Whole atmosphere coupling by the **quasi-6-day wave** during the September 2019 Antarctic sudden stratospheric warming

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[5] Univ. New Brunswick, [6] Univ. Birmingham, [7] IAP Kühlungsborn, [8] NOAA Boulder
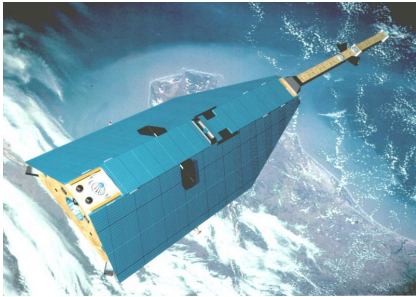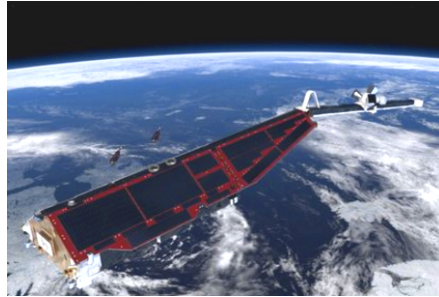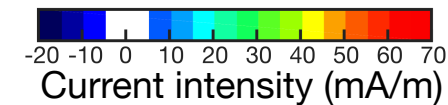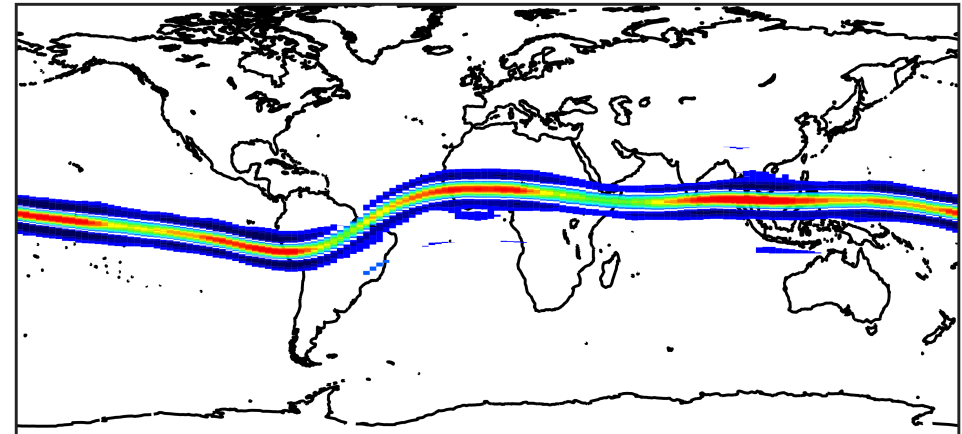
Equatorial Electrojet from Swarm & CHAMP

CHAMP (2000–2009)   Swarm (2013–)

Longitude dependence of the equatorial electrojet (10–12 LT), Swarm 2018–2020

Current intensity (mA/m)
-20 -10 0 10 20 30 40 50 60 70

EEJ intensity (LT = ~12:00)
CHAMP September 2006

J (mA/m)

time (day)

Longitude

CHAMP Orbit
2006/09/10 00:00:00
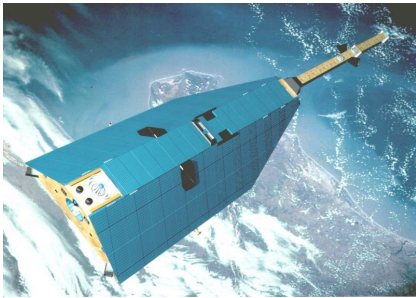
[Yamazaki et al., 2018, JGR]
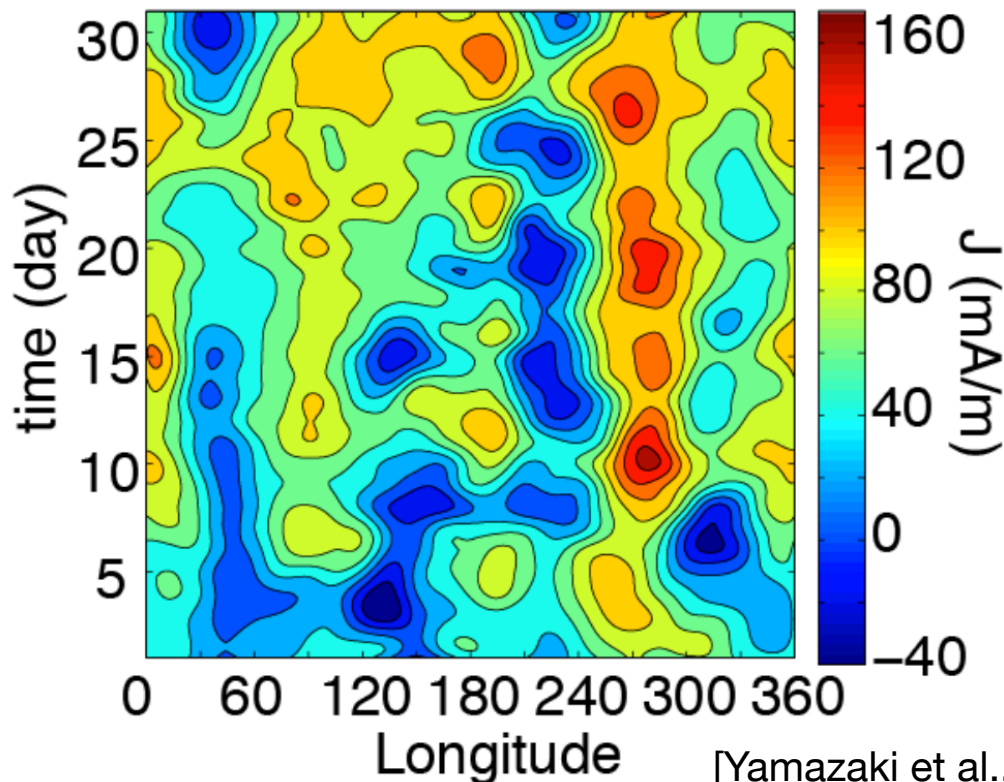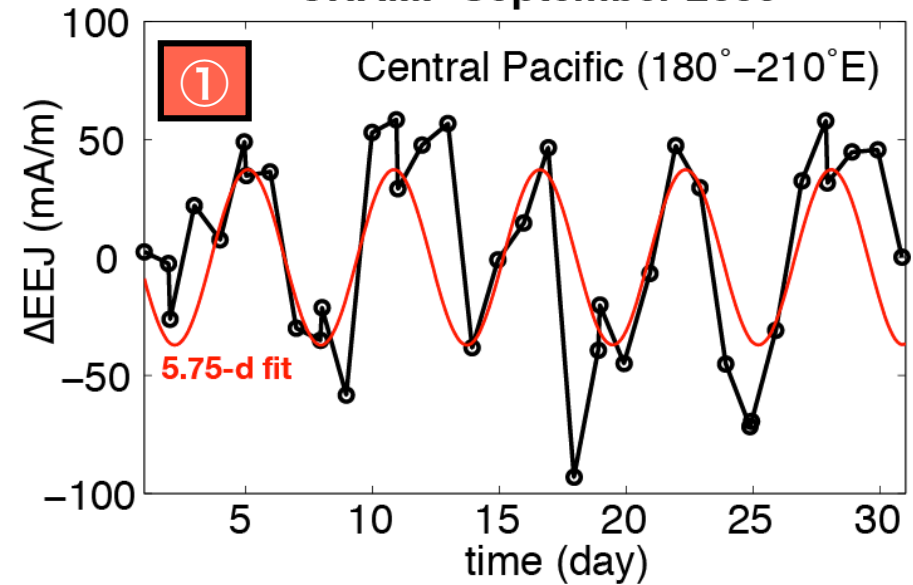
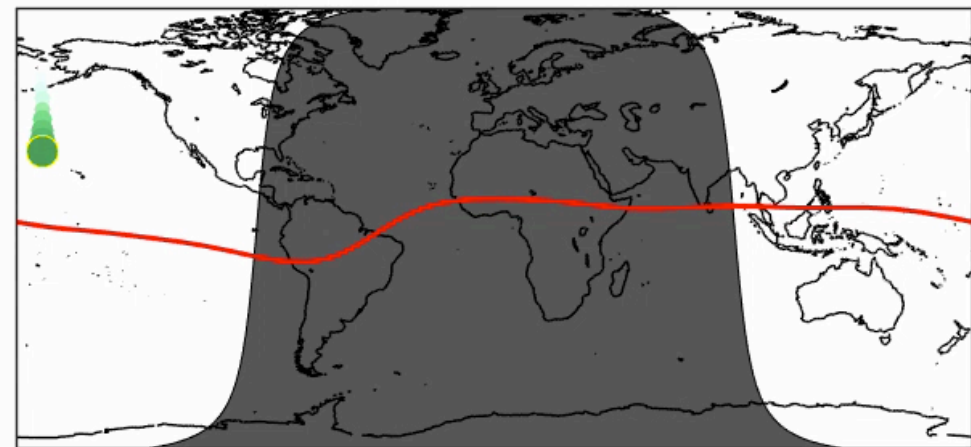# Equatorial Electrojet from Swarm & CHAMP

CHAMP (2000–2009)

Swarm (2013–)

EEJ intensity (LT = ~12:00)

