

SPARC-DA Workshop, Toronto, Sept. 4-9, 2007

# 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.**

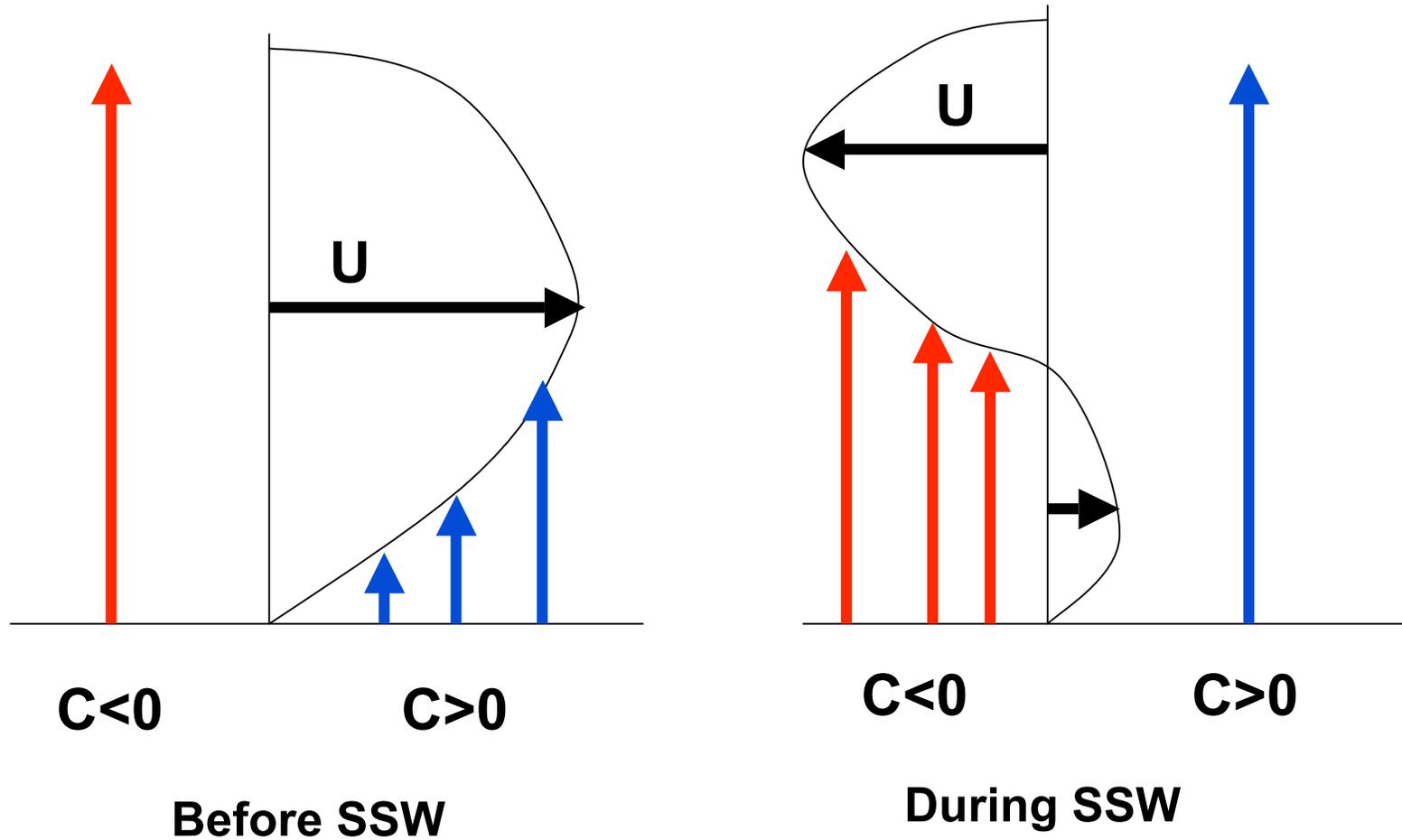
- **Why use Canadian Middle Atmosphere Model Data Assimilation System (CMAM-DAS) analyse?**

**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

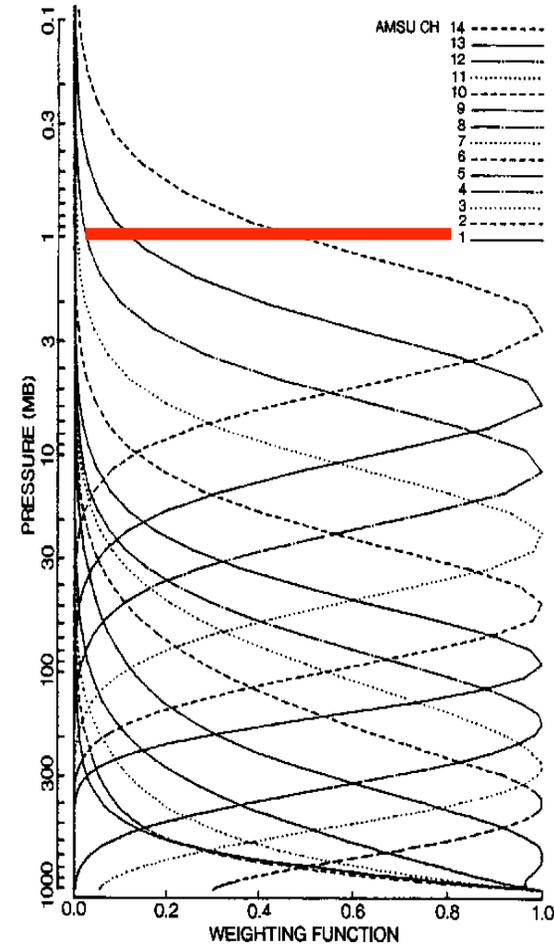
- **T47 spectral model with interactive chemistry, radiation and dynamics.**
- **71 levels from 0-95 km. It uses the Hines GWD scheme.**
- **44 species advected, 127 gas-phase chemical reactions chemistry, heterogeneous chemistry**
- **Incremental analysis updating (IAU) is applied for initialization.**

## **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.

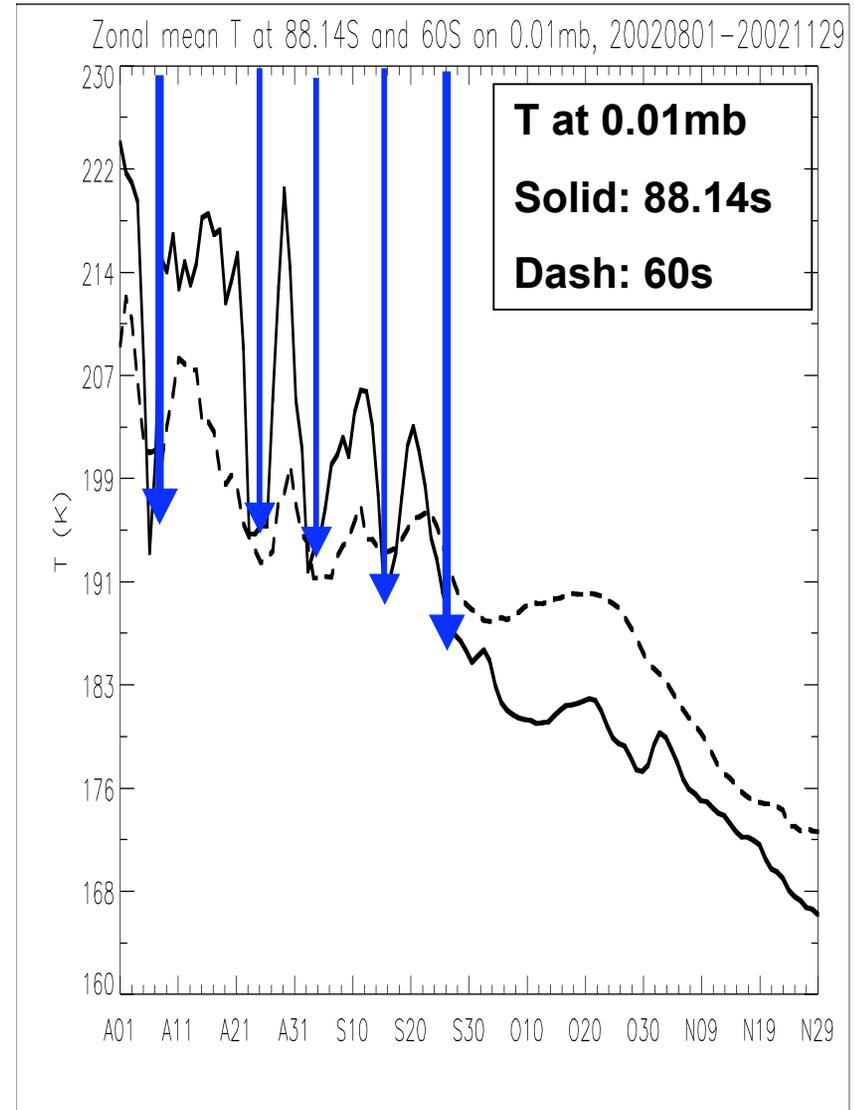
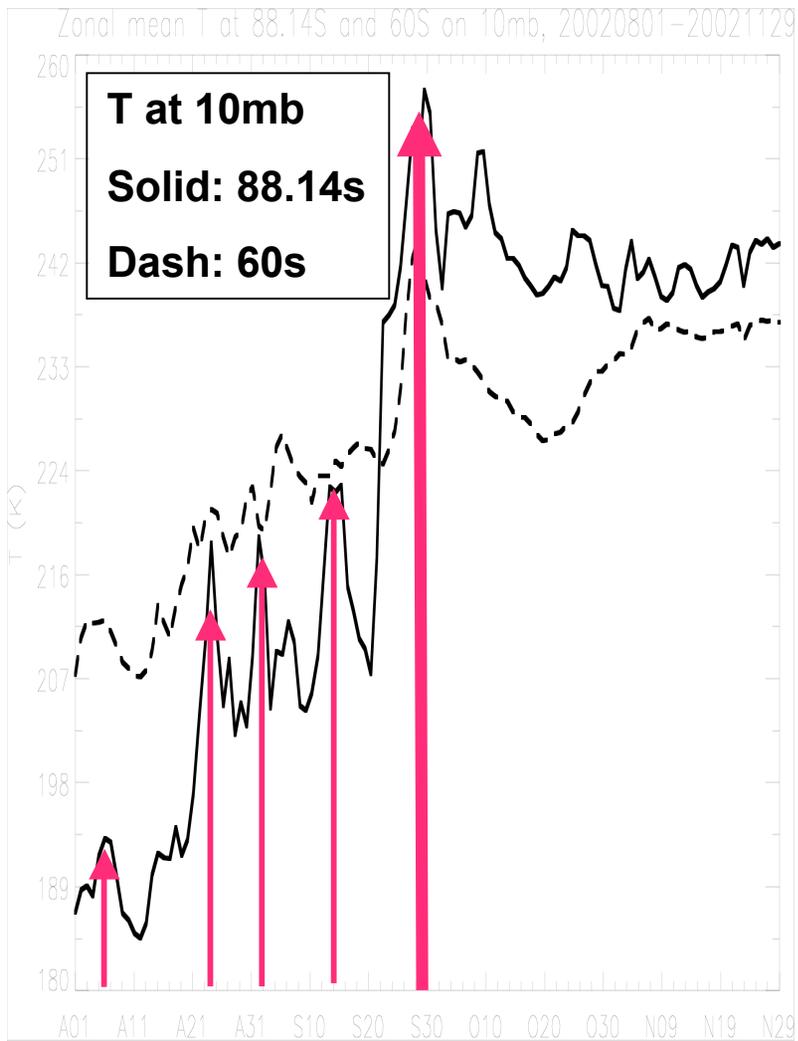


