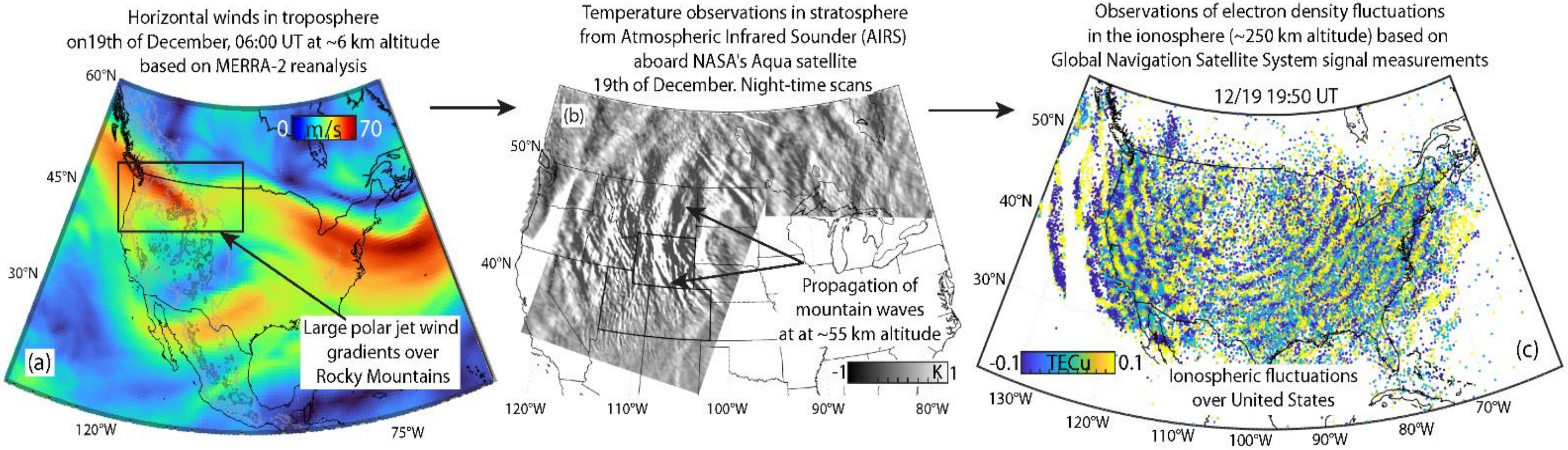
Grand Challenge Report: Impact of Terrestrial Weather on the Space Weather of the Ionosphere-Thermosphere-Mesosphere

Inchin et al., 2024JA032485

MERRA-2
troposphere

AIRS
stratosphere

GNSS
ionosphere



The North American winter storm event in December 2022 excited a wide spectrum of acoustic and gravity waves that made their way up to the ionosphere

Conveners: J. Oberheide, S. Debchoudhury, L. Goncharenko, G. Liu, S. McDonald, F. Sassi, J. Zhang, D. Aggarwal, B. Bergsson, M. Jones, Z. Qiao

Advance the understanding of whole atmosphere interconnections between terrestrial and space weather through combined modeling and observations across different spatial and temporal scales

2024

- Established observational and modeling baselines, 16 talks, 90+ attendance

2025

- Advanced cross-scale data/model comparisons,
  progress towards whole-atmosphere data assimilation,
  15 talks, 70+ attendance (on a Friday afternoon!)

2026

- Moving towards physical mechanisms, 18 talks, Tuesday 10-12, 1:30-3:30

Some of the Data/Models from Year 1 (2024)

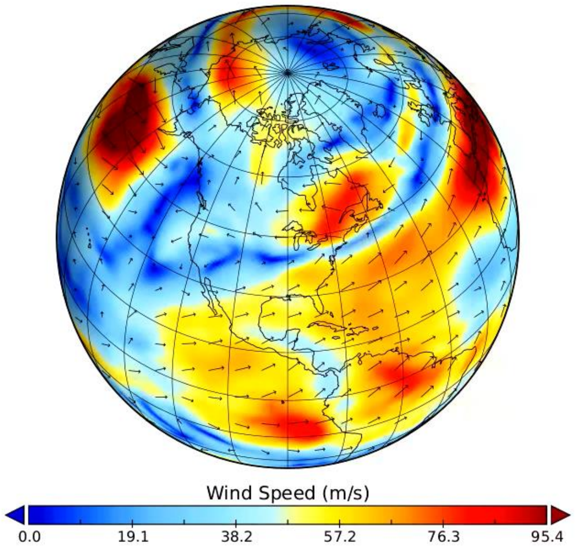
Feature	Parameters	Models	Datasets
Global/Regional Ionosphere	TEC, NmF2 (or fof2), hmF2, NmE (or foE), MUF(3000)F2	SAMI3/WACCM-X WACCM-X TIEGCM Empirical models	Ionosondes ISRs Jason-2/3 GPS receivers GOLD ICON
Global/ Regional Thermosphere	Zonal winds (U), Meridional winds (V), neutral temperature (T), tidal amplitudes, composition, total mass density	WACCM-X TIEGCM WAM-GEOS Empirical models	ICON Meteor radars TIDI SABER GOLD FPIs AWE
Traveling Atmospheric and Ionospheric Disturbances (TADs and TIDs)	periods, wavelengths, speeds, amplitudes, directions of propagation	MAGIC-GEMINI	GNSS TEC, Ionosondes, FPIs, HF/LF, airglow imagers, LIDARs, ISS-based instruments among them
Acoustic shock N-waves in sTEC signals	Time of flight (onset of disturbance), the duration of N-pulse, amplitudes of pulse, Pearson correlation coefficient (r)	MAGIC-GEMINI	sTEC along temporally and spatially varying line-of-sight between a GNSS satellite and a receiver

