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Overview of recent progress in stratospheric and mesospheric data assimilation

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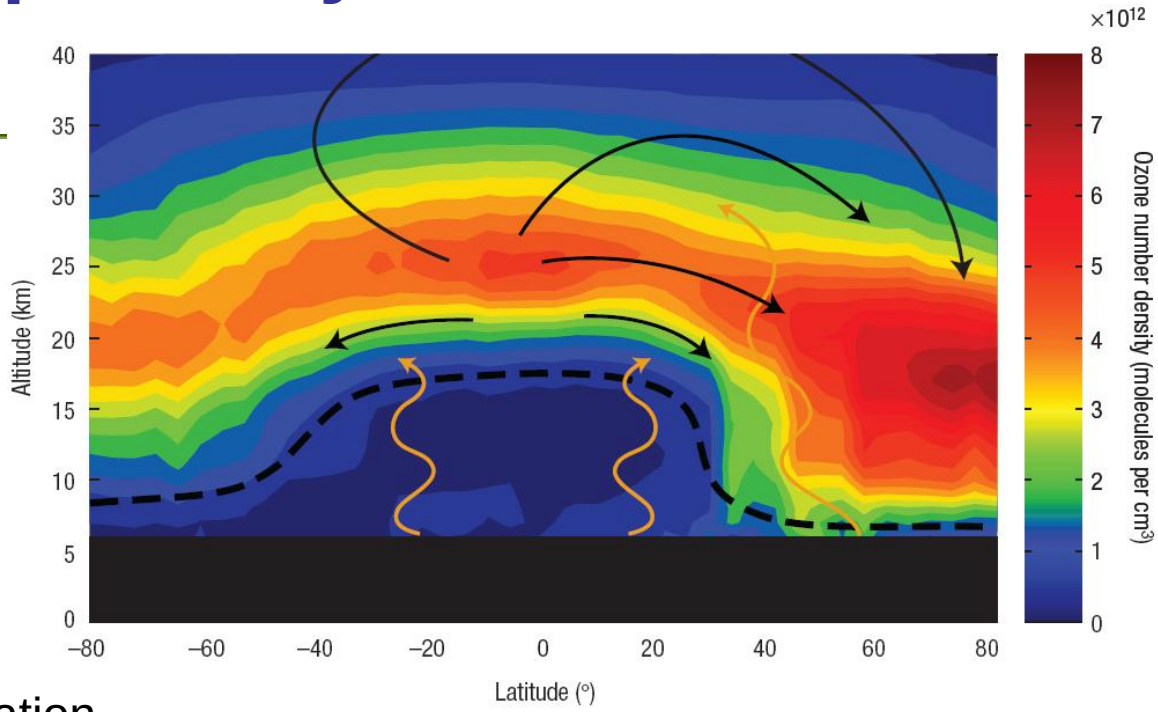
Advances in the past 5 years

- Operational weather centres raising model lids into the mesosphere
- Biases in the stratosphere
- Vertical propagation of information of observations into the mesosphere
- Gravity wave drag: estimating parameters

Middle Atmosphere Dynamics

Ozone from OSIRIS
for March 2004



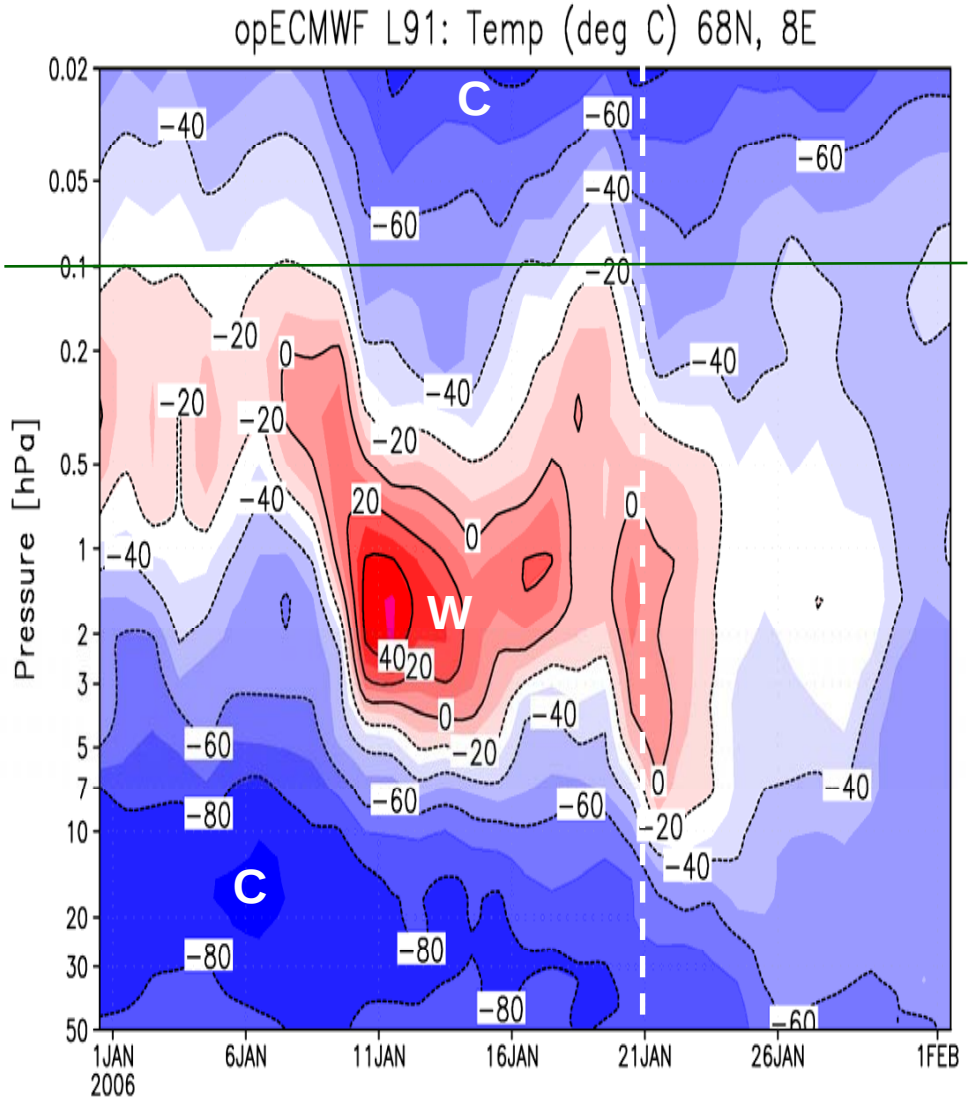
Shaw and Shepherd (2008)

- 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 (quasi-biennial oscillation)

