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Impact of tropospheric and stratospheric data assimilation on the mesosphere during 2002 Antarctic SSW

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Outline

- Motivation
- Introduction of the Canadian Middle Atmosphere Model Data Assimilation System (CMAM-DAS)
- Diagnostics of 2002 Antarctic Stratospheric Sudden Warming (SSW) using CMAM-DAS analyses
- Impact of the data assimilation below the stratopause on the mesosphere
- Conclusions and future work

Motivation

- The mesosphere is largely unconstrained in data assimilation systems due to poor observation coverage.
- The mesosphere is mainly driven by vertically propagating (resolved and unresolved) waves from below.
- These waves, originating in the troposphere and propagating through the stratosphere, can be better represented below the mesosphere by a data assimilation system.
- Through the "corrected" waves the information of data assimilated below the mesosphere can be carried into the mesosphere (during the model integration), and consequently can constrain mesospheric motions.

- **Why use Canadian Middle Atmosphere Model Data Assimilation System (CMAM-DAS) analyse?**

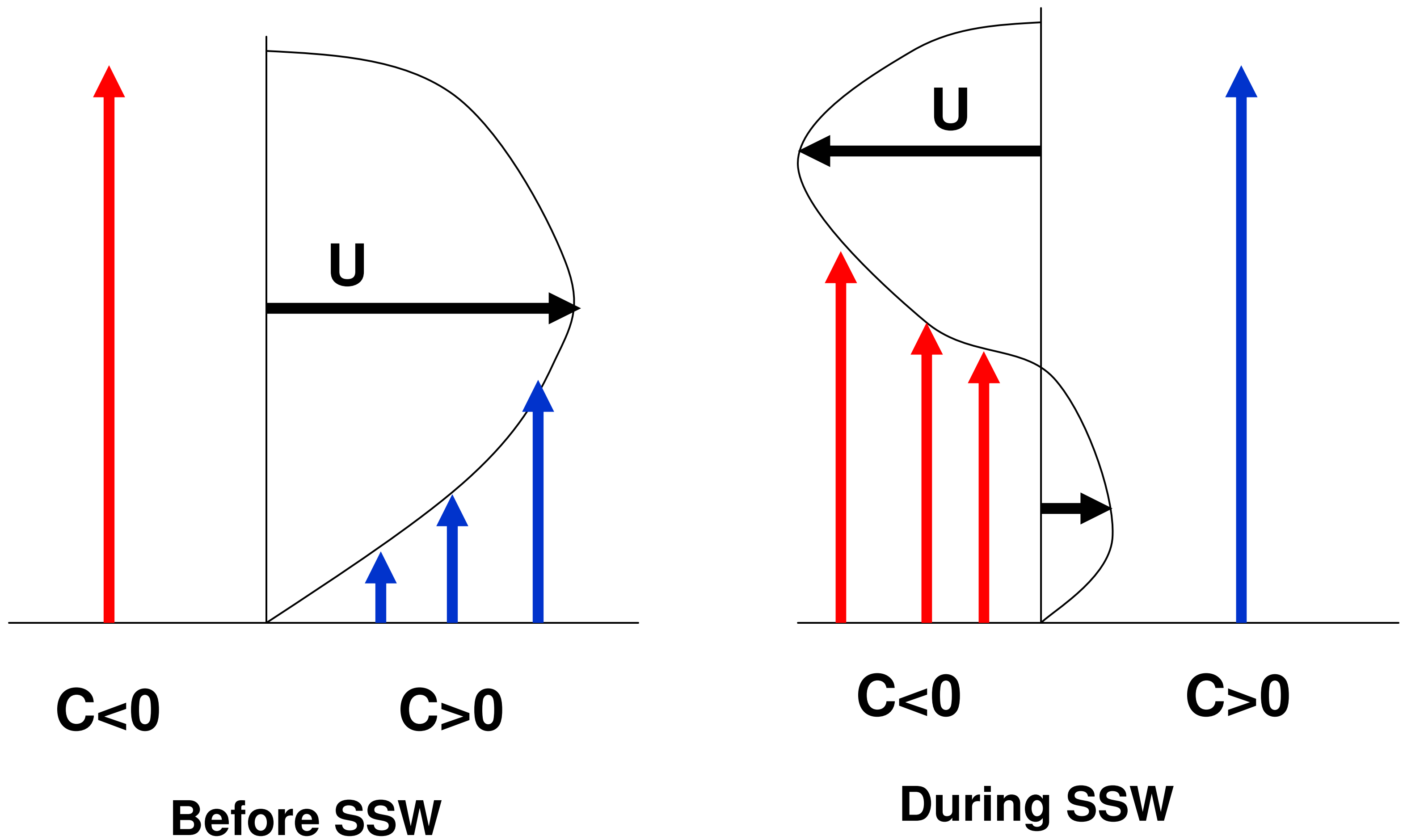
CMAM has the model lid at about 100km, and the observations assimilated in the 3dvar system are below the stratopause. Therefore CMAM-DAS analyses can be used to examine the constraint on mesospheric motions imposed by the data assimilation below.

2002 Antarctic Stratospheric Sudden Warming (SSW)

- During the SSW, stratospheric warming and mesospheric cooling indicates strong coupling between the stratosphere and mesosphere.

- The reversal of wind in the stratosphere during the SSW changes the filtering condition for vertically propagating waves, and thus has impact on stratosphere and mesosphere coupling. Therefore the influence of DA below the stratopause on the mesosphere can be better demonstrated during the SSW.

filtering vertically propagating waves by wind in the winter hemisphere



Introduction of the CMAM-DAS

- **Model in the CMAM-DAS**
- **Assimilation scheme in CMAM-DAS**
- **Observations in CMAM-DAS**

Model

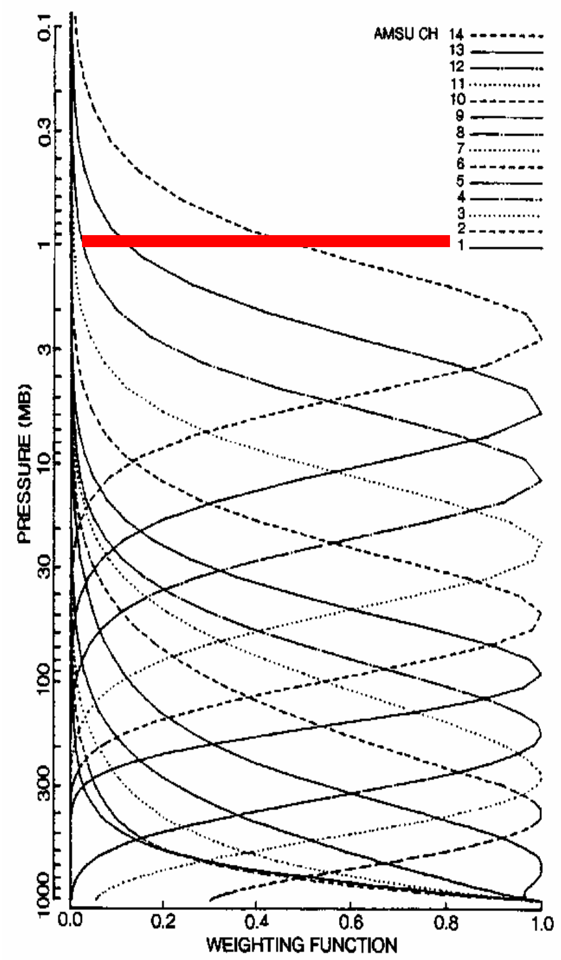
- T47 spectral model with interactive chemistry, radiation and dynamics.
- 71 levels from 0-95 km. It uses the Hines GWD scheme.
- 44 species advected,127 gas-phase chemical reactions chemistry, heterogeneous chemistry
- Incremental analysis updating (IAU) is applied for initialization.

Assimilation scheme

- 3D-variational (3DVAR) assimilation scheme developed by the Canadian Meteorological Center.
- Only dynamic variables (horizontal wind, temperature, moisture variable, and surface pressure) are assimilated every 6 hours.

Observations

- **Conventional obs**:
  sondes, aircraft, surface obs, etc.
- **Satellite obs**:
  AMSU channel. 4-13 on NOAA 15, 16
- **Online background check**
  bias correction, quality control, thinning, etc.



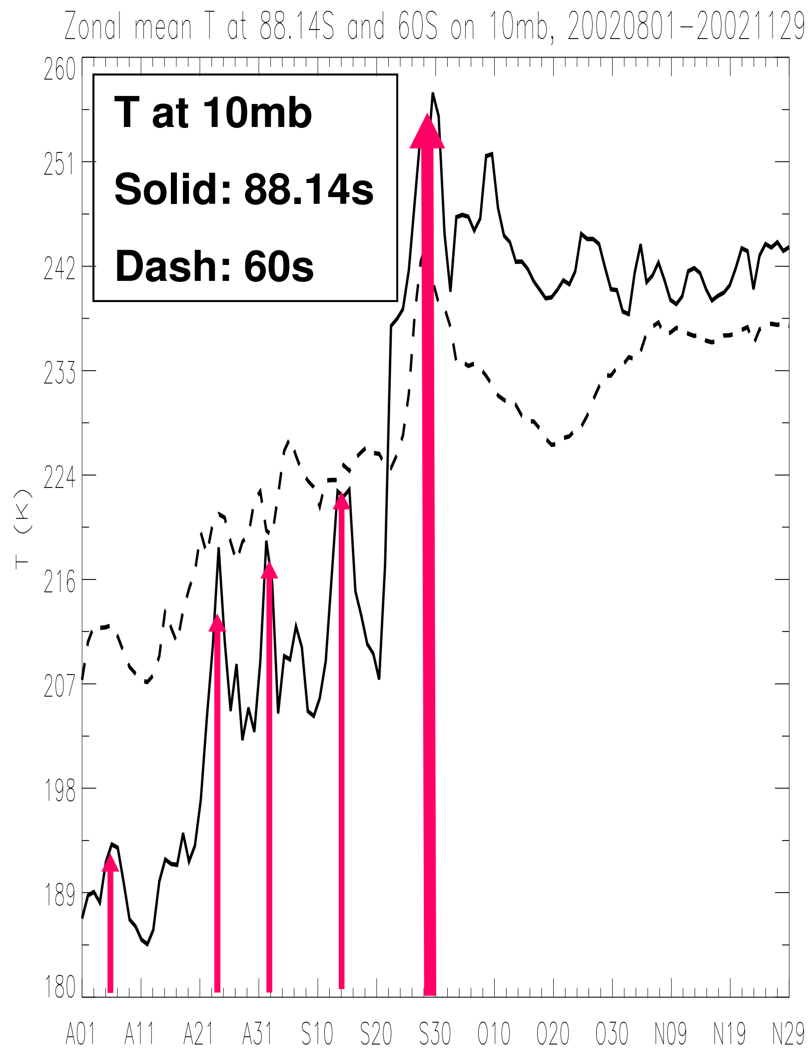
- **In 3dvar, the correlation between the stratosphere and mesosphere is cut off. Thus data assimilation below 1 hpa has NO influence on the mesosphere *during the data assimilation*.**