Subset of the workshop results turned into review article in Surveys in Geophysics:

Oberheide, J., D. Aggarwal, B. Bergsson, S. Chakraborty, S. Debchoudhury, M. Dhadly, F. Gasperini, L. Goncharenko, V. L. Harvey, C. Heale, P. Inchin, J. Li, G. Liu, H.-L. Liu, X. Lu, S. McDonald, M. Neogi, N. Pedatella, F. Sassi, D. Singh, R. Volz, V. Yudin, M. Zettergren, and S.-R. Zhang
Impact of Terrestrial Weather on the Space Weather of the Ionosphere-Thermosphere: Initial Results from a NASA Living With a Star Focused Science Topic
Surveys in Geophysics, 2025
https://doi.org/10.1007/s10712-025-09895-7

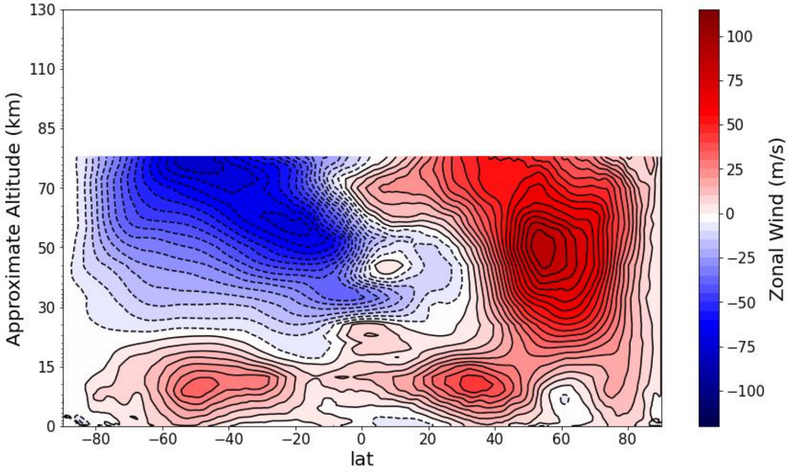
Some of the Data Assimilation Progress from Year 2 (2025)

