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The new Canadian Regional Analysis & Forecasting System: REG-LAM3D

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Internal Seminar, Friday, 19 June 2009, Dorval

1 Meteorological Research Division

2 Canadian Meteorological Center (Development)

3 Météo-France

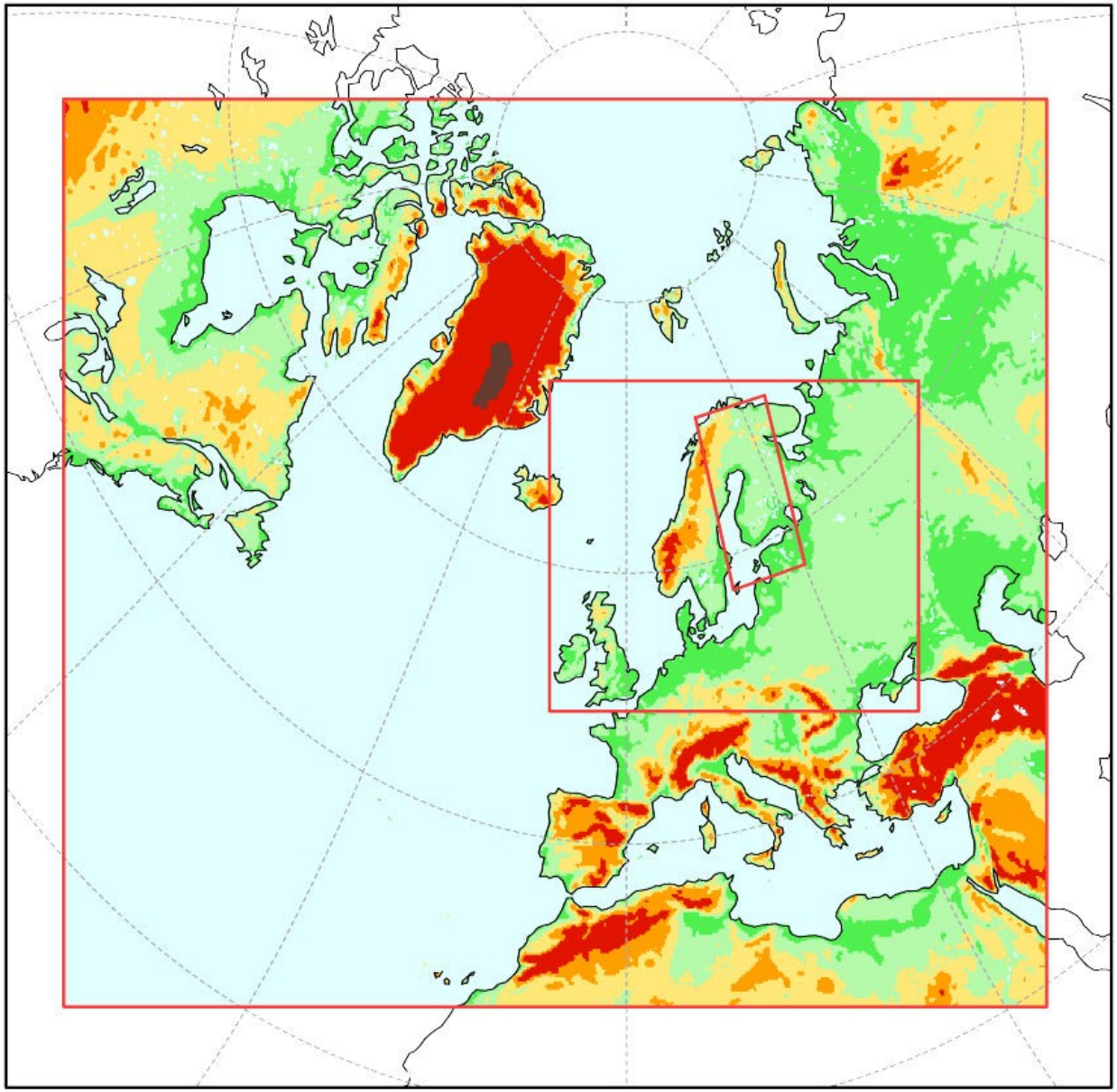
4 Saskatchewan University

5 Canadian Meteorological Center (Operations)

Overview of the talk

- Current LAM data assimilation/forecasting systems in operational centers
- REG-LAM3D DA/Forecasting strategy
- Spectral approaches. New operators, options and configurations supported in 3D-VAR unified code
- Removing obstacles on our way to a robust REG-LAM3D system
- Evaluations of REG-LAM3D against Regional-Strato (Ervig Lapalme).
- Where we are going now: CMC Transfer & 2009-2010 Schedule
- REG-LAM-4D-Var
- VO-LAM3D-15km analysis. Special aspects of the problem + Results with full obs.
- Introduction to QC-LAM3D-1km : Radar data assimilation with McGill.

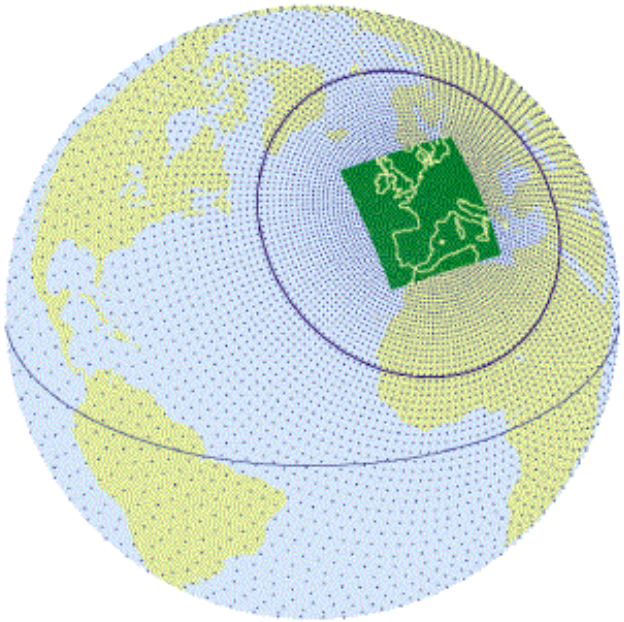
HIRLAM RCR -> HIRLAM MB71 -> AROME



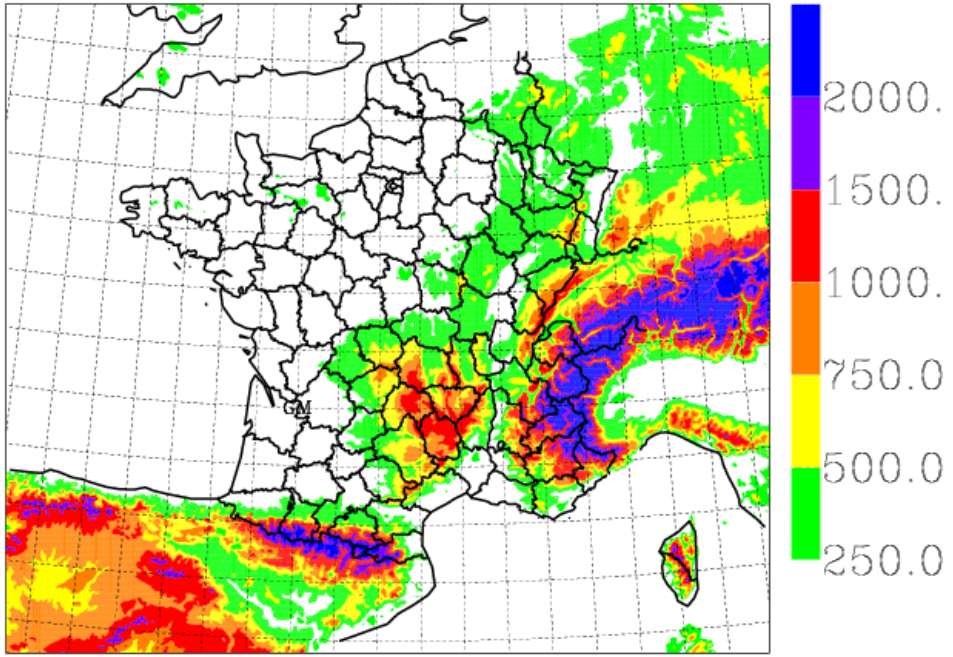
NWP at Météo-France

- NWP systems :
  - ARPEGE : global model (15 km over Europe), 4D-Var, increment at 90 km
  - ALADIN-France : regional model (9.5km), 3D-Var, increment at 9.5 km
  - AROME : meso scale model (2.5km), 3D-Var, increment at 2.5 km

ARPEGE stretched grid and ALADIN-FRANCE domain

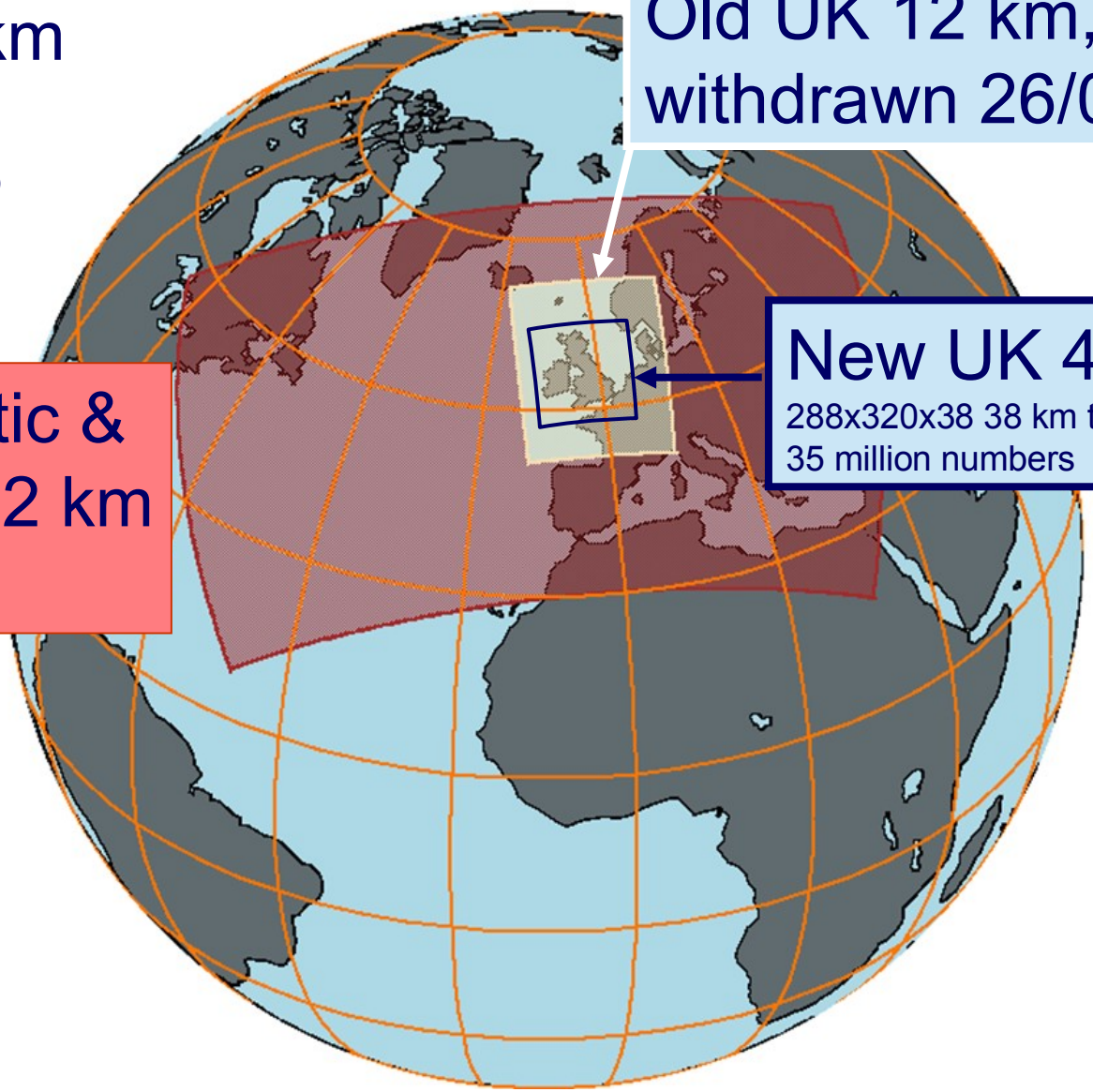


AROME France domain



Unified Model Operational Configurations

Global 40 km
N320L50
640x481x50 63 km top
150 million numbers

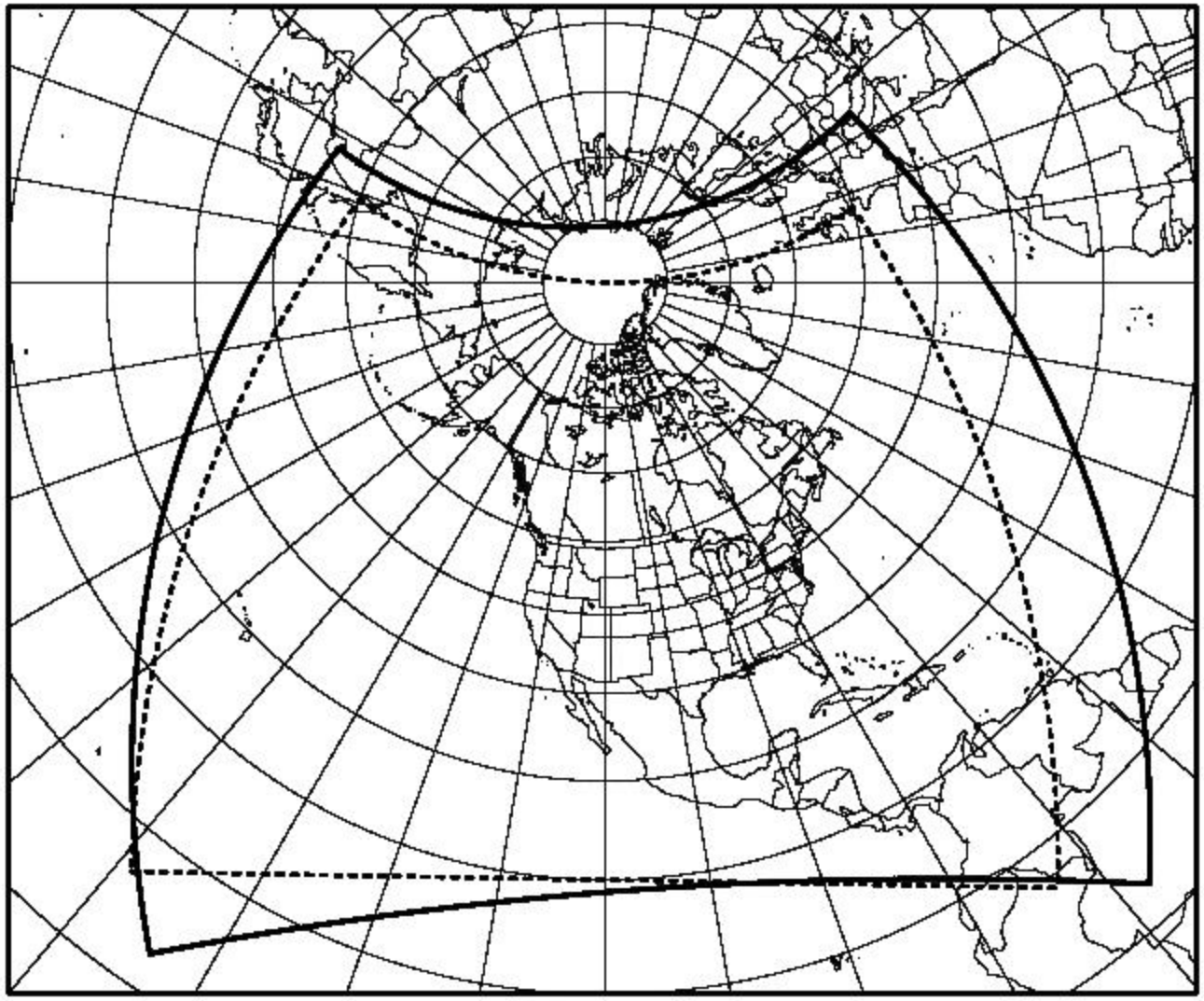


Old UK 12 km,
withdrawn 26/09/06

New UK 4 km
288x320x38 38 km top
35 million numbers

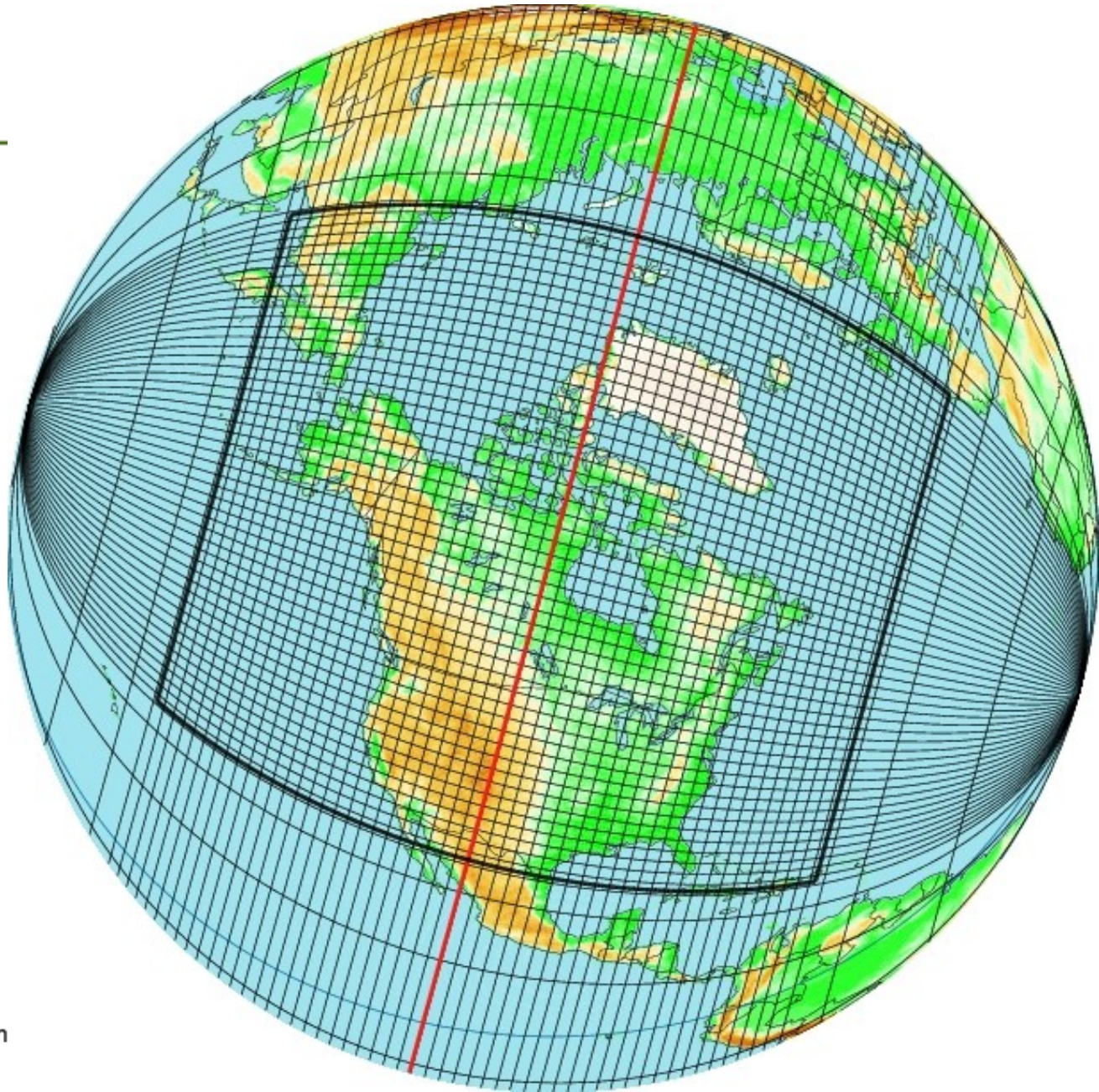
North Atlantic &
European 12 km
720x432x38 38 km top
120 million numbers

SOLID = EXPANDED NAM ; DASHED = OPS NAM



Regional Model
00, 06, 12, 18 UTC

Every 10th grid point shown



671 X 641 grid (66% in 15-km uniform area), 58 levels (soon 80 with Strato)

Assimilation is 3D-Var done with global system at T108 (~180 km)

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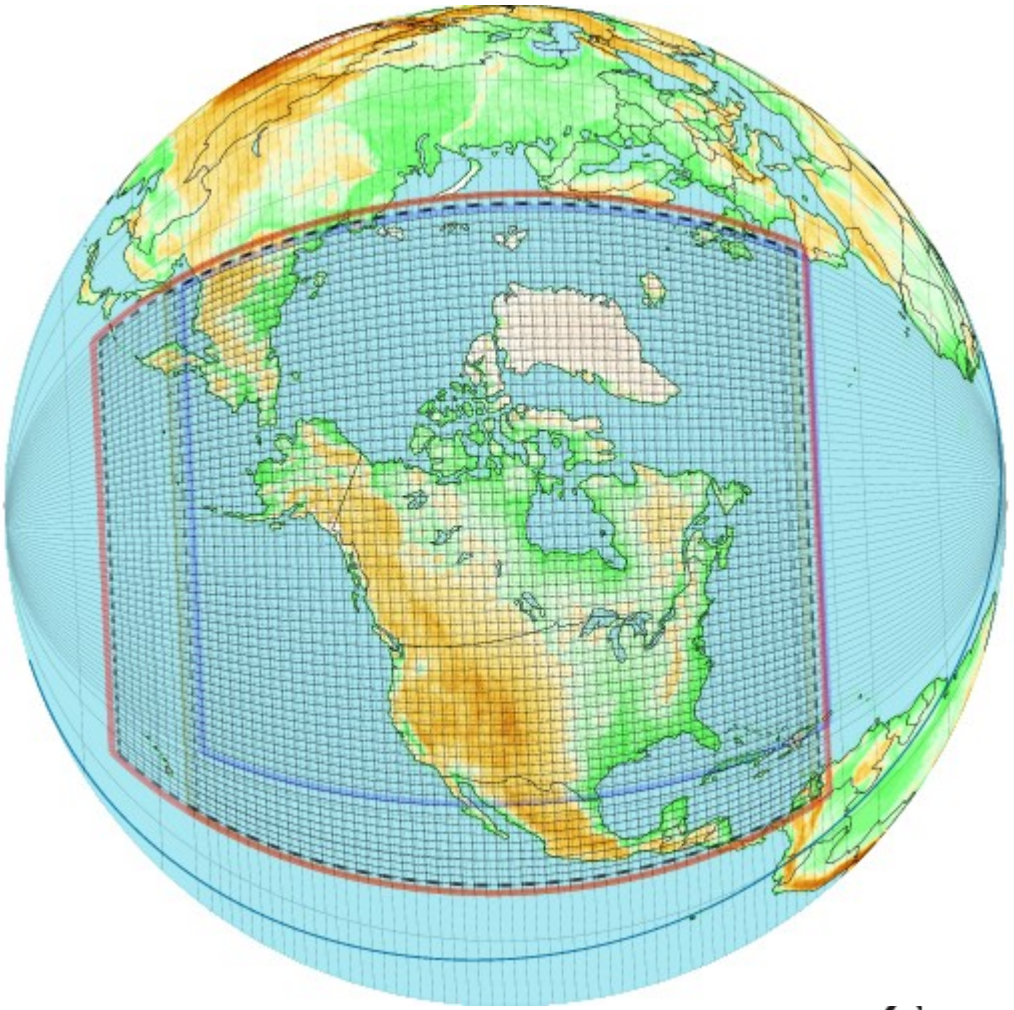
Next regional system: Continental LAM-3DVar REG-LAM3D

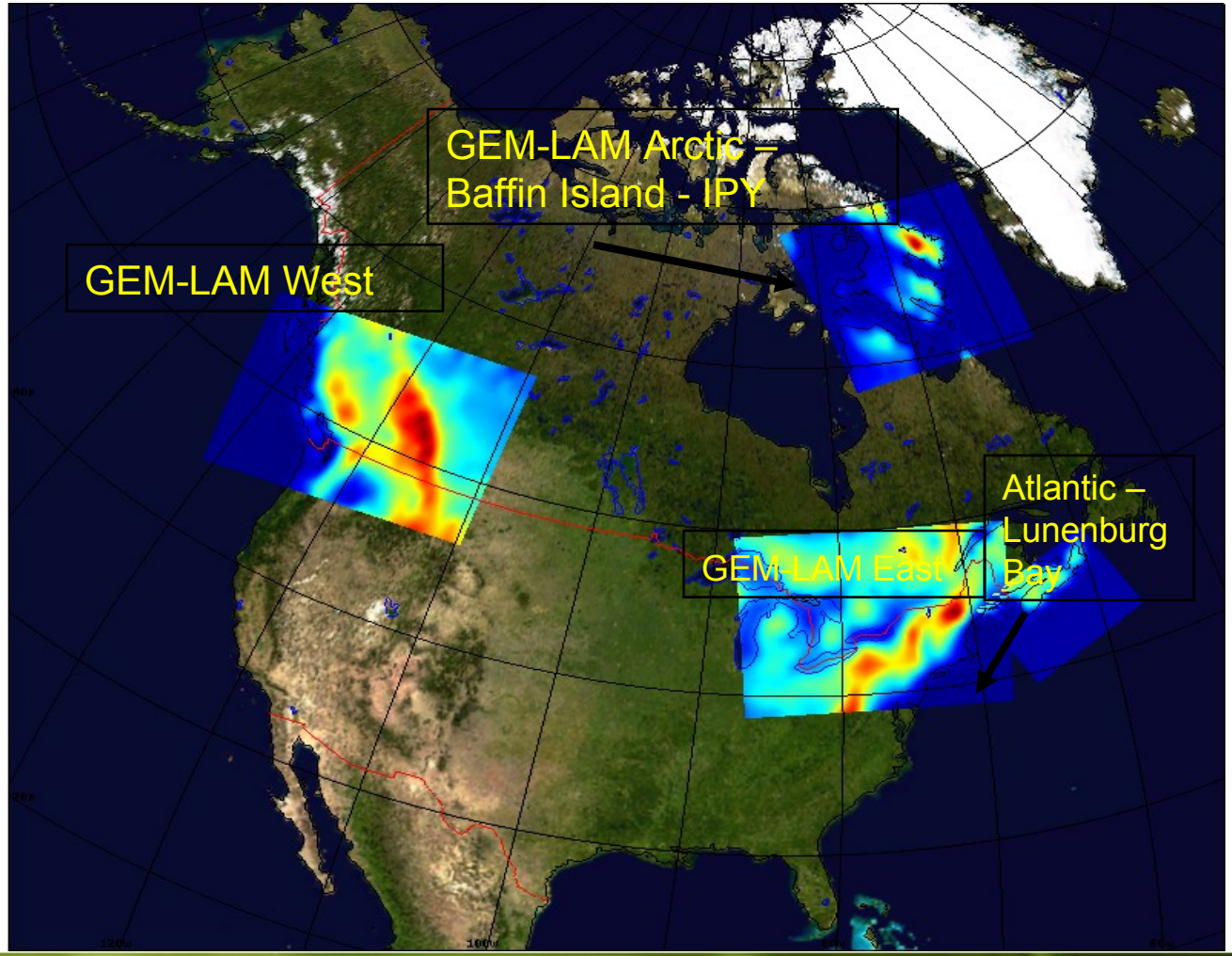
Blue: Current constant resolution portion of GEM regional grid

Red: Proposed GRID of continental LAM, 15-km (649x672) with 3D-Var assimilation at 55 km on LAM-core domain (176x176)

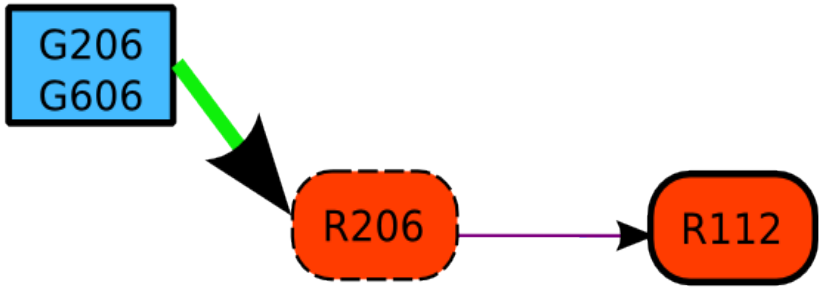
Boundary conditions provided by GEM global at 50 km, run during the LAM data assimilation step

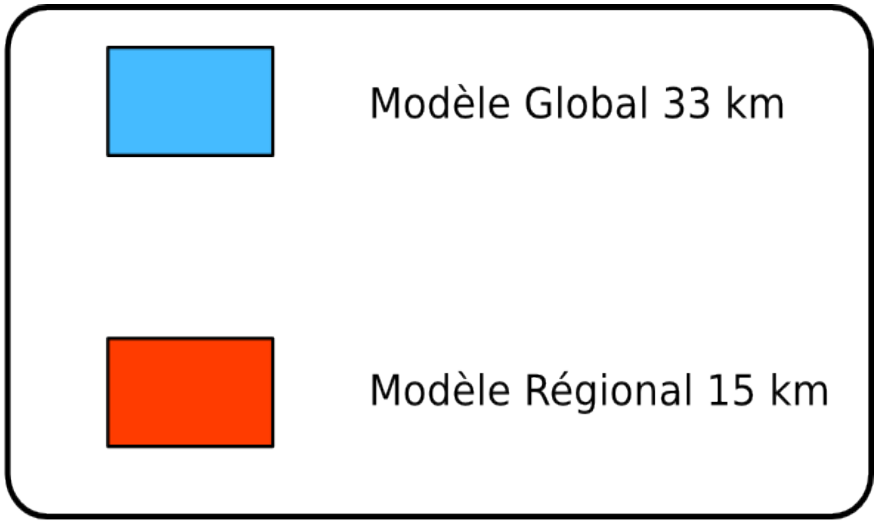


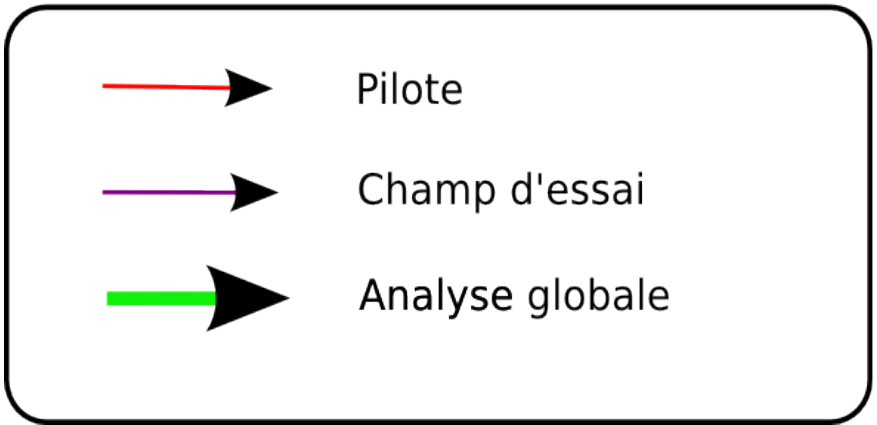
Current local very high resolution windows
Also 1-km window for 2010 winter Olympics

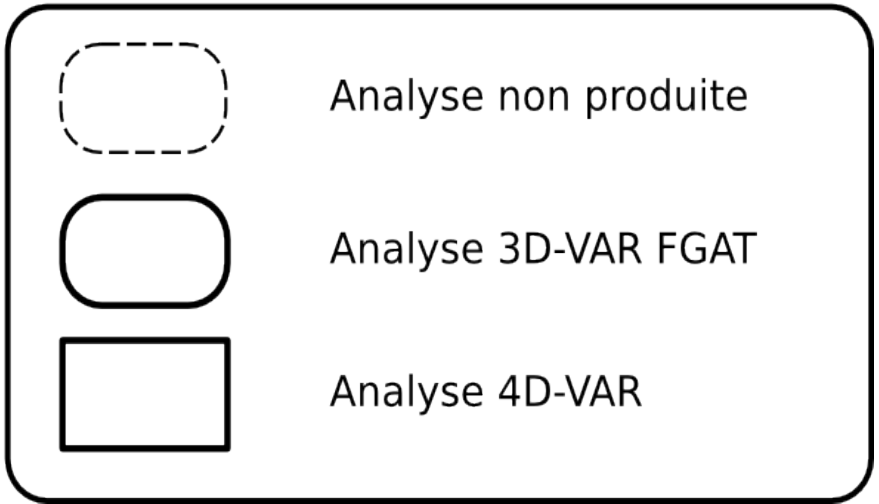


Spin-up Régional

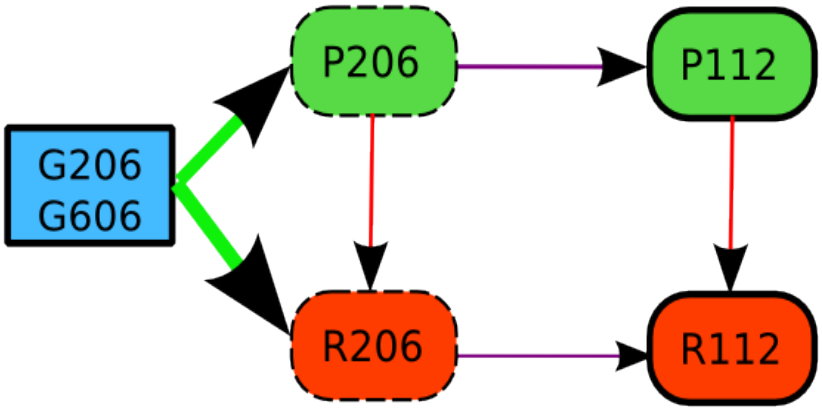


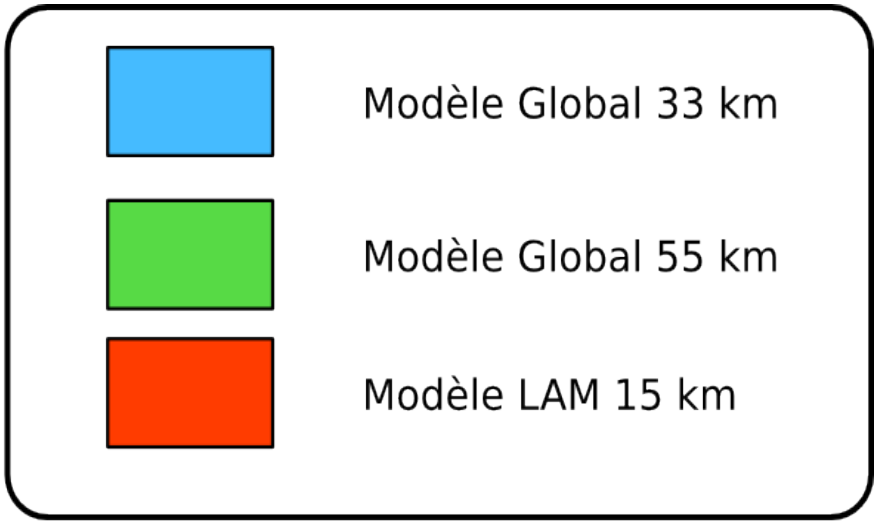


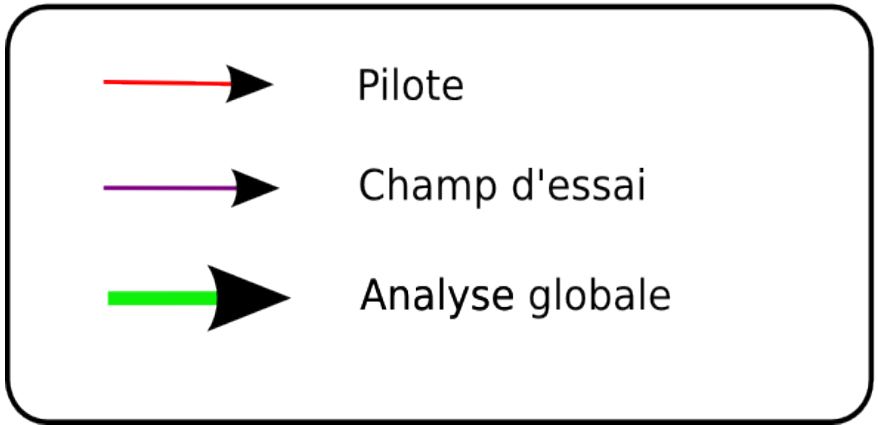


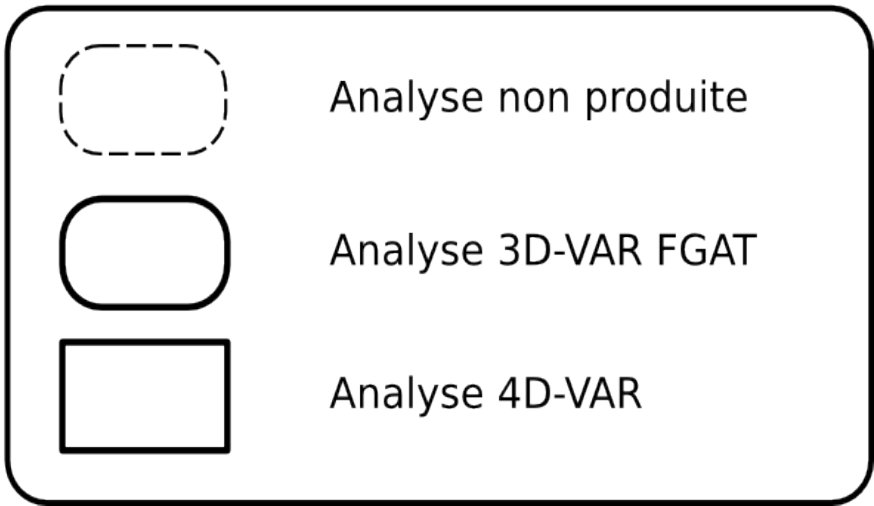


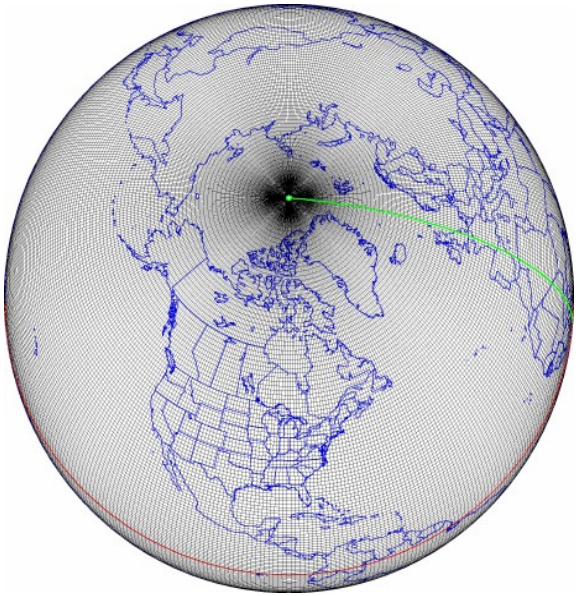
Spin-up REG-LAM3D



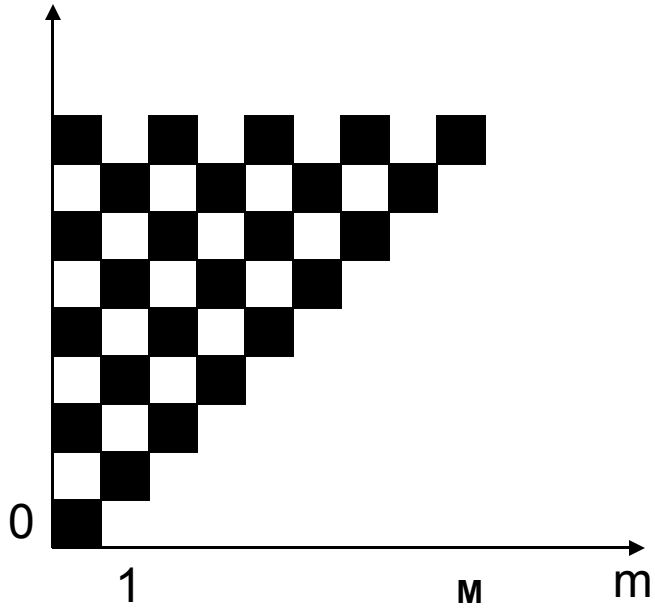






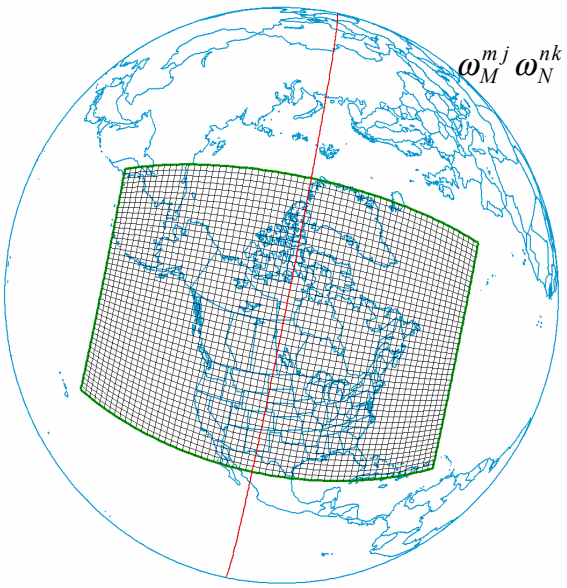


$$\zeta(\lambda,\mu)=\sum_{m=-M}^{M}\sum_{n=|M|}^{M}\zeta_n^m Y_n^m(\lambda,\mu)$$



- **Forward Two-Dimensional DFT** $F_{jk}=\frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} f_{mn}\,\omega_M^{-mj}\,\omega_N^{-nk} \quad j=0:M-1;k=0:N-1$

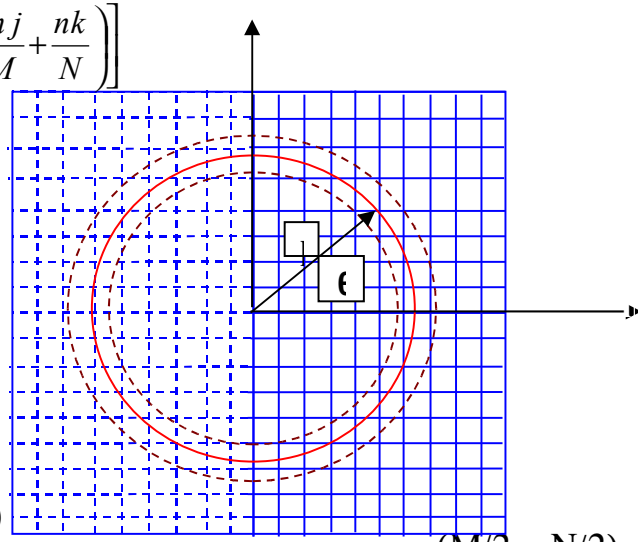
- **Inverse Two-Dimensional DFT** $f_{mn}=\sum_{j=0}^{M-1}\sum_{k=0}^{N-1} F_{jk}\,\omega_M^{mj}\,\omega_N^{nk} \quad m=0:M-1;n=0:N-1$



$$\omega_M^{mj}\,\omega_N^{nk}=e^{i2\pi\left(\frac{mj}{M}+\frac{nk}{N}\right)}=\cos\left[2\pi\left(\frac{mj}{M}+\frac{nk}{N}\right)\right]+i\sin\left[2\pi\left(\frac{mj}{M}+\frac{nk}{N}\right)\right]$$

The integer N must be factorizable in the form:

$$N=2^p 3^q 5^r$$



Specific aspects of the LAM analysis

In 'LU' mode: (Kilometric-scale configuration for transfer to CMC)

- **Uses bi-fourier representation (DFT-2D)**
- **Arakawa-C grid. Analysis increments are bi-periodic on the *extended* computational grid.**
- **Uses a Rotated analysis grid (following same approach as in GEM).**
- **A fast wind-rotation operator (& adjoint) is used at the end of the process of constructing the analysis increment before computing departures with innovation vector at each simulation of 3D-VAR**

In 'GU' & lcva_hemis = .true. mode: (Regional-continental configuration for tranfer to CMC)

- **Uses Hemispheric-spectral representation**
- **Based on symmetrized NH/SH background-error fields and associated statistic file.**
- **mbal_order = 0 enforced !**

New features in 3D-Var

&NAMDIM
nj = 250,
njinc = 250,
njsur = 2,
n i= 250,
niinc = 250,
nisur = 2,
nflev = 80,
nvgaux=0,
ntrunc=100,
ntruncinc=100,
nsaux=0.,
nlatbin=1,

&NAMGRD
multi_grd=0,
grd_typ='LU', (grd_typ='GU')
nila=250,
njla=250,
grd_dx = 0.4832,
grd_dy = 0.4832,
grd_iref = 101,
grd_jref = 71,
grd_latr = 0.0,
grd_lonr= 180.06875,
grd_xlon1=-97.,
grd_xlat1=64.,
grd_xlon2=-85.,
grd_xlat2=75.,
mextendx=74,
mextendy=74,
Glb_pil_n=7,
Glb_pil_s=7,
Glb_pil_e=7,
Glb_pil_o=7,

&NAMCVA
…
lcva_hemis = .false.,
lcva_helm = .true.,
lcva_euclid =.false.,
lsw= .false.,
lsimulcor=.false.,
l1obs= .false.,
cptot= 'SP',
mbal_order = 0,
…

Spectral manipulations

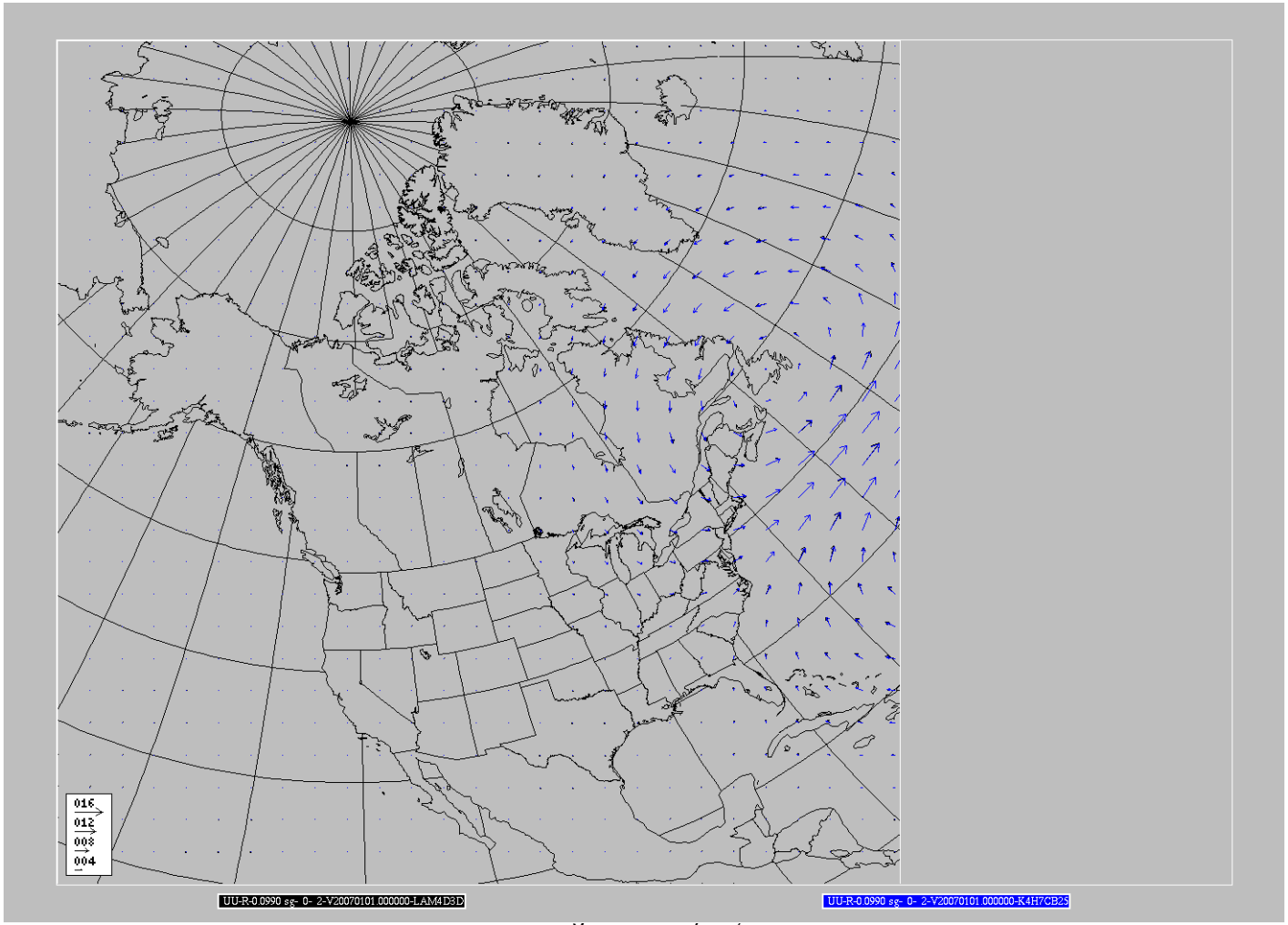
grd_typ = 'GU'

```
do jn = 0, ntrunc
  ila = nind(jm) + jn – jm
  do jk = 1, nksdim
     sp(ila,1,jk) = …
     sp(ila,2,jk) = …
  enddo
enddo
```

grd_typ = 'LU'

```
do jband = 1, nband
  do jm = 1, mbandsp(jband)
    ila = mila(jm,jband)
    do jk = 1, nksdim
       sp(ila,1,jk) = …
       sp(ila,2,jk) = …
    enddo
  enddo
enddo
```

58 Lev; GU versus LU:
1obs_UU = 1.0 ms-1 at 10 hPa (Level 12),
lsimulcor, cptot = 'GD', lsdevsim
Validation + Extension test



The Standard NMC approach for control variables: Initial implementation in REG-LAM3D/4D.

$$\Delta \mathbf{x} \equiv \overbrace{(\Delta\psi, \Delta\chi_b, \Delta T_b, 0, \Delta p_{s_b})^T}^{Balanced} + \overbrace{(0, \Delta\chi_u, \Delta T_u, \Delta q, \Delta p_{s_u})^T}^{Unbalanced}$$

- Construction of P_b from ψ using Local Balance Equation:

$$\nabla^2 \Delta P_b = -\nabla \cdot (f\, k \times \Delta v_\psi)$$

- Spectral form of Regression matrix to derive T_b and p_{sb}:

$$\left[\Delta \tilde{T}_b, \Delta \tilde{p}_{sb}\right] = \tilde{V}\, \Delta \tilde{P}_b$$

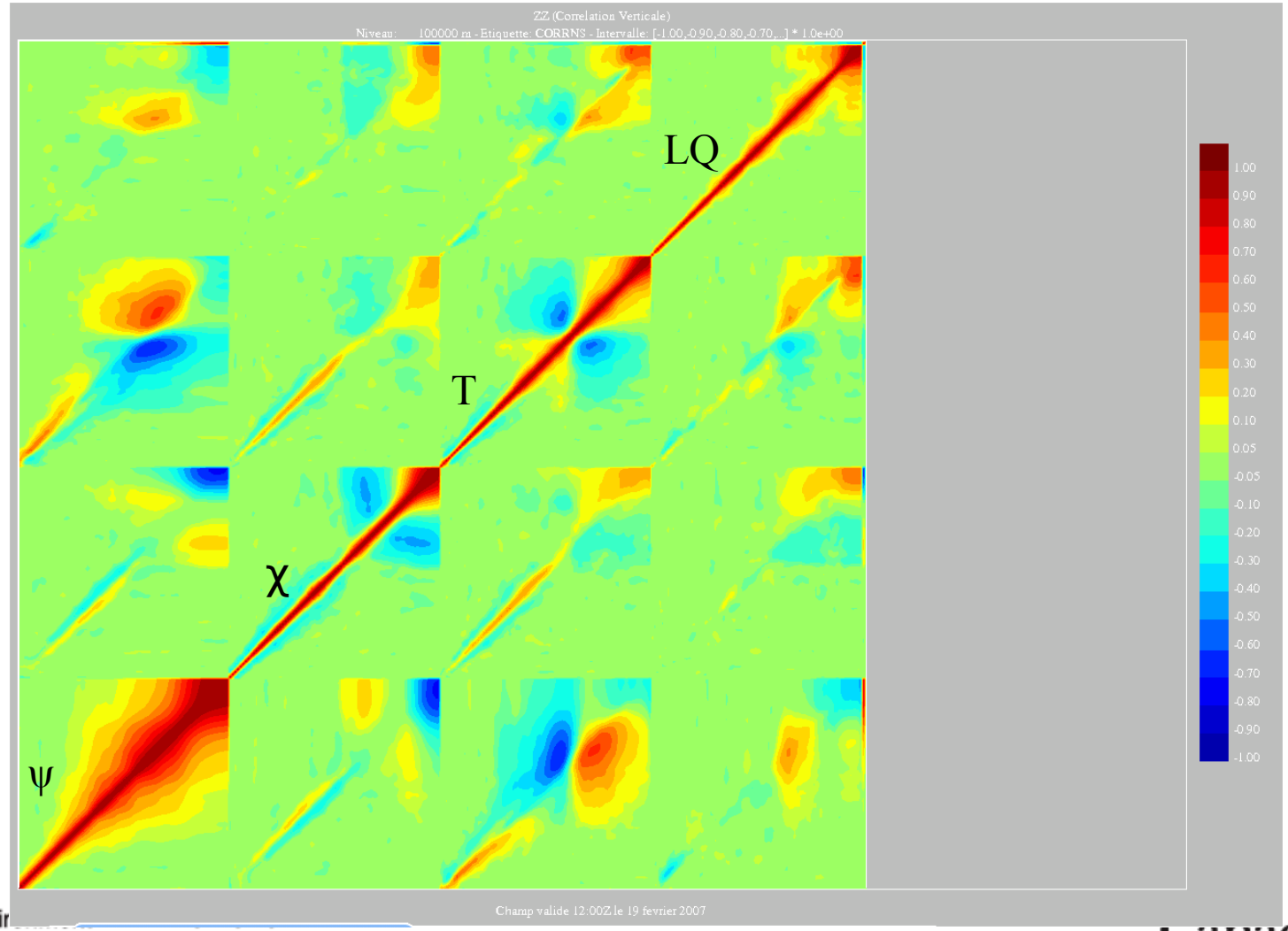
Feb. 2009: New formulation (Transfer to CMC)
Unified "balance-free" control variables:
mbal_order = 0 for REG-VAR & Kilometric Analyses

$$\mathbf{\Delta x} \equiv (\Delta\psi, \mathbf{\Delta}\chi, \mathbf{\Delta}T, \mathbf{\Delta}\ln q, \mathbf{\Delta}p_s)^T$$

Off-diagonal blocs are kept to represent mass-wind coupling and vort-div Eckman couping for each total horizontal wavenumbers.

