Global-Scale Modeling of Wave-Induced Atmospheric Coupling and Validation

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Big picture – whole atmosphere coupling

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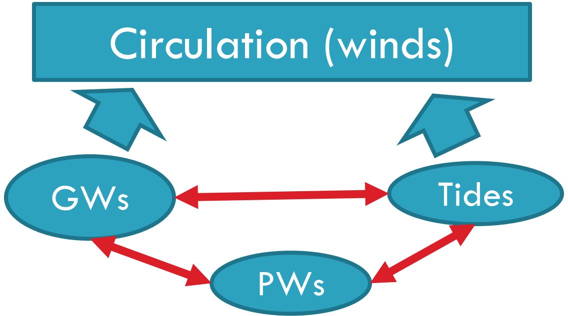
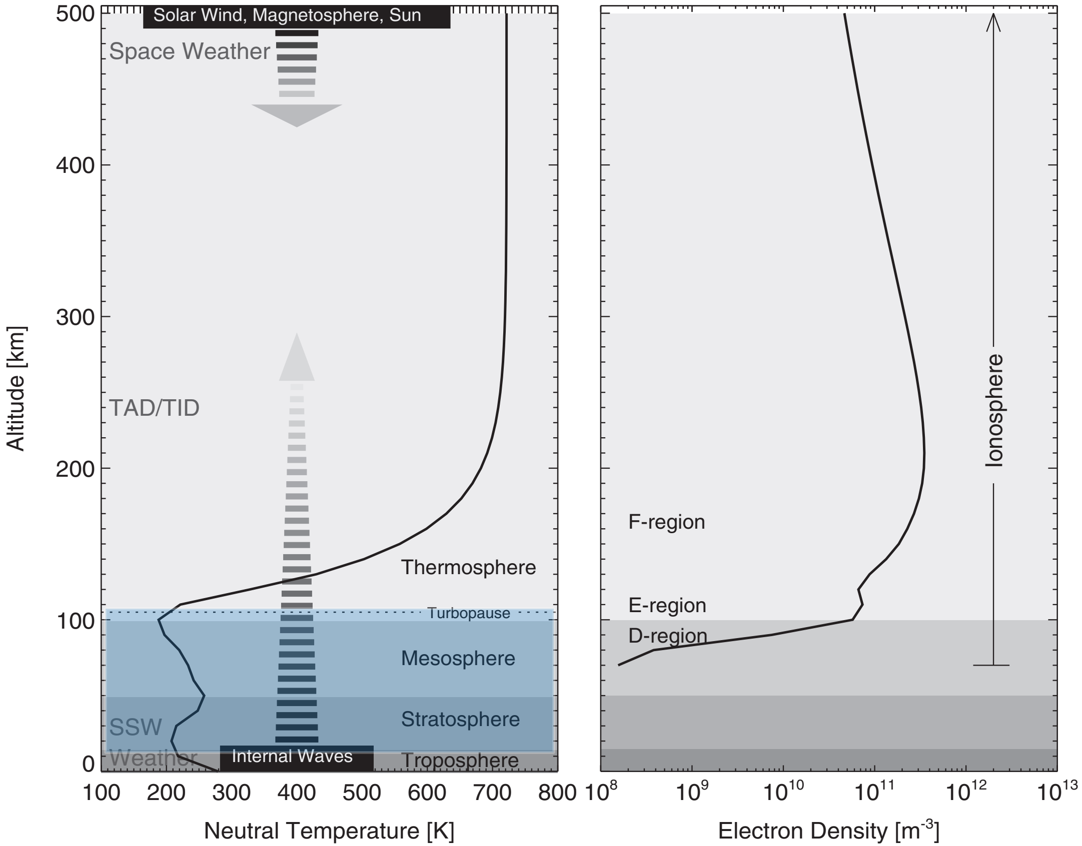
- Energy/momentum transfer processes due to waves and transient processes.
- Studying processes (or atmospheric layers) in isolation yields only a limited understanding of the "true picture".

➔ **Whole atmosphere view**





(Yiğit and Medvedev, 2015, ASR)

Whole atmosphere GW parameterization

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- **Physics:** GW dissipation (β) by
  - molecular diffusion & thermal conduction,
  - ion friction,
  - nonlinear diffusion
  - turbulent viscosity,
  - radiative damping.
- <u>Asymmetry</u> and <u>anisotropy</u>
- Assumptions:
  - Single-column approach
  - Instantaneous response

- **Input**
  - GW spectrum (at the source)
  - $\lambda_H, \overline{u'w'}_0$
- **Output:**
  - Evolution of wave flux
  - GW drag, GW heating/cooling
- No intermittancy factor
- Currently implemented in
  - CMAT2 (UCL, Mason)
  - Leibniz Institute Middle Atmosphere Model
  - Kyushu University Whole Atmosphere GCM
  - MPI-MGCM (MPS Göttingen)
  - Venus-TGCM (NASA Ames, Michigan)
  - M-GITM (University of Michigan)
  - WACCM (NCAR)
  - GEM-Mars (Belgium)

