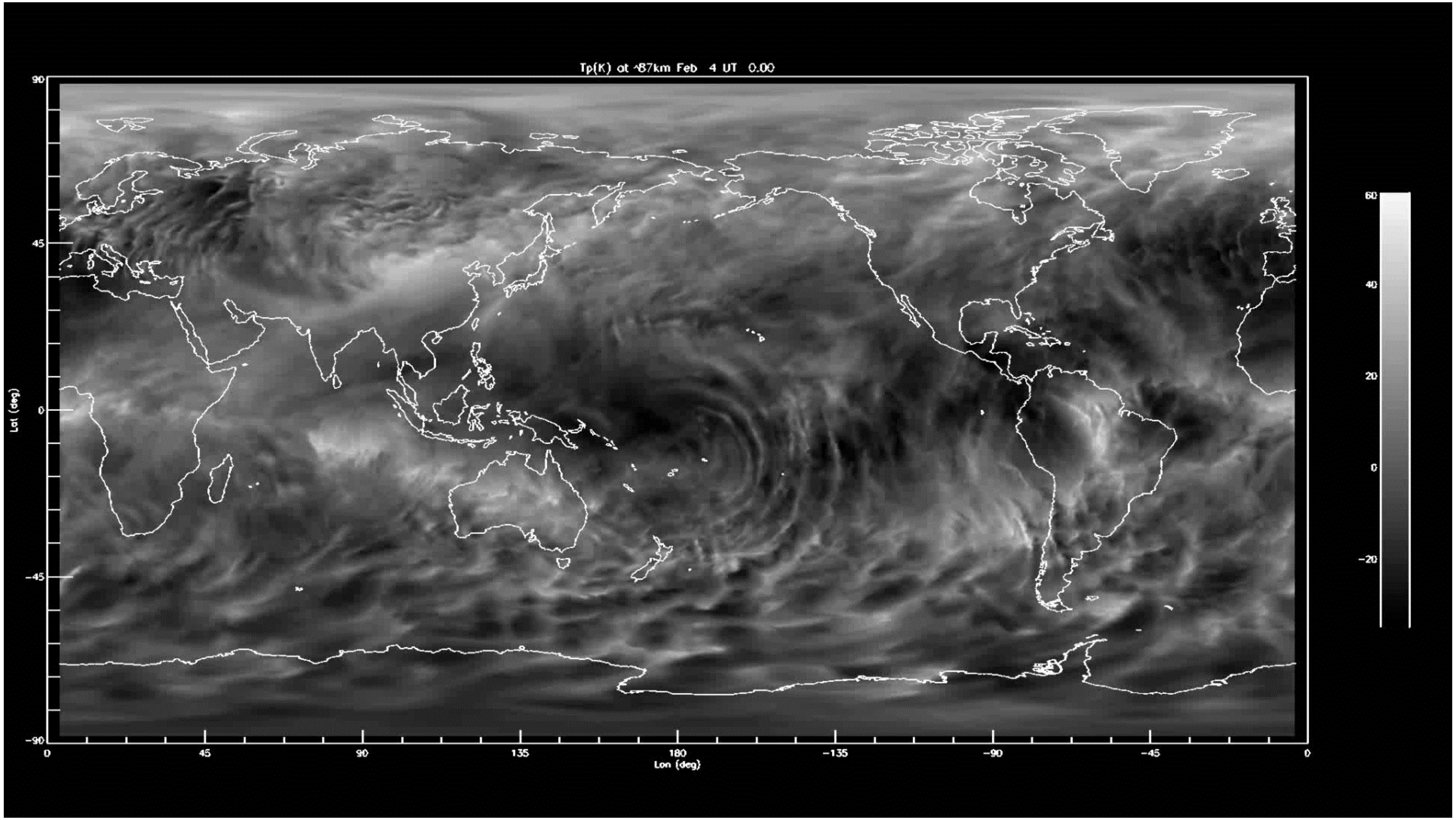
The role of gravity waves in the mesosphere, thermosphere and ionosphere cross-scale coupling and irregularities: Observations and numerical simulations

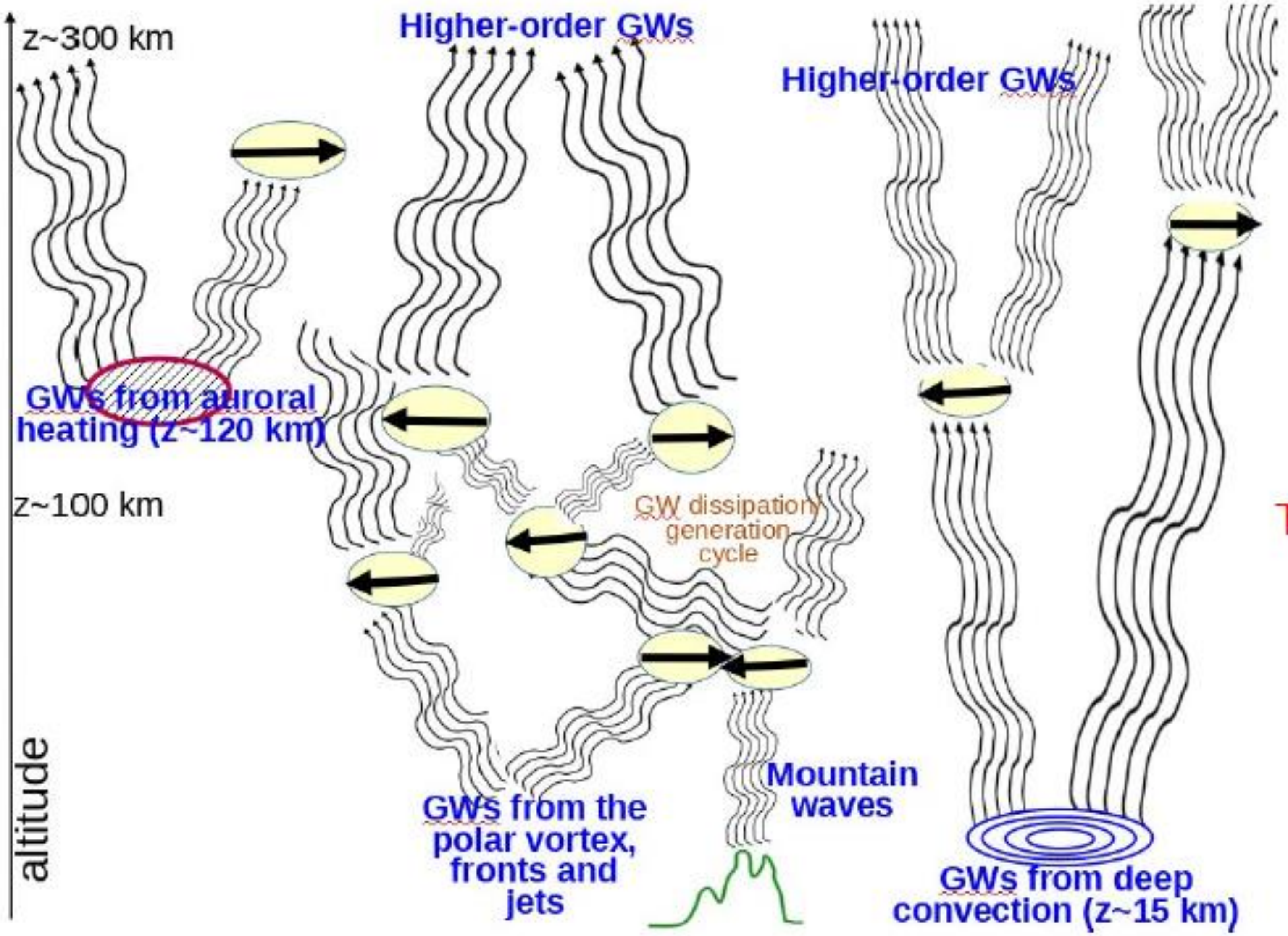
Titus Yuan, Mike Taylor, Sharon Vadas, Erich Becker, Hanli Liu, Jonathan Makela, Brian Harding, Jonathan Snively, Christopher Heale, Cesar Valladares