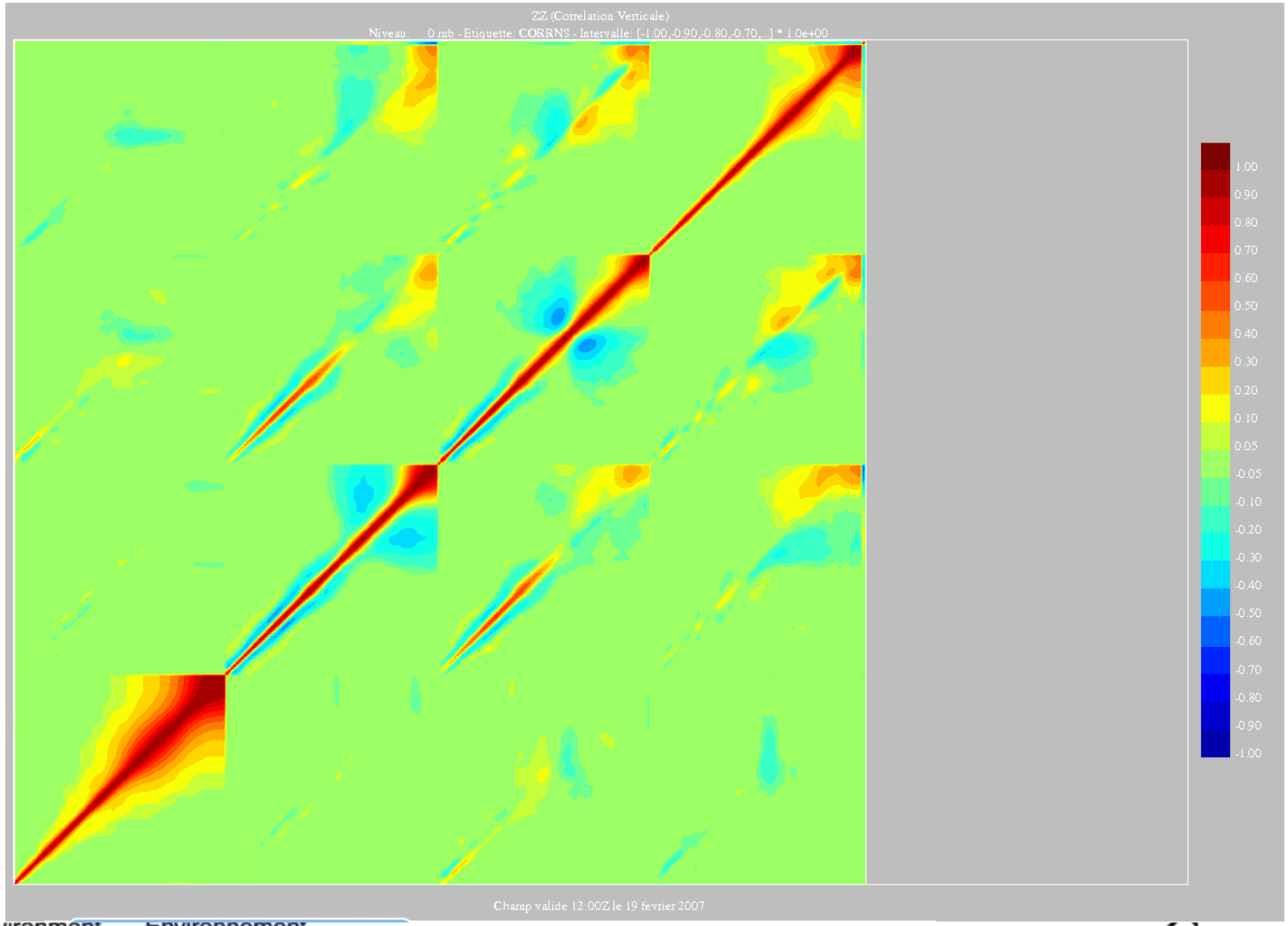
REG-LAM3D-55 km: DFT-2D-100: 250x250; NMC-24-48: Winter 2007-Oper.Strato-Jun-09

k = 5



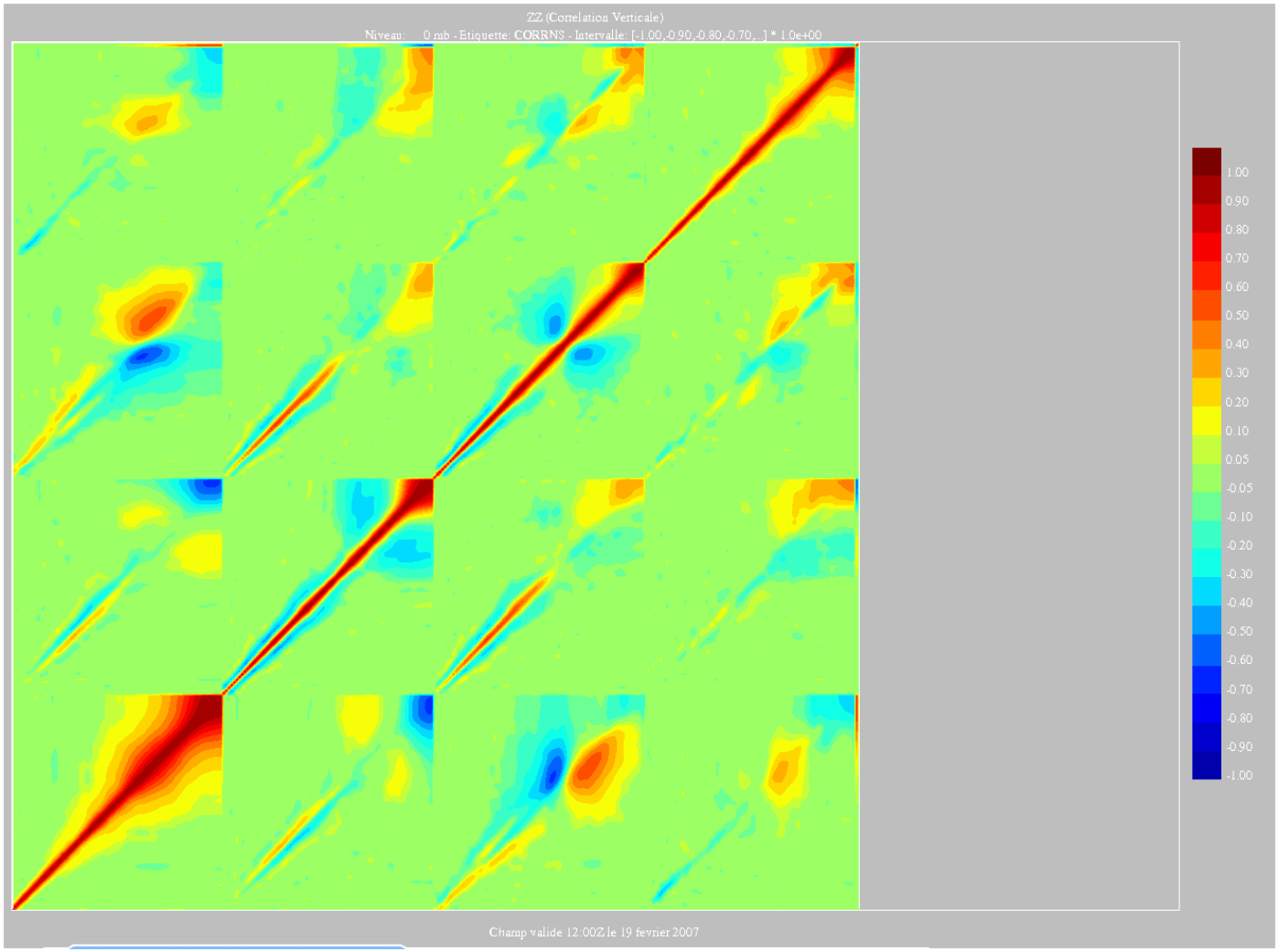
Global statistics:
Global-50 km: T-300: 720x360;
NMC-24-48: Winter 2007-Oper.Strato-Jun-09

n = 20



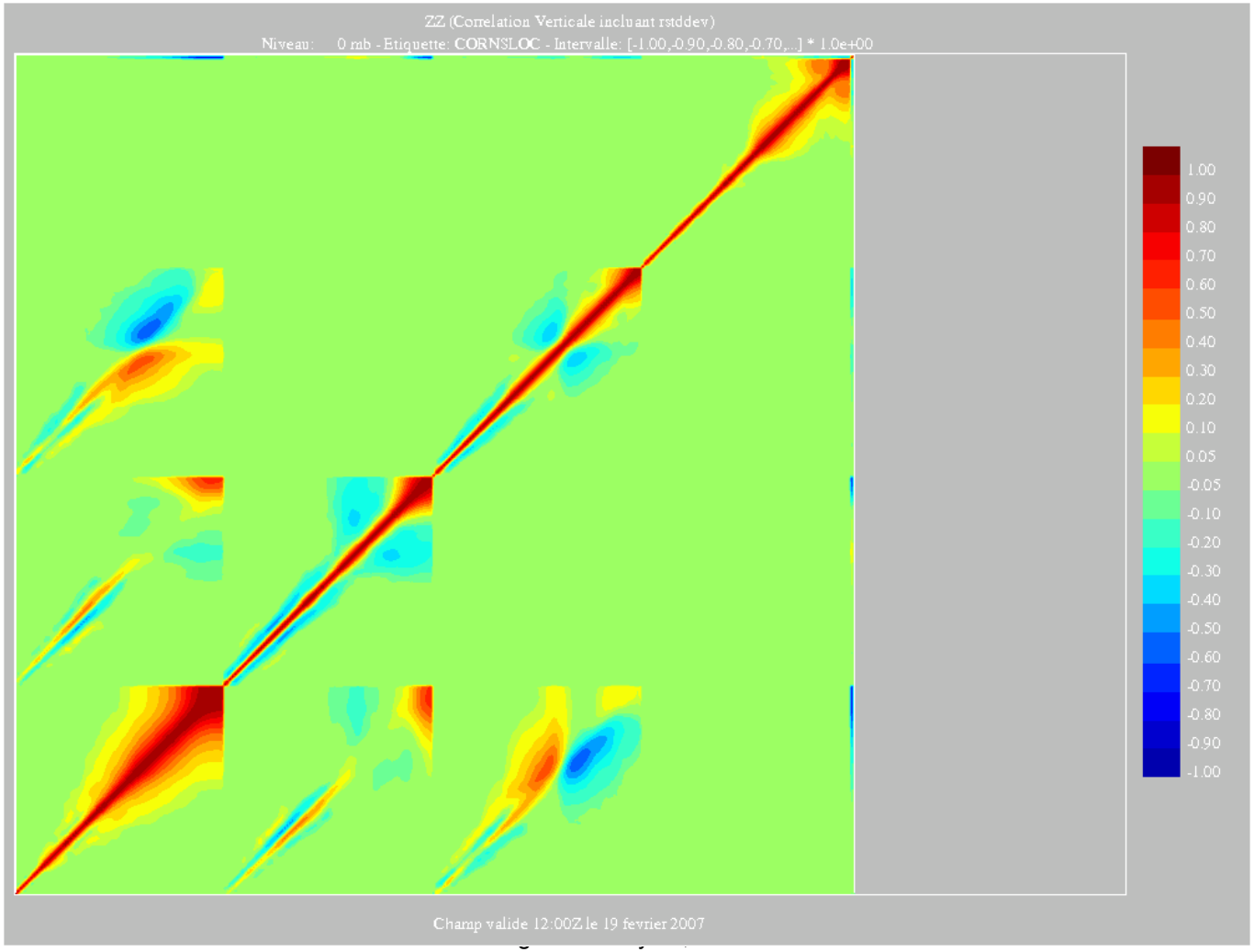
Northern-Hemisphere:
k = 20; Spectral-Hemispheric-50 km: T-300: 720x360;
NMC-24-48: Winter 2007-Oper.Strato-Jun-09

n = 20



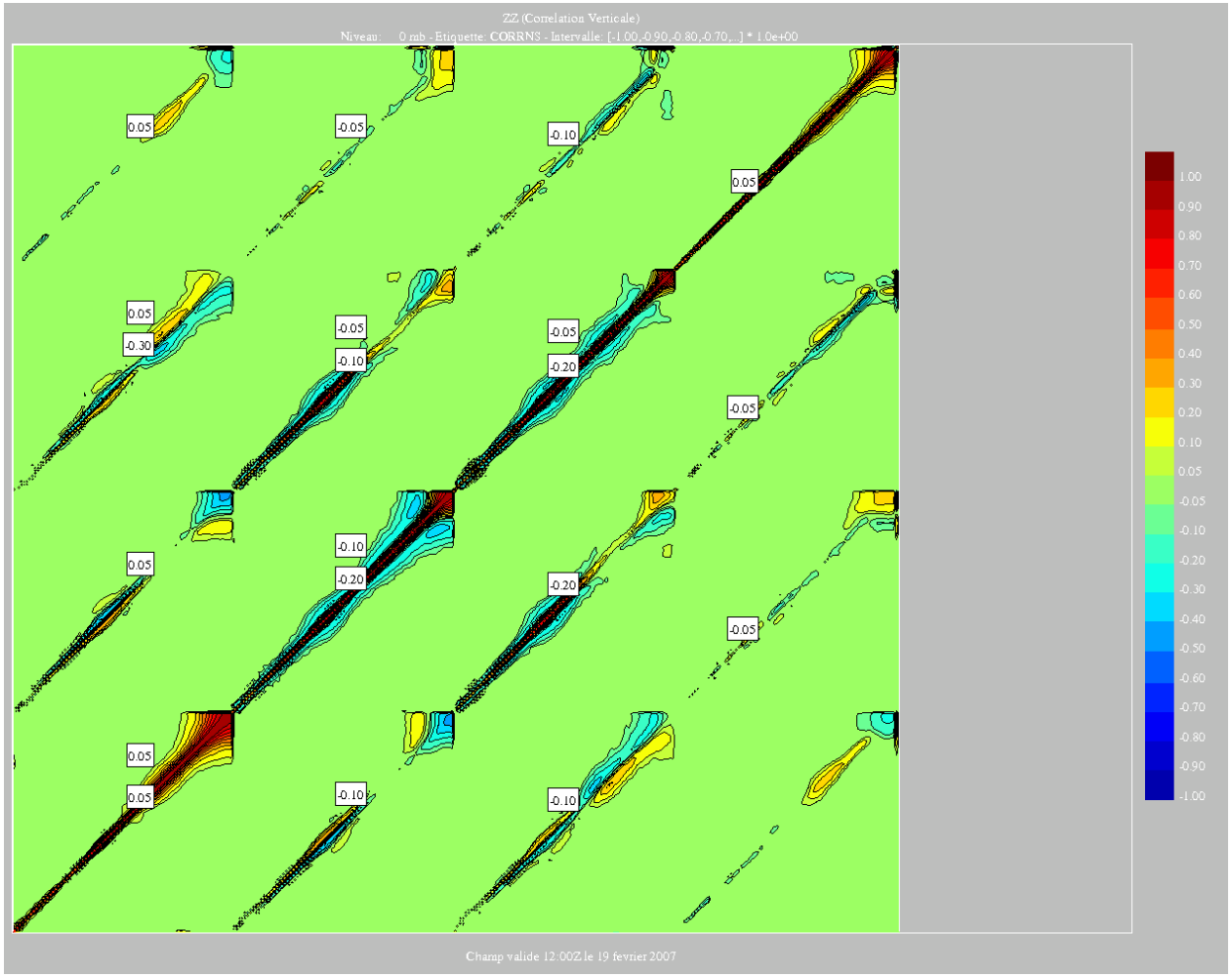
Southern-Hemisphere:
Spectral-Hemispheric-50 km: T-300: 720x360;
NMC-24-48: Winter 2007-Oper.Strato-Jun-09

n = 20



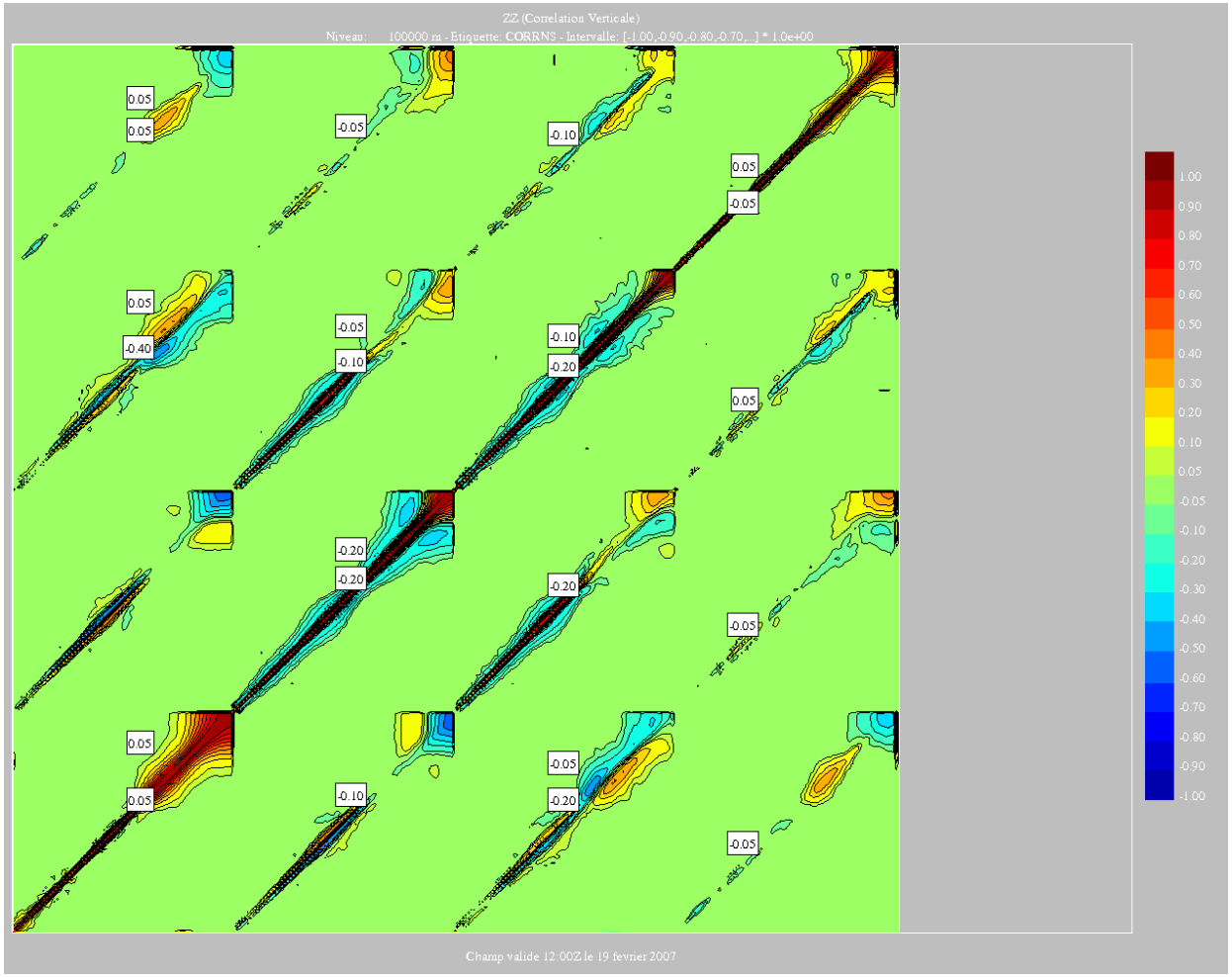
Spectral-Hemispheric-50 km:
T-300: 720x360;
NMC-24-48: Winter 2007-Oper.Strato-Jun-09

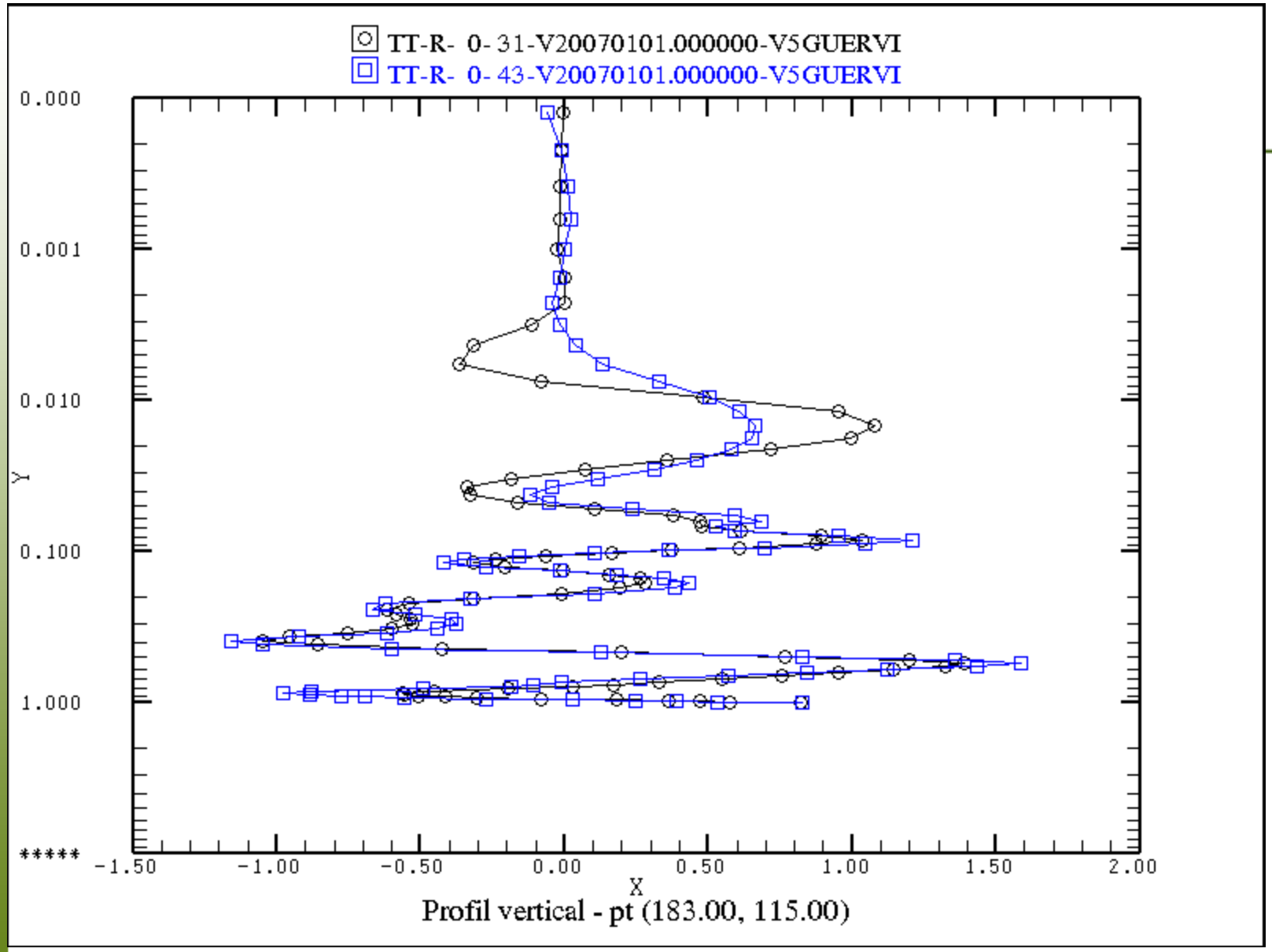
n = 100

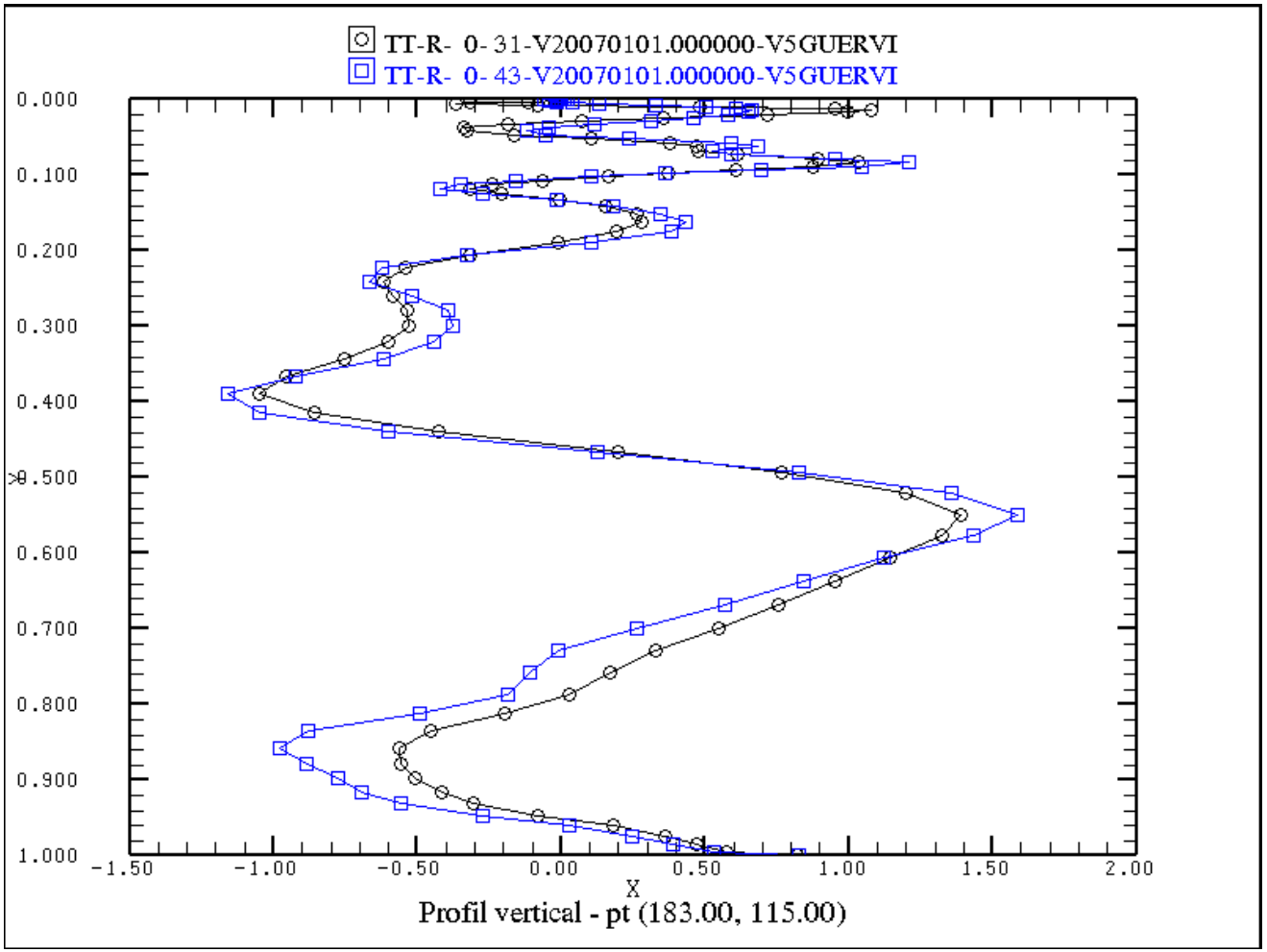


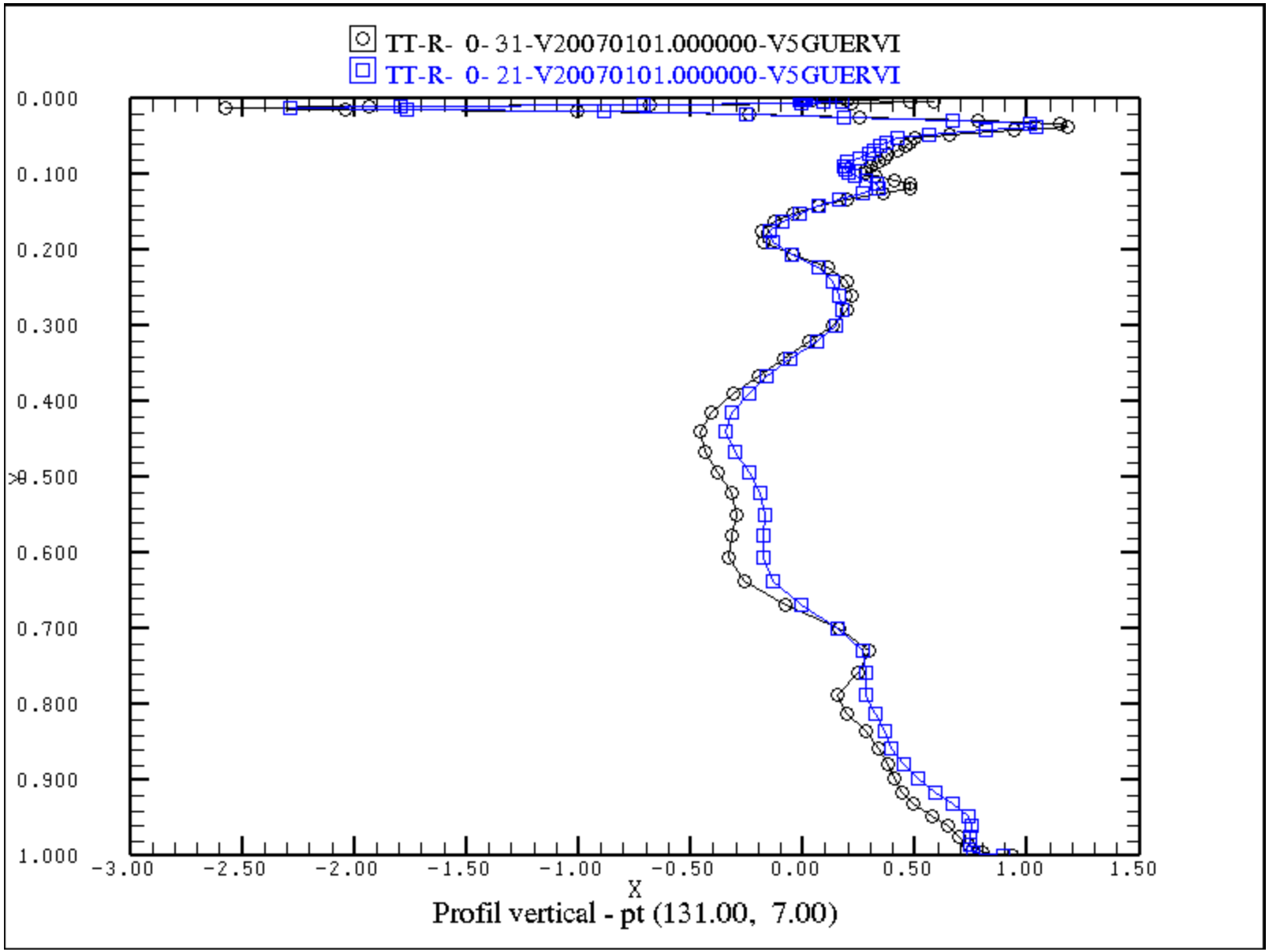
REG-LAM3D-55 km
DFT-2D-100: 250x250;
NMC-24-48: Winter 2007-Oper.Strato-Jun-09

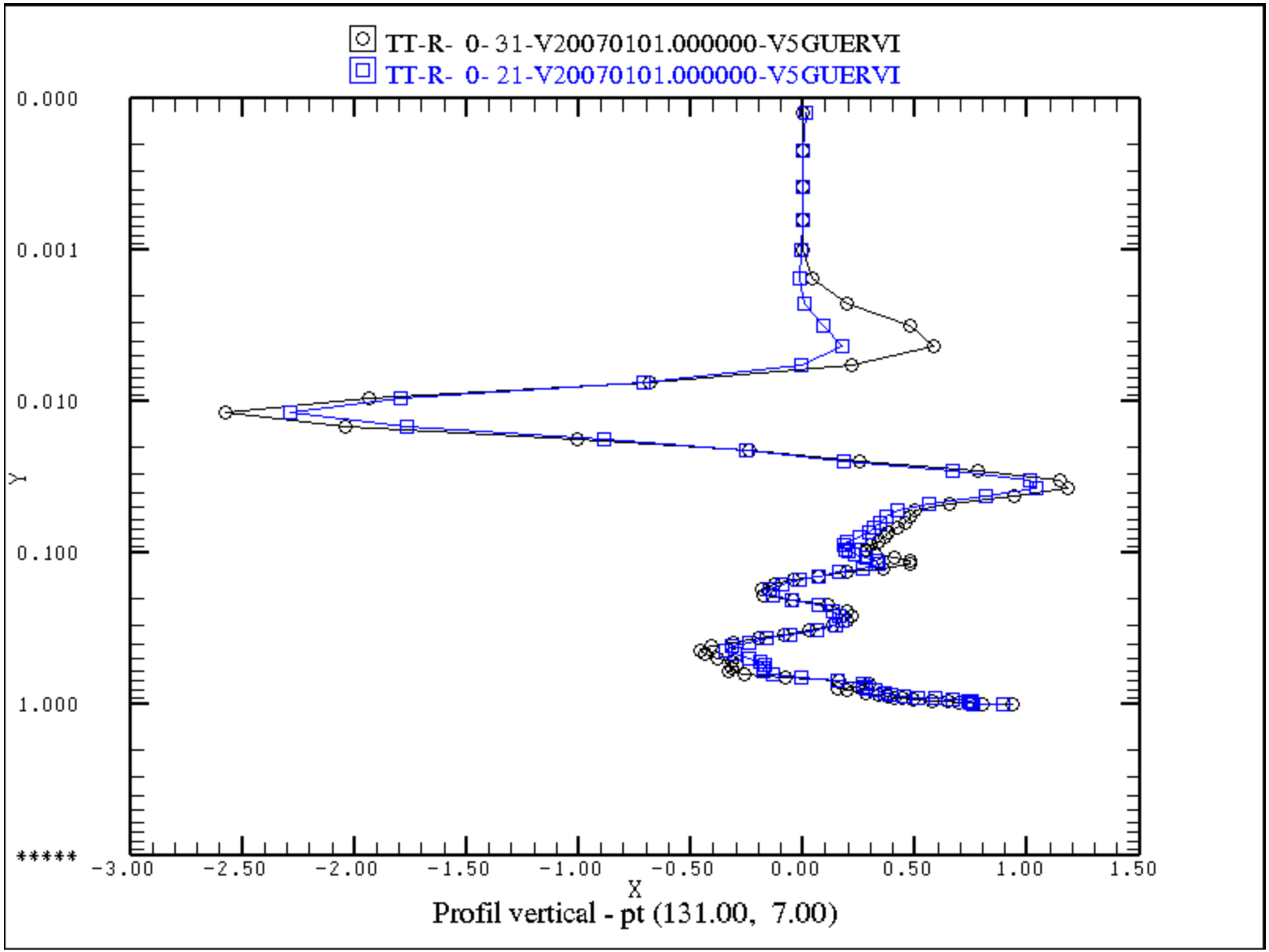
k = 25



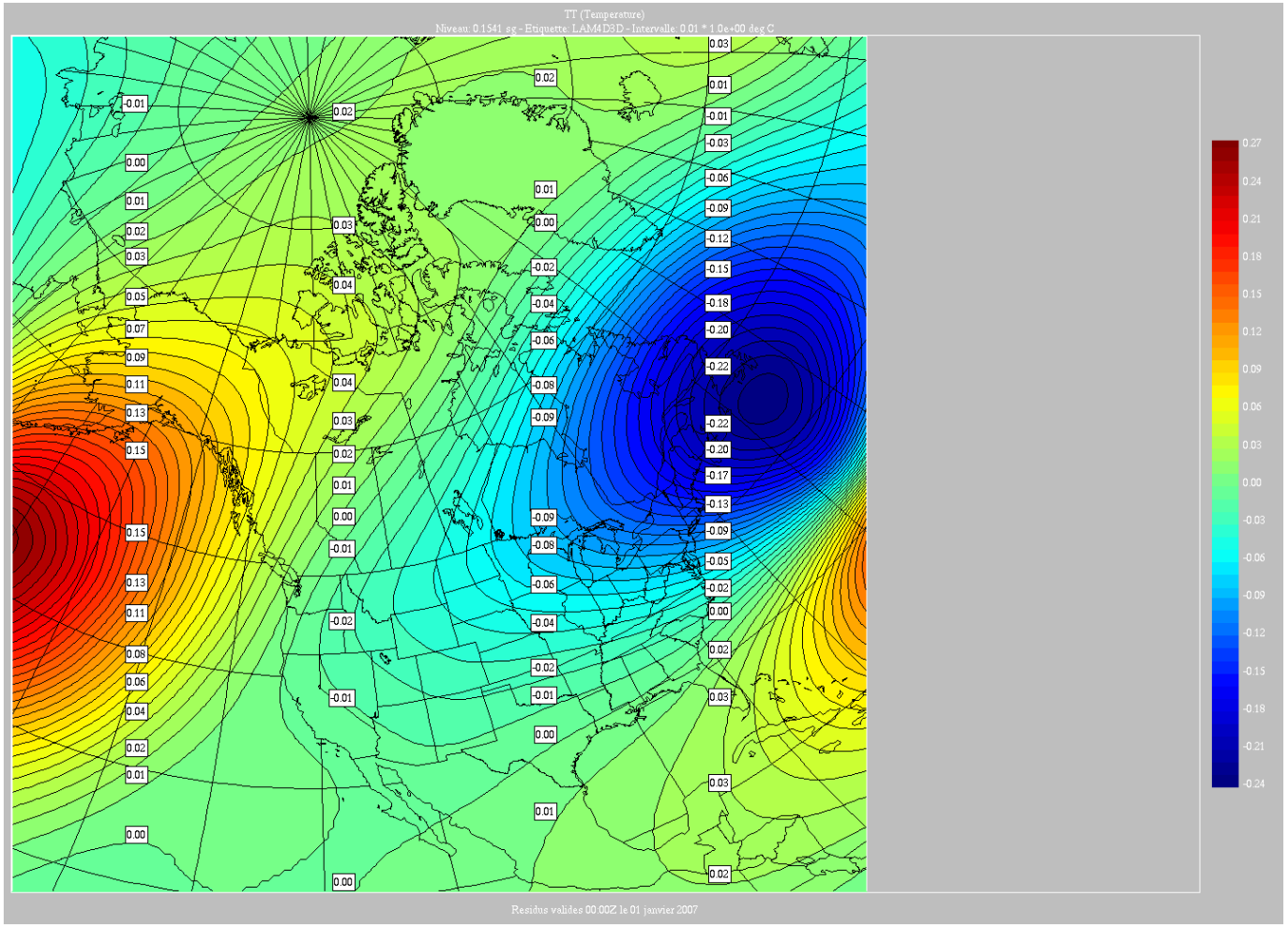

TT-R- 0-31-V20070101.000000-V5GUERVI
TT-R- 0-43-V20070101.000000-V5GUERVI
0.000
0.001
0.010
0.100
1.000
*****
Y
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
X
Profil vertical - pt (183.00, 115.00)


TT-R- 0-31-V20070101.000000-V5GUERVI
TT-R- 0-43-V20070101.000000-V5GUERVI
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
X
Profil vertical - pt (183.00, 115.00)

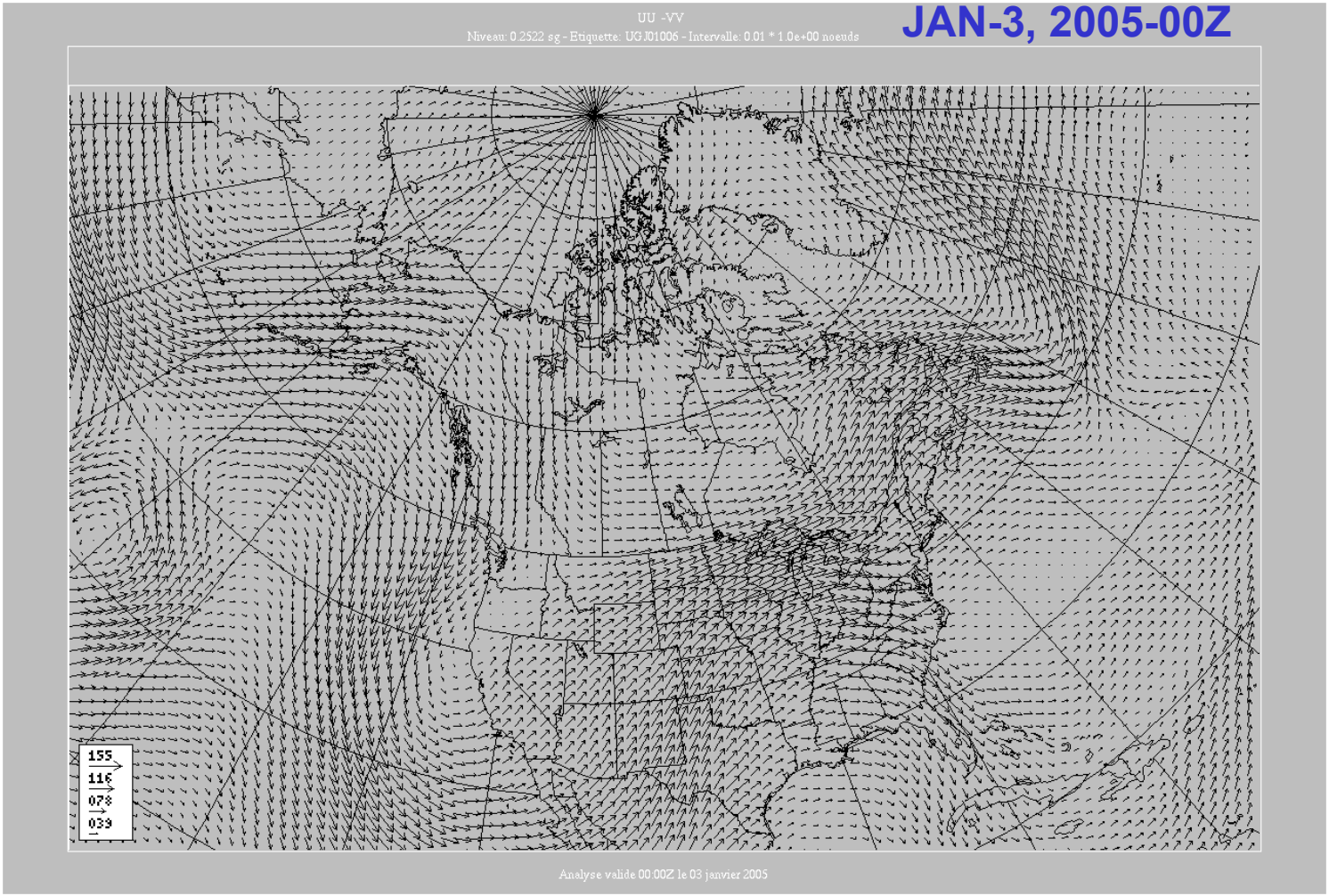

TT-R- 0- 31-V20070101.000000-V5GUERVI
TT-R- 0- 21-V20070101.000000-V5GUERVI
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
-3.00
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
X
Profil vertical - pt (131.00, 7.00)


TT-R- 0- 31-V20070101.000000-V5GUERVI
TT-R- 0- 21-V20070101.000000-V5GUERVI
0.000
0.001
0.010
0.100
1.000
*****
Y
-3.00
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
X
Profil vertical - pt (131.00, 7.00)

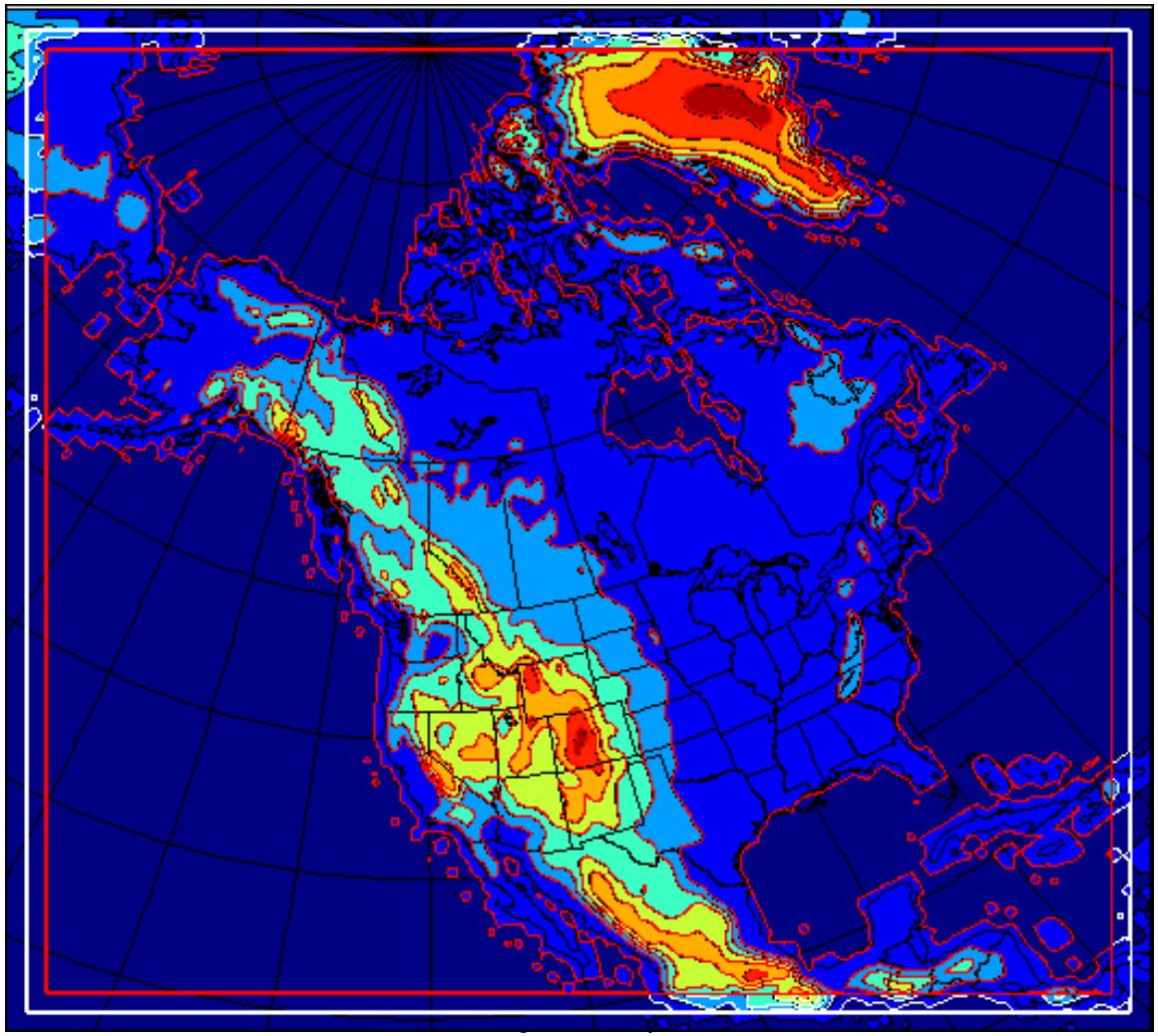
Insufficient 20 % extension of the core NLM grid for DFT-2D: Streamfunction correlation scale at 100 hPa = 2000 km ! ➔ 40 % required. For kilometric-Lam, use correlation-scale criteria also….



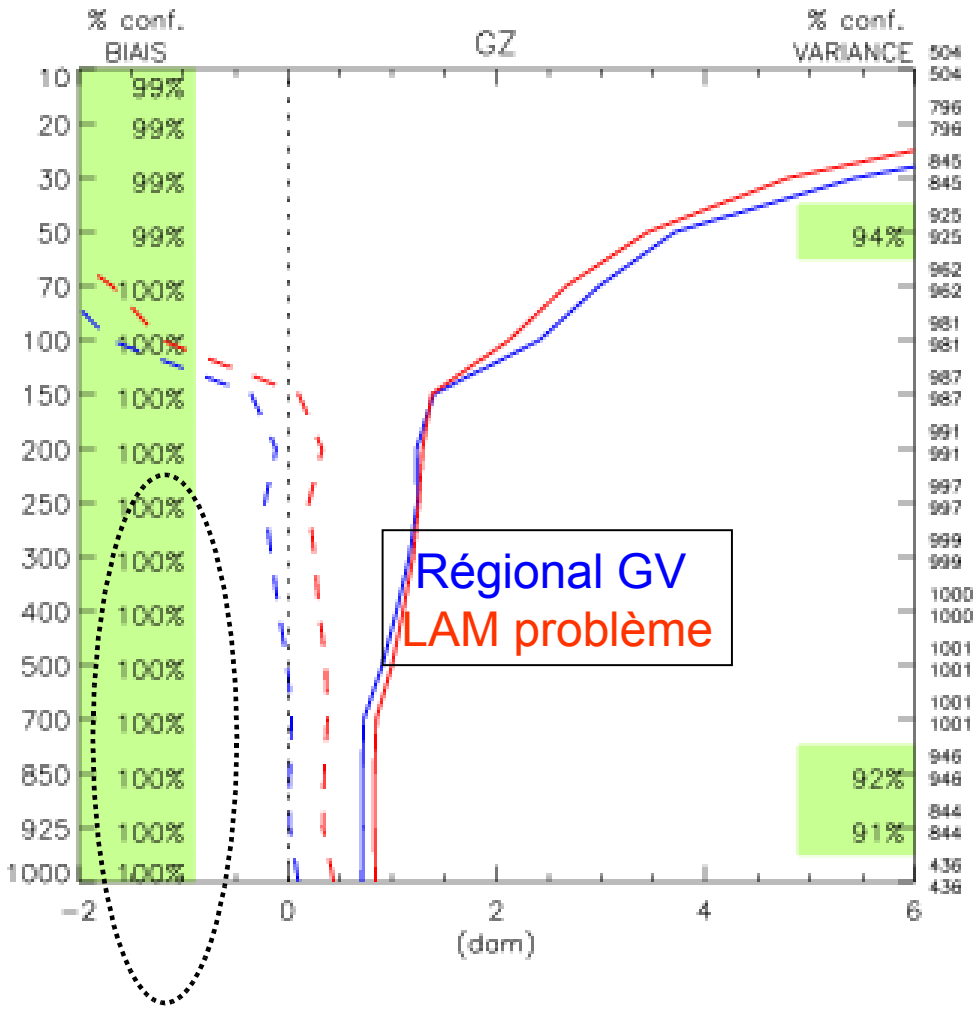
Original REG-LAM grid
Winter jet pushing far south to the wall
➔ Push southern boundary further South.