- In 3dvar, the correlation between the stratosphere and mesosphere is cut off. Thus data assimilation below 1 hpa has NO influence on the mesosphere *during the data assimilation*.
- Information of data assimilation below 1 hpa can be spread into the mesosphere only through the vertically propagating (resolved and unresolved) waves *during the model integration*.

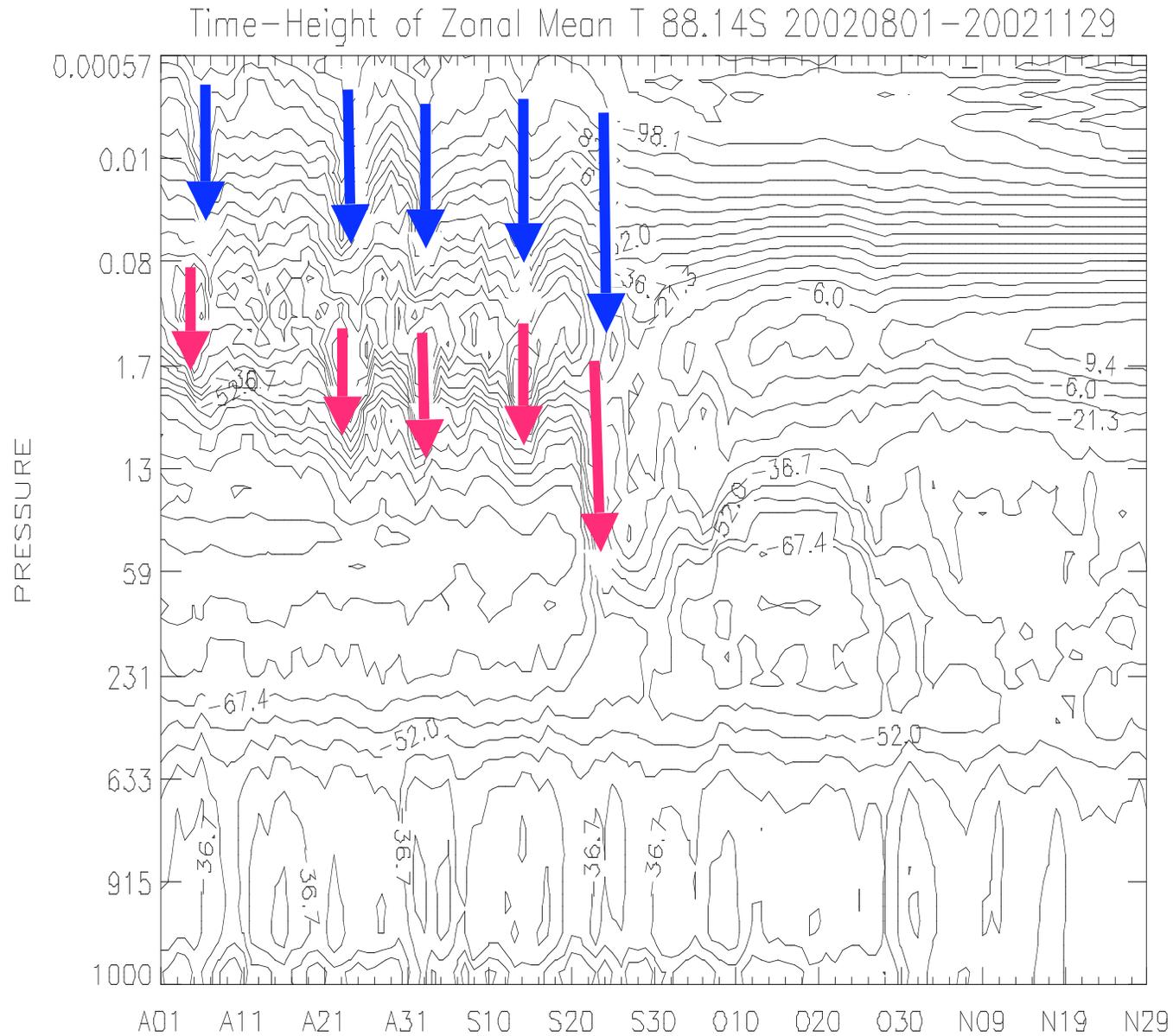
# **Diagnostics of 2002 Antarctic SSW**

## **(I) Changes in temperature**

# Temperature time series during SSW

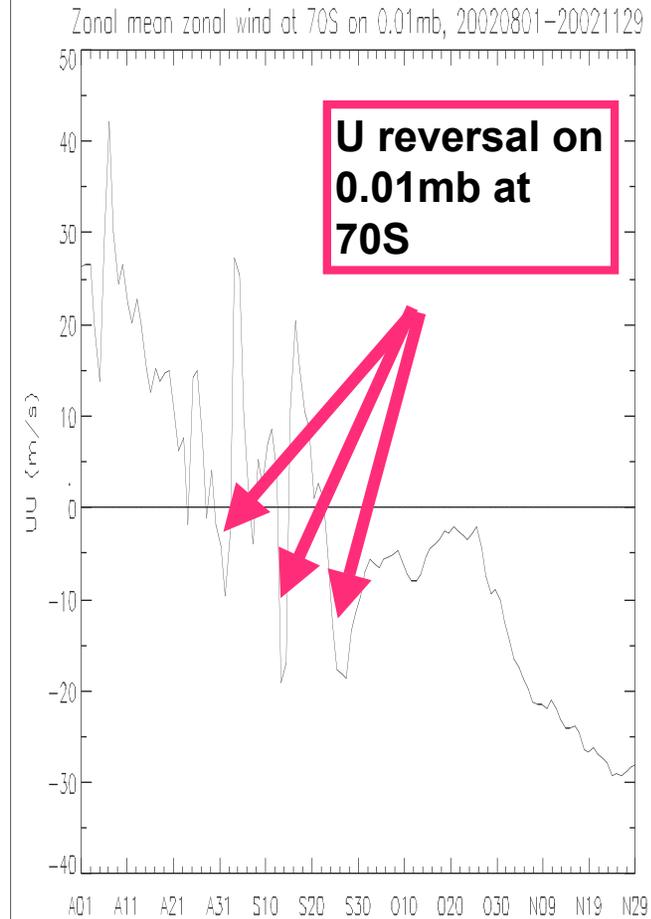
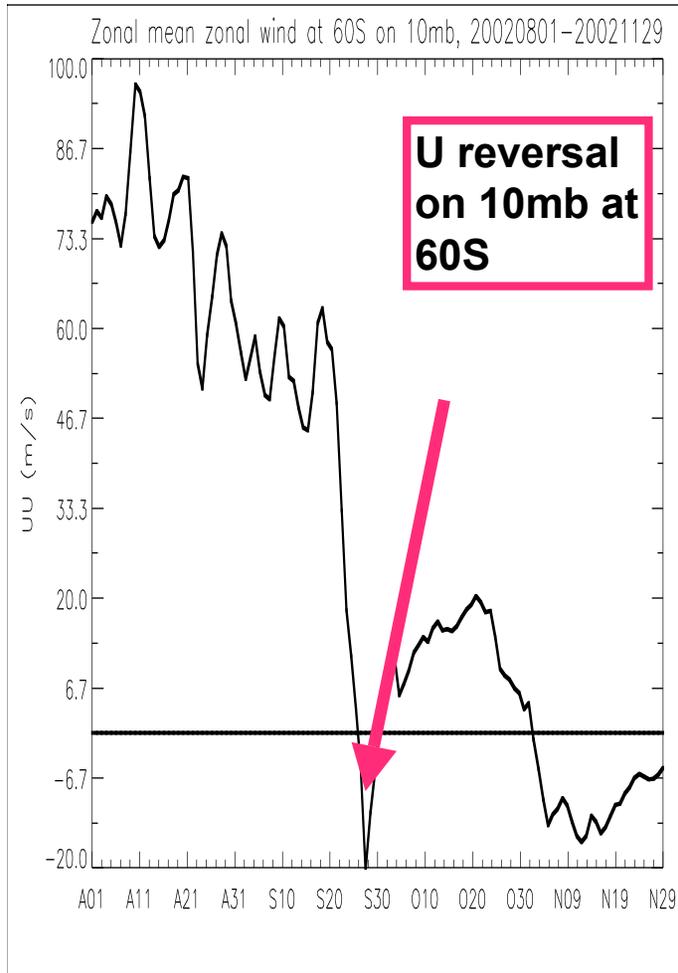