Advances at operational centers

NH winter 2005-6

Figure courtesy of Kirsten Krüger



- Operational model lids are moving to 0.01 hPa (80 km)
- ECMWF, Feb. 1/06 GMAO since 2004 Met Office in 2009
- Can now see meso-spheric coolings above SSWs
- Can see stratopause evolution

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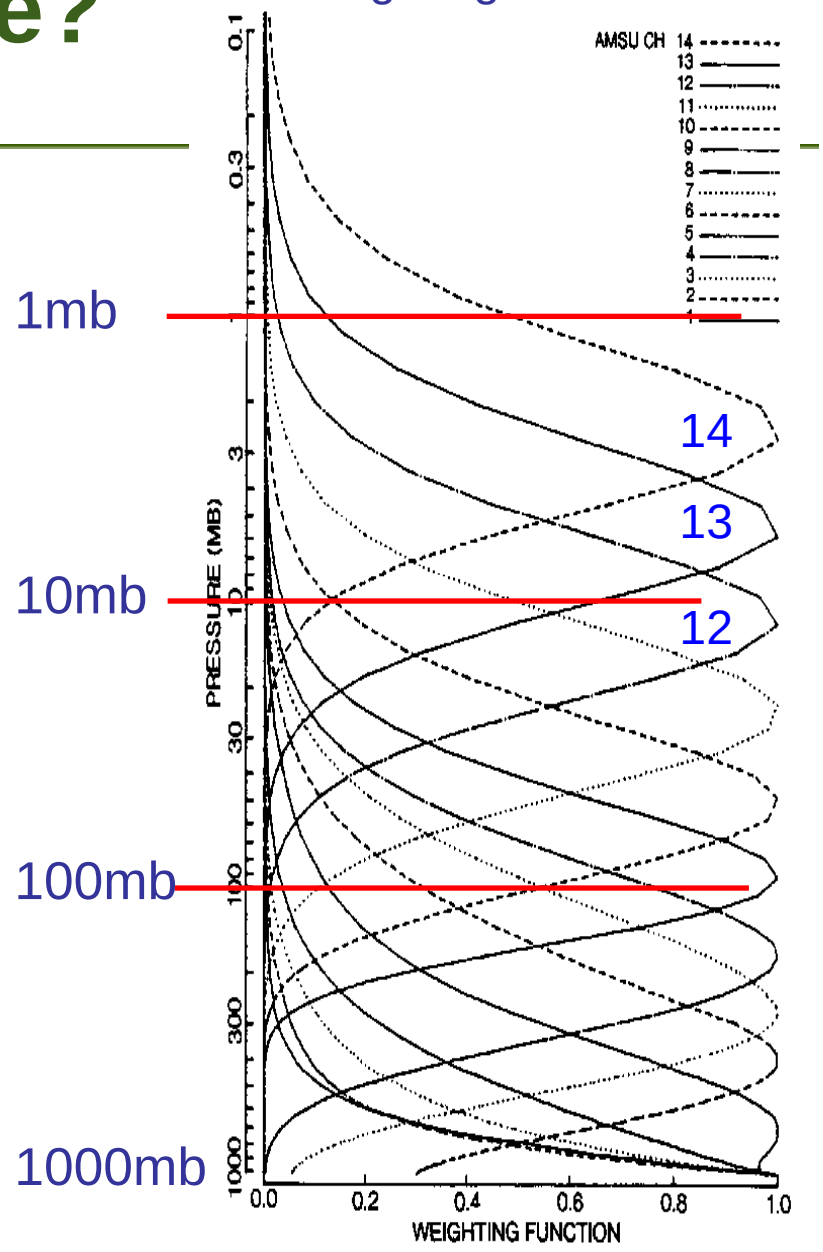
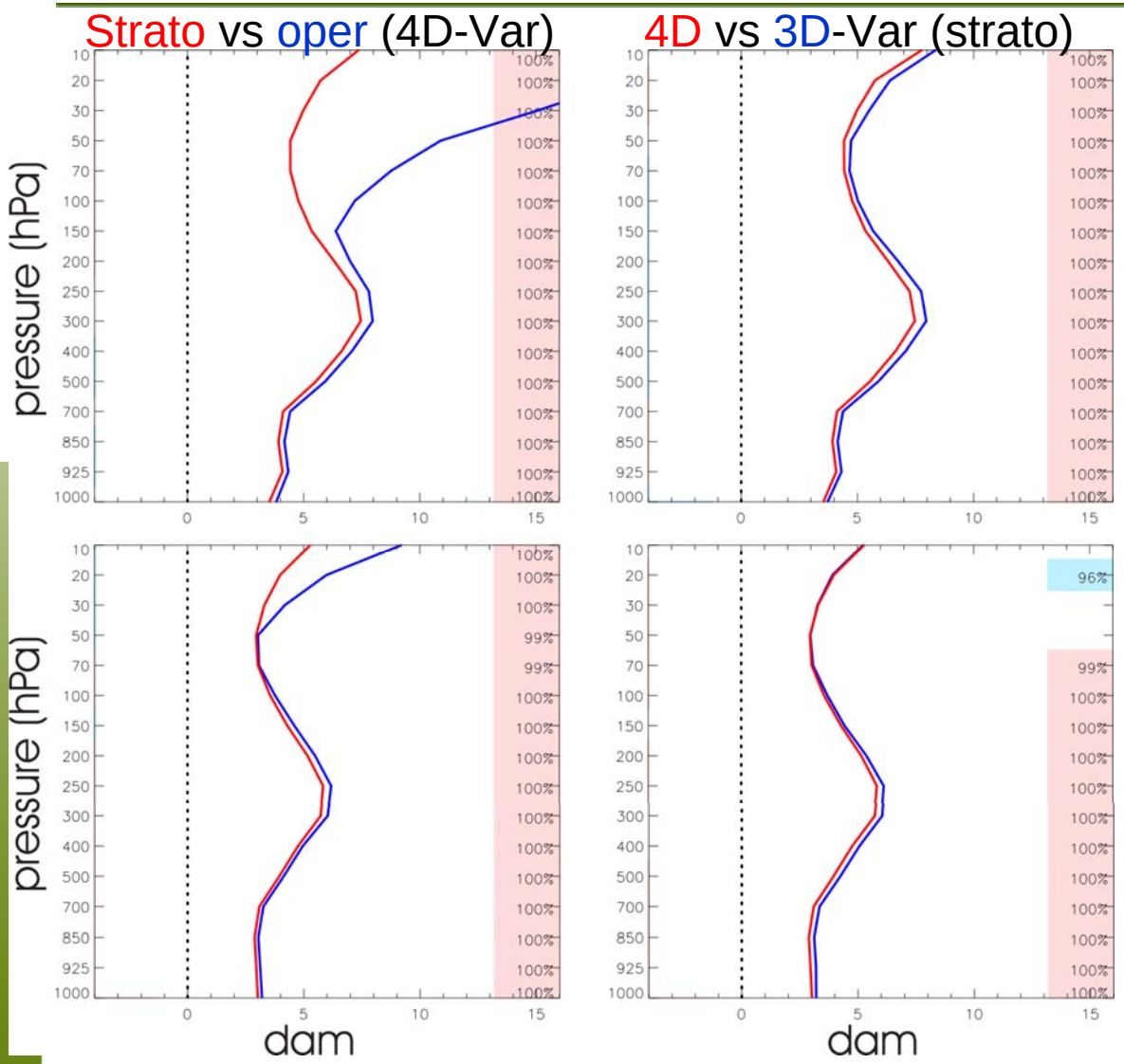
Why the mesosphere?

