A Study of Polar Mesospheric Cloud Structures and the Environment in Which These Structures Form

Brentha Thurairajah
Bradley Department of Electrical and Computer Engineering, Virginia Tech, Blacksburg, VA

CEDAR 2011 – Postdoc Report, 28 June 2011

Thanks to:
Scott M Bailey, David E Siskind (NRL), Cora E Randall (LASP), Michael J Taylor (USU), James M Russell III (HU)
And the entire AIM/CIPS data processing and science team, and NOGAPS ALPHA team

Supported under CEDAR NSF Post-doctoral grant #0924960

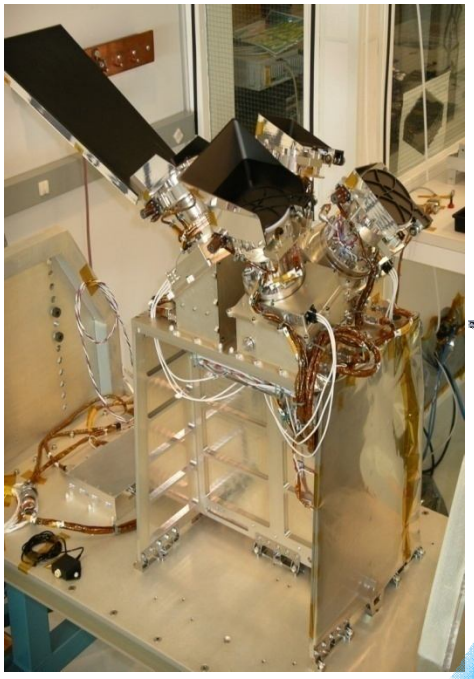
Contents

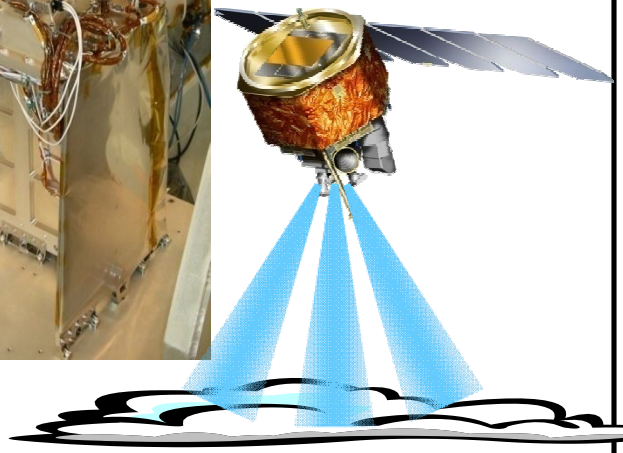
- Cloud Imaging and Particle Size (CIPS) Experiment
- Examples of PMC structures observed by CIPS during the northern hemisphere 2007 season
  - focus on circular 'ice voids'
- NOGAPS ALPHA model results to analyze the environment in which these ice voids form (Case Study of Void I)
- Summary

For more information stop by MLTS-03 in today's CEDAR MLT Poster Session

CIPS: Cloud Imaging and Particle Size Experiment

Aeronomy of Ice in the Mesosphere (AIM) mission was launched on 27 April 2007 and is the first satellite dedicated to the study of PMCs. CIPS is one of three instruments on AIM.

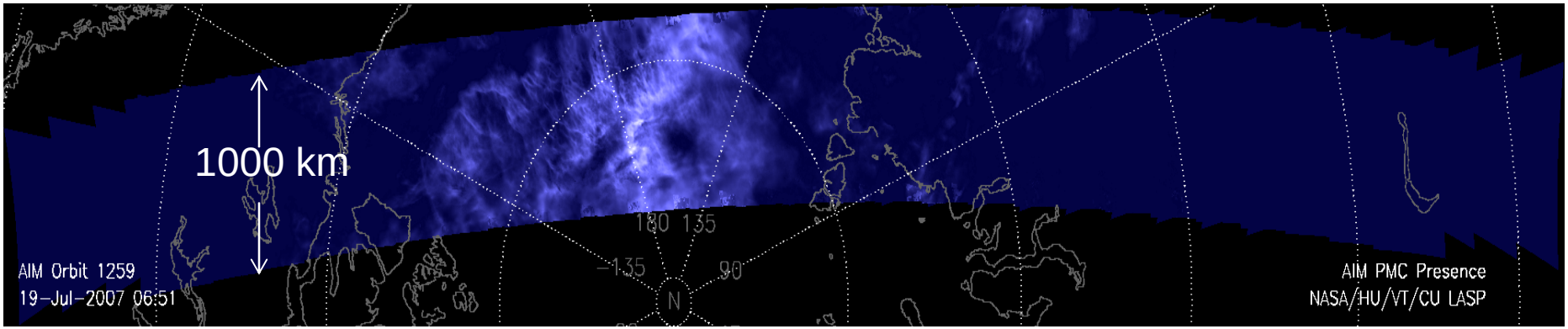




- PMC occurrence, cloud morphology and particle sizes
- Four CCD cameras image PMCs at ~ 83 km.
- CIPS images PMCs with a spatial resolution of 1 x 2 km in nadir and ~5 km at the edges of the forward and aft camera.
- 15 nm passband centered at $\lambda = 0.265\ \mu m$

CIPS: Cloud Imaging and Particle Size Experiment

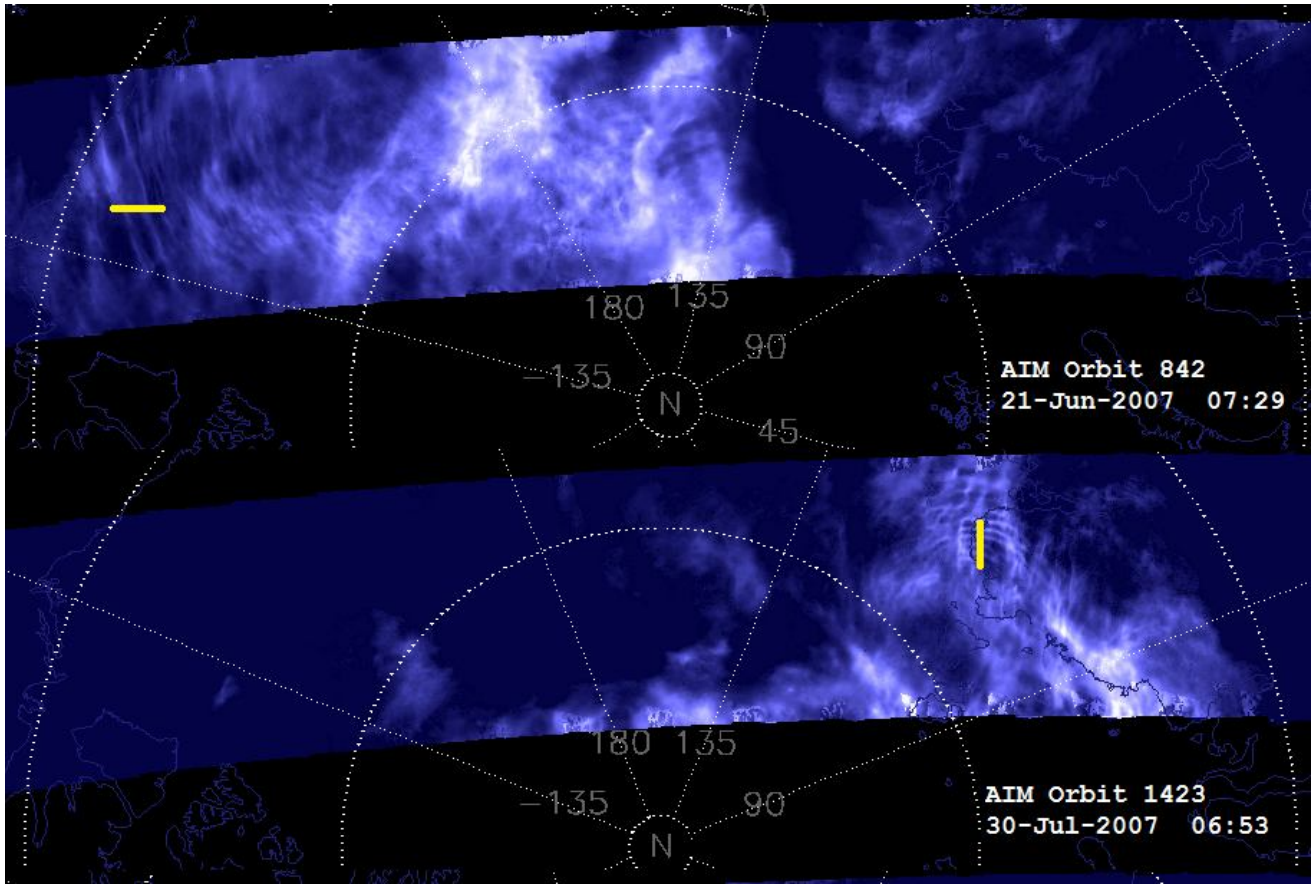
- CIPS records atmospheric and PMC radiance during the PMC season
- Non cloud radiances are removed from the images
- Level 2, v 4.02 data product: PMC images in orbit strips in terms of albedo (10^{-6} sr)



