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Vertical propagation of information in data assimilation systems

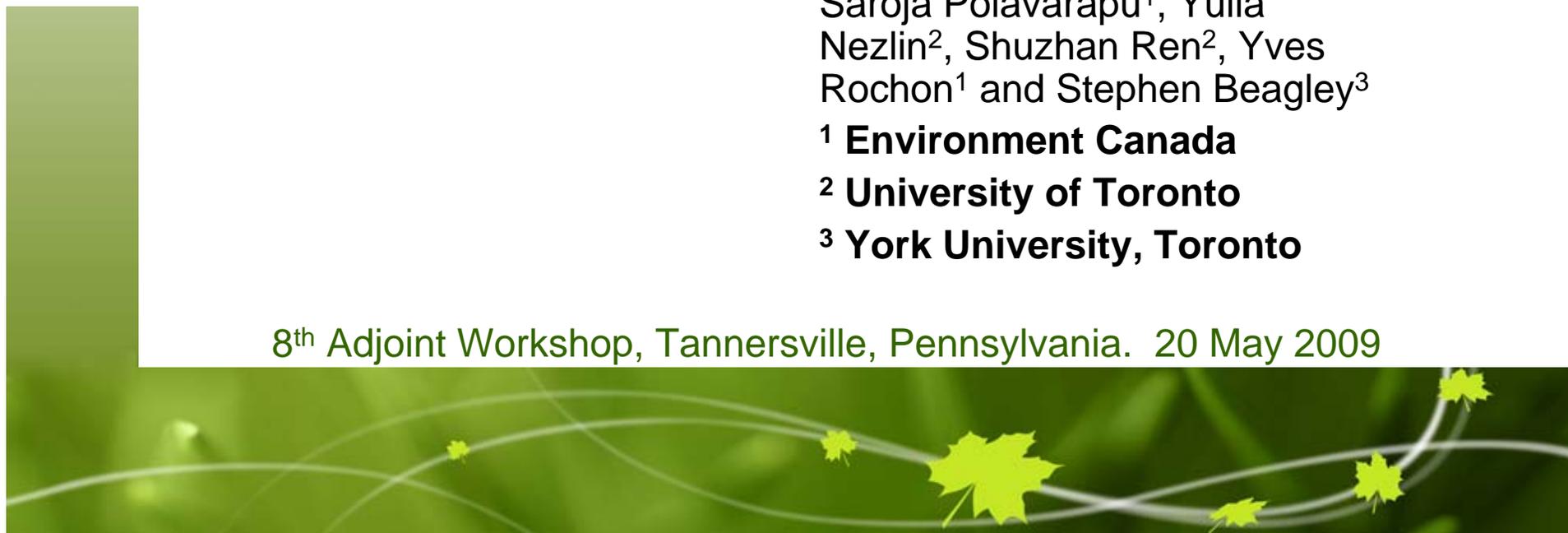
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² **University of Toronto**

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8th Adjoint Workshop, Tannersville, Pennsylvania. 20 May 2009



OUTLINE

- Vertical propagation of information in data assimilation systems occurs through covariances and
 1. Resolved waves during 6-h forecasts
 2. Parameterized impact of sub-grid scale waves on zonal mean
- Can we use the sensitivity of mesosphere to troposphere to help tune gravity wave source parameters?



