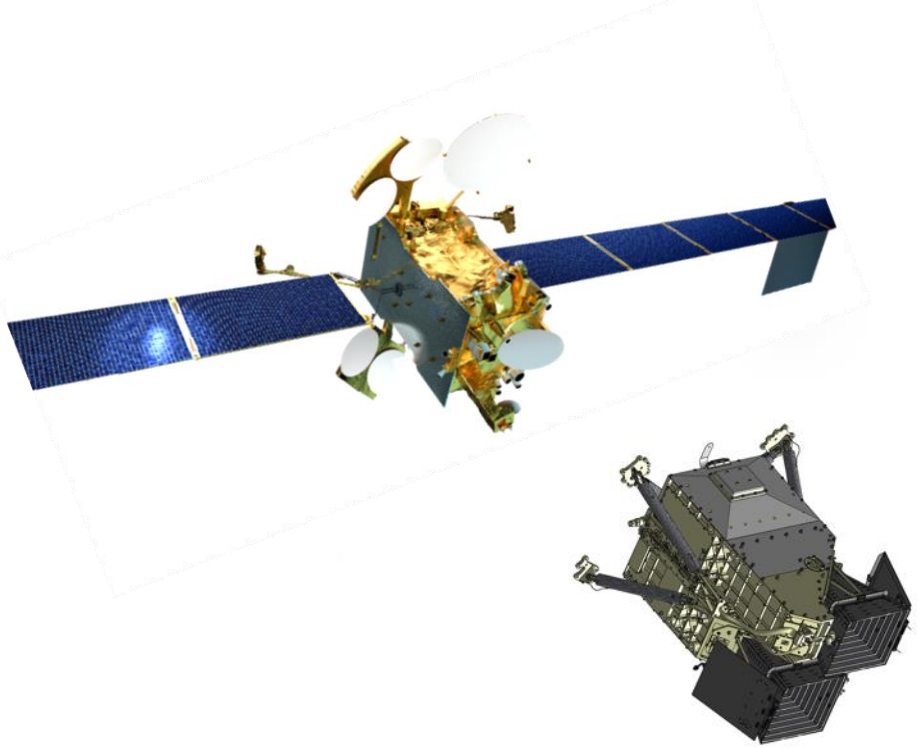
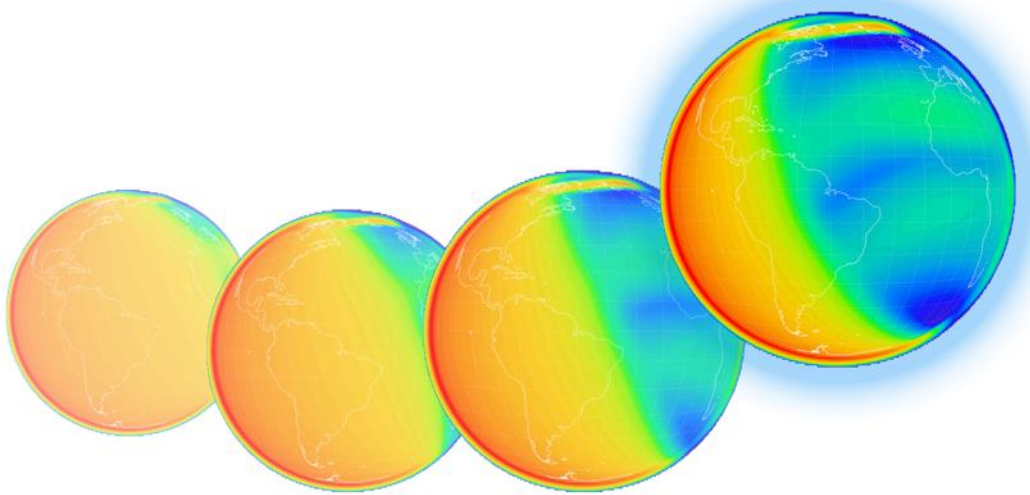


Global-scale Observations of the Limb and Disk (GOLD) Mission Update and First Science Results

Richard Eastes & the GOLD Science Team



Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

Scientific Motivation

- **GOLD is the next logical step in Ionosphere-Thermosphere studies**
  - Decades of research using observations from low earth orbiting (LEO) spacecraft and ground-based facilities
  - *Can not separate daily spatial - temporal variability*
  - Enabled the characterization of the I-T system '**climate**'

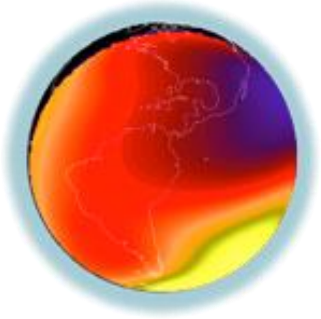
- **GOLD images the I-T system from geostationary orbit (GEO)**
  - NASA Explorers Mission of Opportunity
  - *Near-hemispherical measurements of dayside composition (O/N_2) and temperature with 30-minute cadence*
  - Enables the first characterization of the I-T system '**weather**'

GOLD Mission Overview

- **Host Mission**
  - SES-14, in geostationary orbit at 47.5˚ west (over mouth of the Amazon River)
- **GOLD Instrument**
  - Two identical, independent imaging spectrographs covering 132-162 nm
- **Measurements**
  - Earth's disk
    - Tdisk & O/N_2 - Daytime: from spatial-spectral image cubes of O-135.6 nm and N_2-LBH emission
    - Nmax - Nighttime: from images of O-135.6 nm emission
  - Earth's limb
    - Texo - Altitude profiles of N_2-LBH emission
    - O_2 density profile - Stellar occultations

SES Government Solutions

LASP Laboratory for Atmospheric and Space Physics University of Colorado Boulder

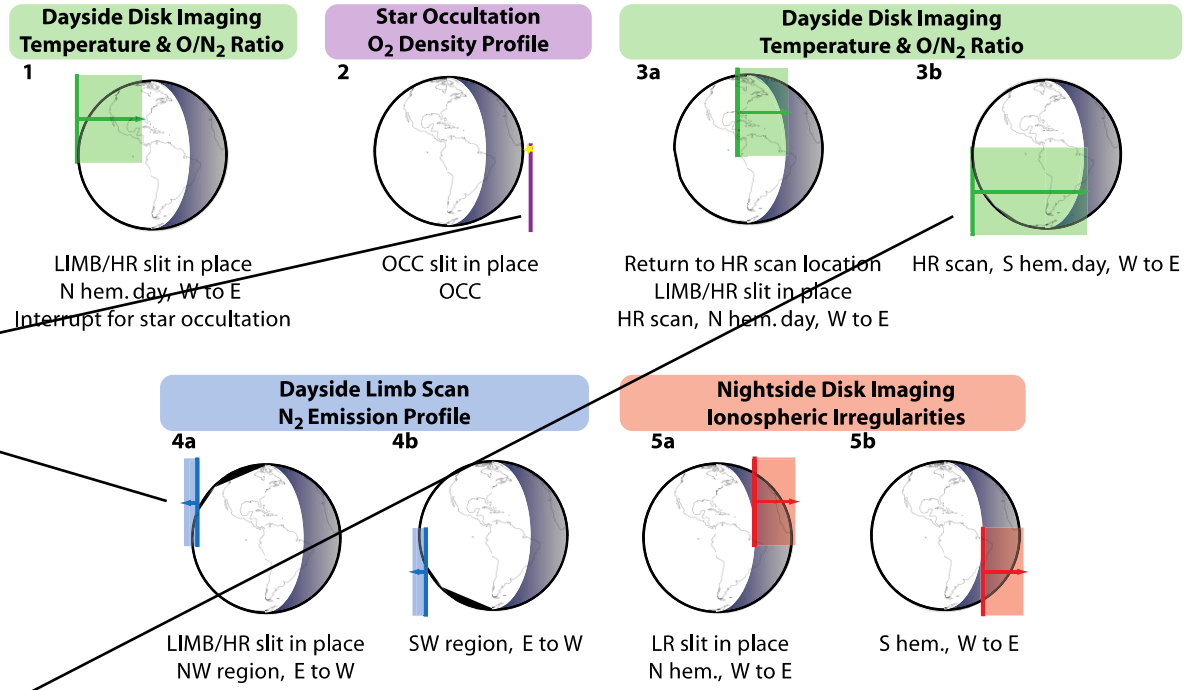


UCF

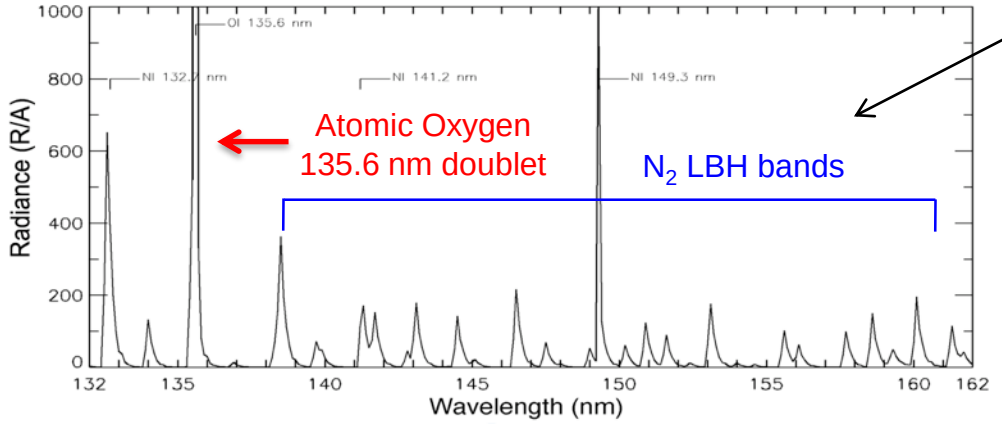
GOLD Uses Whiskbroom Imaging to Build Spatial-Spectral Image Cubes

Technique

- Telescope equipped with a scan mirror images the T-I system onto the slit of an imaging spectrograph
- *The limiting resolution is ~ 50 km*
- Measurements include stellar occultations and altitude profiles on the limb

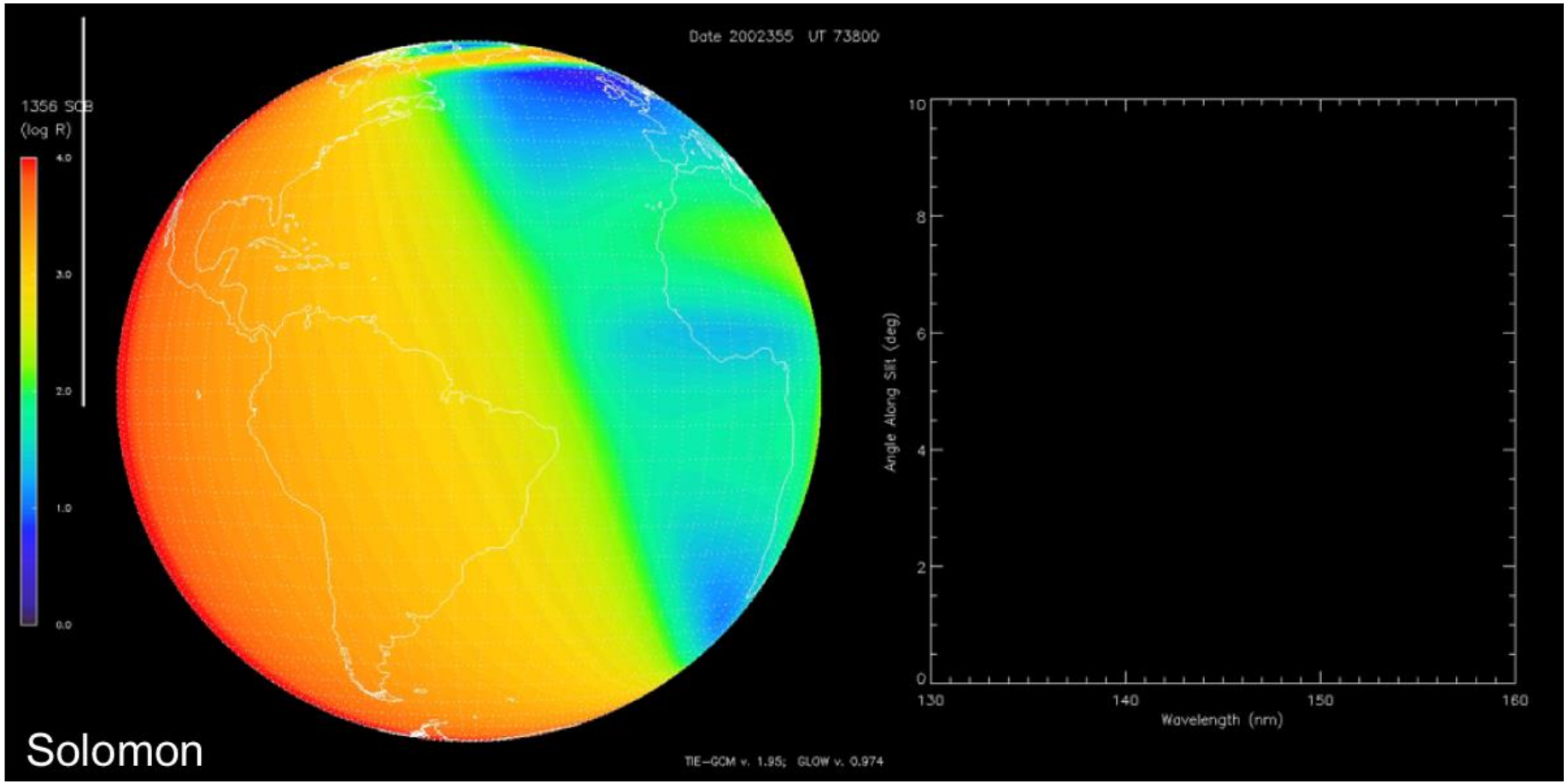


Daytime Far-Ultraviolet Spectrum



The spectrograph records spectra as a function of slit height at each point on the disk

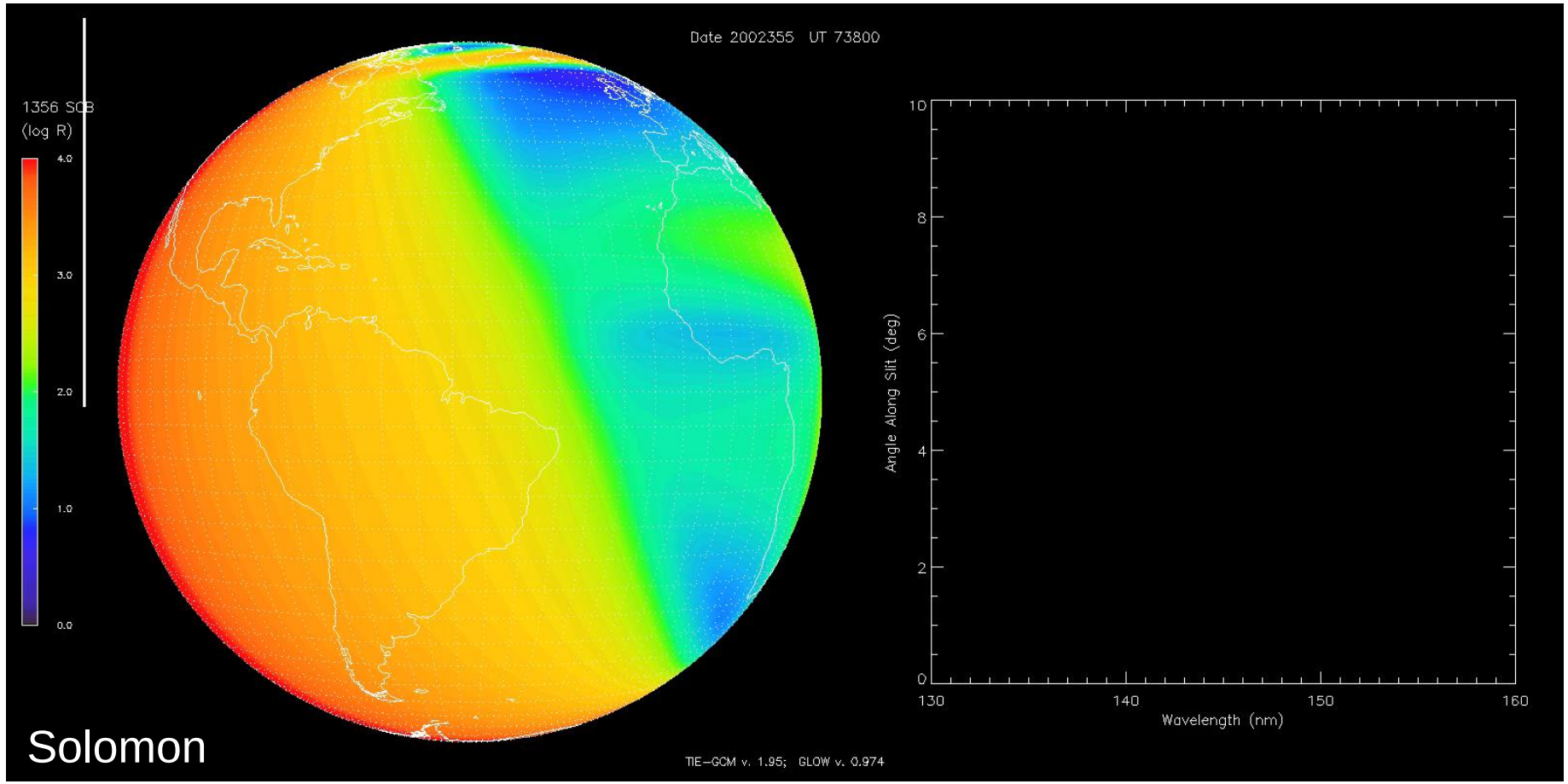
GOLD Disk Imaging Simulation



Disk Image **Detector Image**

- **Entrance slit of one (of two) channel is shown as white rectangle**
- ***Slit step rate and position are commandable, can dwell on selected longitude range***

