Vertical coupling of the middle and lower atmosphere in data assimilation systems

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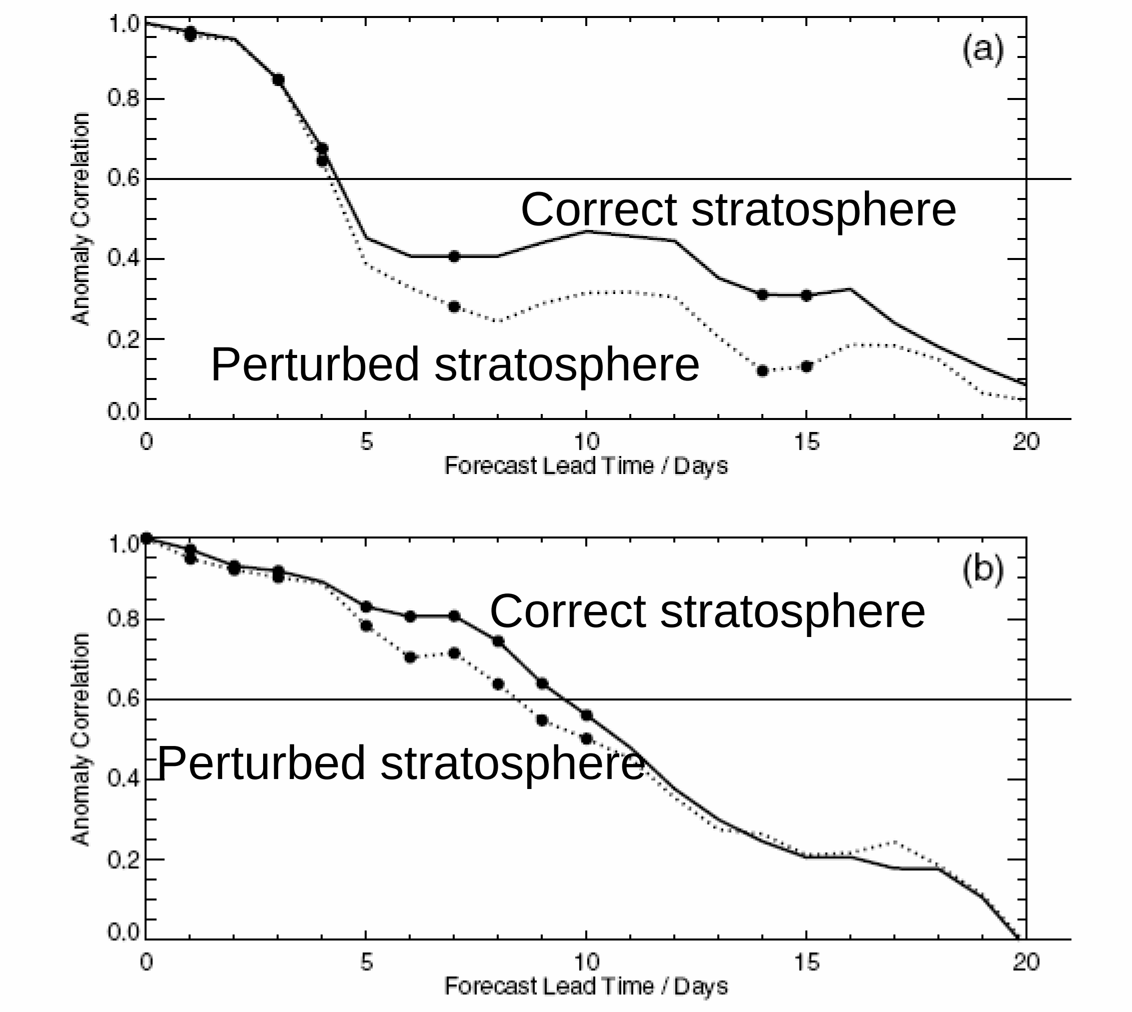
OUTLINE

1. Trend to higher NWP model lids
   - Vertical coupling in analysis step
2. The mesospheric response to analysis increments during the forecast step
   - Vertical coupling through resolved waves
   - Vertical coupling through unresolved waves
3. International Polar Year – SPARC IPY

Impact of stratosphere on tropospheric forecast skill

500 hPa height anomaly correlation



Northern hemisphere

Southern hemisphere

Charlton et al. (2005)

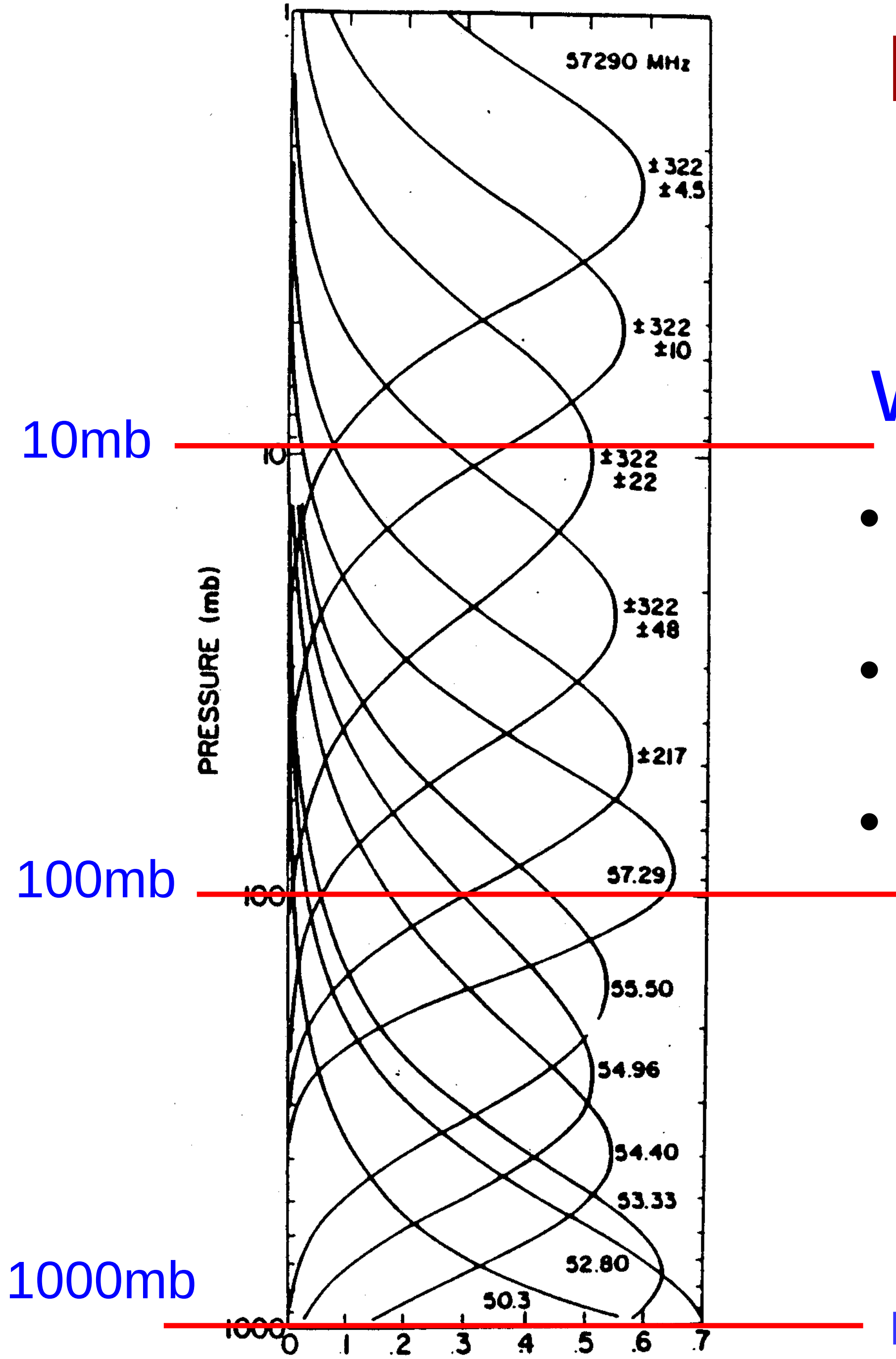
Stratospheric impact on forecasts

- Correct stratosphere has influence on tropospheric forecasts in medium to extended range
- WCRP and THORPEX have “seamless prediction” as an overlapping theme, i.e. extending quality of forecasts between weather and seasonal scales

How does having a correct stratosphere impact analyses?

Need for a stratosphere

- Met Office experience (Mike Kiel):
- Merged global forecast model: High horizontal resolution of weather forecast model + high vertical resolution of stratospheric model
- 80% of the improvement in NWP index due to increased vertical extent!
- P_{MSL} and 500 hPa GZ for 1-,2- and 3-day forecasts most affected



Lower stratosphere

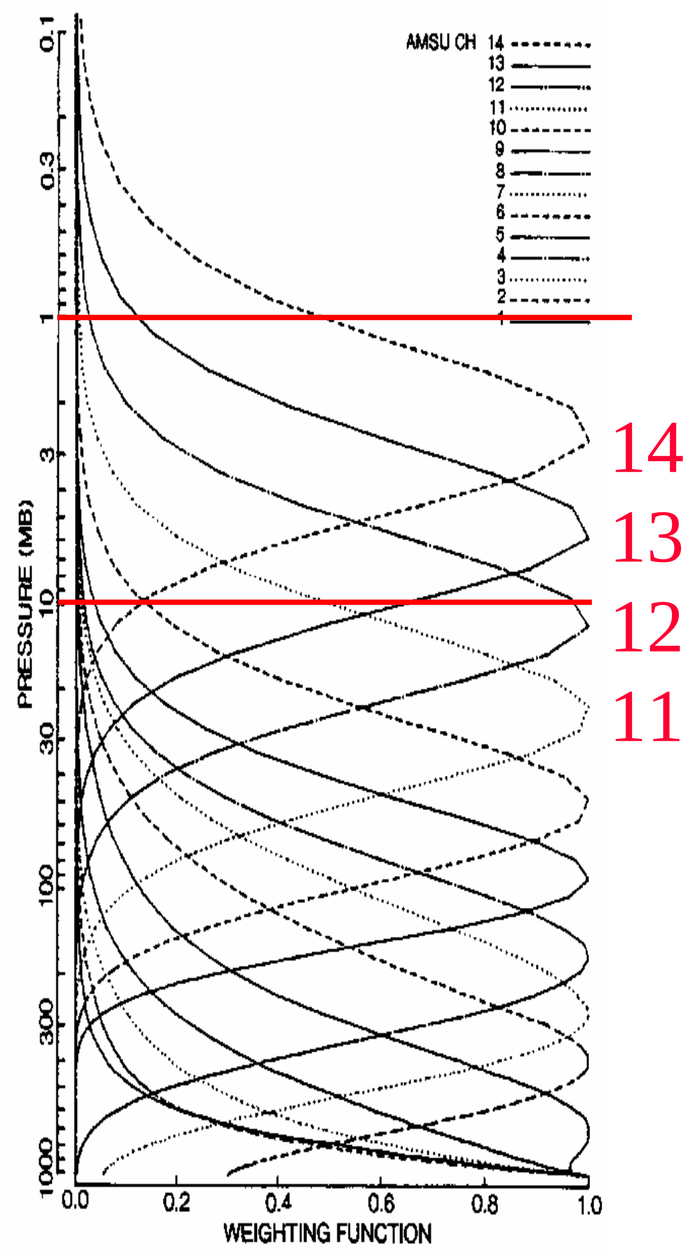
AMSU-A weighting functions

- Tropospheric channels sense lower stratosphere
- Better stratosphere → better assim. of ATOVS
- Add strat ATOVS channels

Houghton et al. (1984)

Upper stratosphere

Normalized AMSU-A weighting functions



- Lower stratospheric channels also sense upper stratosphere
- Better upper stratosphere → better assim. of ATOVS
- Add strat ATOVS channels
- Mesospheric data: AIRS, SSMIS

Need for a mesosphere

- To better assimilate stratospheric radiances move lid to 0.01 hPa (80 km)
- **ECMWF** lid 0.01 hPa Feb. 2006
- **Met Office** to 0.01 hPa in 2007 (0.1 hPa now)
- **NASA-Goddard** GEOS-4 lid 0.01 hPa Jan. 2004