- Satellite radiances sense up to 0.1 hPa
- A model lid at 0.1 hPa means a sponge layer below this so obs (e.g. ch. 12-14) not well assimilated due to sponge
- To resolve Brewer-Dobson circulation, and winter polar temperatures and ozone descent, need good stratopause simulation, so sponge above 0.1 hPa

AMSU normalized weighting functions



Improving the stratosphere improves forecasts even in the troposphere



O-F(5 day) against NH sondes for GZ

Dec. 20 – Jan. 26, 2006 (75 cases)

Winter

Impact of strato extends into troposphere

Summer

June 15 – July 27, 2006 (86 cases)

Charron, Vaillancourt, Roch

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Zonal mean stratopause altitude

Figure courtesy of Gloria Manney

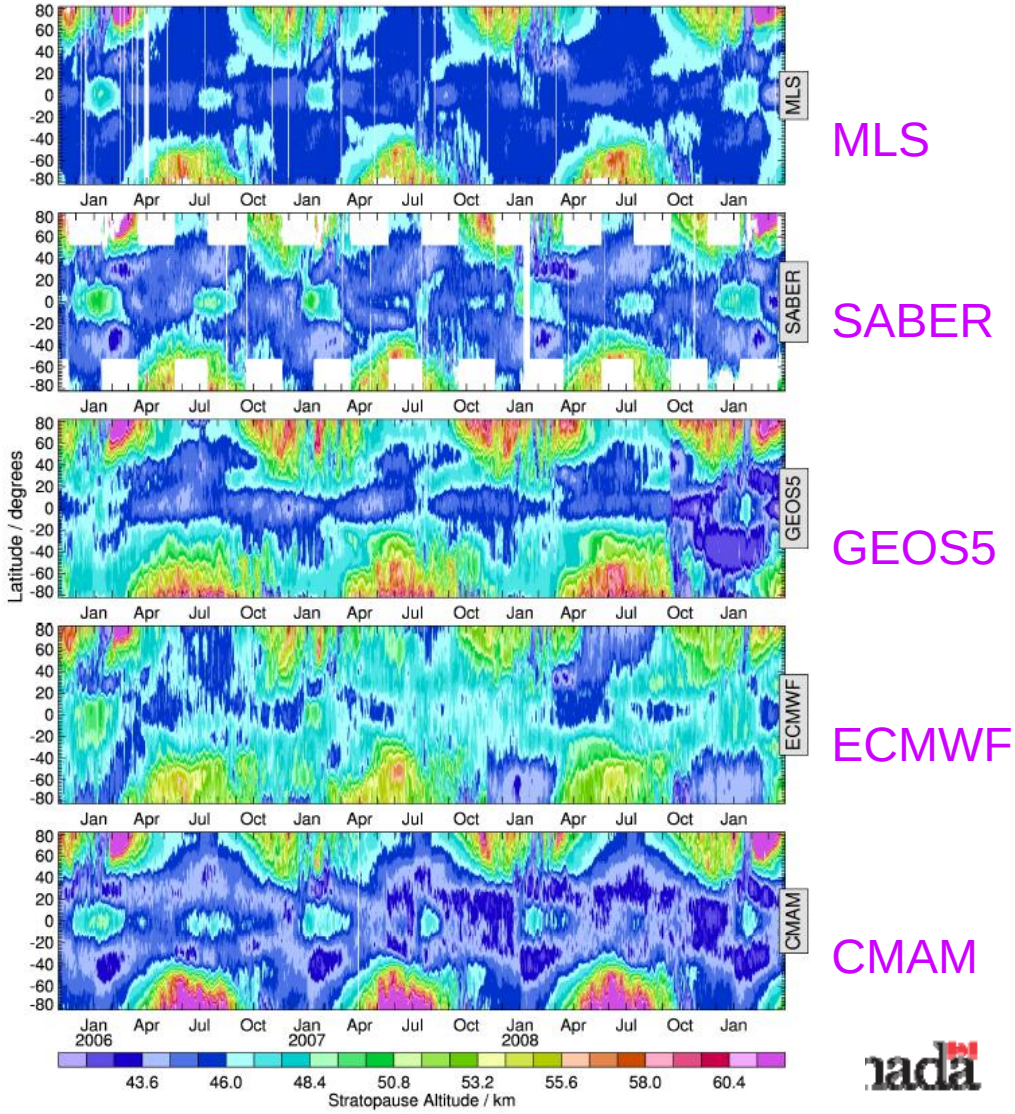
Nov. 2005 to March 2009

- Polar stratopause: high in winter, low in summer

  Analyses have trouble with low summer pole stratopause

- MLS, SABER show clear semi-annual variation in tropics

  Most analyses miss tropical semi-annual oscillation



MLS

SABER

GEOS5

ECMWF

CMAM

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Expect bias in stratosphere

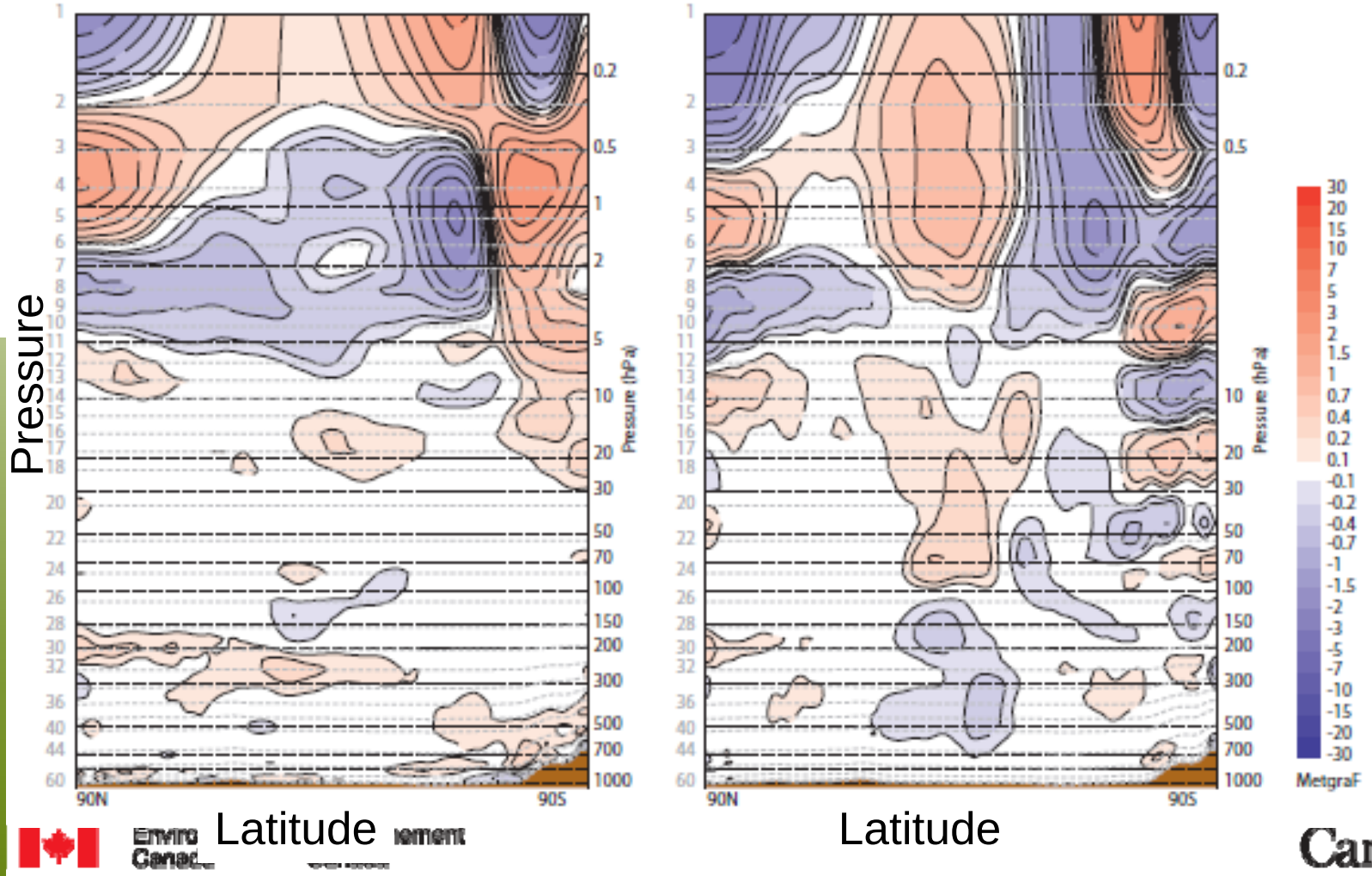
- Since not all waves will be correctly analysed, and some waves are forced by uncertain parameterizations, we should expect errors in forcing of meridional circulation