Problème du biais du géopotentiel du LAM nord-américain : Impact du positionnement de la zone de blending



Prévision de 12 heures: moyenne 13 cas
Région: Amérique du nord



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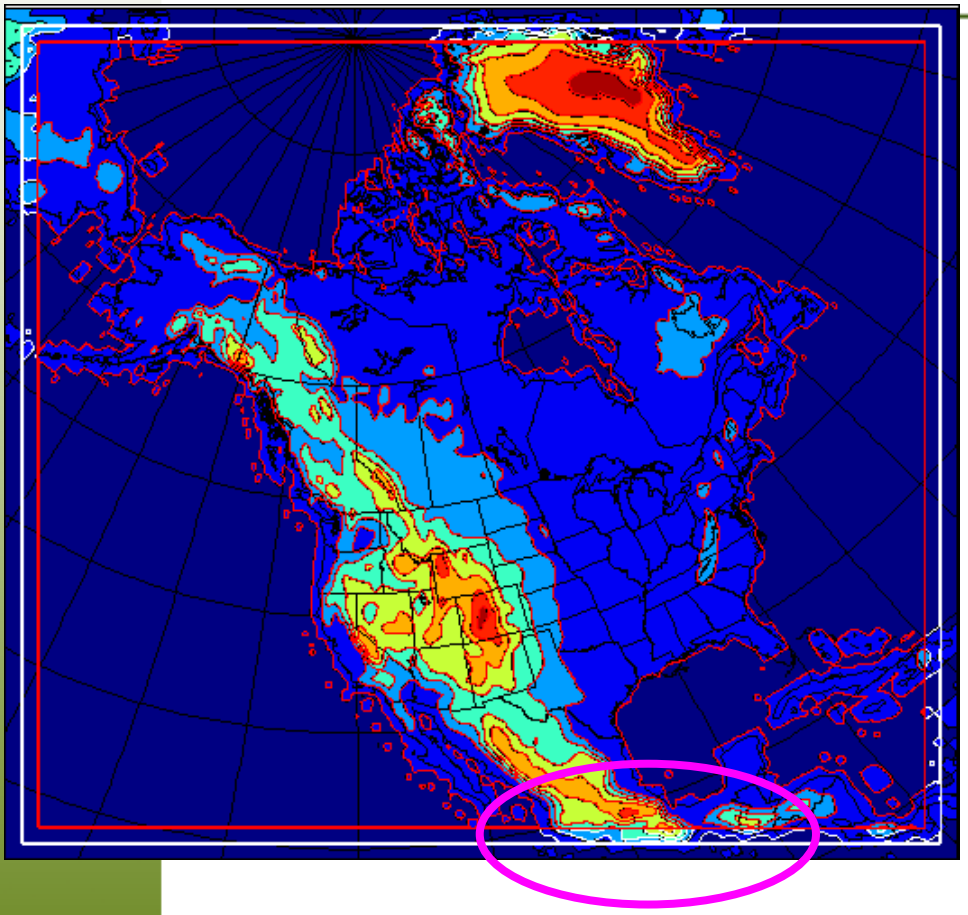
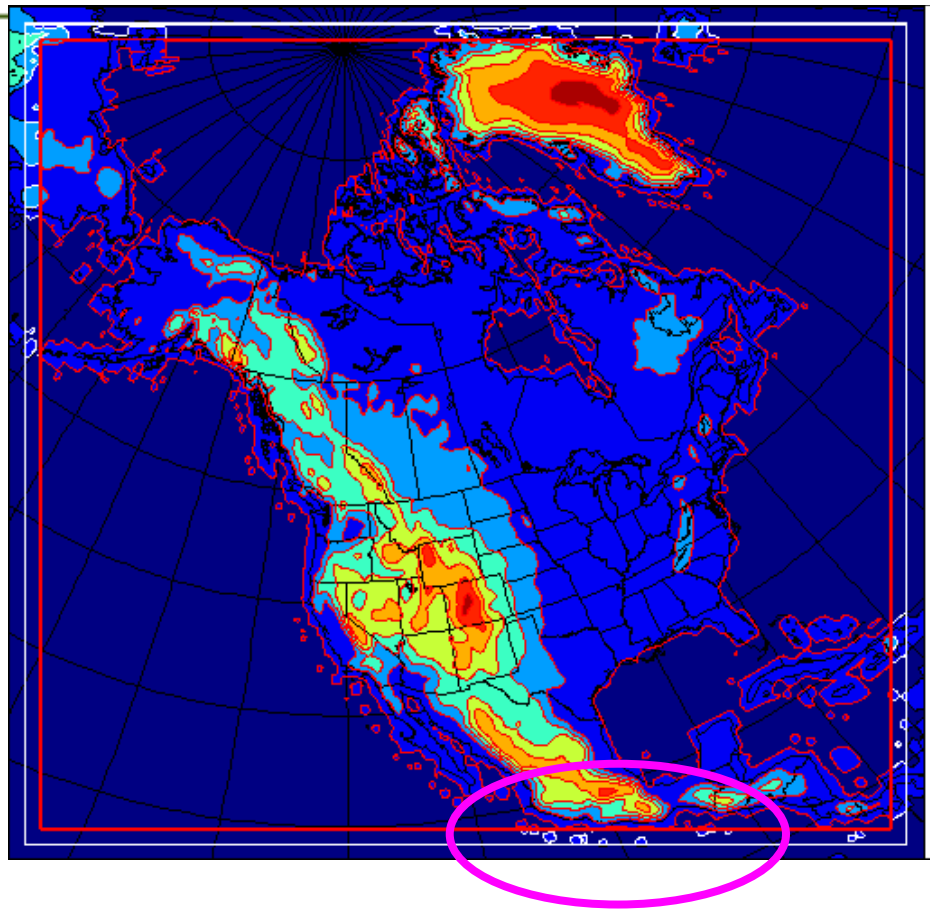
La correction a été d'éloigner la frontière sud de la chaine de montagne Sierra Madre del Sur

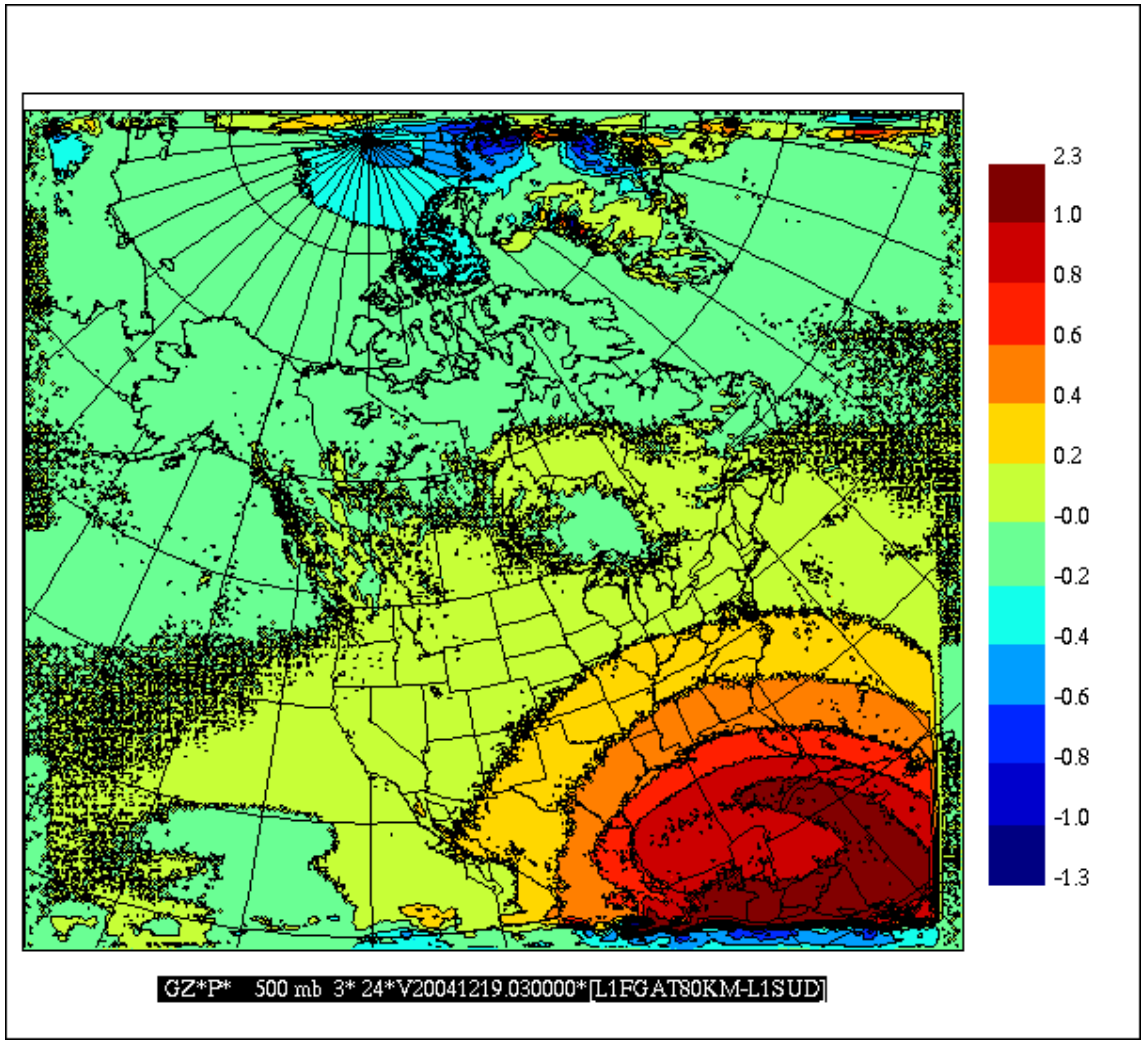


Ancien domaine

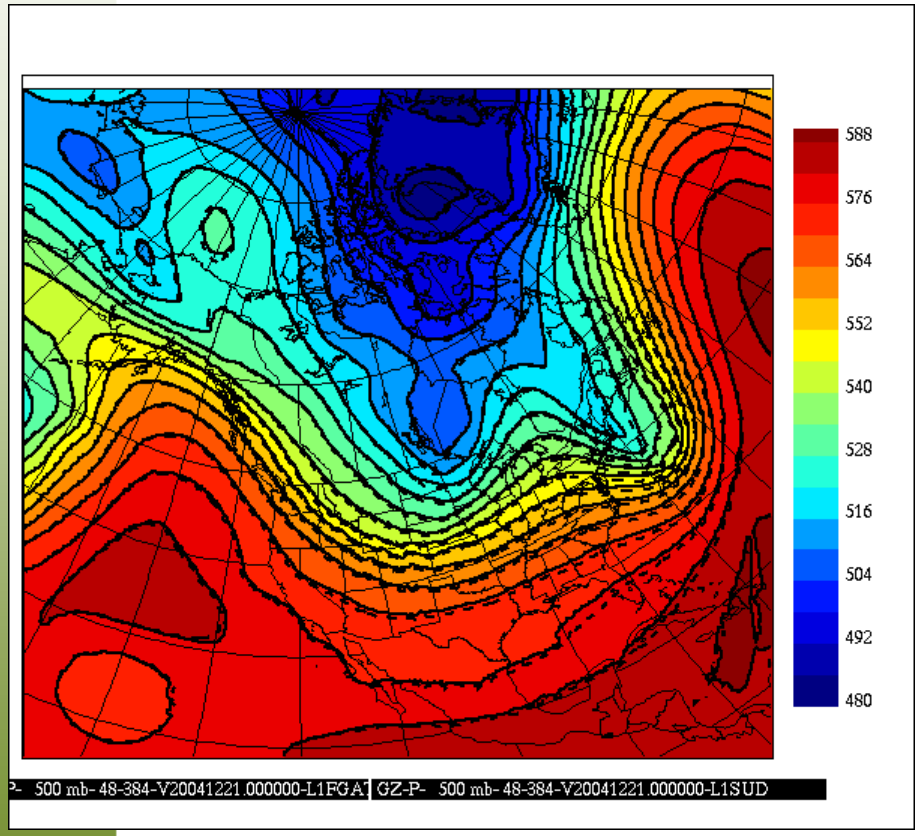


Nouveau domaine

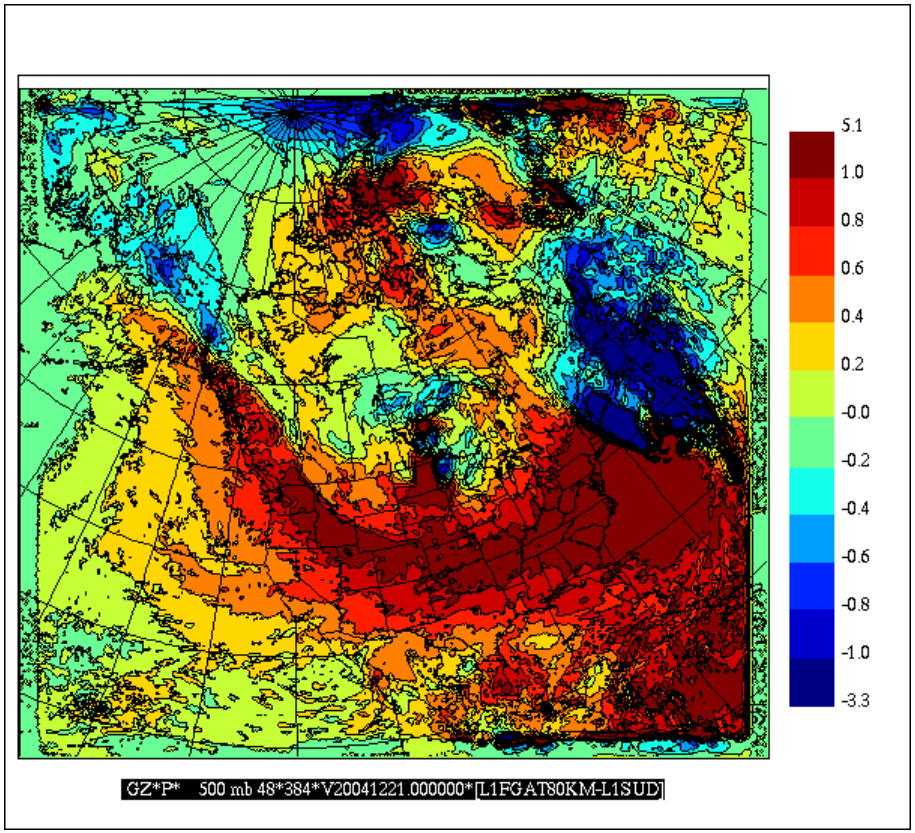
Cas typique: 19 décembre prévision de 3 heures
Différence GZ 500 mb (dam)



Cas typique: 19 décembre prévision de 48 heures



GZ 500 mb (dam)



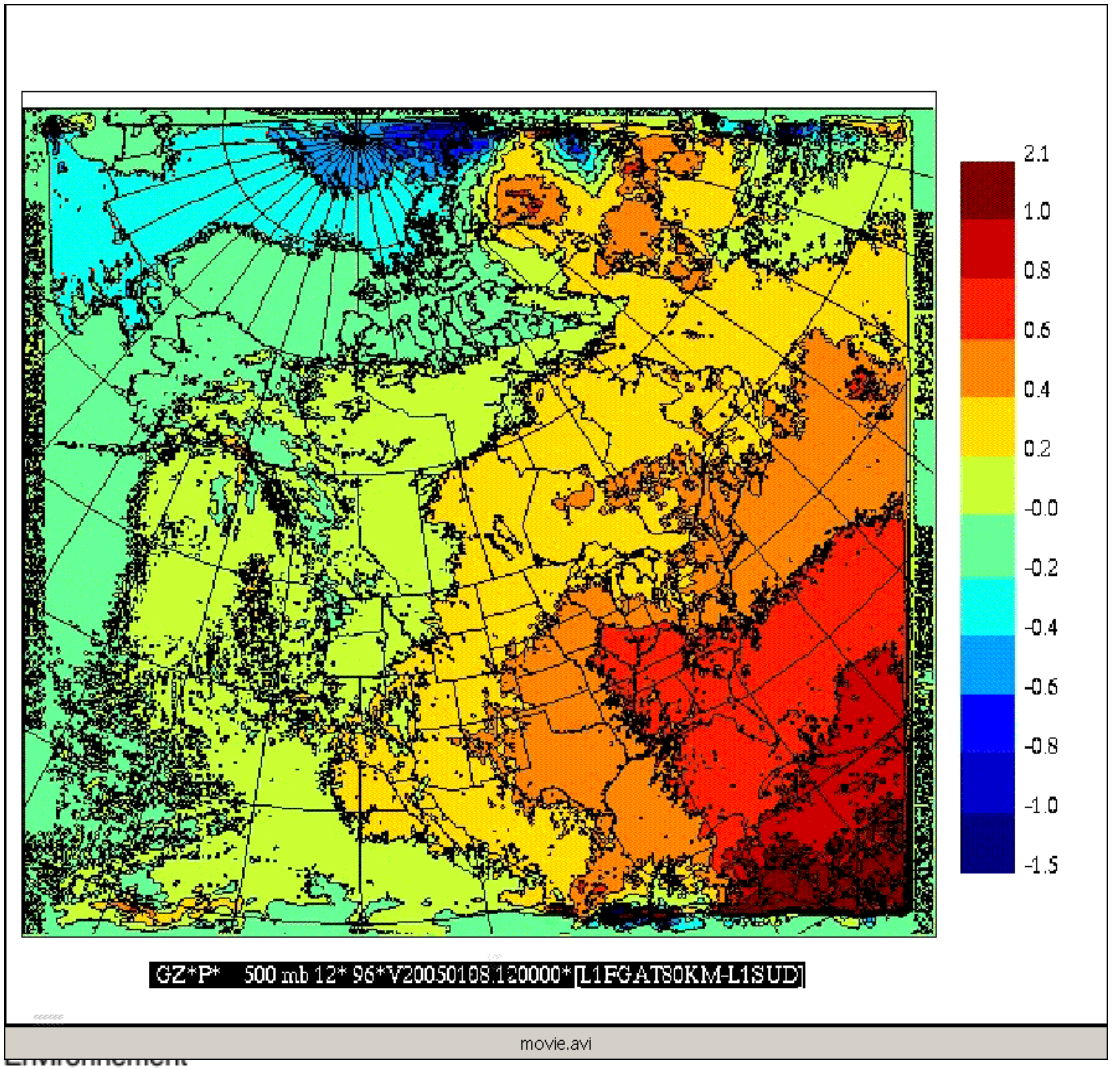
Différence GZ 500 mb (dam)

Expérience originale: trait continu

Expérience avec frontière plus au sud: trait discontinu

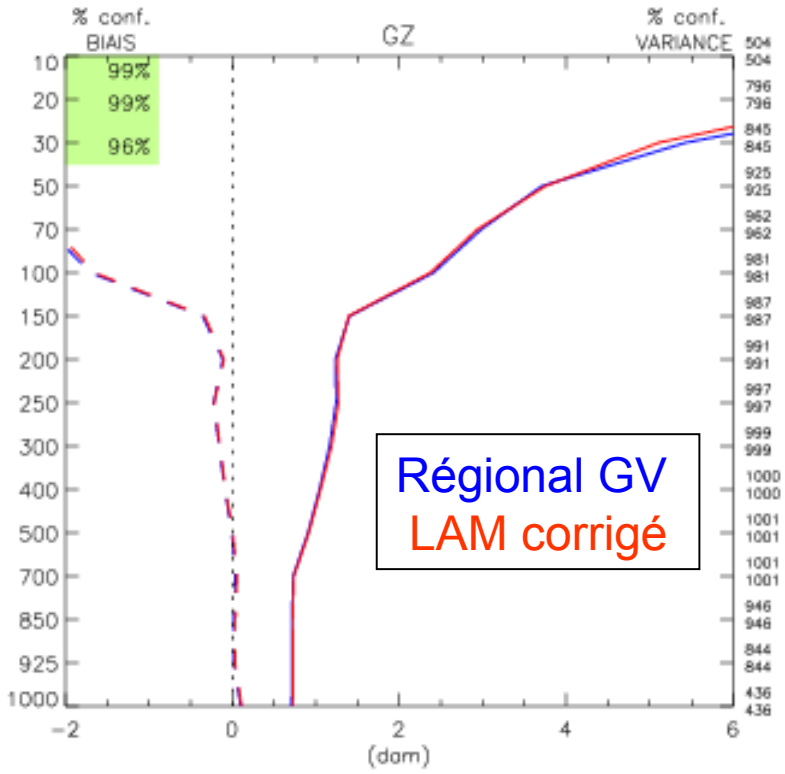
Différences GZ 500 (dam) prévisions 12h

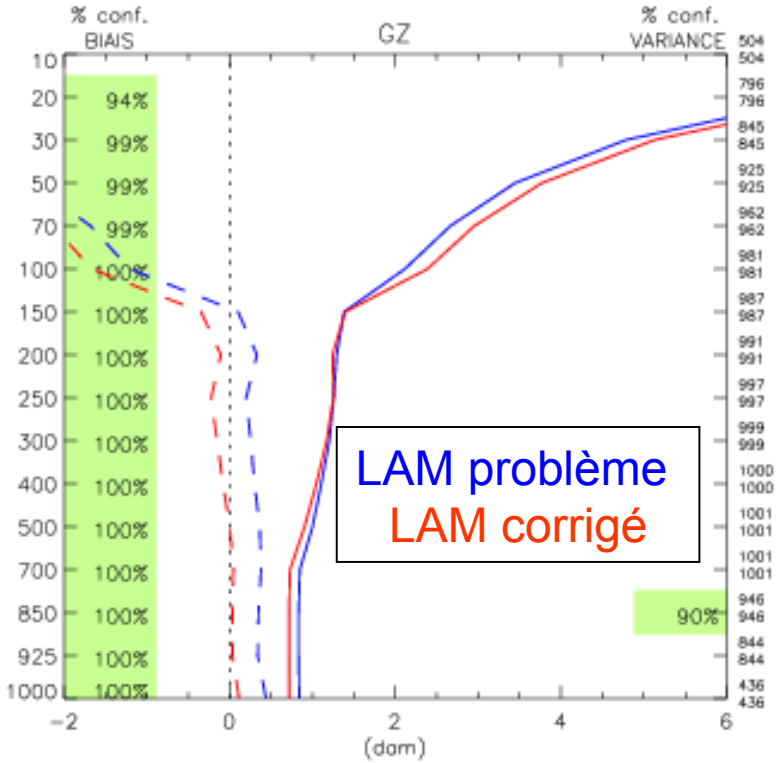
Animation de 13 cas d'hiver montrés séparément



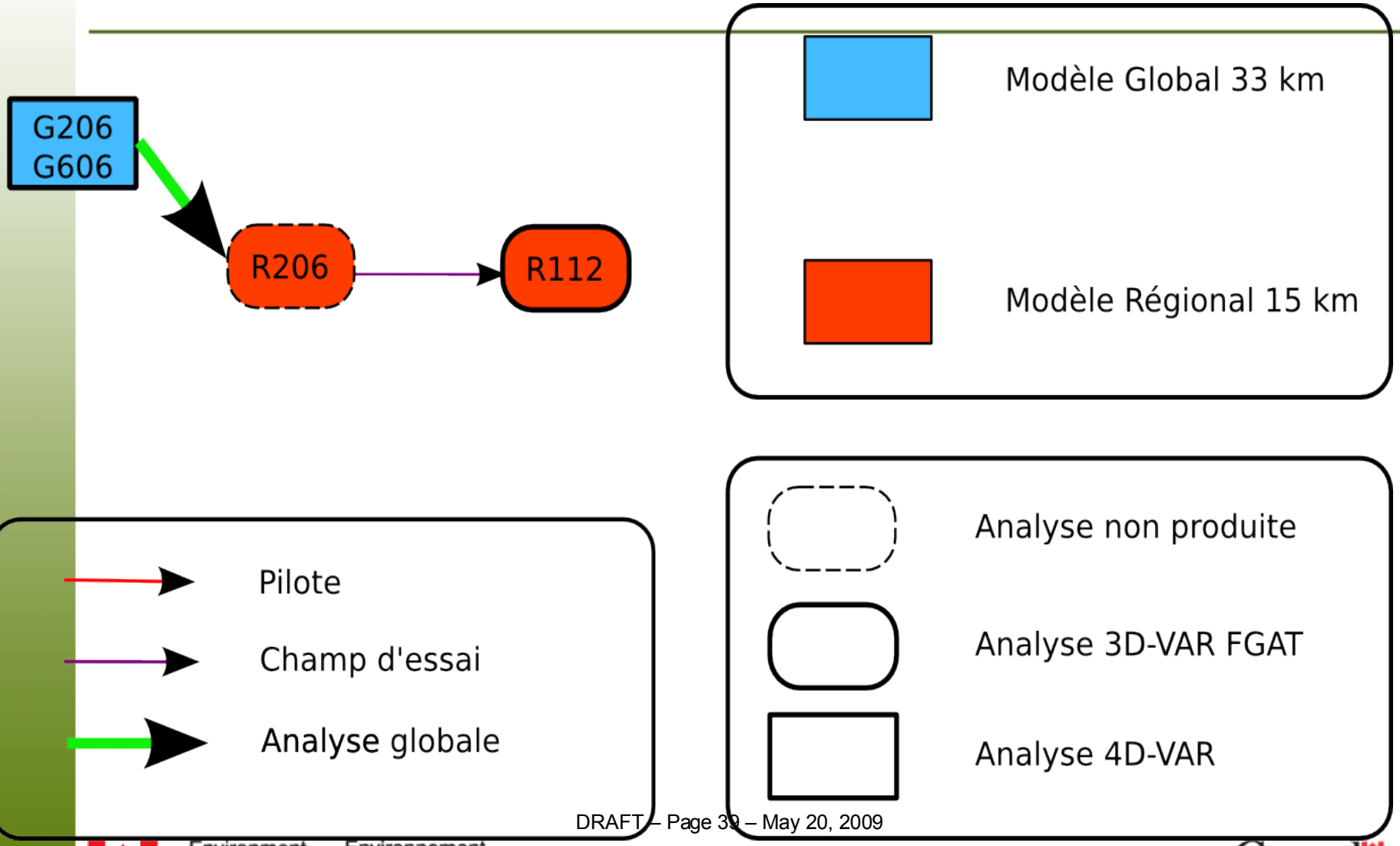
Correction du problème de biais du géopotentiel du LAM: effet sur le biais du GZ lorsque l'on éloigne la frontière sud de la chaine des montagnes Sierra Madre

Prévision de 12 heures: moyenne 13 cas
Région: Amérique du nord

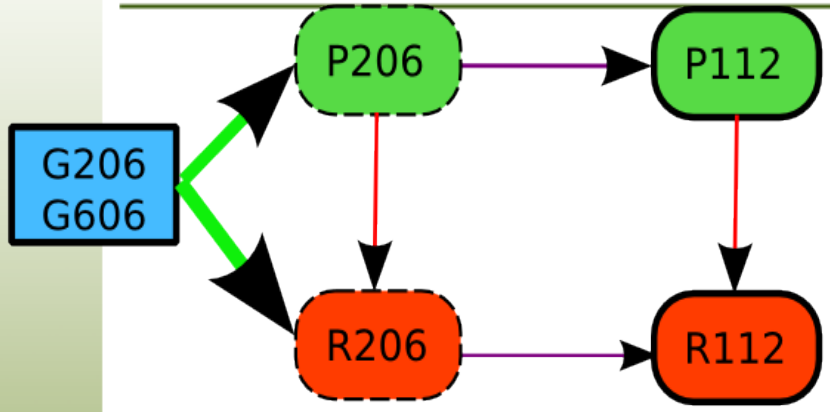


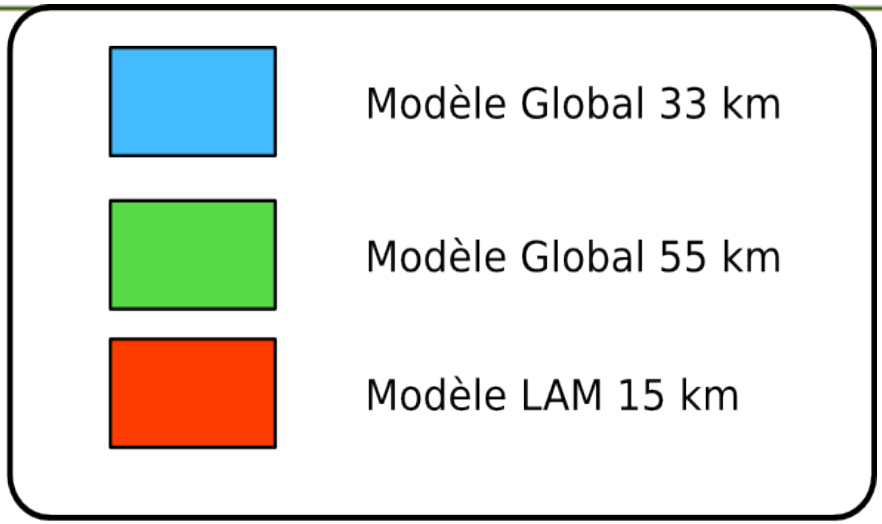


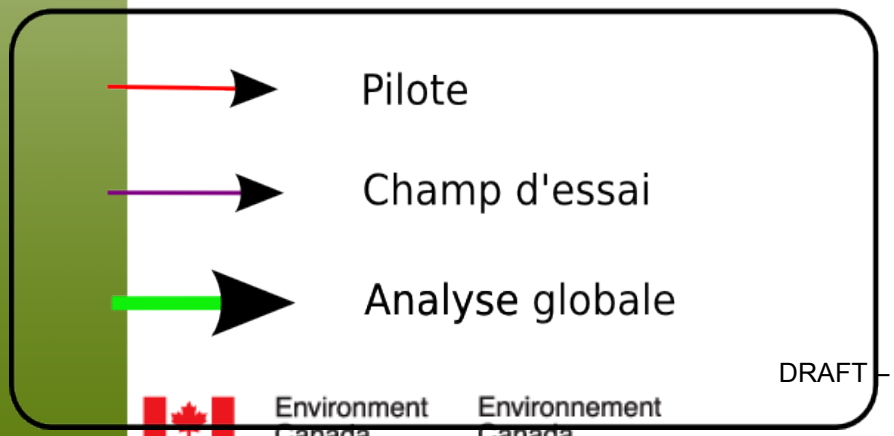
Spin-up Régional

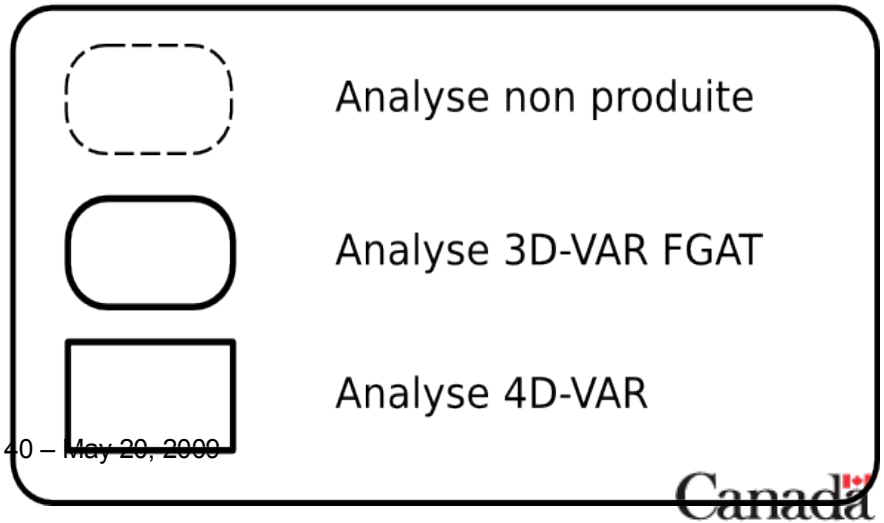


Spin-up REG-LAM3D

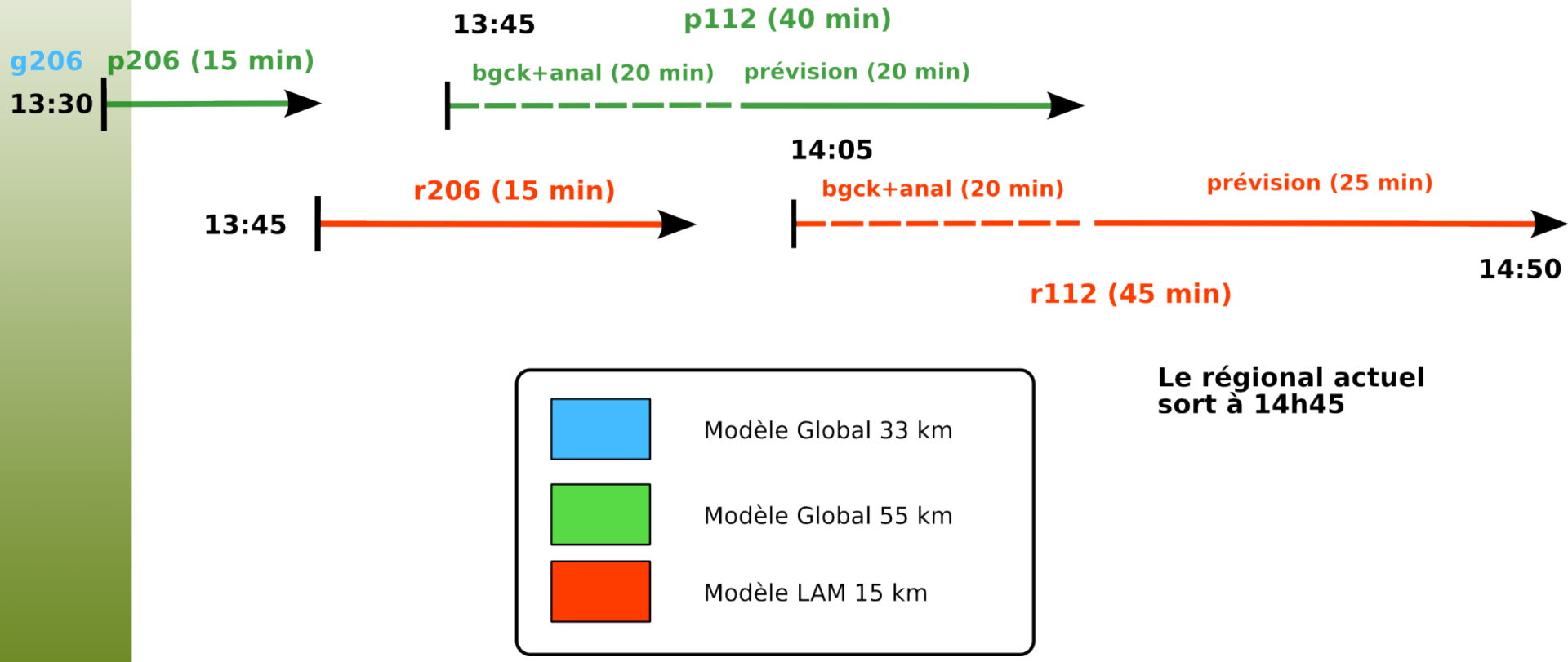






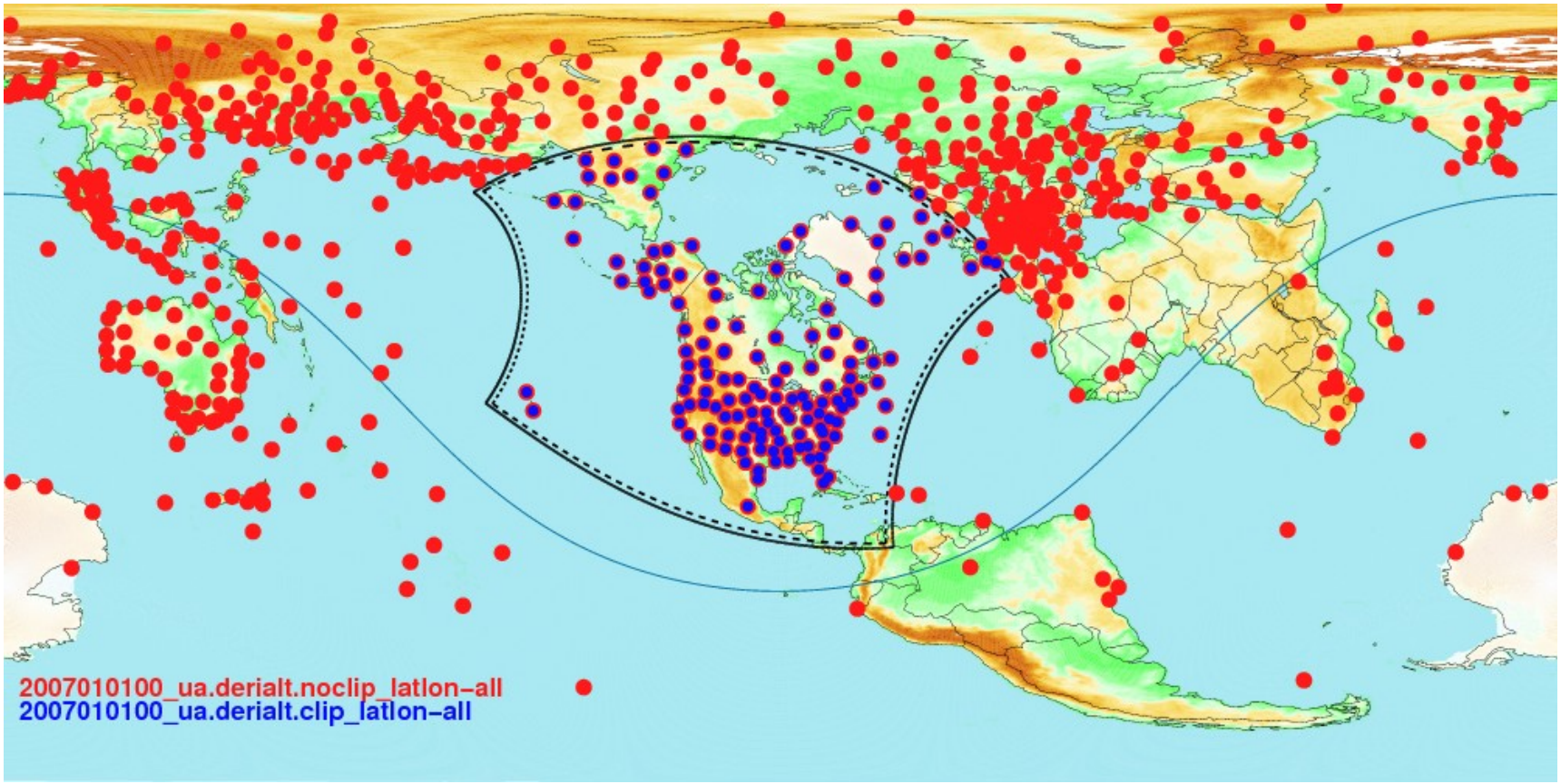


Timings+


13:45
p112 (40 min)
g206
p206 (15 min)
bgck+anal (20 min)
prévision (20 min)
13:30
14:05
r206 (15 min)
bgck+anal (20 min)
prévision (25 min)
13:45
14:50
r112 (45 min)
Modèle Global 33 km
Modèle Global 55 km
Modèle LAM 15 km
Le régional actuel sort à 14h45

Clipping des observations

Combinaison de BURP2RDB et d'un programme C pour filtrer les observations hors du domaine REG-LAM3D



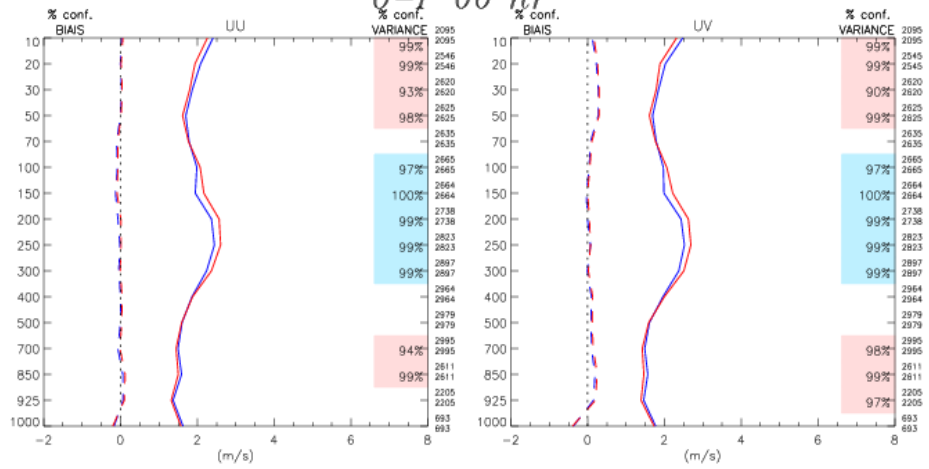
Évaluations

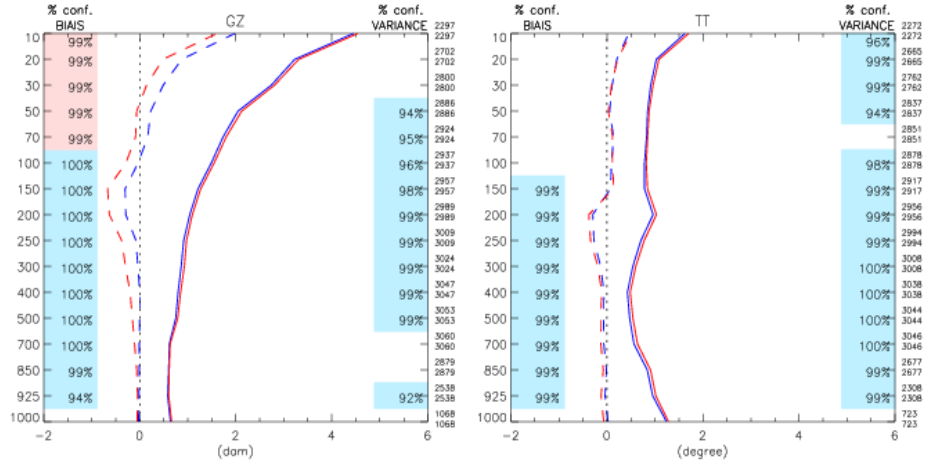
- 40 cas de l'hiver 2007 (1er janvier au 28 février 2007) à toutes les 36 hrs

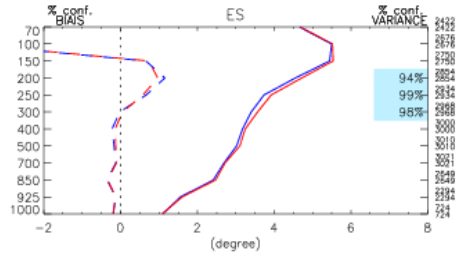
- Régional Strato (ZDA41)
- REG-LAM3D (lam3d_hiv_hemis_bgcklam)

  (ce système sera proposé au CPOP du 7 juillet)
- mêmes observations et même résolution de thinning (e.g. 250km pour les obs. satellitaires)
  - thinning 3D pour REG
  - thinning 4D pour REG-LAM3D

Q-P 00 hr



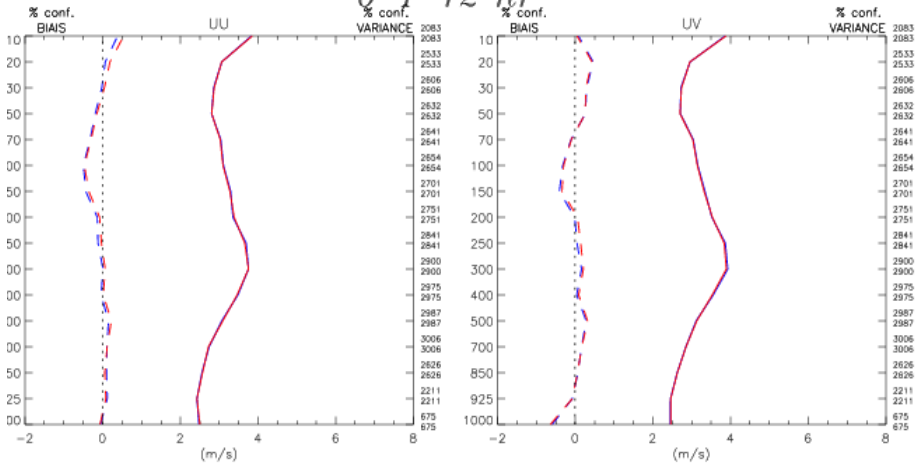


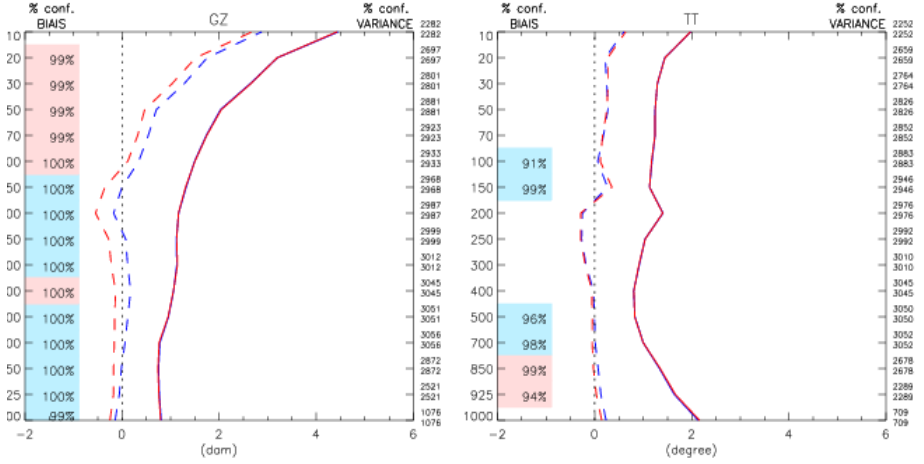


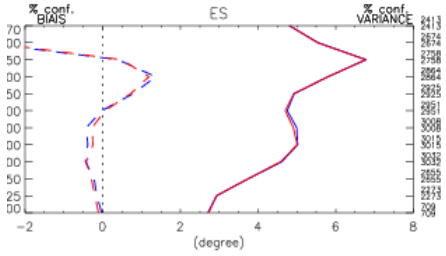
E-T m_ua_048_regzda41 (40)
BIAIS m_ua_048_regzda41
E-T m_ua_048_lamlam3d_hiv_hemis_bgcklam (40)
BIAIS m_ua_048_lamlam3d_hiv_hemis_bgcklam

Type : 0-P 00 hr
Region : Amerique du Nord LAM
Lat-lon: (30N, 150W) (73N, 50W)
Stat. communes

Q-P 12 hr



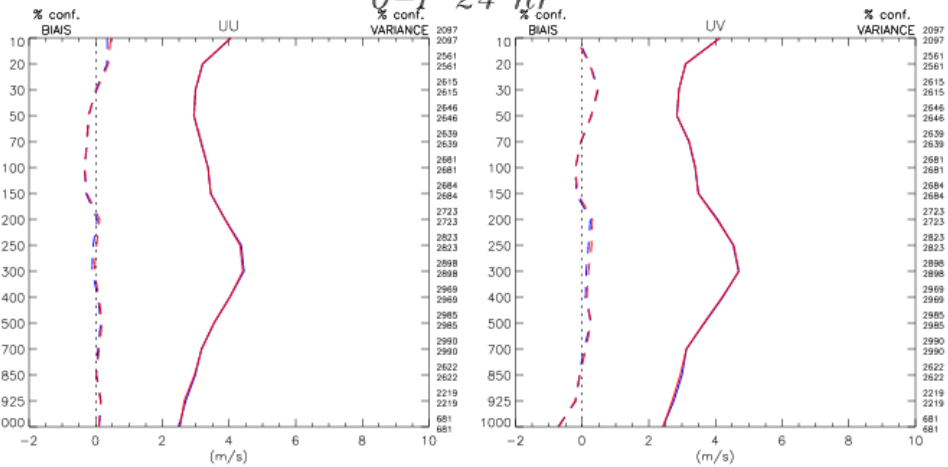


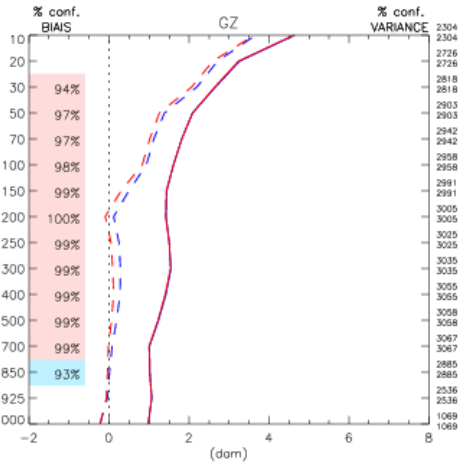


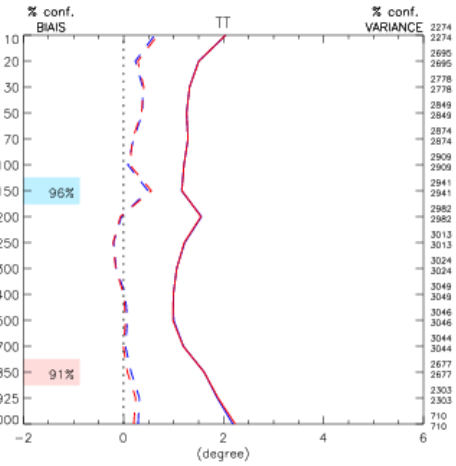
E-T m_ua_048_regzda41 (40)
BIAIS m_ua_048_regzda41
E-T m_ua_048_lamlam3d_hiv_hemis_bgcklam (40)
BIAIS m_ua_048_lamlam3d_hiv_hemis_bgcklam

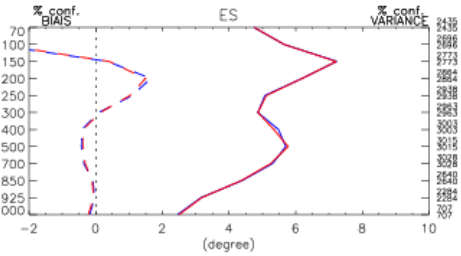
Type : 0-P 12 hr
Region : Amerique du Nord LAM
Lat-lon: (30N, 150W) (73N, 50W)
Stat. communes

Q-P 24 hr





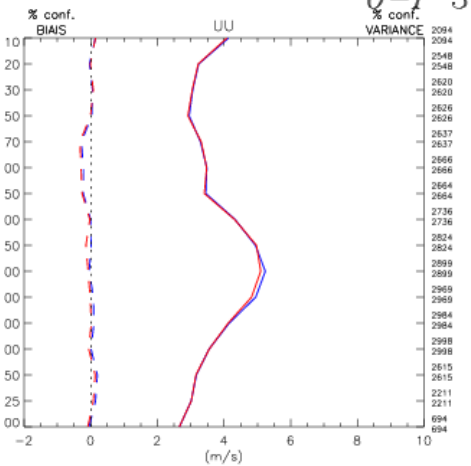


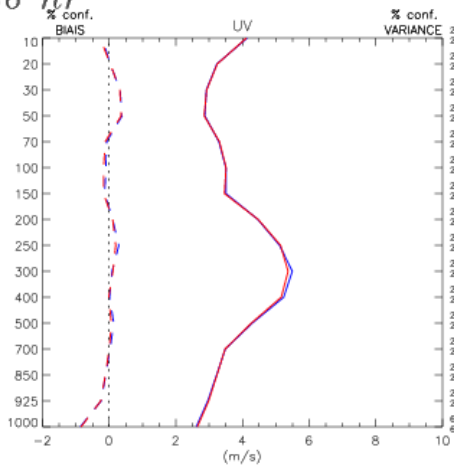


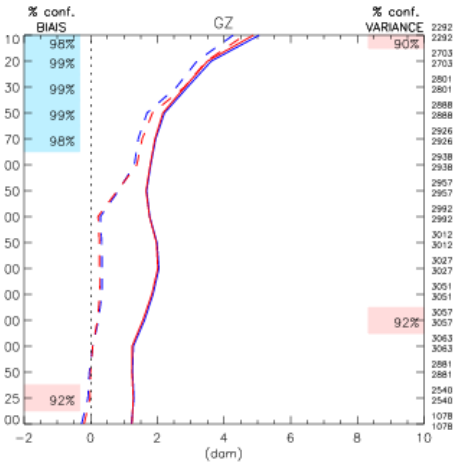
E-T m_ua_048_regzda41 (40)
BIAIS m_ua_048_regzda41
E-T m_ua_048_lamlam3d_hiv_hemis_bgcklam (40)
BIAIS m_ua_048_lamlam3d_hiv_hemis_bgcklam

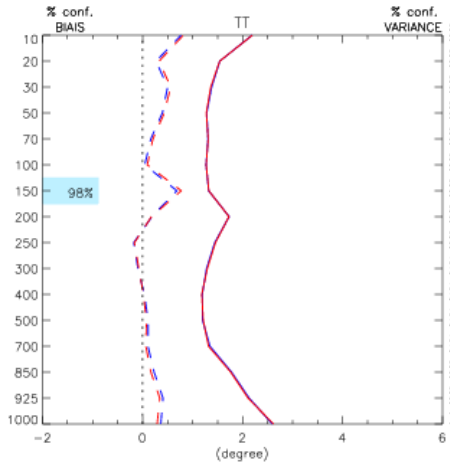
Type : 0-P 24 hr
Region : Amerique du Nord LAM
Lat-lon: (30N, 150W) (73N, 50W)
Stat. communes

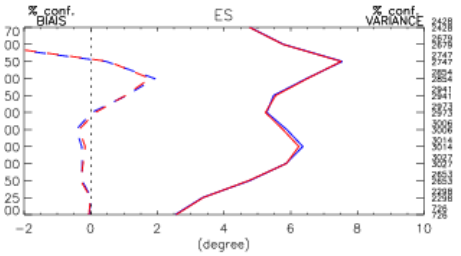
Q-P 36 hr





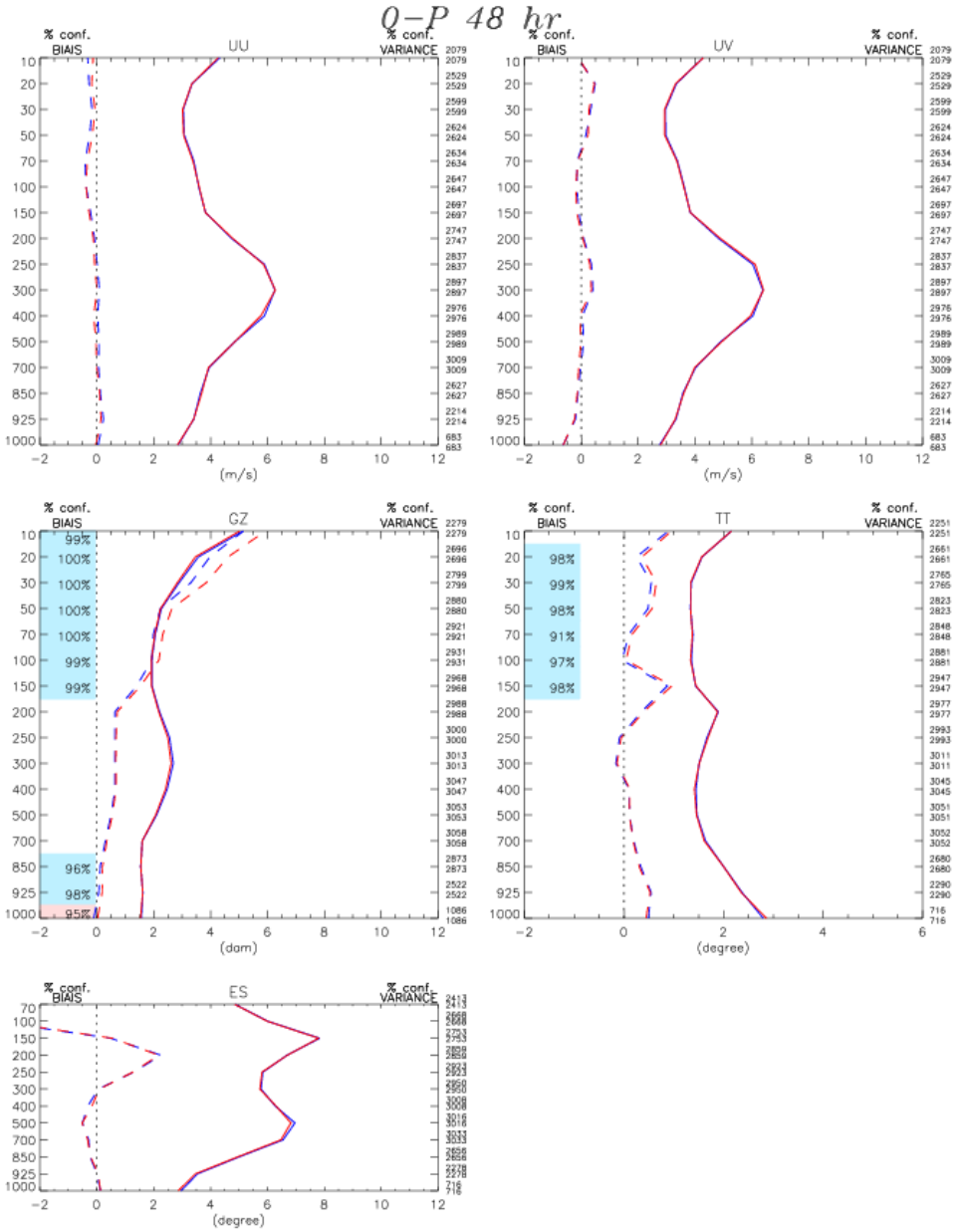






E-T m_ua_048_regzda41 (40)
BIAIS m_ua_048_regzda41
E-T m_ua_048_lamlam3d_hiv_hemis_bgcklam (40)
BIAIS m_ua_048_lamlam3d_hiv_hemis_bgcklam