WACCM-X Gravity Wave Temperatures at 87 km



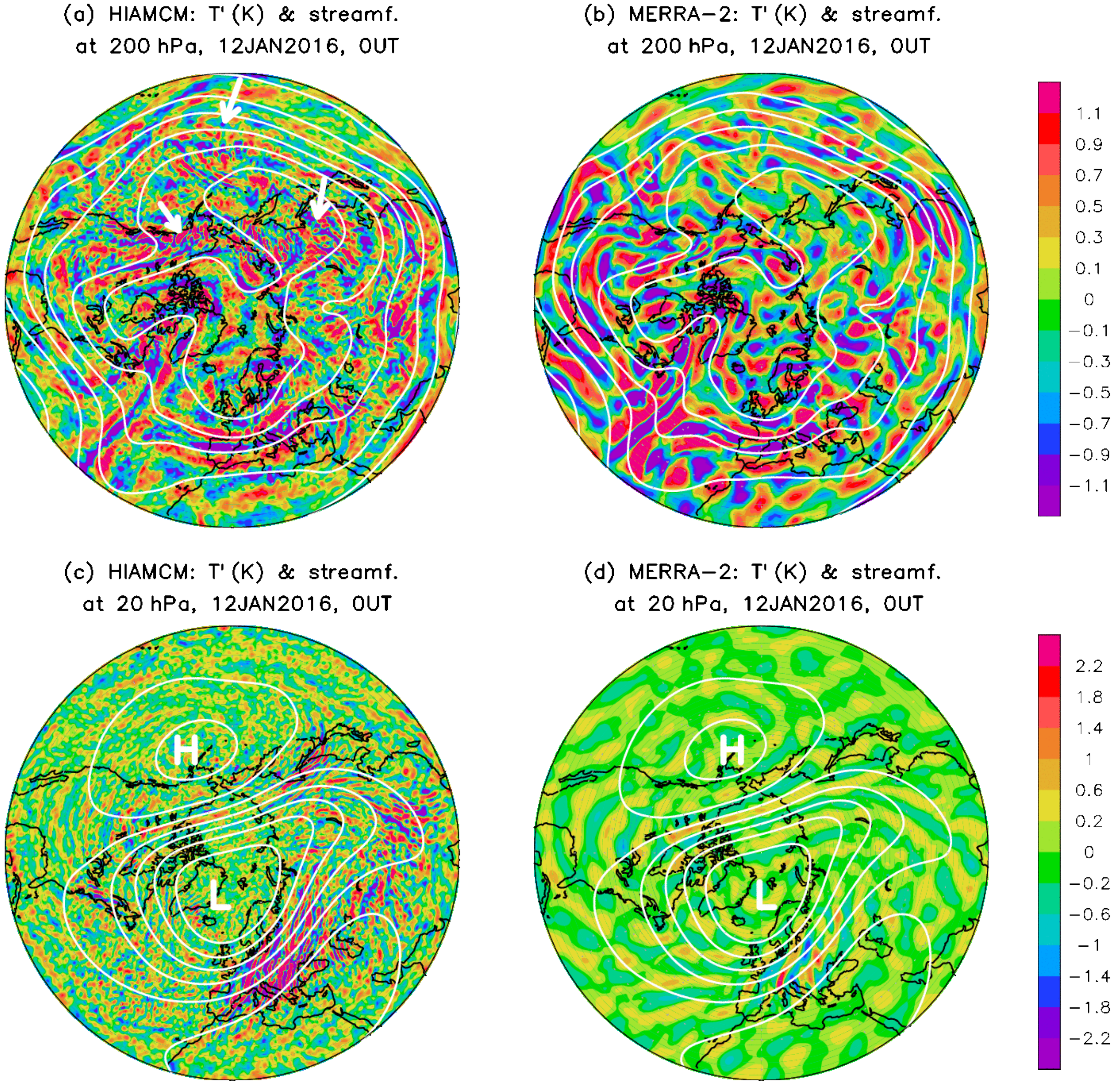
Courtesy of Han-Li Liu, NCAR

Multi-step vertical coupling results in the transfer of a significant amount of momentum and energy from the lower to upper atmosphere



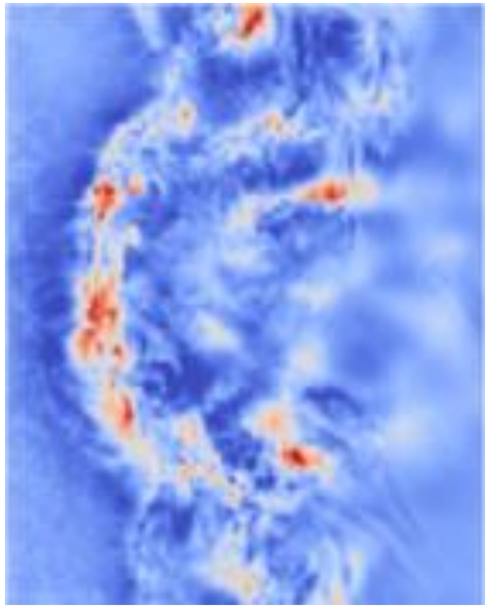
Tonga too!