GOLD Disk Imaging Simulation



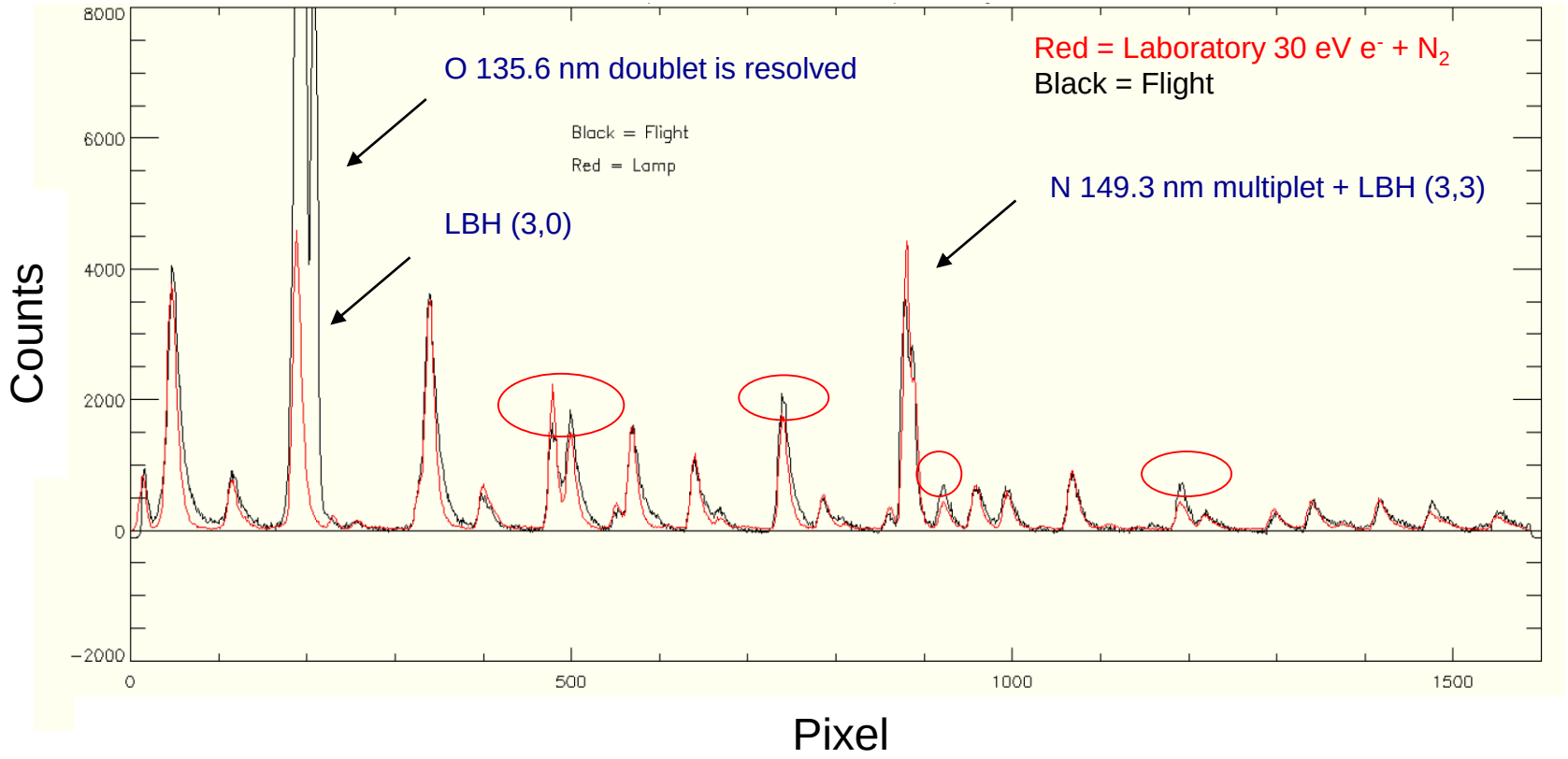
Disk Image **Detector Image**

- **Entrance slit of one (of two) channel is shown as white rectangle**
- ***Slit step rate and position are commandable, can dwell on selected longitude range***

Comparison - Flight to Laboratory Spectrum

Comparison with lamp spectra acquired during ground calibration shows the relative band strengths are in reasonable agreement

Comparison of Laboratory Electron-Impact Spectrum and Flight Data

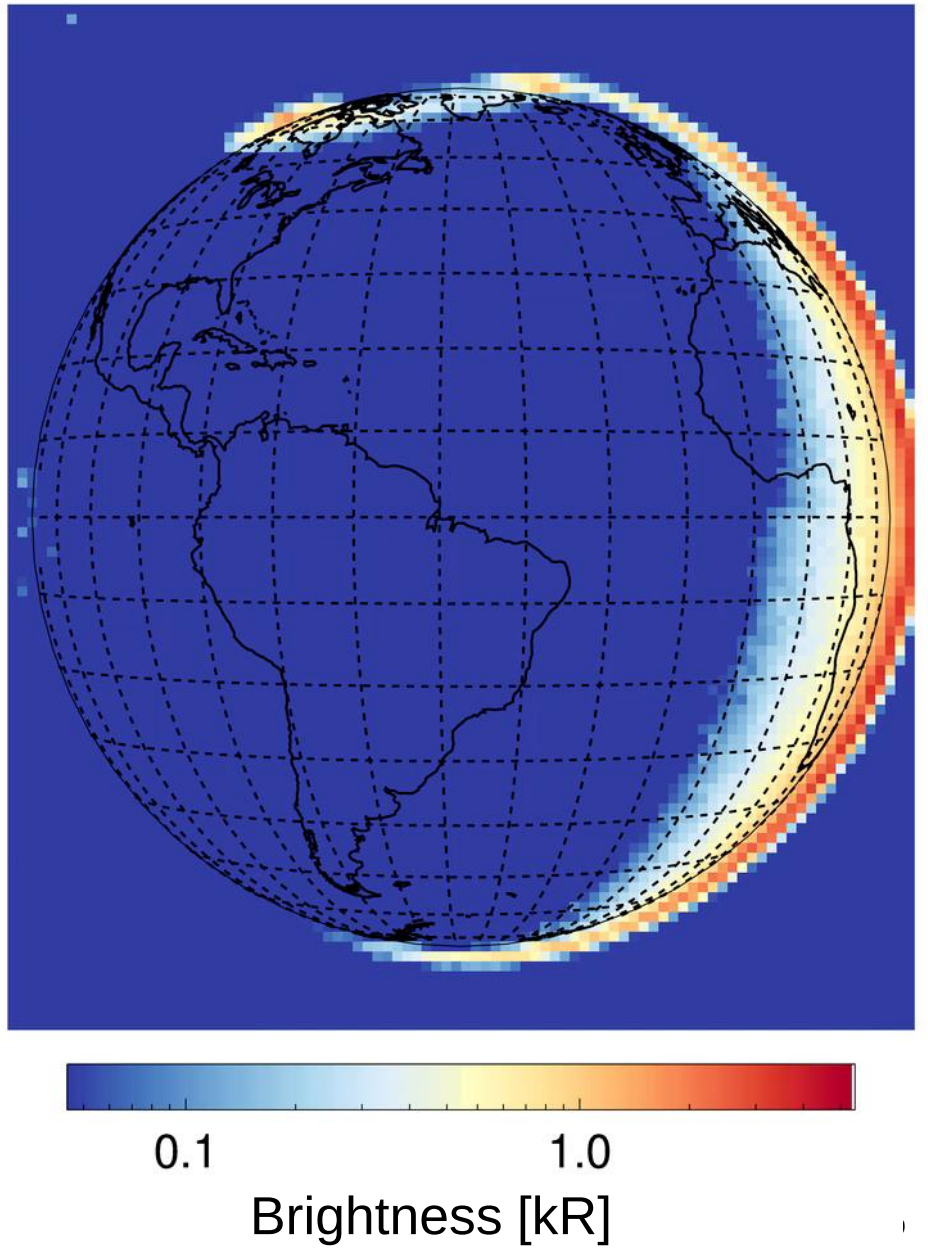


Full Disk Observations at 135 nm

October 9, 2019 0300-2000 LT (0600-2300 UT) observations by channel A

Sum of 135.6 nm emission, which is primarily from atomic oxygen (O)

30 minute cadence for whole image, spatial grid is 125 km x 125 km at nadir

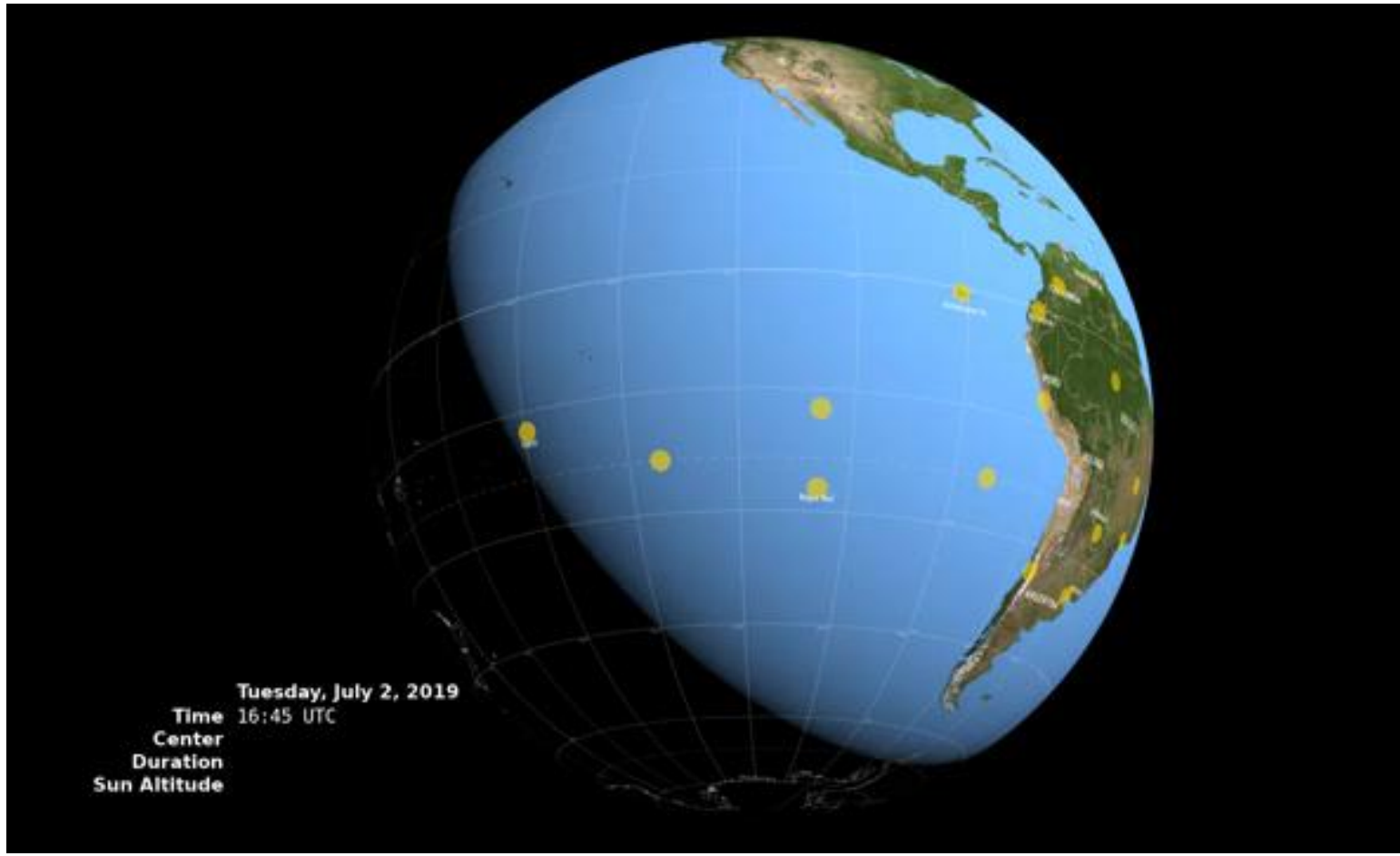


Spatial Perturbations in the Dayglow

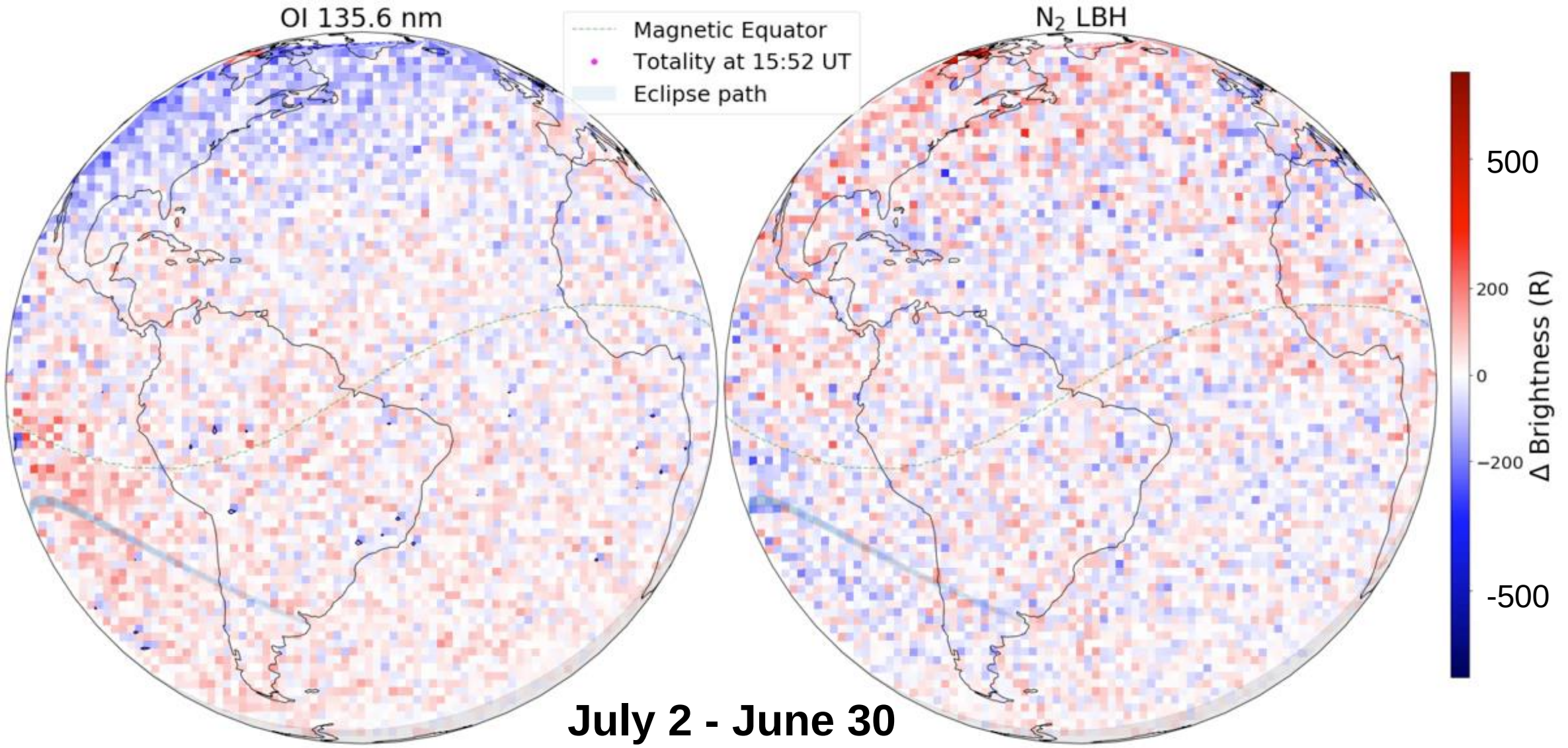
July 2, 2019 Eclipse (example 1)

- **Eclipse starts ~ 17 UT at 37S, 158W**
- ***Greatest duration: 17S, 108.6 W (near longitudes GOLD observes on limb)***
- **Duration of totality: ~ 5 minutes**