Type : 0-P 36 hr
Region : Amerique du Nord LAM
Lat-lon: (30N, 150W) (73N, 50W)
Stat. communes



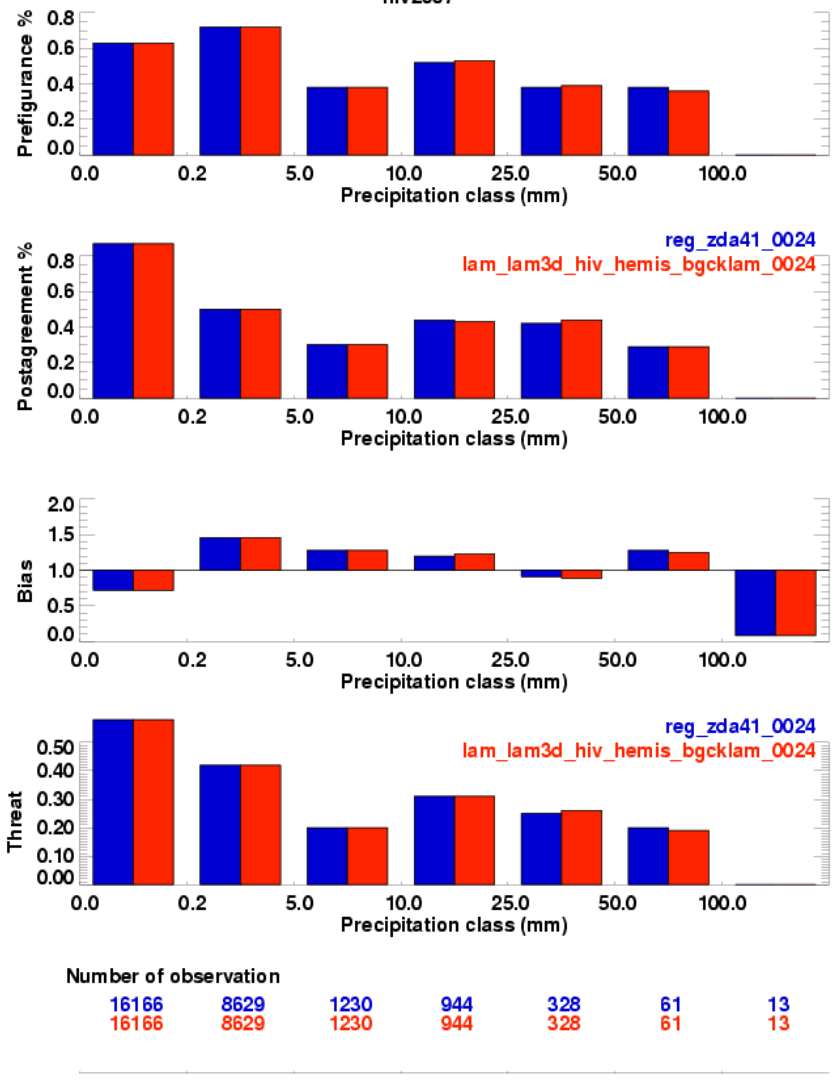
- https://wiki/wiki/REG-LAM3D/Ervig/Description_des_suites_

y 20, 2009

Canada

24 hours precipitation forecast verification against observation

Synoptic network data for valid time 00-12z
00 to 24 hours forecast North AMERICA
hiv2007

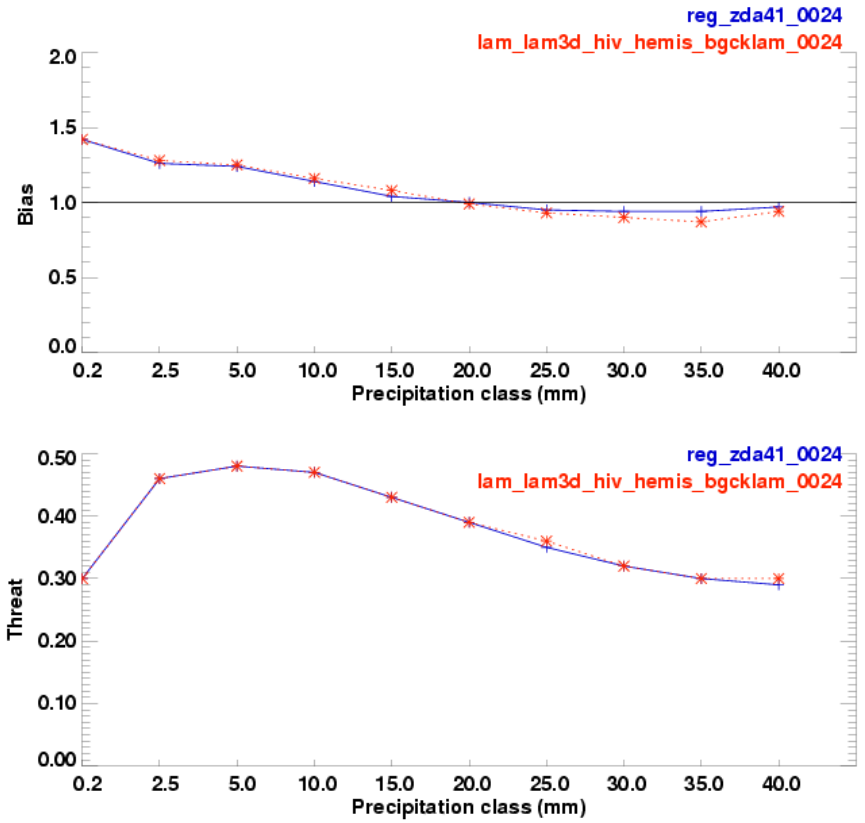


Number of observation

16166	8629	1230	944	328	61	13
16166	8629	1230	944	328	61	13

24 hours precipitation forecast verification against observation

Synoptic network data for valid time 00-12z
00 to 24 hours forecast North AMERICA
hiv2007

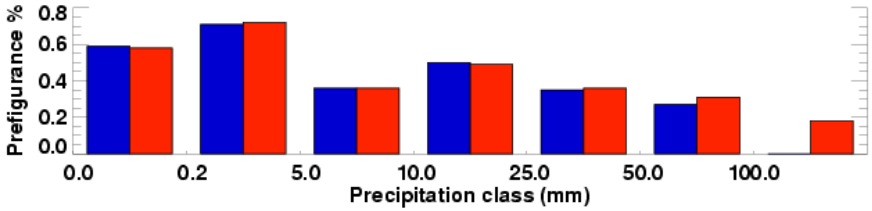


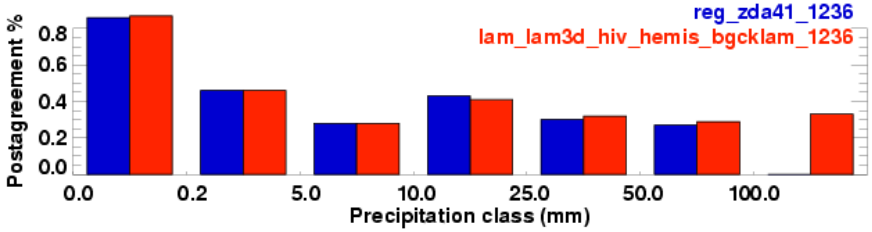
Number of observation

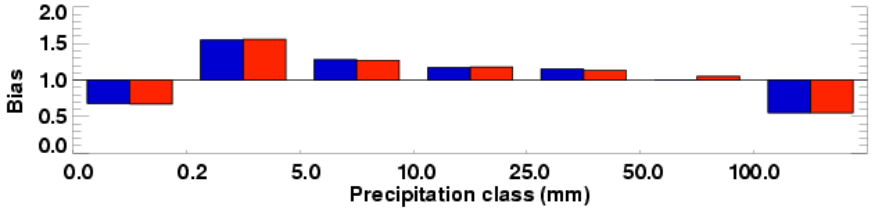
10929	4117	2483	1324	830	566	397	280	207	144
10929	4117	2483	1324	830	566	397	280	207	144

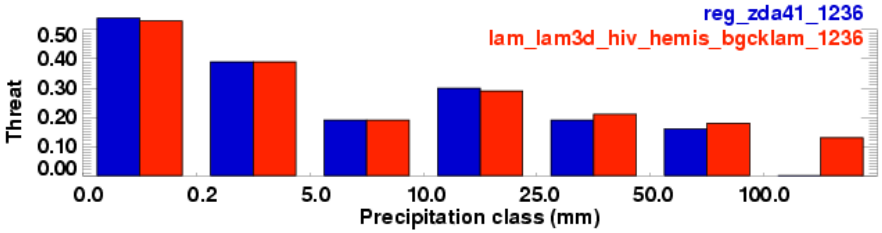
24 hours precipitation forecast verification against observation

Synoptic network data for valid time 00-12z
12 to 36 hours forecast North AMERICA
hiv2007



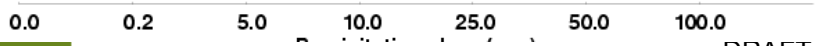






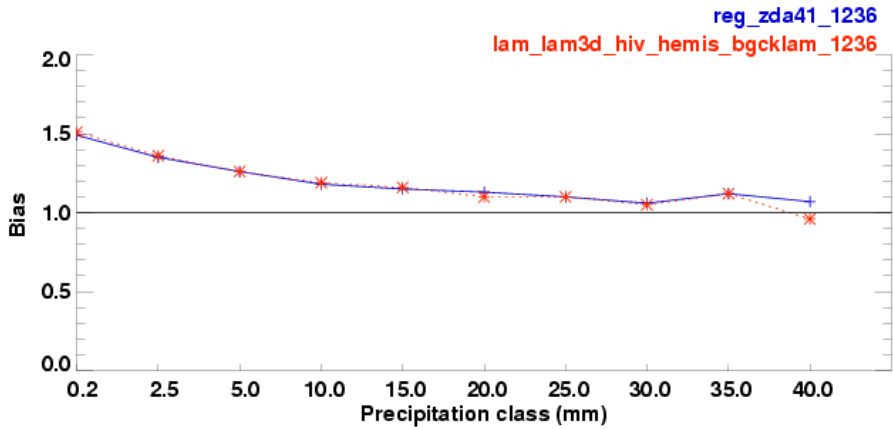
Number of observation

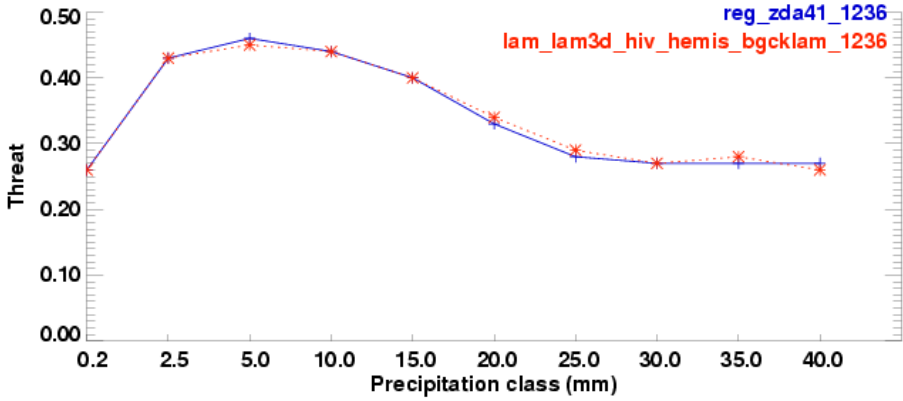
15873	8340	1272	963	266	62	11
15873	8340	1272	963	266	62	11



24 hours precipitation forecast verification against observatio

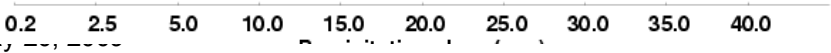
Synoptic network data for valid time 00-12z
12 to 36 hours forecast North AMERICA
hiv2007





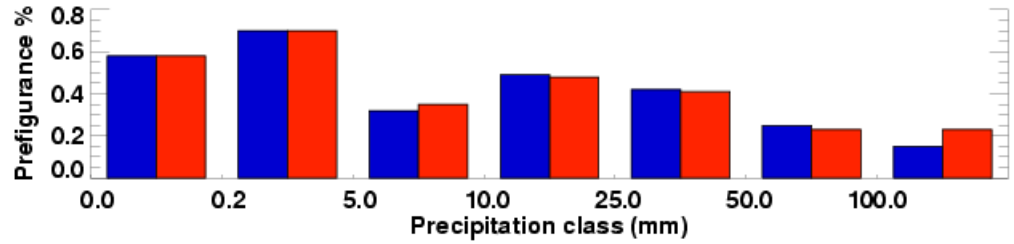
Number of observation

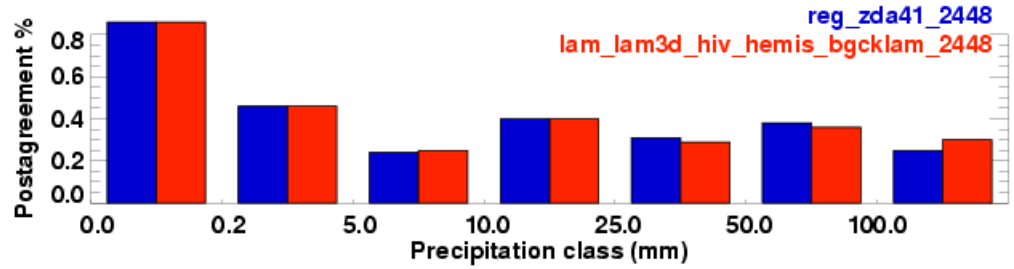
10624	3995	2485	1269	769	510	337	236	164	119
10624	3995	2485	1269	769	510	337	236	164	119

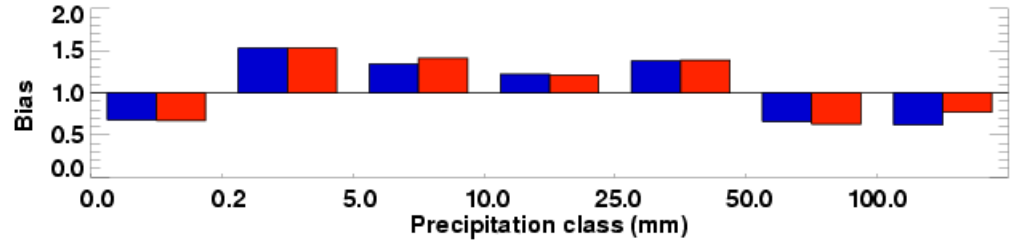


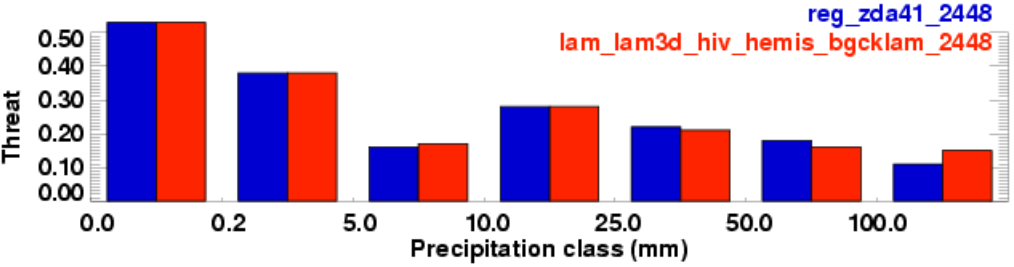
4 hours precipitation forecast verification against observation

Synoptic network data for valid time 00-12z
24 to 48 hours forecast North AMERICA
hiv2007







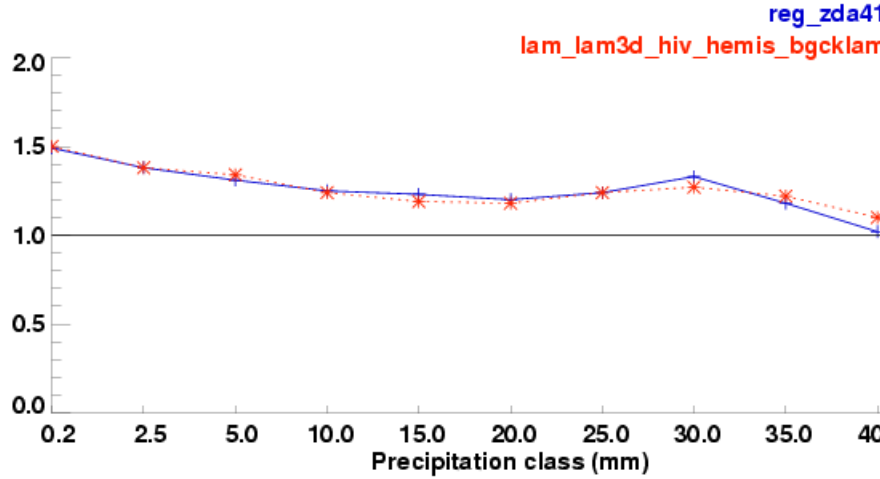


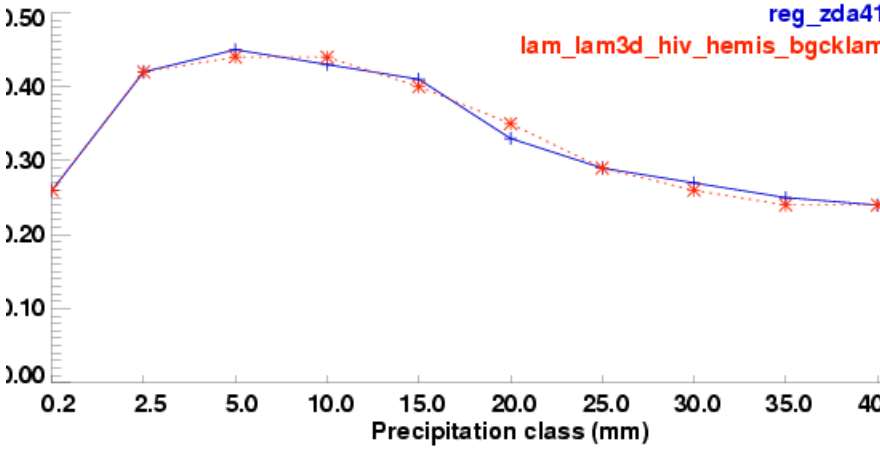
Number of observation

15757	8281	1188	1033	284	71	13
15757	8281	1188	1033	284	71	13

ours precipitation forecast verification against obse

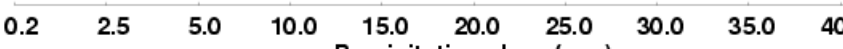
Synoptic network data for valid time 00-12z
24 to 48 hours forecast North AMERICA
hiv2007





Number of observation

10601	4090	2512	1369	856	553	361	233	171
10601	4090	2512	1369	856	553	361	233	171

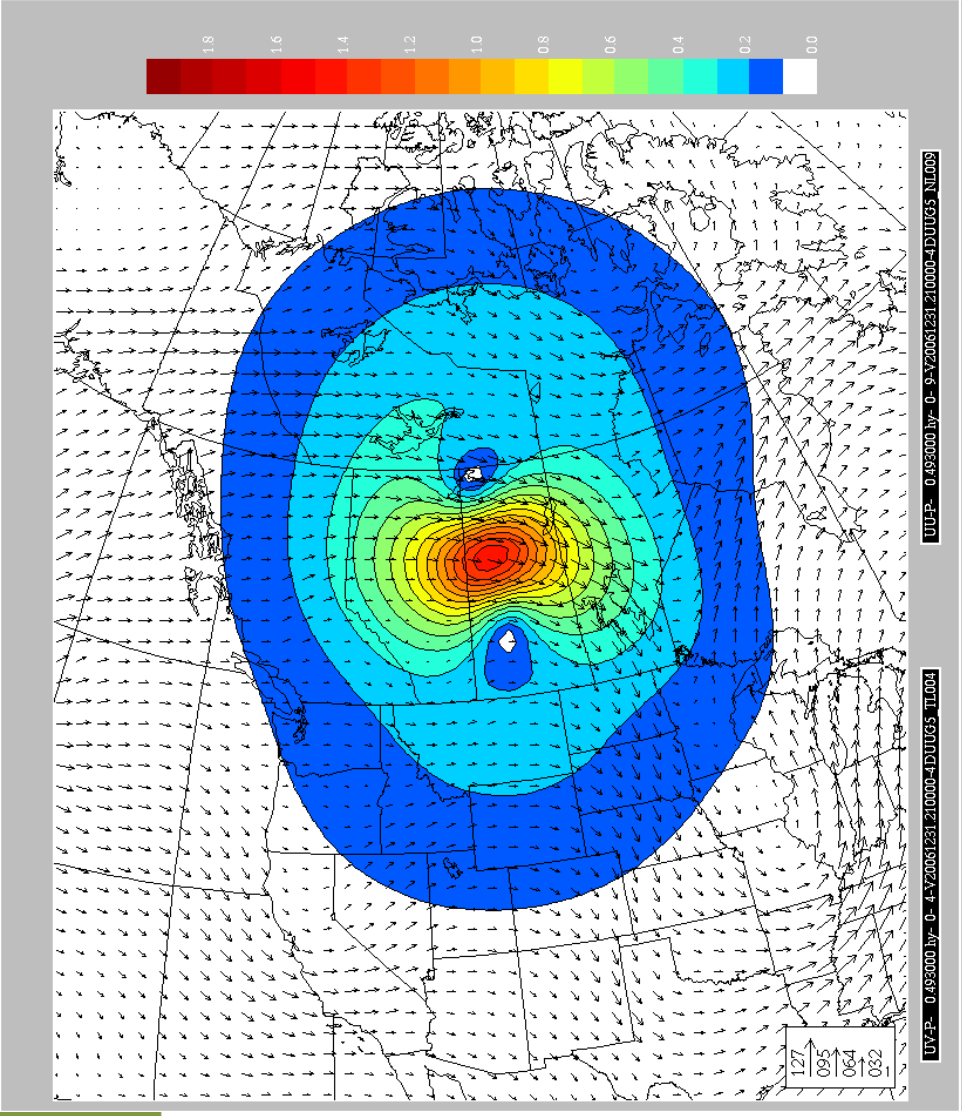


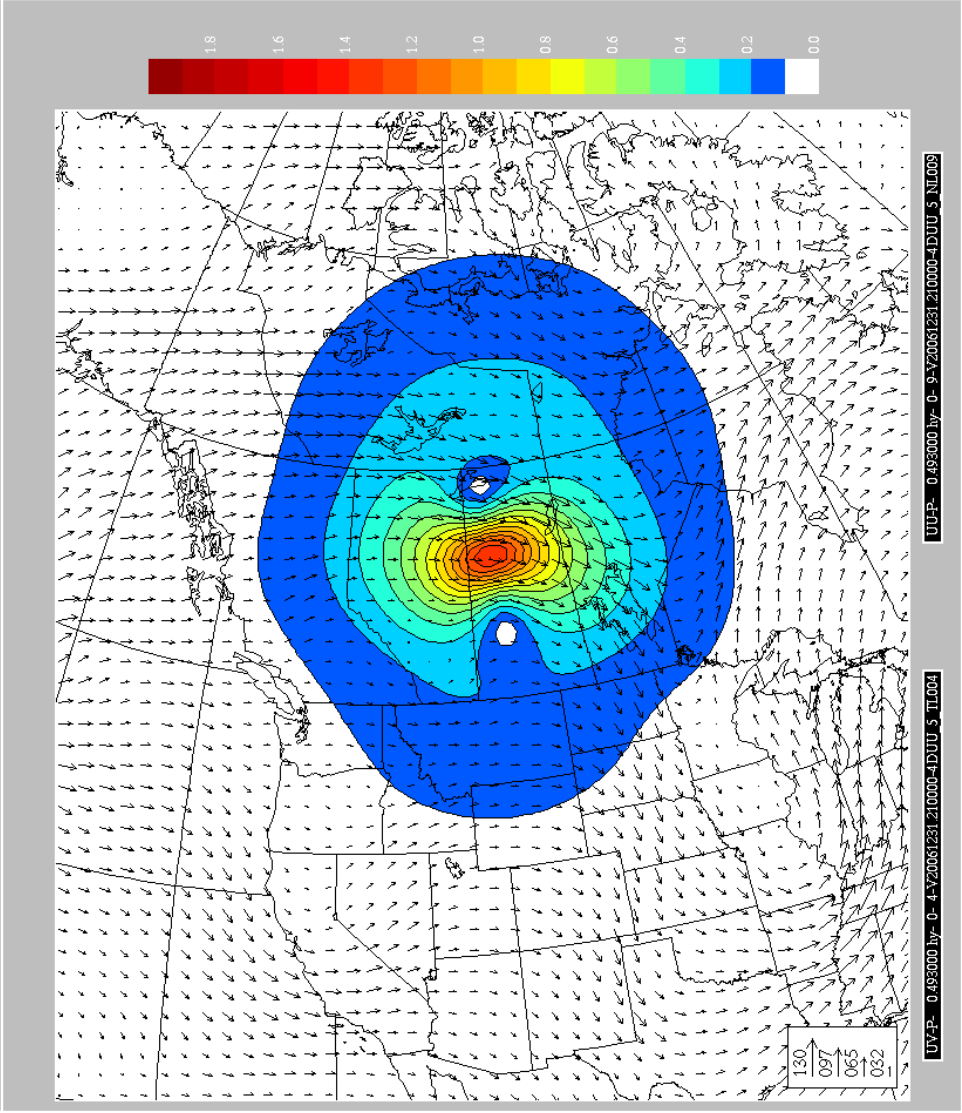
Upgrades to come
REG-LAM3D Schedule

- Increase horizontal resolution on observation thinning (< 250 km)
- Ground-based GPS (end of 2009)
- NH-T200 ➔ NH-T300, (50 km) analysis (MPI 3D-VAR code, 2009)
- Vertical staggering (Completed by end of 2009)
- 80 Levels Tropospheric Version

Vertical piloting (Implement RPN's approach within REG-LAM3D. 2010)

- Diabatic INMI constraint (improving initial vertical motions w.r.t moist-physical processes. Adiabatic version implemented at NCEP in GSI, March 2007). Fillion Internal seminar on this, end of 2009.
- Large-scale Ensemble based background-error covariances (2010)
- Improved coupling with the surface analysis (Marco et al., 2009-2010)
- Pursue REG-LAM4D (???)
- ?? km horizontal resolution (2011)
- Meso-scale observations (radar radial-winds)
- LAM 4D-Var at mesoscale.
- Include real assimilation for 2.5 km LAM's.





4D-Var GLB 170km

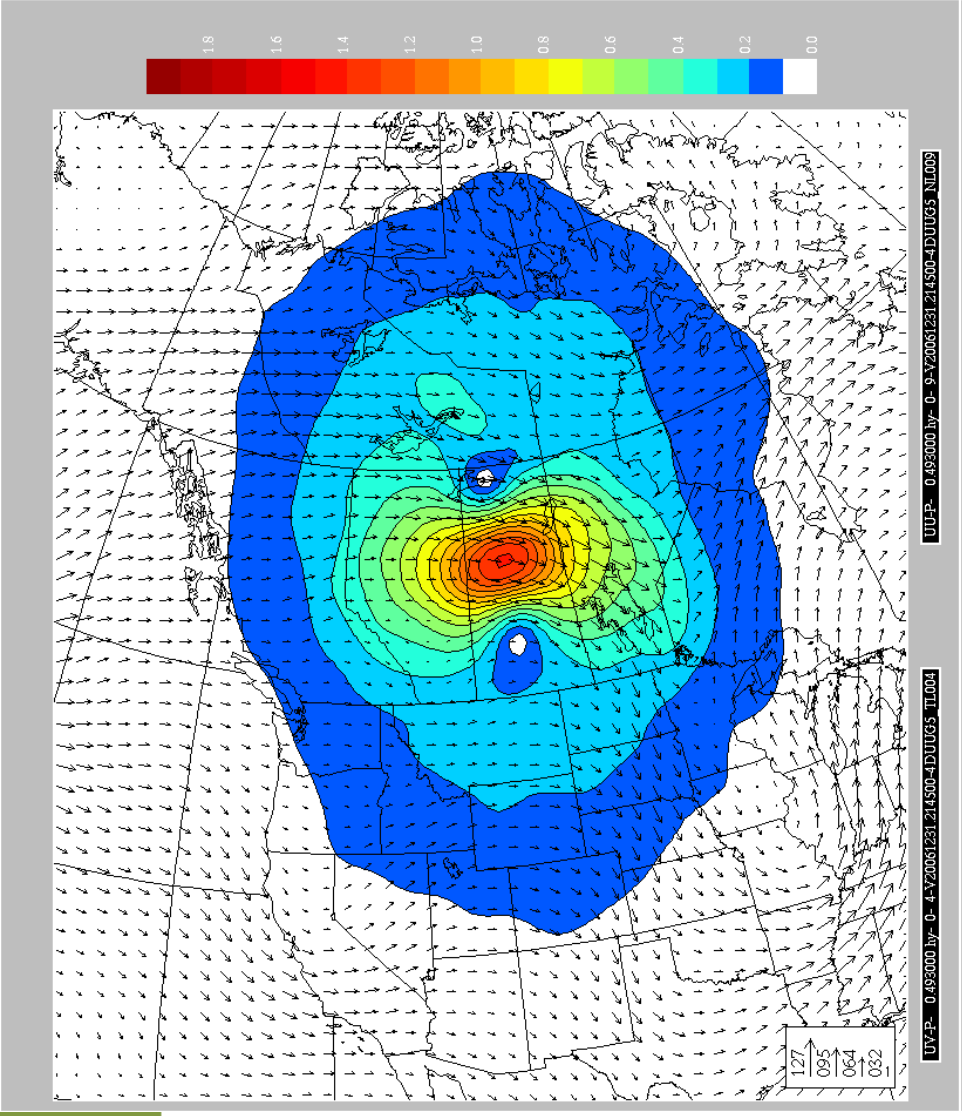
4D-Var LAM 55km

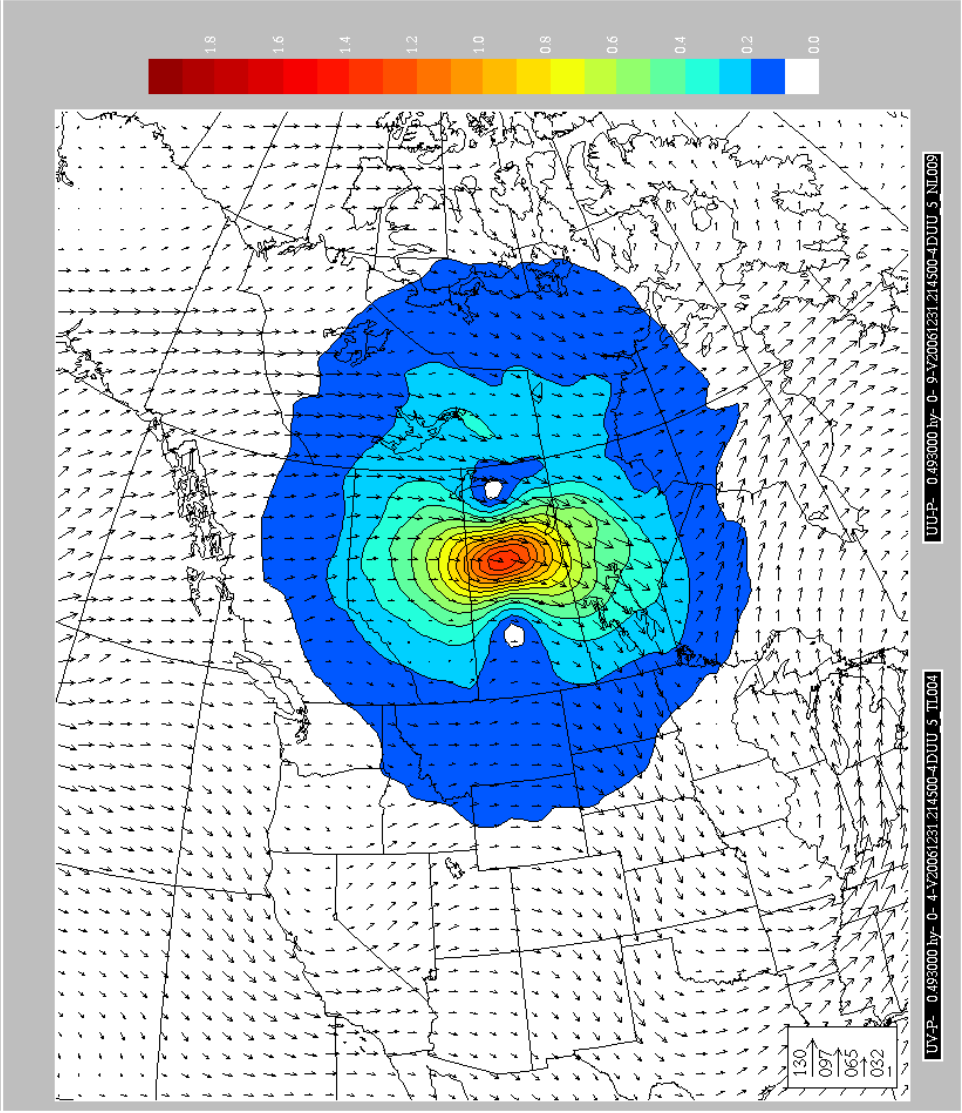
T = -3.00 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

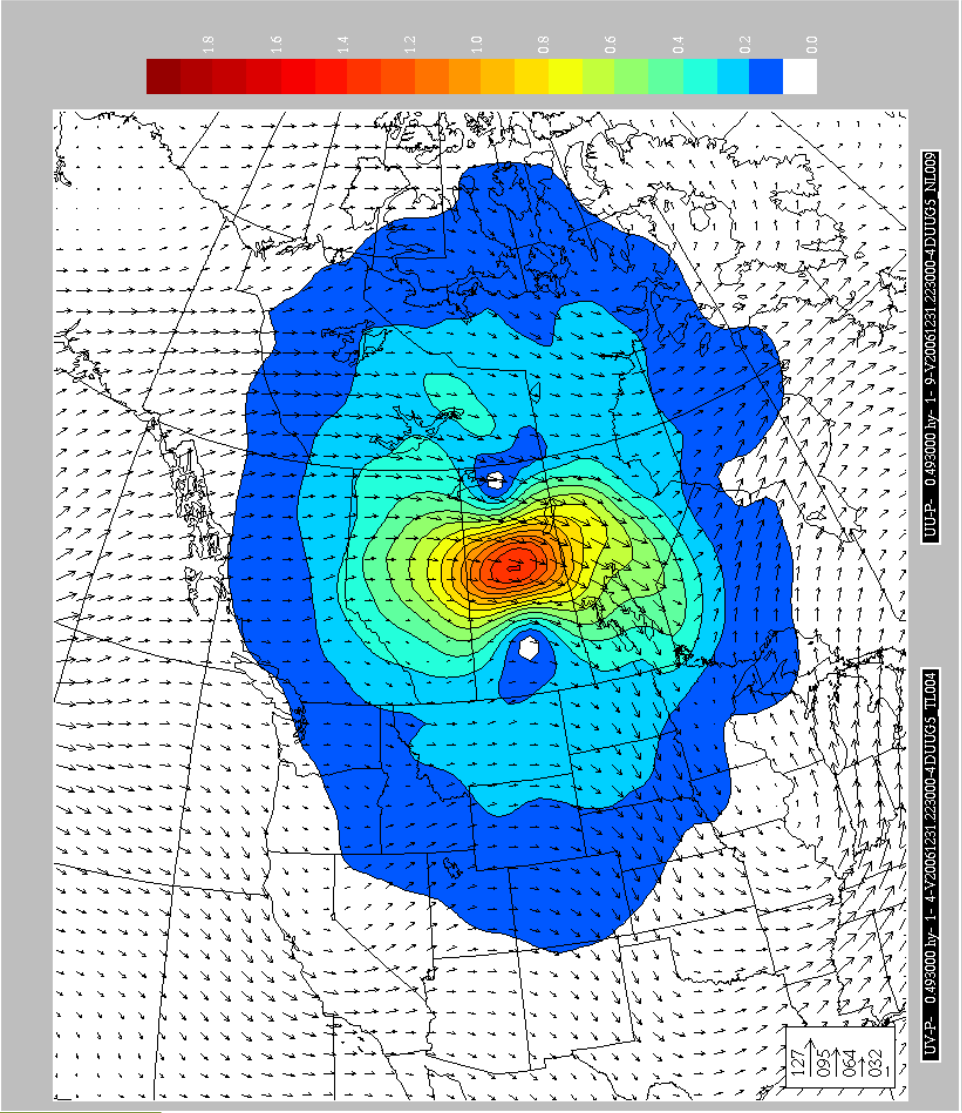
4D-Var LAM 55km

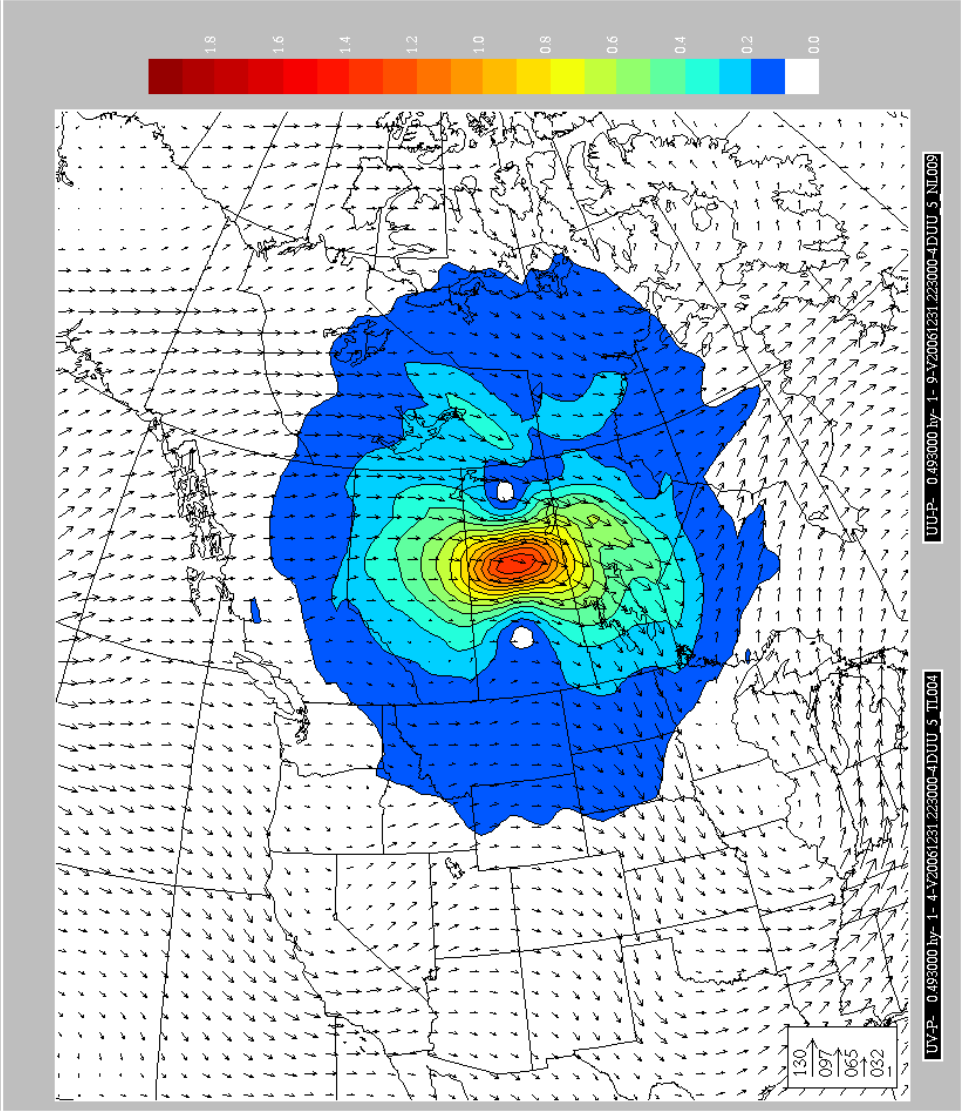
T = -2.15 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

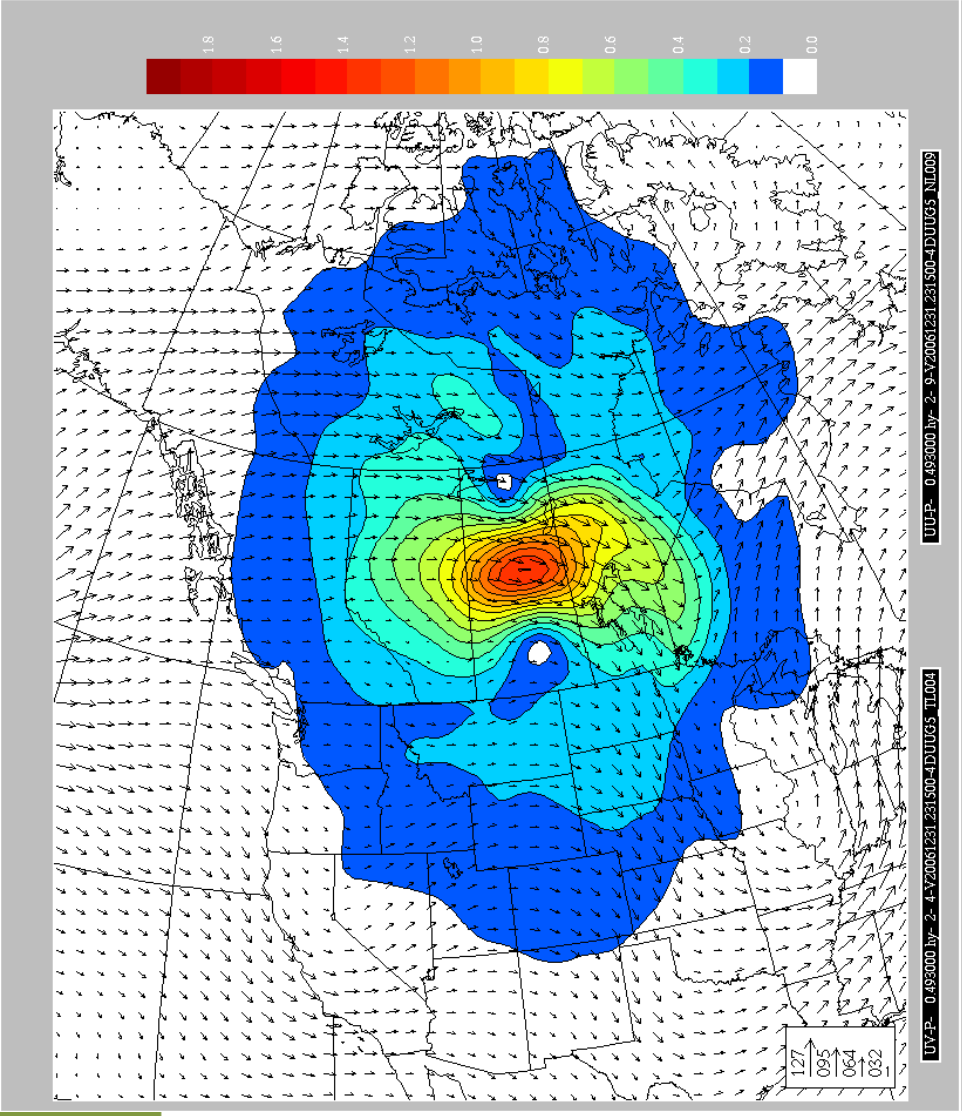
4D-Var LAM 55km

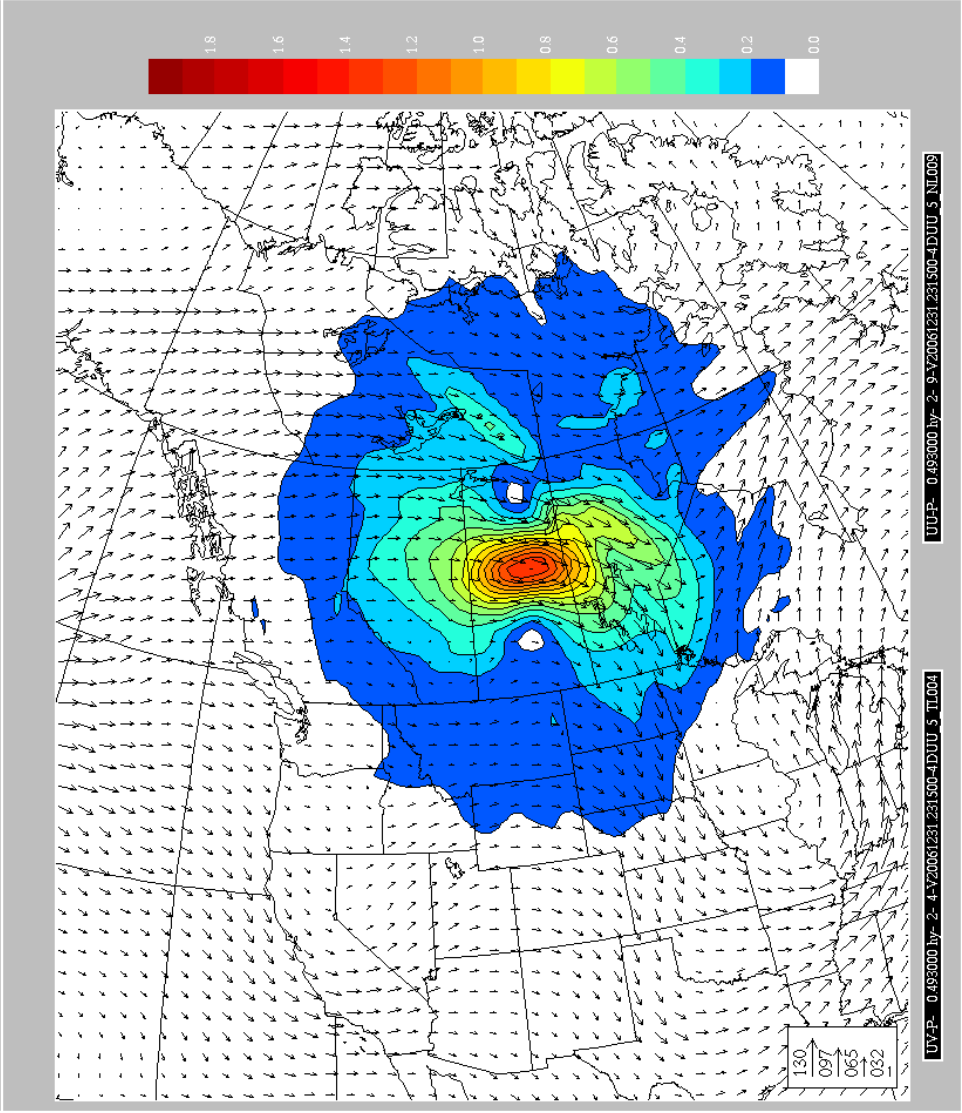
T = -1.30 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

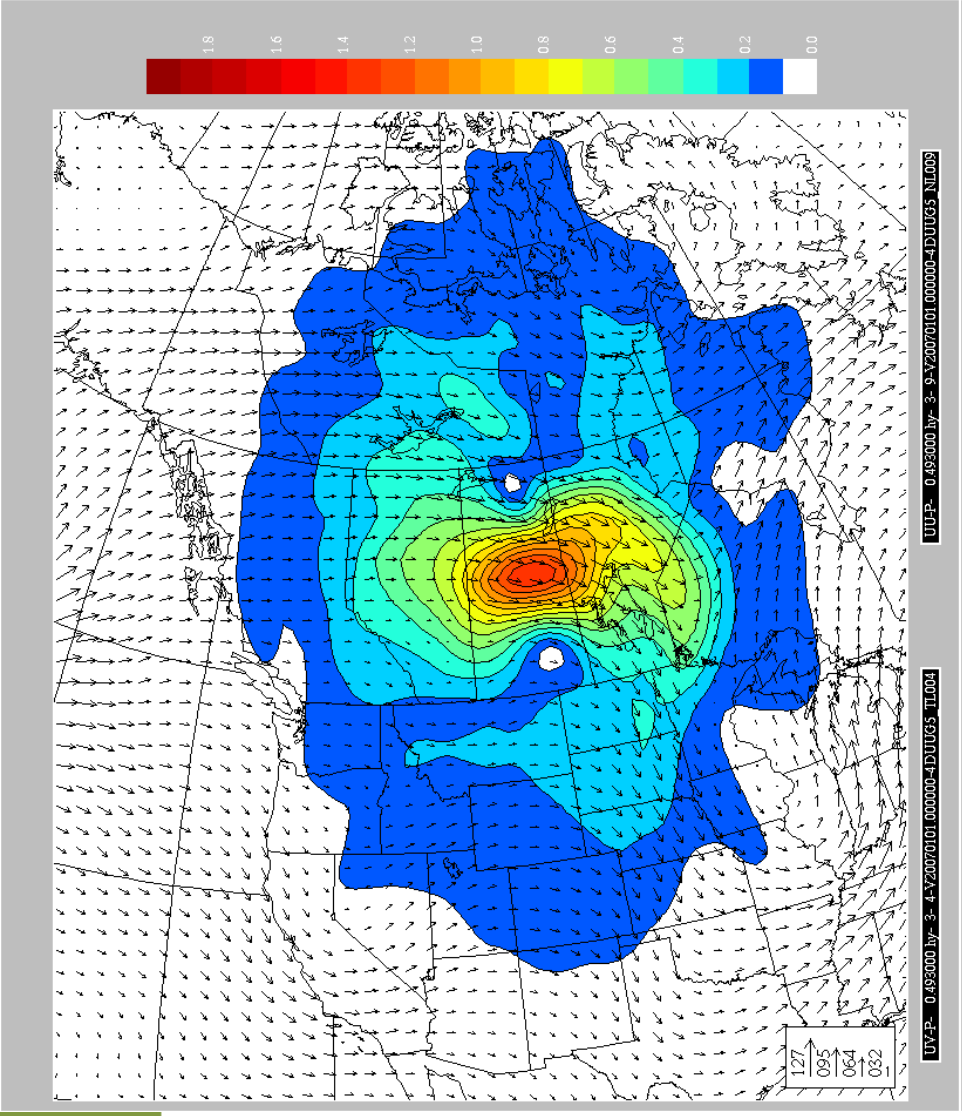
4D-Var LAM 55km

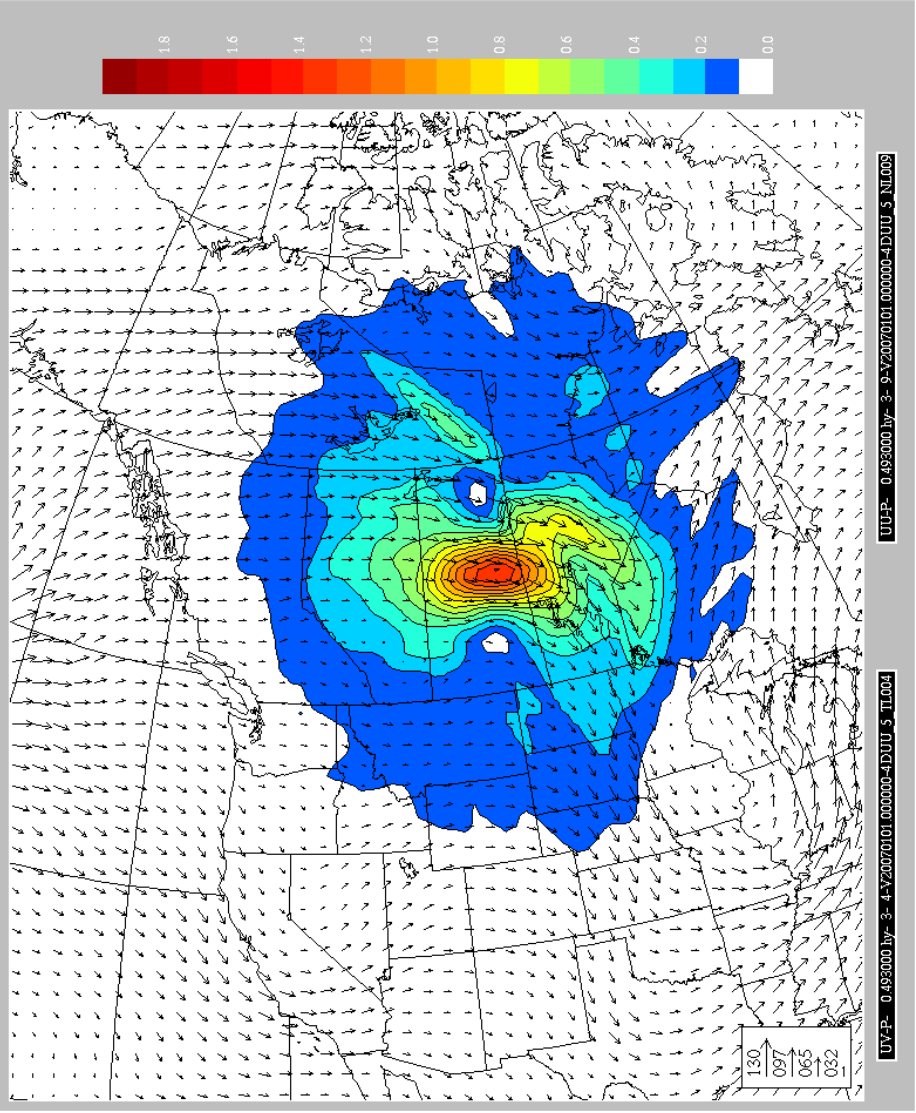
T = -0.45 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