Magnetized planets

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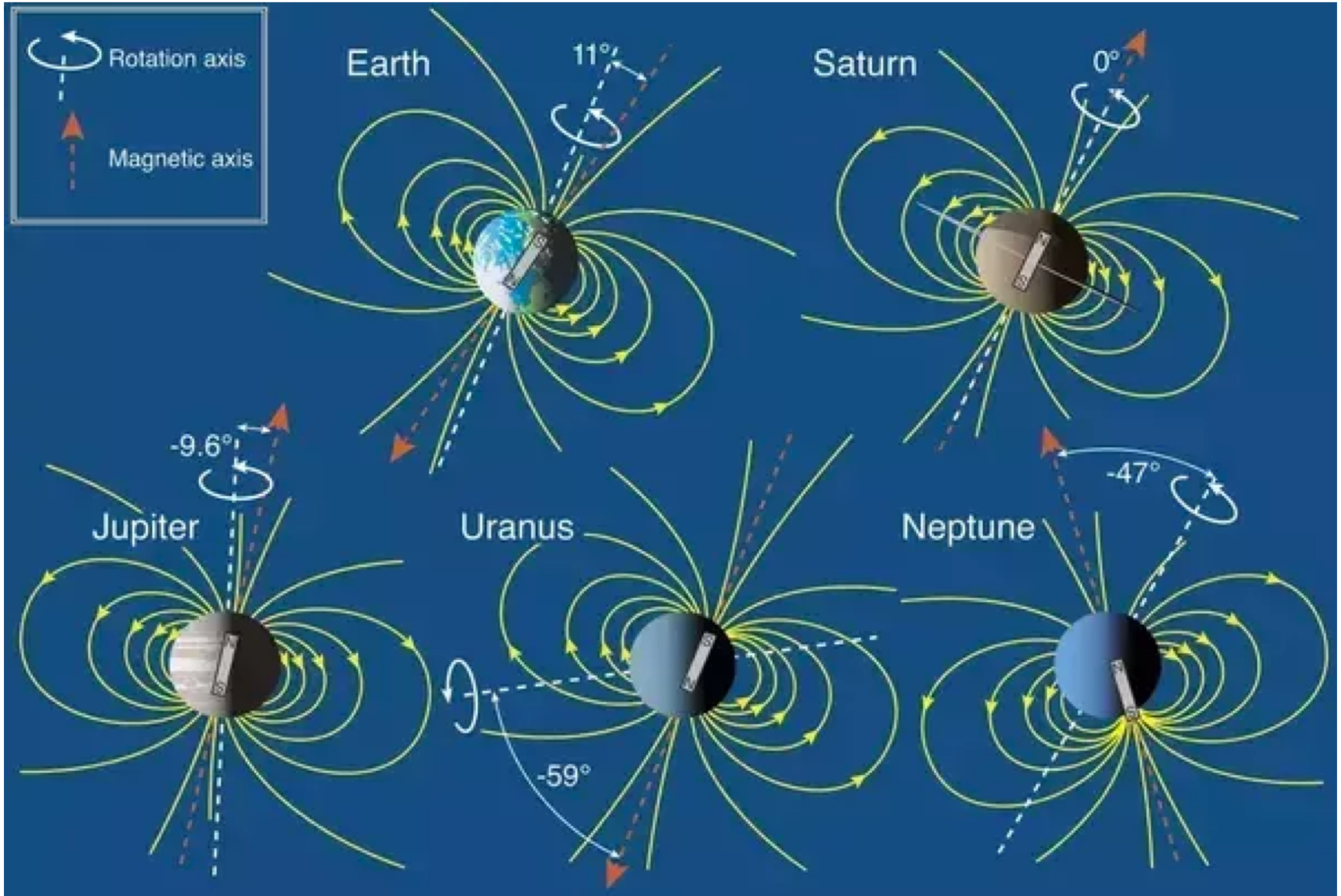