July

Zonal wind

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

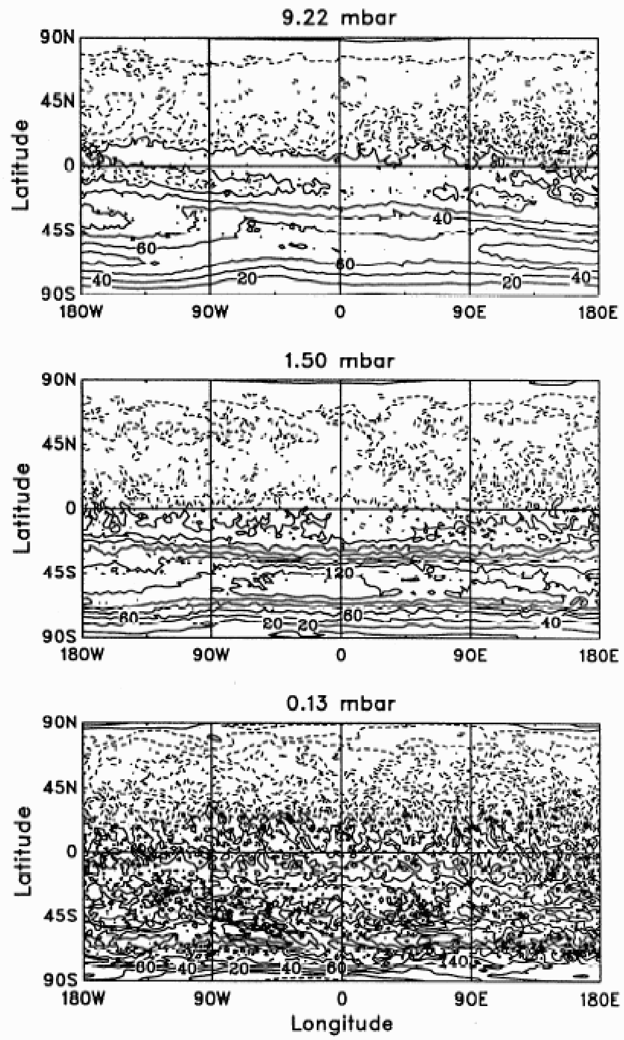


Figure 10. Zonal wind field on three different SKYHI (N90) model levels for a single snapshot in July: 9.22 mbar (top), 1.50 mbar (middle), and 0.13 mbar (bottom). Contour interval = 20 m/s for positive-valued contours and 10 m/s for negative-valued contours.

Lower stratosphere

stratopause

mesosphere

Koshyk et al. (1999)

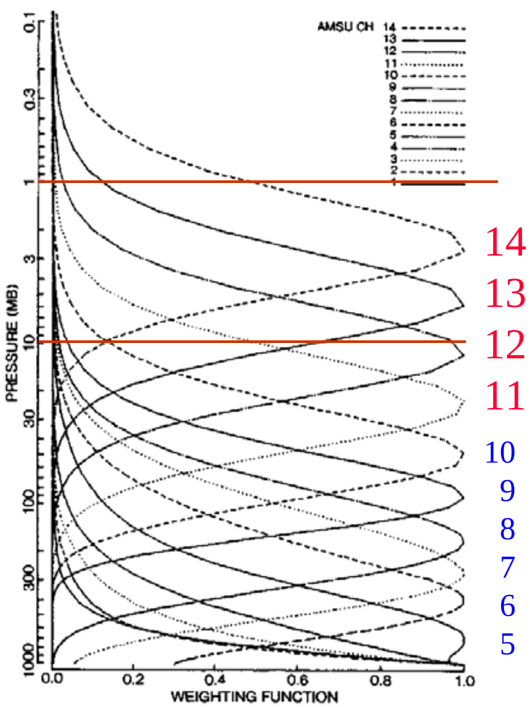
Gravity waves are important

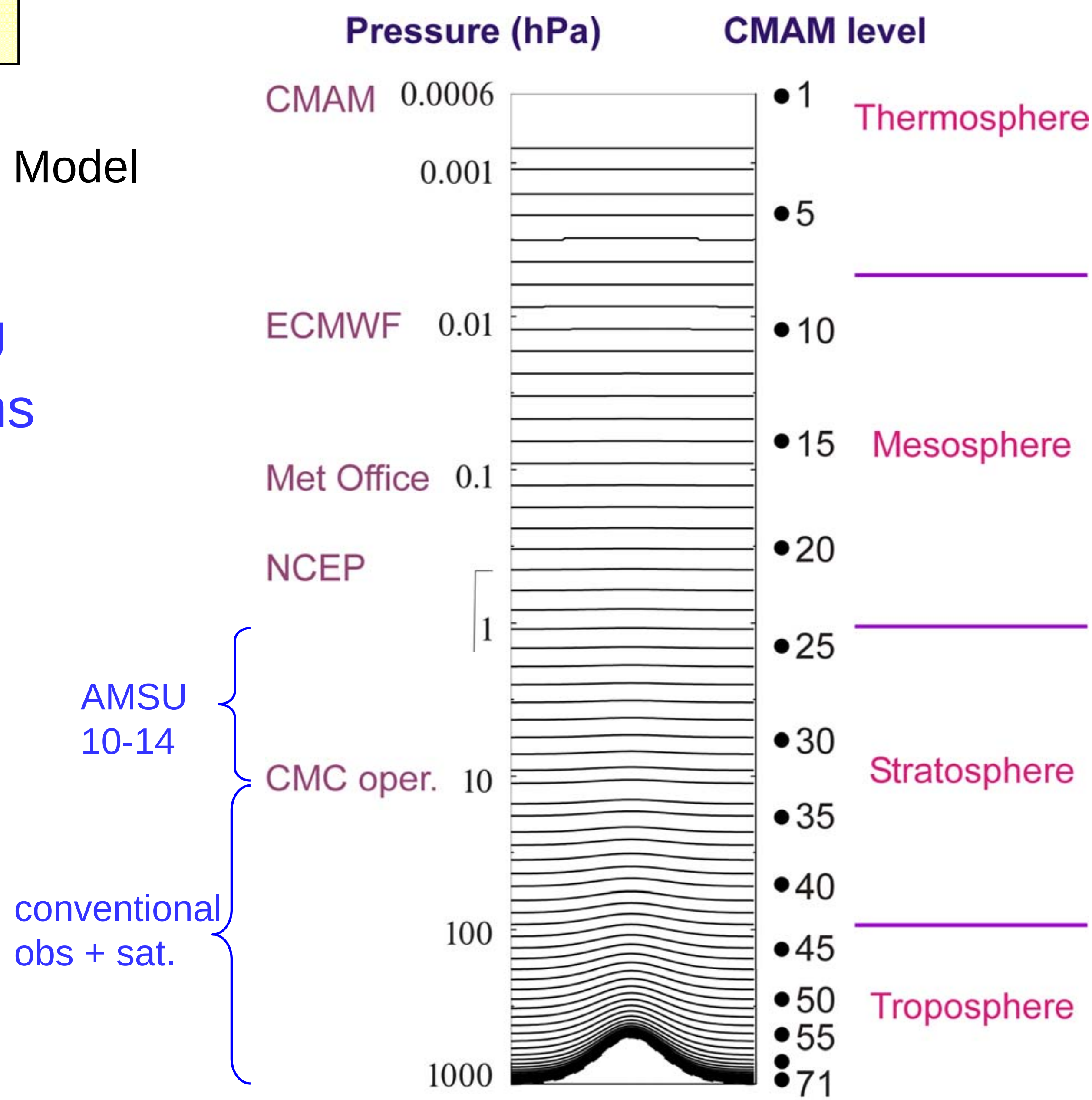
- Exert a “drag” on mean flow, keeping the middle atm far from radiative equilibrium, driving pole-to-pole meridional circulation
- Warm the winter pole in stratosphere
- Impact on tides
- Help drive QBO

CMAM + 3DVar

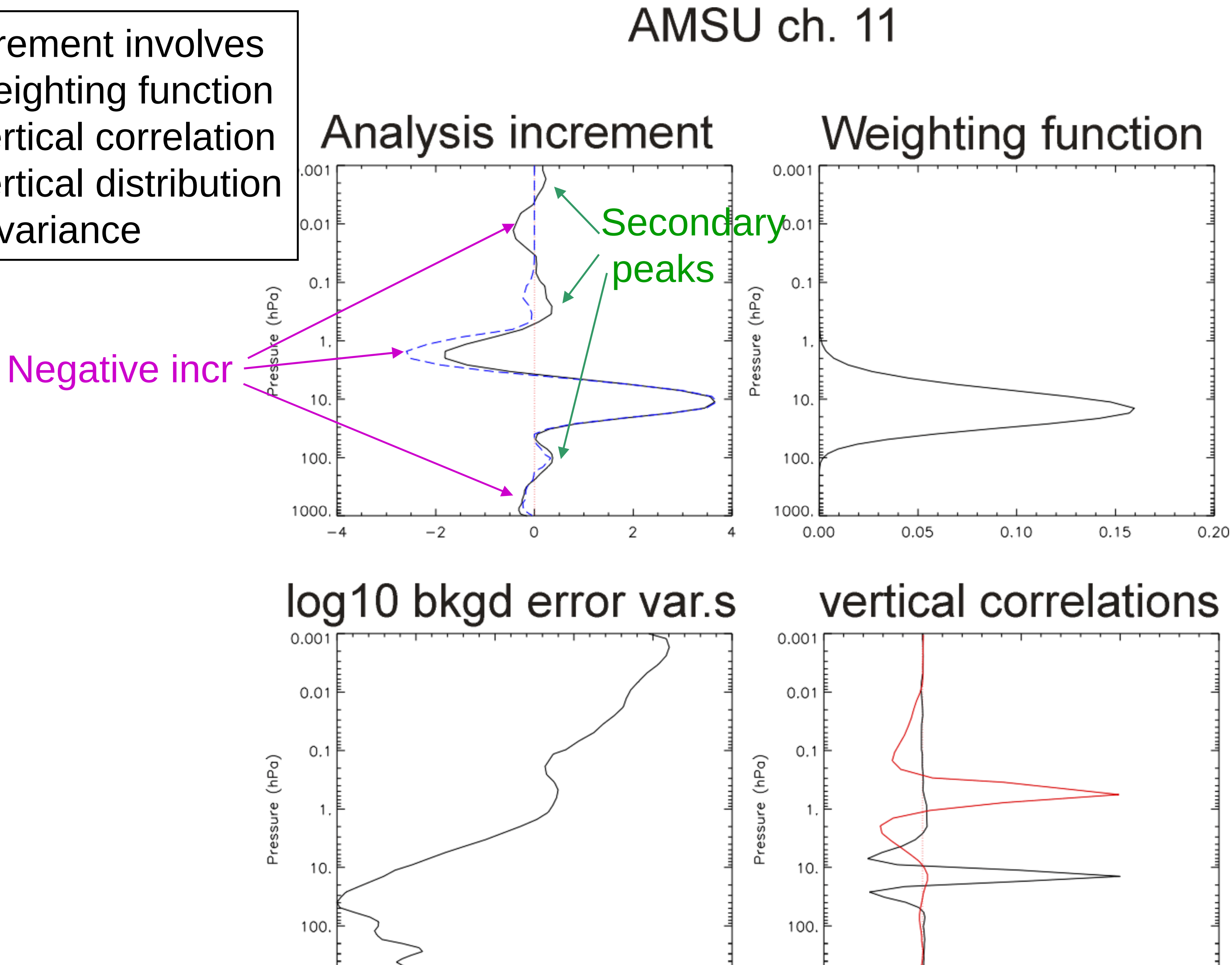
CMAM = Canadian Middle Atmosphere Model

Normalized AMSU Weighting functions





Increment involves
- Weighting function
- Vertical correlation
- Vertical distribution of variance



Polavarapu et al. (2005)

Results from Polavarapu et al. (2005)

- Data insertion in troposphere and stratosphere can lead to increments in the mesosphere through nonzero vertical background error correlations
- Because of large mesospheric variances, extreme sensitivity of results to covariance specification
- Small biases can be amplified by incorrect covs and lead to nophysical results in mesosphere

