# Stratospheric winter weather

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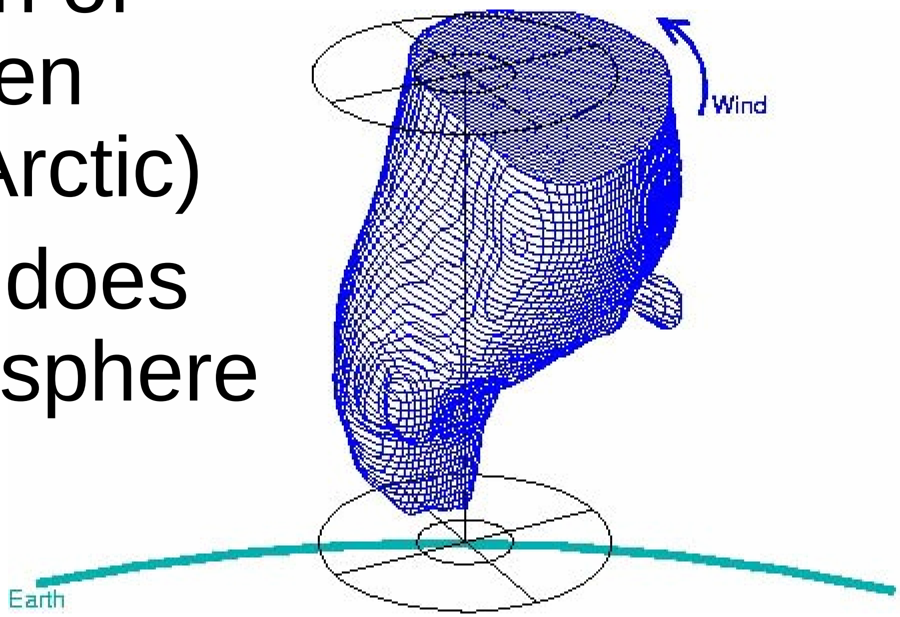
# OUTLINE

1. Impact of polar vortices on troposphere
2. Stratospheric sudden warmings
3. Forecasting the mesosphere

# Winter Polar stratosphere

- Dominated by westerly wind increasing with height: Polar night jet
- Occasional disruption of polar vortex by sudden warming events (in Arctic)
- Stratospheric vortex does not extend into troposphere




http://www.nasa.gov/images/content/113260main_arctic-vortex-447.jpg

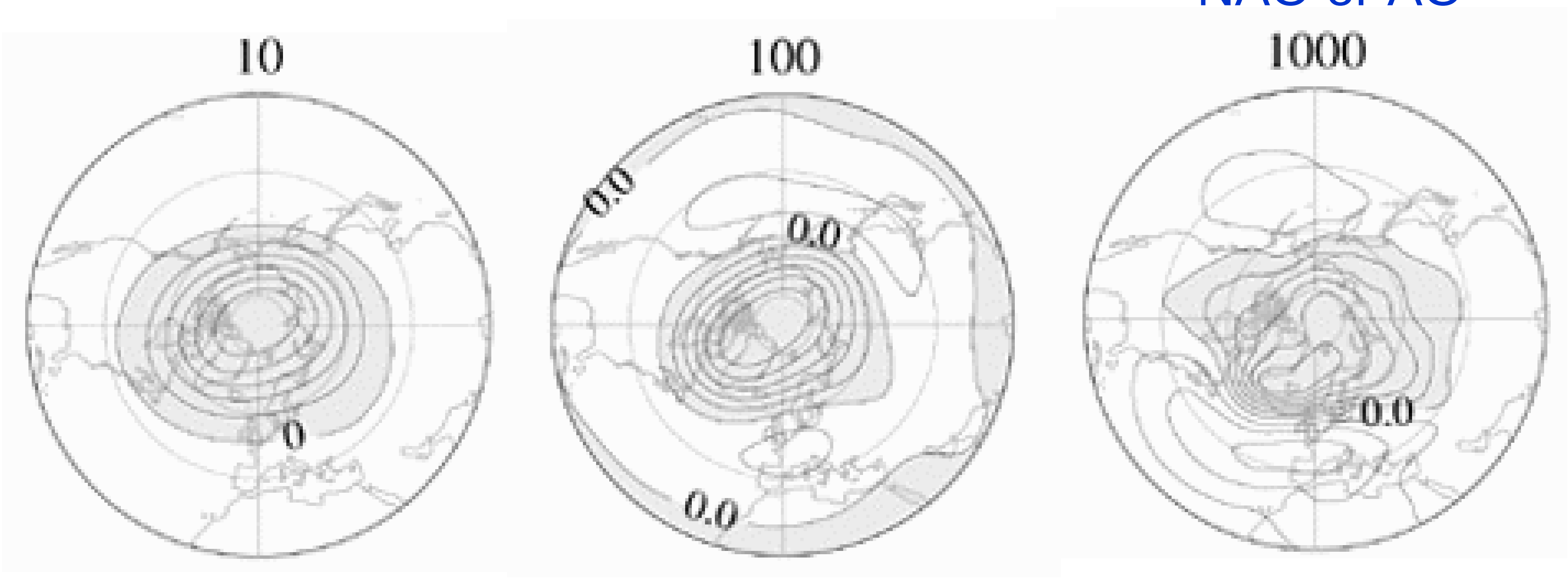
# Northern Annular Mode = NAM

- Useful for characterizing stratospheric regimes
- Leading EOF of slowly varying wintertime, hemispheric geopotential at each pressure level
- Spatial pattern that accounts for greatest fraction of geopotential variance

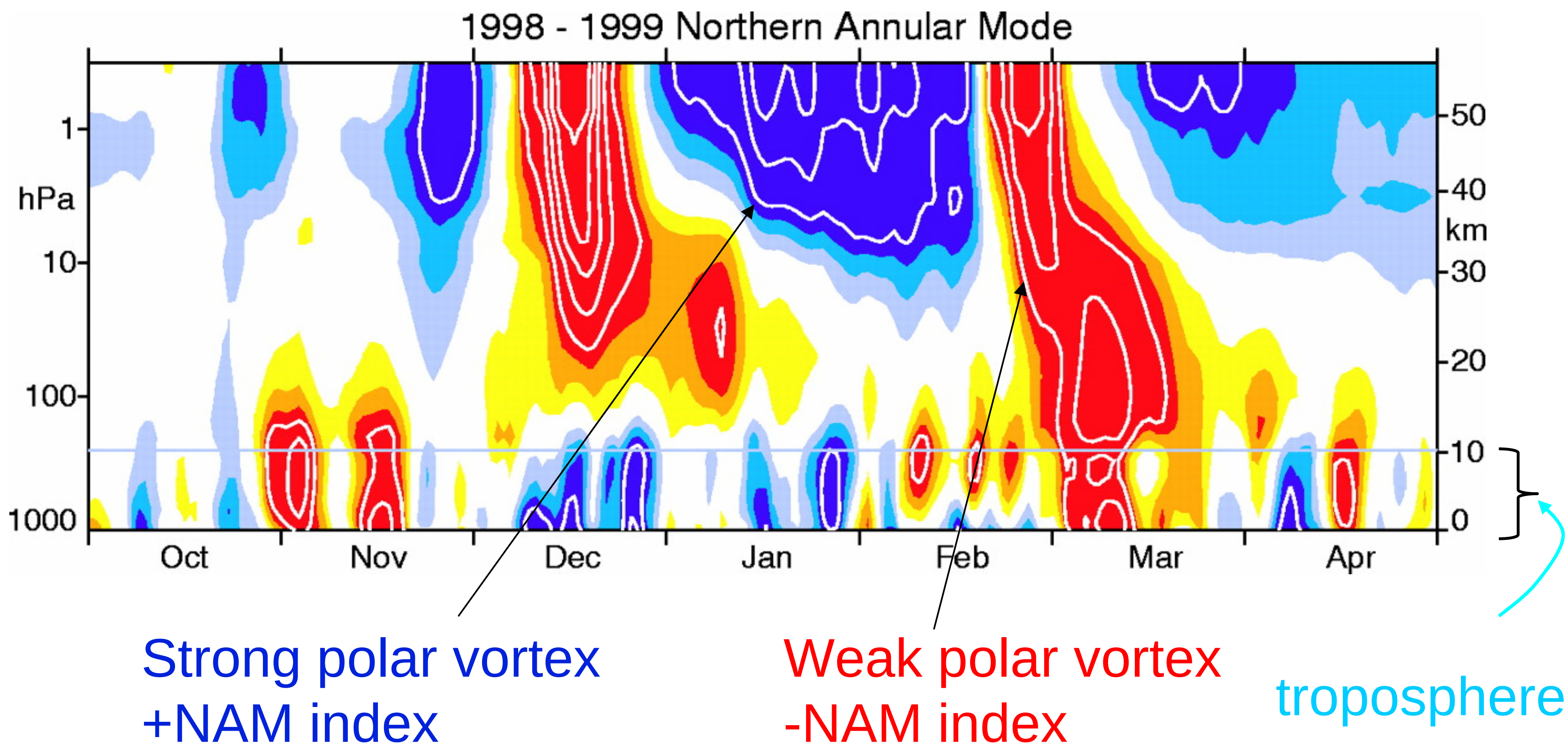
# Northern annular mode patterns in geopotential at 3 heights

NAM is associated with strength of polar vortex

NAM at sfc
NAO or AO

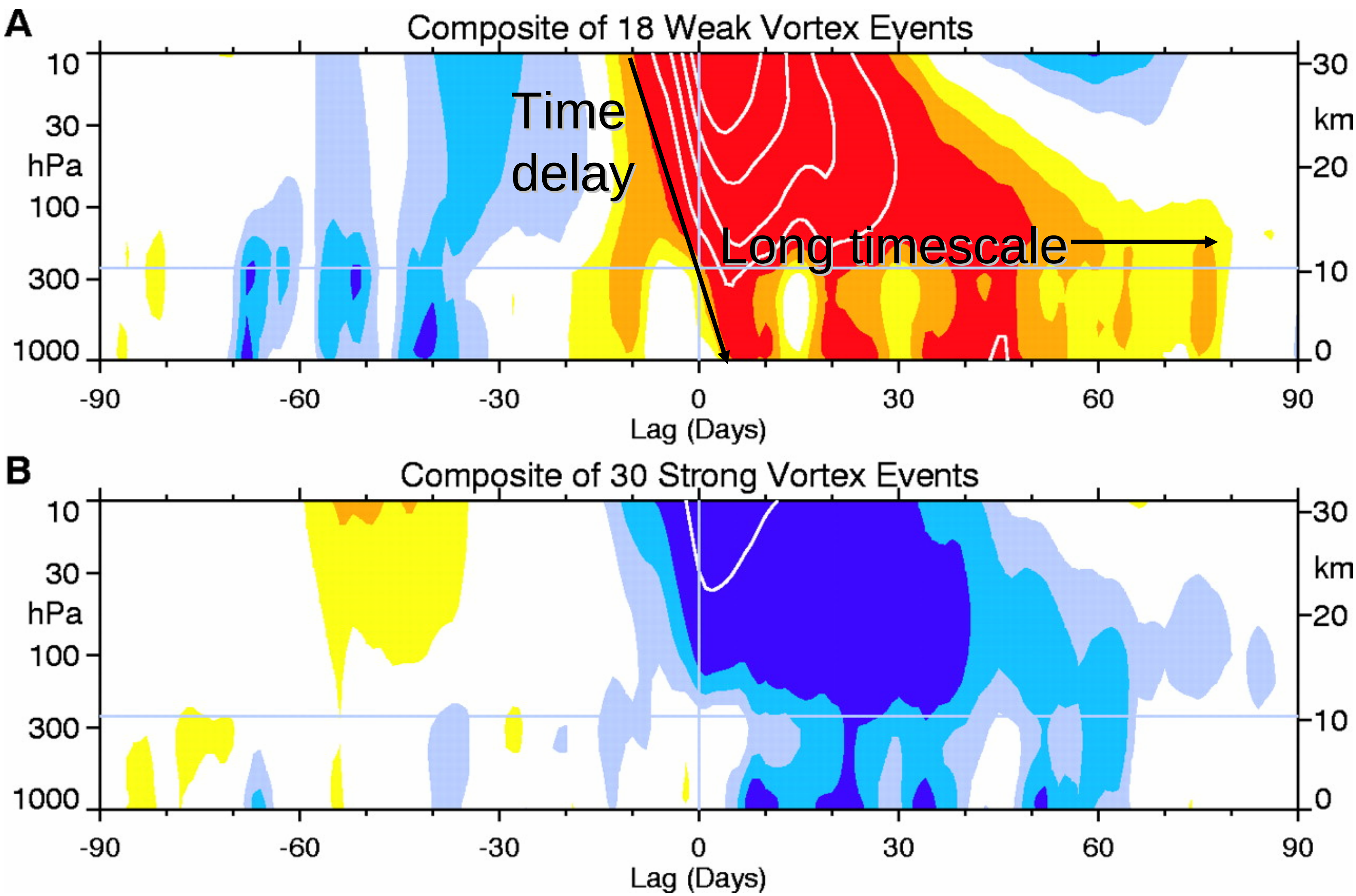



Baldwin and Dunkerton (2001)



