Wave-wave Interactions and Modulation in the Mesosphere and Lower Thermosphere (MLT)

A case study during the 2019 Southern Hemisphere SSW

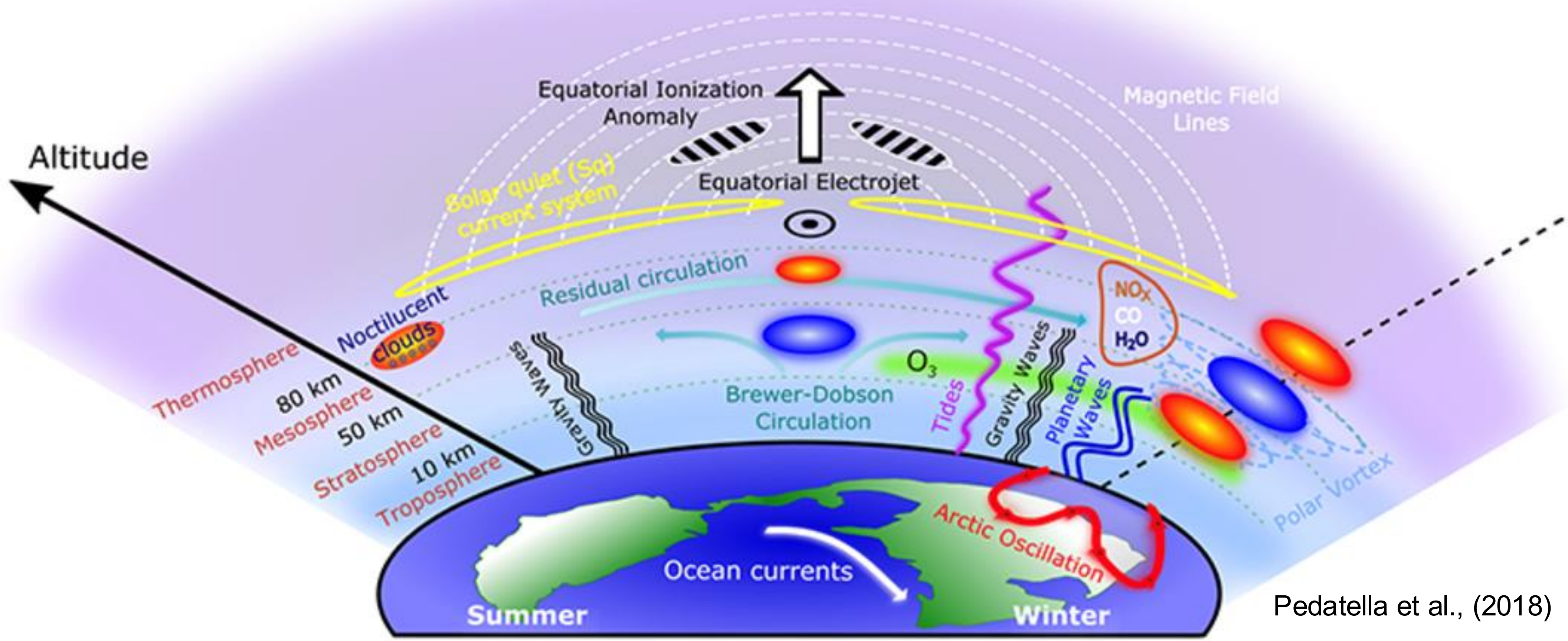
[1]Zishun Qiao, [2]Alan Z. Liu, [1]Nick M. Pedatella, [3]Gunter Stober, [4,6]Iain M. Reid, [5]Javier Fuentes, and [6]Christian L. Adami

[1]NSF NCAR High Altitude Observatory (US), [2]Embry-Riddle Aeronautical University (US), [3]University of Bern (Switzerland), [4]University of Adelaide (Australia), [5]European Southern Observatory (Chile), [6]ATRAD Pty. Ltd. (Australia)