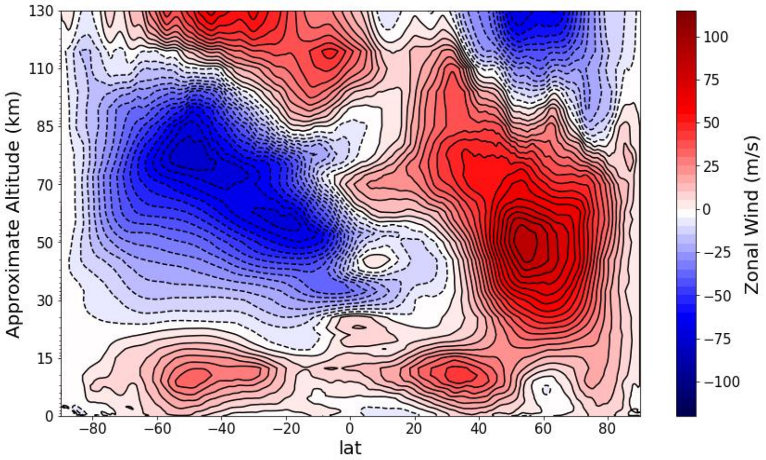
0.0025 hPa



Initial GEOS-MLT results
presented by J. Pettit, F. Sassi and the GEOS-MLT Team

GEOS vs GEOS-MLT in January





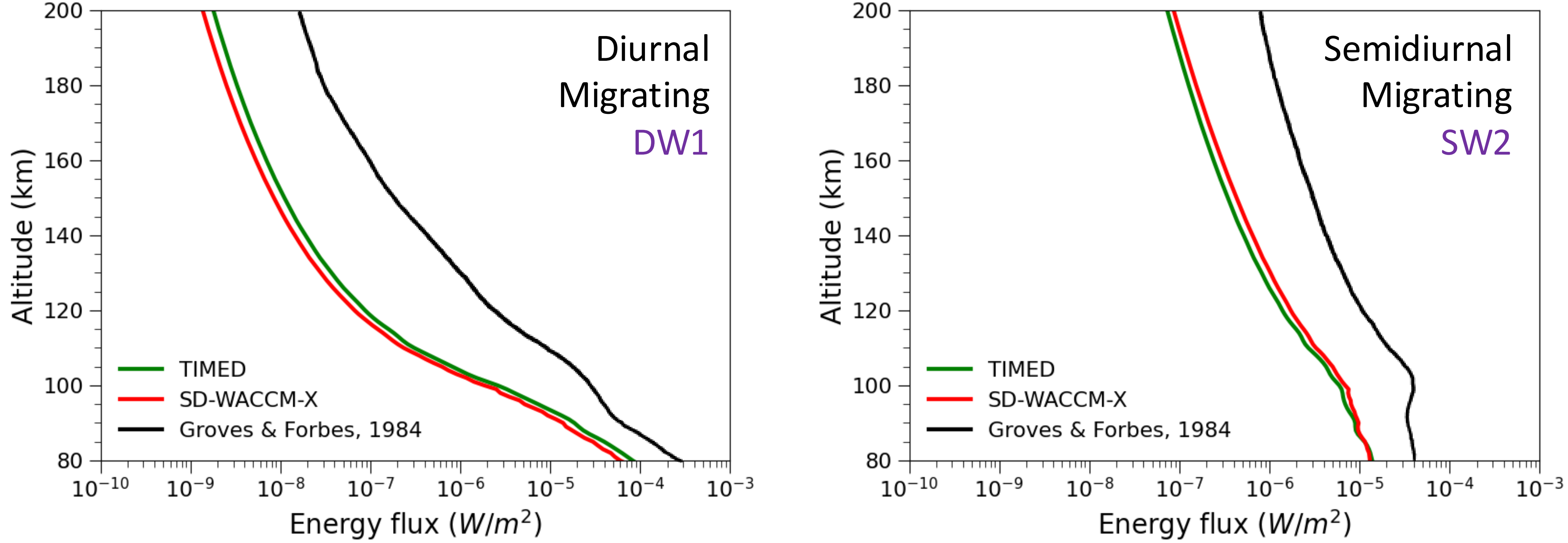
Will get update by F. Sassi
on Tuesday

Some of the Data Assimilation Progress from Year 2 (2025)

Vertical wave energy fluxes due to upward propagating migrating tides

presented by M. Neogi et al., update including GWs and PWs today @ 4 in Xian Lu's session

Global mean - March 2009



TIMED & SD-WACCM-X provide consistent but smaller energy flux values than Groves & Forbes, 1984

