Status of:

The Regional Ensemble Prediction System

and

GEM-Strato

Martin Charron (Meteorological Service of Canada)

Singular Vectors and Markov Chains in Regional Ensemble Forecasting

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Collaborators: Mark Buehner and Paul Vaillancourt

Meteorological Research Branch, Environment Canada

- *The aim of this EPS*
- *Singular vectors with limited area final norms*
- *Physics perturbed by Markov chains*
- *Some initial diagnostics*

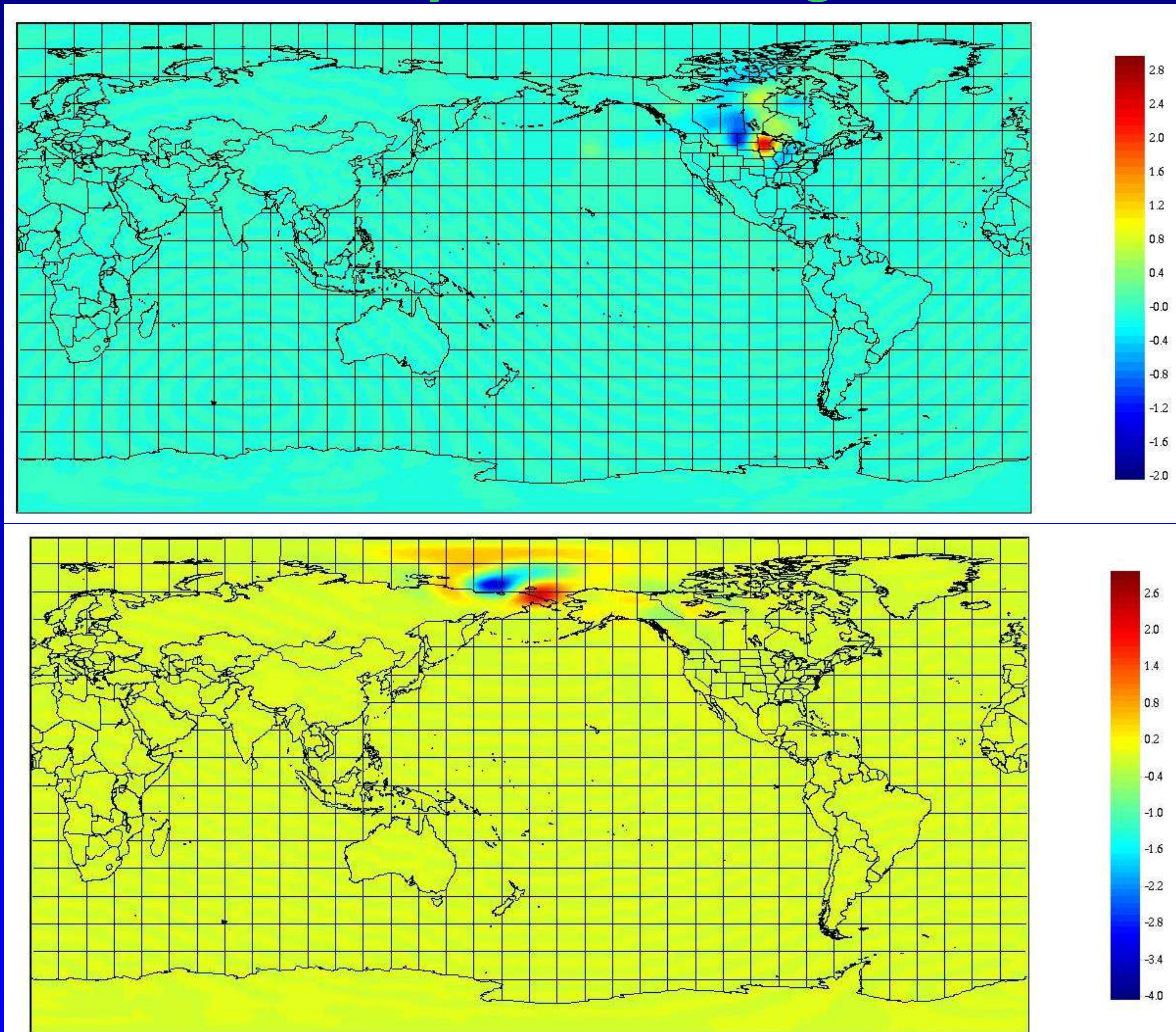
Goals of this EPS

- *Probabilistic 2-day forecasts over North America*
- *Focus is on quantitative precipitation forecasts*
- *Provide informations on forecast uncertainties*
- *Probabilistic counterpart to the deterministic 2-day forecast model:*
  - *Stretched global grid with maximum resolution of 15 km over North America*
  - *Forecasts started twice daily at 00Z and 12Z from lower resolution global analyses*
  - *12-hour spin-up during which data are assimilated (3D-VAR) at each 6 hours*

Singular vector calculation

- Optimisation period is 48h
- 10 singular vectors are calculated on a low resolution global grid (120x60, or about 250 km at 45° lat.)
- Initial norm is global
- Final norm is located over a domain covering North America
- SVs are interpolated to the resolution of the pilot model

Examples of a singular vectors



Temperature perturbation at 700 hPa

Piloting strategy of the limited area model

- *Each singular vector (plus and minus) is used to perturb the driving model at t=0*
- *20 driving and LAM simulations*
- *The LAM resolution is about 30 km*
- *The driving model resolution is 150 km*

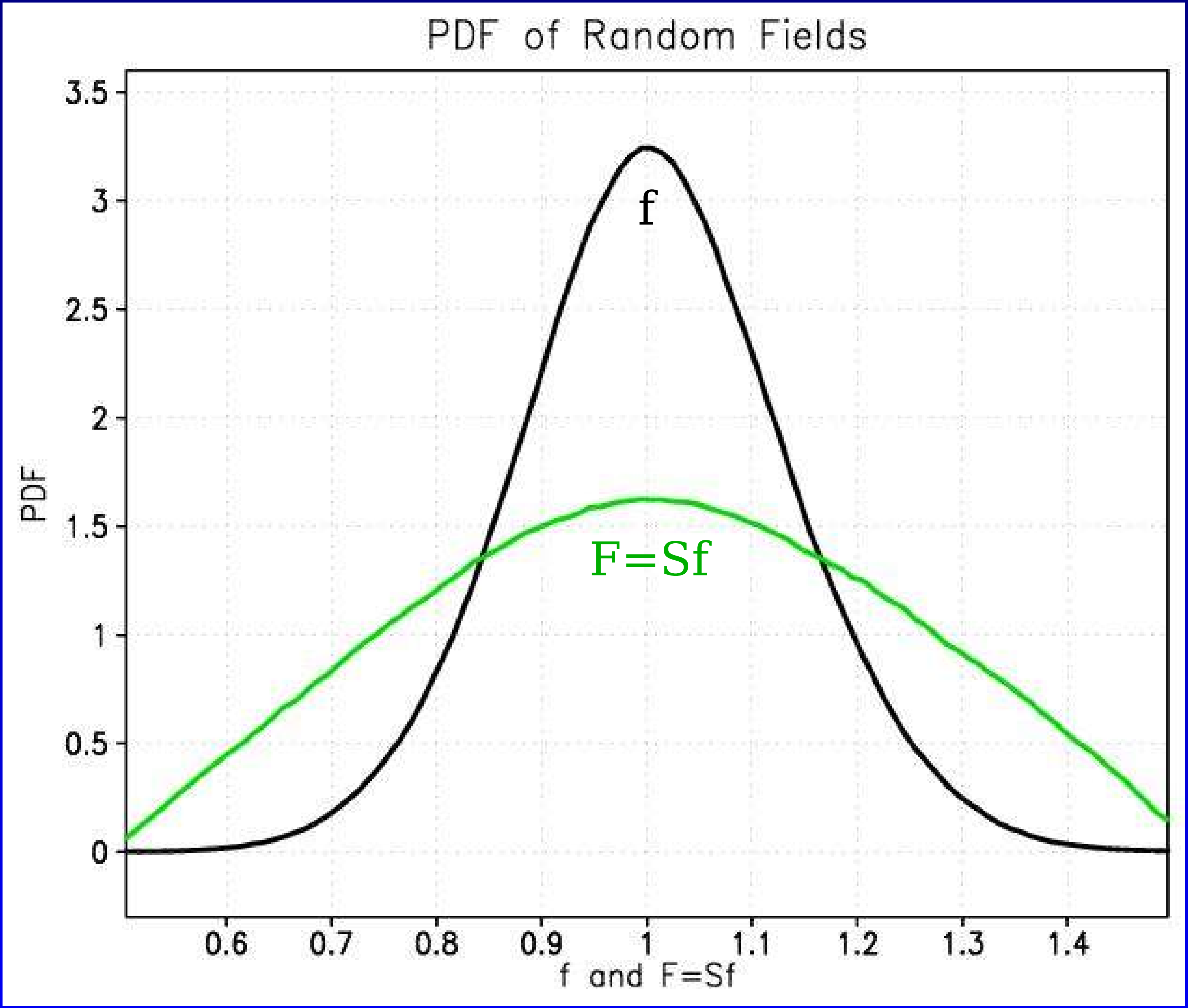
Physics perturbations with Markov processes

- *Physical parameters/tendencies can be perturbed by a function F(λ,φ,η,t) given by:*

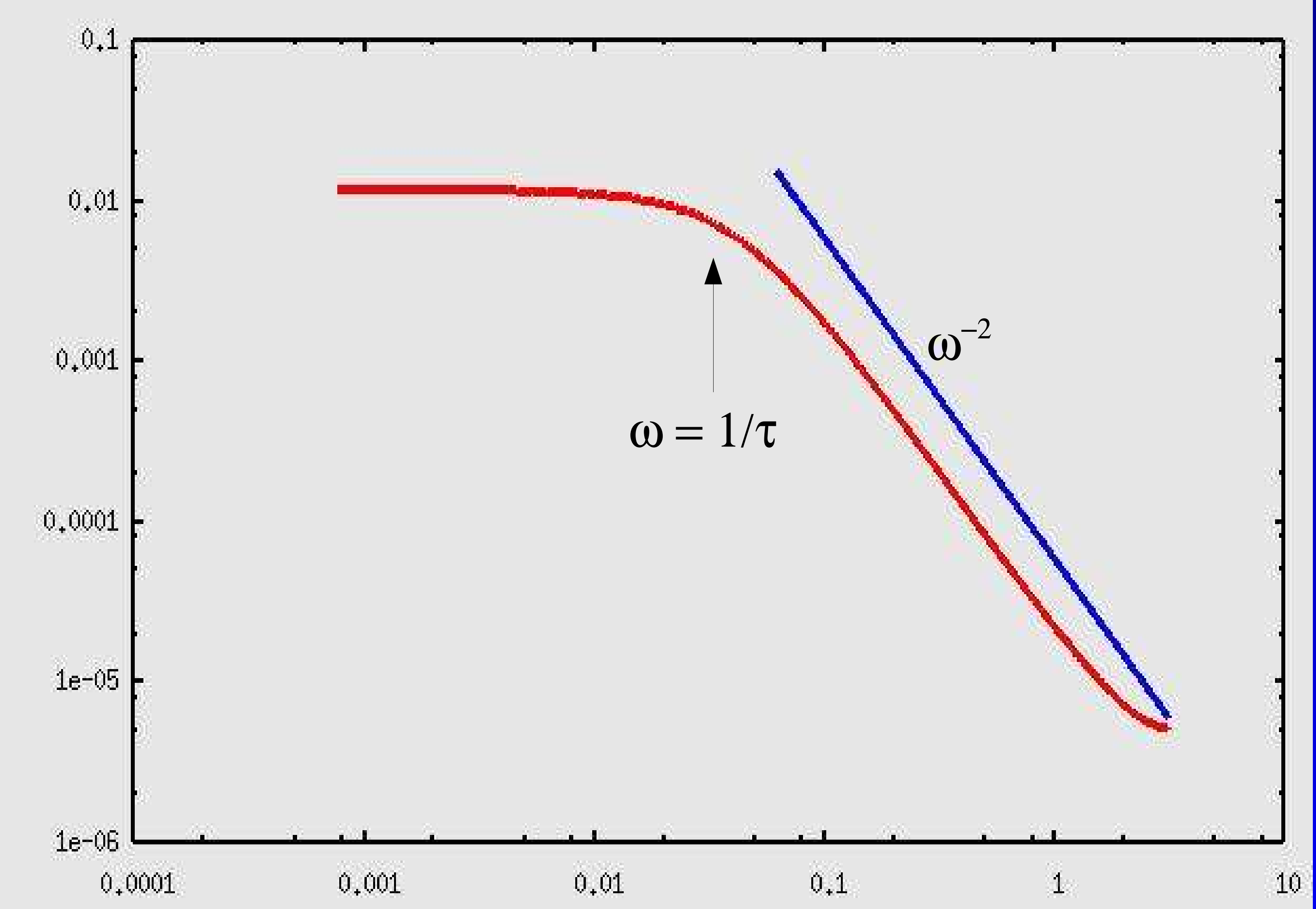
$$f(\lambda,\varphi,\eta,t)=\sum_{l=0}^{L}\sum_{m=-l}^{l}\sum_{k=0}^{K}a_{lmk}(t)Y_{lm}(\lambda,\varphi)e^{ik\eta}$$

$$a_{lmk}(t)=e^{-\Delta t/\tau}a_{lmk}(t-\Delta t)+R(t)$$

$$F(\lambda,\varphi,\eta,t)=Sf(\lambda,\varphi,\eta,t)$$


PDF of Random Fields
3.5
3
2.5
2
1.5
1
0.5
0
PDF
f
F=Sf
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
f and F=Sf

Mean Power Spectrum of First Order Markov Chain



$\omega \, \Delta t$

We perturb CAPE in the Kane-Fritsch convection scheme

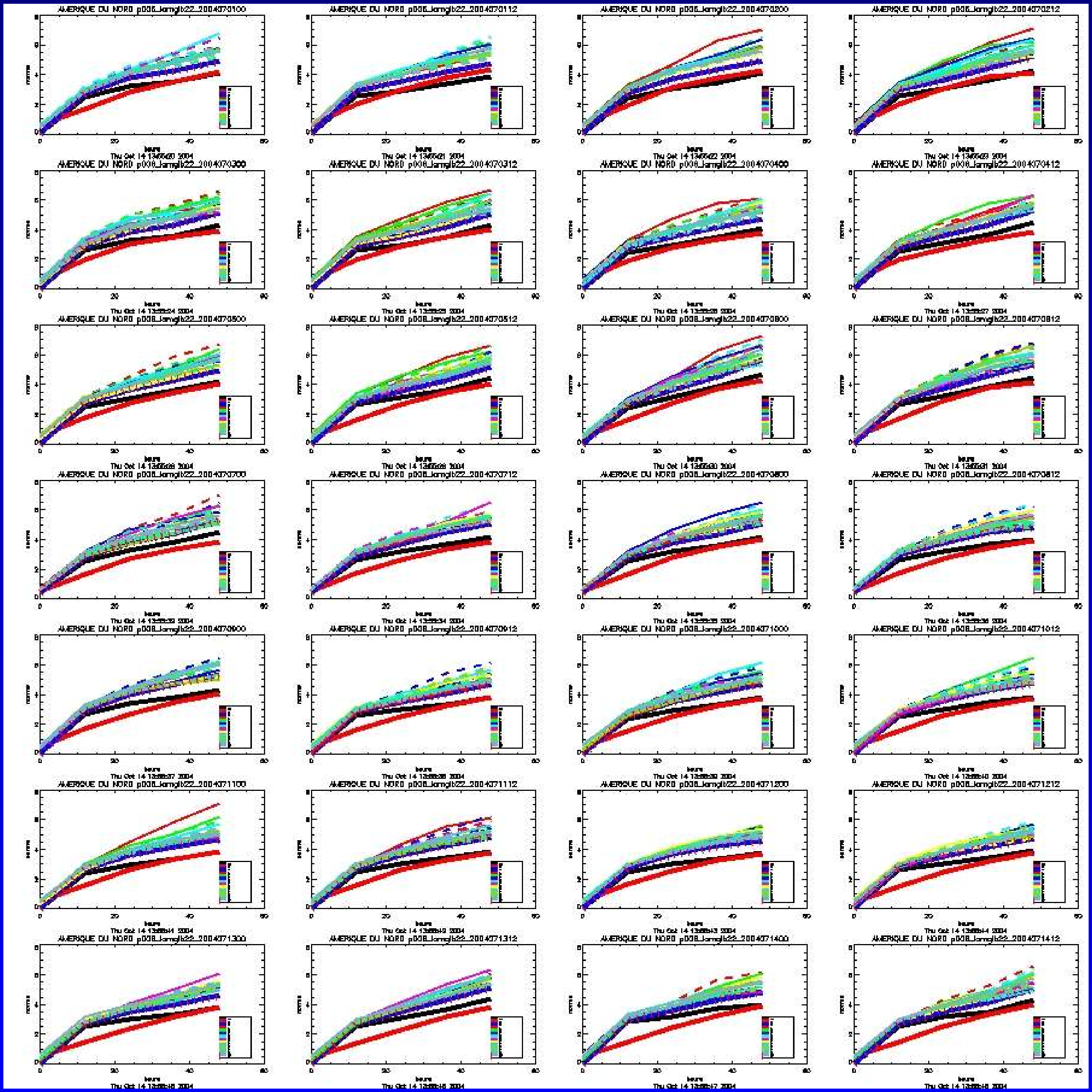
- *Only the LAMs are perturbed with Markov chains*
- *CAPE perturbation similar to Lin and Neelin (GRL 2000), except*
  - *CAPE becomes CAPE*F*(λ,φ,t)
- *Decorrelation time scale: 24 hours*
- *Truncation of the perturbed field: T7*