From NASA

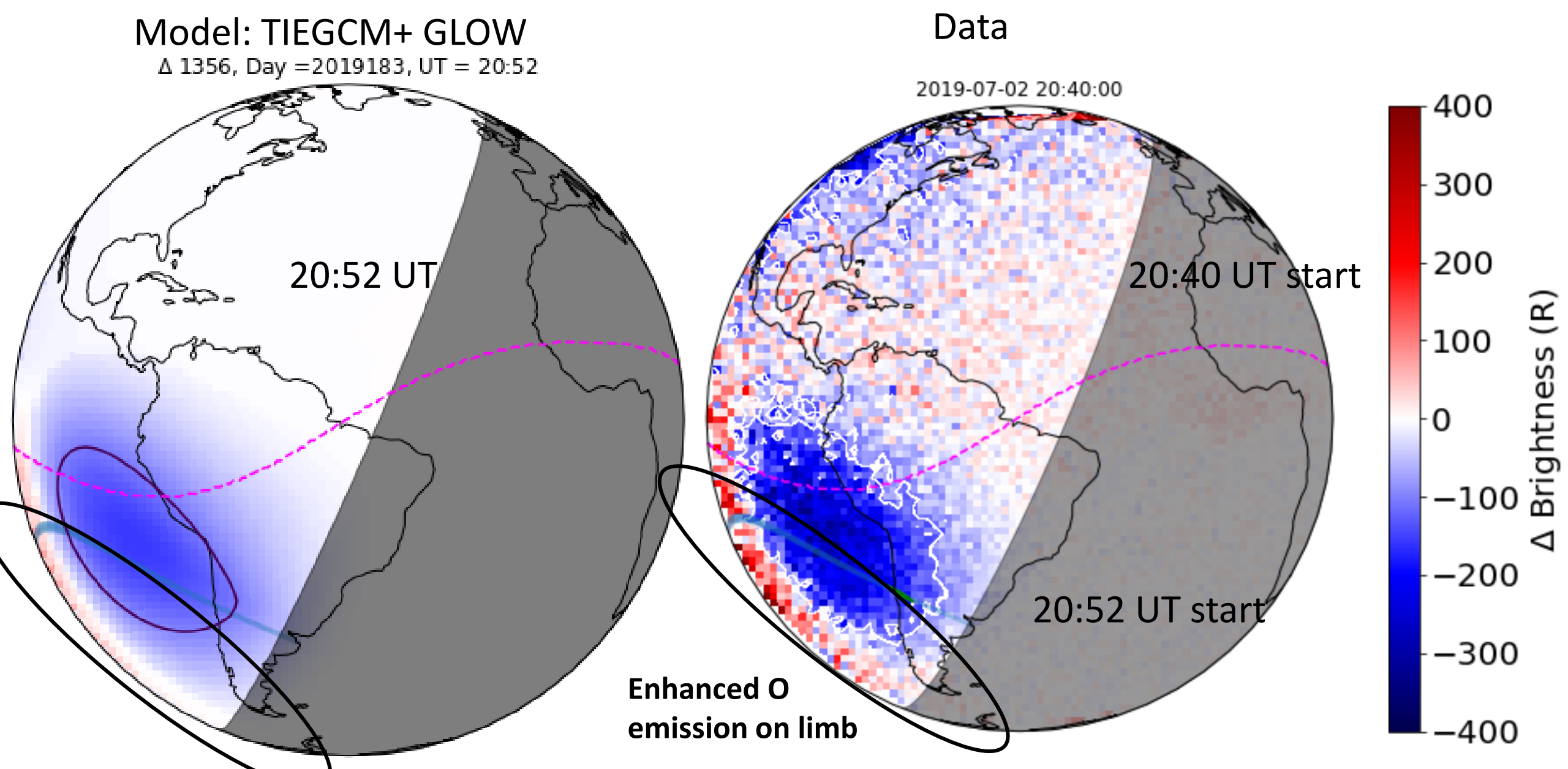


GOLD Observation: Difference from Previous Day

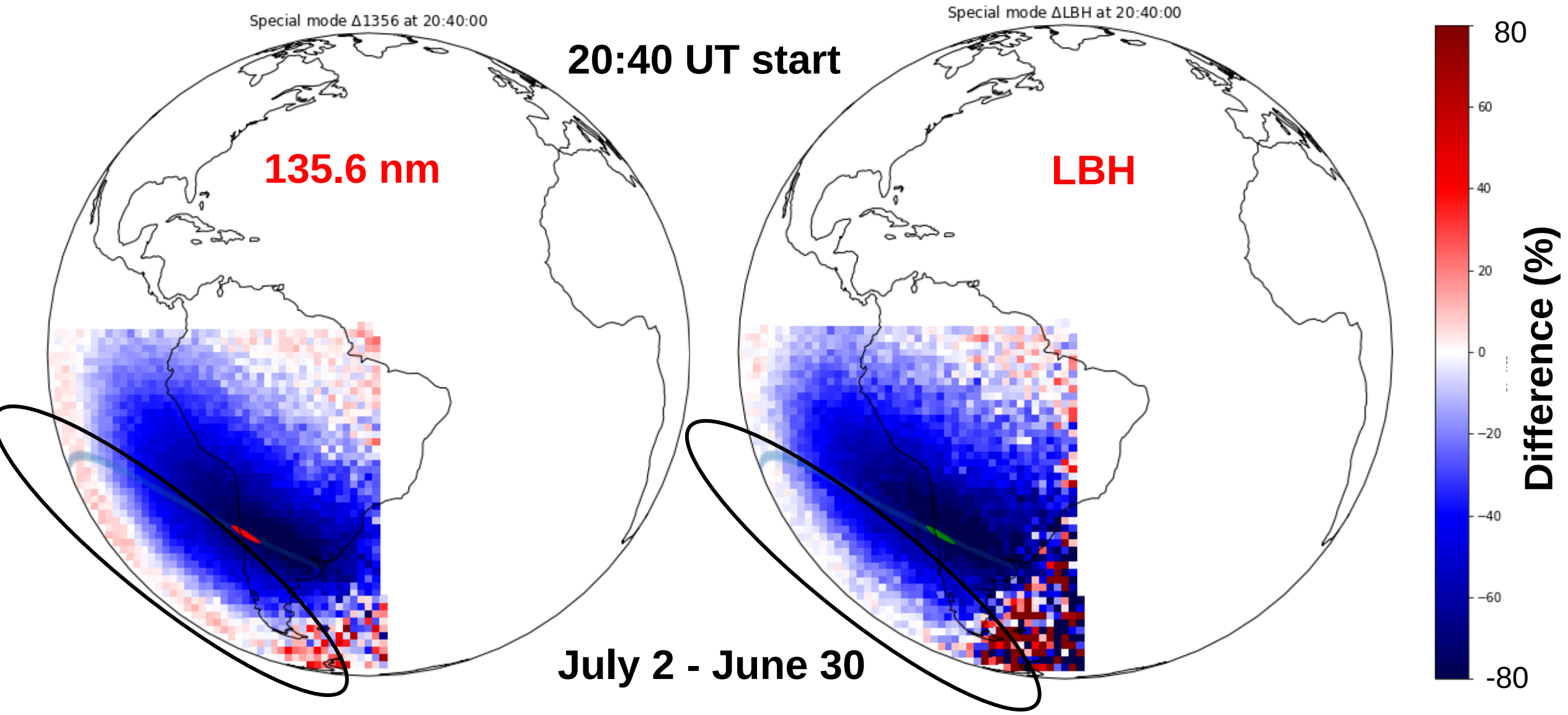


July 2 - June 30

Observed versus Modeled Difference at 135.6 nm

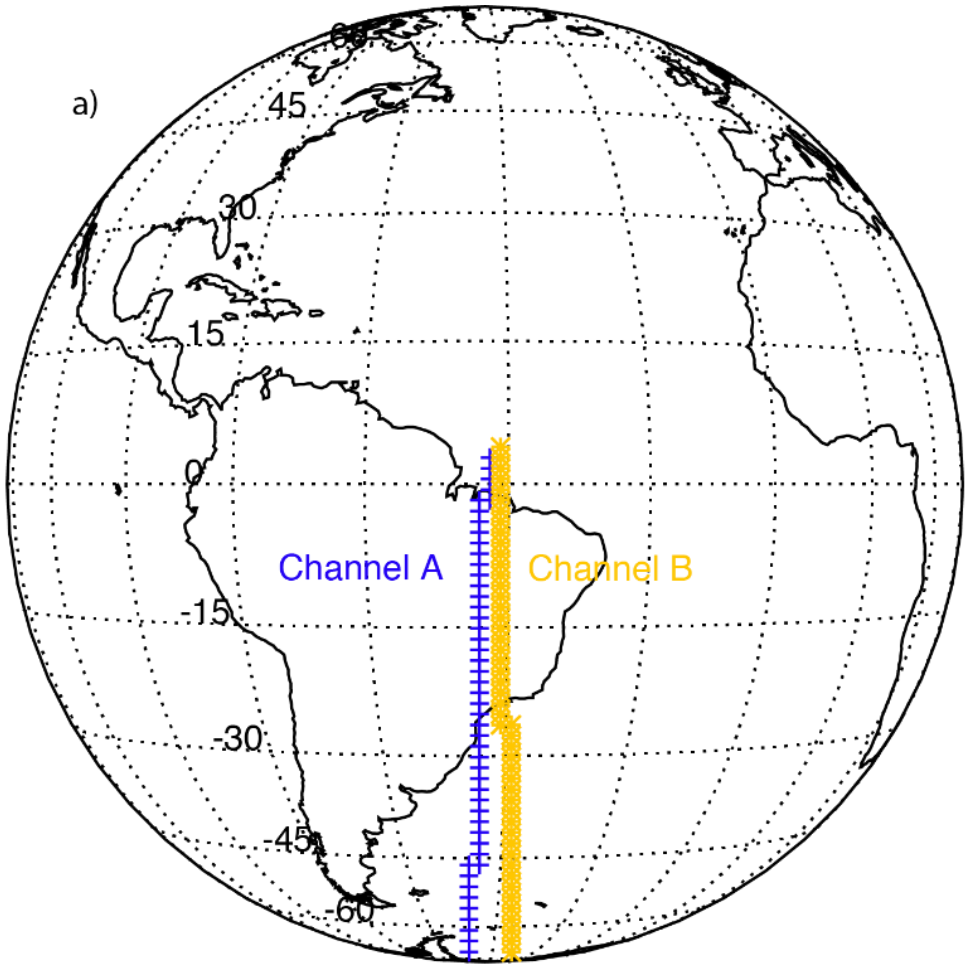


Second GOLD Channel (in a “Special Mode”)



Atmospheric Waves (Dayglow Example 2)

fields-of-view



October 13, 2018

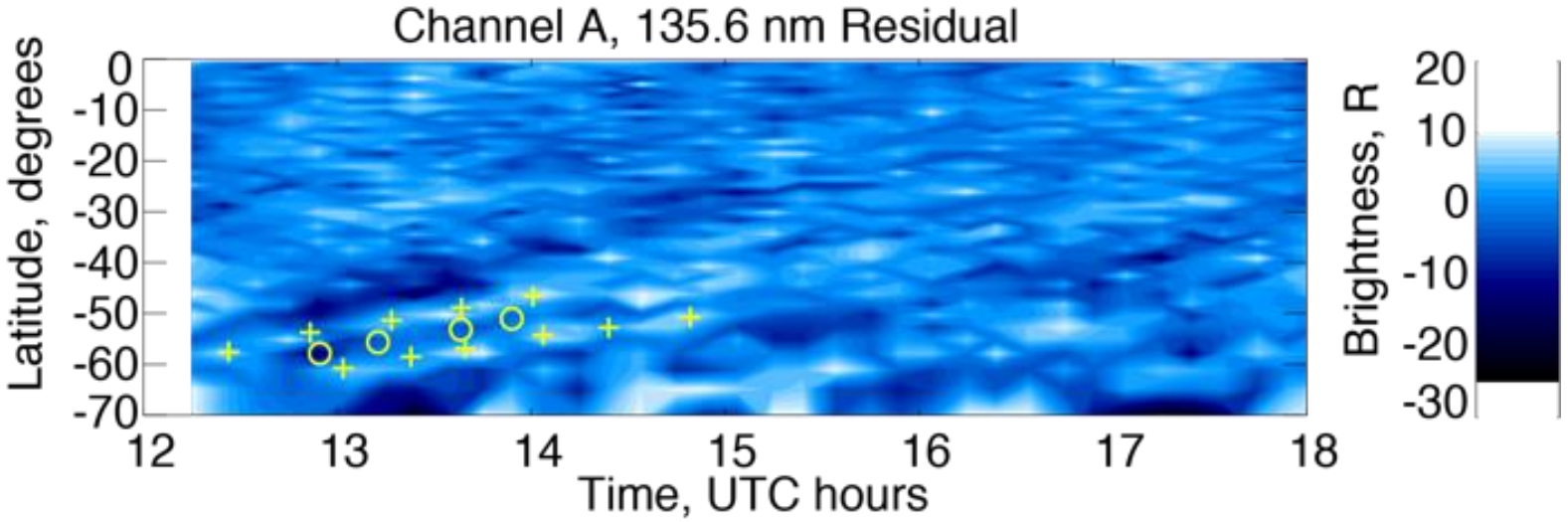
Both channels observed at fixed locations for 6 hours

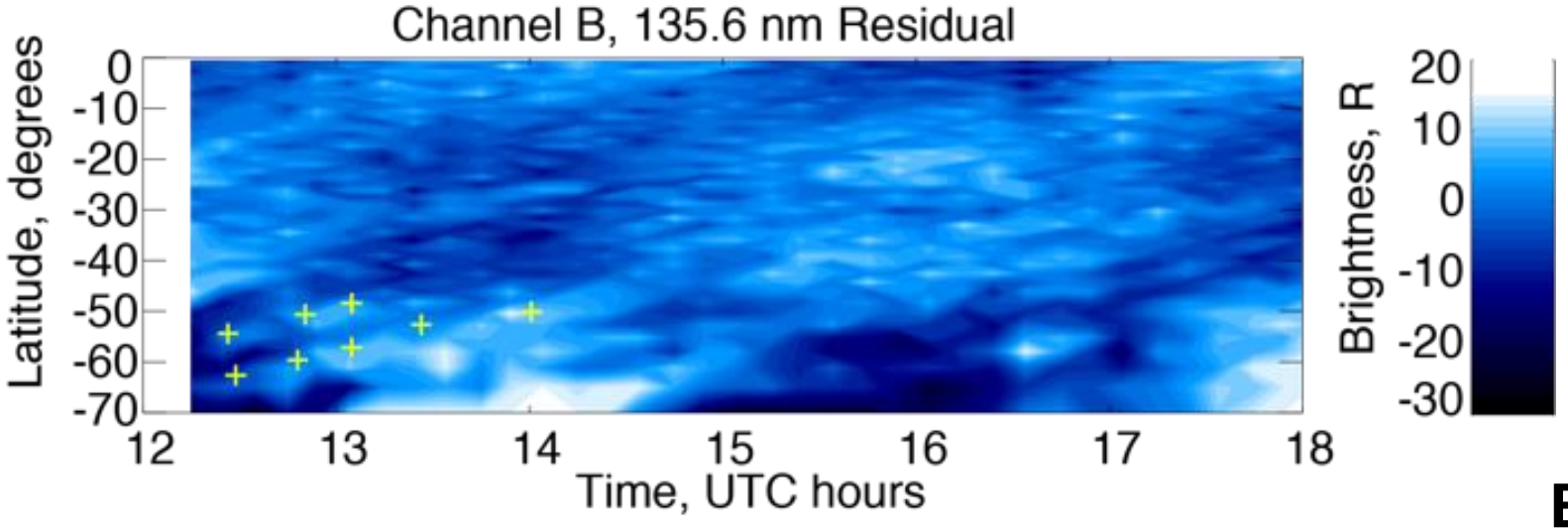
Channels view adjacent locations

Temporal difference for changes indicative of propagation direction

K_p index was initially 2 or less, increased to ~4 during last 3 hours

Yes, There are Waves





Brightness difference from background as function of time and latitude.

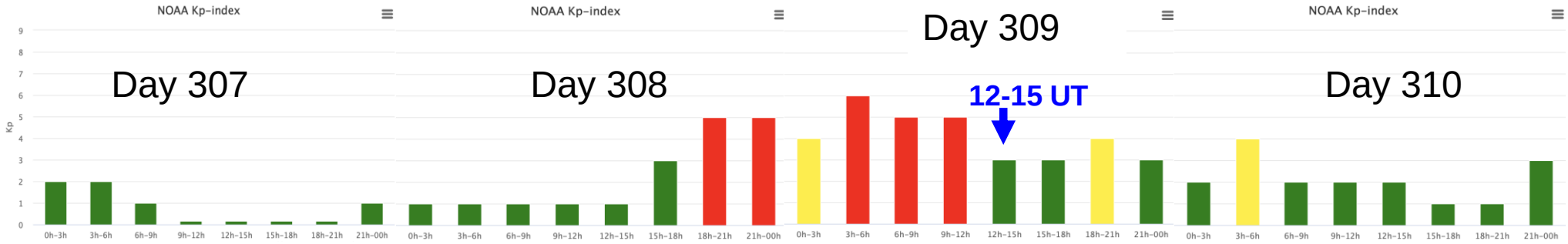
Locations of apparent wave features marked by symbols (plus and circle)

England et al. (2019, in review)

Geomagnetic Storms (Dayglow Example 3)

Storm-time changes in the middle thermosphere (~160 km)

NOAA 3-hourly Kp-index



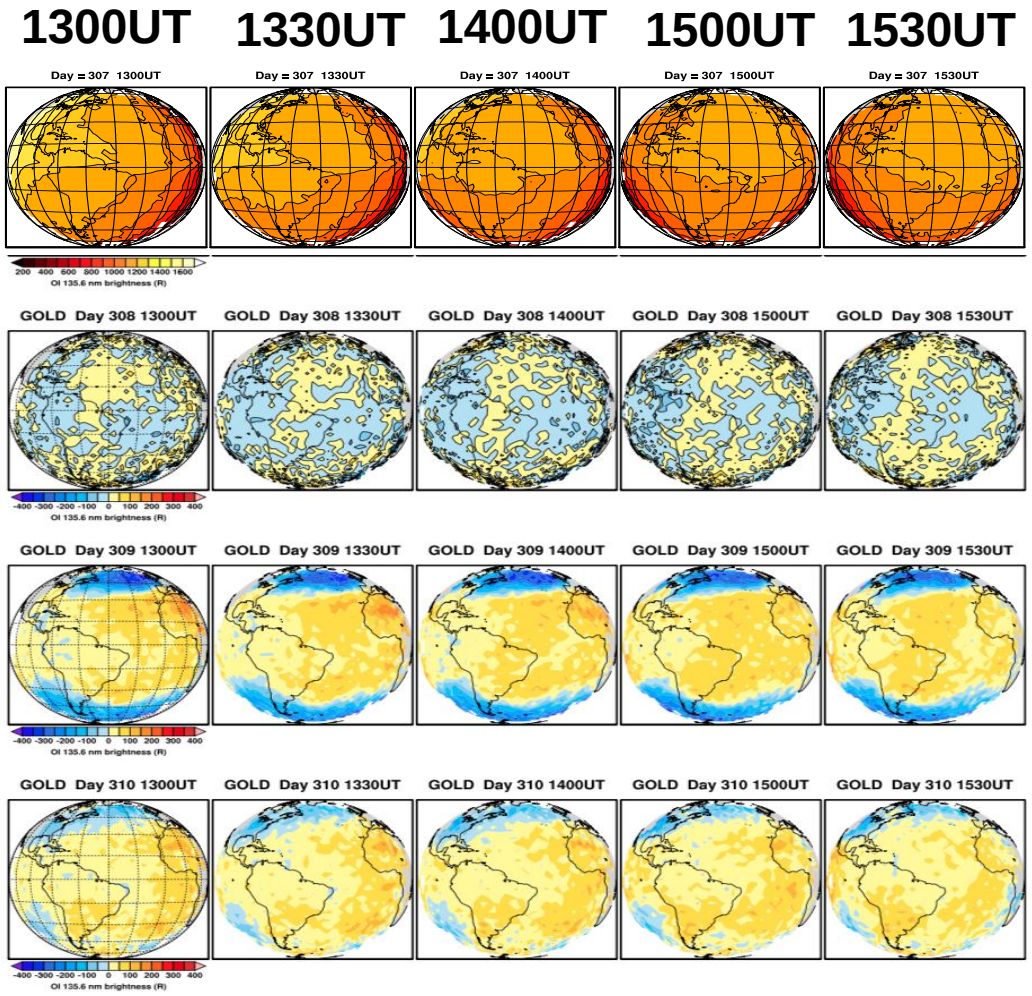
Day 307 – 310 (Nov. 3rd – 6th 2018)

Observations: GOLD (135.6 nm brightness; indicator of O density near 160 km)

Modeling: TIE-GCM + GLOW (brightness)

How Does a Storm Alter the O Densities?

