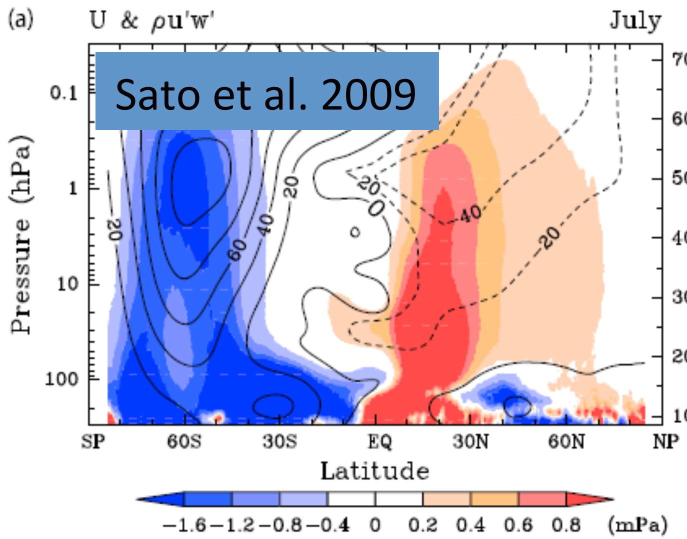
Non-vertical propagation of gravity waves generated over the monsoon region and its effect on polar mesospheric clouds

Brentha Thurairajah[1]
David Siskind[2]
Scott Bailey[1]
Justin Carstens[1]

[1]Space@VT, Virginia Tech, Blacksburg, USA
[2]Naval Research Laboratory, Washington DC, USA

2016 SPARC Gravity Wave Symposium
16-20 May 2016

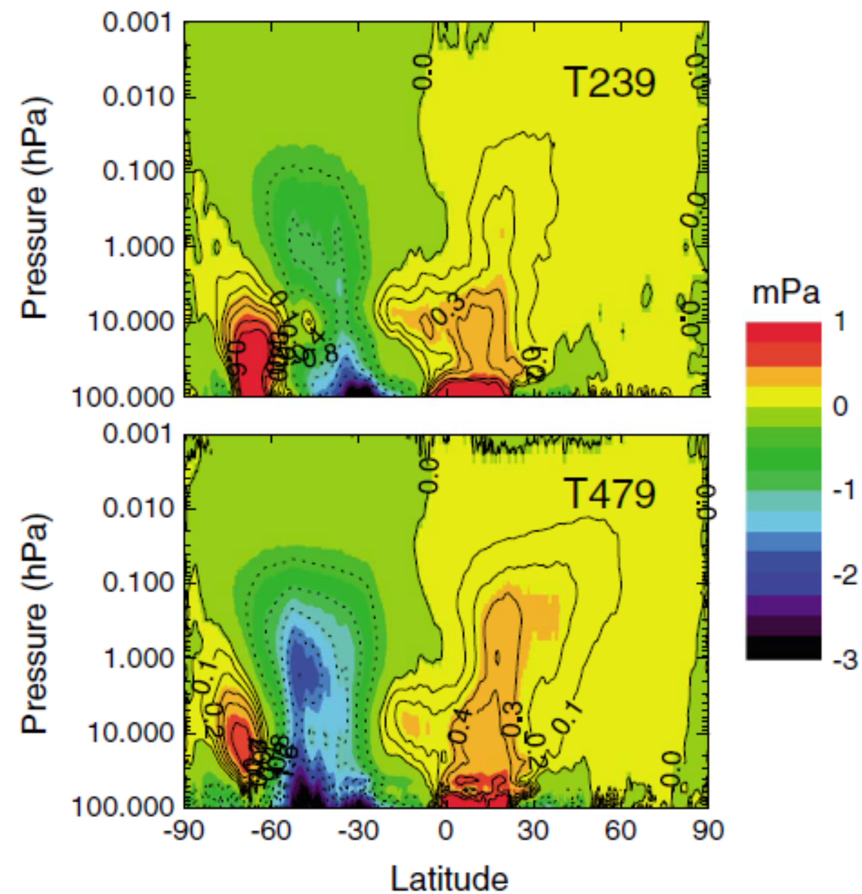
Motivation: From Sato et al., (2009) '*On the Origins of mesospheric gravity waves*': "The monsoon regions are the most important window to the middle atmosphere in summer because of the easterlies associated with the monsoon circulation"



Latitudinal propagation of GWs
The easterly jet in the summer hemisphere exhibits a slanted structure above 50 km in the mesosphere

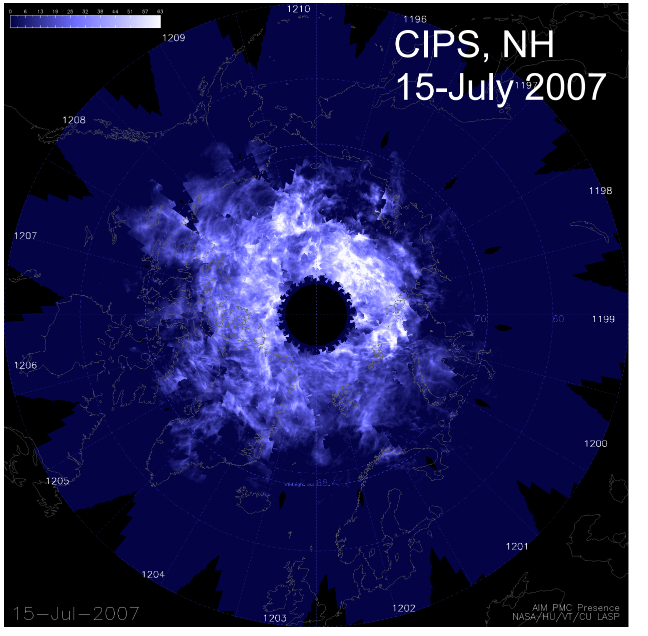
Easterly winds are associated with the monsoon circulation → Wave focusing into the jet → allow eastward propagating GWs to enter the middle atmosphere.