Some Diagnostics

$$E_i(t)=\frac{1}{V}\int_V [\frac{1}{2}(u_i-u_a)^2+\frac{1}{2}(v_i-v_a)^2+\frac{c_p}{2T_r}(T_i-T_a)^2]dS\,d\eta$$

- *Energy-like norm*
- *Integration over the LAM domain*
- *«i» is for a particular ensemble member, the ensemble mean, and the control run*
- *One calculates the standard deviation s from:*

$$\sigma^2(t)=\frac{1}{N-1}\sum_{i=1}^{N}\frac{1}{V}\int_V [\frac{1}{2}(u_i-\bar{u})^2+\frac{1}{2}(v_i-\bar{v})^2+\frac{c_p}{2T_r}(T_i-\bar{T})^2]dS\,d\eta$$

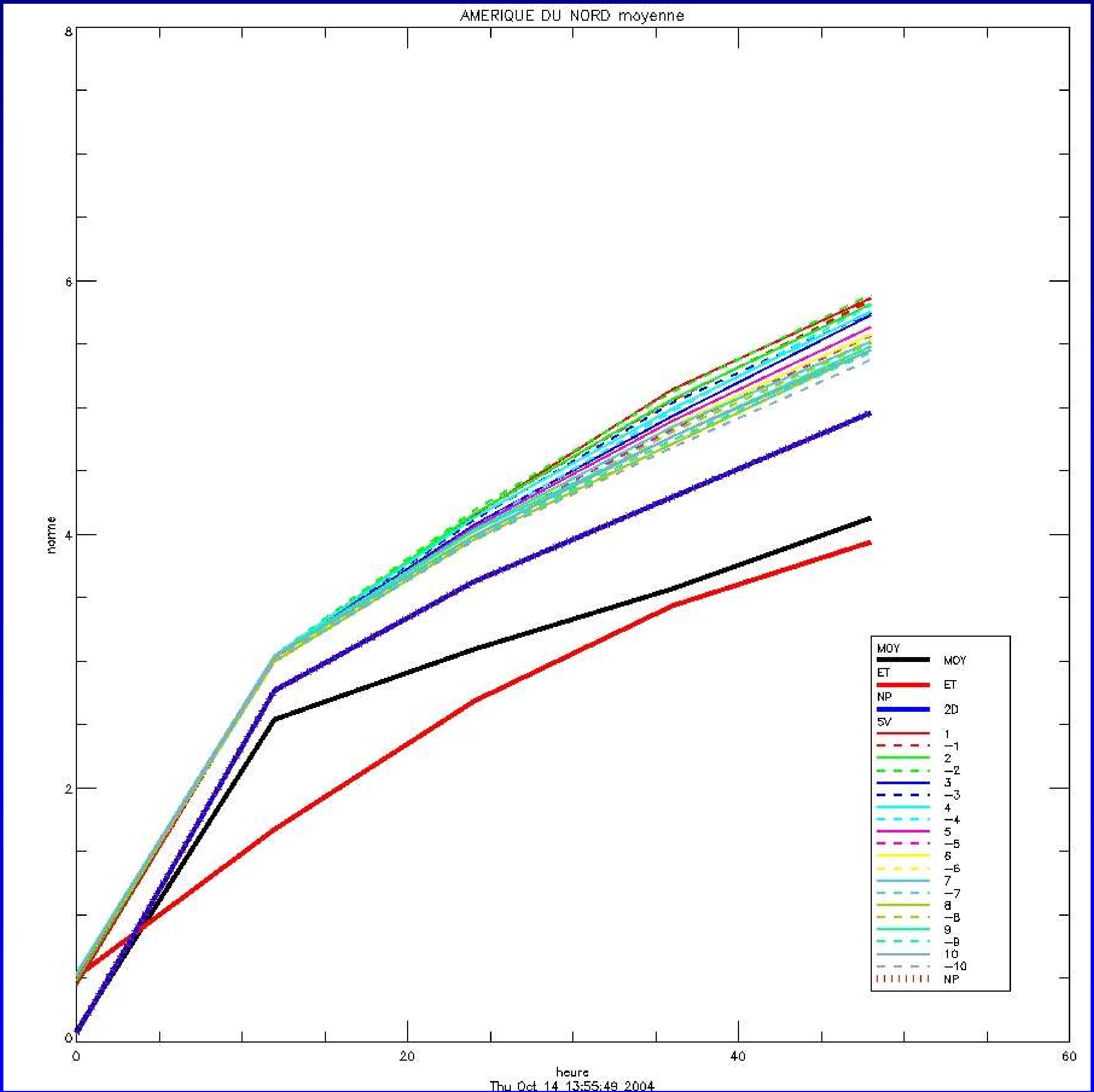


Energy-like errors and ensemble spread.

Blue: Unperturbed

Black: Ens. Mean

Red: Ens. Std Dev.



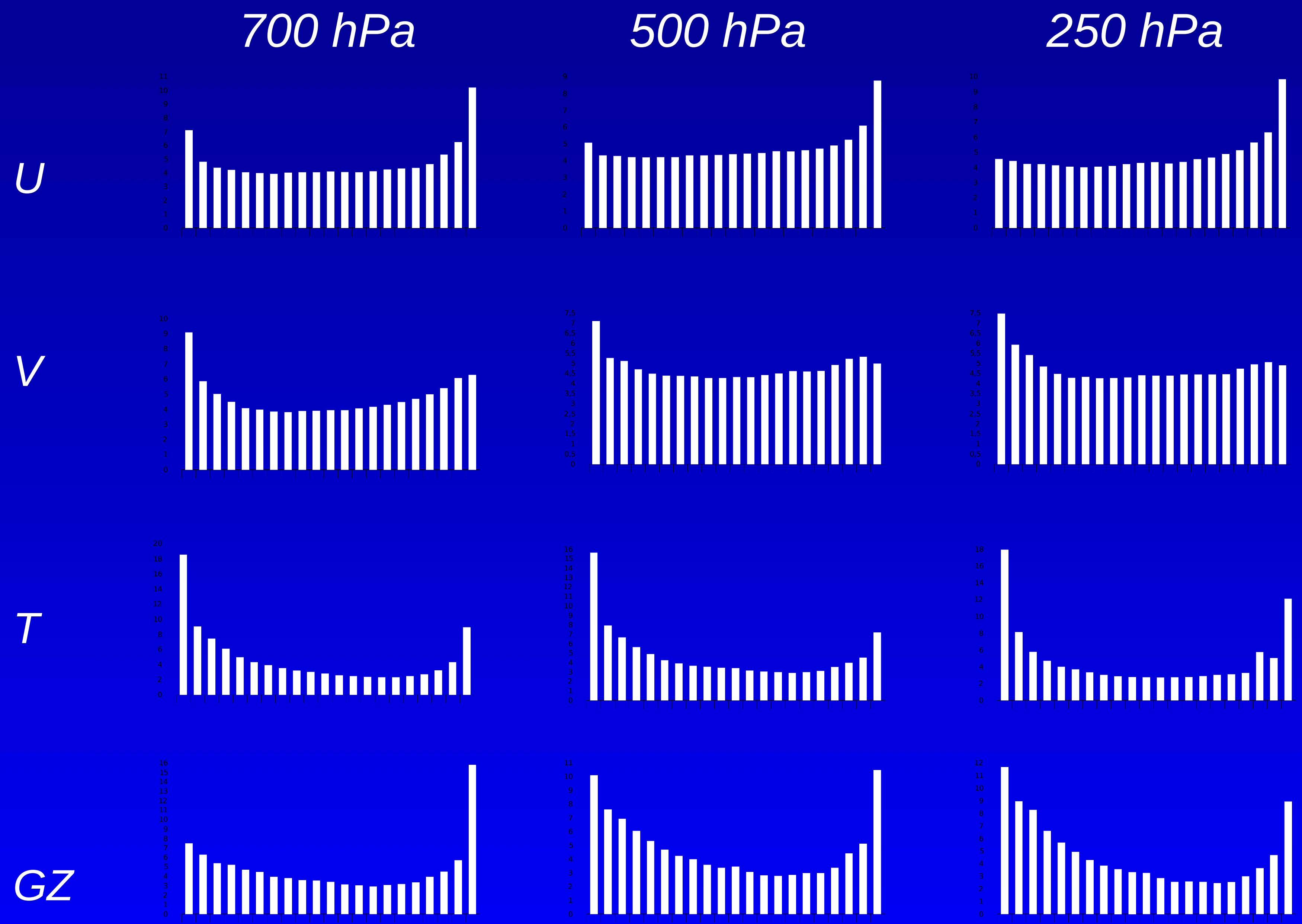
Energy-like errors and ensemble spread.

Blue: Unperturbed

Black: Ens. Mean

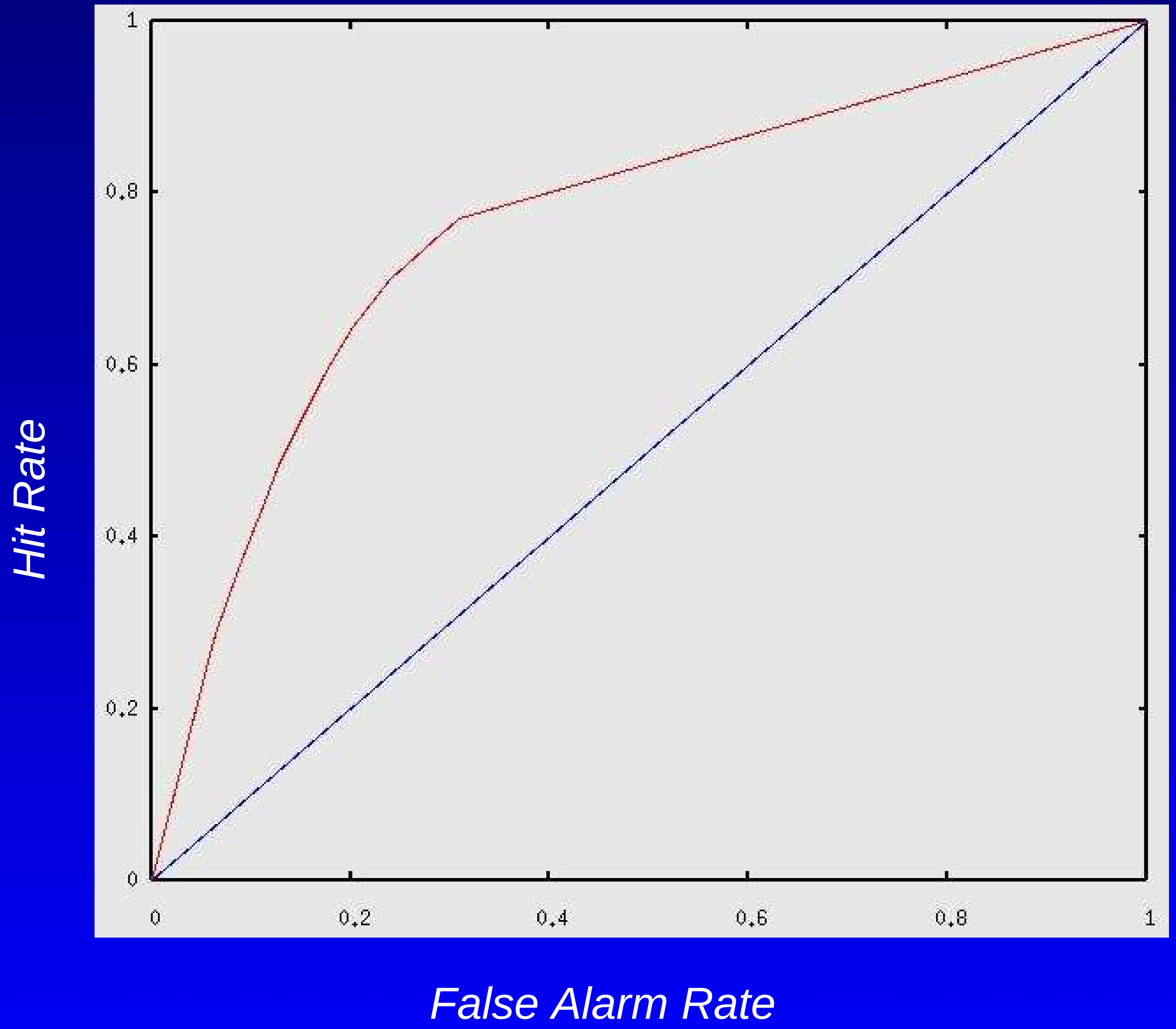
Red: Ens. Std Dev.

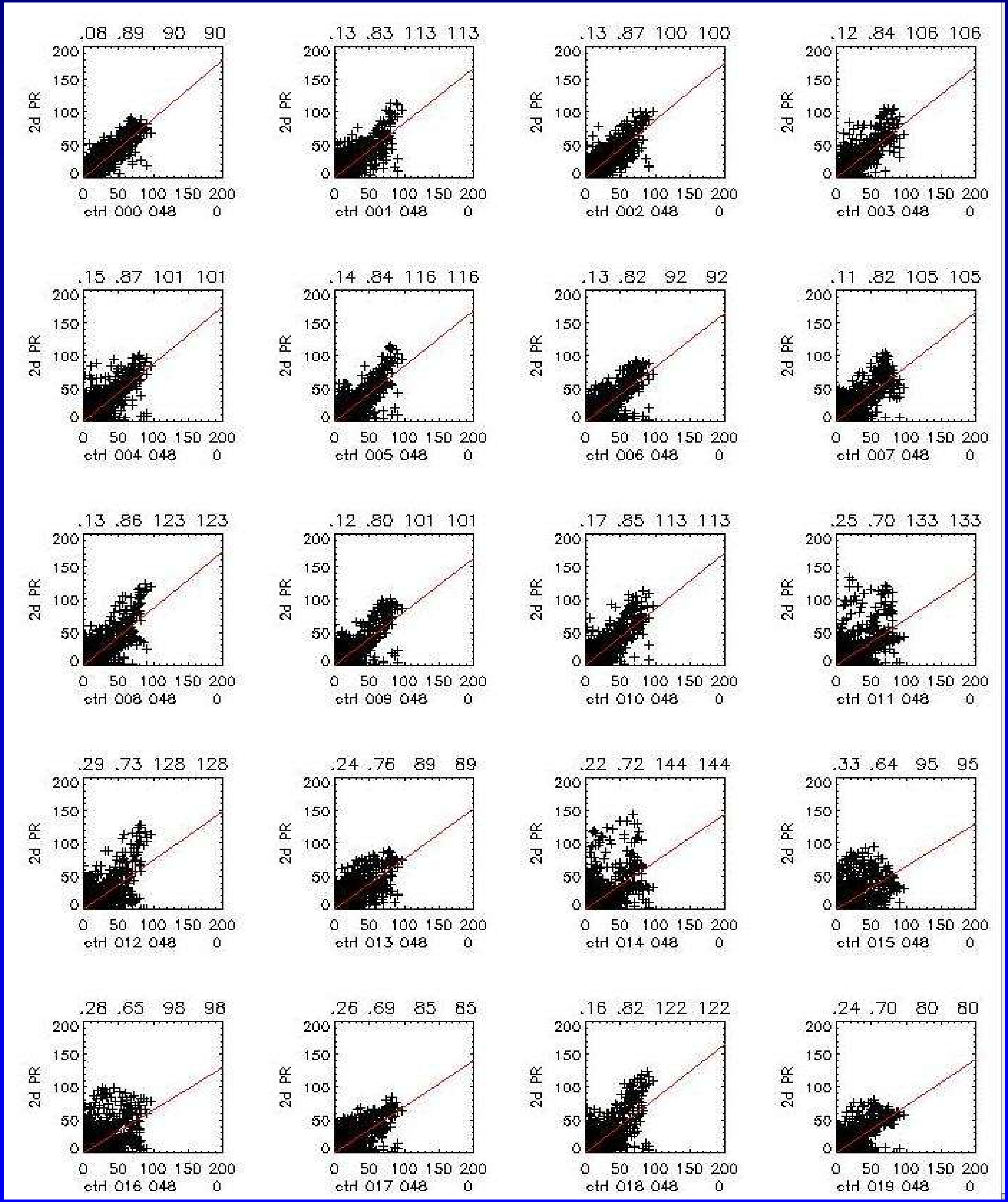
Talagrand Diagrams (July 1 to 14, 2004)



Relative Operating Characteristics (ROC) Scores for Precipitation

- *48-hour accumulation greater than 5 mm*
- *Dataset contains the real time daily gridded precipitation analysis over the US*
- *Data Sources: River Forecast Center: ~6000 gauge stations per day and Climate Anomaly Data Base: ~several hundred gauge stations per day*
- *Analysis form modified Cressman scheme at resolution 0.25°*