CEDAR Workshop, June 26, 2025

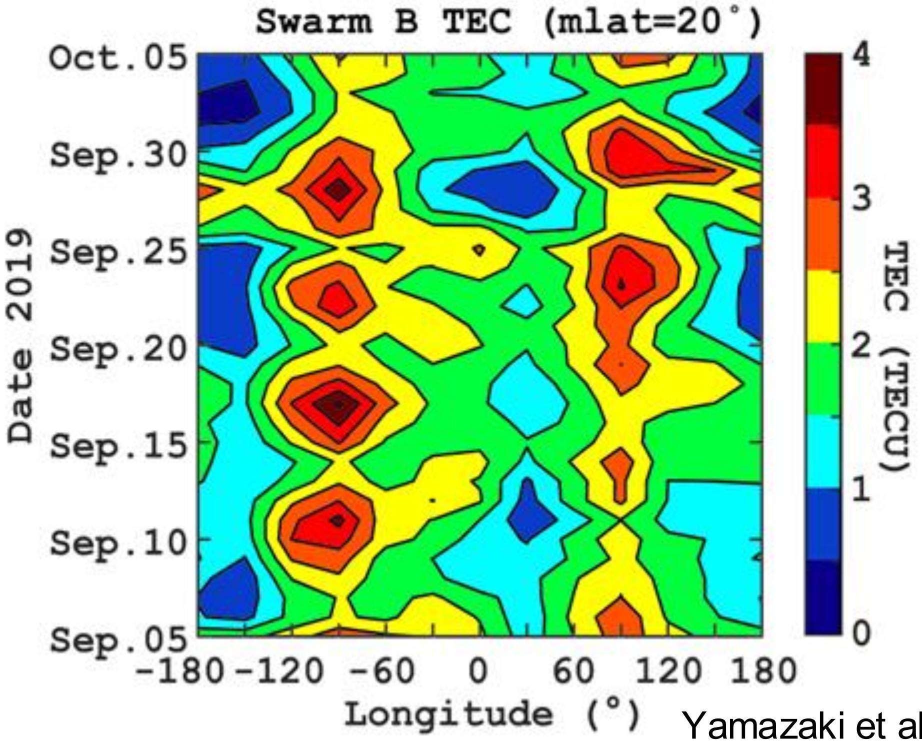
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Sudden Stratospheric Warmings (SSWs) are dynamical disturbances that produce anomalous wave activities and temperature responses in the whole atmosphere

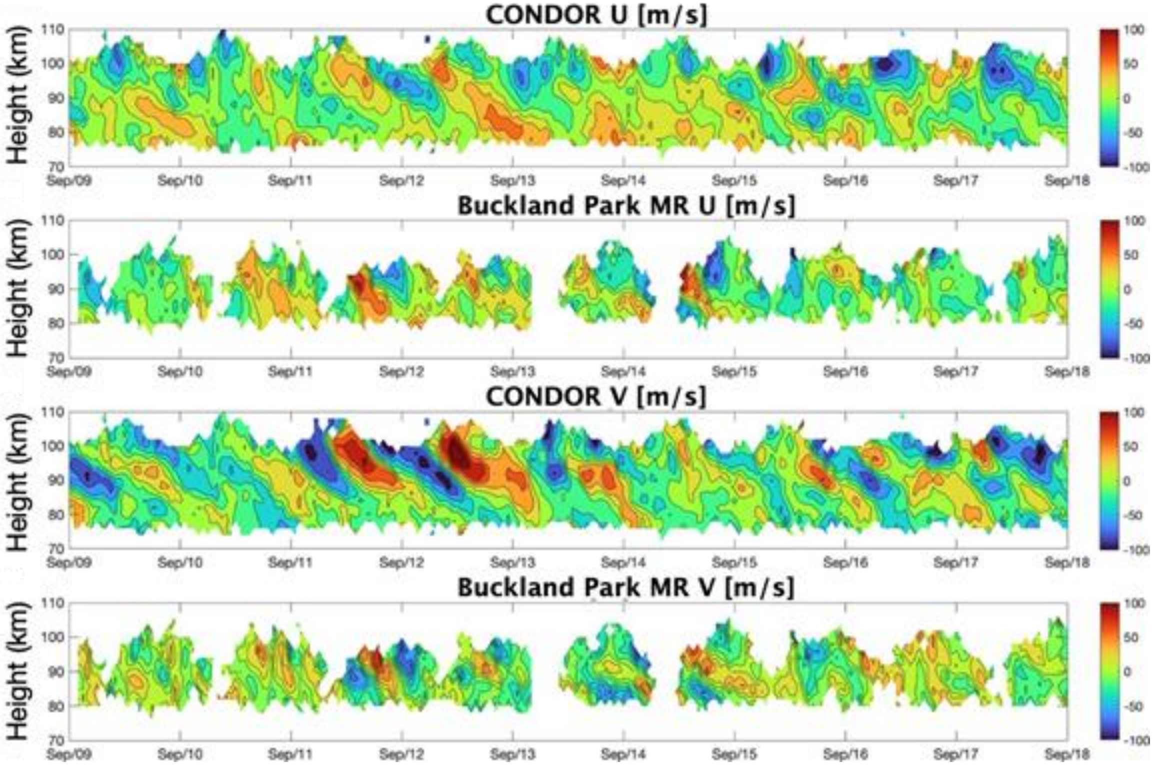


Pedatella et al., (2018)