Magnetic field effects and GW dissipation

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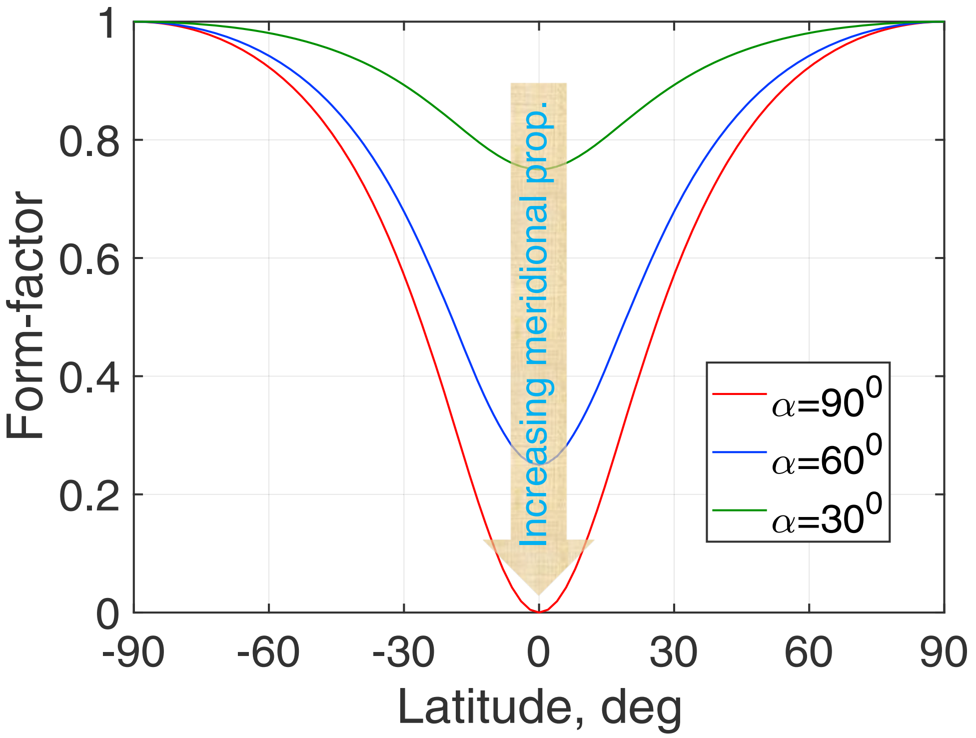
- Ion friction damping ←→ magnetic field **geometry**
- GW propagation direction
  - depends on propagation azimuth wrt. geomagnetic latitude
    - $\alpha = 0°$: pure zonal prop.
    - $\alpha = 90°$: pure meridional prop.
  - independent of |**B**|

$$\beta_{\text{ion}}^{j} = \frac{\nu_{\text{ni}} N}{k_h |c_j - \bar{u}|^2} \underbrace{\left(\cos^2\alpha + \sin^2\alpha \cos^2\gamma \right)}_{\mathbf{F}},$$



(Medvedev, Yiğit, Hartogh, 2017, JGR-Space)

Magnetic field effects and GW dissipation

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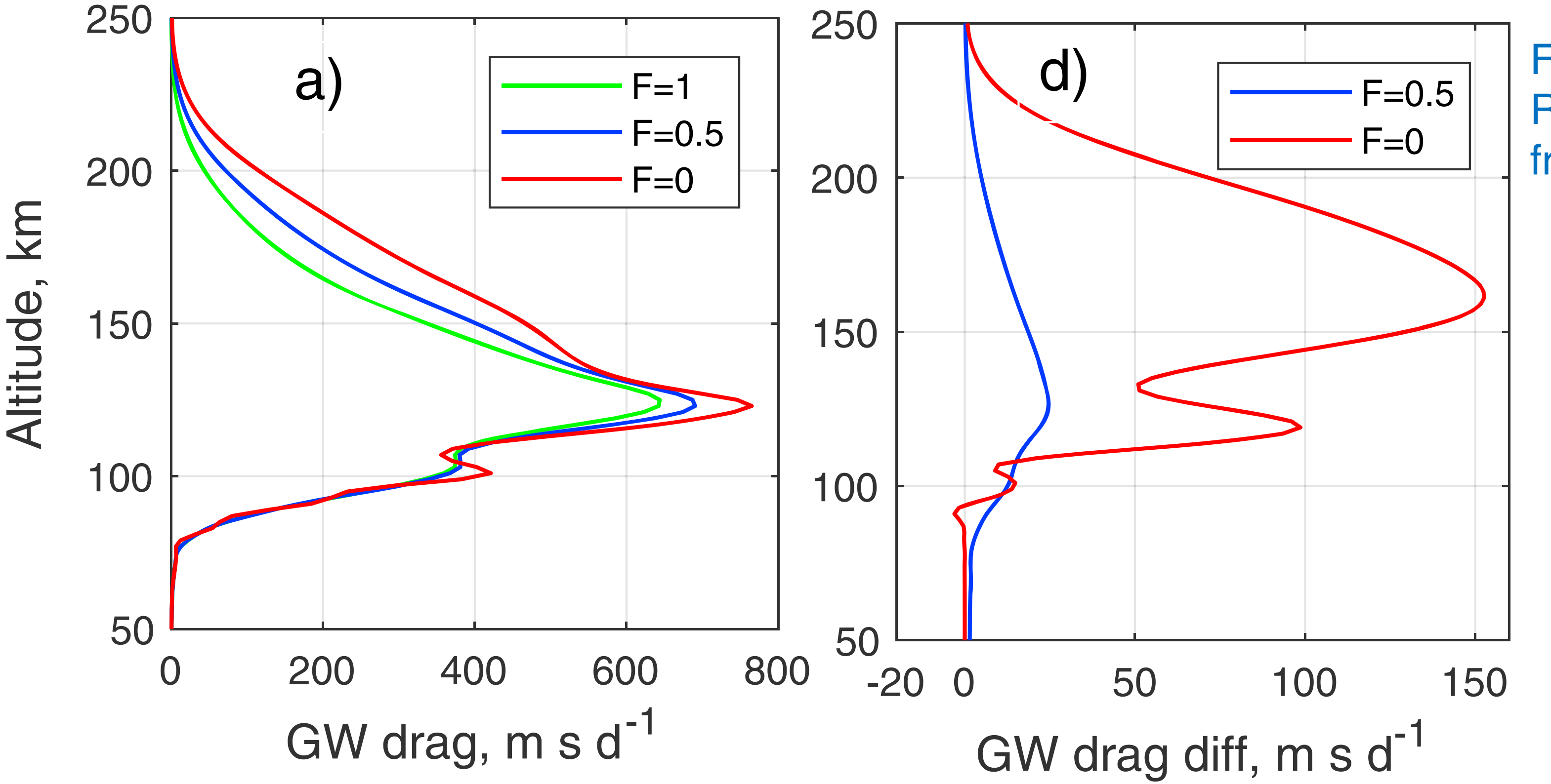