Momentum Flux from NOGAPS-ALPHA model (Siskind, 2014)



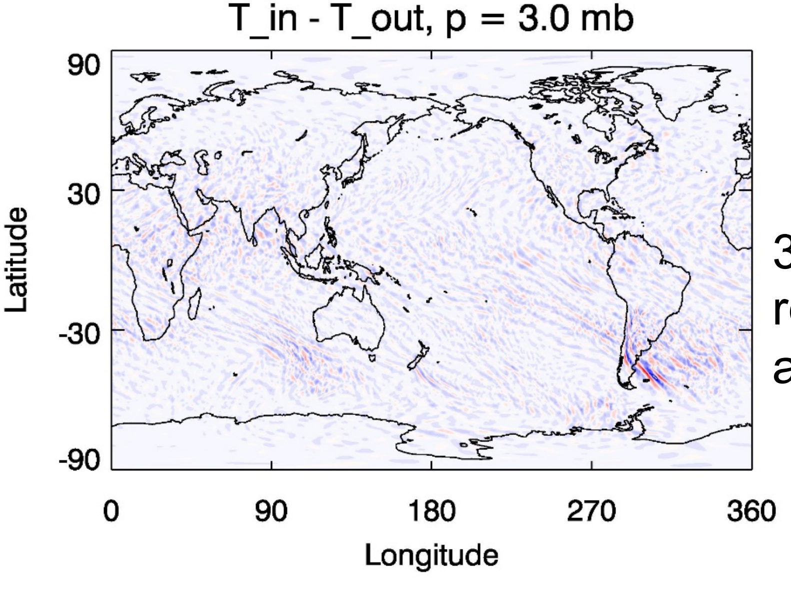
Data and model:

Observational Study to understand the influence of monsoon GWs on PMCs during the NH 2007 summer



1. SABER/TIMED temperatures to derive GW parameters

2. PMC Occurrence Frequency from the Cloud Imaging and Particle Size (CIPS) experiment on the AIM satellite

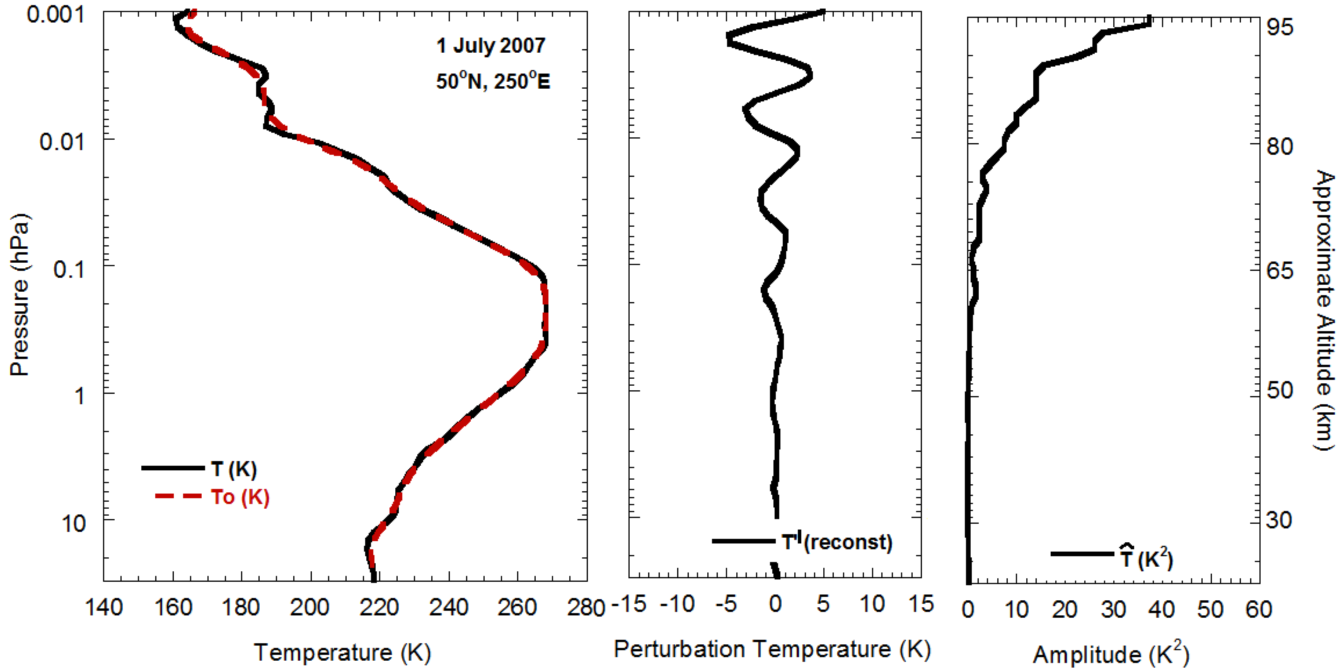


3. NOGAPS-ALPHA model results (high resolution model to calculate GWMF and assimilated model results for wind analysis)

Method - GWs from SABER: Calculate Amplitude and Momentum Flux (MF) from perturbation temperature (Ern et al. 2011).