# Time-height cross section of zonal mean T at 88.14S

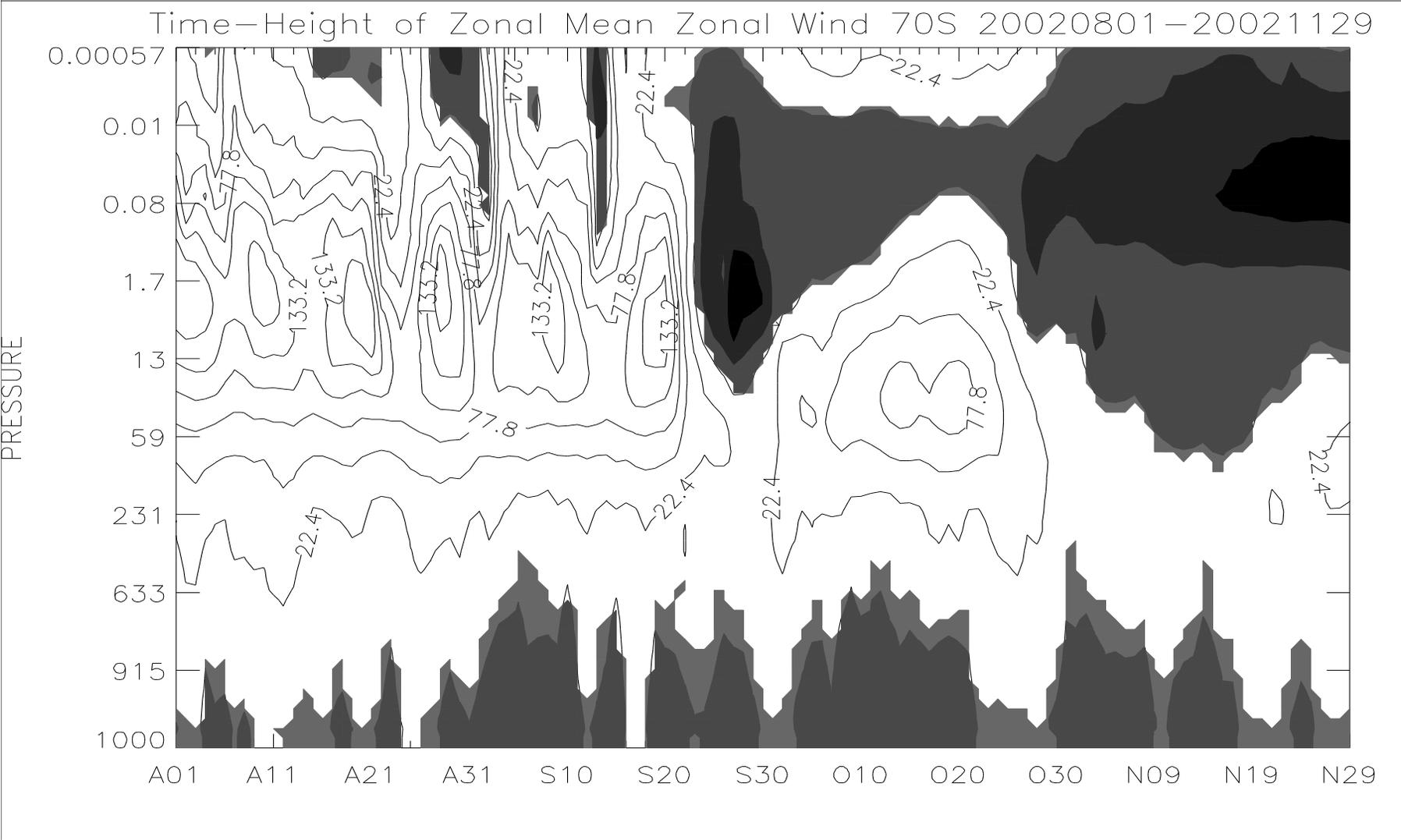


## **(II) Changes in wind**

# Time series of zonal mean zonal wind during SSW

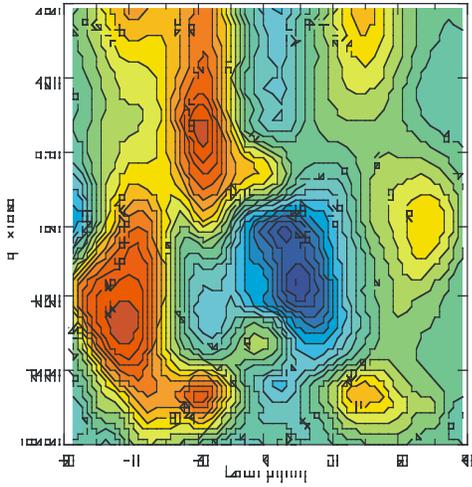


# Time-height cross section of zonal mean zonal wind at 70S

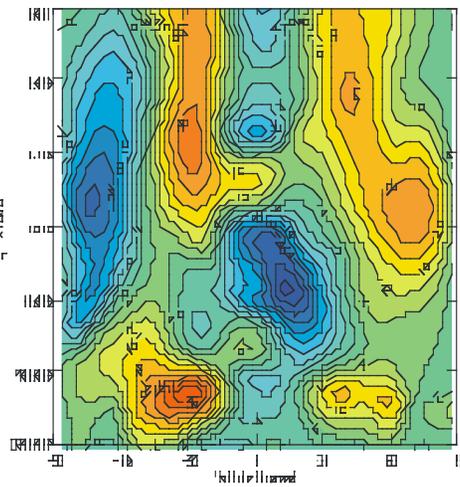


# Zonal mean zonal wind

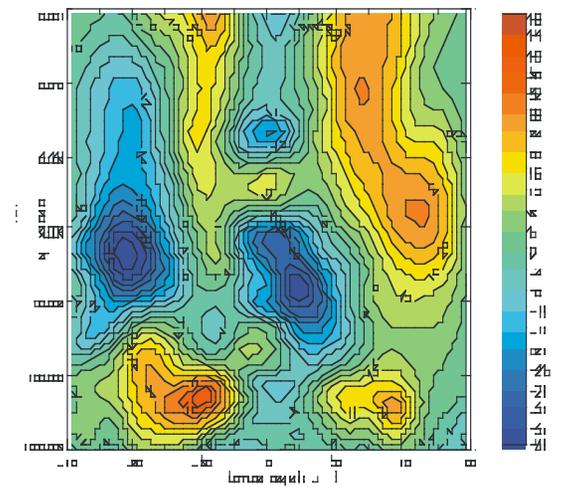
Sept. 15



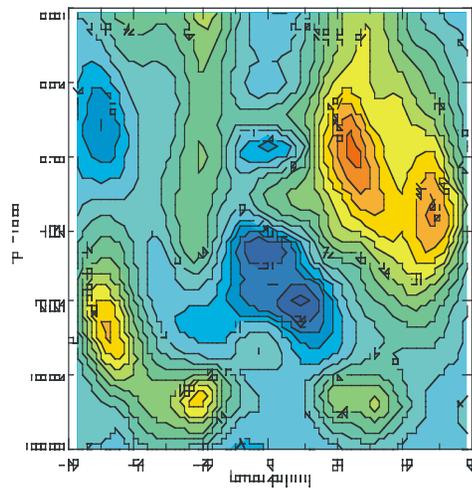
Sept. 25



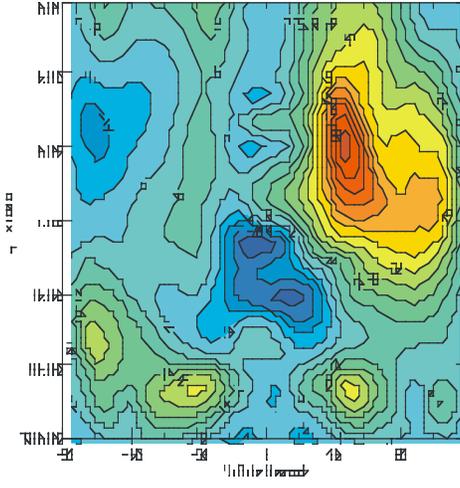
Sept. 28



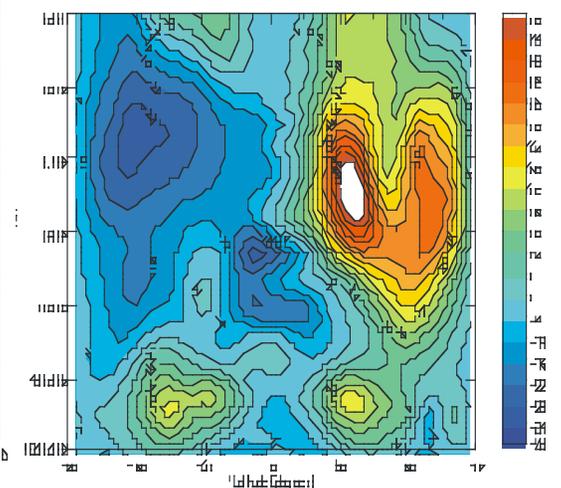
Oct. 15



Oct. 25



Nov. 01



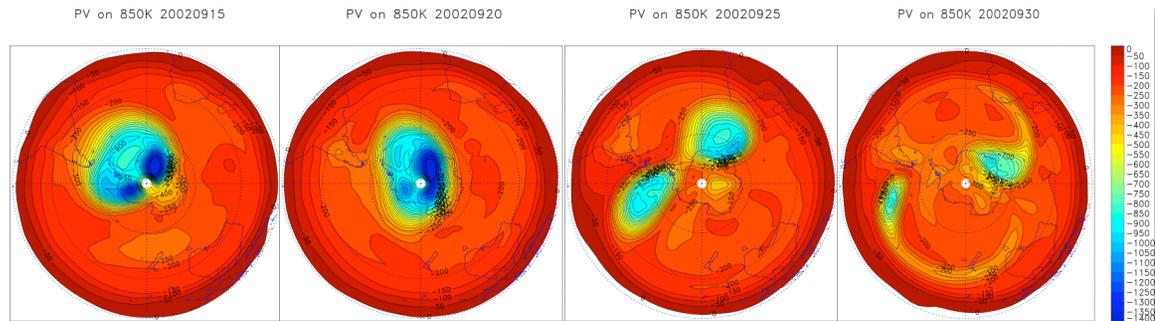
### **(III) Changes in potential vorticity**