F<1:
Reduced ion friction damping

(Medvedev et al., 2017, JGR-Space)

CMAT2 general circulation model (GCM)

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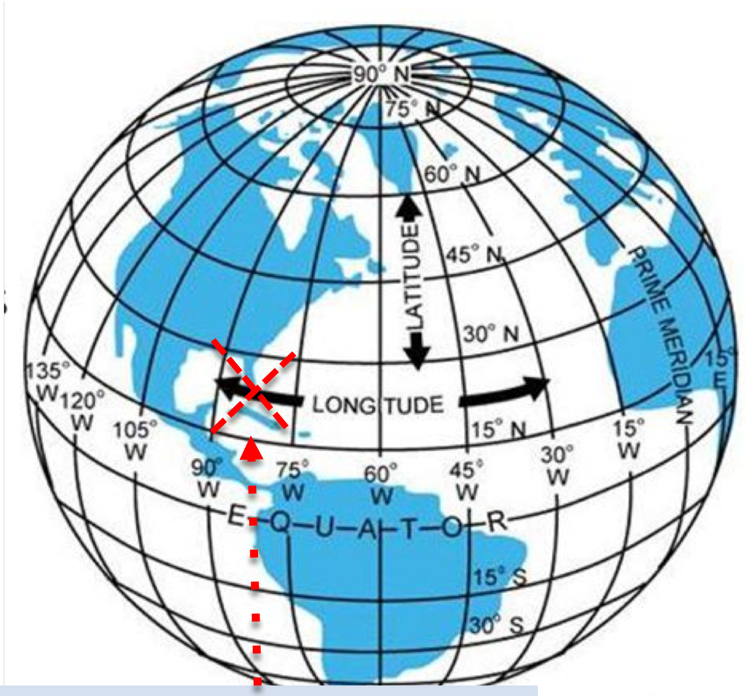
→ GCM

- CMAT2 (Coupled Middle Atmosphere Thermosphere-2)
  - ~15-500 km
  - $2^o \times 15^o$ resolution
  - Planetary waves, tides from (GSWM, NCEP)
  - Realistic magnetic fields from IGRF
  - Coupled to solar and geomagnetic inputs
  - High-latitude momentum and energy sources.



Gravity wave parameterization [Yiğit et al. 2008, JGR]

Motivation: Modeling of GWs during a minor warming

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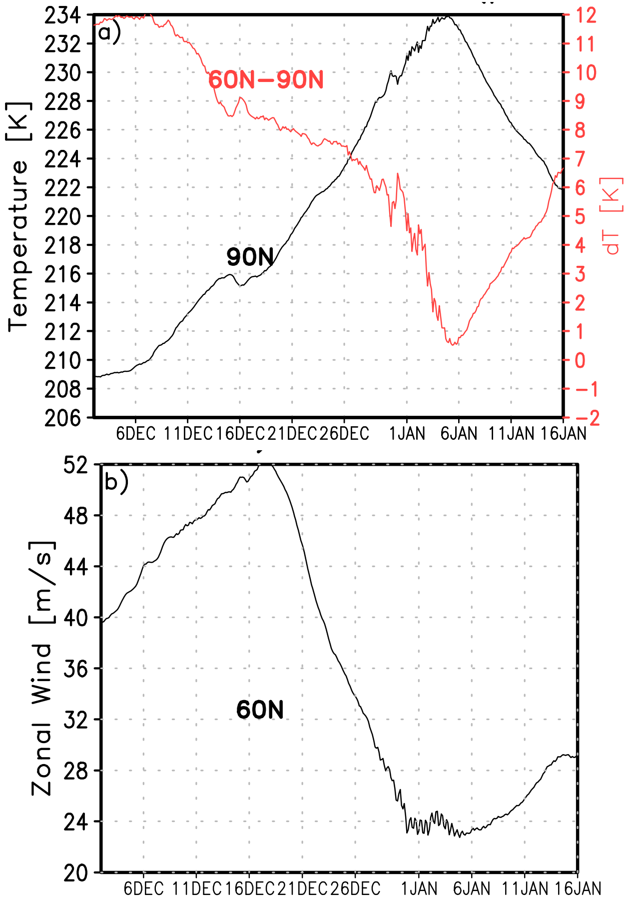

