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ICASE
AEROSPACE SCIENCE ENGINEERING

Seventh International Conference on Aerospace Science & Engineering

Institute of Space Technology, Islamabad Pakistan

December 14-16, 2021

Build Geodetic Space Weather Research: Coupling Processes Between Magnetosphere, Thermosphere and Ionosphere

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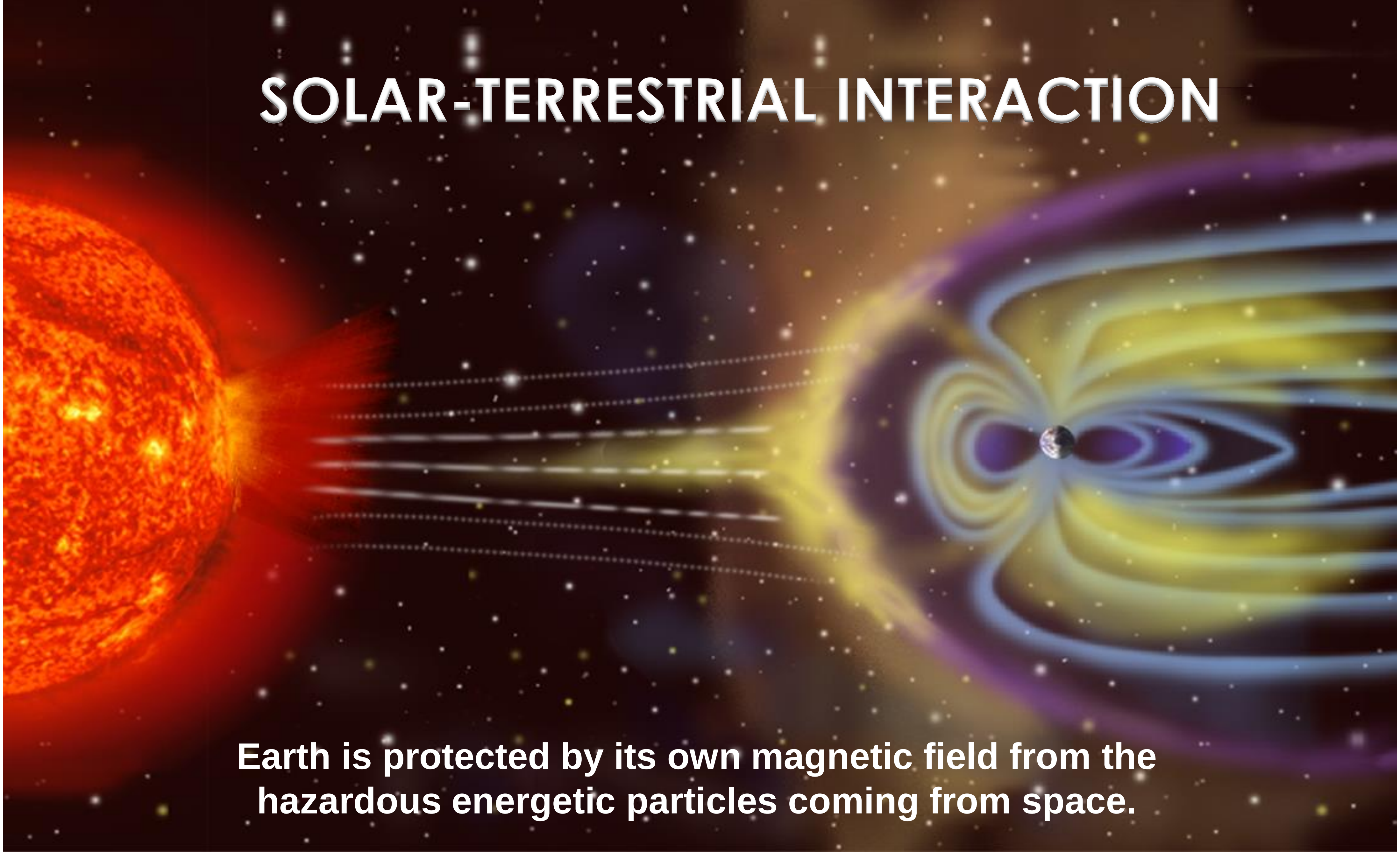
ICASE 2021, December 14-16, 2021, Islamabad, Pakistan

OUTLINE

1. Introduction
2. Methods
3. Results
4. Acknowledgments
5. Pictures
6. Thanks

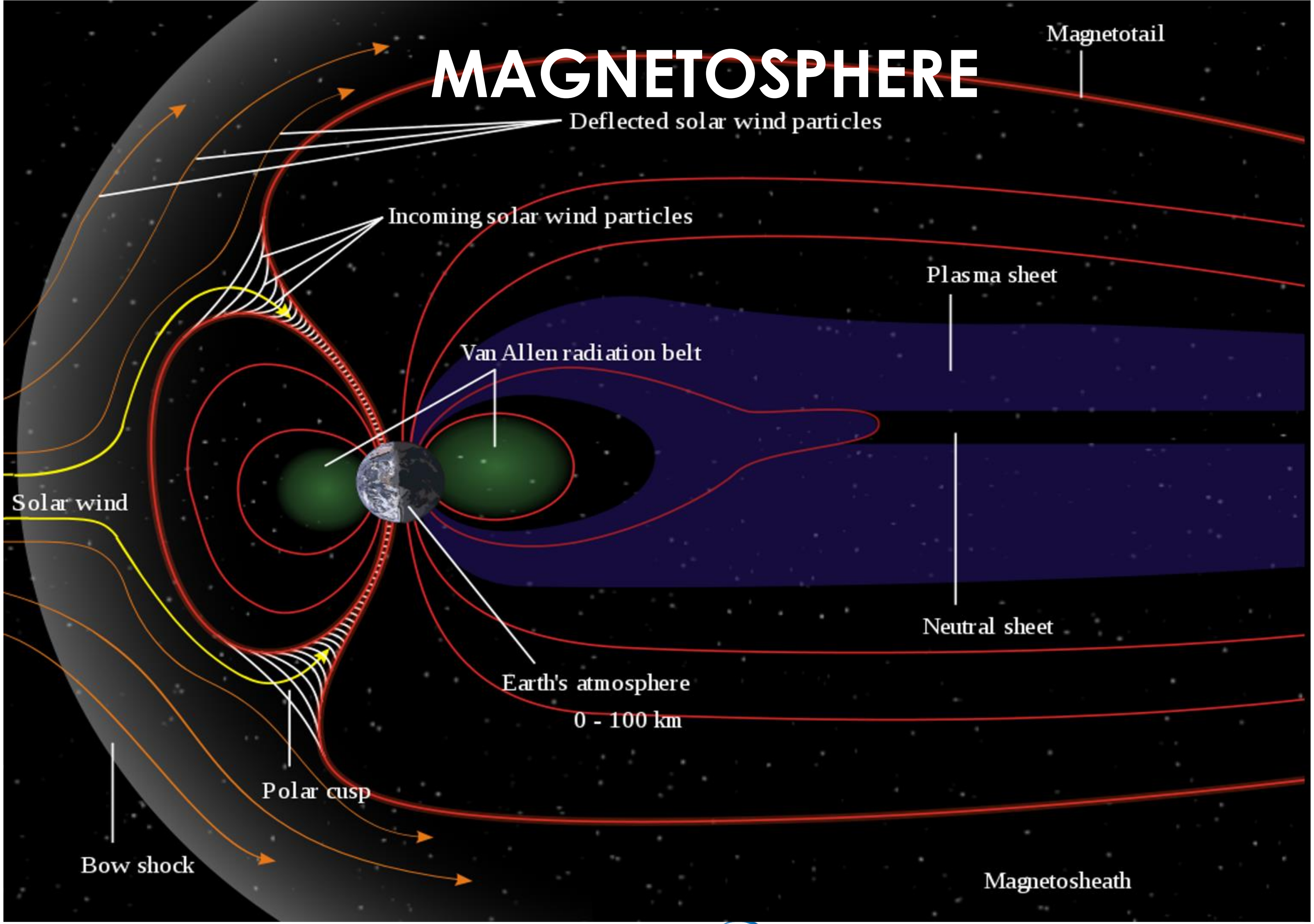
SOLAR-TERRESTRIAL INTERACTION



Earth is protected by its own magnetic field from the hazardous energetic particles coming from space.