CHAMP September 2006

[Yamazaki et al., 2018, JGR]

CHAMP September 2006

① Central Pacific (180˚–210˚E)

5.75-d fit

CHAMP September 2006

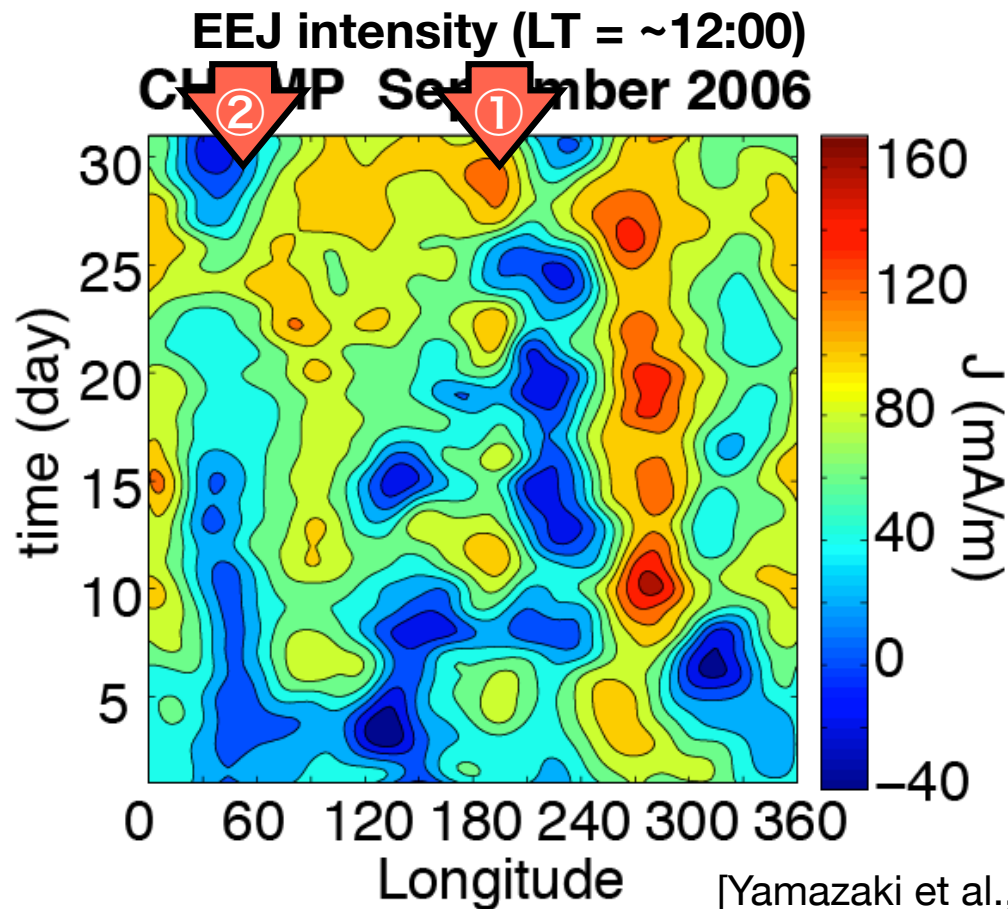② West Africa (30˚–60˚E)
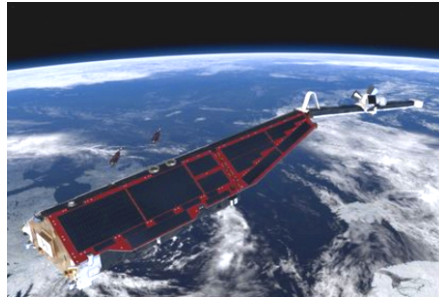
5.75-d fit

Yamazaki et al. (yamazaki@gfz-potsdam.de)
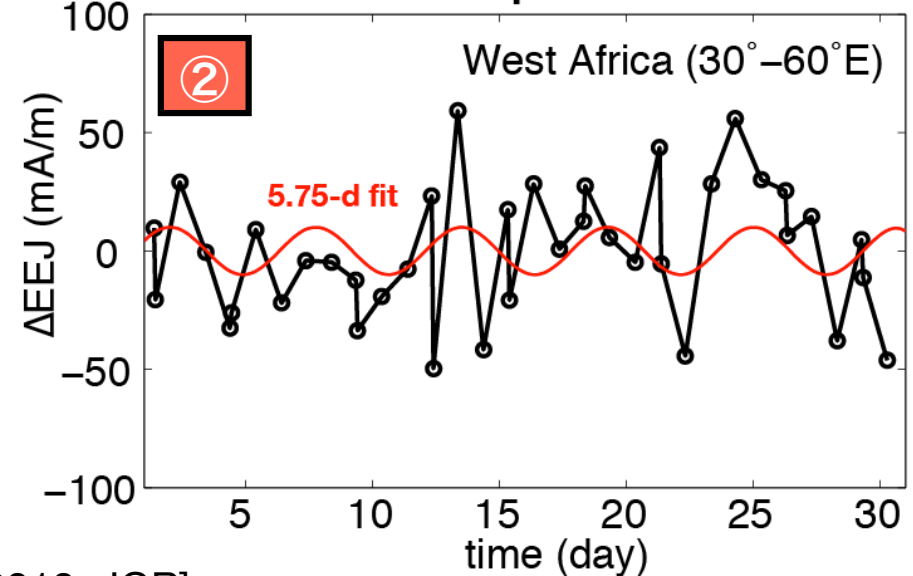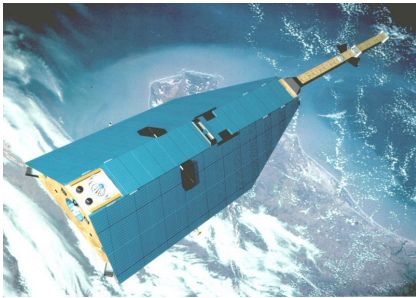
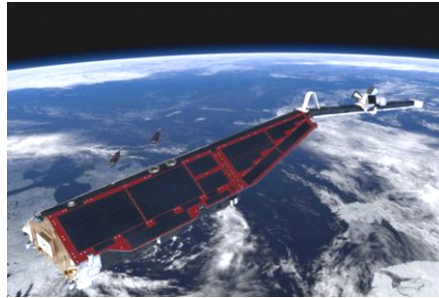# Equatorial Electrojet from Swarm & CHAMP

CHAMP (2000–2009)

Swarm (2013–)

CHAMP EEJ

Ionosphere, ~110 km
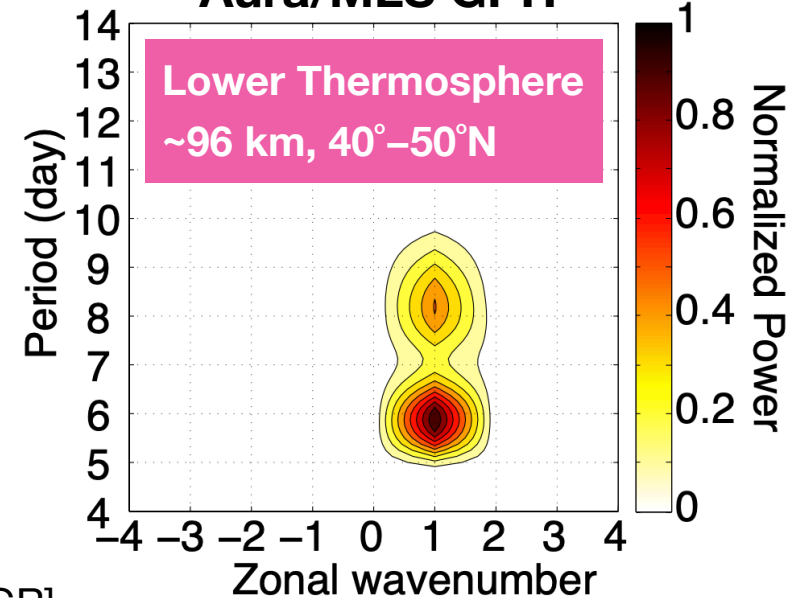
EEJ intensity (LT = ~12:00)
CHAMP September 2006

Longitude

time (day)

J (mA/m)

Period (day)

Zonal wavenumber

Normalized Power

Aura/MLS GPH

Lower Thermosphere ~96 km, 40°–50°N

Period (day)

Zonal wavenumber

Normalized Power

[Yamazaki et al., 2018, JGR]

Quasi-6-Day Wave (Q6DW)

Zonal Neutral Wind Amp

TIME-GCM

[Pedatella et al., 2012, JGR]

(1,1) mode in geopotential height

DAY=00
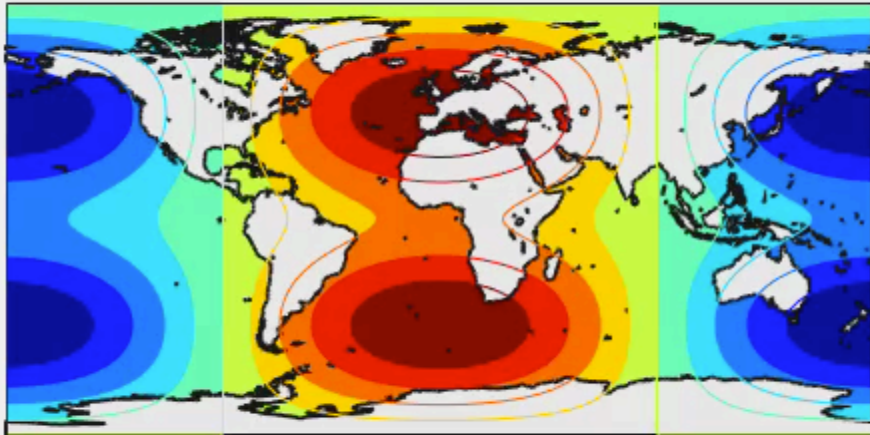
Main Characteristics

- Zonal wave number = 1
- Traveling westward
- Period = ~6 days
- Symmetric about the equator
- Max amplitude in the MLT
- ~Rossby normal mode (1,1) of linear wave theory

