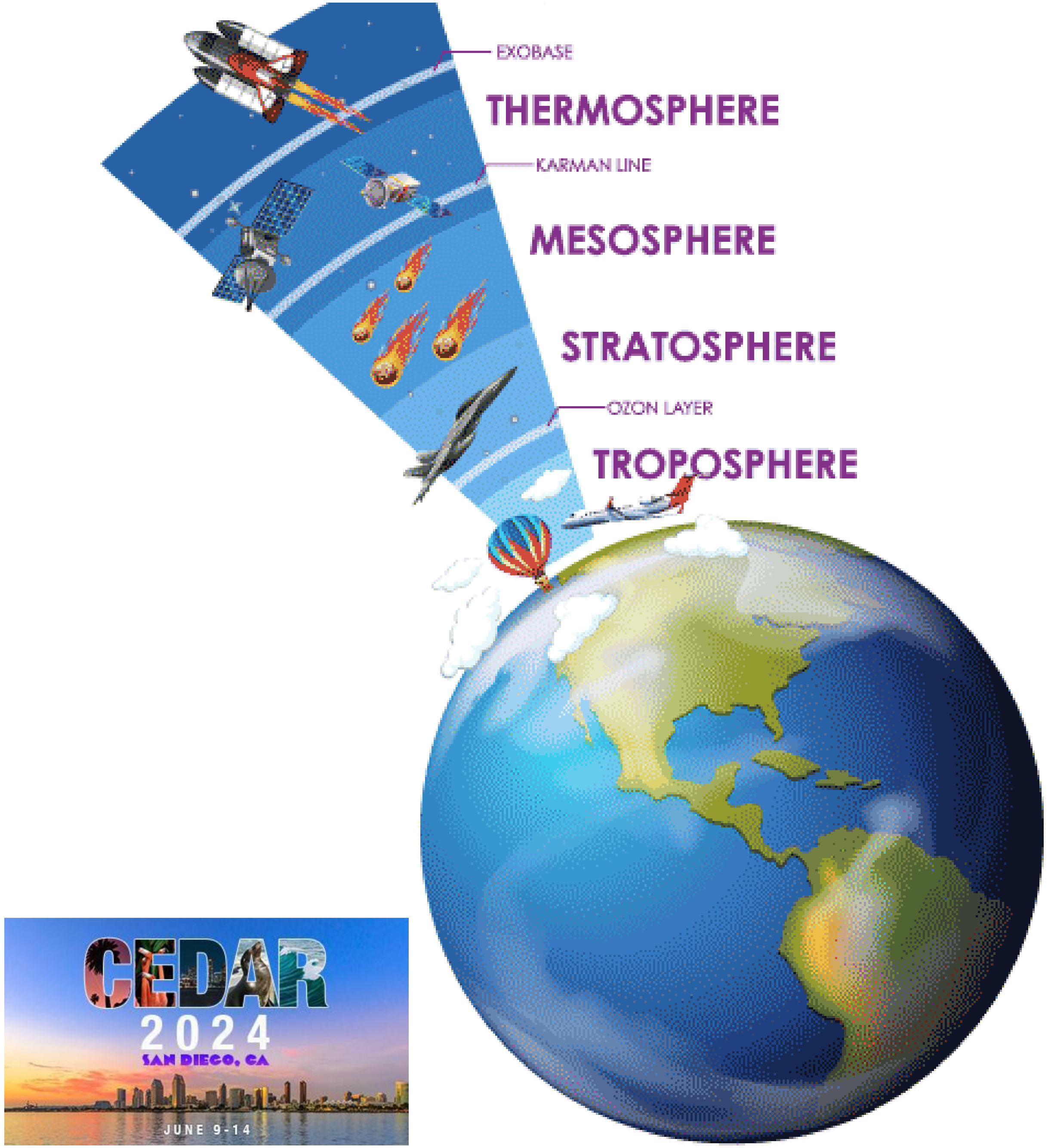


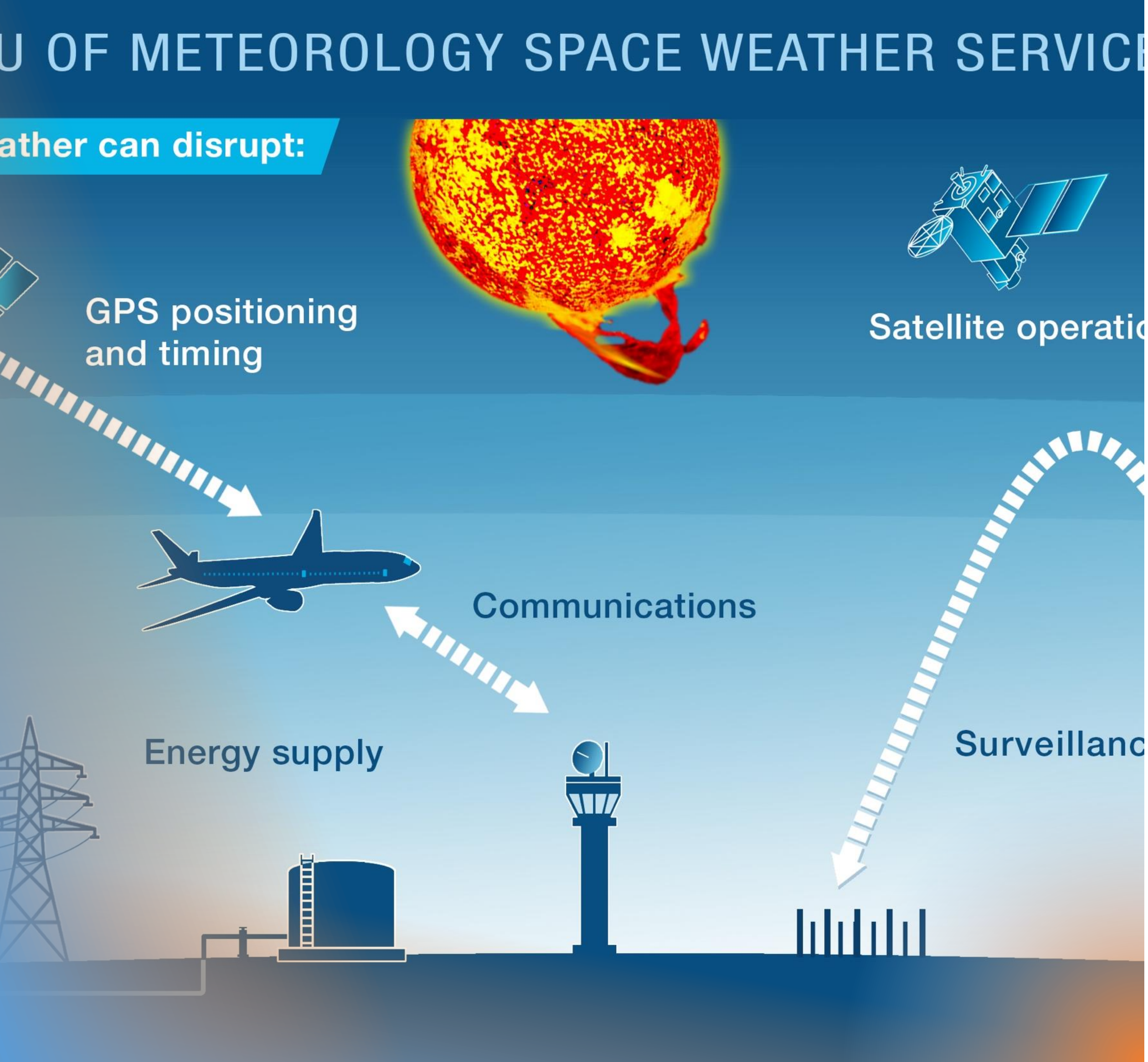
Mesosphere-Thermosphere-Ionosphere Coupling