http://sec.gsfc.nasa.gov/popscise.jpg

MAGNETOSPHERE



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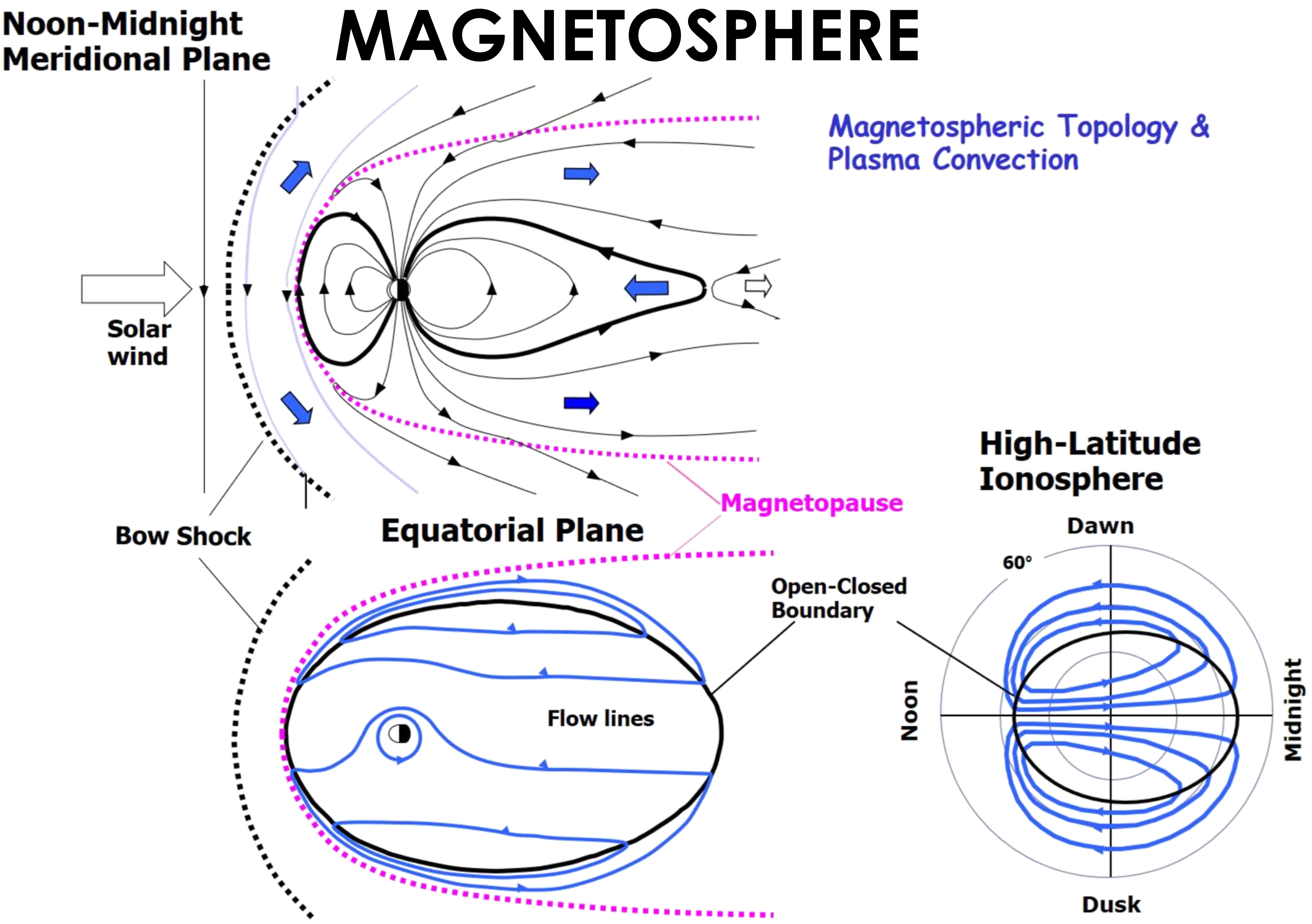
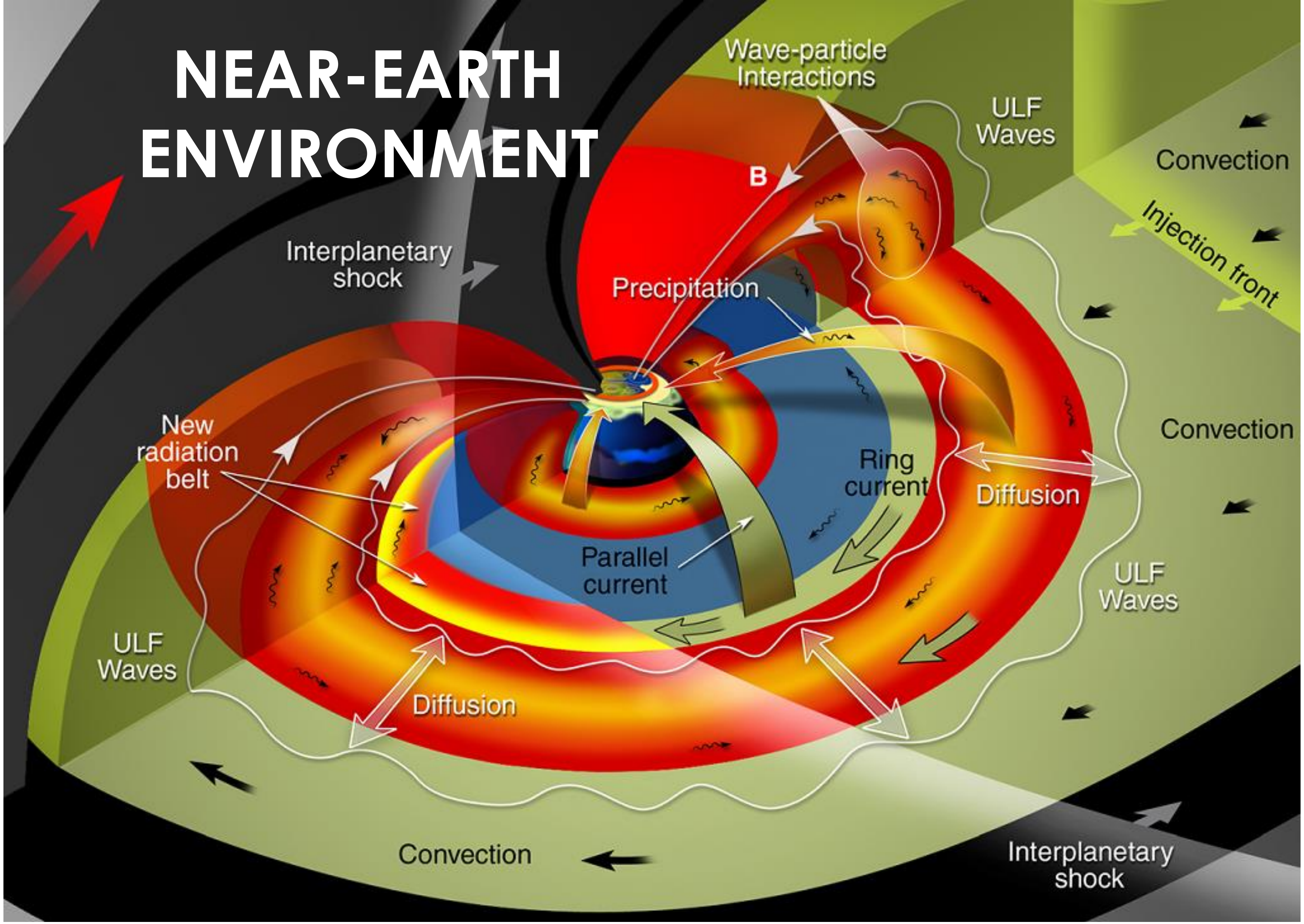
MAGNETOSPHERE

Magnetospheric Topology & Plasma Convection



Lu, G (2007) Summer School

NEAR-EARTH ENVIRONMENT

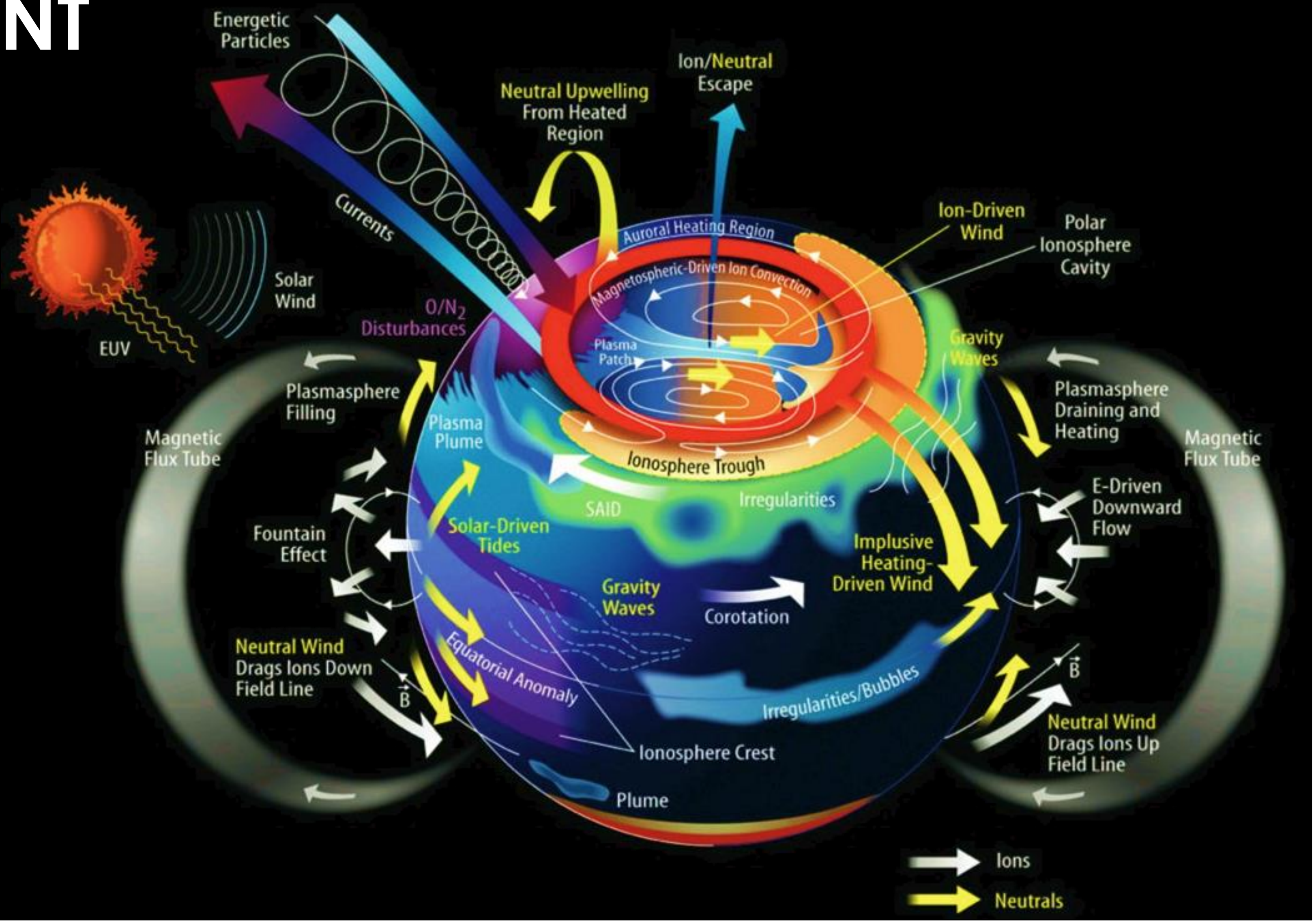


Mauk et al. (2013)

NEAR-EARTH ENVIRONMENT

The understanding of coupled processes in the Magnetosphere-Thermosphere-Ionosphere (**MTI**) is still a challenge.