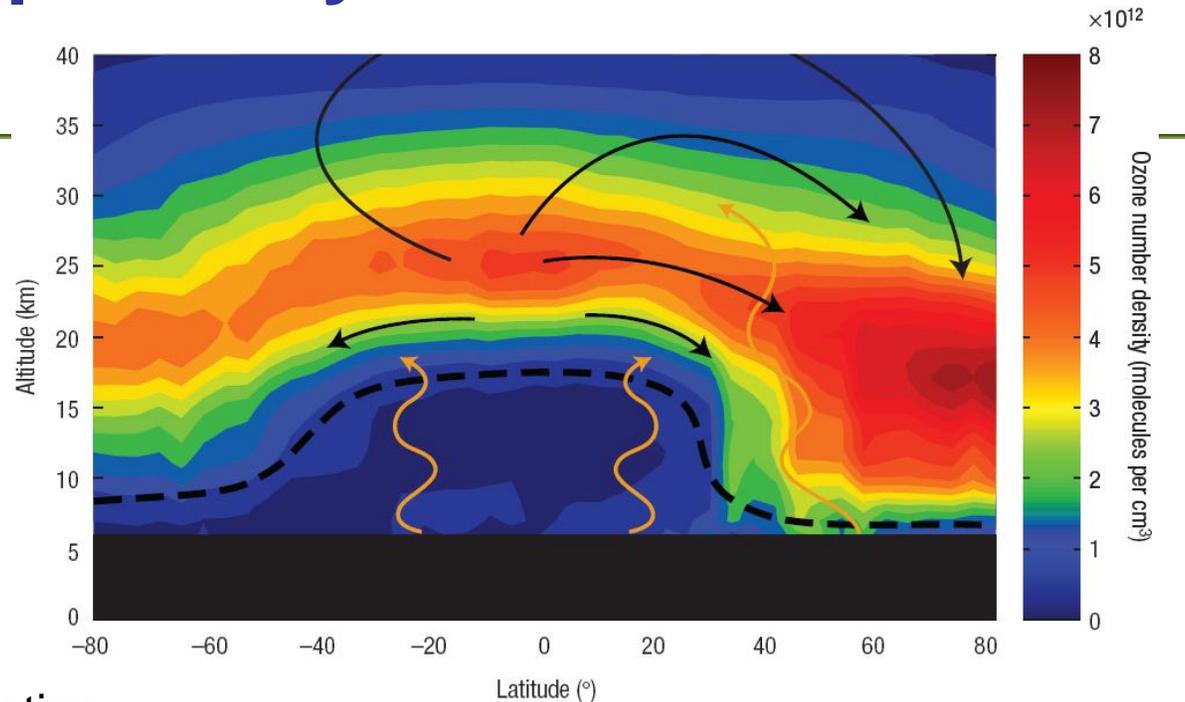
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Middle Atmosphere Dynamics

Ozone from OSIRIS
for March 2004



Shaw and Shepherd (2008)

- Brewer-Dobson circulation
 - wave driven, thermally indirect
 - affects temperature, transport of species
- Gravity waves also important
 - Help drive meridional circulation
 - Warm the winter pole in stratosphere
 - Impact on tides
 - help drive the QBO



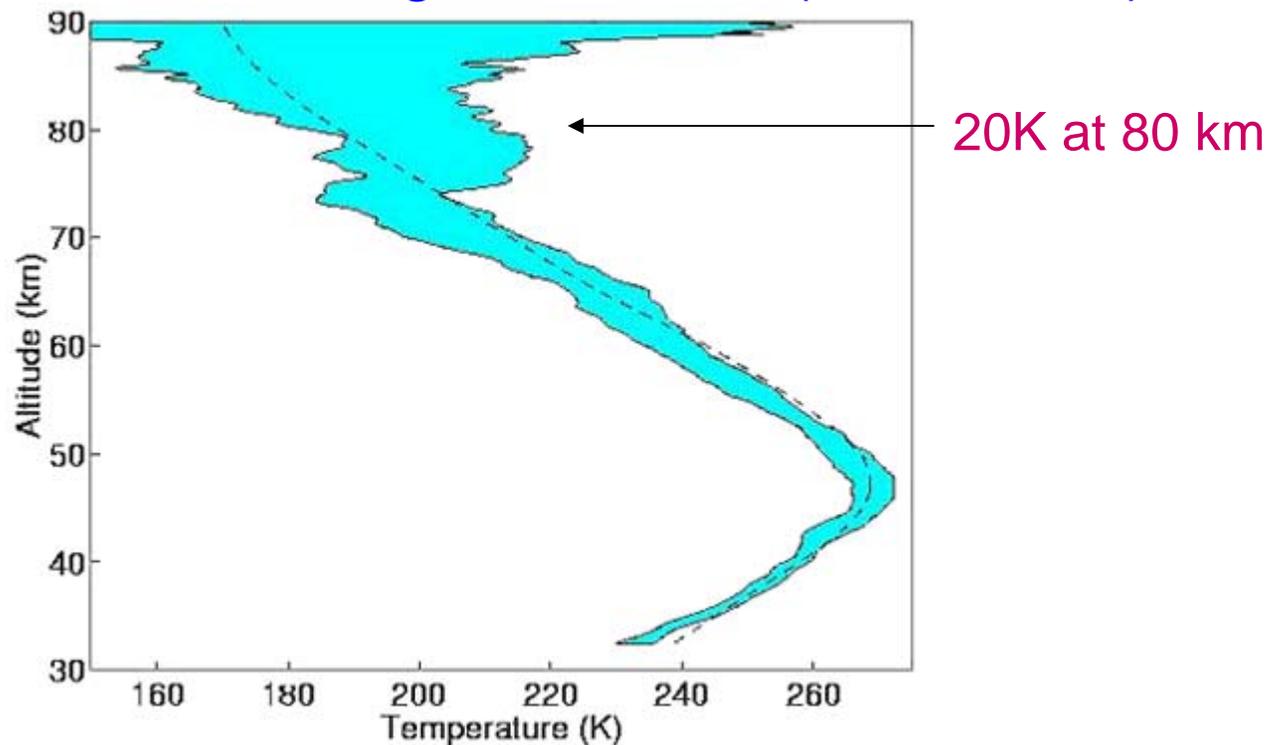
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Gravity waves may be viewed as noise in the troposphere, but they are prevalent in the mesosphere and are part of the signal!