**Sept. 15**

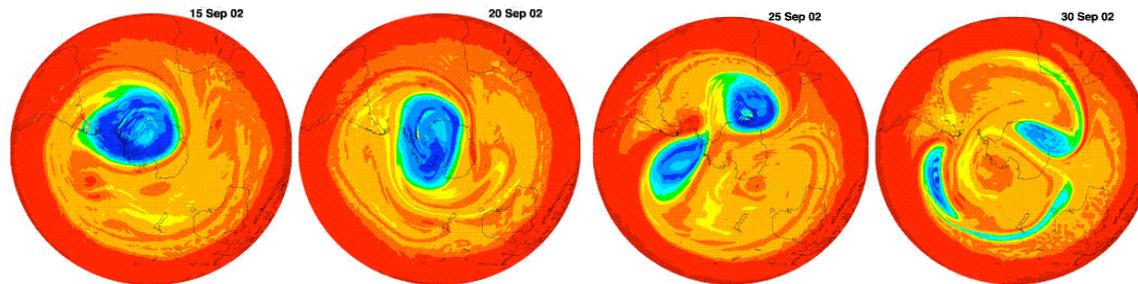
**Sept. 20**

**Sept. 25**

**Sept. 30**



**CMAM-DAS  
PV on 850K**



**ECMWF PV  
on 850K**

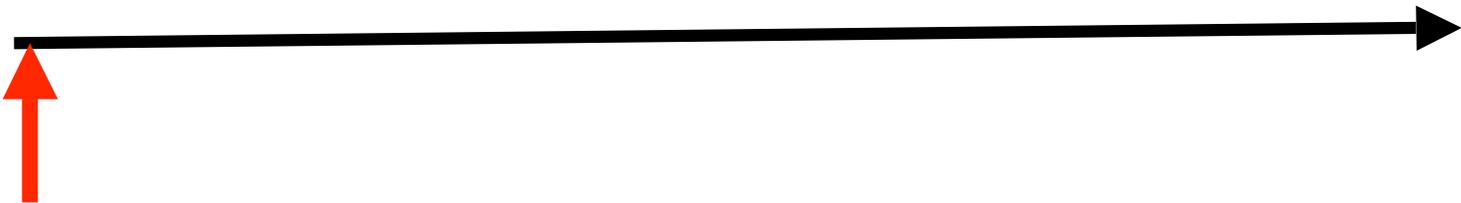
# **Impact of data assimilation below the stratopause on the mesosphere**

## (I) control DS vs. DS with initial perturbation

control data assimilation: IAUC



data assimilation with initial  
perturbations from IAUC: ENS1



Initial perturbations on Sept. 11<sup>th</sup>, 2002

# Temperature difference (IAUC-ENS1)

Sept. 11, 2002

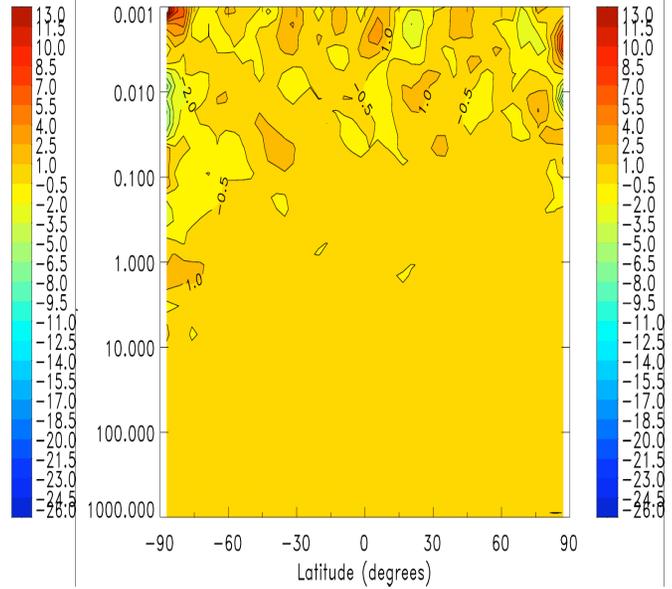
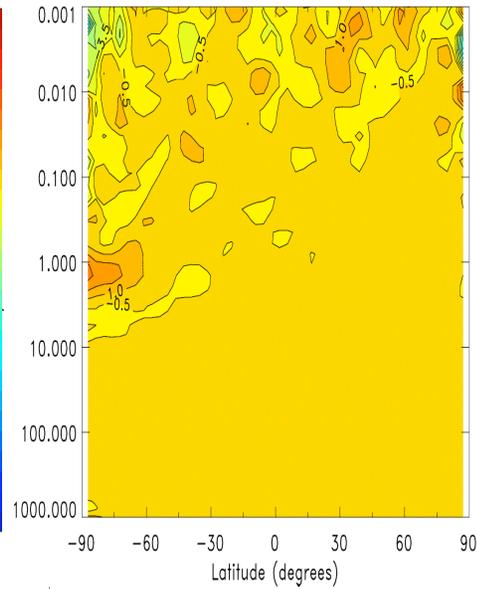
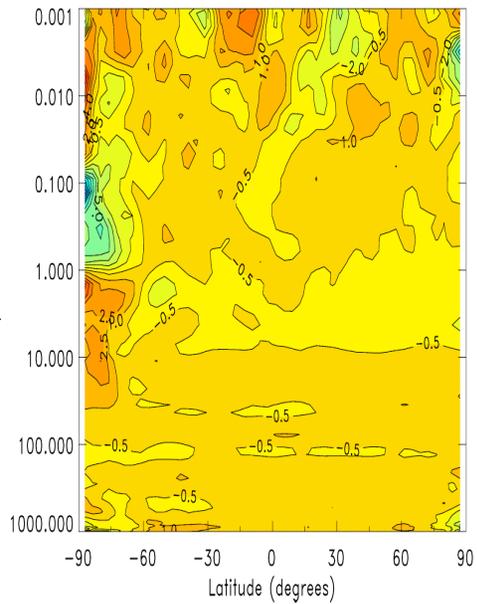
Sept. 20, 2002