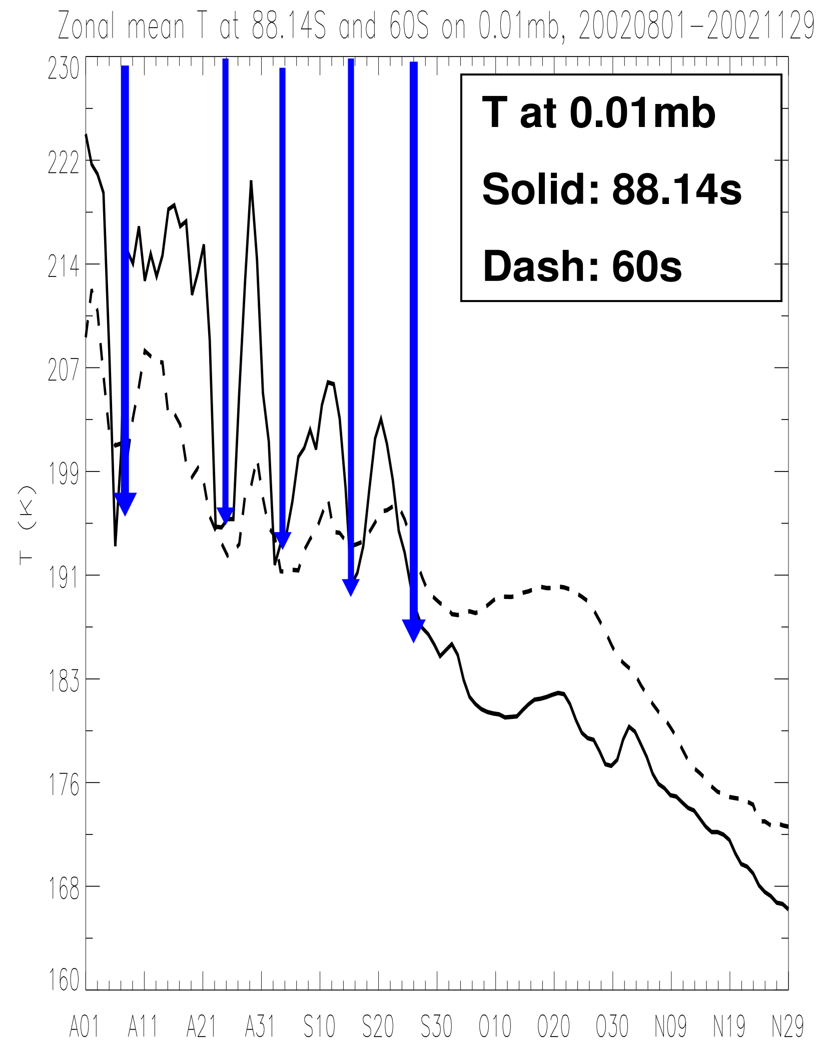
- **Information of data assimilation below 1 hpa can be spread into the mesosphere only through the vertically propagating (resolved and unresolved) waves *during the model integration.***