- Errors in forcing of meridional circulation will create a latitudinally varying bias
- Measurements (e.g. nadir sounders) also have bias
- Bias in measurements is often removed prior to assimilation by assuming forecast is unbiased

Zonal mean temperature analysis increments for August 2001

Dee and Uppala (2008)

ERA-Interim

ERA-40



Variational bias correction

Derber and Wu (1998)

Model for bias

Bias parameters

$$\mathbf{b}(\beta, \mathbf{x}) = \sum_{i=0}^{N_P} \beta_i \mathbf{p}(\mathbf{x}_i)$$

Model state

predictors

$$J(\mathbf{x}, \beta) = \left(\mathbf{x}^b - \mathbf{x}\right)^T \mathbf{B}_x^{-1} \left(\mathbf{x}^b - \mathbf{x}\right) + \left(\beta^\beta - \beta\right)^T \mathbf{B}_\beta^{-1} \left(\beta^\beta - \beta\right)$$

$$+ \left(\mathbf{y} - \mathbf{h}(\mathbf{x}) - \mathbf{b}(\mathbf{x}, \beta)\right)^T \mathbf{R}^{-1} \left(\mathbf{y} - \mathbf{h}(\mathbf{x}) - \mathbf{b}(\mathbf{x}, \beta)\right)$$

Bias parameters are determined using fit to all observations

Bias correction will adjust for bias in observations ($\mathbf{y}$), obs operator ($\mathbf{h}$), and model state ($\mathbf{x}$)

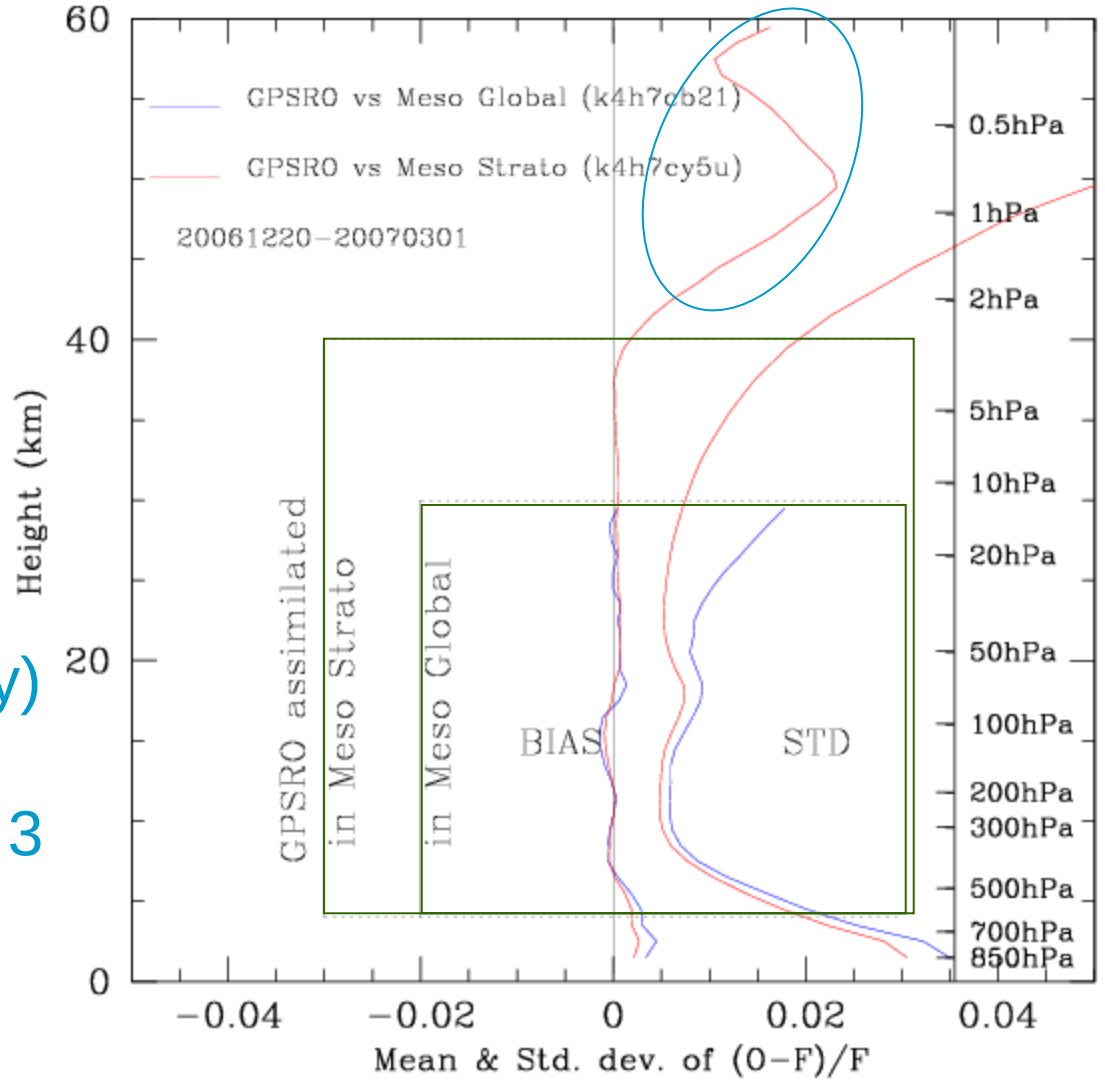
Forecasts are biased in the upper stratosphere