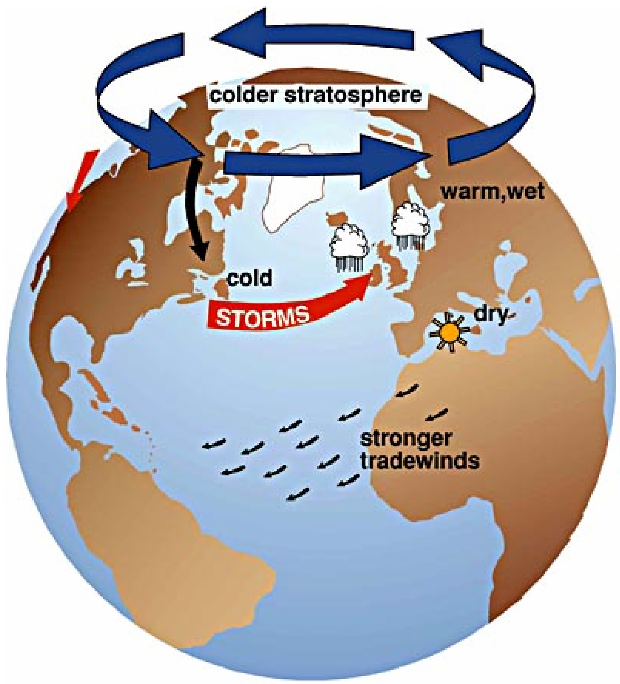

The contour interval is 0.5, with values between  0.5 and 0.5 unshaded.

Baldwin and Dunkerton (2001)



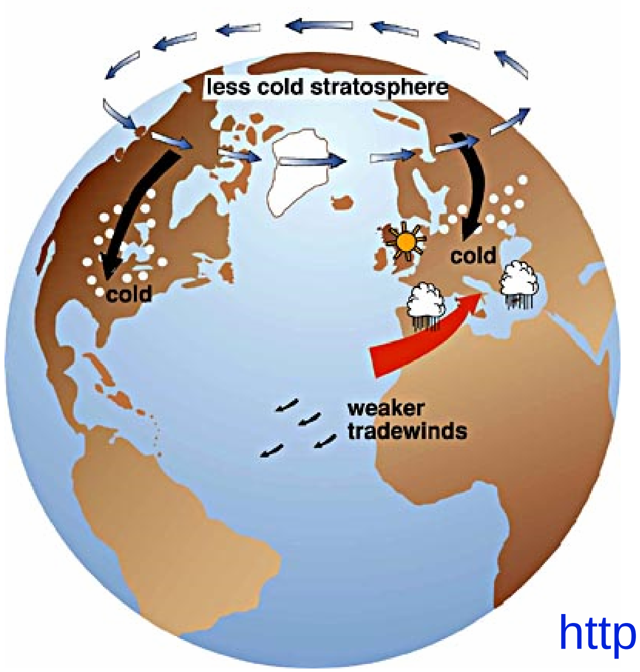

The events are determined by the dates on which the 10-hPa annular mode values cross -3.0 and +1.5, respectively.

Baldwin and Dunkerton (2001)




## Strong vortex: +NAM

- cool winds across eastern Canada,
- North Atlantic storms bring rain and mild temperatures to northern Europe
- drought conditions prevail in the Mediterranean region

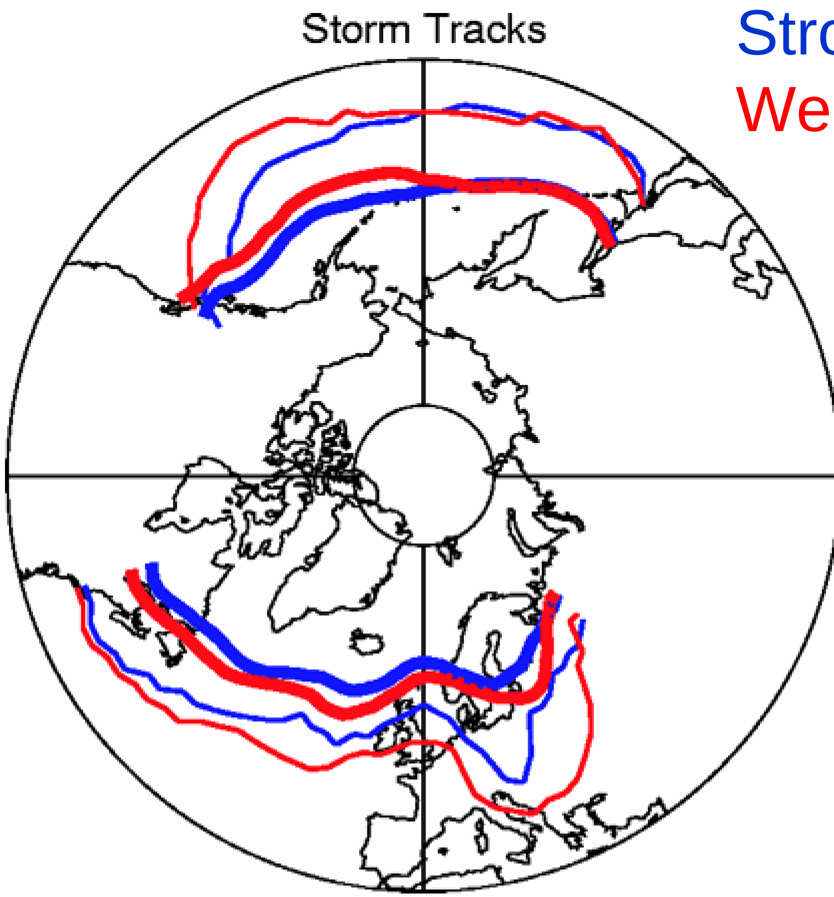



## Weak vortex: -NAM

- cold air plunges into the midwestern United States and western Europe
- storms bring rain to Mediterranean

http://depts.washington.edu/uweek/archives/1999.07.JUL_22/

# Average latitudes of surface cyclones




Strong vortex regime
Weak vortex regime

The data span 1961-1998, and each data point represents the average of a 15° band in longitude. The thin lines indicate the lowest latitude at which a cyclone frequency of one per two weeks is expected.

Baldwin and Dunkerton (2001)

# Summary

- “Forecast models that do not adequately resolve the stratosphere will likely not be able to simulate the additional predictive skill from the stratospheric memory effect.” Baldwin et al. (2003)
- Proposed mechanism: lower stratospheric circulation affects waves in upper troposphere
- Details of mechanism not understood

# Stratosphere-Troposphere Dynamical Coupling Initiative

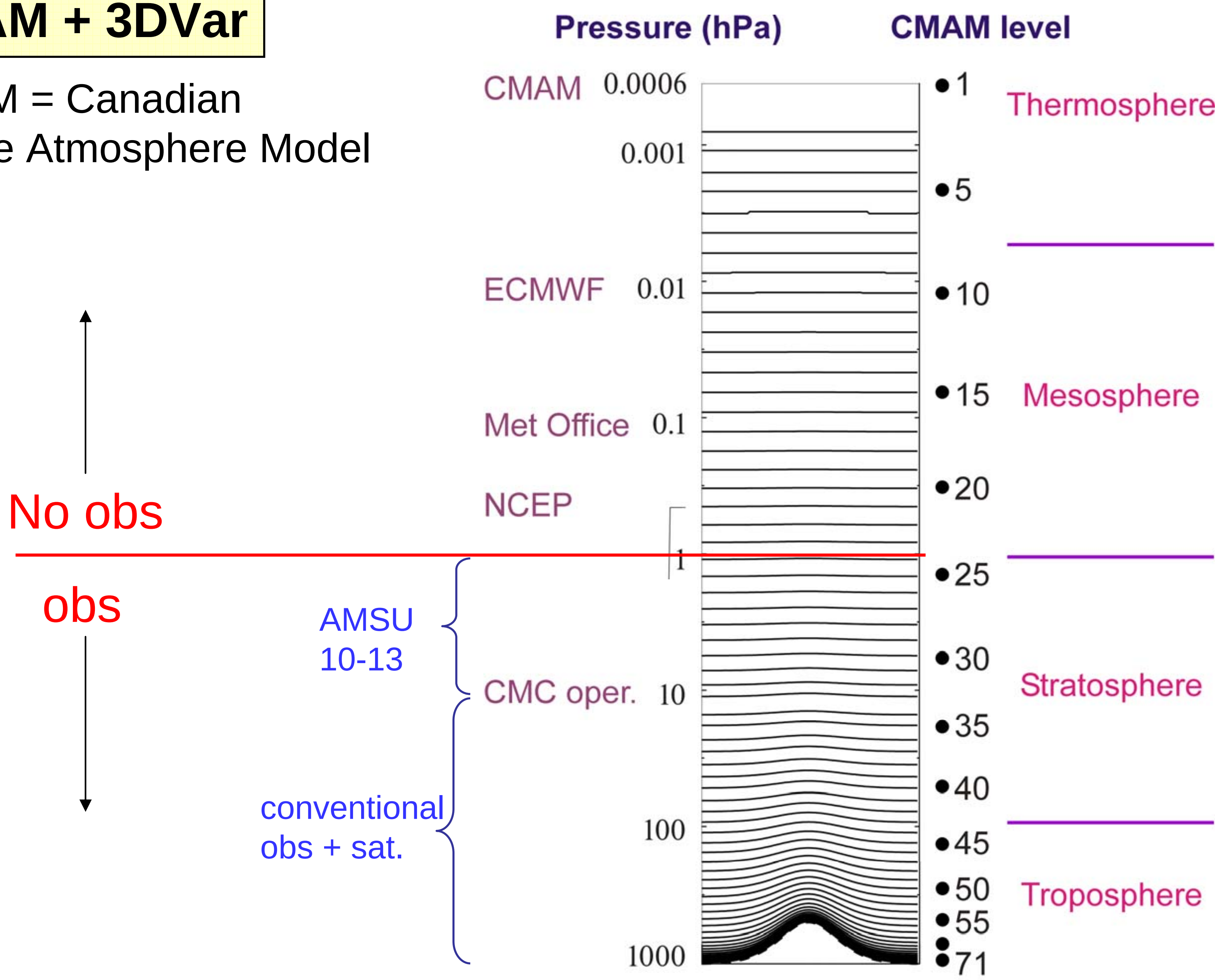
- World Climate Research Program's SPARC initiative
- How does the stratosphere affect tropospheric weather forecasts, on time scales from 10 days to a season?
- How does the stratosphere affect long-term trends in tropospheric climate?
- By what mechanisms do the stratosphere and troposphere act as a coupled system?
- Theme leaders: M. Baldwin (USA), S. Yoden (Japan)

http://www.atmosp.physics.utoronto.ca/SPARC/initiativesNEW2005STRA.html

Coupling of the stratosphere and mesosphere during the SH stratospheric sudden warming

# CMAM + 3DVar

CMAM = Canadian
Middle Atmosphere Model



# How is information propagated from the data region to the mesosphere?

- Analysis step (3D-Var): Covariances spread information spatially
- Forecast step: model forecast can propagate information in the vertical through dynamics

# Indirect coupling through GWD

- Here we explore the coupling of the mesosphere and lower atmosphere through parameterized gravity wave fluxes (in Gravity Wave Drag schemes).
- Information inserted in the lower atmosphere adjusts the planetary waves, whose EP flux influence zonal mean wind, which filters GWs

# Stratospheric Sudden Warming (SSW)

- Dramatic event: T increases near pole of 40-60 K in 1 week at 10 hPa
- Every couple of years in NH (+2002 SH)
- Major SSW (1+2), Minor SSW (1 only)
  1. Poleward increase of zonal-mean temperature between 60° and pole at 10 hPa
  2. Zonal mean zonal wind reverses
- Mechanism: Rossby wave propagates up from troposphere, interacts with mean flow (Matsuno 1971).