T profiles over one night from lidar (42°N,81°W)



R.J. Sica (U Western Ontario)

<http://pcl.physics.uwo.ca/science/temperature/>



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CMAM + 3DVar

CMAM = Canadian Middle Atmosphere Model

How does information propagate into the mesosphere?

No obs

obs

AMSU 10-13

CMC oper. 10

conventional obs + sat.

NCEP

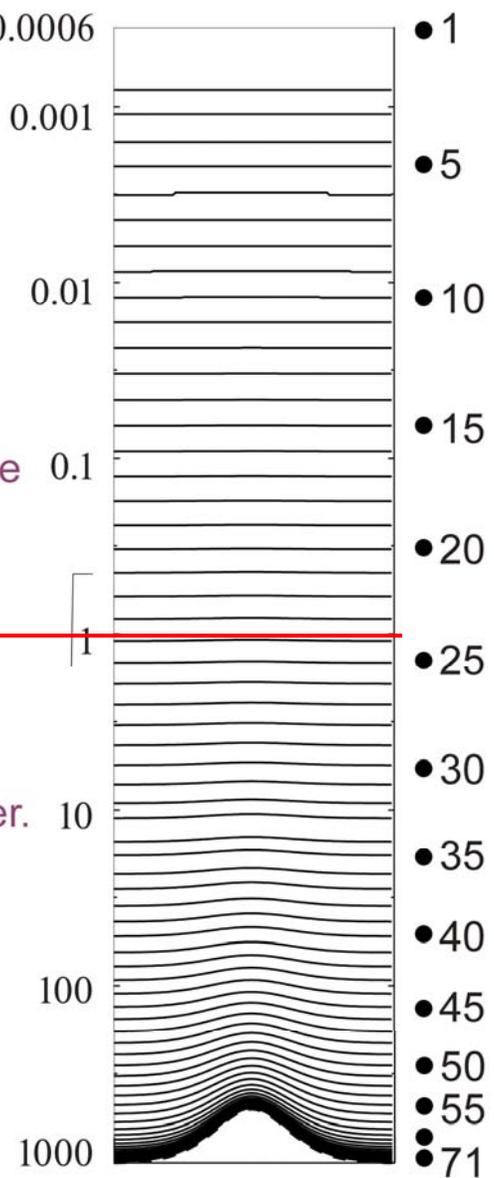
ECMWF 0.01

Met Office 0.1

CMAM 0.0006

Pressure (hPa)