Ionospheric Effects

- Early studies: e.g., Fraser [1977]
- Early review: Laštovička [2006]
- Global data: e.g., Gu et al. [2014]

Quasi-6-day Wave Effects on the Ionosphere –Recent Results

Yamazaki et al. (yamazaki@gfz-potsdam.de)

Q6DW in the Atmosphere vs. Ionosphere

GIM low-latitude TEC 14 LT

Aura/MLS geopotential height ~96km
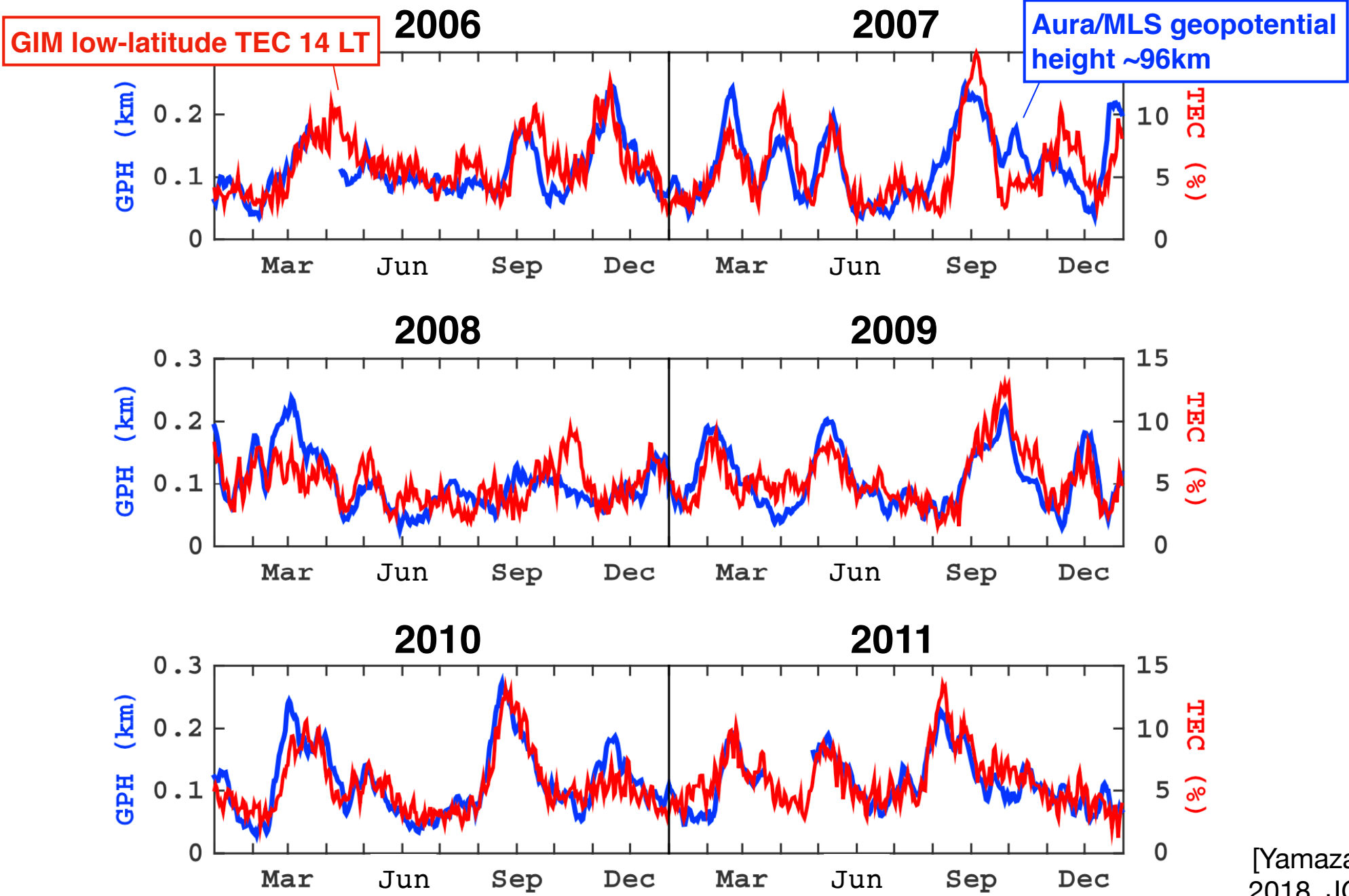
[Yamazaki, 2018, JGR]

Q6DW in the Atmosphere vs. Ionosphere

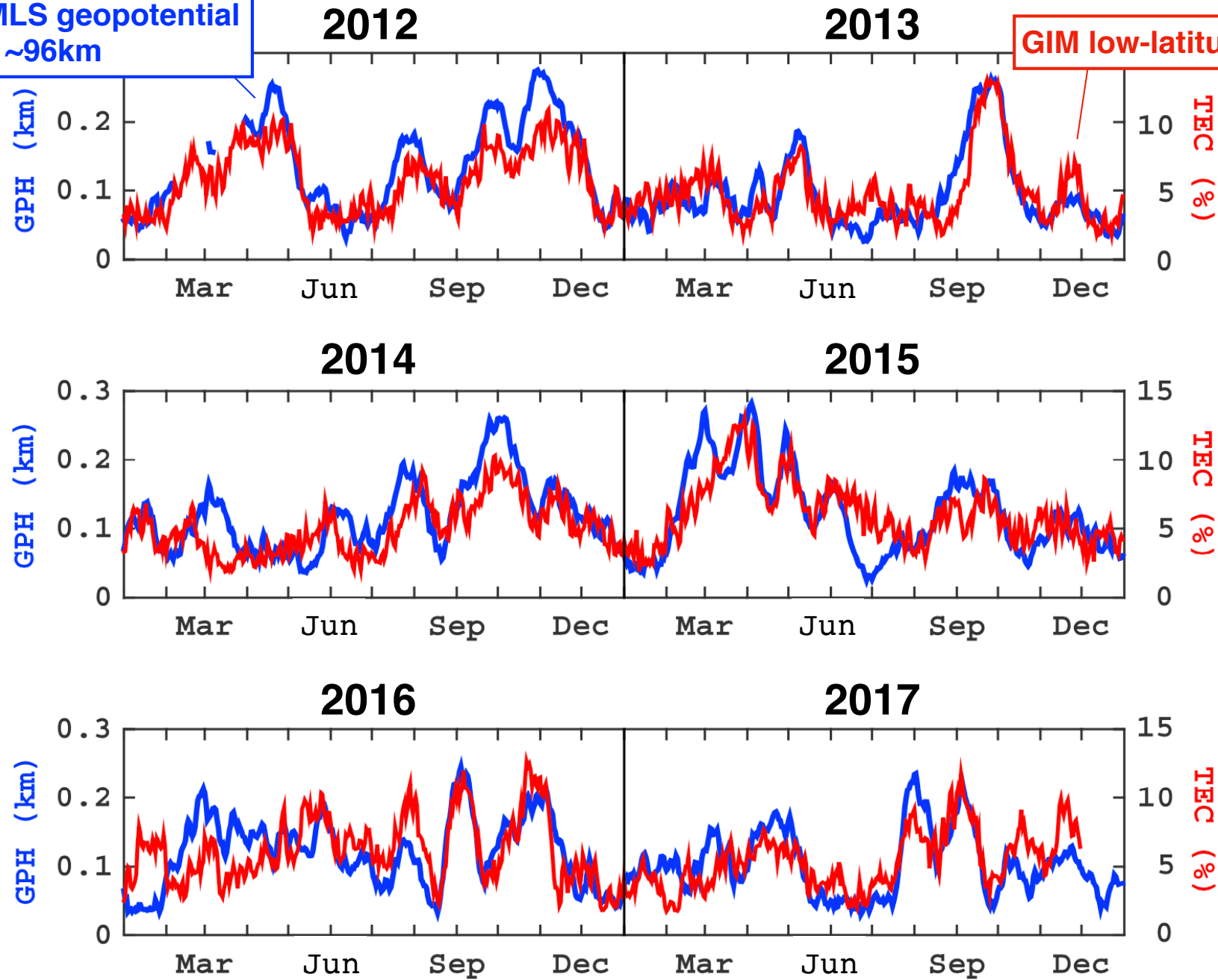Aura/MLS geopotential height ~96km

GIM low-latitude TEC 14 LT

[Yamazaki, 2018, JGR]