Variations in the upper atmosphere are strongly influenced by solar and magnetospheric forcing.



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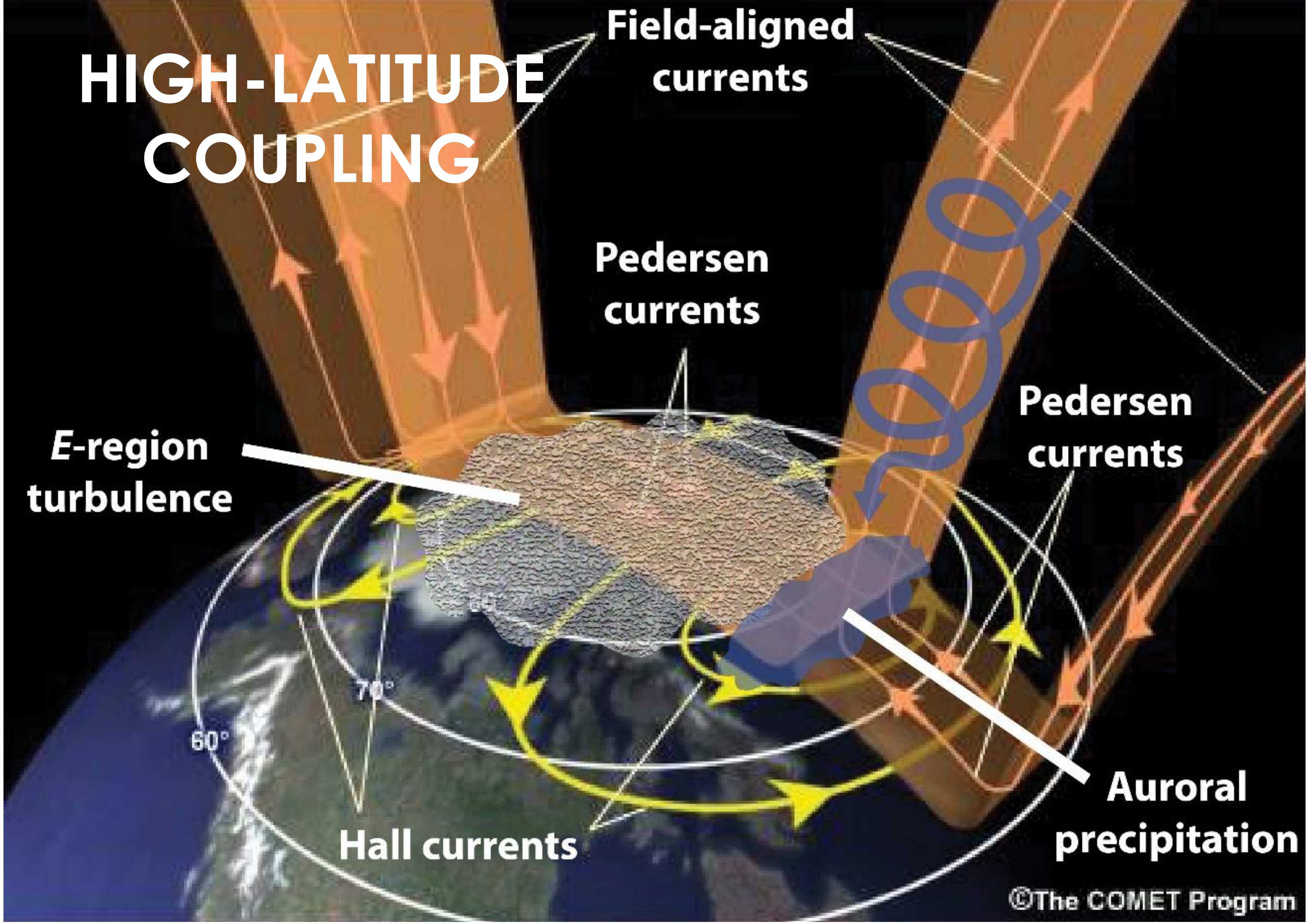
HIGH-LATITUDE COUPLING



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UPPER-ATMOSPHERE PHYSICS

Atmospheric Density column under Hydrostatic Equilibrium (above ~100 km):

$$N(z_0)=\int_{z_0}^{\infty} n(z_0)\exp\left[-\frac{z-z_0}{kT/m_i g}\right]dz = Hn(z_0)$$

z	is altitude
g(z)	is acceleration of gravity
r	is mass density
k	is Boltzmann's constant
m_i	is molecular weight of species

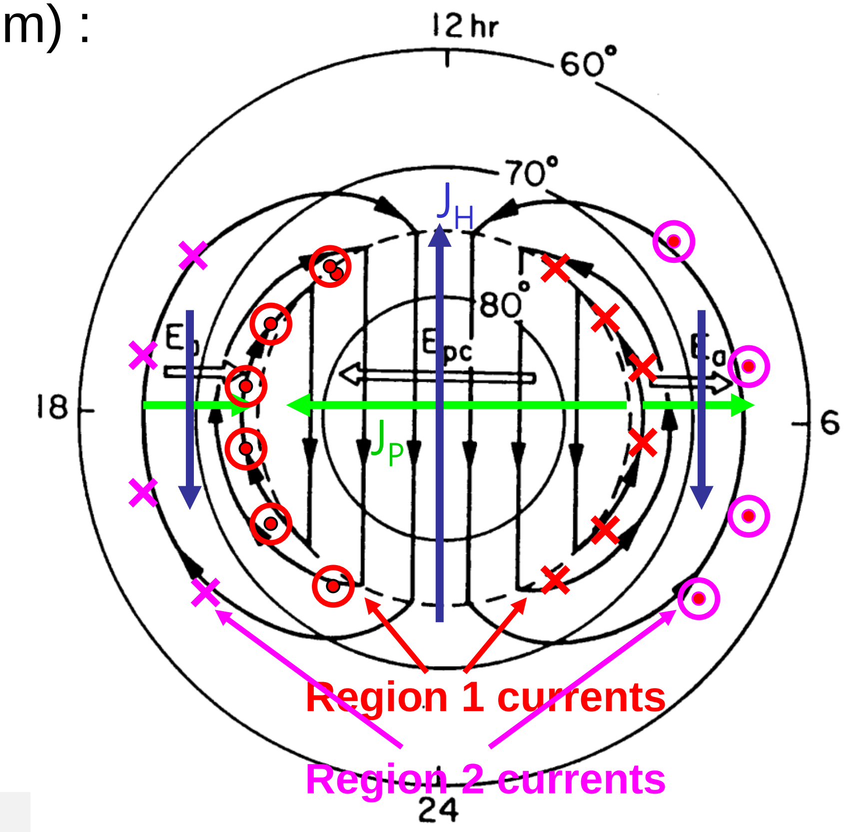
Electromagnetic Energy Dissipation (Poynting's theorem) :

$$\vec{J}\cdot\vec{E} = \underbrace{\left(\Sigma_P\vec{E}+\Sigma_H\vec{b}\times\vec{E}\right)}_{\text{Horizontal current}}\cdot\vec{E} = \underset{\text{Joule heating}}{\Sigma_p E^2}$$

Field-aligned Current: $j_{||} = -\nabla\cdot\vec{J}$

E including neutral wind is:

$$\vec{E}\rightarrow\vec{E}' = (\vec{E}+\vec{U}\times\vec{B}) = -(\underset{\text{Plasma drift velocity}}{\vec{V}} - \underset{\text{Neutral wind velocity}}{\vec{U}})\times\vec{B}$$

