Multi-instrument examination of the response in the thermosphere and ionosphere to a quasi 6-day planetary westward wave event

COUP-12

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Introduction

A quasi 6-day westward planetary wave (**Q6DW**) is **a fast westward propagating Rossby wave** event having periods of ~ 6 days and wave number 1.

Q6DW plays a critical role in linking the *lower atmospheric forcing to ionospheric variability* [1,2]

There are **more Q6DW events showing up in the ionosphere** when compared to Q6DE [3]

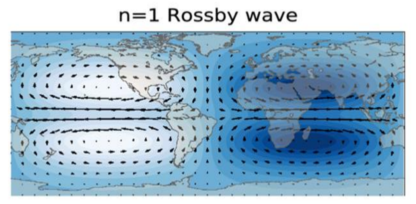


Figure 1. Rossby Wave. Credit: Vasylkevych and Zagar (2021)

Motivation

- The ionosphere is seen to change from one day to the other. This region is embedded inside the thermosphere and the IT system accommodates satellites in Low-Earth orbit, where these satellites are subject to satellite drag due to the variability of this system
- Some of the modulations of the ionosphere can be caused by the *Sun or solar wind or magnetospheric/geomagnetic processes*. Below the ionosphere, *lower atmospheric waves* (planetary wave, tides, gravity wave) can internally modulate this region. A prime example of planetary wave like oscillation in the ionosphere internally driven from the lower atmosphere is **Q6DW**
- Motivation: *Are there any evidence of **Q6DW** showing up at **upper** thermospheric and ionospheric **F-region** altitudes? Does SD-WACCM-X agree with observations of **Q6DW** at these altitudes?*

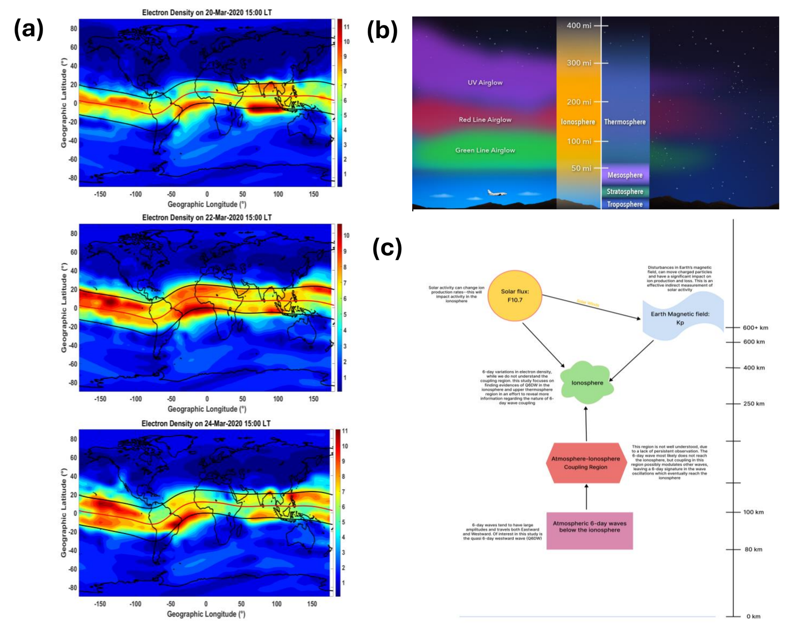


Figure 2 (a) Electron Densities at ~350 km altitude from COSMIC-GIS at 15:00 LT on March 20 (top panel), 22 (middle panel), and 24 (bottom panel), 2020. The geomagnetic equator is indicated by the curved red line, and the two curved black lines depict the ±20° geomagnetic latitude (b) Extracted from NASA's Goddard Space Flight Center and Mary Pat Hrybyk-Keith. Accessible at https://svs.gsfc.nasa.gov/12960/ (c) Pictorial summary of the motivation for this work. The altitudes are approximate, and they are not drawn to scale