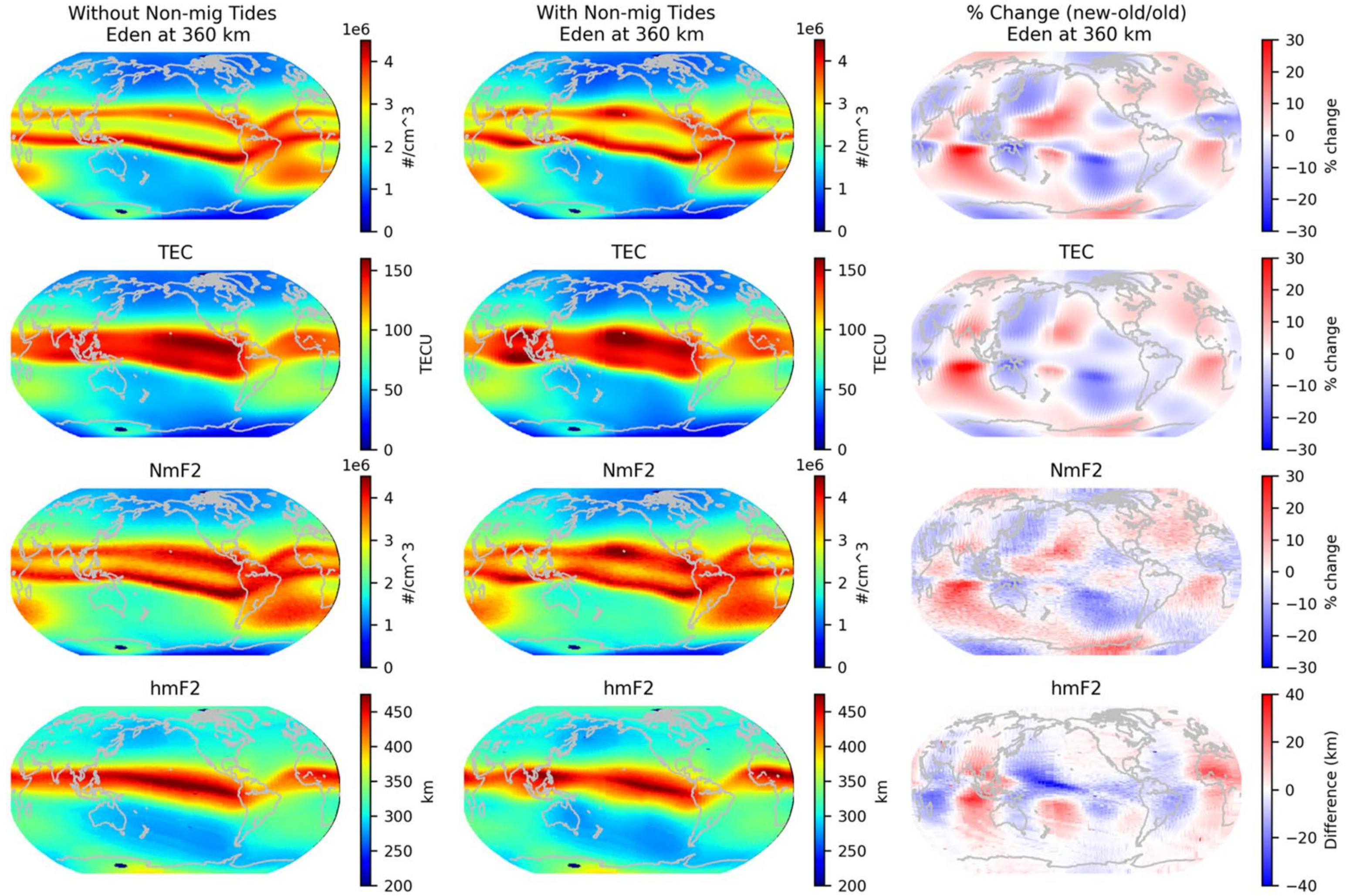
Year 3 (2026)

A few teasers for Tuesday...

Ionosphere With and Without Non-migrating Tides

Day=235 of 2024, LST=15

% change = $\frac{New - old}{old} \times 100$



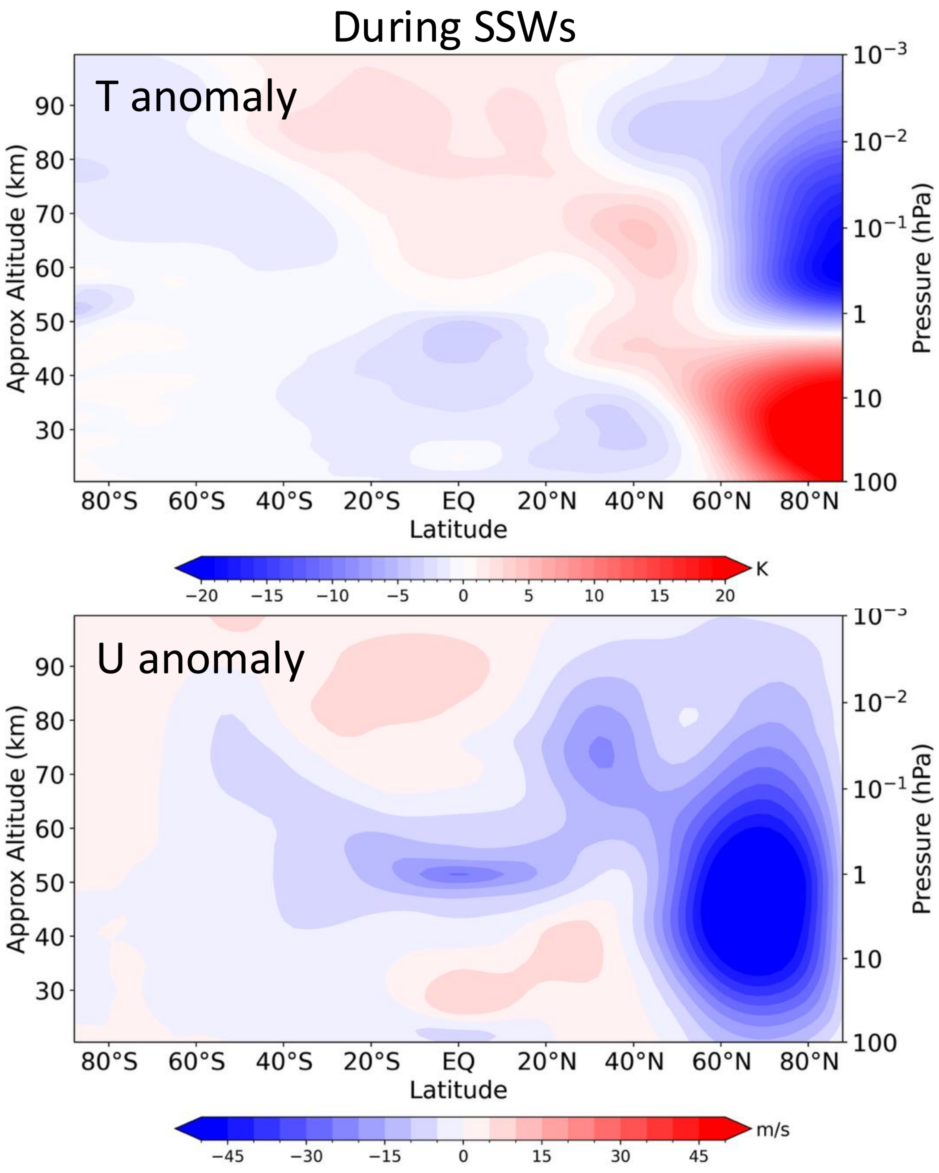
% change shows the contribution of upward propagating non-migrating tides

