Assimilation des radiances hyperspectrales AIRS

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Environment Canada Environnement Canada

Canada

Les radiances infrarouges au CMC

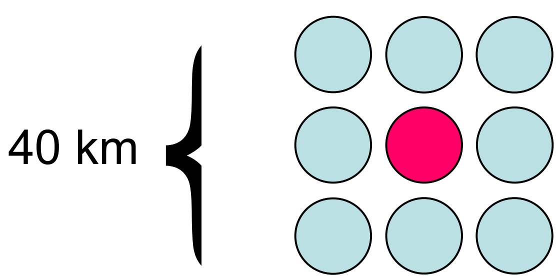
- Assimilation d’un seul canal, 6.7μm, pour domaine GOES-E/W. Rien ailleurs !

- Disponibles mais non assimilées: GOES sounder (18), Meteosat (9), HIRS (18), AIRS (2378), IASI (8471)

➡ Priorité mise sur hyperspectral AIRS (2007) et IASI (2008)
Support de ASC pour 3 ans (2005-2008)

AIRS

- Atmospheric Infrared Radiance Spectrometer
- Onboard AQUA (A-Train suite) since May 2002
- 2378 channels, cover 4.1-15.5 micron
- 281 subset received at CMC
- FOV 13.5 km at nadir, swath 1650 km
- One of 9 received, effective resolution 40 km
- Warmest in 3X3 neighborhood (“golf ball”) sent
- 6-h file contains 4 orbits, 81000 locations



Pourquoi tant de canaux?

- Exploiter au maximum la technologie infrarouge actuelle permettant une résolution spectrale de l'ordre de 1 cm^{-1}
- Les études (e.g. Rabier et al., 2002) de contenu d'information pour NWP démontrent qu'avec 86 canaux IASI, on réduit l'erreur de background TT de 1.5 K a 0.9 K. Avec 300 canaux: 0.7 K. Limite IASI (8461 canaux): 0.5 K.
- Pour la résolution verticale effective TT: 86 canaux: 2.0 km, 300 canaux: 1.5 km, limite IASI: 1 km. Pour humidité 300 canaux: 2 km, limite IASI: 1.5 km
- La redondance a un apport positif: réduction du bruit.

Nombreuses applications/produits (notamment a JPL):

- Cartographies de GES: CO_2, CH_4, CO, N_2O + O_3, H_2O +aérosols
- Cartographie de l' émissivite de surface
- Signatures spectrales donnent info sur propriétes optiques des nuages

Méthode d'assimilation: variationnelle classique

Minimiser: $J(x) = (x-x_b)\, \mathbf{B}^{-1}\, (x-x_b)^T + (H(x) - y)\, \mathbf{O}^{-1}\, (H(x)-y)^T$

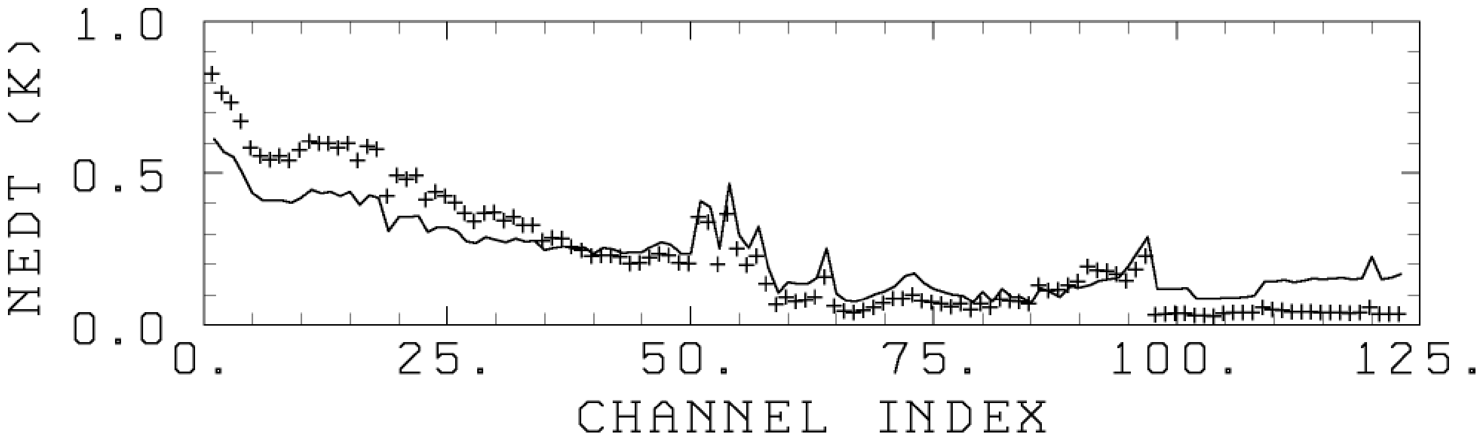
Pour les radiances:

H(x) = modele de transfert radiatif (unités BT: temp. de brillance)

y: observations BT, "débiaisées", jugées non-affectées par nuages

O: matrice d'erreur d'observation (diagonale): inclut bruit radiométrique, erreur du modele H, échelles non résolues

AIRS intrument noise



15.3 13.5 6.2 4.1 micron

Full line: at 250 K; + at mean BT value

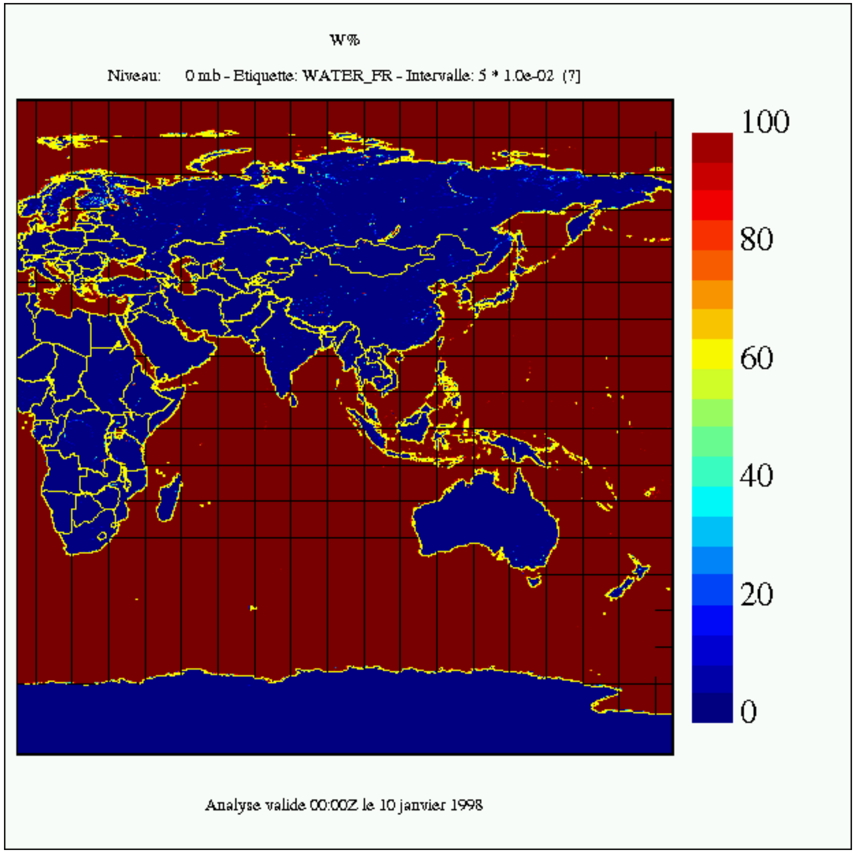
Excellent quality, very stable since launch

Radiative transfer model inputs

- From trial fields
  - T, q profiles up to 0.1 mb (extrapolation needed)
  - TG (skin temperature)
  - Ps
- Ozone profile (climatology: Fortuin & Kelder 1998)
- CO_2: fixed, but variable profile possible with RTTOV-8
- Other gases: fixed, allowed to vary with RTTOV-9 (N2O, Ch4, CO).
- Surface emissivity: modeled over ocean (wind speed and view angle dependent). Based on surface type over land. Ice/snow analyses also used as input.