Figure courtesy of Josep Aparicio

Compare EC global model forecasts to GPS RO data

(O-F)/F
O=GPS-RO
F=6h forecast

Refractivity (~density) too low →forecasts are too warm above 3 hPa



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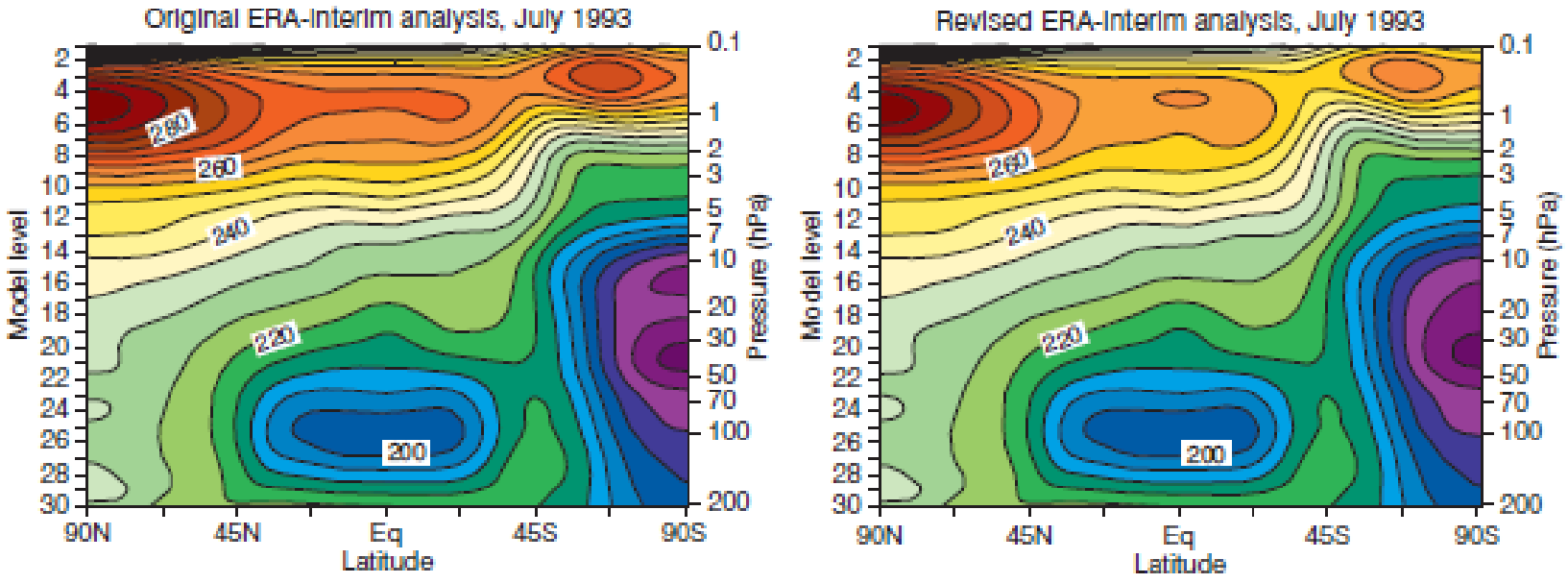
Do not bias correct obs at model top

Dee and Uppala 2008

- Bias correction for SSU ch. 3 (peak ~2 hPa) too large compared to accuracy of instrument
- Assume SSU correct. Do not bias correct it (except scan angle bias)
- Zonal mean temperature reduced. (Model forecast was biased warm)
- In general: anchor analyses at top using uncorrected data (SSU ch. 3 or AMSU ch. 14)

