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The stratospheric influence on the troposphere in the context of operational medium-range weather forecasts

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SPARC Data assimilation workshop, Exeter, 22 June 2010

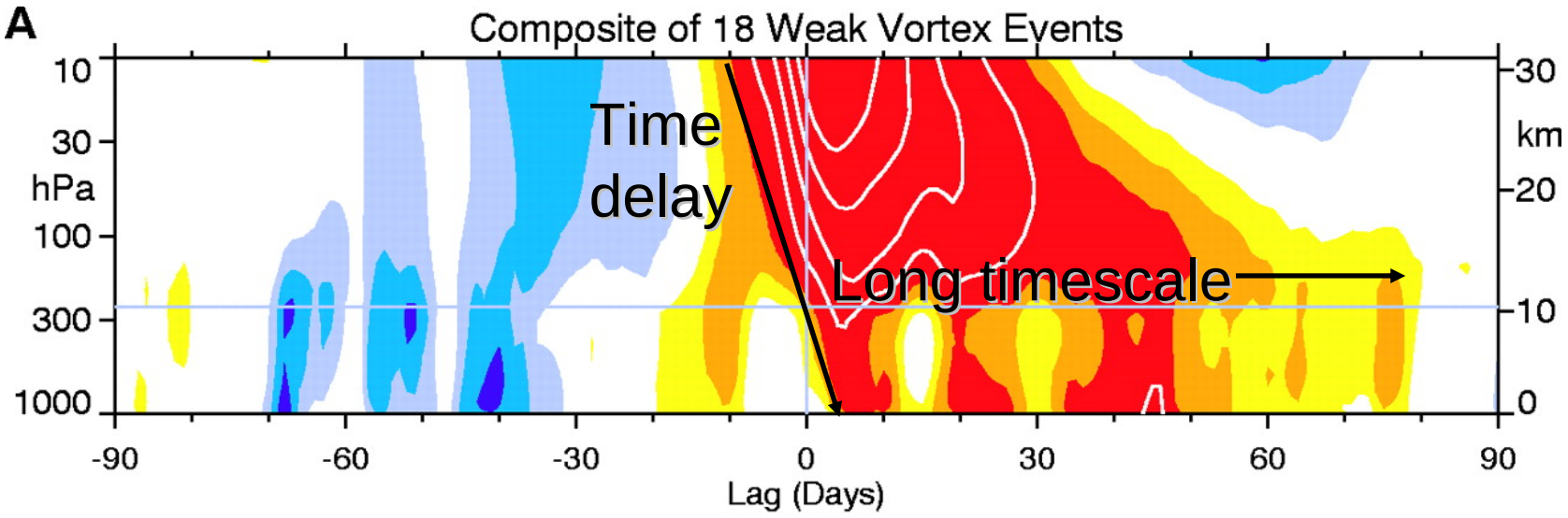
Operational weather forecasting

- Operational model lids are moving to 0.01 hPa (80 km)
- ECMWF, Feb. 1/06, GMAO since 2004, Met Office in 2009

If goal is improved tropospheric weather forecasts, why raise weather forecast model lids above stratopause?

Good stratospheric representation may help improve troposphere forecasts

- Lower stratospheric NAM is a better predictor of surface AO pattern 10 days later than the AO itself (Baldwin 2003, Science)
- Stratospheric initial conditions affect 15-day tropospheric forecasts (Charlton et al. 2004, QJRMS)

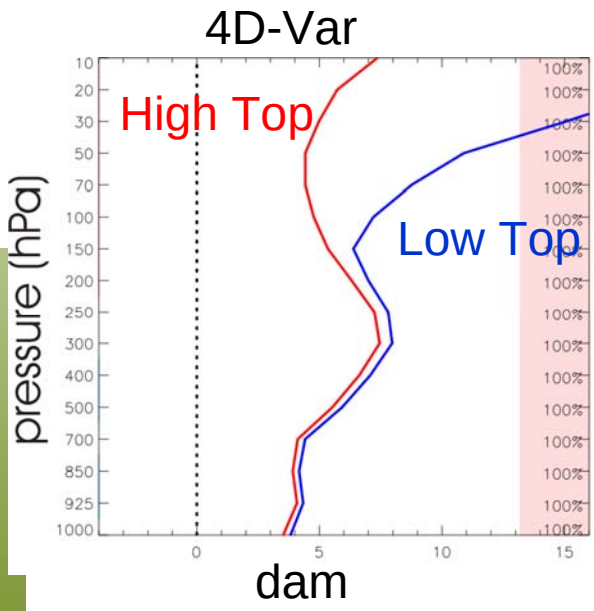


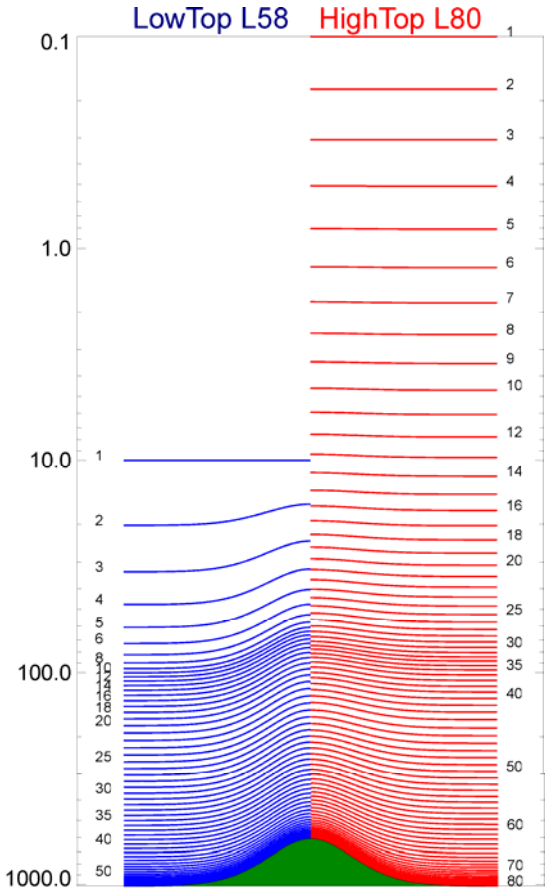
Baldwin and Dunkerton (2001)

Improving the stratosphere improves 5-day forecasts in the troposphere

On June 22, 2009 Canadian Meteorological Centre implemented operationally a global stratospheric model (0.1 hPa) for medium range weather forecasts

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





Winter

Dec. 20 – Jan. 26, 2006 (75 cases)

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Improving the stratosphere improves 5-day forecasts in the troposphere