CMAM level



Thermosphere

Mesosphere

Stratosphere

Troposphere



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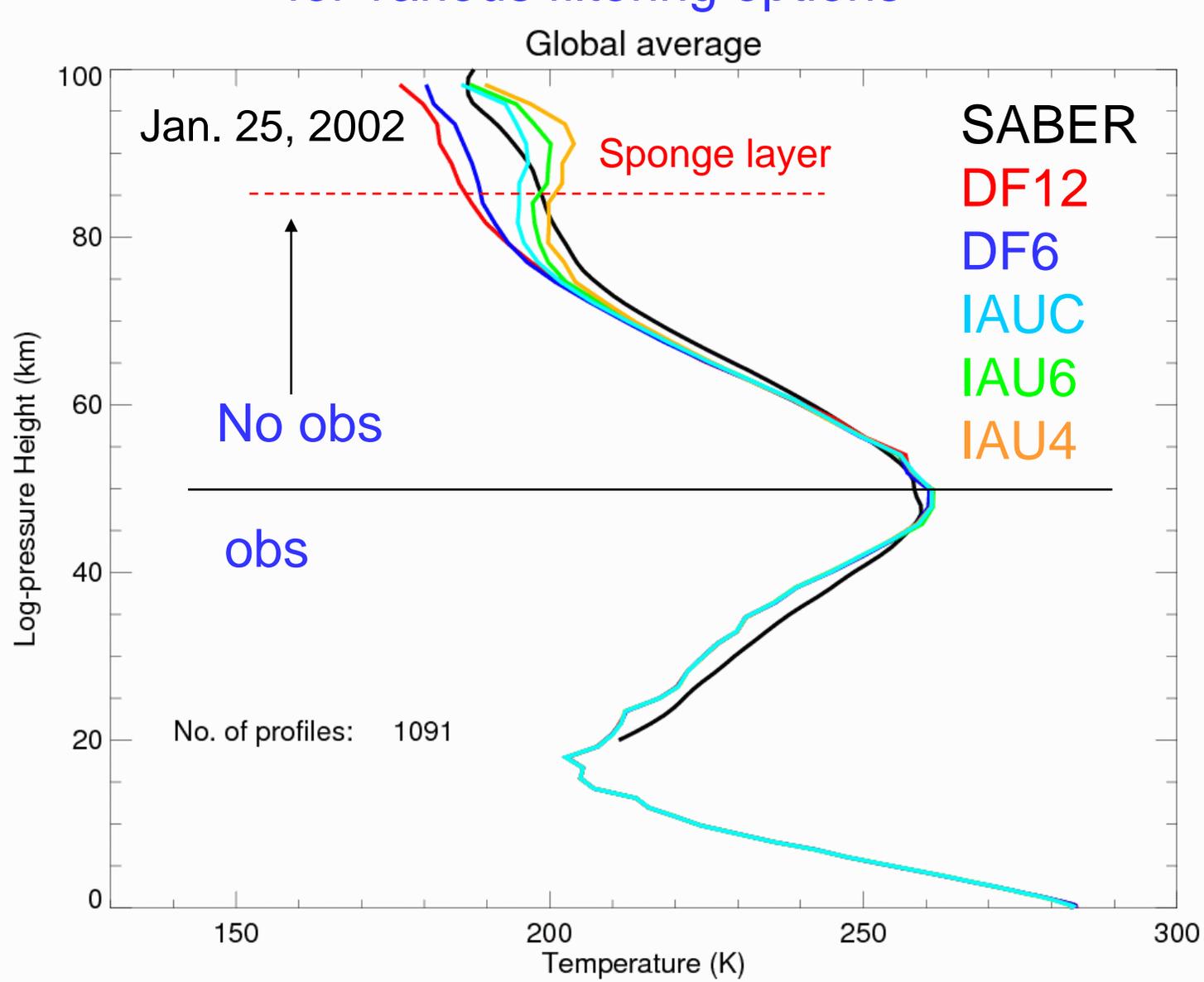


How is information propagated from the data region to the mesosphere?

- **Analysis step** (3D-Var): Covariances spread information spatially
 - To avoid this, correlations are modified to ensure no increments in mesosphere
- **Forecast step**: model forecast can propagate information in the vertical through dynamics