Changes in O 135.6 nm B(R) from before the storm indicate changes



~ 1100 R at noon
~ 750 R at 0600 LT

< 100 R change in the quiet-time, pre-storm; possibly tidal forcing

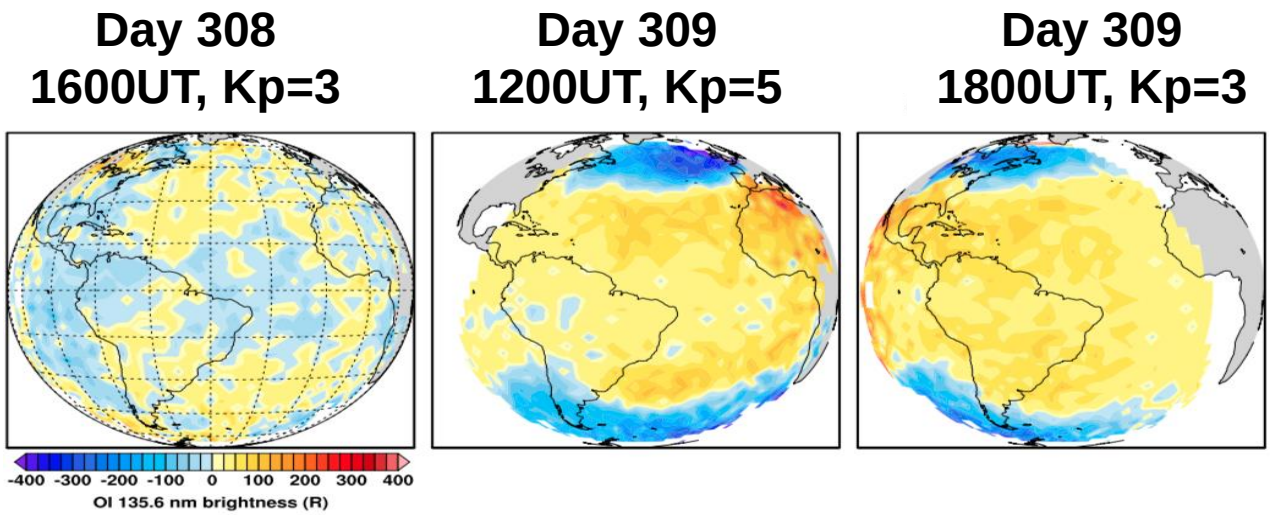
O depletion by 300-400 R (~ 40%) at high latitudes; decreased O/N_2

Depletion fades during the recovery phase

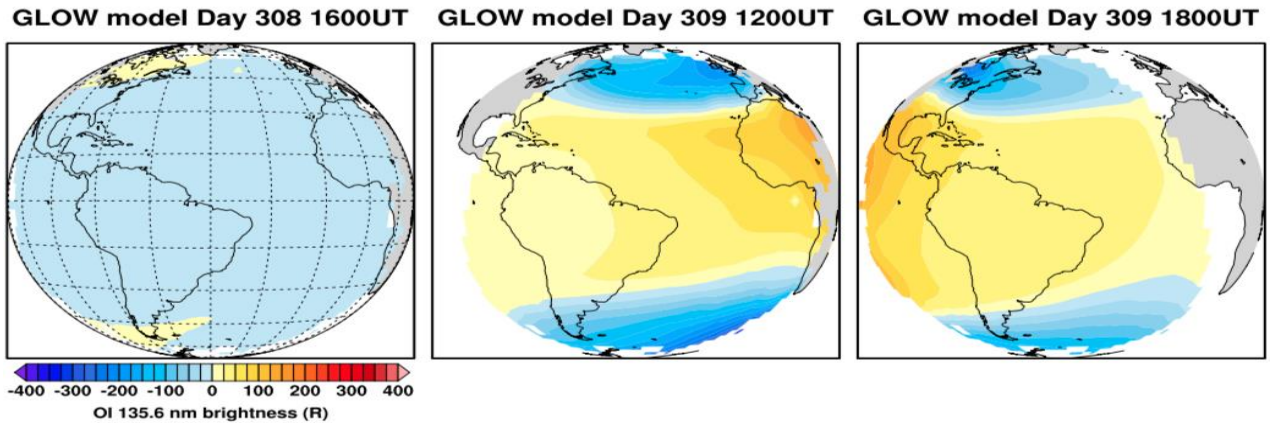
Do Observations and Models Agree?

135.6 nm brightness: GOLD vs. TIE-GCM + GLOW

GOLD



TIE-GCM + GLOW

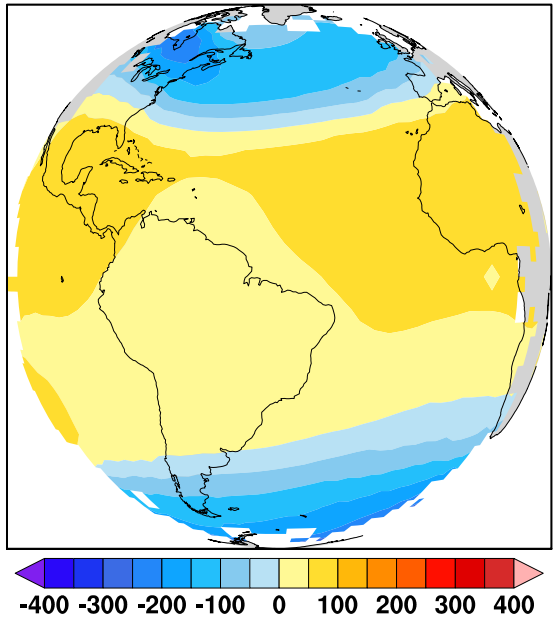


- **Pre-storm: model missed mid-latitude enhancement**
- ***Storm-period: modeled depletion in the northern hemisphere was 100-200 R low (~1/2 observed)***
- **Wave forcing seen pre-storm may be important factor during the storm**

Observations vs. Models

Modeled Difference O Emission During Storm

GLOW Day 309 UT1500

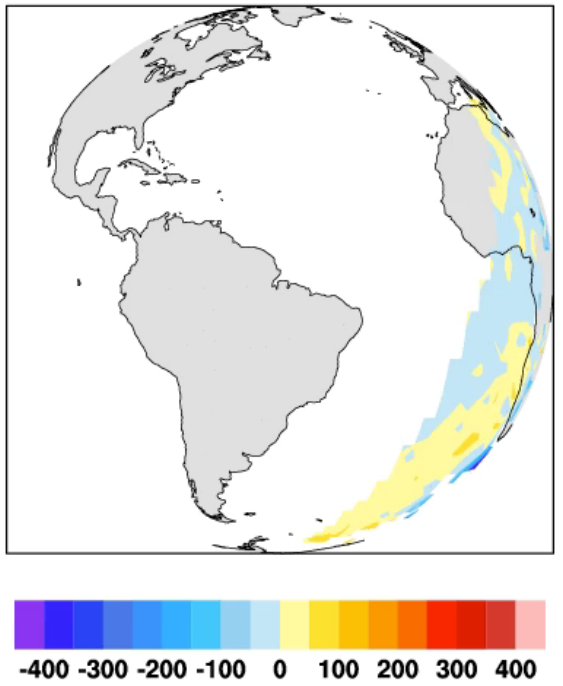


△ 135.6 nm (R/nm)

- Geomagnetic storm (Kp=6) began on Nov 4, 2018
- *Oxygen emission in the auroral region decreases*
- Shows that storm decreased O density near 160 km
- *Observed decrease is ~2 times greater than modeled*
- GOLD will lead to better modeling of space weather events

GOLD Observed Difference O Emission During Storm

GOLD Day 308 0630UT

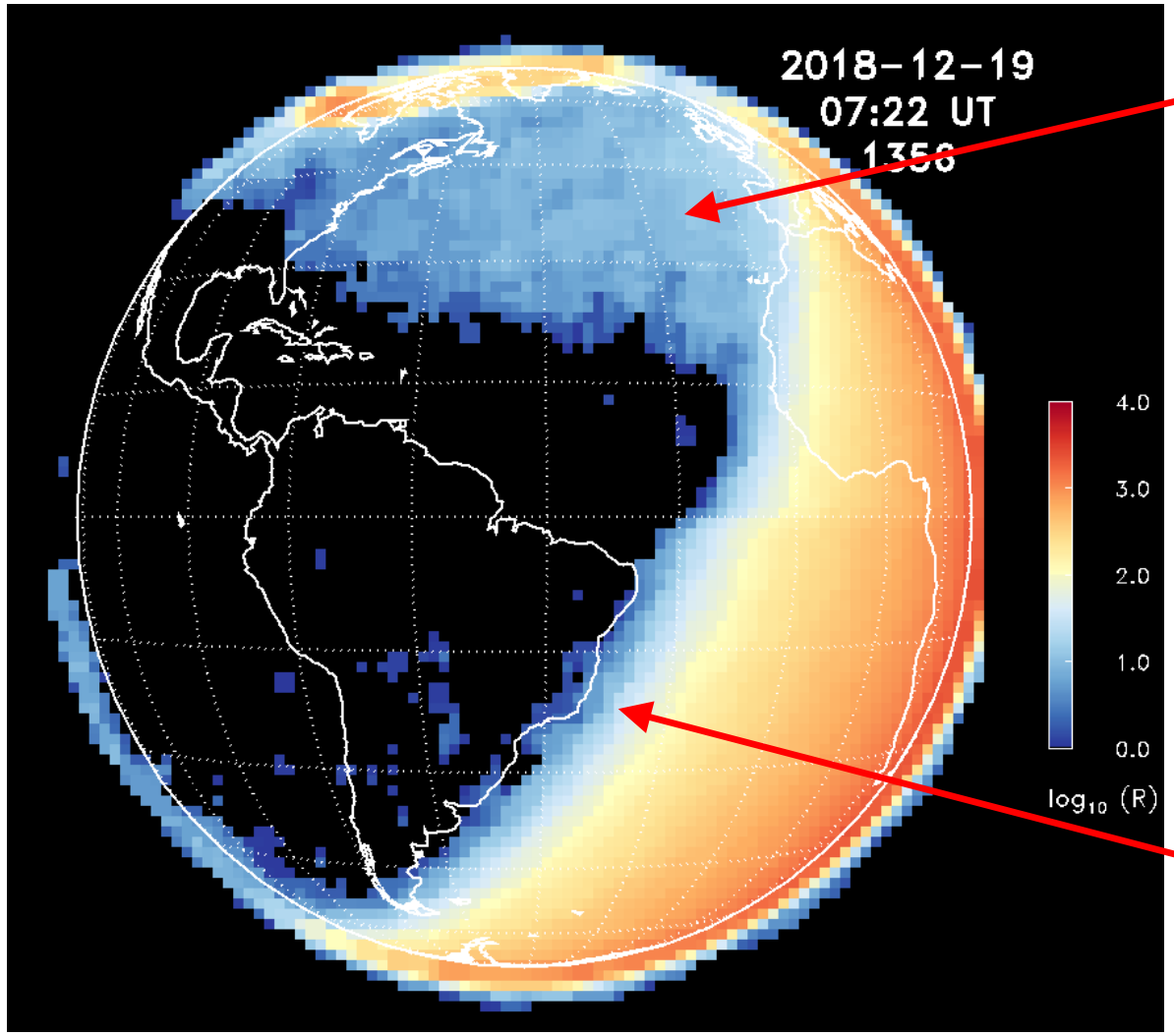


△ 135.6 nm (R/nm)

Gan et al. (2019, in review)

“Offspring” of the Dayglow

Full Disk Scan at ~4 Local Time (O line)

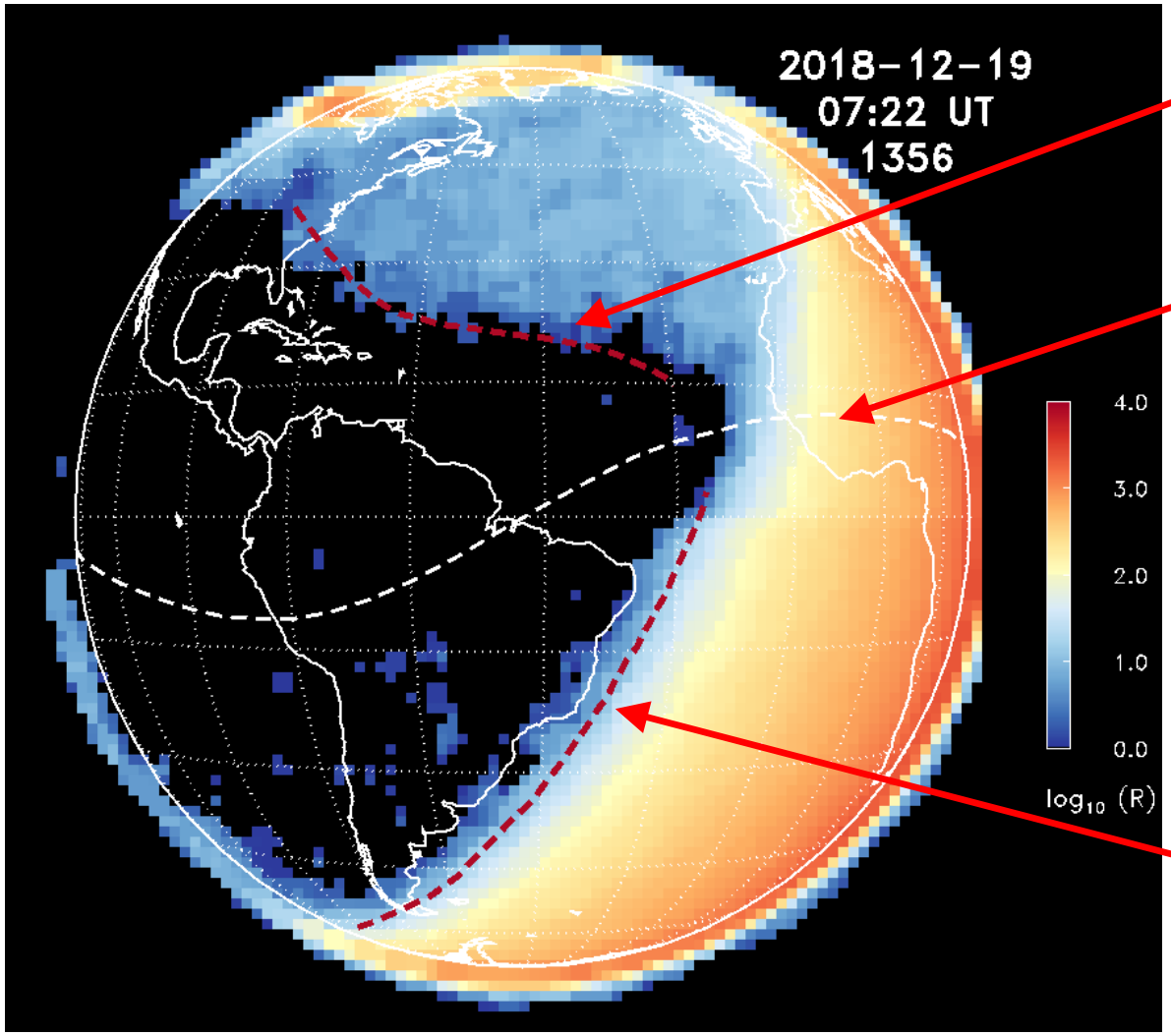


Predawn O 135.6 nm emissions

Dawn terminator

Dayglow Conjugate Point Emissions

Full Disk Scan at ~4 Local Time (O line)