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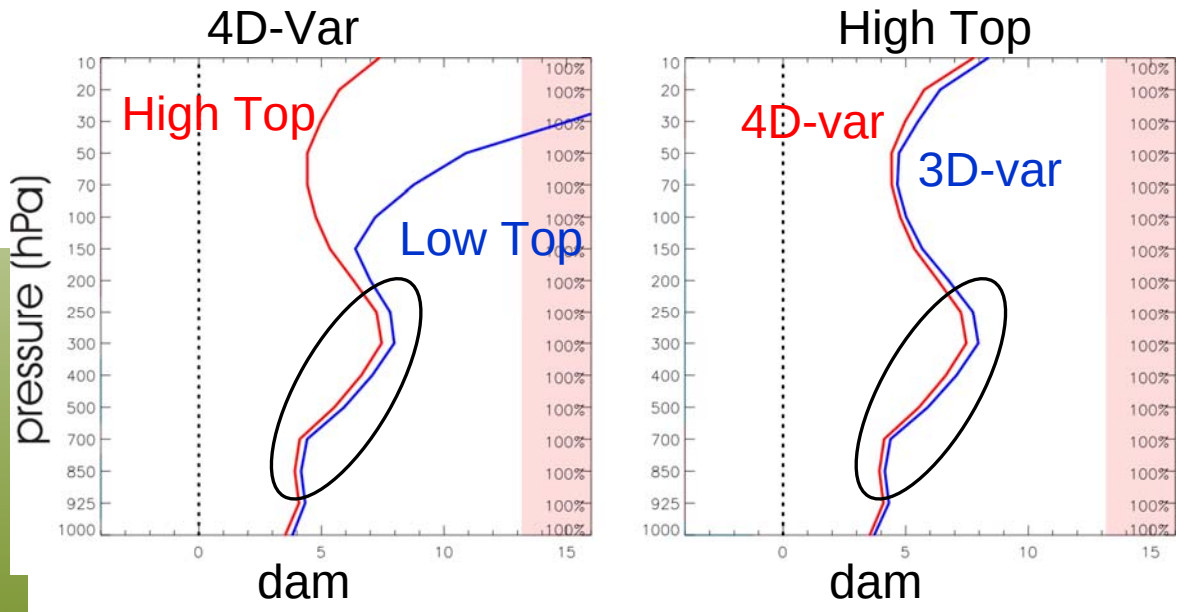


A good stratosphere impacts troposphere forecasts as much as 4D-Var

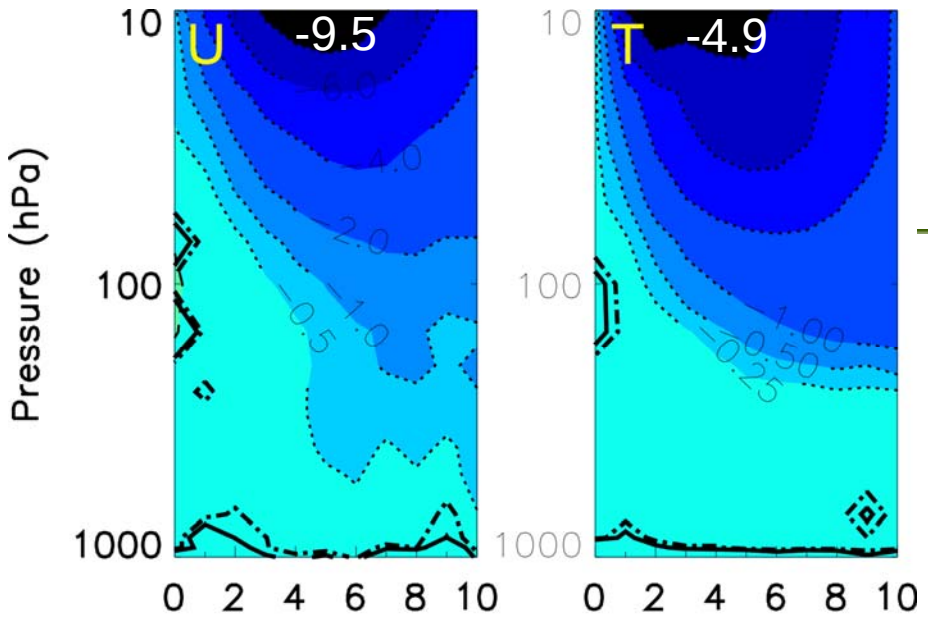
Winter

Dec. 20 – Jan. 26, 2006 (75 cases)

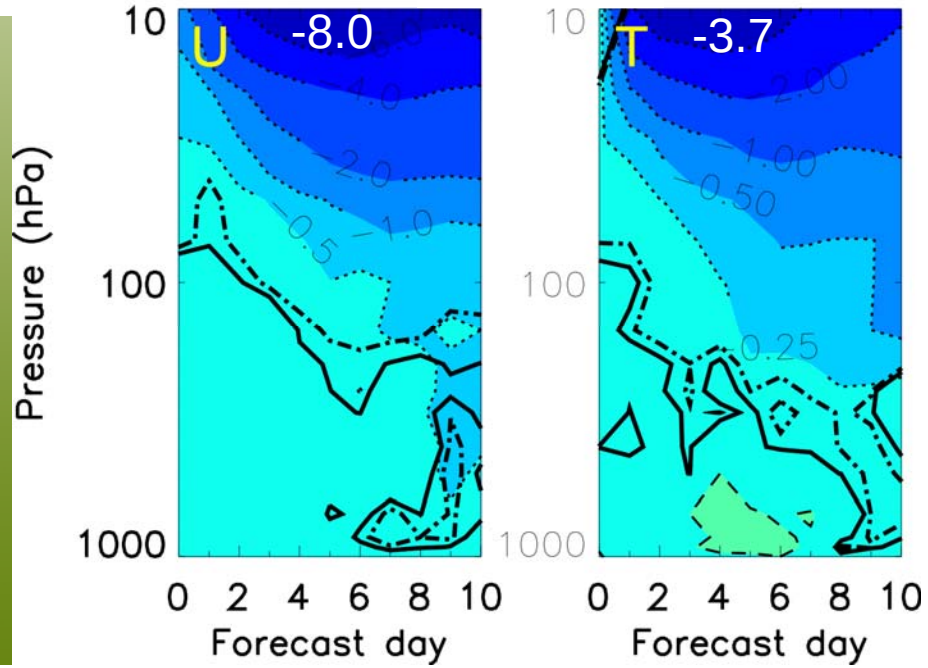
Are other forecasts improved?

- Compare forecast errors of new High Top (0.1 hPa) system with old Low Top (10 hPa) system
- Forecast error = Forecast – radiosonde obs
- Diff = Error stddev (High Top) – Error stddev (Low Top)
- Negative (blue) means High Top errors are lower

NH winter



SH winter



Improvement in forecast error stddev

Winter NH

Dec. 26 – Feb. 2, 2007 (77 cases)

Winter SH

June 22 – Aug. 21, 2006 (122 cases)