Q6DW Signatures in PRE

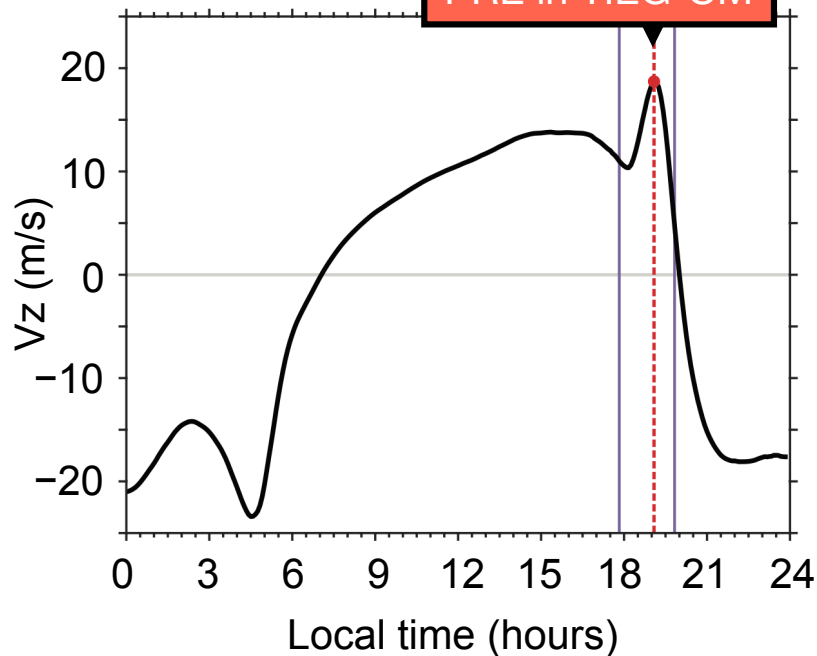= **P**re-**R**eversal **E**nhancement of the equatorial vertical plasma drift

NCAR TIE-GCM

- One-year run
- Solar max: $F_{10.7}=200$
- Quiet condition: Kp=1
- MERRA/TIMEGCM forcing

Eq. vertical plasma drift
DoY=305
Lon=80°W

PRE in TIEG-CM

Amplitude spectra of zonal wavenumber = 1 (westward propagating) component

Zonal wind over the equator at lower boundary ~97 km

PRE equatorial vertical plasma drift velocity ~350 km
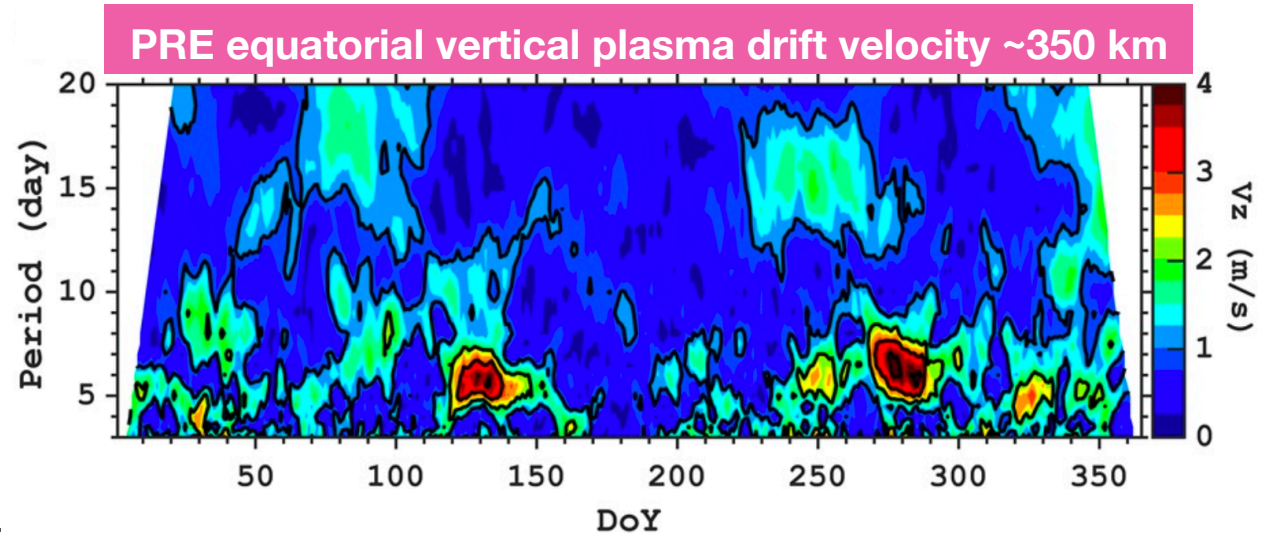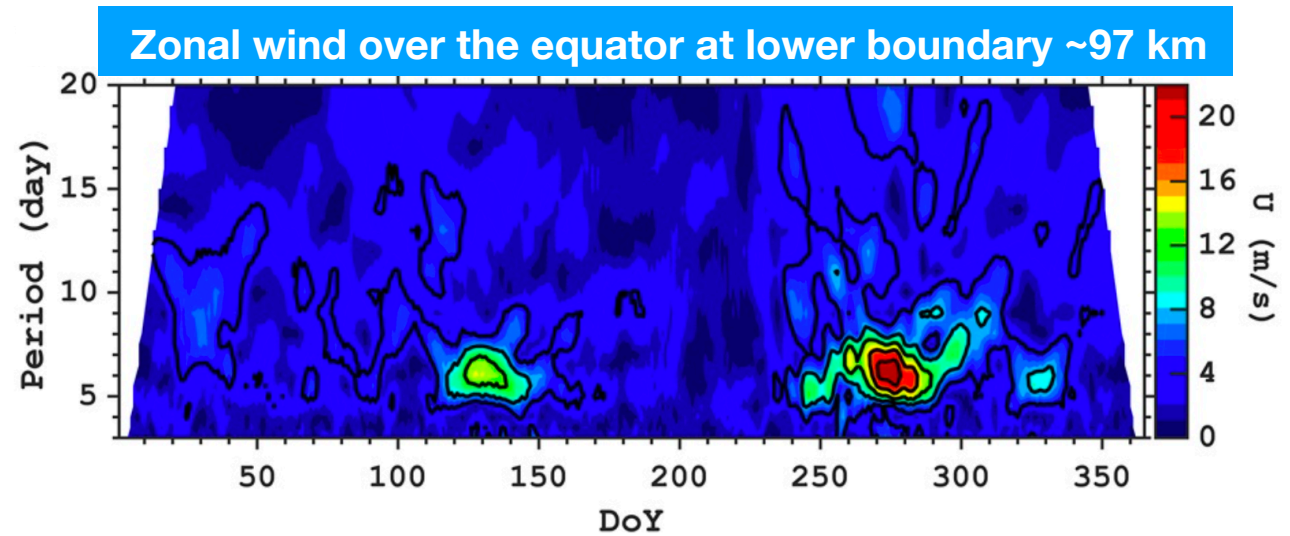
[Yamazaki & Diéval, 2021, Space Weather]

Yamazaki et al. (yamazaki@gfz-potsdam.de)
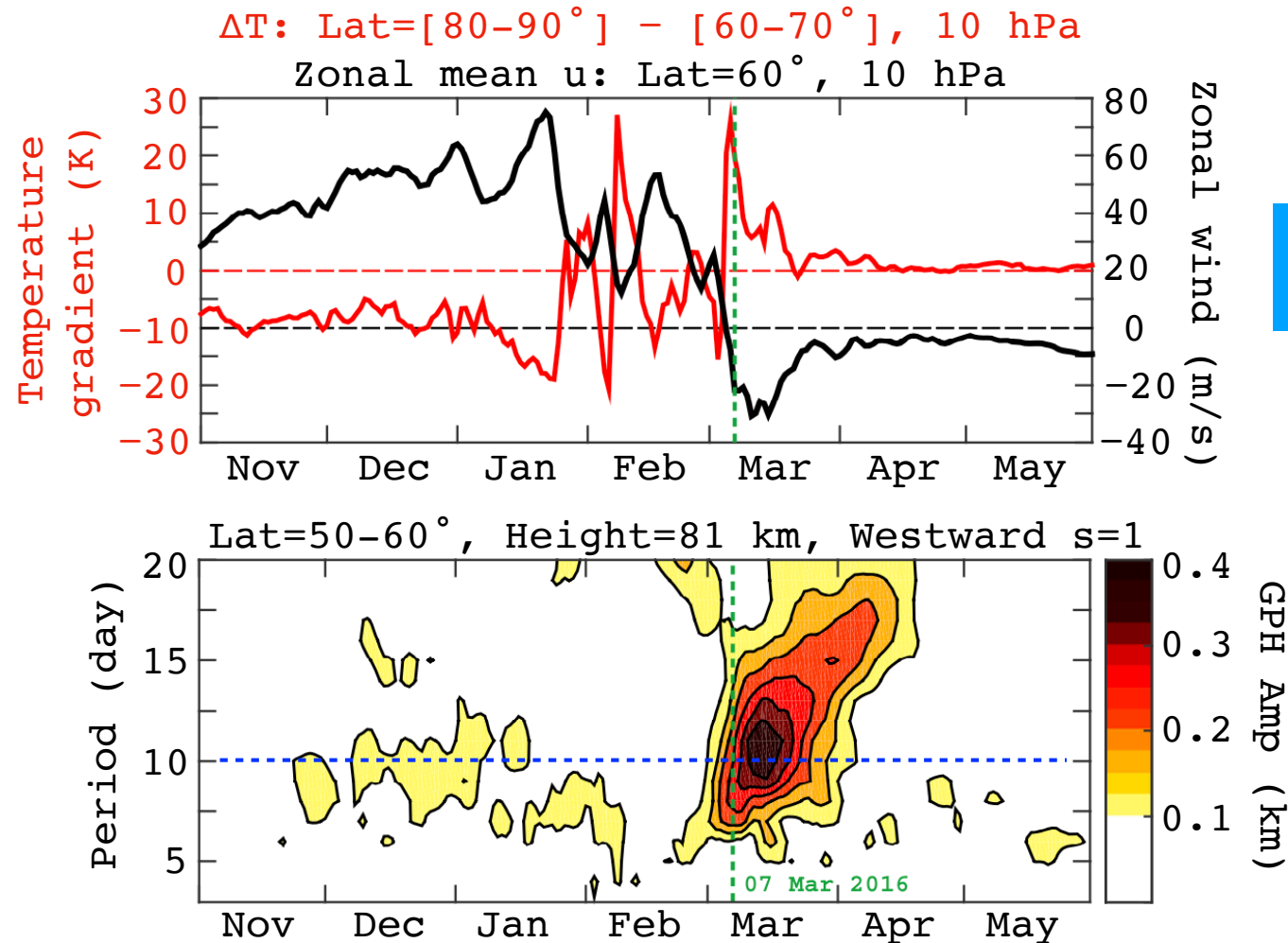
Quasi-6-day Wave Event during September 2019 Antarctic Sudden Stratospheric Warming