Komal Kumari

ASP Postdoctoral Fellow I

High Altitude Observatory

National Center for Atmospheric Research



<u>MTI (Mesosphere-Thermosphere-Ionosphere) coupling predominantly governs dynamical space weather at all locations.</u>

Scientific objective: To understand geophysical dynamics of the near-Earth space and feed into computer model to deliver accurate prediction

Space weather prediction:

Important to predict ionized state of atmosphere

Important to predict atmospheric composition in near-Earth space

Near-Earth space weather study tools

Ground-Based Instruments:

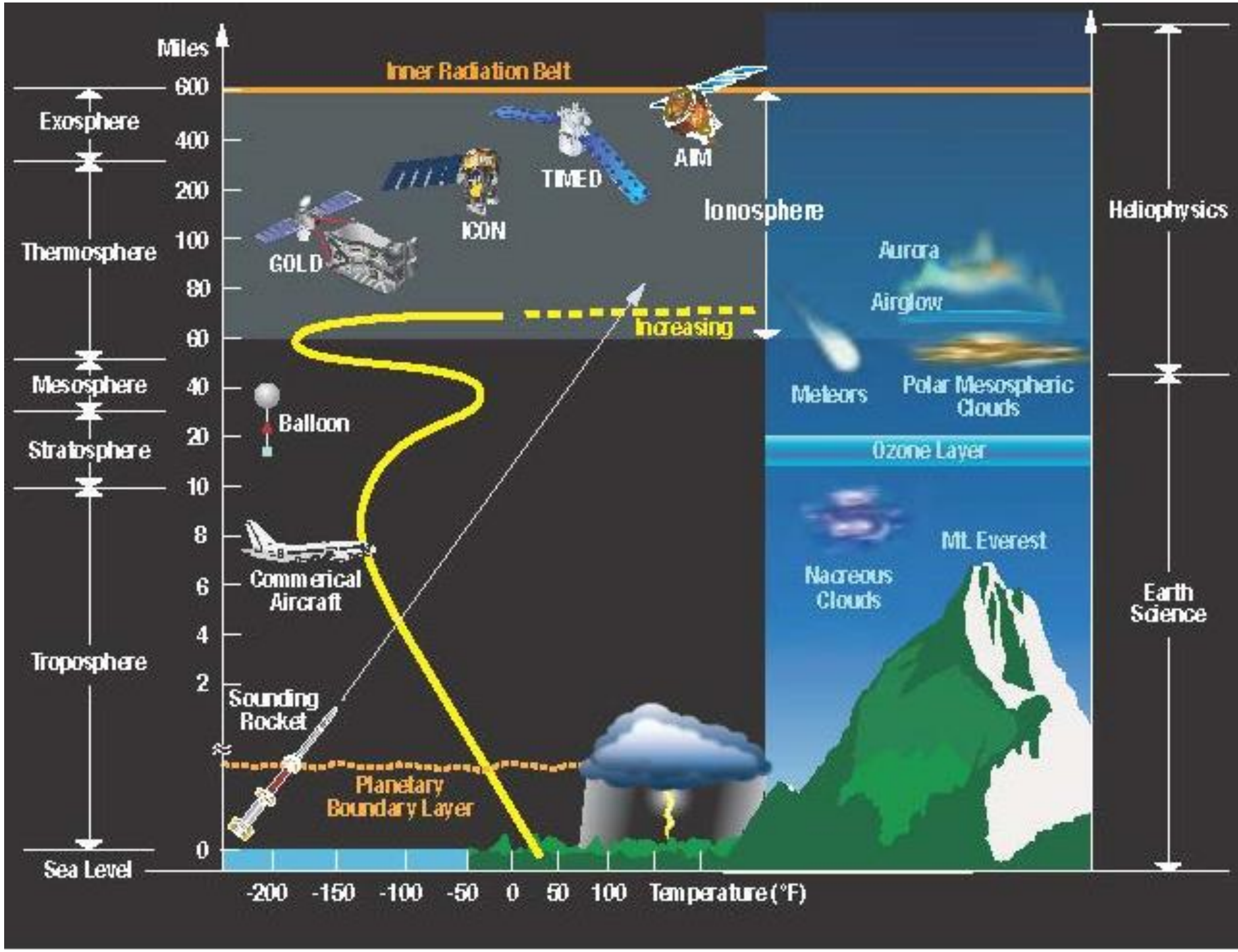
- Magnetometers
- Radars and Ionosondes
- GPS Receivers
- All-sky Cameras (FPI, SDI)
- LIDAR Systems

Space-based instruments:

- TIMED
- ICON
- GOLD
- COSMIC
- Sounding Rockets

Models:

- Whole atmosphere models e.g., WACCM-X
- Data Assimilation models
- Physics-based I-T models (boundaries ~100 km)
- Empirical Models