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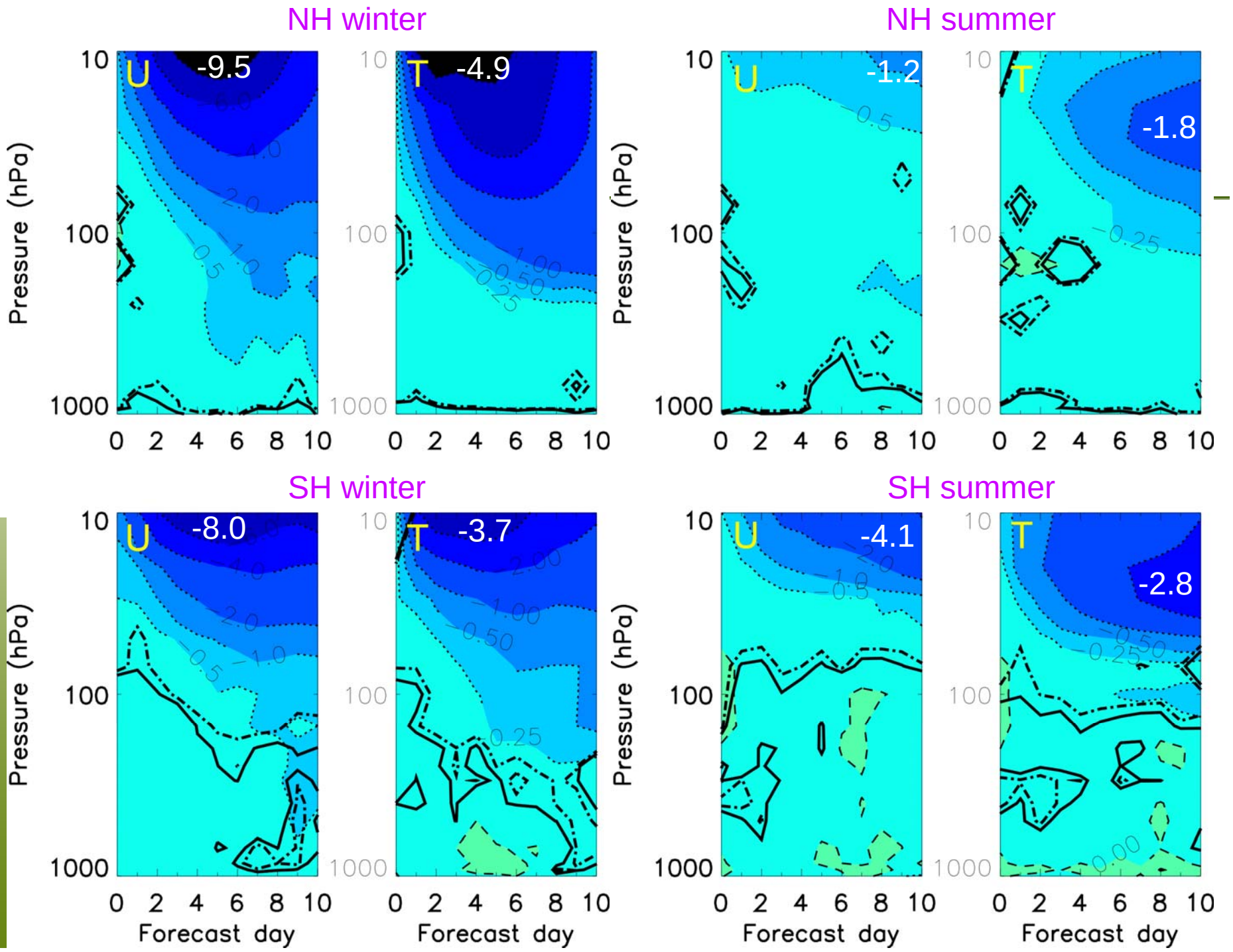

NH winter
NH summer
SH winter
SH summer
U
T
-9.5
-4.9
-1.2
-1.8
-8.0
-3.7
-4.1
-2.8
Pressure (hPa)
Forecast day
10
100
1000
0 2 4 6 8 10

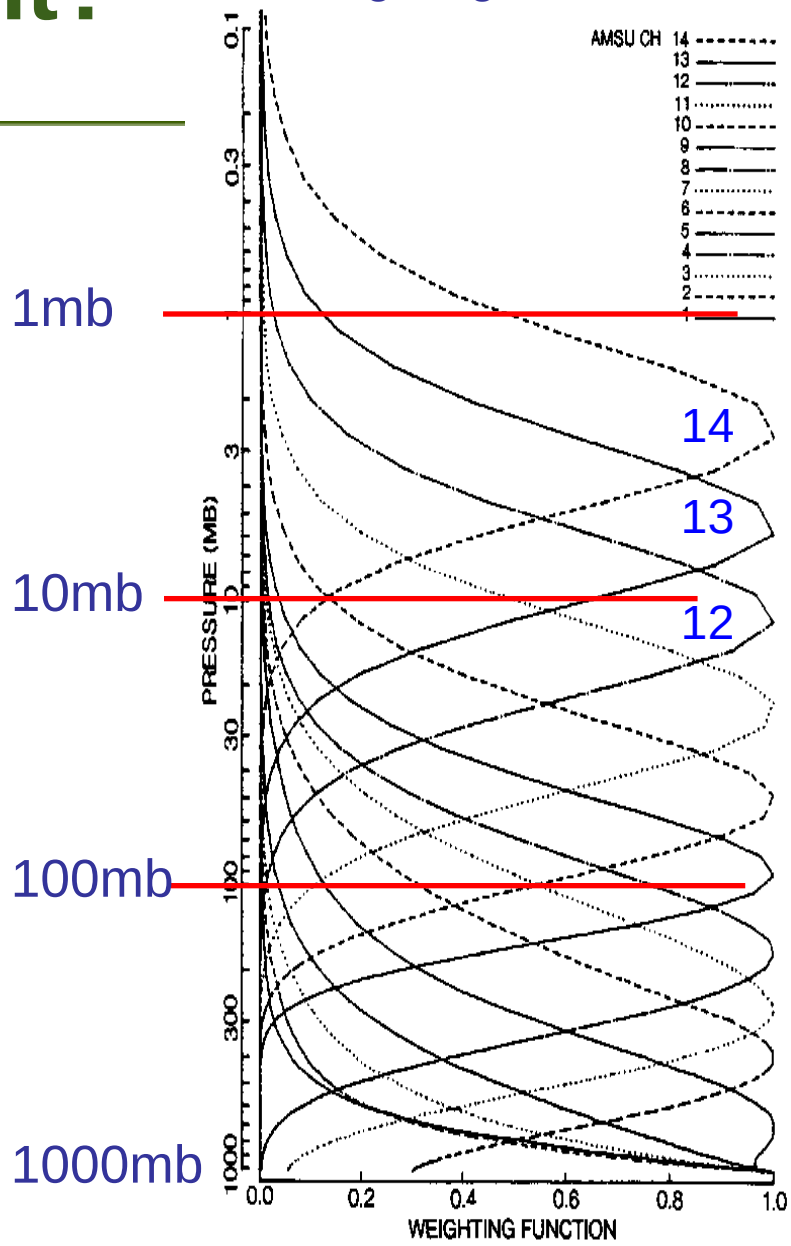
Results

- Forecast error standard deviations are improved at all forecast ranges in winter
- Improvement is much greater in winter than summer (improvement depends on season, not hemisphere)
- Improvement in skill spreads downward with forecast range in winter
- Improvement in troposphere is comparable to that seen when upgrading from 3D to 4D-Var in winter

Why the improvement?

- Changes to the model
  - raised lid height, new radiation, raised and weakened sponge layers, GWD scheme, etc.
- Differences in observation sets
  - extra obs: AMSU 11-14, GPSRO
- Changes in way obs are assimilated
  - AMSU 9-10 obs errors were reduced