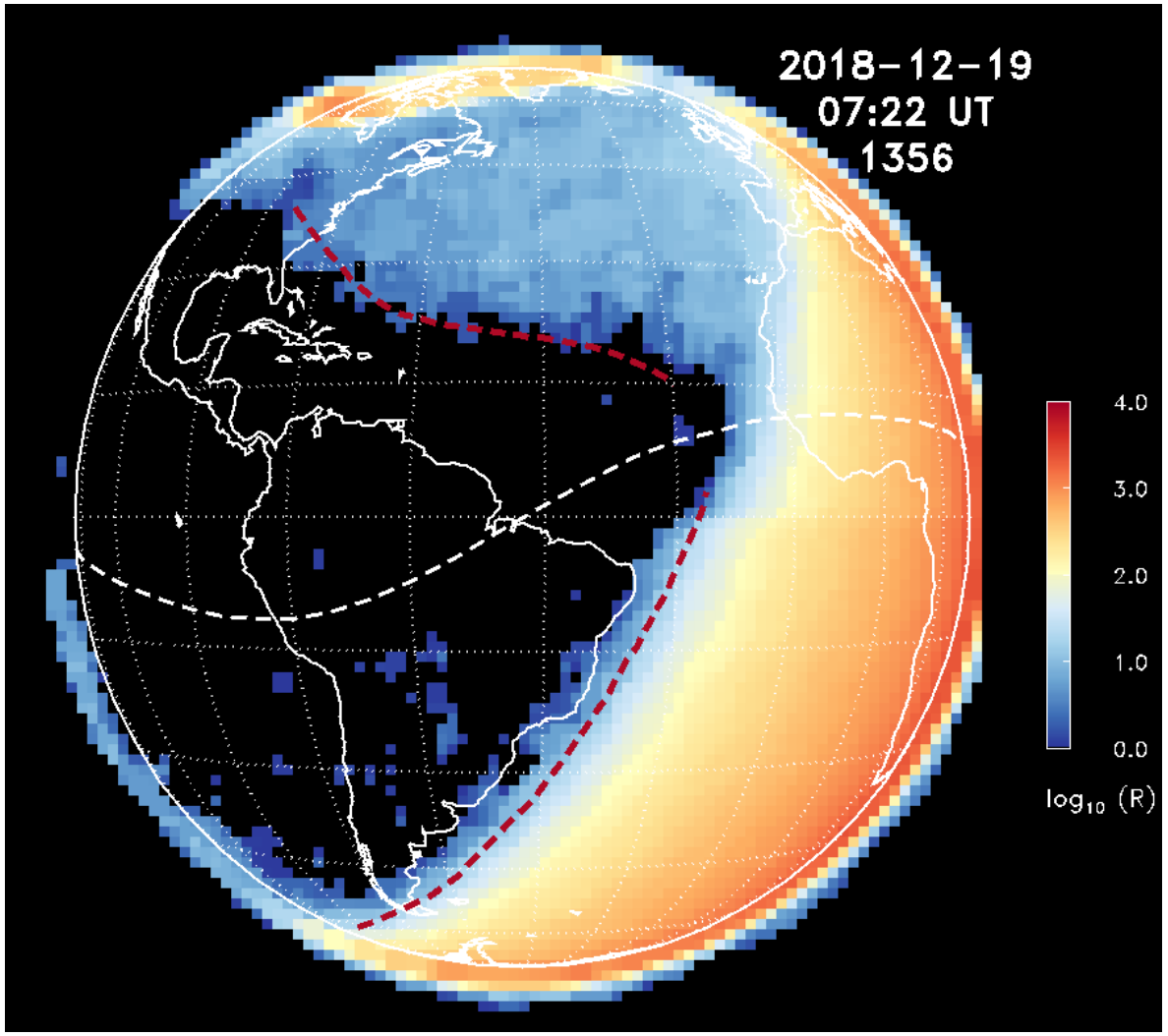
Magnetic conjugate to dawn terminator

Magnetic equator

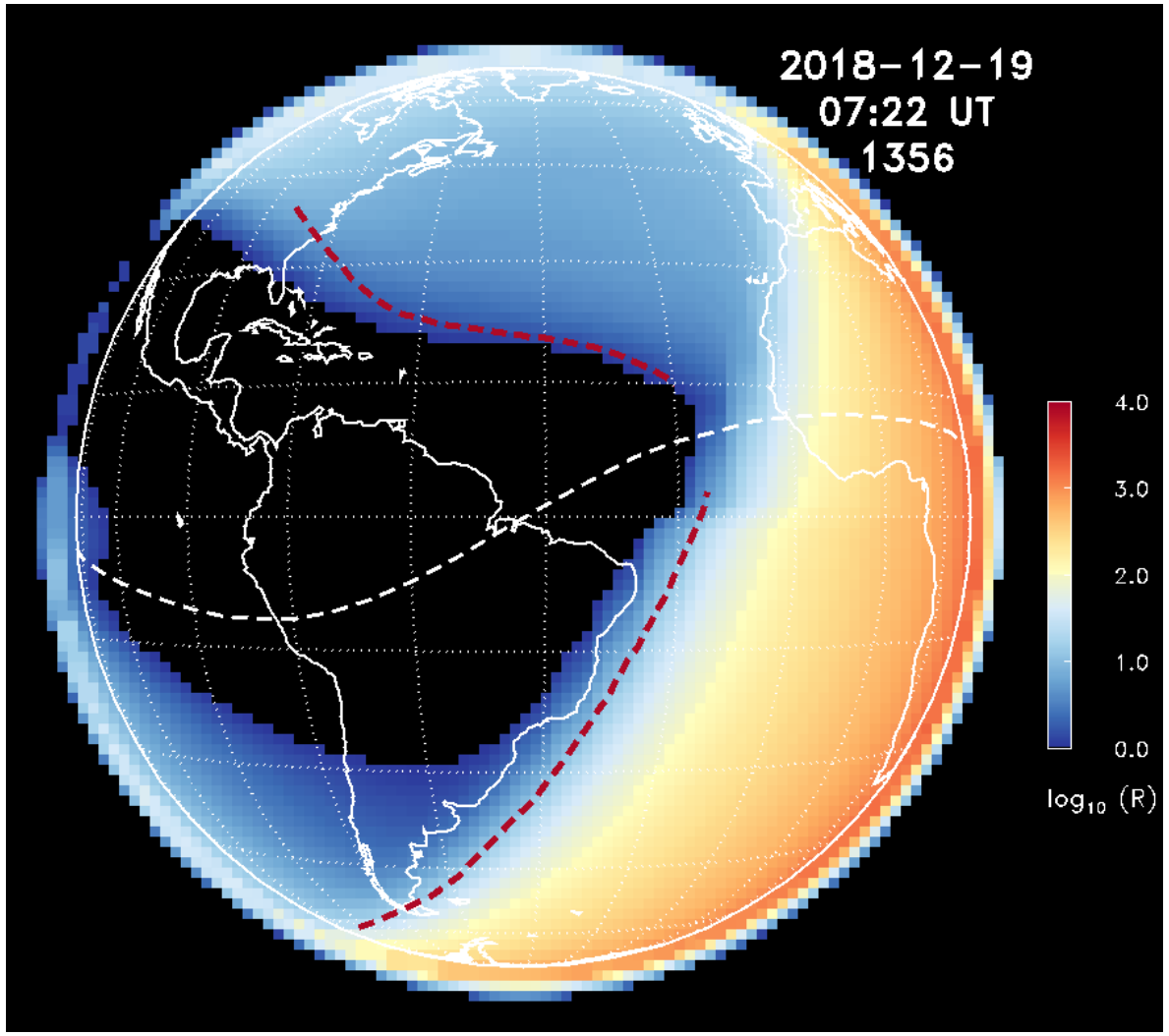
Dawn terminator

Dayglow Conjugate Point Emissions

Full Disk Scan at ~4 Local Time (O line)

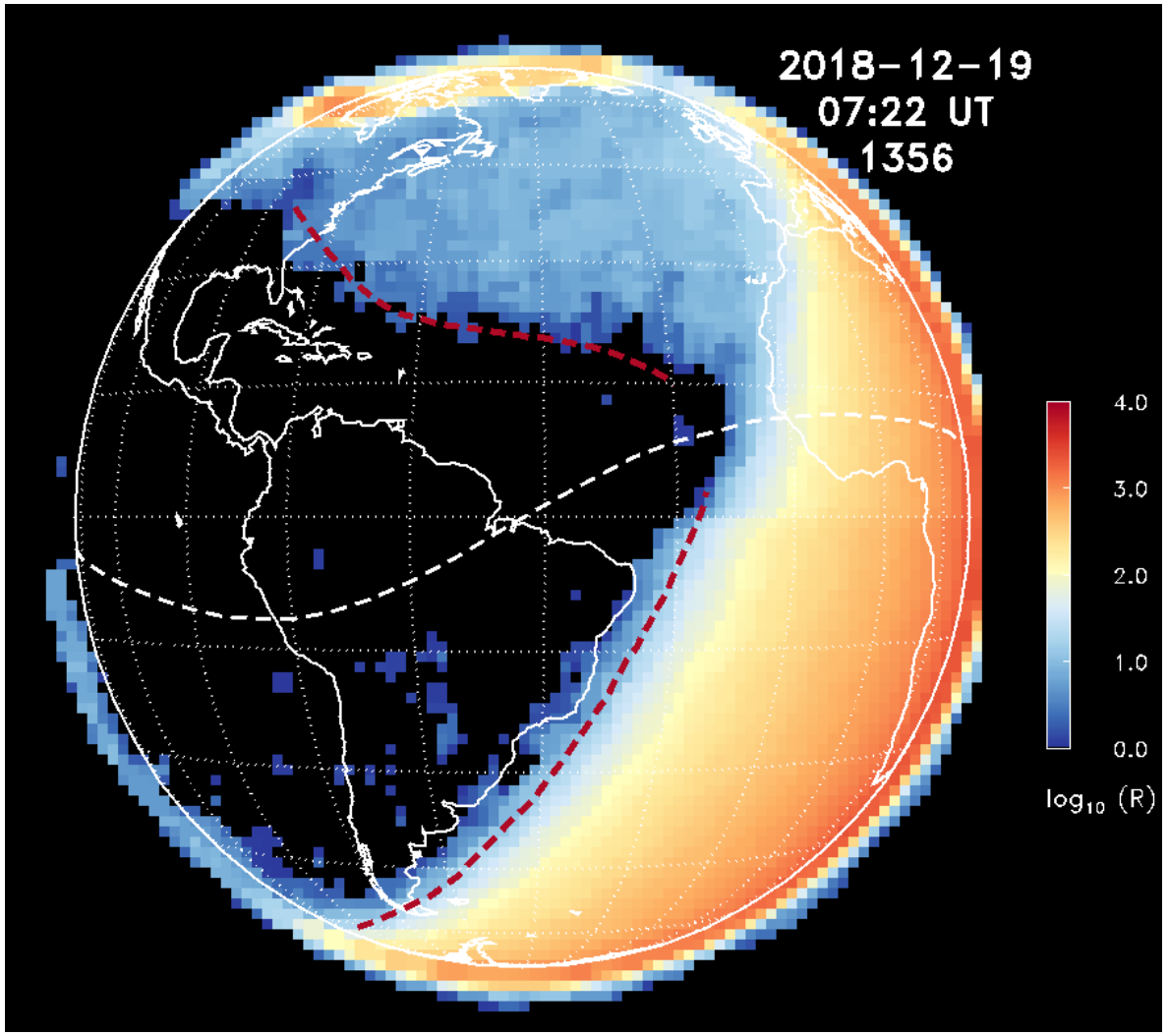


Model at ~4 Local Time (O line)

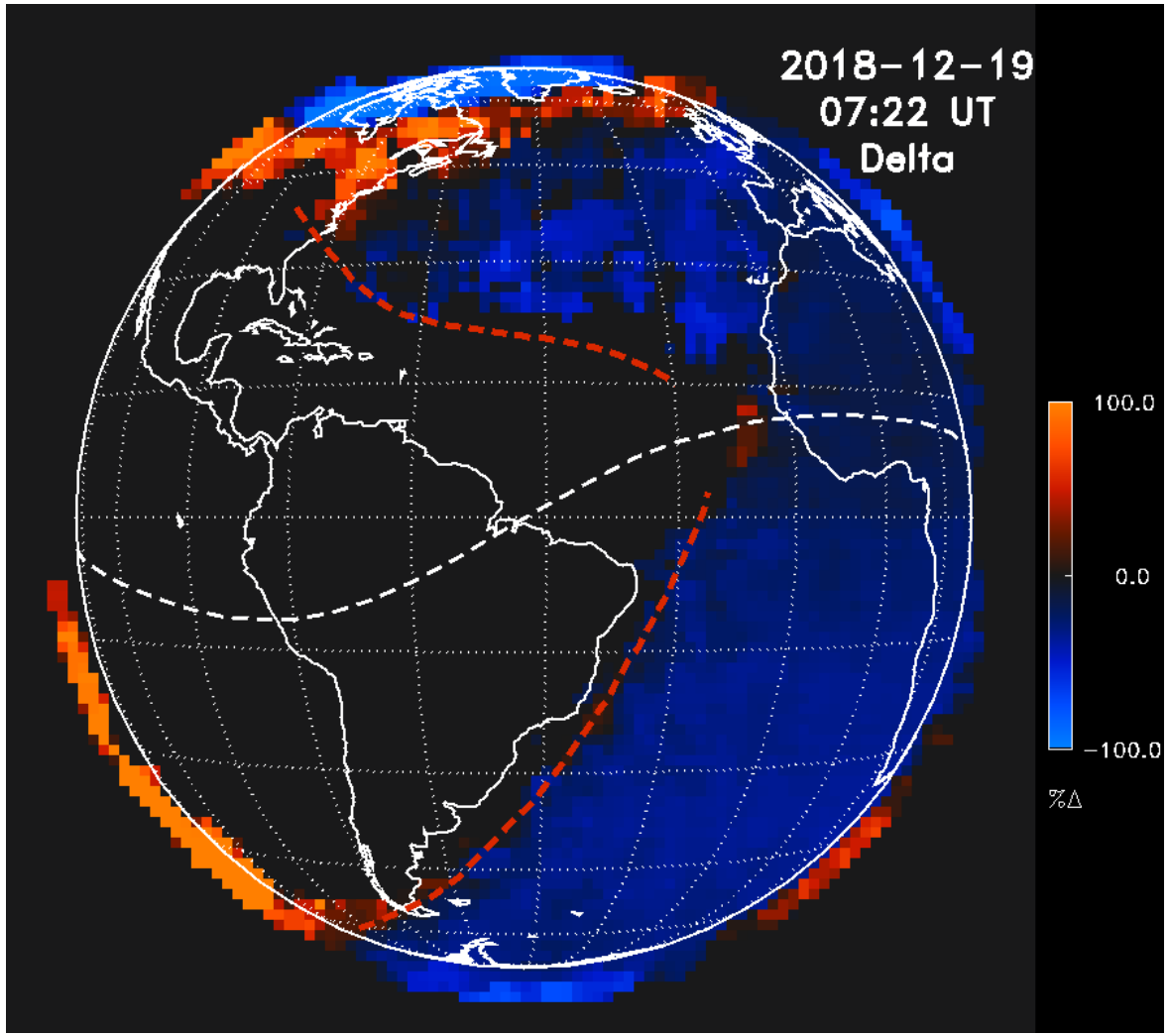


Dayglow Conjugate Point Emissions

Full Disk Scan at ~4 Local Time (O line)

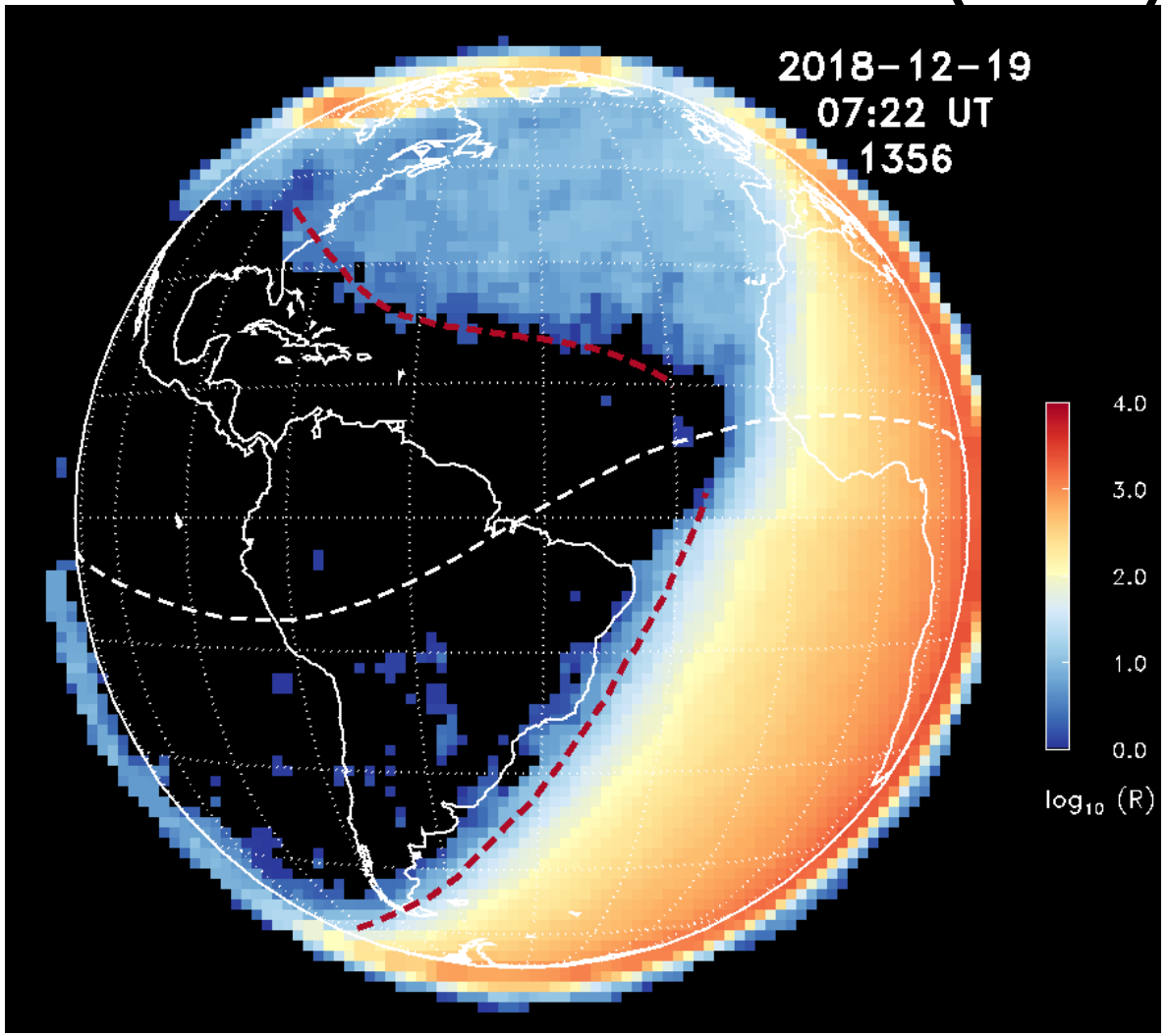


Model – Observations (O line)

