Environment Canada | Environnement Canada

Canada

Data assimilation for climate applications

Saroja Polavarapu
Meteorological Research Division
Environment Canada, and,
University of Toronto

MOCA-09, Session M01, Montreal, Canada, 21 July 2009

Learning about models with data assimilation

- Data assimilation involves combining measurements and model forecasts to get a “best” estimate of the atmospheric state on the model grid
- Data assimilation in atmospheric science is primarily used for obtaining an initial condition for launching numerical weather forecasts
- For climate applications, apart from reanalyses, the data assimilation process can be a diagnostic tool:
  - Confronting models with measurements can lead to insight into model deficiencies → useful for climate modellers
  - Comparing analyses and “new” measurements can give additional information on analysis quality, → feedback to assimilators

OUTLINE (Examples)

1. Comparing constituent forecasts (without constituent assimilation) to measurements

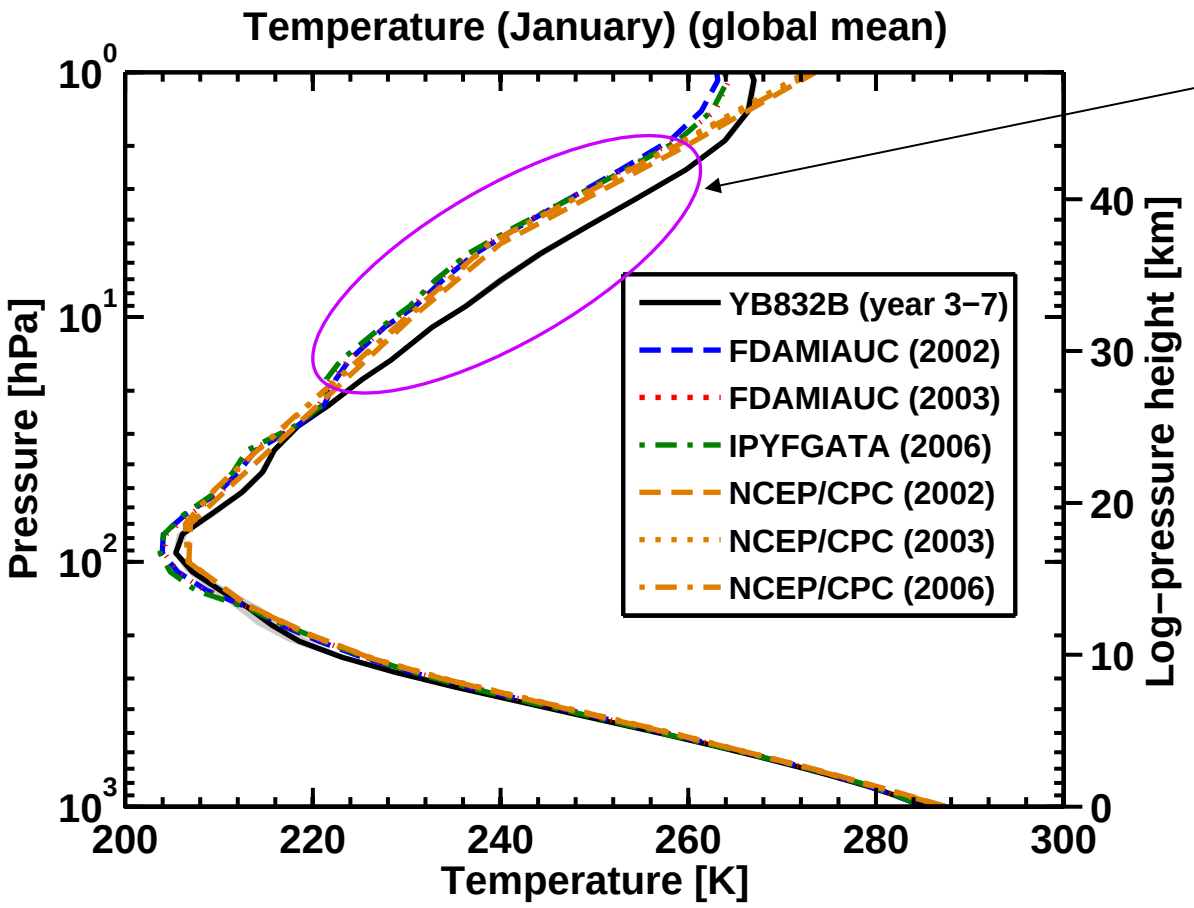
2. Using data assimilation to document slaving of zonal mean mesosphere to lower atmosphere

3. Estimating parameters in gravity wave drag schemes

4. Mesospheric 2-day wave

Assimilation of temperature

Figure courtesy of Andreas Jonsson



CMAM climatology is too warm in upper stratosphere

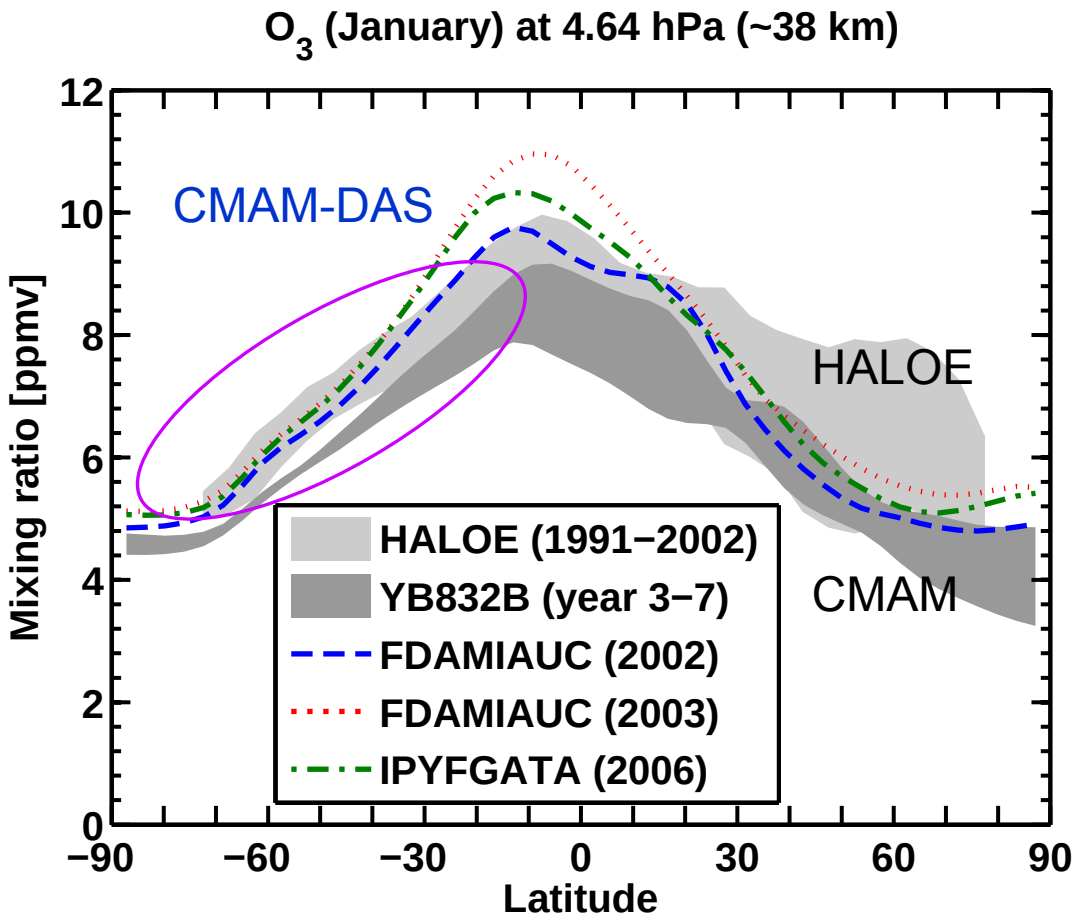
Data assimilation improves global mean temperature

Temperature assimilation impacts ozone

Figure courtesy of Andreas Jonsson

CMAM has too little ozone in upper stratosphere.