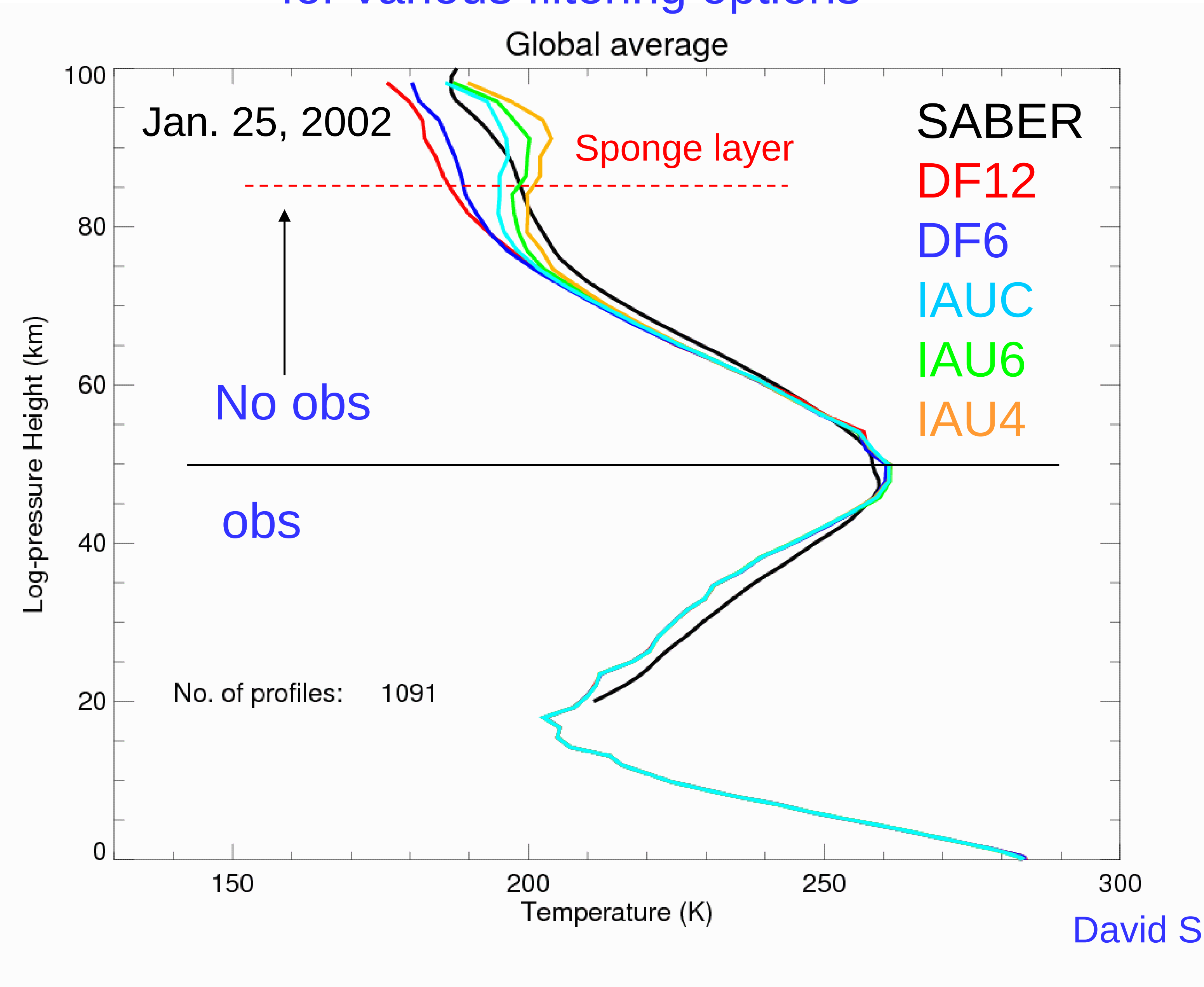
Conclusions - 1

- Even without mesospheric data, having a mesosphere challenges the assimilation step!
- On the other hand, waves propagate information upward. Can we use this information in the forecast step?

2. Mesospheric coupling and the forecast step

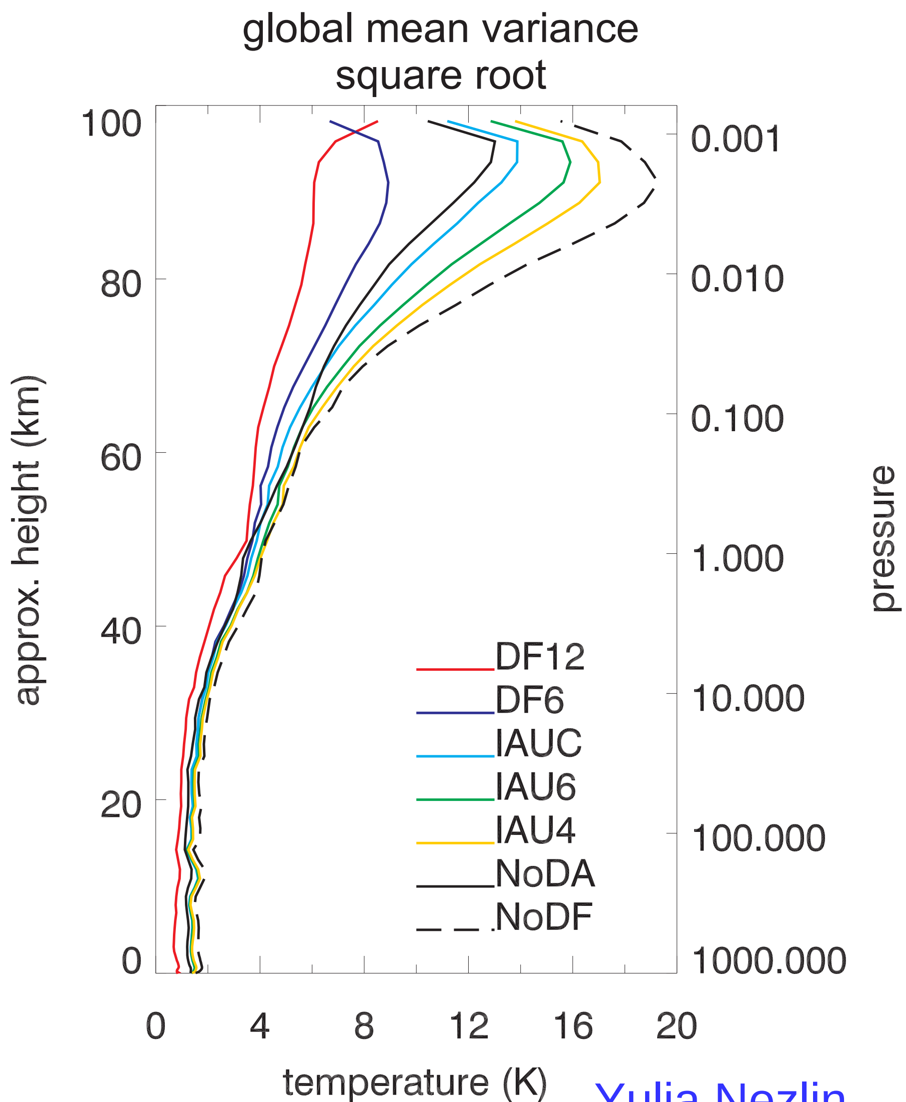
2a. Vertical coupling through resolved waves

Global mean temperature profiles at SABER locations for various filtering options