Sept. 29, 2002

DT iauc-ens1 0911

DT iauc-ens1 0920

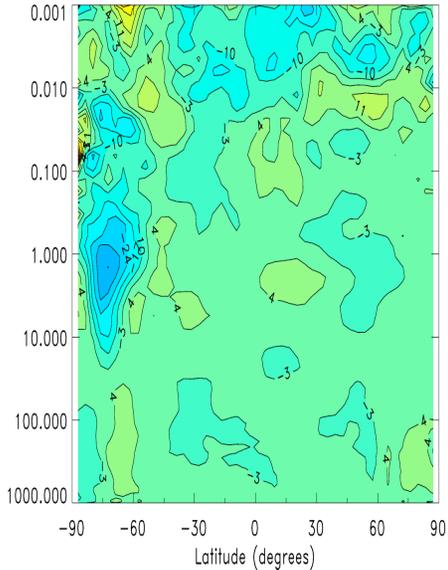
DT iauc-ens1 0929



# zonal mean zonal wind difference

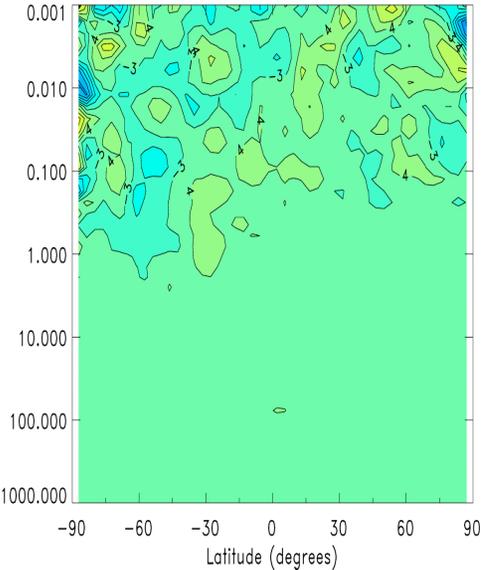
**Sept. 11, 2002**

DU iauc-ens1 0911



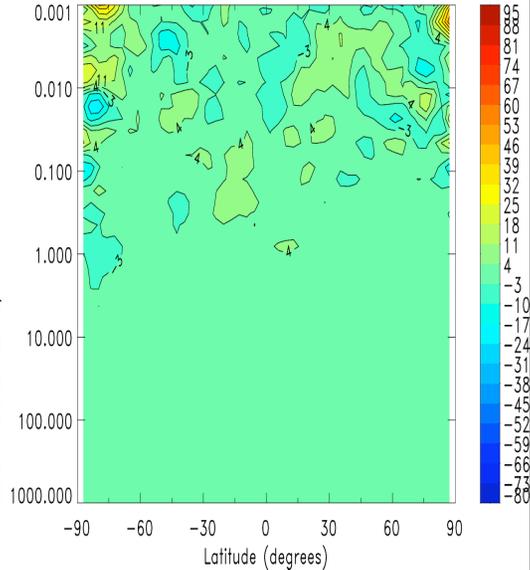
**Sept. 20, 2002**

DU iauc-ens1 0920



**Sept. 29, 2002**

DU iauc-ens1 0929



## (II) control DS vs. forecasts

control data assimilation: IAUC



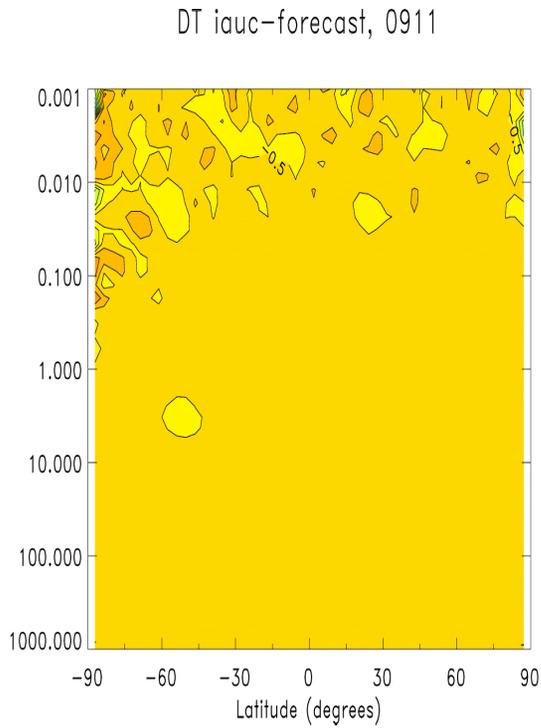
forecast from Sept. 11<sup>th</sup>, 2002 with initial perturbations from **IAUC**



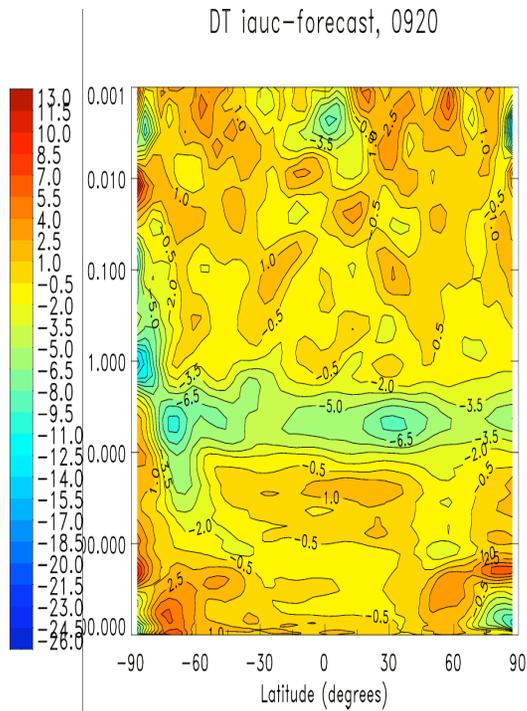
Initial perturbations on Sept. 11th, 2002