M-T-I Coupling

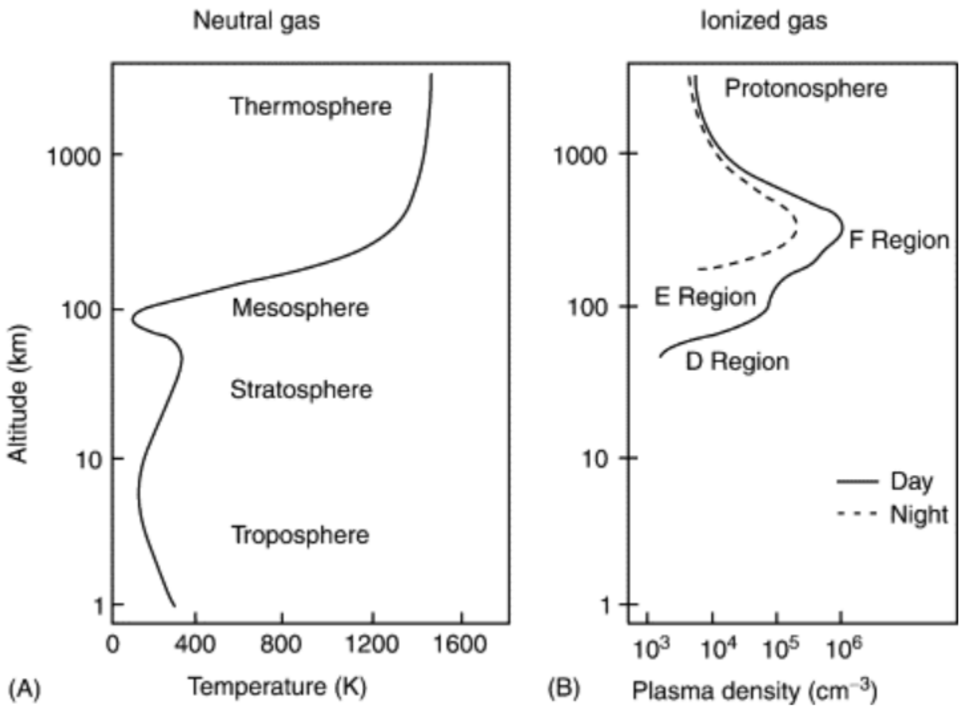
- Due to ion-neutral collisions primarily in the E-region, the ionosphere and the mesosphere-thermosphere are closely coupled.
- depends on neutral and ion density
- Occur all the times and at all latitudes
- Both global and local scale
- Both chemical and dynamic processes.

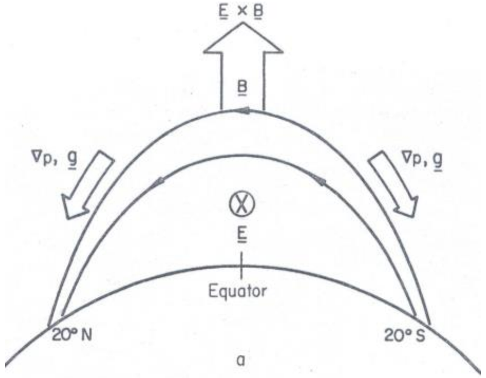
- Examples:

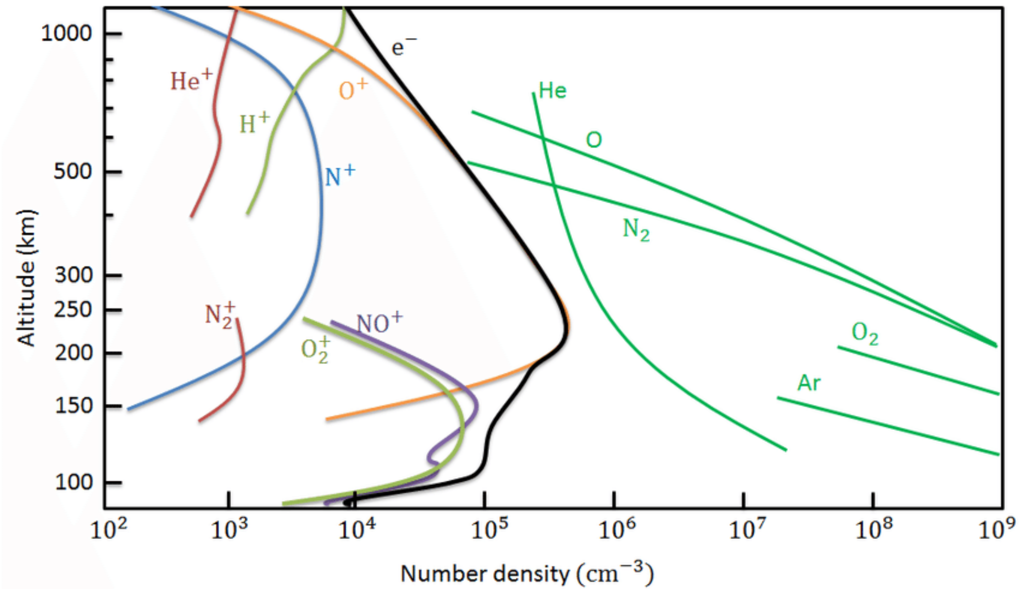
$$O^+ + N_2 \rightarrow NO^+ + N$$

$$O_2^+ + O \rightarrow O_2 + O^+$$

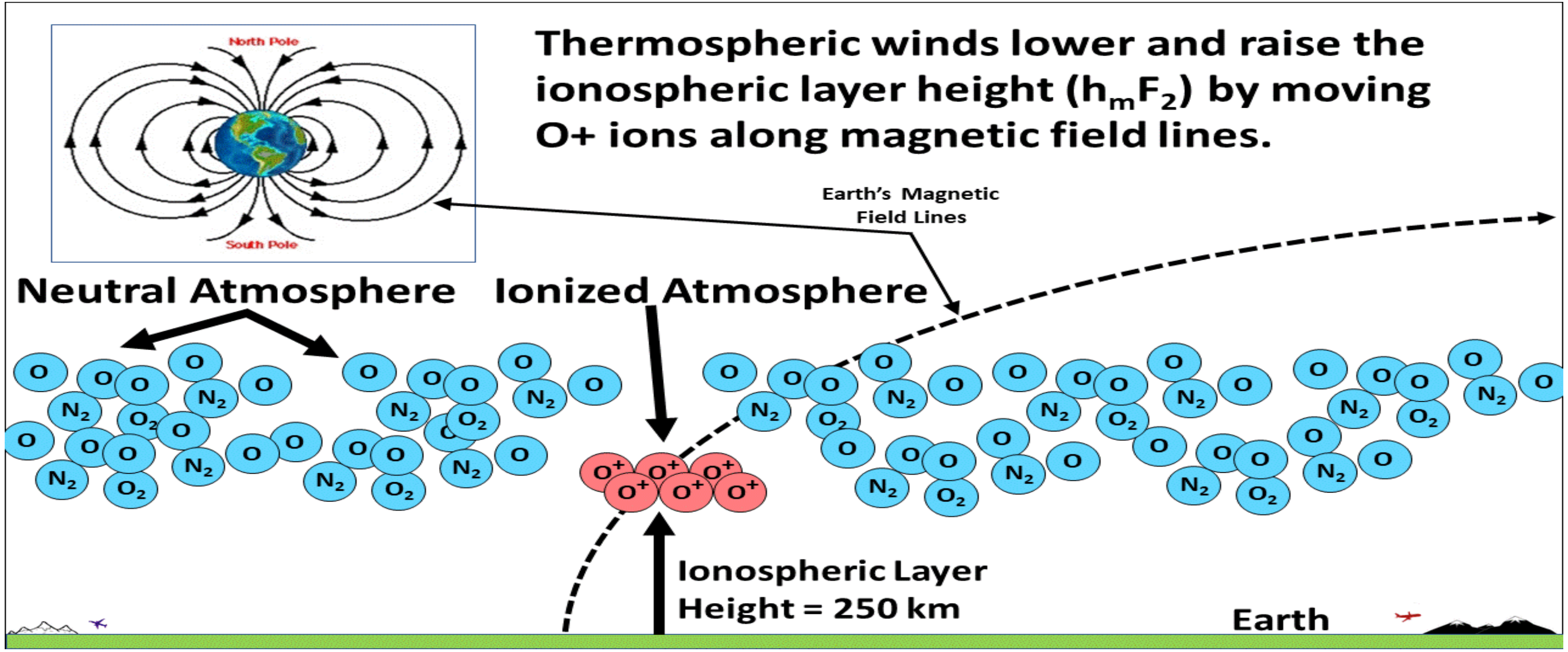
Chemical process changes thermosphere density or composition and circulation

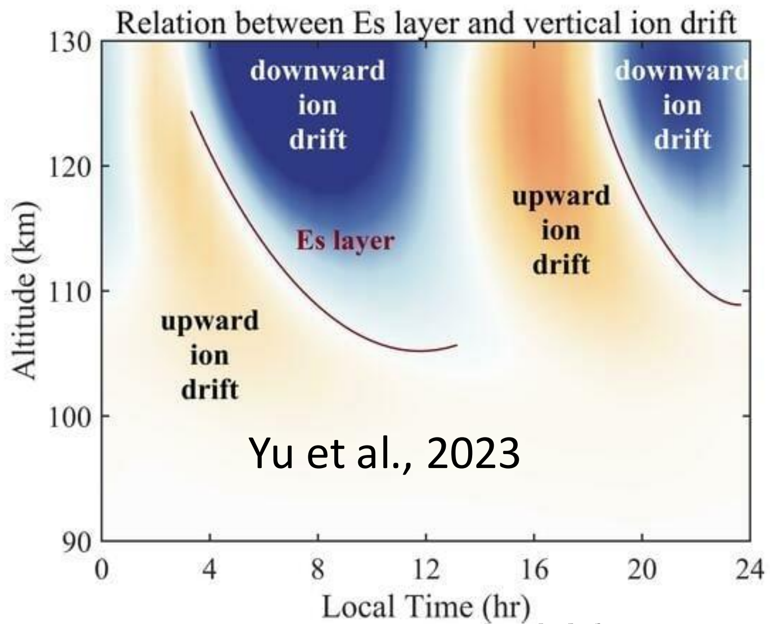






The E and F regions are coupled through dynamic processes like electric fields and currents generated by ion-neutral interactions.





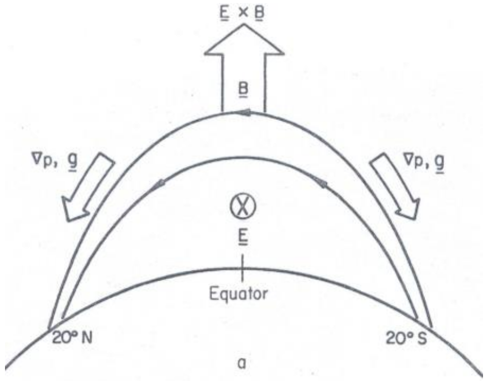
Dynamical processes:

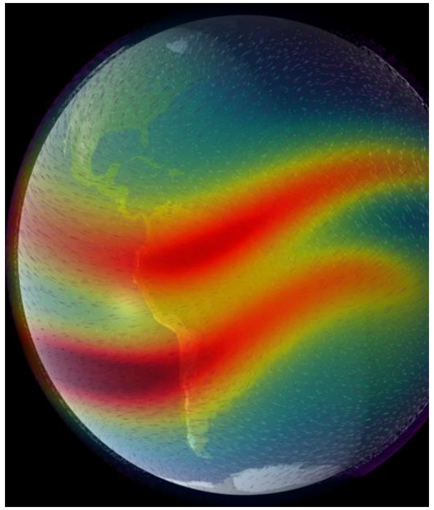
Neutral influence to ionosphere

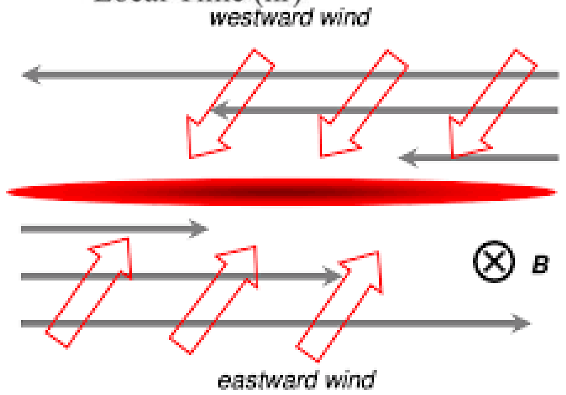
1. Neutral Wind Dynamo
2. Equatorial Ionization Anomaly
3. Formation of Sporadic E Layers
4. Equatorial Plasma Bubbles