Courtesy of M. Dhadly

- SAMI3 ionosphere with and without terrestrial generated upward propagating non-migrating tides in MSIS and HWM.
- Figure shown at a fixed LST to illustrate the impact of upward propagating non-migrating tides.
- Distinct wave-like pattern of alternating positive (red) and negative (blue) differences across the globe are visible.
- Large regional variations in electron density and TEC up to ±30%. Major changes around the equator, but impacts extends to polar latitudes.
- hmF2 vary by as much as ±40 km due to upward propagating non-migrating tides.

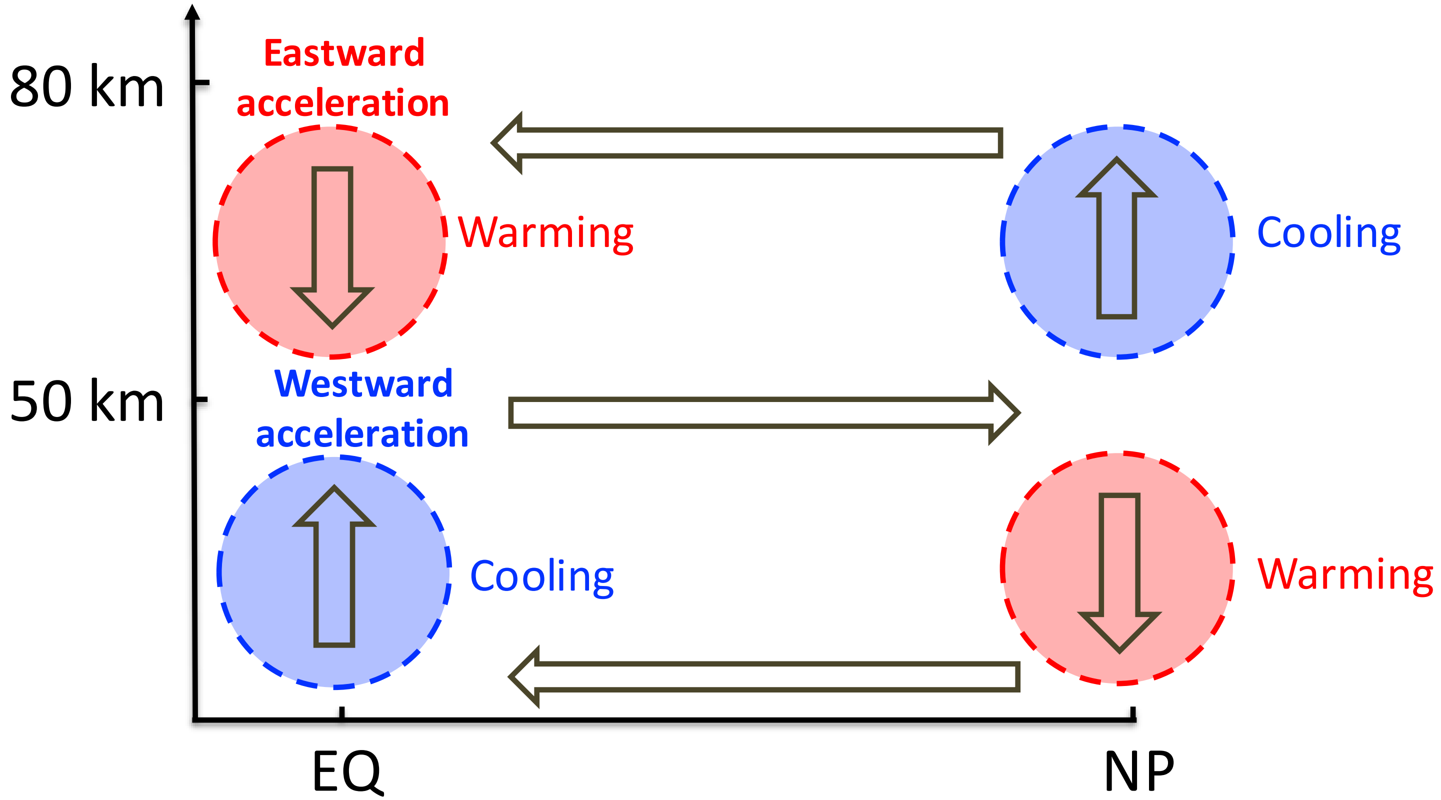
Modulation of the Semi-Annual Oscillation (SAO) by Stratospheric Sudden Warmings (SSWs) as seen in JAWARA