# PV on the 850K isentropic surface (near 10 hPa)

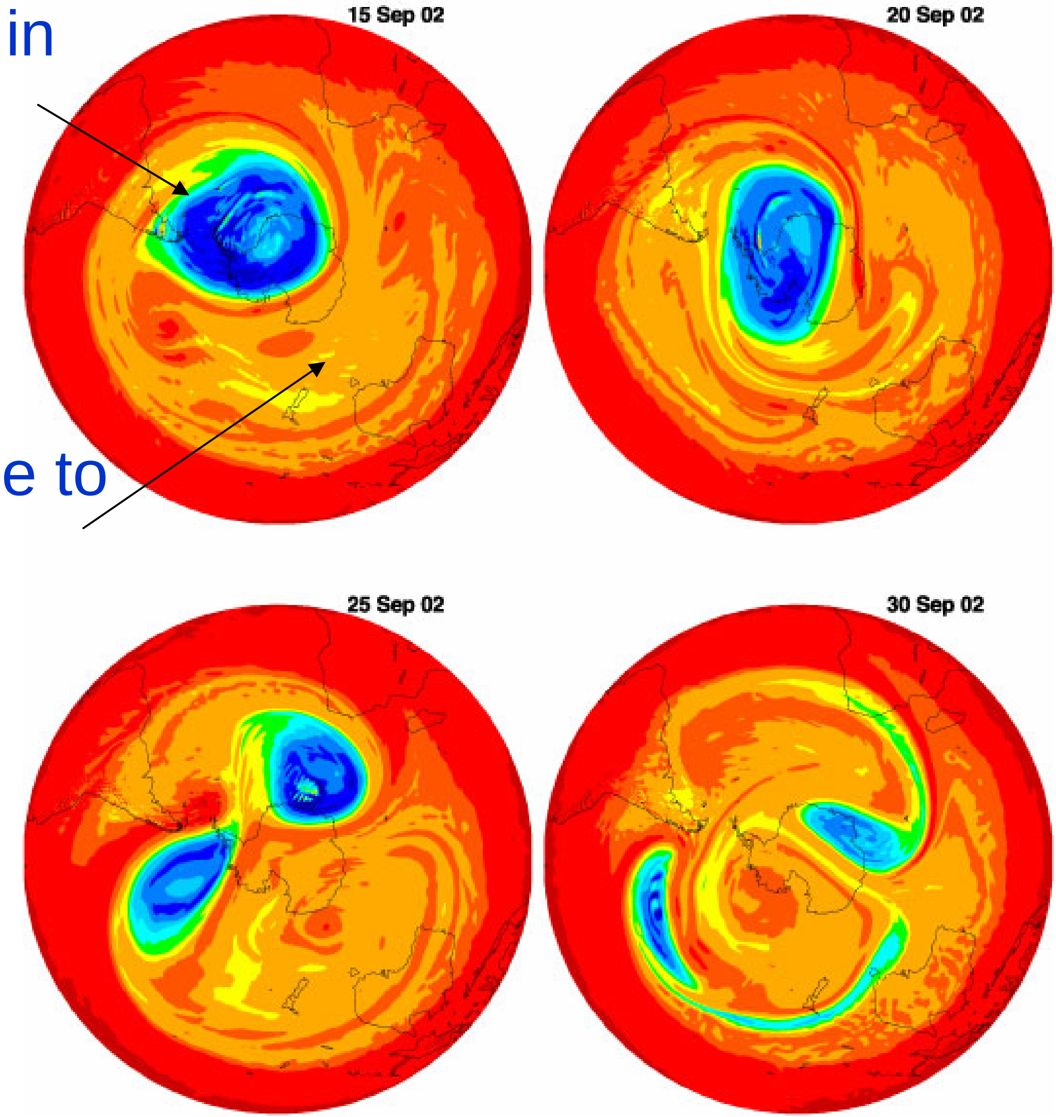
## From T511 ECMWF analyses during 15-30 Sept. 2002

High PV air in polar vortex

15 Sept.

Weak PV gradients due to mixing by anticyclone

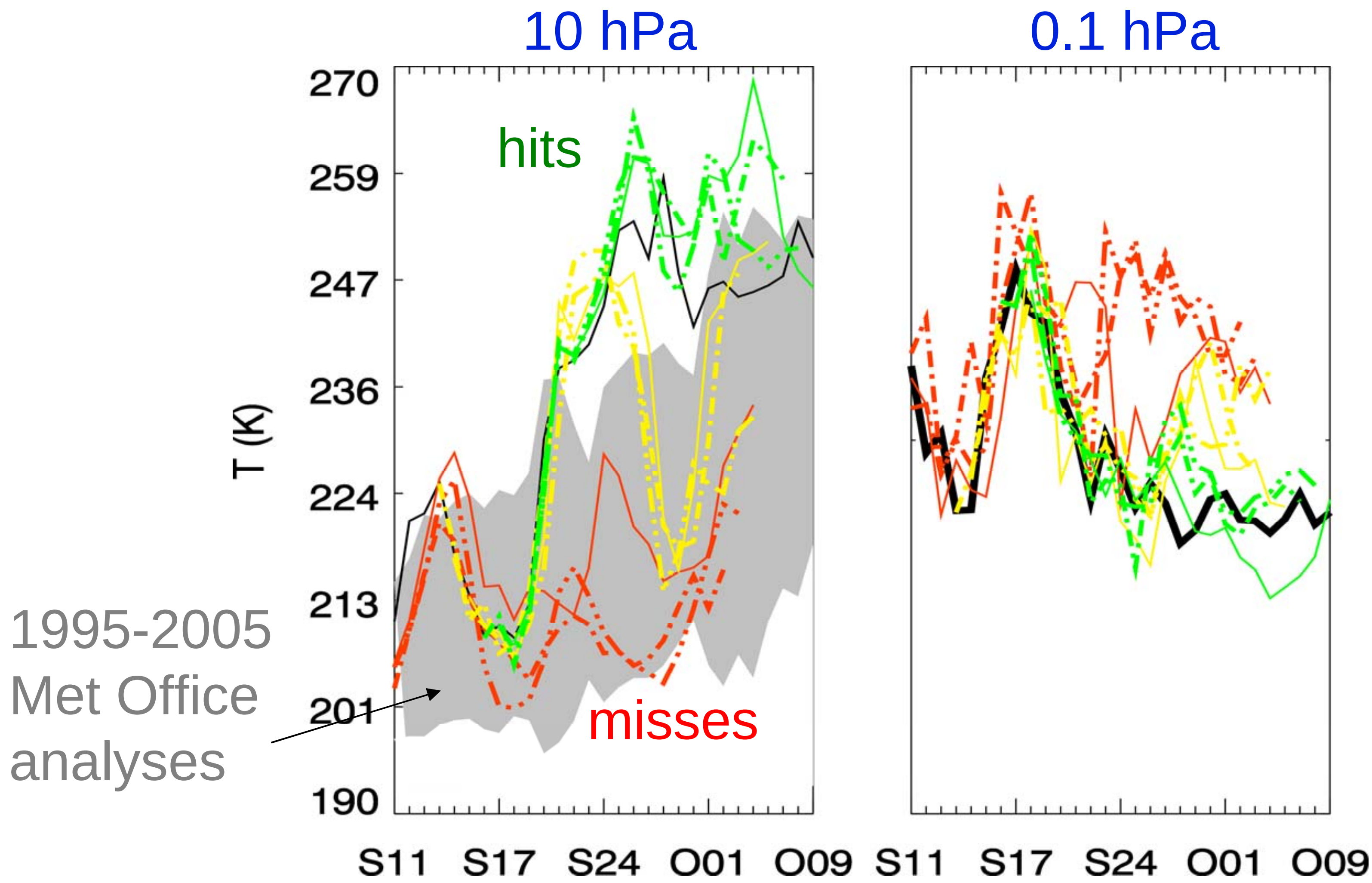
20 Sept.




25 Sept.

30 Sept.

# South Pole temperature in 2002 during stratospheric warming



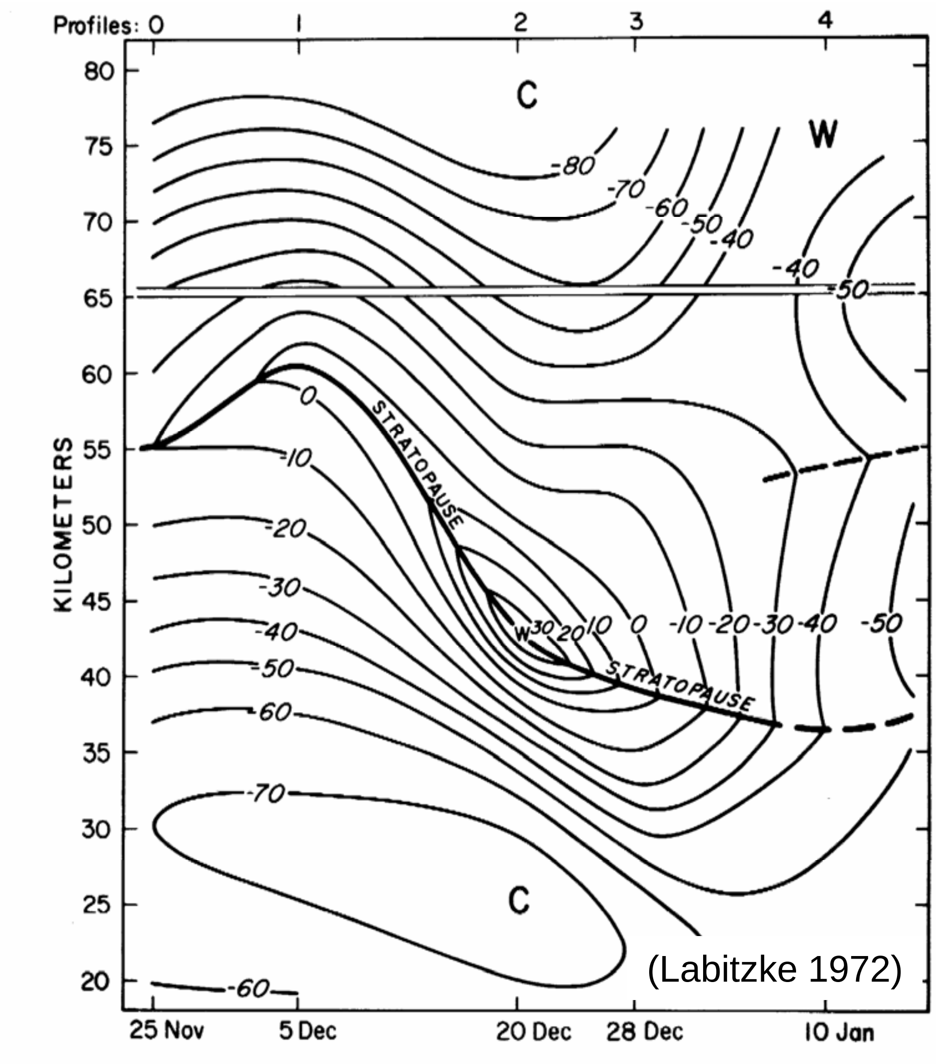

Ren et al. (2007)