$$MF_{SABER} = \frac{1}{2}\rho\frac{k_h}{m}\left(\frac{g}{N}\right)^2\left(\frac{\hat{T}}{To}\right)^2$$

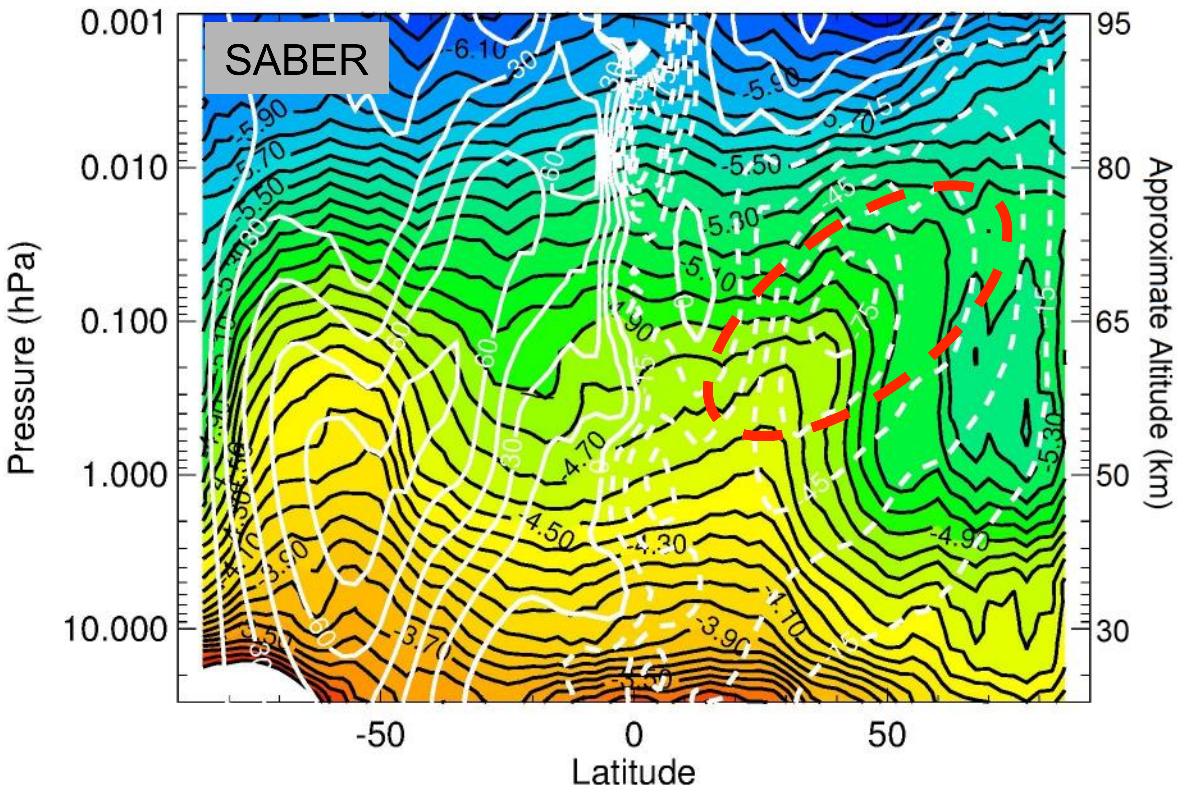
- To is the background temperature calculated as the sum of zonal mean temperature and PW (WN1-5) components
- $\hat{T}$ = GW amplitude



- Horizontal wavelengths ($1/k_h$) are calculated from the phase difference between adjacent profiles

-Vertical wavelengths (1/m) are calculated from wavelet analysis

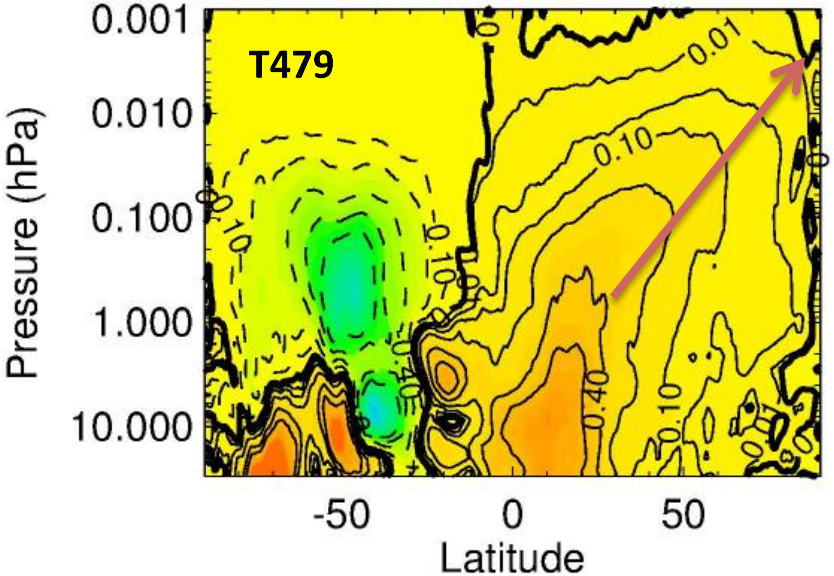
Gravity Wave Momentum Flux (GWMF) from SABER