Motivation & Background of the 2019 Southern Hemisphere (SH) minor SSW

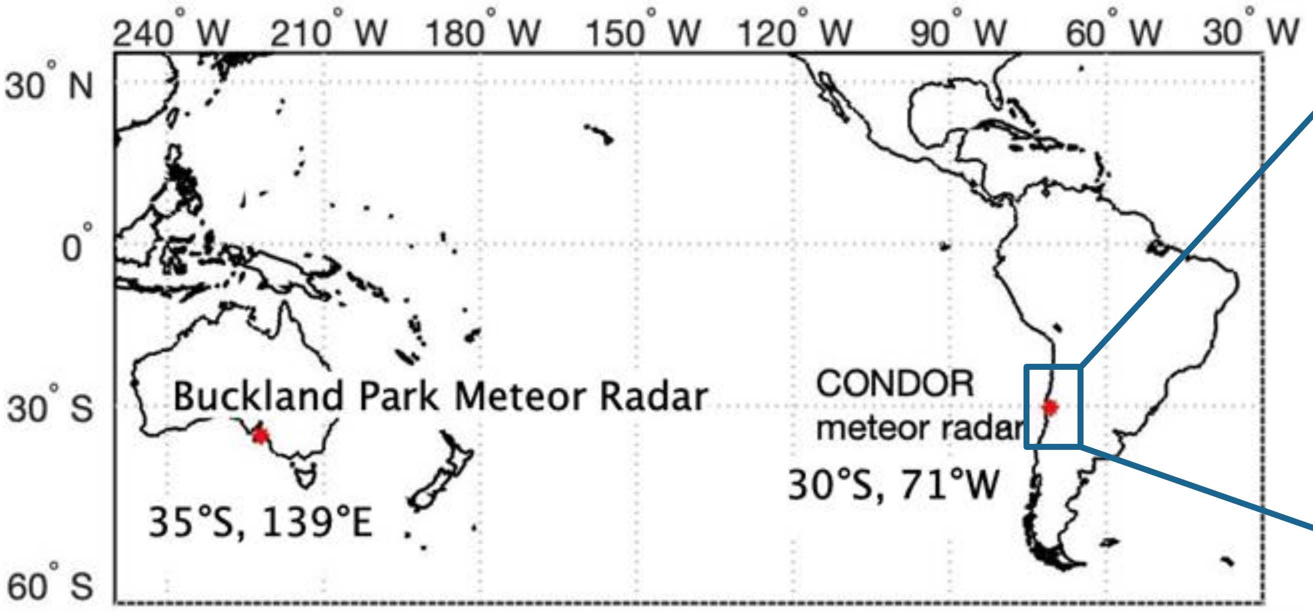


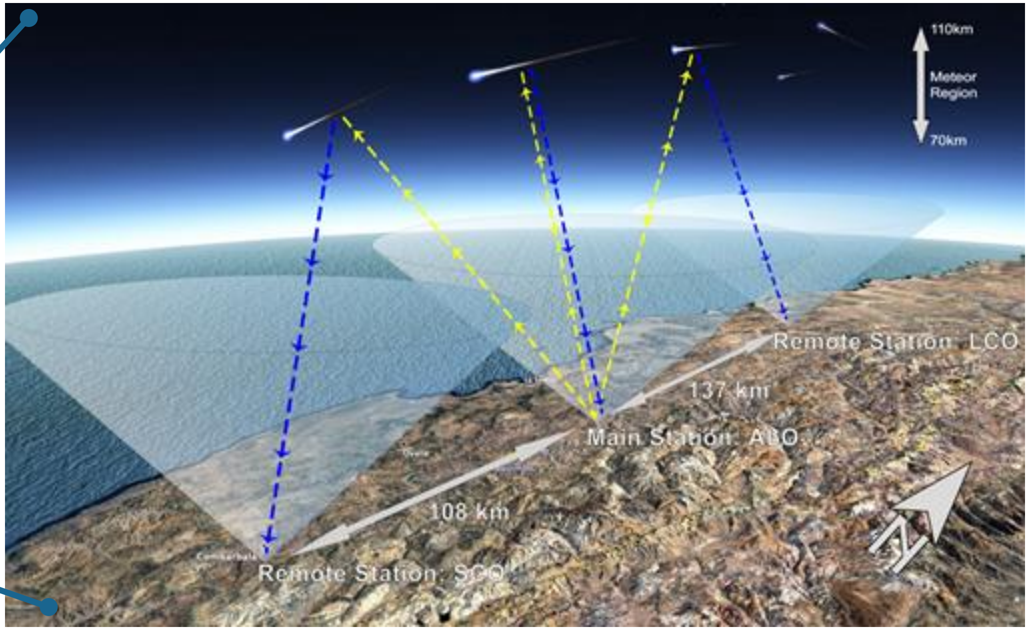
Yamazaki et al., (2020)