Data and Methods

Instruments

The ICON mission explores the connection between the Earth's atmosphere and ionosphere while traveling eastward and continuously imaging the thermosphere and ionosphere. MIGHTI retrieves neutral winds between 90-300 km, Ion Velocity Meter (IVM) measures plasma density, ion velocity, and ion temperature in-situ, Far Ultra-Violet (FUV) measures O 135.6 nm and N_2 LBH airglow as a means of retrieving $\Sigma O/N_2$, and limb profiles of O and N_2 and O+ density at night, and Extreme Ultra-Violet (EUV) measures EUV O+ airglow at 61.6 nm and 83.4 nm in order to retrieve O+ density during the day [4,5]

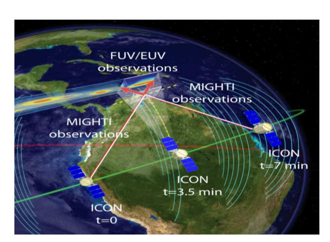


Figure 3. Credit: UCB/SSL

The GOLD mission tracks how the neutral atmosphere and ionosphere respond to forcing from the Sun, magnetosphere and lower atmosphere. At ~ 160 km GOLD measures O/N_2 and neutral temperature (Tdisk) and its extended limb observations measure atmospheric emissions up to ~ 350 km [6,7]

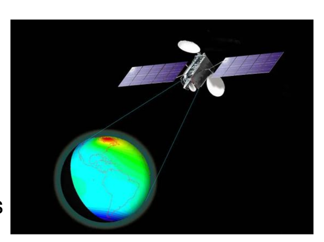


Figure 4. Credit: NASA

COSMIC-2 satellite measures electron density profiles in the ionosphere using radio occultation (RO) techniques [8]

Figure 5. Credit: UCAR/COSMIC

The SABER instrument onboard NASA's TIMED satellite measured kinetic temperatures that retrieved from measurements of CO_2 emissions at 15 and 4.3 µm wavelengths within the altitude range of ~20–120 km at a vertical resolution of ~2 km [9]

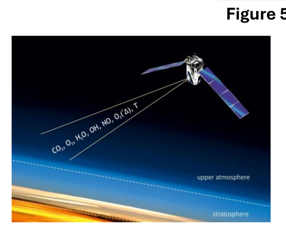


Figure 6. Credit: NASA

Data

The data used in this study include:

ICON-MIGHTI L3 Zonal and Meridional Wind | L3 Temperature | ICON IVM | O/N_2 | Airglow Brightness | GOLD O/N_2 and Tdisk | WACCM-X FORMOSAT-7/COSMIC-2 IVM and GIS Electron Density | SABER Temperature | NASA's OMNIWeb F10.7 and Kp index | Madrigal GNSS TEC

Methods

A least square fit wave model was designed to fit SABER temperature and the other parameters to get the **Q6DW** amplitudes using the equation:

$$A\cos(n\Omega t + m\lambda - \phi)$$

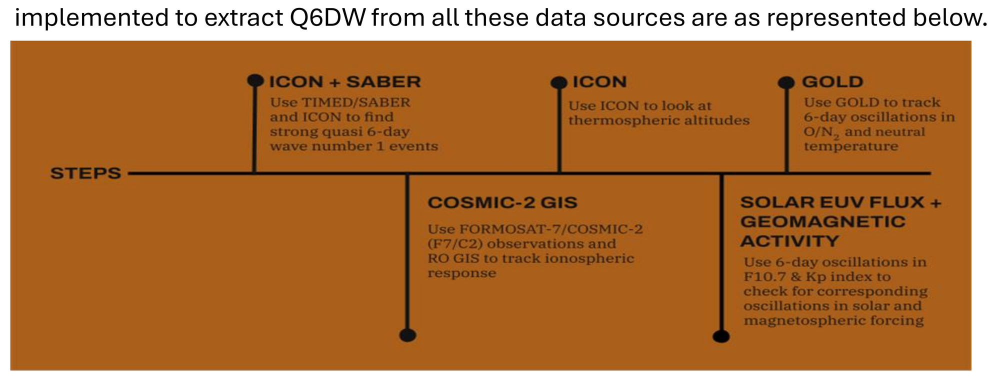
$A, n, \Omega, t, m, \lambda$ *and* ϕ denotes the amplitude, frequency(/day), Earth's rotation's rate, universal time (days), zonal wavenumber, longitude (radian), and phase, respectively. $n \geq 0, m = \cdots -4, -3, -2, -1, 0, +1, +2, +3, +4, \ldots$ and Ω is expressed as $\Omega = \frac{2\pi}{day}$.