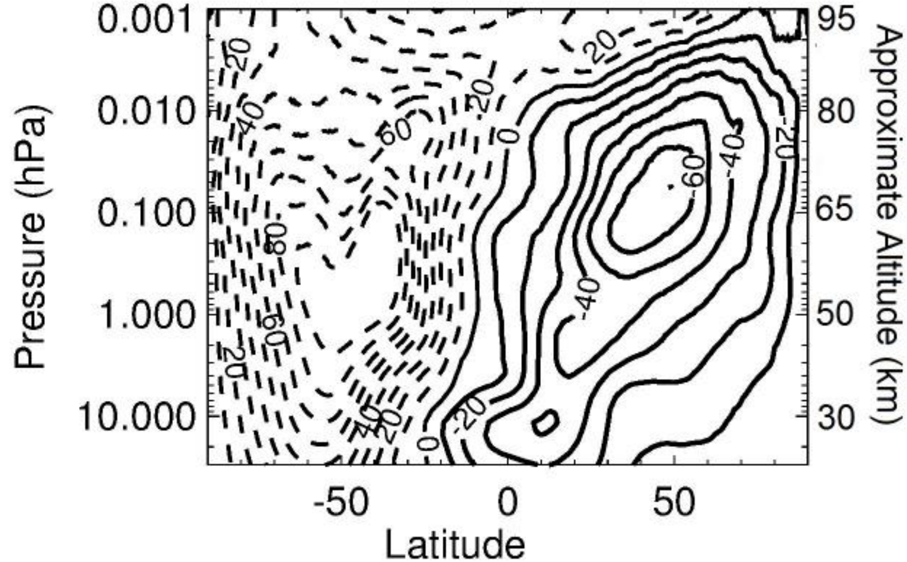
- July 2007
- GWMF units are in $\log_{10}$(hPa).
- White contours are the horizontal winds calculated from SABER geopotential height

Slanted structure of the GWMF could suggest a ‘non-vertical’ propagation of GWs from low latitudes, low altitudes to high latitudes, high-altitudes.

GWMF from high resolution NOGAPS-ALPHA for July 2007



$$MF_{NOGAPS} = \rho u'w'$$

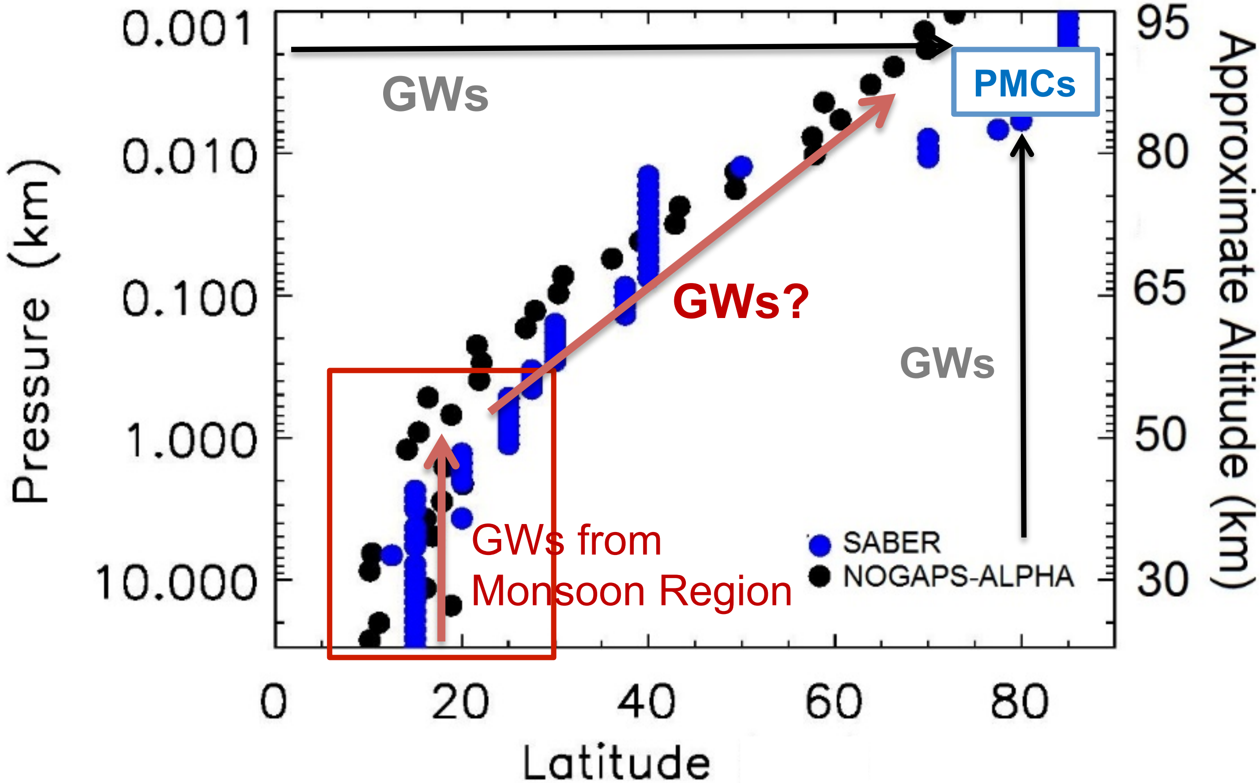


Zonal Wind (m/s)

Since SABER GWs cannot give us direction we use high-resolution NOGAPS-ALPHA data from July 2007 to show the **eastward propagating gravity waves** (confirms the direction of propagation).