1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Hit Rate
False Alarm Rate



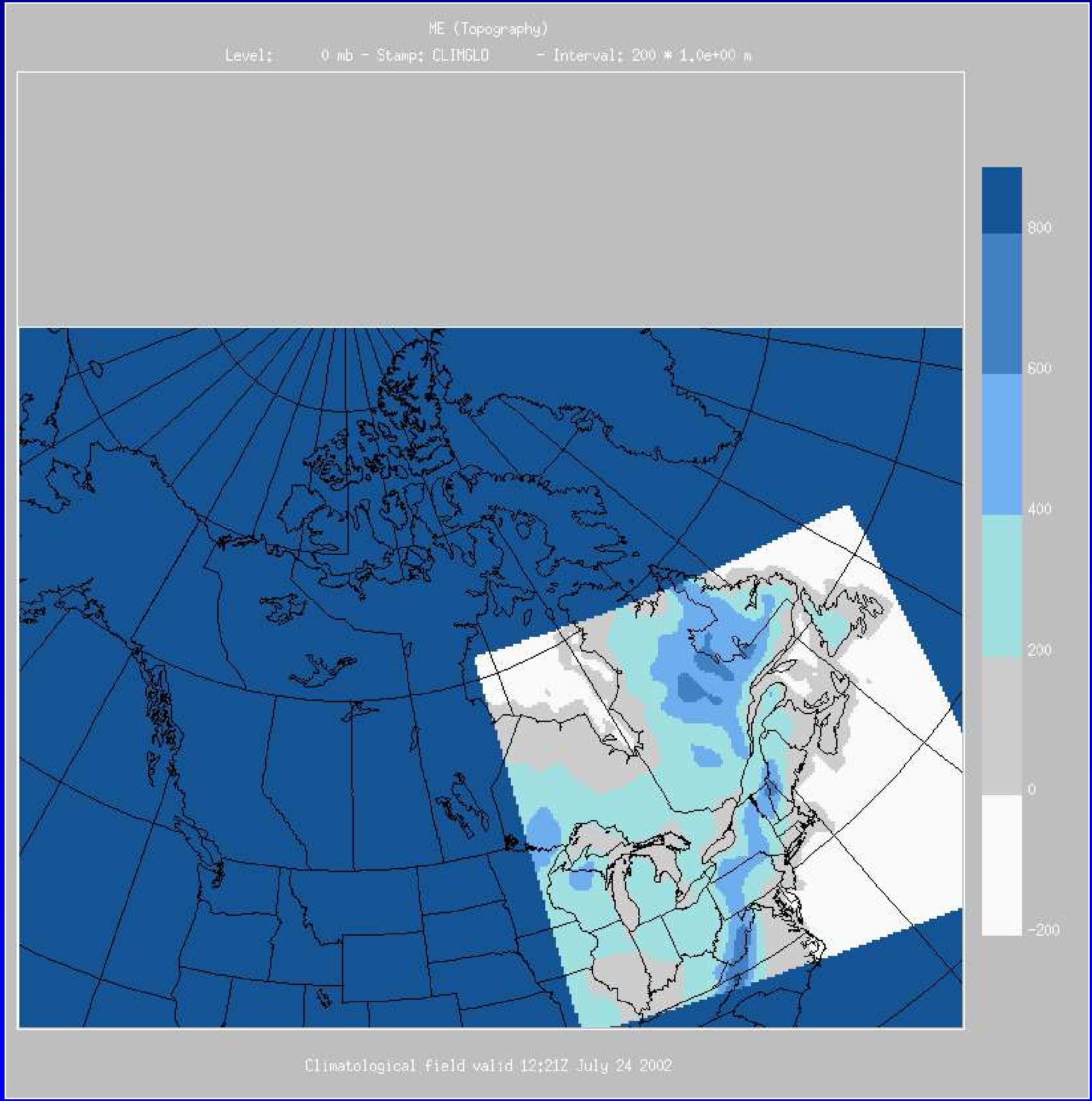
Scatter Plots:

Perturbed CAPE
vs.
Unpert. CAPE

for 48-hour accum. precip. forecasts for each member at a given date.

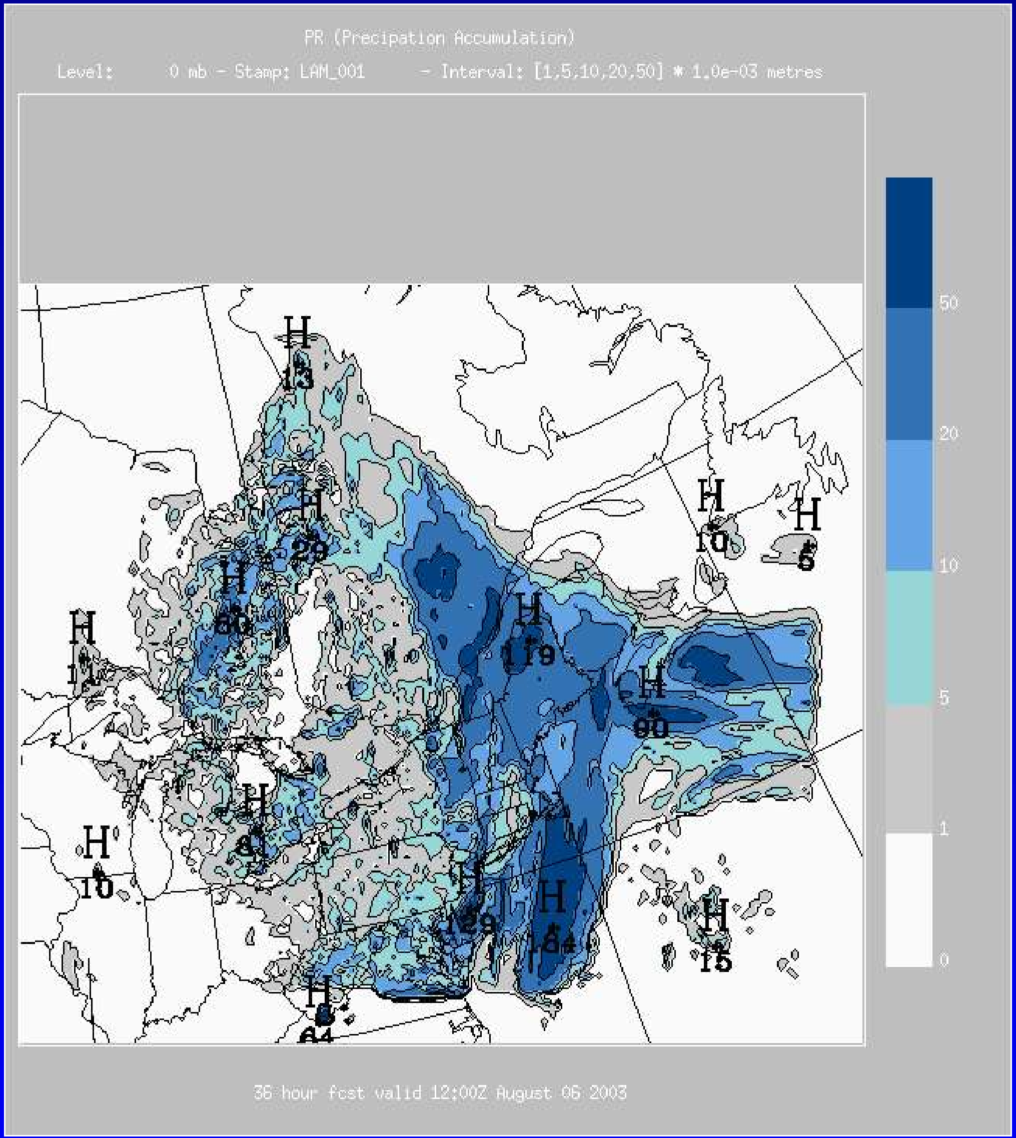
A Regional EPS at 15 km Resolution

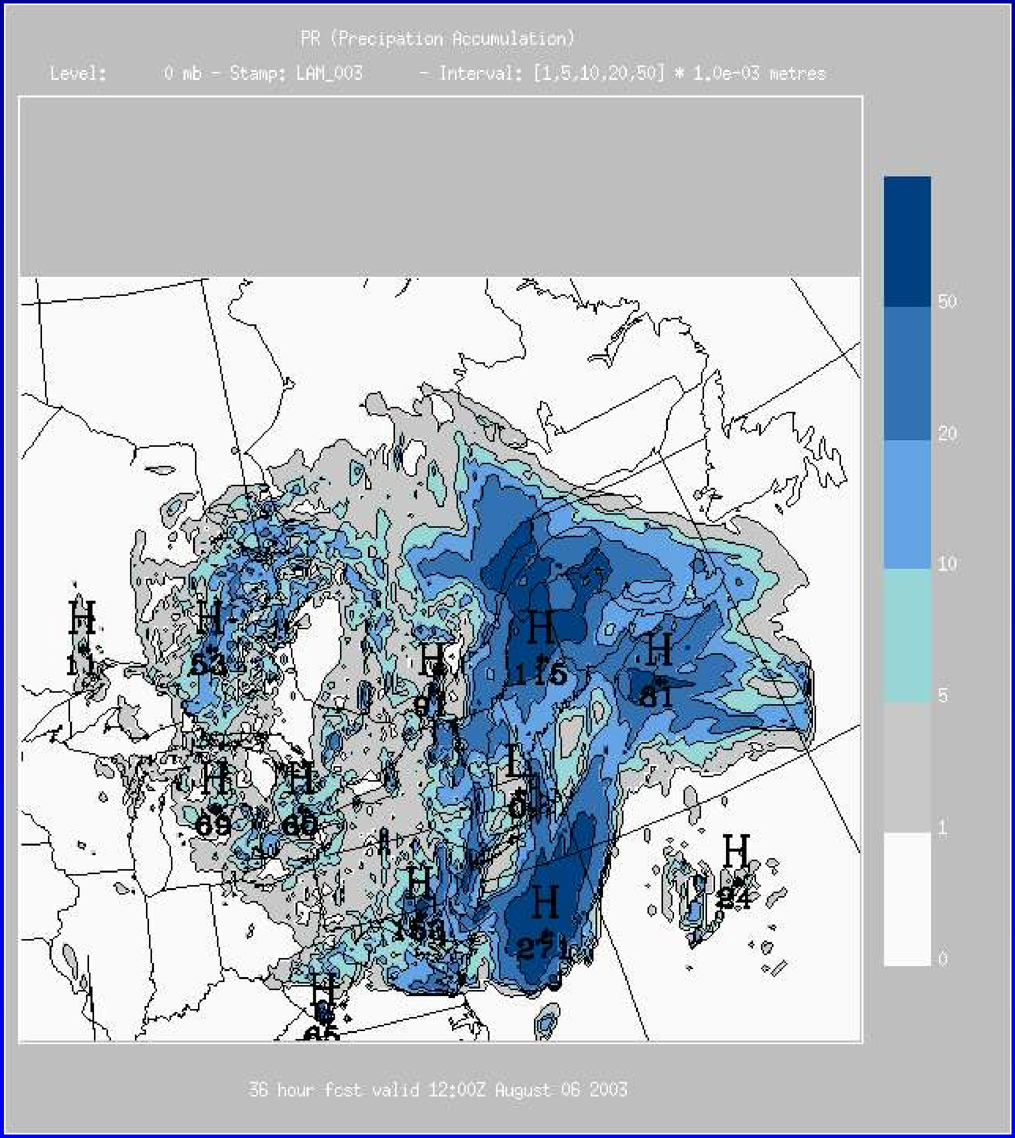
- Domain over Eastern Canada
- Same approach as continental EPS
- Resolution is 15 km
- SV optimization time is 24 hours
- SV resolution: 240x120
- Driving model is GEM at 400x200
- Post-doc: Li Xiaoli



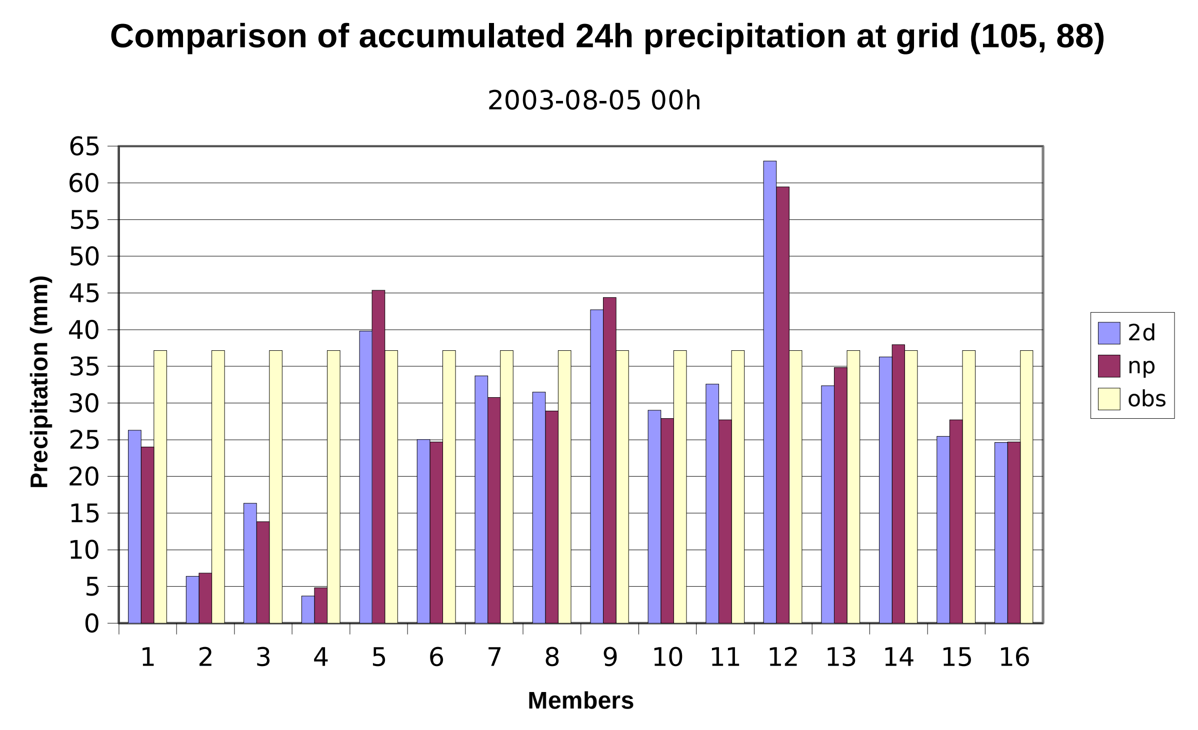
Precipitation pattern of two different members