Diagnostics of 2002 Antarctic SSW

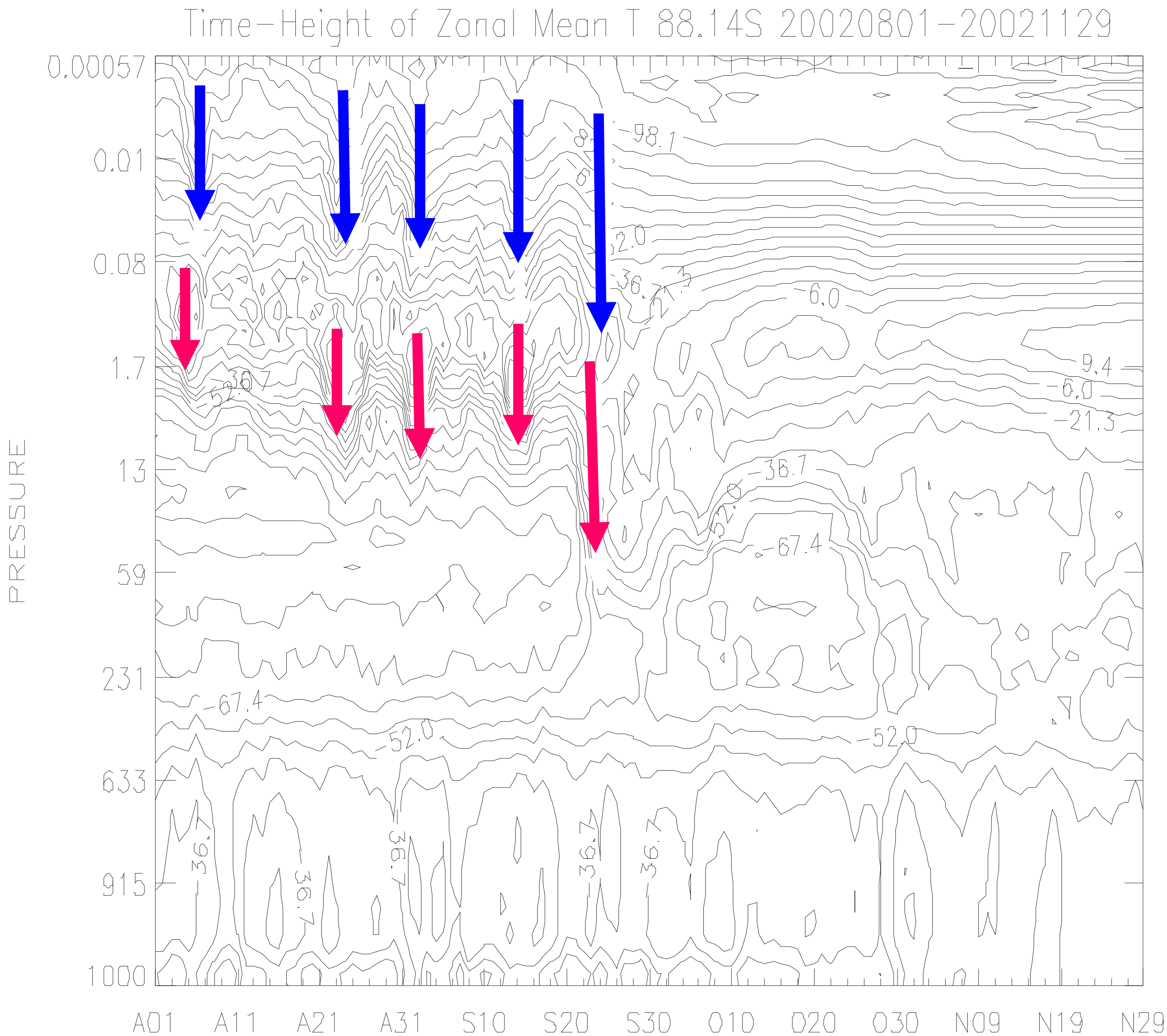
(I) Changes in temperature

Temperature time series during SSW



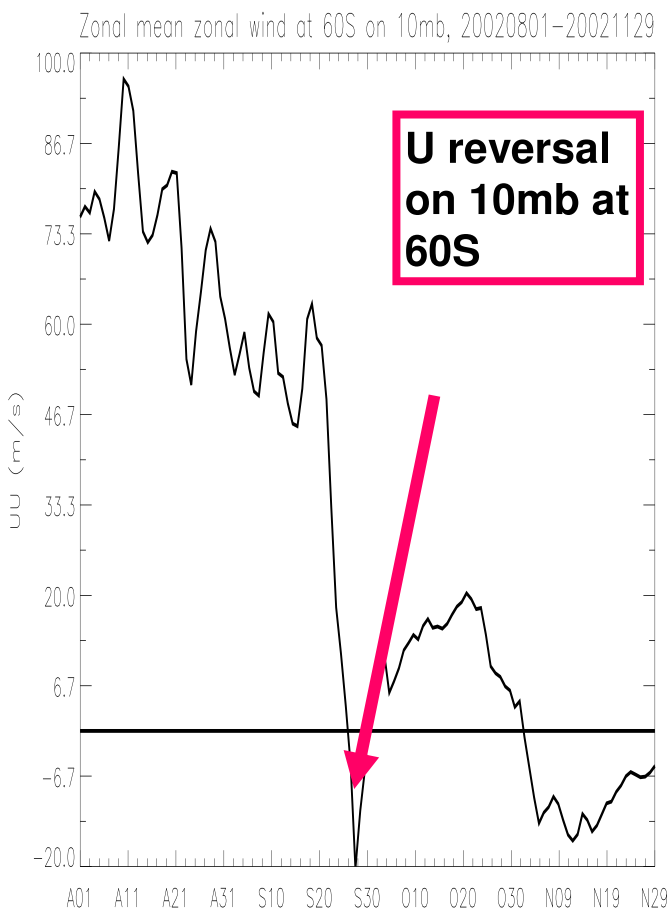


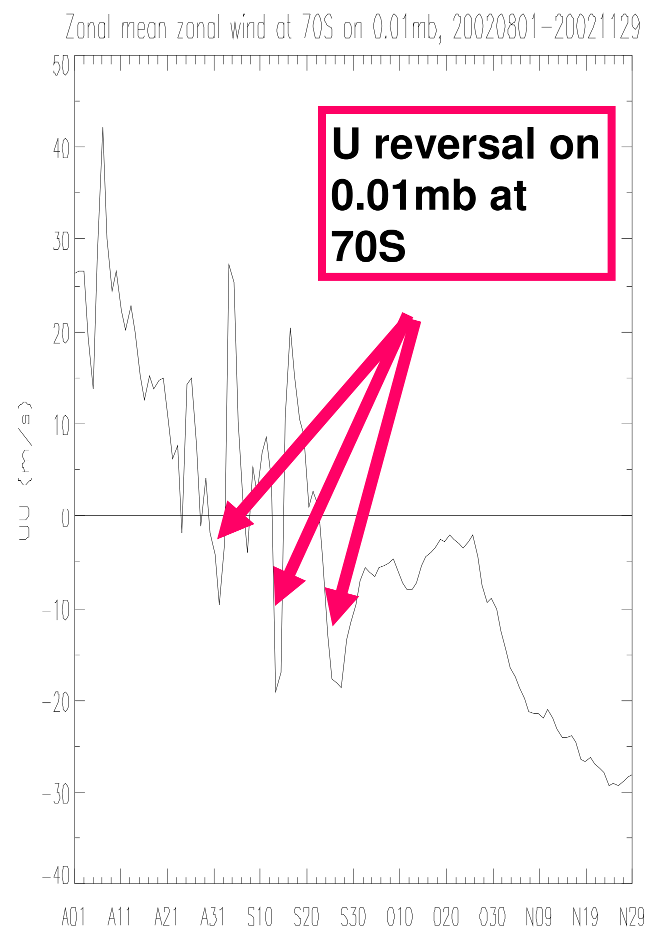
Time-height cross section of zonal mean T at 88.14S