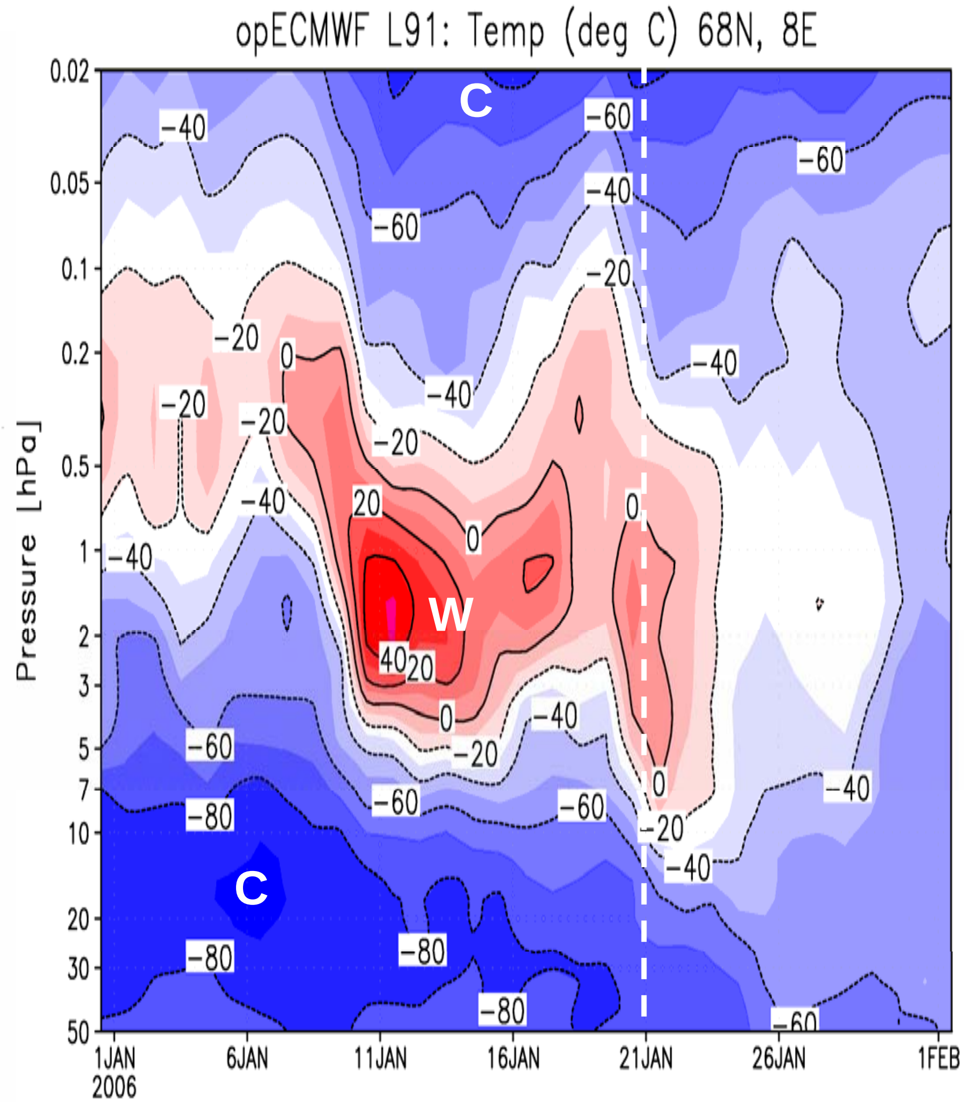
# Mesospheric Coolings

schematic diagram

NH winter 2005/06

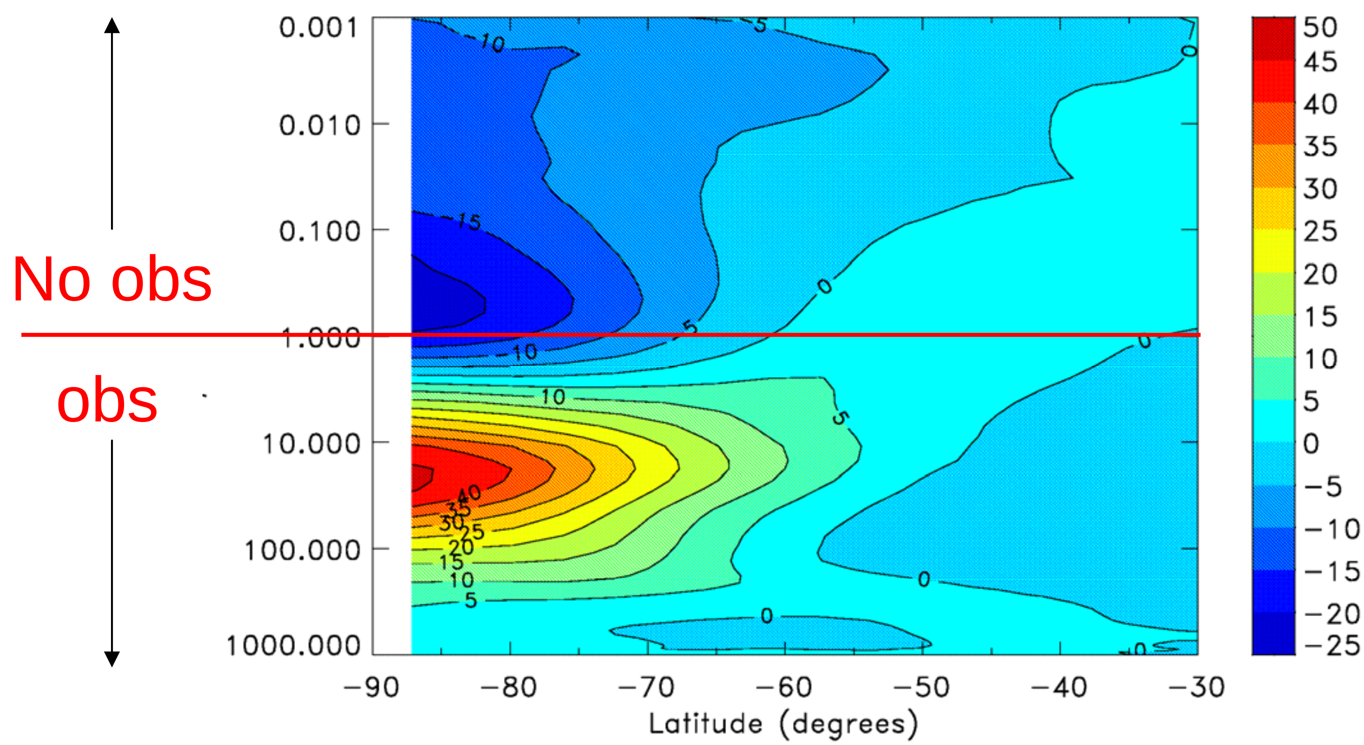
**Courtesy of Kirstin Krüger**



# <“hits”> - <“misses”>

Zonal mean temperature difference (K)




“hits” are colder in the mesosphere

“hits” are warmer in the stratosphere

Ren et al. (2007)

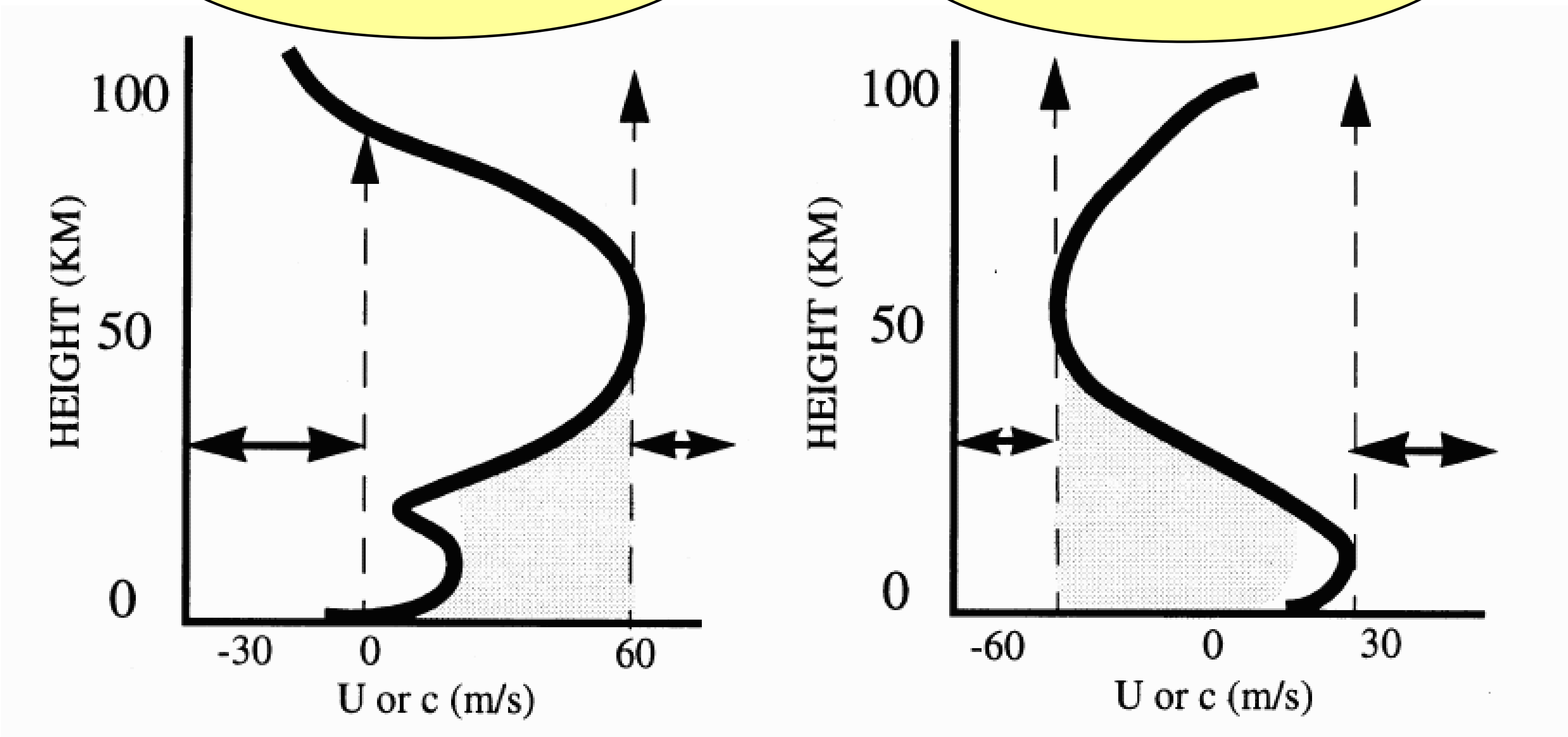
# Critical level filtering of gravity waves by background mean winds