1. 2019 SH Sudden Stratospheric Warming (SSW) is **a rare SH SSW** (NH SSWs occur ~6 times per decade in average);
2. **Quasi-6-Day Wave (Q6DW) are greater than the average** in September, globally observed in the MLT region and ionosphere;
3. **Motivation**: Does this strong **Q6DW** activity impact on **tides and Gravity Waves (GW)** propagation, thus, contribute to the 6-day periodicity in the ionosphere?

Ground-based instruments: a pair of meteor radar at ~30ºS



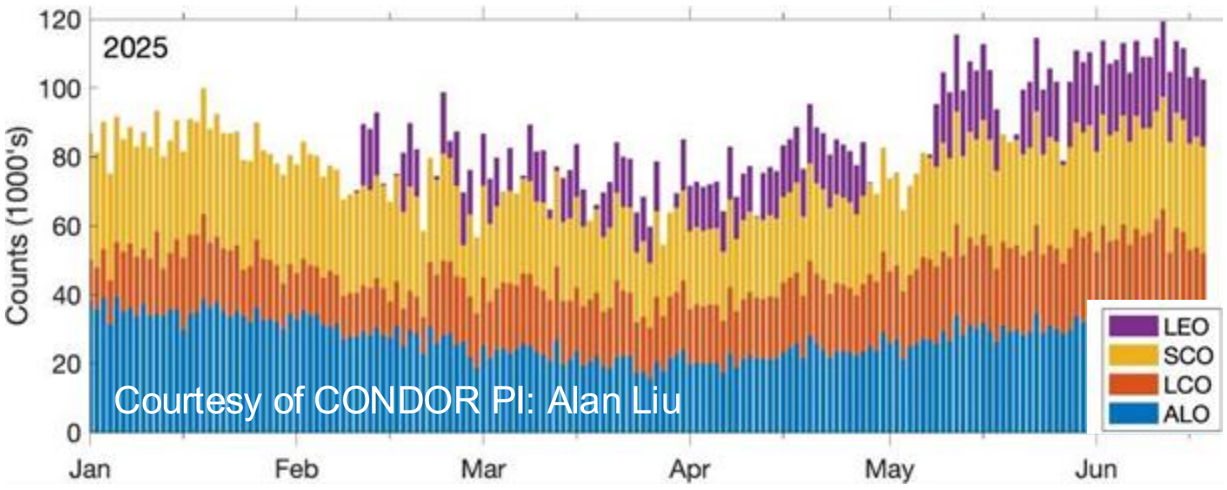


CONDOR: a recent multi-static meteor radar system (Qiao et al., 2025). More description in the paper:

Table 1. Specs of two meteor radars used in Qiao et al., (2024).

	Radar Specs	Site, lat, long, Height	Status during SSW
CONDOR	Freq: 35.15MHz **High power (48kW) & high detection rate (30,000/day/site)**	ALO, 30º S, 71ºW, 2520m	From 06/26/2019
		SCO, 31º S, 70ºW, 1140m	From 07/14/2019
		LCO, 29º S, 71ºW, 2339m	From 02/20/2020
Buckland Park MR	Freq: 55Mhz Power: 18kW	Main, 34.6ºS, 138.5ºE, 302m	ST mode not MLT
		Remote, 35.1ºS, 138.8ºE, 2m	10 days of wind used