AIM: http://aim.hamptonu.edu/index.html
CIPS: http://lasp.colorado.edu/aim/

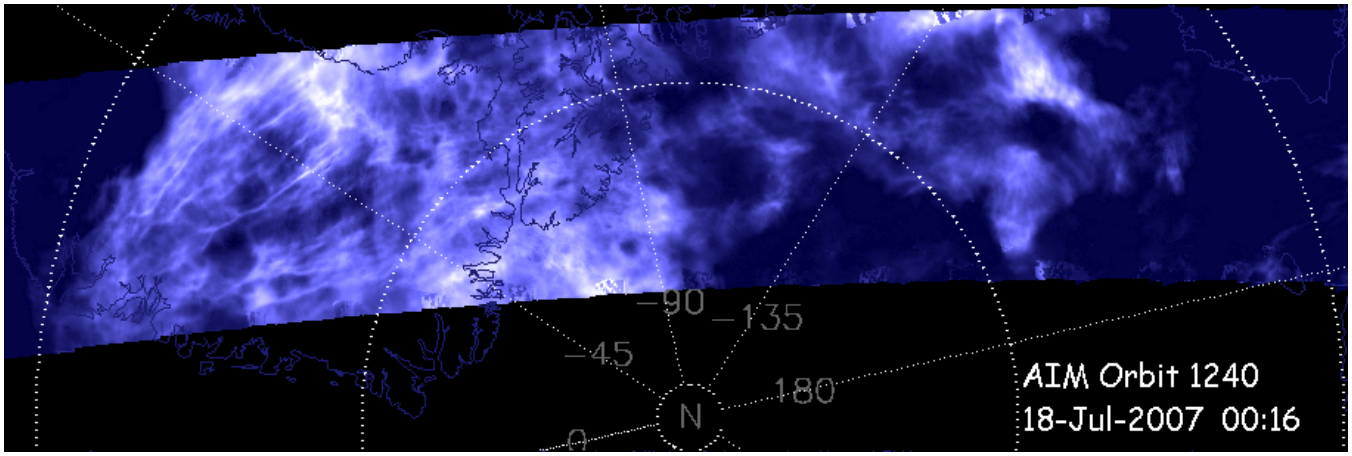
Examples of PMC Structures seen during the 2007 Northern Hemisphere Season

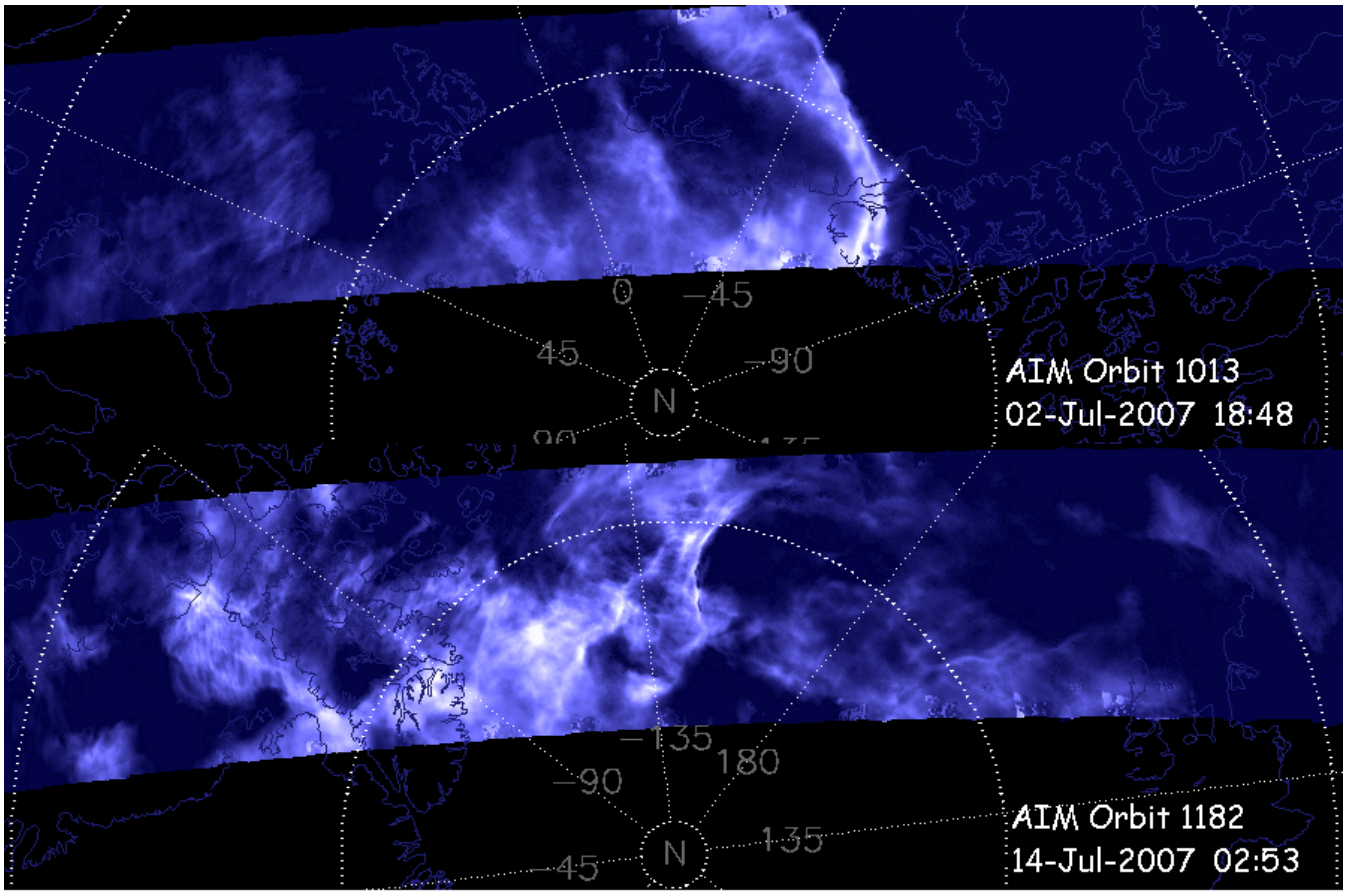
CIPS PMC images also show (upper) Veil, (middle) Billow, (middle) Band, and (lower) Whirl structures.