WINTER

GWs c<0 break, drag reduces westerlies

SUMMER

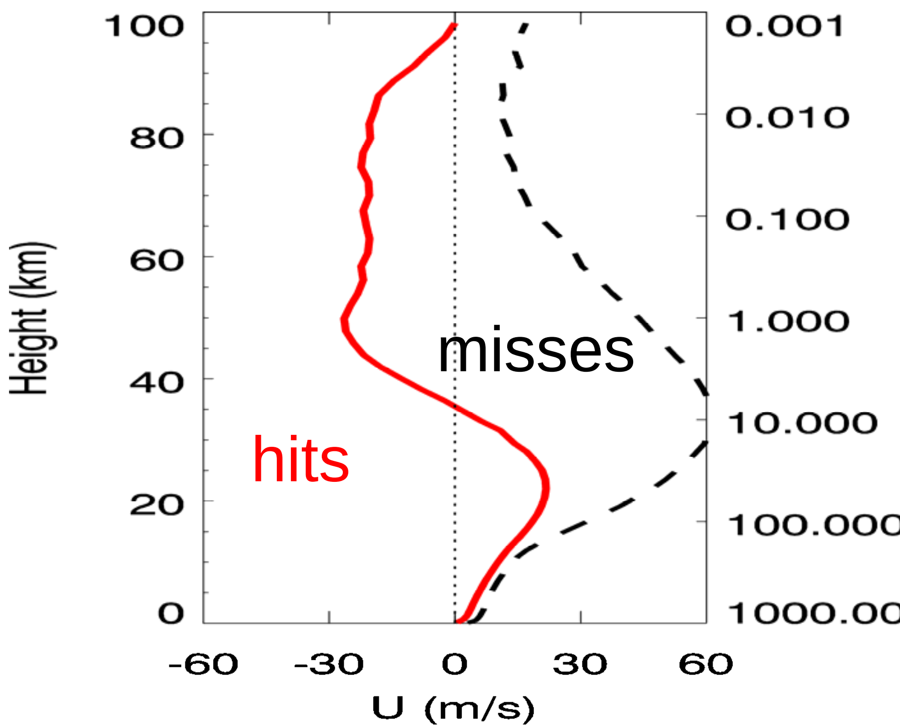
GWs c>0 break, drag reduces easterlies



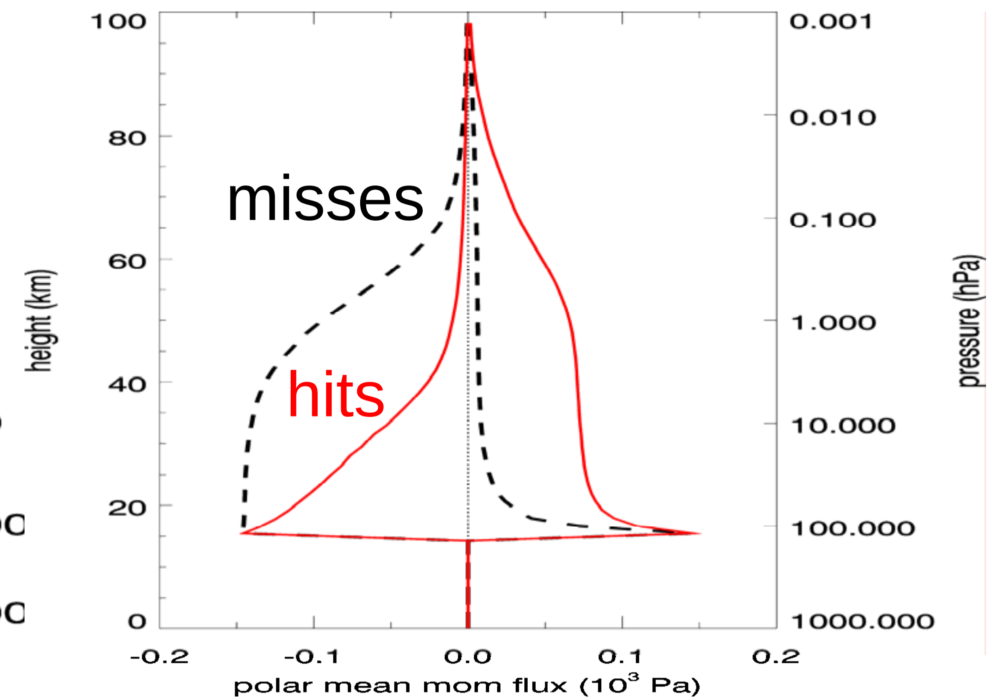

McLandress (1998)

Averages over Sept. 25 – Oct. 1, 2002

Zonal mean U at 60ºS




Momentum flux due to GWs poleward of 60ºS

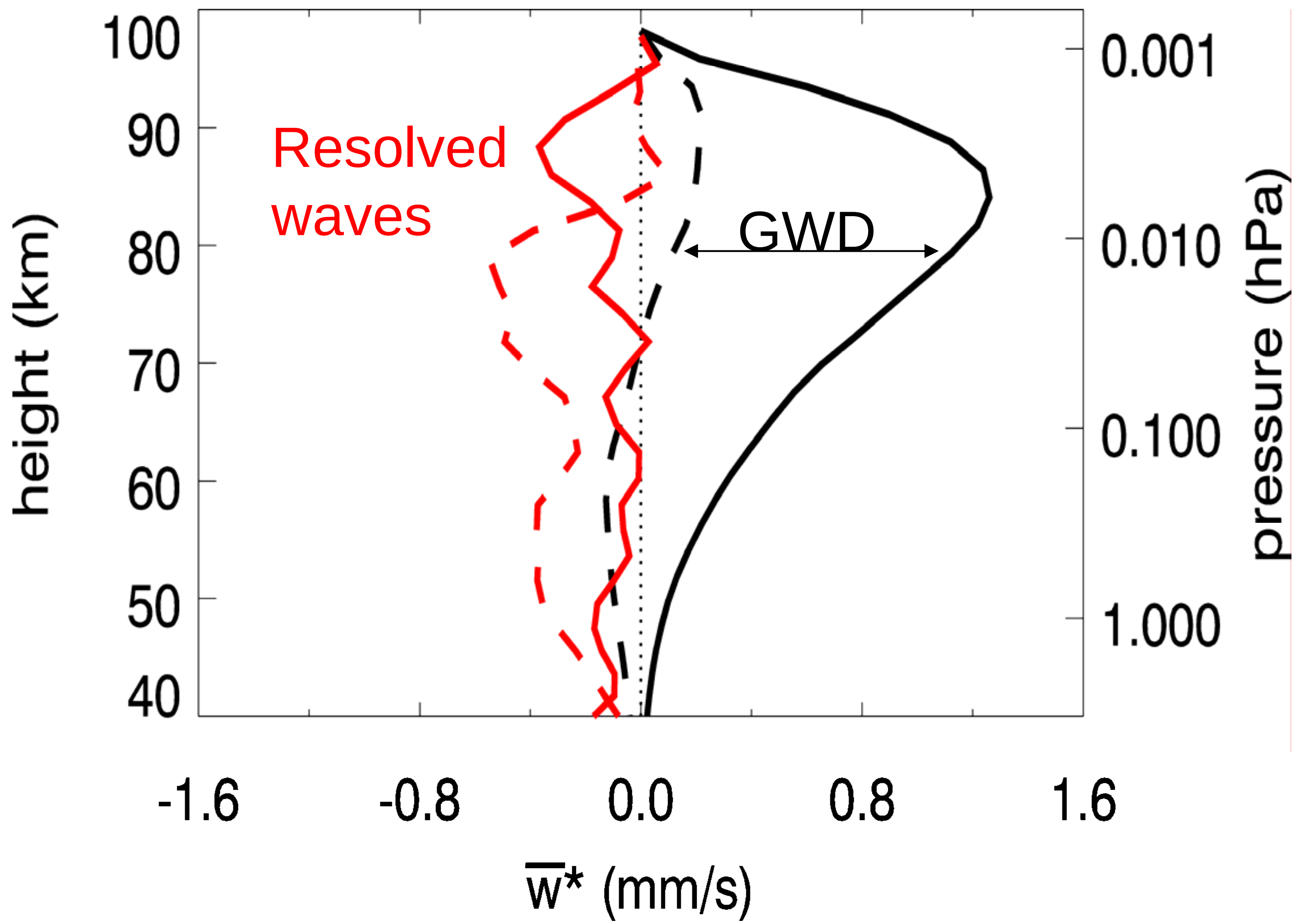



Flux due to westward travelling GWs

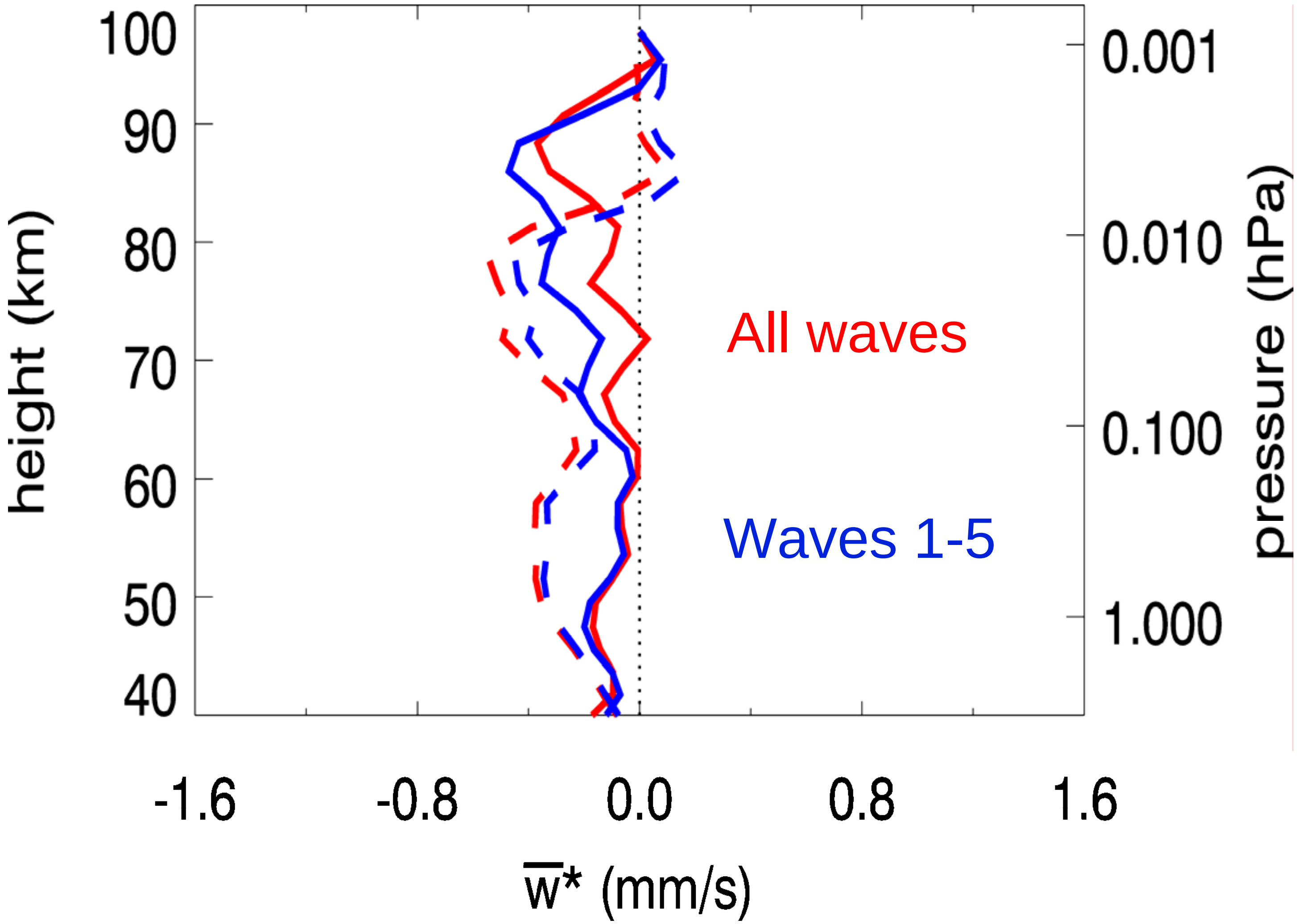
Flux due to eastward travelling GWs

Ren et al. (2007)