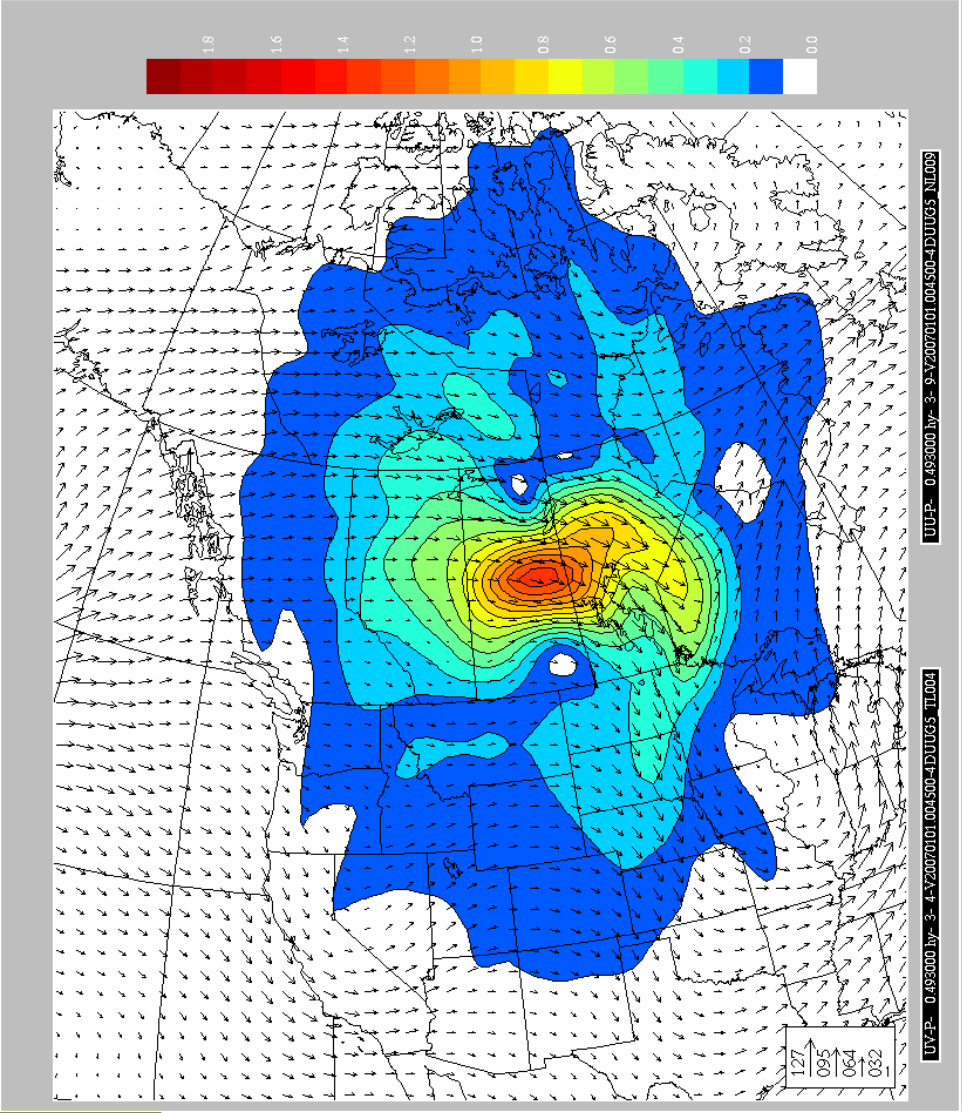
4D-Var LAM 55km

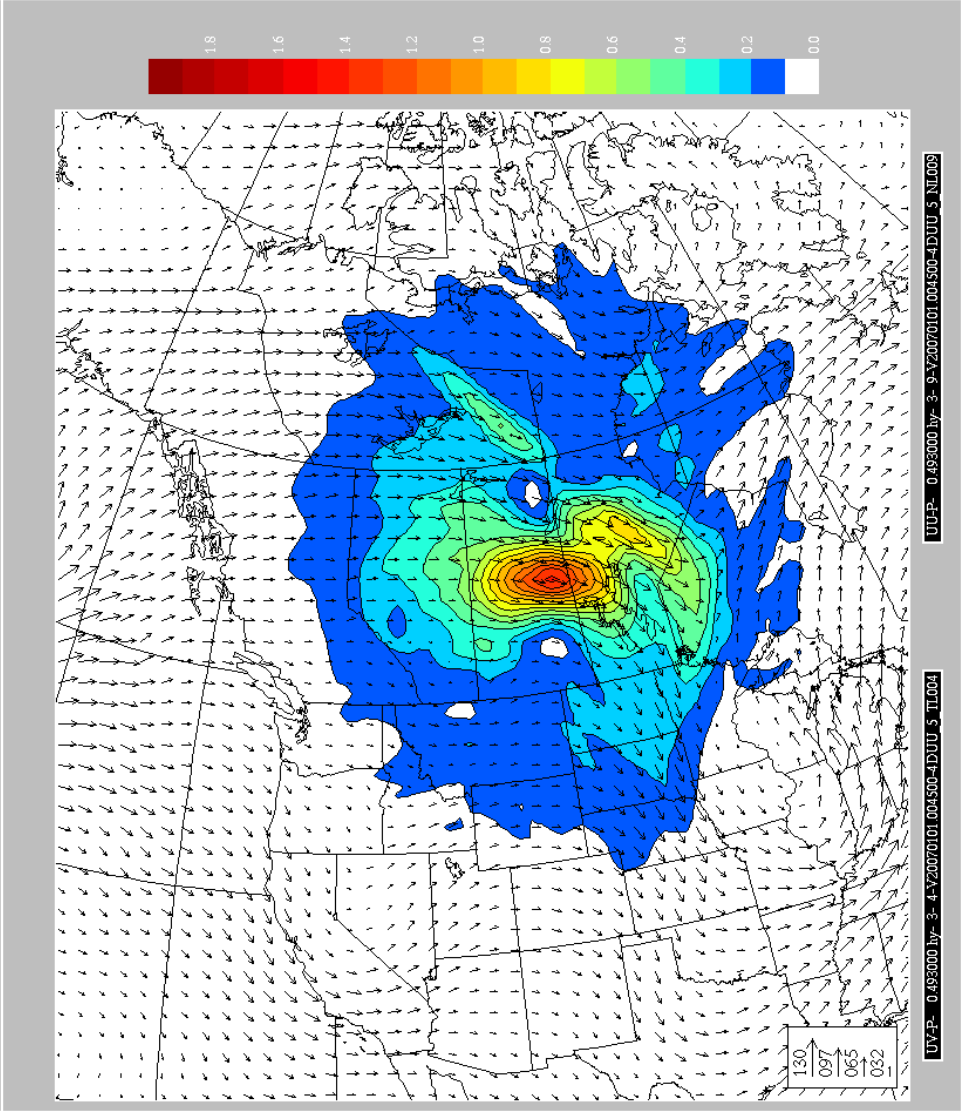
T = +0.00 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

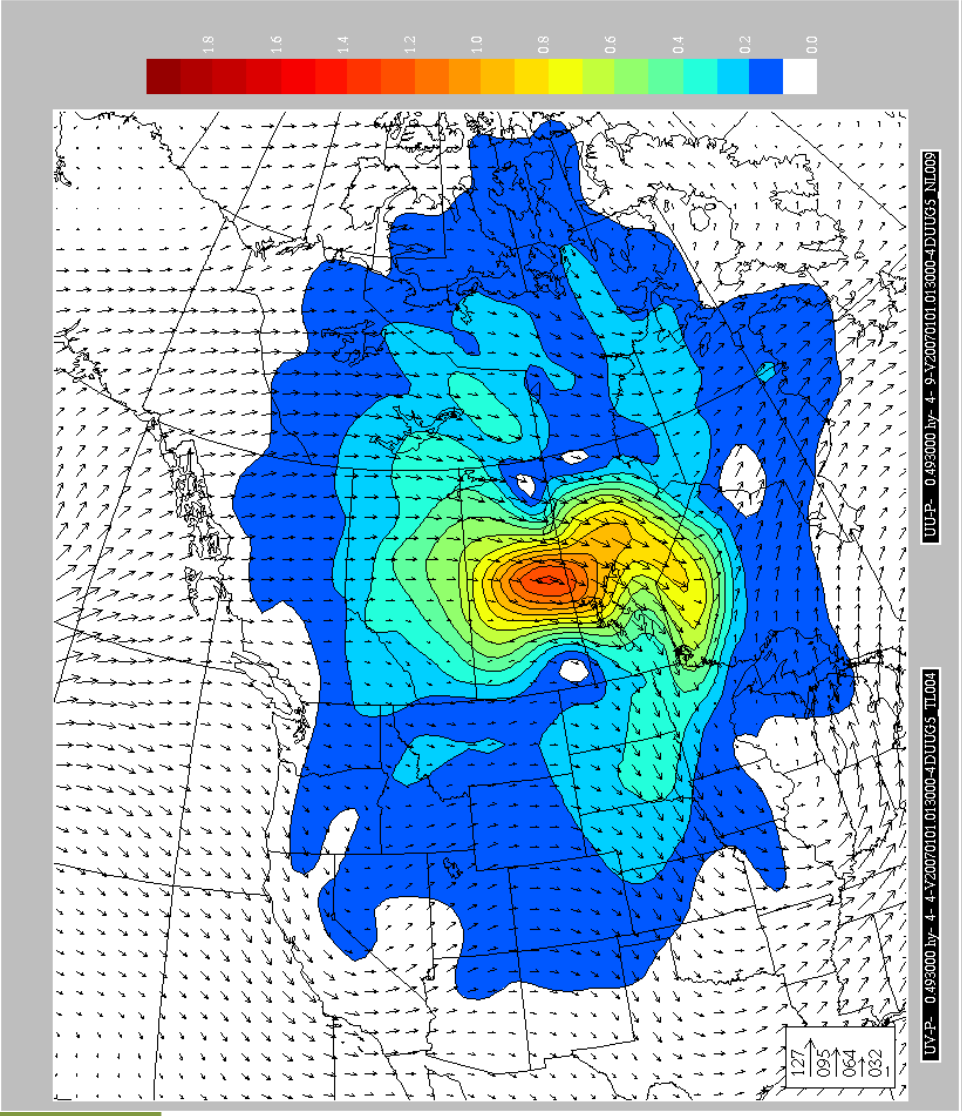
4D-Var LAM 55km

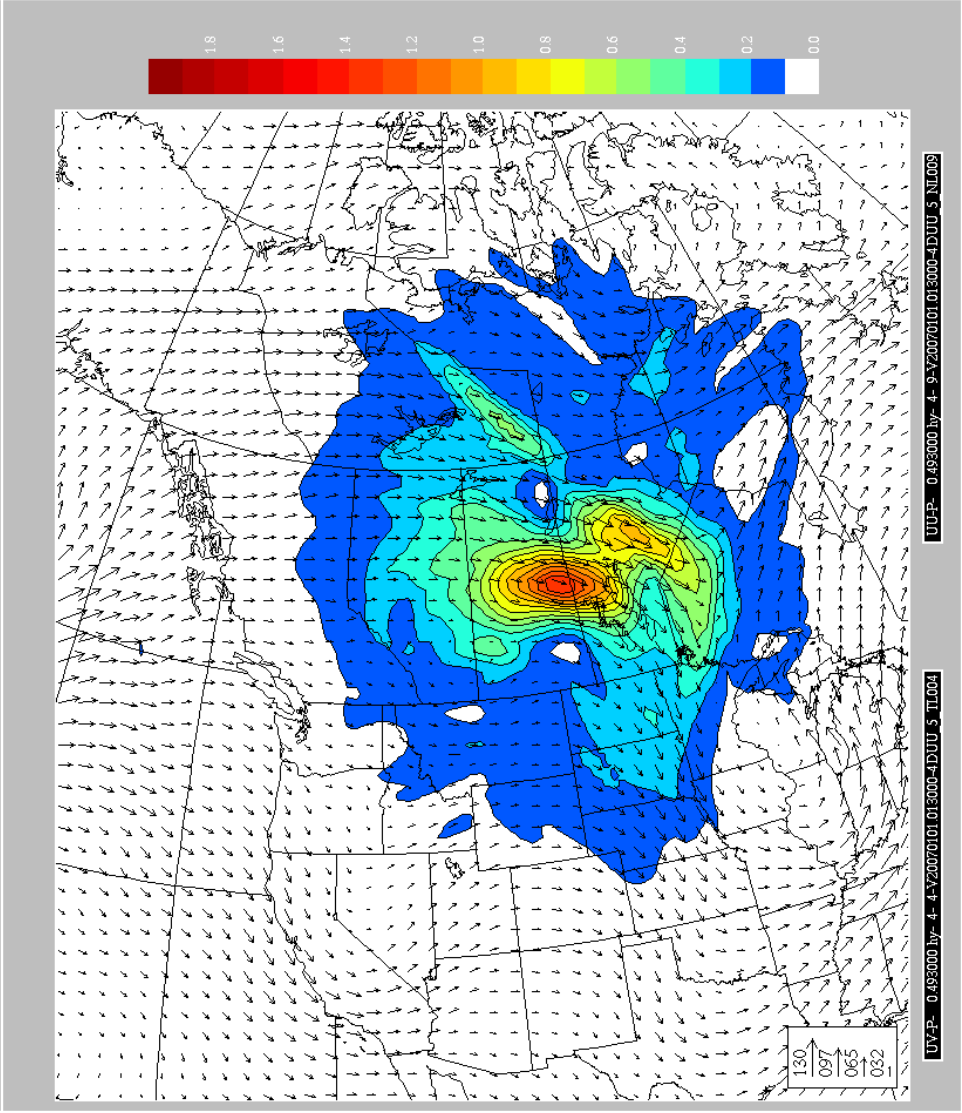
T = +0.45 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

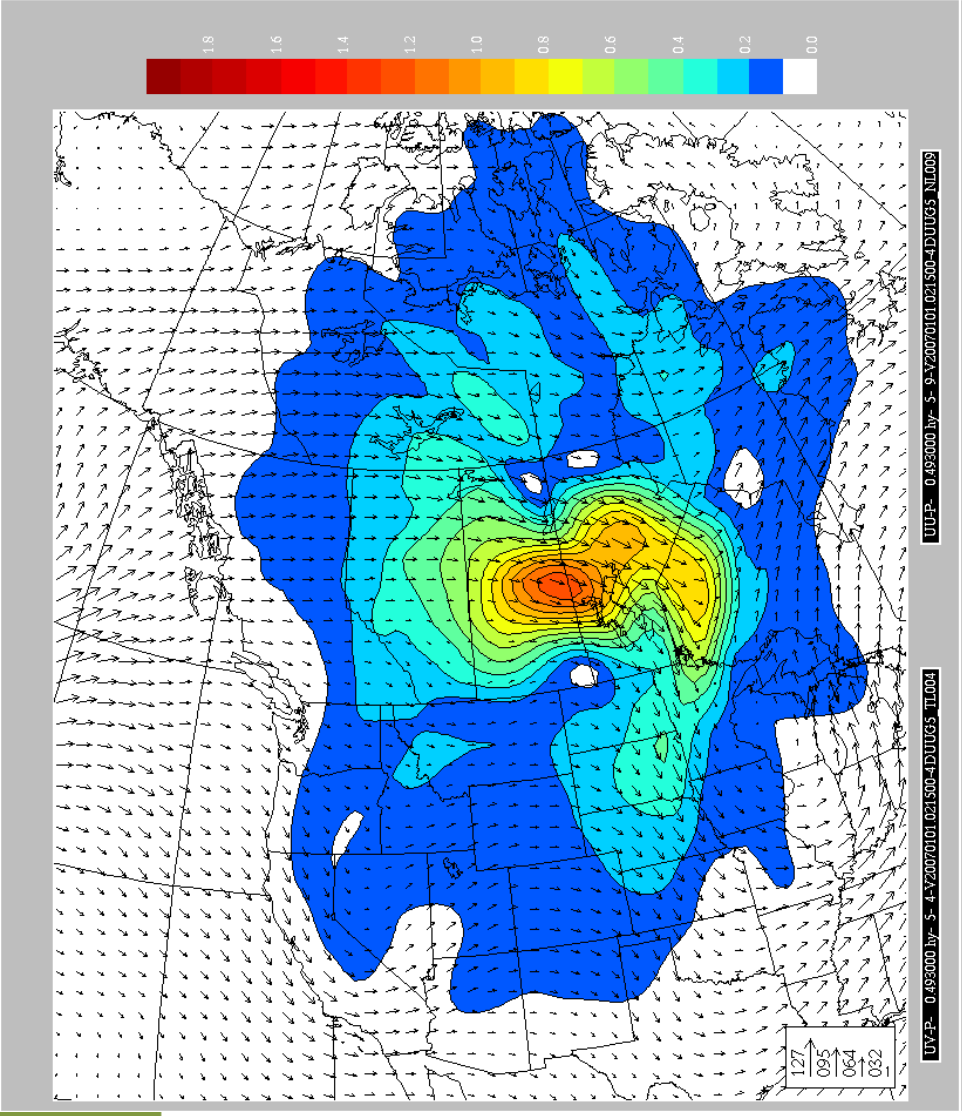
4D-Var LAM 55km

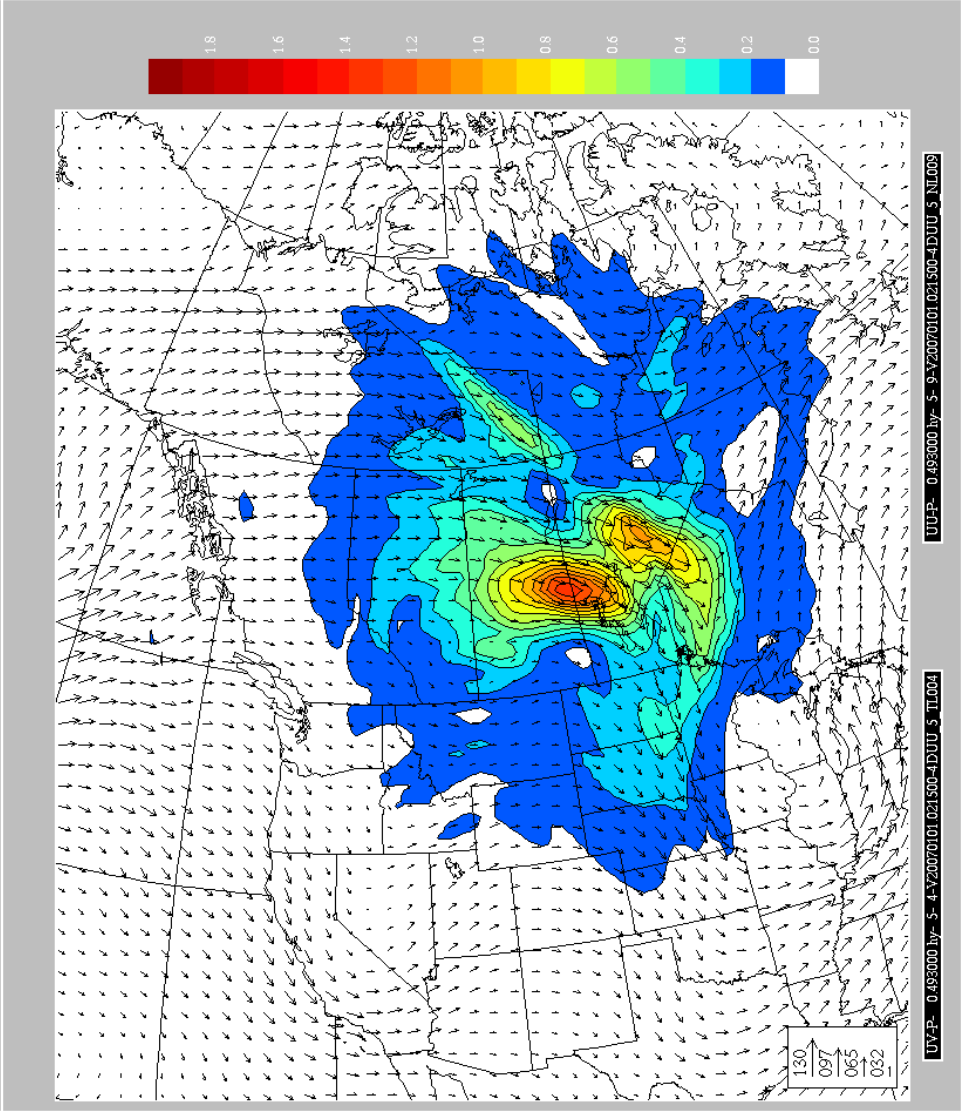
T = +1.30 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

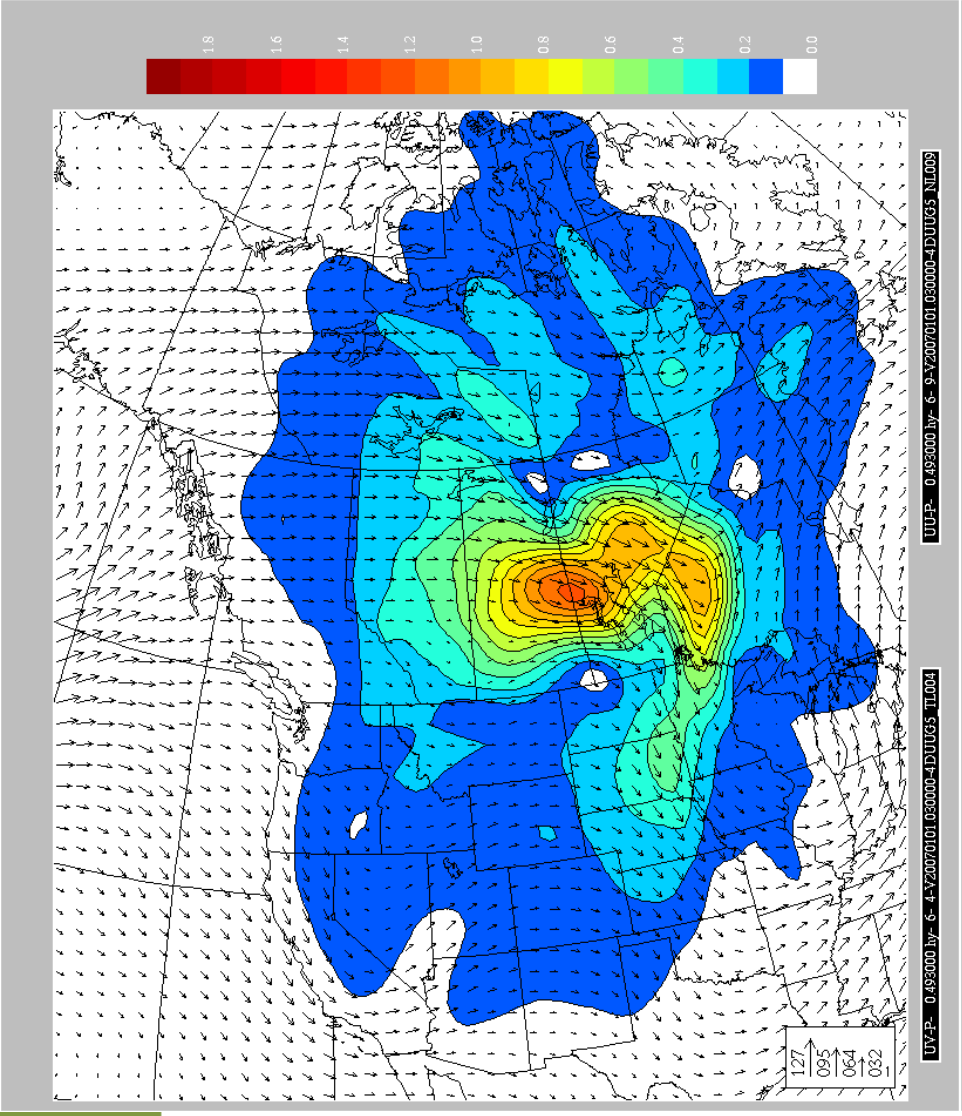
4D-Var LAM 55km

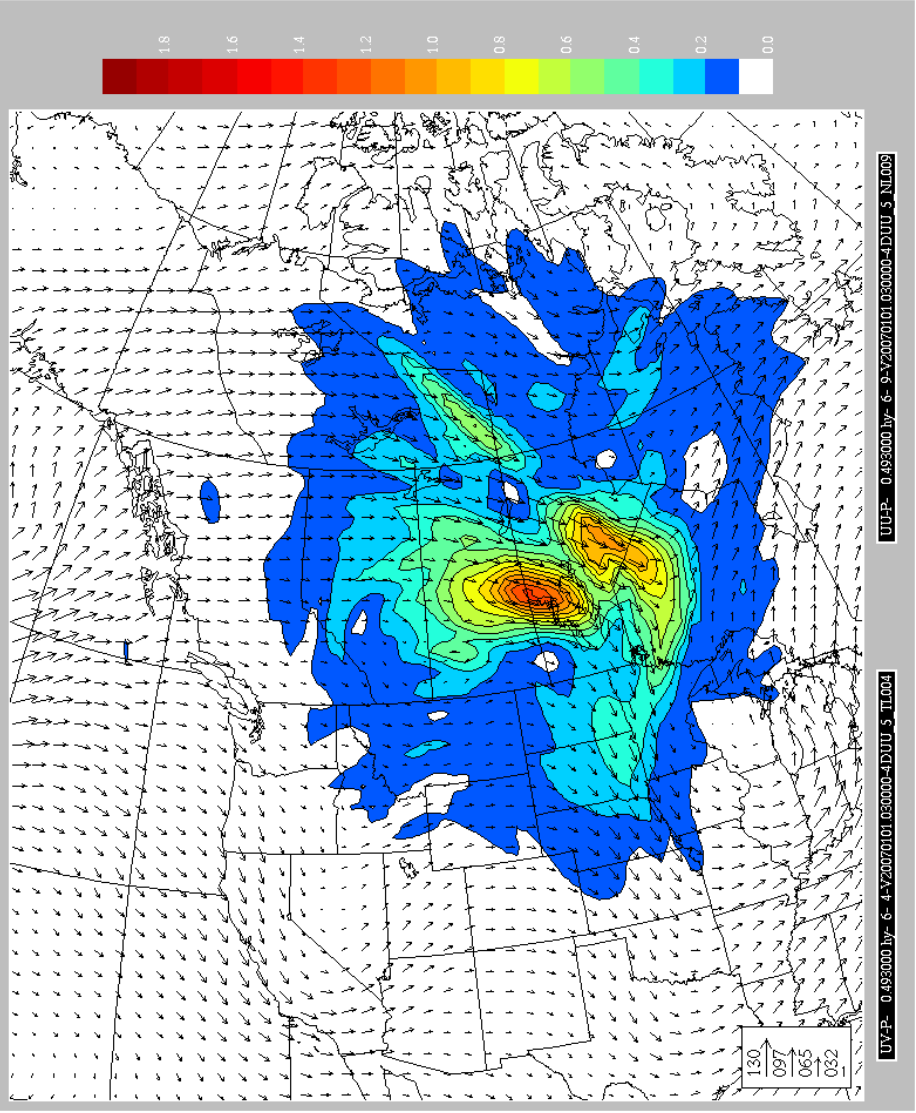
T = +2.15 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

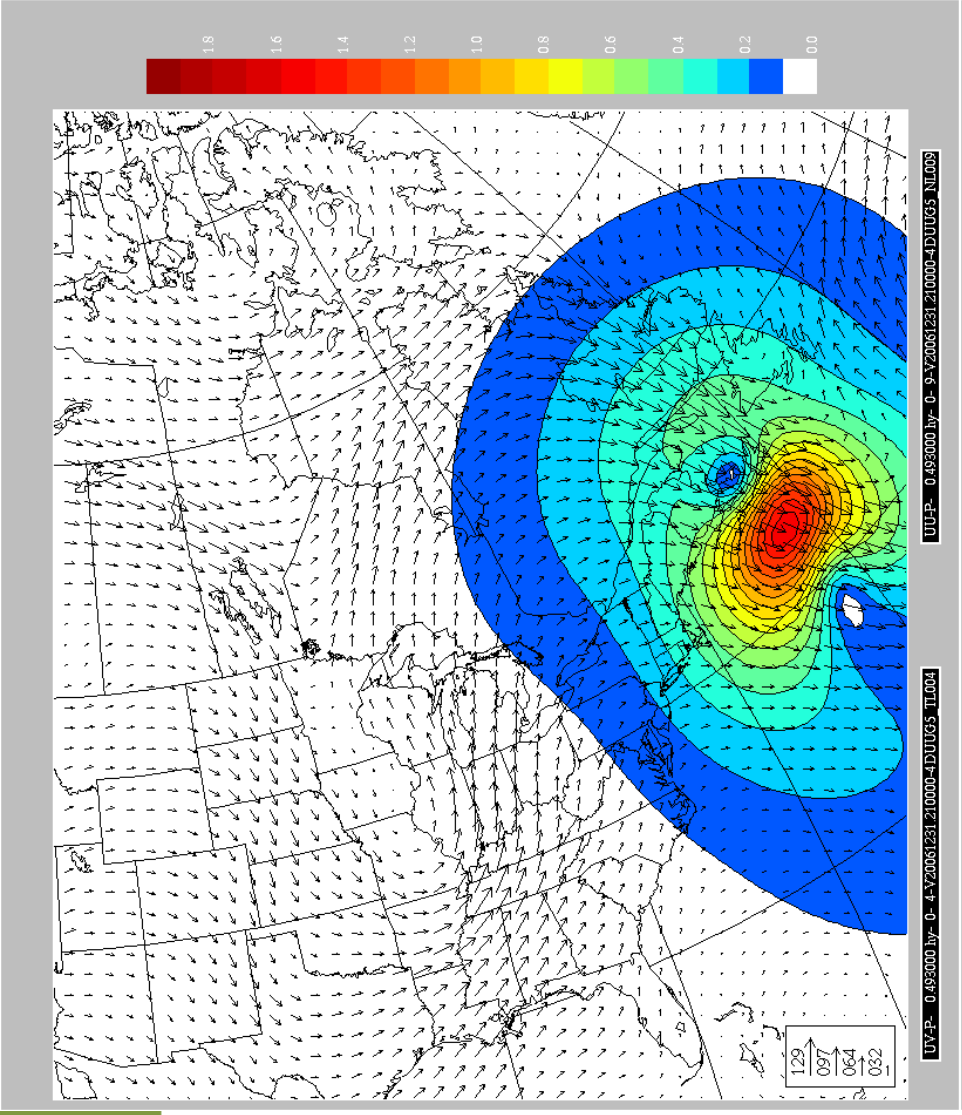
4D-Var LAM 55km

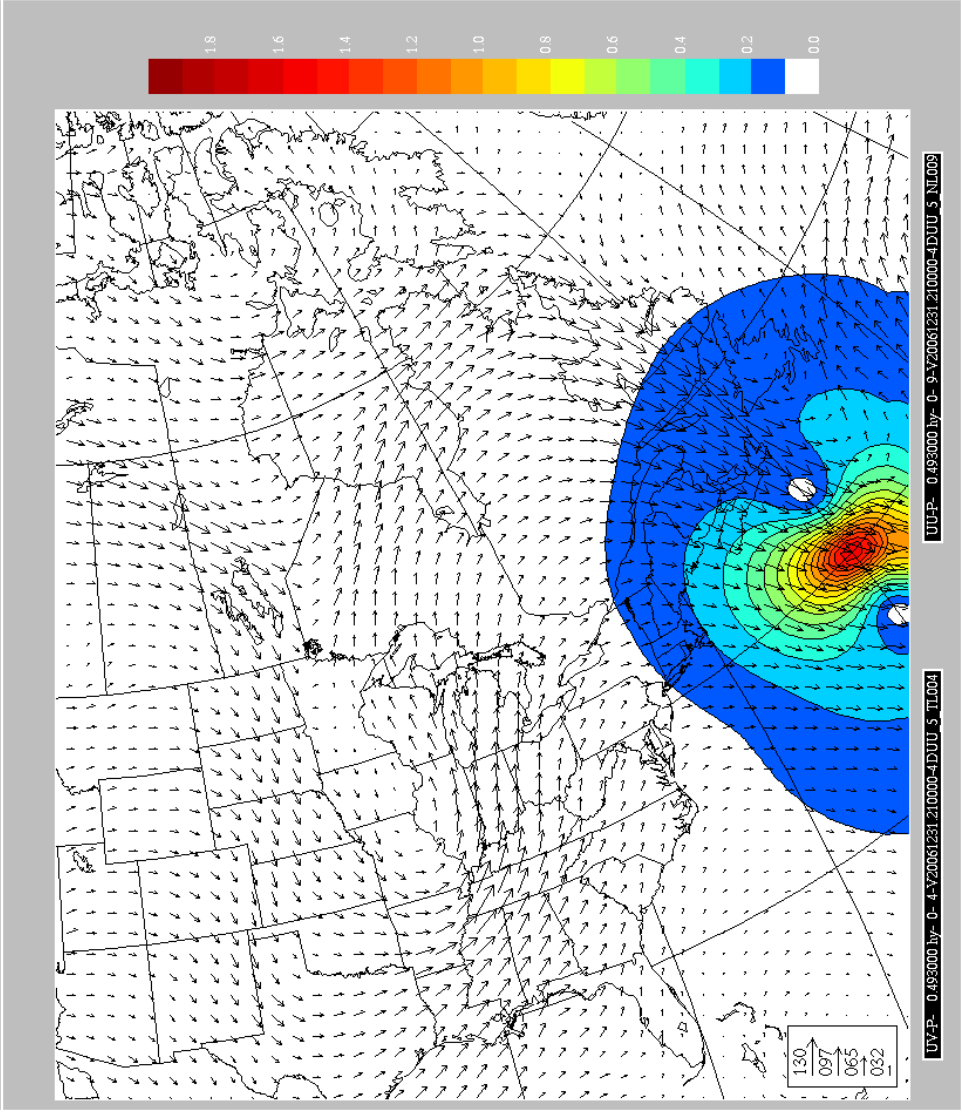
T = +3.00 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

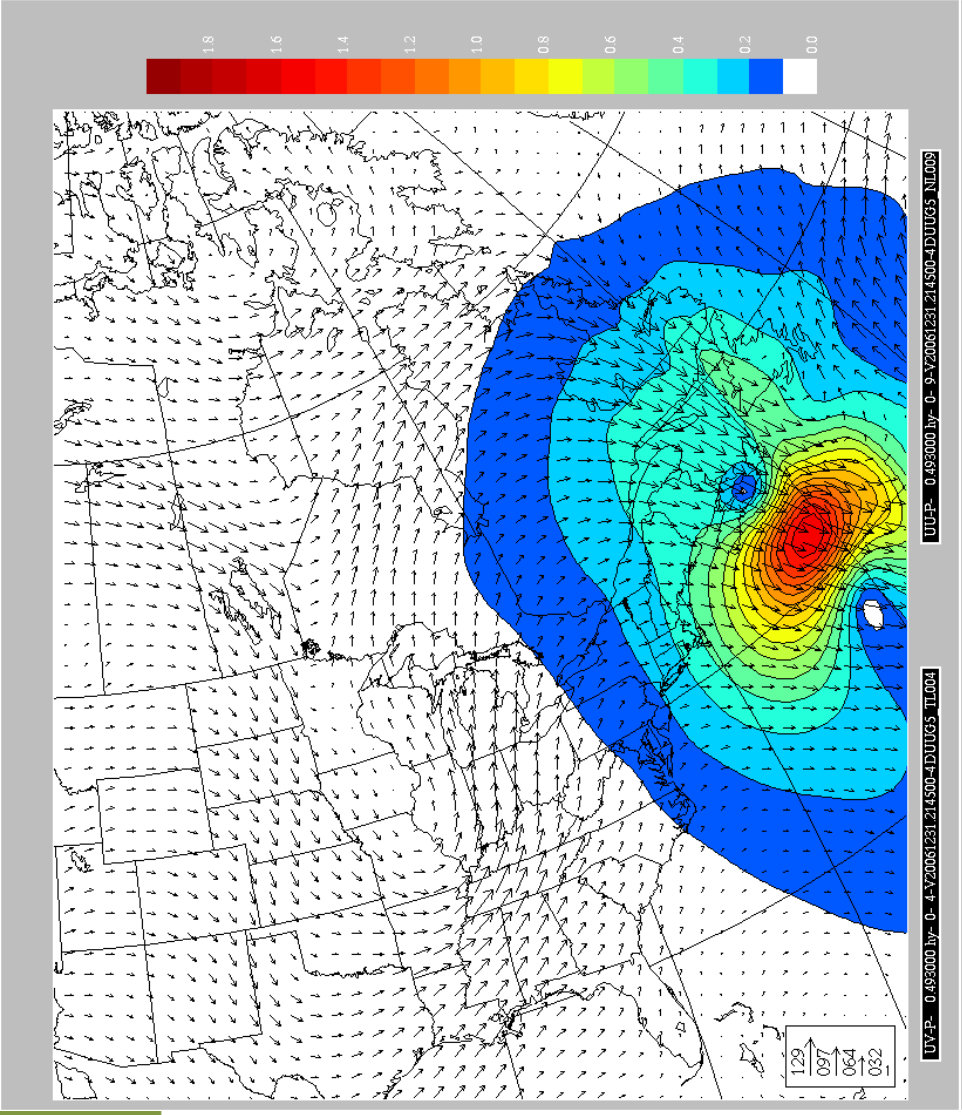
4D-Var LAM 55km

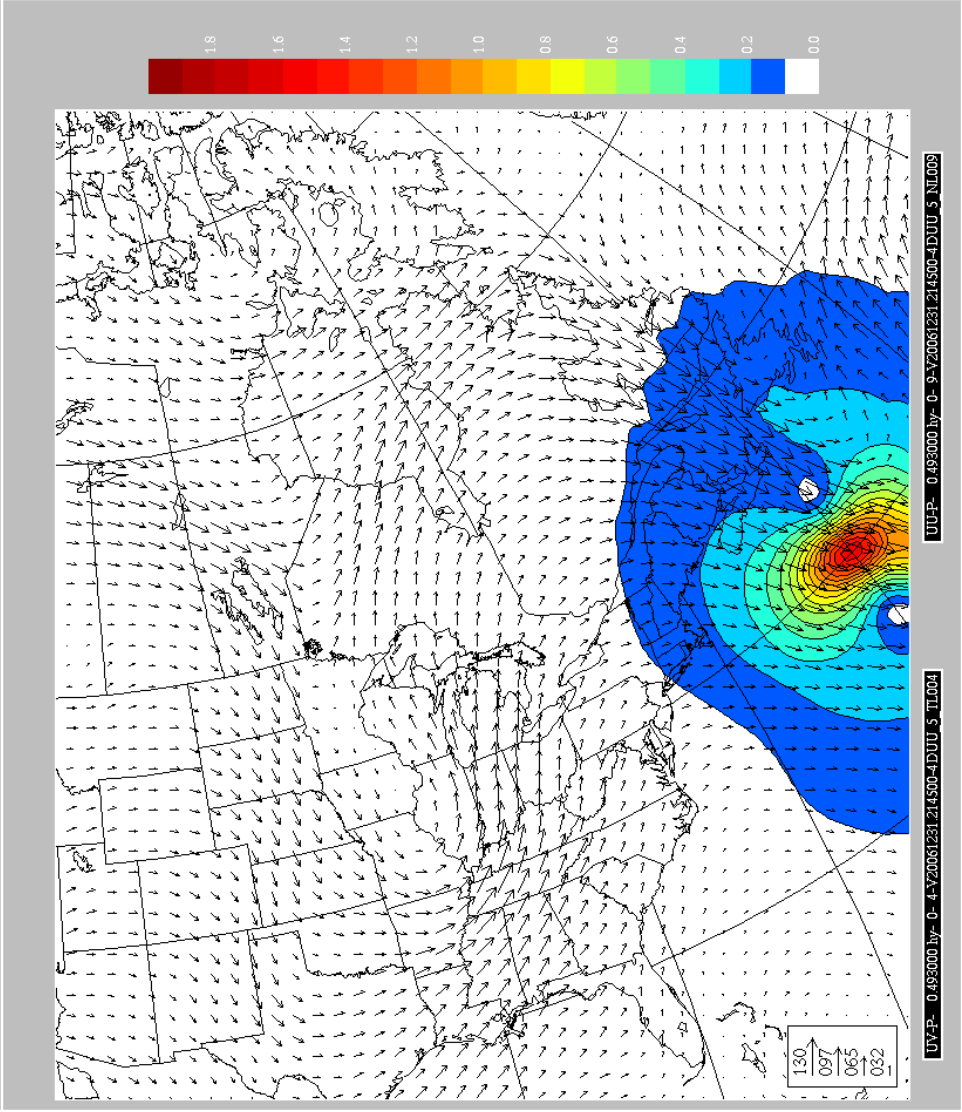
T = -3.00 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

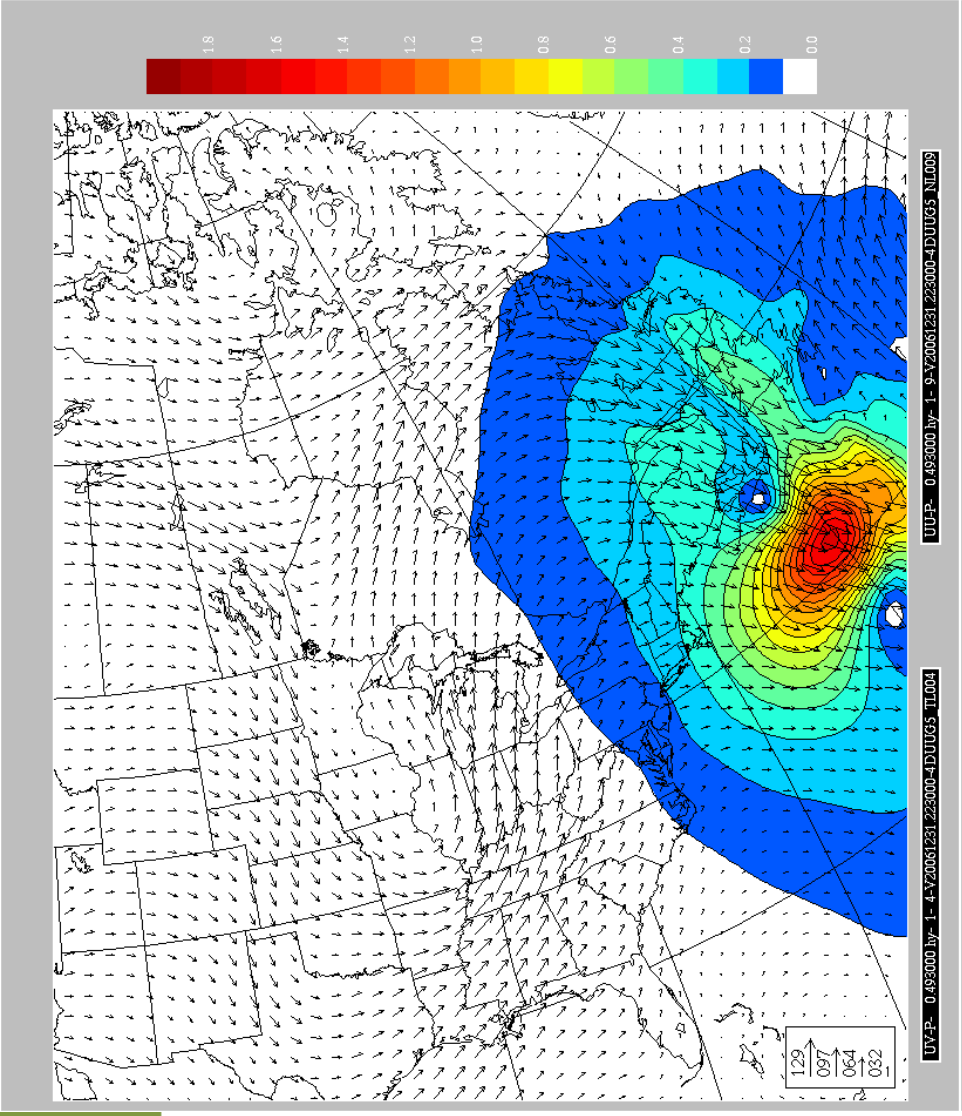
4D-Var LAM 55km

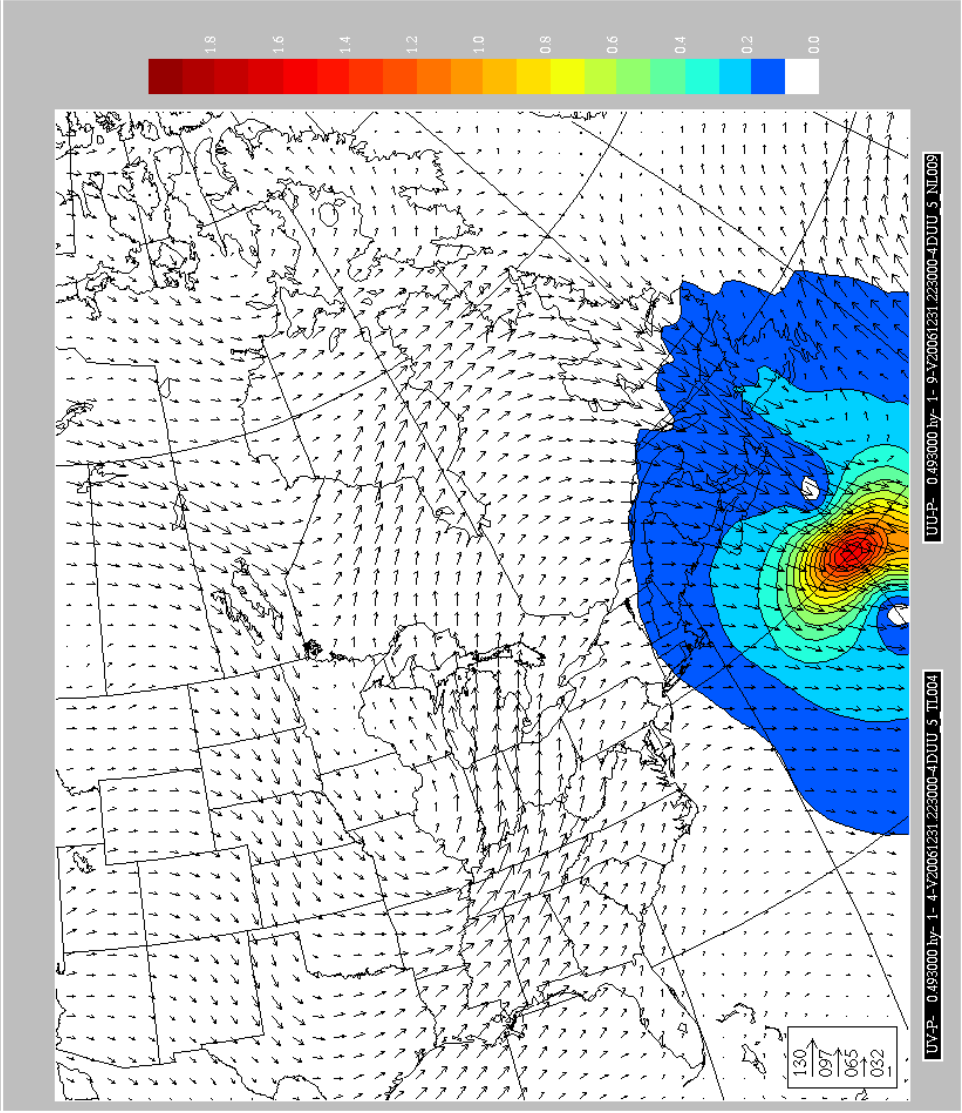
T = -2.15 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

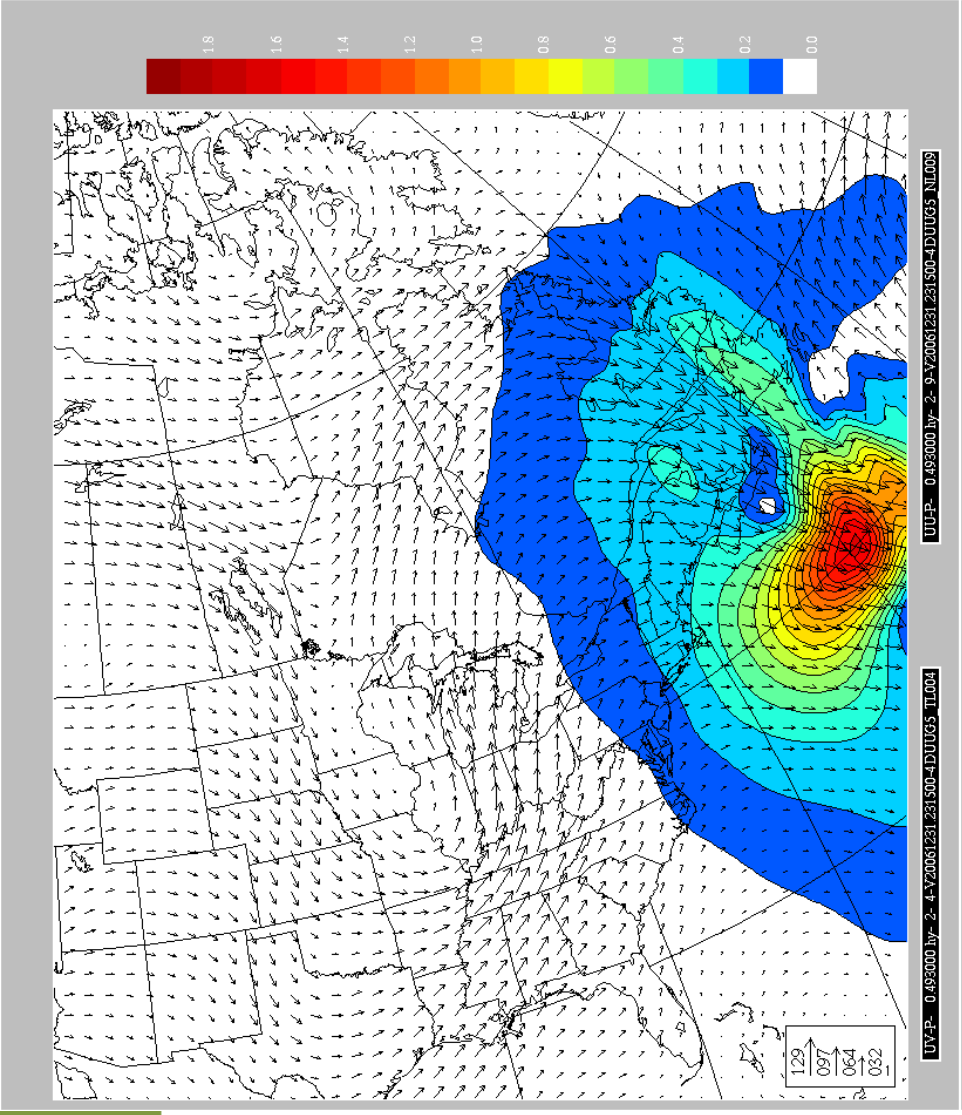
4D-Var LAM 55km

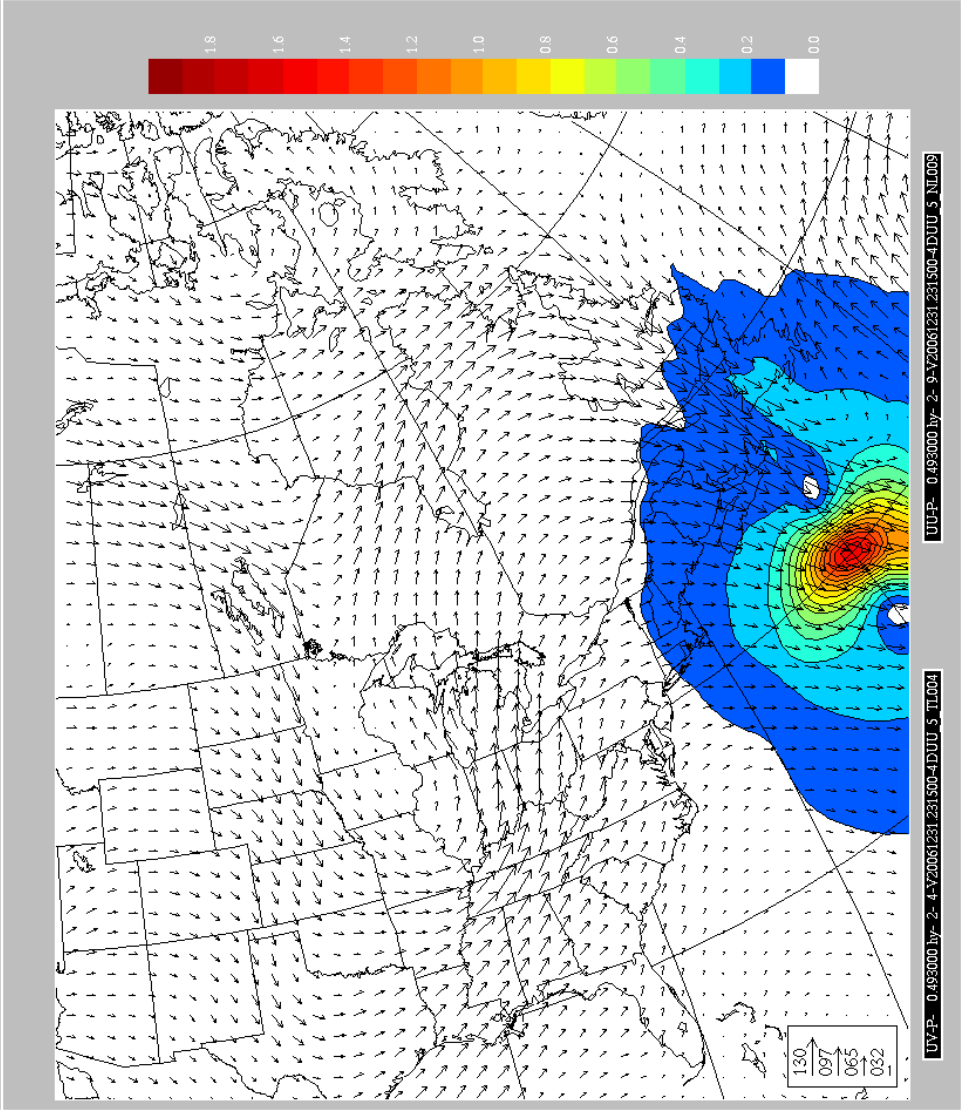
T = -1.30 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