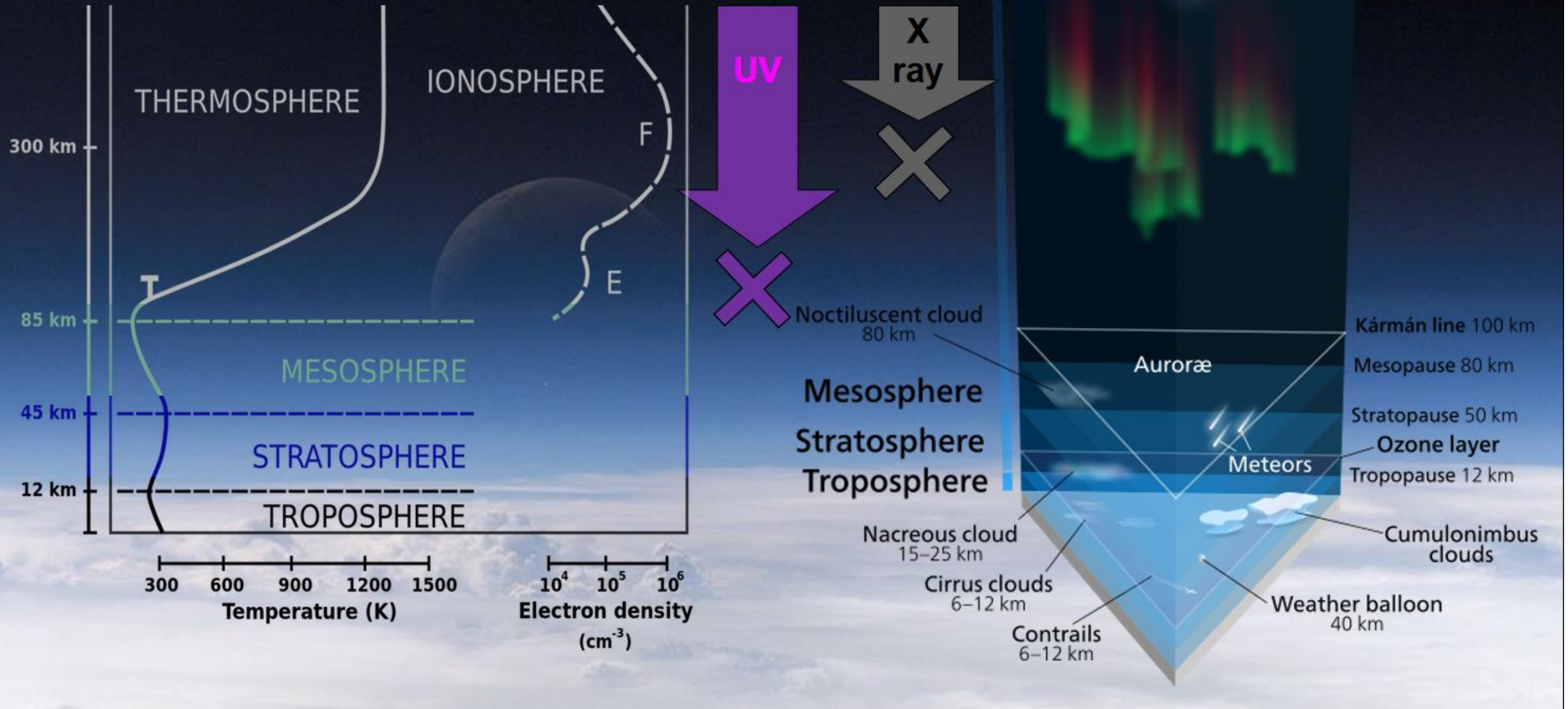


Region 1 currents

Region 2 currents

Lu, G (2007) Summer School

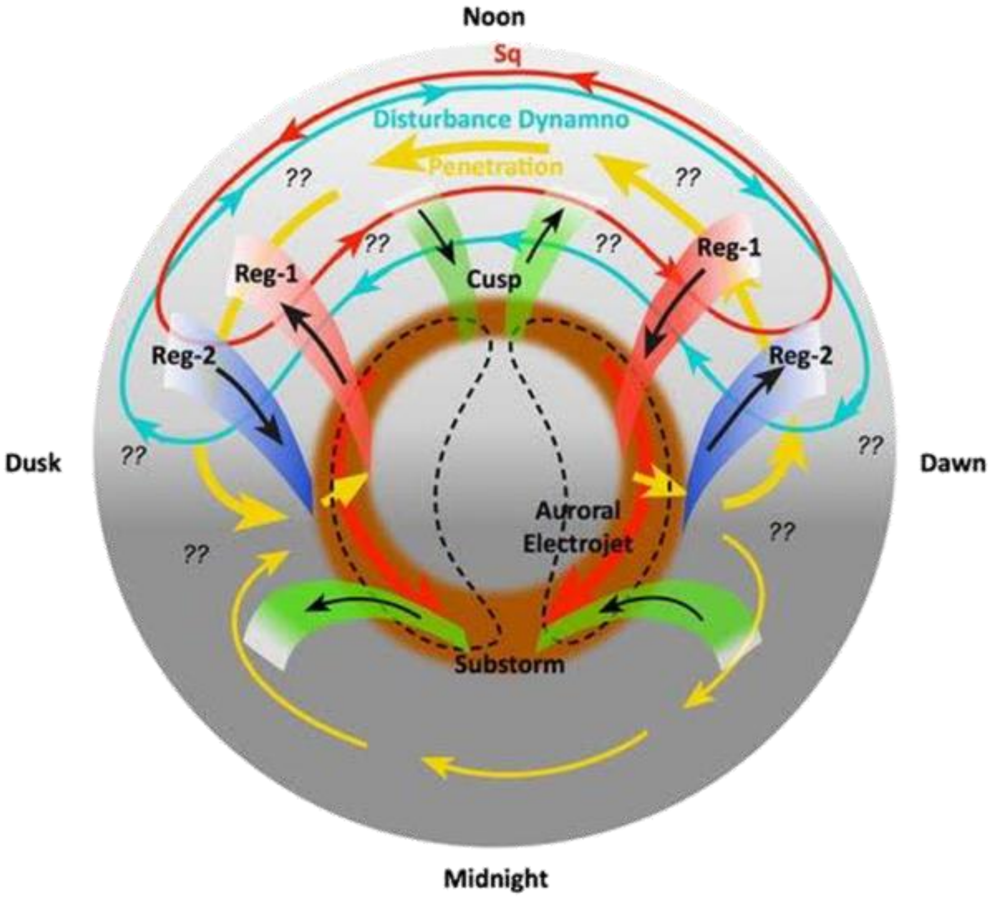
ATMOSPHERIC COUPLING

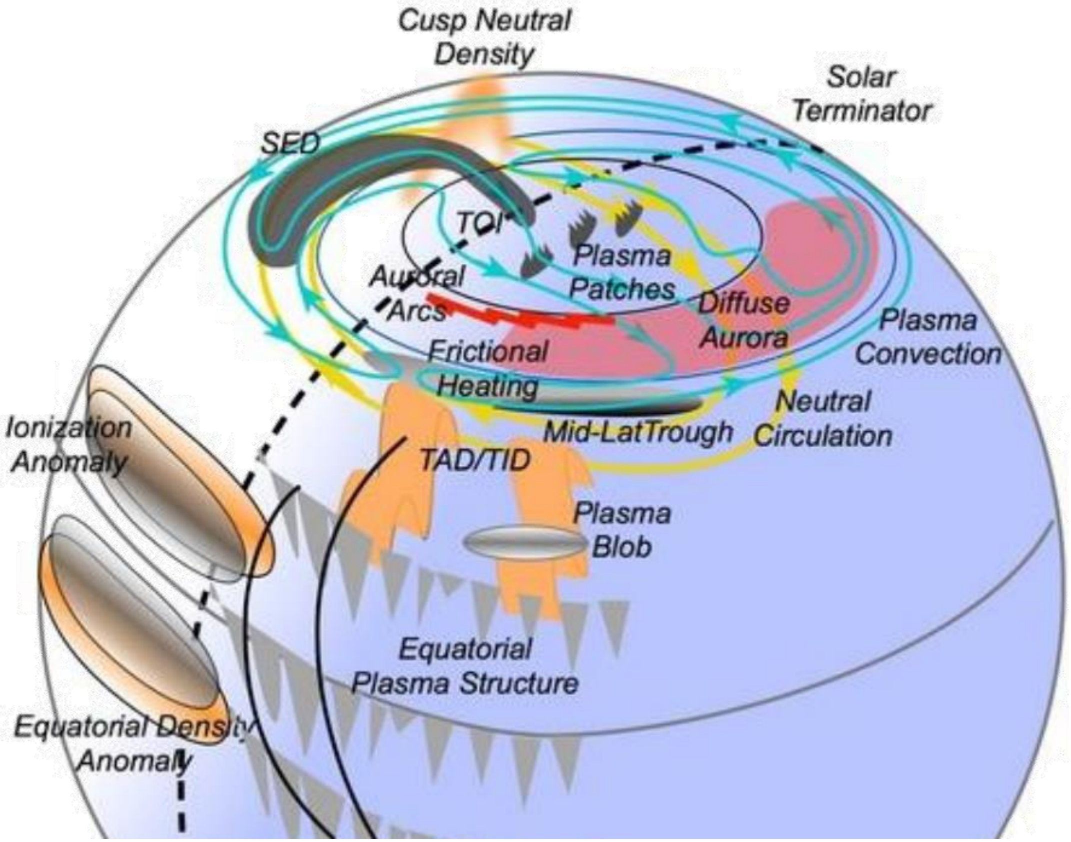


On the one side, highly energetic **solar radiation is absorbed in the thermosphere**, through ionization/dissociation of molecules, and thus **creating the ionosphere**.

ATMOSPHERIC COUPLING

On the other side, MTI is strongly influenced by **wave motions from the lower atmosphere**, and is coupled through **energetic particle precipitation and field-aligned currents**.





Heelis and Maute (2020)

UPPER-ATMOSPHERE PHYSICS

Thermodynamic equation:

$$\frac{\partial T_n}{\partial t}=\underbrace{\frac{ge^z}{p_0C_p}\frac{\partial}{\partial Z}\left\{\frac{K_T}{H}\frac{\partial T_n}{\partial Z}+K_EH^2C_p\rho\left[\frac{g}{C_p}+\frac{1}{H}\frac{\partial T}{\partial Z}\right]\right\}}_{\begin{array}{c}\textit{Molecular}\\ \textit{conduction}\end{array}}-\underbrace{\mathbf{v}_n\cdot\nabla T_n}_{\textit{Advection}}-\underbrace{W\left(\frac{\partial T_n}{\partial Z}+\frac{R^*T_n}{C_p\bar{m}}\right)}_{\textit{Adiabatic}}+\underbrace{\frac{Q^{\exp}-e^zL^{\exp}}{C_p}}_{\textit{Heating}}-\underbrace{L^{imp}T_n}_{\textit{Radiation}}$$

Momemtum equations:

Zonal velocity

$$\frac{\partial u_n}{\partial t}=\underbrace{\frac{ge^z}{p_0}\frac{\partial}{\partial Z}\left[\frac{\mu\partial u_n}{H\partial Z}\right]}_{\text{Viscosity}}+\underbrace{f^{corr}v_n}_{\text{Coriolis}}+\underbrace{\lambda_{xx}\left(v_{ExB,x}-u_n\right)+\lambda_{xy}\left(v_{ExB,y}-u_n\right)}_{\text{Ion drag}}-\underbrace{\mathbf{v}_n\cdot\nabla u_n}_{\begin{array}{c}\text{Horizontal}\\ \text{advection}\end{array}}+\underbrace{\frac{u_nv_n}{R_E}\tan\lambda}_{\text{Mommentum}}-\underbrace{\frac{1}{R_E\cos\lambda}\frac{\partial\Phi}{\partial\phi}}_{\text{Pressure gradient}}-\underbrace{W\frac{\partial u_n}{\partial Z}}_{\begin{array}{c}\text{Vertical}\\ \text{advection}\end{array}}-\underbrace{hd_u}_{\begin{array}{c}\text{Horizontal}\\ \text{diffusion}\end{array}}$$