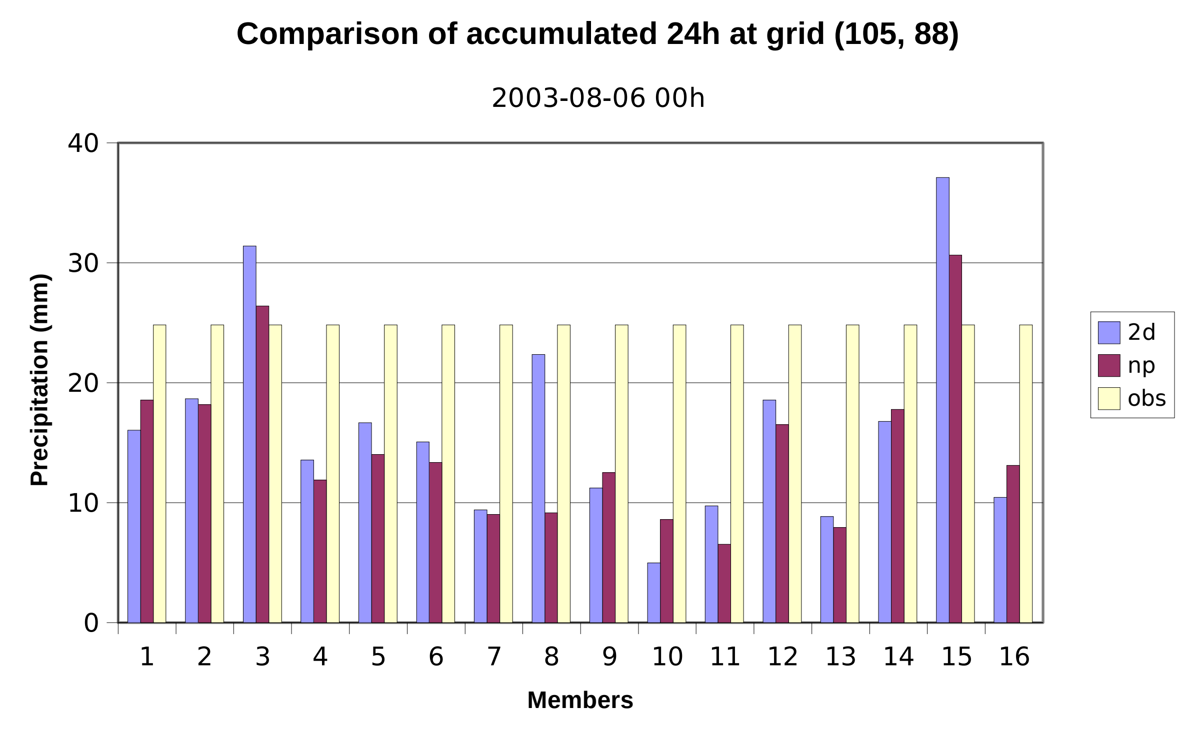
24 hour accumulation on August 5, 2003



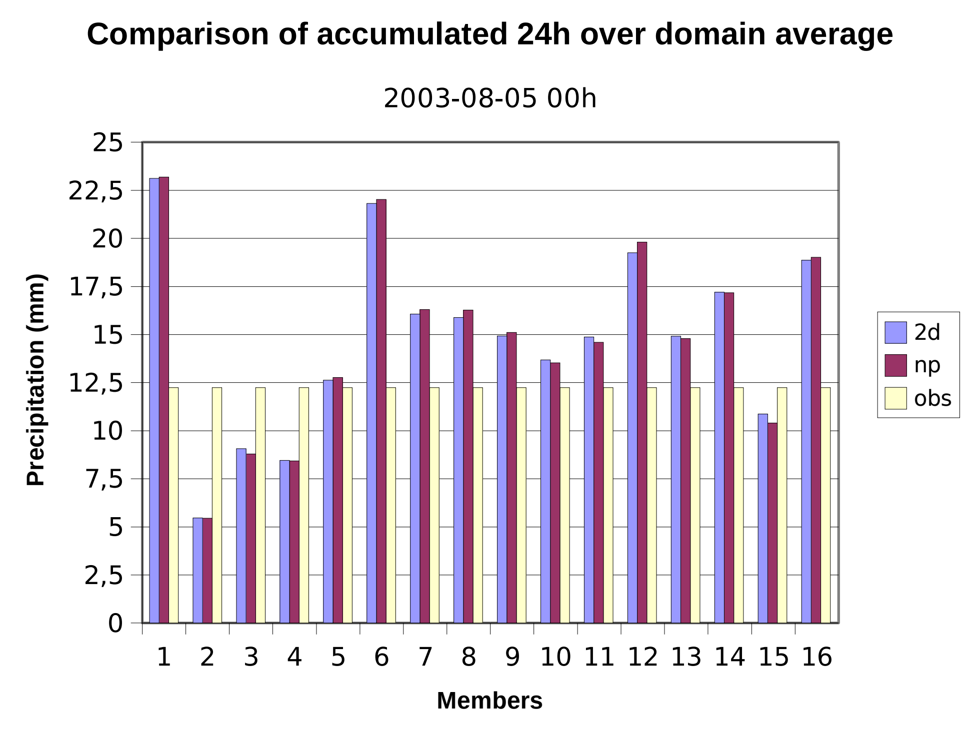


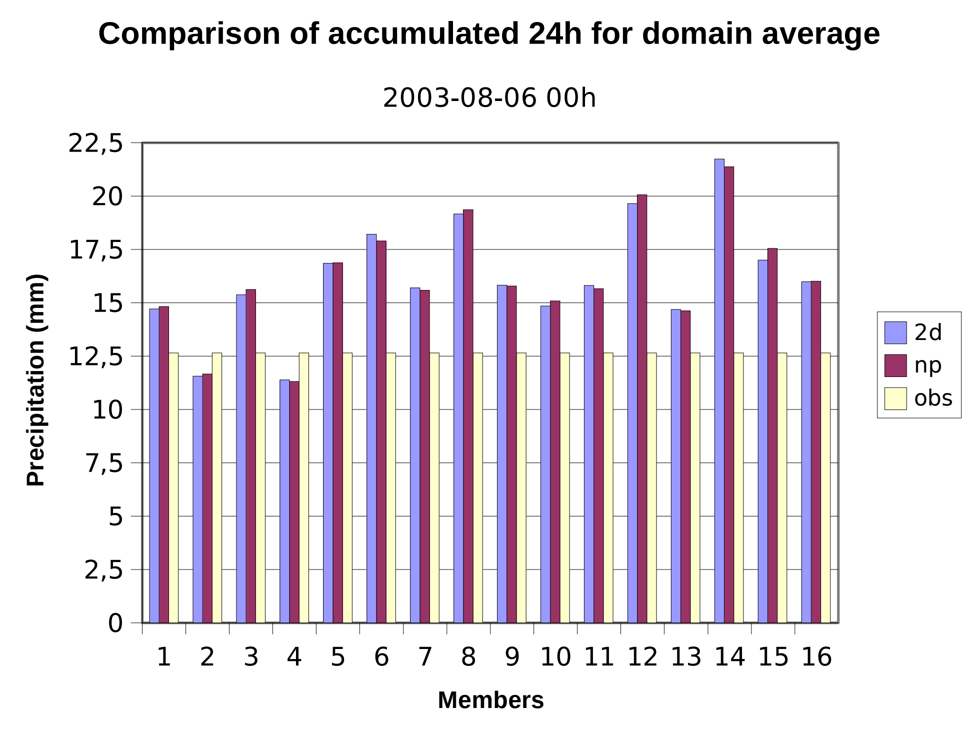
Impact of perturbing CAPE on precipitation





- ➔ *Perturbing the ICs with SVs has more impact on precip than perturbing CAPE*


Comparison of accumulated 24h over domain average
2003-08-05 00h
Precipitation (mm)
Members
2d
np
obs


Comparison of accumulated 24h for domain average
2003-08-06 00h
Precipitation (mm)
Members
2d
np
obs

Some remarks

- *Still a lot of fine tuning to perform and variants to test:*
  - *Try different truncations and time scales for Markov chains*
  - *Find suitable parameters/tendencies to perturb*
  - *Try SVs on the LAM grid based on rotational norm*

Long term objectives

- *Find a better way to account for uncertainties of the model, perhaps by introducing parameterizations that are inherently stochastic*
- *Develop a regional ensemble Kalman filter (stretched grid or limited area model)*
- *Compare the singular vector approach and a (still to be built) regional EnKF for regional ensemble predictions*

GEM-Strato: Current Status, Future Developments and Projects

Martin Charron (Meteorological Service of Canada)

Collaborators (list probably incomplete):

Cécilien Charette (MSC):	*Data assimilation*
Bernard Dugas (MSC):	*Model development*
Jacek Kaminski (York U.):	*Chemistry data assimilation*
Jack McConnell (York U.):	*Chemistry*
Richard Ménard (MSC):	*Chemistry data assimilation*
Donald Talbot (MSC):	*Model development*
Paul Vaillancourt (MSC):	*Model development*
Katja Winger (UQAM):	*Climate simulations*

Outline

1. *Short description*
2. *Non-orographic gravity wave parameterization*
3. *3D-VAR experiments with GEM-Strato*
4. *Climate simulations with GEM-Strato*
5. *Upcoming model developments*
6. *Upcoming projects*

Overview of GEM-Strato

- *top at 0.1 hPa*
- *80 levels*
- *horizontal resolution of 400x200 (data assimilation) and 240x120 (climate mode)*
- *mostly same parameterizations as GEM-Operational*
- *Hines non-orographic GWD*
- *no condensation applied on humidity above the 70 hPa level (temporary)*

Overview of GEM-Strato (cont'd)

- *radiation: Fomichev scheme from mid-stratosphere to model top*
- *3D-VAR data assimilation experiments for the period Dec. 2001 to March 2002*
- *climate runs focusing on the impact of Hines parameterization*

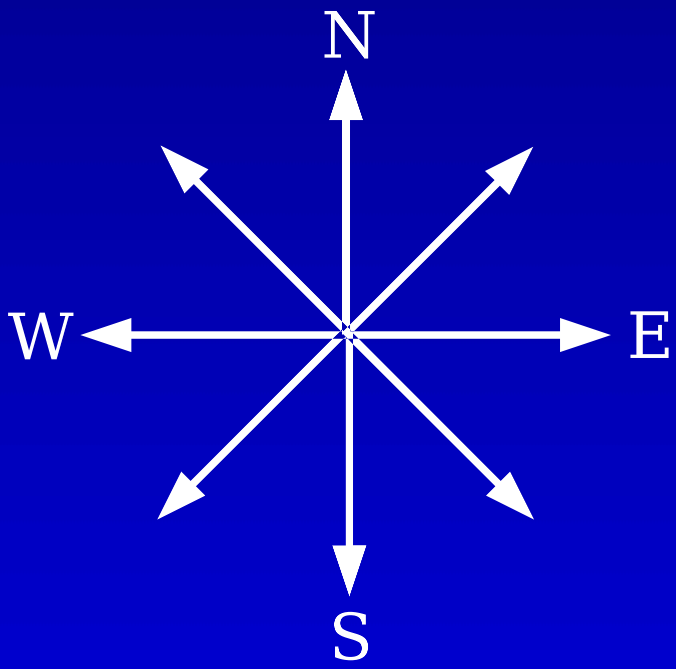
Hines Non-Orographic Gravity Wave Parameterization (1)

- *represents sub-grid scale gravity waves from non-orographic sources*
- *convection, instabilities, fronts, geostrophic adjustment*
- *climatology of sources mostly unknown*
- *source spectra totally unknown*

➔ *geographical distribution of sources is uniform and isotropic*

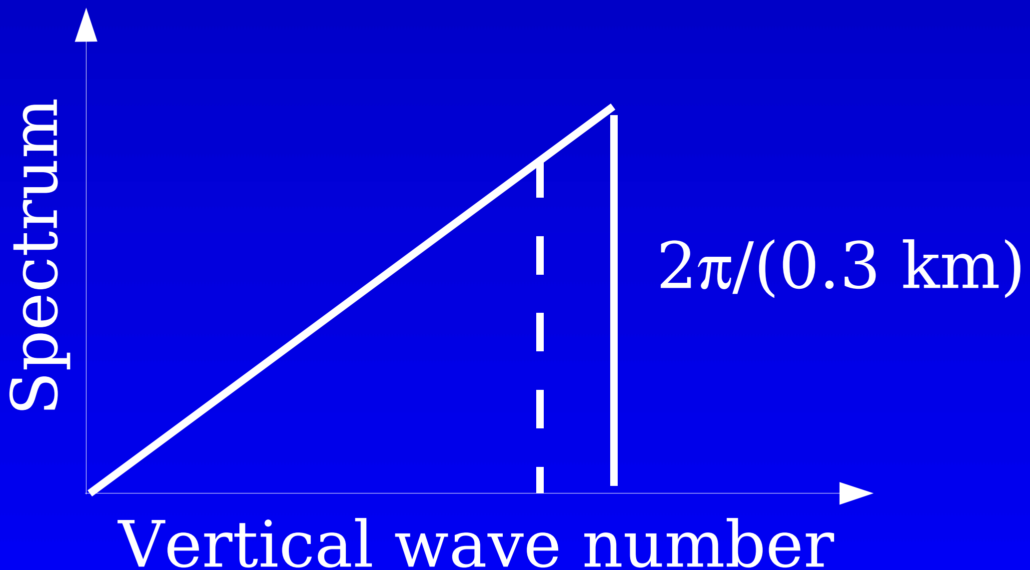
➔ *source from fronts (Charron and Manzini, JAS 2002) not coded in GEM yet*

Hines Non-Orographic Gravity Wave Parameterization (2)



From a given tropospheric level and at each grid point, waves are launched isotropically in 8 directions

A simple initial wave spectrum is employed



Hines Non-Orographic Gravity Wave Parameterization (3)

Some characteristics:

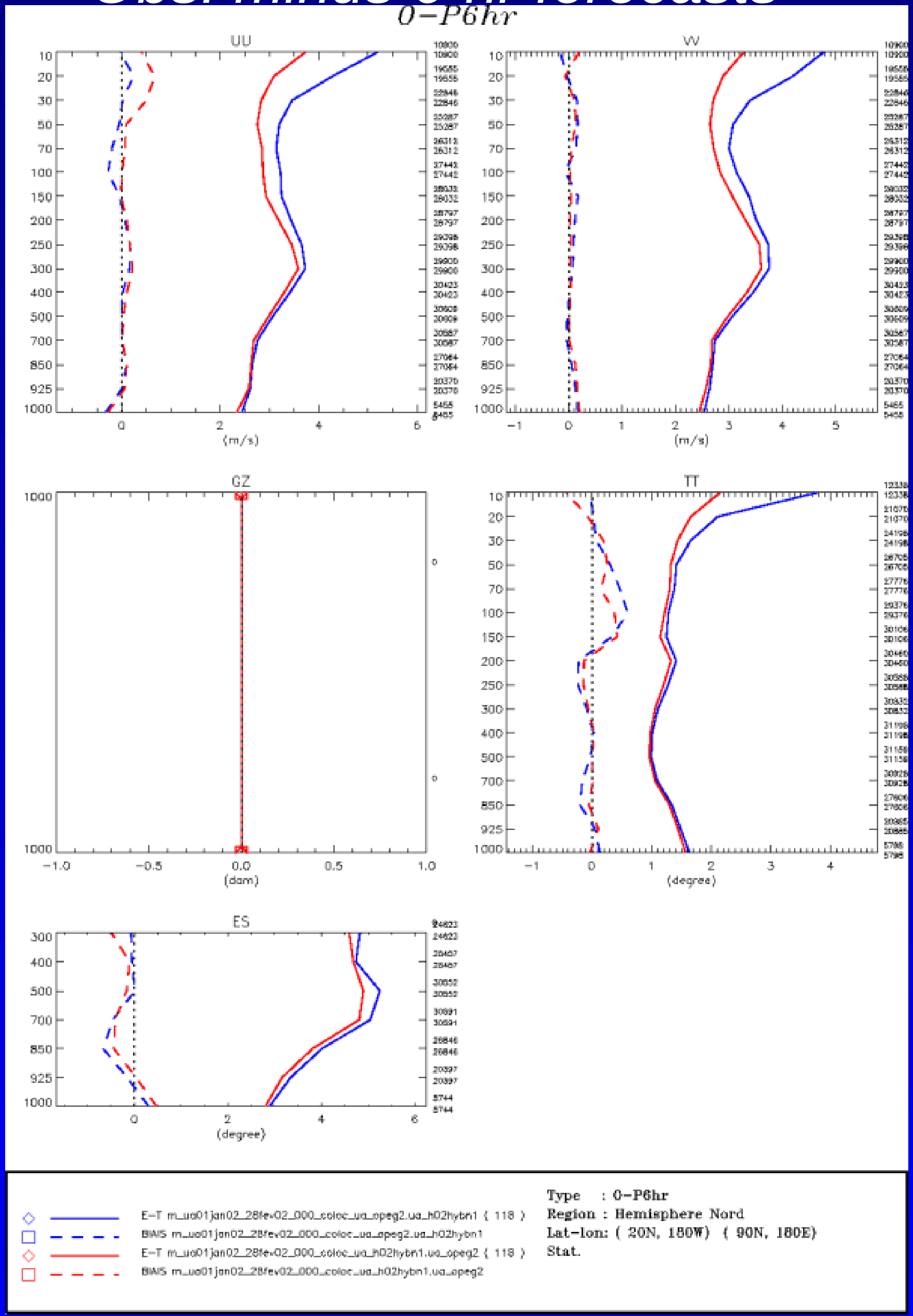
- *launching height: ~ 4 km above surface*
- *gravity wave amplitude at launching height: 1 m/s*
- *equivalent horizontal wavelength: 100 km*
- *forcing on winds near the model top: ~ 50 to 100 m/s/day*

3D-VAR Experiments with GEM-Strato

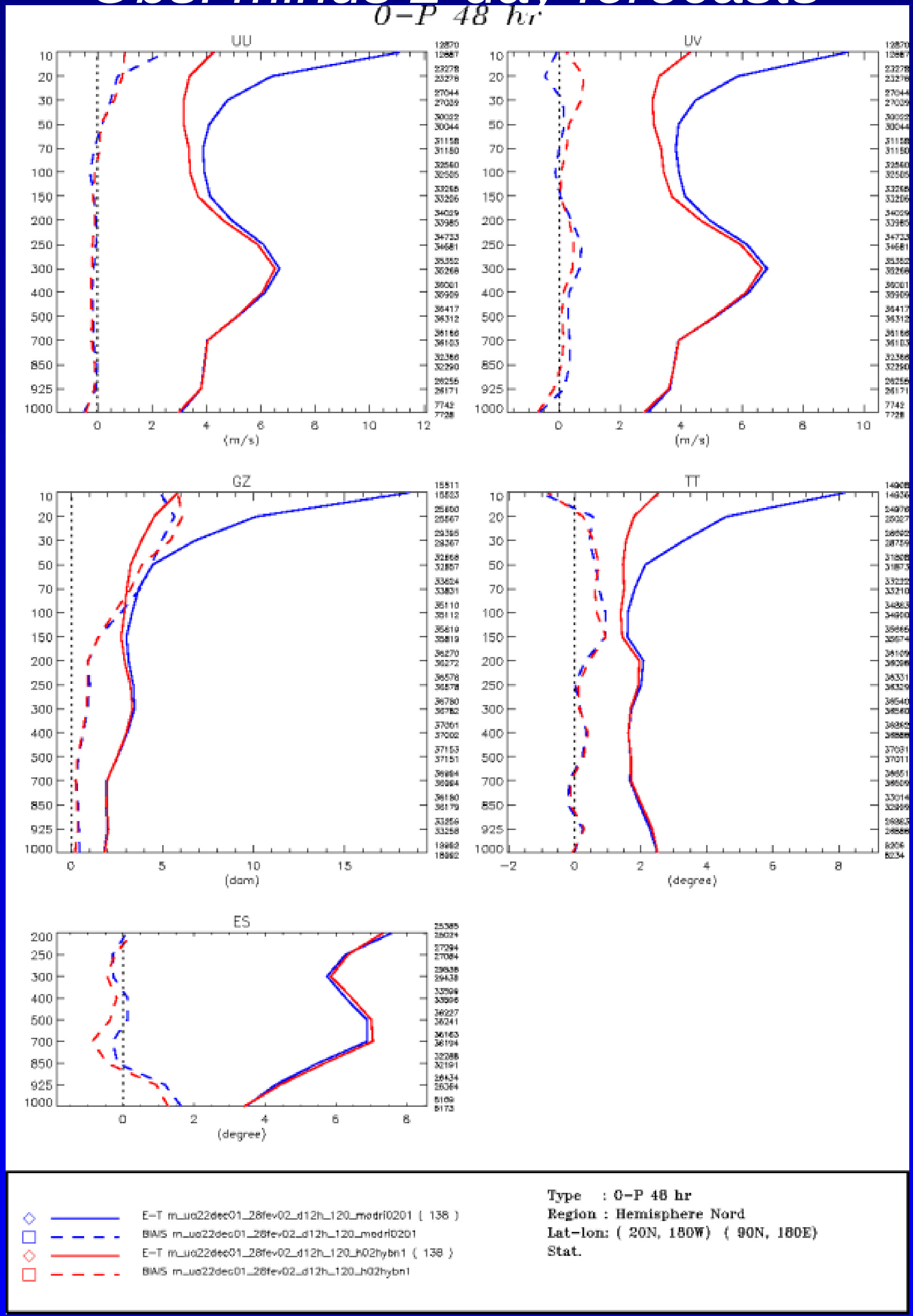
(from Cécilien Charette and Clément Chouinard)