Resolved GWs: HIAMCM versus MERRA-2

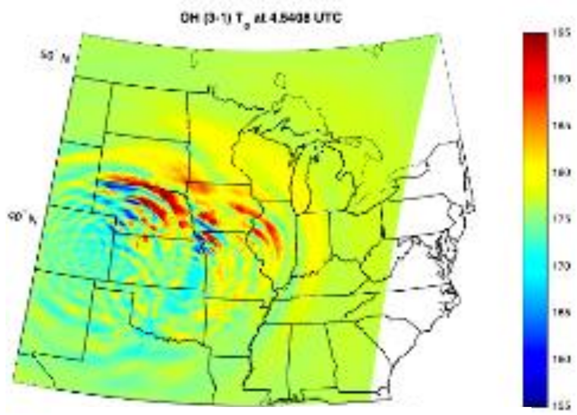


- GWs perturbations defined using the spectral fomulation: $n>30 \leftrightarrow \lambda_h<1350$ km. These scales are not nudged.
- Large-scale (inertia) GWs in the upper troposphere occur in the HIAMCM like in MERRA-2.
- HIAMCM simulates additional medium-scale GWs that are not resolved in MERRA-2.
- Strong damping of GWs in the stratosphere of MERRA-2.

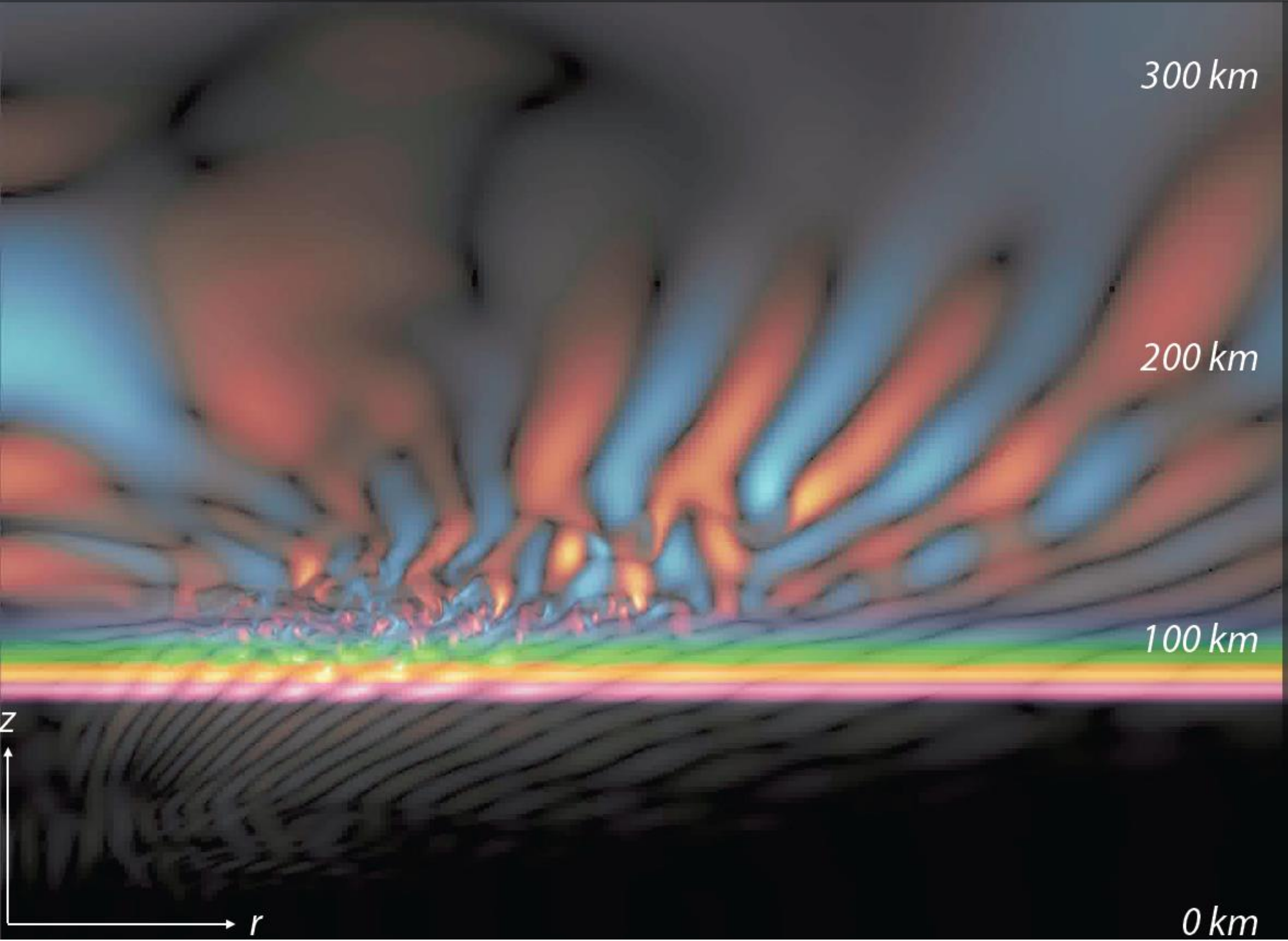
Regional/Local



Finite Volume - GATS



MAGIC - ERAU



Opportunity:

Leverage Mesopause Measurements to Understand ITM Dynamics.