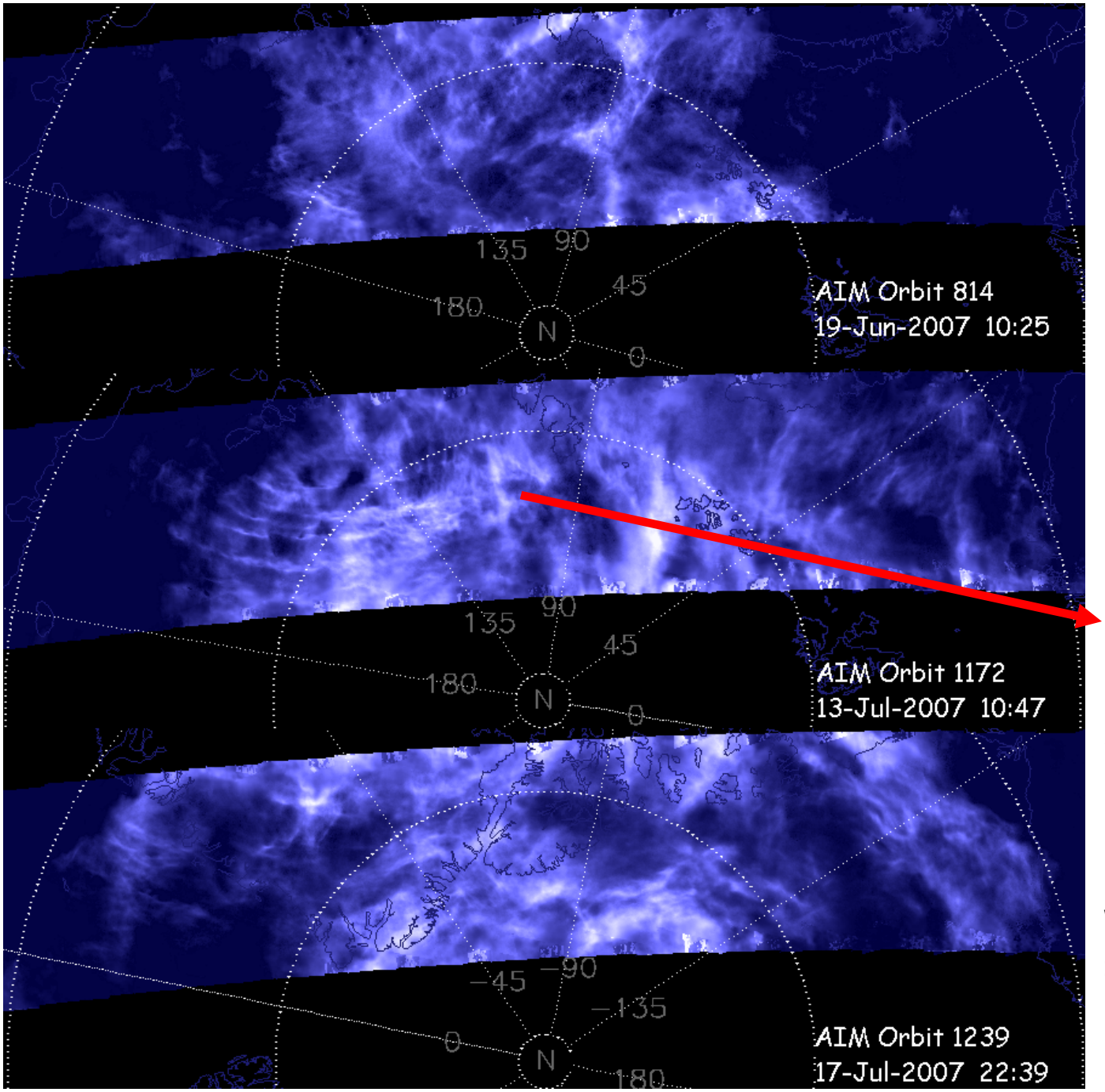
- Bands and billows identified as gravity wave structures have been characterized by e.g. Taylor et al., [2010]; Chandran et al., 2009.

- "..horizontal wavelengths of all detected, prominent, quasi monochromatic waves range from <50 to 500 km" – [Taylor et al., 2010].





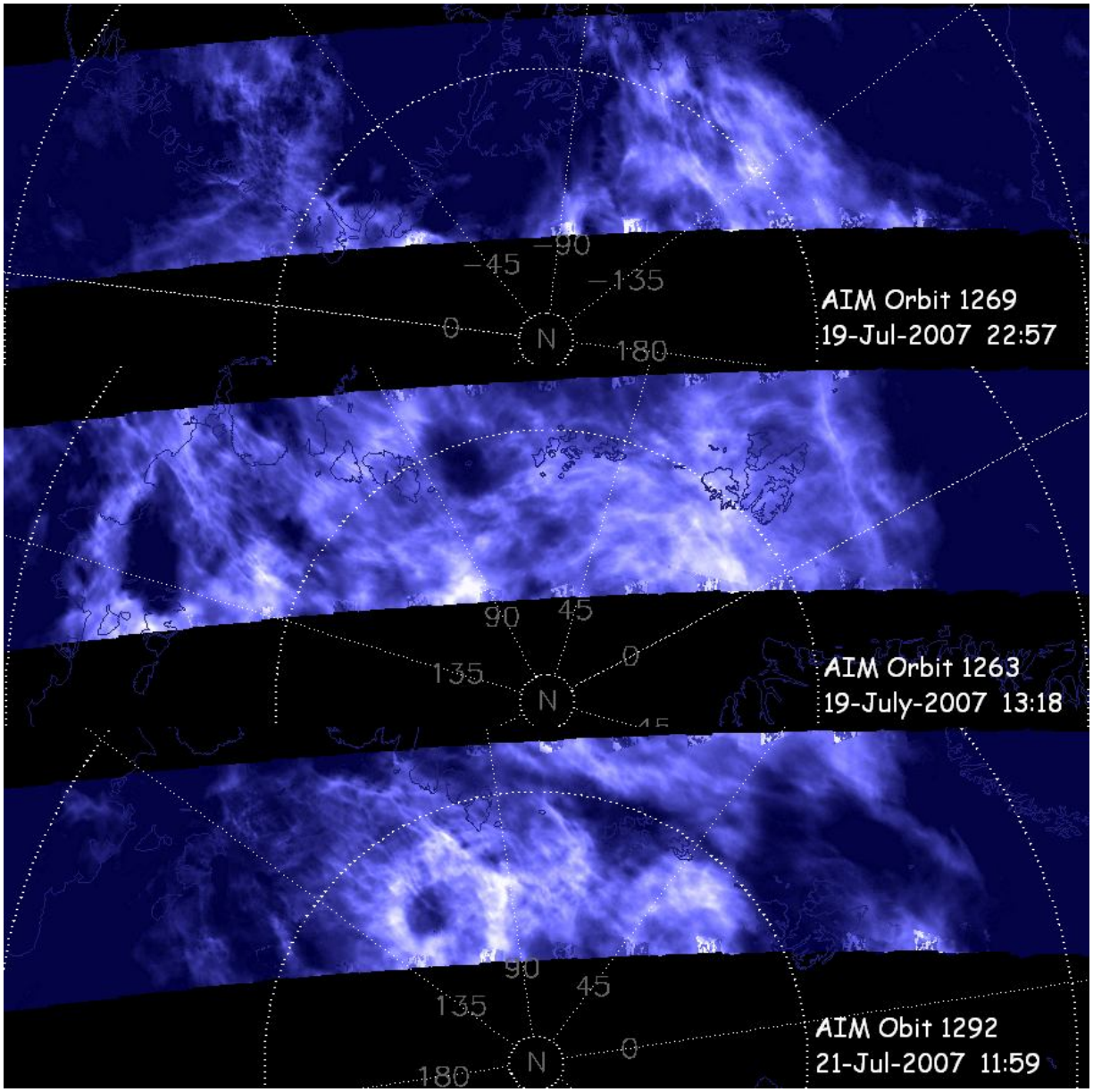
- Series of three adjacent circles of ice rings
- CIPS also observes isolated bands of bright clouds
- These clouds appear to serve as a boundary between two different air masses and thus we refer to them as 'fronts'