Courtesy of J. Zhang



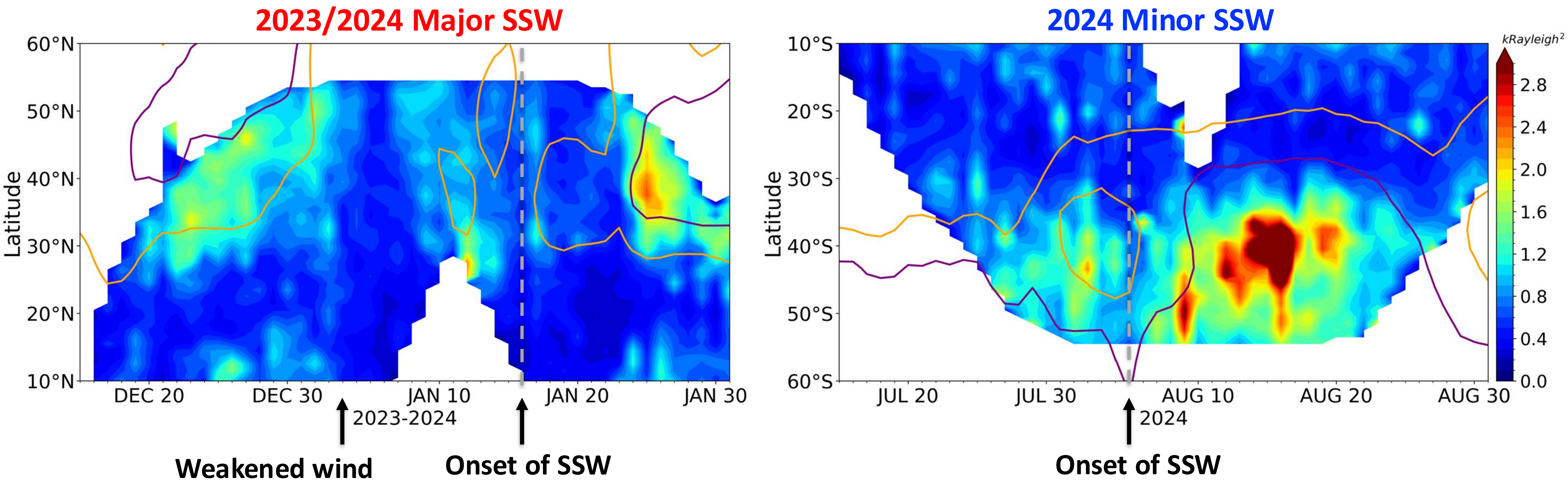
- SSWs modulate the meridional temperature gradient.
- Through thermal wind balance, this results in westward acceleration at 50 km and eastward acceleration at 80 km.

-> SSWs significantly intensify the westward stratospheric SAO and amplify the eastward mesospheric SAO.



Gravity wave (GW) variation during Sudden Stratospheric Warmings (SSWs) observed by AWE