With temperature assimilation, ozone is improved due to temperature dependence of ozone loss cycles



Measurement or model bias?

Figure courtesy of Michaela Hegglin

ACE and CMAM

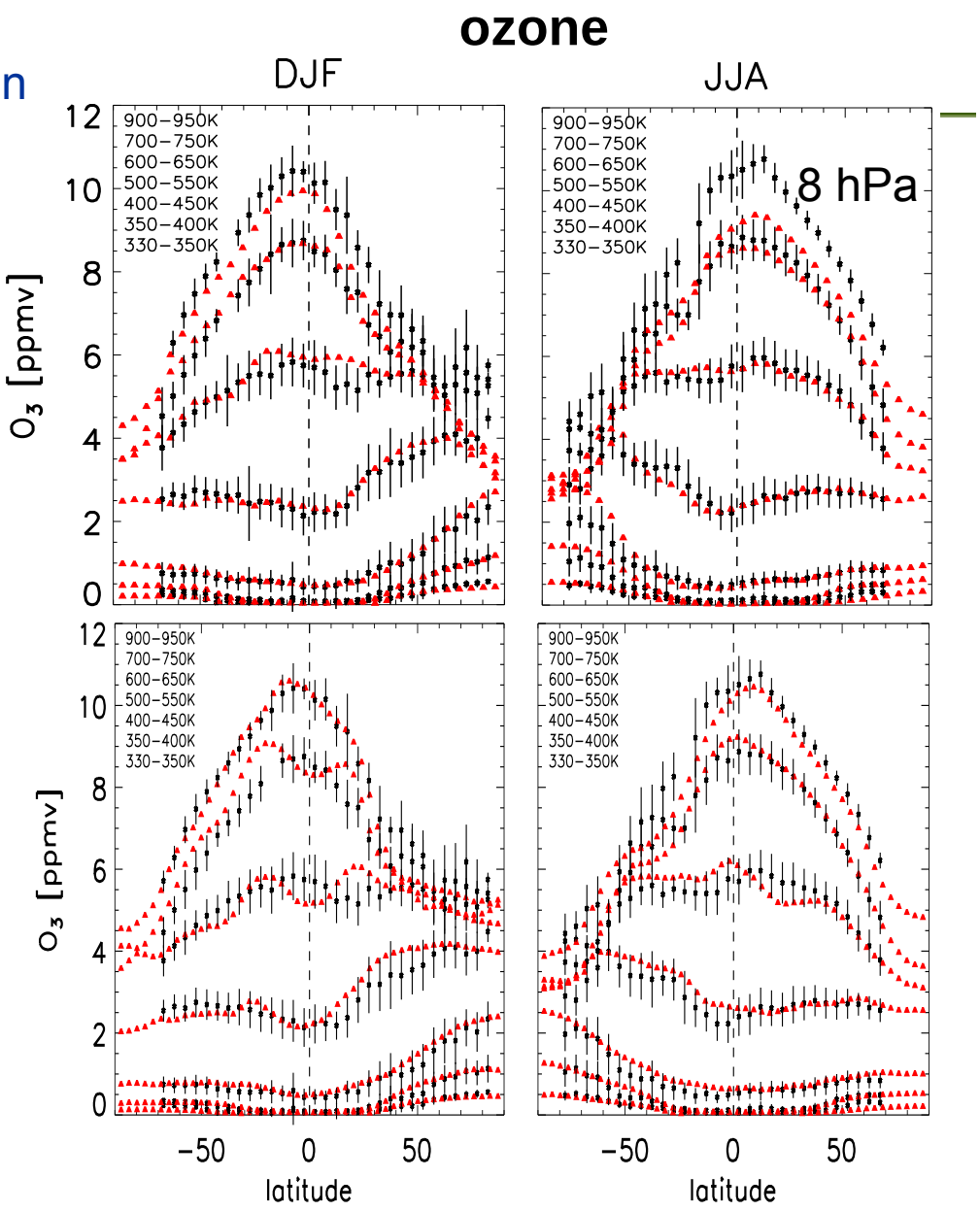
Good agreement between model and observations, except JJA low bias at 900-950 K.

Mismatch in upper stratosphere originally thought due to ACE (Hegglin and Shepherd, 2007)

ACE and CMAM-DAS (2002)

CMAM-DAS improves agreement with ACE in upper stratosphere. Relative bias is due to CMAM.

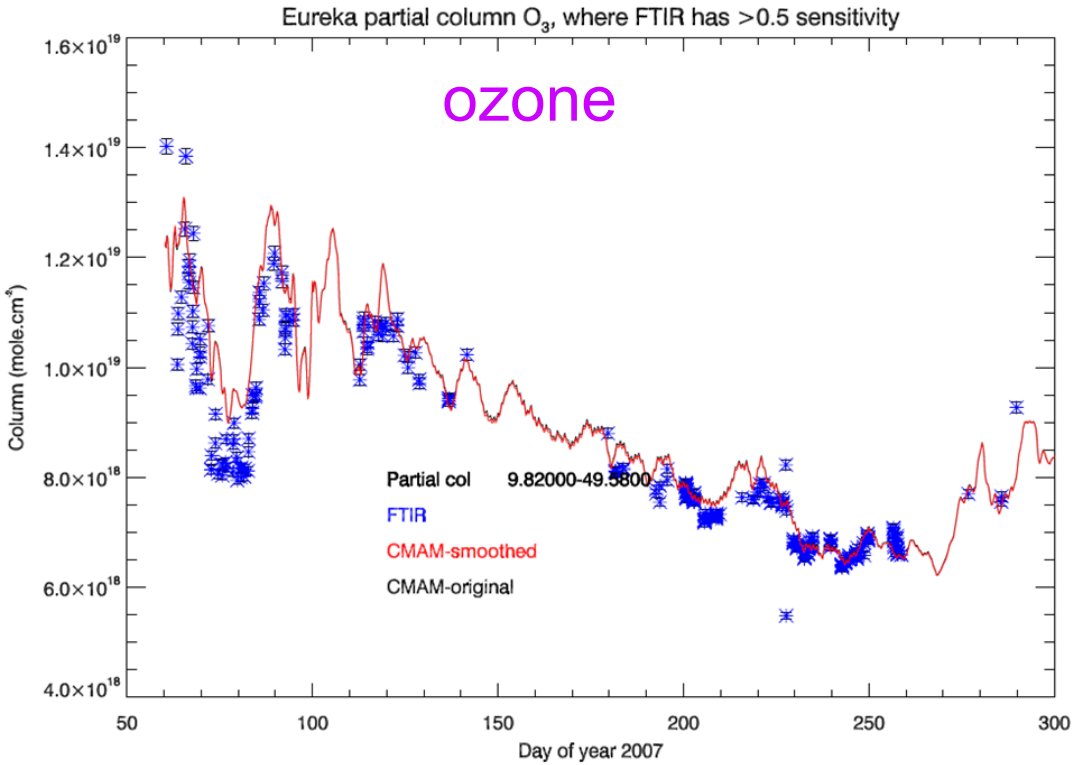
CMAM-DAS shows double peak in tracer meridional profile within the tropical pipe. Transport issues?