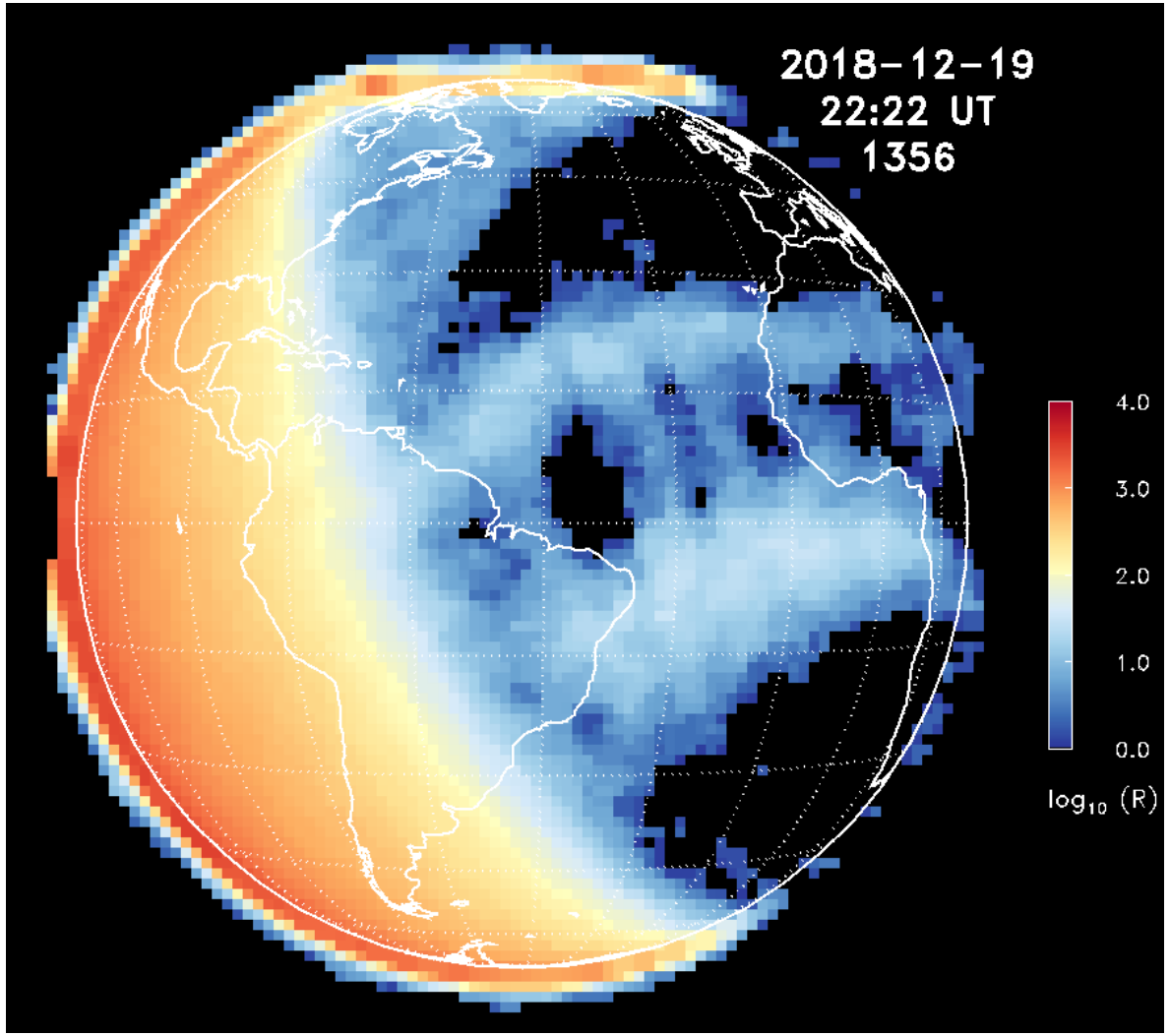


Dayglow Conjugate Point Emissions

Full Disk Scan at ~4 Local Time (O line)



Full Disk Scan at ~19 Local Time



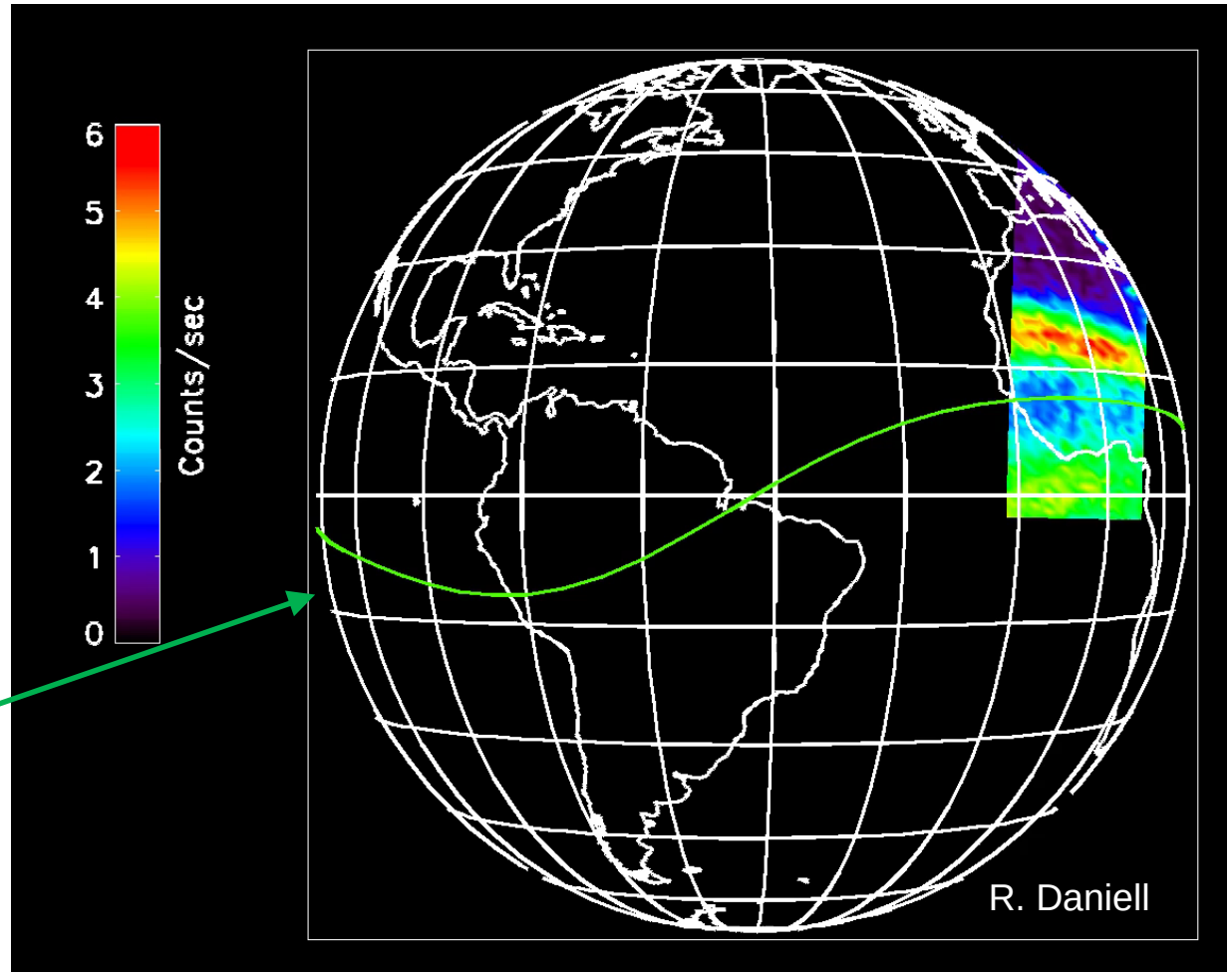
Solomon et al. (2019 submission pending)

Nightglow Observations

GOLD's Nightside Observing Mode Targets the EIA

- **Nightside Observations Focus on O 135.6 nm emissions from Equatorial Ionization Anomaly**
- ***Spatial Resolution ~ 100 km***
- **Single channel 17-20 LT; 30 min imaging cadence**
- ***Both channels 20-21 LT; 15 min imaging cadence***
- **Green line marks the magnetic equator**

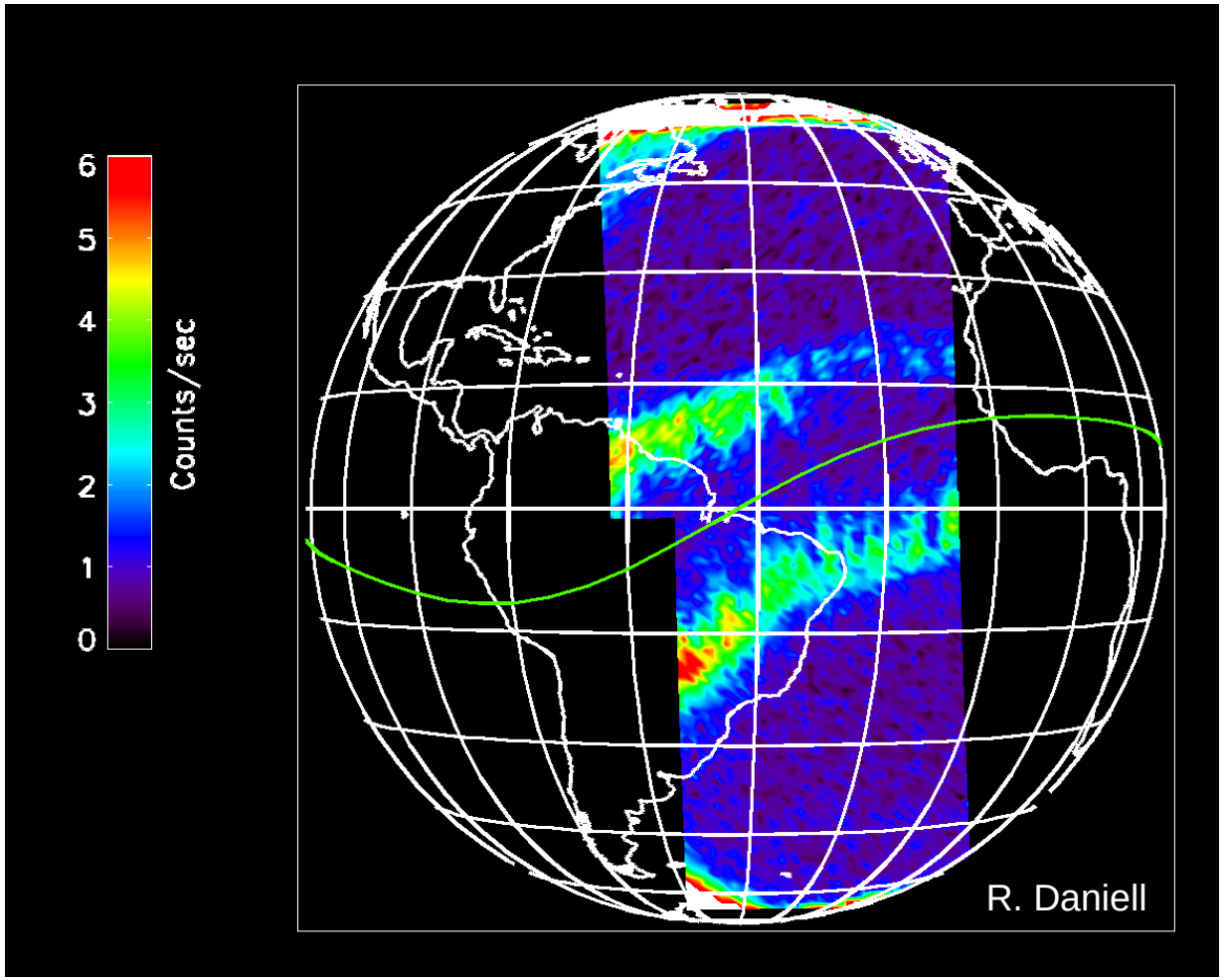
October 17, 2018 (day 290)



GOLD Routinely Observes Plasma Depletions (Bubbles)

- **The increased signal-to-noise available with the nightside observing mode reveals a complex and variable EIA structure**

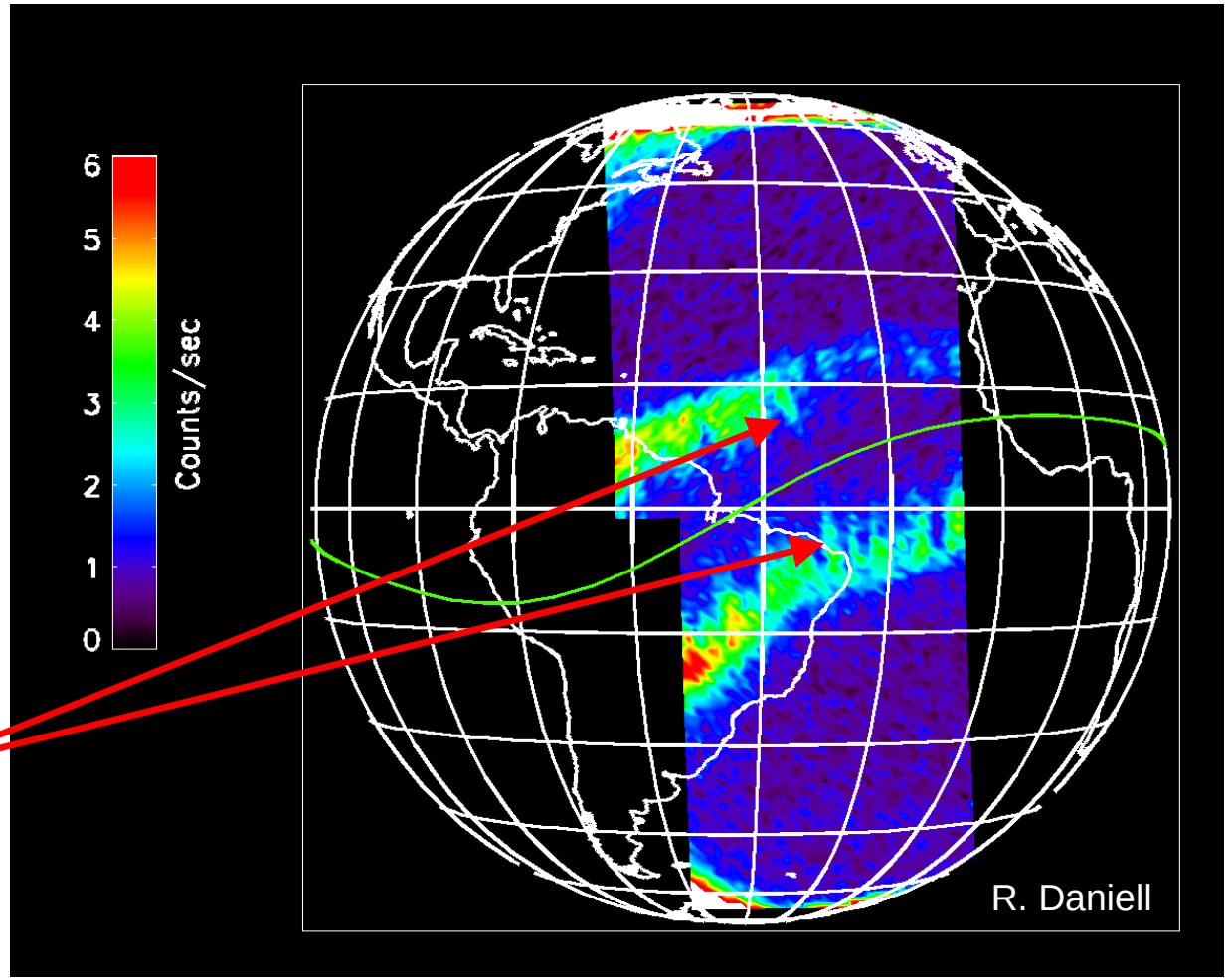
October 17, 2018 (day 290)



GOLD Routinely Observes Plasma Depletions (Bubbles)