AMSU normalized weighting functions



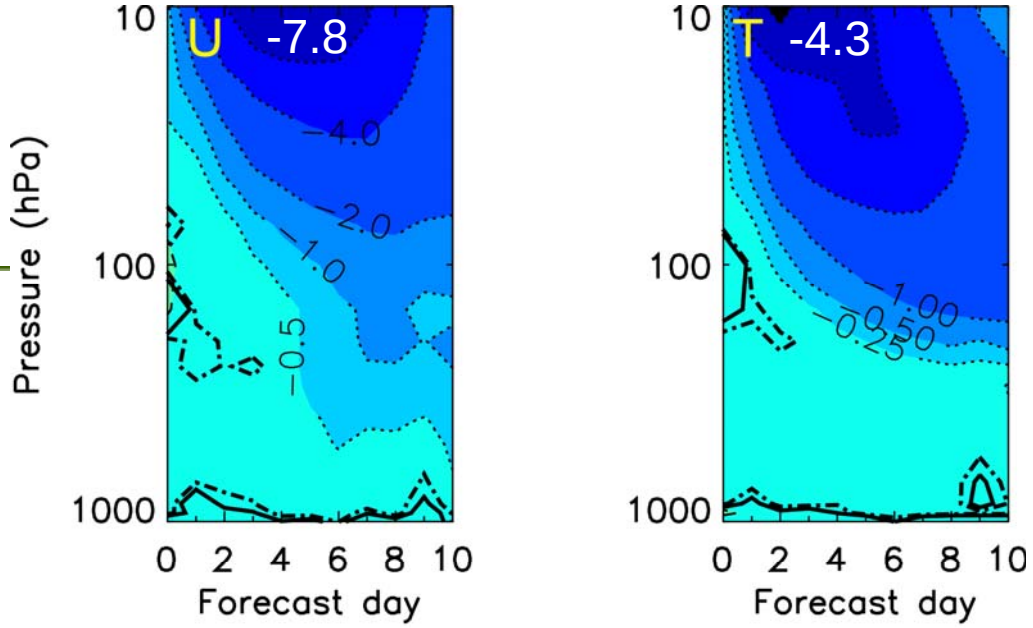
Sets of assimilation cycles

Experiment	Assimilation scheme	Extra observations	Reduced obs errors	Model
K4H7CX5U	4D-Var	AMSUA 11-14, GPSRO 30-40 km	AMSUA 9-10	High Top
S4H7CX5U	4D-Var		AMSUA 9-10	High Top
T4H7CX5U	4D-Var			High Top
K4H7CB21	4D-Var			Low Top
K3H7CY5M	3D-Var	AMSUA 11-14, GPSRO 30-40 km	AMSUA 9-10	High Top
S3H7CY5M	3D-Var		AMSUA 9-10	High Top

Winter NH stddev obs vs model

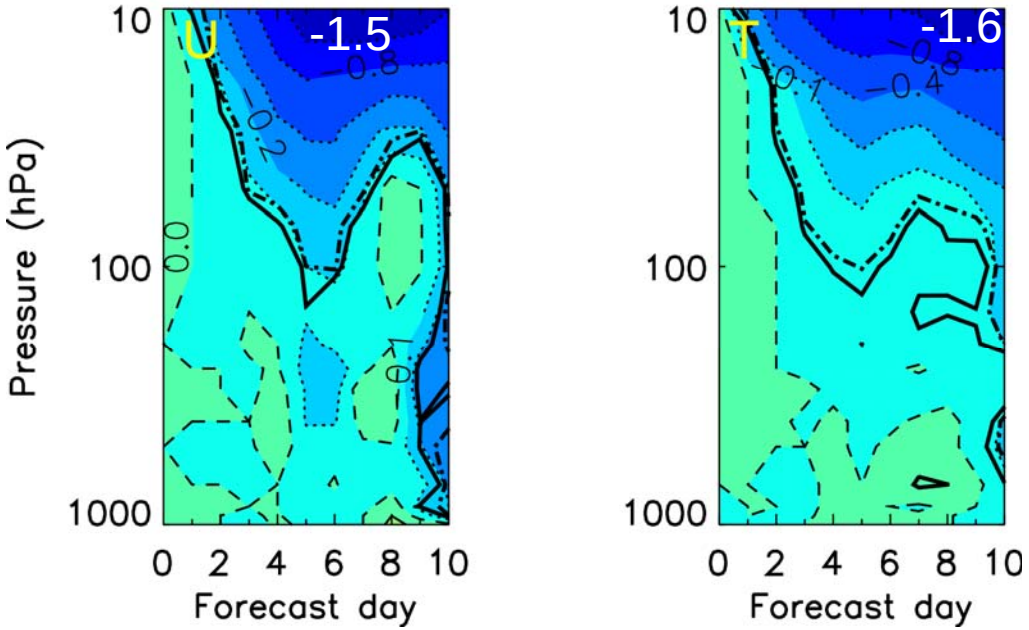
Impact of model changes

Most of the improvement is due to changes in model



Contour intervals not the same!

Impact of obs changes



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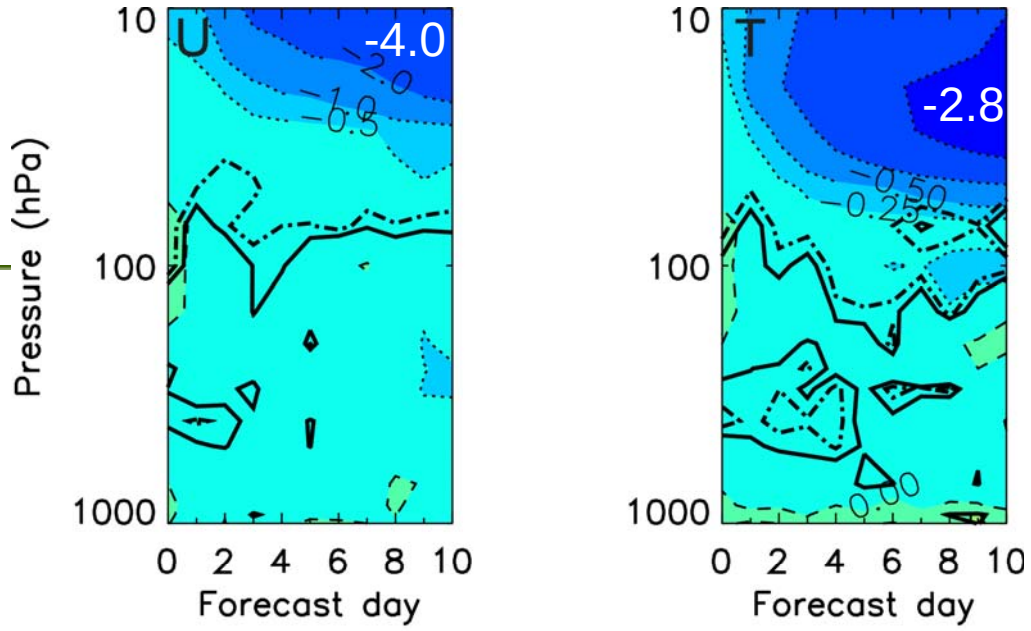
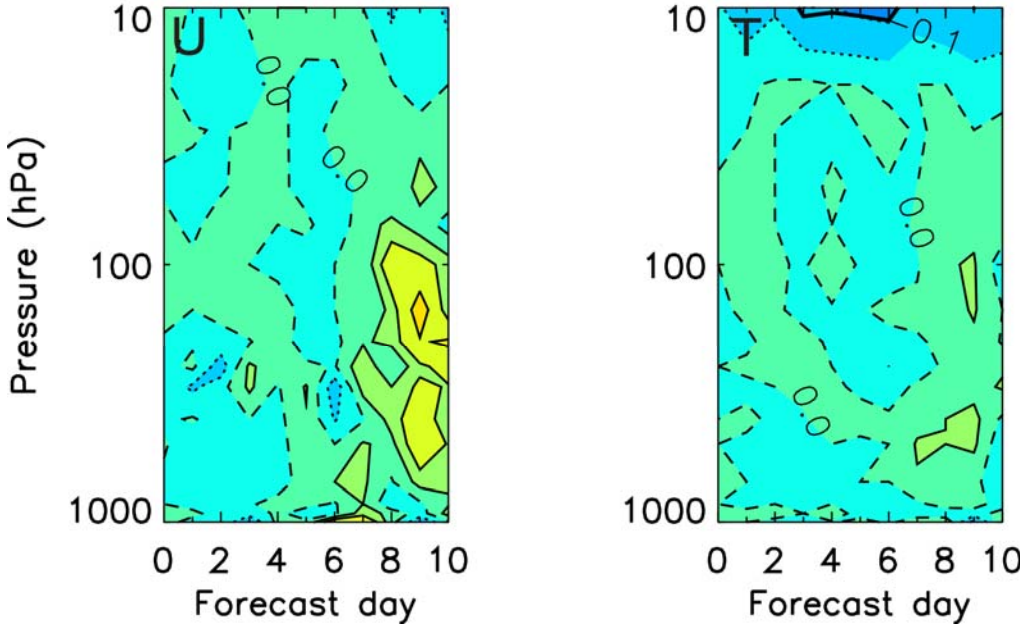
Summer SH stddev obs vs model