# Temperature difference

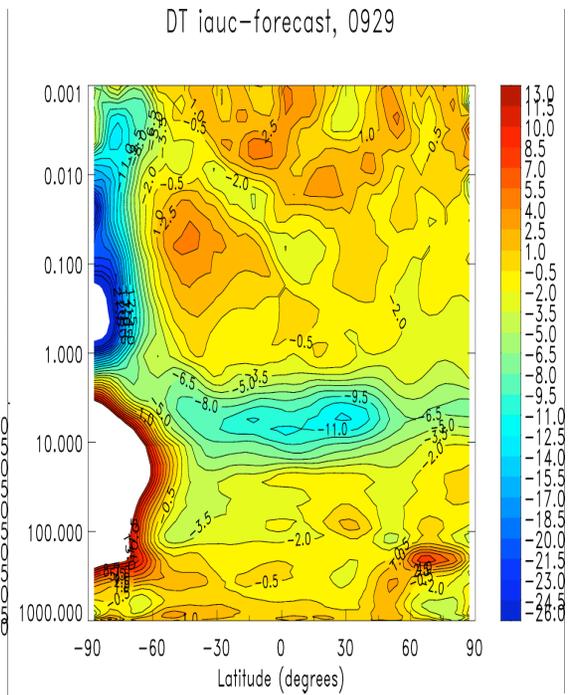
Sept.11th, 2002



Sept.20th, 2002



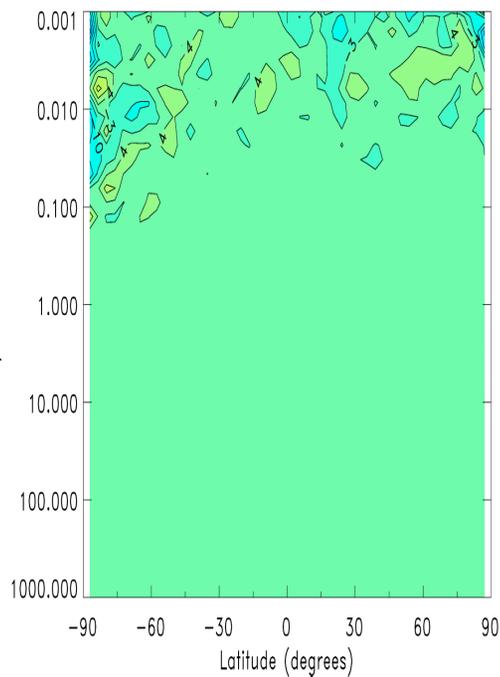
Sept.29th, 2002



# zonal mean zonal wind difference

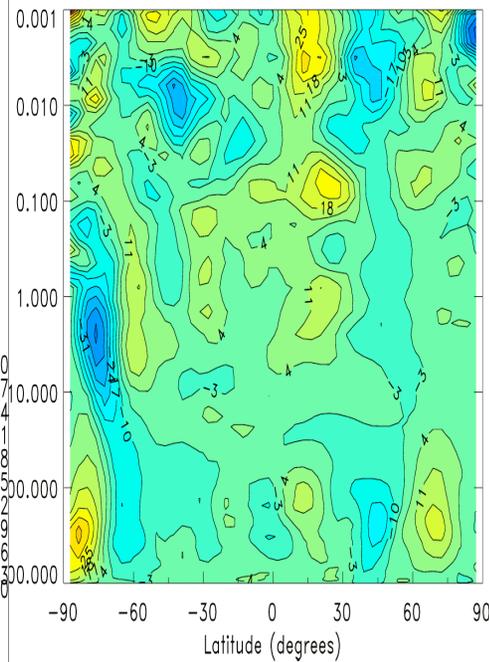
**Sept. 11th, 2002**

DU iauc-forecast, 0911



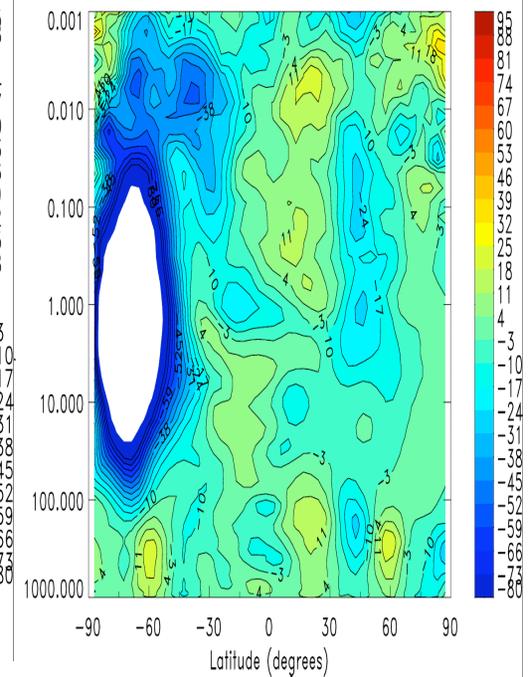
**Sept. 20th, 2002**

DU iauc-forecast, 0920



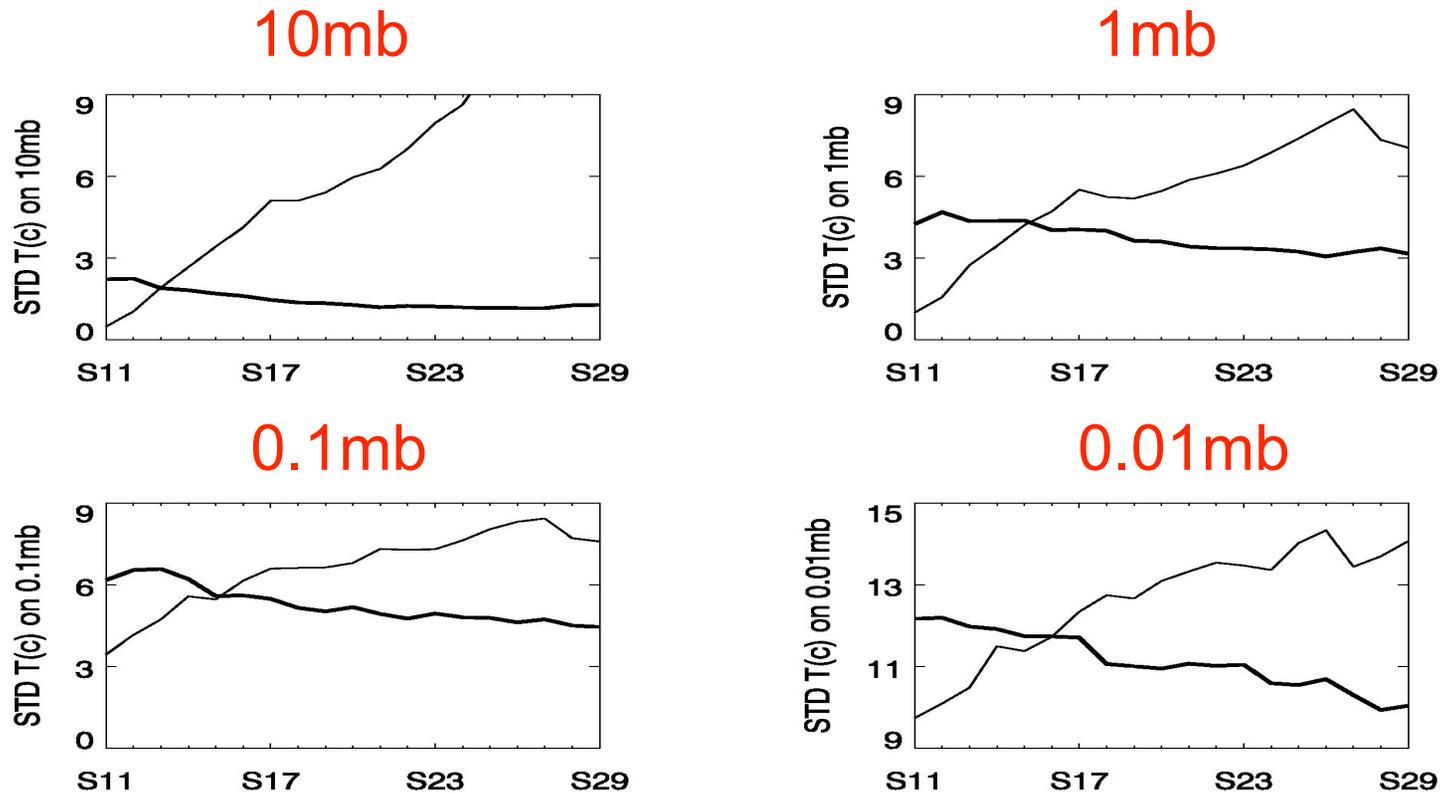
**Sept. 29th, 2002**

DU iauc-forecast, 0929



**(III) quantifying IUAC-ENS1 and IAUC-FORECAST**

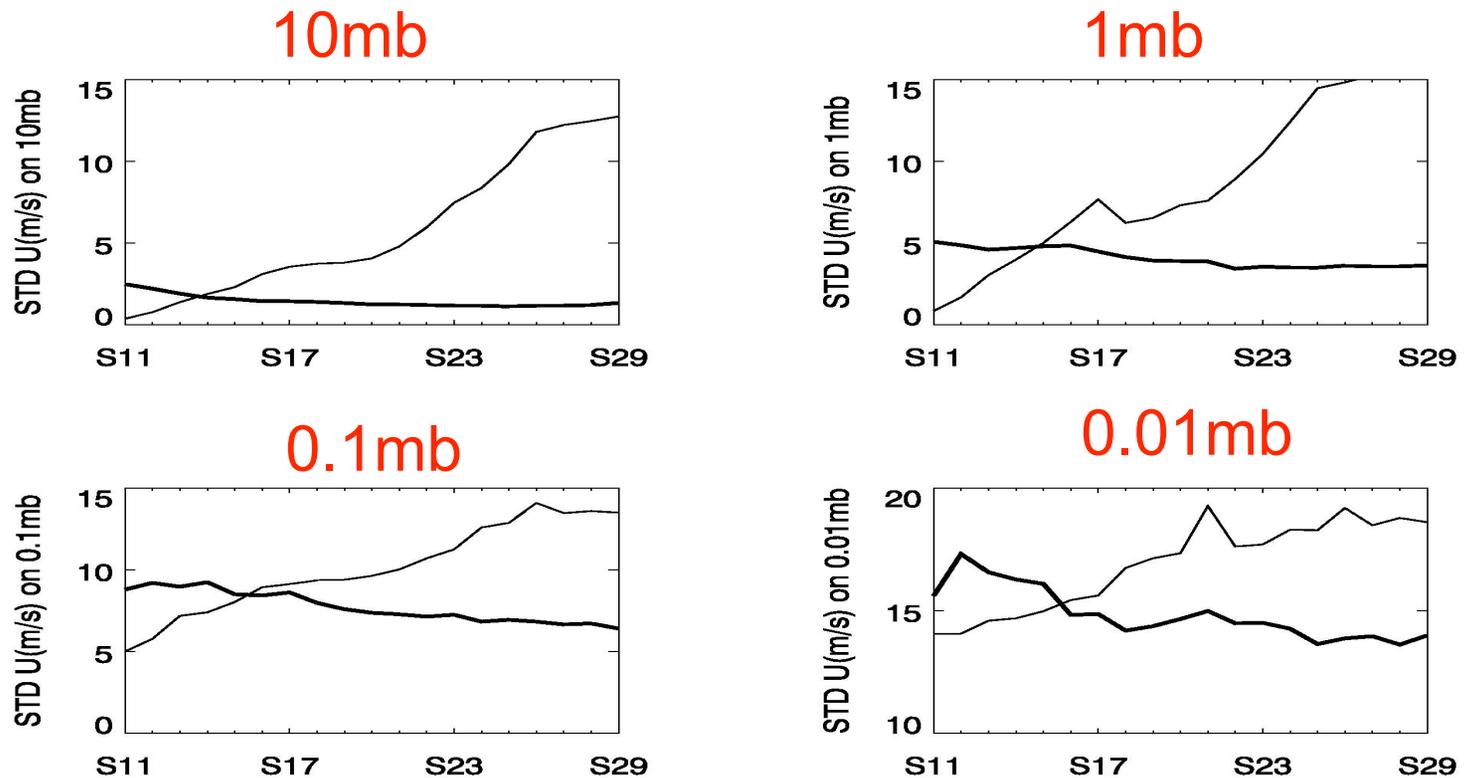
# Time series of the square root of globally averaged variance of temperature difference



**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: IAUC



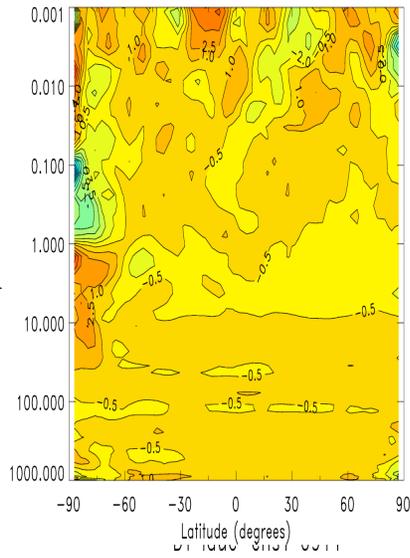
data assimilation with initial  
perturbations from **IAUC** but with  
**GWD** turned off: ENS3