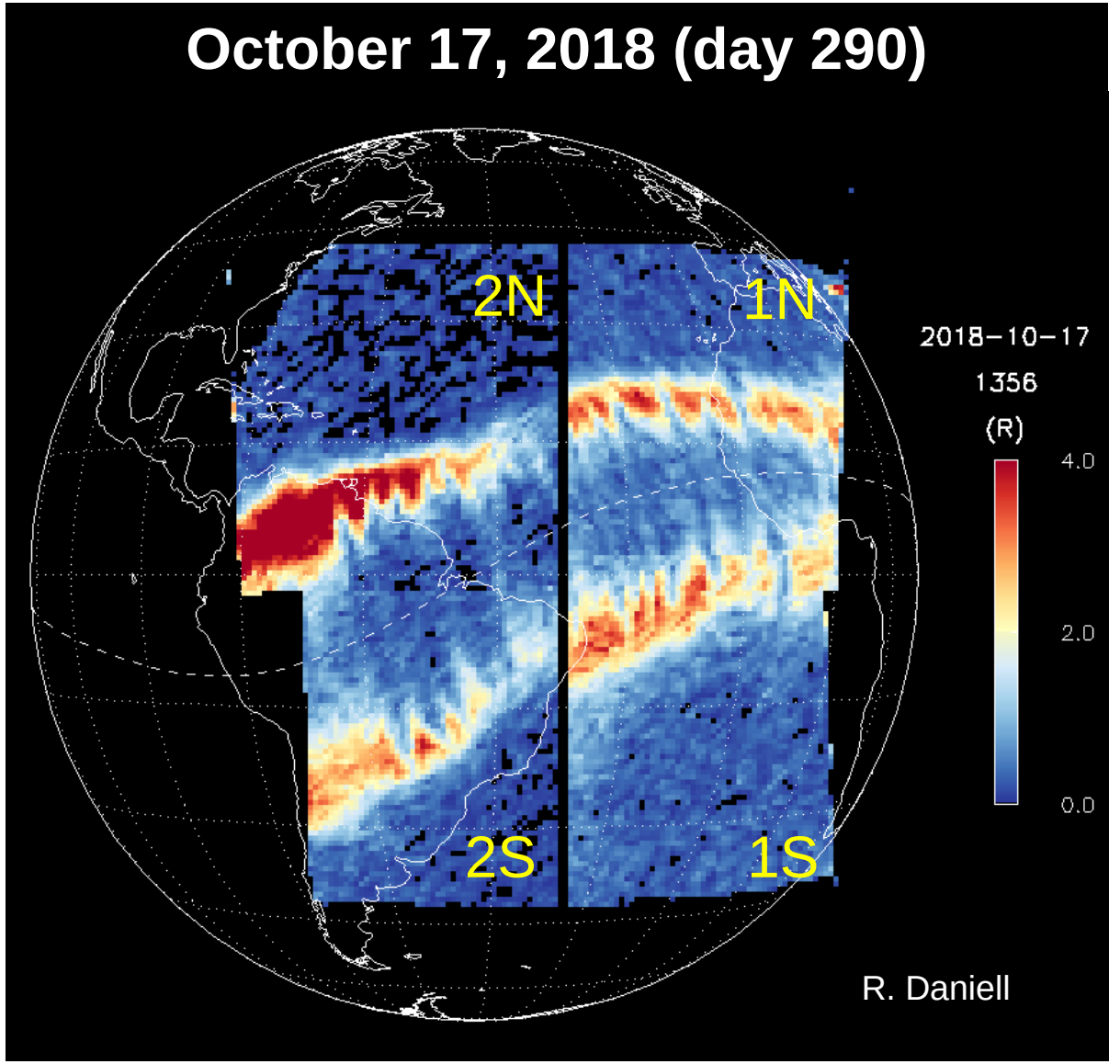
- **The increased signal-to-noise available with the nightside observing mode reveals a complex and variable EIA structure**
- ***Plasma depletions initially appear as the lack of emission on the equatorial edges of the bright crests***
  - **Produced by instabilities generated near the magnetic equator**
  - ***Symmetric about the magnetic equator***
  - **Aligned ~ N-S along field lines**
- ***GOLD observed depletions 80% of the days in Oct – Dec 2018***

October 17, 2018 (day 290)



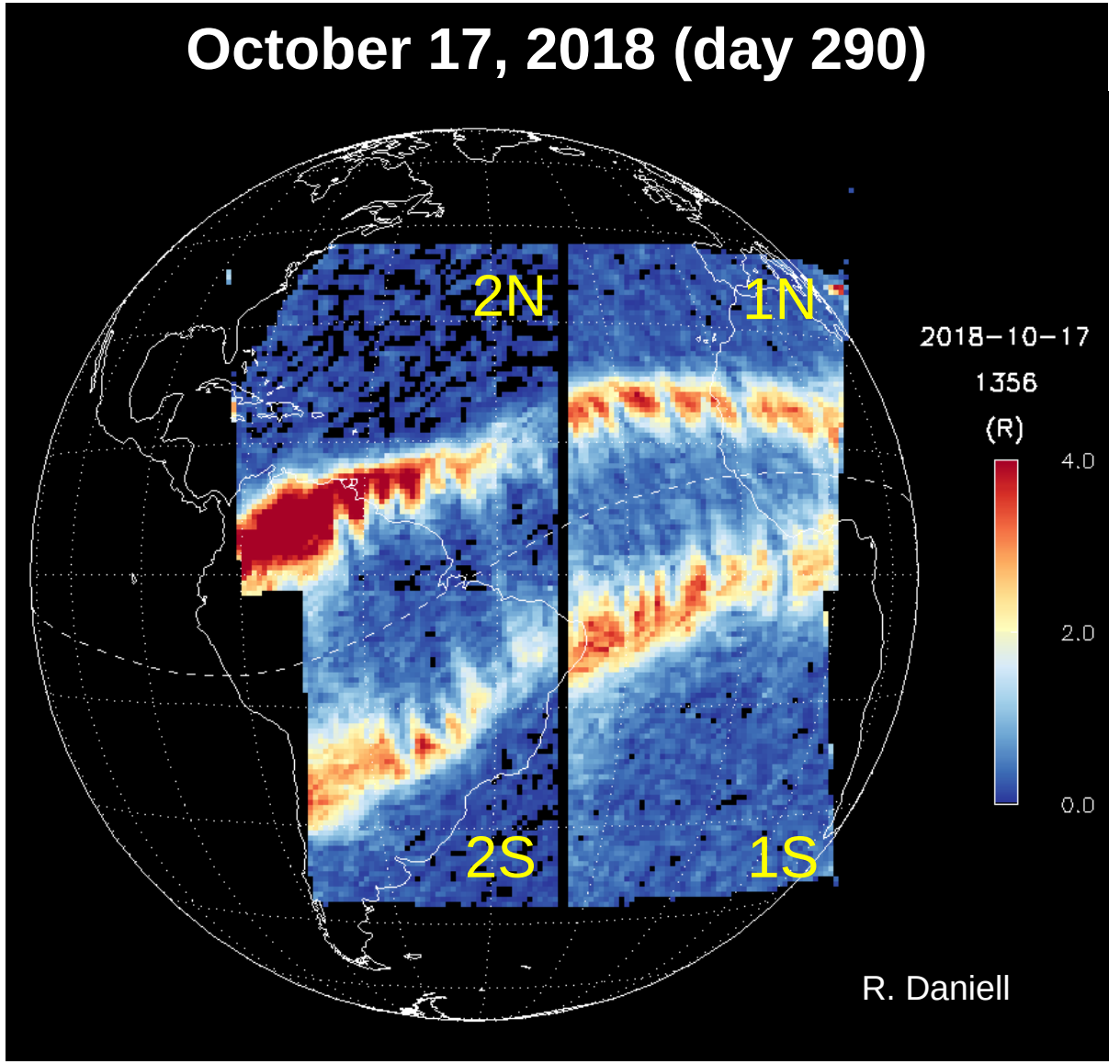
Some Nights Exhibit Quasi-Periodic Depletions

- **Images constructed from two pairs of N-S scans of ~ 30˚ longitude, each pair taken near sunset**
- ***Image pairs are separated in time by 2 hours***



Some Nights Exhibit Quasi-Periodic Depletions

- Images constructed from two pairs of N-S scans of ~ 30˚ longitude, each pair taken near sunset
- *The GOLD instrument observed extensive quasi-periodic structures on some nights*
- Some periodic behavior, defined as at least 3 equally spaced depletions, appeared on ~ 30 nights in October – December 2018
- *Spacing varied from night to night*
- Periodic seeding mechanism? Large scale wave structures have been suggested



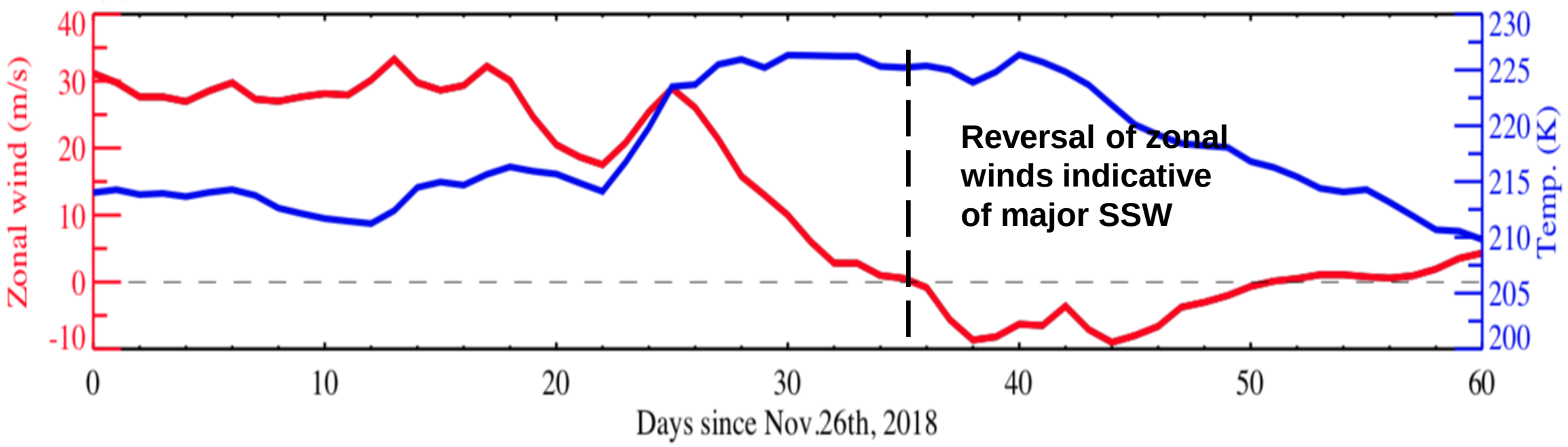
Eastes et al. (GRL, 2019)

Planetary Wave Coupling to the Ionosphere?

Sudden Stratospheric Warming Event during 2018-19 Winter

Equatorward zonal winds consistent with a major SSW event

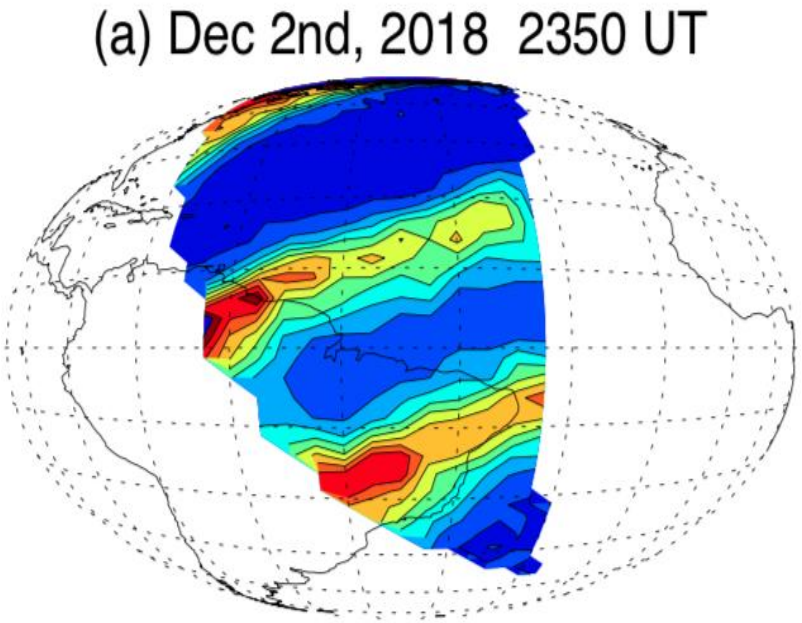
NCEP reanalysis at Latitude = 60N, Altitude = 30 km



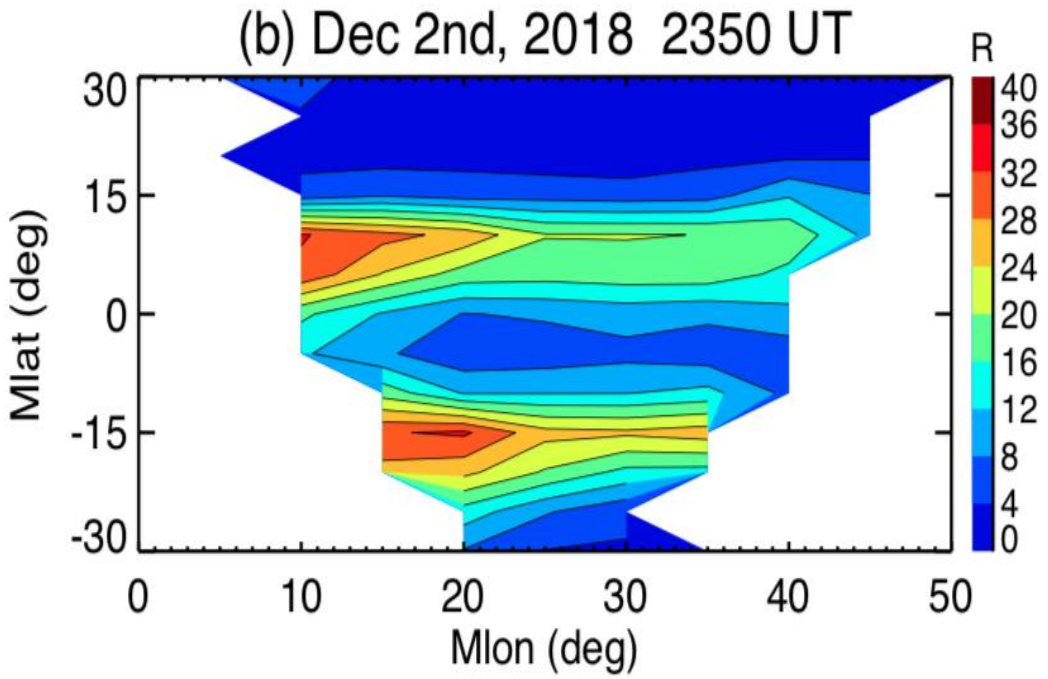
****Planetary waves are often enhanced significantly during SSW**

Nightside Imaging During 2018-19 Winter

Original, geographic coordinates

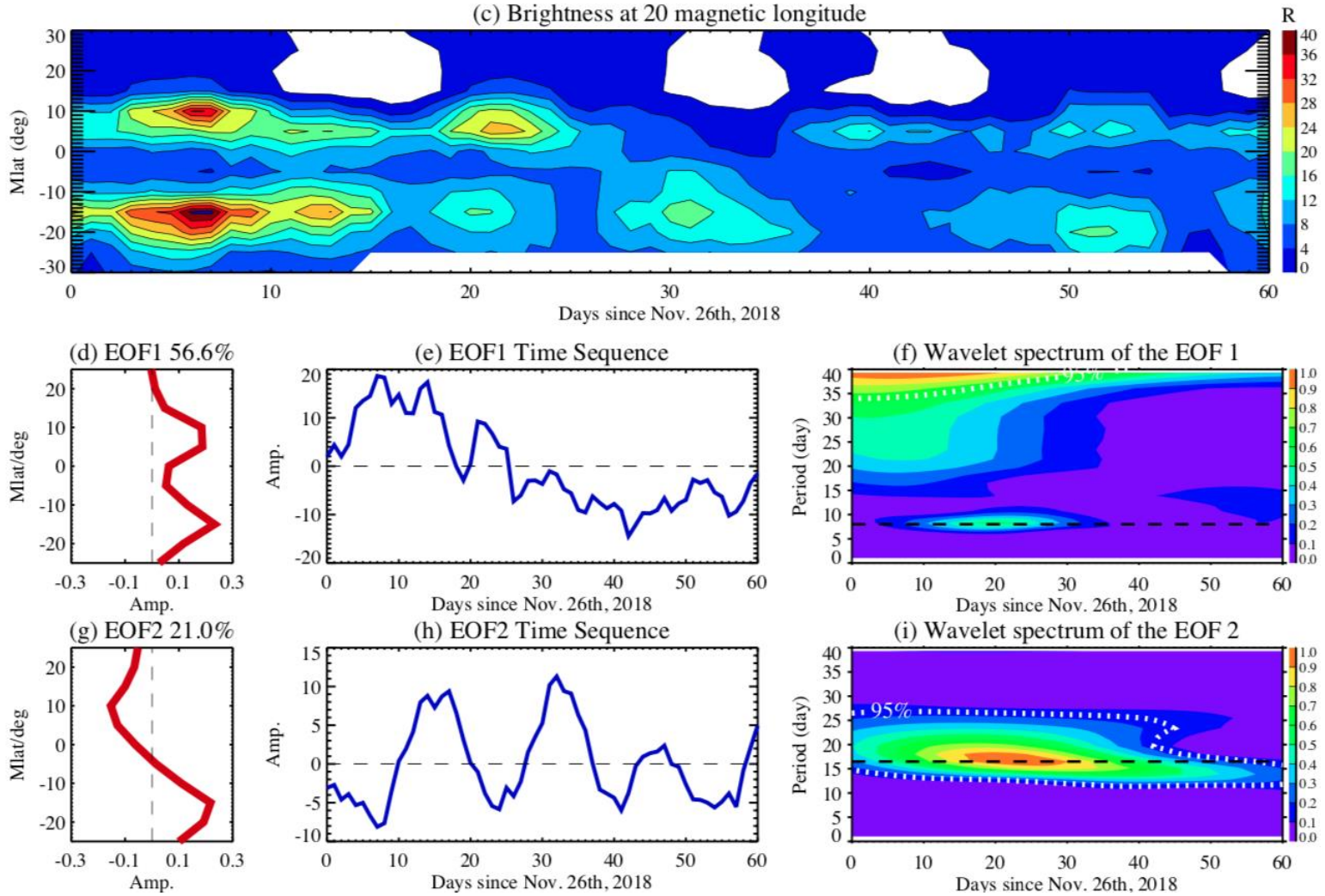


Remap images into magnetic coordinates



The crests are asymmetric with respect to the magnetic equator in the magnetic coordinate system