More than U & V: GW variance, temperature, etc. from CONDOR data



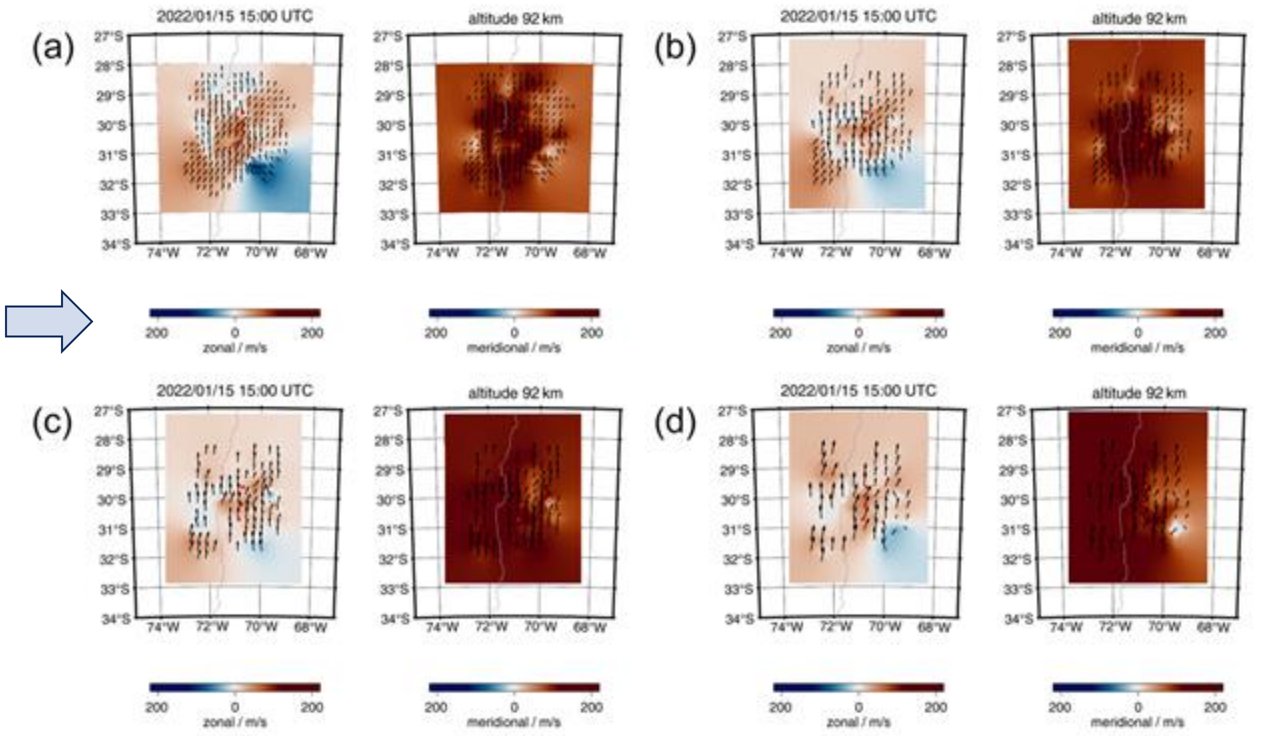
Exceeding 100K meteor detections per day

$$T_{radar} = S \cdot log_{10}e \cdot \left(2\frac{dT}{dz} + \frac{mg}{k}\right)$$

$$\Lambda = \Sigma\left((v'_{rad})^2 - (v'_{radm})^2\right)^2$$

Temperature gradient model by Hocking et al., (1999) based on slope of D_a

GW wind variances and momentum fluxes (Stober et al., 2021)



Qiao et al., (2025)

Tomographic reconstruction for individual GWs: 30×30 km spacing with 30/10/5 min resolutions, 3 min with 40×40 km spacing