$n \neq 0$ denotes wave traveling in the zonal direction. $m < 0$ represent waves propagating eastward while those with $m > 0$ propagate westward, and waves with $m = 0$ denotes standing oscillations.

For the ICON-MIGHTI L3 parameters, a convolution approach is adopted to design a wave model that extract their Q6DW amplitudes using the equation:

$$\phi(\lambda, i) = \frac{\pi\,\lambda}{180} + \frac{2\pi\, i}{d}$$

d is the denotes the period of the wave in days and i denotes the integer for the day index. The overall approach of the steps that was implemented to extract Q6DW from all these data sources are as represented below.



Compare with SD-WACCM-X Simulations

Figure 7. An overview of the technique that was used in this study.

References

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Results

Tracking Strong Q6DW Event

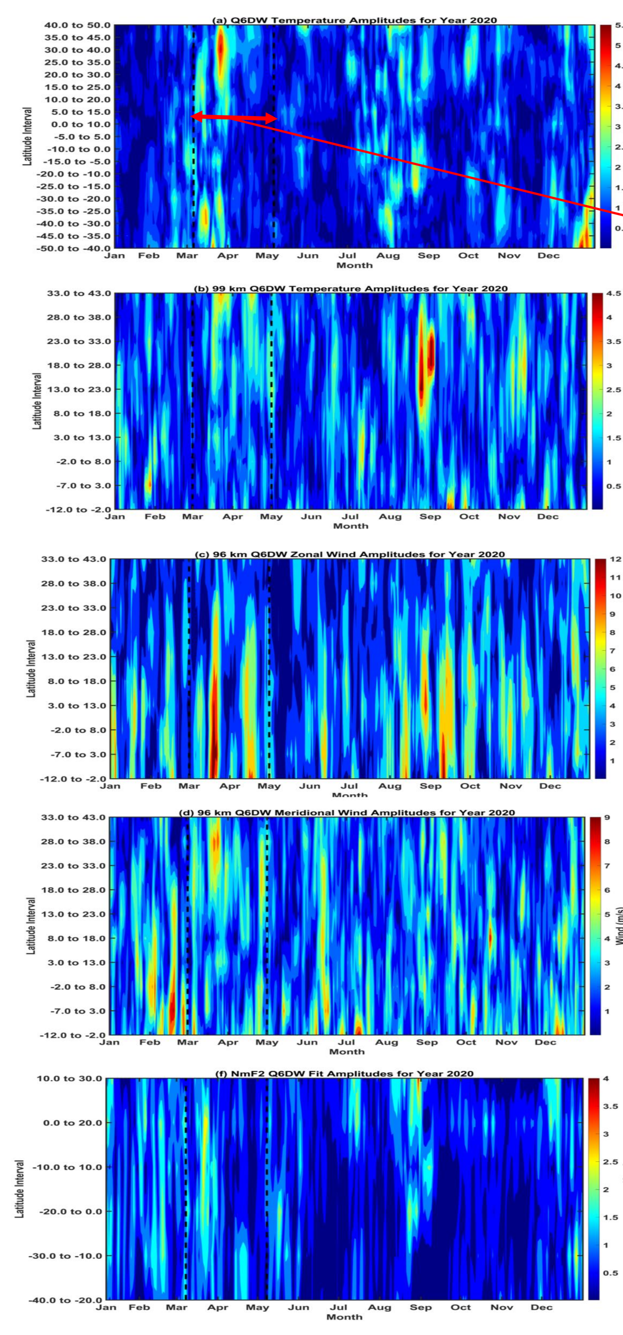

Figure 8. (a) Amplitudes of Q6DW oscillations derived from SABER temperature observations at ~ 100 km altitude (b) Amplitudes of Q6DW oscillations derived from ICON-MIGHTI temperature observations at ~ 99 km altitude. Amplitudes of Q6DW oscillations derived from ICON-MIGHTI zonal (c) and meridional (d) wind observations at ~ 99 km altitude (e) Amplitudes of Q6DW oscillations derived from COSMIC-GIS NmF2 peak electron density at ~ 250 - 450 km altitude.