Environment Canada Environnement Canada

Comparison of CMAM-DAS chemistry to Eureka FTIR

Figure courtesy of Rebecca Batchelor



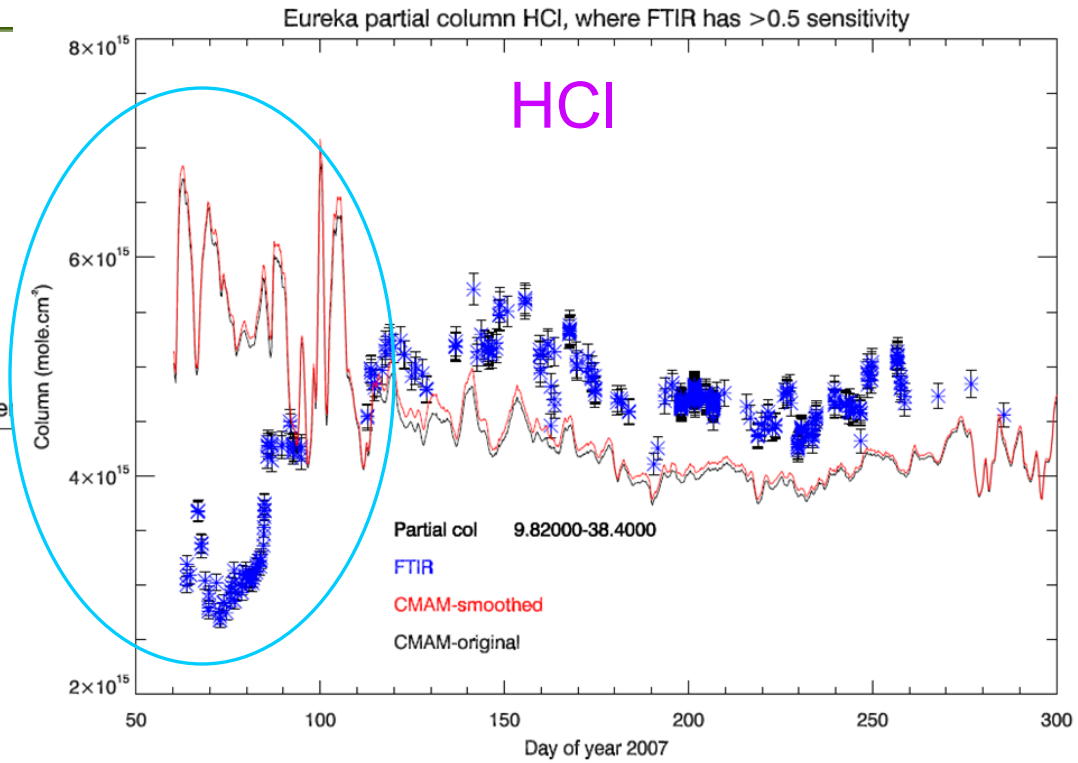
- Compare to polar point measurements (80 N) of partial column ozone
- CMAM-DAS has no ozone assimilation
- Good agreement over 250 days (longer too)
- But CMAM has 50 or so species. What about the others?
- Talk was J03 Monday 14:00