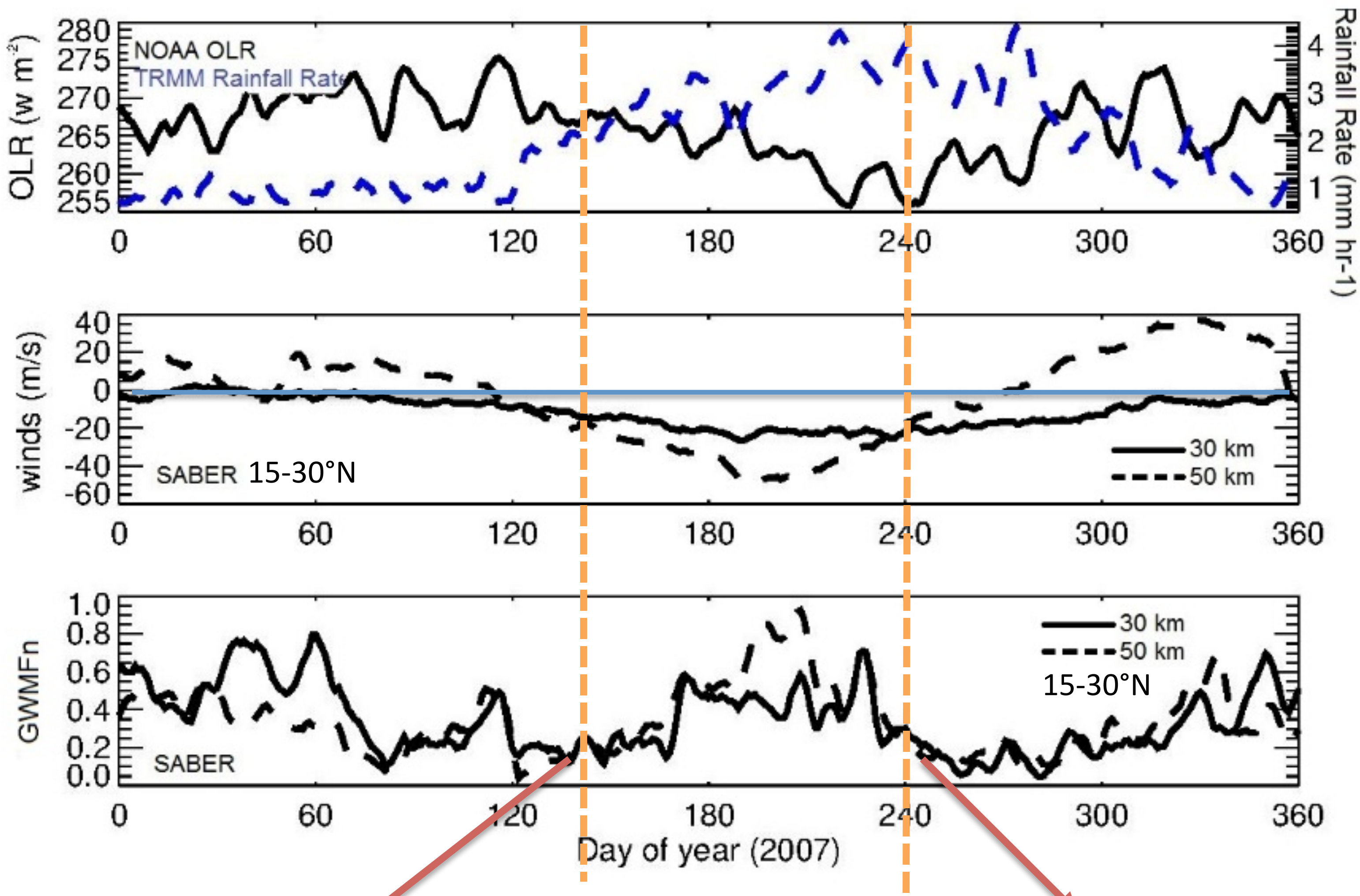
Slanted Structure → Non-vertical propagation of GWs?

The circles indicate the location (latitude) of maximum momentum flux at each altitude.



Possible source/direction of monsoon generated stratospheric GWs influencing the high latitude middle atmosphere

Annual variations and monsoon GWs in the tropical stratosphere



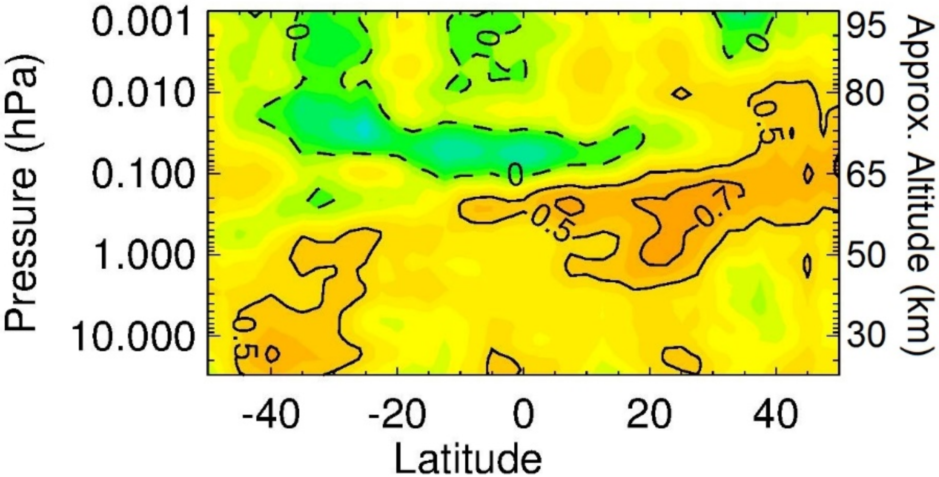
Start is controlled by monsoon activity and winds?