Responses of Thermosphere and Ionosphere to Q6DW Event

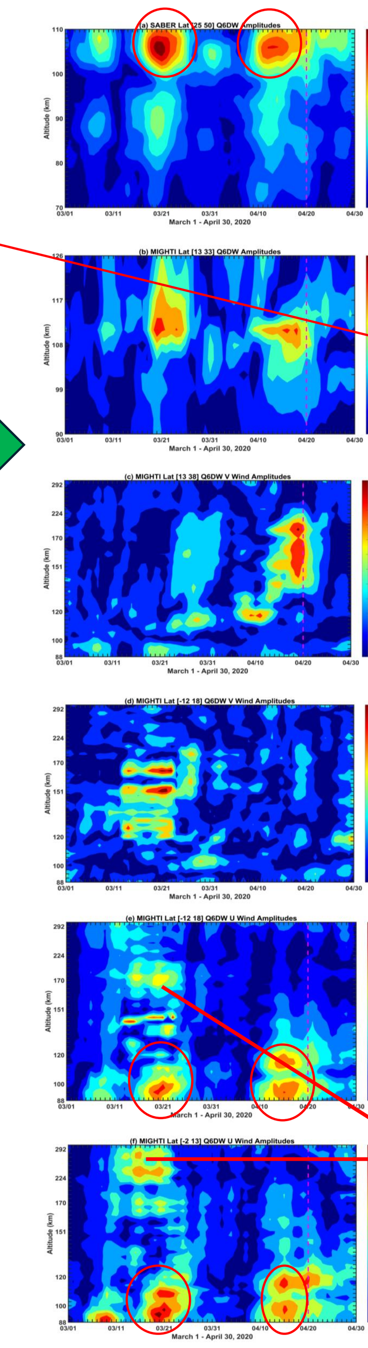

Figure 9. Vertical structure of Q6DW in temperature, neutral winds and electron densities during March 1 – April 30, 2020. (a) SABER Temperature Q6DW fit (b) ICON-MIGHTI Temperature Q6DW fit (c-d) ICON-MIGHTI Meridional Wind Q6DW fit (e-f) ICON-MIGHTI Zonal Wind Q6DW fit. The dash magenta line indicates that there was a geomagnetic storm on April 20, 2020

Strong **Q6DW** event. There are other prominent **Q6DW** events as well. The focus of this study is on the March-April 2020 event.

For the March-April 2020 event, there are two significant **Q6DW** events in the neutrals, greeline and F-region electron densities, on *03/21* and *04/10*, respectively. Both **Q6DW** signatures are not very clear for the redline.

The prominent **Q6DW** redline signatures are impacted by the minor April 2020 geomagnetic storm

The **Q6DW** in greenline signature just above 100 km altitude on *03/21* is driven by a combination of O_2^+ density, atomic oxygen, and photoelectrons of molecular nitrogen – Both neutral density and ion density contribute to this greeline fluctuation.

Q6DW signatures do not get to the higher altitudes by themselves. They do this aided with the activity of secondary waves and interaction with tides.