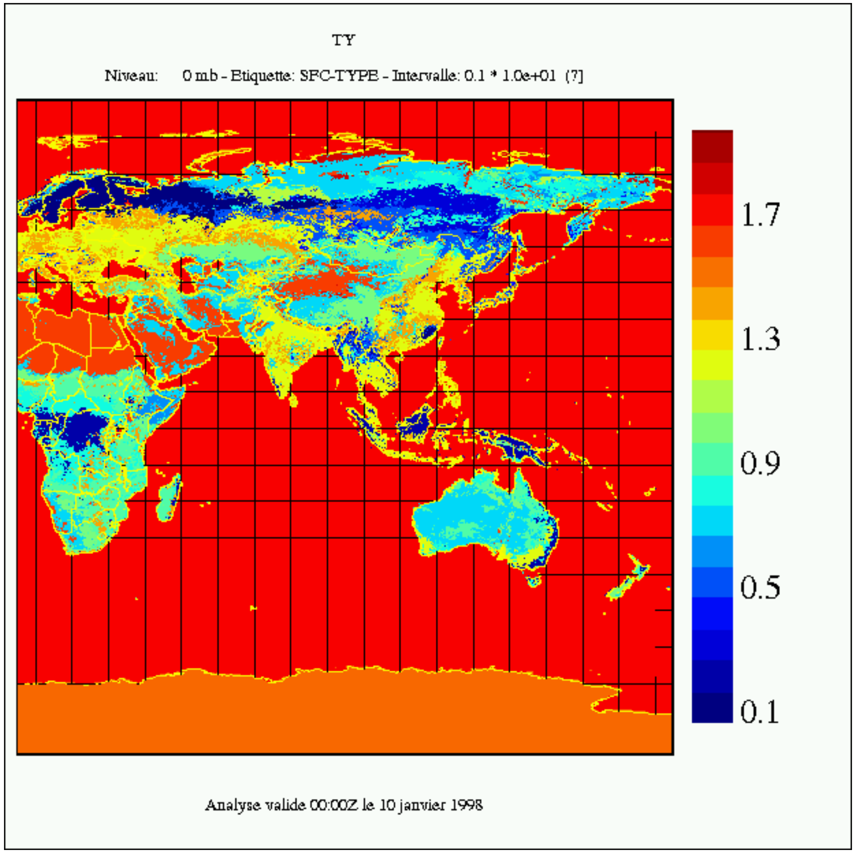
CERES input info at 16 km

Percent of water



For land/sea mask, coast detector

surface type



for emissivity definition vs wavelength

AIRS QUALITY CONTROL (QC)

- Gross check: BT > 150 K, BT < 350 K
- NESDIS noise flag = 0 (OK). Recently found important: local info.
- Cloudy or clear ? Based on window channel+ trial T profile