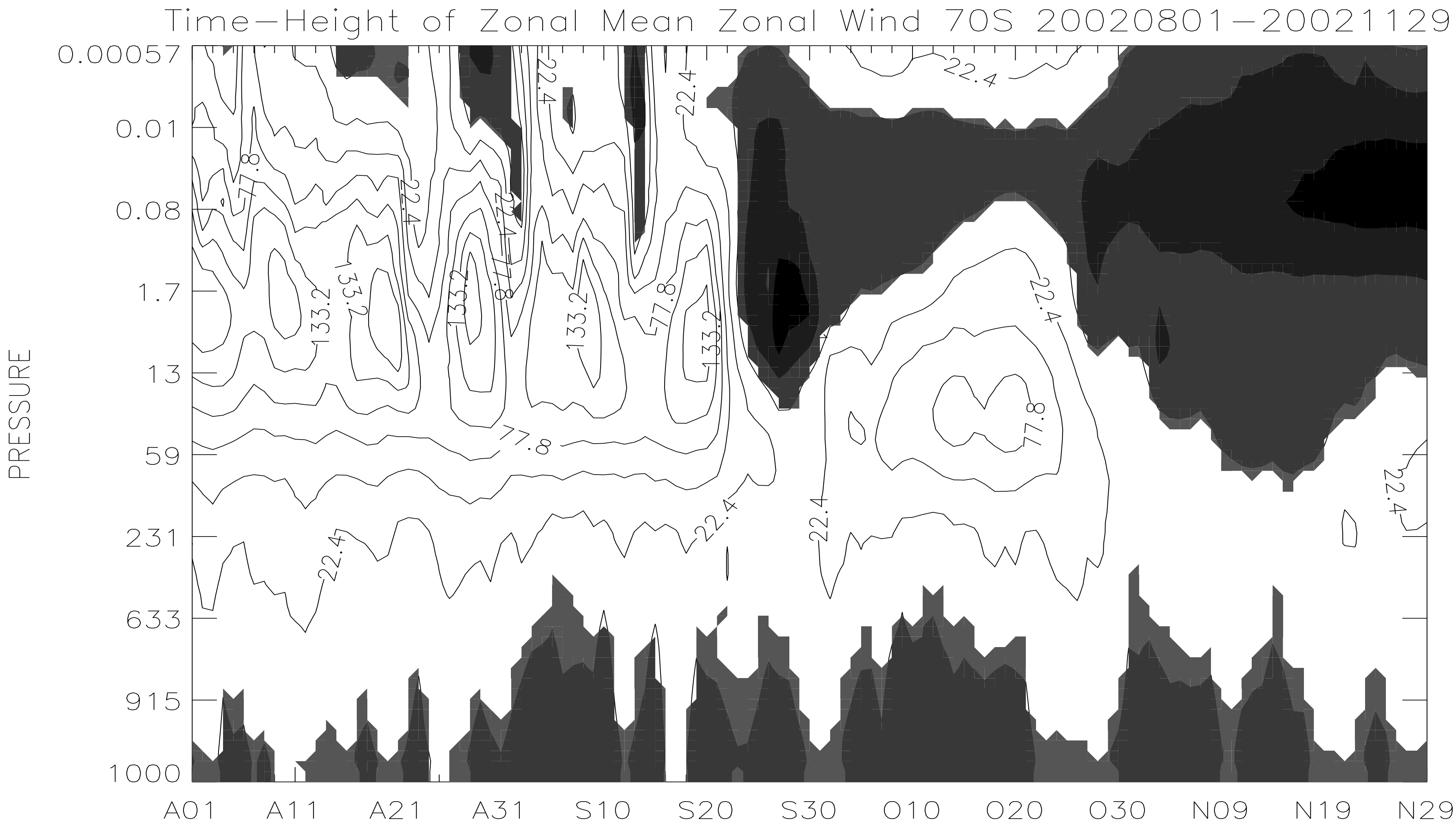
(II) Changes in wind

Time series of zonal mean zonal wind during SSW



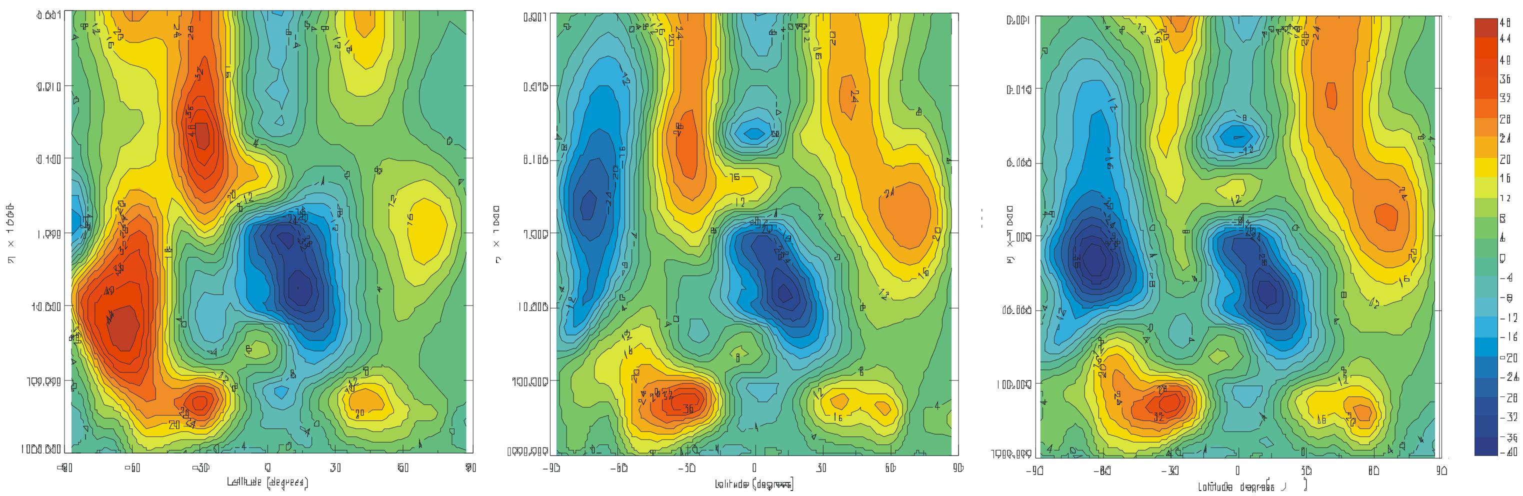


Time-height cross section of zonal mean zonal wind at 70S

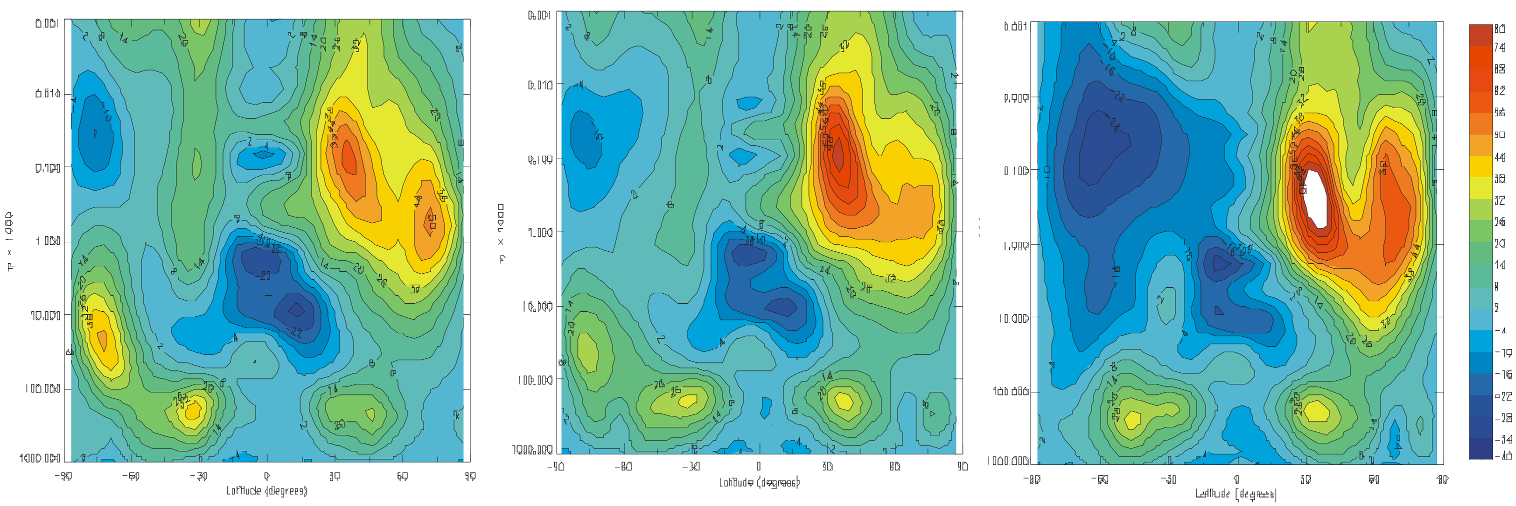


Zonal mean zonal wind

Sept. 15 | Sept. 25 | Sept. 28

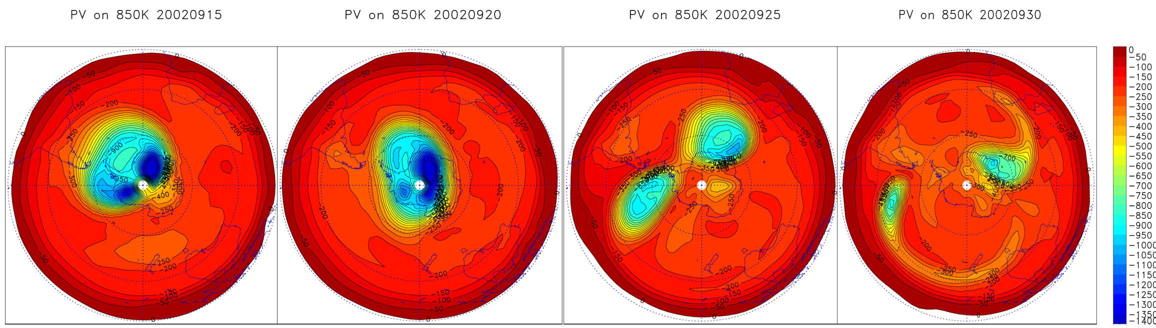


Oct. 15 | Oct. 25 | Nov. 01

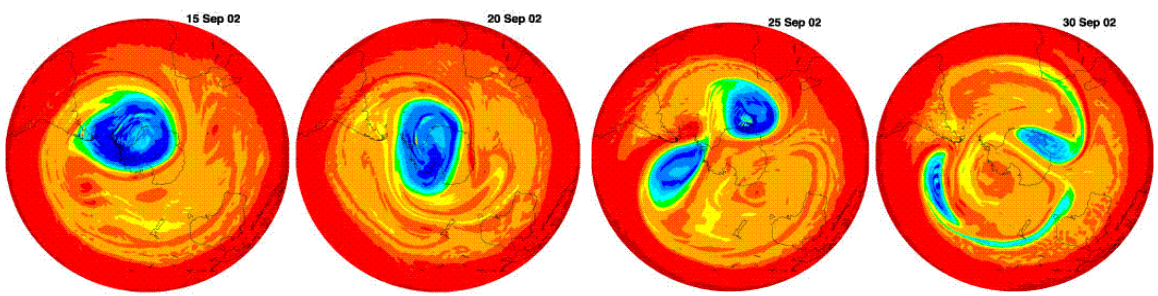


(III) Changes in potential vorticity

Sept.15 Sept. 20 Sept. 25 Sept. 30



CMAM-DAS PV on 850K



ECMWF PV on 850K

Impact of data assimilation below the stratopause on the mesosphere

(I) control DS vs. DS with initial perturbation

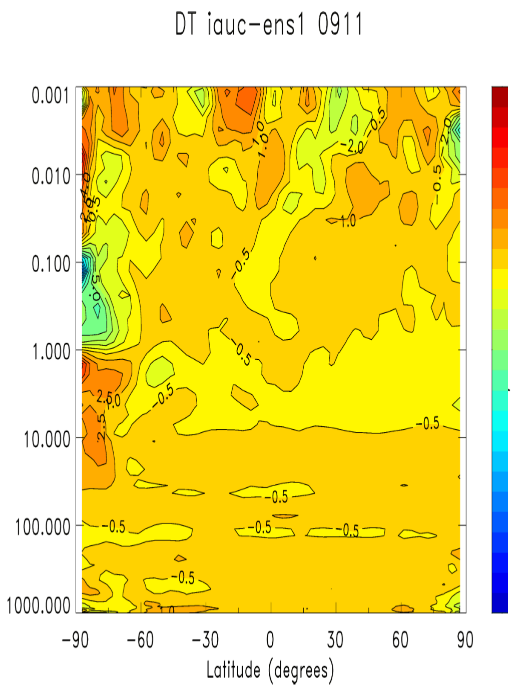
control data assimilation: IAUC

data assimilation with initial perturbations from IAUC: ENS1

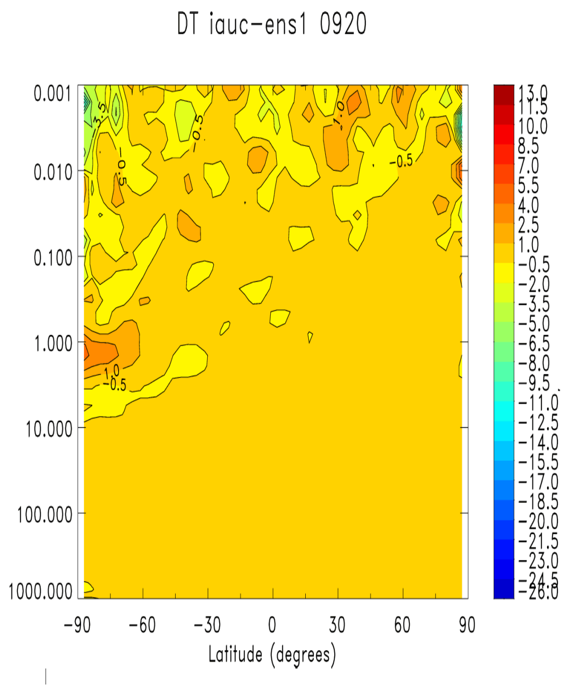
Initial perturbations on Sept. 11th, 2002

Temperature difference (IAUC-ENS1)