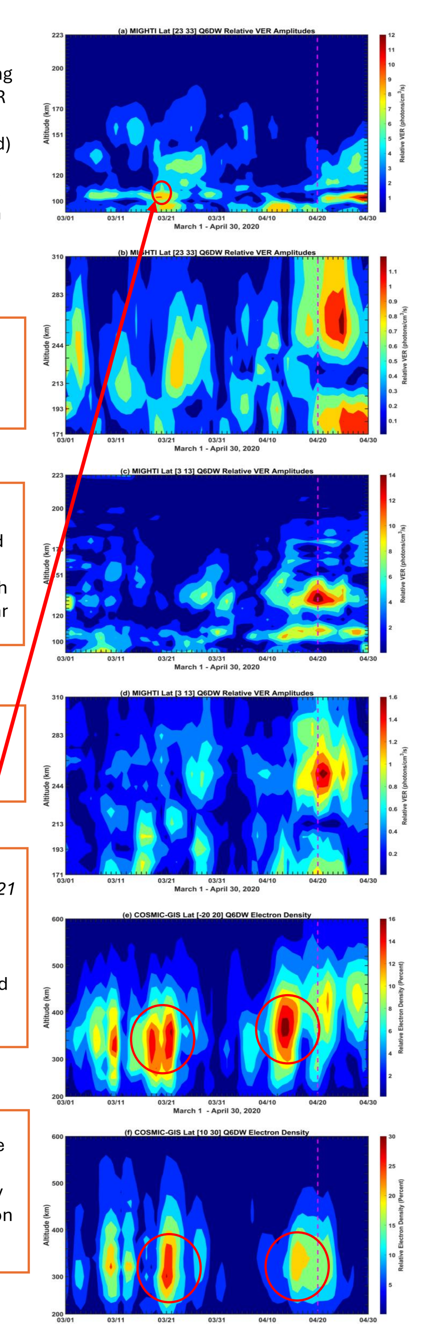

Figure 10. Vertical structure of Q6DW in Airglow Brightness and electron densities during March 1 – April 30, 2020. (a&c) ICON-MIGHTI Greenline Q6DW fit (b&d) ICON-MIGHTI Redline Q6DW fit (e-f) COSMIC-GIS electron densities Q6DW fit. (g) ICON-MIGHTI Meridional Wind Q6DW fit. The dash magenta line indicates that there was a geomagnetic storm on April 20, 2020

Q6DW signatures in GOLD O/N_2 peak ed couple of days before the minor April 2020 geomagnetic storm. GOLD Tdisk only sees the 03/21 event.