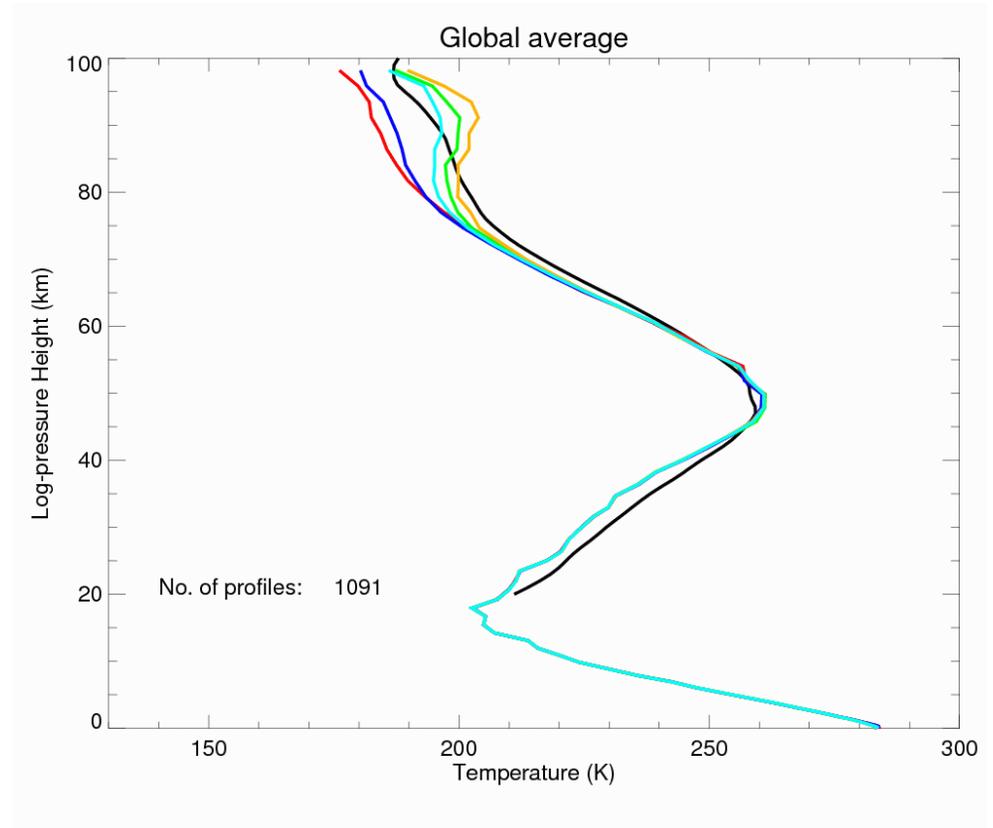
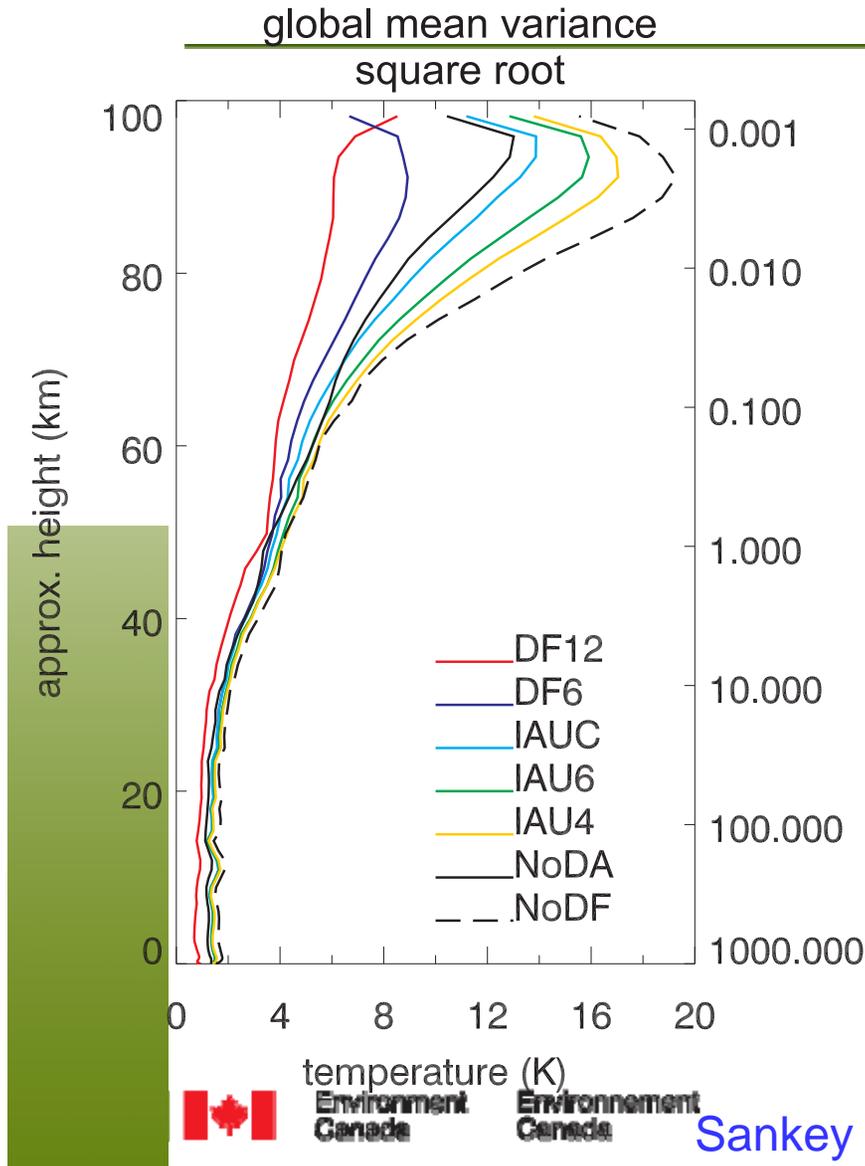


Global mean temperature profiles at SABER locations for various filtering options



Sankey et al. (2007)

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



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

Sankey et al. (2007)



-
- Changing the assimilation scheme in the stratosphere and troposphere has huge impacts on the mesosphere!
 - Resolved waves (real or spurious) in the lower atmosphere propagate up to the mesosphere
 - Small errors lower down can look big in the mesosphere