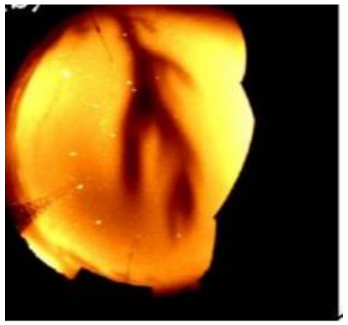
Ionosphere feedback to neutral

Ion drag

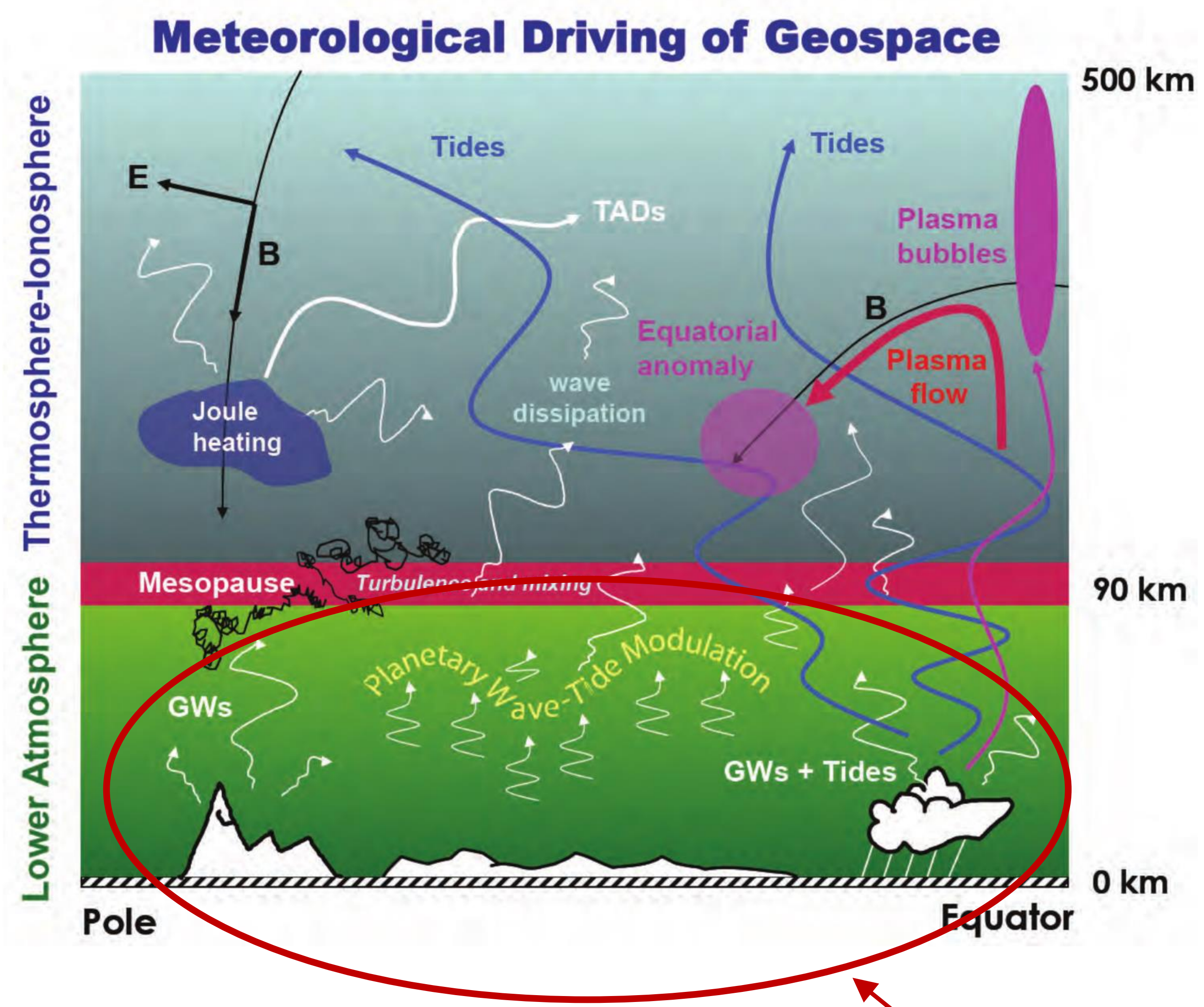








Dynamical processes : Multiscale coupling from below



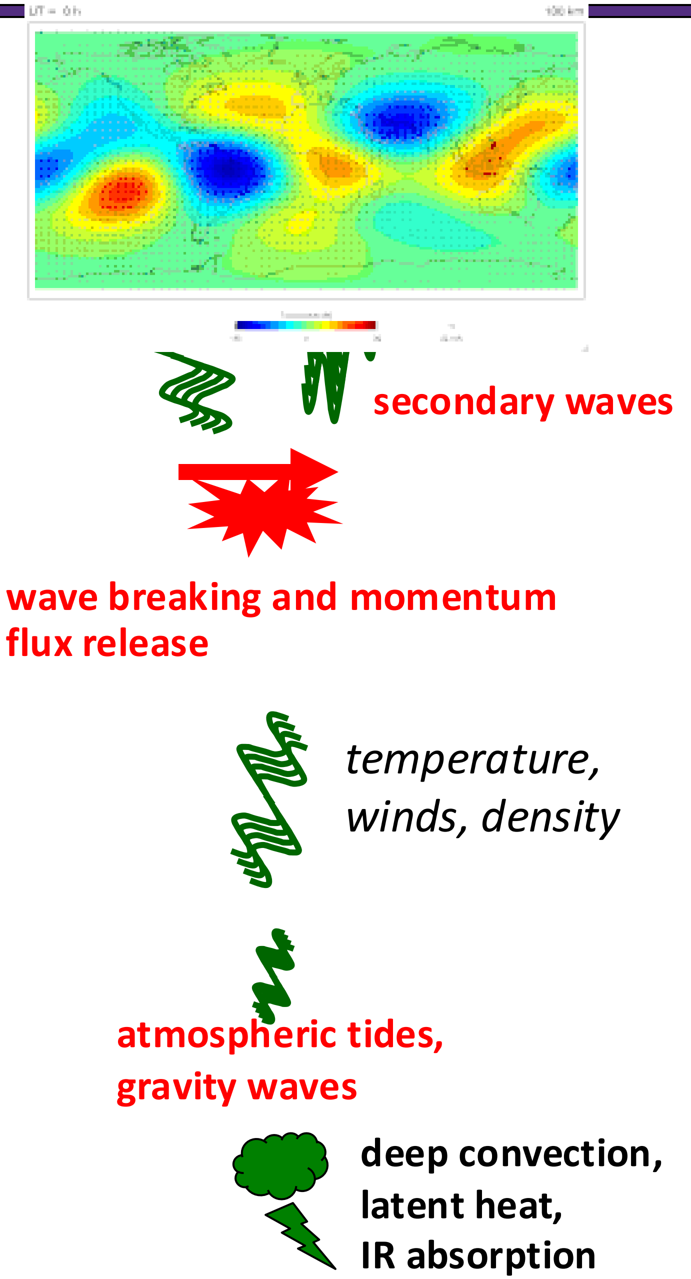
Courtsey: Jeff Forbes

Wave Spectrum

Gravity Waves
min-hours
10's – 1000 km

Tides
24, 12, 8 hours
1000's to
10,000km

Planetary Waves
2-20 days
1000's to 10,000 km

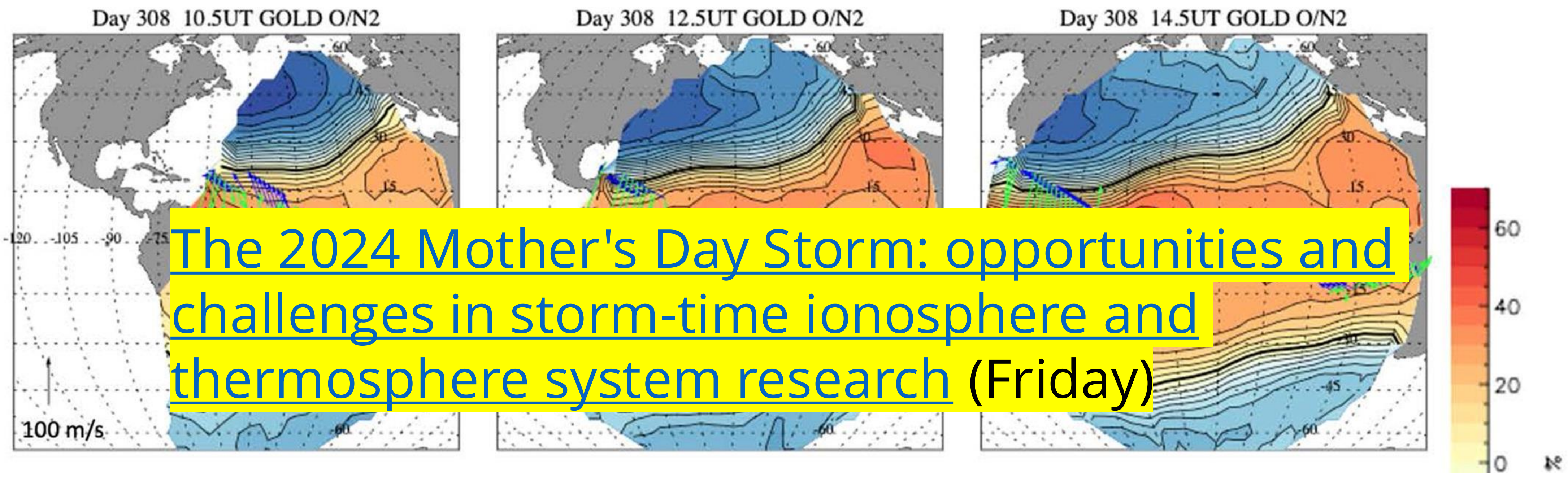


~10^{16} J per day (**120 GW**) wave energy

Space weather drivers: forcing from above and forcing from below

- Forcing from above e.g., Aurora, storm, eclipse, flare
- Forcing from below e.g., Volcano, Sudden stratospheric warmings (SSW)

https://www.astronomy.com/science/northern-lights-history-aurora-sightings/

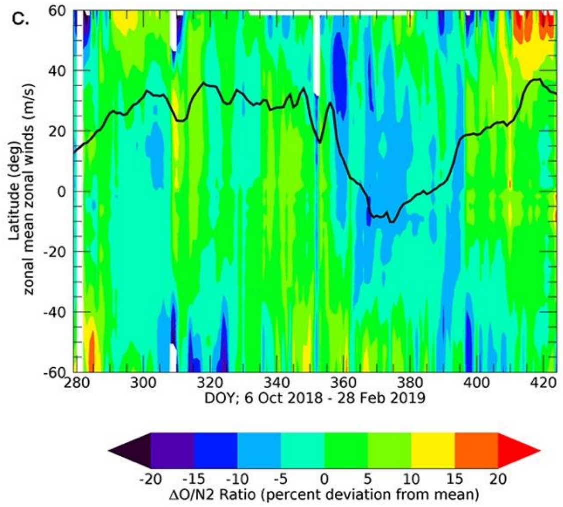