Courtesy of B. Martinez



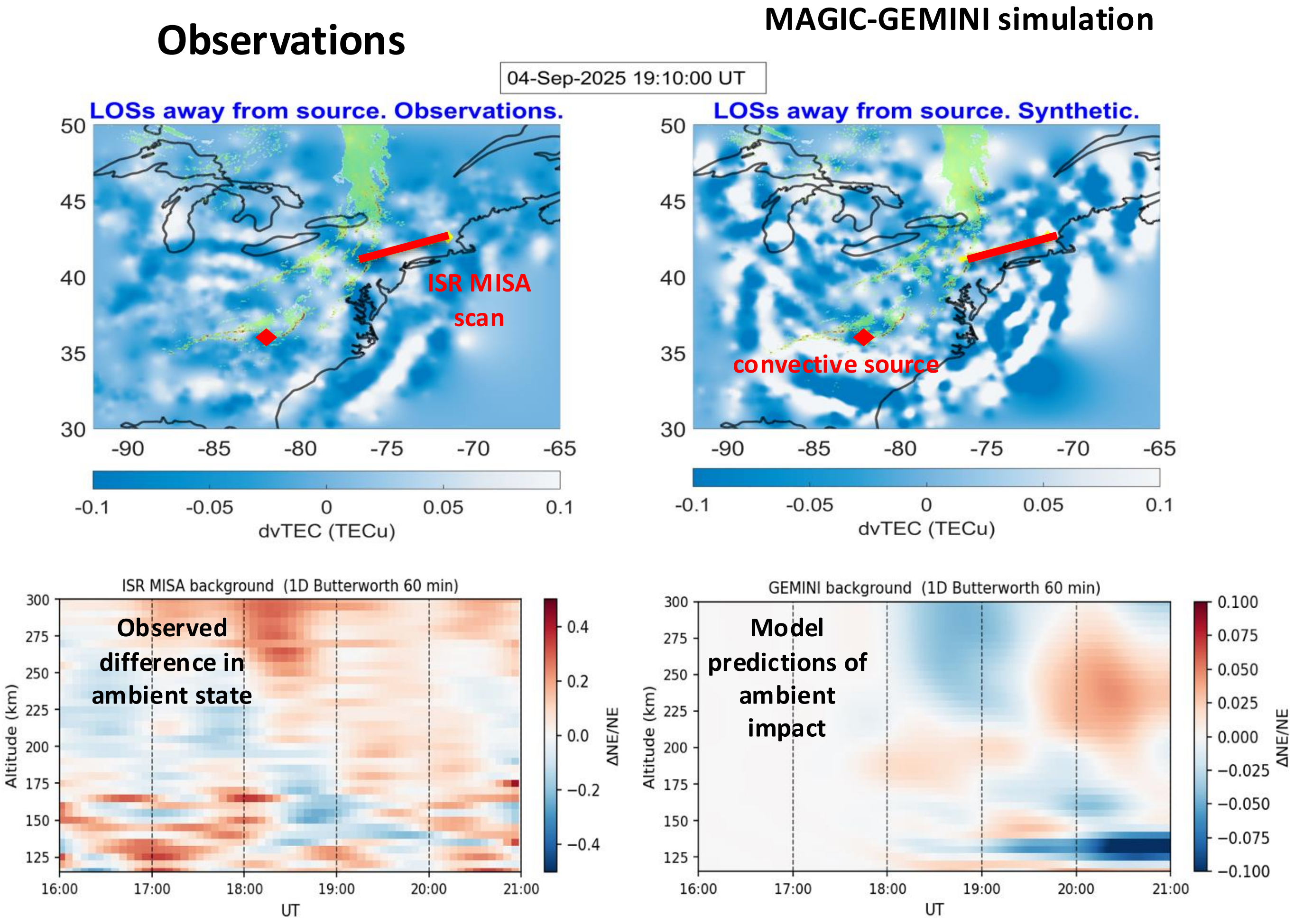
Line contours are zonal-mean MERRA-2 wind speed values of 30 m/s (orange) and 50 m/s (purple) at 50 km.
Shaded contours are AWE radiance variance, which indicates the strength of GW activity.

- AWE observed weakened GW activity at 87 km in the Northern Hemisphere and Southern Hemisphere following the onsets of SSW.