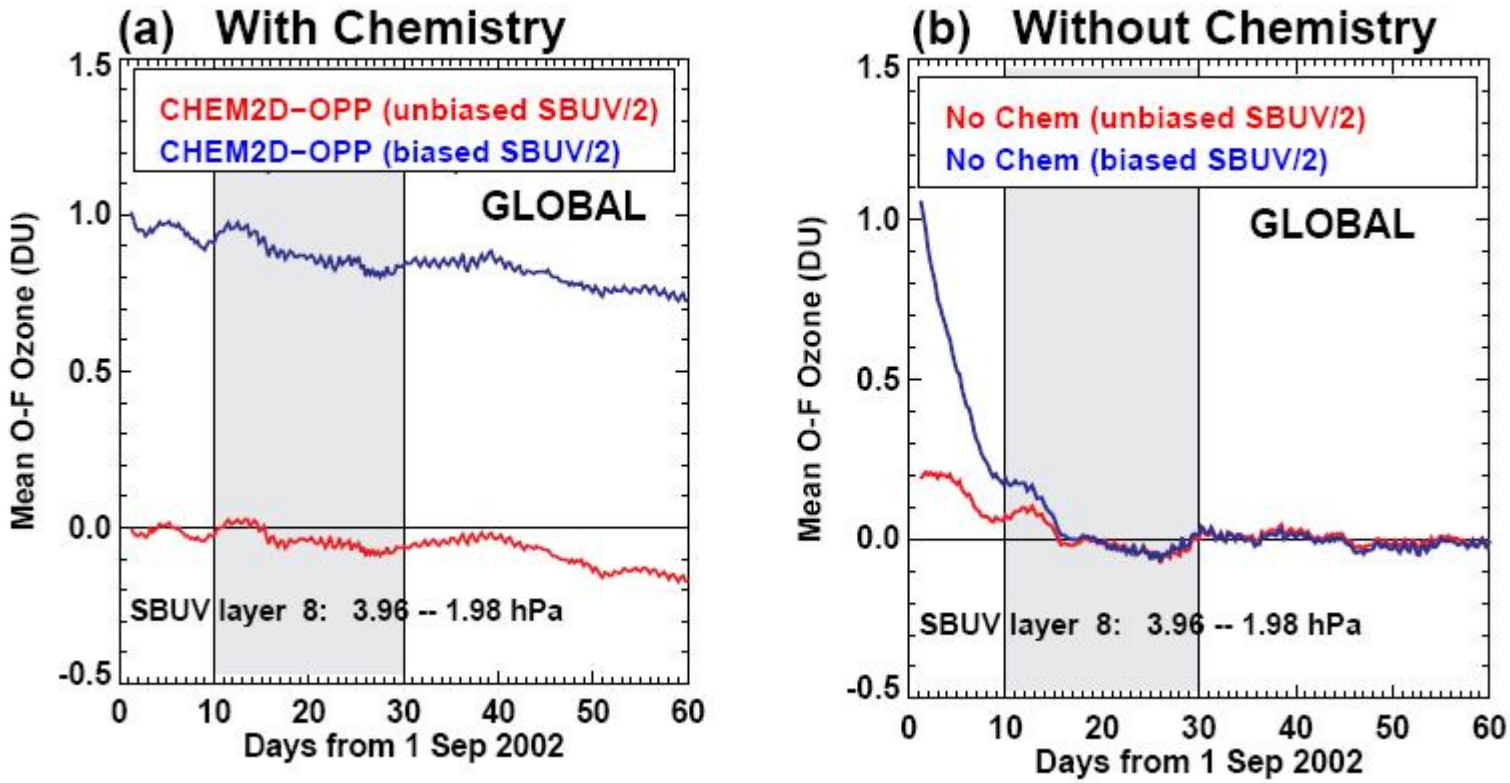


Summary: stratospheric T bias

- Variational bias correction helps improve bias in tropospheric analyses
- Anchoring analyses with uncorrected obs near model top means forecast brought closer to raw obs
- But sensors are on multiple platforms and sensors appear or disappear (e.g. SSU to AMSU change)
- Ideally, should correct forecast error bias by improving model
- Nadir sounders sense deep layers in stratosphere so vertical structure in analyses reflects vertical correlations in background error
- Need more limb measurements with high vertical resolution! E.g. GPS-RO

Impact of chemistry in upper stratosphere on assimilation

Coy et al. (2007)

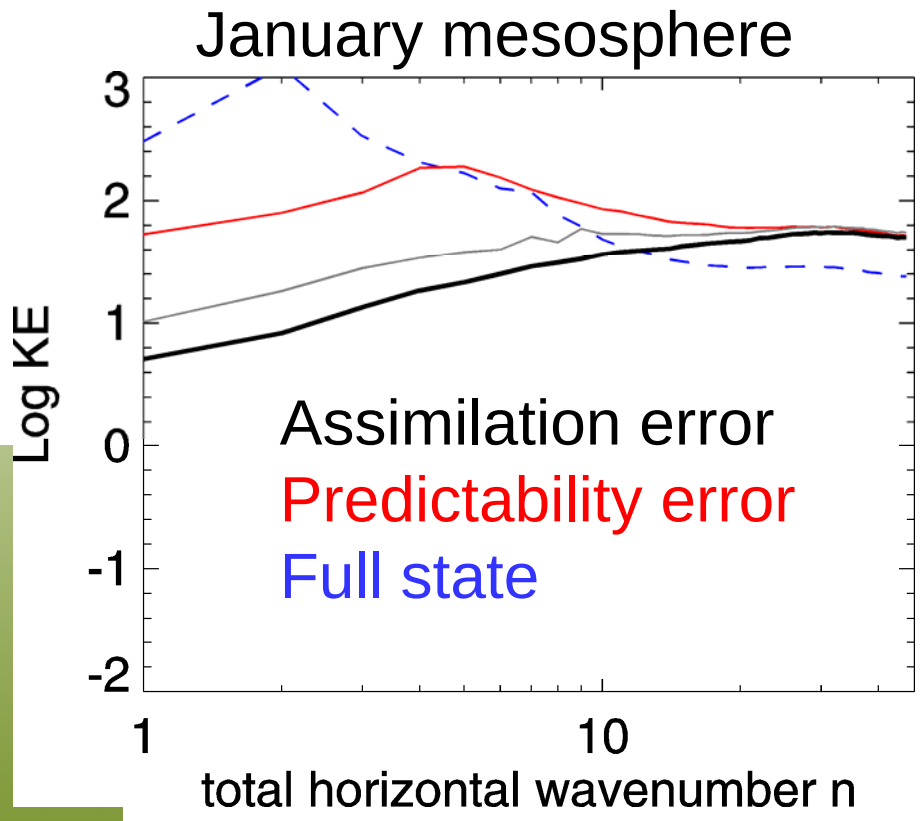


- t(ozone) ~ 1 day for SBUV layer 8 (2-4 hPa)
- Obs bias → Analysis bias → Forecast bias, if no chemistry.
  So O-F bias → zero
- Obs bias → Analysis bias → 0 if chemistry damps ozone.
  So O-F bias → O bias Can detect obs bias!

Moving on up (to the mesosphere)

- A model lid near the mesopause helps improve simulation of stratosphere
- The mesosphere is now part of weather forecasting domain
- With observations in the troposphere and stratosphere only, what happens to the mesosphere? Is it improved?