Observations Show ~16-Day Oscillations



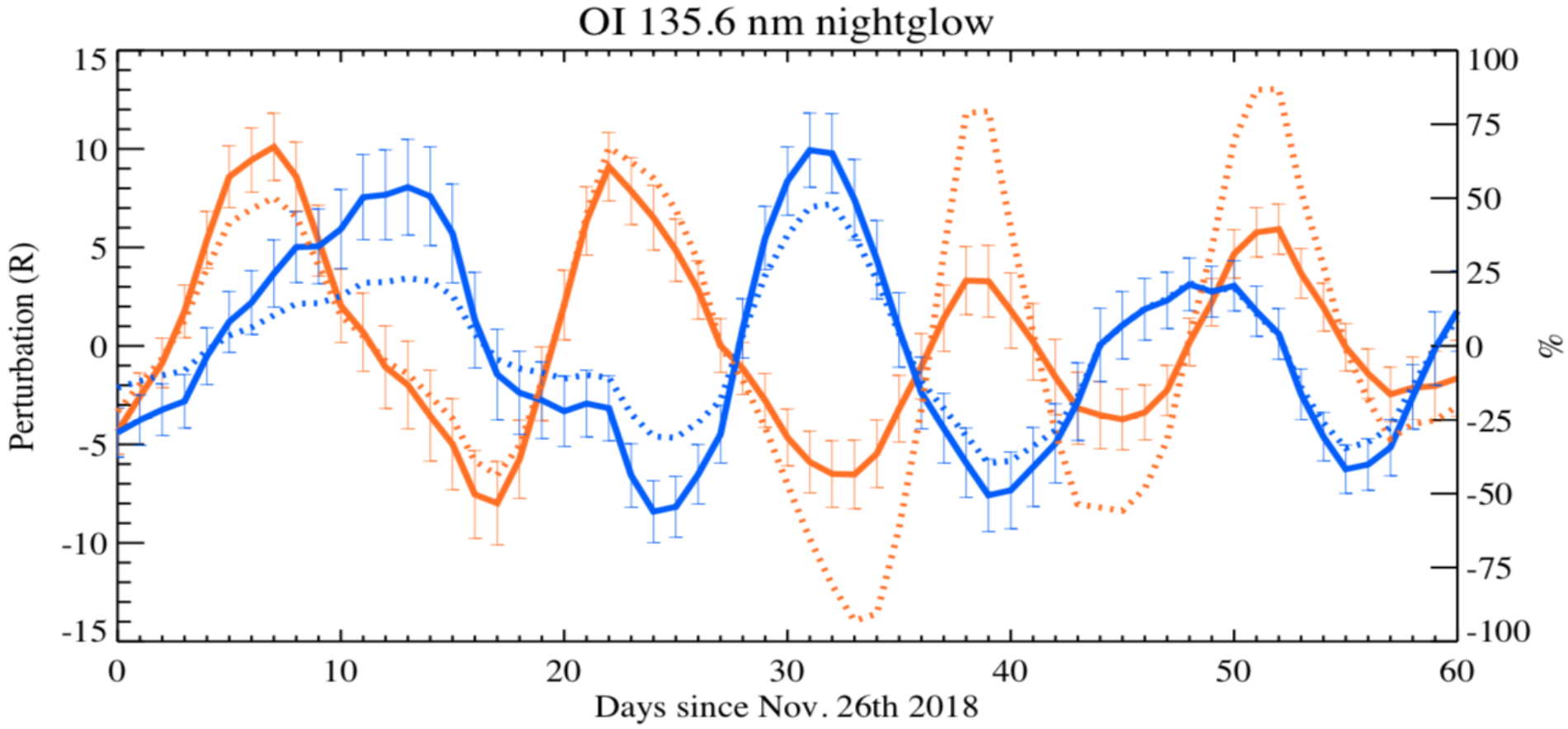
Empirical Orthonormal Function (EOF)
EOF1: ~ 9-day

EOF2: ~16-day

Using brightness versus time in 10 degree section centered on 20 degrees mag. longitude

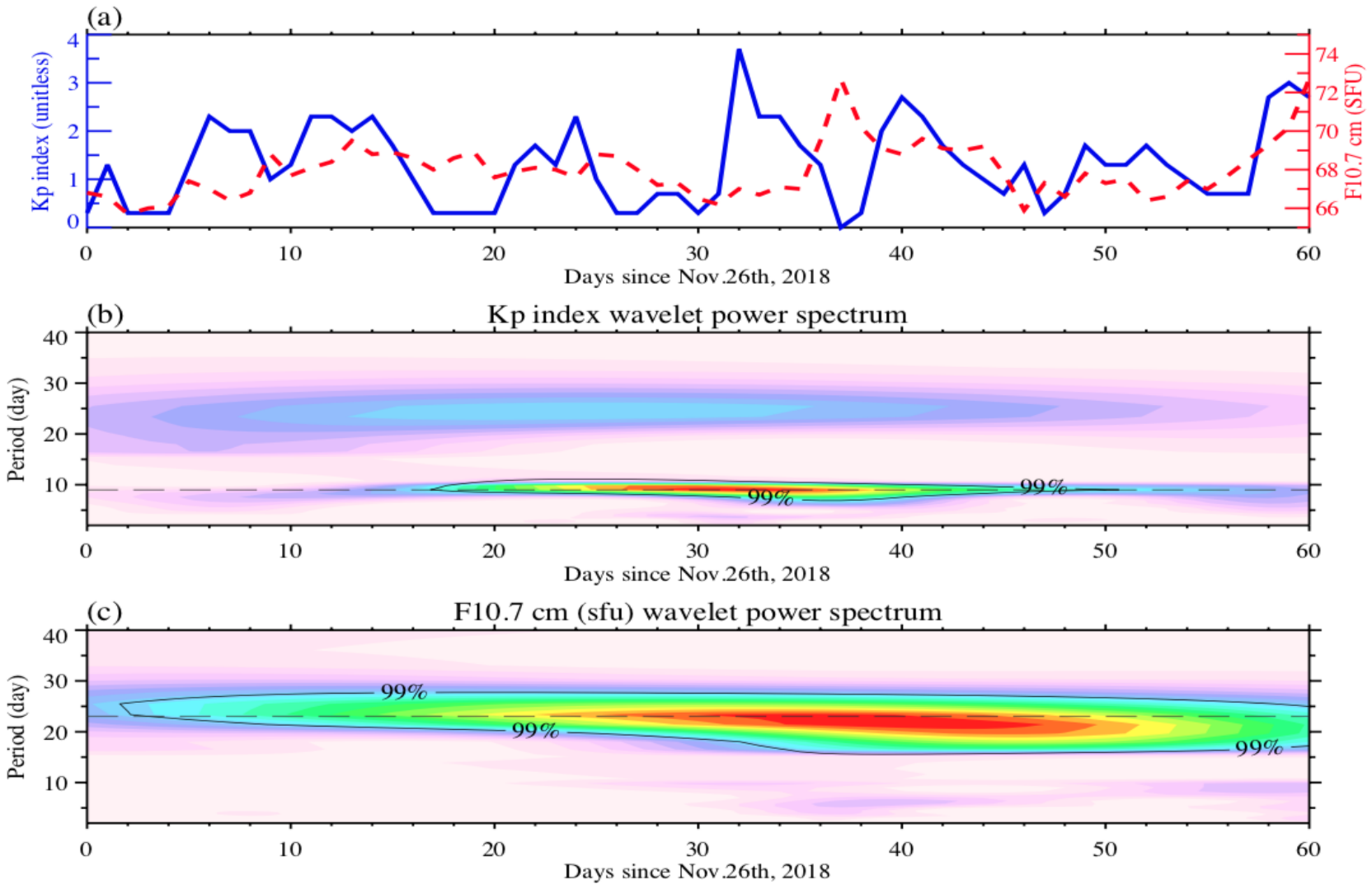
North vs. South EIA Crest Relative Variation

Brightness differences from 20-day running means



*** Solid: absolute difference. Dash: percent (%) difference**

Inputs From Above: Kp and F10.7 cm



Kp: 27 and 9 day periodicity;

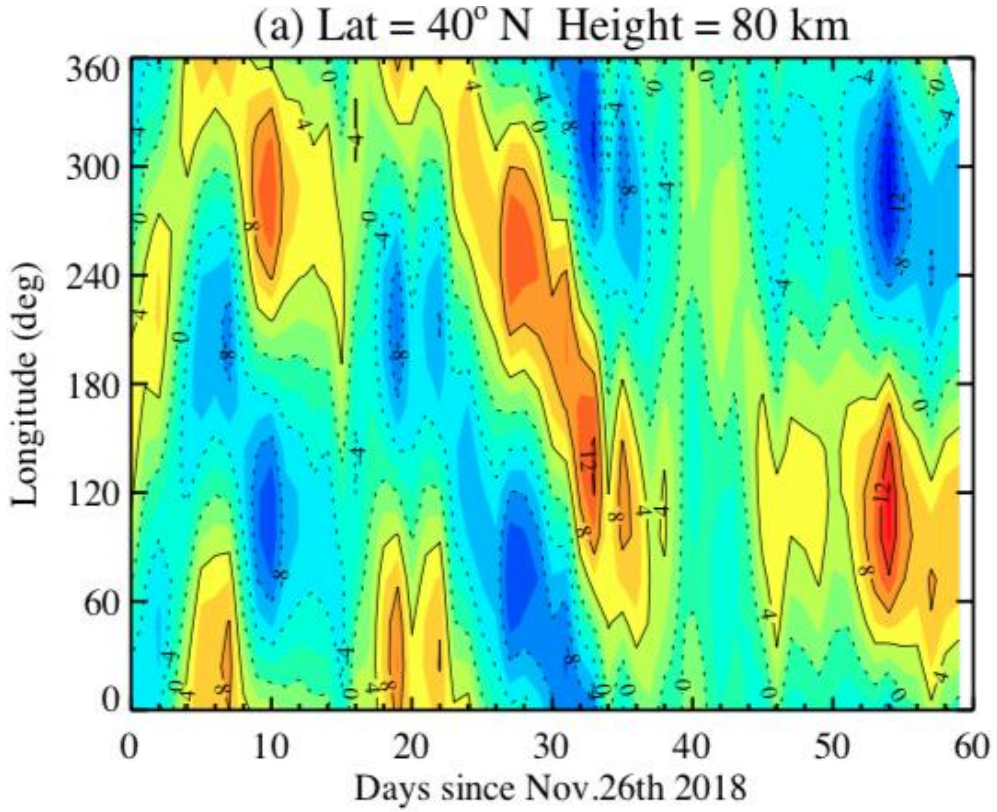
F10.7 cm: ~ 24 day periodicity;

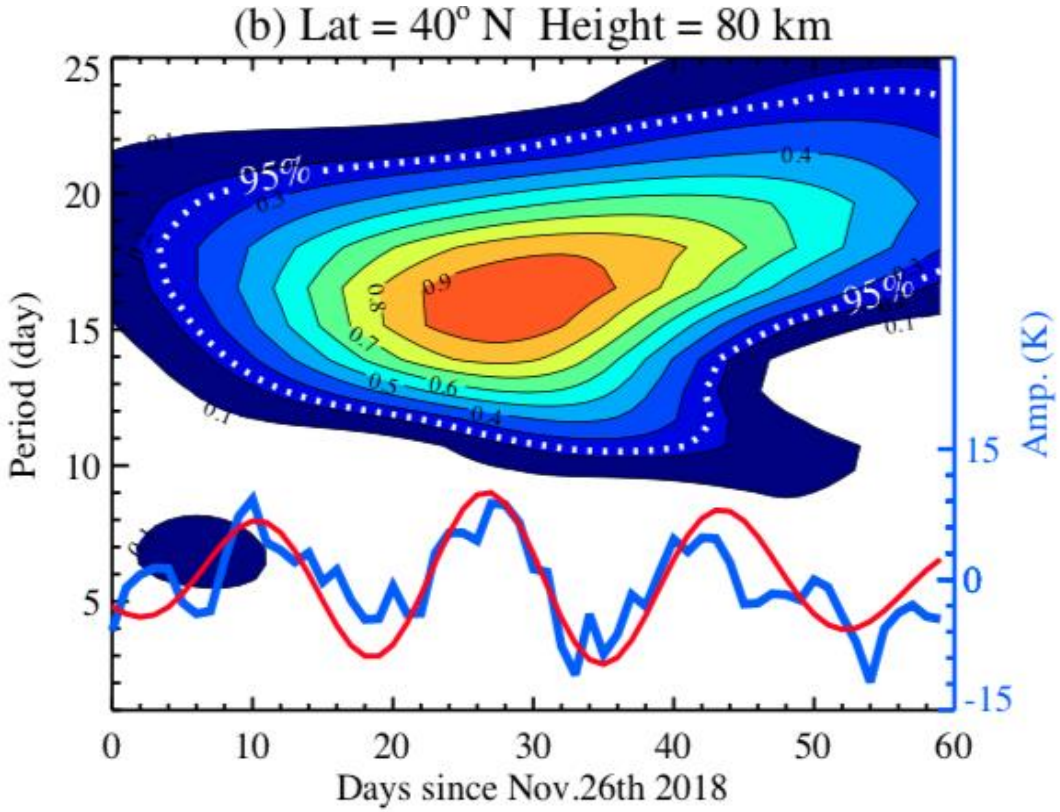
therefore, planetary wave periodicities of 10-20 and < 8 days will be distinct

Inputs from Below: SABER Saw Enhanced 16-day Wave

SABER T Anomalies

Contour plot: wavelet analysis of T anomalies
Blue curve: T anomalies at 285 E
Red curve: sine wave fit to T anomalies at 285 E





Spectrum analyses confirm a quasi-16-day wave, westward propagating, zonal wavenumber 1 in the mesosphere

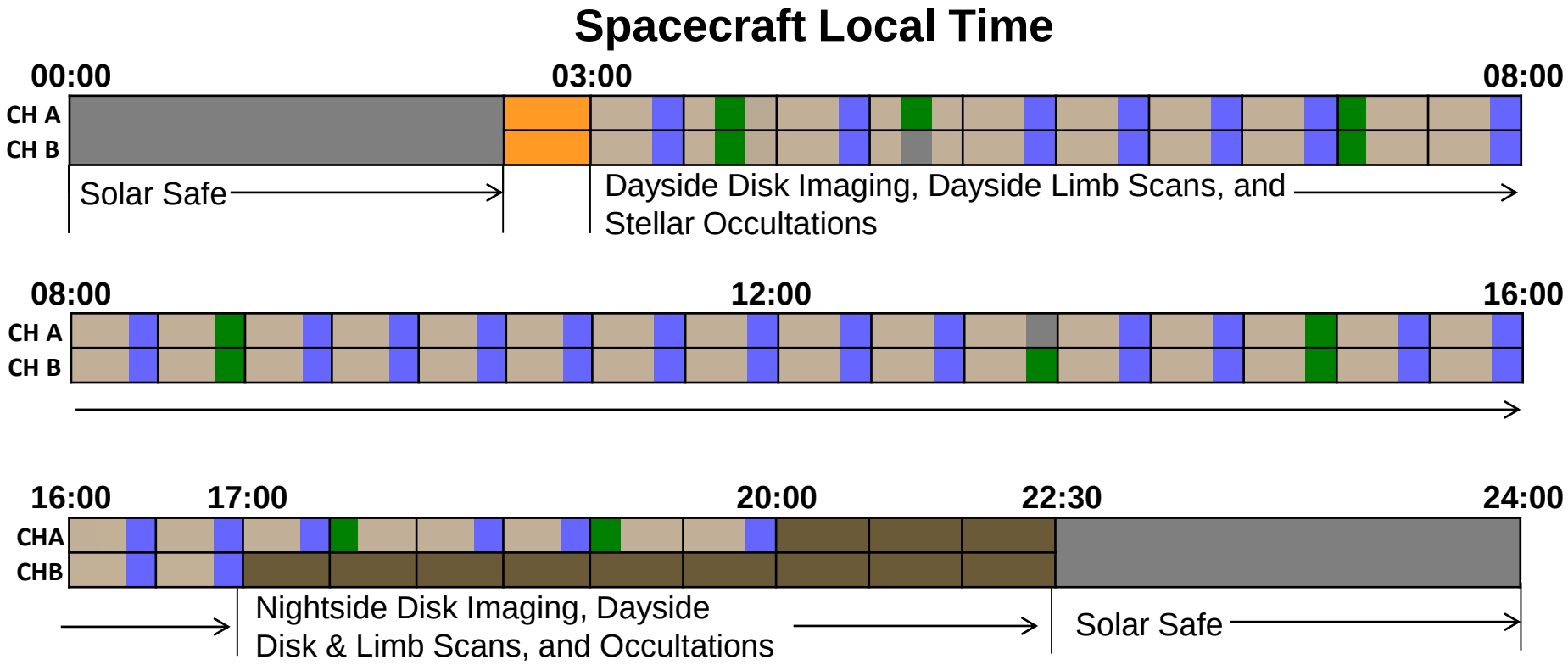
Gan et al. (2019, pending submission)

Summary

- **Appear to observe larger changes during eclipse than expected in the oxygen emissions**
- ***Atmospheric gravity waves in the thermosphere have been observed and tracked***
- **Observations suggest that storm-time changes in the oxygen densities in the thermosphere may be 30-40% greater than models predict**
- ***Observations of nightside emission at points magnetically conjugate to the dayglow may match well with initial model calculations except at locations near the aurora***
- **Nightside emissions show more structure than was anticipated, including for the first time, significant 16-day oscillations that appear related to the 16-day wave activity lower in the atmosphere**

backup

GOLD Daily Observation Example



Observations of Earth's Space Environment

- Dayside Disk Imaging
- Nightside Disk Imaging
- Dayside Limb Scan
- Stellar Occultations