- Three different configurations of ice ring structure, in the shape of the number three, a series of concentric arc like structures, and two halves of consecutive rings adjacent to each other

- Example of gravity wave structure with curved wave crests and report a horizontal wavelength of 128 ± 5 km (Taylor et al., 2010)

CIPS also observes circular structures termed 'ice voids'



- Voids I and II are characterized based on size, and void III is similar in size to void II but is also associated with an arc of bright ice ring surrounding the void.

- It is not clear whether these 'ice free' regions are devoid of ice or if they are regions of ice clouds with radii smaller than the CIPS UV detection threshold near 30 nm.

Outline

- Cloud Imaging and Particle Size (CIPS) Experiment
- Examples of PMC structures observed by CIPS during the northern hemisphere 2007 season
  - focus on circular 'ice voids'
- NOGAPS ALPHA model results to analyze the environment in which these ice voids form (Case Study of Void I)
- Summary

Use NOGAPS ALPHA to Study Void Environment

➢We use the NOGAPS ALPHA model to investigate the meteorology that could be responsible for the formation of voids.

➢The NOGAPS ALPHA model is a high altitude global numerical weather prediction system. NOGAPS ALPHA consists of both a spectral forecast model and a data assimilation component- (NAVDAS: NRL Atmospheric Variational Data Assimilation system) assimilates MLS & SABER temperature and water vapor

- output global analysis fields every six hours (00:00, 06:00, 12:00, 18:00)
- vertical resolution of 60 pressure levels from the ground to 0.0005 hPa
- effective horizontal resolution of 2^o latitude x 2^o longitude.
- We use the hourly output from the spectral forecast component to calculate parcel trajectories

Atmospheric State from NOGAPS ALPHA

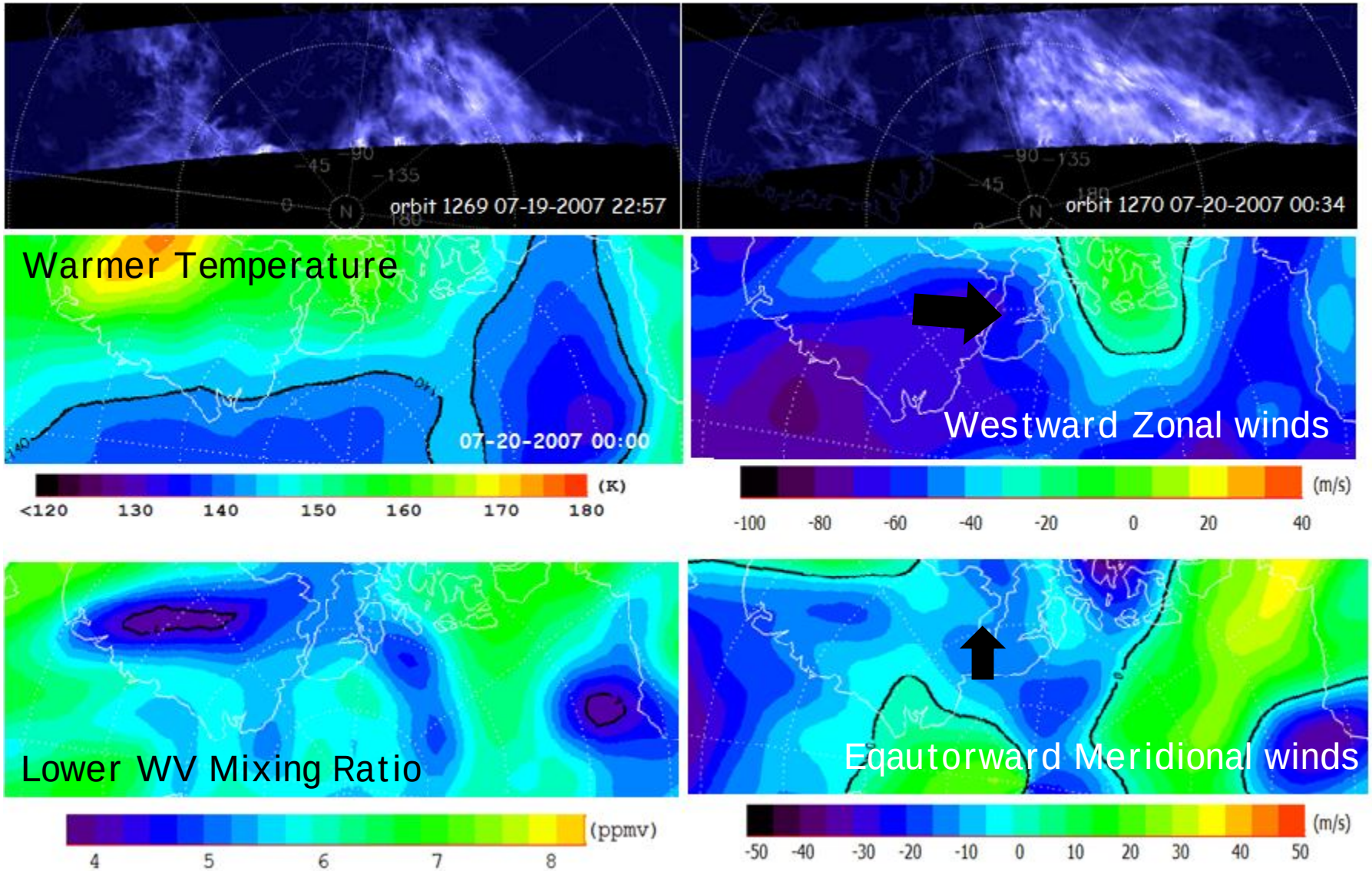
- what happens at the same time and 6:00 hours earlier (center of the void and at ~84 km (0.006 hPa))