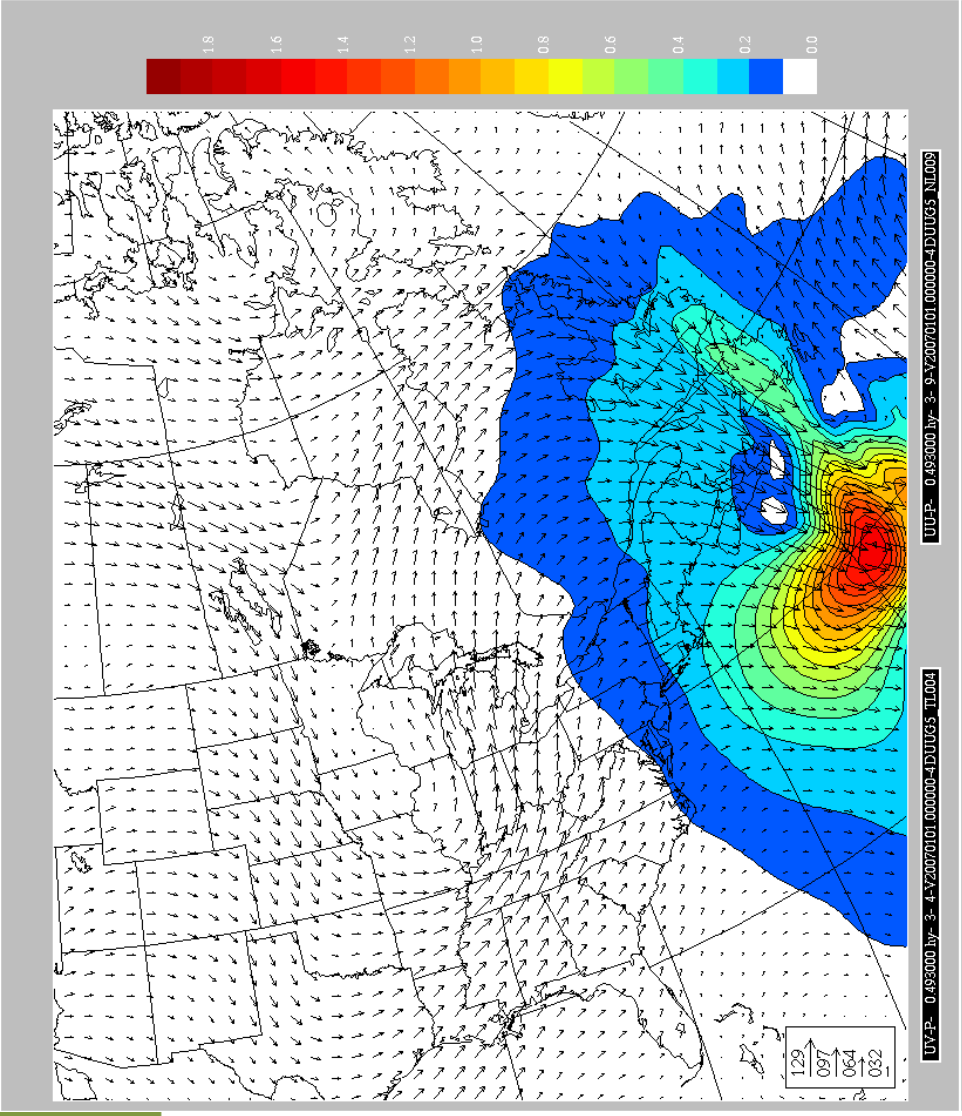
4D-Var LAM 55km

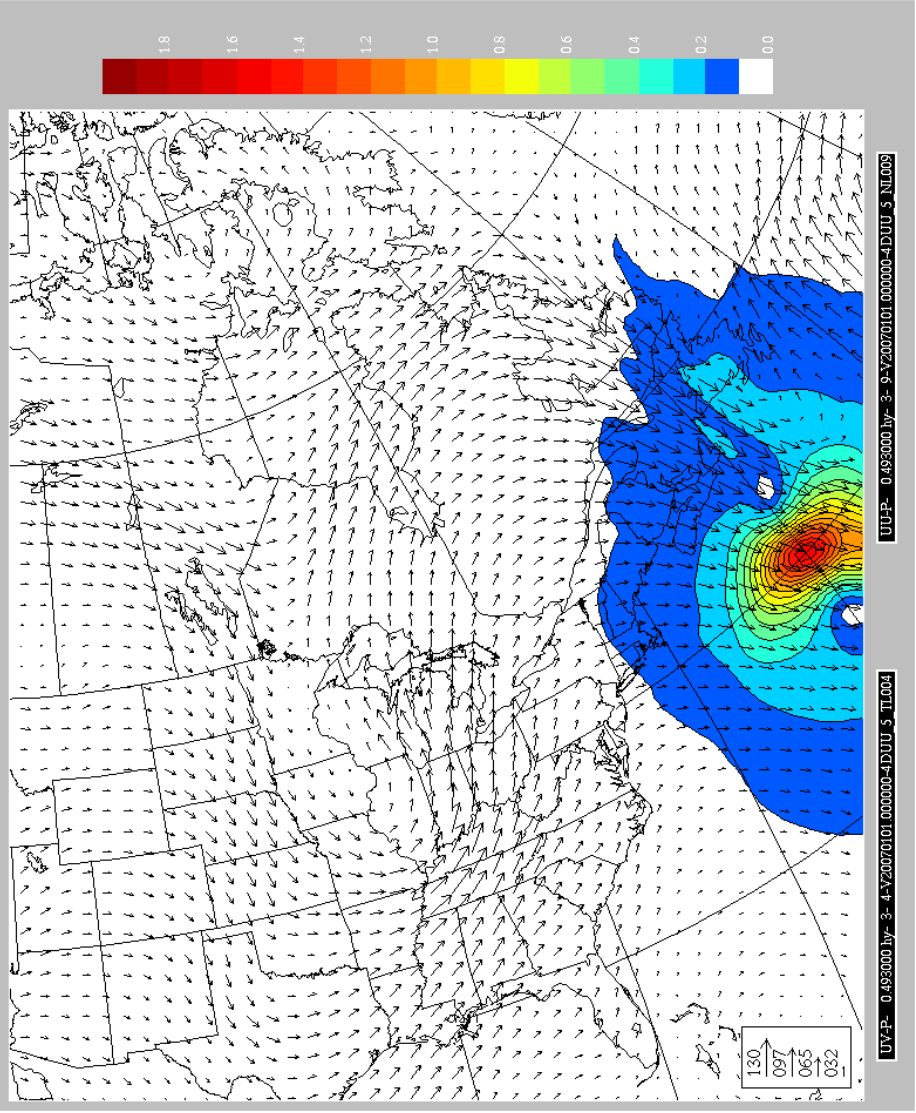
T = -0.45 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

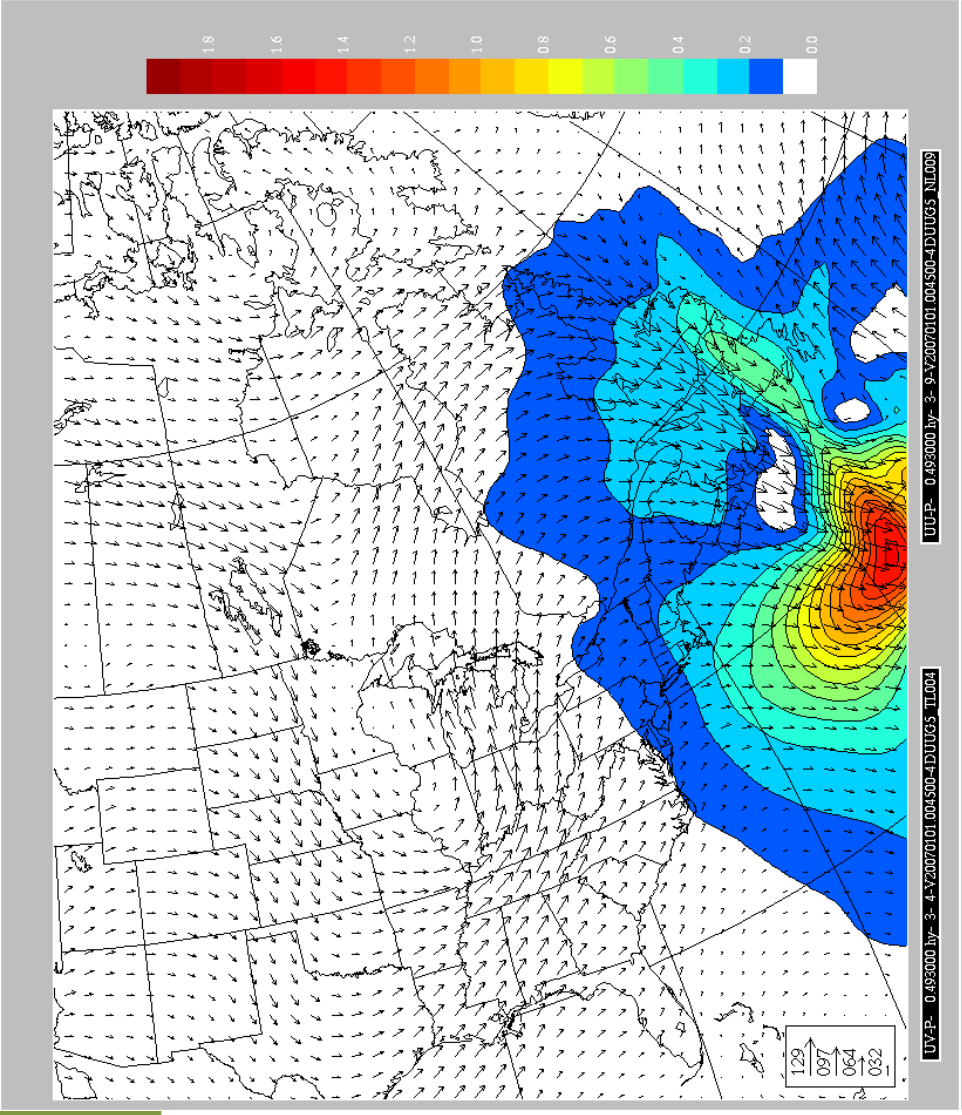
4D-Var LAM 55km

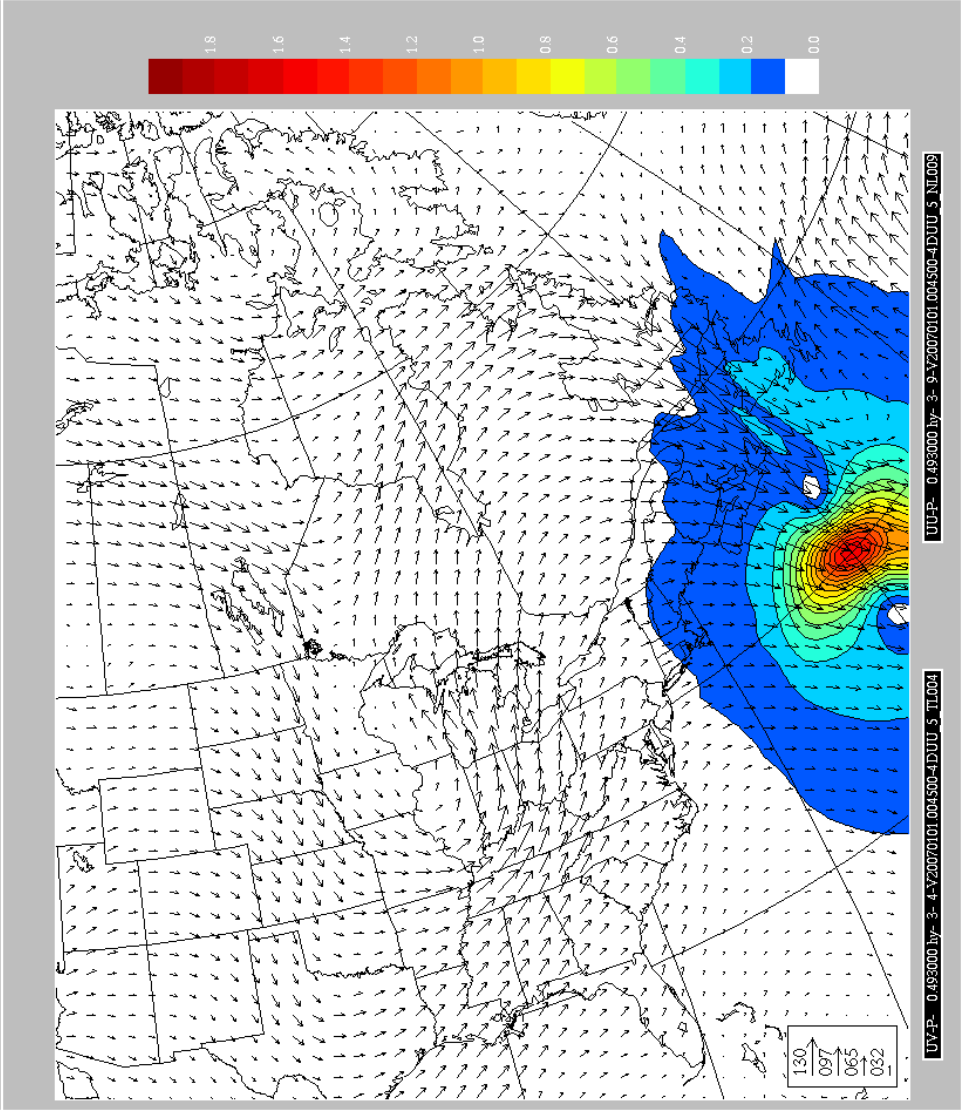
T = +0.00 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

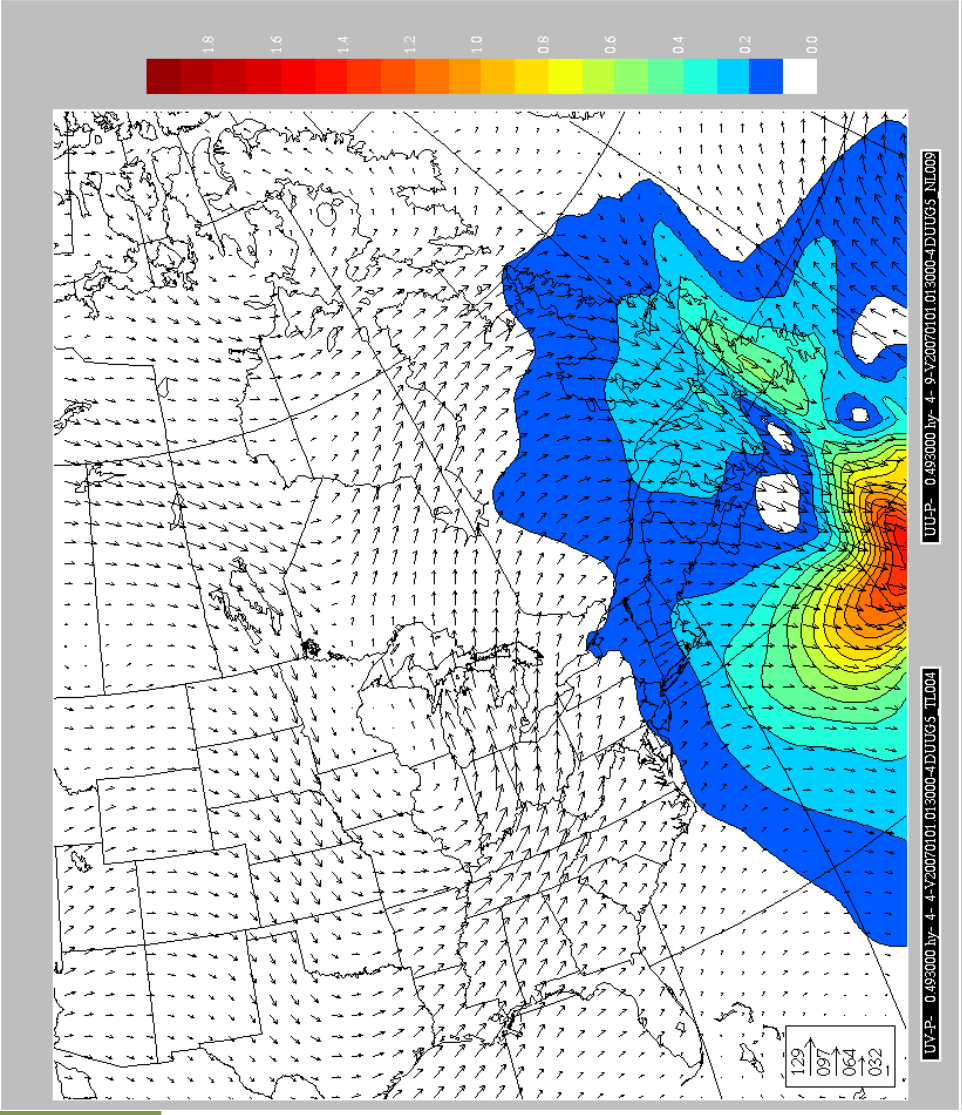
4D-Var LAM 55km

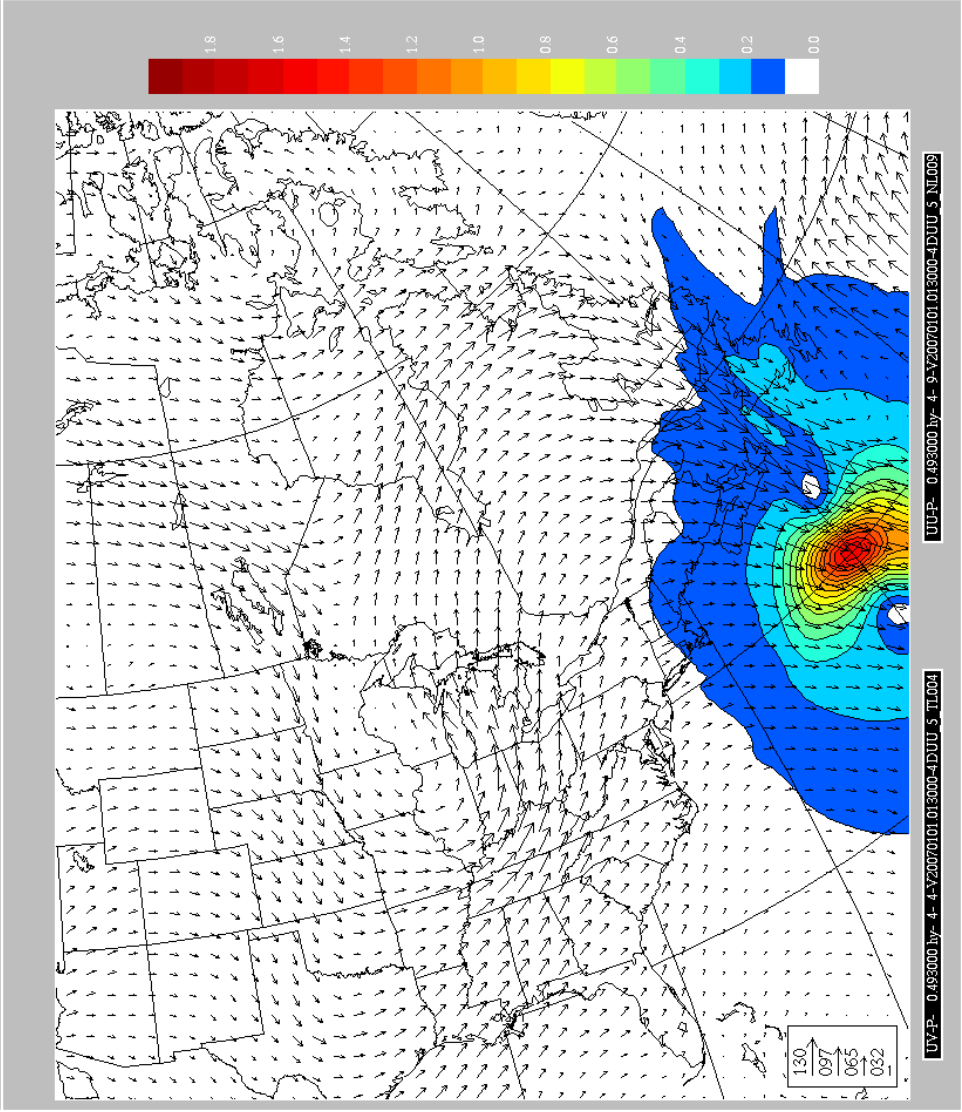
T = +0.45 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

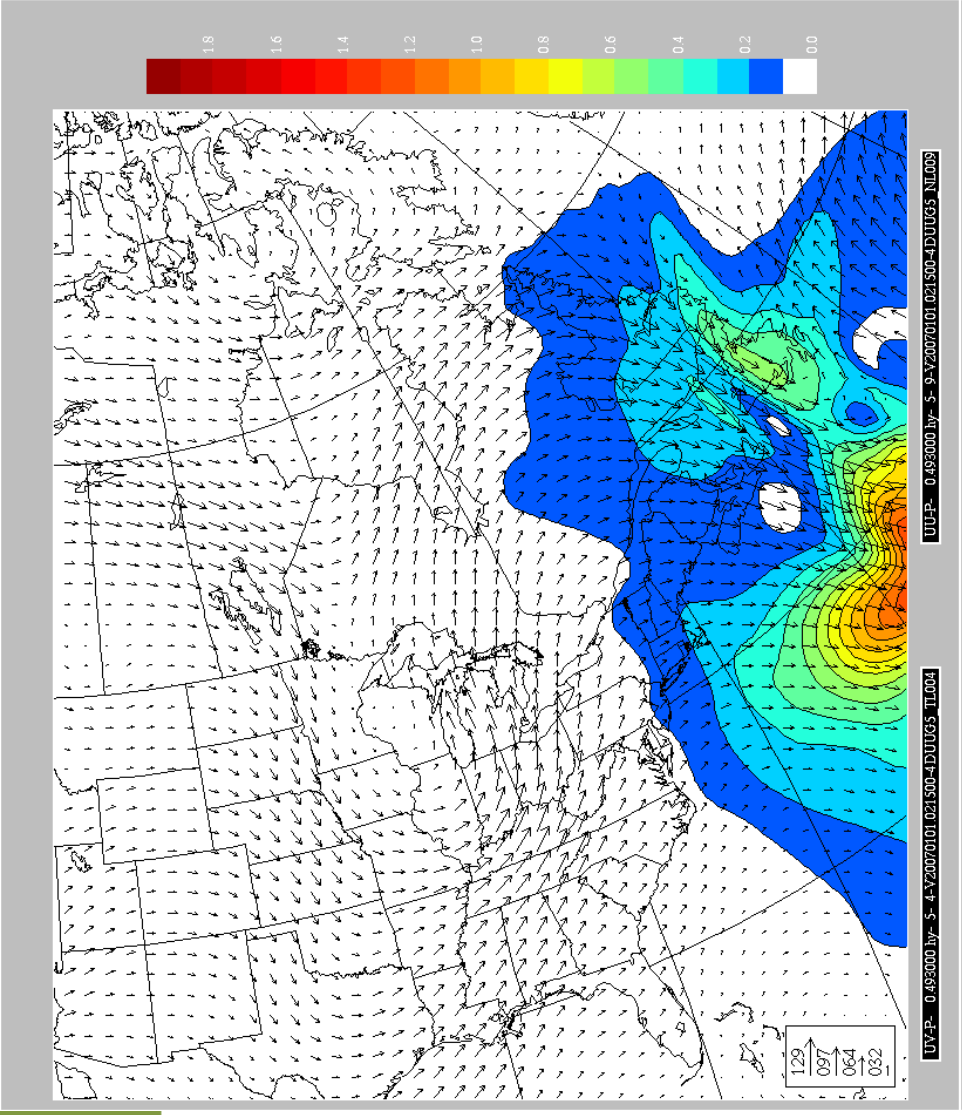
4D-Var LAM 55km

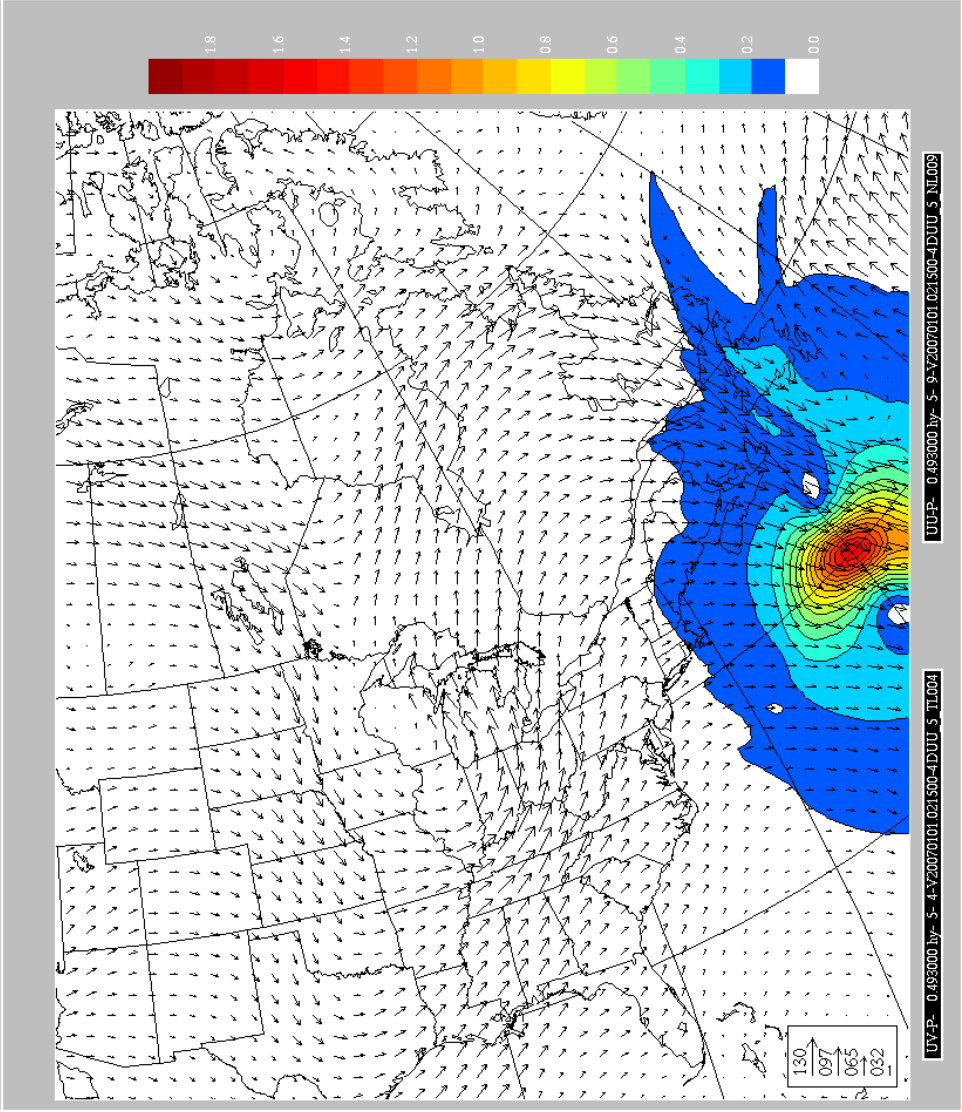
T = +1.30 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

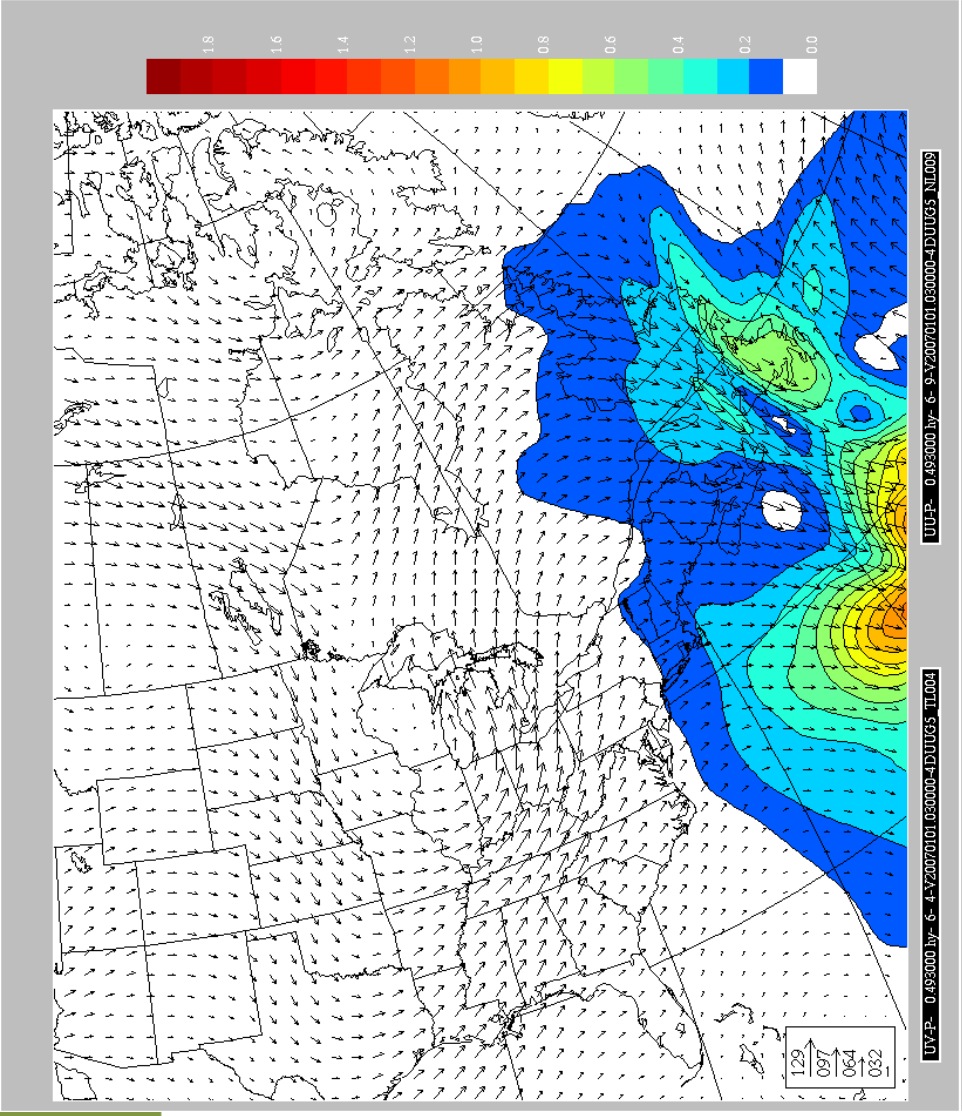
4D-Var LAM 55km

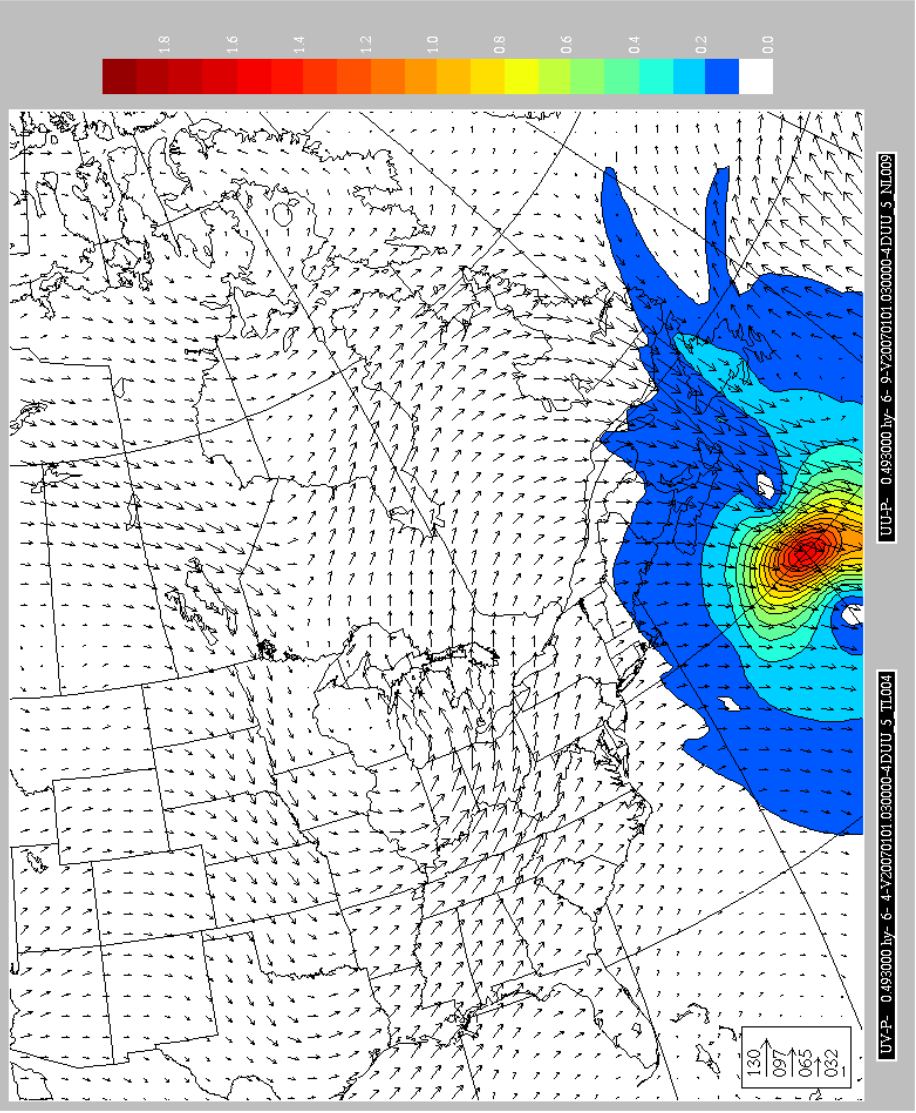
T = +2.15 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





4D-Var GLB 170km

4D-Var LAM 55km

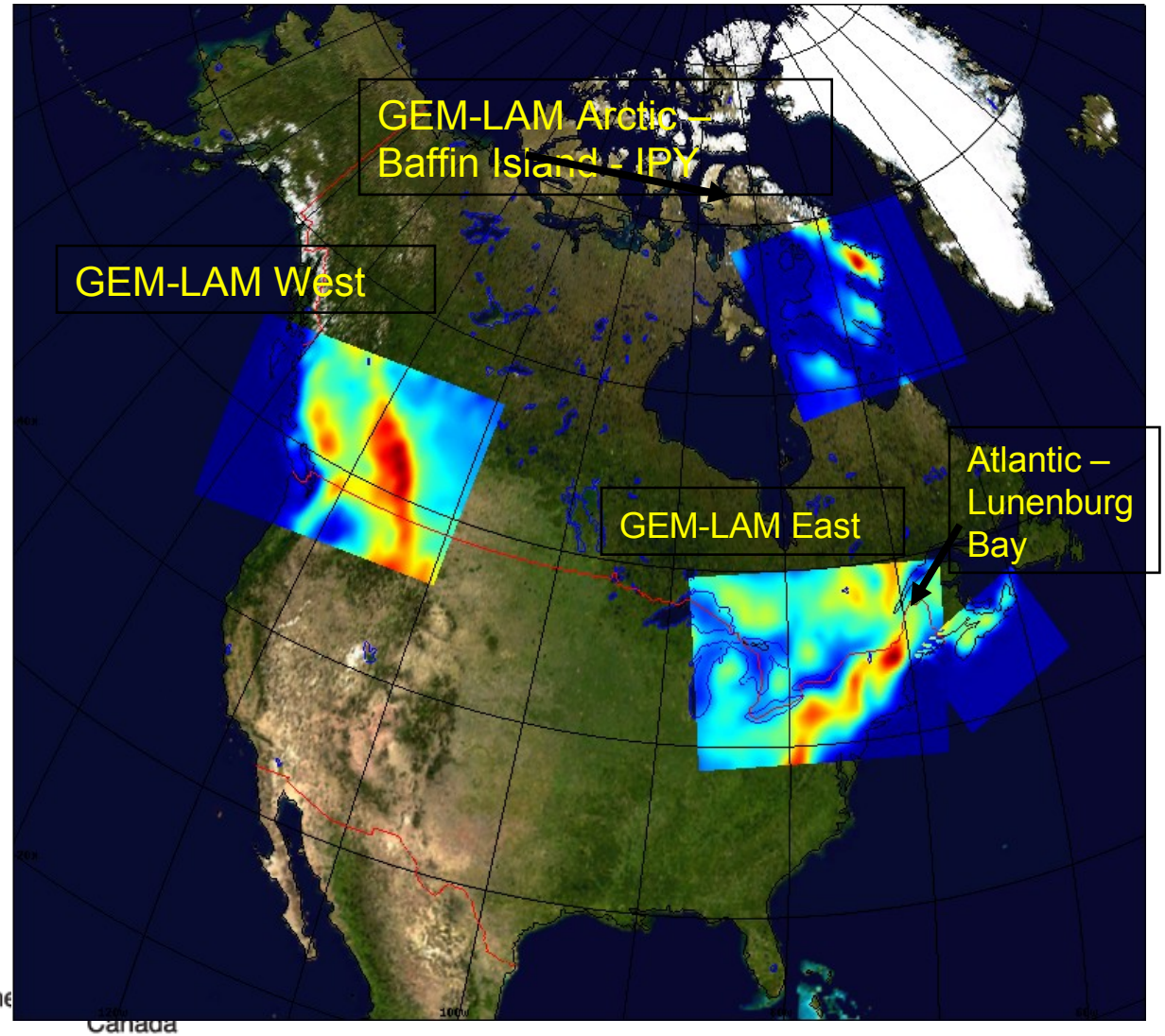
T = +3.00 hr

Environment Canada Environnement Canada

Canada

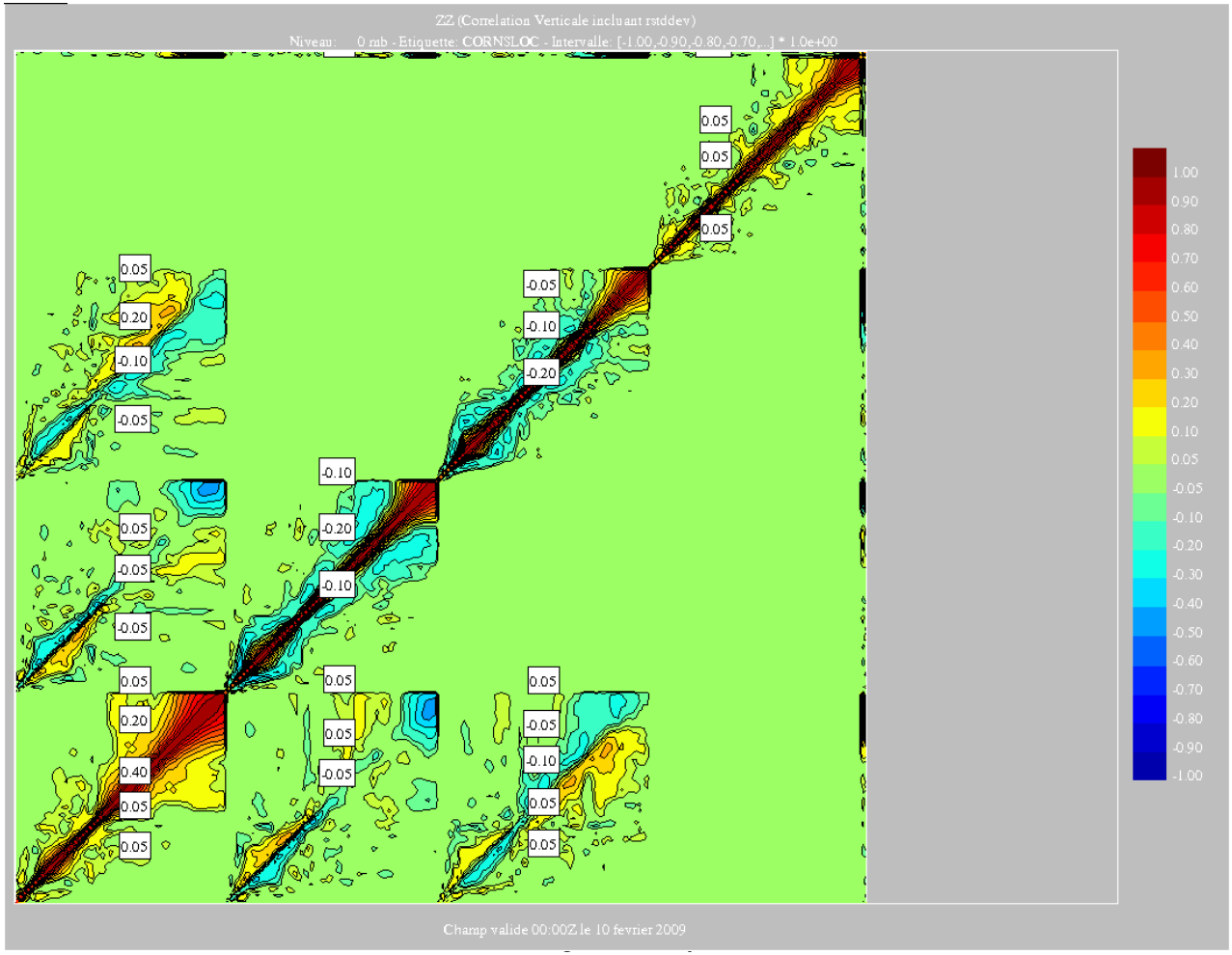
Obs Vent 500 mb

Current local very high resolution windows
Also 1-km window for 2010 winter Olympics



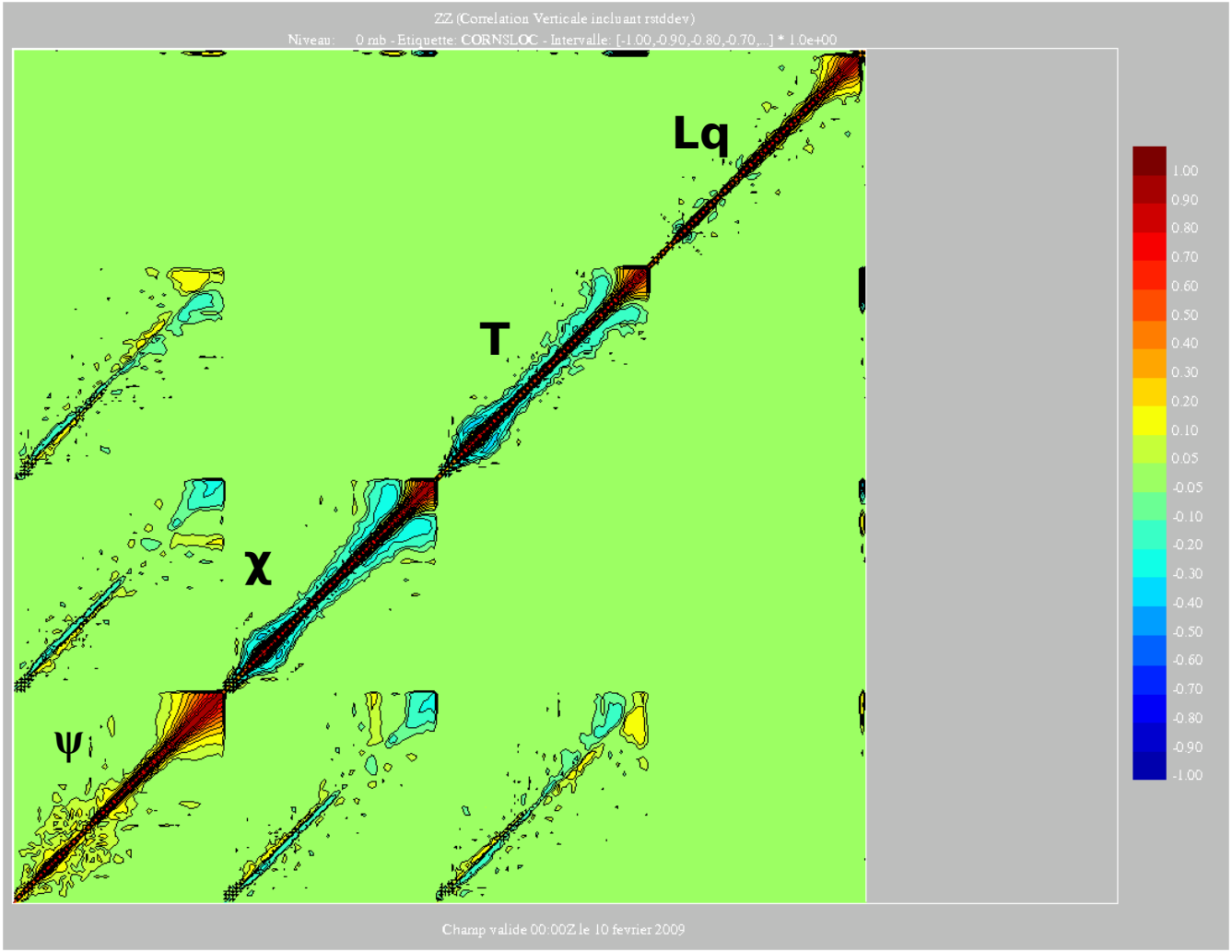
VO-LAM3D-15km
3000 km x 2500 km domain
NMC-12-06h GEM-15km LAM Fcst diff; 150 samples (FEB-Mar 09)

k = 5



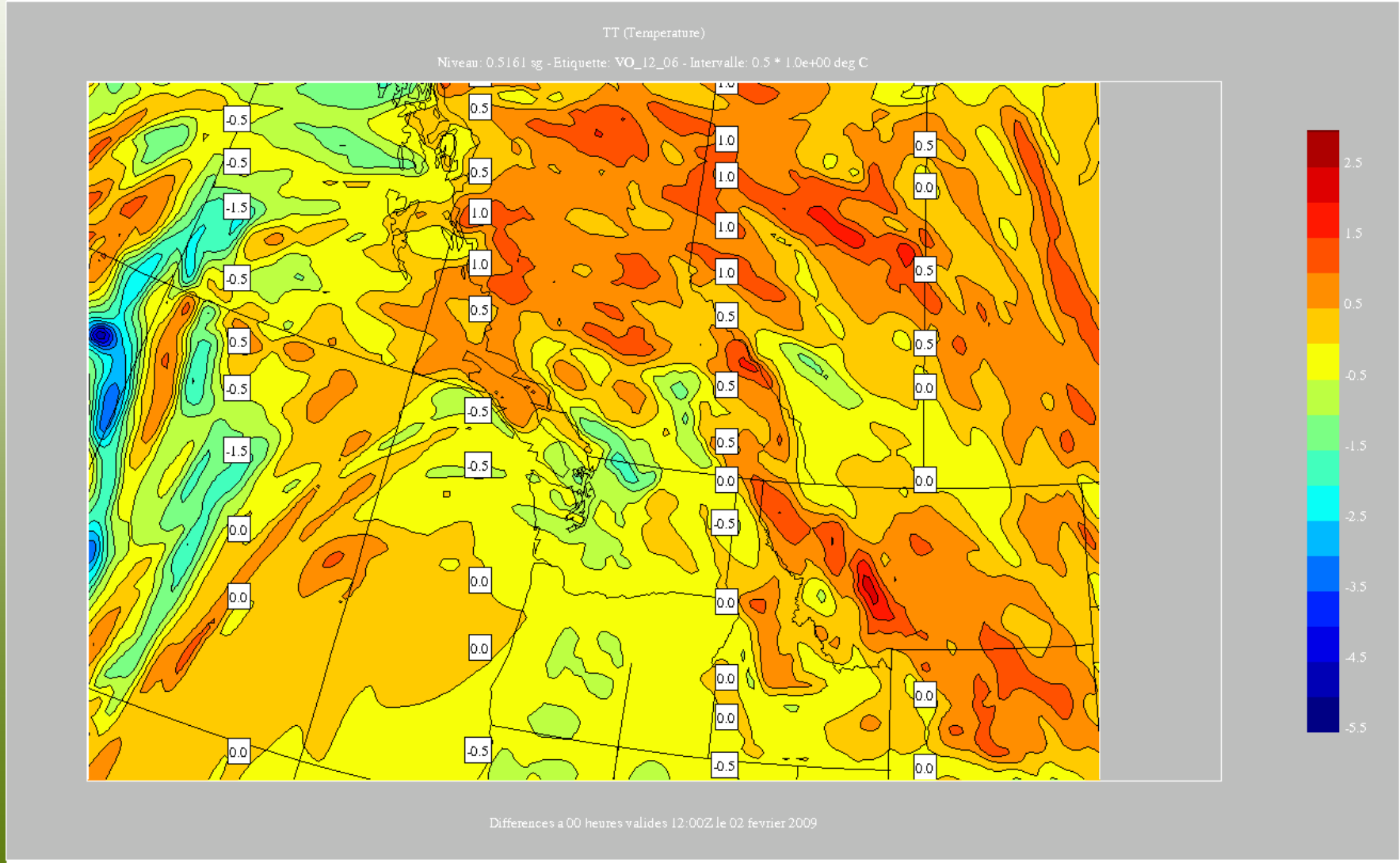
VO-LAM3D-15km
3000 km x 2500 km domain
NMC-12-06h GEM-15km LAM Fcst diff; 150 samples (FEB-Mar 09)

k = 25



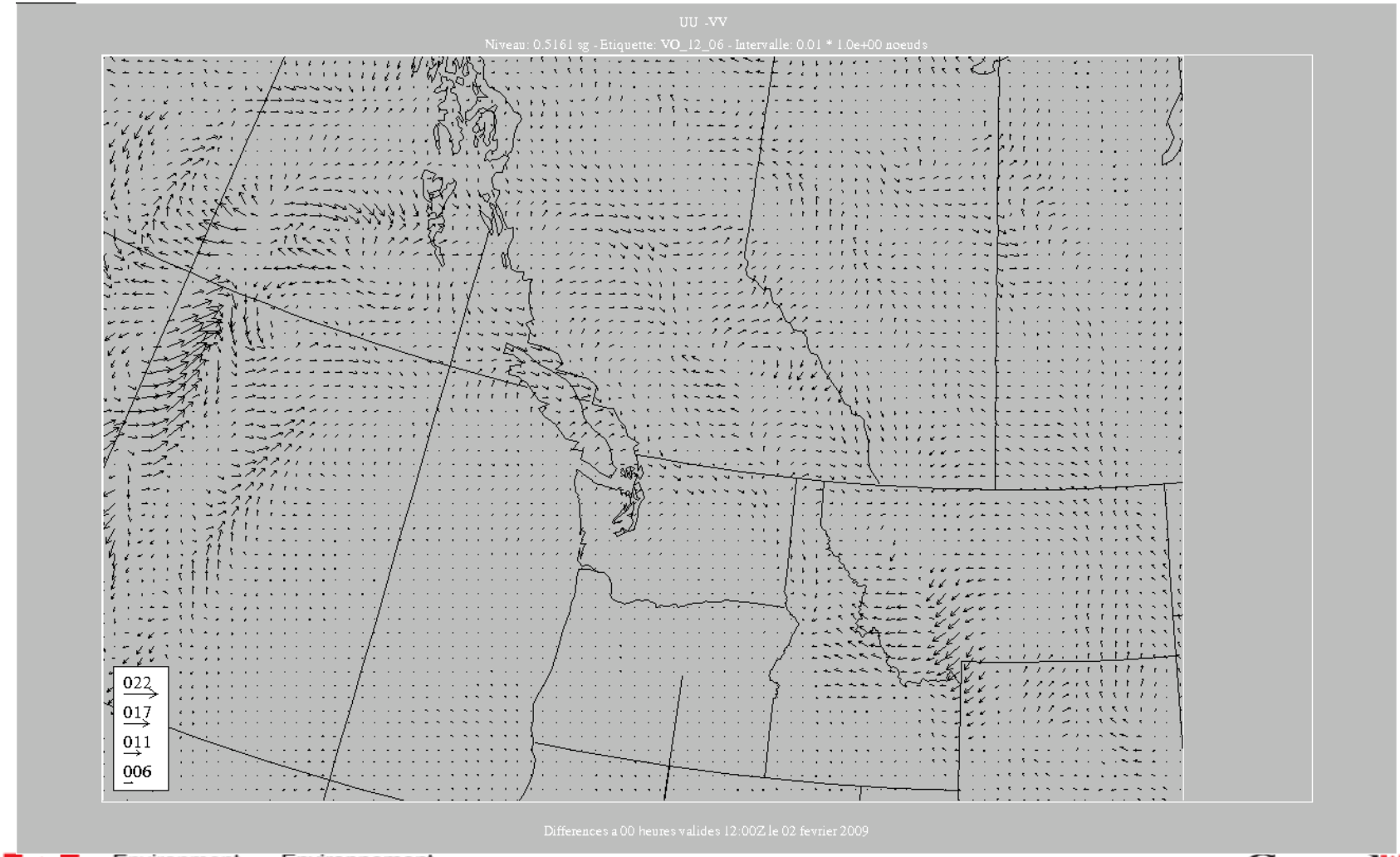
Temperature forecast error at 500 hPa

NMC-12-06h GEM-15km LAM Fcst diff; 150 samples (FEB-Mar 09)