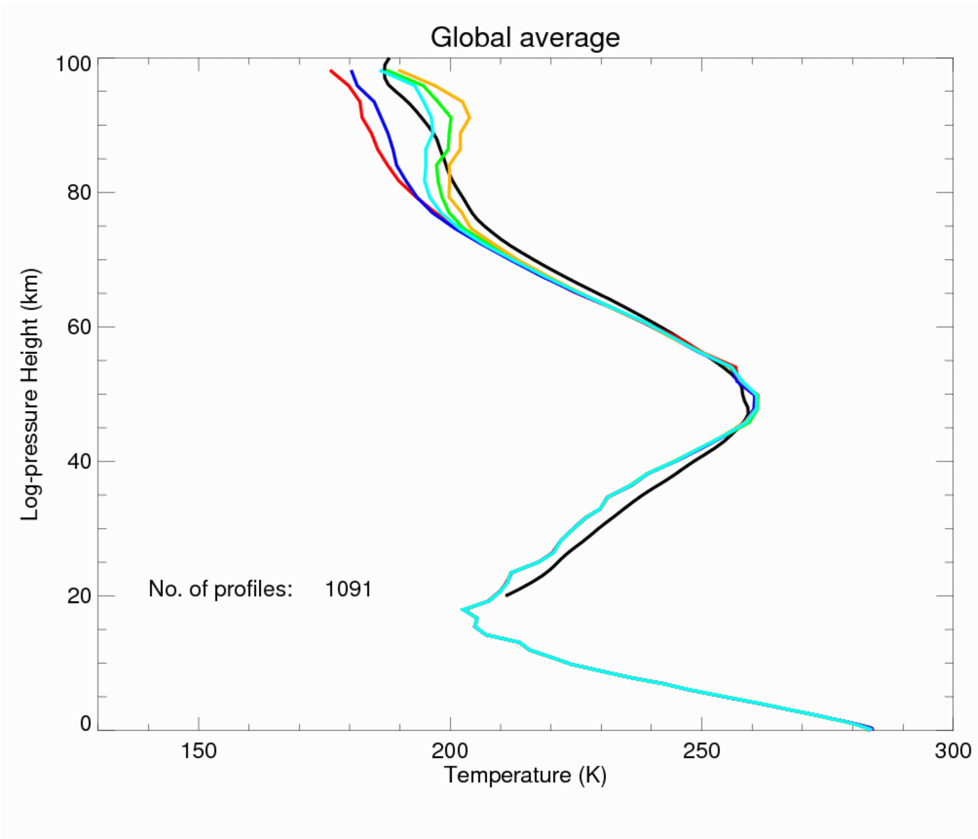


David Sankey

There are more resolved waves in the upper mesosphere with less filtering

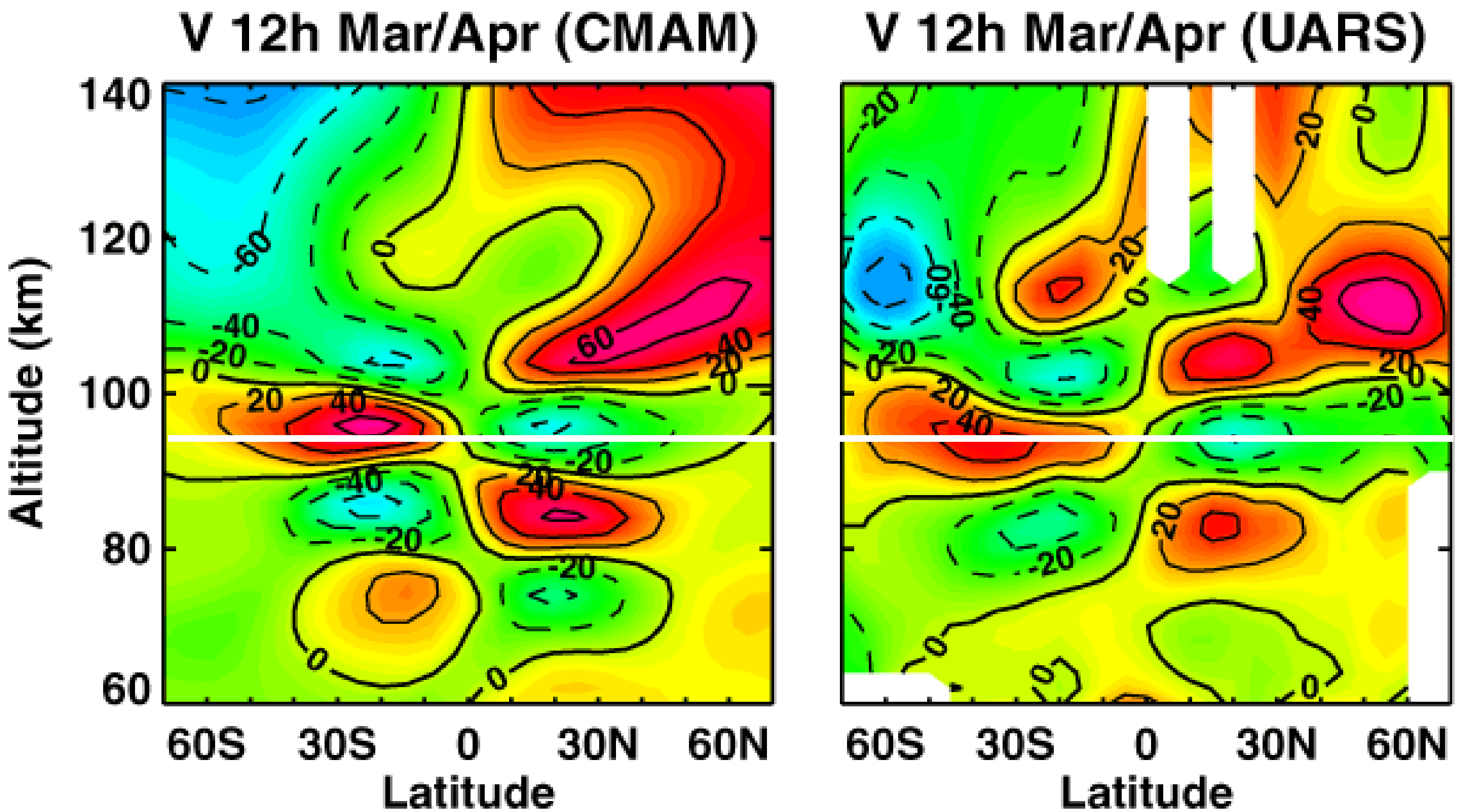


Yulia Nezlin



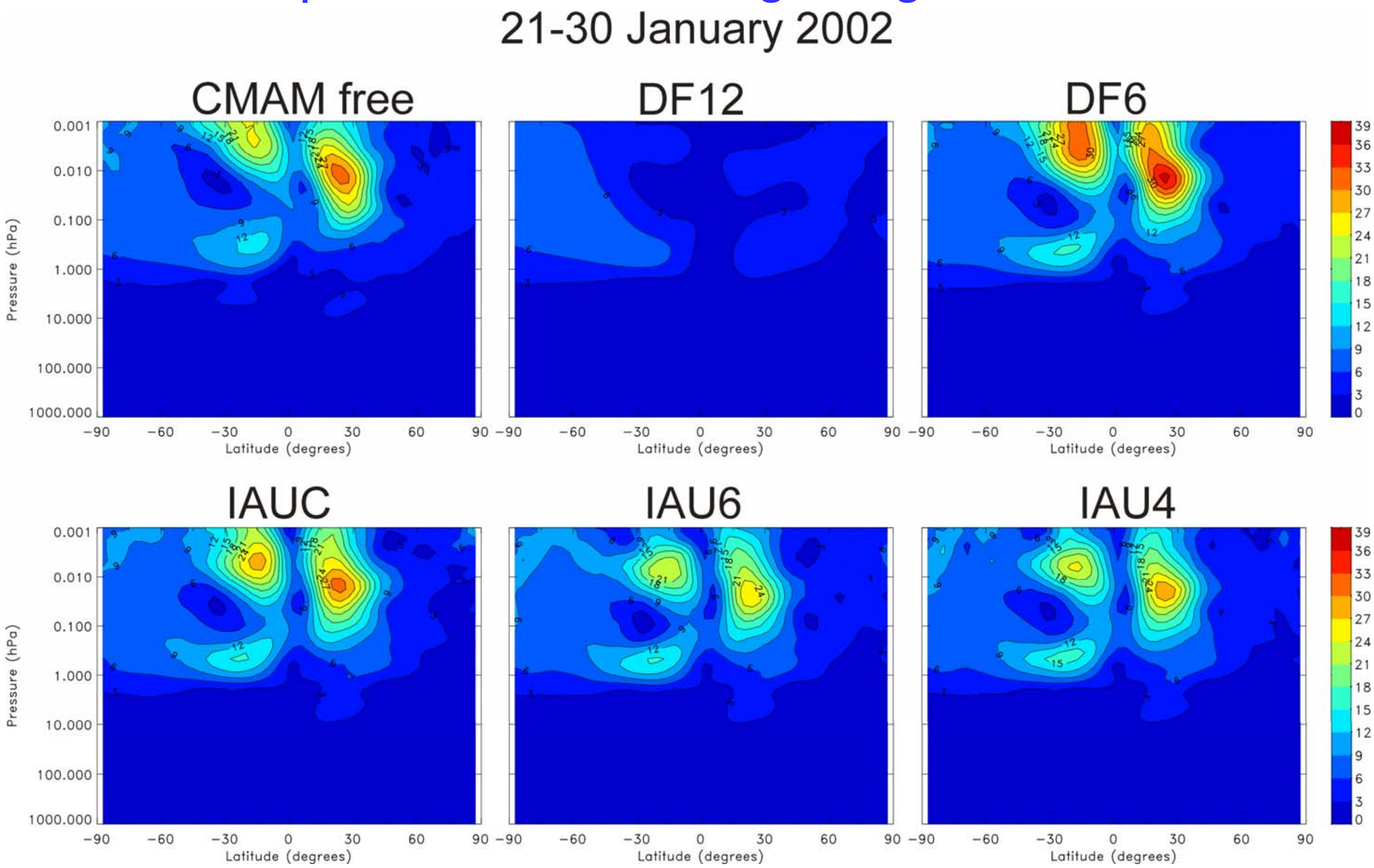
More waves --> more damping --> more heating

Propagating diurnal thermal tide



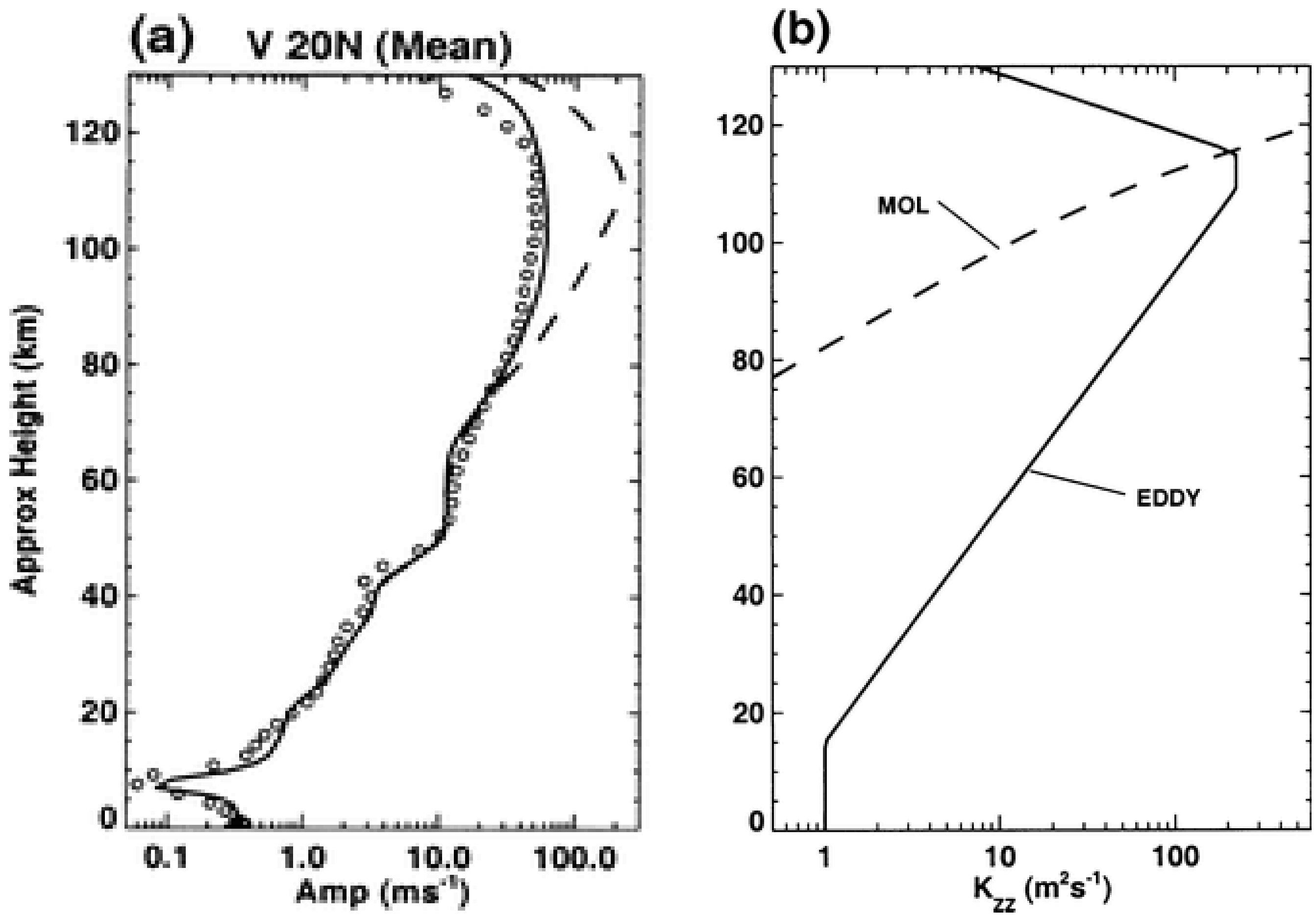
Beagley *et al.* (GRL 2000)

Impact of filters on migrating diurnal tide



Sankey, Polavarapu, McLandress

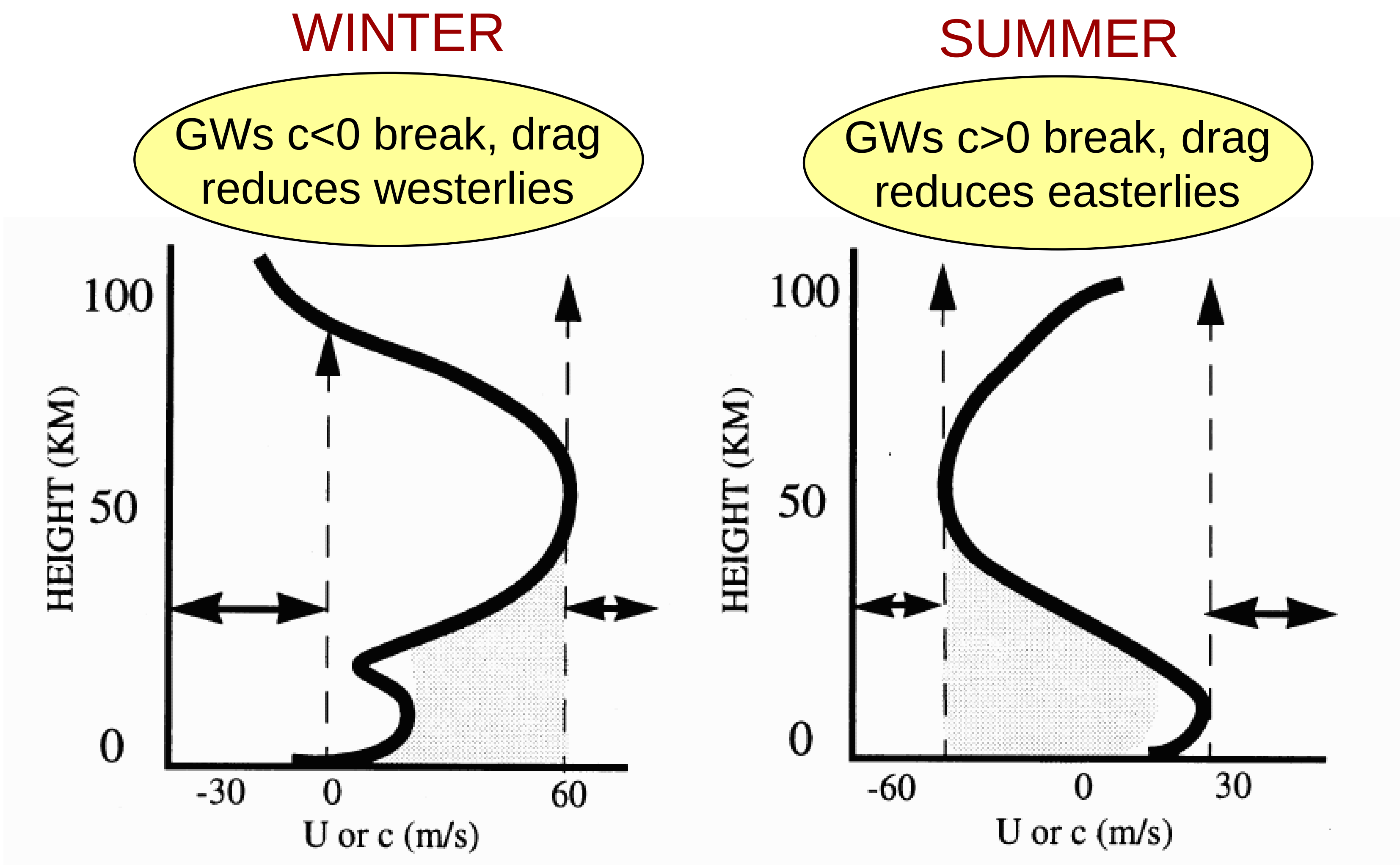
- To represent the CMAM tide (circles) in a linear tidal model, strong eddy viscosity must be invoked (lines)
  - The implication is that this is at least partly associated with interactions with resolved GWs



McLandress (2002 JAS)