Tropospheric and stratospheric obs help determine large scales in mesosphere

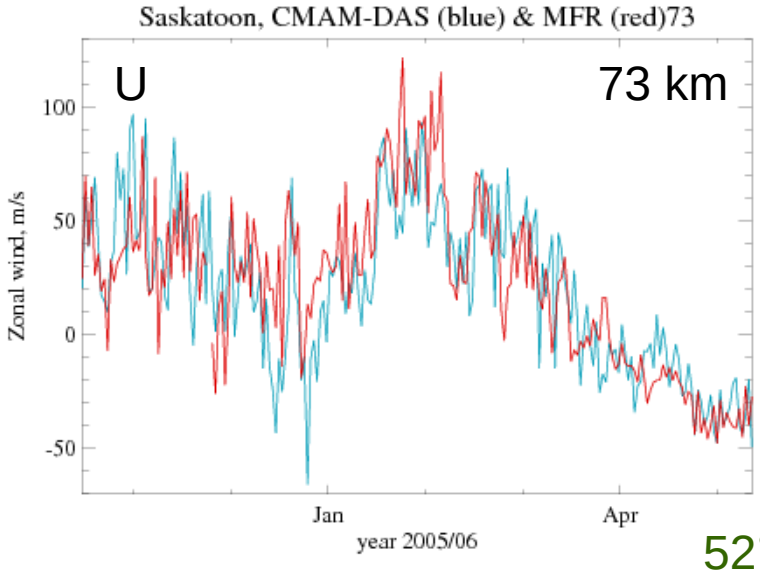


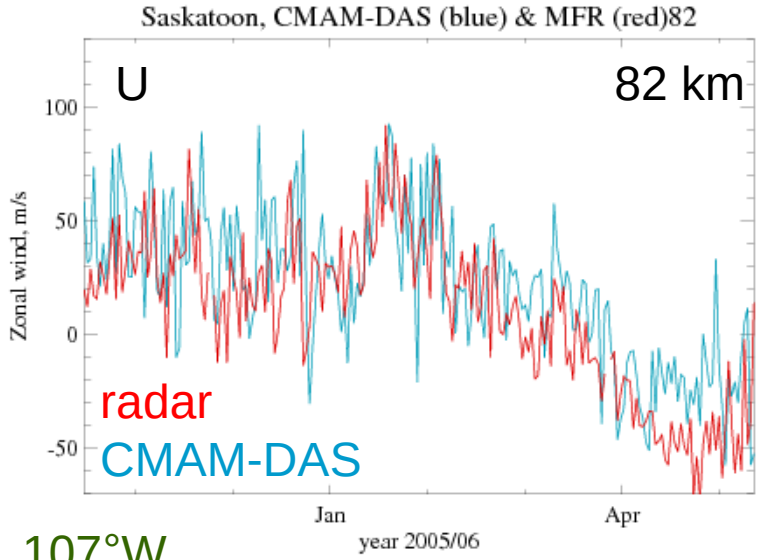
Nezlin et al. (2009)

- "Reference" is model generated, so known
- Obs below mesosphere only in CMAM-DAS
- Model forecast propagates information from troposphere and stratosphere to mesosphere

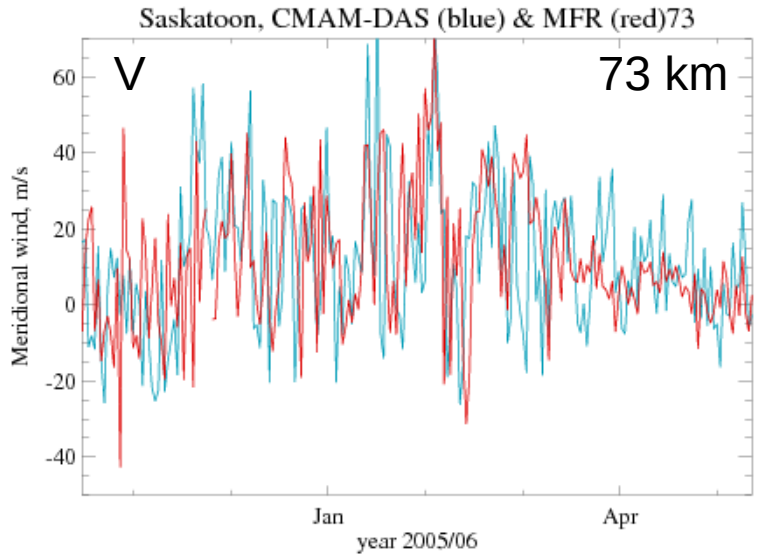
Mesospheric analyses have some value even when obs only below 45 km

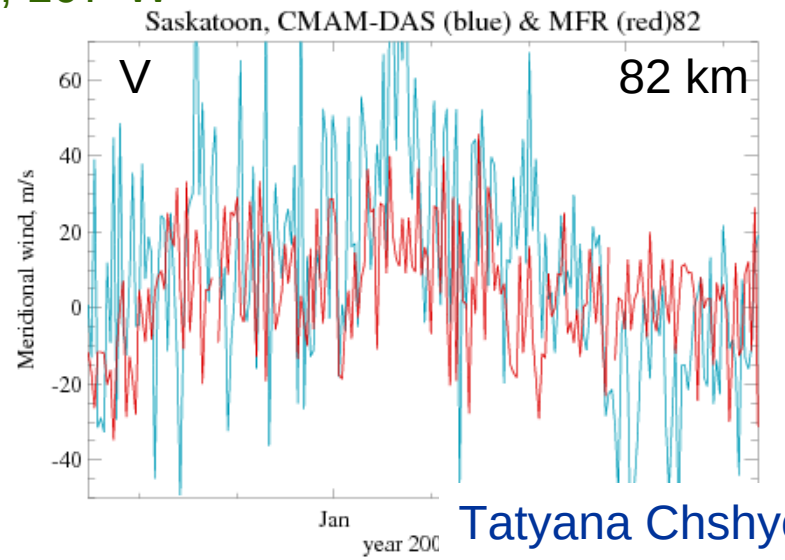
Compare CMAM-DAS to Saskatoon radar winds at noon