	T (K)	T' (K)	WV mixing Ratio (ppmv)	Zonal Wind (m/s)	Meridional Wind (m/s)
06/10 (#678)	142.4 (+7.7)	9.8 (+10.8)	3.1 (-1.3)	W	N - S
06/23 (#874)	132.1 (-2.0)	6.6 (+2.5)	4.1 (+0.2)	W	N – S
07/14 (#1191)	136.2 (+10.1)	6.5 (+11.4)	4.8 (-2.3)	W - E	N - S
07/20 (#1269)	146.0 (+15.9)	10.5 (+10.6)	4.1 (-1.4)	W – E	S
07/24 (#1332)	145.5 (+3.9)	9.7 (+7.4)	3.8 (-1.4)	W - E	N - S

Vertical Winds

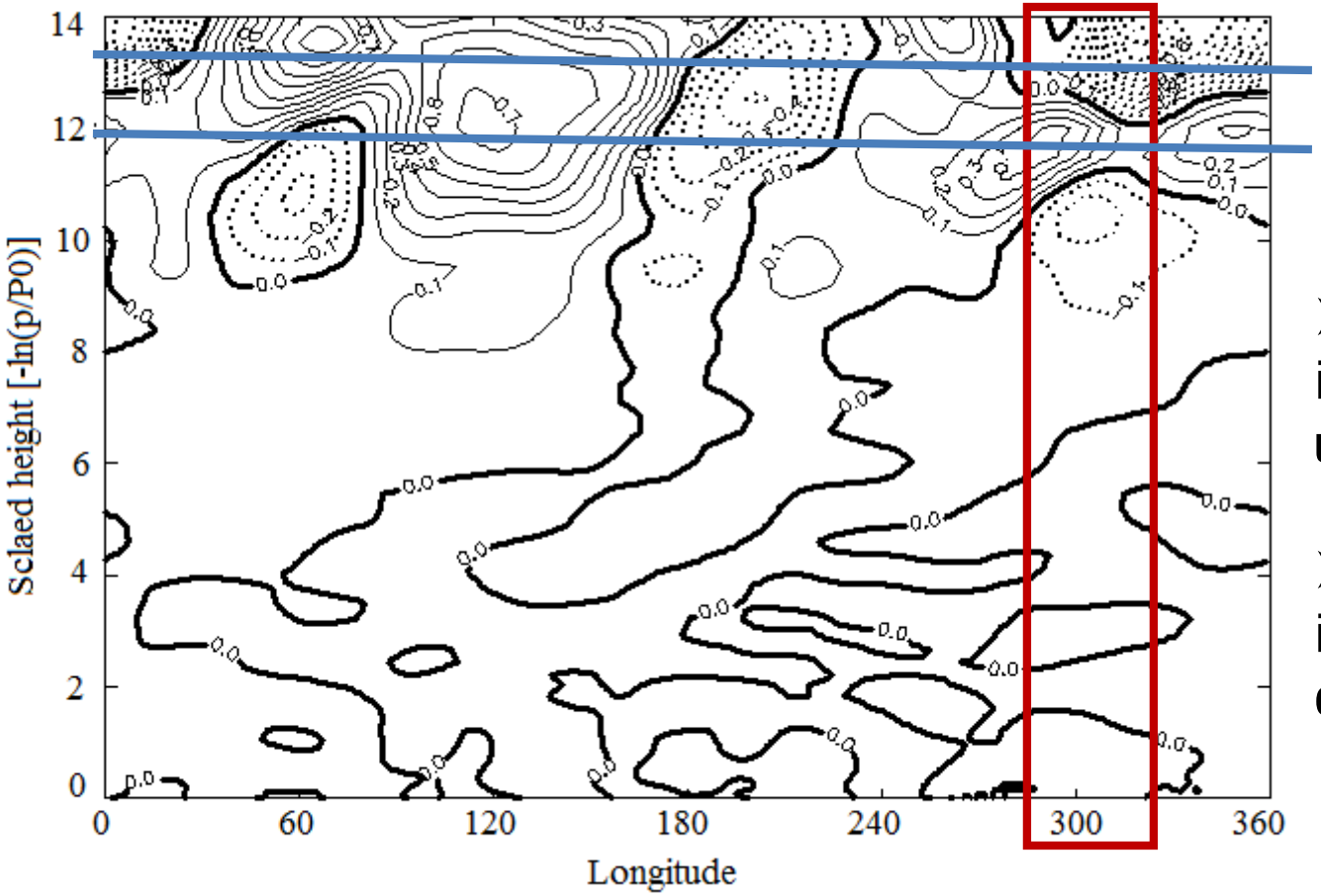
➢Downdrafts precede void?

Case Study – Ice Void Observed in Orbit 1269



Case Study – Ice Void Observed in Orbit 1269

Vertical winds indicate that the formation of voids may be preceded by downdrafts