Planetary-wave Enhancement during SSW

SSW = sudden stratospheric warming

ΔT: Lat=[80–90˚] – [60–70˚], 10 hPa
Zonal mean u: Lat=60˚, 10 hPa

Final warming in March 2016

Lat=50–60˚, Height=81 km, Westward s=1

07 Mar 2016
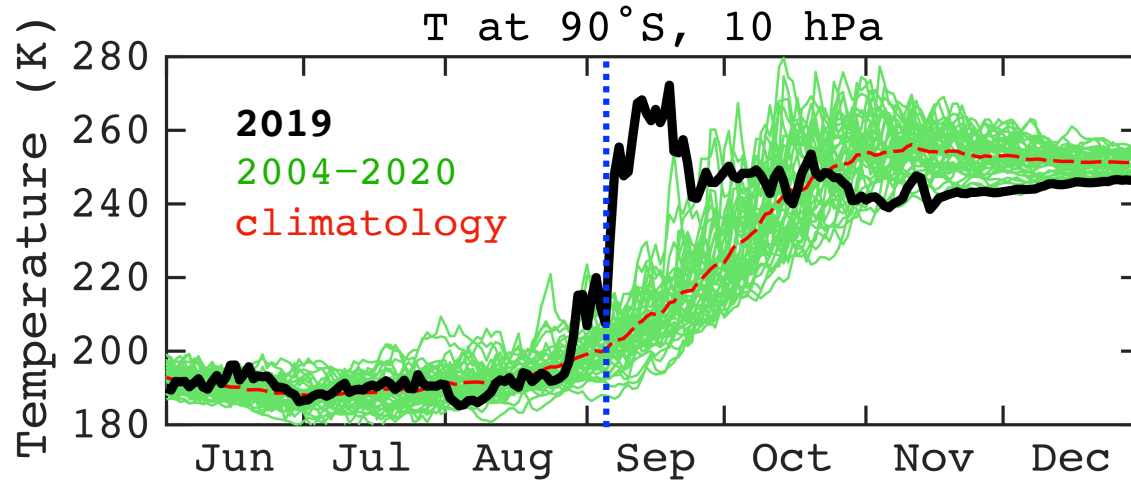
Large quasi-10-day wave in the MLT

MLT = mesosphere & lower thermosphere
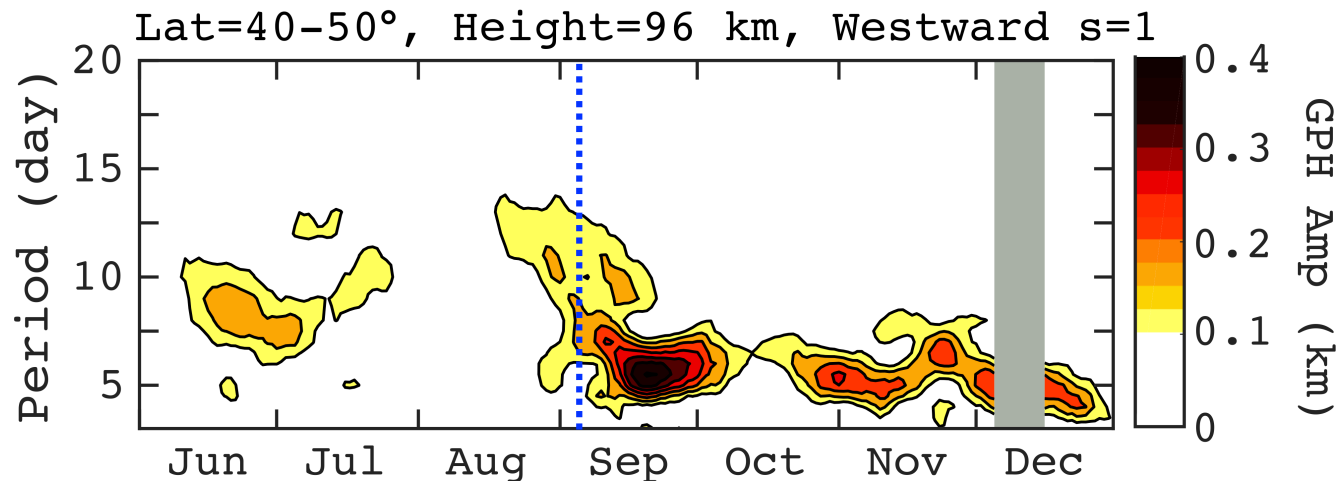
2015–2016

[Yamazaki & Matthias, 2019, JGR]