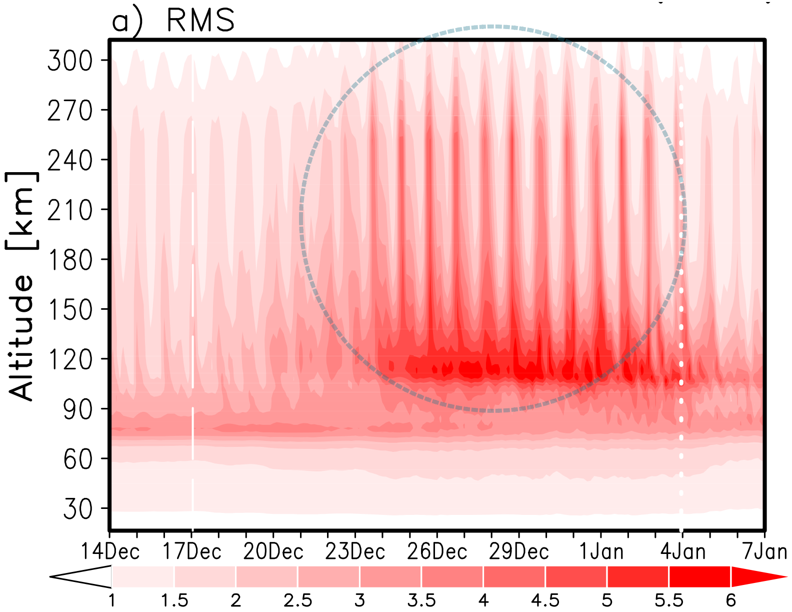

- Thermospheric GW activity increases up to a factor of three during a minor warming
- CMAT2 + Whole atmosphere GW param.

  [Yiğit and Medvedev, 2012, GRL]

GW activity – ionosphere during a major warming

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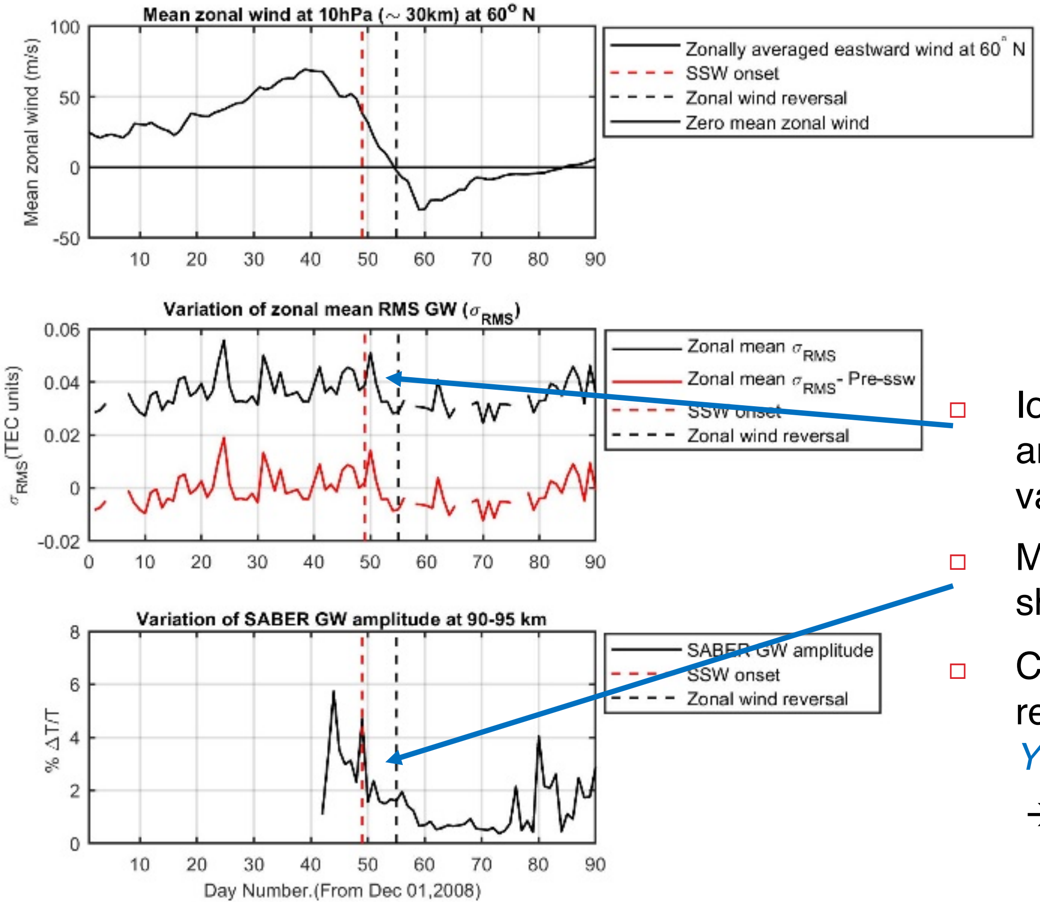
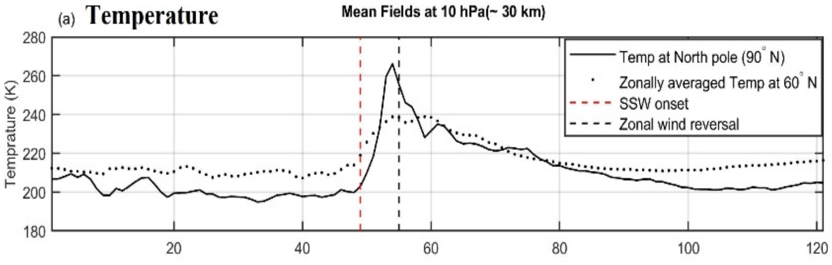