2b. Vertical coupling through unresolved gravity waves

Critical level filtering of gravity waves by background mean winds



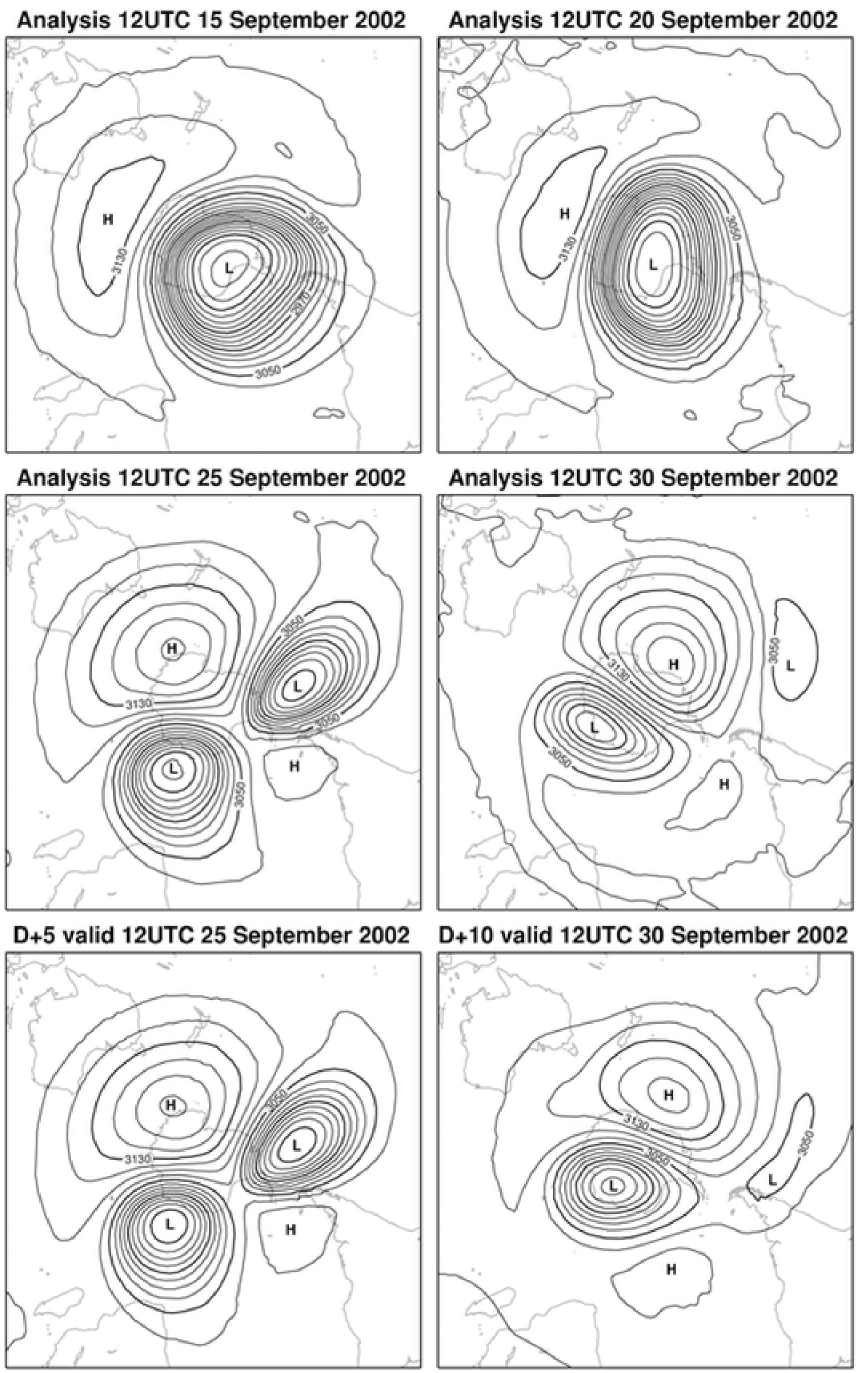
McLandress (1998)

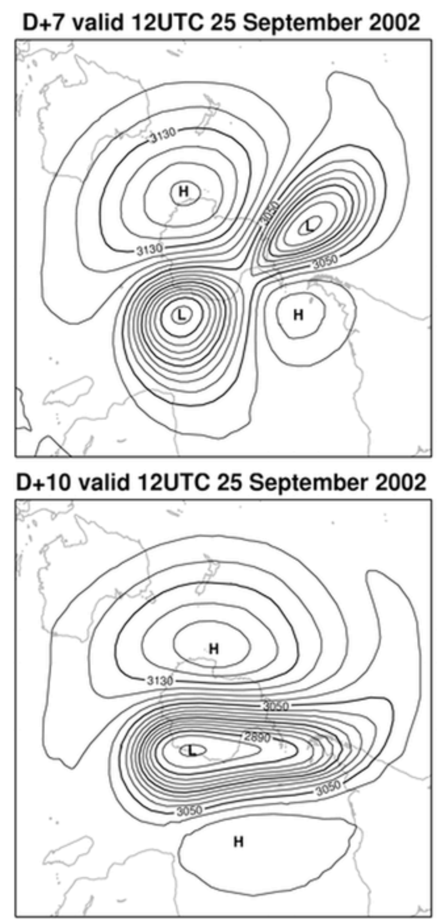
Stratospheric Sudden Warming (SSW)

- 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).

2002 SH SSW
ECMWF
10 hPa height fields

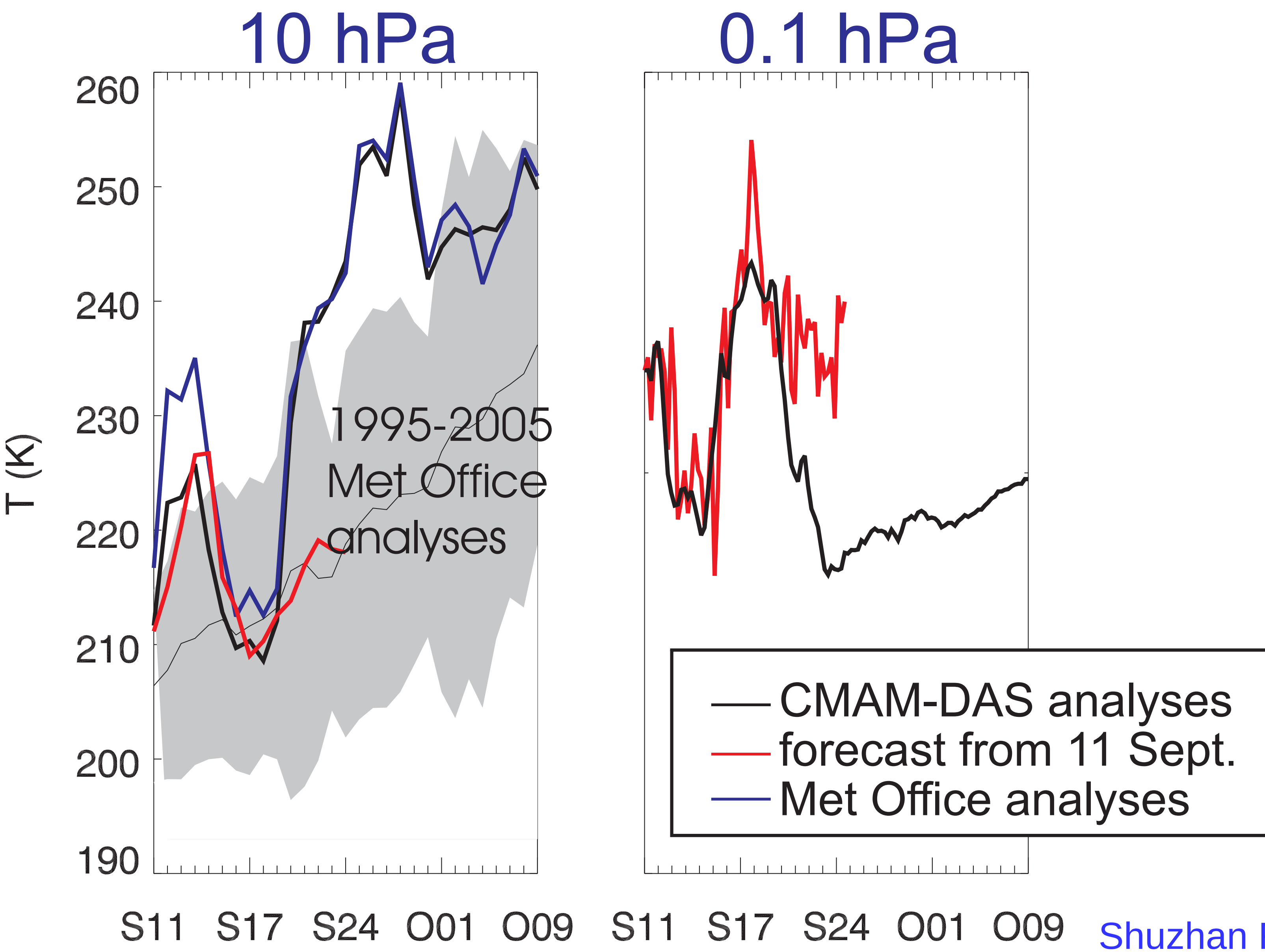
Simmons et al. (2005, JAS)