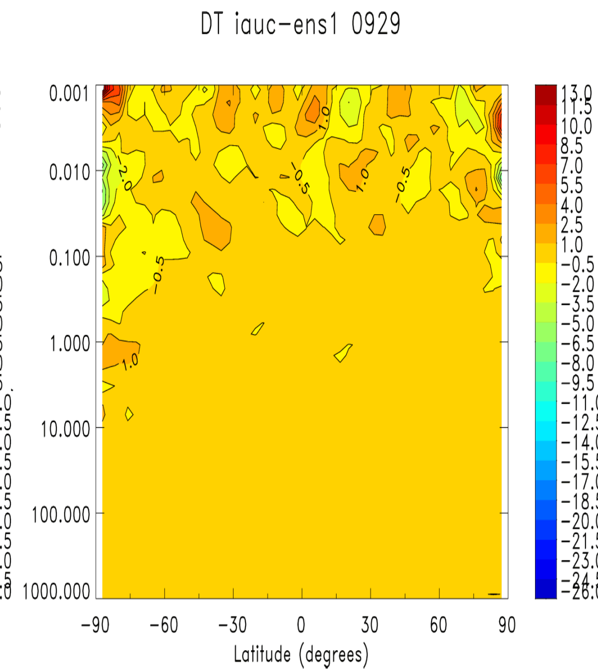
Sept.11, 2002



Sept. 20, 2002

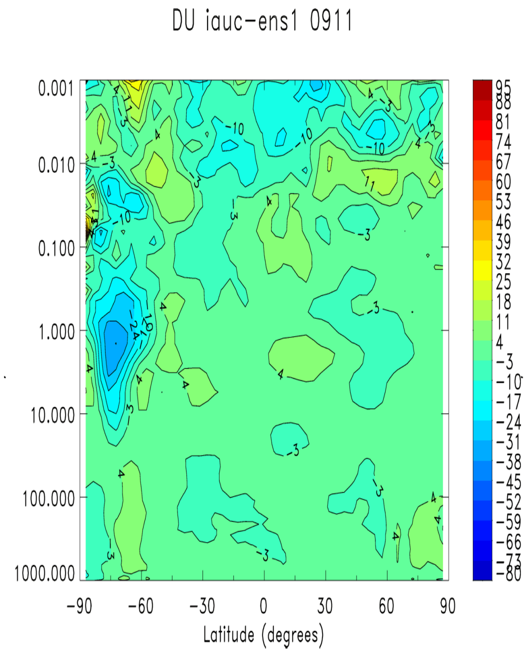


Sept. 29, 2002

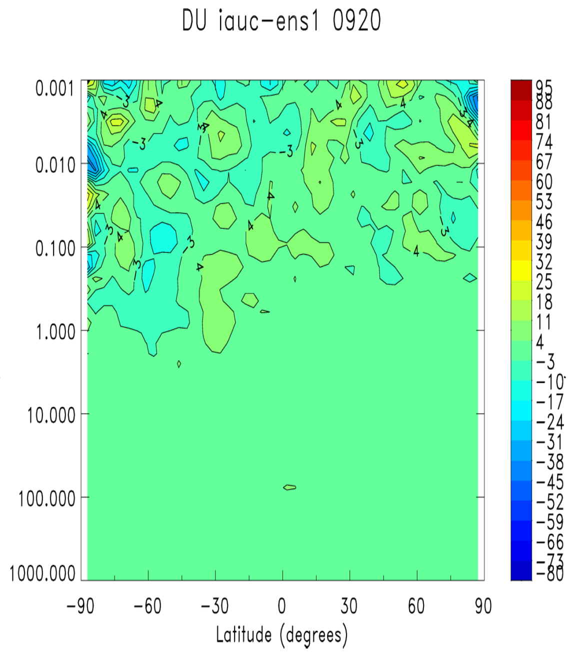


zonal mean zonal wind difference

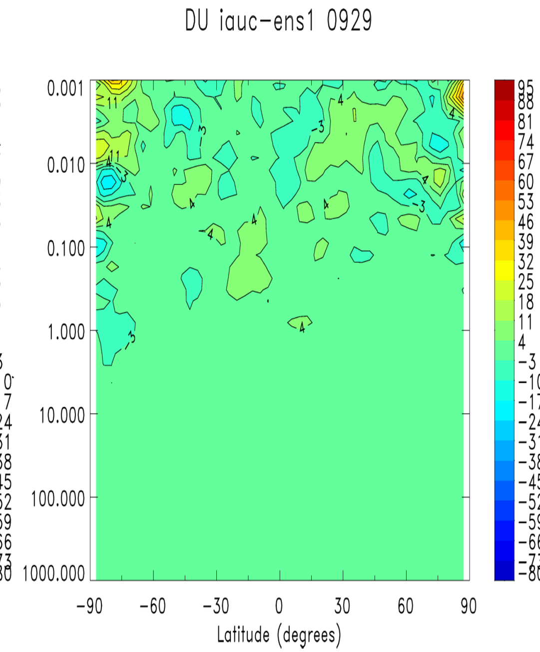
Sept.11, 2002



Sept. 20, 2002



Sept. 29, 2002



(II) control DS vs. forecasts

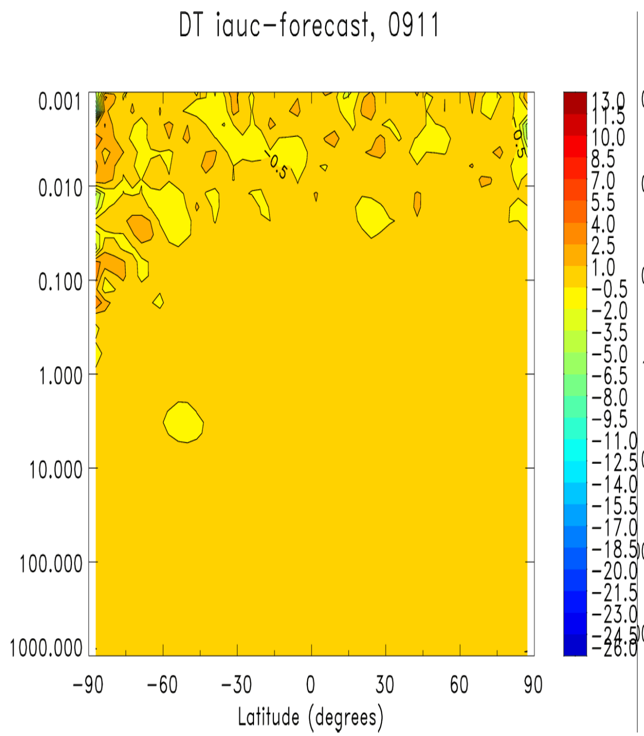
control data assimilation: IAUC

forecast from Sept. 11th, 2002 with initial perturbations from IAUC

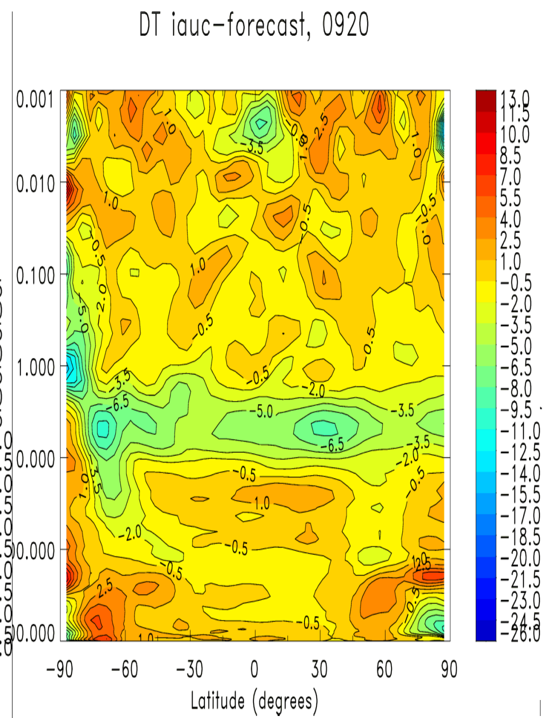
Initial perturbations on Sept. 11th, 2002