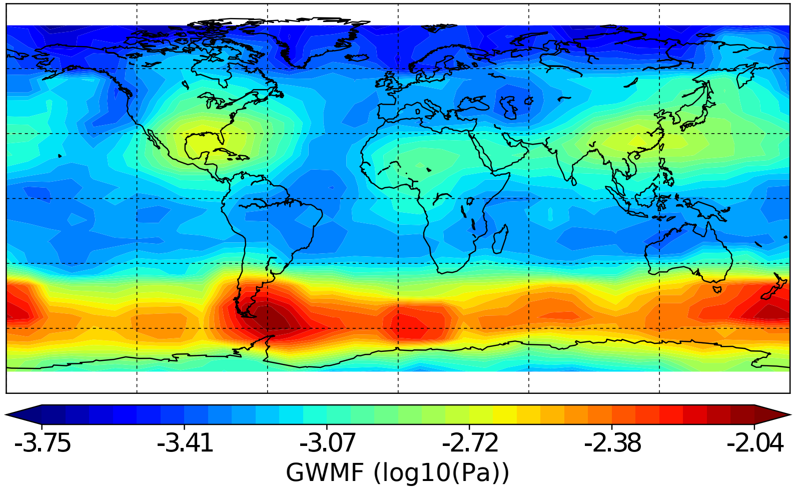
- Ionospheric GW activity from GPS-TEC decreases around u-reversal as observed in terms of TEC variations.
- Middle atmosphere GW activity from SABER also shows similar decrease.
- Competition between westerly and easterly GWs in a region of weak easterly/westerly winds *[Nayak and Yiğit, 2019]*

→ Decrease in GW activity

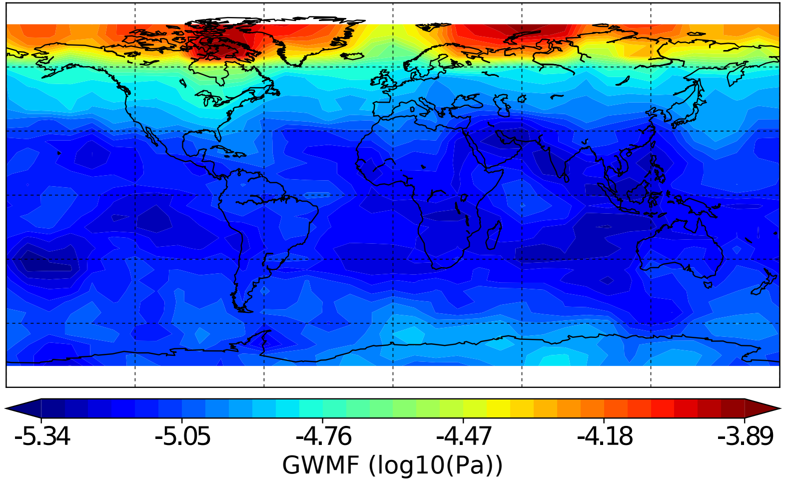
Global observations of gravity waves

Gravity wave momentum flux

30 km



90 km



- In July 2013 observed by SABER/TIMED at 30 and 90 km *[Trinh et al., 2018, AG]*
- As GWs propagate upward their spectra evolve latitudinally
- GCMs needed to fill in the gap