Q6DW and September 2019 Antarctic SSW

SSW = sudden stratospheric warming

September 2019 Antarctic SSW

Large quasi-6-day wave in the MLT

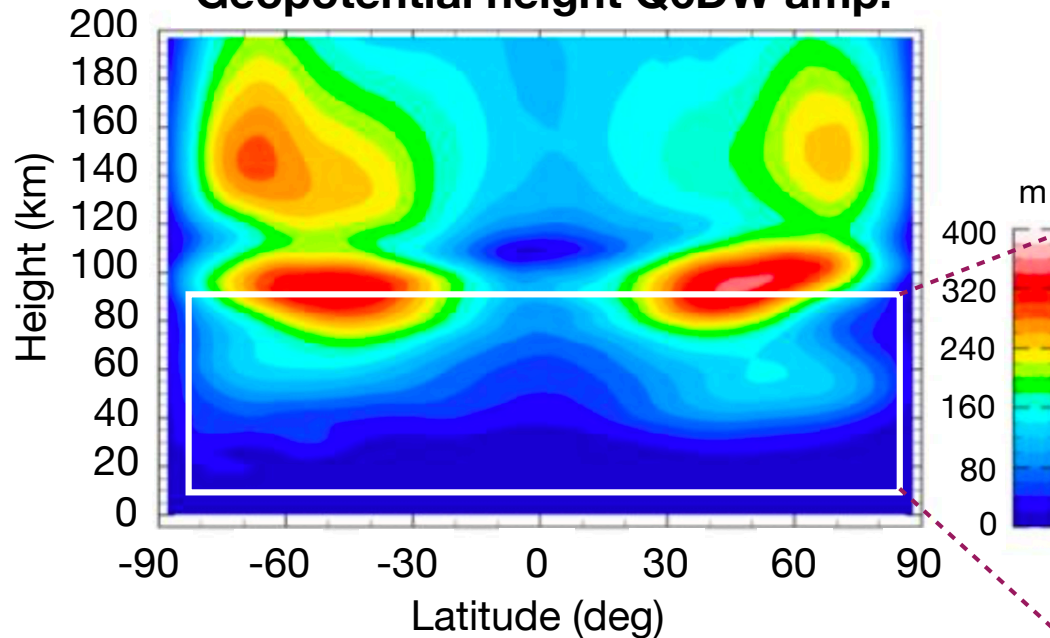MLT = mesosphere & lower thermosphere

[Yamazaki et al., 2020, GRL]
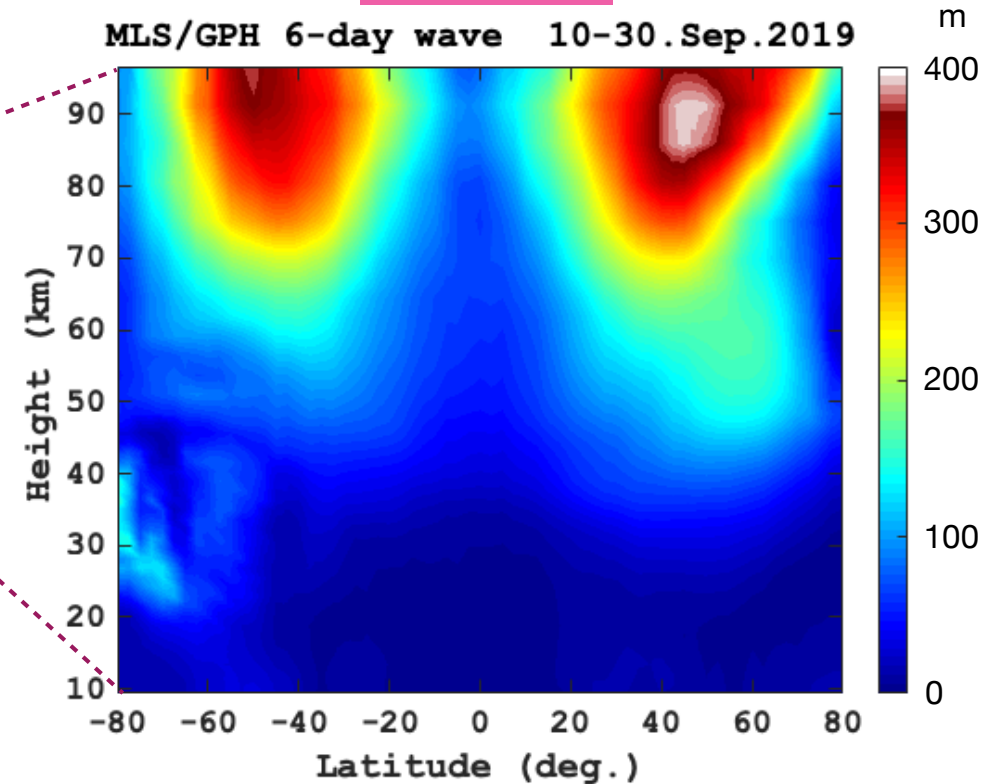
Q6DW and September 2019 Antarctic SSW

SSW = sudden stratospheric warming

GAIA model

Geopotential height Q6DW amp.

GAIA **Zonal wind Q6DW amp.**

Aura/MLS

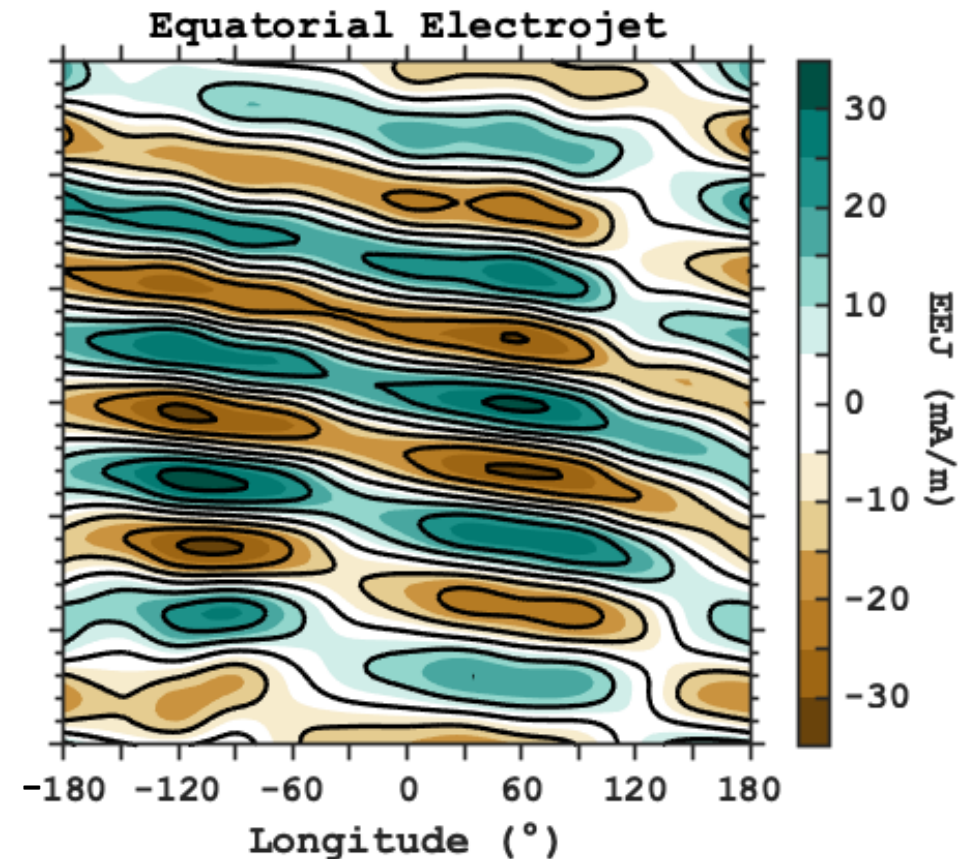[Miyoshi & Yamazaki, 2020, JGR]

Yamazaki et al. (yamazaki@gfz-potsdam.de)
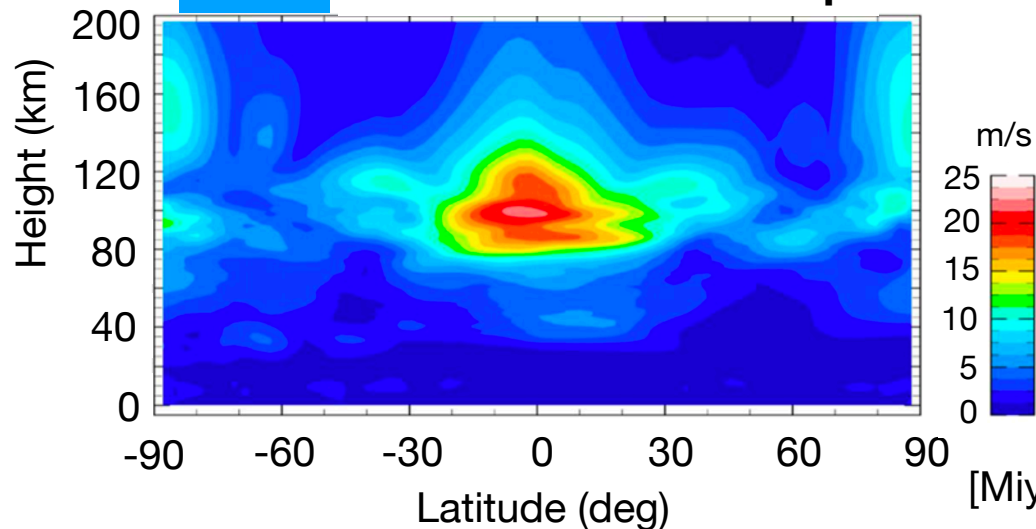
Equatorial Electrojet Response

Swarm B L2 EEJ ~12 LT, ~110 km
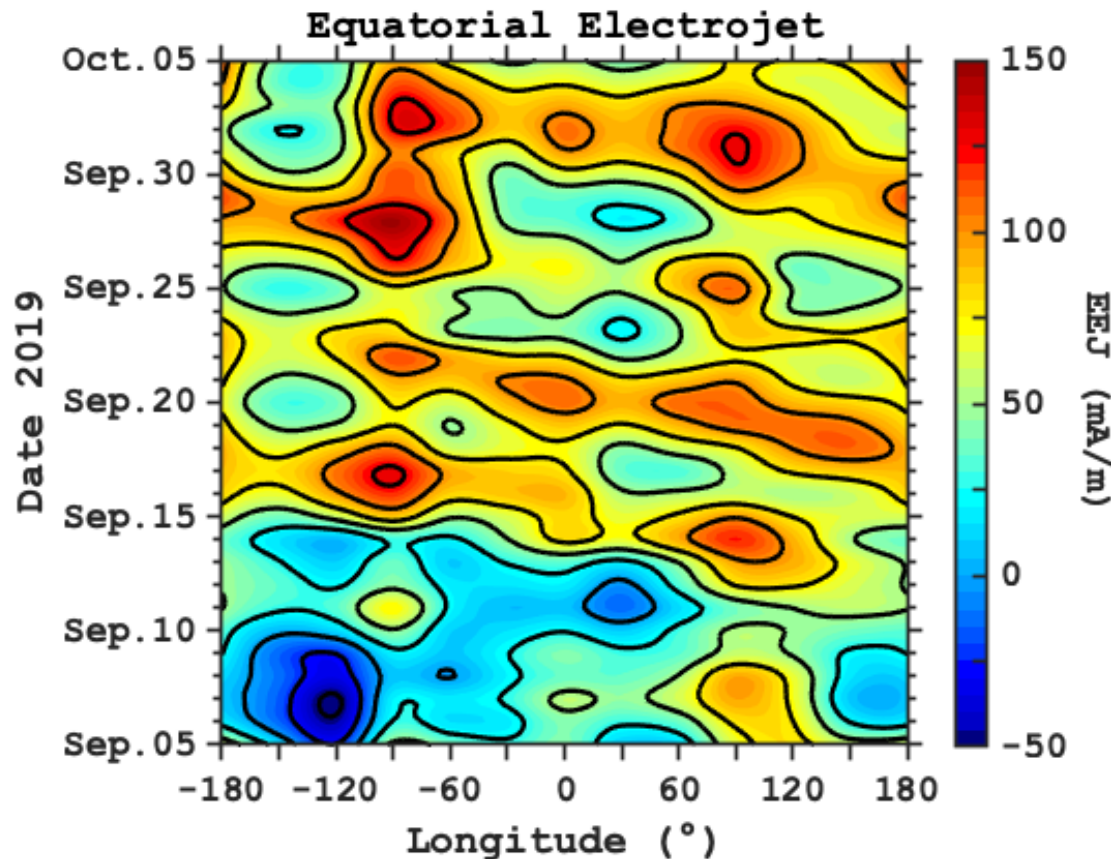
Bandpass filtered (4.5-7.5d)