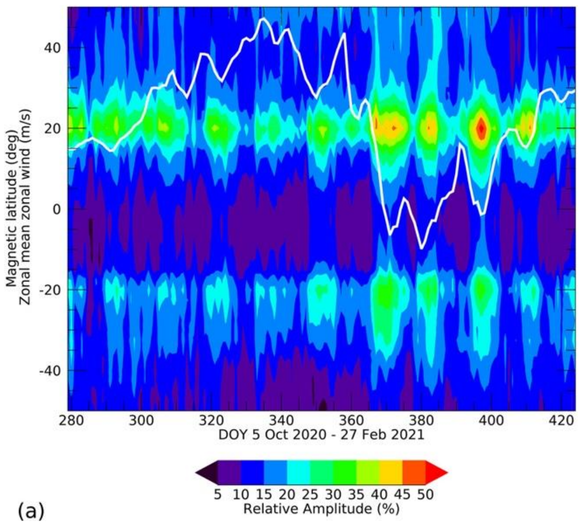
The 2024 Mother's Day Storm: opportunities and challenges in storm-time ionosphere and thermosphere system research (Friday)

Origin above: Geomagnetic storm

- GOLD observed the substantial changes of 60%–70% in thermosphere column density ratios (Gan et al., 2023)
- Storm time O/N2 decrease at high latitude due to upwelling associated with the divergence of horizontal winds due to Joule heating, which transports N2 molecules to higher altitudes and substantially depletes O/N_2 at high latitudes, while downwelling due to converged horizontal winds can enhance the O/N_2 at low latitudes.
- Equatorward neutral wind surge *via* Joule and auroral heating which impacts ion and electron density in F-region at all latitudes