More Findings

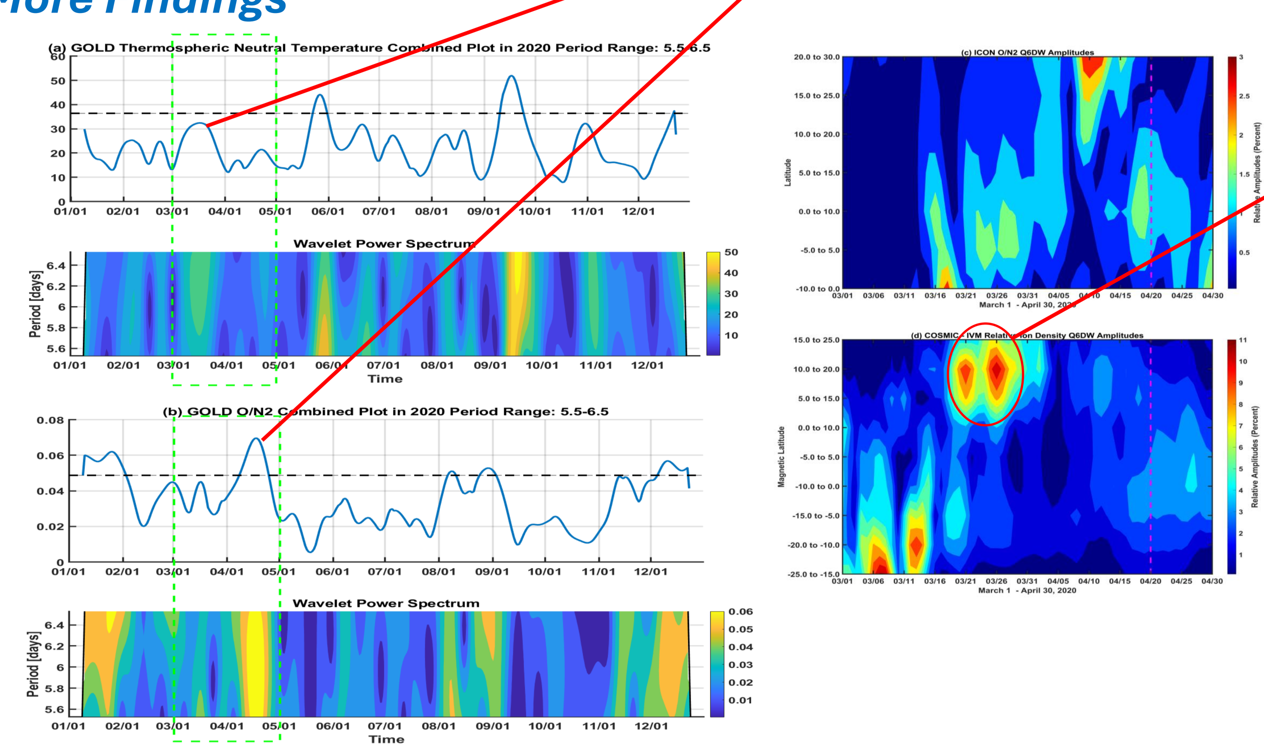

Figure 11. (a) 6-day oscillations during the year 2020 (a) neutral temperature (b) O/N2 .Latitudinal structure of Q6DW during March 1 – April 30, 2020. (c) ICON O/N2 Q6DW fit (d) COSMIC-2 IVM Q6DW fit. The dash green box indicates the March-April 2020 period. The dash magenta line indicates that there was a minor geomagnetic storm on April 20, 2020

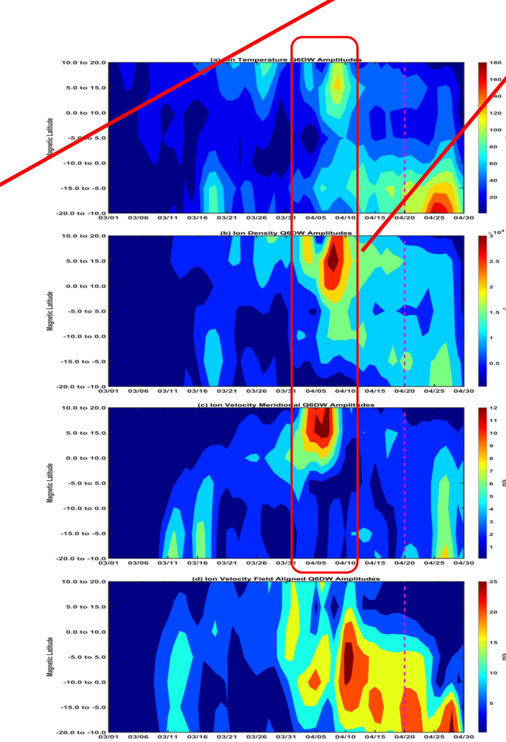

Figure 12. Latitudinal structure Q6DW in ICON-IVM observations during March 1 – April 30, 2020. (a) Ion Temperature Q6DW Fit (b) Ion Density Q6DW Fit (c) Ion Velocity Meridional Q6DW Fit (d) Ion Velocity Field Aligned Q6DW Fit. . The dash magenta line indicates that there was a geomagnetic storm on April 20, 2020