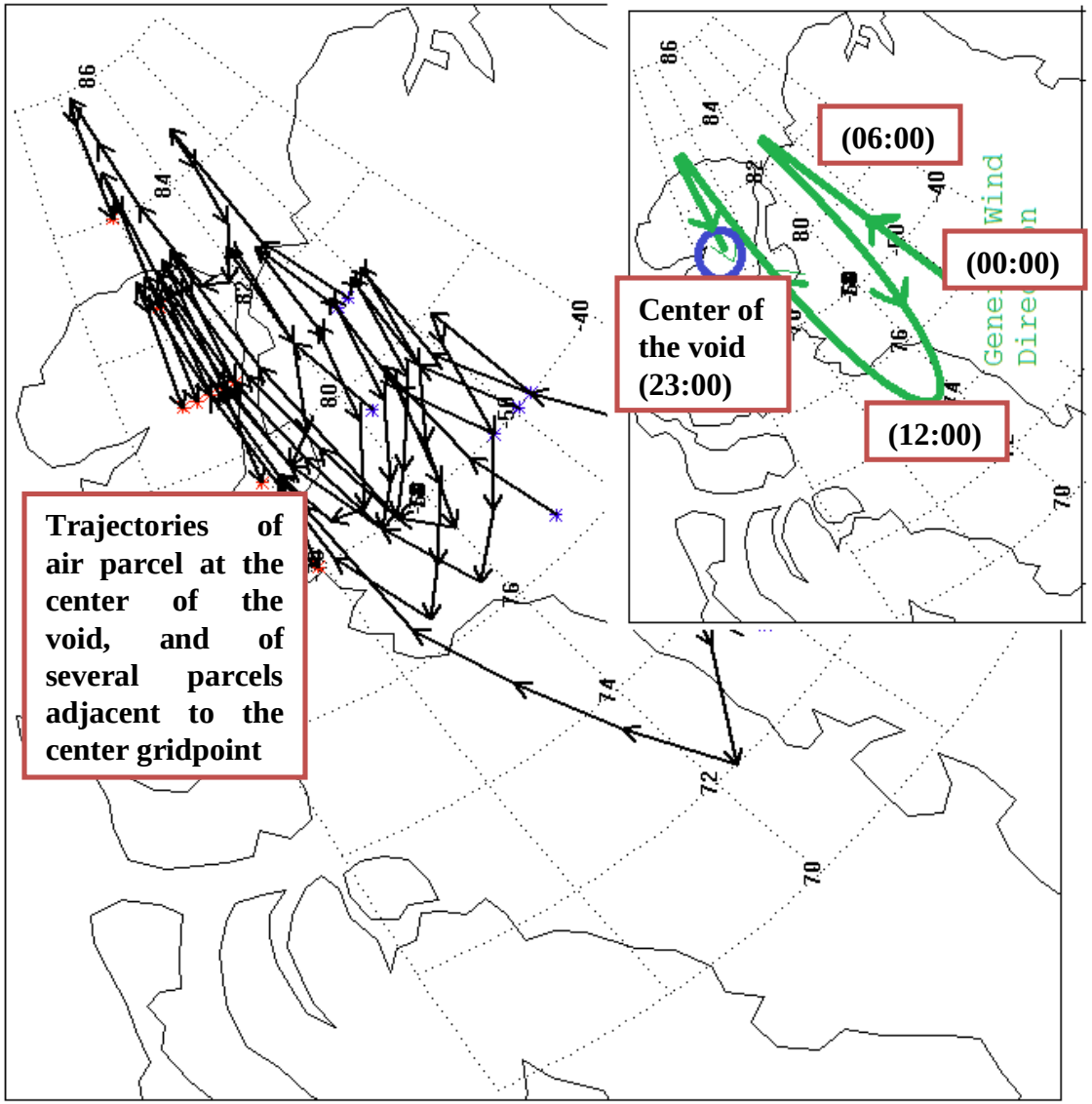


~84-87 km

- Positive indicates upwelling
- Negative values indicate downwelling

Vertical winds ~6 hours prior to the observed ice void I (19-July @ 18:00)

Advection: Tracking the History of an Air Parcel at 81°N, 290°E at ~84 km (0.006 hPa)



- Used horizontal winds ($\sqrt{(u^2+v^2)}$ from the NOGAPS ALPHA forecast model (output every one hour)
- Followed these winds for approximately 24 hours
- Did not consider vertical winds.

Spectral Analysis of NOGAPS ALPHA Temperatures

In the polar summer mesosphere planetary wave signals, including waves of quasi 5-day and 2 day period, and tidal signatures of diurnal and semi-diurnal tides have been previously reported [e.g. Eckermann et al., 2009; Nielson et al, 2010; Stevens et al., 2010]

- We analyze the wave variability by applying a continuous wavelet transform, W(a,b) (*Torrence and Compo, 1998*) with complex Morlet basis function to a 1-D time series of NOGAPS ALPHA temperatures.

- This technique allows us to resolve the dominant wavenumbers both as a function of time and location.

$$W(a,b) = \sqrt{a} \int_{\infty}^{-\infty} \hat{x}(f)\hat{\Psi}^{*}(af).\exp[i(2\pi f)b]df$$

$$\Psi(\eta) = \frac{1}{\pi^{-1/4}} e^{i\omega_0 \eta} e^{-\eta^2/2}$$

Resolve Waves using Wavelet Analysis

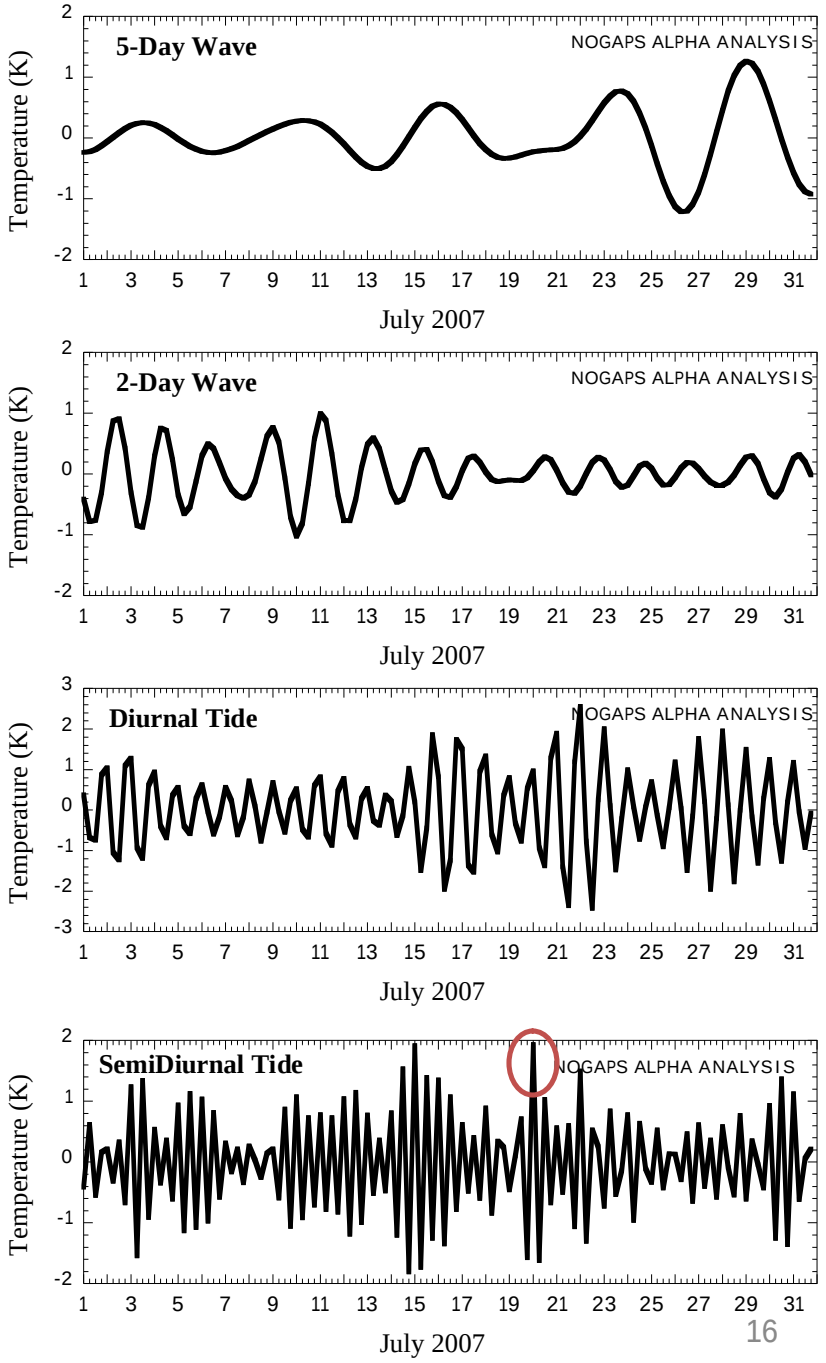
•Calculated from temperature averaged over 0.006-0.002 hPa (~84-87km) and over 81ºN (± 2) degree latitude.