Observations & modeling of GW activity: Challenges

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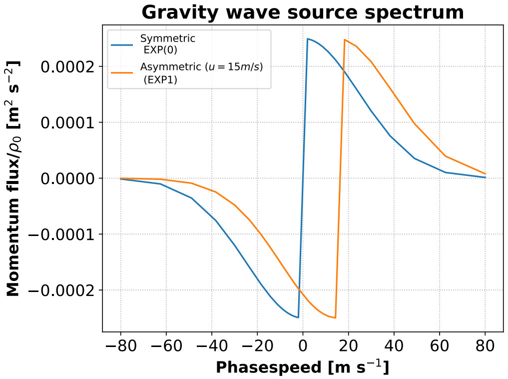
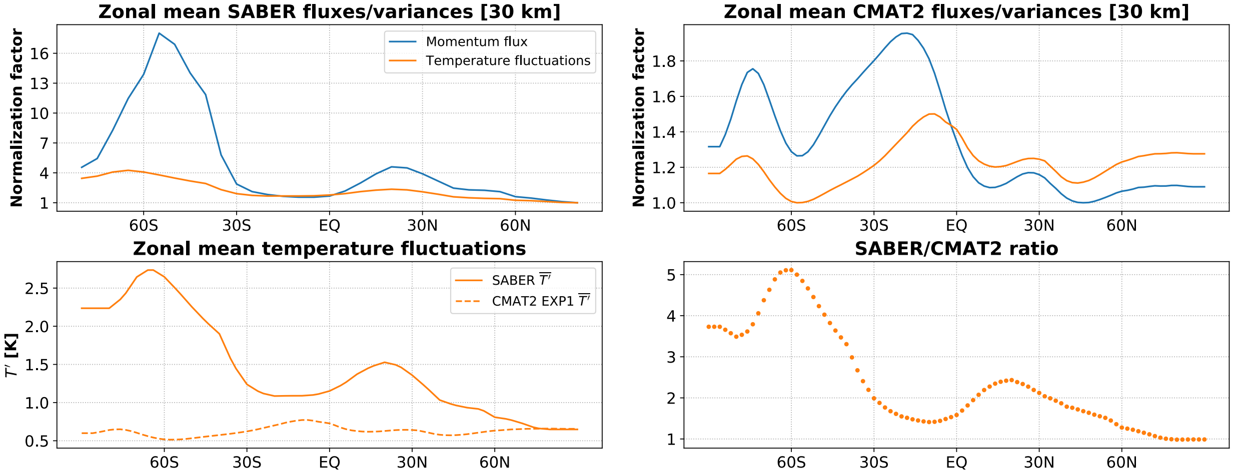


- GW source spectrum: Whole atmosphere GW parameterizations
  - Total GW activity due to all waves in the spectrum.
  - M=32 harmonics.



- Implementation of observed GW activity in CMAT2+GW scheme
  - Which harmonics have what flux?
  - Observations and models capture different scales.
  - Comparison of mean fields.

Gravity wave thermal effects in the Martian atmosphere

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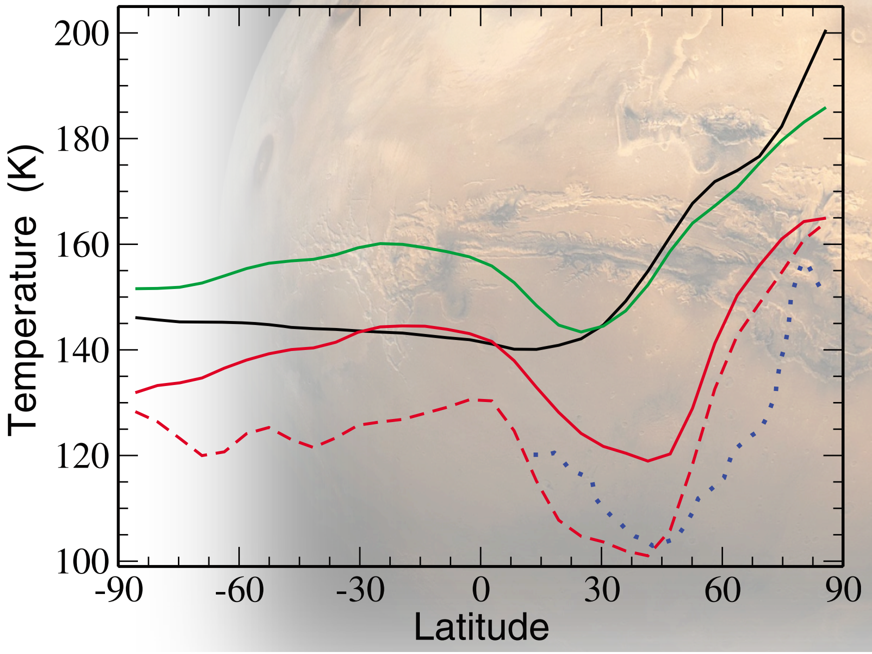

Simulated temperature (≈120 km):
- Night-time temperature inferred from ODY aerobraking measurements
- without GWs
- with only dynamical effects of GWs
- with both dynamical and thermal effects
- night-time T with dynamical and thermal GW effects

(Medvedev and Yiğit, 2012)

- Accounting for subgrid-scale gravity waves with a whole atmosphere GW parameterization within a Martian GCM helps better reproduce the Mars Odysey (ODY) aerobraking temperature measurements.