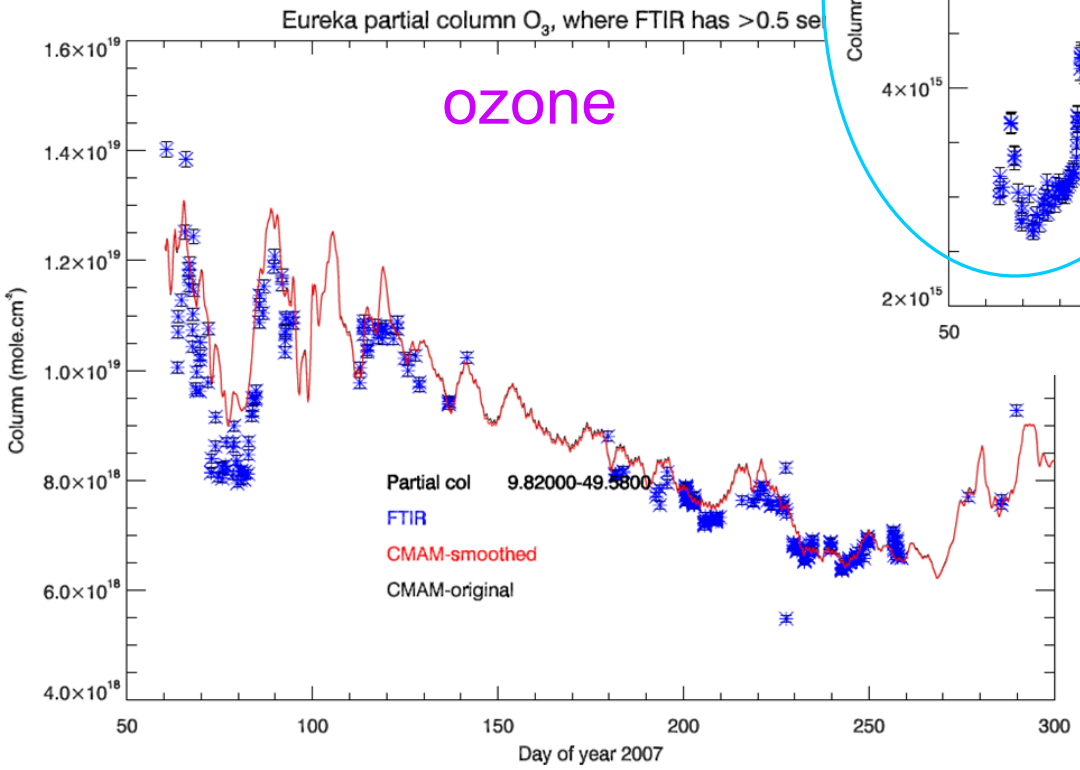
Canada

Comparison of CMAM-DAS chemistry to Eureka FTIR

Figure courtesy of Rebecca Batchelor

CMAM HCl is too high



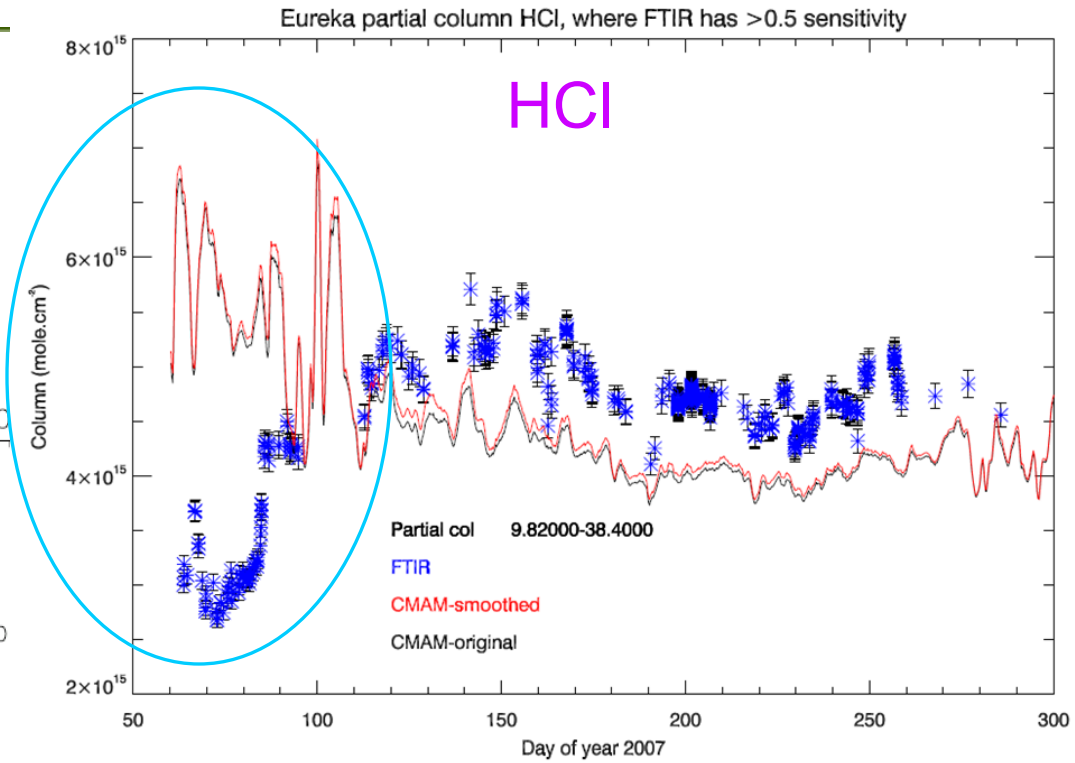


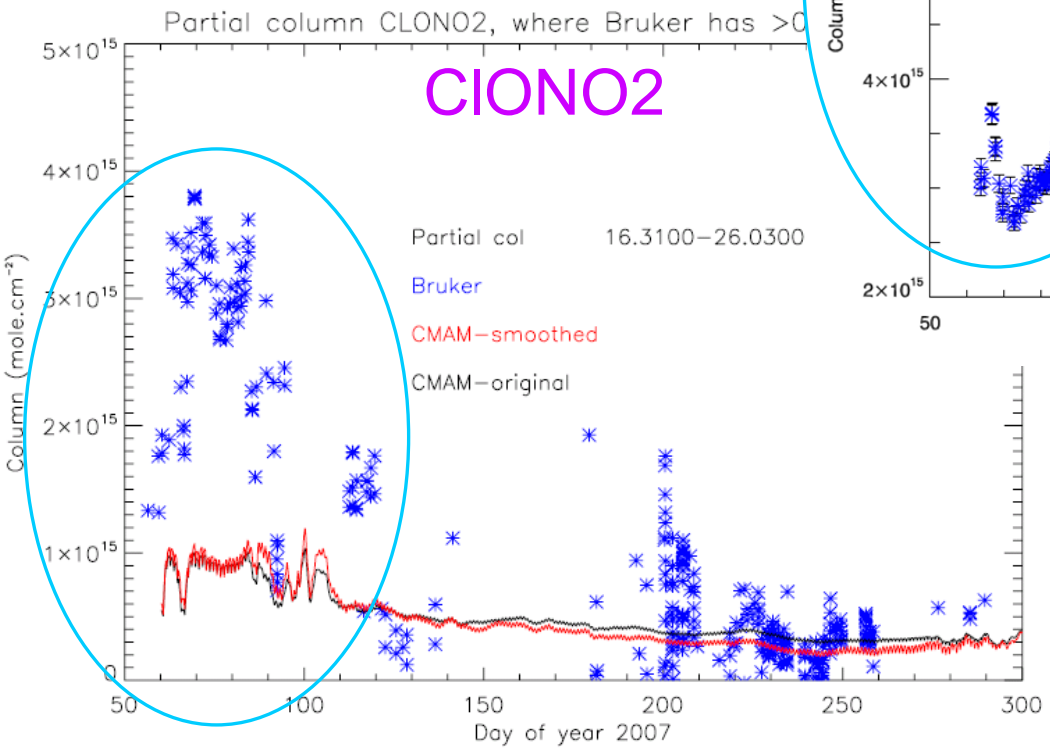
Canada

Comparison of CMAM-DAS chemistry to Eureka FTIR

Figure courtesy of Rebecca Batchelor

HCl is too high
$ClONO_2$ too low
Total Cl is fine





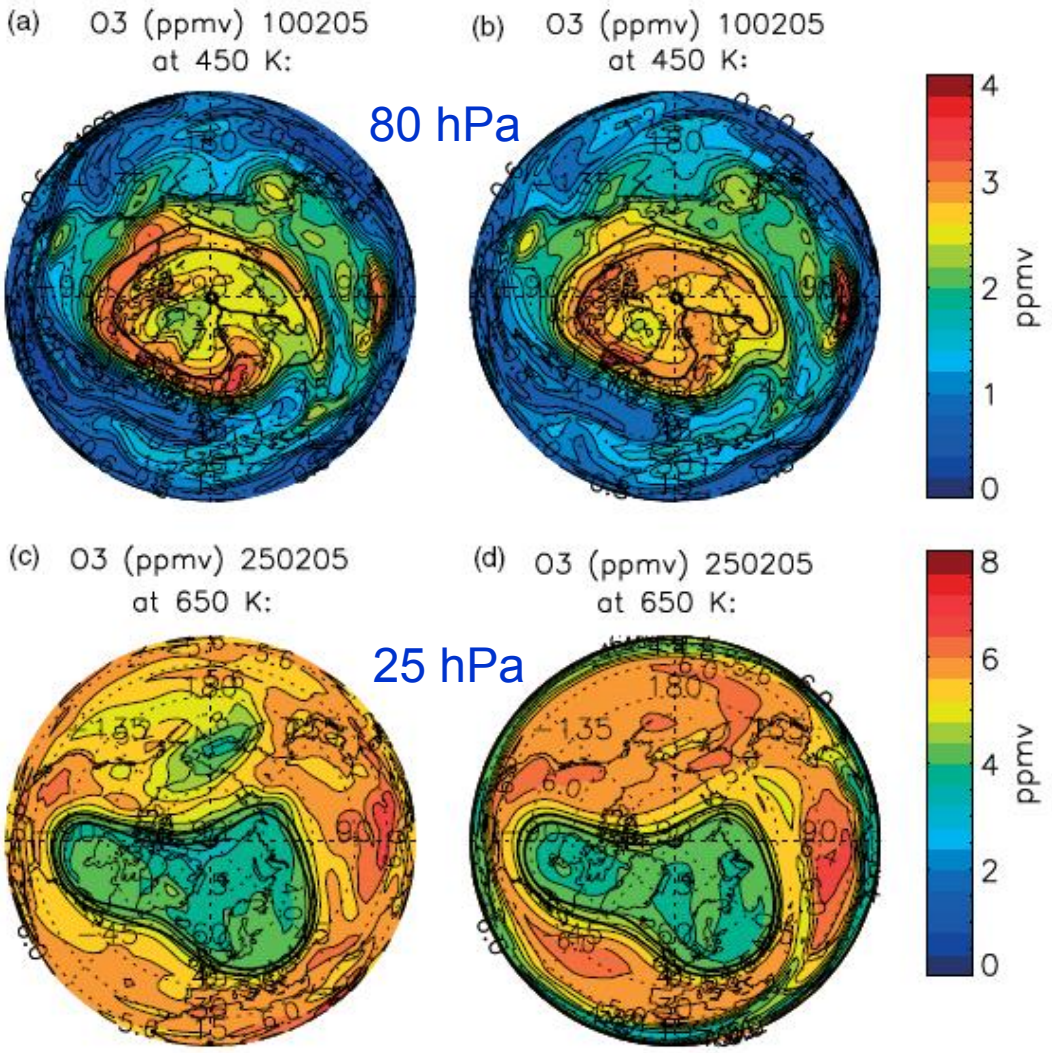
- partitioning of Cl is local only. HCl not advected separately
- PSC module had no NAT chem
- mesoscale dynamics important?
- T forecast are poor?

Canada

Estimating Arctic ozone loss

Jackson and Orsolini (2008)

Ozone assimilation Reference assimilation



- Compute difference between assimilated ozone run and reference run (both have T, winds assim.). Reference starts from spun-up ozone state
- Lower stratosphere: transport errors worse in reference run, smearing vortex edge
- Can see ozone depletion outside vortex too
- Talk: M01 Tuesday 11:30

Canada

Summary: Assimilation with a Chemistry-Climate Model (CCM)

- Even without chemical data assimilation, dynamic variable assimilation with a chemistry-climate model can give useful information
  - Temperature dependence of loss cycles should lead to improved agreement with measured constituents where chemistry dominates over transport. If not, provides feedback to assimilators on temperature assimilation.
  - Case of separating model from measurement error
  - Can more quickly identify issues with chemistry model (a few months of assimilation compared to years of running in climate mode)

- With chemistry assimilation, can compare to unassimilated case to determine chemical loss (Jackson and Orsolini, 2008). Artifacts of assimilation cannot be excluded.