- From December 2001 to March 2002
  - higher model top allows more data to be assimilated
  - AMSU-A channels with a non-negligible tail above 10 hPa
  - otherwise, same assimilation procedure as operational 3D-VAR
  - results are for the Northern Hemisphere

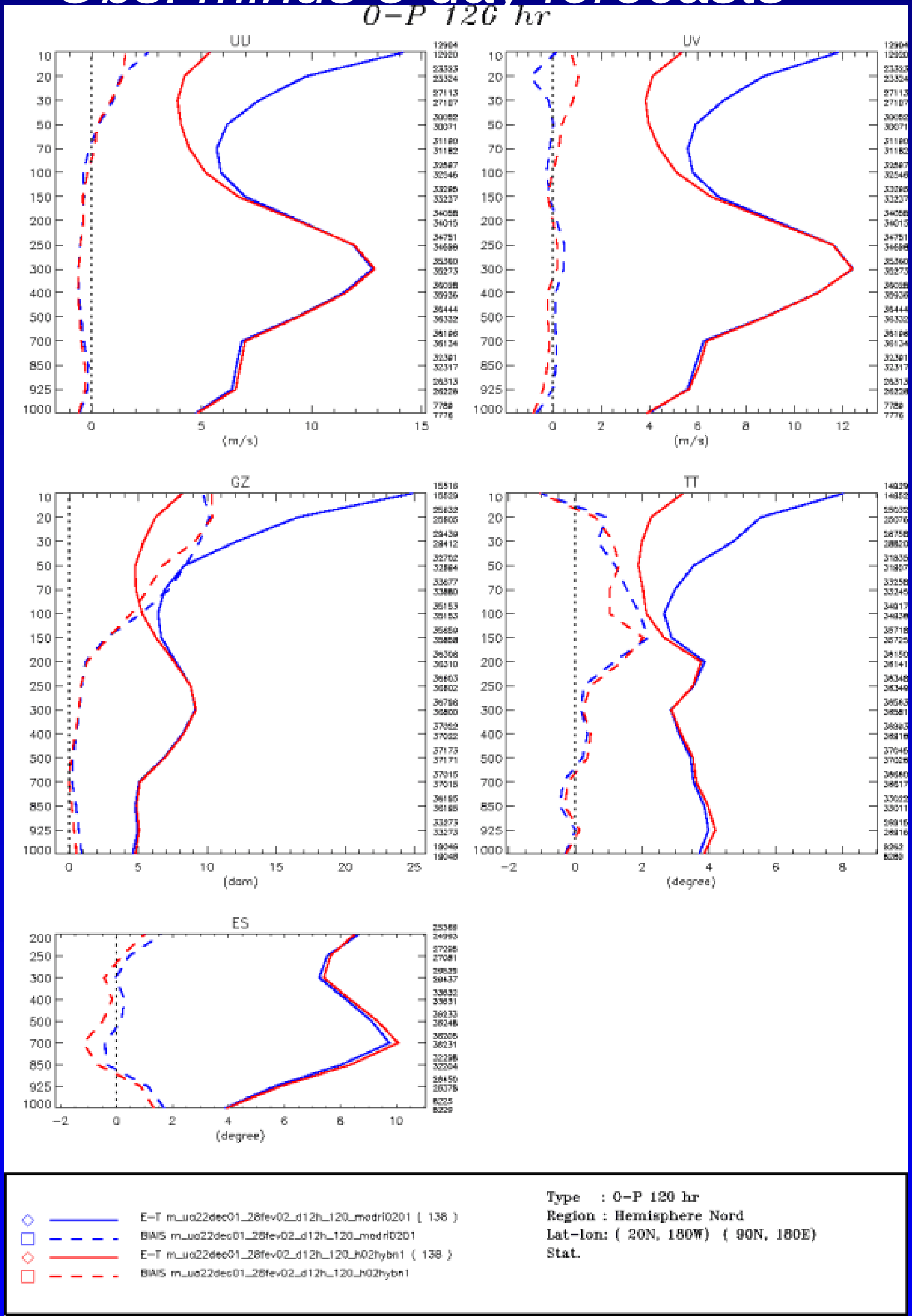
Obs. minus 6-hr forecasts



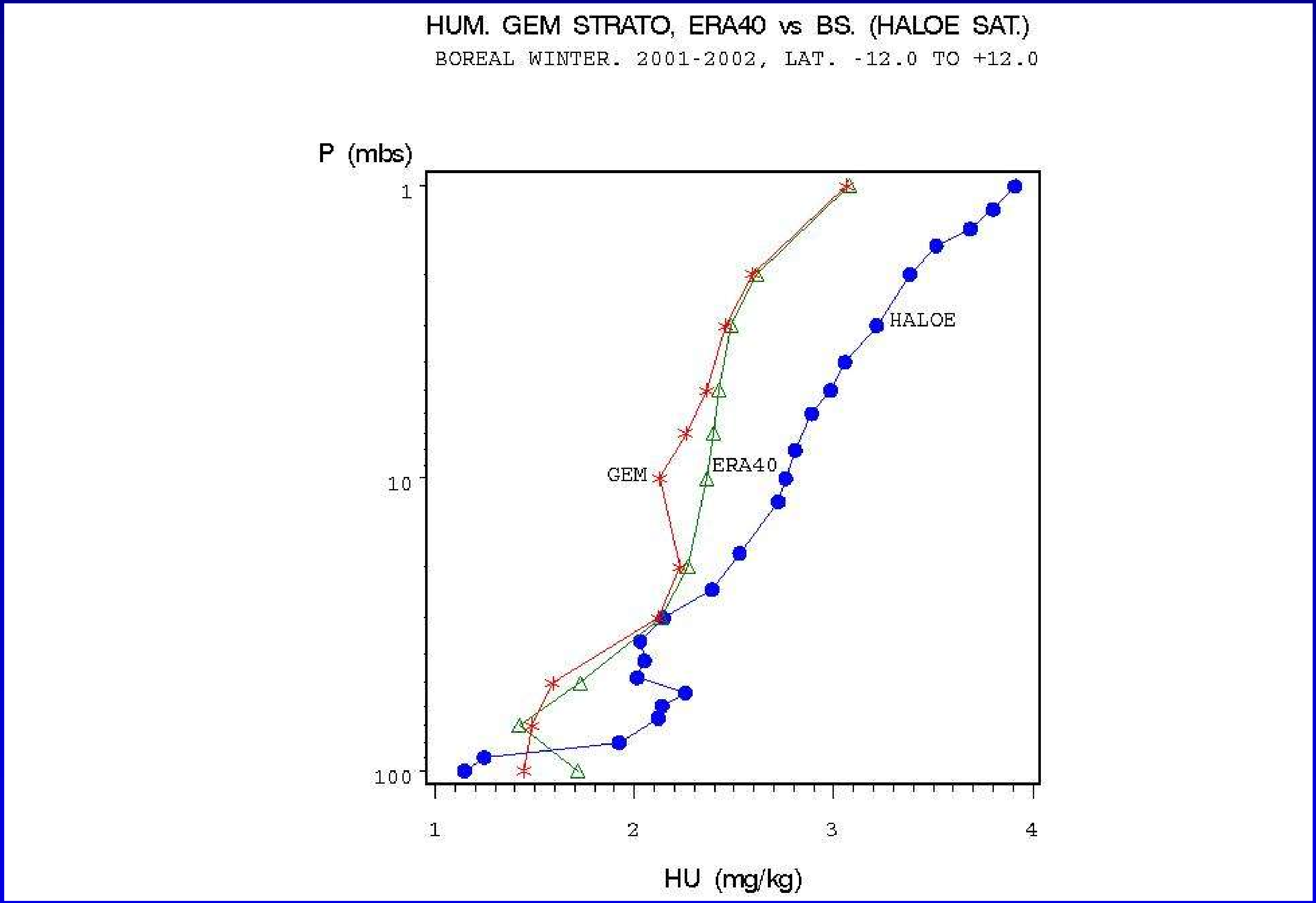
Obs. minus 2-day forecasts



Obs. minus 5-day forecasts



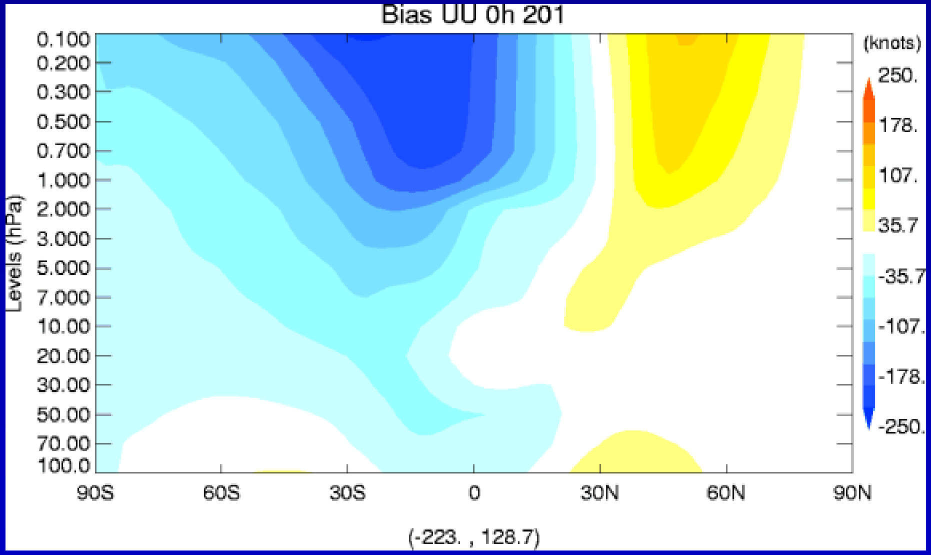
Mean humidity, GEM-Strato, ERA40, and HALOE data over the Tropics



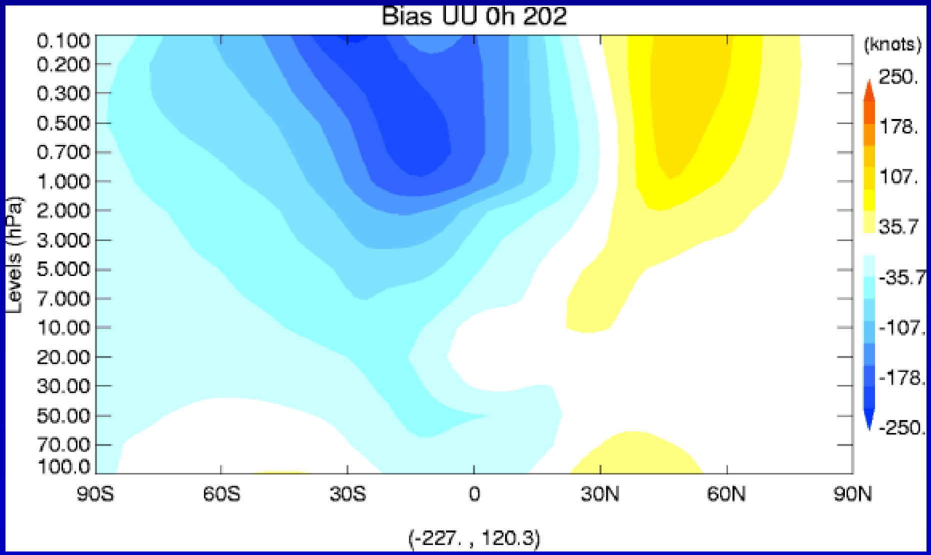
(produced by Alain Robichaud)

Mean January 2002 Zonal Wind Analysis

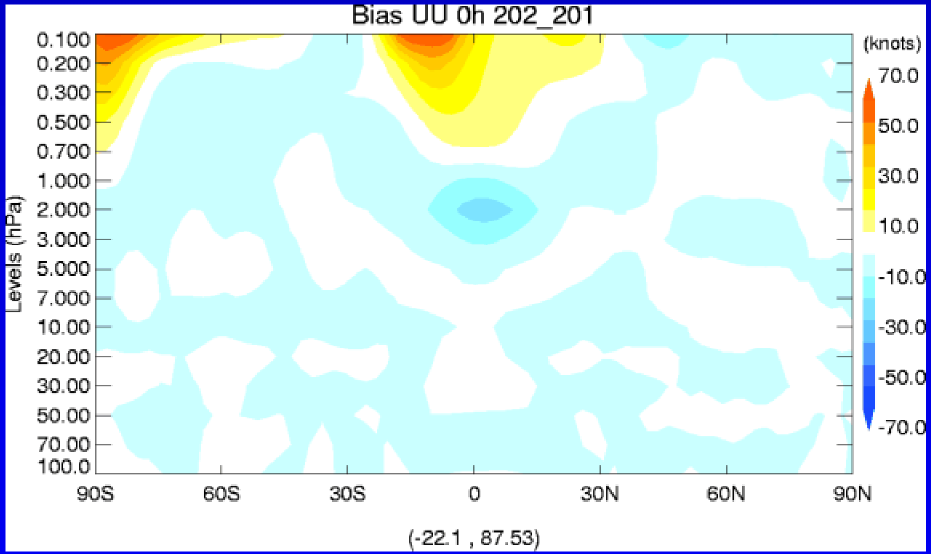
Without Hines



With Hines



Difference

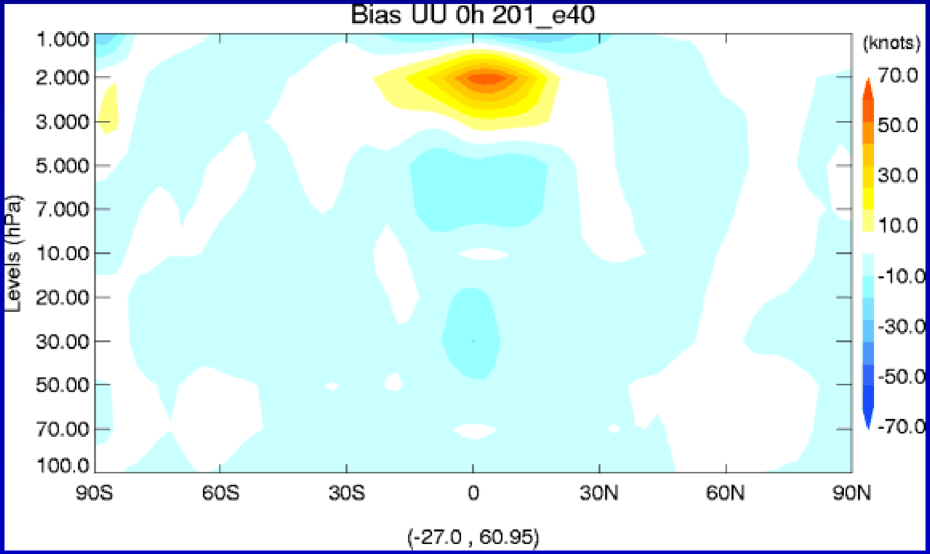


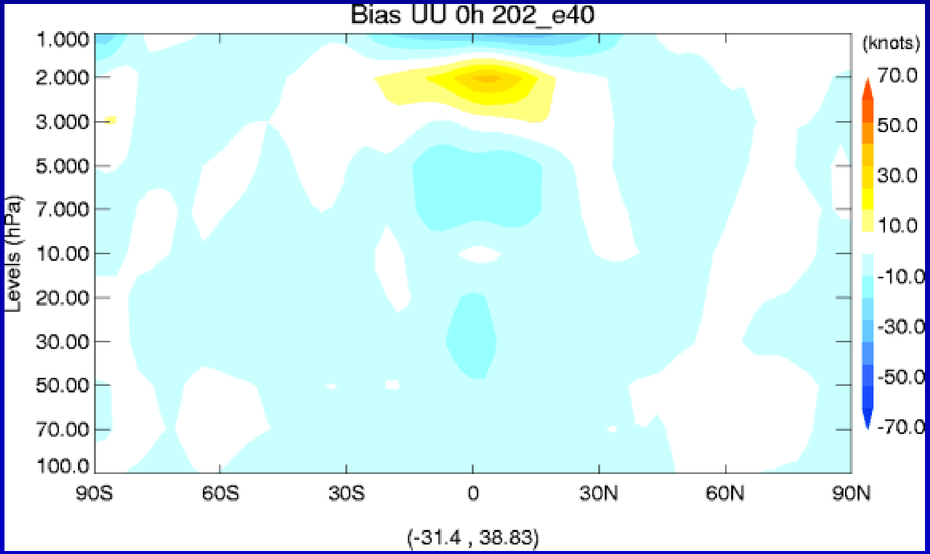
(produced by Cécilien Charette)