Averages over Sept. 25 – Oct. 1, 2002



Averages over Sept. 25 – Oct. 1, 2002

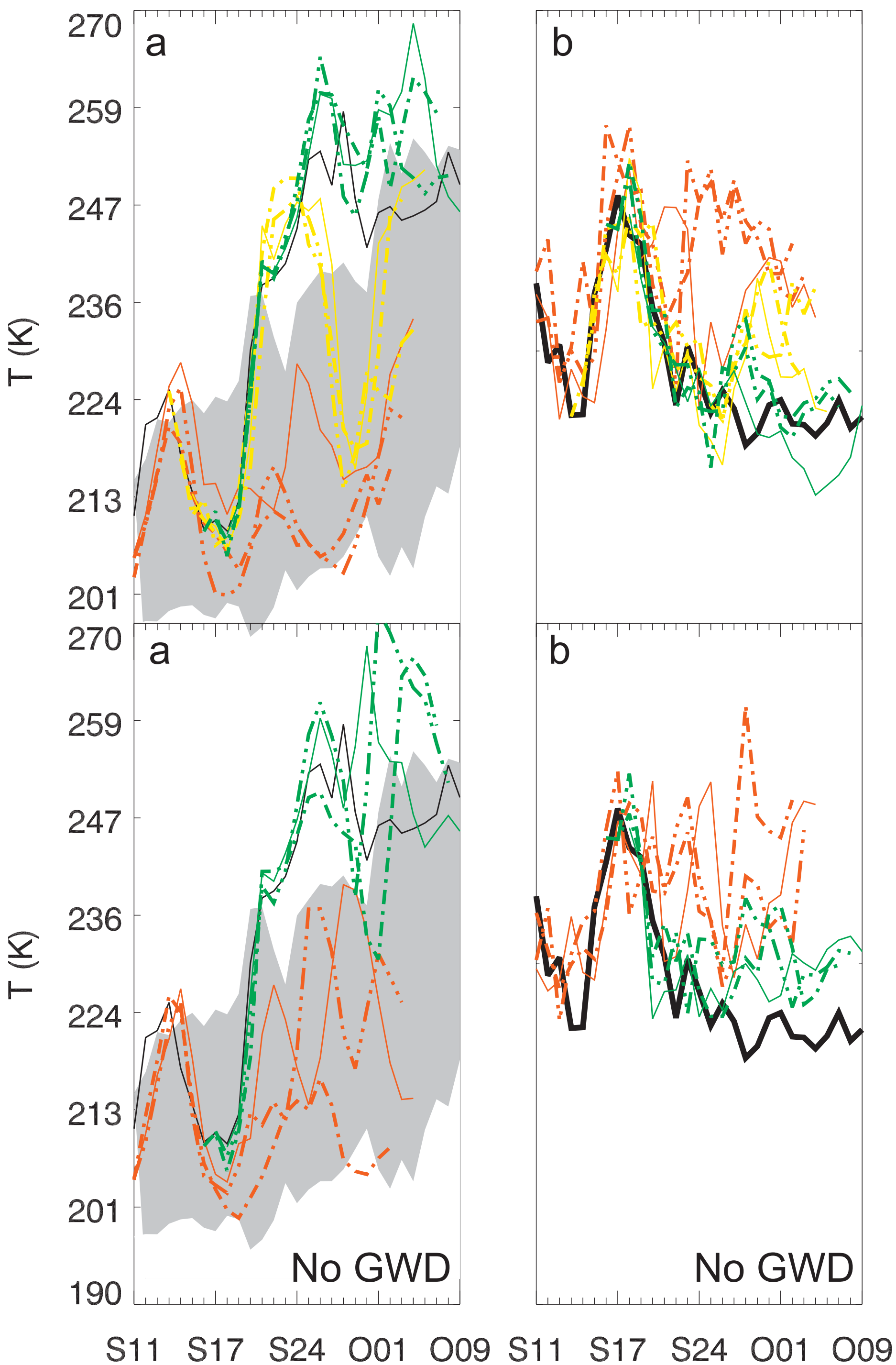


# What if there were no Gravity Wave Drag scheme?

## What would happen to the Stratospheric Sudden Warming?

Without gravity wave drag:

- GCM can fail
- In DA system, winds are kept to reasonable values by data insertion in troposphere and stratosphere.




Ensemble of forecasts

Hits Misses

Repeat ensemble without GWD

Hits Misses

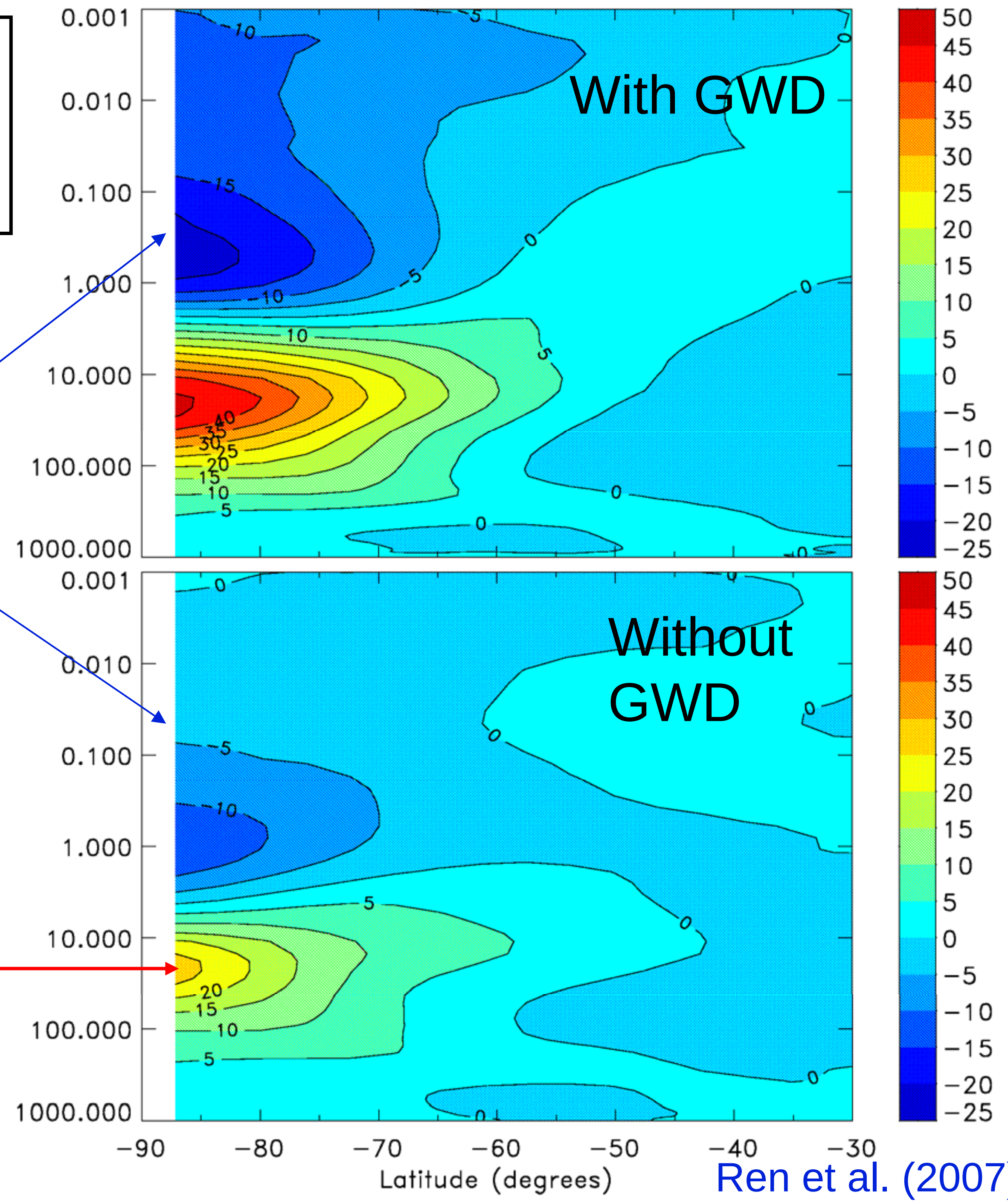
Hits are still hits and
misses are still misses!

Ren et al. (2007)

Zonal mean temp. difference between "hits" and "misses"

Vertical extent of mesospheric cooling is reduced

Stratospheric warming is half the amplitude




Ren et al. (2007)

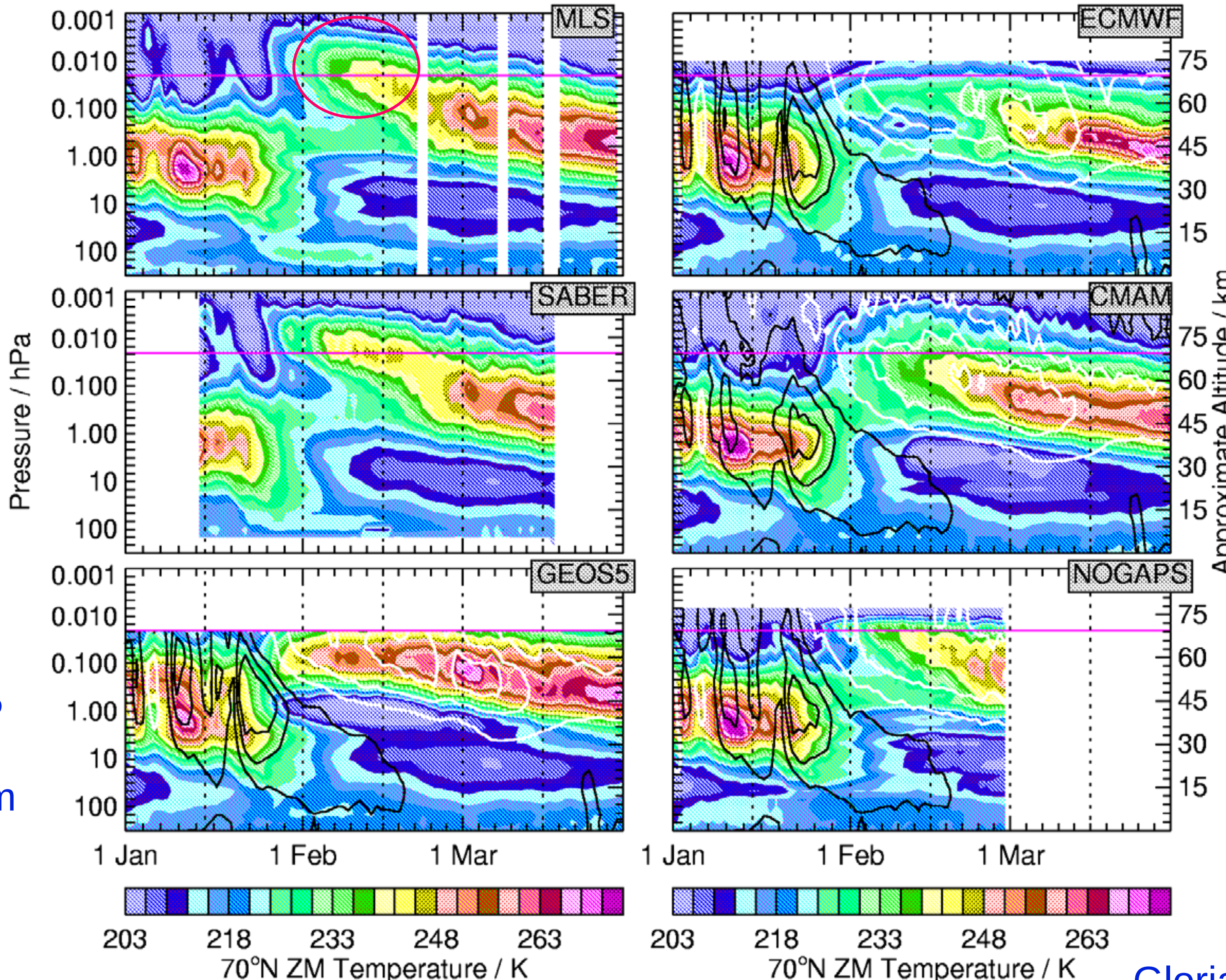
# Summary of 2002 SSW study

- Planetary waves responsible for mesospheric cooling below 60 km
- Gravity waves (resolved and parameterized) become important above 60 km
- Mesospheric cooling is mainly due to parameterized GWs above 75 km
- Observations inserted in stratosphere and troposphere indirectly impact the mesosphere through a GWD scheme!