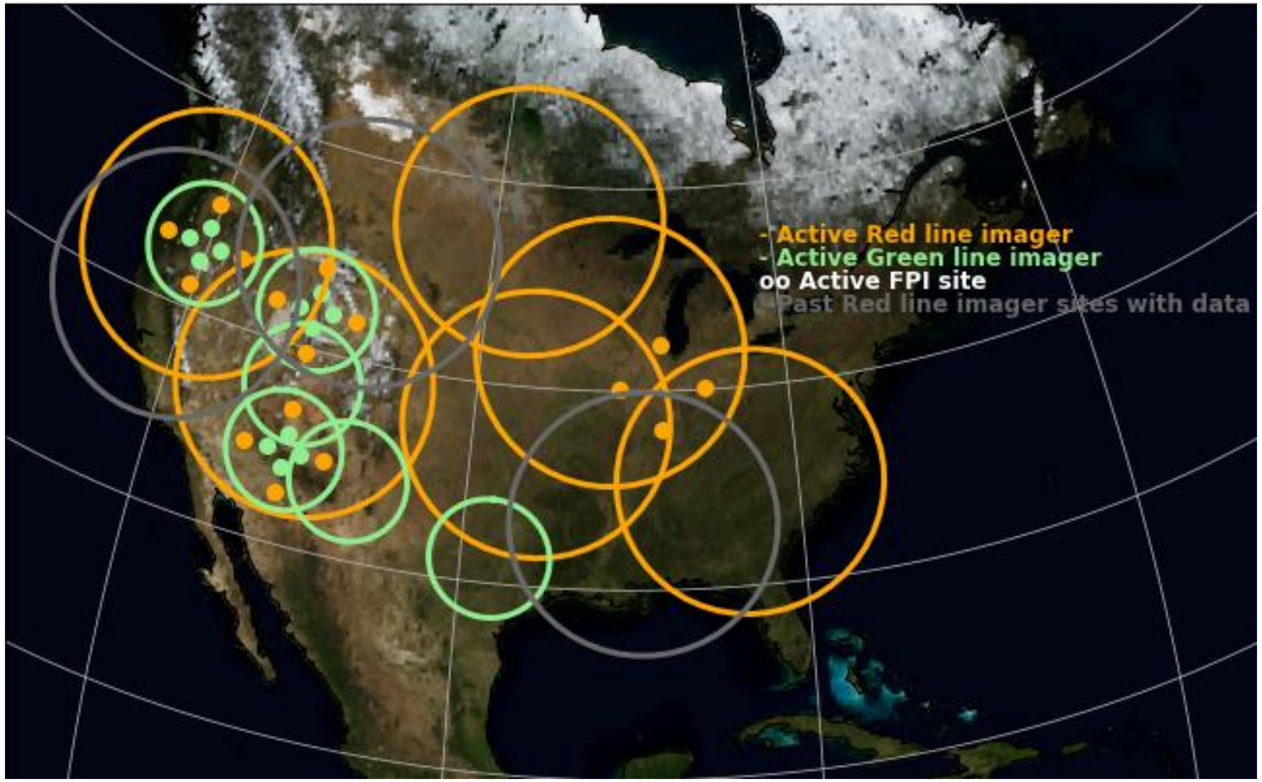
~80-100 km

Observable via Neutral Densities

(from ground/space)

MANGO DASI Ground-based network

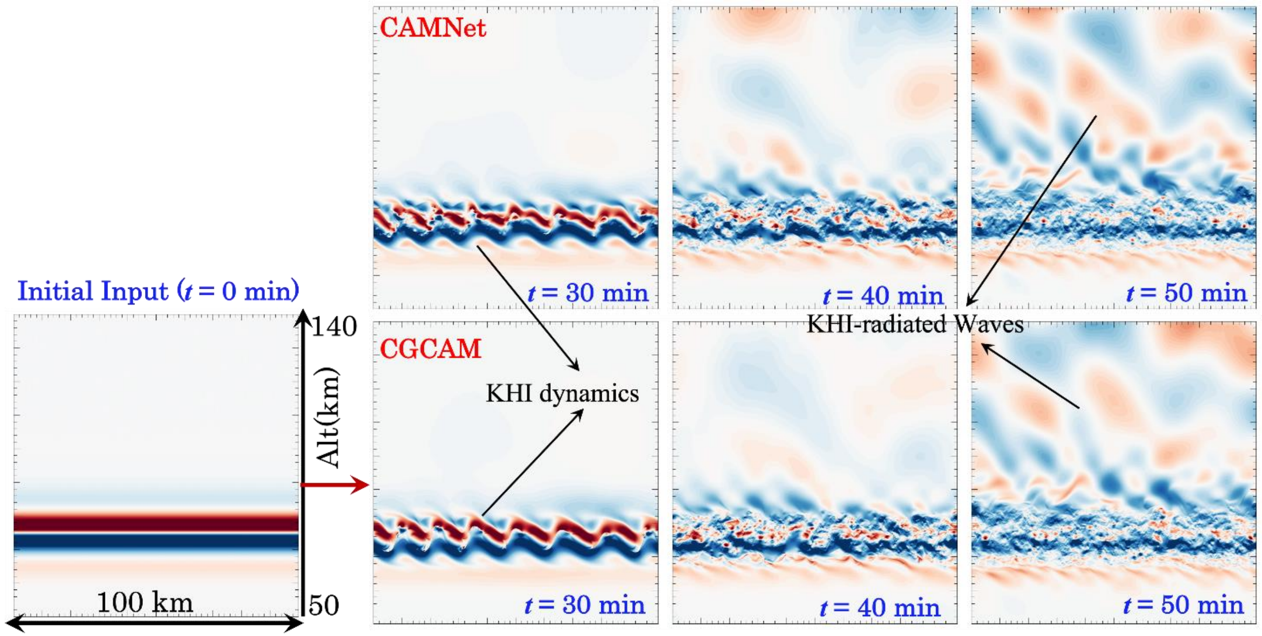
1. Investigate vertical propagation of thermospheric variability relative to F-region dynamics
2. Study the relative impact of lower atmospheric forcing with respect to magnetospheric forcing on the mid-latitude thermosphere and ionosphere
3. Determine spatial scales of the lower and upper thermospheric winds