Contours
20 dam

South Pole Temperature in 2002



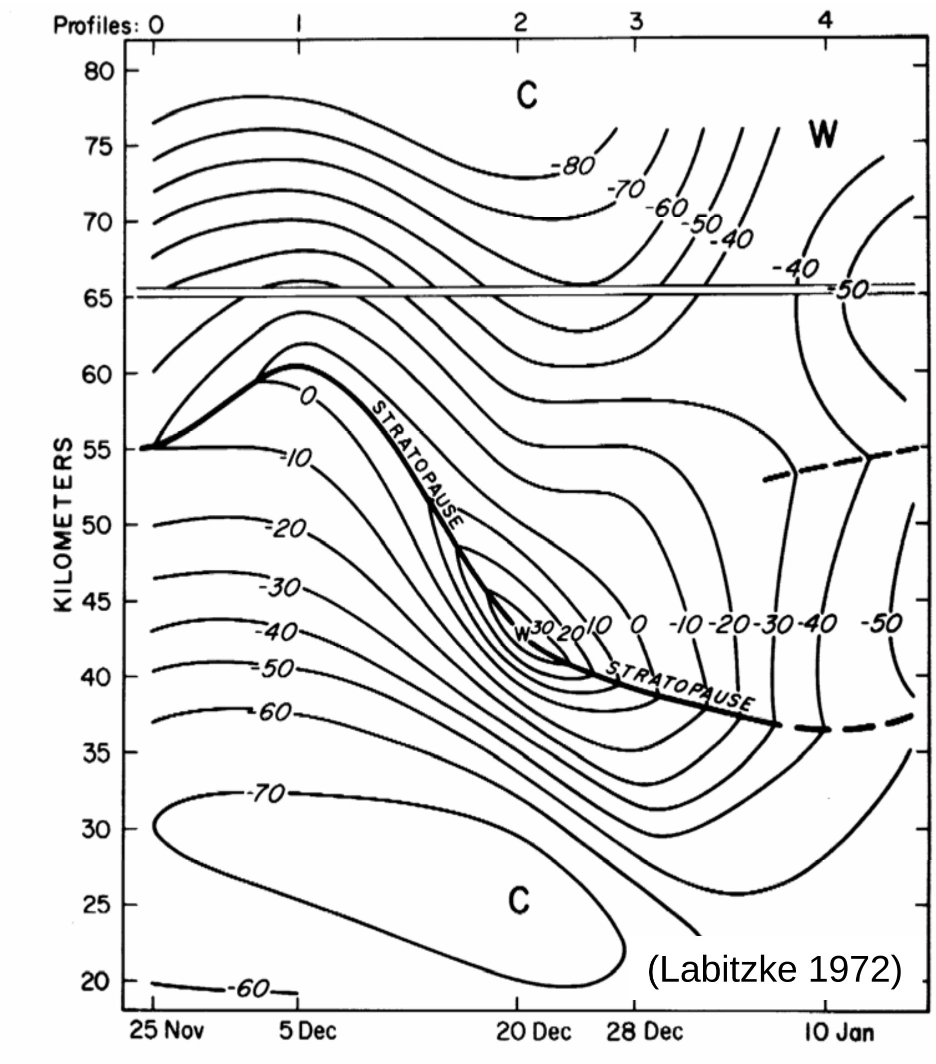
Shuzhan Ren

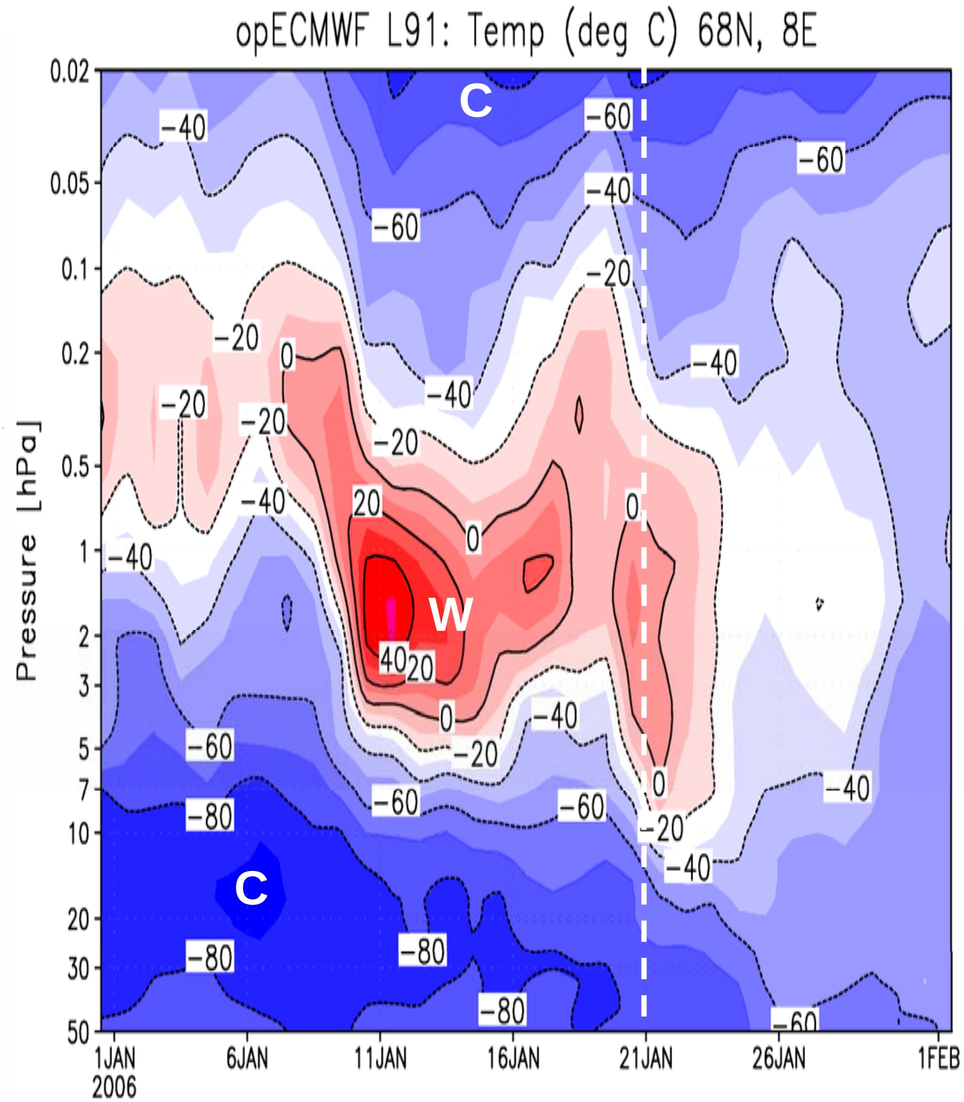
Mesospheric Coolings

schematic diagram

NH winter 2005/06

Courtesy of Kirstin Krüger

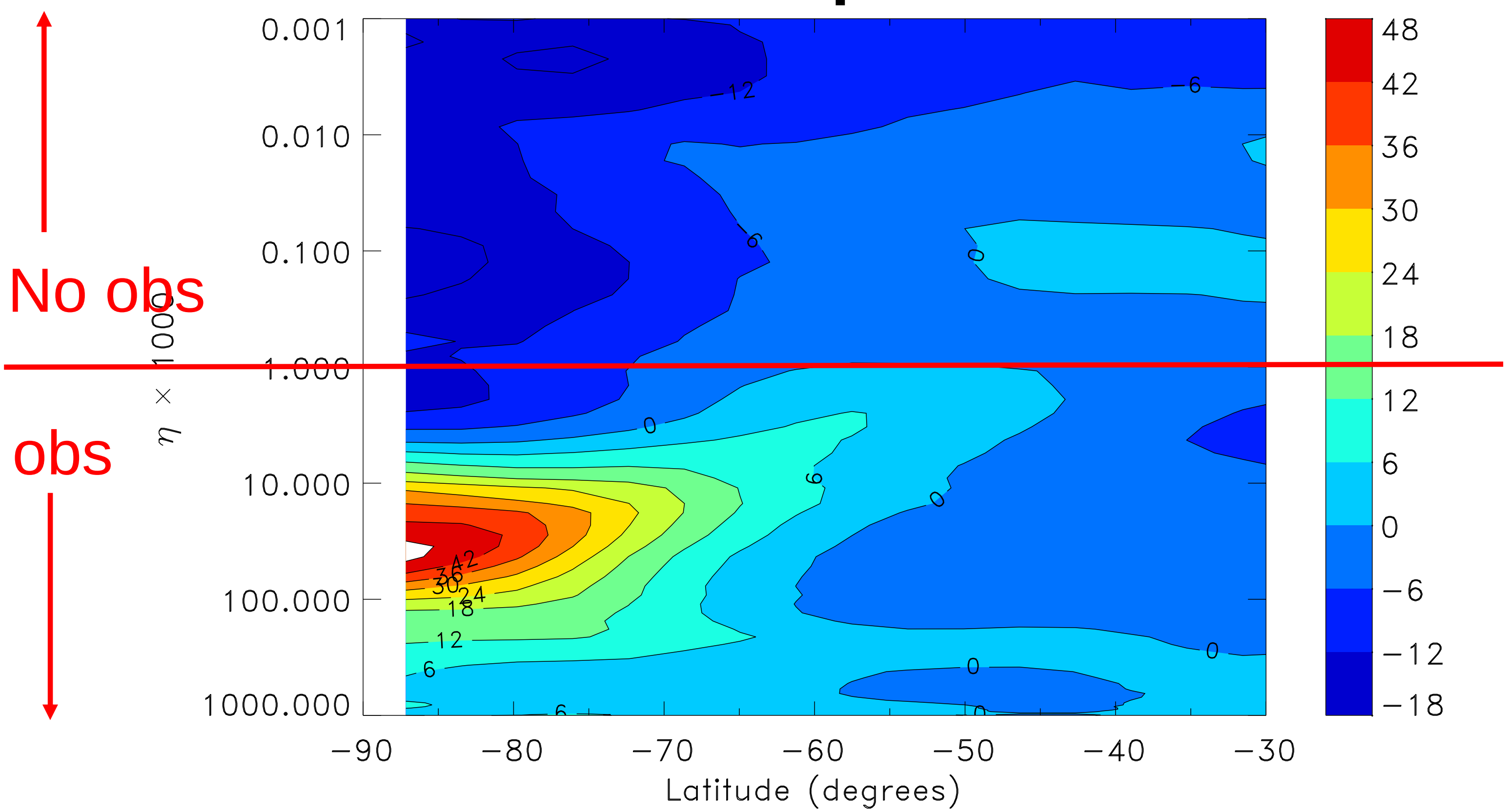




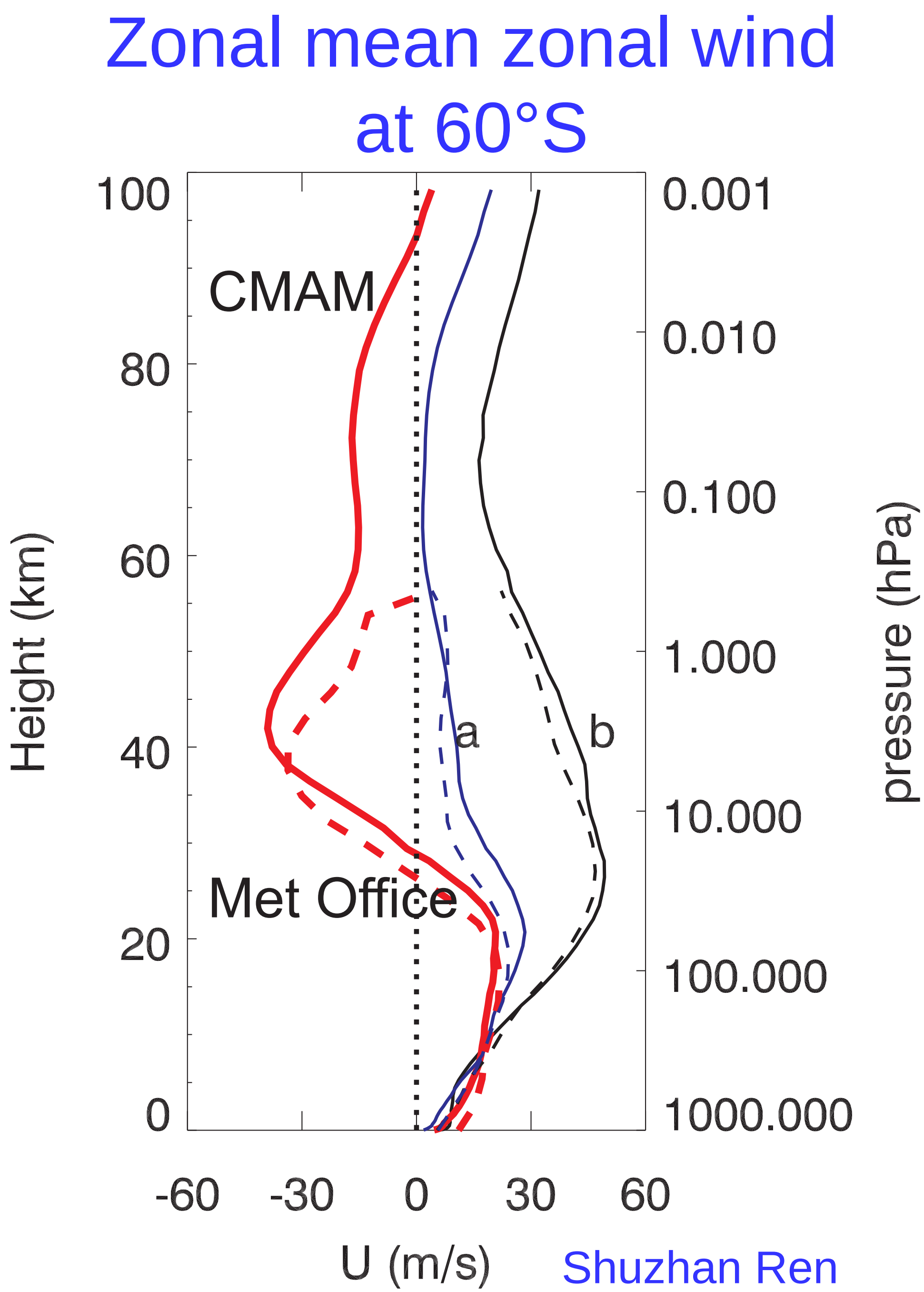
Analysis minus 15-day forecast

25 Sept. 2002

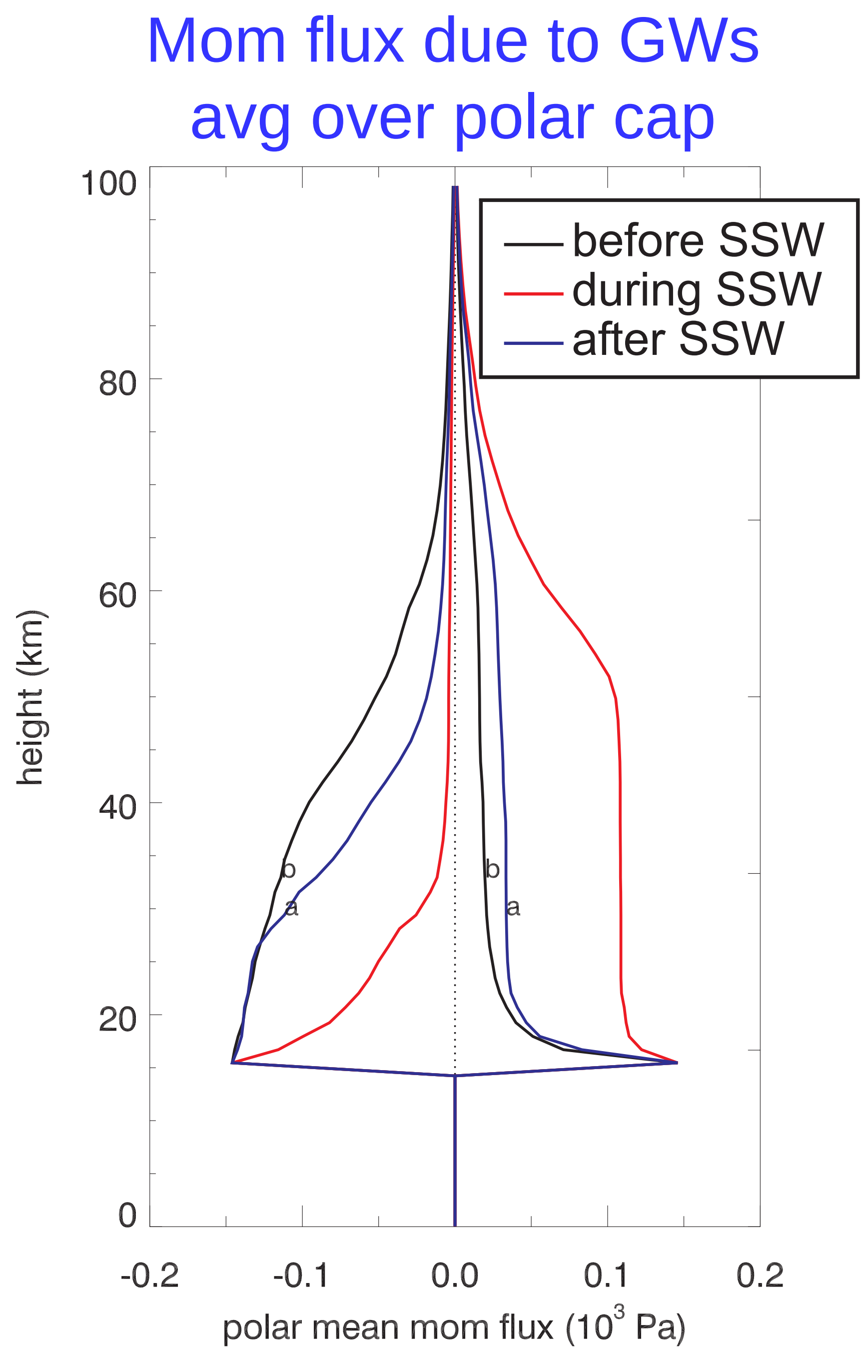
Zonal mean temperature diff



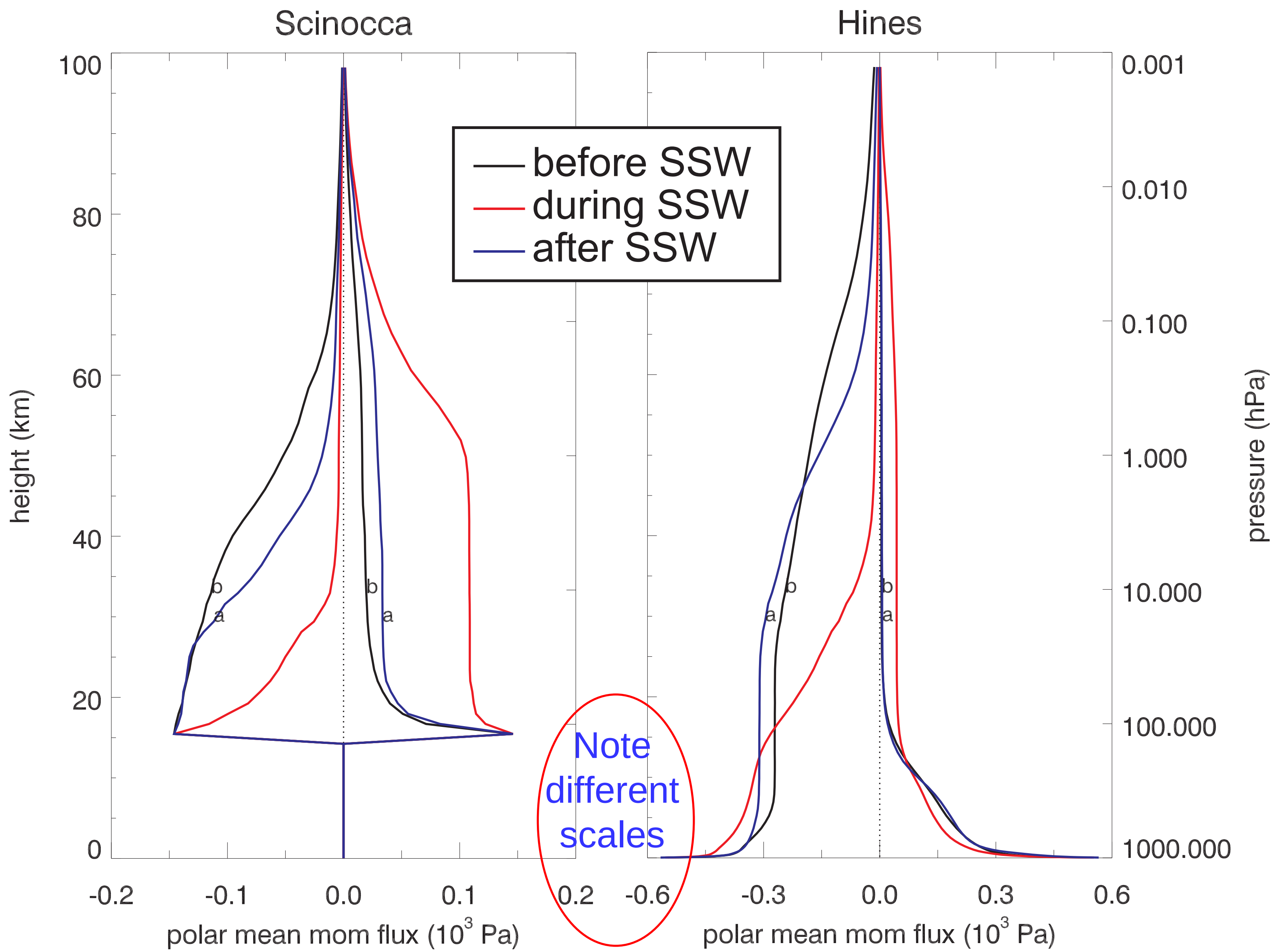
Shuzhan Ren

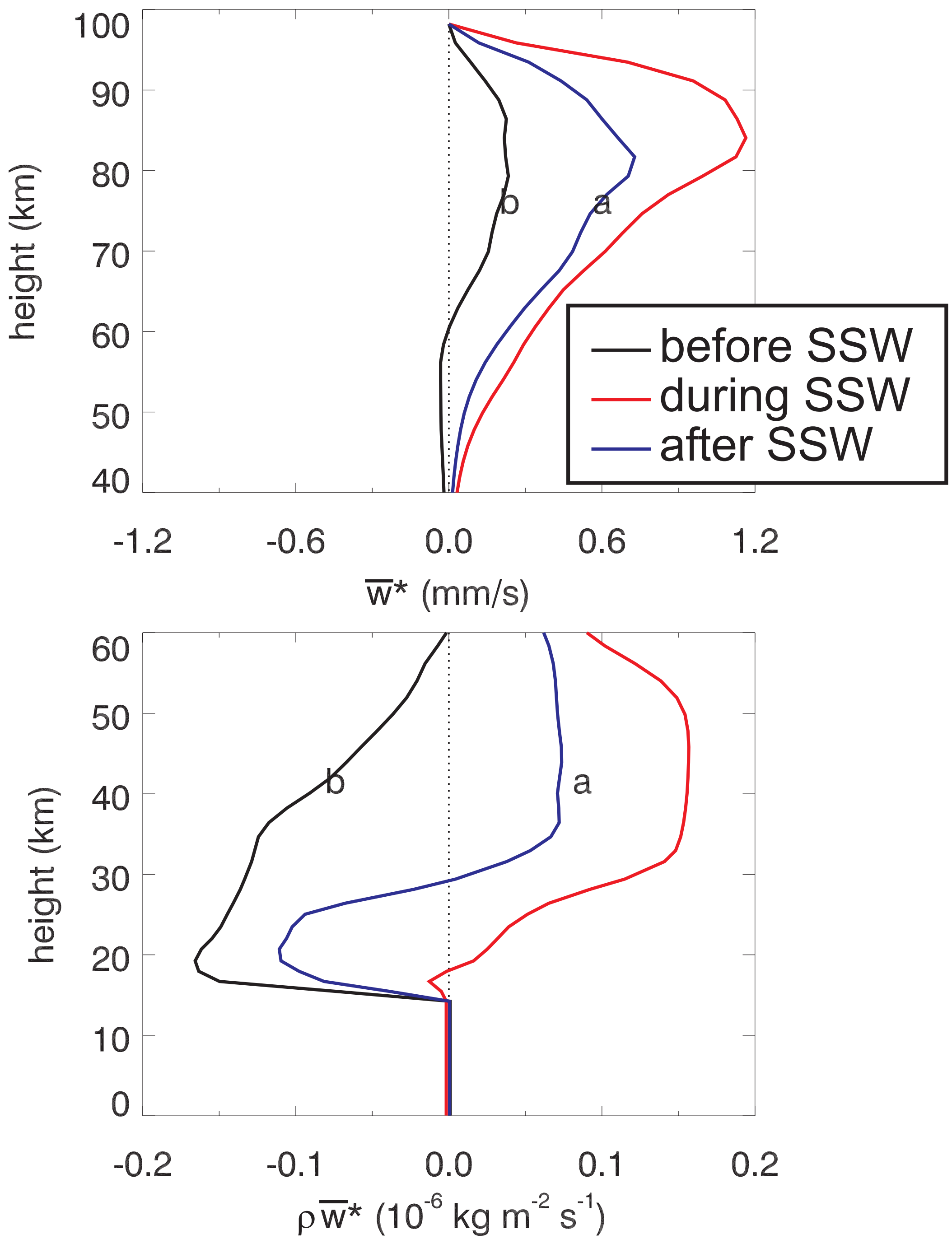

Zonal mean zonal wind at 60°S
CMAM
Met Office
a
b
Height (km)
100
80
60
40
20
0
pressure (hPa)
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
-60
-30
0
30
60
U (m/s)

Shuzhan Ren


Mom flux due to GWs avg over polar cap
before SSW
during SSW
after SSW
height (km)
100
80
60
40
20
0
b
a
b
a
-0.2
-0.1
0.0
0.1
0.2
polar mean mom flux (10^3 Pa)

Gravity wave response depends on GWD scheme used





Impact of waves on mean flow changes the residual circulation

Holton mechanism:

Mesospheric coolings are due to change in GW filtering by zonal flow changes during SSWs.

Conclusions - 2

- Vertical propagation of resolved waves from data region into the mesosphere :
  – creates heat when the GWs are damped. Filtering methods can have big impact on mesosphere.
  – can affect the diurnal tide. Because of nonlinear wave interactions, increased damping does not necessarily lead to increased tidal amplitudes