•Averaged signal amplitude (wave oscillation)

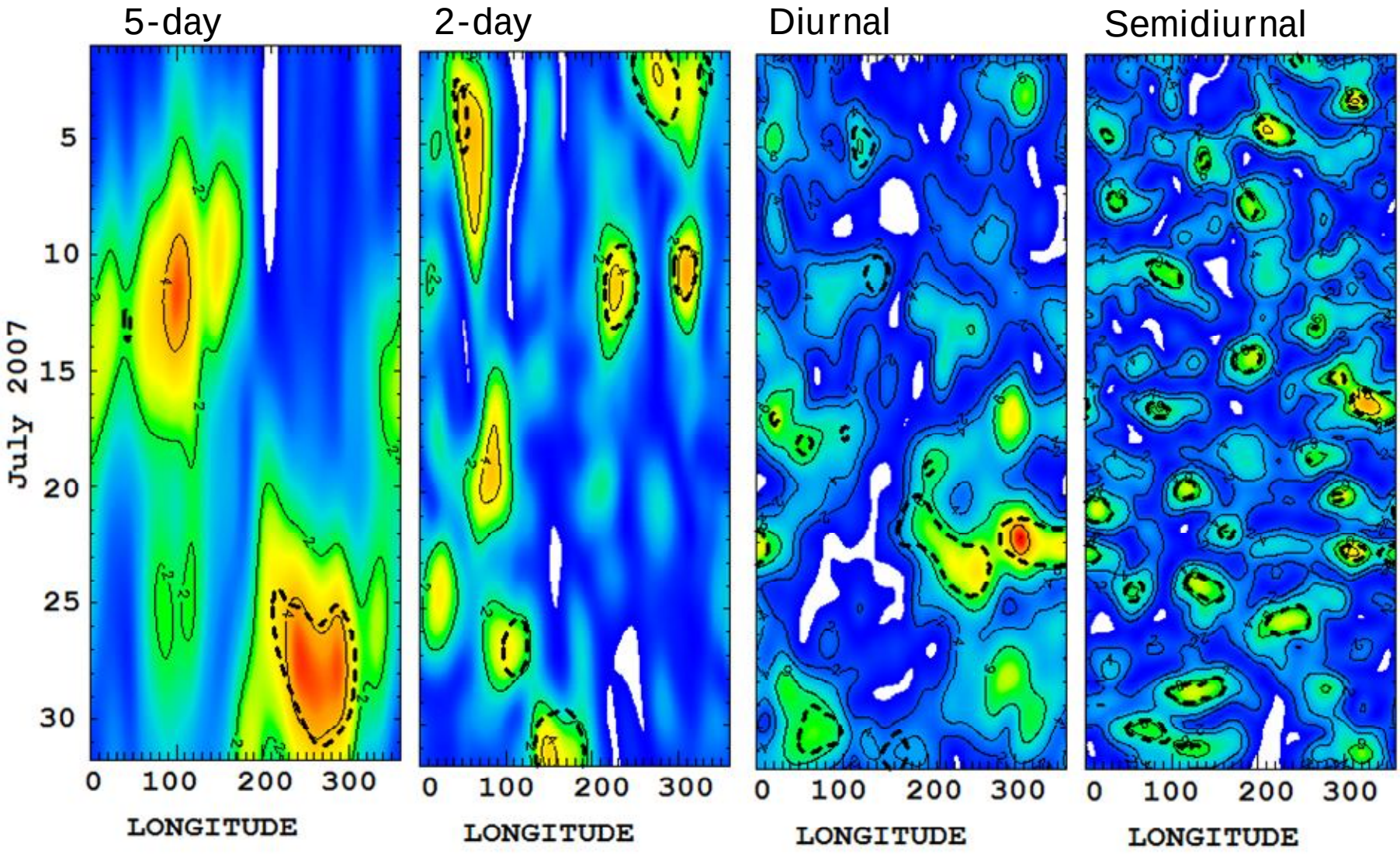
•Scale averaged wavelet variance (wavelet power spectrum)

•Bandwidth used to identify
- ➢ 5 day signal = 4.1 to 6.5 days
- ➢ 2 day signal = 1.8 to 2.2 days
- ➢ Diurnal Tide = 0.86 – 1.2 days
- ➢ Semidiurnal tide = 0.5 – 0.6 days

Time Series of Wave oscillation for July 2007

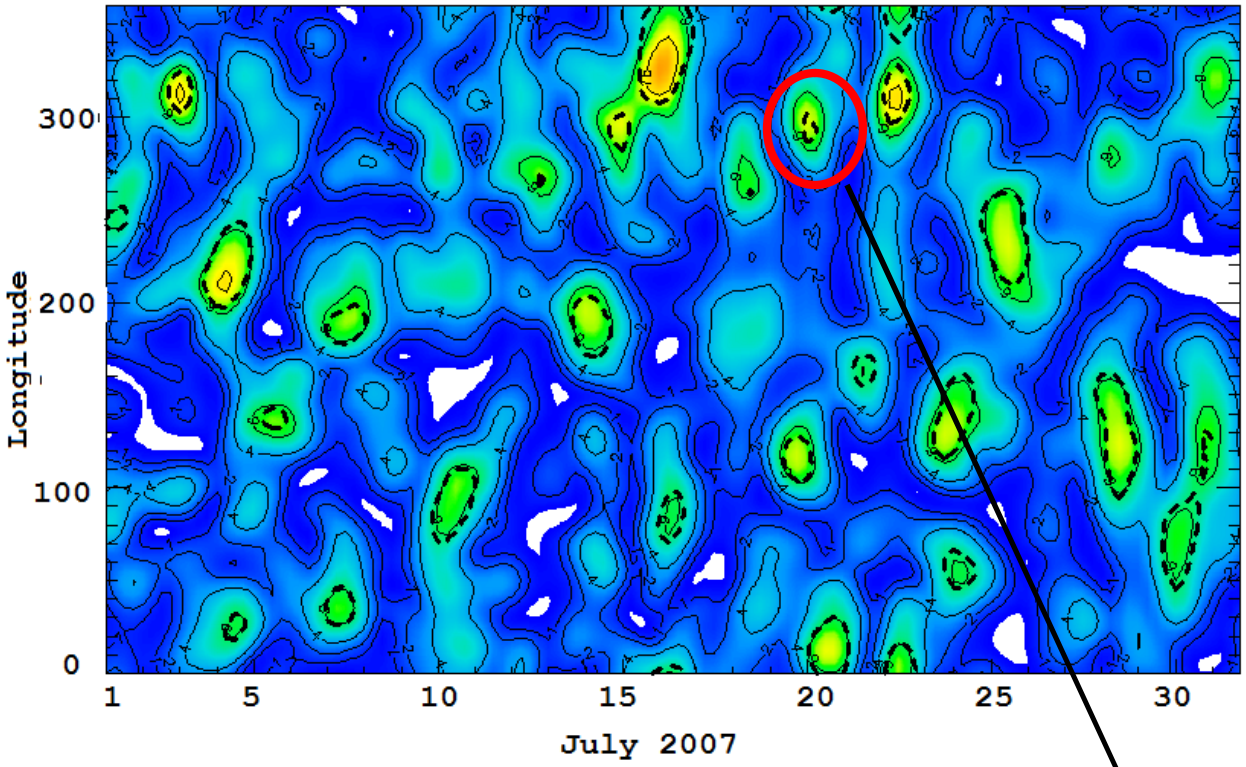


Hovmöller Plots of Temperature Variance (K^2)



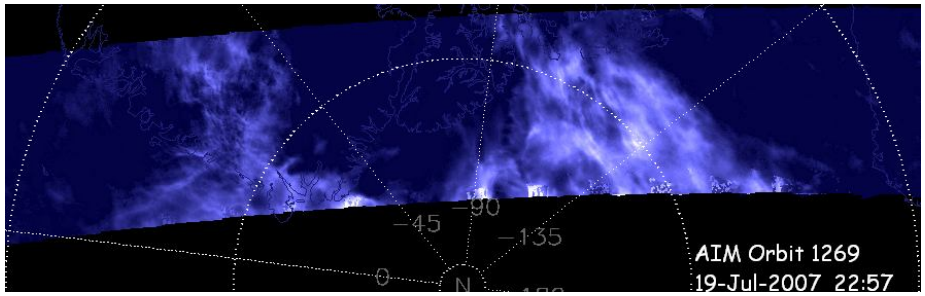
- The dashed line represents the 95% confidence level