AGWs impact on ionosphere: Campaign with Millstone Hill ISR

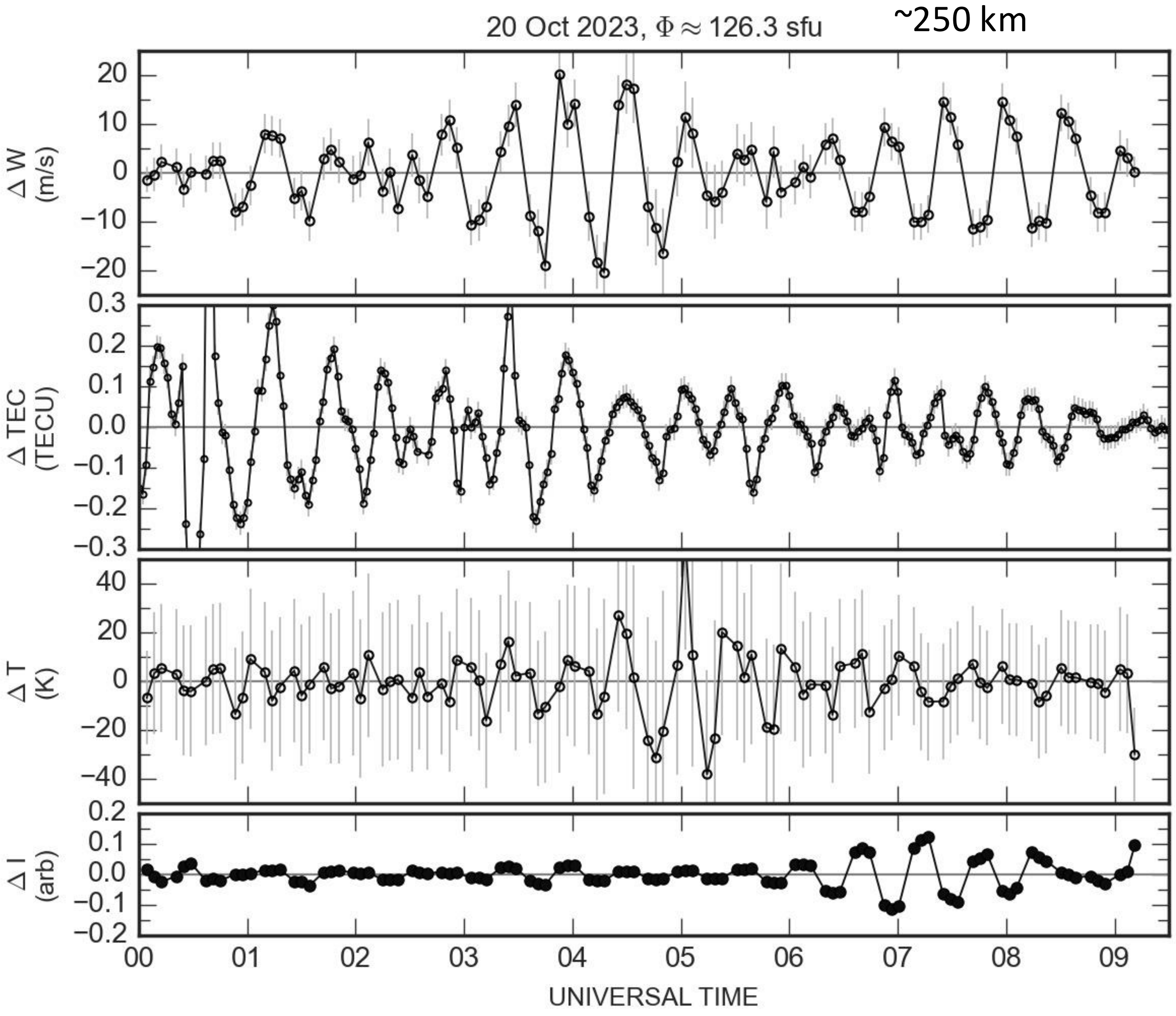
- A Millstone-Hill ISR campaign was conducted from Sep 2-5, 2025, to investigate the impact of acoustic gravity wave (AGW) propagation on ionospheric ambient states (*Inchin et al. 2025*), that recorded a convection event on Sep 4.

- MAGIC-GEMINI simulation predicts stronger amplitudes (~2x) compared to observations. The ambient states were, however, much elevated compared to simualation possibly due to elevated geomagnetic levels.



Courtesy of S. Debchoudhury

due to orographic GWs



Vertical wind oscillations seen in FPI data for Argentina Leoncito FPI

Examination of GNSS data shows significant oscillations in the plasma spatial distribution.

Temperature fluctuations

Results from 630 nm ASI

Courtesy of J. Meriwether

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Tuesday 10 – 12

S. Girijakumary – GWs & IT coupling, AWE, HR-WACCM-X

S.R. Zhang – Long-term GNSS MSTID and WACCM-X

K. Kumari – HR-WACCM-X sims of MSTID during SSW

B. Martinez – AWE GWs during 2024 SH SSW

P. Inchin – Weather generated GWs and MSTID forecasting

D. Aggarwal – Ionospheric tides, dynamo vs field-aligned winds

L. Wilcoxson – Derecho storm effects in IT

J. Meriwether – Vertical winds and TEC from El Leoncito

S. Debchoudhury – Convective AGW-driven TIDs

Tuesday 1:30 – 3:30

J. Zhang – SSW modulation of SAO in JAWARA (zoom)

H.L. Liu – Hurricane Helene in AWE, GNSS, WACCM-X, JAWARA and NAVGEM

B. Pineyro – Nonlin. Evolution & dissipation of conv. GWs

M. Dhadly – New MSIS and HWM with nonmig. tides

F. Sassi – GEOS-MLT development

E. Villalba – Constraining neutral wave perturbations from TEC signatures

G. Liu – GEOS-FP and concentric waves

S. Kumar – NH & SH vortex impacts on ITM

L. Goncharenko – Ion. pert. linked to the vortex strength