Summary & Future

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1. Direct [3-D] GW propagation into the thermosphere & global effects *[Yiğit et al. 2009].*
2. Direction of GW propagation and damping are influenced by the geometry of the magnetic fields *[Medvedev et al., 2017].*
3. GWs-major warmings: Ionospheric GW activity decreases during the main phase of a major SSW *[Nayak and Yiğit, 2019].*
4. Adjusting GW source spectrum wrt satellites can improve the GW-related dynamics in the upper atmosphere [current work]

- **Future research & challenges:**
  - Ionospheric effects
  - Self-consistent GCM simulations of geomagnetic effects and GWs

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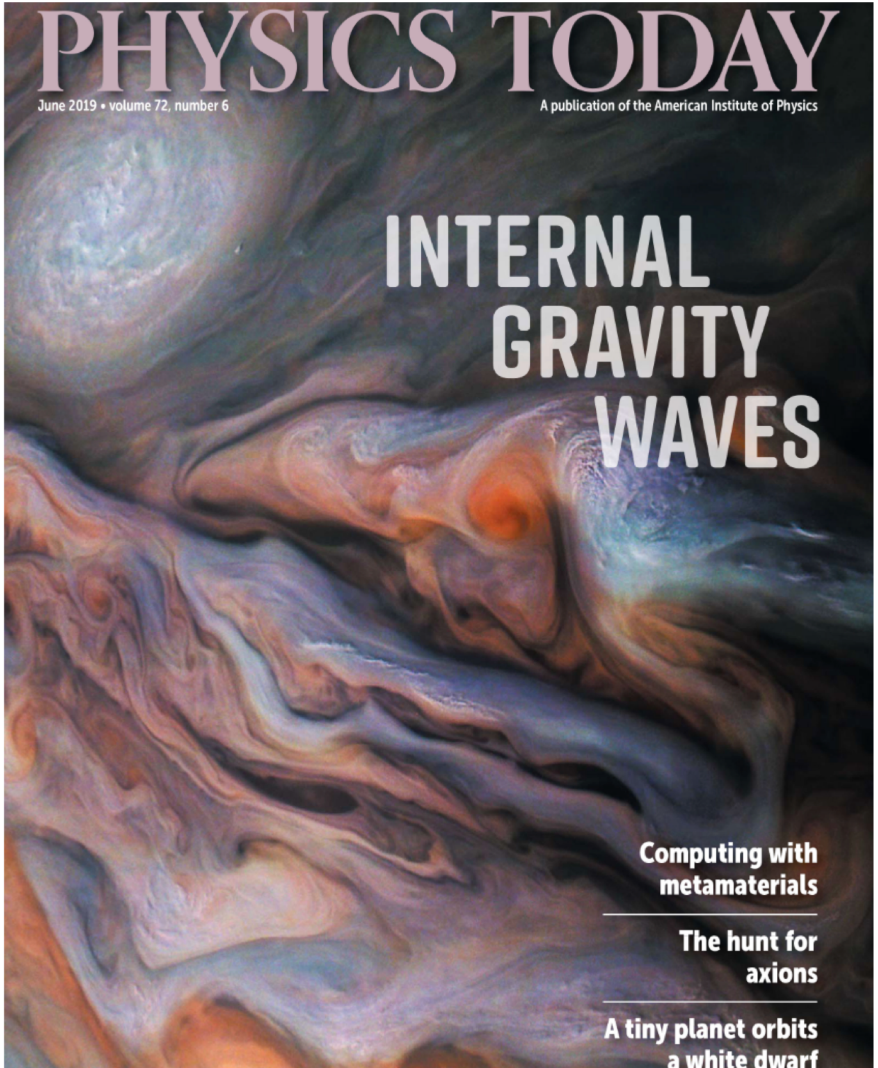

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cover: Images of Jupiter's swirling atmosphere, such as the one shown here taken by NASA's Juno spacecraft, have provided an unprecedented look at the gas giant's atmosphere. On **page 40**, Erdal Yiğit and Alexander Medvedev discuss the role of gravity waves in the atmospheric dynamics of Jupiter, Earth, and other planets.

(Image courtesy of NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstädt/ Seán Doran.)