2. Using data assimilation to document slaving of zonal mean mesosphere to lower atmosphere

Use CMAM-DAS with no mesospheric measurements

Zonal mean stratopause altitude

Figure courtesy of Gloria Manney

Nov. 2005 to March 2009

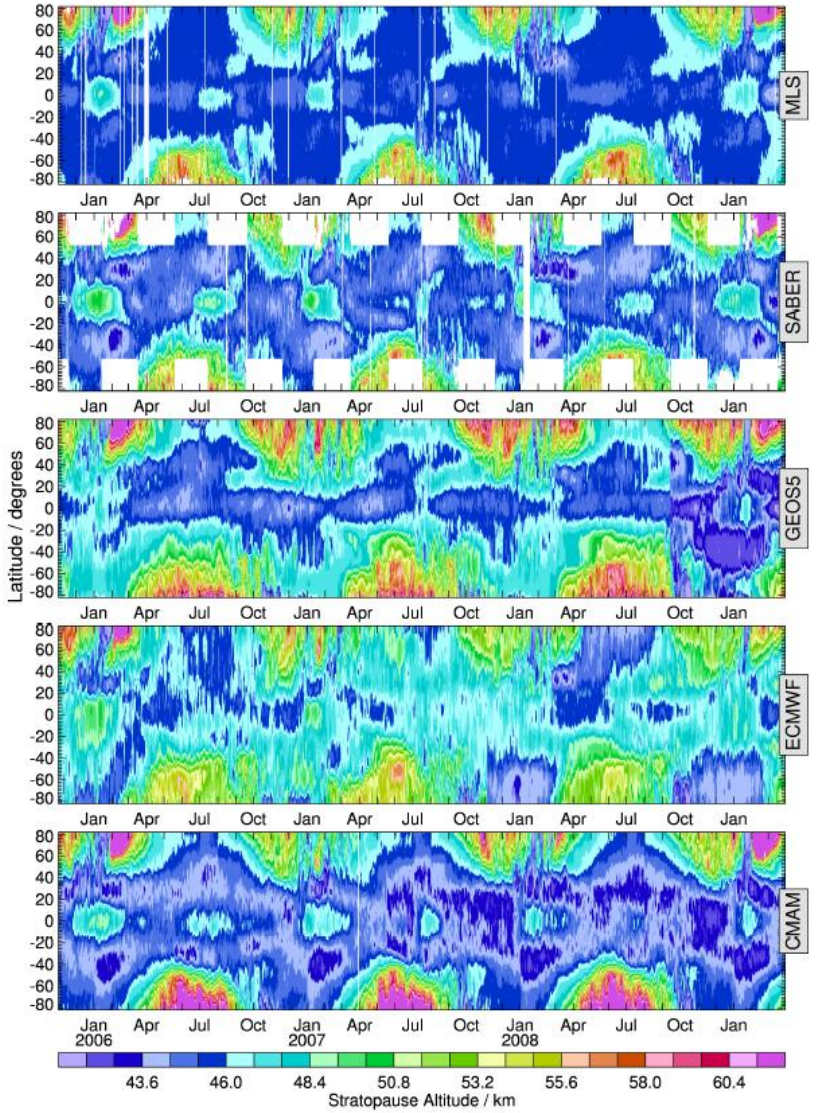
- Polar stratopause: high in winter, low in summer

  Analyses have trouble with low summer pole stratopause

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

  Most analyses miss tropical semi-annual oscillation

- Talk by Manney: M01 Tuesday 14:00



MLS

SABER

GEOS5

ECMWF

CMAM

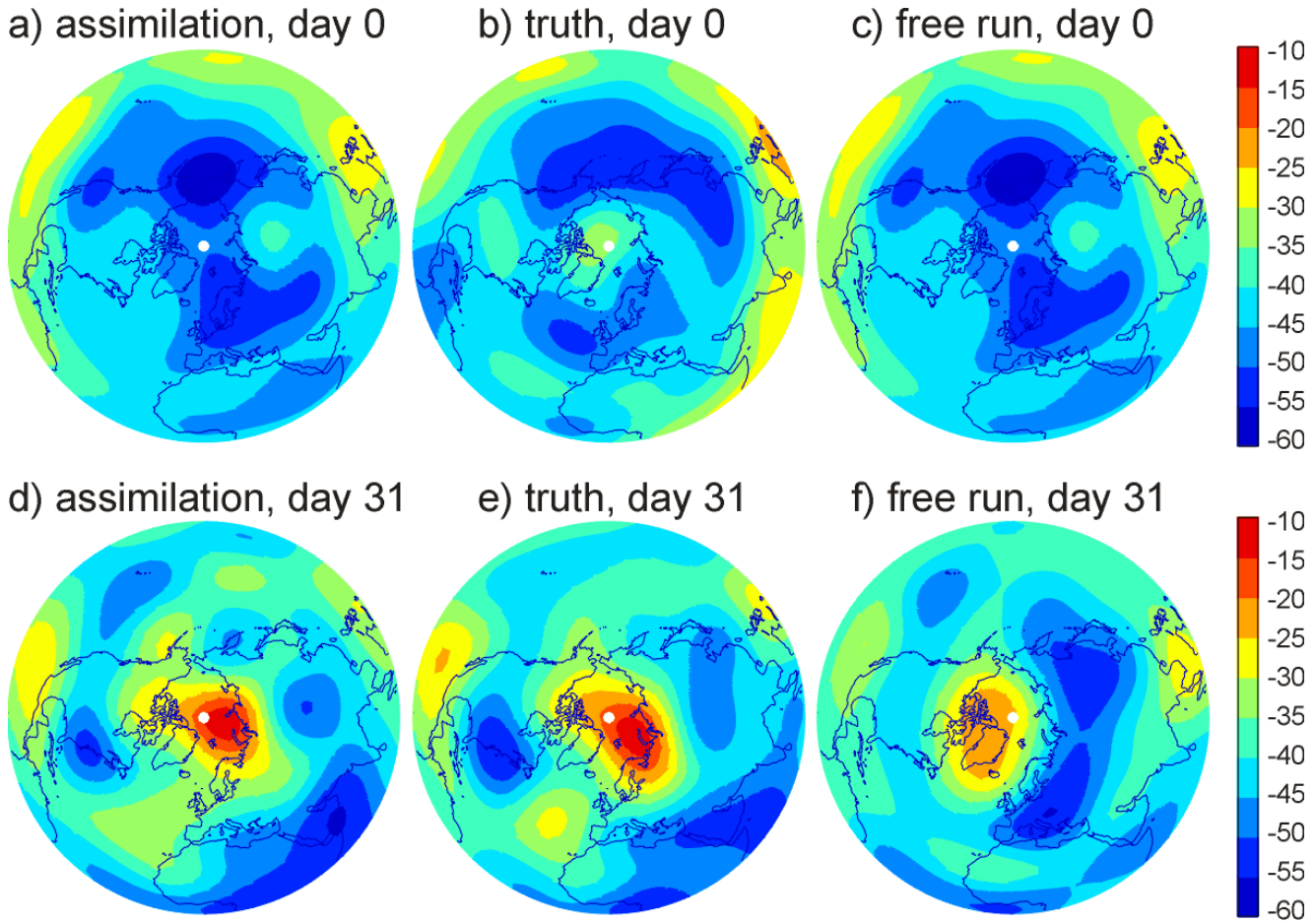
Environment Canada

Environnement Canada

Assimilating data below the mesosphere improves large scales in mesosphere

Nezlin et al. (2009)

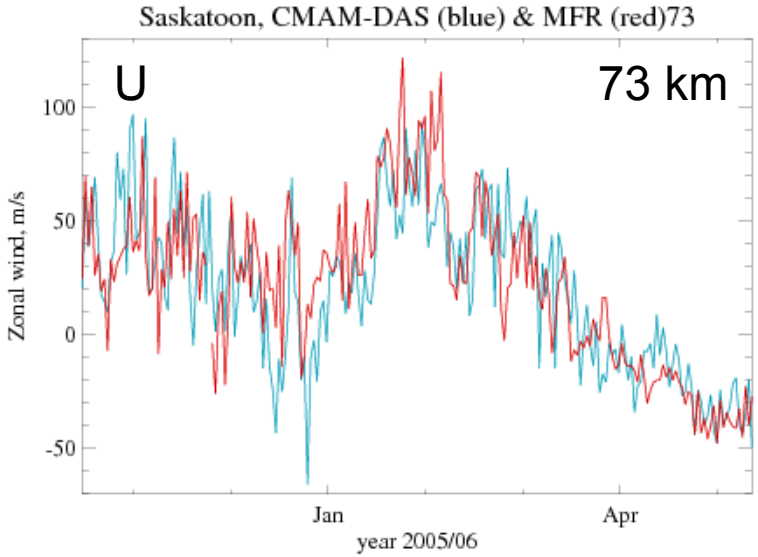
Temperature at 65 km spectrally truncated to T10