Impact of model changes

Only changes in model contribute to improvement

Impact of obs changes





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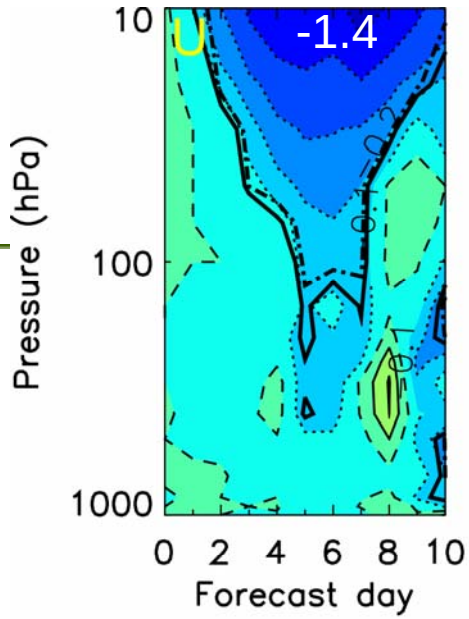
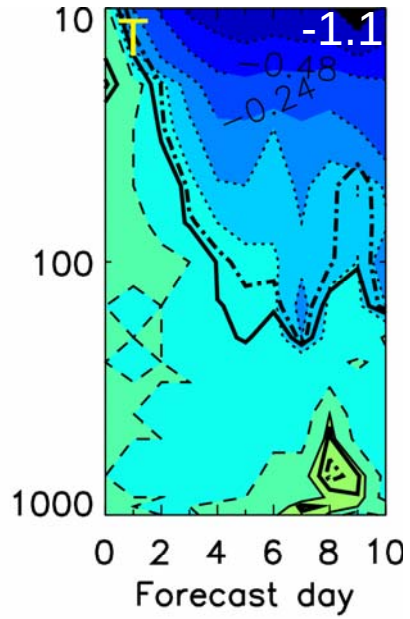
Winter NH stddev Impact of obs

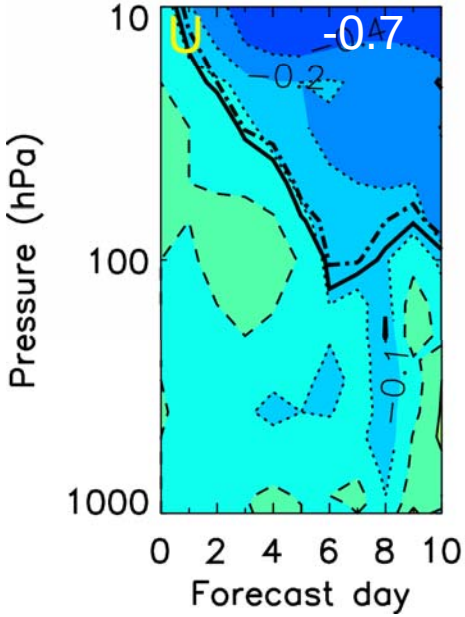
4D-Var

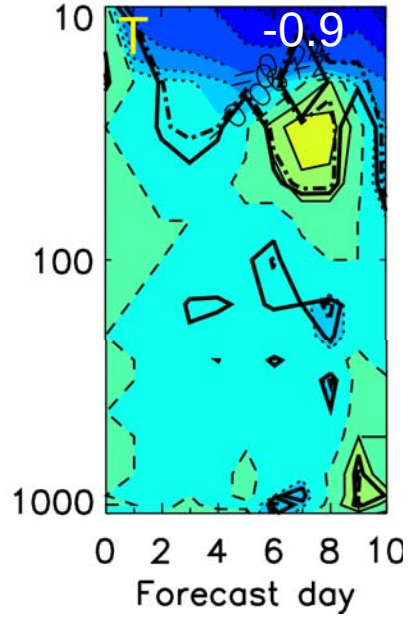




Extra obs have larger impact with 4D-Var

3D-Var





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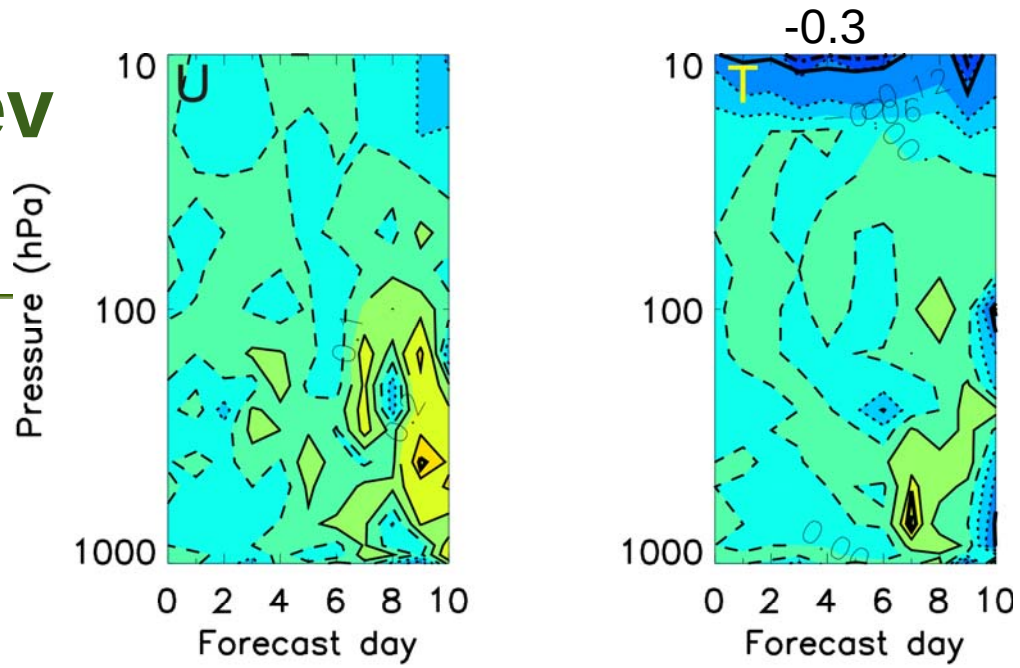
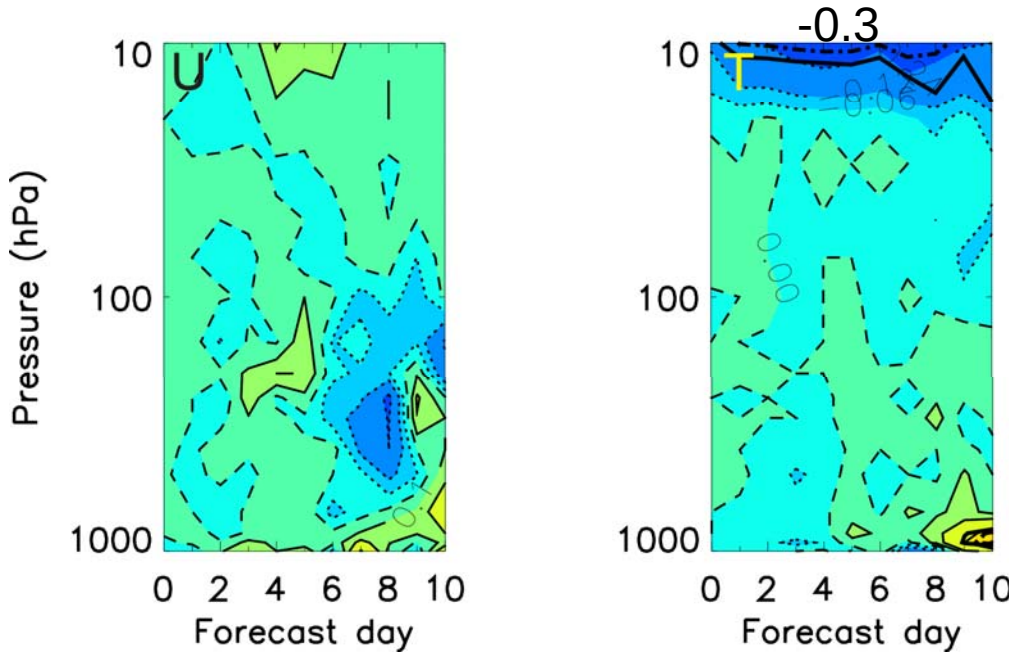
Summer SH stddev Impact of obs