Information from below propagates to the mesosphere (through resolved and parameterized waves). Is the mesosphere improved?

# 70ºN zonal mean temperatures during 2006 SSW

Stratopause is above 0.01 hPa!




ECMWF too low too cold

GEOS-5 too low too warm

Gloria Manney

- Low lids of operations models deterrent to study of stratopause region
- Research models with higher lids show improvement relative to operational systems, in this region
  - CMAM-DAS with no mesospheric DA
  - NOGAPS-ALPHA with MLS, SABER data

ECMWF, GMAO, Met Office
have model lids above 80 km

Is it worth forecasting the mesosphere?

# July

Zonal wind

contours:
20 m/s (pos)
10 m/s (neg)

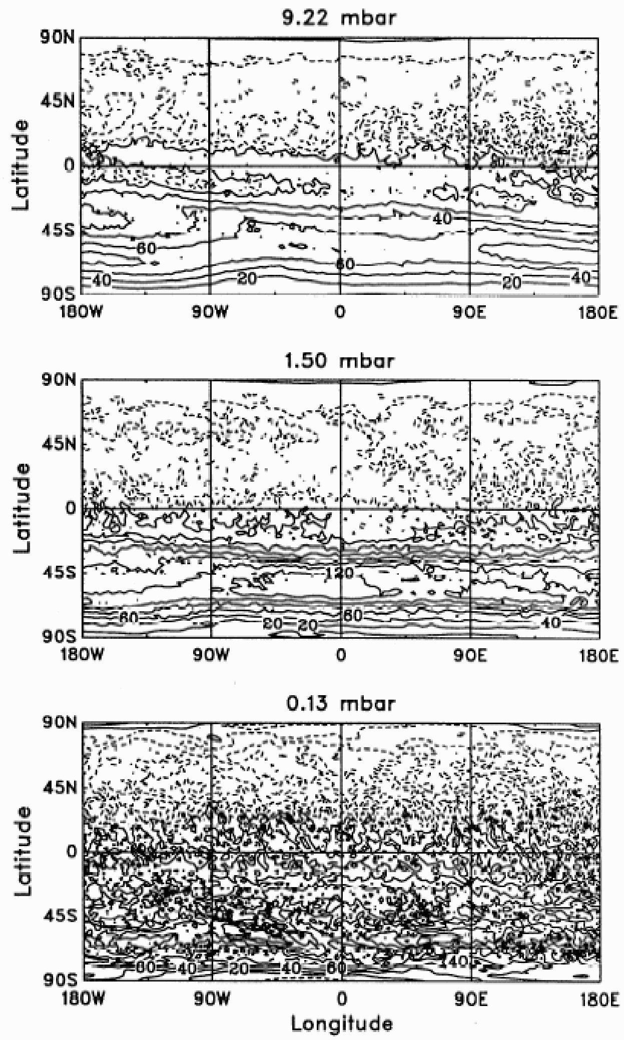



**Figure 10.** Zonal wind field on three different SKYHI (N90) model levels for a single snapshot in July: 9.22 mbar (top), 1.50 mbar (middle), and 0.13 mbar (bottom). Contour interval = 20 m/s for positive-valued contours and 10 m/s for negative-valued contours.

Lower stratosphere

stratopause

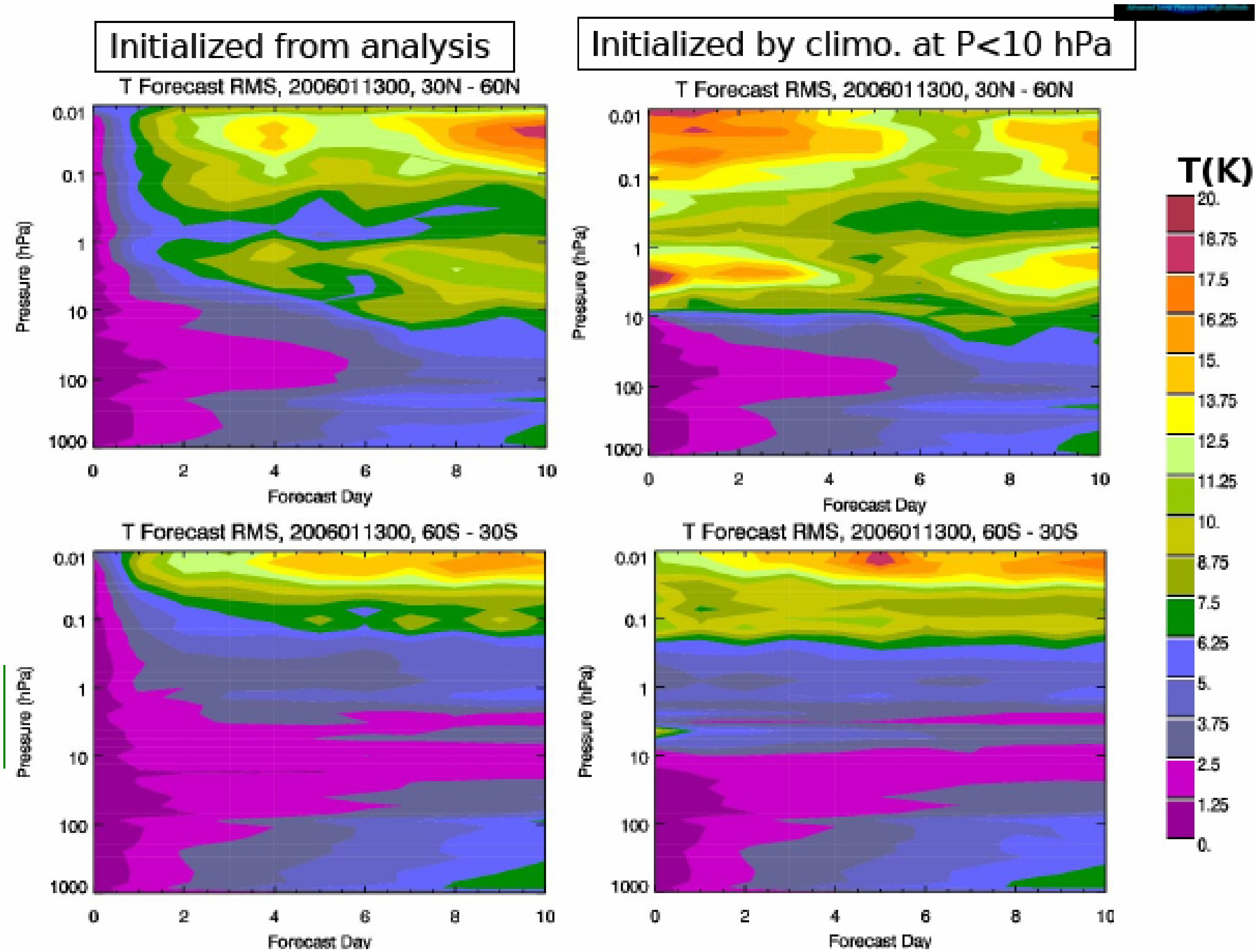
mesosphere

Koshyk et al. (1999)

# Predictability of the mesosphere and stratosphere and SSW

Winter
mid-lat

Summer
mid-lat

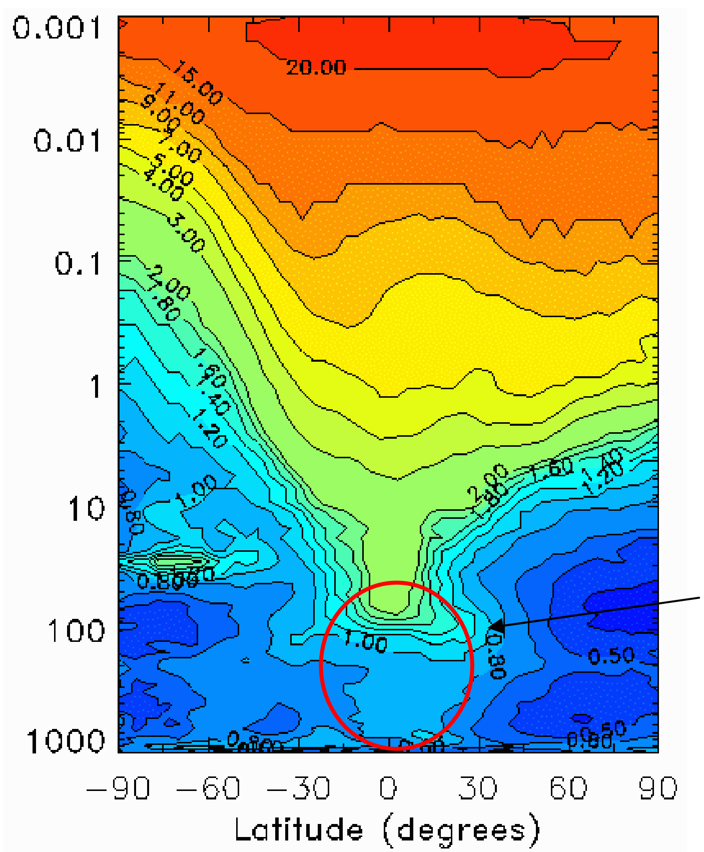



Karl Hoppel, NRL

# Predictability of the mesosphere??

T Forecast errors
(from simulations)

After a month of assimilation STD (forecast –truth):