- Vertical propagation of information through unresolved (GW) waves affects mesosphere
  – Clear impact of obs on mesosphere thru model response. Confirm Holton filtering mechanism.
  – Can we use mesospheric obs to constrain GWD parameters, e.g. sources?

3. International Polar Year (IPY)

SPARC –IPY project

SPARC = Stratospheric Processes And their Role in Climate
SPARC is a WCRP project
WCRP = World Climate Research Programme

SPARC = Stratospheric Processes And their Role in Climate

SPARC-IPY project overview

Officially endorsed by IPY in Sept. 2005

- Goal: document dynamics, chemistry and microphysical processes within the polar vortices during the IPY.
- Focus on coupling of strat-trop and strat-meso
- Deliverable: a well organized data set of (1) measurements and (2) analyses of the polar stratosphere during IPY
- Will use SPARC Data Center facilities
- Output: SPARC reports, SPARC Newsletter articles and peer reviewed research publications

DA participants

ECMWF	Europe	Dyn, …
Met Office	U.K.	Dyn, O3
NCEP	U.S.A.	Dyn, O3
GMAO	U.S.A.	Dyn, O3
KNMI	Netherlands	O3
BADC	U.K.	HIRDLS - O3, H2O, CH4, N2O
GEM-Strato	Canada	Dyn, O3,…
CMAM-DAS	Canada	Dyn, O3,…
DARC	UK	Dyn, O3,…
More?		

How will this happen?

- Main effort by SPARC Data Assimilation Working Group (DAWG)
- Because SPARC International Project Office is in Canada, lot of data handling done here
- Help from ¼ Research Associate (Diane Pendlebury, U of Toronto)
- Help from Stefan Liess (SPARC Data Center) SUNY, Long Island, New York

Where are we?