4D-Var

No significant impact of obs changes in summer

3D-Var





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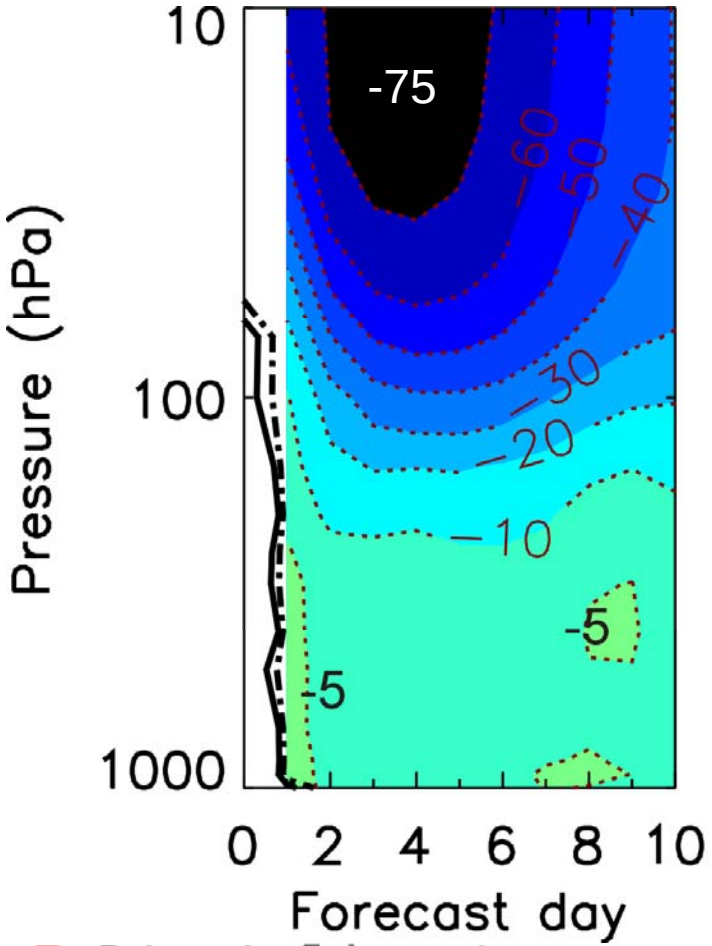
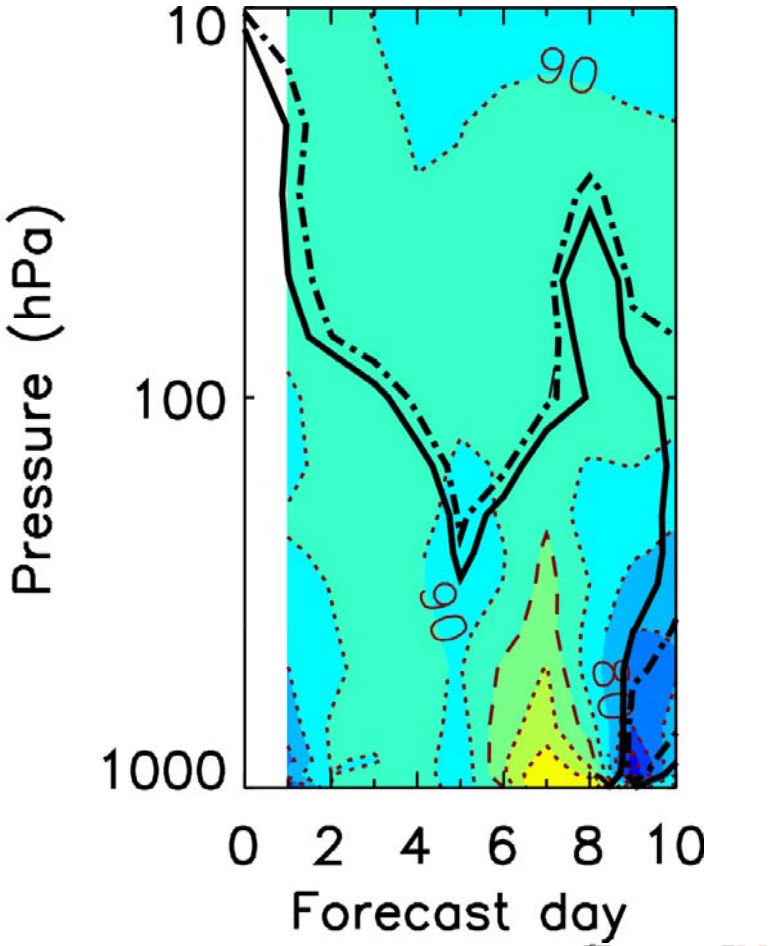
Attribution of the improvement

Geopotential height standard deviation (%) NH winter

(High Top – Low Top)/Low Top



Impact of model/(High Top – Low Top)