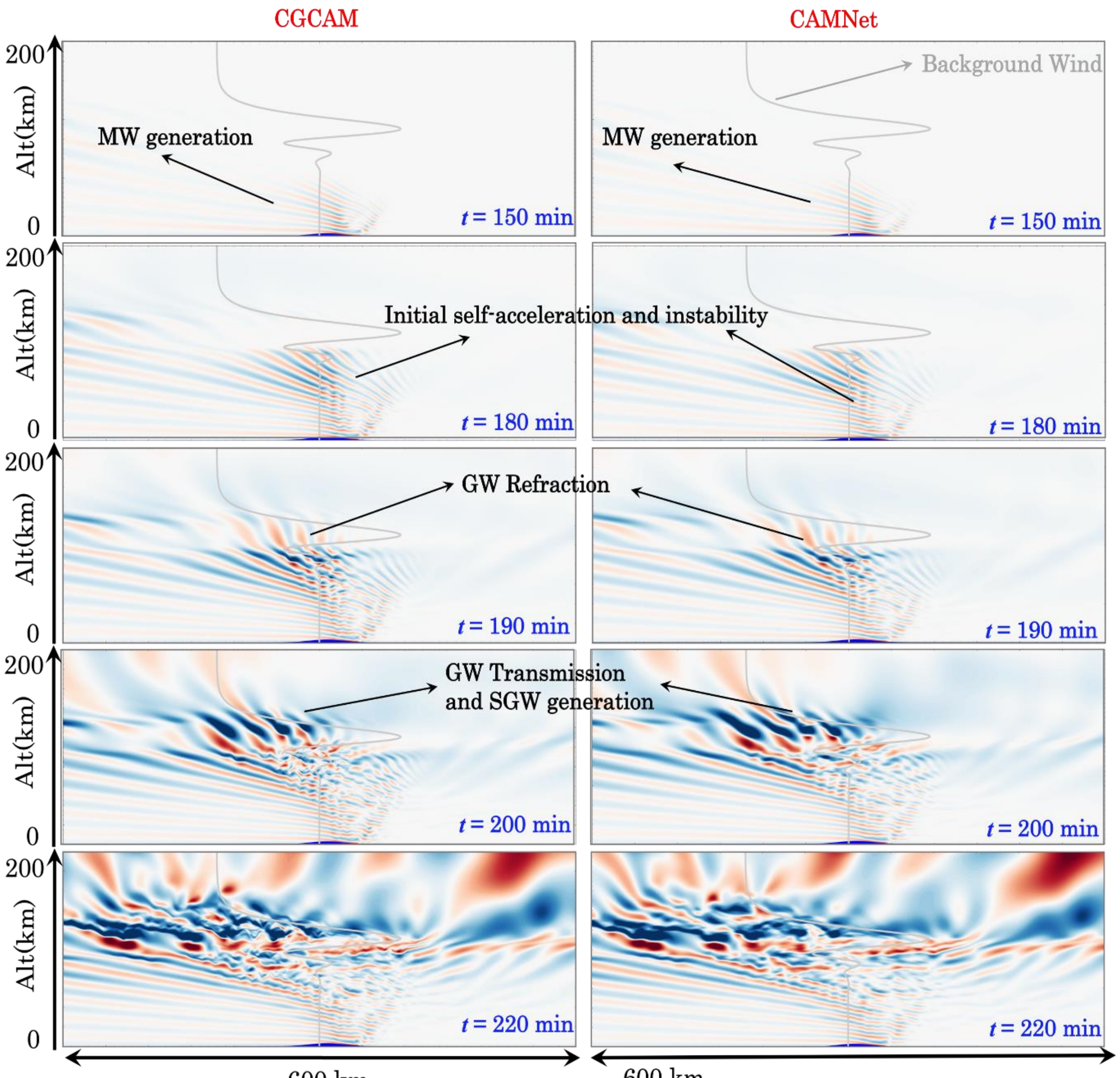


Build on MANGO and NATION networks through adding new FPI and imager sites, focusing in the western US where observing conditions are generally favorable

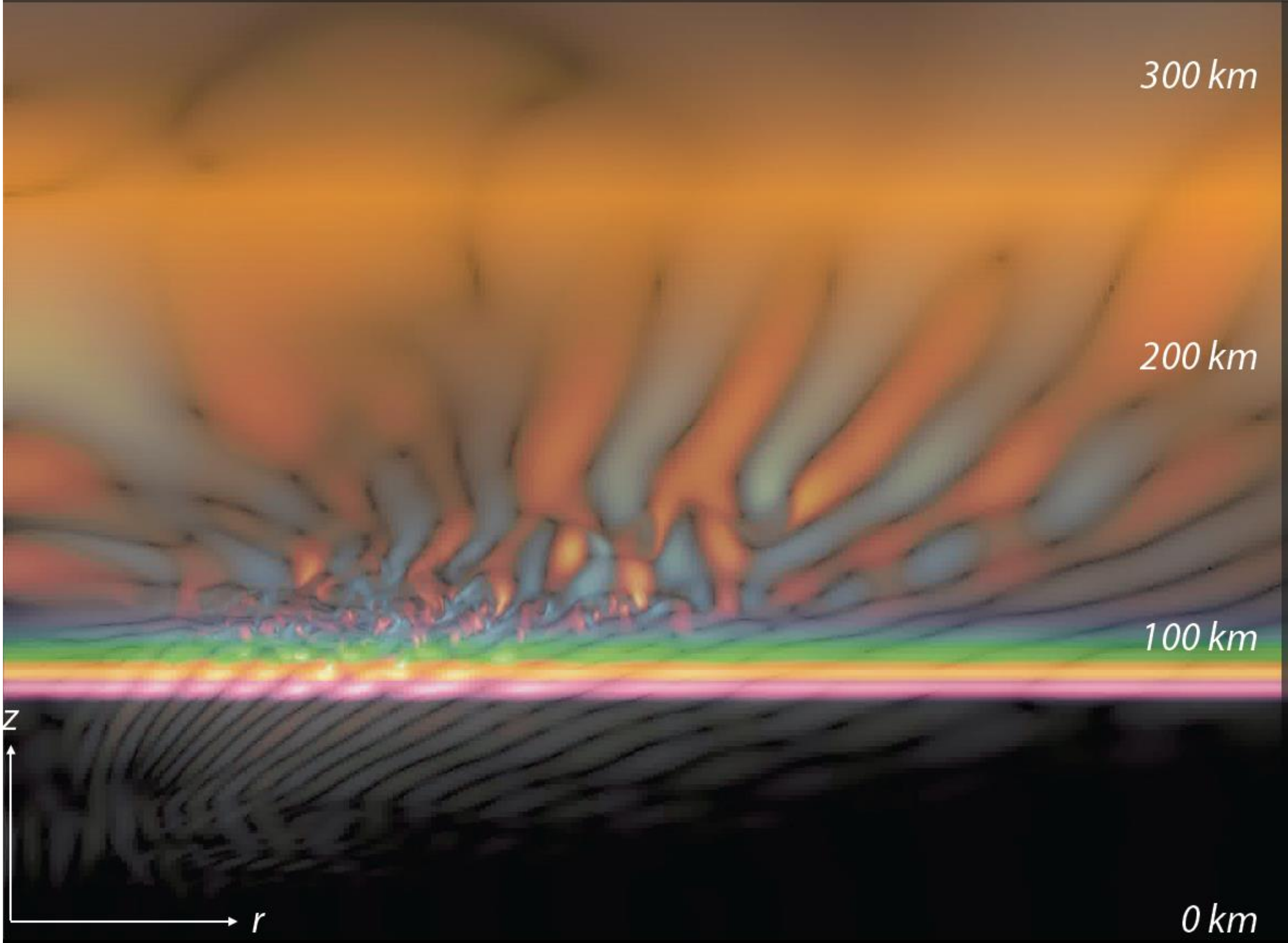
Gravity wave investigations facilitated by Machine Learning

	CAM-Net (1 A100 GPU)	CGCAM(36 CPU cores)
KHI	~0.8s	~30 mins
MW	~0.5s	~40 mins





Dong et al., (2023). GWs emitted from KHI, GRL, https://doi.org/10.1029/2022GL102674. (**Editor Highlighted**)