**NO GWD**

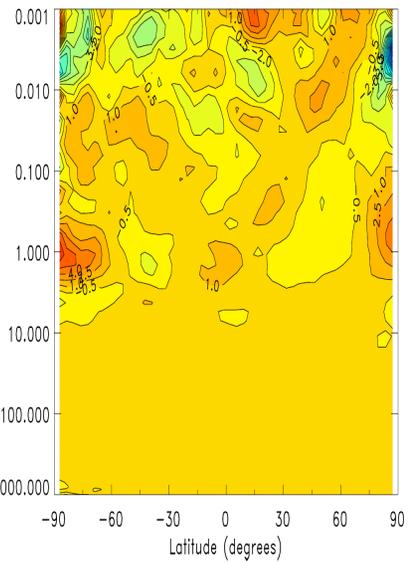
**Sept. 11th, 2002**

DT iauc-ens3 0911



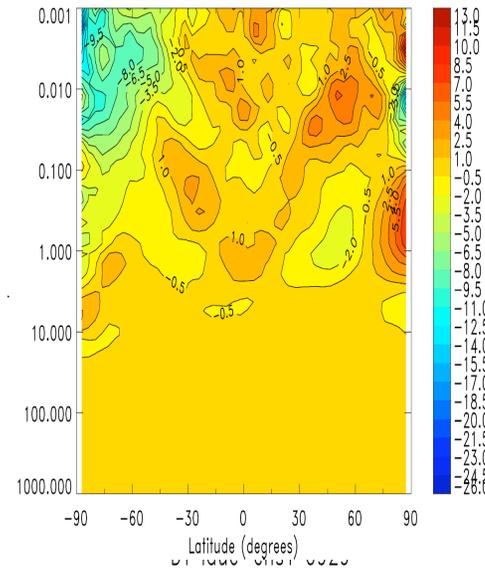
**Sept. 20th, 2002**

DT iauc-ens3 0920



**Sept. 29th, 2002**

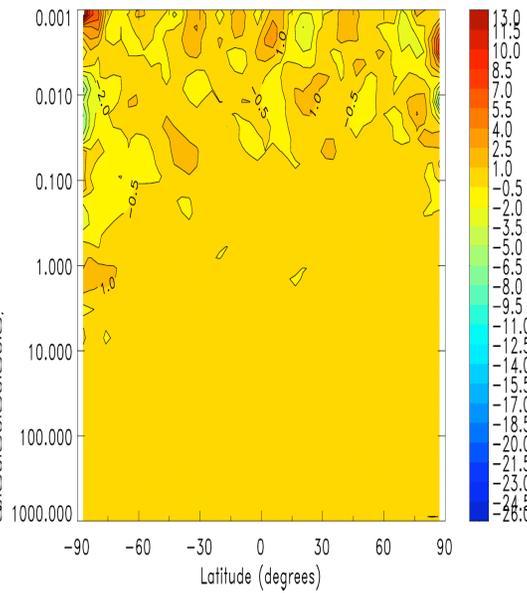
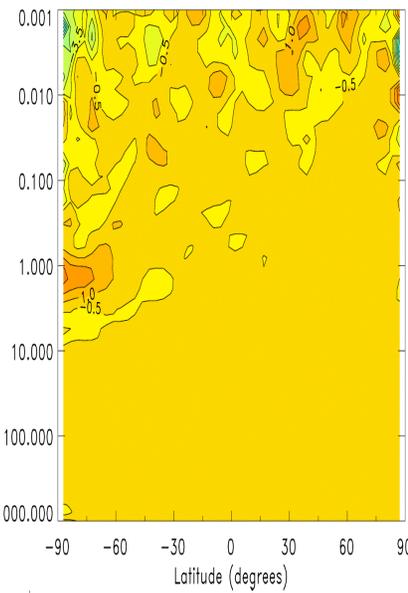
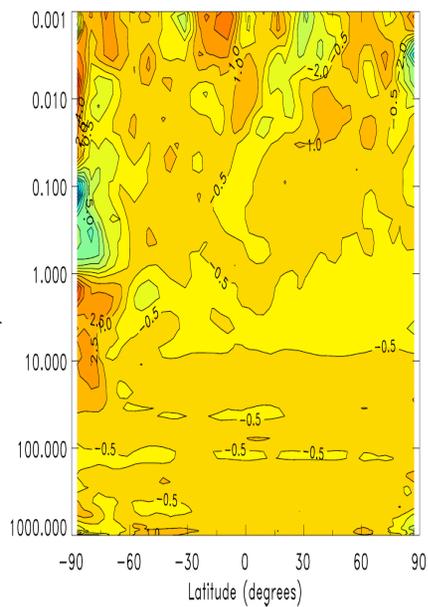
DT iauc-ens3 0929