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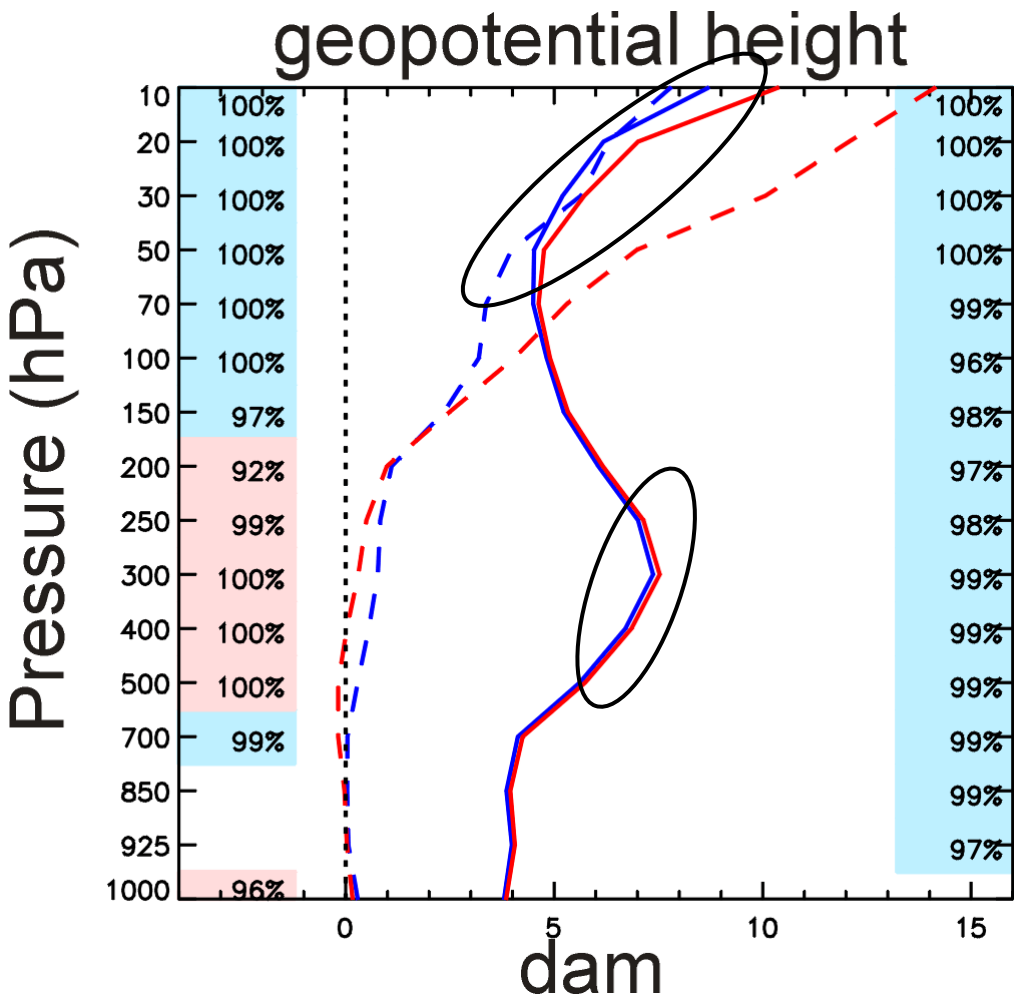
Which model changes explain improvement?

- Run forecast experiments. Systematically remove added-changes to see which change can explain the improvement in forecast errors.
- Model degradations tested:

1. Revert to old radiation scheme
2. Mimic the old sponge layer: Lower the sponge to 50 hPa (24 levels) and increase its intensity so the coefficient is equivalent to that used in the 10 hPa model
3. Reduce vertical resolution in lower stratosphere: Remove extra 7 levels below 10 hPa and adjust the remaining levels such that they coincide with those of the Low Top model
4. Place the lid height at 10 hPa, remove GWD and methane oxidation, but keep vertical resolution comparable to High Top model and set the sponge layer equivalent to that in the Low Top model

Does new radiation scheme explain improvement?