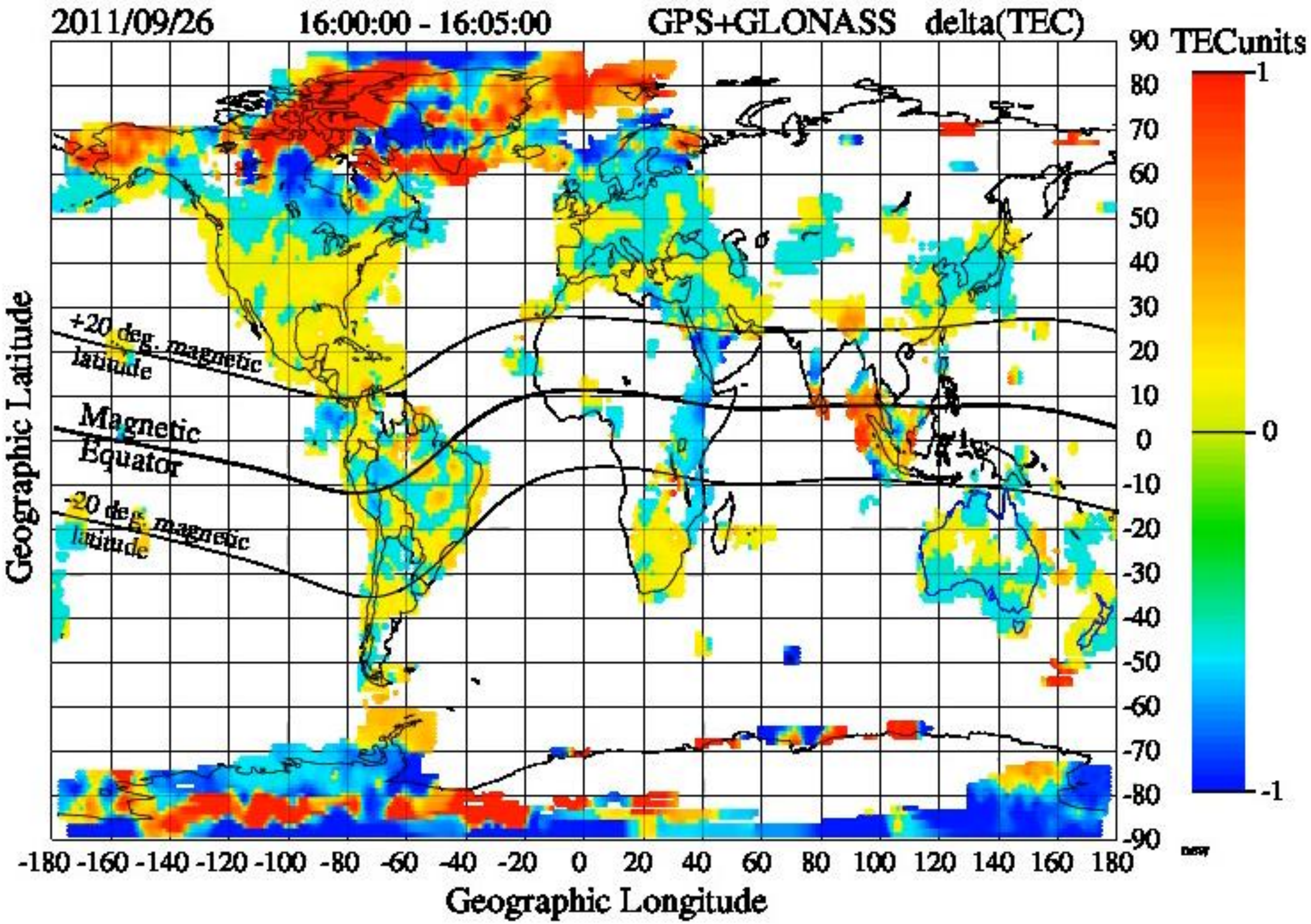


Opportunity: Leverage Ionospheric Datasets to Measure and Understand Neutral Dynamics in ITM.

~100-180+ km
Observable via Ionospheric Coupling

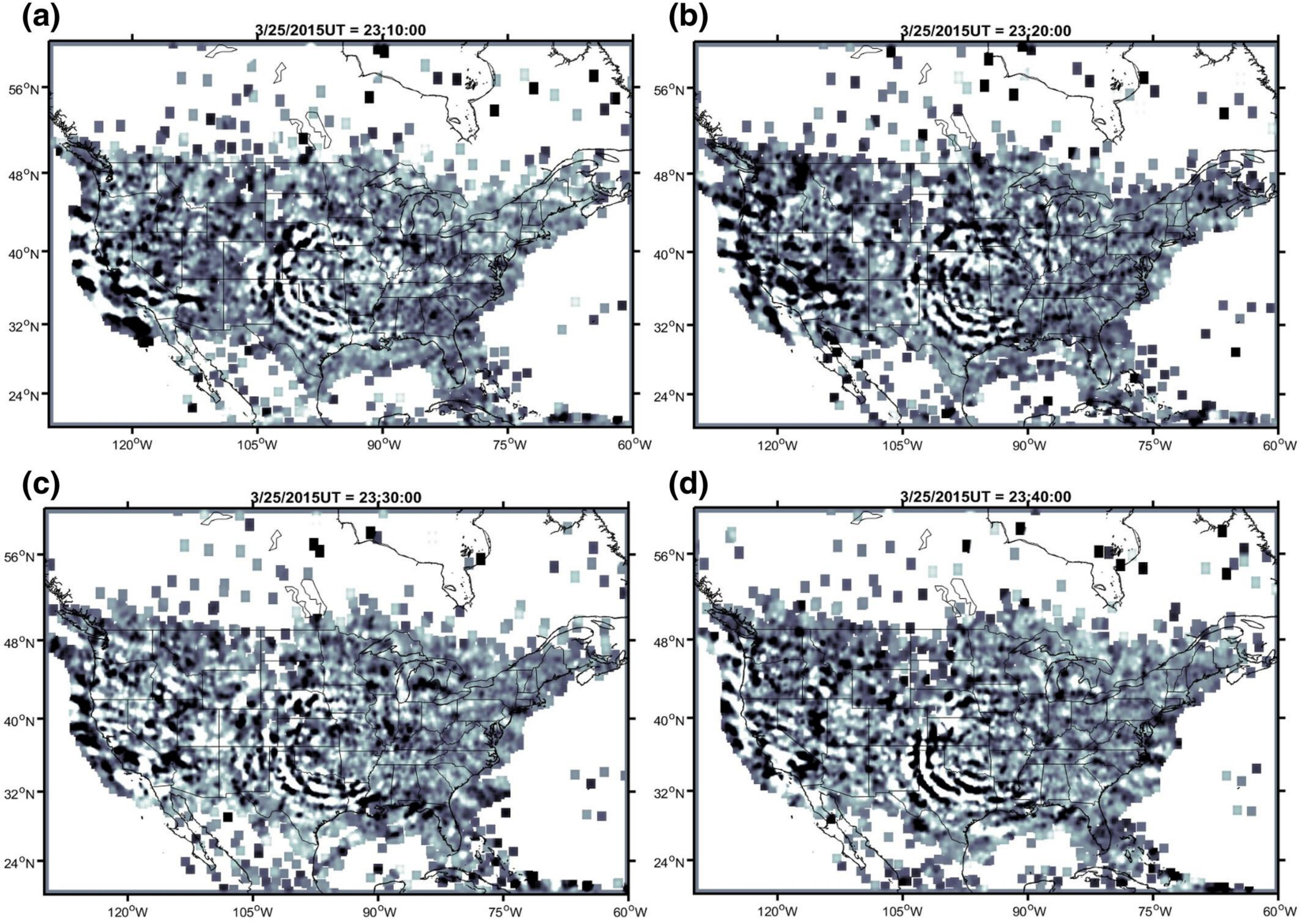
~80-100 km
Observable via Neutral Densities
(from ground/space)