Gold O/N2 (Oberheide et al., 2020)





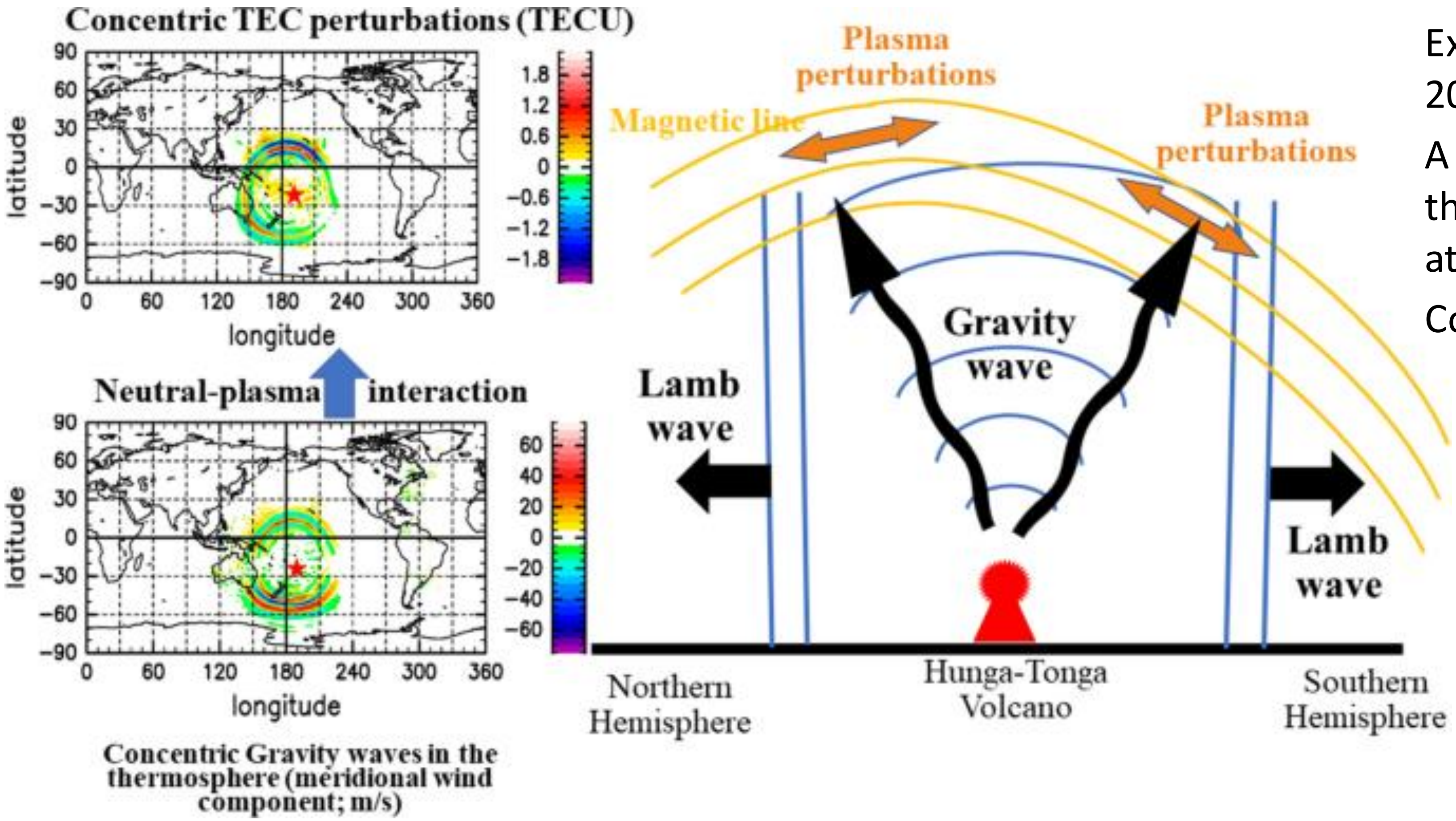
Cosmic2 GIS Ne (Oberheide, 2022)

Origin below: Sudden Stratosphere Warmings (SSW)

- Stratospheric winds variation of <10 m/s change ionospheric plasma tides by a factor of 2 and O/N_2 composition by 10%
- Semidiurnal enhancements substantially modify the low latitude F-region ionosphere, mainly through tidally driven E-region dynamo changes with resulting mapping of polarization electric fields into the F-region and vertical plasma drifts.
- Enhanced tides cause more wave breaking in the lower thermosphere, thus setting up an upward/poleward two-cell circulation in the lower thermosphere that depletes atomic oxygen.

Whole-Atmosphere Interconnections between the Polar Vortex and the Ionosphere-Thermosphere-Mesosphere: New Insights from Recent Modeling and Observational Studies (Thursday)

Origin below: Hunga-Tonga Explosion



Explosion: 15th January 2022, Pacific Ocean, 20S 175W

A volcanic eruption generates gravity waves that propagate upward into the atmosphere.