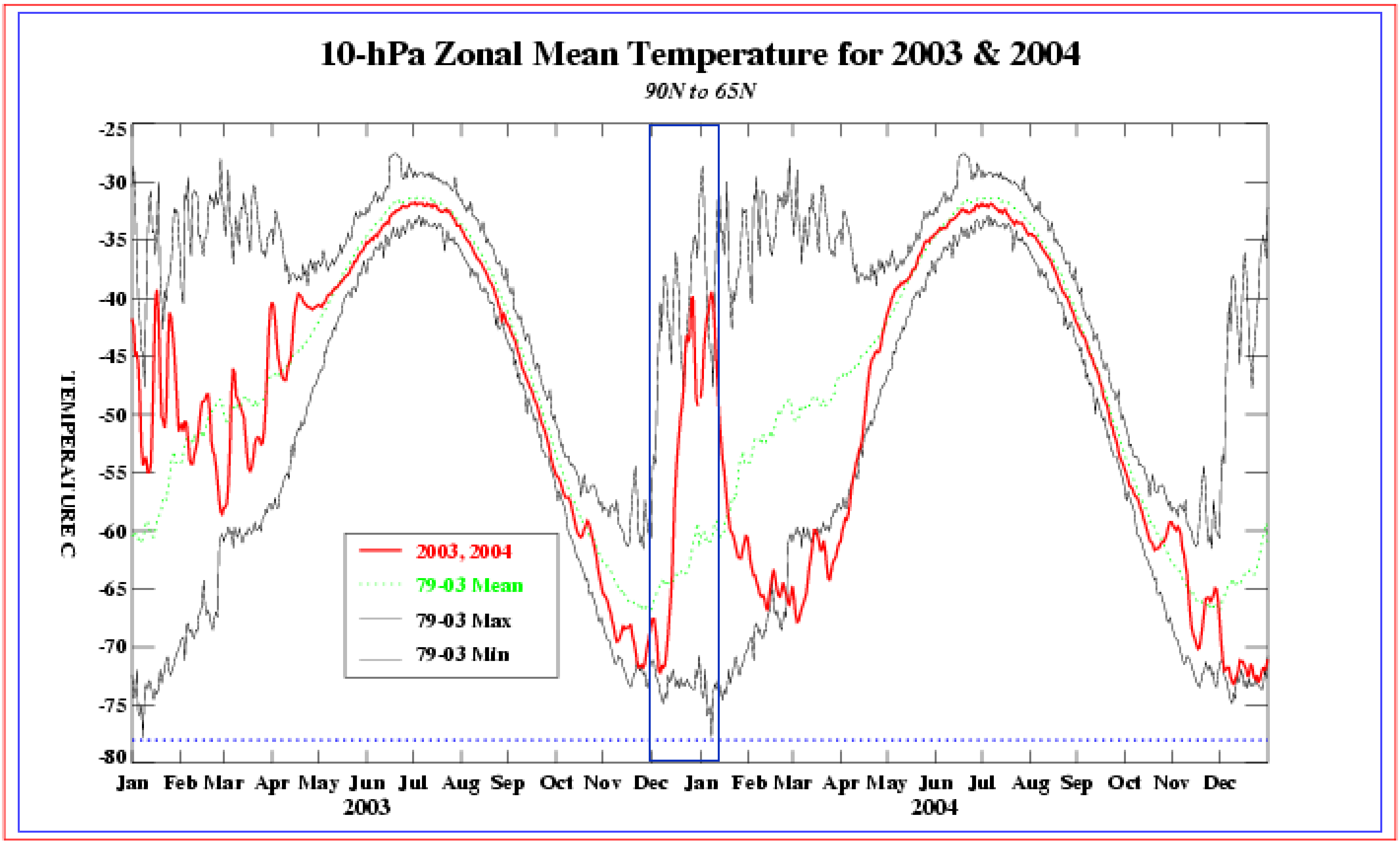
- Confirmed participants (9)
- Data licence agreement from ECMWF
- Data providers to use native formats (GRIB for NWP centers)
- SPARC to provide user interface
- Need to choose variables, parameters to archive
- Need a sample file to ensure sufficient hardware is present to handle data

GEM-Strato for IPY

- GEM-Strato-BIRA - Developed by Ménard, Gauthier, Chabrillat, Robichaud, Rochon, Charette, Charron, DeGrandpré, Yang, McConnell, Kaminski…
- Real-time forecasting of Stratospheric Sudden Warmings (SSWs) (above + Reszka + Polavarapu)
  - GEM-global 240 x 120 (1.5º x 1.5º)
  - 0.1 hPa lid (80 levels)
  - BIRA chemistry (50+ species)
  - GWD, new radiation
  - Winter case: 2003-4
  - Assess timings (elapsed, CPU, turnaround)
  - Assess forecasts

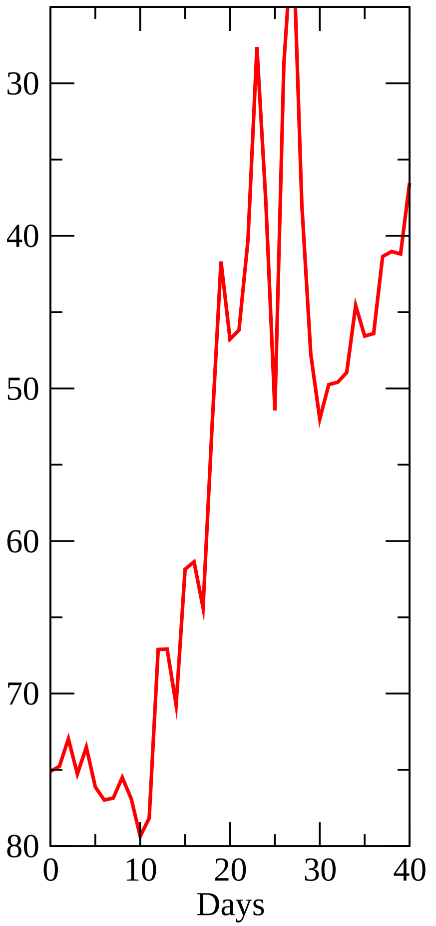
December 2003 Stratospheric Sudden Warming

NCEP CPC



GEM-Strato-BIRA

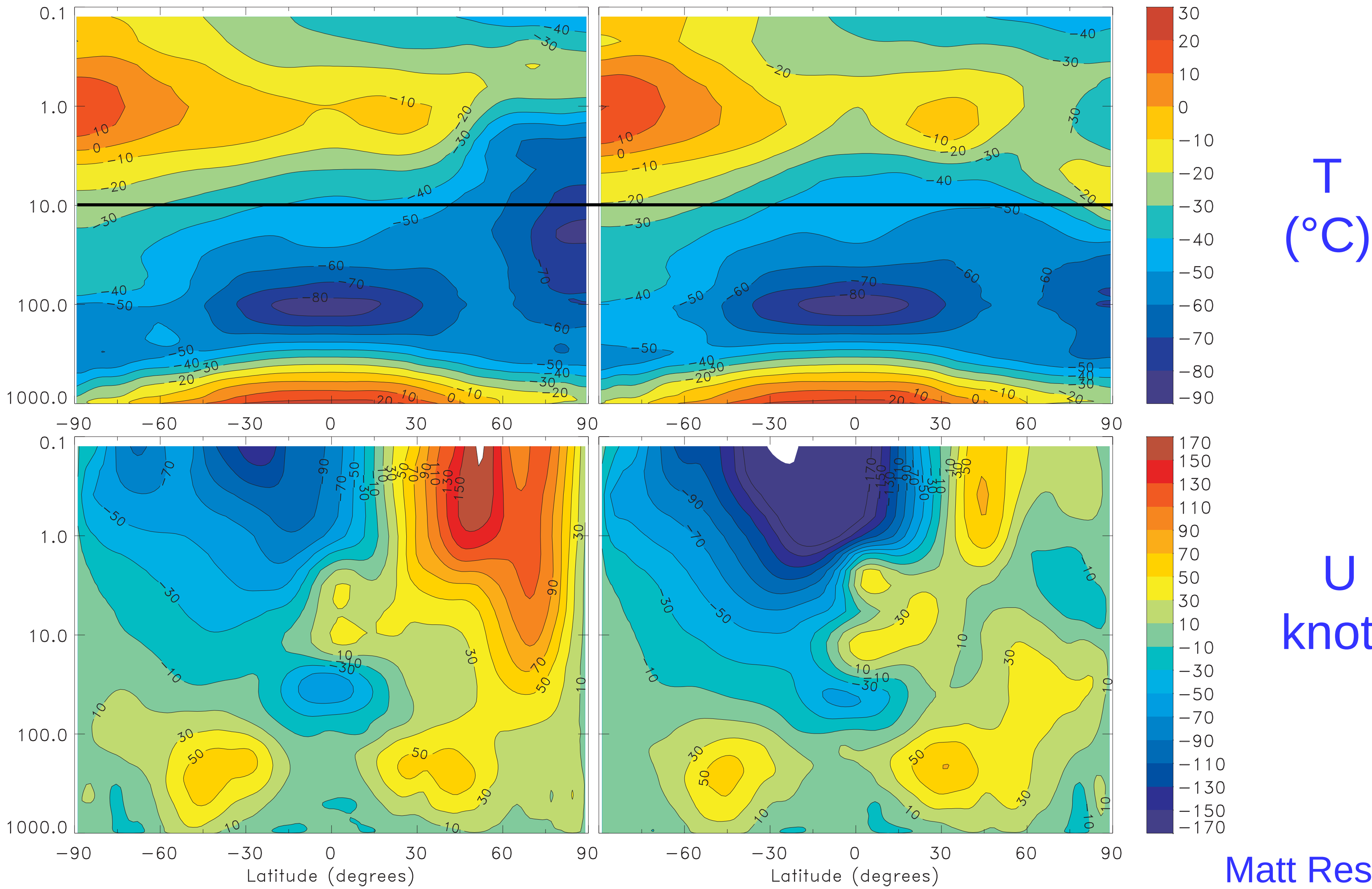
10 hPa T, 90°N



Matt Reszka

GEM-Strato-BIRA analyses

Before SSW	During SSW
06Z Dec. 1, 2003	06Z Dec. 28, 2003



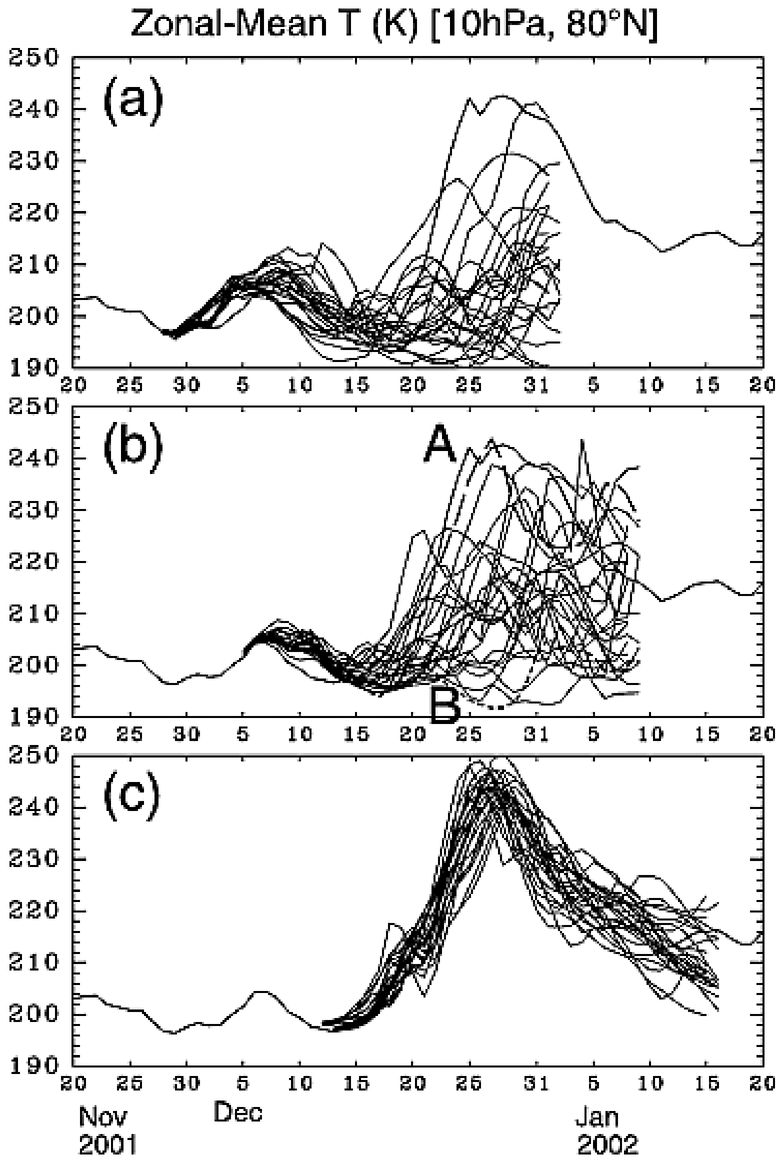
Matt Reszka

Predictability of SSWs

4 weeks
before
All fail

3 weeks
before
Some good

2 weeks
Before
All good



28 Dec. 2001 peak

T106, 0.4 mb, 40 lev

JMA ens prediction

25 members

Mukougawa et al. (2005, GRL)

Summary - 3

- Stratospheric Sudden Warmings are an important component of polar variability
- Growing evidence of stratospheric influence on troposphere
- SSWs involve coupling of stratosphere and mesosphere
- SSWs will be a focus of study of SPARC-IPY
- Real-time forecasts of SSWs desirable

The End