Analysis of LSTIDs observed on September 26, 2011, based on Haystack TEC files



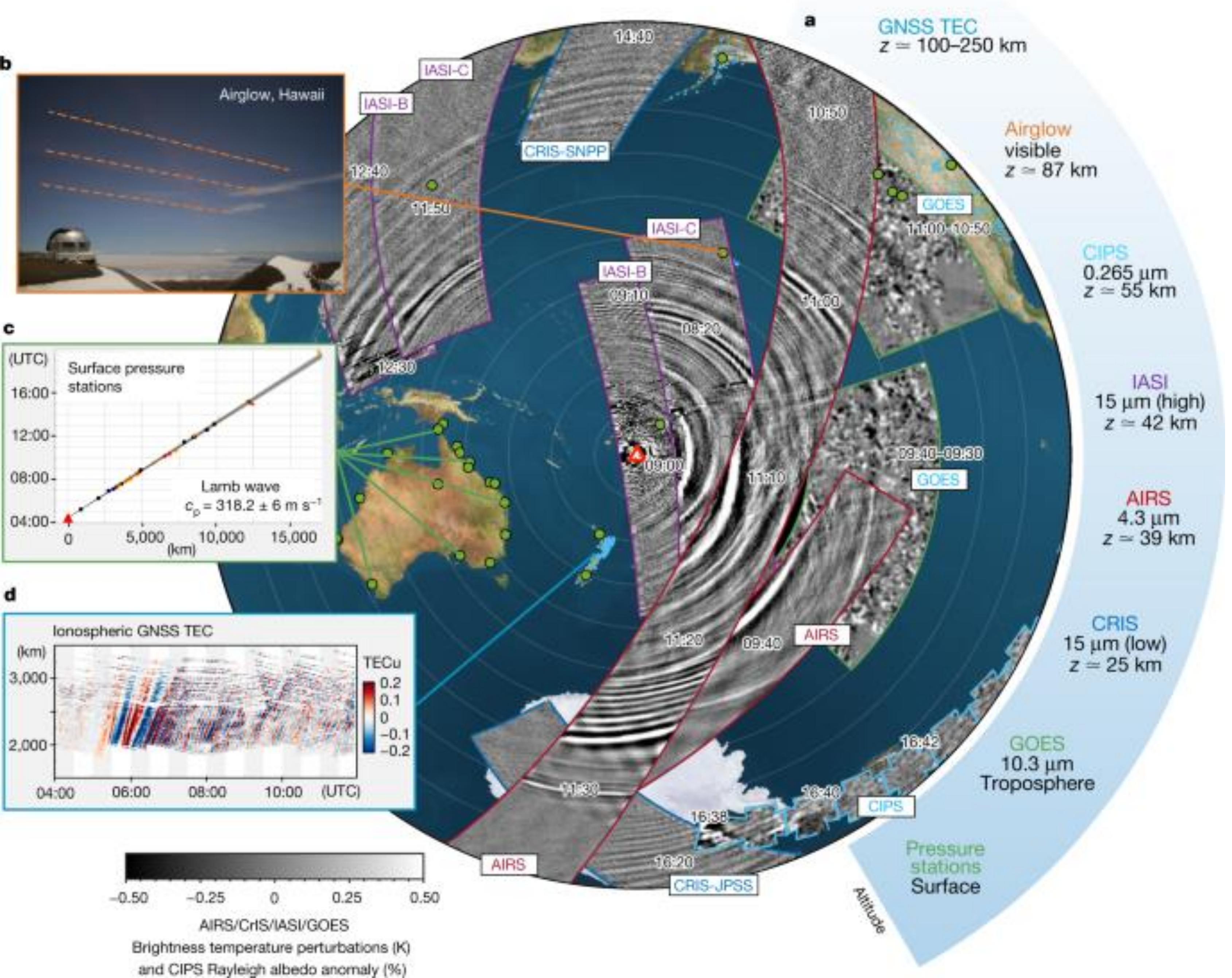
Curtesy of Cesar Valladares

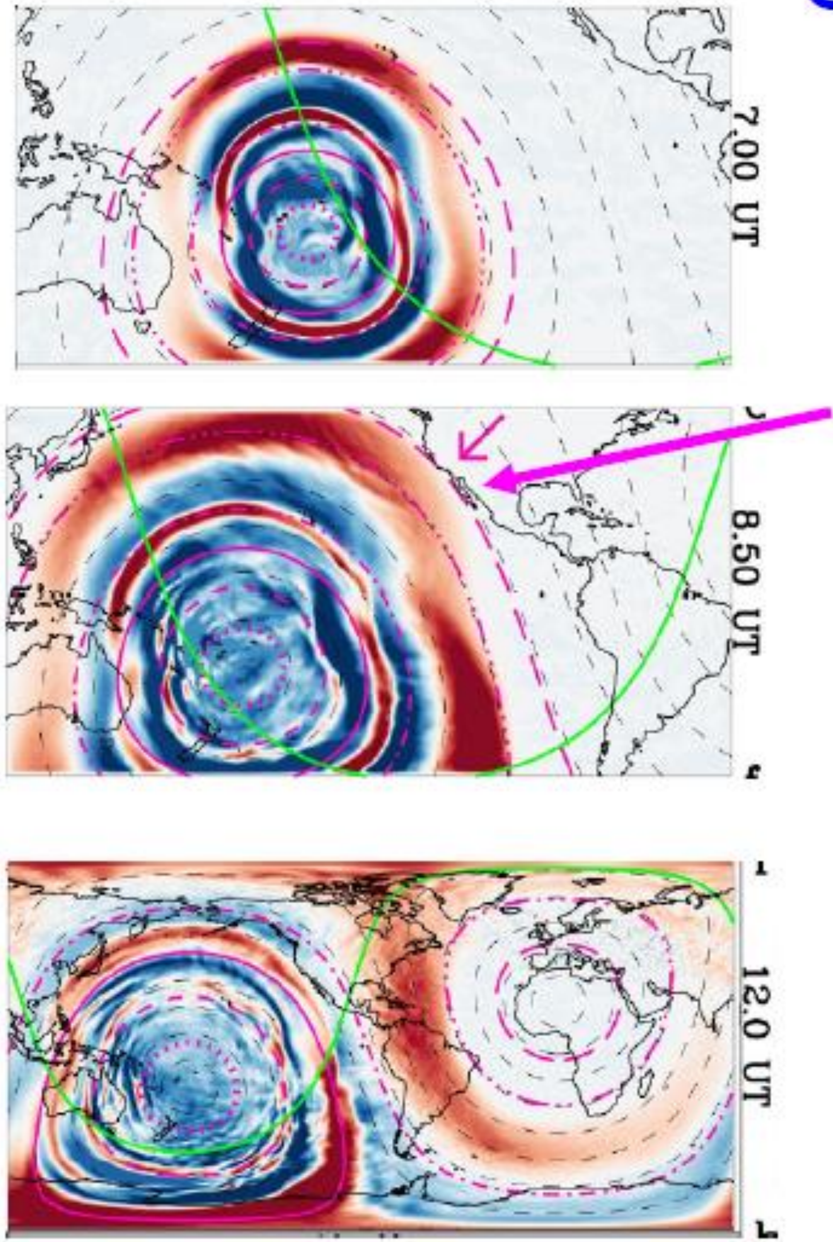
Concentric Secondary Gravity Waves in the Thermosphere and Ionosphere Over the Continental United States on March 25–26, 2015 From Deep Convection