Temperature difference

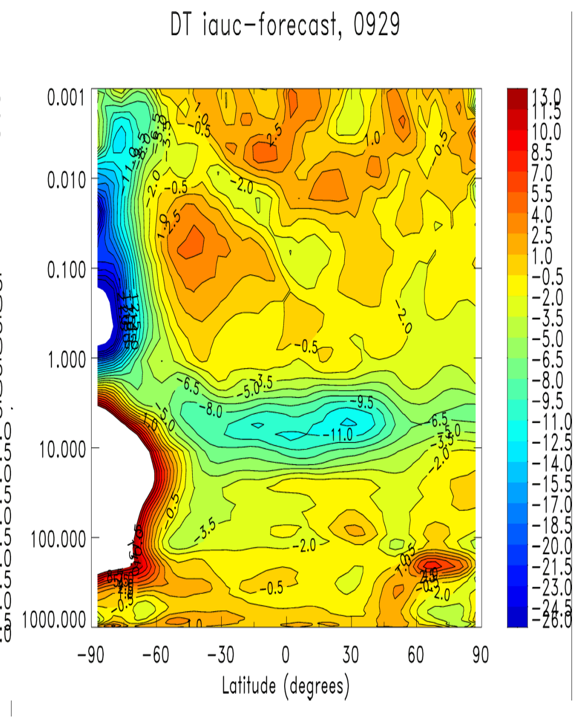
Sept.11th, 2002



Sept.20th, 2002

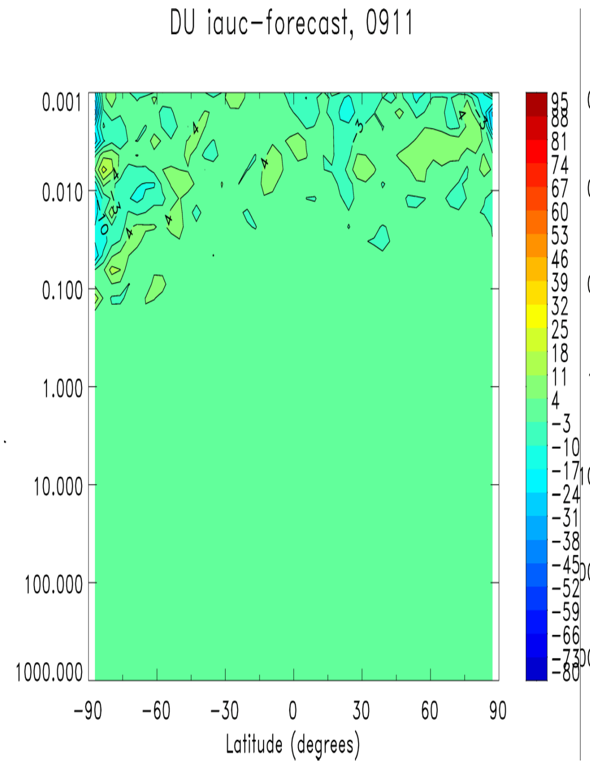


Sept.29th, 2002

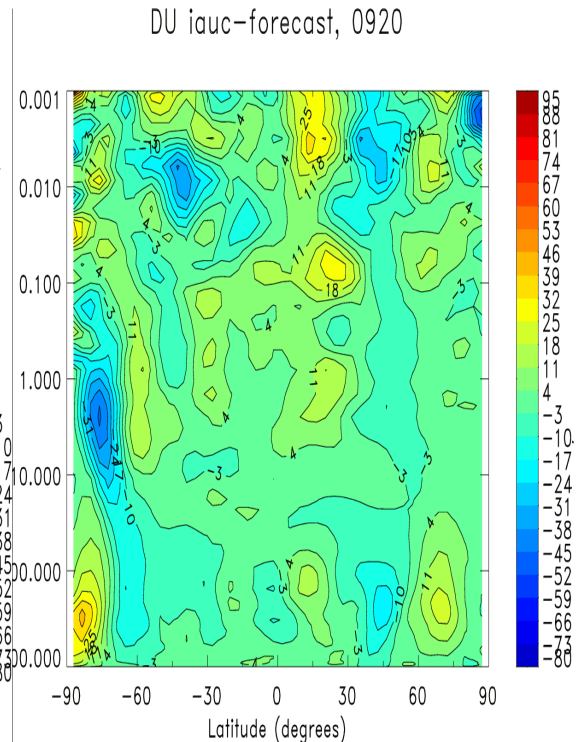


zonal mean zonal wind difference

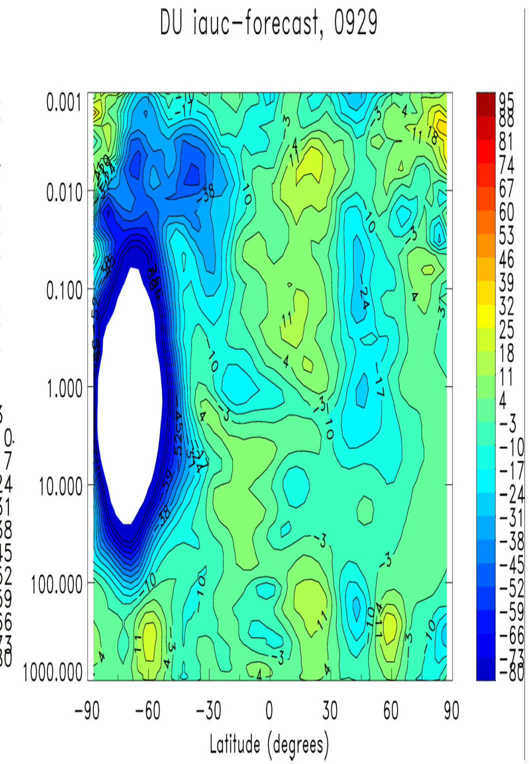
Sept.11th, 2002



Sept. 20th, 2002

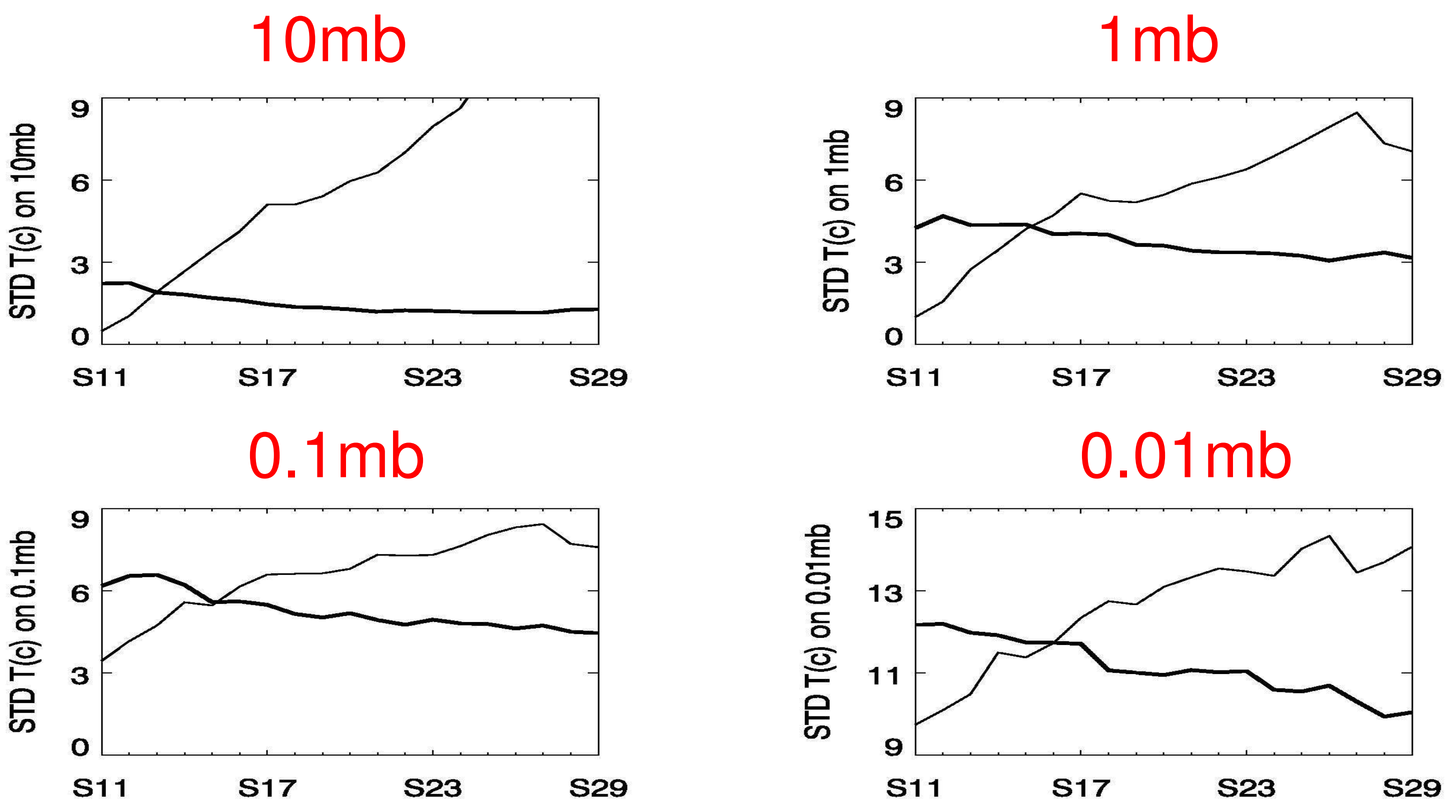


Sept. 29th, 2002



(III) quantifying IUAC-ENS1 and IAUC-FORECAST

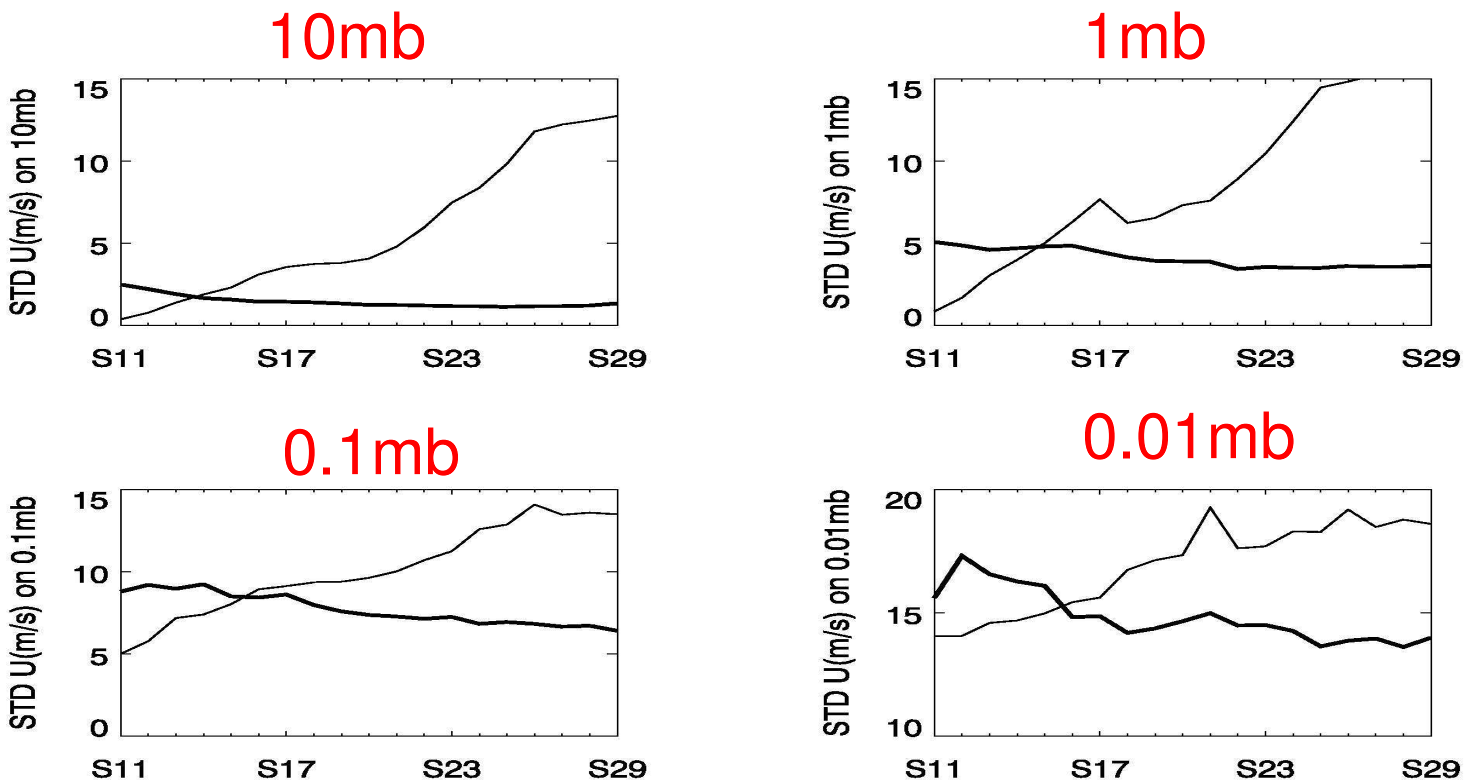
Time series of the square root of globally averaged variance of temperature difference



thick lines: iauc minus ens1

thin lines: iauc minus forecast

Time series of the square root of globally averaged variance of zonal wind difference



thick lines: iauc minus ens1

thin lines: iauc minus forecast

The contribution of unresolved GWD in propagating data assimilation information into the mesosphere