Meridional velocity

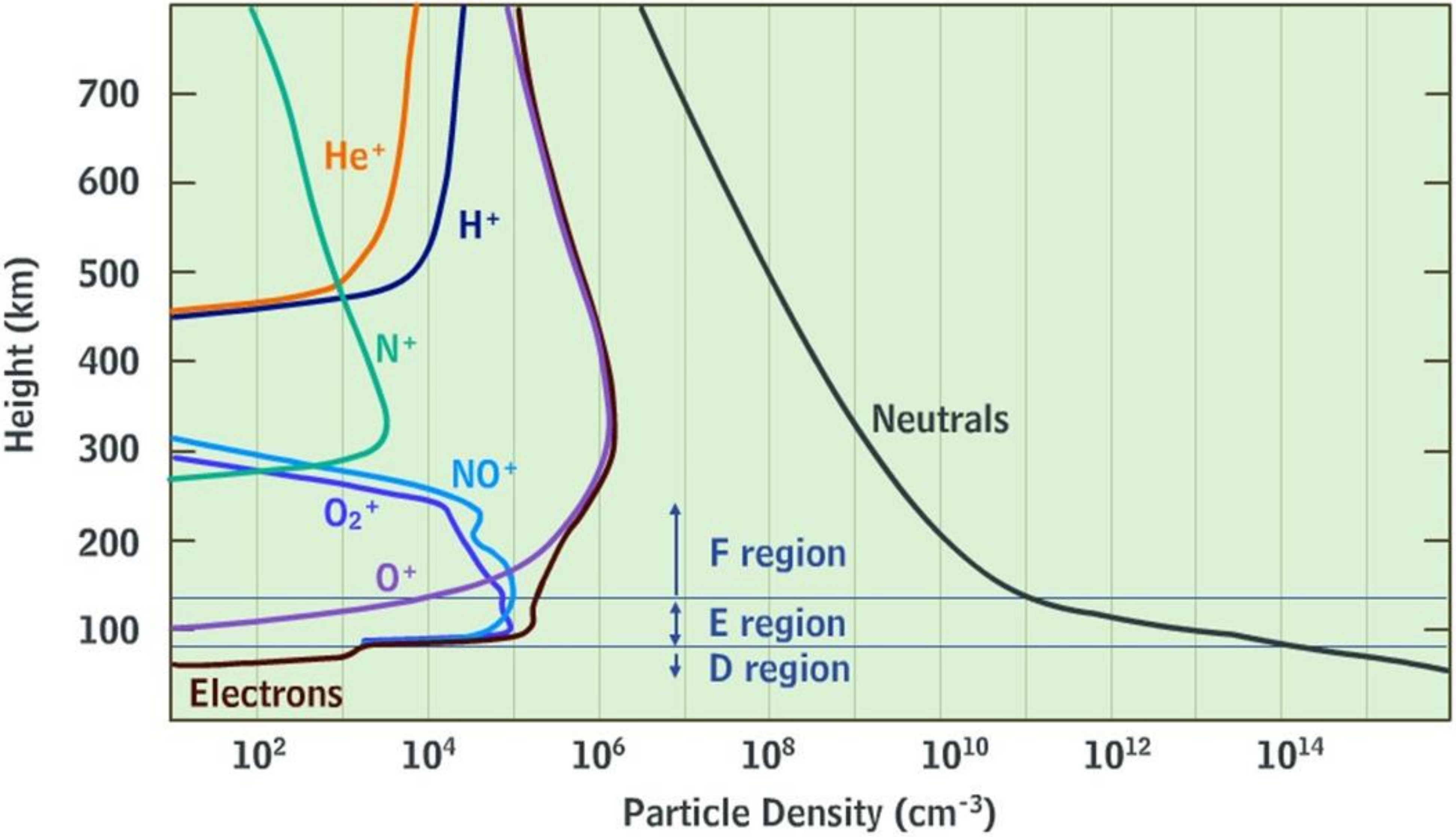
$$\frac{\partial v_n}{\partial t}=\underbrace{\frac{ge^z}{p_0}\frac{\partial}{\partial Z}\left[\frac{\mu\partial v_n}{H\partial Z}\right]}_{\text{Viscosity}}-\underbrace{f^{corr}v_n}_{\text{Coriolis}}+\underbrace{\lambda_{yy}\left(v_{ExB,x}-u_n\right)+\lambda_{xy}\left(v_{ExB,y}-u_n\right)}_{\text{Ion drag}}-\underbrace{\mathbf{v}_n\cdot\nabla v_n}_{\begin{array}{c}\text{Horizontal}\\ \text{advection}\end{array}}+\underbrace{\frac{u_nv_n}{R_E}\tan\lambda}_{\text{Mommentum}}-\underbrace{\frac{1}{R_E}\frac{\partial\Phi}{\partial\lambda}}_{\text{Pressure gradient}}-\underbrace{W\frac{\partial v_n}{\partial Z}}_{\begin{array}{c}\text{Vertical}\\ \text{advection}\end{array}}-\underbrace{hd_v}_{\begin{array}{c}\text{Horizontal}\\ \text{diffusion}\end{array}}$$

Continuity equation:

$$\frac{d\Psi}{dt}=\underbrace{-e^z\tau^{-1}\frac{d}{dz}\left\{\frac{m}{m_{N_2}}\left(\frac{T_0}{T}\right)^{0.25}\alpha^{-1}L\Psi\right\}}_{\begin{array}{c}\textit{Molecular}\\ \textit{diffusion}\end{array}}+\underbrace{e^z\frac{d}{dz}\left\{K(z)e^{-z}\frac{d\Psi}{dz}\right\}}_{\begin{array}{c}\textit{Eddy}\\ \textit{diffusion}\end{array}}-\underbrace{V\cdot\nabla\Psi}_{\begin{array}{c}\textit{Horizontal}\\ \textit{advection}\end{array}}-\underbrace{\omega\frac{d\Psi}{dz}}_{\begin{array}{c}\textit{Vertical}\\ \textit{advection}\end{array}}+\underbrace{S-R}_{\begin{array}{c}\textit{production}\\ \textit{and}\\ \textit{recombination}\end{array}}$$

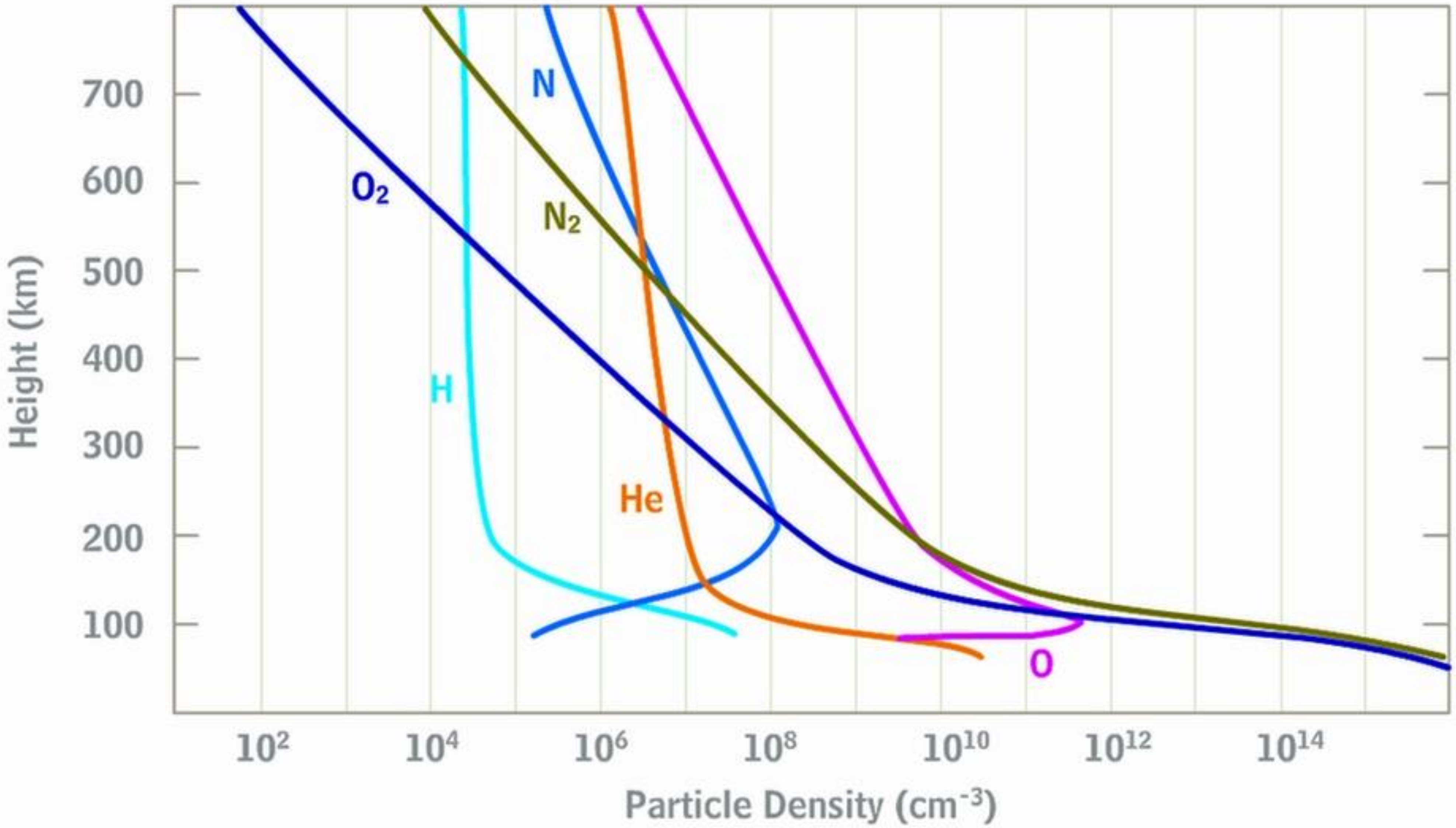
Maute, A (2018)