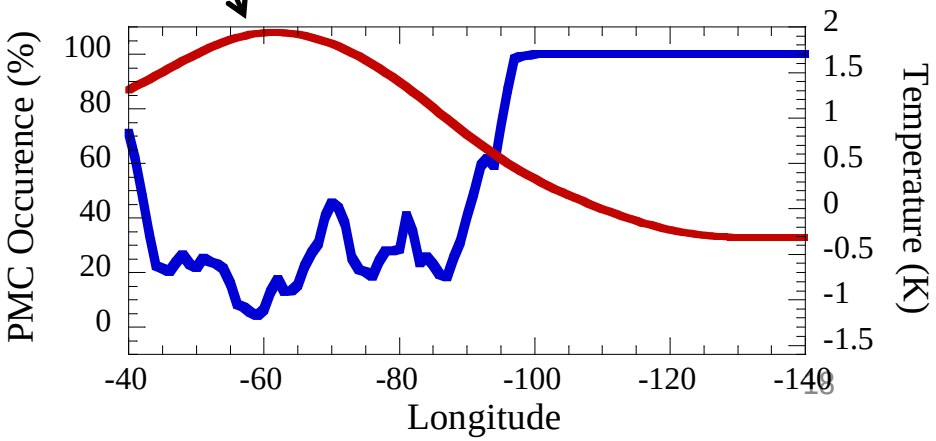
Hovmöller Plots of Temperature Variance (K^2)



Semidiurnal temperature amplitude is higher during occurrence of the void

But this does not apply to ALL voids





Summary

✓CIPS observes a wealth of interesting PMC structures.

✓Voids are characterized by increasing temperatures (and perturbation temperatures), decreasing wv mixing ratio, and appear to be preceded by downwelling vertical winds.

✓Ice voids I are observed in three consecutive orbits → have a lifetime of at least three hours or less. Voids I do not have a longitudinal variability.

✓Case Study shows that advection might bring warmer air from low latitudes

✓Wavelet analysis indicates that the semidiurnal tide amplitudes are higher during occurrence of some voids.

? Why are ice voids circular?

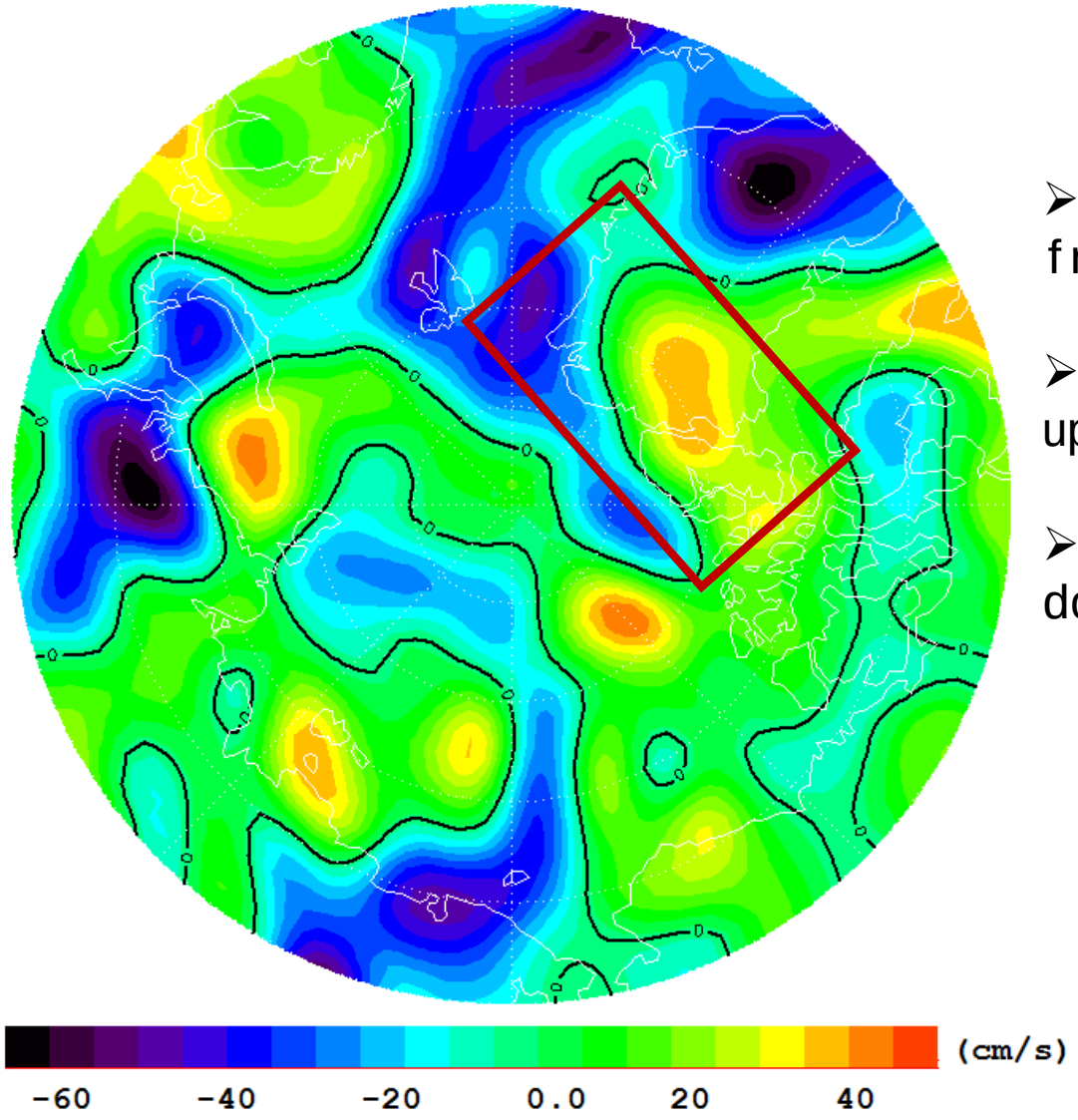
Ongoing and Future Study:

- **Use higher resolution NOGAPS output to study Voids II and III**
- **Analyze voids with SD-WACCM output**
- **Extend analysis to other NH PMC seasons and SH PMC seasons**

In this time of year you can enjoy the beauty of the polar mesospheric clouds. With our high-angle illumination, we were able to capture a thin layer of noctilucent clouds at sunset.

Astronaut Douglas Wheelock

Case Study – Ice Void Observed in Orbit 1269



- Vertical Wind calculated from divergence of the flow
- Positive indicates upwelling
- Negative values indicate downwelling

Dynamics – Resolve Waves using Wavelet Analysis

•Calculated from temperature averaged over 0.006-0.002 hPa (~84-87km) and over 81N (± 2) degree latitude.

•Averaged signal amplitude (wave oscillation)

•Scale averaged wavelet variance (wavelet power spectrum)

•Bandwidth used to identify
- ➢ 5 day signal = 4.1 to 6.5 days
- ➢ 2 day signal = 1.8 to 2.2 days
- ➢ Diurnal Tide = 0.86 – 1.2 days
- ➢ Semi-diurnal tide = 0.5 – 0.6 days