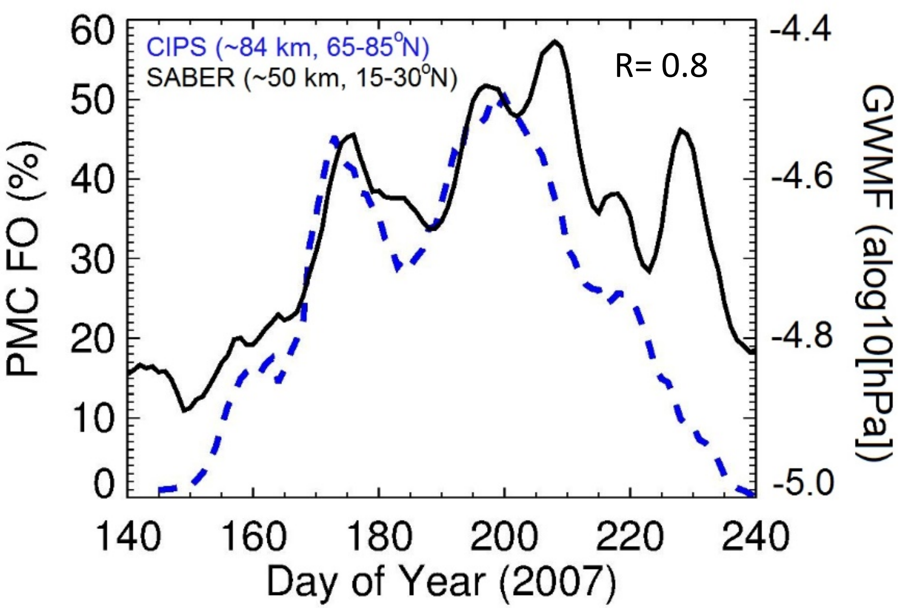
NH 2007 PMC season

End is controlled by filtering by winds

Monsoon GWs and PMCs

Correlation coefficient between PMC at ~84 km, 65-85°N, and global GWMF



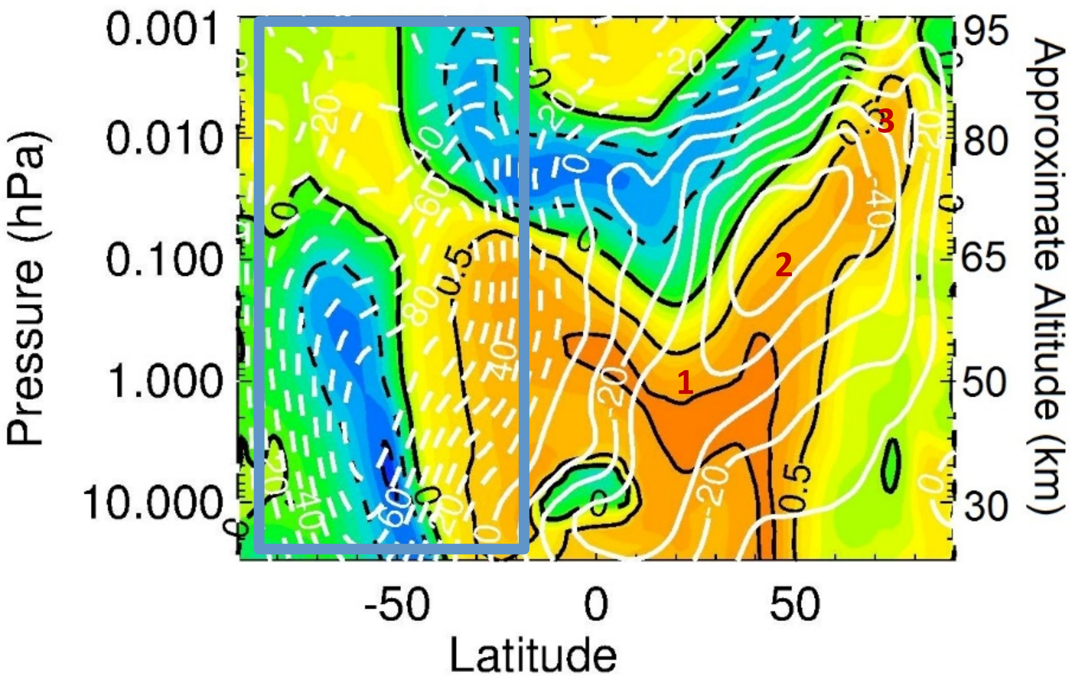


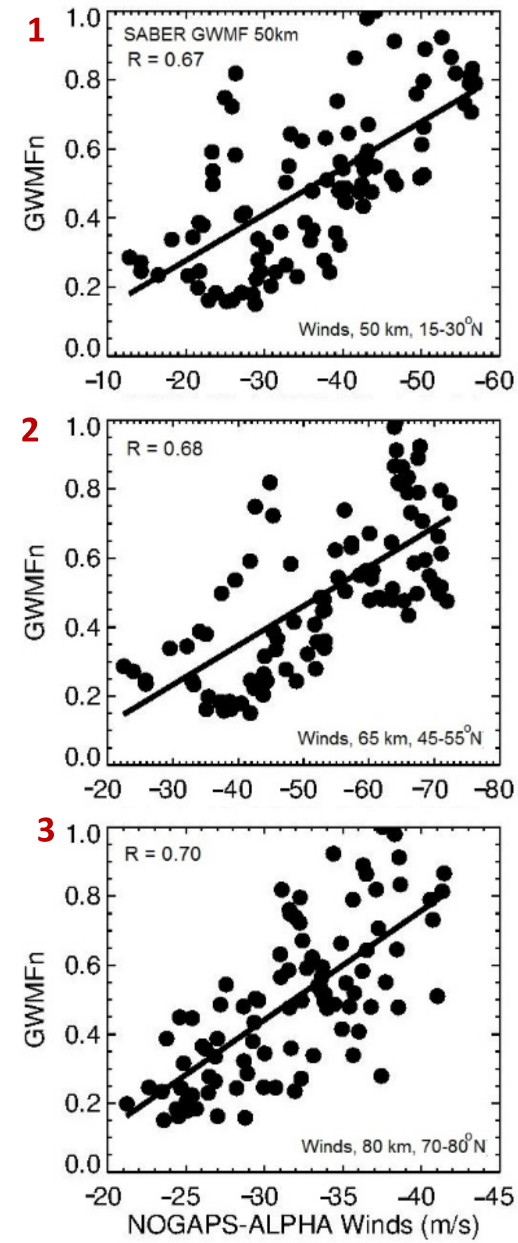
The high correlation (>0.5) implies:

- the large scale circulation influencing PMCs also influence monsoon stratospheric GWs (and SH lower stratospheric GWs)
- monsoon GWs influence the high latitude middle atmosphere via wave focusing into (slanted structure) of the easterly winds.

Monsoon GWs and Winds

Correlation coefficient between time-series of monsoon (15-30°N) GWMF at ~50 km and NOGAPS-ALPHA zonal winds during the NH PMC season



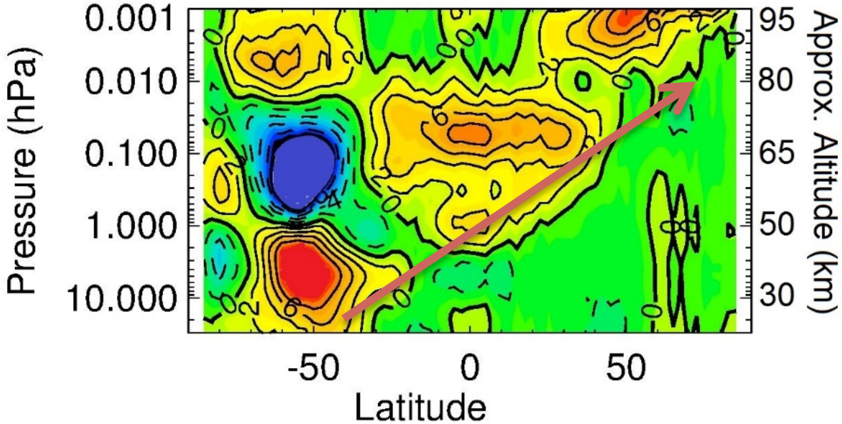


Positive correlation is not relevant since westerly winds will not allow eastward propagating waves

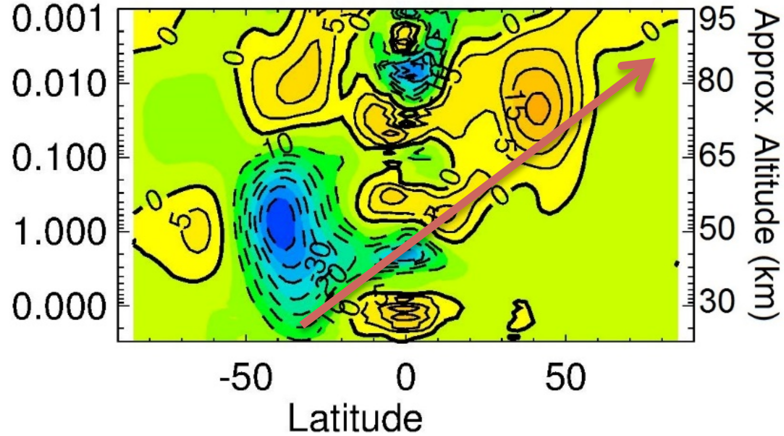
Slanted structure agrees with non-vertical propagation of GWs to reach the polar mesosphere and influence PMCs

Influence of SH PWs on monsoon GWs

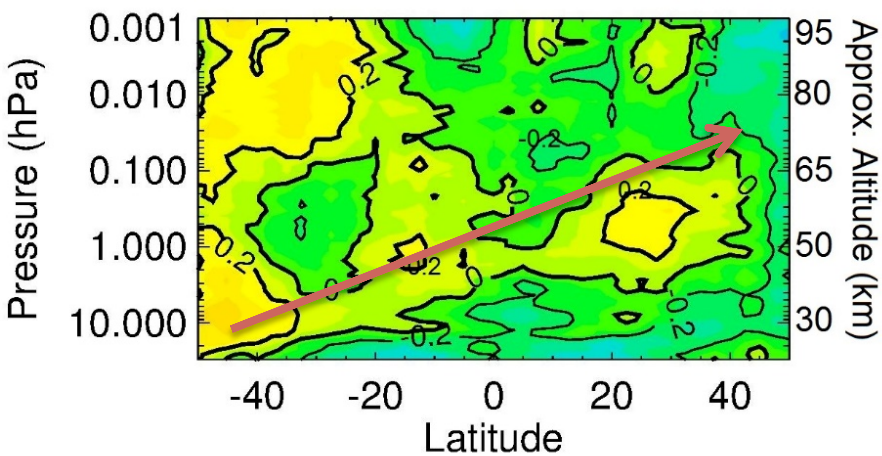
SABER: T_July 2007 – T_July 2009



SABER: U_July 2007 – U_July 2009



Anomalies of temperature and winds show the expected basic structure, associated with the coupling between the SH lower stratosphere, the equatorial stratosphere, and NH polar mesosphere; also seen in NOGAPS-ALPHA data (Siskind et al., 2011)



Preliminary Analysis
Correlation between MERRA PWs (EPz) at 10 hPa, 60°S and SABER GWMF for July 2007

Summary

First observational study to understand the influence of monsoon generated gravity waves on polar mesospheric clouds.