Concentric Ionosphere perturbations

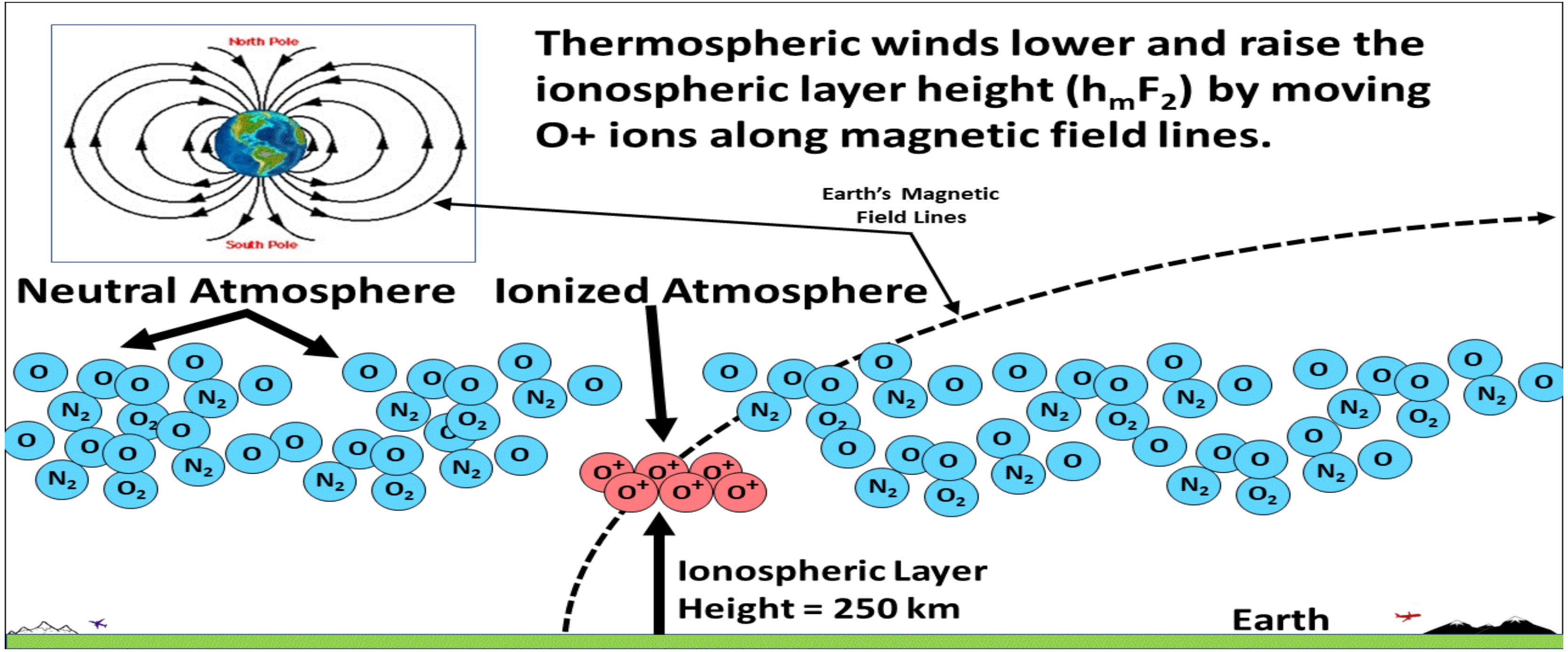
Miyoshi & Shinagawa, 2023

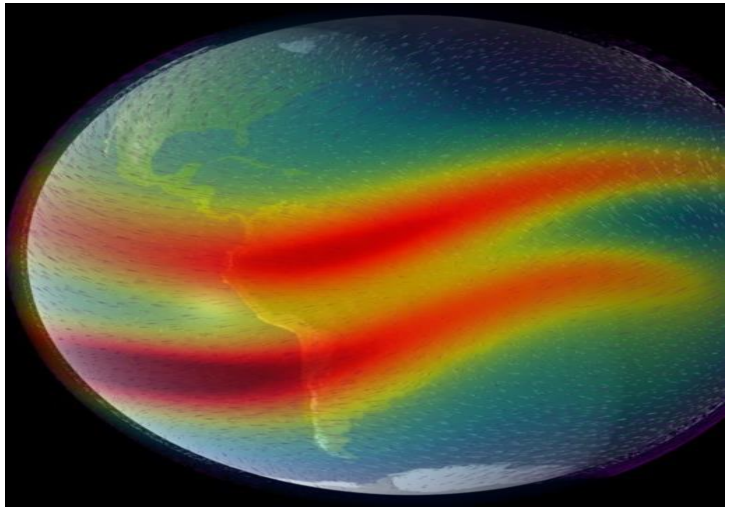
Key conclusions:

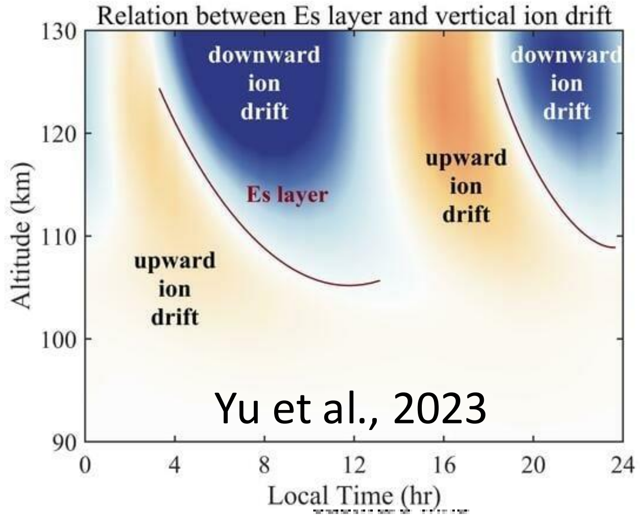
- Understanding ion-neutral interactions through **both chemical and dynamic processes** is essential for comprehending MTI (Mesosphere-Thermosphere-Ionosphere) coupling.
- The neutral atmosphere exerts **multiscale coupling mechanisms** on the ionosphere, driven by wave-wave interactions **originating from the lower atmosphere**.
- During **space weather events**, it is vital to understand and predict the coupling effects on space weather dynamics during **both quiet and active geomagnetic periods**.

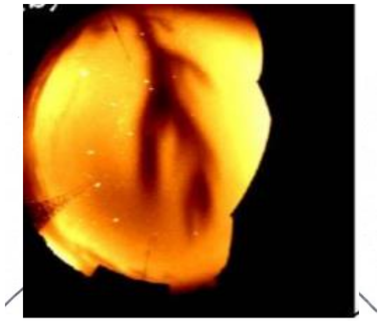
Key takeaways for CEDAR student participants:

- Identify open questions and gaps in our understanding of space weather through workshop sessions.
- Examine how observations and models are being utilized to study space weather dynamics during space weather events.









Dynamical processes:

Neutral influence to ionosphere

1. **Neutral Wind Dynamo**: In the ionospheric E-to-F-region, thermospheric winds can move the F region plasma through ion-neutral collisions both vertically and horizontally along geomagnetic field lines, drivi ionospheric currents, generating electric fields and influencing plasma distribution.
2. **Formation of Sporadic E Layers**: Vertical and horizontal wind shears in the neutral atmosphere can lead the convergence of ions and high ion density in metal layers in MLT region.
3. **TIDs seeding Equatorial Plasma Bubbles:** Wind perturbations create polarization electric field by modulating plasma density (or TIDs) via ExB drift, providing seeding effects for plasma bubbles via the Rayleigh-Taylor instability in the postsunset bottomside F-region via plasma depletion and TEC depletion

Ionosphere feedback to neutral

Ion drag: Ion-neutral collisions exert a drag force on neutral winds modifying its speed and direction