[Yamazaki et al., 2020, GRL]
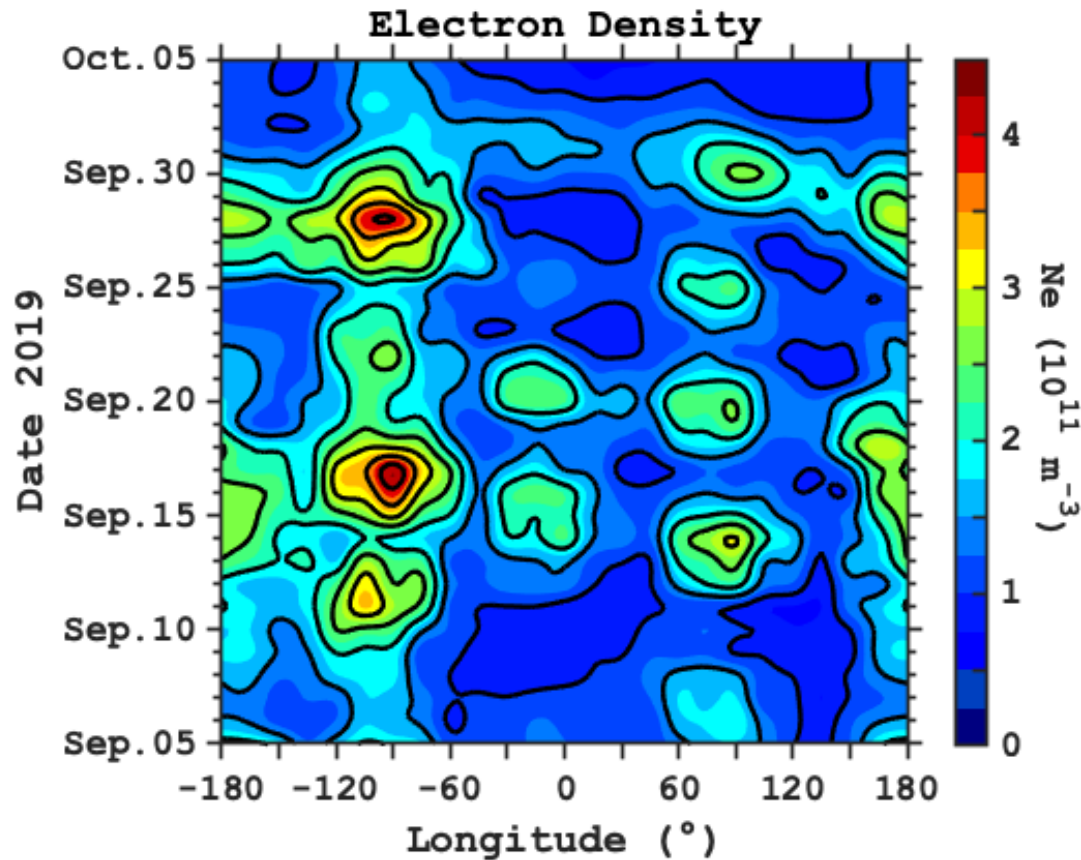
Plasma Density Response

Swarm B L1b Ne

~12 LT, ~510 km, 20° mag lat

Swarm B L2 TEC

~12 LT, >510 km, 20° mag lat
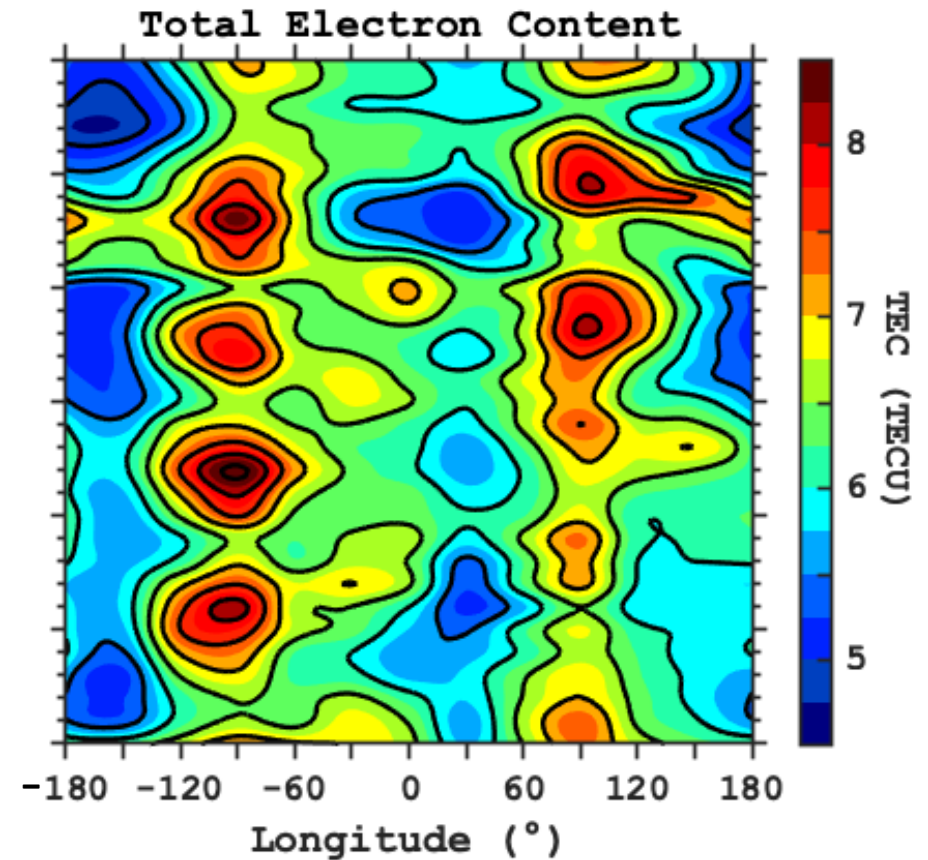
[Yamazaki et al., 2020, GRL]

EEJ in GAIA model vs. Swarm

EEJ = equatorial electrojet

Bandpass filtered (~6 days) equatorial electrojet intensity

- Variable meteorological forcing
- Constant solar and magnetospheric forcing

[Yamazaki et al., 2020, GRL]

Mechanism for 6-day EEJ Oscillations

EEJ = equatorial electrojet

Bandpass filtered (~6 days) equatorial electrojet intensity

[Miyoshi & Yamazaki, 2020, JGR]