52°N, 107°W





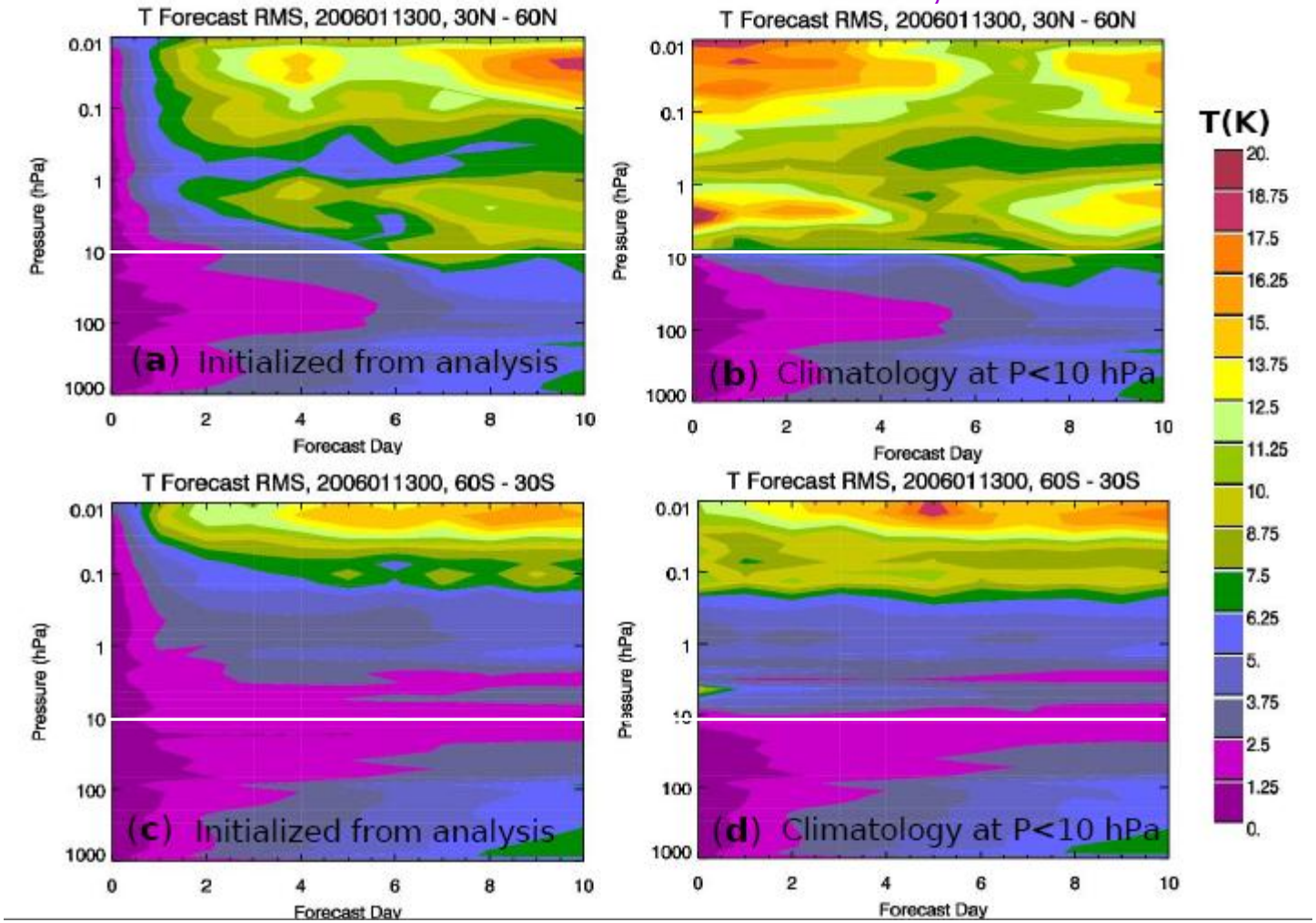
Tatyana Chshyolkova

Assimilating mesospheric obs is useful esp in winter

Hoppel et al. (2008, SPARC Newsletter no. 30, p.30)

Forecasts from analyses

Forecasts from climatology
UARS-URAP, CIRA above 10 hPa



- NRL's model NOGAPS-ALPHA T79L68, lid at 96 km
- SABER, MLS temperature assimilated 32-0.01 hPa
- 12 forecasts during Jan-Feb 2007

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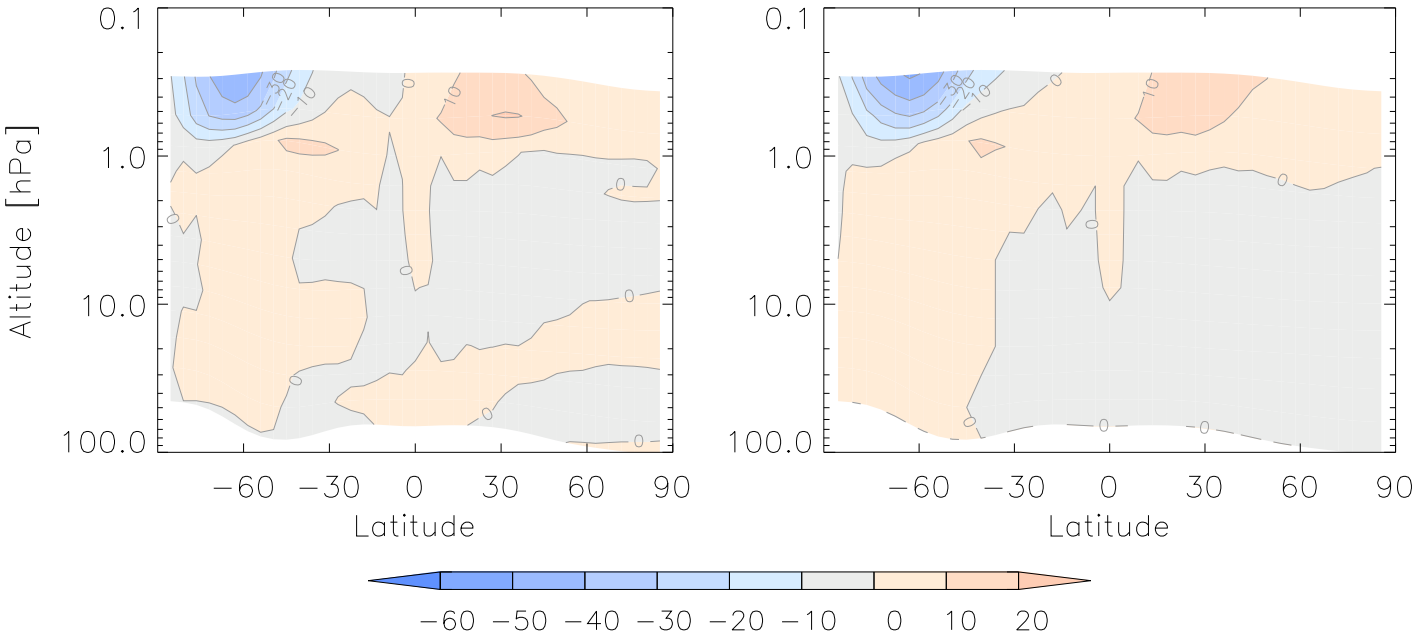
Information propagation through a Gravity Wave Drag (GWD) scheme

- 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

Estimating GW source parameters

Figure courtesy of Manuel Pulido



Missing zonal force for July 2002 due to unresolved waves. Estimated with a 4DVar assimilation system (Pulido and Thuburn 2008, JC).

Forcing from Scinocca (2003, JAS) GWD scheme using the optimum parameters (Pulido et al. 2009, in preparation).

Invited talk by Manuel Pulido: Friday 9:00 Room 520F

Poster today at 15:00 J21

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Summary

- Operational weather centres raising model lids into the mesosphere
- Bias remains an issue in upper stratosphere and mesosphere
- Observations from tropo and stratosphere can define large scales in mesosphere
- Can apply assimilation methods to estimate parameters in Gravity wave drag schemes