6-day Oscillations in Ground-based TEC, Solar and Geomagnetic Forcing

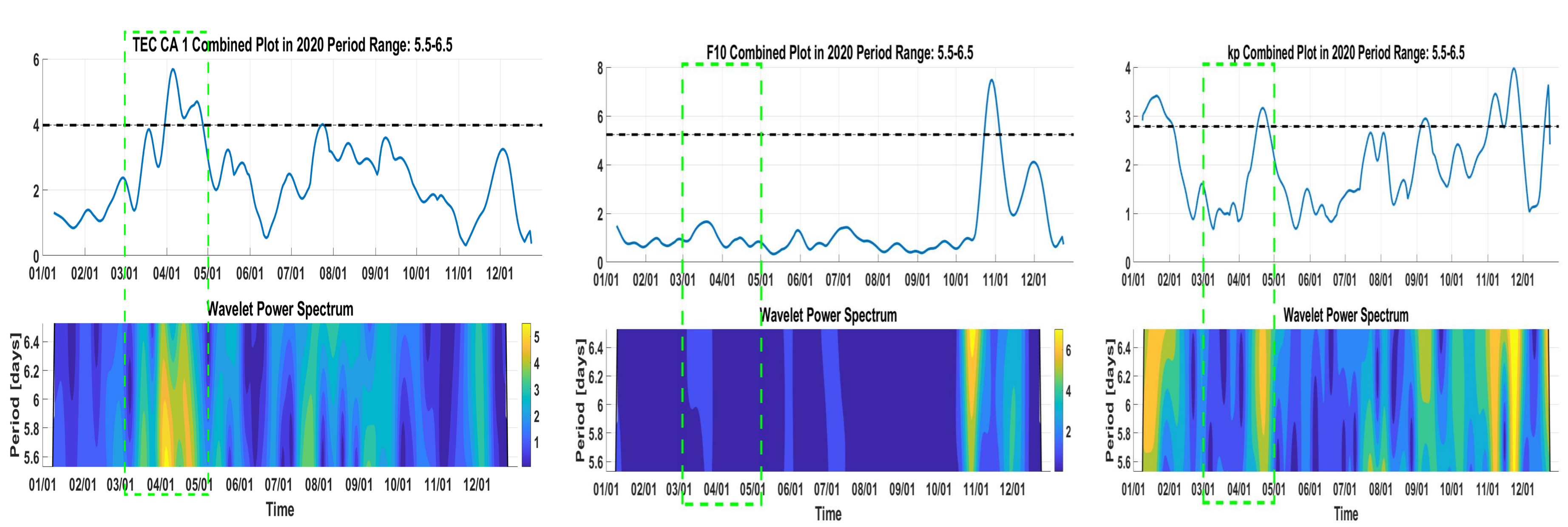

Figure 13. (right) Central America TEC **(middle)** F10.7 and Kp **(left)** index 6-day oscillations during the year 2020. The dash green box indicates the March-April 2020 period

Ongoing Work: SD-WACCM-X Perspectives

SD-WACCM-X captures the 03/21 and 04/10 **Q6DW** events very clearly:

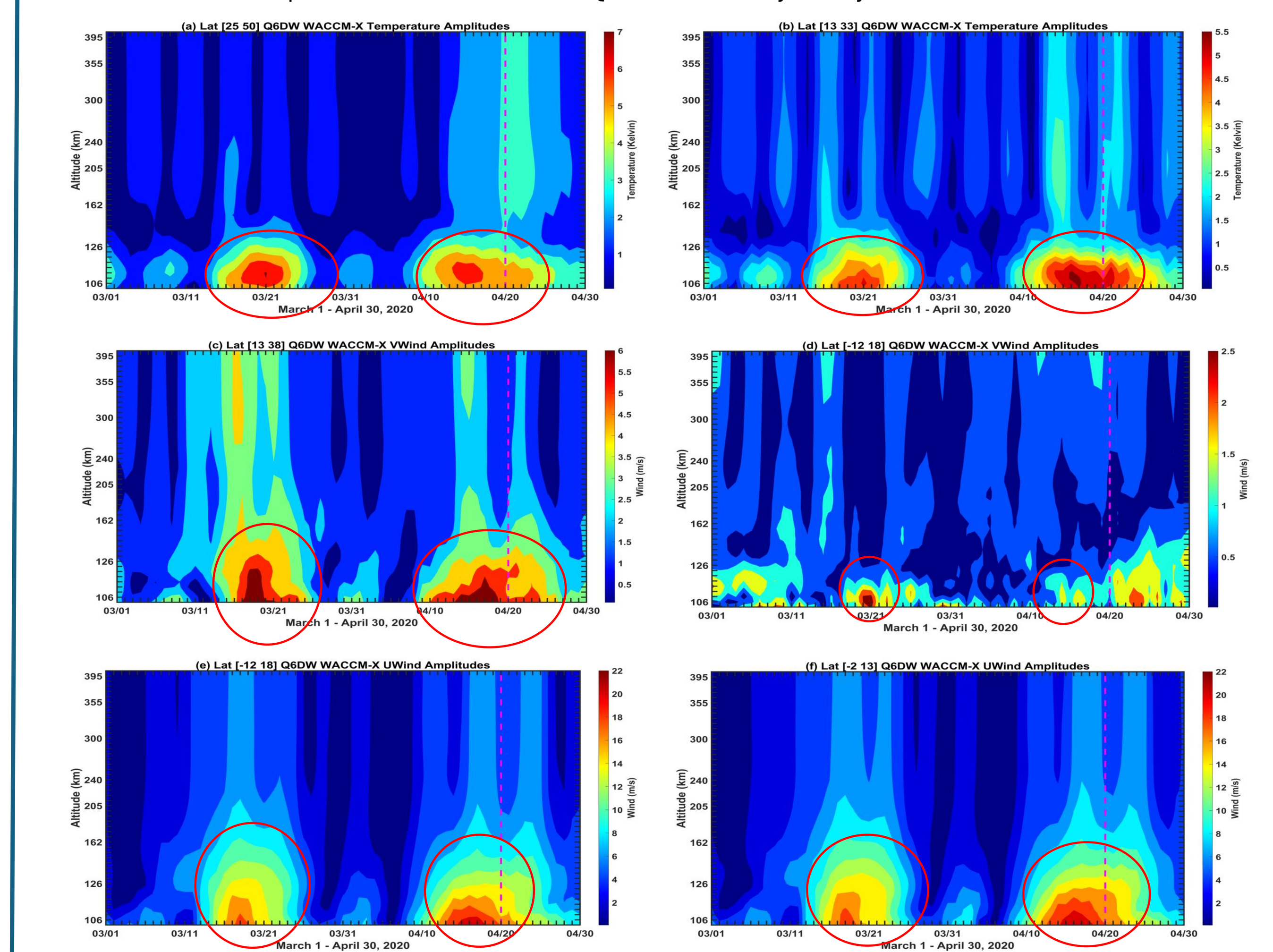

Figure 14. Vertical structure of Q6DW in WACCM-X temperature and neutral winds during March 1 – April 30, 2020. (a) WACCM-X Q6DW fit for SABER Temperature latitude (b) WACCM-X Q6DW fit for ICON-MIGHTI Temperature latitude (c-d) WACCM-X Q6DW fit for ICON-MIGHTI Meridional Wind latitudes (e-f) WACCM-X Q6DW fit for ICON-MIGHTI Zonal Wind latitudes. The dash magenta line indicates that there was a geomagnetic storm on April 20, 2020. The dash magenta line indicates that there was a geomagnetic storm on April 20, 2020

ICON IVM sees **Q6DW** at a later time that COSMIC-IVM sees **Q6DW**. Part of the reason for this could be due to ICON-IVM sampling bias – ICON-IVM's sampling is sensitive to different latitudes and times of a day as day changes such that the signature of the Q6DW event could be related to the time of the day that is revolving with day number.

Coupling Mechanisms/Pathways	Are there evidence of Q6DW signatures during the March-April 2020 event?
F-region wind modulation	Yes
Modified dynamo region	Yes
Modified O/N2 circulation	No
Q6DW showing up in the ionosphere and upper thermosphere	Yes
Modified ExB drift	Partially Yes
6-day periodic signatures in electron density	Yes
6-day periodic signatures in geomagnetic activity	Partially Yes
6-day periodic signatures in solar EUV flux	No

Conclusions and Future Work

- The response in the thermosphere and ionosphere to **Q6DW** wave events during March-April 2020 is examined.
- **Q6DW** is clearly seen at some upper thermospheric and ionospheric altitudes. There is a significant correspondence between the amplitude of **Q6DW** for the neutrals and those of COSMIC-GIS electron density and 6-day oscillations in ground-based total electron content, indicating that the Q6DW in the lower and middle atmosphere induced an ionospheric response at **F-region ionospheric altitudes**.
- The observed greeline and redline **Q6DW** signatures are not necessarily revealing that the neutral atmosphere is oscillating 100% - some of the oscillations are from the oscillations in the ions as well.
- Evidence of Q6DW is not very clear in GOLD O/N_2. But it can be seen in ICON O/N_2 for the 04/21 Q6DW event
- There is a possibility that some of the forcing contributing to the activities of these wave events are due to geomagnetic or magnetospheric forcing.
- Future work is to examine if the SD-WACCM-X model tracked O/N_2 variation.
- Another future work is to do a modeling study that will isolate the effect of the minor geomagnetic storm in the Q6DW redline brightness and GOLD O/N_2

Acknowledgements

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