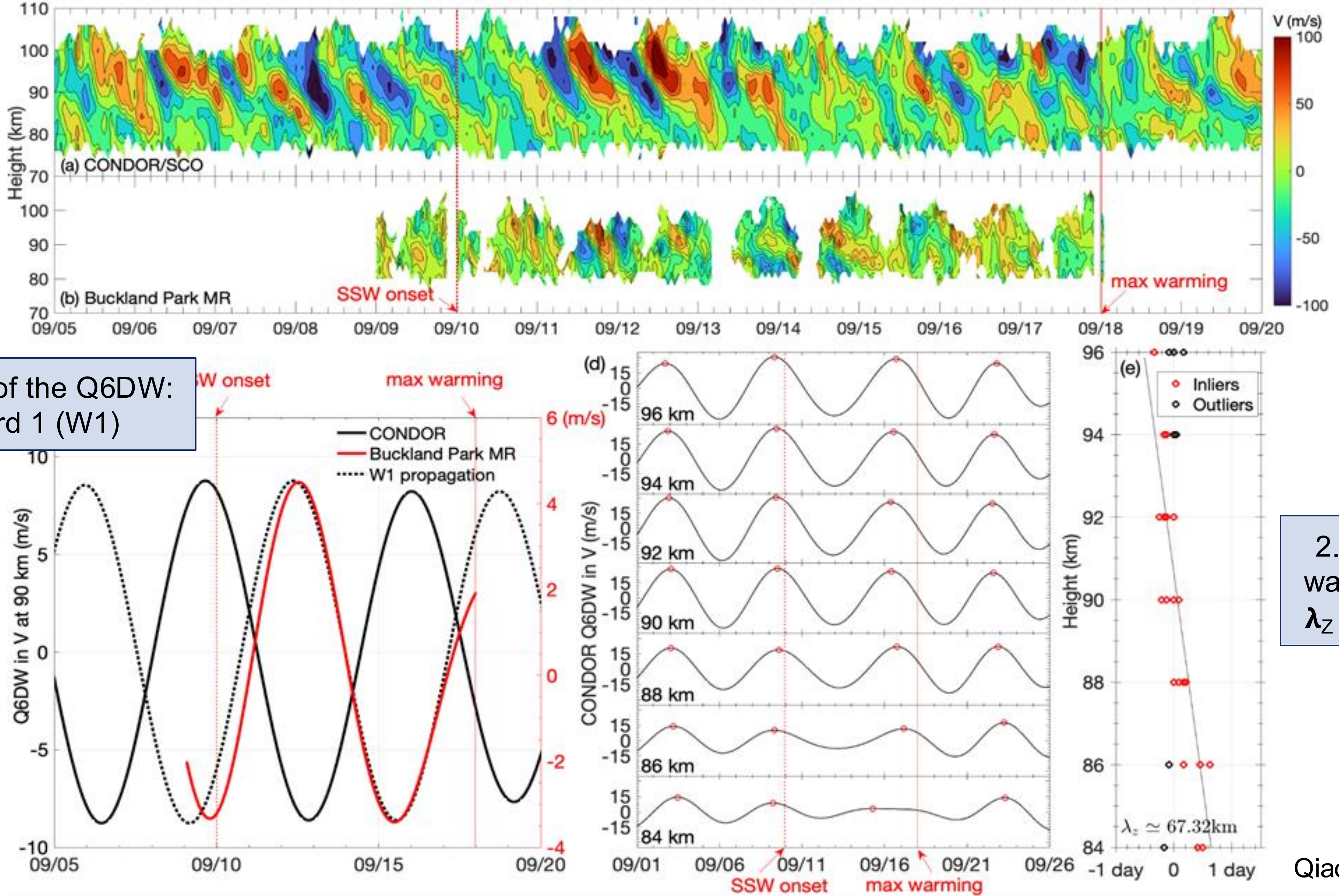
$$\mathbf{F} = \hat{\mathbf{j}}F_y + \hat{\mathbf{k}}F_z$$

$$F_y = -\overline{u'_0 v'_0} = -\frac{1}{2}\Re\{\tilde{u}_{Q6DW}\tilde{v}^*_{Q6DW}\}$$

$$F_z = \frac{gf}{N^2}\frac{\overline{\theta'_0 v'_0}}{\theta_S} = \frac{gf}{N^2}\frac{\Re\{\tilde{\theta}_{Q6DW}\tilde{v}^*_{Q6DW}\}}{2\theta_S}$$

- With U, V, and T of the Q6DW, the *local* Eliassen-Palm (EP) flux can be calculated with assumption of temporal average
- Strengthens and relative importance of the momentum flux and heat flux of the Q6DW can be investigated

151.75º longitudinally spaced CONDOR and Buckland Park meteor radar meridional winds are combined to diagnose the parameters of Q6DW