Mean January 2002 Zonal Wind Analysis

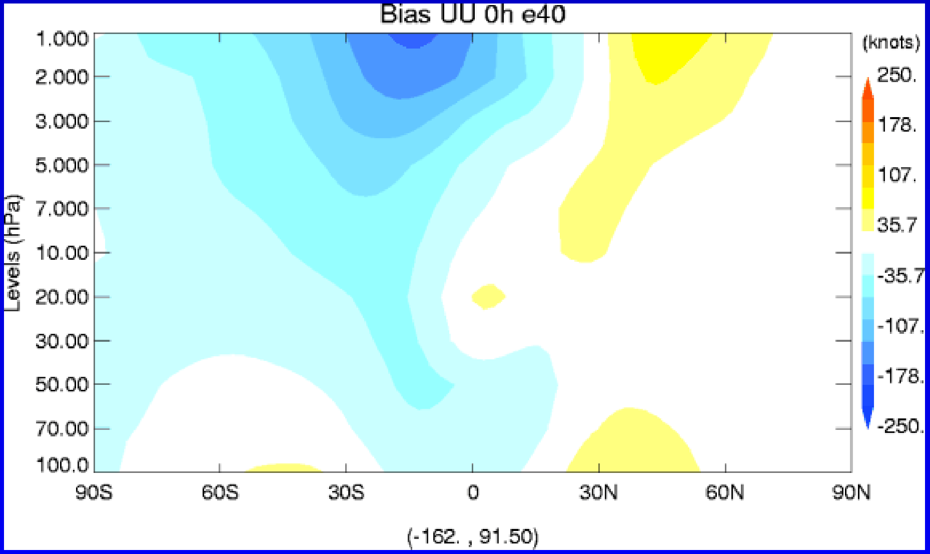
No Hines – ERA40

With Hines - ERA40





ERA40



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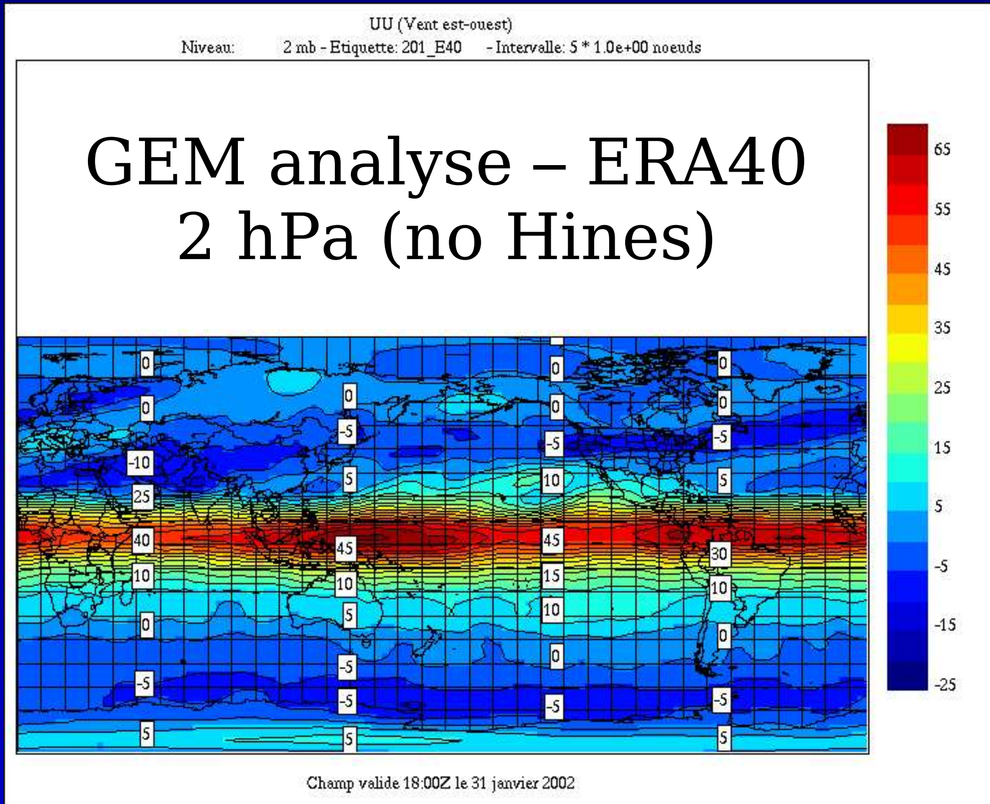
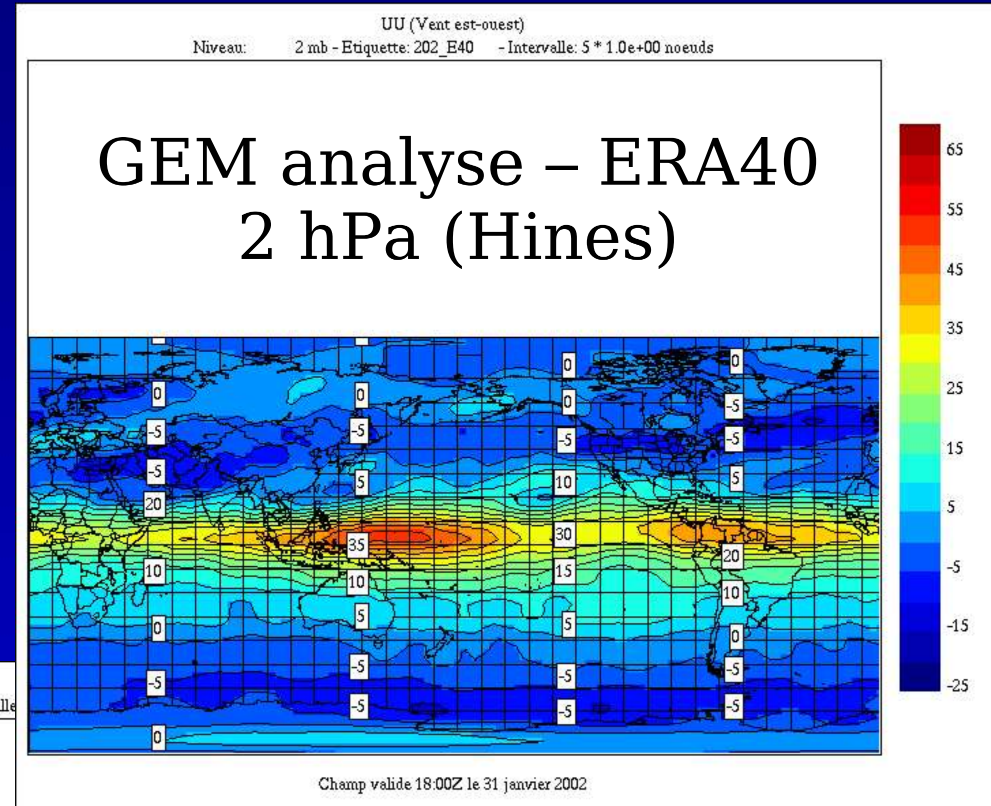
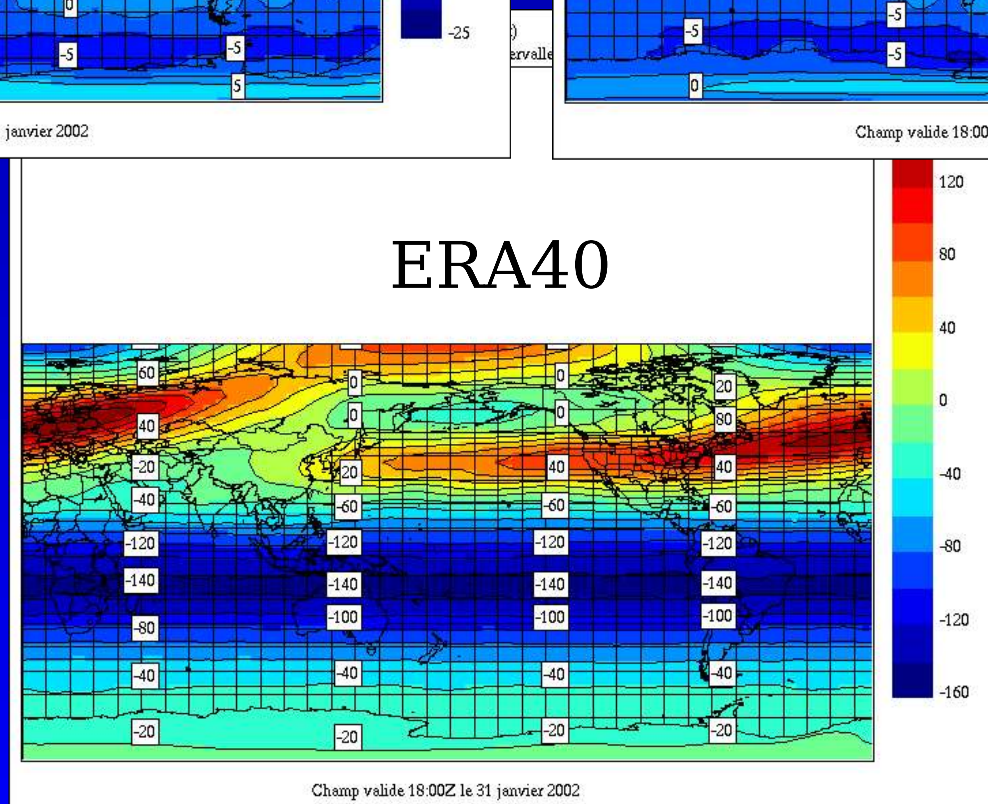




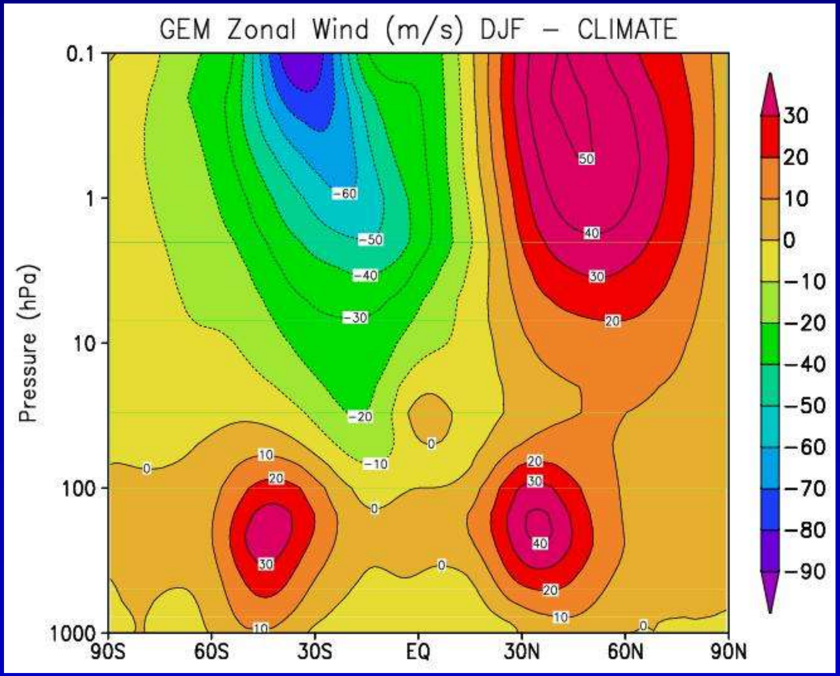


(produced by Cécilien Charette)

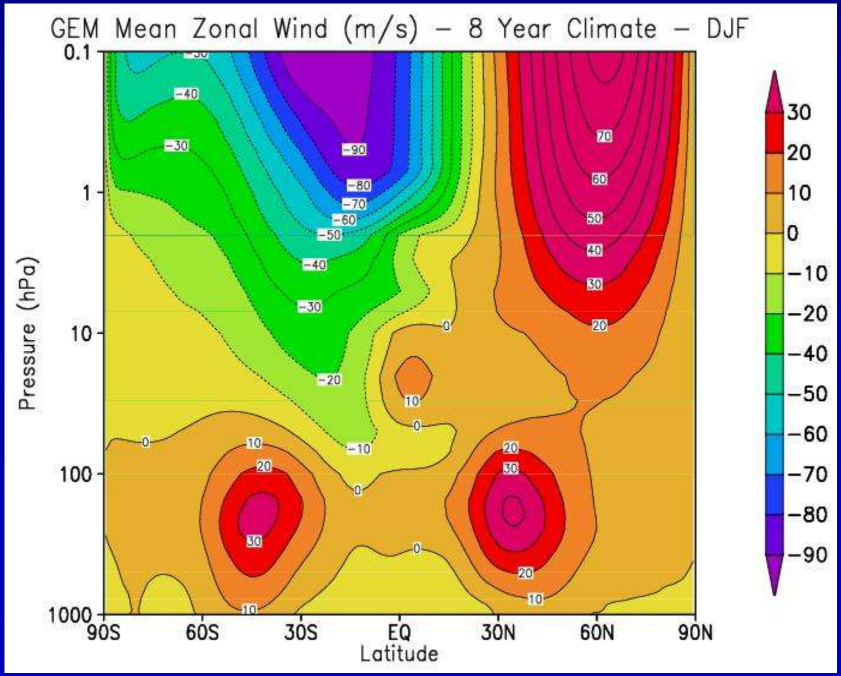
Climate Simulations with GEM-Strato

- *15-year climate simulation*
- *determine biases and model variability*
- *impact of Hines GWD parameterization*
- *horizontal resolution: 240x120 (1.5°)*
- *vertical resolution: 80 levels (surface to 0.1 hPa)*
- *prescribed ozone and SST*
- *hybrid vertical coordinate*