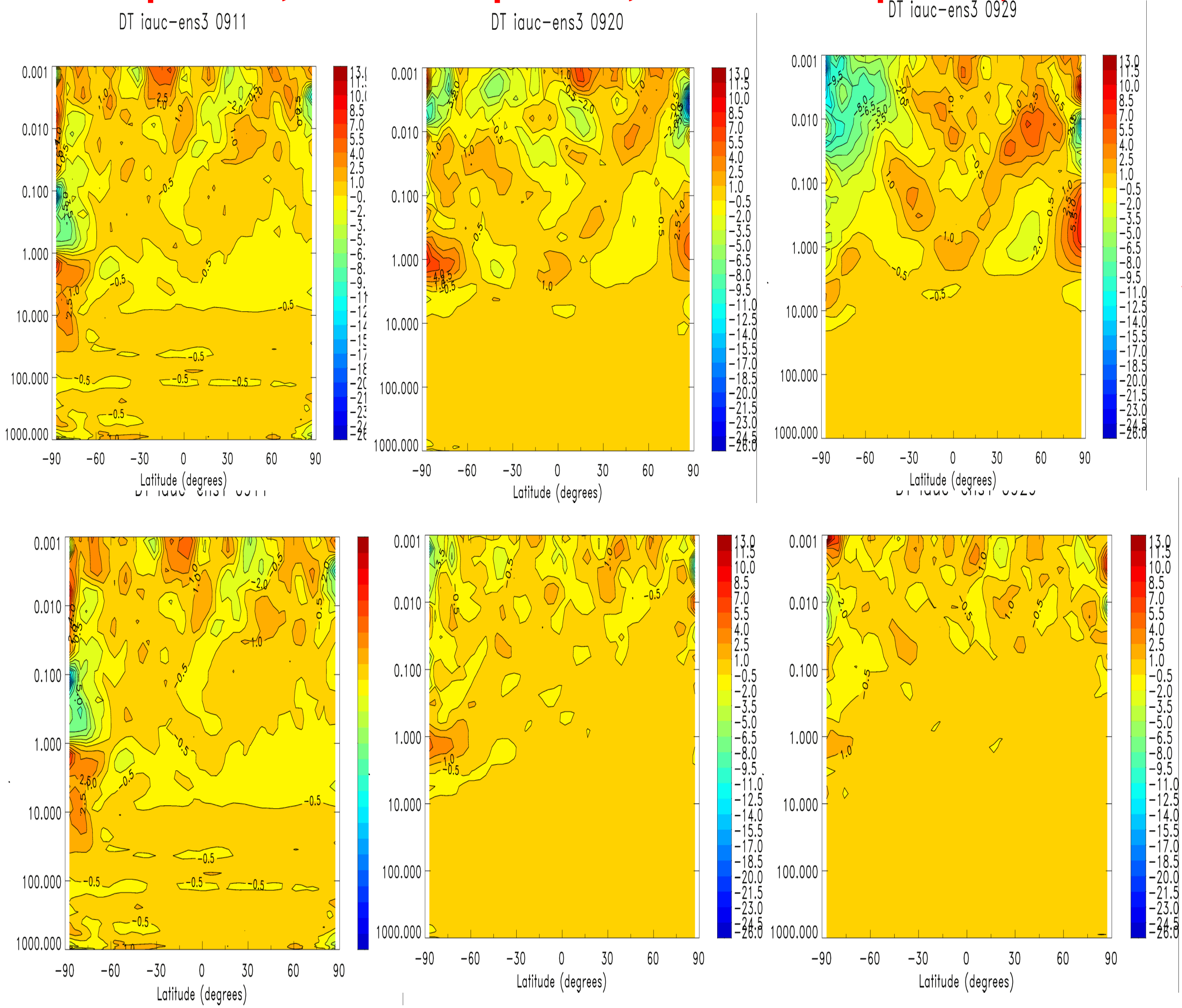
control data assimilation: <u>IAUC</u>

data assimilation with initial perturbations from IAUC but with GWD turned off: <u>ENS3</u>