**DT**

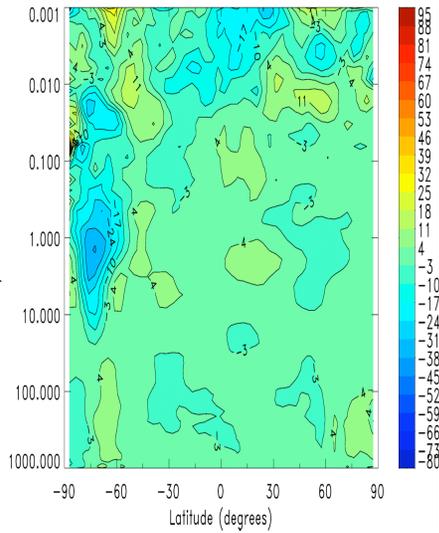
**IAUC-ENS3**  
**without GWD**

**IAUC-ENS1**  
**with GWD**

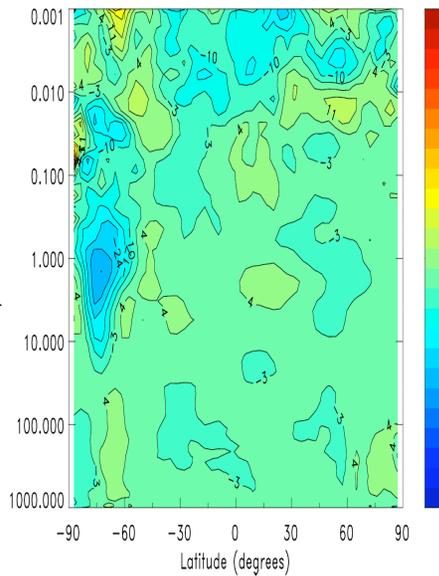


**Sept. 11th, 2002**

DU iauc-ens3 0911

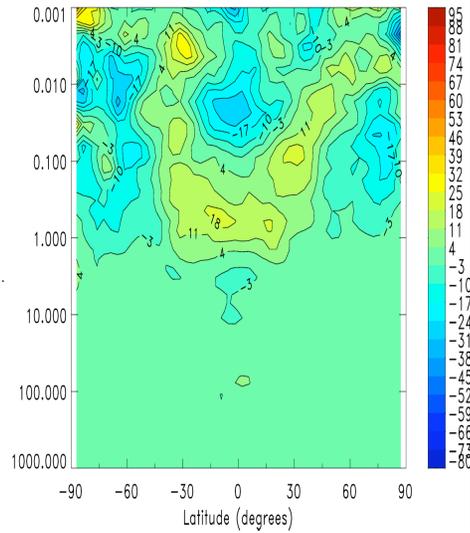


DU iauc-ens1 0911

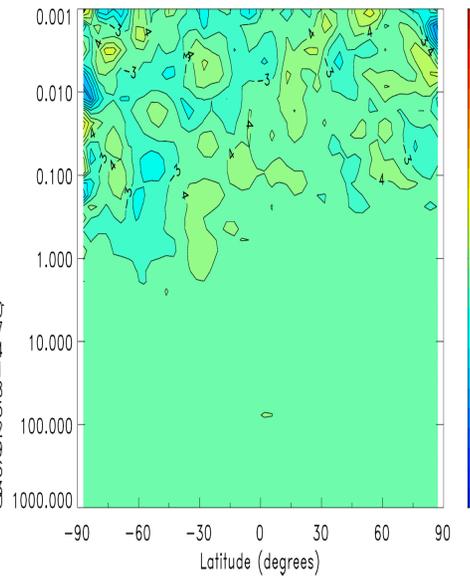


**Sept. 20th, 2002**

DU iauc-ens3 0920

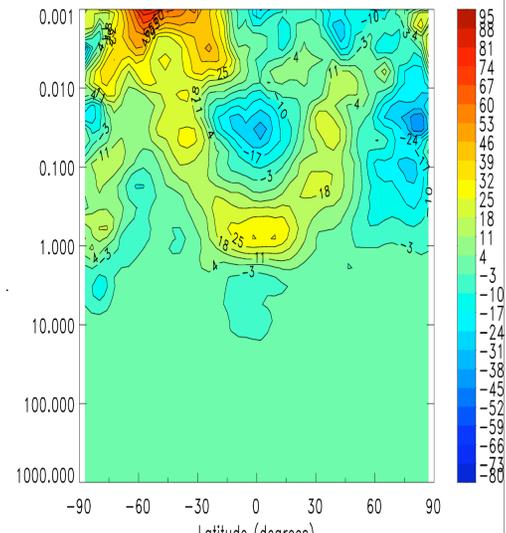


DU iauc-ens1 0920

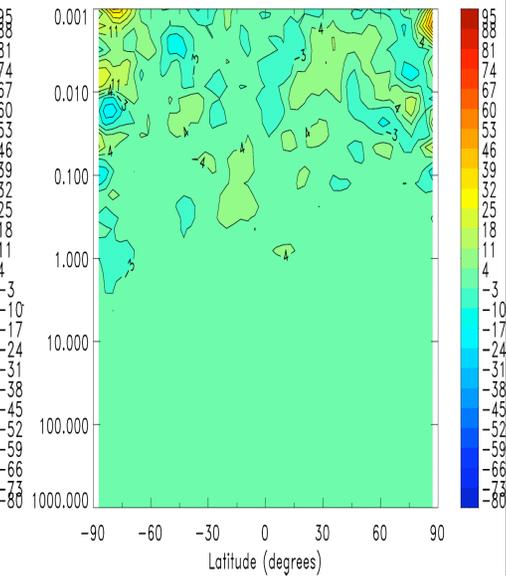


**Sept. 29th, 2002**

DU iauc-ens3 0929



DU iauc-ens1 0929

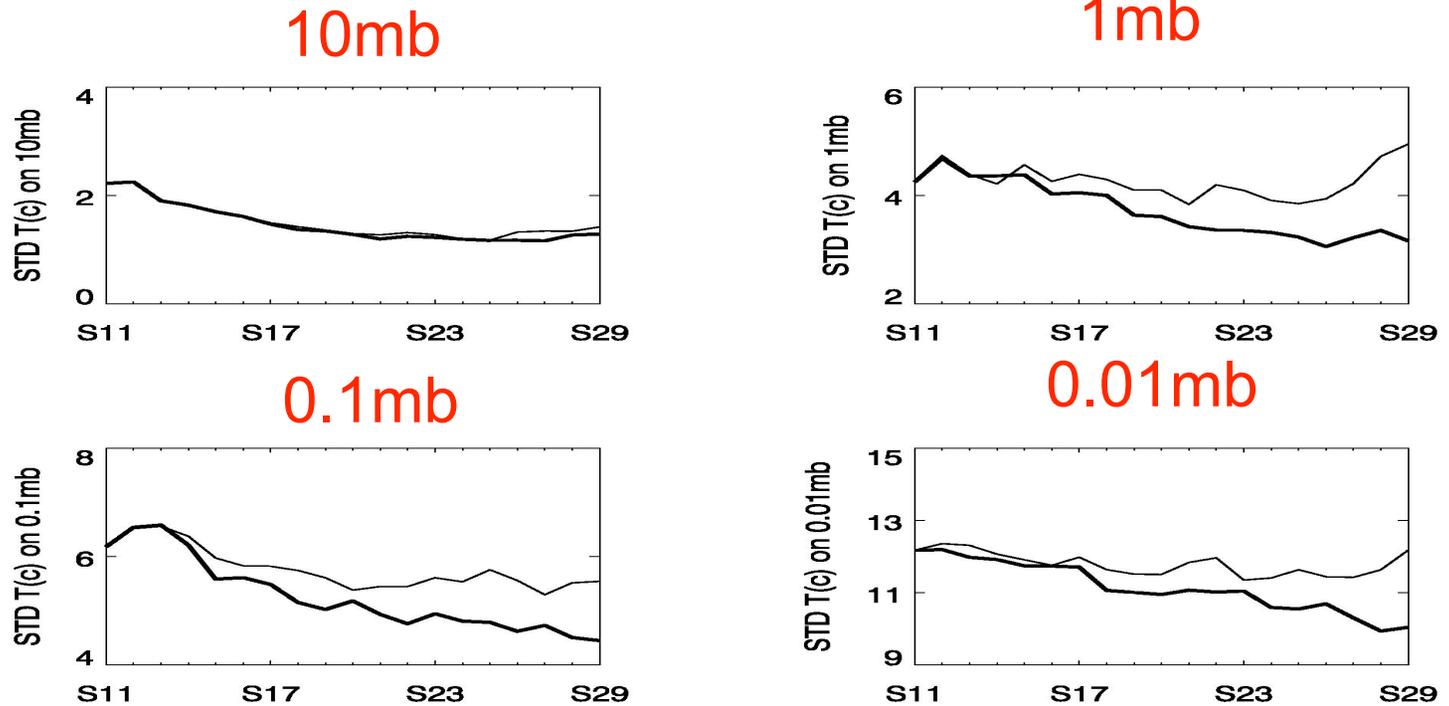


**DU**

**IAUC-ENS3  
without GWD**

**IAUC-ENS3  
with GWD**

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

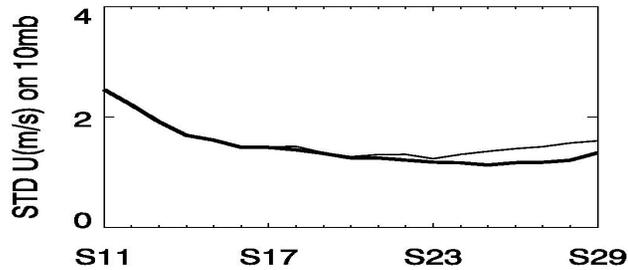


**thick lines: iauc minus ens1**

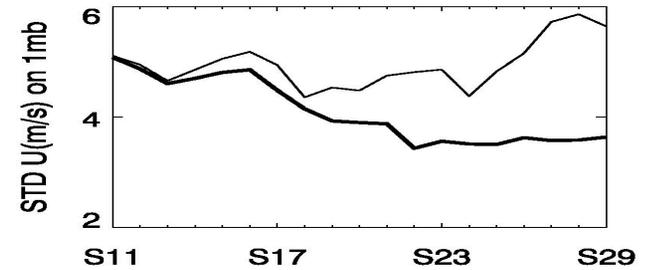
**thin lines: iauc minus ens3**

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

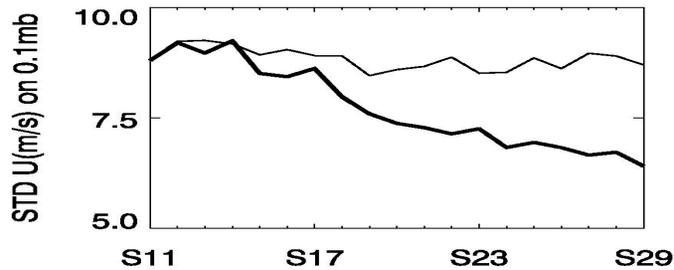
10mb



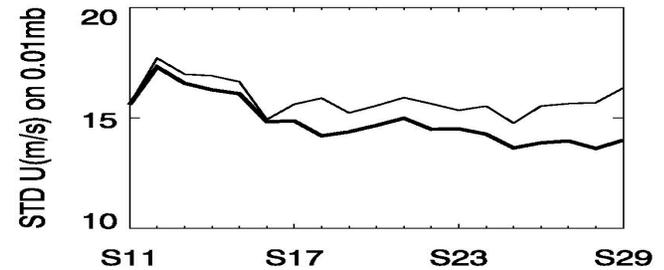
1mb



0.1mb



0.01mb



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):

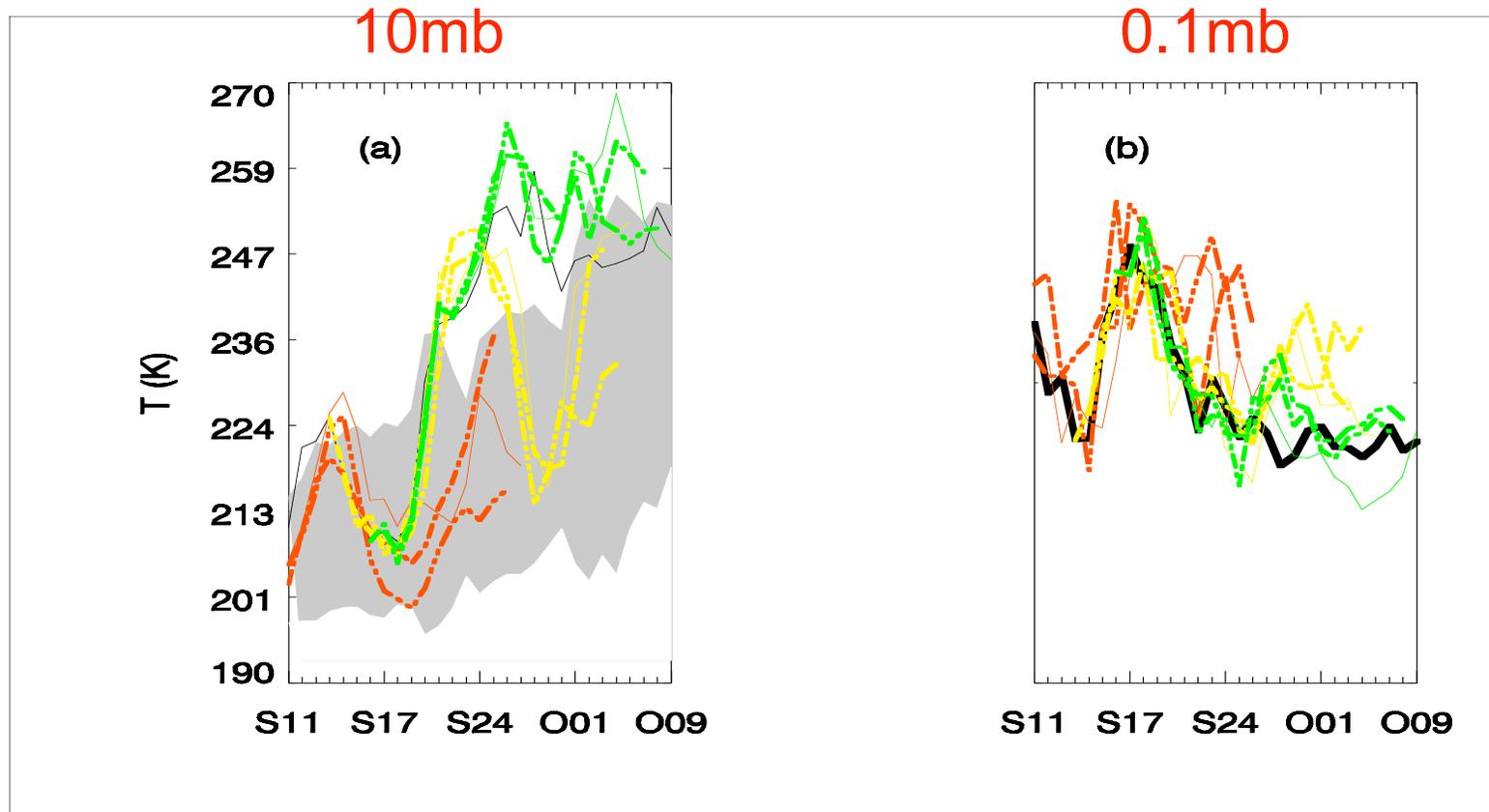
$$\bar{w}^* = -\frac{1}{a\rho_0 \cos \phi} \frac{\partial}{\partial \phi} \left( \int_z^\infty \left( \frac{\rho_0 \bar{\mathcal{F}} \cos \phi}{2\Omega \sin \phi} \right)_{\phi=const.} dz' \right) \quad (1)$$

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

$$\bar{\mathcal{F}} = \nabla \cdot \mathbf{F} + \mathcal{G} \quad (2)$$

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



----- : Sept. 6

-.-.-. : Sept. 7

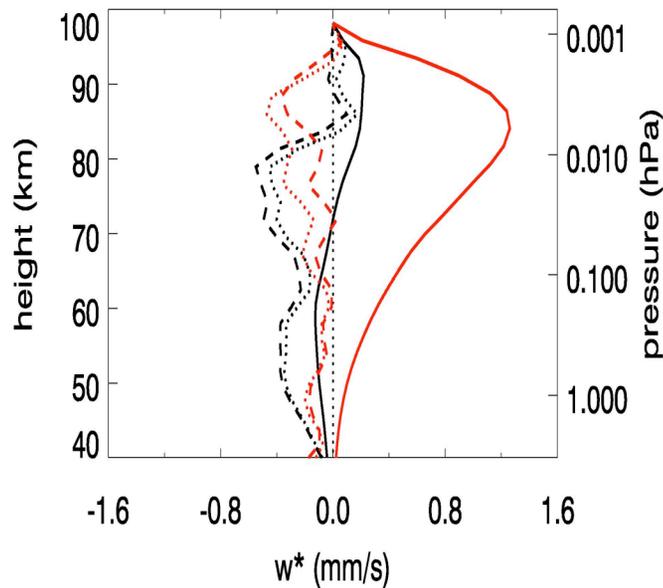
\_\_\_ : Sept. 9

----- : 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).



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

**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 ( $k < 5$ )

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# 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.