The monsoon GWs in the tropical stratosphere influence the NH polar summer mesosphere (via non-vertical propagation, owing to the slanted structure of the easterly winds).

The stratospheric monsoon GWs and PMCs could be modulated by the same large scale circulation (via teleconnection between the southern hemisphere lower stratosphere)

Thank You

References:

Ern, M., P. Preusse, J. C. Gille, C. L. Hepplewhite, M. G. Mlynczak, J. M. Russell, III, and M. Riese (2011), Implications for atmospheric dynamics derived from global observations of gravity wave momentum flux in stratosphere and mesosphere, *J. Geophys. Res*., 116, D19107, doi: 10.1029/2011JD015821.

Sato, K., S. Watanabe, Y. Kawatani, Y. Tomikawa, K. Miyazaki, and M. Takahashi (2009), On the origins of mesospheric gravity waves, *Geophys. Res. Lett*., 36, L19801, doi:10.1029/2009GL039908.

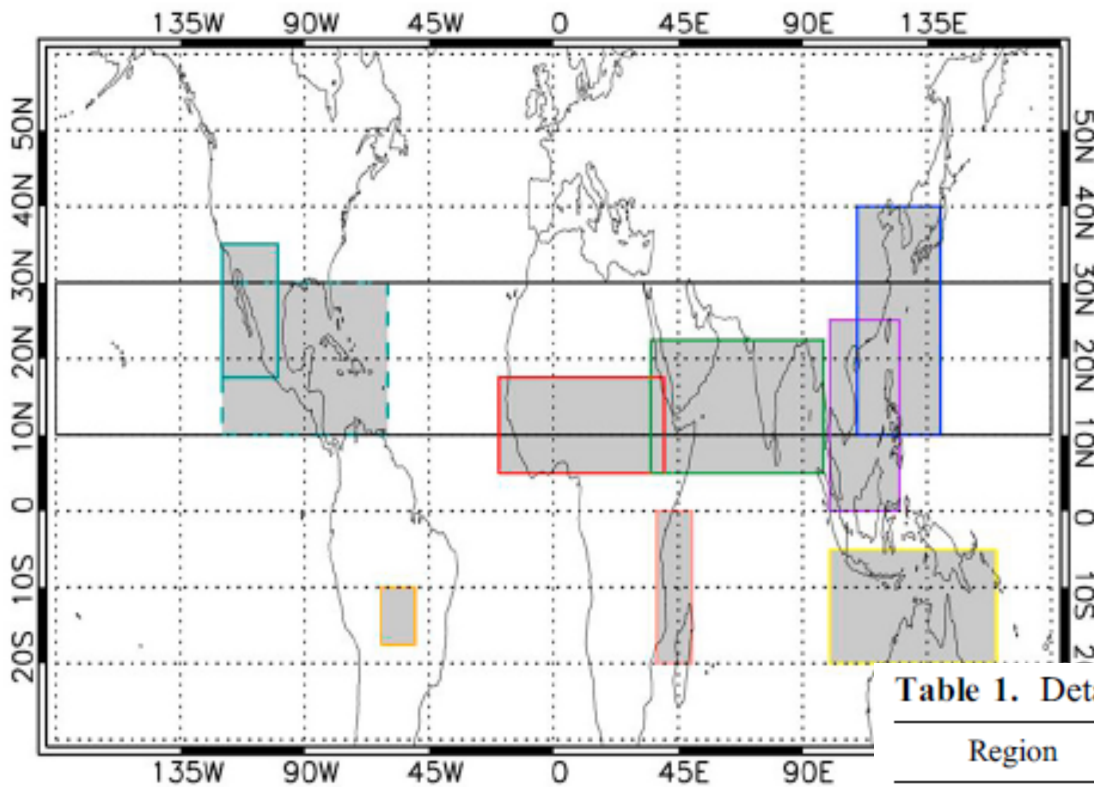
Siskind, D. E., M. H. Stevens, M. Hervig, F. Sassi, K. Hoppel, C. R. Englert, and A. J. Kochenash (2011), Consequences of recent Southern Hemisphere winter variability on polar mesospheric clouds, *J. Atmos. Solar-Terr. Phys.*, *73*, 2013-2021

Siskind, D. E. (2014), Simulations of the winter stratopause and summer mesopause at varying spatial resolutions, *J. Geophys. Res. Atmos*., 119, doi:10.1002/2013JD020985.

Wright, C. J., and J. C. Gille (2011), HIRDLS observations of gravity wave momentum fluxes over the monsoon regions, *J. Geophys. Res*., 116, D12103, doi:10.1029/2011JD015725.

BACKUP

From Wright and Gille, JGR, 2007



Monsoon regions studied in their paper.

Table 1. Details of the Regions Studied[a]

Region	Latitude	Longitude	Period
Africa	5°N–17.5°N	20°W–40°E	May–Sep
Australia	5°S–20°S	100°E–160°E	Dec–Mar
East Asia	10°N–40°N	110°E–140°E	Jun–Aug
North America	17.5°N–35°N	100°W–120°W	Jun–Sep
SEWIO	0°S–20°S	37.5°E–50°E	Nov–Mar
South America	10°S–17.5°S	50°W–62°W	Oct–Mar
South Asia	5°N–22.5°N	35°E–97.5°E	Jun–Sep
South China Sea	0°N–25°N	100°E–125°E	May–Oct
North America (2)	10°N–30°N	60°W–120°W	n/a

[a]Definitions have been taken from *Li and Zeng* [2002], except for the second North American region, which is defined in section 4.4.