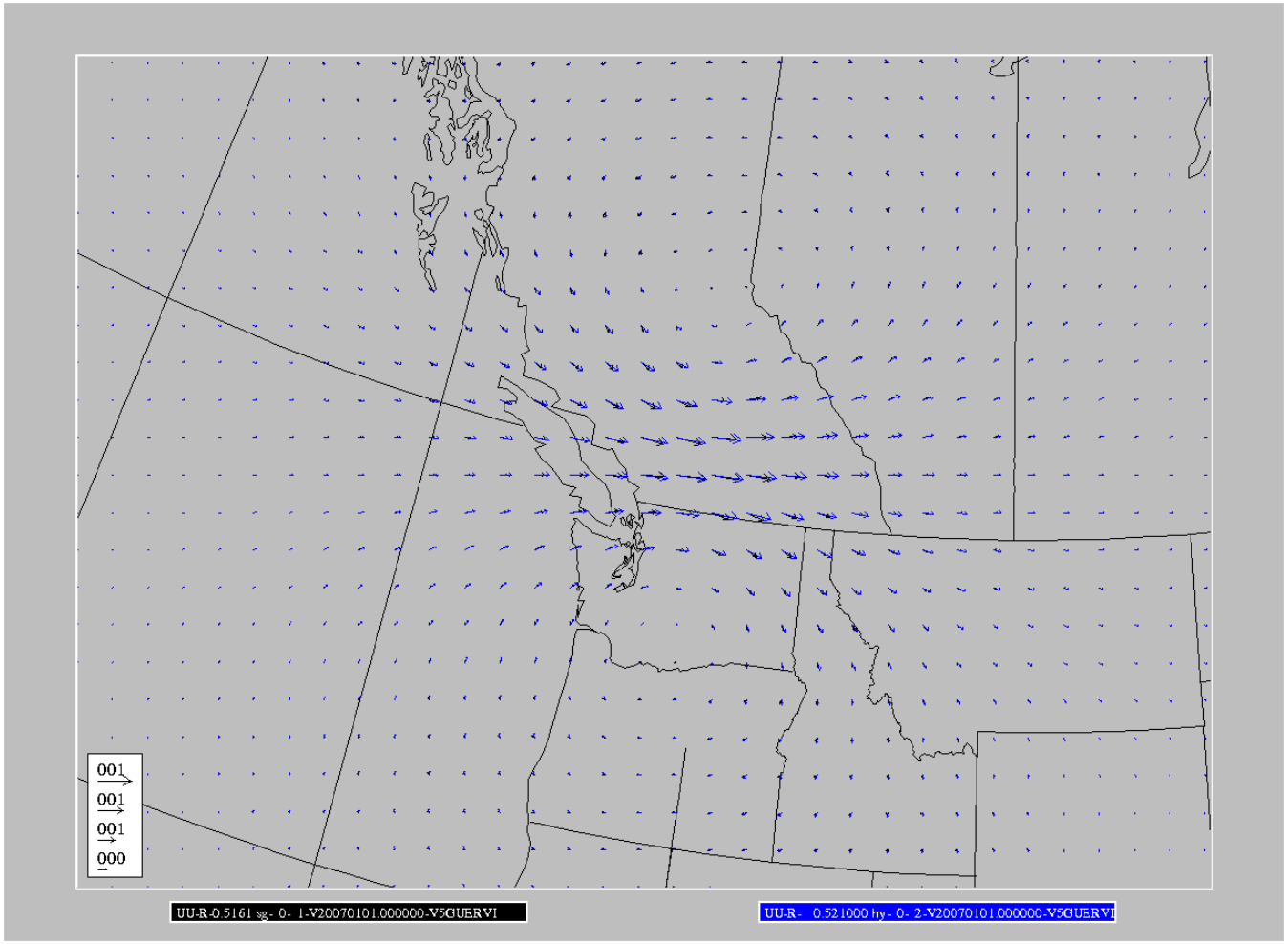


Wind forecast error at 500 hPa
12h-06h LAM-15km forcasts

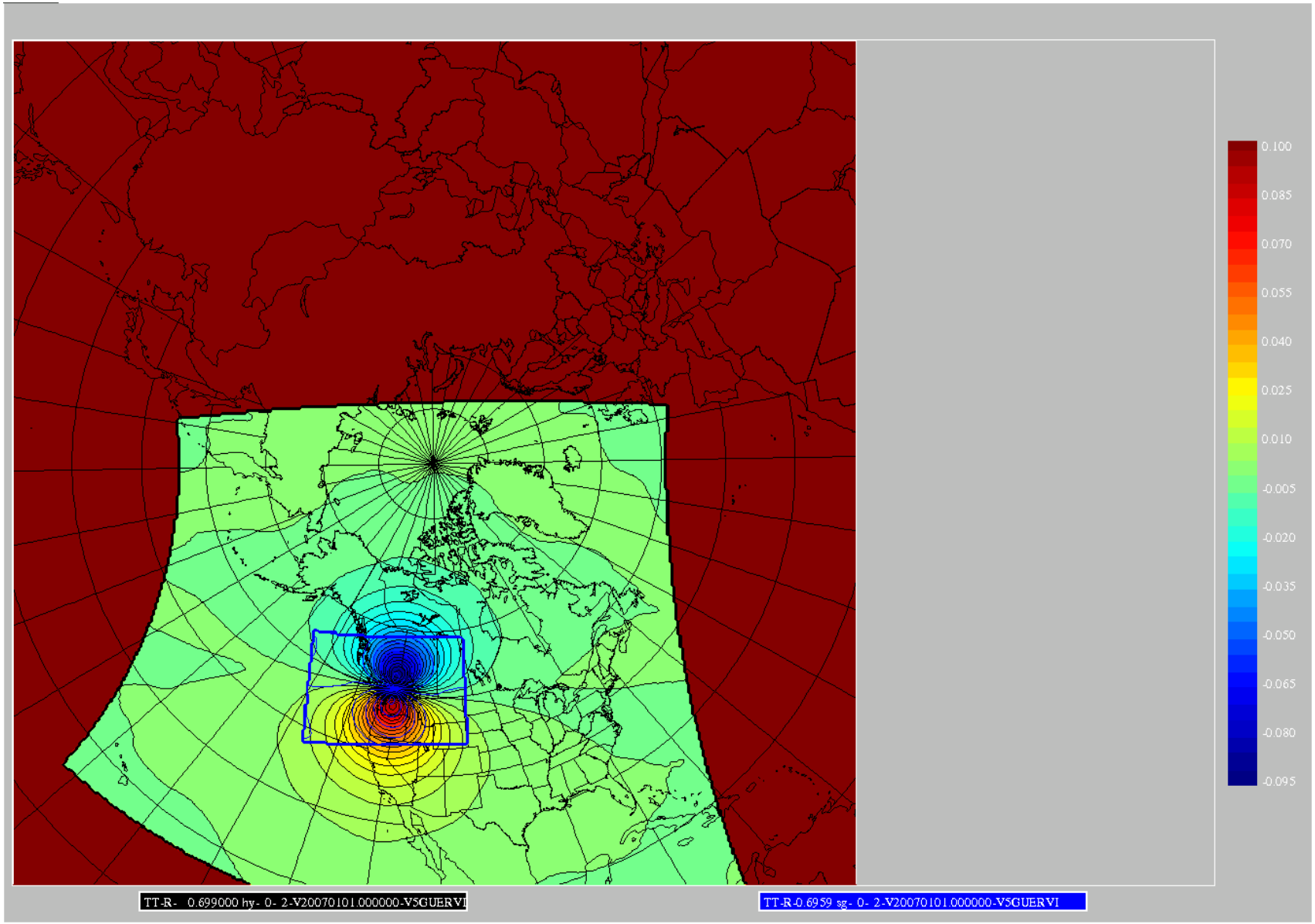
NMC-12-06h GEM-15km LAM Fcst diff; 150 samples (FEB-Mar 09)



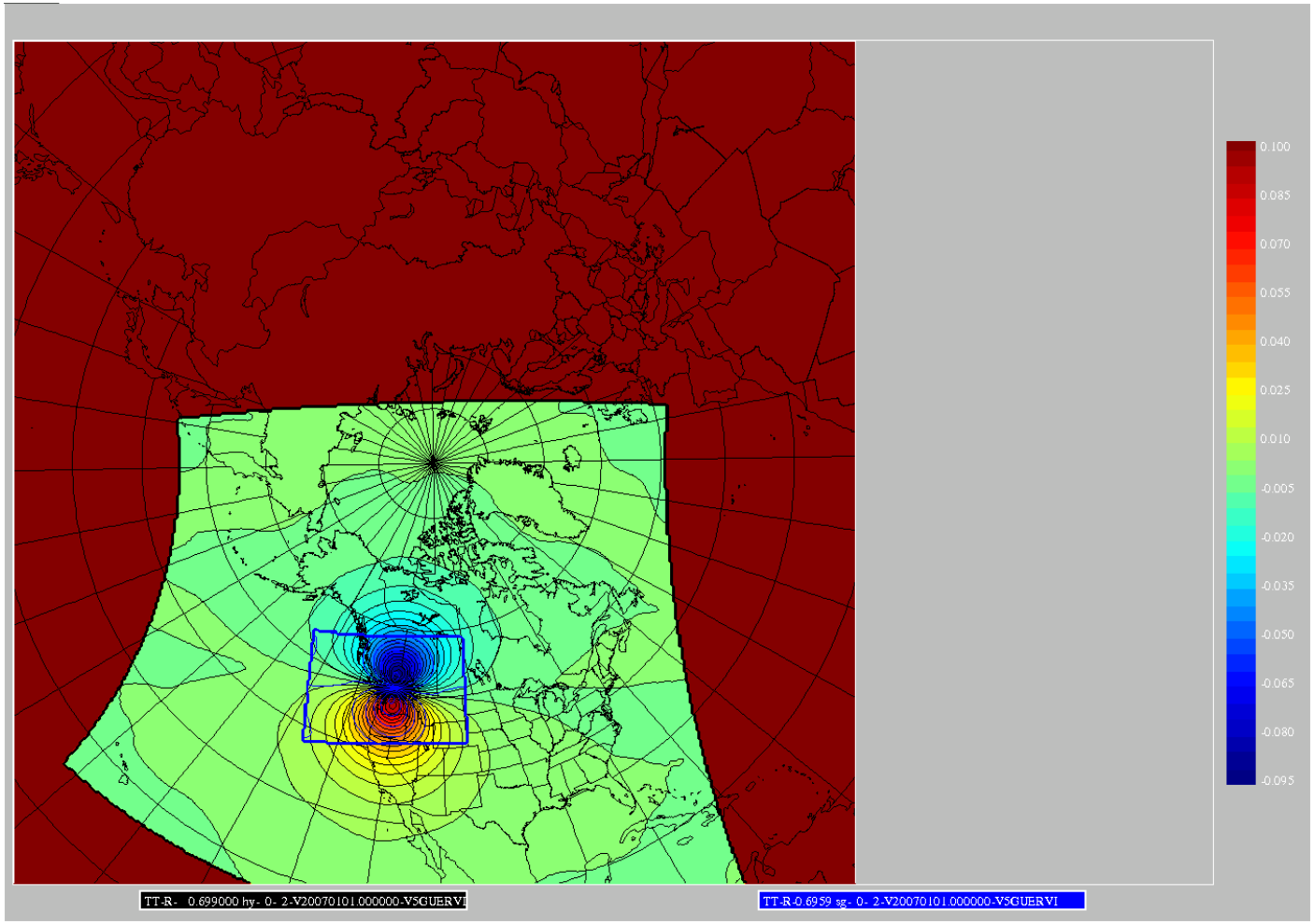
TT Incr. 700 hPa; 1-Obs-UU-500 hPa
LU-15km versus LU-55 km



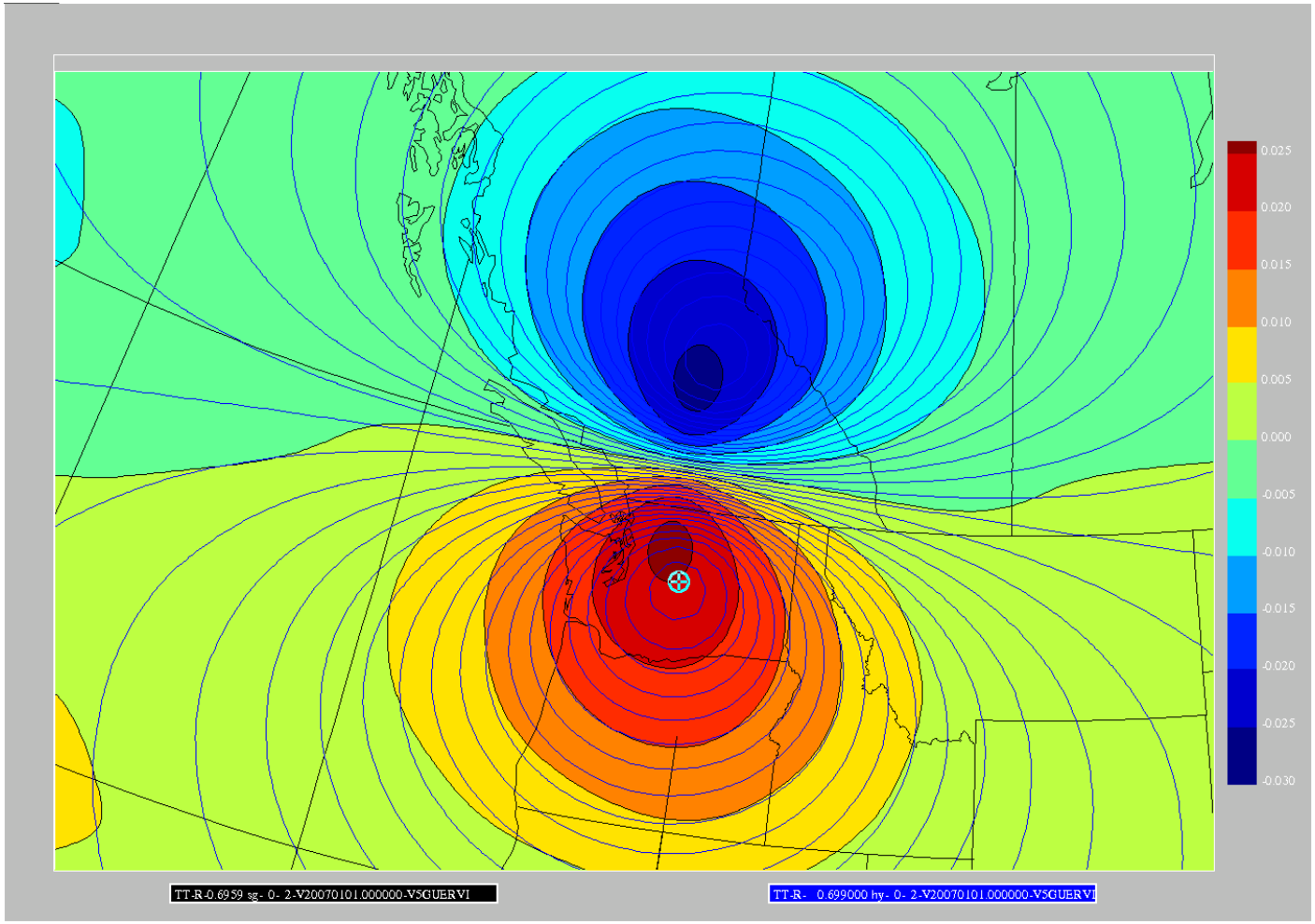
TT Incr. 700 hPa; 1-Obs-UU-500 hPa
LU-15km versus LU-55 km



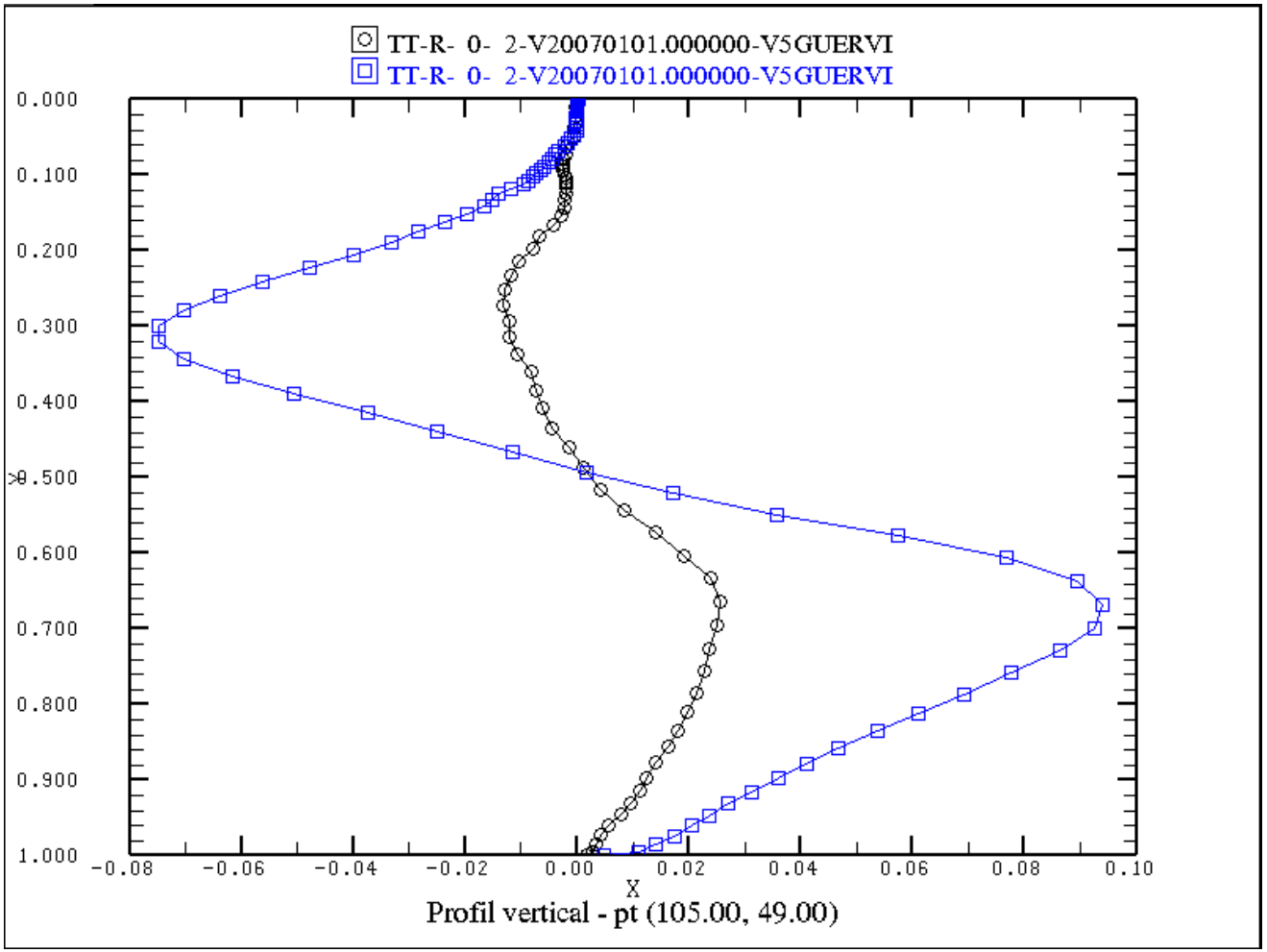
TT Incr. 700 hPa; 1-Obs-UU-500 hPa
LU-15km versus LU-55 km



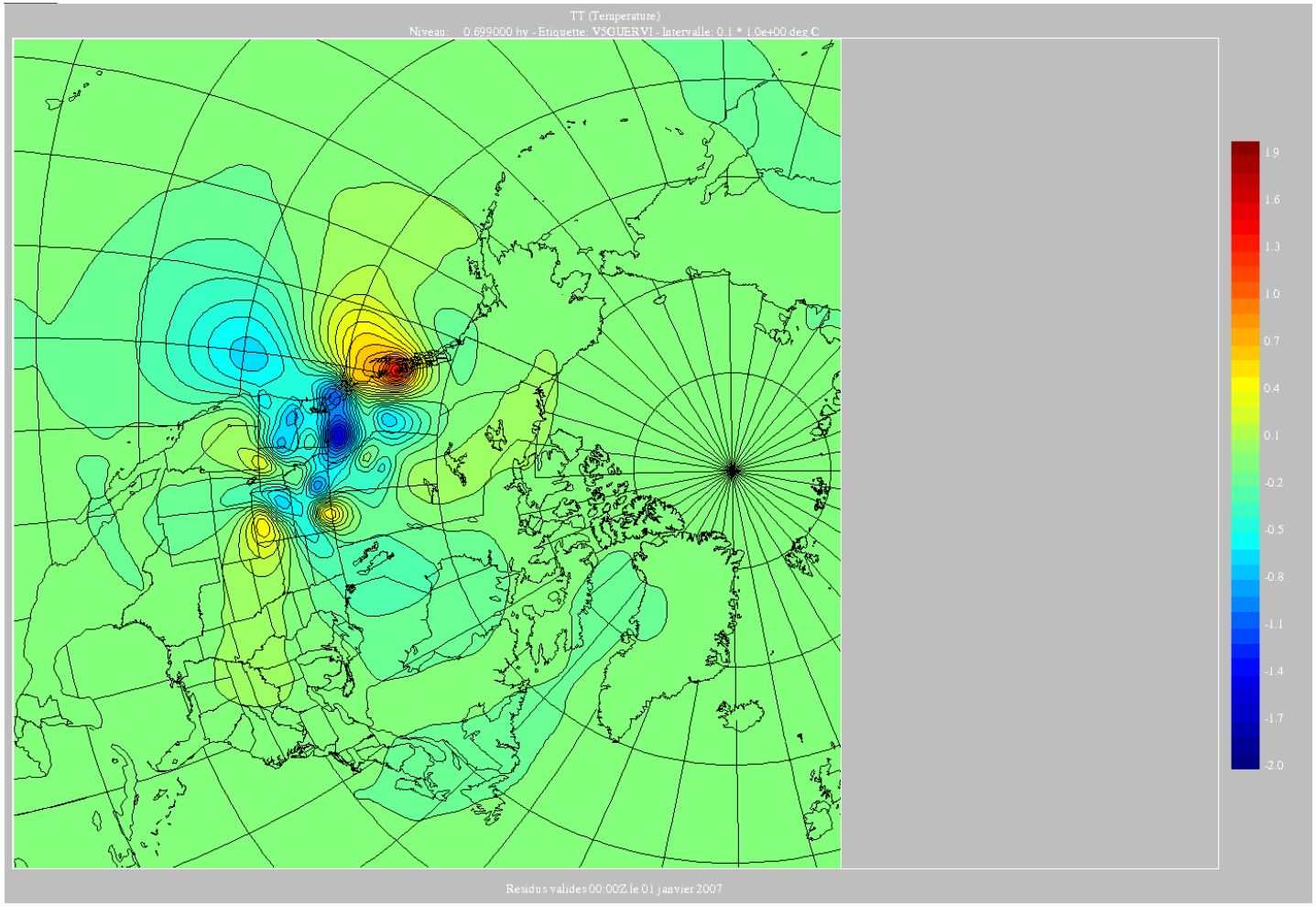
TT Incr. 700 hPa; 1-Obs-UU-500 hPa
Lu-15 km versus LU-55 km



TT Incr. Over Center H
Lu-15 km versus LU-55 km

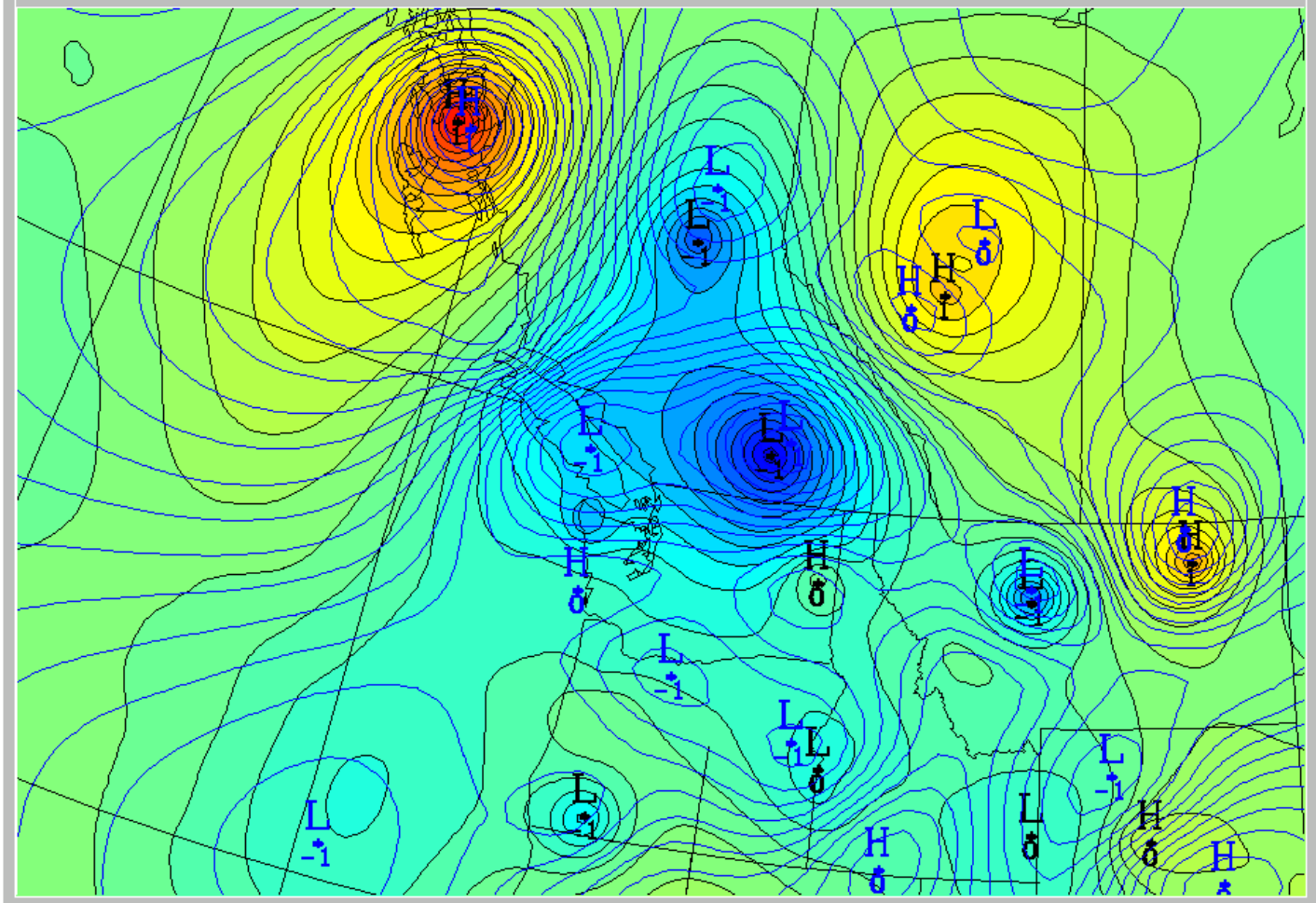


Radiosonde data, TT incr. 500 hPa, LU-55km

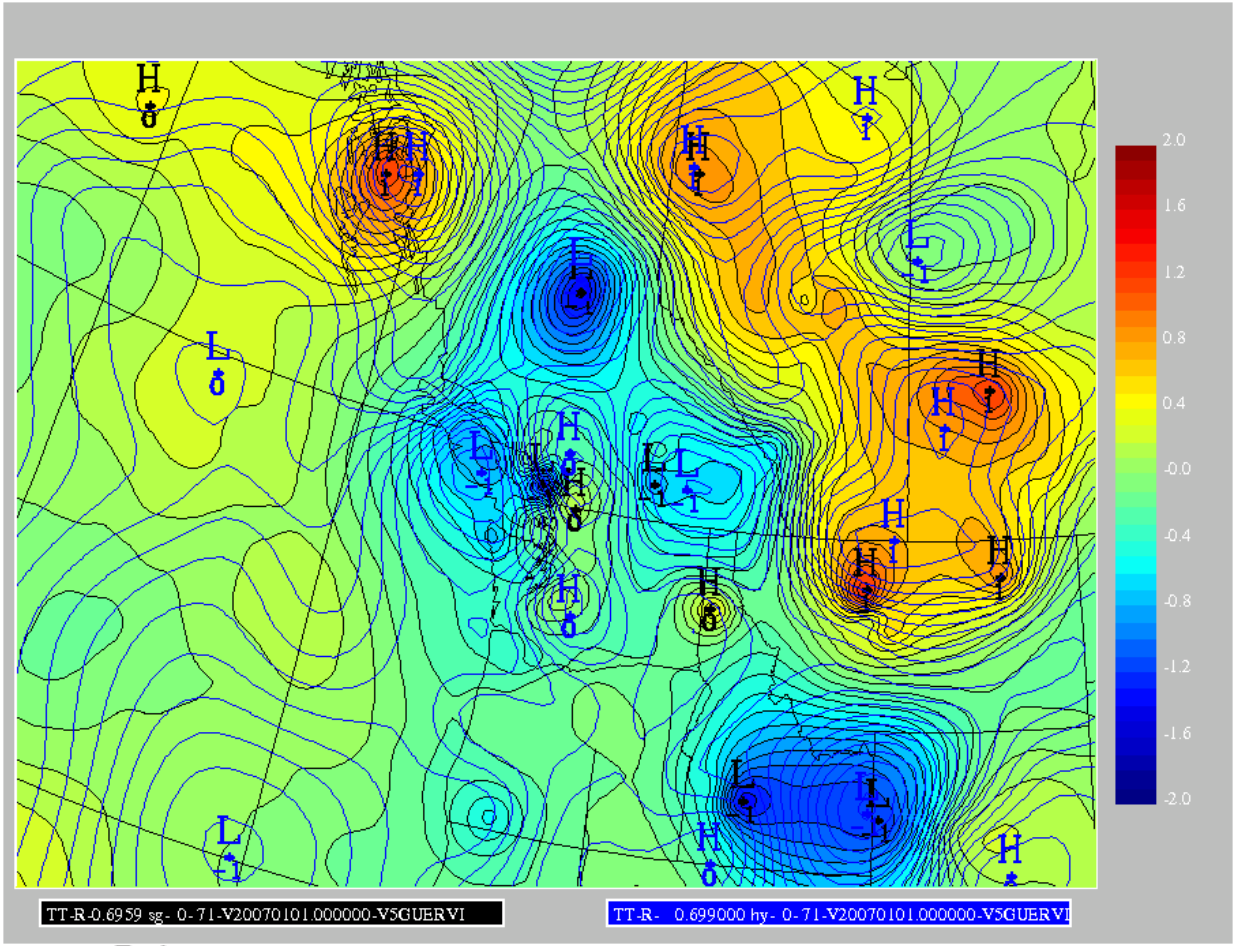


Radiosonde data

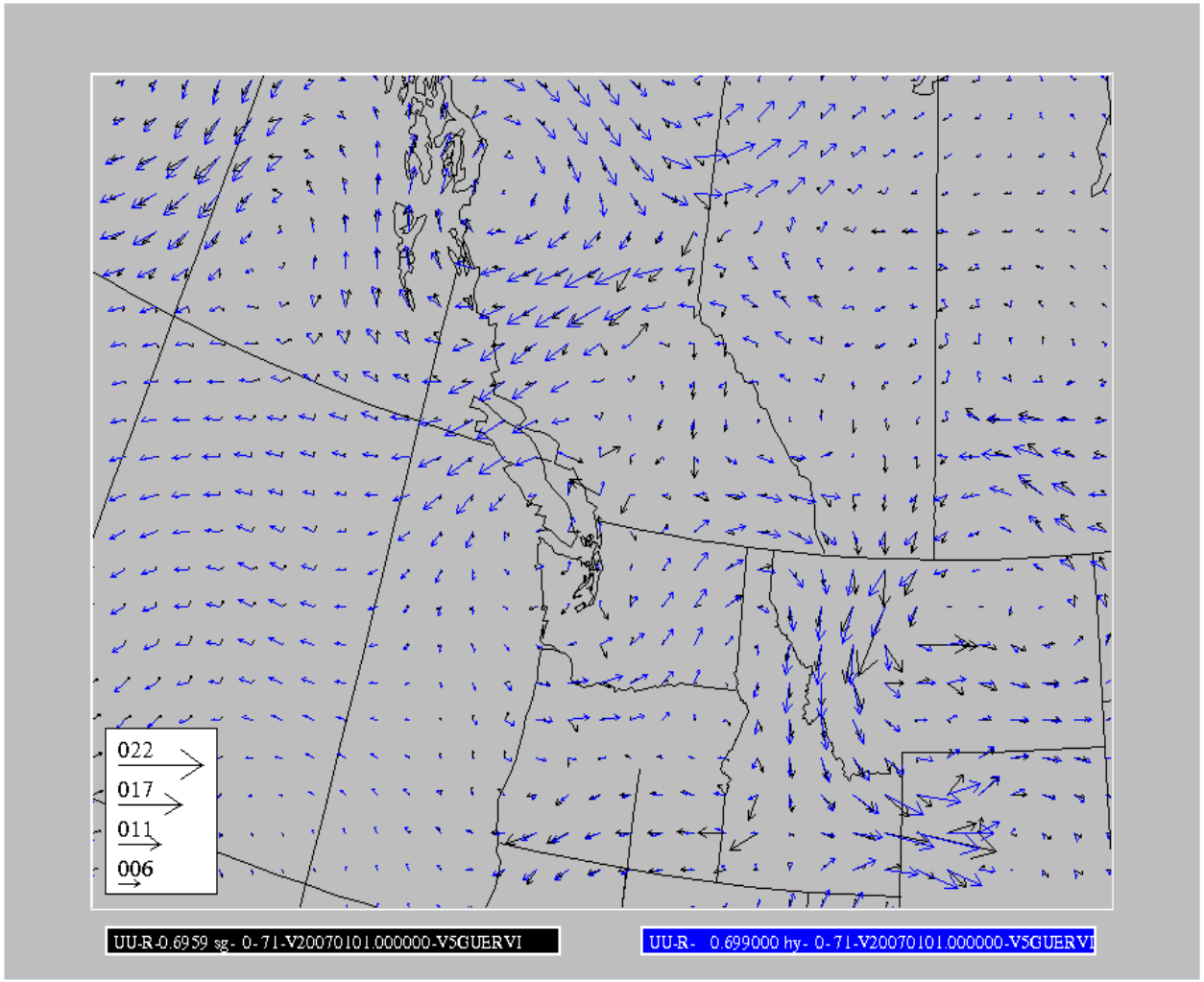
TT incr. 700 hPa, LU-15 versus LU-55km



TT incr. 700 hPa, LU-15 km versus LU-55 km: Data assimilated: ua, ai, sw, sf, to, bo, go, pr, sc, ro



Wind incr. 700 hPa, LU-15 km versus LU-55 km:
Data assimilated: ua, ai, sw, sf, to, bo, go, pr, sc, ro



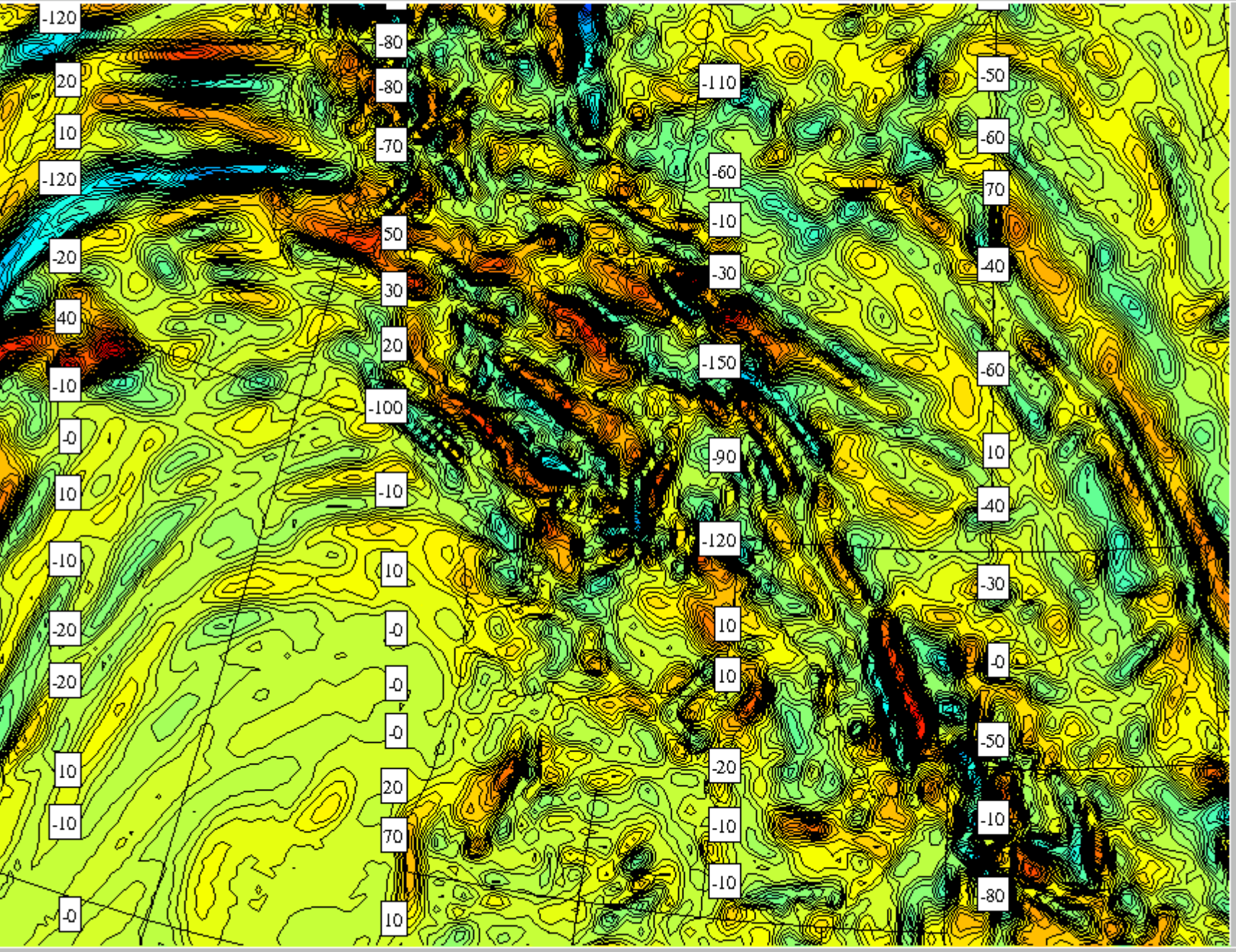
VO-LAM-3D, 2.5km

- Generate 2.5km forecast error samples (Mailhot et al. Sept 2009)
- Compute B statistics, NMC-type at 2.5 km.(Sept. 2009)
- Examine Impact of VO-LAM-3D, 15km & 2.5km on GEM-2.5 forcasts. (CMC collaboration).

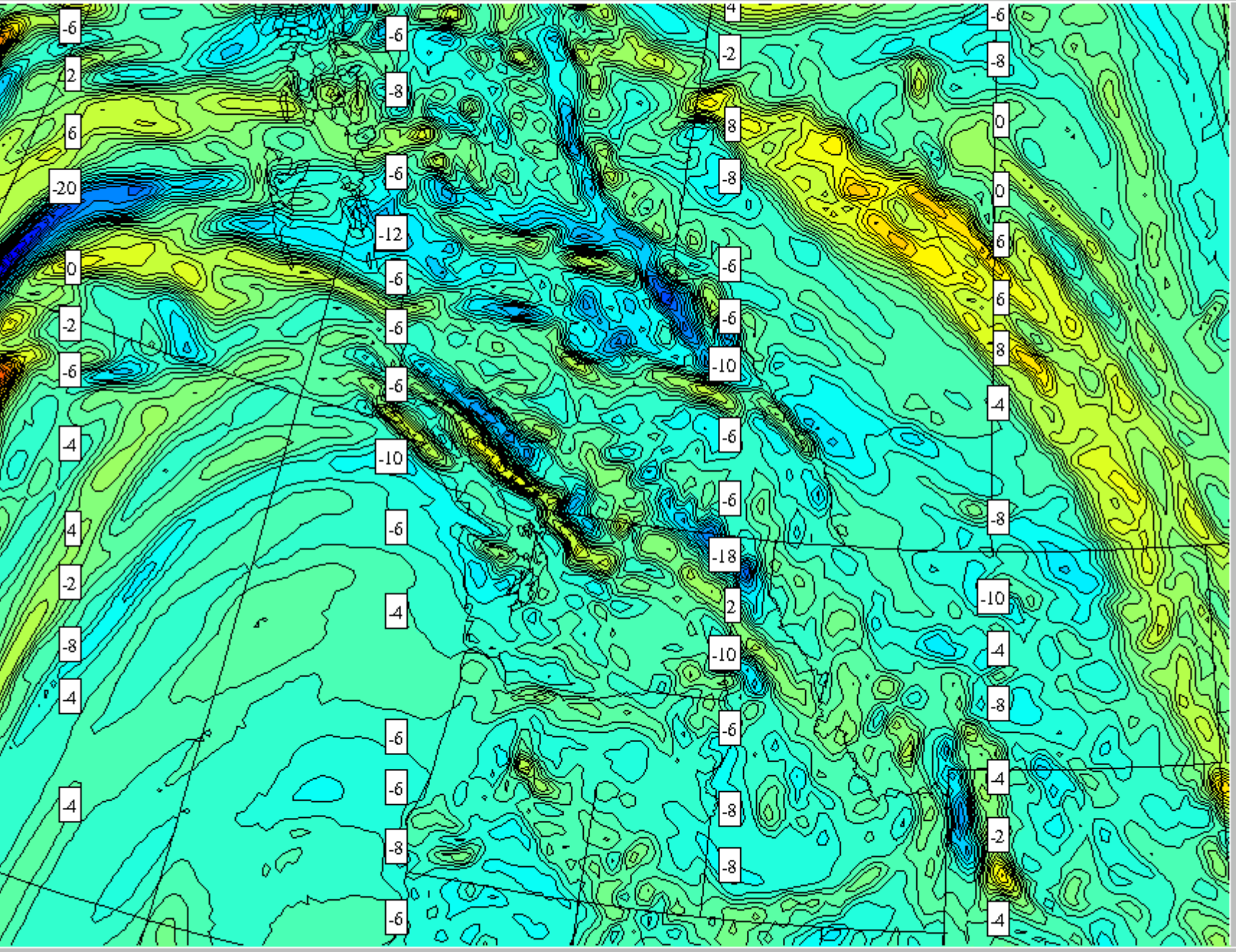
QC-VAR-3D-1km: Radar Data Assimilation EC-McGill Collaboaration (Zawadzki et al)

- Perform NMC-6h Background error statistics at 2.5 km over QC-Grid. Ensemble approach to be explored also.
- Implement radial wind obervation operator
- Etc…
- Work starting Sept. 2009. Kao-Shen Chung PhD. At McGill to assist.

Niveau: 0.5161 sg - Etiquette: VO_12_06 - Intervalle: 10 * 1.0e-06 (/sec),



Niveau: 0.5161 sg - Etiquette: VO_12_06 - Intervalle: 2 * 1.0e-05 /sec



Spherical Harmonics

$$\nabla^2 Y_n^m = -\frac{n(n+1)}{a^2} Y_n^m \qquad Y_n^m = P_n^m(\mu)\ e^{im\lambda}$$

Bi-Fourier

$$\nabla^2 = \frac{1}{a^2\cos^2\theta}\left\{\frac{\partial^2}{\partial\lambda^2} + \cos\theta\frac{\partial}{\partial\theta}\left(\cos\theta\frac{\partial}{\partial\theta}\right)\right\} \qquad ¿\ \frac{1}{a^2\cos^2\theta}\frac{\partial^2}{\partial\lambda^2} + \frac{1}{a^2}\frac{\partial^2}{\partial\theta^2} \approx \frac{1}{a^2}\frac{\partial^2}{\partial\lambda^2} + \frac{1}{a^2}\frac{\partial^2}{\partial\theta^2} = \frac{1}{a^2}\left(\frac{\partial^2}{\partial\lambda^2} + \frac{\partial^2}{\partial\theta^2}\right)$$

$$\left(\frac{\omega_{j+1,l} - 2\omega_{j,l} + \omega_{j-1,l}}{(\Delta\lambda)^2}\right) = \frac{e^{2\pi im/J} + e^{-2\pi im/J} - 2}{(\Delta\lambda)^2} = p(m) = \frac{2\left[\cos\left(\frac{2\pi m}{NI} - 1\right)\right]}{(\Delta\lambda)^2}$$

$$\nabla^2_{m,n} = \frac{1}{a^2}(p(m) + q(n)) \qquad q(n) = \frac{2\left[\cos\left(\frac{2\pi n}{NJ} - 1\right)\right]}{(\Delta\theta)^2}$$

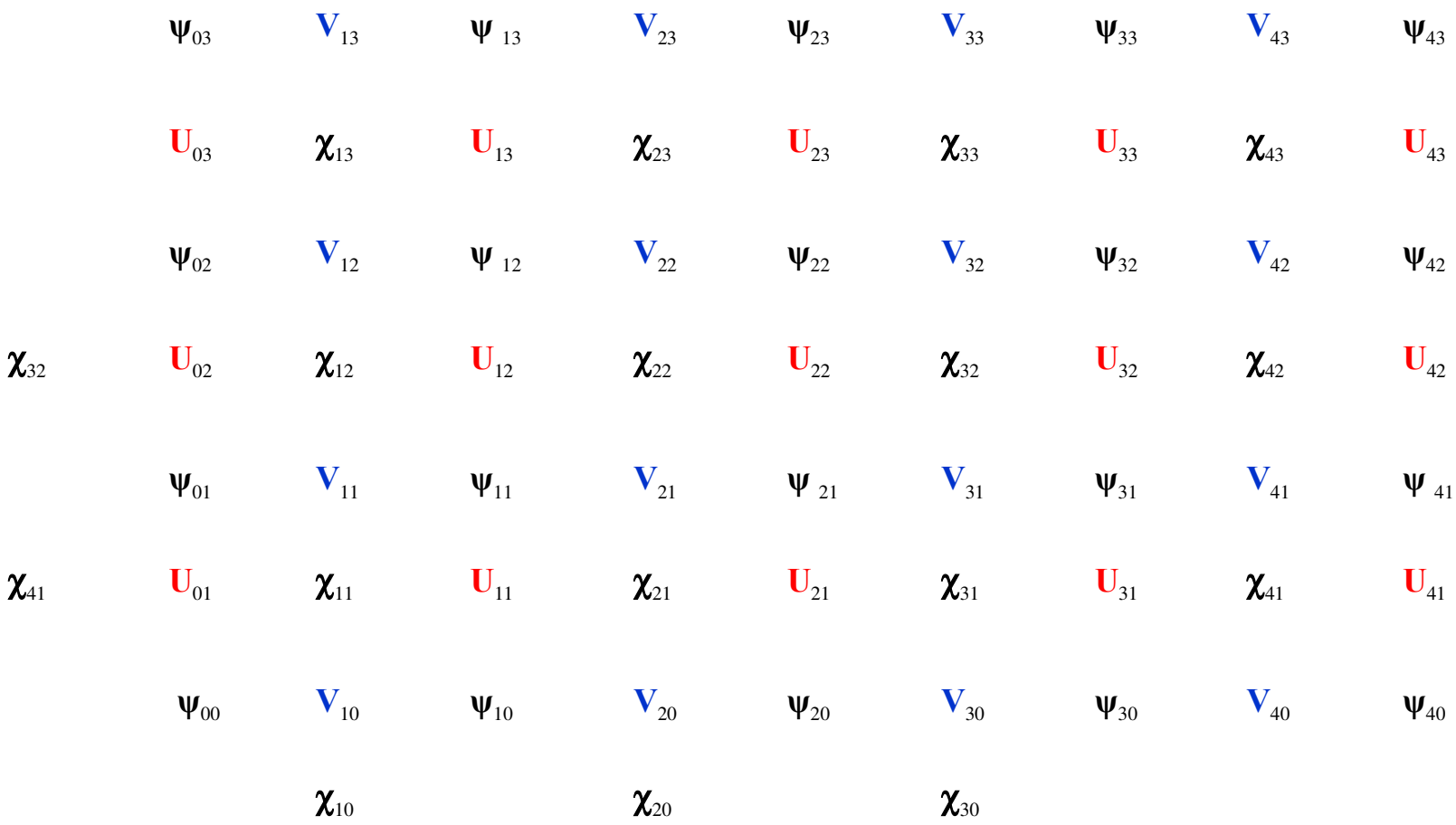
if $\Delta\lambda = \Delta\theta$

$$\nabla^2_{m,n} = \frac{2}{a^2\Delta^2}\left[\cos\left(\frac{2\pi m}{NI}\right) + \cos\left(\frac{2\pi n}{NJ}\right) - 2\right]$$

$$¿\ rlaplam(m,n)$$

$$\nabla^{-2}_{m,n} = rilamlam(m,n) = 1.0/rlaplam(m,n);\ 0\ for\ (m,n) = (0,0)$$

LAM-Var Arakawa-C Analysis Grid



$$(\psi,\chi) \rightarrow (U,V) \rightarrow (\zeta,D) \rightarrow (\psi,\chi)$$

$$\zeta = \frac{1}{a\cos^2\theta}\left(\frac{\partial V}{\partial \lambda} - \cos\theta\frac{\partial U}{\partial \theta}\right) \quad ; \quad U = u\cos\theta \qquad D = \frac{1}{a\cos^2\theta}\left(\frac{\partial u}{\partial \lambda} + \frac{\partial(v\cos\theta)}{\partial \theta}\right)$$

Using wind-images we have:

$$\zeta = \frac{1}{a\cos\theta}\left(\frac{\partial v}{\partial \lambda} - \frac{\partial(u\cos\theta)}{\partial \theta}\right) \qquad D = \frac{1}{a\cos^2\theta}\left(\frac{\partial U}{\partial \lambda} + \cos\theta\frac{\partial V}{\partial \theta}\right) \quad ; \quad V = v\cos\theta$$

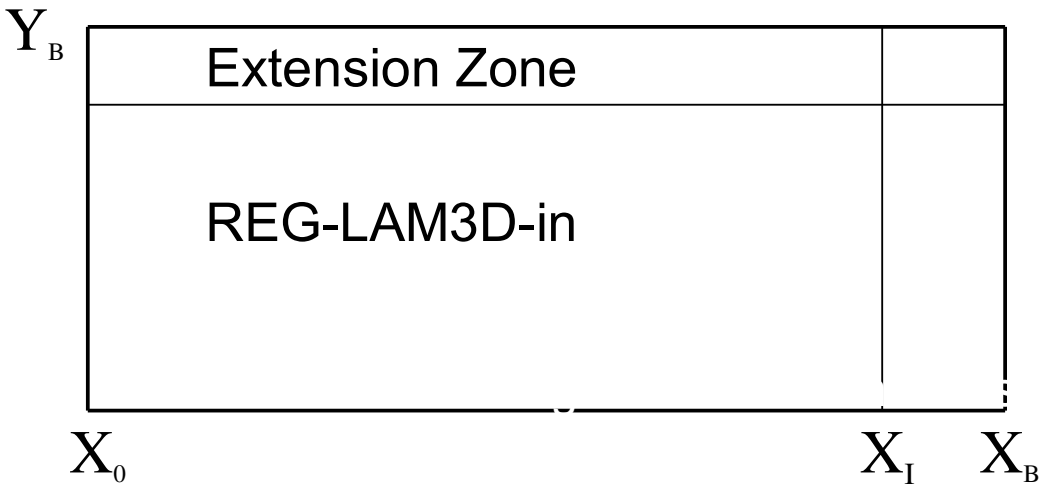
According to the placement of ζ, D variables on the computational grid, we get the discretized version as:

$$D^{i,j} = \frac{1}{a\cos^2\theta_j}\frac{U^{i+\frac{1}{2},j} - U^{i-\frac{1}{2},j}}{\Delta\lambda_{i+\frac{1}{2}}} + \frac{1}{a}\frac{V^{i,j+\frac{1}{2}} - V^{i,j-\frac{1}{2}}}{\Delta\mu_j}$$

$$\zeta^{i+\frac{1}{2},j+\frac{1}{2}} = \frac{1}{a\cos^2\theta_{j+\frac{1}{2}}}\frac{V^{i+1,j+\frac{1}{2}} - V^{i,j+\frac{1}{2}}}{\Delta\lambda_{i+\frac{1}{2}}} - \frac{1'}{a}\frac{U^{i+\frac{1}{2},j+1} - U^{i+\frac{1}{2},j}}{\Delta\mu_{j+\frac{1}{2}}}$$

Haugen & Machenhauer (1993)

Machenhauer's extension's procedure



$$g(x,y)=a_0(y)+a_1(y)\cos x'+b_1(y)\sin x'+b_2(y)\sin 2x'$$

where $x' \equiv \pi \dfrac{(x-x_I)}{(x_B-x_I)}$

$$a_0=g(x_I)+g(0)$$
$$a_1=\left[g(x_I)-g(x_B)\right]/2$$
$$b_1=\left[g'(x_I)-g'(0)\right]/2\alpha$$
$$b_2=\left[g'(x_I)+g'(x_B)\right]/4\alpha$$

$$g'(x_I)=\left[g(x_I)-g(x_I-\Delta x)\right]/\Delta x$$
$$g'(x_B)=g'(0)=\left[g(\Delta x)-g(0)\right]/\Delta x$$

.