JGR Space Physics, Volume: 126, Issue: 2, First published: 06 December 2020, DOI: (10.1029/2020JA028275)

Wright et al., 2022





Vadas et al., 2023

Atmospheric Waves Experiment (AWE) Mission Science

Ludger Scherliess, USU, Principal Investigator

Jeffrey Forbes, CU, Deputy Principal Investigator

David Fritts, GATS, Project Scientist

Stephen Eckerman, NRL, Co-Investigator

Diego Janches, NASA/GSFC, Co-Investigator

Han-Li Liu, NCAR, Co-Investigator

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Grand Challenges (Identified in Session Proposal):

Year 1

1. **The Roles of Gravity Waves (GWs) in IT coupling:** How do various scales of GWs couple into and change the ionosphere and thermosphere's large scale neutral background?
2. **Specifics of GW Dynamics:** What are the effects of GW dissipation/deposition of energy and momentum in the upper atmosphere? What are their global distributions and seasonal variations? What are the effects of tide and planetary waves on gravity wave propagations?

Year 2

1. **The Roles of GWs in IT coupling:** How do various scales of GWs couple into and change the ionosphere and thermosphere's regional state and variable evolutions?
2. **Specifics of GW dynamics:** What is the best / most-efficient operational mode for existing local instrument clusters to address the small-scale waves effects/contributions in the GCMs?

Year 3

1. **The Roles of GWs in IT coupling:** What are the relationships between GWs and TIDs/TADs? What portion (spectrum) of the TID is induced by GWs coming from lower altitude?
2. **Specifics of GW dynamics:** How do GWs evolve from below to define the ITM wave spectrum? What are the relative roles of primary, secondary and tertiary waves and their effects on the ITM?

GC Year 2 agenda

Monday

- Ludger/Dominique (Invited), AWE update (20-minute)
- Dave Fritts/Wenjun Dong, Vertical Coupling by Secondary Gravity Waves, (Invited) 20-minute)
- Tyler Mixa: KHI that are modulated by a background mountain wave. (10-min)
- Erich Becker, Sharon Vadas, Sebastijan Mrak: Mountain waves over the western US in January 2017: Higher-order gravity wave generation and thermosphere-ionosphere disturbances. (10-min)
- Alan Liu (invited), Recent Progress of Gravity Wave and Instability Studies at Andes Lidar Observatory. (15-minute)
- Endawoke Yizengaw: The Forcing from Below and the Longitudinal Dependence of Its Impact (10-min)
- Sevag Derghazarian: Connections Between Stratospheric Gravity Waves, the Polar Vortex and Medium Scale Traveling Ionospheric Disturbances (10-min)
- Masaru Kogure: Concurrent Observations of Stratospheric Concentric Gravity Waves and Concentric Traveling Ionospheric Disturbances over the Continental US in 2022 (10-min)
- Cesar Valladares/Aaron Bukowski, The formation of LSTIDs using SAMI3 and a thermosphere model. (10-min)

Thursday

- Erdal Yigit (invited) Modeling and Observation of Thermospheric Gravity Waves in Terrestrial and Planetary Atmospheres, (15-minute)
- Xinzhao Chu (invited) Lidar Highlights: Gravity Waves, Atmosphere-Ionosphere Coupling, and Mother's Day Storm in Antarctica, (15-minute)
- Jiarong (AWE) Gravity Wave Activity during the 2024 Sudden Stratospheric Warmings Observed by Atmospheric Waves Experiment (AWE). (10-min)
- Yucheng (ANGWIN) Winter-time GW coupling in the mesosphere over Antarctica (10-min)
- Min-Yang Chou: Modeling the post-midnight EPBs with SAMI3/SD-WACCMX: Gravity wave seeding and LSWS, (10-min)
- Katrina Bossert Using citizen science and OH airglow to reveal quiet, normal, or interesting days of gravity waves and instabilities over Poker Flat, AK, (10-min)
- Jessica Norell Mesospheric Gravity Waves and Instabilities at Poker Flat (10-min)
- Jintai/Biff Gravity waves and KHI observations (10-min)
- Jonathan Modeling of Acoustic-Gravity Wave interactions and Coupling with the Ionosphere (10-min)

backup

Past/Recent Advances in ITM-Region GW Coupling:

(Prior results in last 10 years that have advanced small-scale ITM process studies…)

1. **Radio/GNSS Measurements of AGW-TIDs** — E.g., *Nishioka et al.*, 2013; *Azeem et al.*, 2015; and others have highlighted the utility of GNSS TEC for AGWs.

2. **Campaign, Mission, and Networked Instrument Investigations** — E.g., DEEPWAVE, PMC Turbo (*Fritts et al.*), towards understanding large-amplitude GW evolutions; fortuitous space-based airglow imagery (Suomi's DNB, with by *S. D. Miller*, *J. Yue* et al.).

3. **Models that capture more physics and that can be more-easily used with or by others** — Model interoperability and higher resolutions enable continued progress.

4. **Model *and* Data Achievements of High Resolutions and Coverage** — Models and datasets are taking steps towards capturing the necessary spectrum and span/duration of events. *Instrument networks are denser, individual sensors are better and lower-cost.*

5. **Identification in Inter/Multi-disciplinary Value of Data** — e.g., for earth sciences and natural hazards diagnostics.

6. **Numerous detailed modeling & data investigations** — leveraging all of the above.