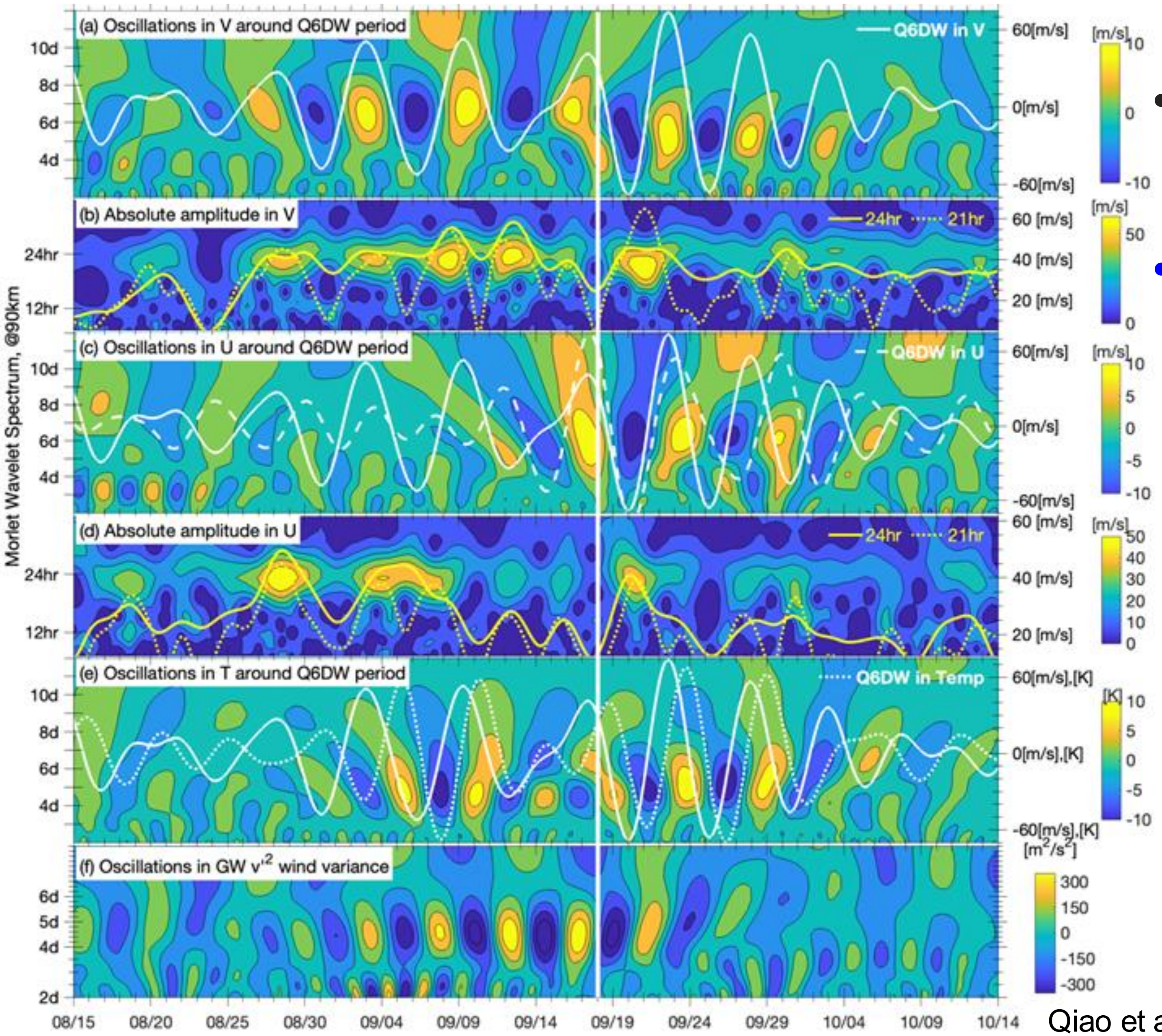


Characteristic of the Q6DW:
1. Westward 1 (W1)

2. vertical wavelength
$\boldsymbol{\lambda}_Z \simeq 67$ km

Qiao et al., (2024)