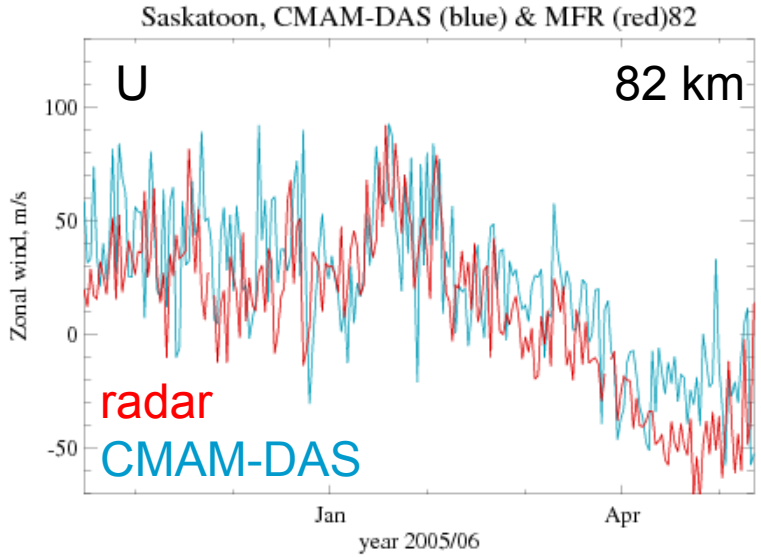


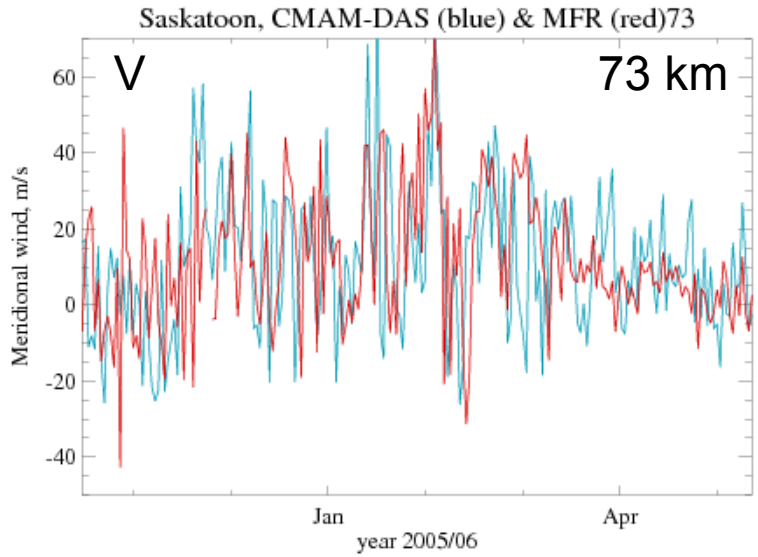
Talk by Nezlin: M01 Tuesday 14:30

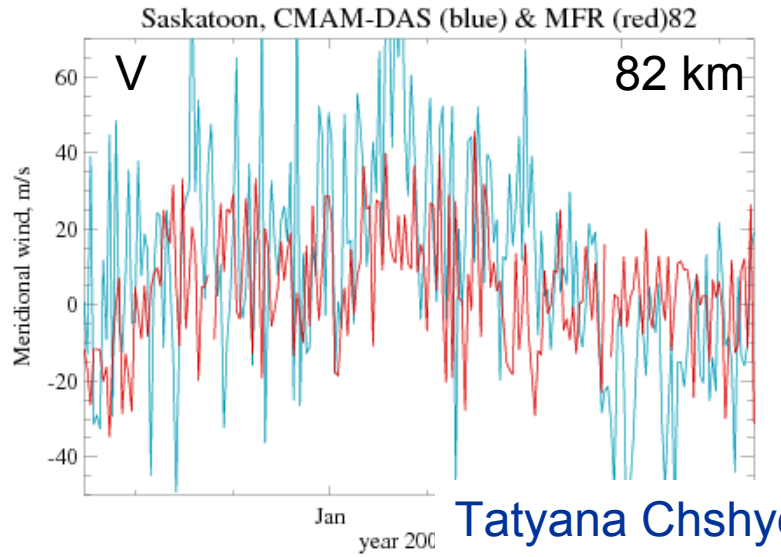
Mesospheric analyses have some value even when obs only below 45 km

Compare CMAM-DAS to Saskatoon radar winds at noon





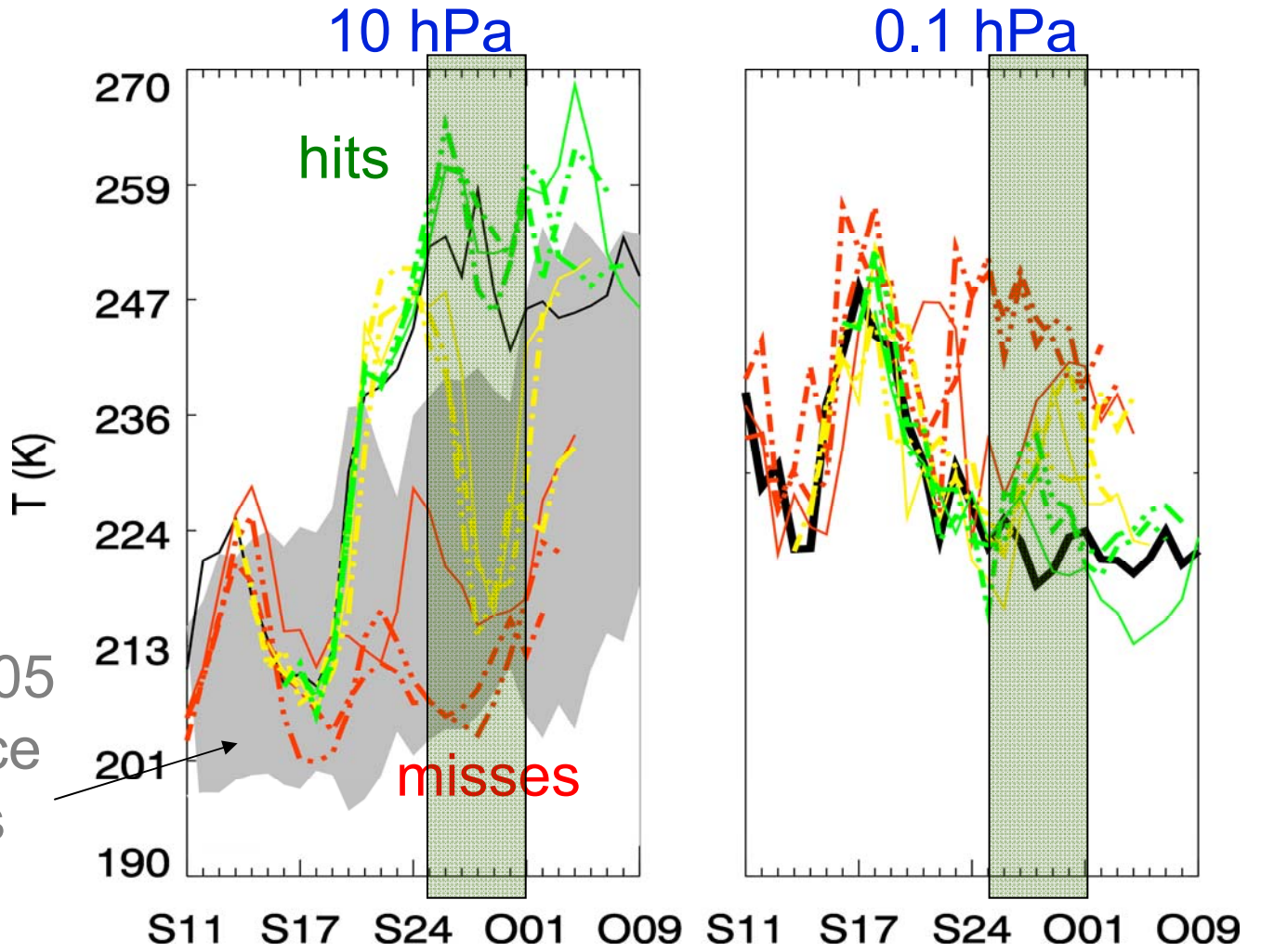




Tatyana Chshyolkova

South Pole temperature in 2002 during stratospheric warming

Ren et al. (2008)