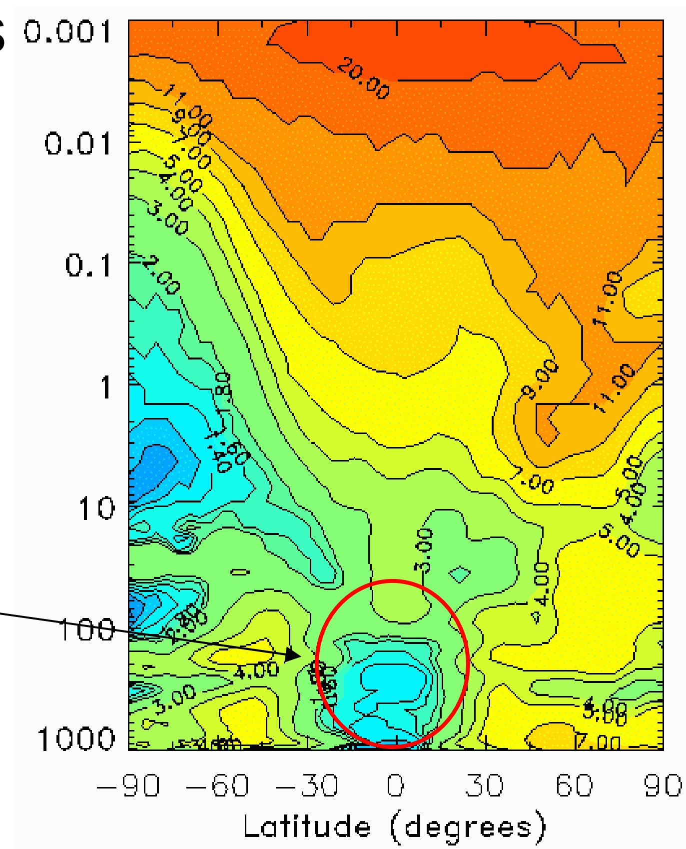

Error looks same in mesosph

Not much difference in tropics

T Predictability errors

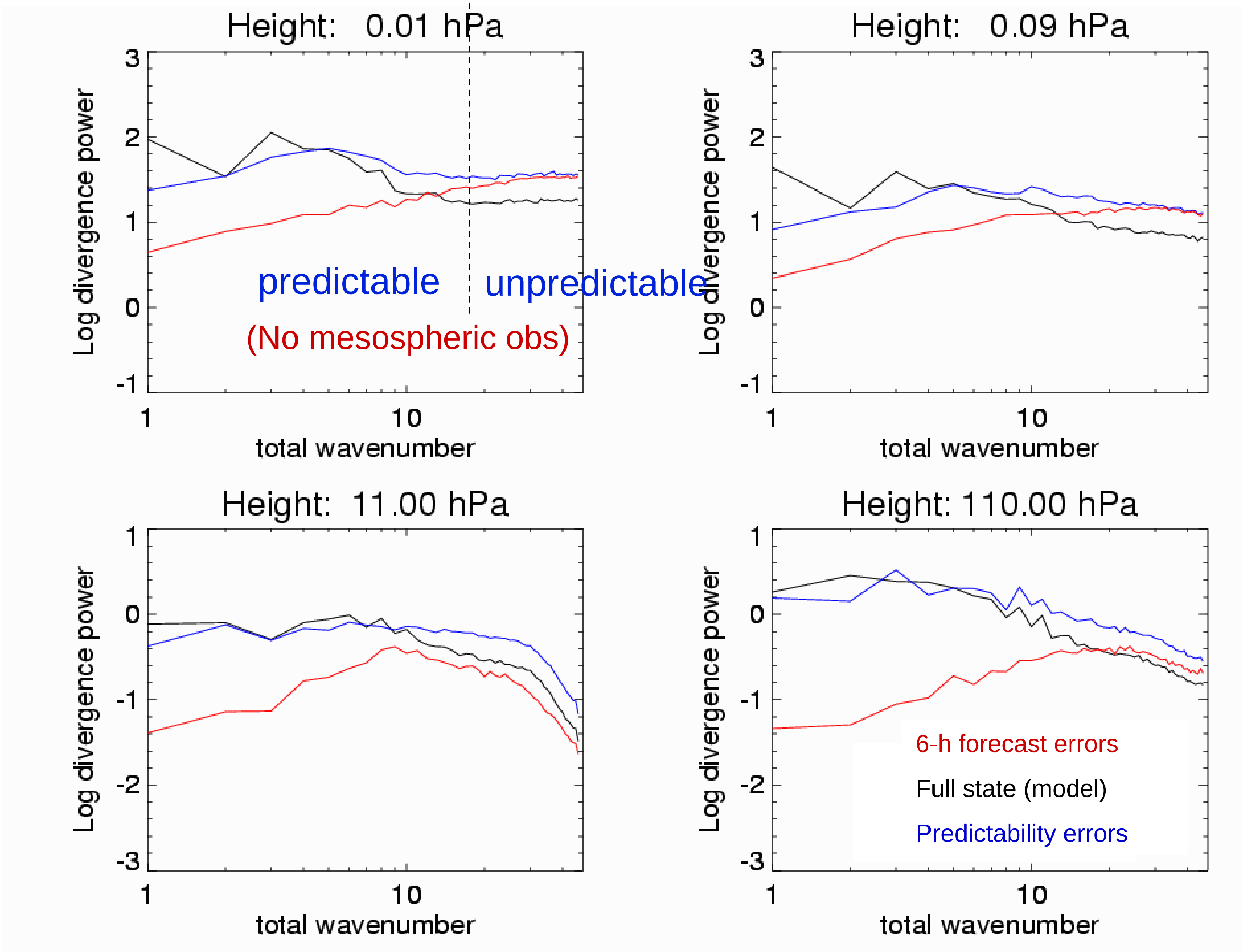
After a month of a model run

STD (truth2 –truth):




Yulia Nezlin
Yves Rochon

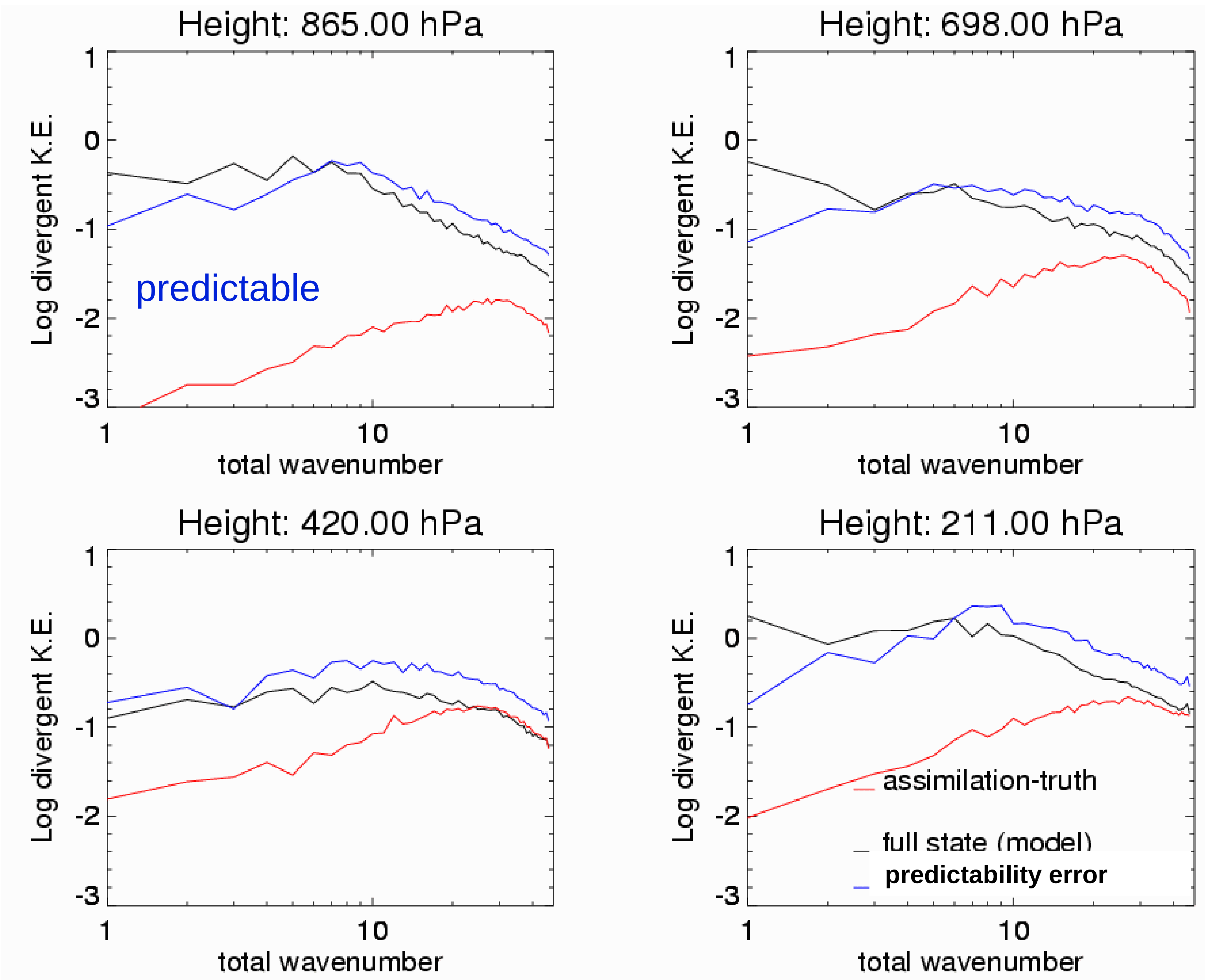
# Predictability error spectra: mesosphere





Yulia Nezlin
Yves Rochon

# In the troposphere




6-h forecast errors

Full state (model)

Predictability errors

Yulia Nezlin
Yves Rochon

# Summary

- There is some value in assimilating mesospheric data. There is some predictability!

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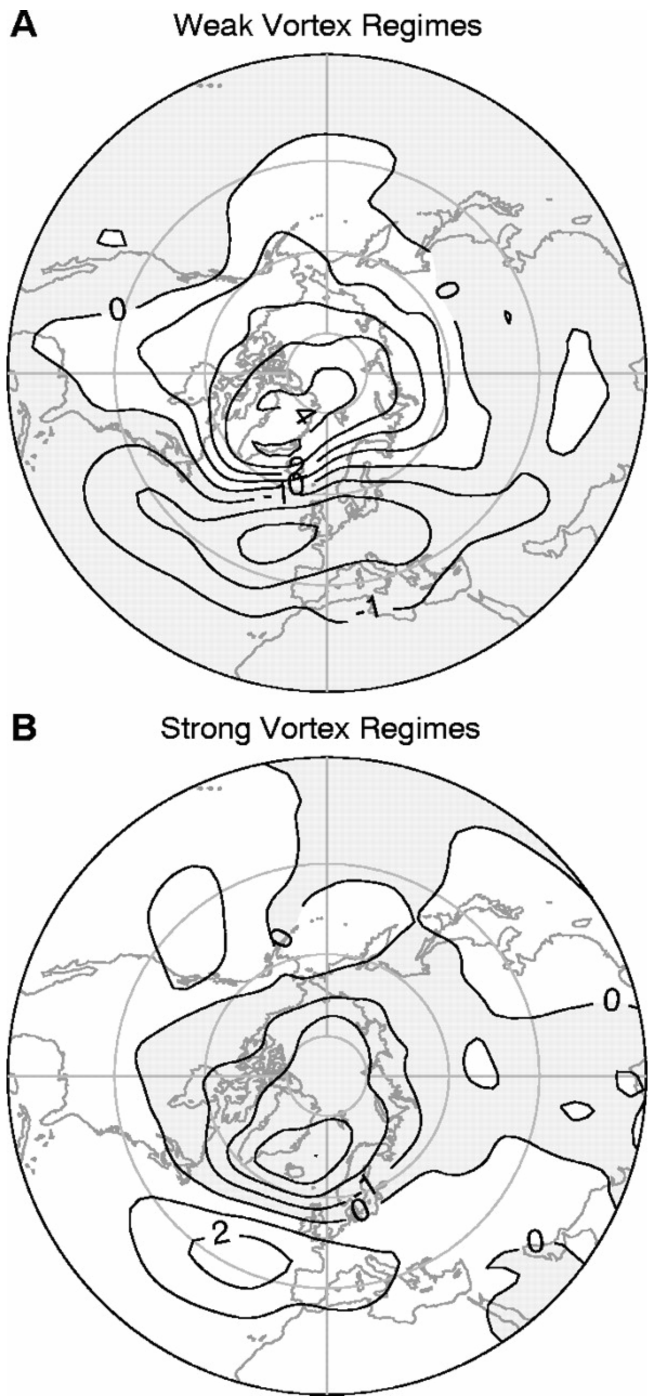
# The End




# Surface pressure anomalies after stratospheric events look like the Arctic Oscillation

Average sea-level pressure anomalies (hPa)

Baldwin and Dunkerton (2001)