UPPER ATMOSPHERE COMPOSITION



http://www.meted.ucar.edu

NEUTRALS



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UPPER-ATMOSPHERE CHEMICAL PROCESSES

Photoionization:

$h\upsilon + O \Rightarrow O^+ + e^-$

$h\upsilon + O_2 \Rightarrow O_2^+ + e^-$

$h\upsilon + N_2 \Rightarrow N_2^+ + e^-$

Collisional Ionization:

$e^- + O \Rightarrow O^+ + 2e^-$

Charge Exchange:

$H + O^+ \Rightarrow H^+ + O$

$O_2 + O^+ \Rightarrow O_2^+ + O$

$N_2 + O^+ \Rightarrow N_2^+ + O$

Conversion:

$N_2^+ + O \Rightarrow NO^+ + O$

$N_2 + O^+ \Rightarrow NO^+ + O$

Recombination:

$O + O + N_2 \Rightarrow O_2 + N_2$

Dissociative Recombination:

$O_2^+ + e^- \Rightarrow O + O$

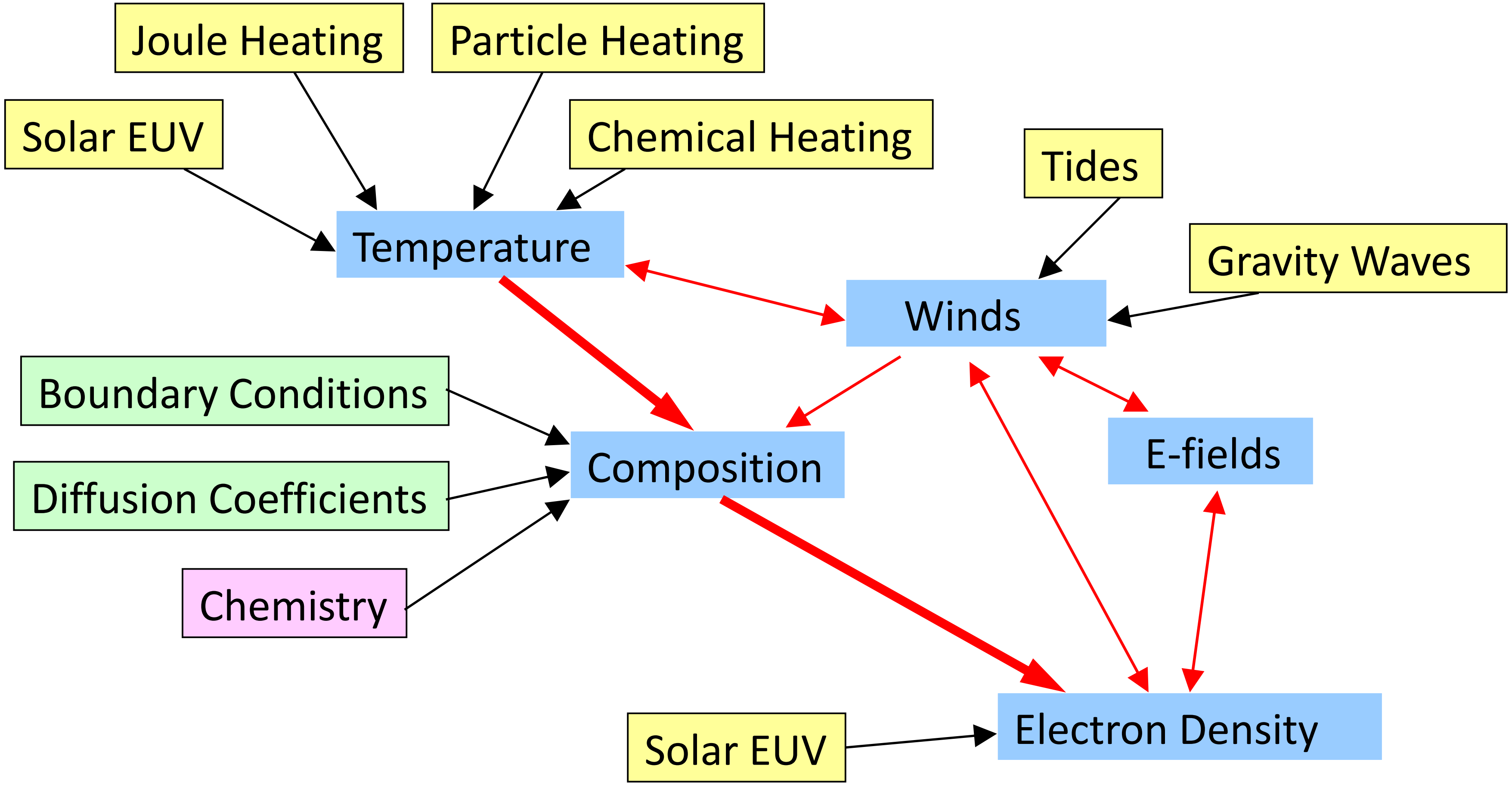
$N_2^+ + e^- \Rightarrow N + N$

$NO^+ + e^- \Rightarrow N + O$

Radiative Recombination:

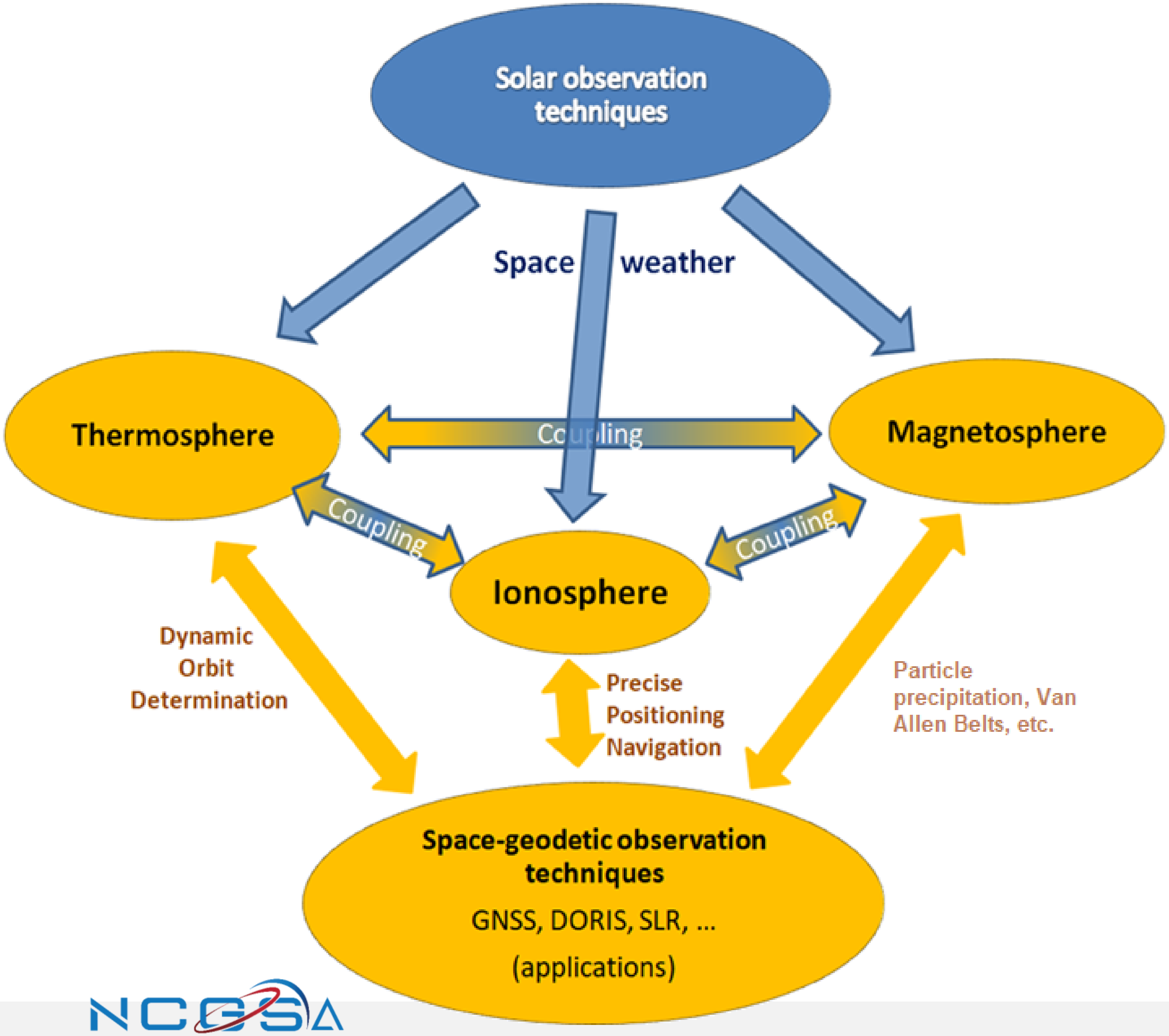
$O^+ + e^- \Rightarrow h\upsilon + O$

UNDERSTANDING UPPER-ATMOSPHERE PHYSICS



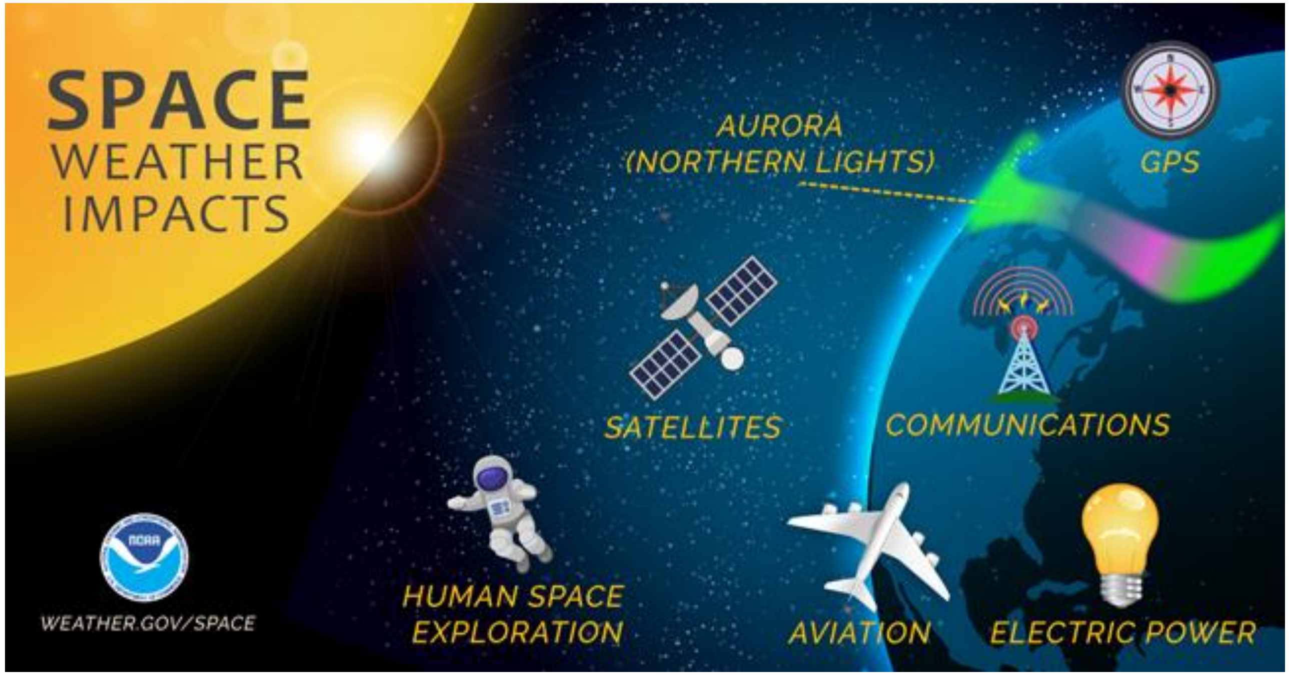
GEODETIC SPACE WEATHER RESEARCH

Research on upper atmosphere aims to contribute for a better **understanding** of Space Weather phenomena within the coupled MIT system, and for the formulation of **predictive models** of the near-Earth space environment.



SPACE WEATHER IMPACTS

- **Radio signal propagation** in the ionosphere, affecting GNSS, communications, etc.;
- **Drag force** on **Low Earth Orbit** (LEO) satellites; and
- **Power and internet outages** due to intense **electric currents** induced during geomagnetic storms, **killer electrons**, etc.



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A CHALLENGE TO UNDERSTAND THE MIT SYSTEM

Addressing the challenges related to the coupled MIT system requires significant advances in **geodetic observations** of plasma and neutral density, "compositions", and "velocities", observations of energetic particles and "magnetic field perturbations" both in space and on ground, as well as **advanced theoretic and numerical modeling** capabilities.

JOINT STUDY GROUP: MIT COUPLING

Implemented at International association of Geodesy (**IAG**) Inter-Commission Committee on Theory (**ICCT**); joint with IAG Global Geodetic Observing System (**GGOS**), Focus Area on Geodetic Space Weather Research (**FA-GSWR**); **IAG Commission 4 Positioning & Applications**; and **IAG Sub-Commission 4.3 Atmosphere Remote Sensing**.

Chair: Andres Calabia (Nanjing University Information Science Technology, China, University of Alcalá, Spain).
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17. Ayomide Olabode (Obafemi Awolowo University, Nigeria)

https://ggos.org/about/org/fa/geodetic-space-weather-research/groups/jsg1-coupling-processes/

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Space and Astroparticle Group

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Universidad de Alcalá

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MultiDark
Multimessenger Approach for Dark Matter Detection

CETA Ciemat

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Space/Planetary Exploration & Science (SPES)

Satellite Navigation and Remote Sensing Group (SNARS)

Welcome ...

Space/Planetary Exploration & Science (SPES) at SHAO led by Prof. Shuanggen Jin, aims to research and develop in space/planetary exploration techniques and methods, Earth/Planetary space environment, atmosphere, ionosphere, topography, surface processes, interior structure and dynamics as well as their interactions from, to and between satellites and/or Earth/Planetary surface using GNSS, InSAR, Space Geodesy, Millimeter Radiometry, (Near-) Infrared Sensors, LiDAR, Gravimeter, Accelerometer, Altimeter and Magnetometer, mainly including:

- Satellite Navigation and Space Geodesy
  (Satellite Navigation, Space Geodesy, GNSS-Reflectometry and GNSS Meteorology)
- Remote Sensing & Environmental Change
  (Remote Sensing, Satellite Gravimetry, Atmo/Ocean/Hydrologic Environment Change)
- Space/Planetary Exploration and Science
  (Space/Planetary Exploration, Atmo-/Ionosphere, Surface Process and Geodynamics)

Prof. Dr. Shuanggen Jin (AE/EAS/RANS/TUBA Members & IUGG Fellow)
Presidents of IAPS (2015-19), CPGPS (2016-17) & AOGS PS (2018-20)
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YESS community

*"The **YESS community** strives to help shape the future of Earth system science, by fostering international and transdisciplinary leaders of tomorrow who pioneer the development and delivery of research and knowledge, which provide solutions to benefit society, towards a more equitable and sustainable future".*

World Meteorological Organisation

WCRP

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GAW

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https://www.yess-community.org/

Early Career Researchers
NETWORK OF NETWORKS

APECS
Association of Polar Early Career Scientists

YHS

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Institute of Space Technology

ISLAMABAD, PAKISTAN

14th - 16th
DECEMBER 2021

Dr. Andres Calabia Aibar

KEYNOTE SPEAKER

Andres Calabia is a recognized academician & accomplished professional, skilled in topics of space geodesy, navigation & remote sensing. His research interests focus on upper atmosphere environments & coupling between Earth & space weather. In his early career, he has worked as a Geomatics Engineer in Spain & the UK. Then, he completed his Ph.D. at Shanghai Astronomical Observatory, Chinese Academy of Sciences, China, & a postdoctoral position at the University of Colorado Boulder, USA. Dr. Calabia has made significant contributions with a number of original results, including 20 peer-reviewed SCI journal papers, and several conference proceedings & book chapters.

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University of Alcalá, Alcalá de Henares, Madrid
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SELECTED PUBLICATIONS 2020-2021

Andres Calabia

Department of Physics and Mathematics, University of Alcalá, Alcalá de Henares, Madrid, Spain.

School of Remote Sensing and Geomatics Engineering, Nanjing University Information Science Technology, Nanjing, China.

ICASE 2021, December 14-16, 2021, Islamabad, Pakistan

2020

JGR Space Physics

AGU ADVANCING EARTH AND SPACE SCIENCE

Check for updates

RESEARCH ARTICLE

10.1029/2019JA027703

Special Section:
Long-term changes and trends in the Middle and Upper Atmosphere

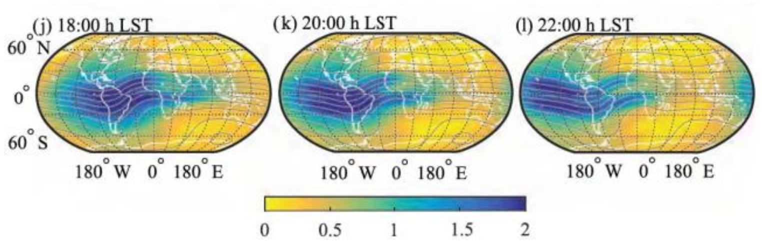
New Modes and Mechanisms of Long-Term Ionospheric TEC Variations From Global Ionosphere Maps

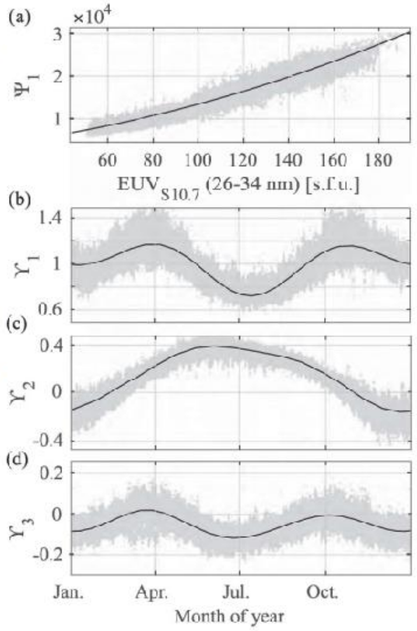
Andres Calabia[1,2] and **Shuanggen Jin**[1,2,3]

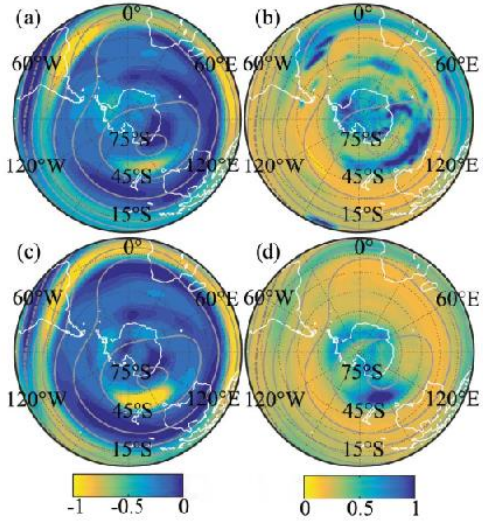
[1]School of Remote Sensing and Geomatics Engineering, Nanjing University of Information Science and Technology, Nanjing, China, [2]Jiangsu Engineering Center for Collaborative Navigation/Positioning and Smart Applications, Nanjing, China, [3]Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai, China