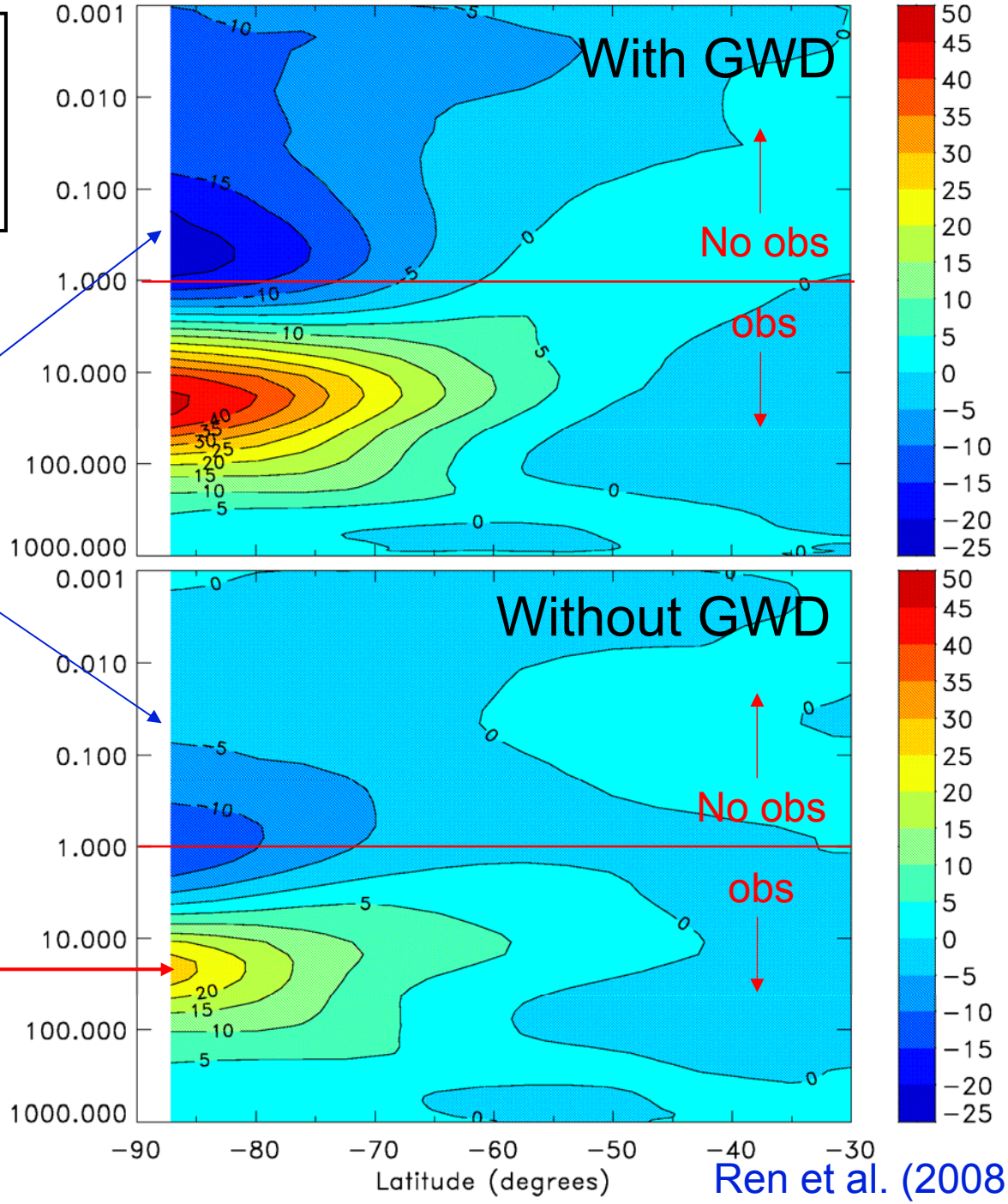
1995-2005 Met Office analyses

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

Time mean: Sept. 25-Oct. 1
Ensemble mean, zonal mean

Vertical extent of mesospheric cooling is reduced

Stratospheric warming is half the amplitude



Ren et al. (2008)

Environment Canada Environnement Canada

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

- In a model simulation (forecasts), GWD is driving amplitude and vertical extent of mesospheric cooling above stratospheric warmings (Ren et al. 2008)
- 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 (Pulido and Thuburn 2005,6,8)

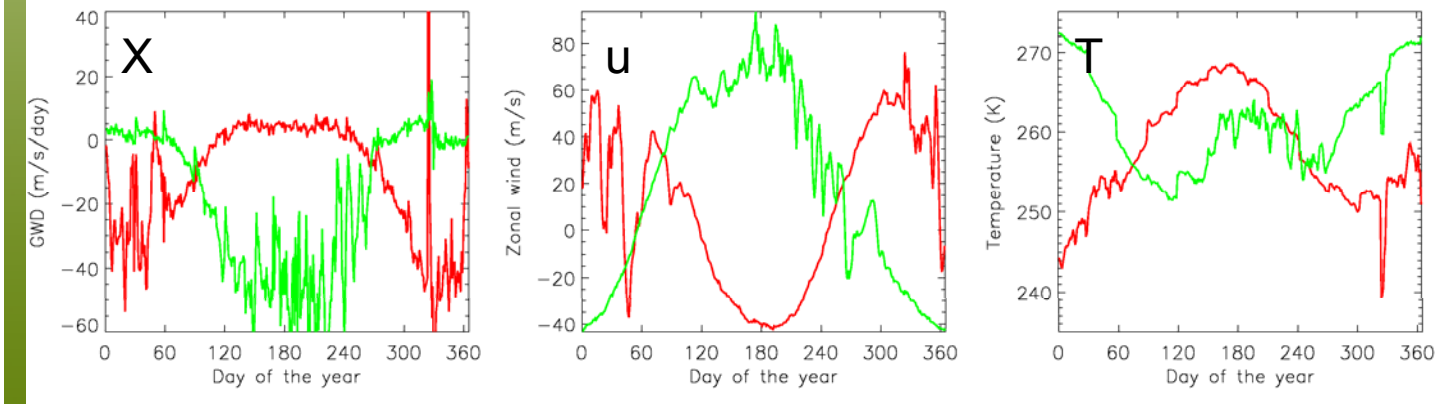
3. Estimating parameters in gravity wave drag schemes

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
- Can estimate 3D daily drag field. Resulting drag field consistent with previous estimates
  - Strength and location of winter deceleration centres
  - Descent of drag with QBO, SAO in tropics