NO GWD

DT

Sept. 11th, 2002 | Sept. 20th, 2002 | Sept.29th, 2002

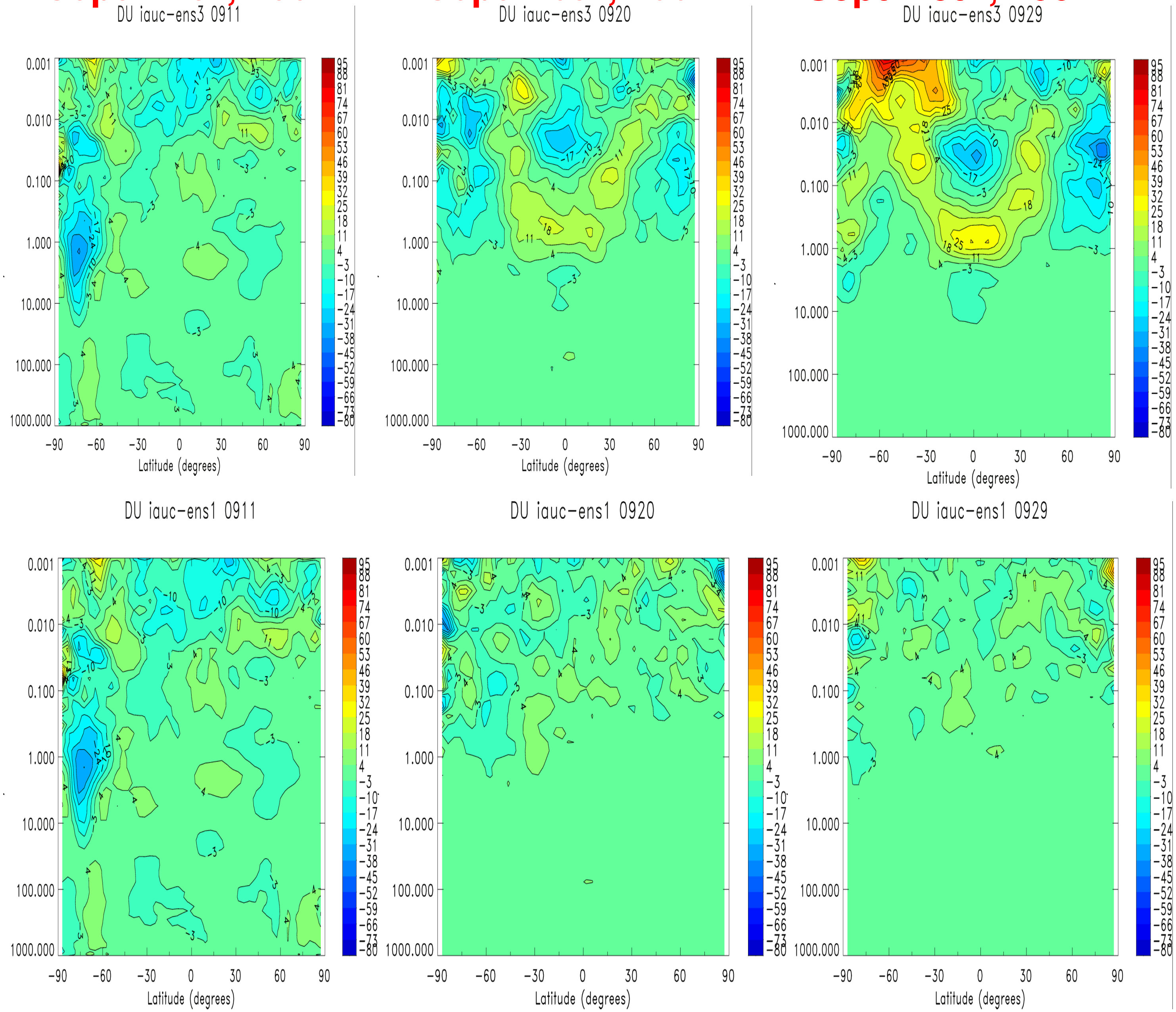


IAUC-ENS3
without GWD

IAUC-ENS1
with GWD

Sept. 11th, 2002 | Sept. 20th, 2002 | Sept. 29th, 2002

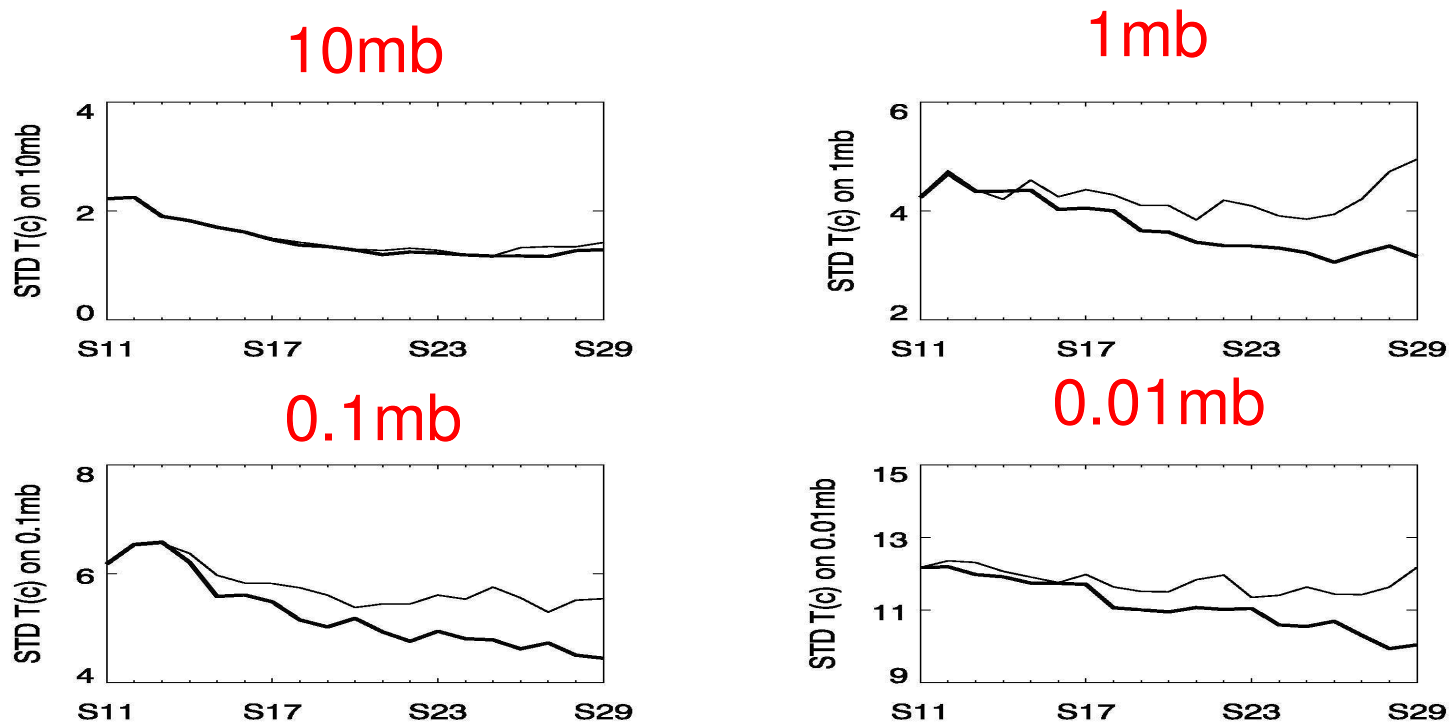
DU



IAUC-ENS3
without GWD

IAUC-ENS3
with GWD

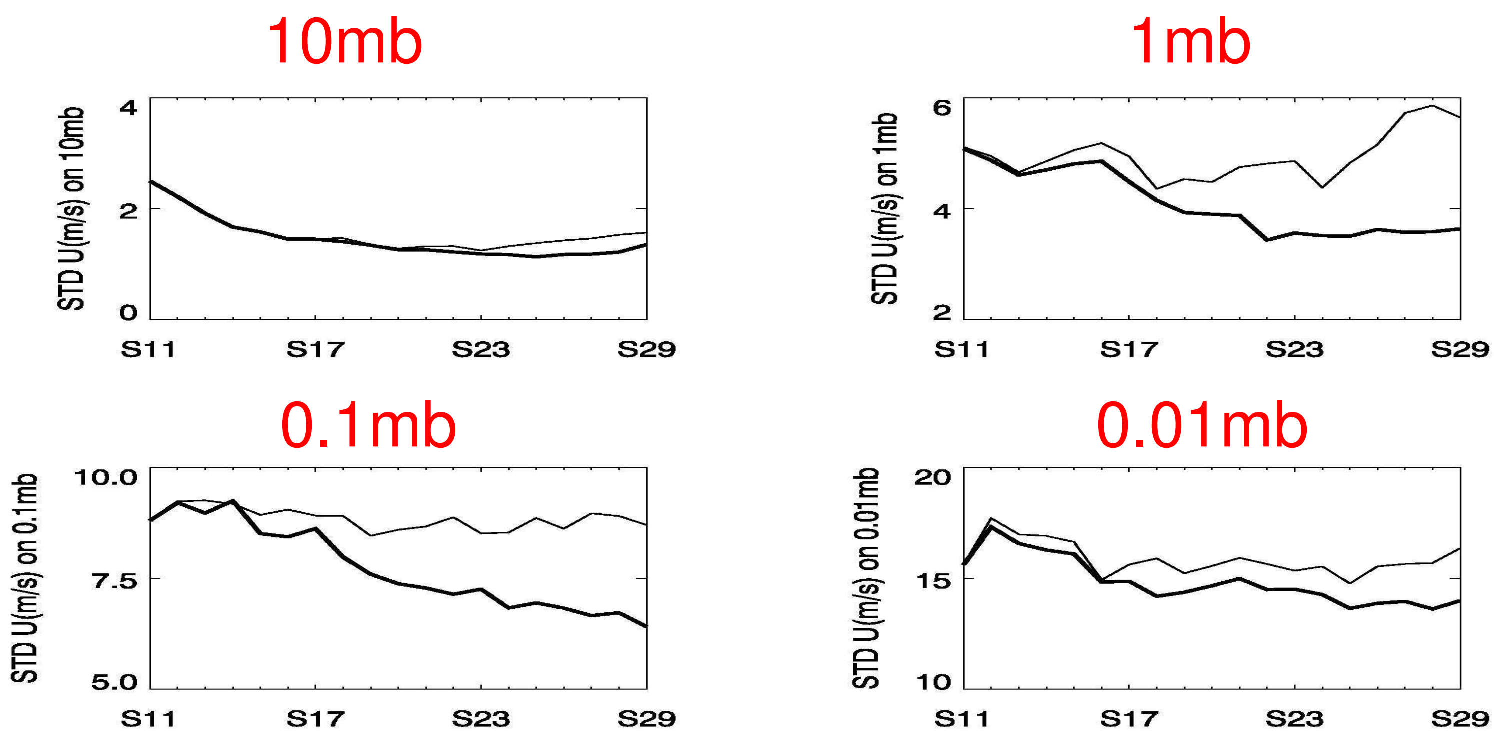
Time series of the square root of globally averaged variance of temperature difference



thick lines: iauc minus ens1

thin lines: iauc minus ens3

Time series of the square root of globally averaged variance of zonal wind difference



thick lines: iauc minus ens1

thin lines: iauc minus ens3

Contribution of unresolved waves vs. contribution of resolved waves

Equation for the vertical component of the mean residual circulation $\bar{w}^*$ in the QG limit (Haynes et al., 1990, McIntyre 1987):

$$\bar{w}^* = -\frac{1}{a\rho_0 \cos\phi} \frac{\partial}{\partial\phi} \left(\int_z^\infty \left(\frac{\rho_0 \bar{\mathcal{F}} \cos\phi}{2\Omega \sin\phi} \right)_{\phi=const.} dz' \right) \tag{1}$$

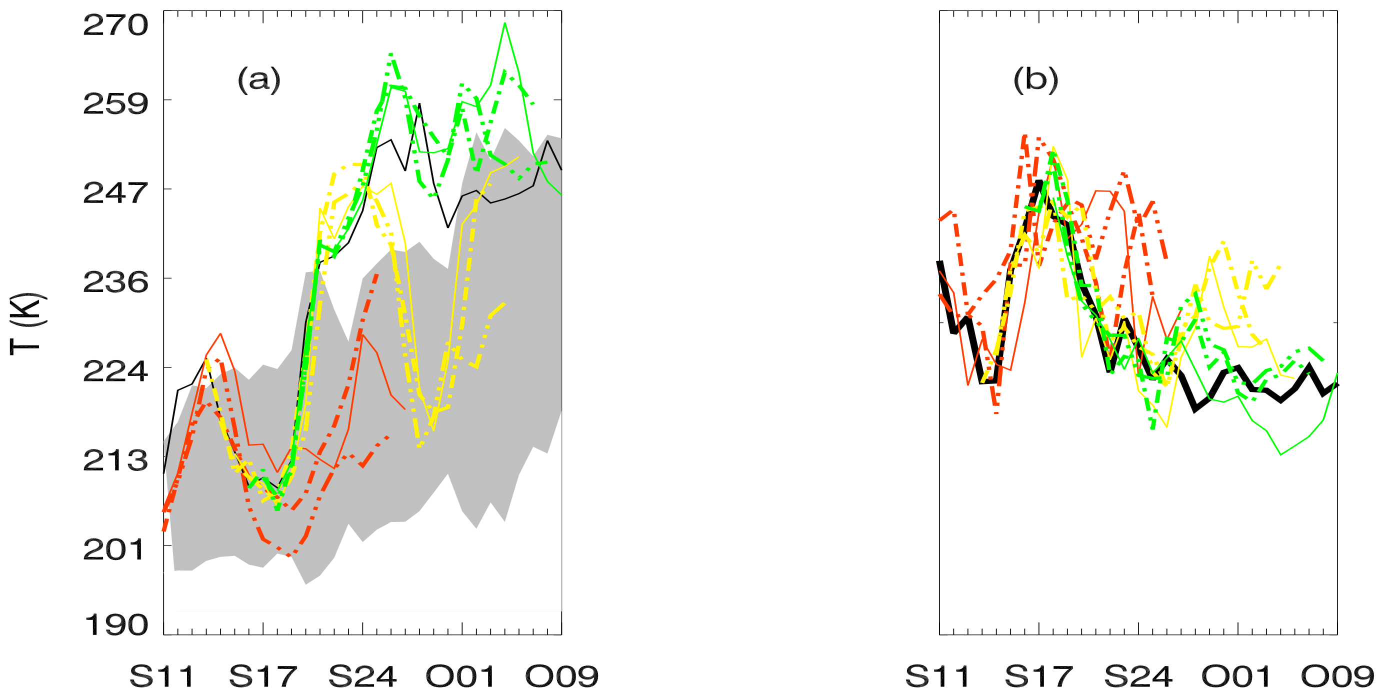
Since $\bar{\mathcal{F}}$ cantains resolved part and nonresolved part, i.e.,

$$\bar{\mathcal{F}} = \nabla \cdot \mathbf{F} + \mathcal{G} \tag{2}$$

where $\mathbf{F}$ is the E-P flux, and $\mathcal{G}$ is the force generated from gravity wave breaking and from other dissipative processes, $\bar{w}^*$ can be decomposed into resolved part and unresolved part.

time series of temperature at 88.14s

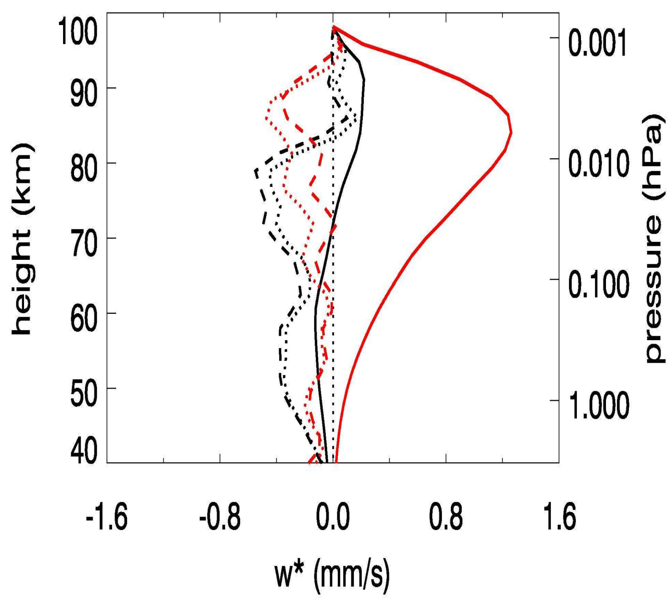
10mb   0.1mb



----- : Sept. 6
_._. : Sept. 7
___: Sept. 9

----- : Sept. 17
_._. : Sept. 18
___: Sept. 19

the contribution from resolved waves, planetary waves and subgrid scale waves to the cooling during Sept. 25 - Oct. 1, 2002 over the south pole (Saroja).



Red: the ensemble average of forecasts that capture the SSW.

Black: the ensemble average of forecasts that miss the SSW.

_______: subgrid waves

---------: resolved waves

..........: planetary waves (k<5)

.

W*>0: cooling,
W*<0: warming

Conclusions and future work

- 2002 Antarctic SSW is identified from CMAM-DAS analyses.
- Due to the high lid of CMAM, CMAM-DAS analyses can be used to examine the constraint of DA below the stratopause on the mesosphere.
- The constraint of data assimilation below the stratopause on motions in the mesosphere is demonstrated.
- Unresolved GWs make a bigger contribution in spreading DA information into the mesosphere than resolved waves during the SSW.
- Observations above the mesopause will be used to examine the DA constraint in the future.