Key Points:

- The solar and the magnetospheric forcing are the main drivers of nonperiodic ionospheric TEC variations
- Main periodic contributions to TEC variations are related to the frequencies of the solar rotation, annual, and subharmonics
- TEC anomaly has been found at about 15° from the South magnetic dip at the night side, more prominent around 52°S 155°E







Journal of Atmospheric and Solar–Terrestrial Physics 199 (2019) 105207

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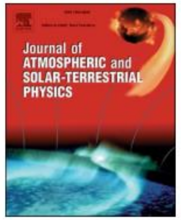
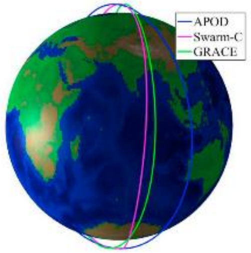
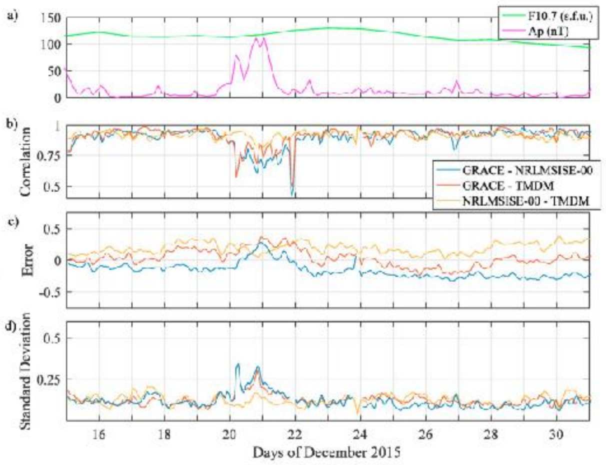


Assessment of new thermospheric mass density model using NRLMSISE-00 model, GRACE, Swarm-C, and APOD observations

Andres Calabia, Geshi Tang *, Shuanggen Jin **

School of Remote Sensing and Geomatics Engineering, Nanjing University of Information Science and Technology, Nanjing, 210044, China





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Space Weather

2021

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RESEARCH ARTICLE

10.1029/2020SW002645

Special Section:
Small Satellites for Space Weather Research and Forecasting Workshops

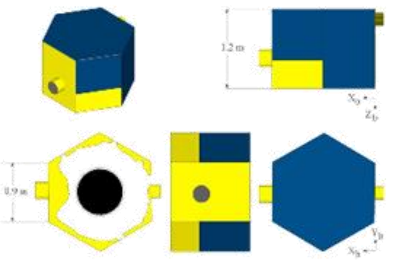
Upper-Atmosphere Mass Density Variations From CASSIOPE Precise Orbits

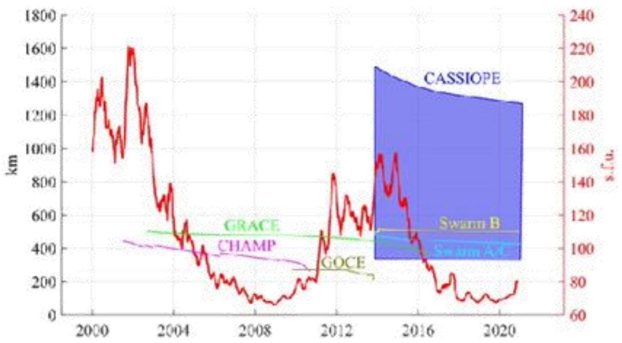
Andrés Calabia[1,2] and **Shuanggen Jin**[1,3]

[1]School of Remote Sensing and Geomatics Engineering, Nanjing University of Information Science and Technology, Nanjing, China, [2]School of Land Surveying, Geodesy and Mapping Engineering, Universidad Politécnica de Madrid, Madrid, Spain, [3]Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai, China

Key Points:

- Thermospheric mass densities are estimated from CAScade SmallSat and IOnospheric Polar Explorer precise orbits
- The detailed thermospheric mass density responses are obtained during the February 2014 geomagnetic storm
- CASSIOPE-derived thermospheric mass density is better than the NRLMSIS-00 model to reflect responses to the storm





JGR Space Physics

RESEARCH ARTICLE

10.1029/2021JA029540

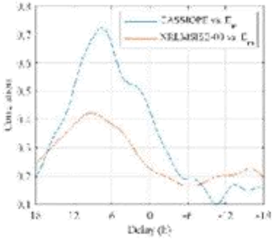
Thermospheric Mass Density Disturbances Due to Magnetospheric Forcing From 2014–2020 CASSIOPE Precise Orbits

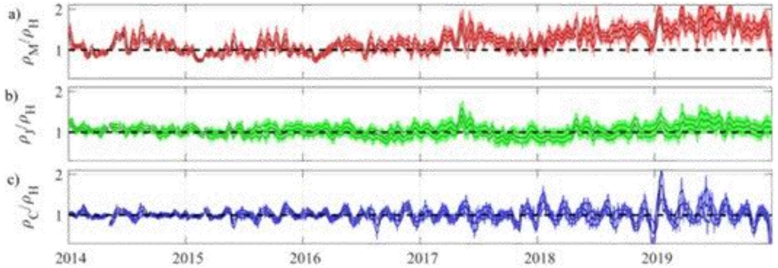
Andrés Calabia[1] and **Shuanggen Jin**[1,2]

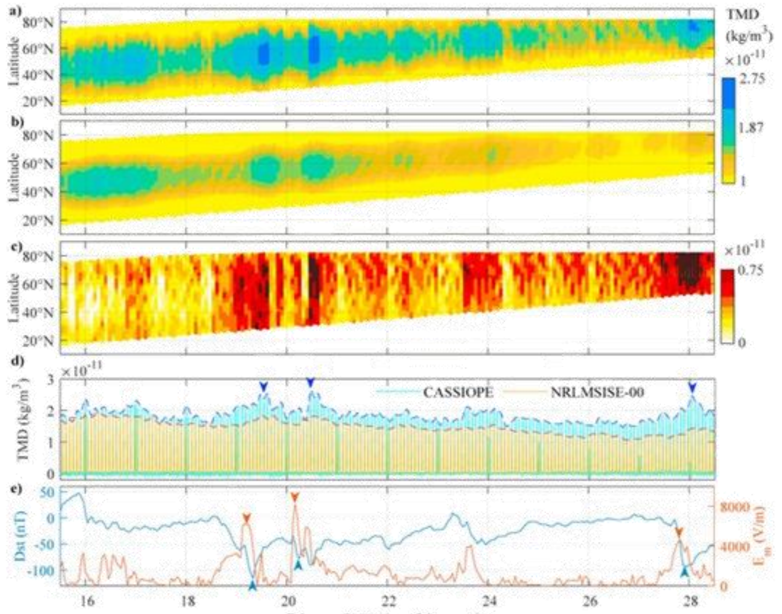
[1]School of Remote Sensing and Geomatics Engineering, Nanjing University of Information Science and Technology, Nanjing, China, [2]Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai, China

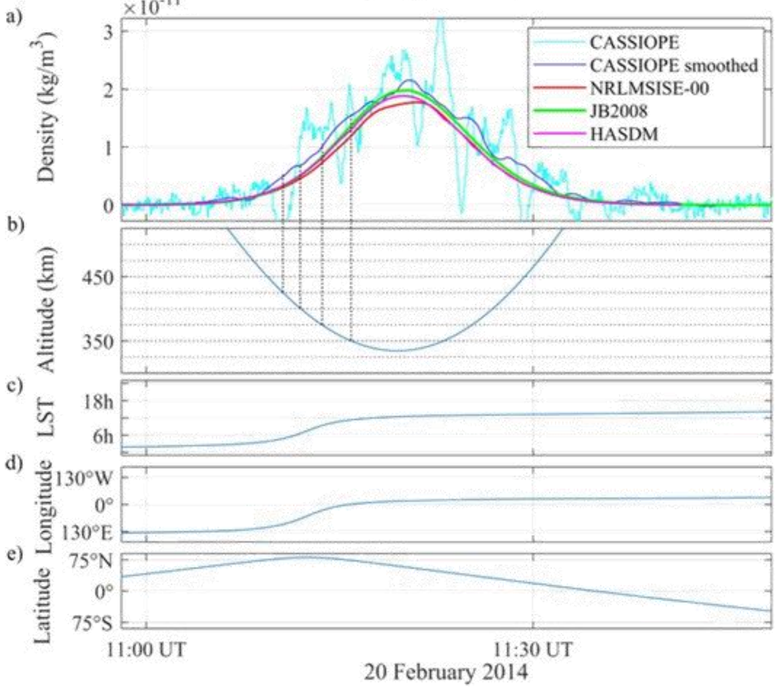
Key Points:

- Thermospheric mass densities from 2014 to 2020 are estimated from CAScade SmallSat and IOnospheric Polar Explorer Global Navigation Satellite System (GNSS) precise orbits
- The high-resolution thermospheric mass densities inferred from commercial-off-the-shelf GNSS receivers are validated
- The density disturbances due to magnetospheric forcing are investigated for correlations and time-delay responses to models and indices









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Upcoming Frontiers Research Topic

Advances on upper-atmosphere characterization for geodetic space weather research and applications'

Guest Editors:
Andrés Calabia aibar, Nanjing University of Science and Technology,
Gang Lu, National Center for Atmospheric Research (UCAR)

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Thank you!

Dr. Andres Calabia Aibar

Space geodesy, navigation, and remote sensing. Data analysis and algorithm development.

Research interests
Upper atmosphere environments and coupling between Earth and space weather, the repercussions of these environments on satellites, and the utilization of geodetic techniques to interpret the planetary variability, and to test, validate, and develop geophysical models.

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