Evolution of daily zonal mean fields in 2002 at 0.24 hPa

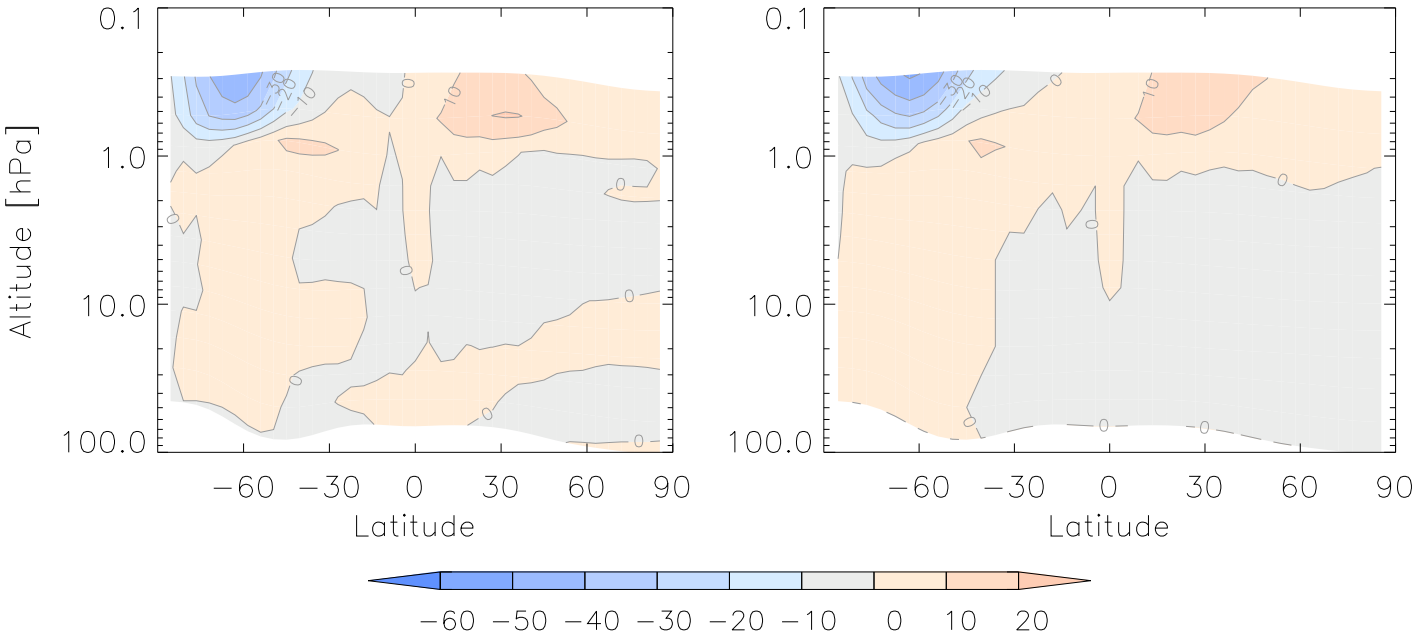


60°N 60°S

Can see daily variations, e.g. SSWs

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).

See invited talk by Pulido: Friday 9:00 Room 520F

Poster: J21 Friday 15:00

Environment Canada Environnement Canada

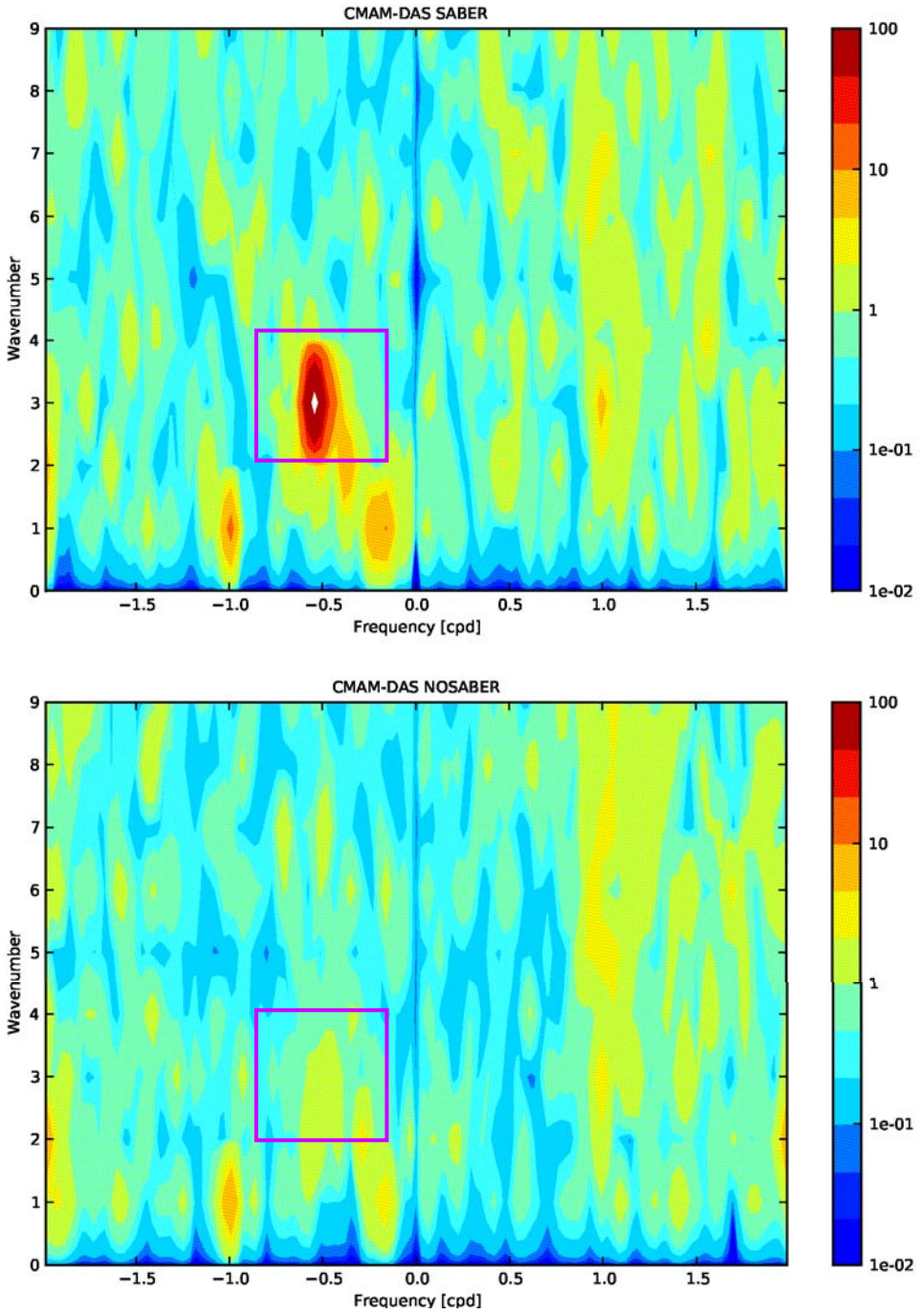
Canada

4. Mesospheric 2-day wave

Two-day wave

Figure courtesy of Martin Keller

- Mesospheric 2-day wave is captured in CMAM-DAS analyses with SABER obs
- Why?
  A. Insertion of increments every 6 h
  B. Mean state improved so that instability can occur
- Determining what measurements bring also tells you what model is doing right (or wrong)
- See poster by Keller today session M01 at 15:00



SPARC Data Assimilation Working Group

- Annual workshops: 2002 – Baltimore, 2003 – Florence, 2005 – Banff, 2006 – Noordwijk, 2007 – Toronto
- Mix of data assimilators, users of assimilation products, and experts in measurements, modeling, dynamics and chemistry
- 2009: MOCA-09 subsessions
  - M01: Middle atm science
  - J21: Adv in data assim: Friday afternoon
  - Working group meeting: Friday morning
    - INVITED SPEAKERS: Using DA to improve climate models: Mark Rodwell, Manuel Pulido, Craig Bishop
    - SPARC IPY archive (Mar/07 – Mar/09)
    - 2010 workshop – Exeter, England (June 21-23)