Tidal Modulation by the Q6DW

Interacting waves

DW1 × **Q6DW**

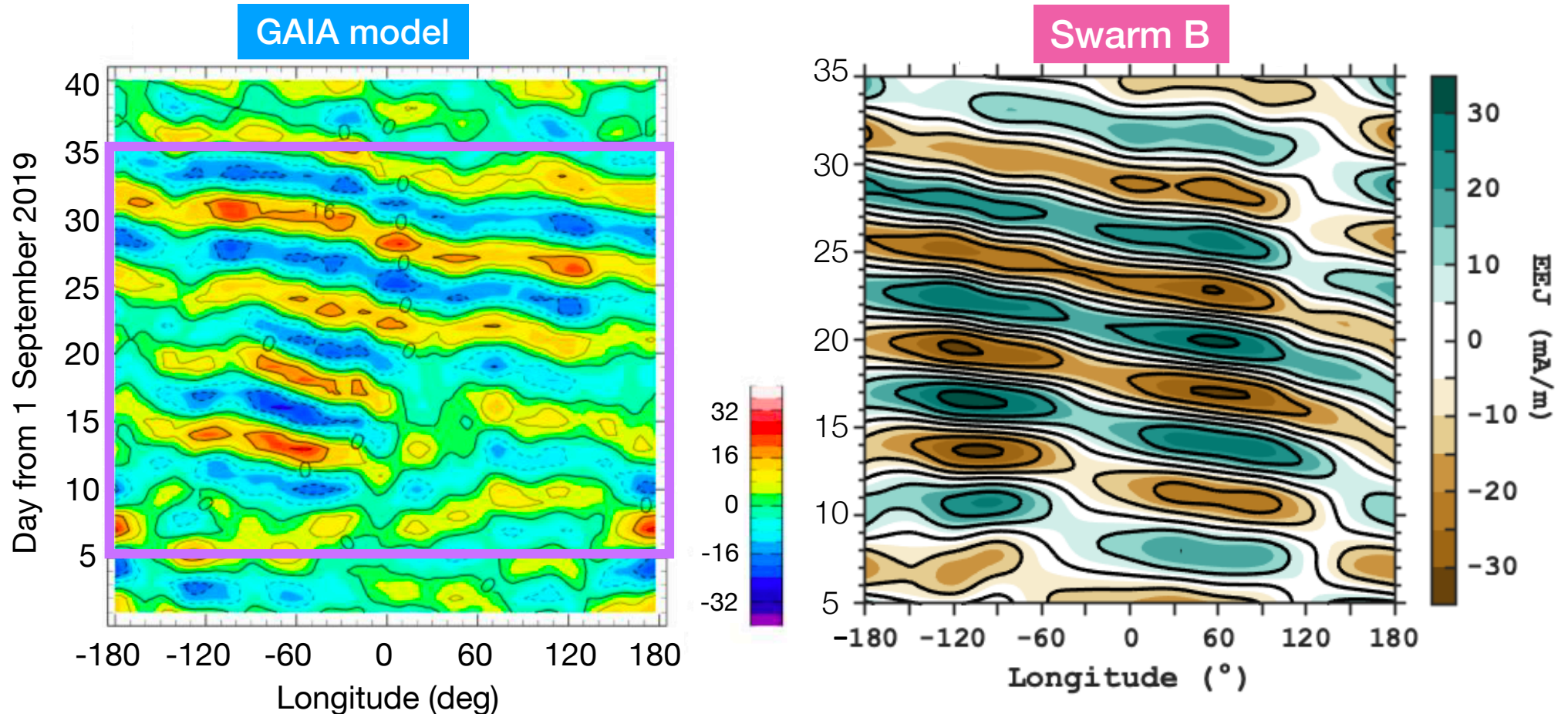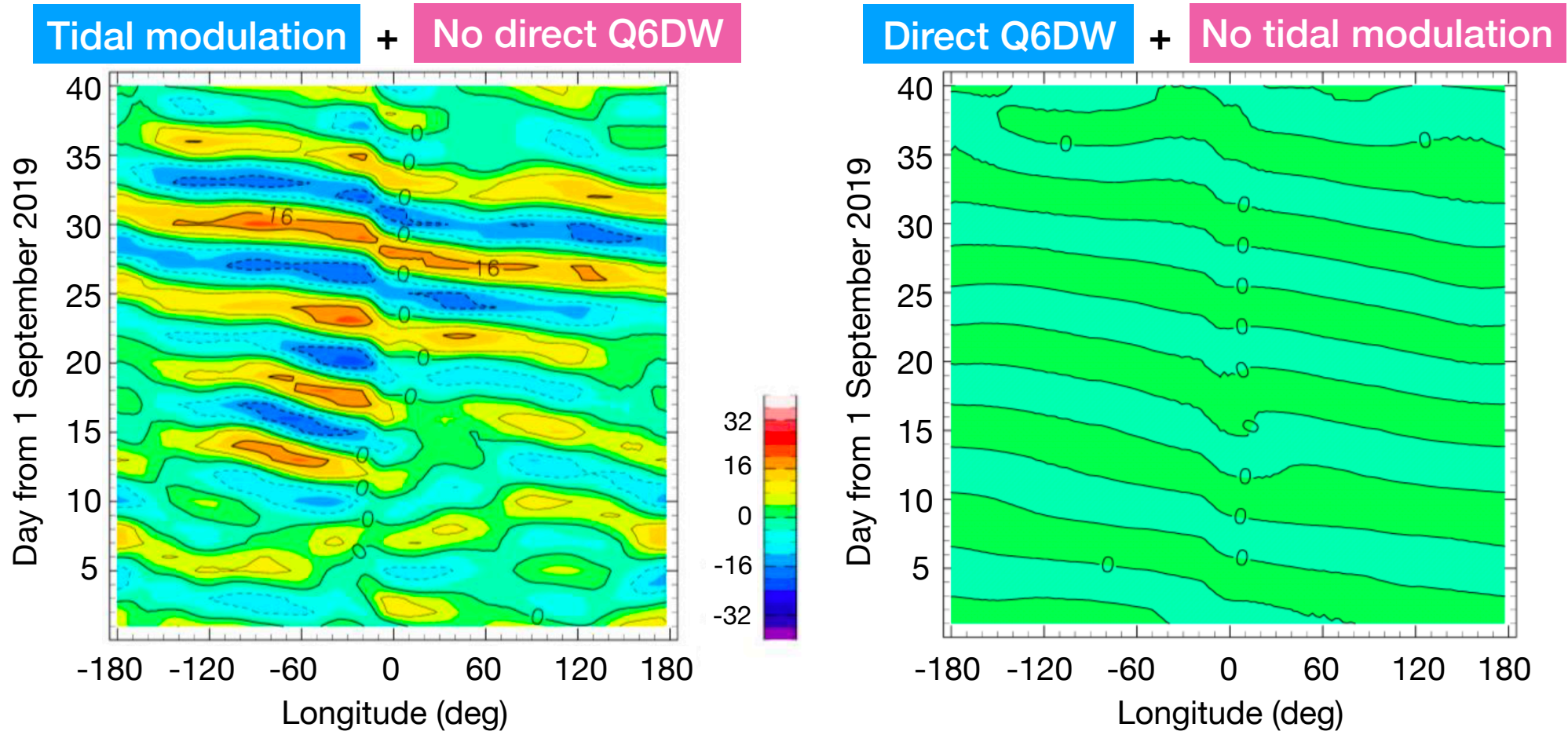Migrating diurnal tide | Quasi-6-day wave

⇓ Non-linar interaction

Secondary waves

29h0 + **21hW2**

29-hour wave wavenumber= 0 | Westward 21h wave wavenumber=2

Interacting waves

SW2 × **Q6DW**

Migrating semidiurnal tide | Quasi-6-day wave

⇓ Non-linar interaction

Secondary waves

13hW1 + **11hW3**

Westward 13h wave wavenumber=1 | Westward 11h wave wavenumber=3

Tidal Modulation by the Q6DW

Interacting waves
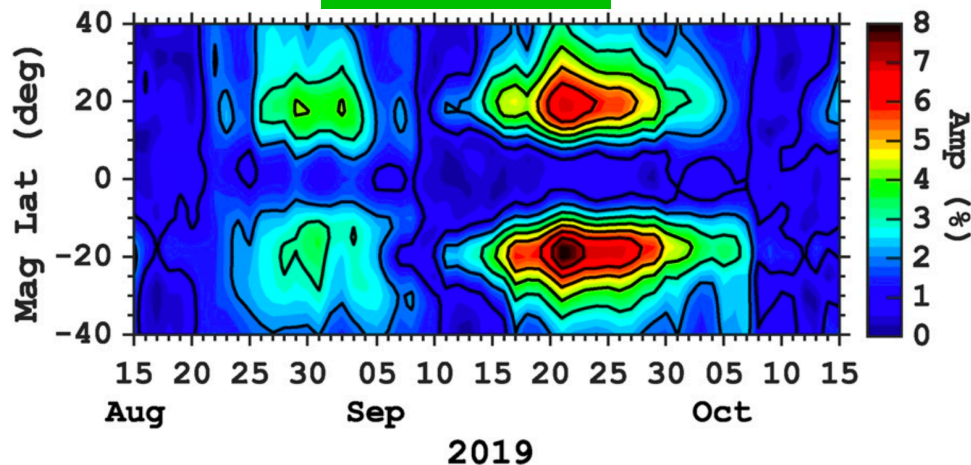
DW1 × **Q6DW**

Migrating diurnal tide — Quasi-6-day wave

⇓ Non-linar interaction

Secondary waves

29h0 + **21hW2**

29-hour wave wavenumber= 0 — Westward 21h wave wavenumber=2

→ TEC 29h0

Interacting waves

SW2 × **Q6DW**

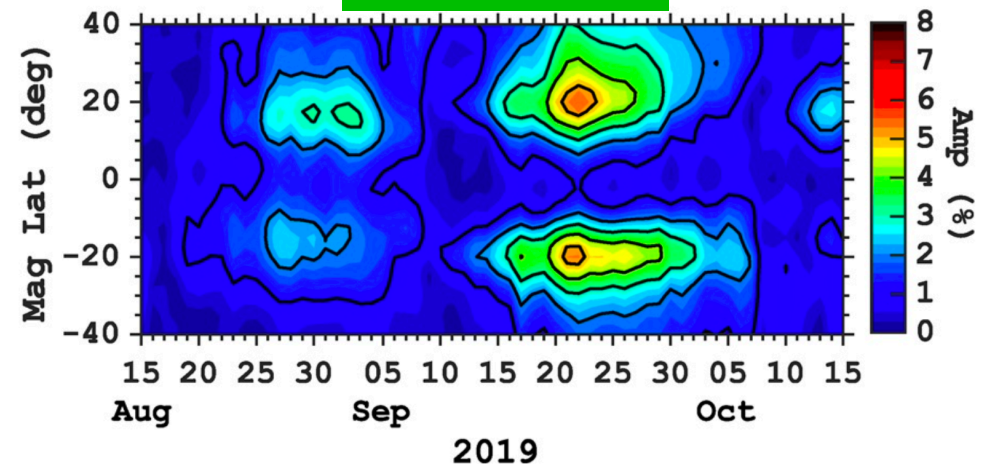Migrating semidiurnal tide — Quasi-6-day wave

⇓ Non-linar interaction

Secondary waves

13hW1 + **11hW3**

Westward 13h wave wavenumber=1 — Westward 11h wave wavenumber=3

→ TEC 13hW1

[Yamazaki & Miyoshi, 2021, JGR]

Yamazaki et al. (yamazaki@gfz-potsdam.de)

Summary & Conclusions

- **Quasi-6-day wave (Q6DW) can have a significant impact on the ionosphere**

- **Q6DW signatures can be found in the equatorial electrojet intensity and dayside plasma densities at low latitudes**

- **Q6DW can drive 6-day variation in the pre-reversal enhancement of the equatorial vertical plasma drift**

- **Exceptionally strong Q6DW is observed in September 2019, following Antarctic sudden stratospheric warming**

- **GAIA model reproduces the Q6DW and ionospheric response**

- **The ionospheric response is due to tidal modulation by the Q6DW**

- **Secondary wave signatures are observed in the ionosphere**

Thank you for your attention