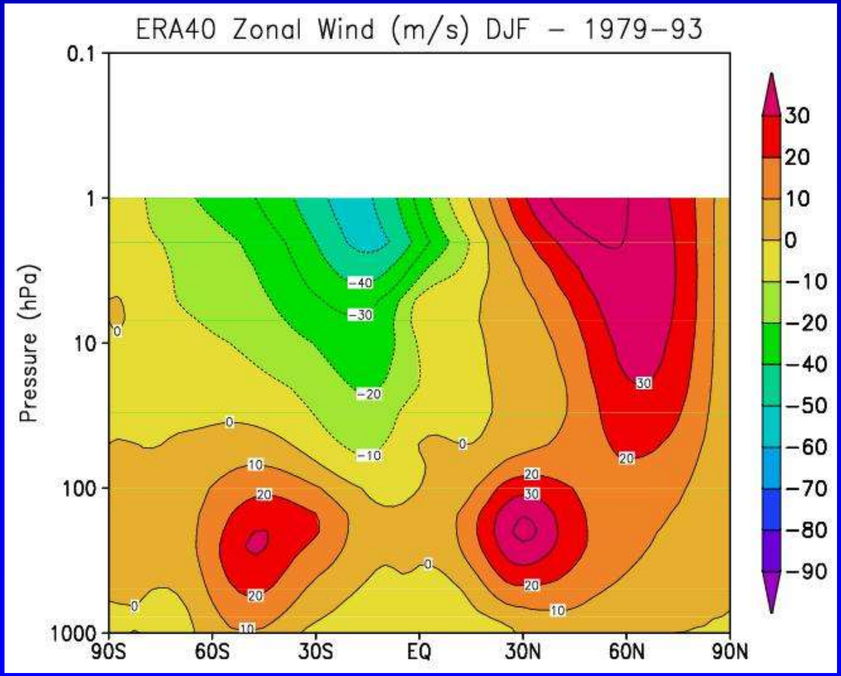
With Hines GWD



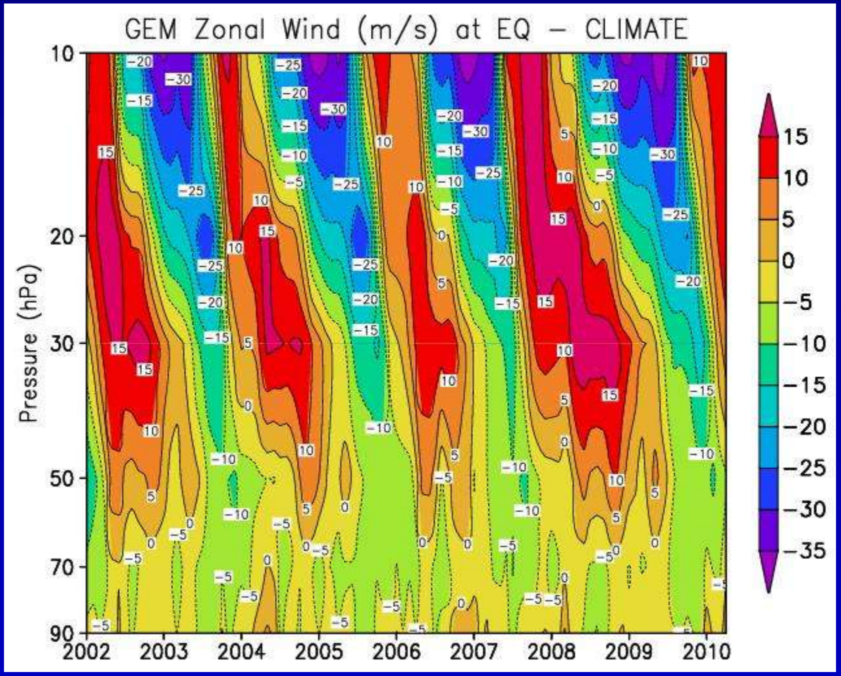
Without Hines GWD



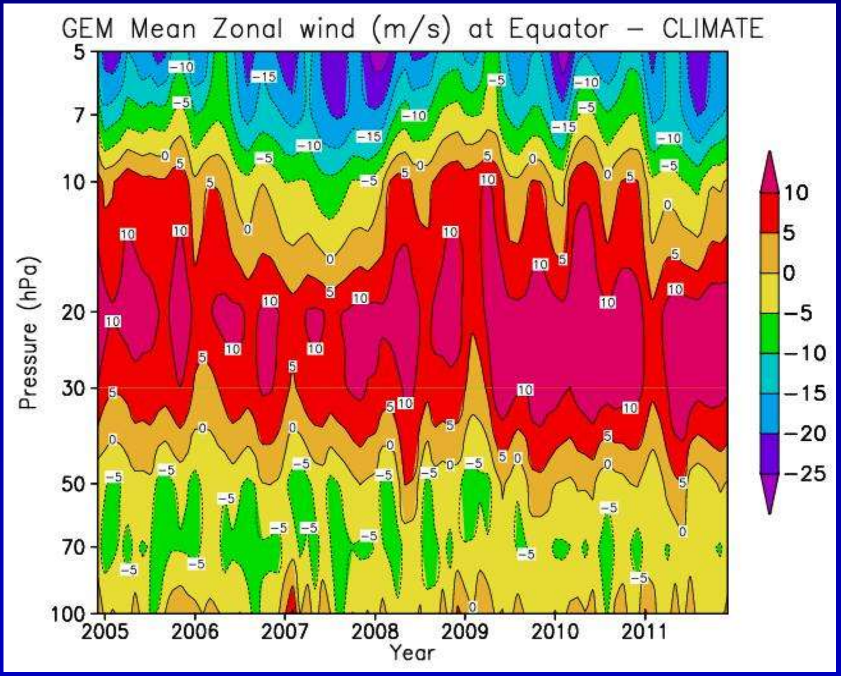
ERA40

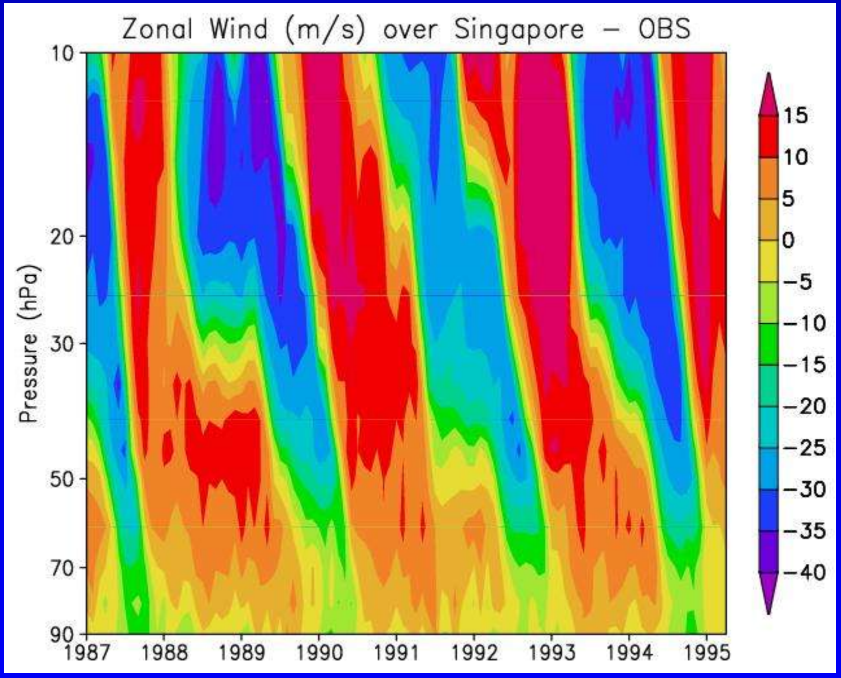


With Hines GWD



Without Hines GWD



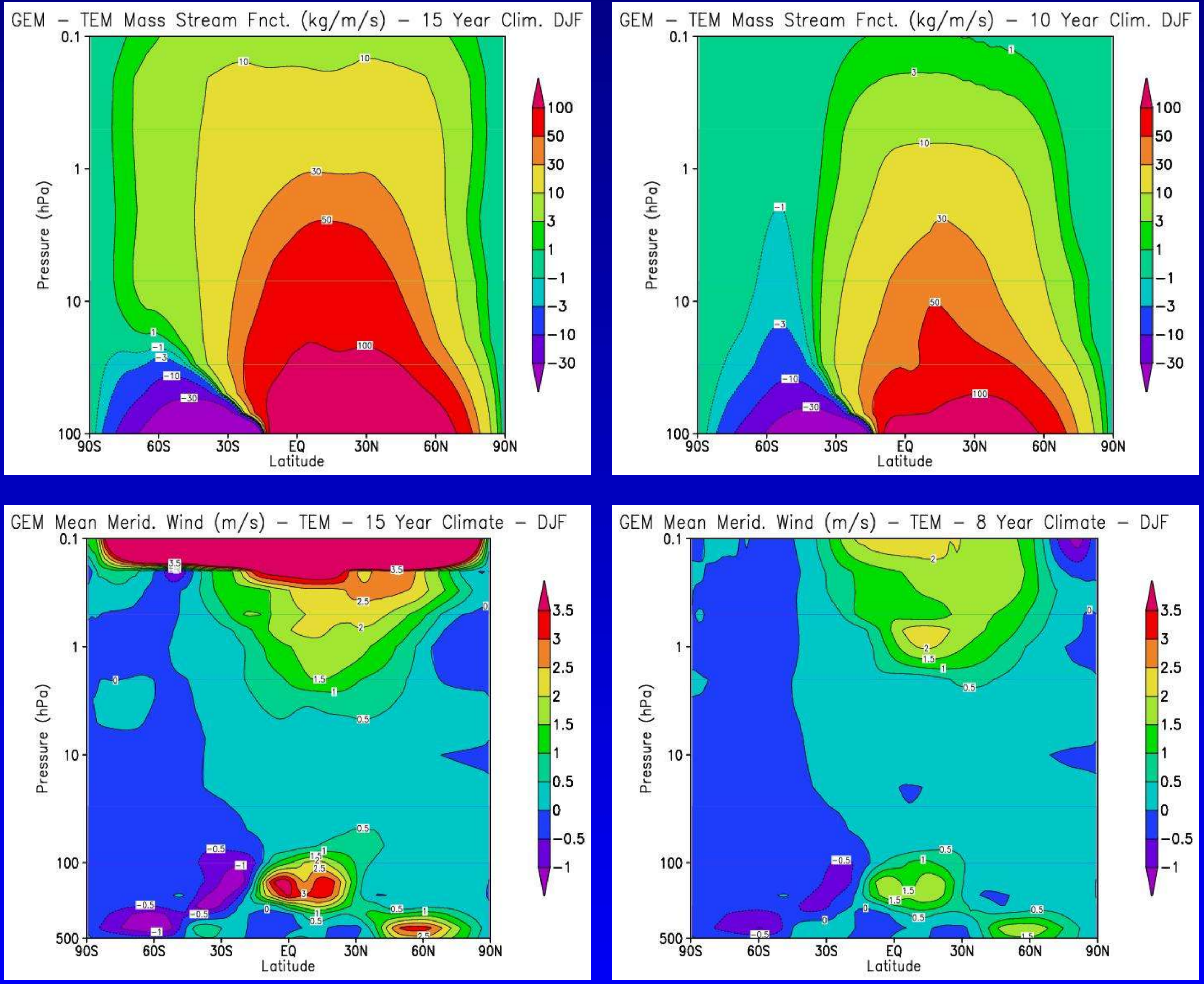


- *Model simulation is more a BO than a QBO (period of 24 months)*
- *Winds too weak below 50 hPa*
- *But general structure is OK, in particular, latitudinal extent is within about [-15° ,15°] (not shown)*