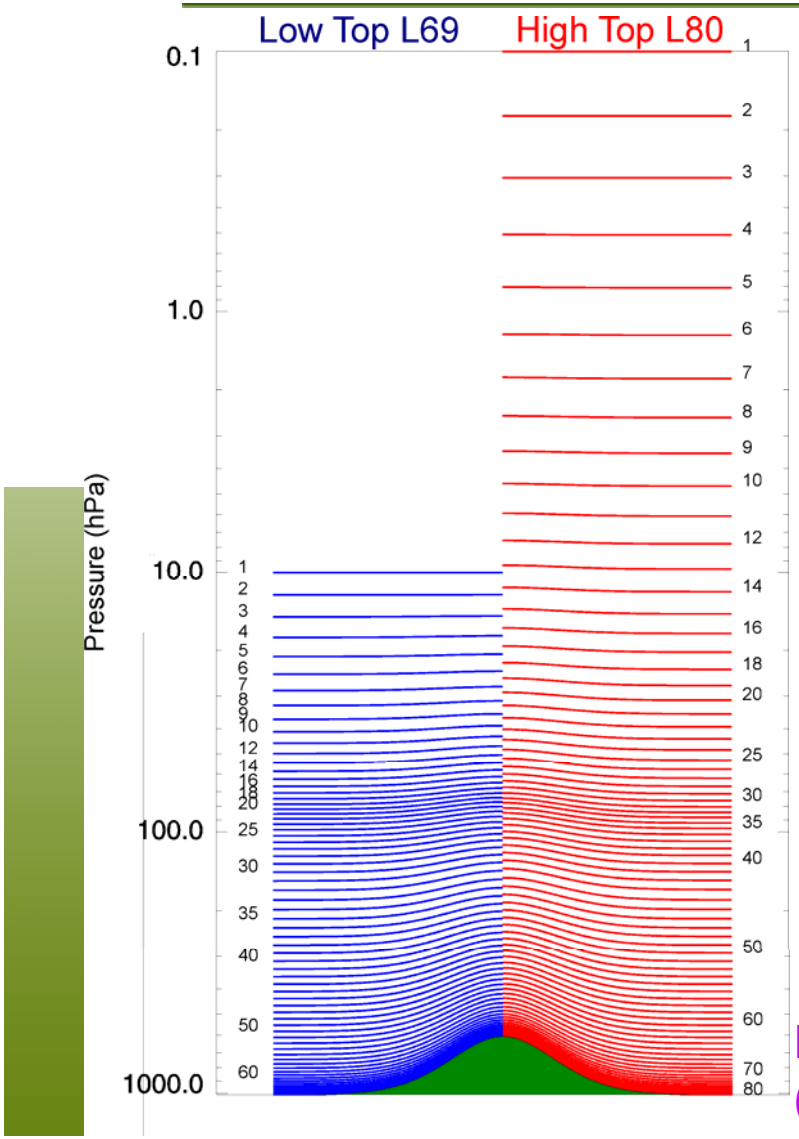


O-F(5 day) against NH sondes

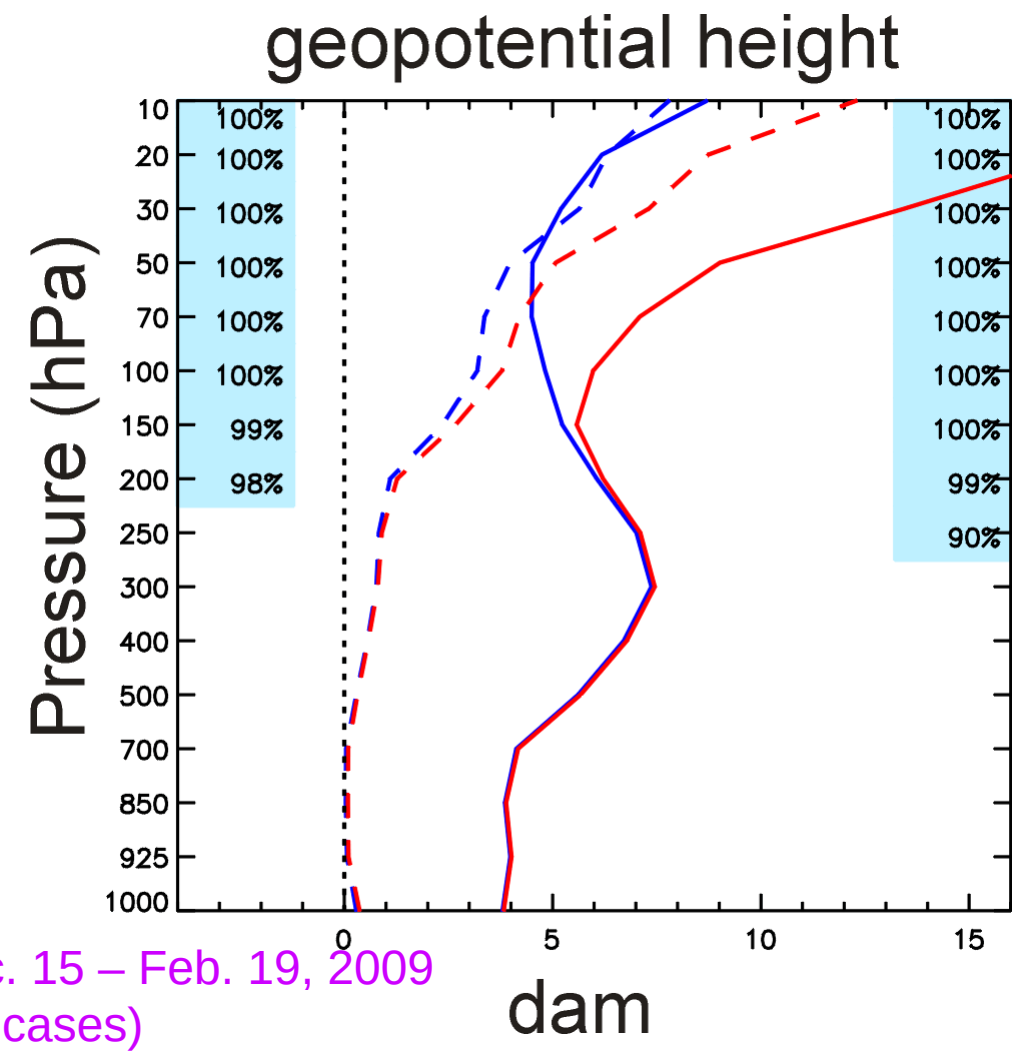
Degrade model by reverting to old radiation scheme

Dec. 15 – Feb. 19, 2009 (45 cases)

Does lid height explain improvement?



O-F(5 day) against NH sondes



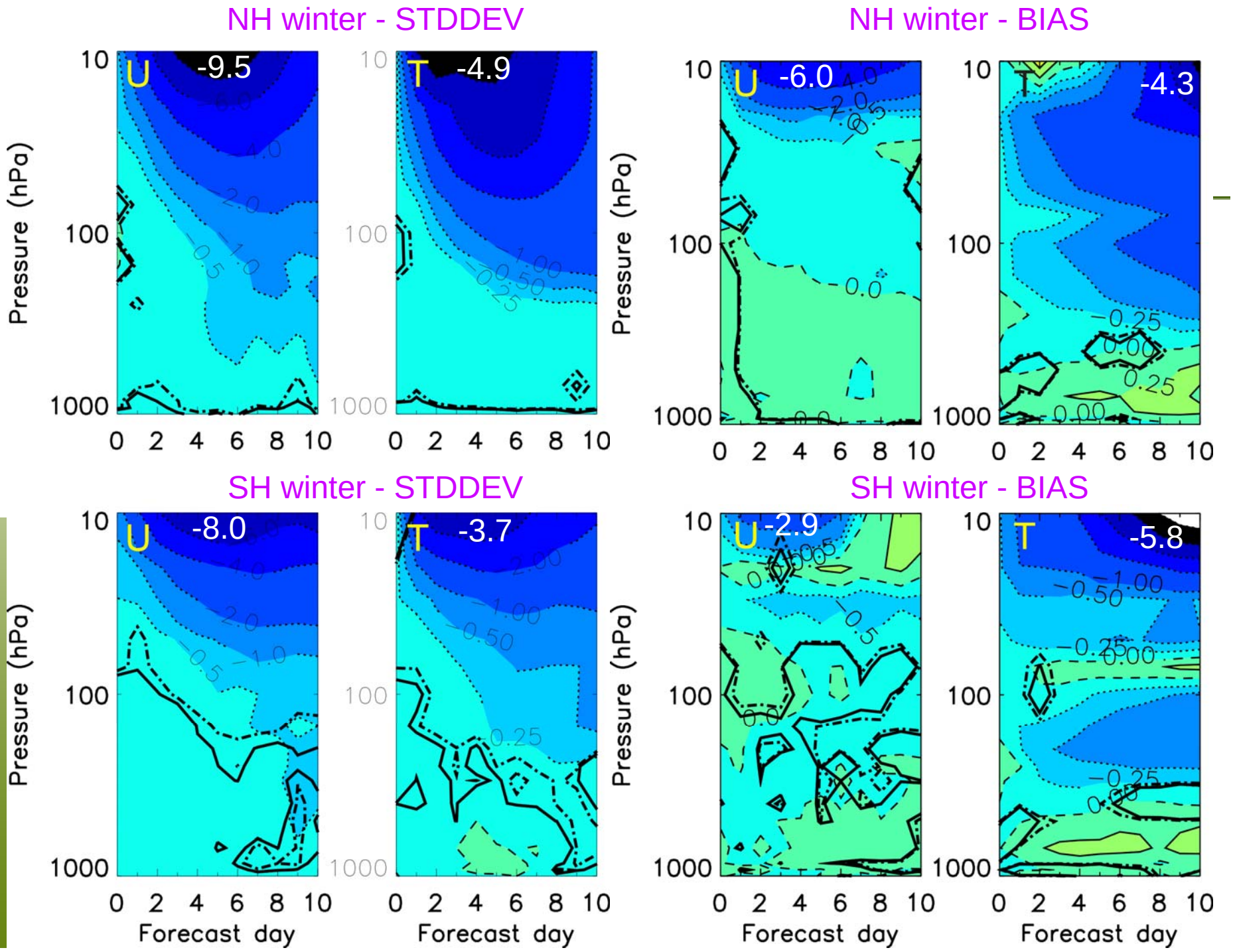
Dec. 15 – Feb. 19, 2009
(45 cases)

Which model changes explain improvement?

- The new radiation scheme explains some (~25%) of the impact in the troposphere.
- The lid height explains almost all of the improvement in the stratosphere
- The cycling of the forecast with the analysis step allows improvements to increase and spread

Summary

- High Top (0.1 hPa) model has improved tropospheric forecasts compared to Low Top (10 hPa) model. Improvement in 5-day forecast scores comparable to going from 3D to 4D-Var
- Greatest improvement is seen in winter. Skill propagates downward with forecast range, reaching surface by day 10 (in winter).
- Changes to model are responsible for 90% of improvement (stratosphere and troposphere). Extra obs have biggest impact at day 9.
- Extra obs have no significant impact in summer hemisphere
- Extra obs have larger impact with 4D-Var than 3D-Var
- Which model changes? Location of lid, new radiation scheme.
- Improvement in stddev larger than improvement in bias (winter). Transient events are being better resolved. Not shown.


NH winter - STDDEV
NH winter - BIAS
SH winter - STDDEV
SH winter - BIAS
U
T
-9.5
-4.9
-6.0
-4.3
-8.0
-3.7
-2.9
-5.8
Pressure (hPa)
Forecast day
10
100
1000
0 2 4 6 8 10