The extension is carried out first in the x-direction and then in the y-direction.

$$\underbrace{\quad}_{} = \underbrace{\frac{\cos^2\theta_j}{a^2\,\Delta\mu_j\,\Delta\bar{\mu}_{j-1}}}_{a_j}\psi^{i,j-1} - \underbrace{\frac{1}{a^2\Delta\mu_j}\left[\frac{\cos^2\theta_j}{\Delta\bar{\mu}_{j-1}} + \frac{\cos^2\theta_{j+1}}{\Delta\bar{\mu}_j}\right]}_{b_j}\psi^{i,j} + \underbrace{\frac{\cos^2\theta_{j+1}}{a^2\,\Delta\mu_j\,\Delta\bar{\mu}_j}}_{c_j}\psi^{i,j+1}$$

$$+ \frac{1}{a\cos^2\bar{\theta}_j}\frac{\partial^2\psi}{\partial\lambda^2}$$

$$= a_j\,\psi^{i,j-1} - (a_j + c_j)\,\psi^{i,j} + c_j\,\psi^{i,j+1} + \frac{1}{a\cos^2\bar{\theta}_j}\frac{\partial^2\psi}{\partial\lambda^2}$$

$$\omega_j(\theta) = \frac{1}{J}\sum_{m=0}^{j-1}\tilde{\omega}_m(\theta)\;\mathrm{E}^{\mathrm{mj}} \quad ; \qquad \mathrm{E}^{\mathrm{mj}} \equiv e^{2\pi i\,jm/J}$$

$$\left(\frac{\omega_{j+1,l} - 2\omega_{j,l} + \omega_{j-1,l}}{(\Delta\lambda)^2}\right) \qquad \Delta\lambda_i = \lambda_{i+1} - \lambda_i\,; \quad i = 1,\ldots,NI-1 \quad ; \quad \Delta\sin\theta_j = \sin\theta_{j+1} - \sin\theta_j \;\; ; \;\; j = 1,\ldots,NJ-1$$

$$a_l\,\tilde{\omega}_{m,l-1} + b_l\,\tilde{\omega}_{m,l} + c_l\,\tilde{\omega}_{m,l+1} = \tilde{R}_{m,l}$$

$$\mathbf{A}_\theta \equiv \begin{bmatrix} b_1 & c_1 & 0 & \ldots & 0 & 0 & \beta \\ a_2 & b_2 & c_2 & \ldots & 0 & 0 & 0 \\ 0 & 0 & 0 & \ldots & 0 & 0 & 0 \\ 0 & 0 & 0 & \ldots & a_{L-1} & b_{L-1} & c_{L-1} \\ \alpha & 0 & 0 & \ldots & 0 & a_L & b_L \end{bmatrix}$$

Wind-rotations (uvrot2uv.ftn, auvrot2uv.ftn)

Step 1

$$v = \frac{dr}{dt} = \frac{dx}{dt} i + \frac{dy}{dt} j + \frac{dz}{dt} k = \mu \hat{\lambda} + \nu \hat{\theta}$$

$$v_x = -\sin\lambda\mu - \cos\lambda \sin\theta\nu ;$$
$$v_y = \cos\lambda\mu - \sin\lambda \sin\theta\nu$$
$$v_z = \cos\theta\nu$$

Step 2

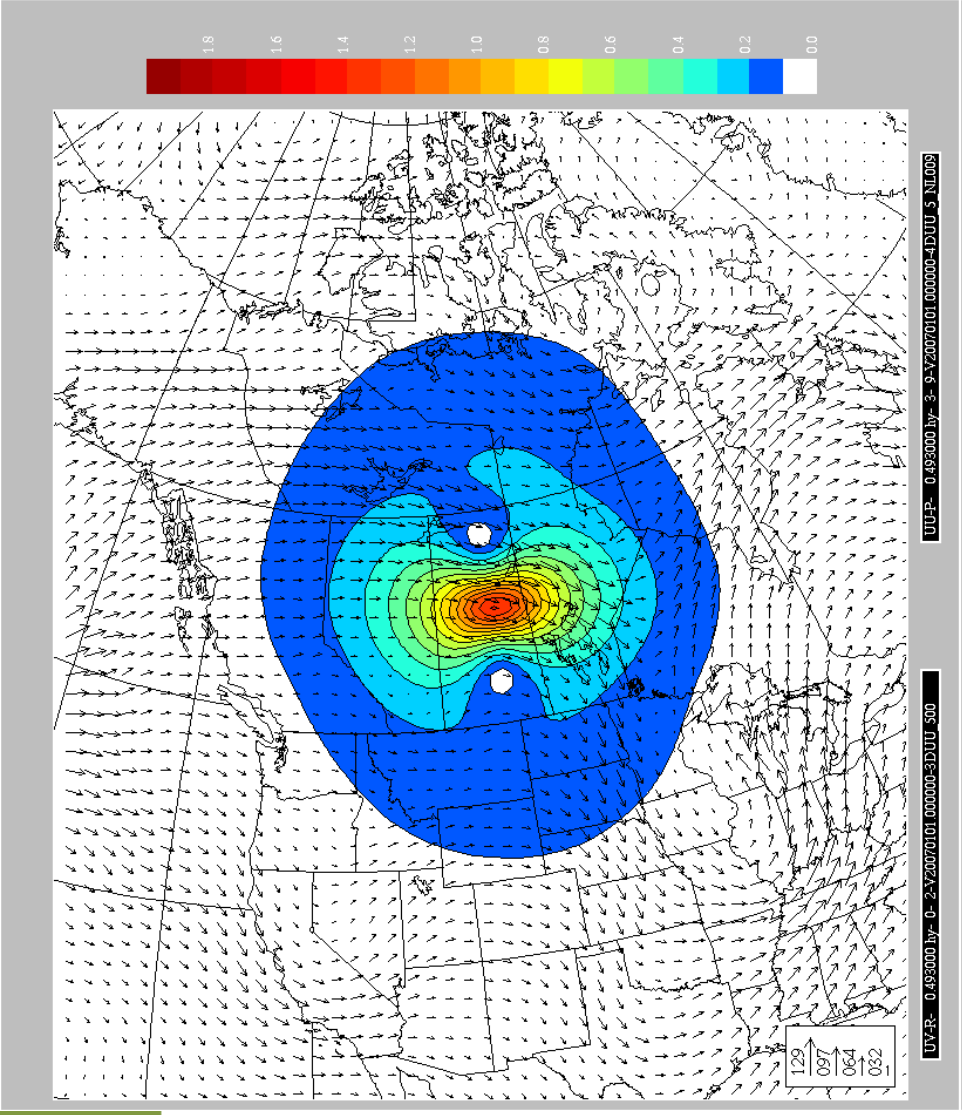
$$\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \Re^T \begin{bmatrix} v_x' \\ v_y' \\ v_z \end{bmatrix}$$

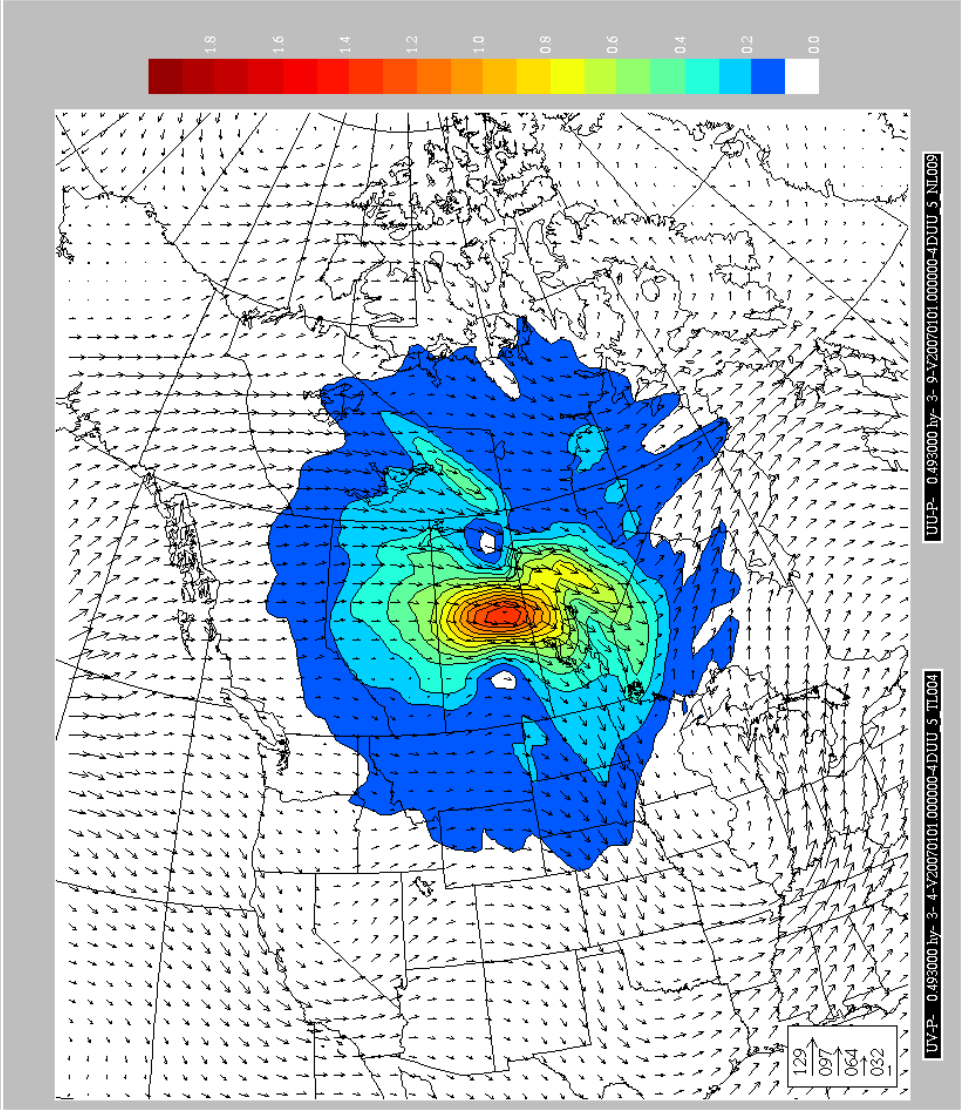
- **Step 3**

$$\mu = -\sin\lambda v_x + \cos\lambda v_y$$

$$\nu = -\frac{1}{\sin\theta}\left(\cos\lambda v_x + \sin\lambda v_y\right) = v_1$$

$$v = \frac{v_z}{\cos\theta} \equiv v_2$$





3D-Var LAM 55km

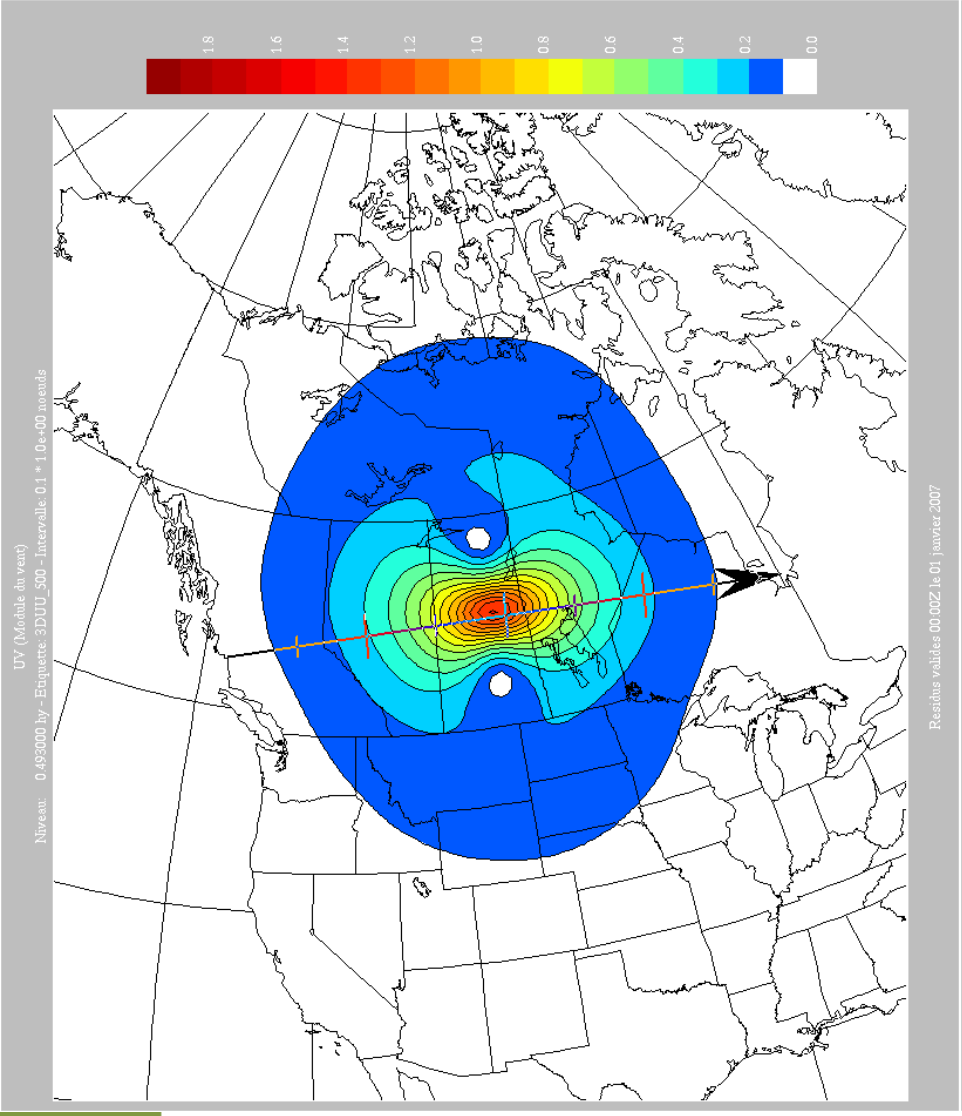
4D-Var LAM 55km

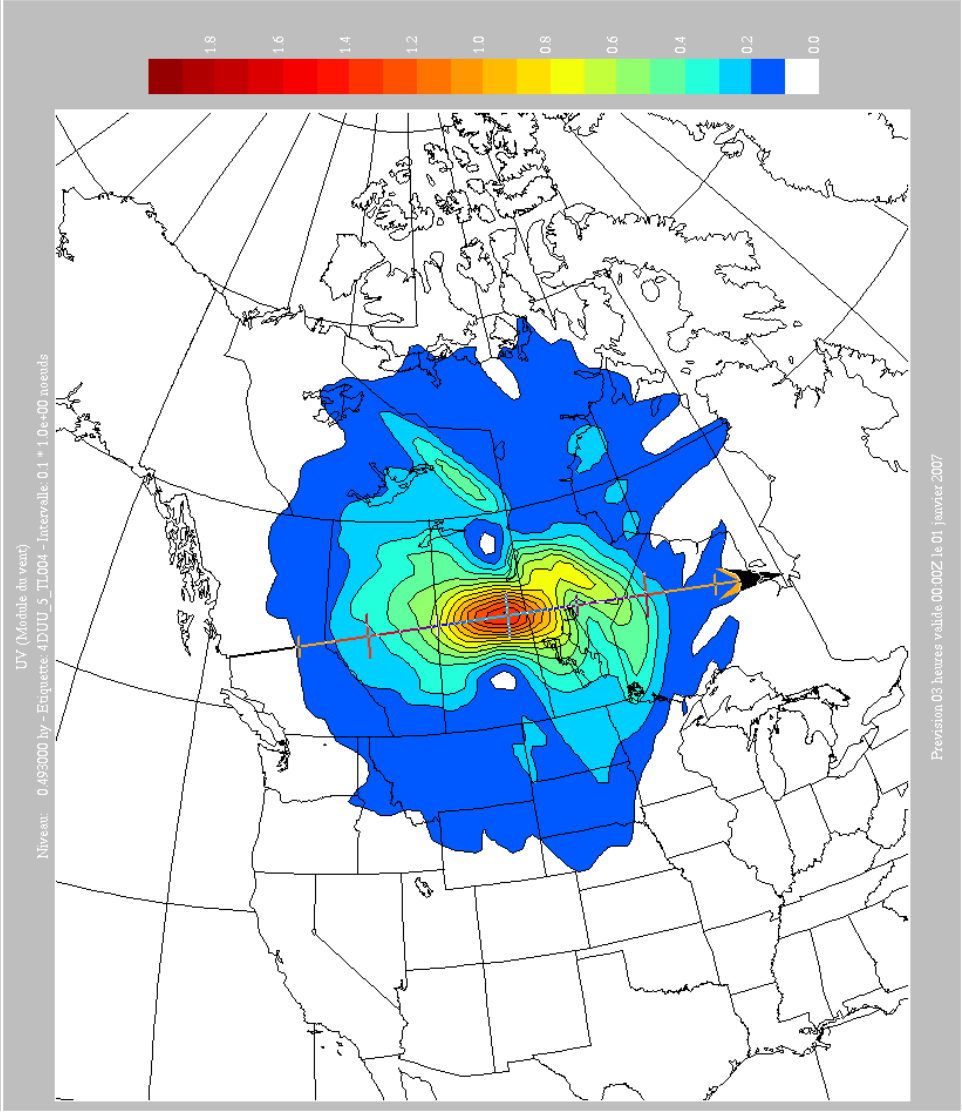
T = +0.00 hr

Environment Canada Environnement Canada

Canada

Obs Vent 500 mb





3D-Var LAM 55km

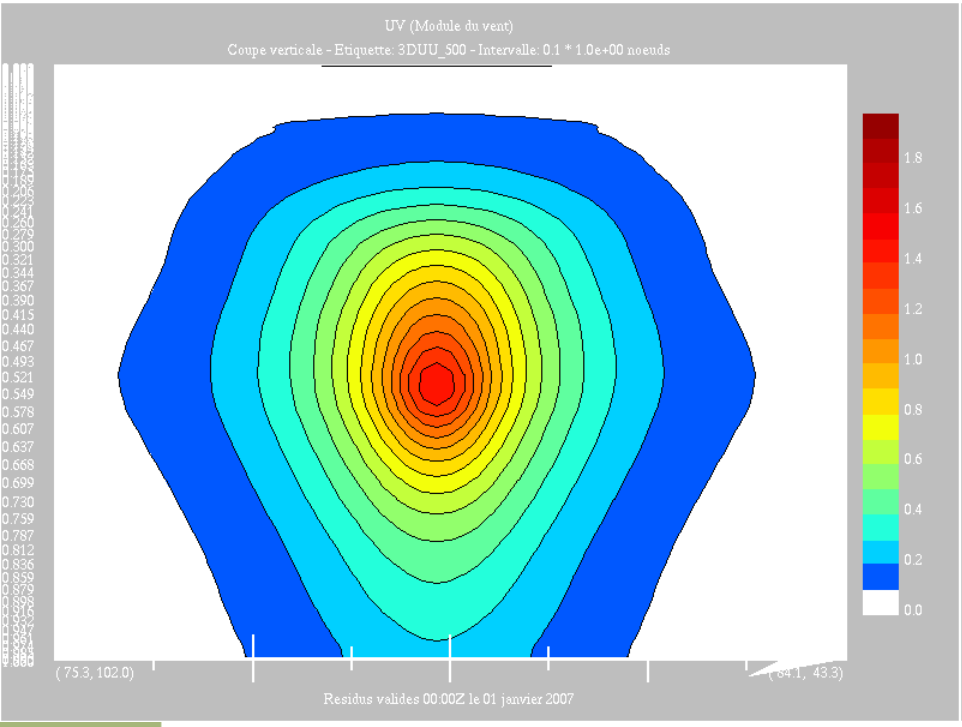
4D-Var LAM 55km

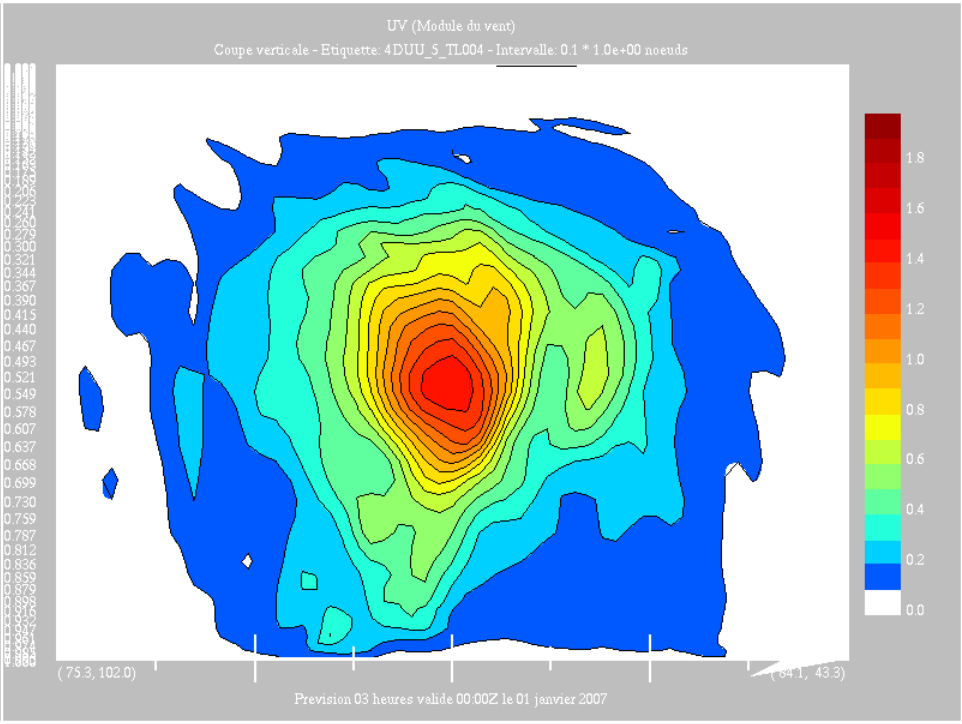
T = +0.00 hr

Environment Canada Environnement Canada

Obs Vent 500 mb

Canada





3D-Var LAM 55km

4D-Var LAM 55km

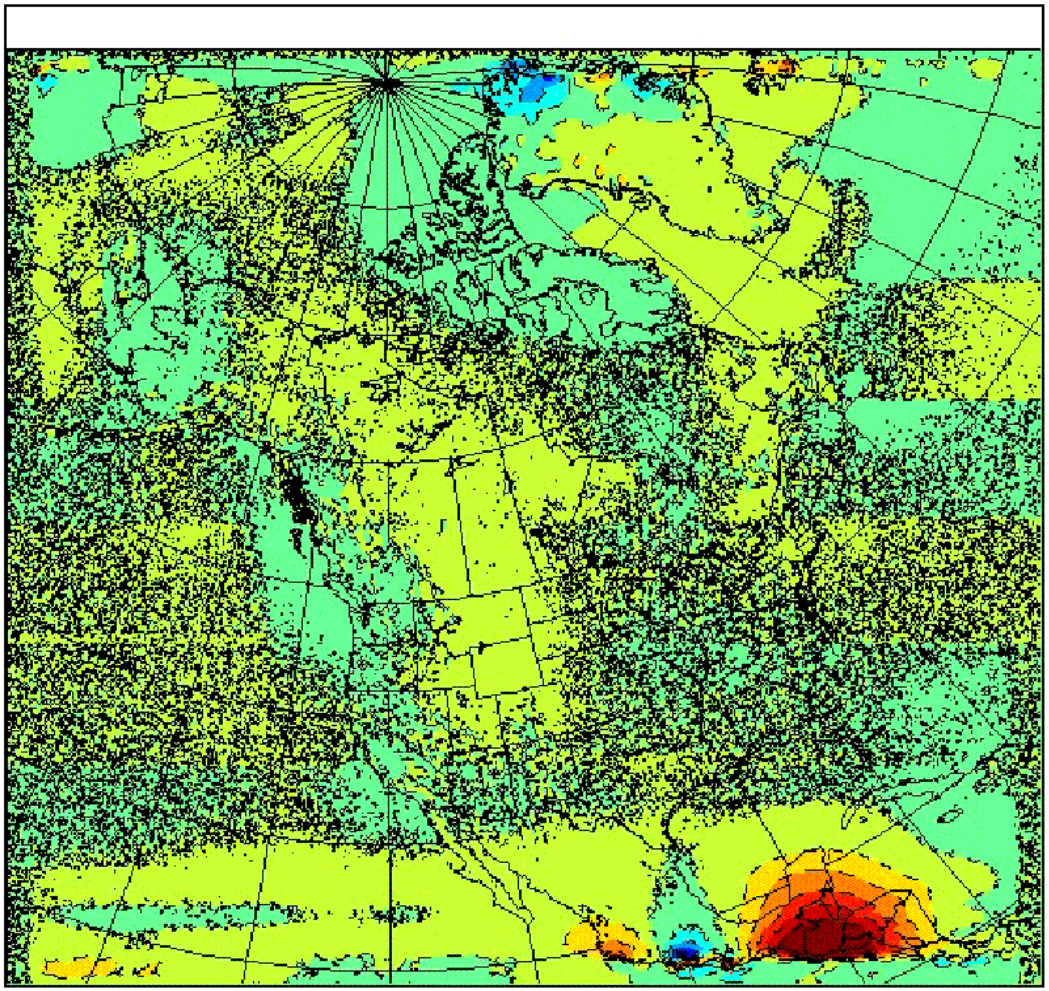
T = +0.00 hr

Environment Canada Environnement Canada

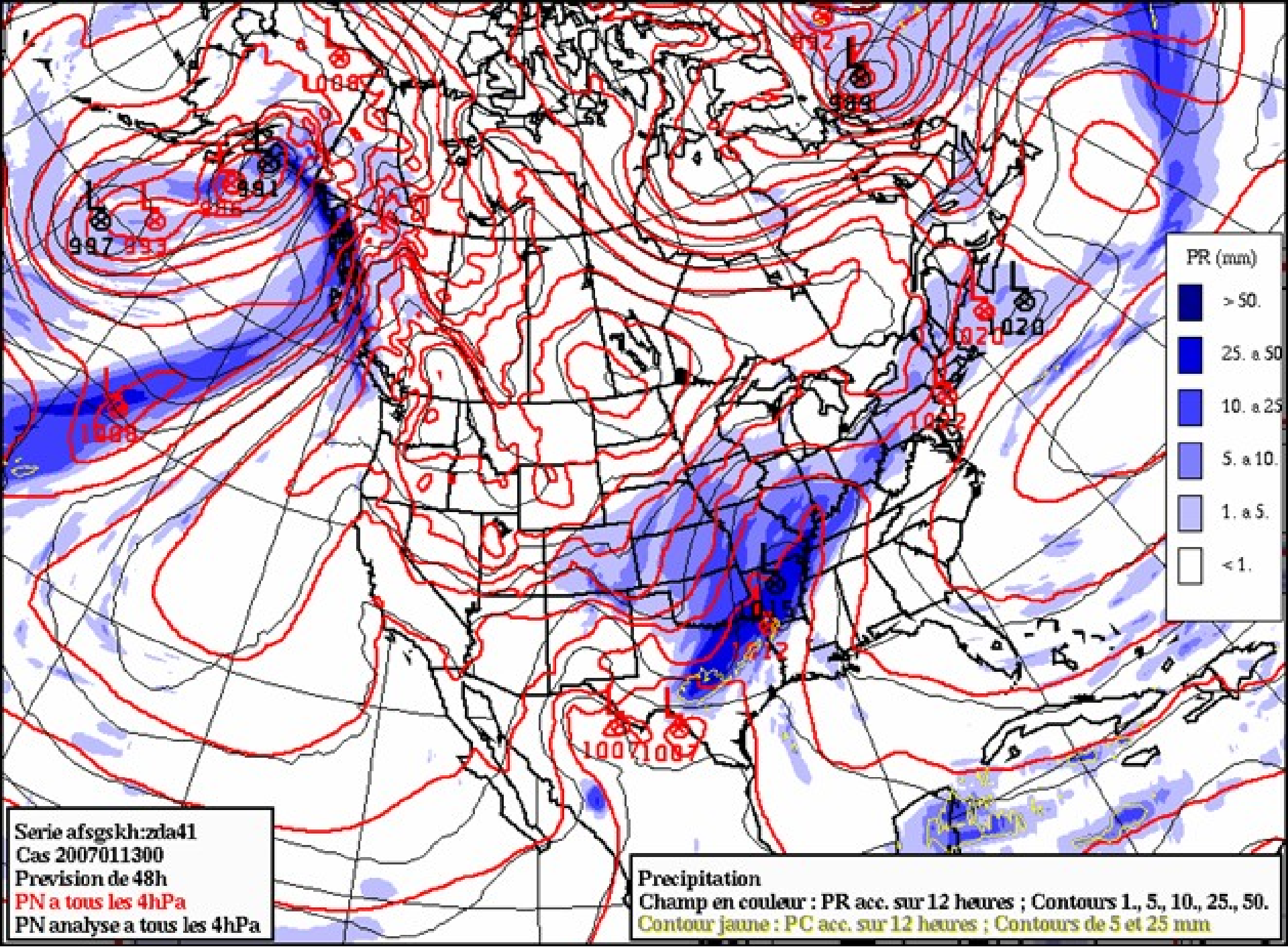
Canada

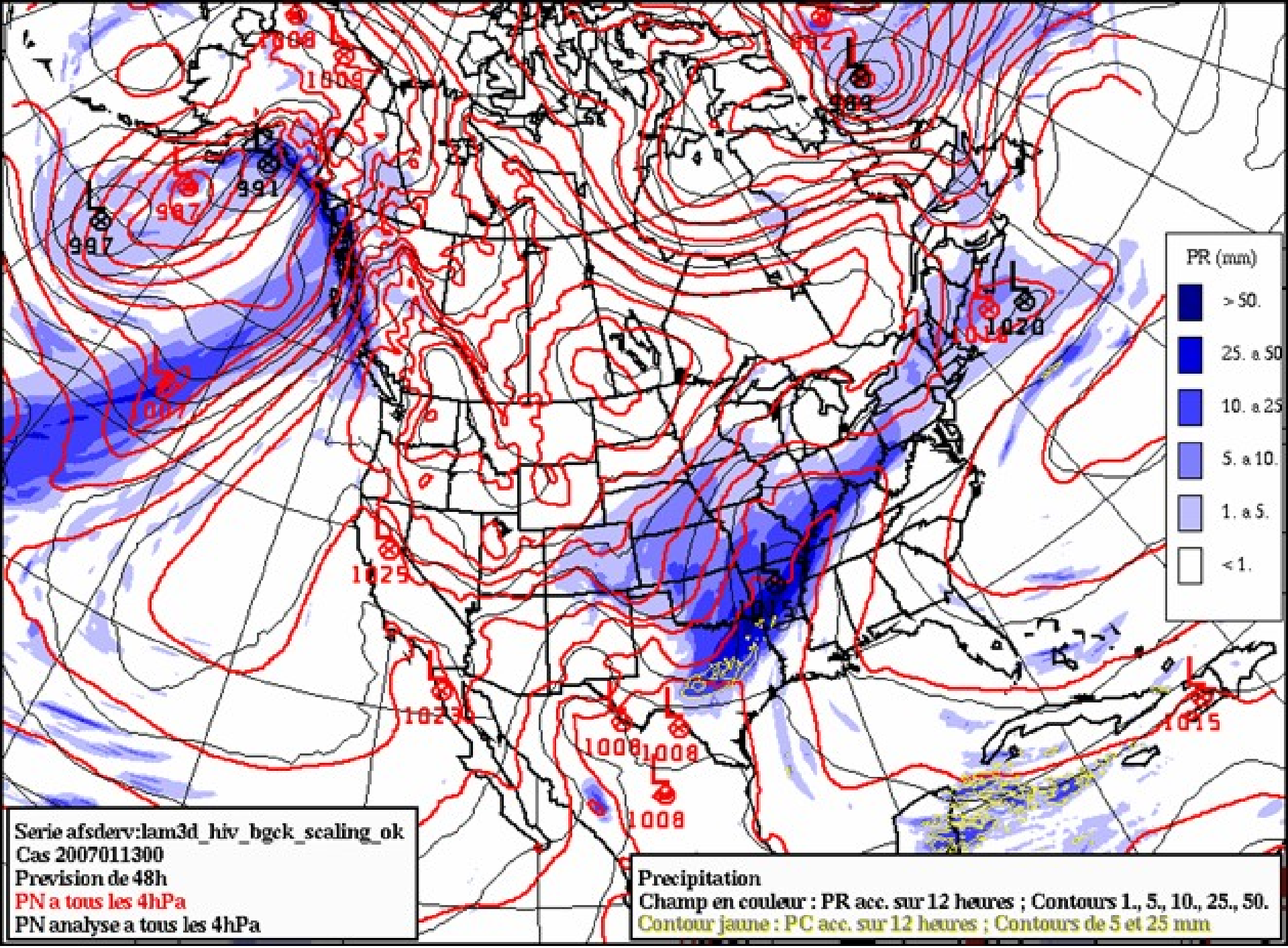
Obs Vent 500 mb

Animation (1 à 48 h) des différences GZ 500 (dam)
Moyenne des 13 cas d'hiver

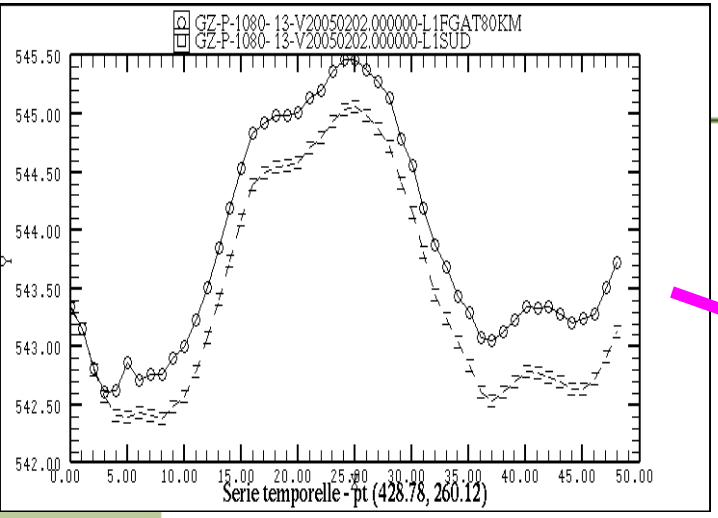


Canada

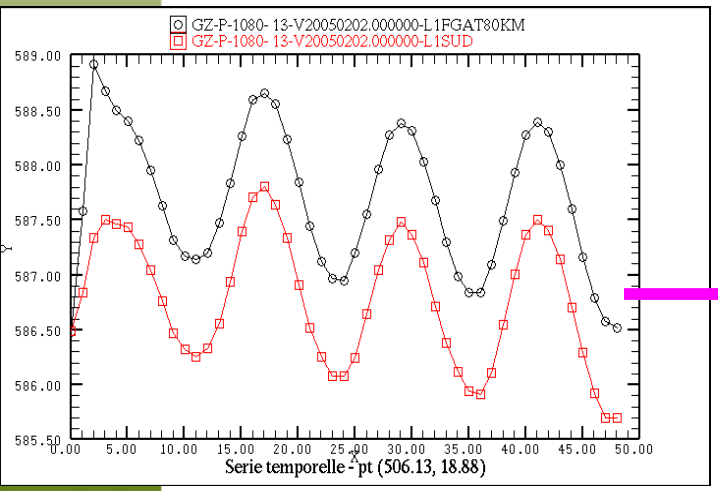

PR (mm)
> 50.
25. a 50.
10. a 25.
5. a 10.
1. a 5.
< 1.
Serie afsgskh:zda41
Cas 2007011300
Prevision de 48h
PN a tous les 4hPa
PN analyse a tous les 4hPa
Precipitation
Champ en couleur : PR acc. sur 12 heures ; Contours 1., 5., 10., 25., 50.
Contour jaune : PC acc. sur 12 heures ; Contours de 5 et 25 mm

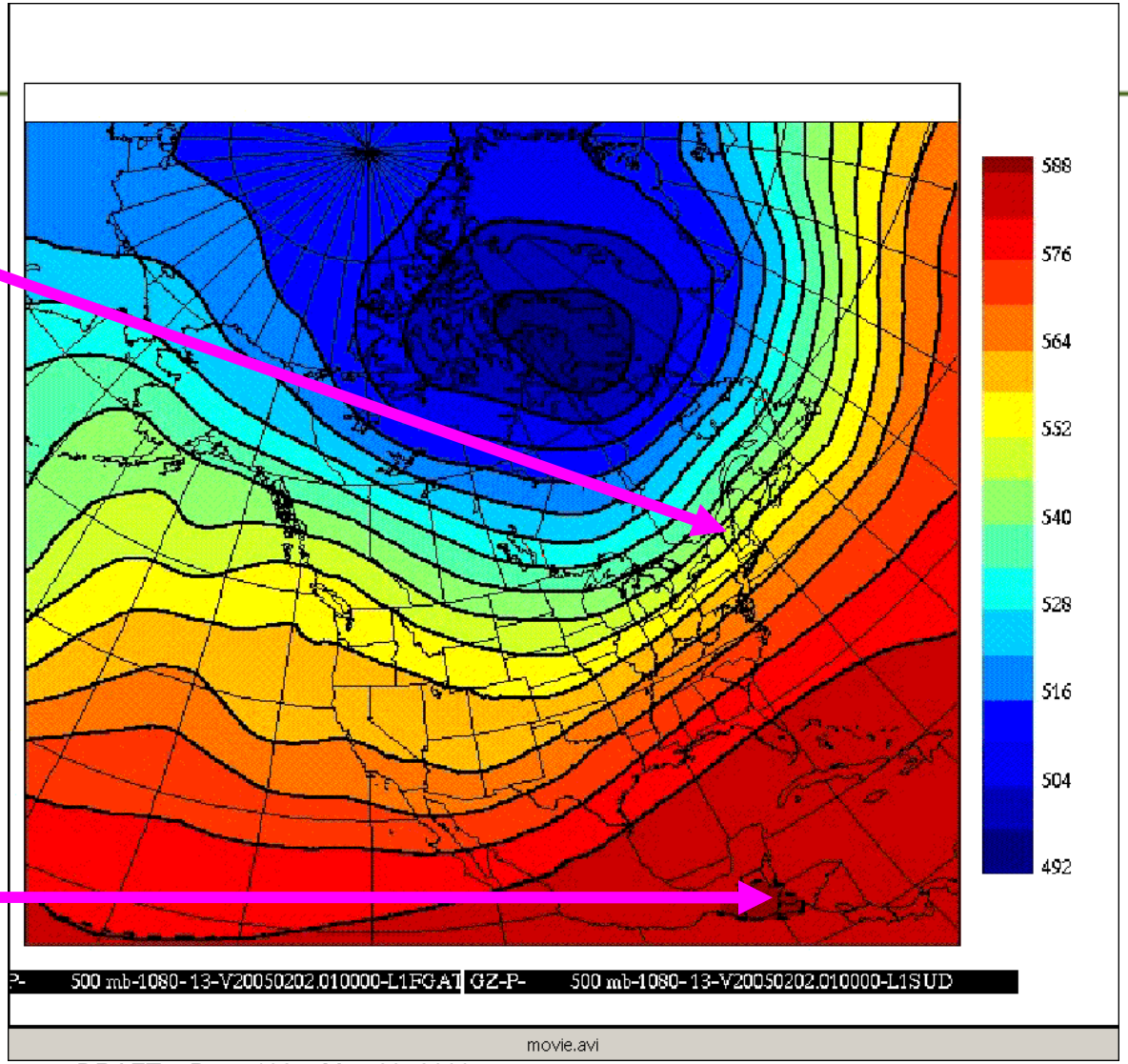

PR (mm)
> 50.
25. a 50.
10. a 25.
5. a 10.
1. a 5.
< 1.
1008
1009
991
997
997
1004
1025
1023
1008
1008
1008
1020
1015
Serie afsderv:lam3d_hiv_bgck_scaling_ok
Cas 2007011300
Prevision de 48h
PN a tous les 4hPa
PN analyse a tous les 4hPa
Precipitation
Champ en couleur : PR acc. sur 12 heures ; Contours 1., 5., 10., 25., 50.
Contour jaune : PC acc. sur 12 heures ; Contours de 5 et 25 mm

Animation (1 à 48 h) GZ 500 (dam)
Moyenne des 13 cas d'hiver



Séries temporelle GZ 500 mb





Replacing GEM-REG with GEM-LAM

- Current GEM-REG is a global model, with a higher resolution central window and variable resolution moving away from this window.
- For assimilation, current approach is tied to Global assimilation and datasets (much coarser resolution).
- Proposed replacement is GEM-LAM on the continental scale at 15-km, including independent 3D-Var at 55-km.
- Initial implementation limits changes to model and assimilation (e.g. same physics, datasets, etc).
- Initial forecast quality to be very similar to that of GEM-REG due to conservative approach taken.
- Much further improvements to be included after 2010 Olympics.

$J_b = \frac{1}{2}\chi^T\chi \quad (3.4.2)$, we make a change of analysis variables of the form:

$x - x_b = L\chi \quad (3.4.3)$ s.t. $B = ¿^T \quad (3.4.4)$

$\Delta\xi \equiv C_V^{-1/2}\,\Delta\tilde{x}$; $\Delta\tilde{x} = (\Delta\tilde{\psi}, \Delta\tilde{\chi}_u, \Delta\tilde{T}_u, \Delta\tilde{q}, \Delta\tilde{p}_{s_u})^T$ $\Delta\tilde{\psi} = F(\Delta\psi/\sigma_\psi)$

$r_{k_t}(m,n) = E\Lambda E^{-1}$ $\quad$ CORNS $= E\Lambda^{1/2}E^T$

$Min \quad J = J_b + J_o$

$= \frac{1}{2}\Delta\xi^T\Delta\xi + \frac{1}{2}(H(x) - y)^T R^{-1}(H(x) - y)^T$

$= x_b + RWGDF^{-1}C_V^{1/2}\Delta\xi$ $\quad D = diag(\sigma_\psi, \sigma_{\chi_u}, \sigma_{T_u}, \sigma_q, \sigma_{ps_u})$

$\tilde{N}J = \tilde{N}J_b + \tilde{N}J_o = Dx + H^T R^{-1}(H(x) - y)$

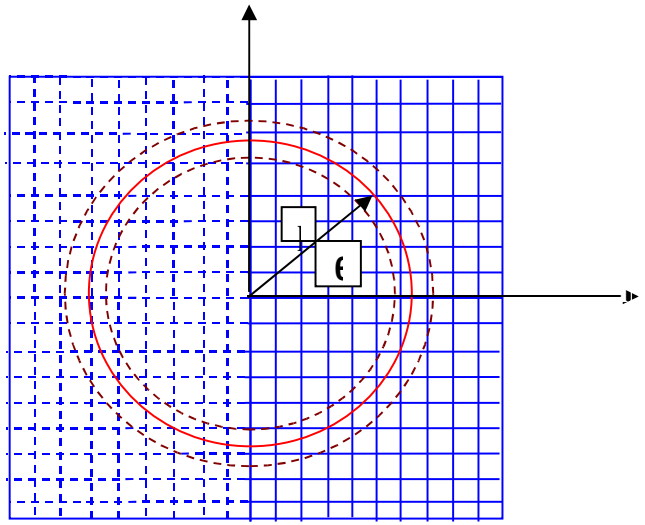
$$\rho(s)=\int_{-M}^{M}\int_{-N}^{N}\tilde{f}_{mn}\tilde{f}^{*}_{mn}\exp\left[2\pi i\left(\frac{ms_x}{L_x}+\frac{ms_y}{L_y}\right)\right]dm\,dn$$

$$dm\,dn=\int_{-M}^{M}\int_{-N}^{N}|\tilde{f}_{mn}|^2\,dm\,dn=\int_{-M}^{M}\int_{-N}^{N}\gamma_{mn}\,dm\,dn=1$$

$$\int_{-M}^{M}\int_{-N}^{N}\tilde{f}_{mn}\tilde{f}^{*}_{mn}$$

$$\rho(s)=\frac{2\pi L_x L_y}{D^2}\int_{0}^{K*}|\tilde{\rho}(k*)|^2 k* J_0\left(2\pi i\frac{k*s}{D}\right)dk*$$

$$L^2=-2\frac{\rho(r)}{\nabla^2\rho(r)}=\left(\frac{D}{2\pi}\right)^2\frac{\sum_{2k_t=0}^{K_t}\overline{|\tilde{\rho}^{mn}_{k_t}|^2}\,k_t}{\sum_{k_t=0}^{K_t}\overline{|\tilde{\rho}^{mn}_{k_t}|^2}\,k_t^3}$$



$$B_{klm}^{k\,\mathrm{ln}} = \frac{1}{2\pi}\int_{0}^{2\pi} \overline{\tilde{a}_{pqm}\tilde{a}_{pqn}}\, d\theta$$

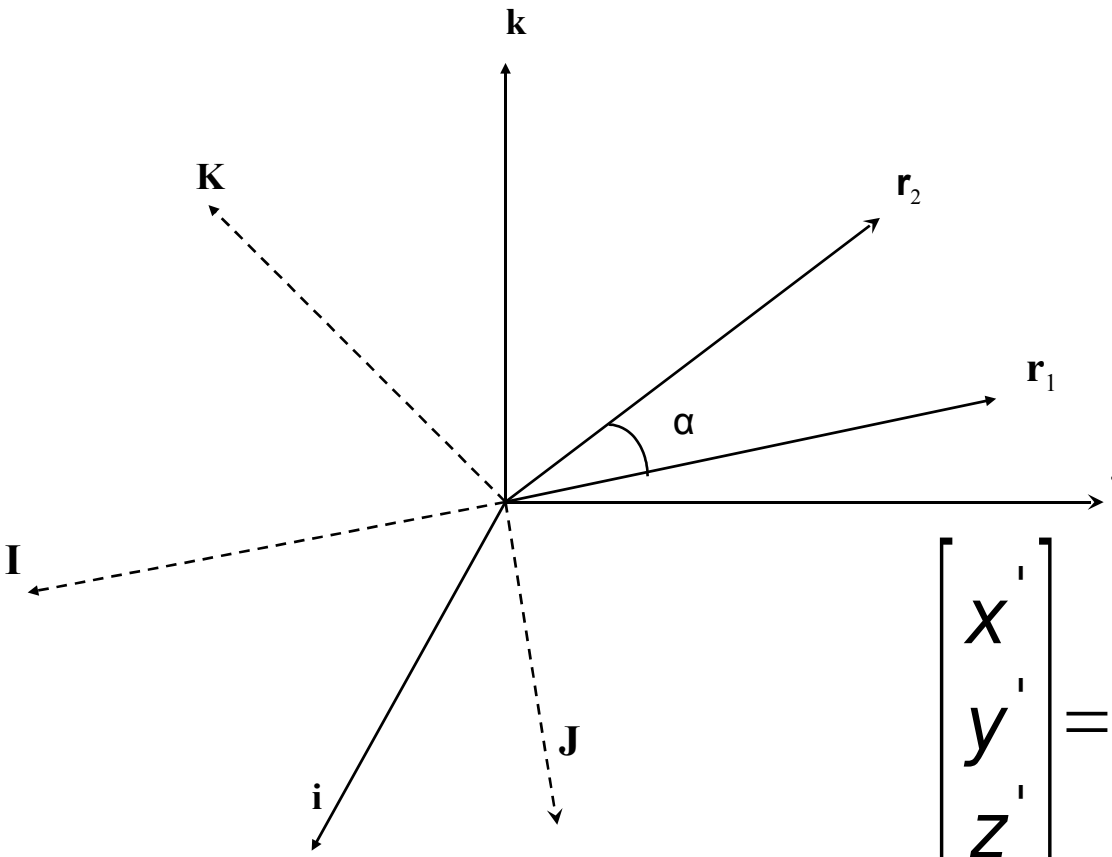
$$B_{klm}^{k\,\mathbf{ln}} = \frac{1}{2\pi}\int_{0}^{2\pi} \overline{\tilde{a}_{pqm}\tilde{a}_{pqn}}\, d\theta \rightarrow B_{k_t}^{mn} = \frac{1}{mban\,\{d'(k_t)} \sum_{jtot=1}^{mband(k_t)} \overline{\tilde{a}_{k_t m}\tilde{a}_{k_t n}}$$

$$mban\,\{d'(k_t) = 2\,\mathrm{mband}(k_t) - \alpha\,,$$

$$\sigma_m^2 = \frac{2\pi \mathrm{MN}}{N_{s^2}} \sum_{j=0}^{K_t} B_{k_t}^{mm} k_t^j;\ \gamma_m(k_t) \equiv \frac{B_{k_t}^{mm}}{\sigma_m^2}$$

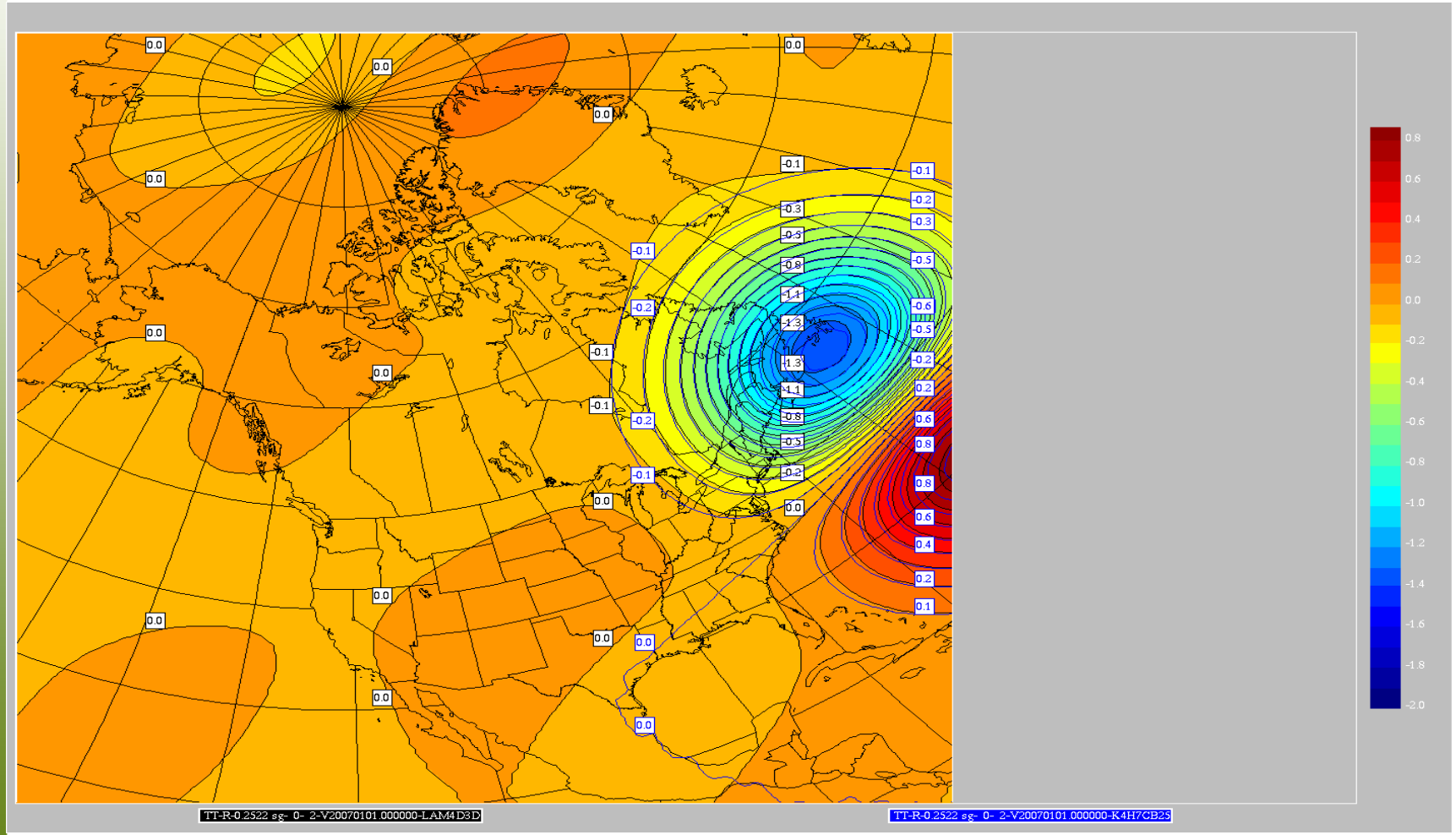
$$r_{k_t}(m,n) = \frac{B_{k_t}^{mn}}{\sigma_m \sigma_n \sqrt{\gamma_m(k_t)}\sqrt{\gamma_n(k_t)}} \quad = \mathrm{CORNS}$$

Rotation Matrix



$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \Re \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

1-Obs UU-500 hPa: T-increment



LAM-4D

3D-Var 10.2.2 / LAM GEM332

Boucle externe 15 km:
- NL : Analyse = LAM 15km / Pilote = Cubes creux GLB 55km

Boucle interne 55 km:
- LOOP1 = 25 it. LOOP2 = 25 it.
- NL : Analyse = LAM 15km / Pilote = Cubes pleins GLB 55km
- TL : Pilote = Persistence