Q6DW-diurnal tide interaction and modulation on gravity wave variances

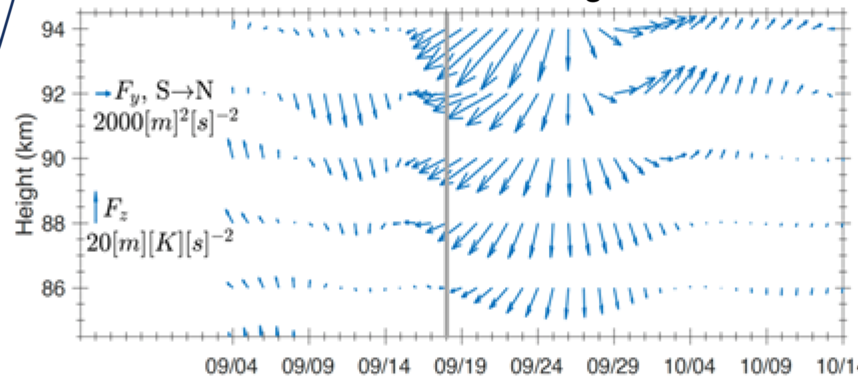


Q6DW is strong before / during / after the SSW max warming

Diurnal tide is amplified every 6 days, and a **21 hr child wave** appears in V

Enhanced Q6DW momentum flux and heat flux around max warming

SSW max warming

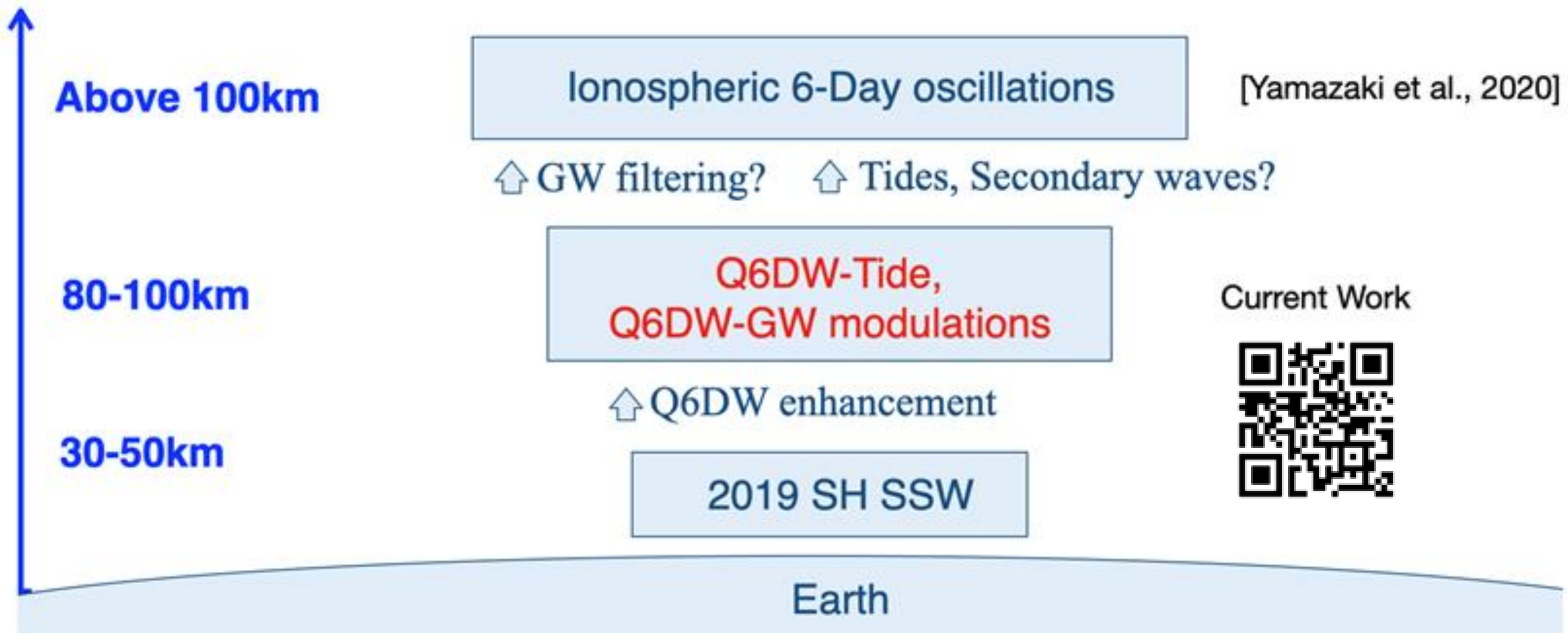


Gravity wave meridional wind variance has a 4-5 days response

Qiao et al., (2024)

Two potential ways of the 6-day periodicity penetration into the ionosphere

- A strong W1 Q6DW activity associated with the rare 2019 SH minor SSW is determined by two meteor radars at 30º S.
- First result of meteor radar observed Q6DW E-P flux indicates **an enhancement during the SSW**.
- Both **GW wind variance** and **diurnal tide amplitude** indicate a strong, clear quasi-6-day periodicity in meridional winds.
- Q6DW-Diurnal Tides-GW interactions in the MLT region may contribute to the reported ionospheric 6-day variability (Yamazaki et al., 2020).



My first CEDAR back to 2019…

Acknowledgement: NSF AGS-1828589, NSF NCAR ASP GVP & Postdoc Fellowship