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Information propagation through a Gravity Wave Drag (GWD) scheme

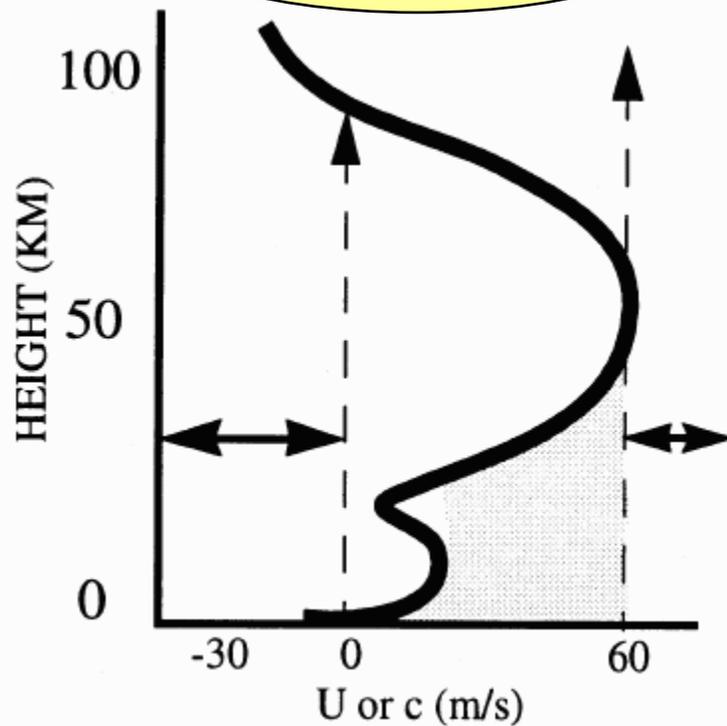
- What is a GWD scheme?
 - Poor resolution of climate models means not enough gravity wave forcing of meridional circulation
 - Not enough downwelling or warming over winter pole leads to “cold pole problem”. Evident in SH where fewer PWs.
 - To solve this, effect of subgrid scale GWs on mean flow is parameterized using assumptions about GW sources in the troposphere
 - Forcing term is added to momentum equations
- Information inserted in the lower atmosphere adjusts the planetary waves, whose EP flux divergence influences zonal mean wind, which filters GWs