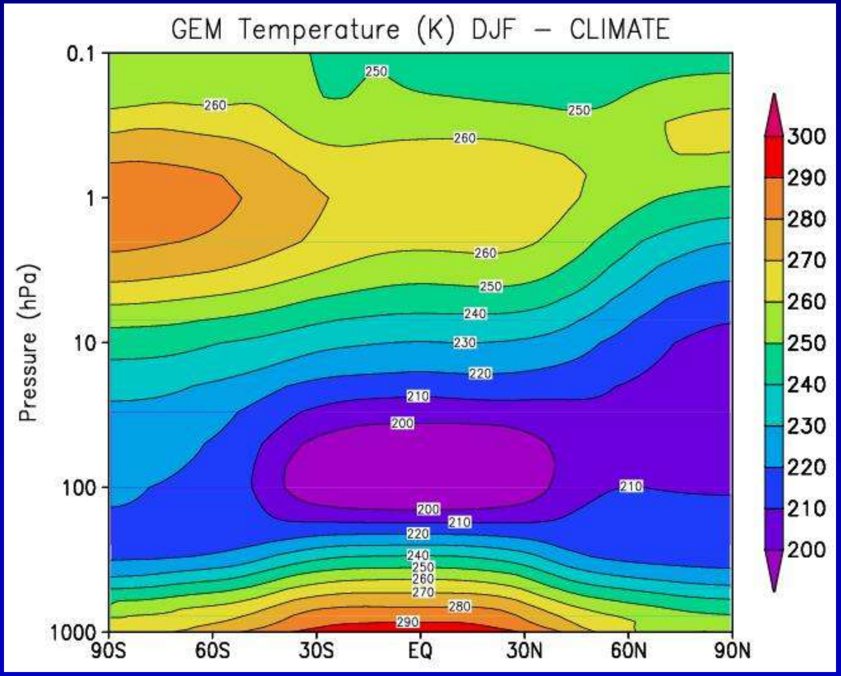
With Hines GWD | *Without Hines GWD*

TEM mass stream function

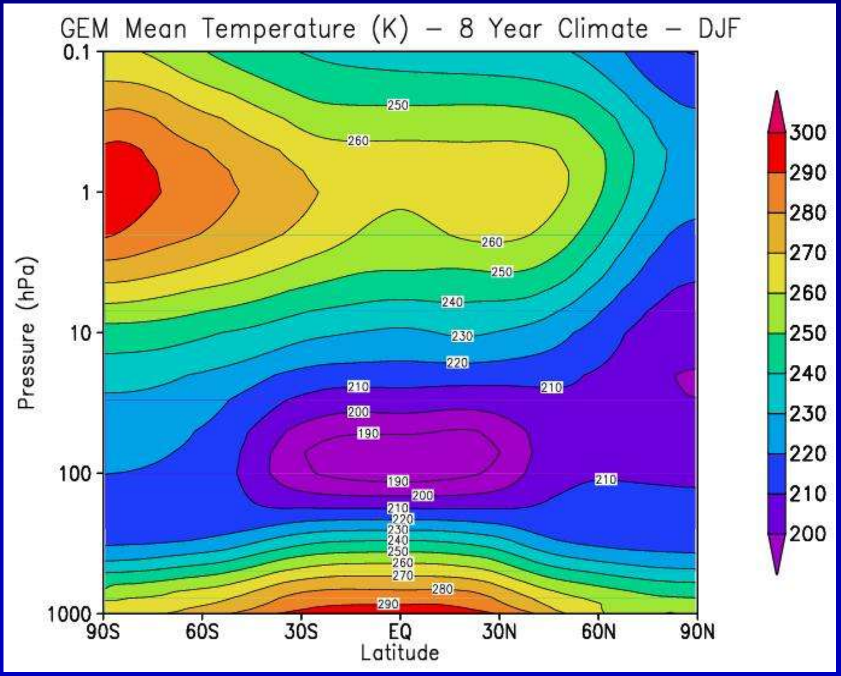
TEM merid. velocity



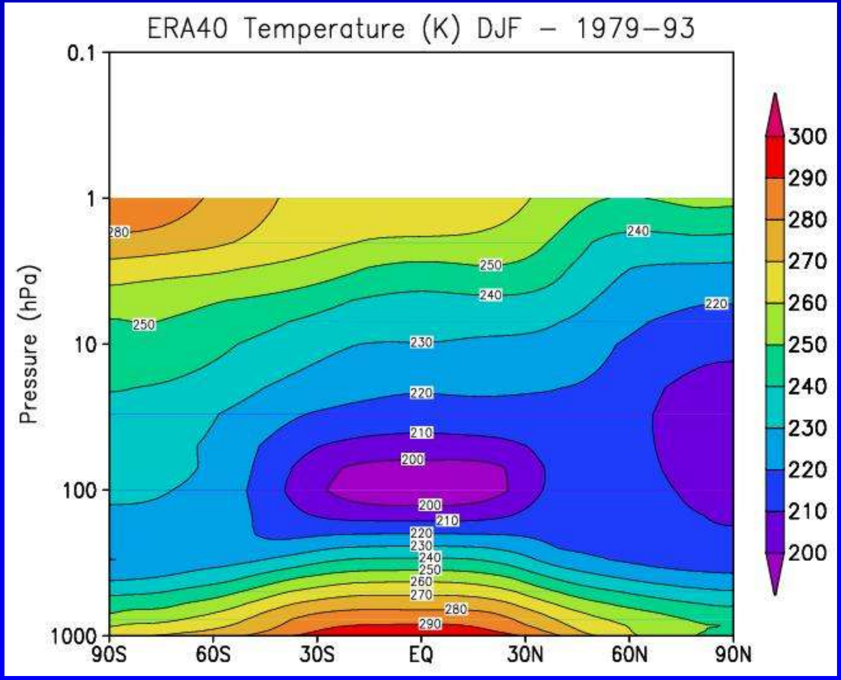
With Hines GWD

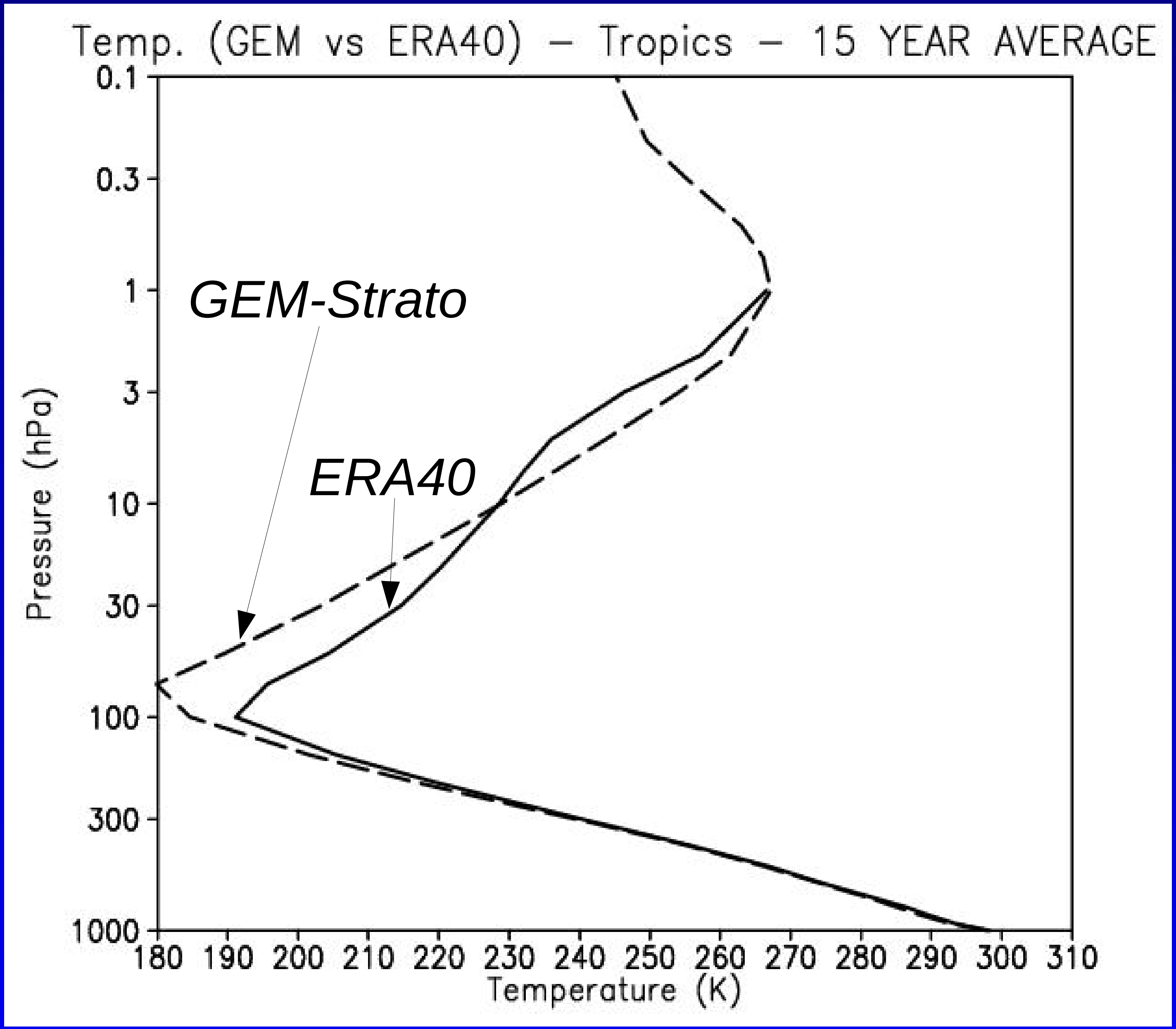


Without Hines GWD



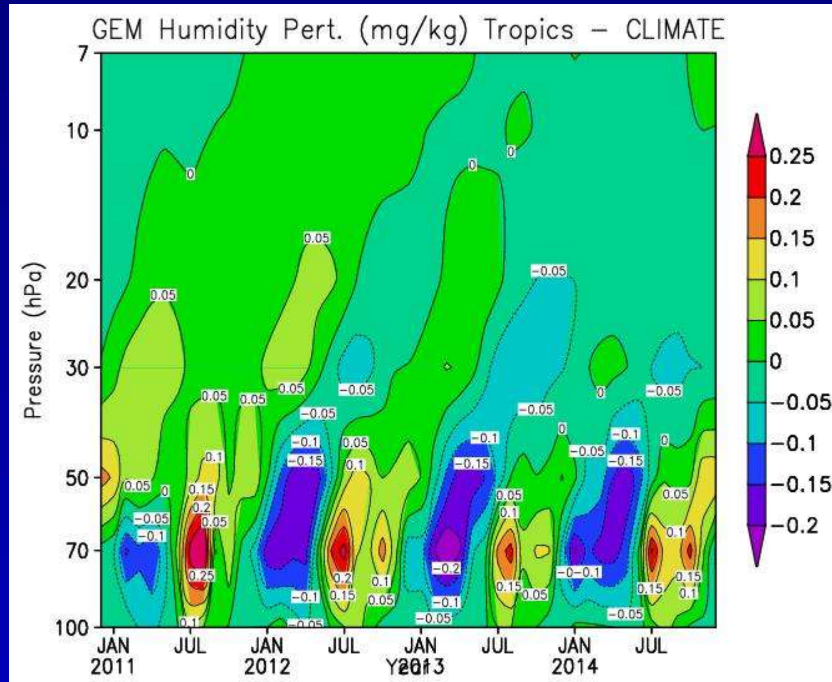
ERA40

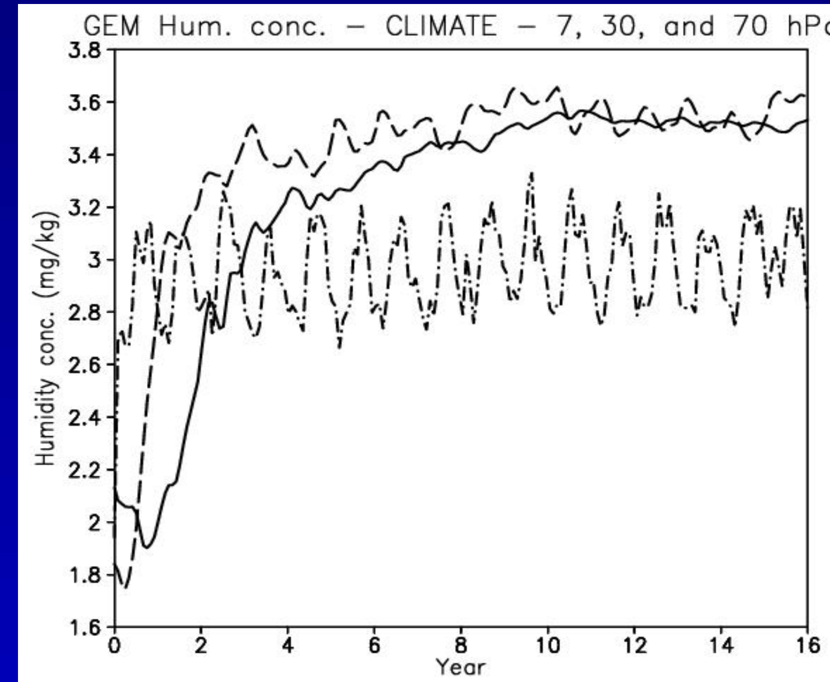




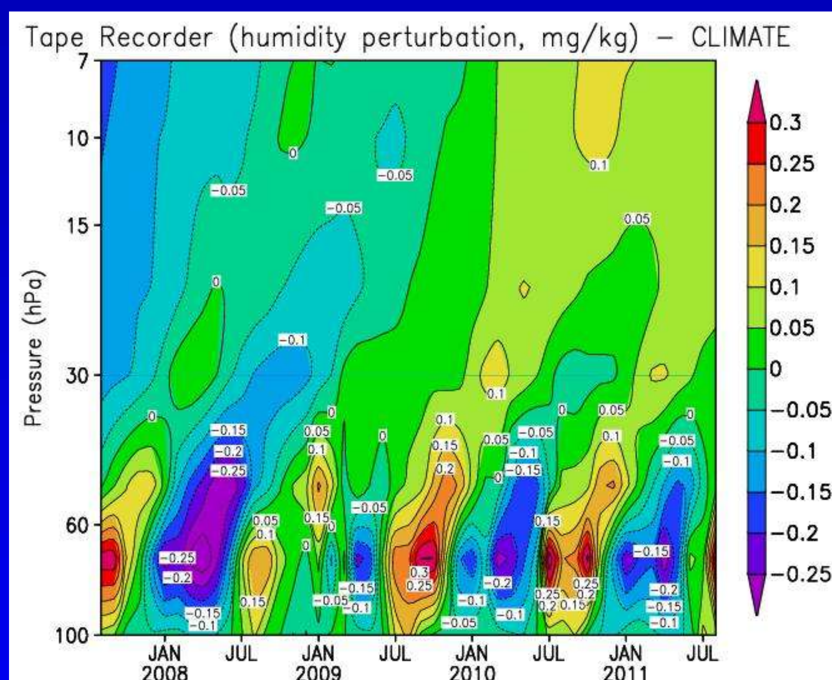
Temp. (GEM vs ERA40) – Tropics – 15 YEAR AVERAGE
GEM-Strato
ERA40
Pressure (hPa)
0.1
0.3
1
3
10
30
100
300
1000
180 190 200 210 220 230 240 250 260 270 280 290 300 310
Temperature (K)

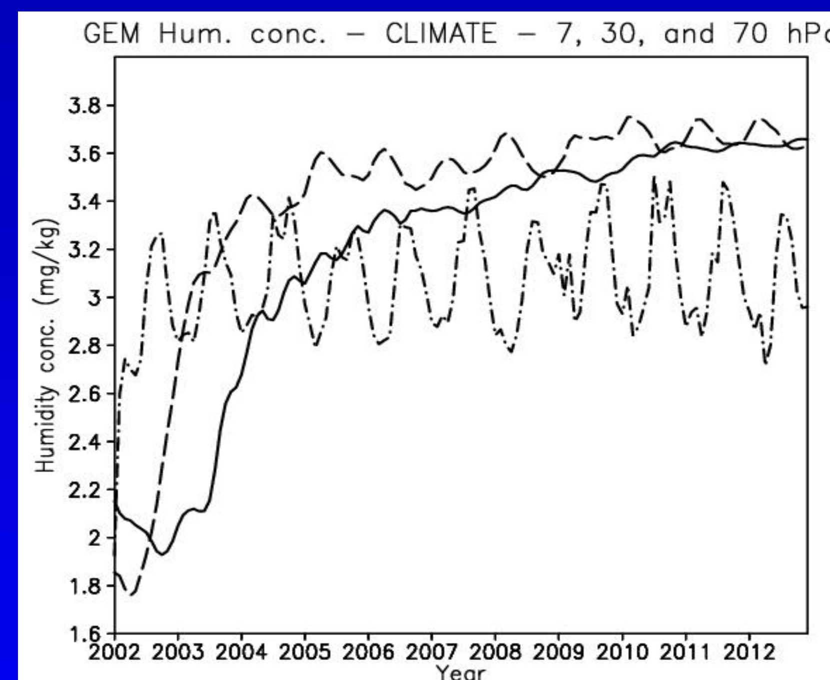
With Hines





Without Hines



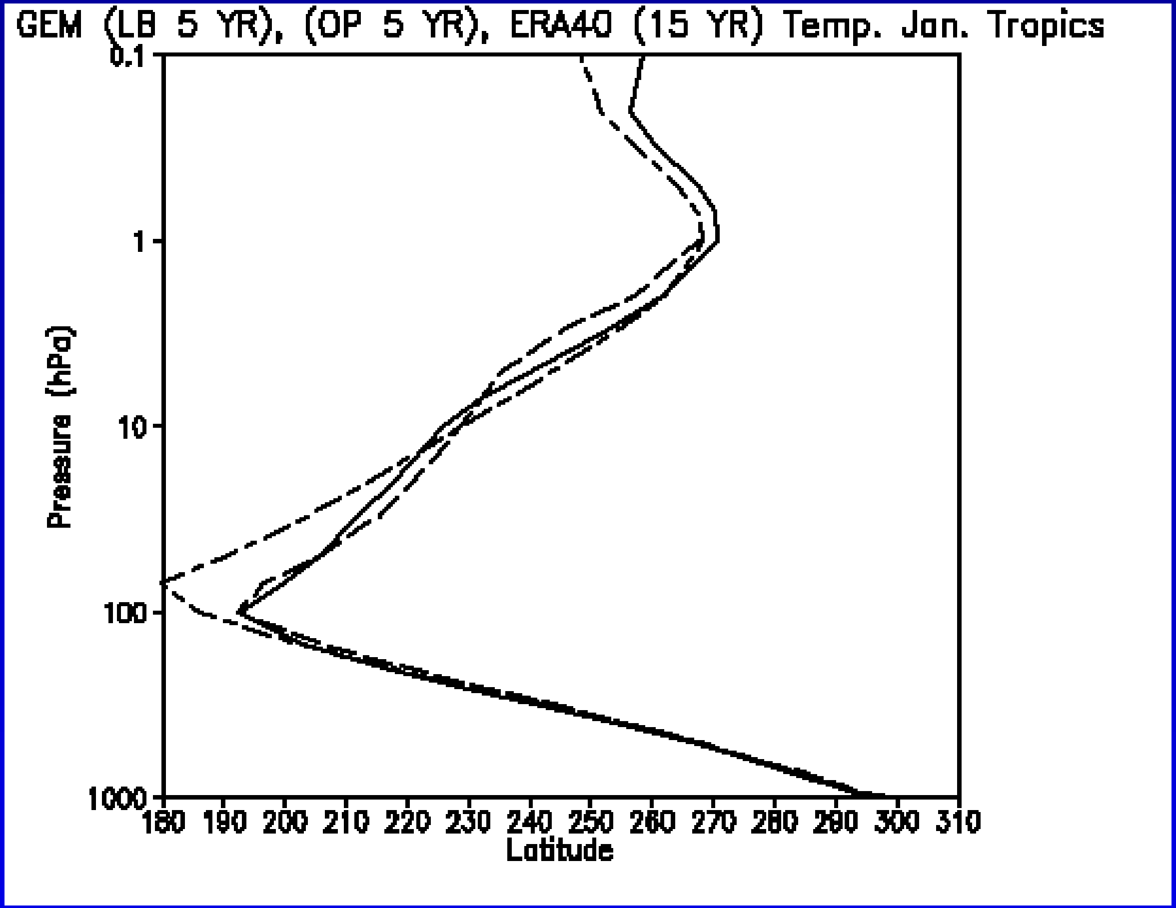


Upcoming Model Developments

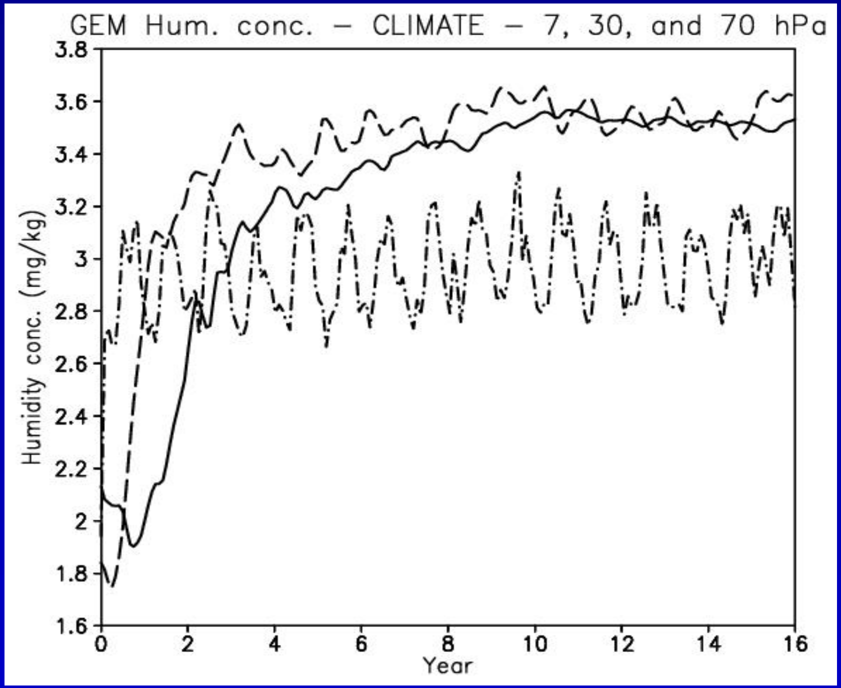
- *New radiation code: Li and Barker (2003)*
  - *from surface to model top*
  - *correlated k-distribution scheme*
  - *treats short and long waves*
  - *can deal interactively with H_2O, O_3, CO_2, N_2O, CH_4, and four CFCs*
- *Use GEM-MesoGlobal physics package*
  - *fine tuning for coarser resolution*
  - *adjust interactions between radiation, convection, and clouds*

Impact of Li and Barker's (2003) radiation scheme on the GEM tropical tropopause

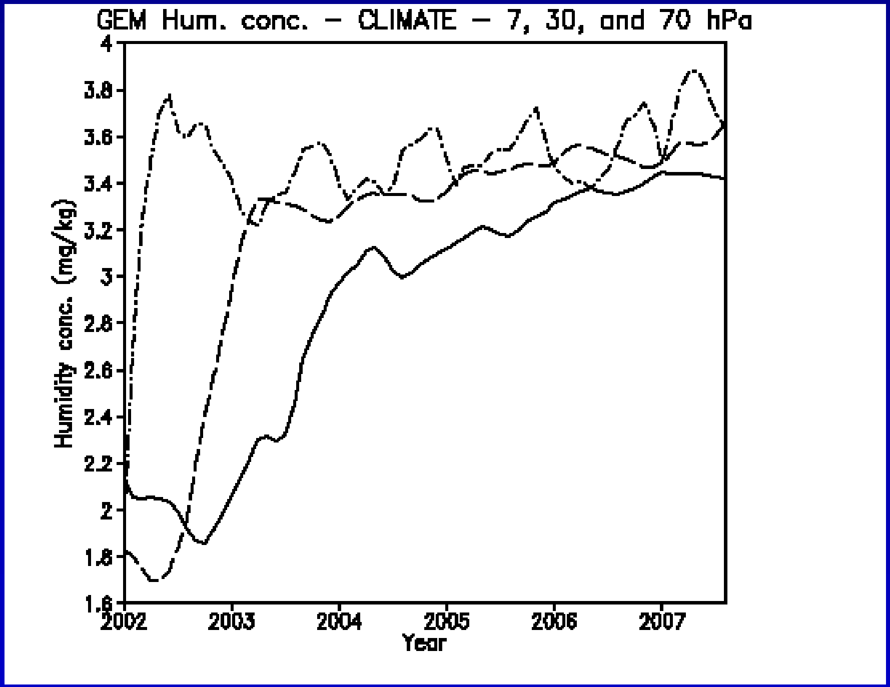
- *Long dashed line: ERA40*
- *Solid line: Li and Barker*
- *Long-short dashed line: Operational radiation*



Operational radiation scheme



Li and Barker's radiation scheme



Li and Barker's scheme produces a warmer (and better) tropical tropopause temperature, which allows more water vapour in the stratosphere. There is a serious need to investigate cross tropical tropopause transport processes in GEM.

Upcoming Projects

- *Coupled chemical-dynamical data assimilation (funded by the European Space Agency and MSC)*
  - *York U.: coupled chemical-dynamical model*
  - *MSC: GEM-Strato developments and DA*
  - *BISA: chemical data assimilation and chemistry transport models*

➔ *chemical weather*

Upcoming Projects (continued)

- *AIRS radiance assimilation (Sylvain Heilliette, Louis Garand, Alain Beaulne)*
  - *extend the use of hyperspectral IR radiance (AIRS, later IASI) to the lower stratosphere*
  - *study complementarity with AMSU (microwave)*
  - *evaluation of analyses and of the resulting forecasts*
  - *3D-VAR experiments*
  - *validation of the ozone and temperature fields*