Critical level filtering of gravity waves by background mean winds

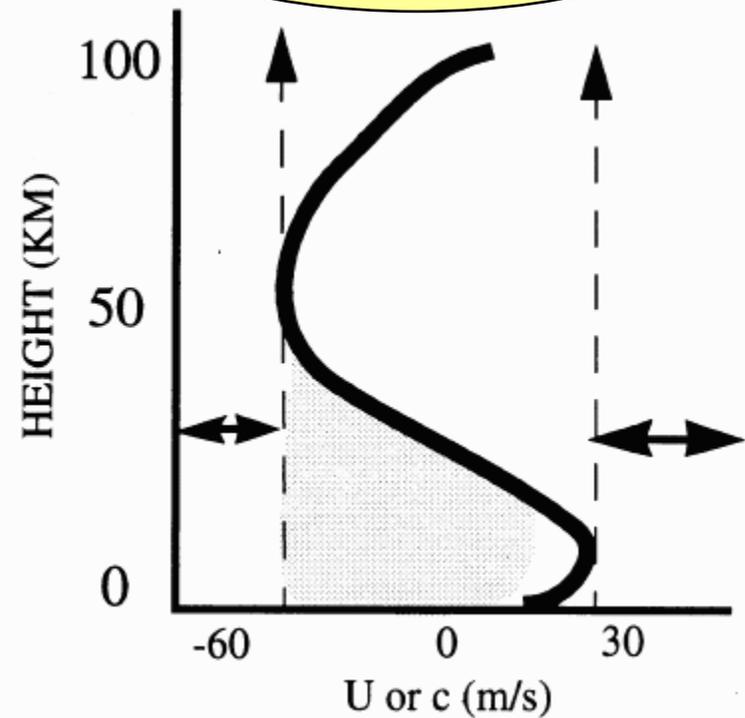
WINTER

GWs $c < 0$ break, drag reduces westerlies



SUMMER

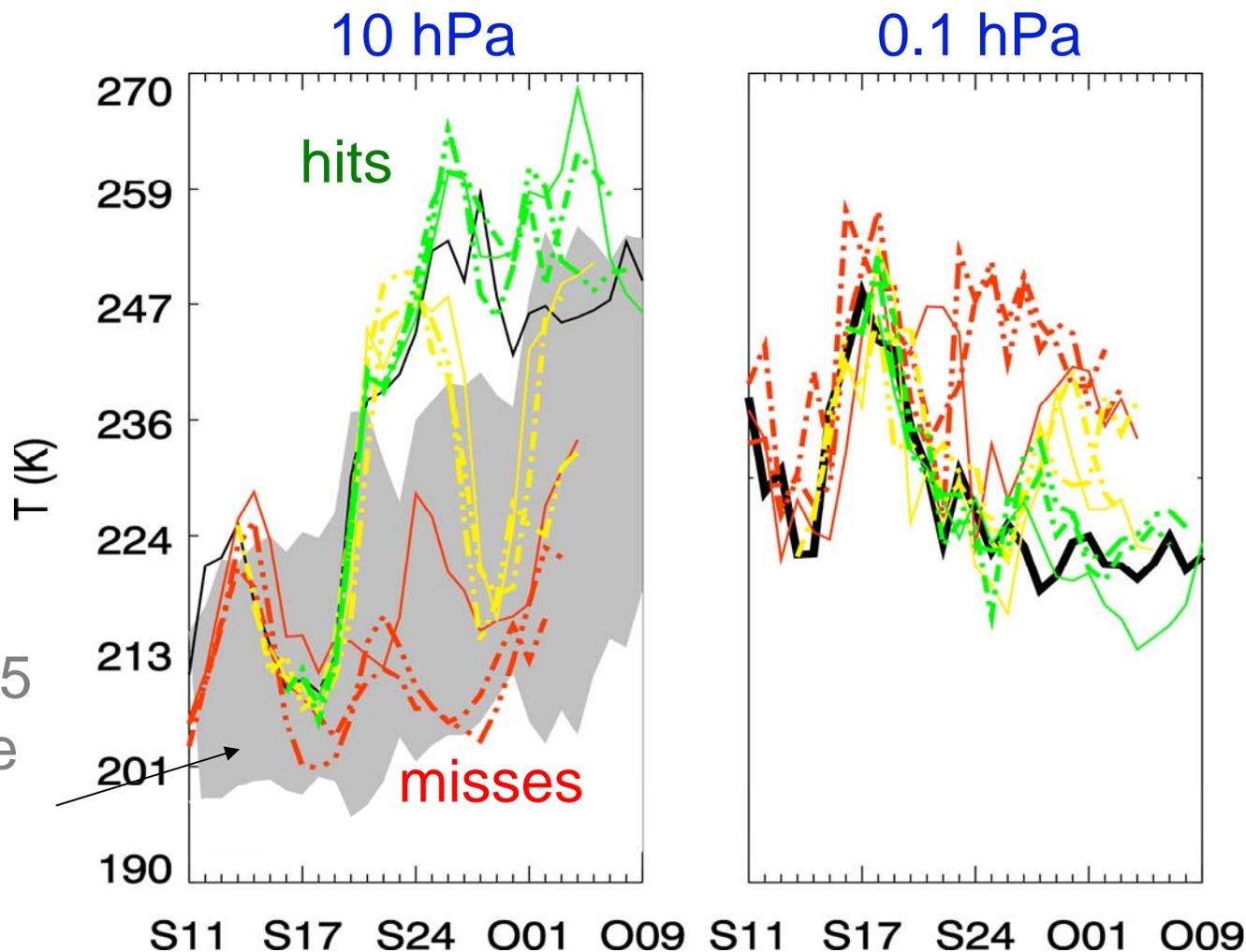
GWs $c > 0$ break, drag reduces easterlies



South Pole temperature in 2002 during stratospheric warming

6-8 Sept
14-16 Sept
17-19 Sept

1995-2005
Met Office
analyses



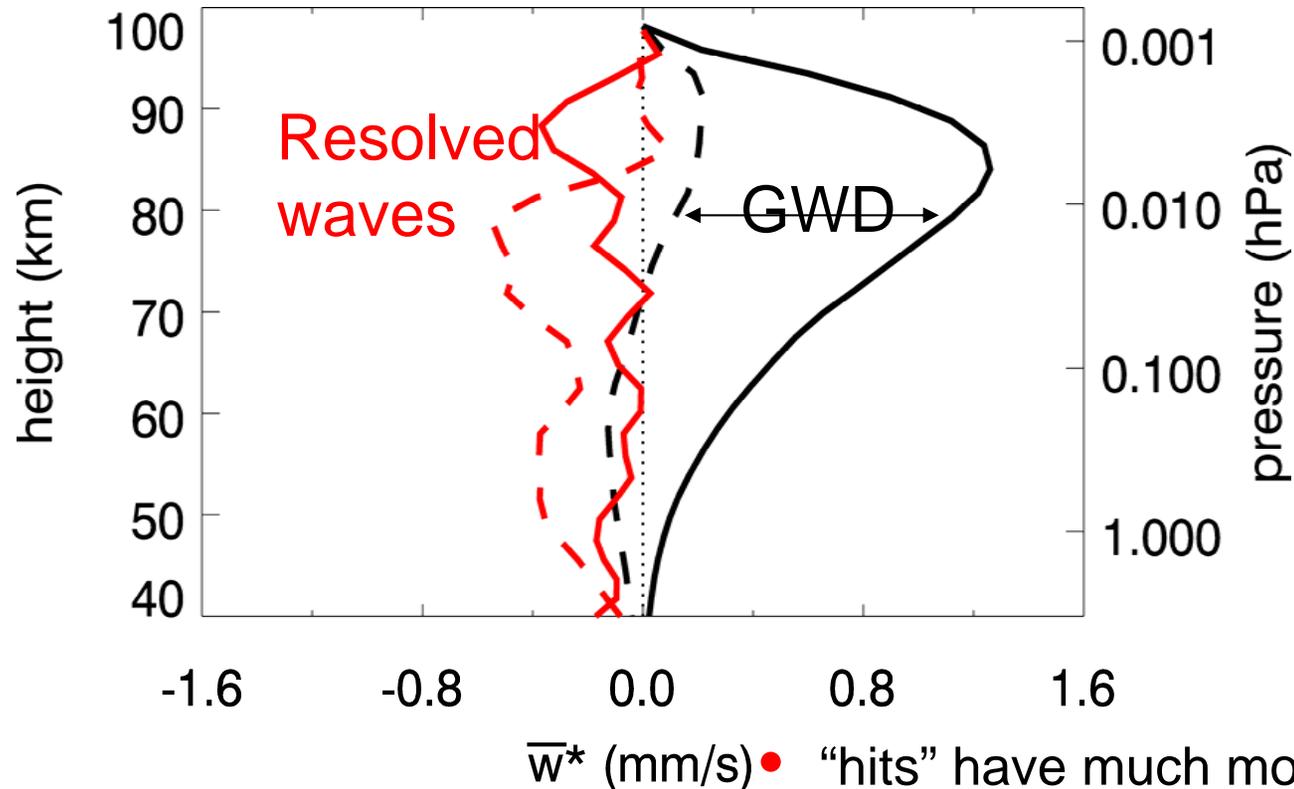
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Ren et al. (2008)

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Upwelling or cooling during 2002 SSW



Profiles are ensemble and time (28 Sept. to 1 Oct. 2002) avg.

- “hits” have much more cooling due to GWD at 80 km
- “hits” have more cooling due to resolved waves below 80 km



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Ren et al. (2008)

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Gravity Wave Drag (GWD) scheme couples information in troposphere and mesosphere

- In forecasts, GWD is driving amplitude and vertical extent of mesospheric cooling above stratospheric warmings
- With the lower atmosphere constrained by obs, zonal mean mesosphere is slaved to it and is predictable through GWD
- If model forecast does not match observations, GWD scheme needs adjusting
- Can use assimilation tools to identify gravity wave drag force



Using 4D-Var to estimate forcing due to gravity wave drag

Pulido and Thuburn (2005,2006,2008)

- Instead of using mismatch between observations and forecast to determine initial conditions (ICs), assume ICs correct and determine drag on u and v
- Knowns: u, v, T (Met Office analyses)
- By forcing equations with drag, a response includes geostrophic part and transient gravity waves
- Only rotational part of drag is estimated (one 3D field)
- Can estimate 3D daily drag field. Drag assumed constant over 24 h.
- Resulting drag field consistent with previous estimates
- Can we tune parameters in GWD schemes using data assimilation? (work in progress by Pulido)

Summary

- In a 3D assimilation scheme, information can propagate vertically during the forecast step through
 - Resolved waves
 - Parameterized effect of subgrid scale waves
- Since the mesosphere is to a large extent slaved to the lower atmosphere, observations of the troposphere and stratosphere help define large scales in mesosphere
Nezlin et al. (2009, Tellus)
- Since the mesosphere is very sensitive to perturbations in the lower atmosphere, we may be able to use mesospheric measurements to tune parameters in the troposphere (e.g. related to gravity wave sources)