  * Garand-Nadon 1998 algorithm

  * NESDIS daytime cloud fraction > 5% = cloudy

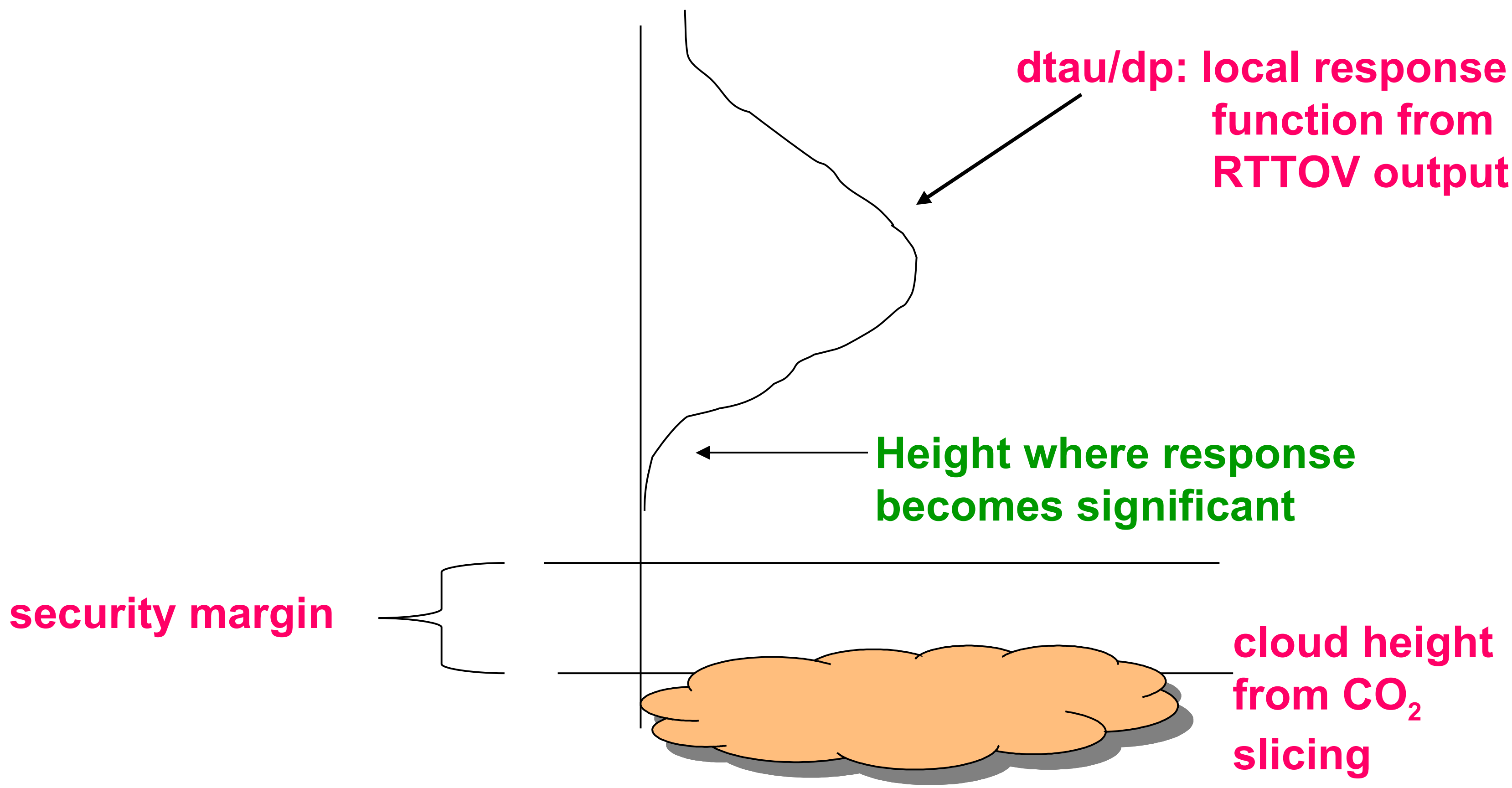
  * Invert RTE for TS using BT(window) assuming trial T,q profile perfect

    - if |TS(window) – TS(guess)| > 2K(ocean) or 4K(not ocean), cloudy

4. If cloudy, is the radiance cloud-affected? Answer from CO_2 slicing of cloud height estimate + local response function: cloud must be below level where response function (dtau/dp) becomes significant + security margin of at least 50 hPa

Is the radiance clear?

- CO_2 slicing: 12 estimates of cloud height from as many channels coupled with a reference profile peaking near the surface. Mean of valid estimates used.
- Security margin is max (50 hPa, std among valid estimates)



CO_2 slicing

For the pair: Reference and k channels (12.2 to 14.4 μm)
Reference channel peaks low (sensitive to all clouds). Other channels peak at various heights. From $R_o = R_{clr}(1\text{-}Ne) + Ne\ R_{cld}$

$$(R_{clr}-R_o)_k \,/\, (R_{clr} - R_o)_{ref}$$

$$- [Ne(R_{clr}-R_p)]_k \,/\, [Ne(R_{clr} - R_p)]_{ref} = F(p)$$

Ne cancels, assuming same emissivity in k and ref channels.
F(p) minimum defines top pressure cp.
Effective cloud fraction then obtained from either channel:

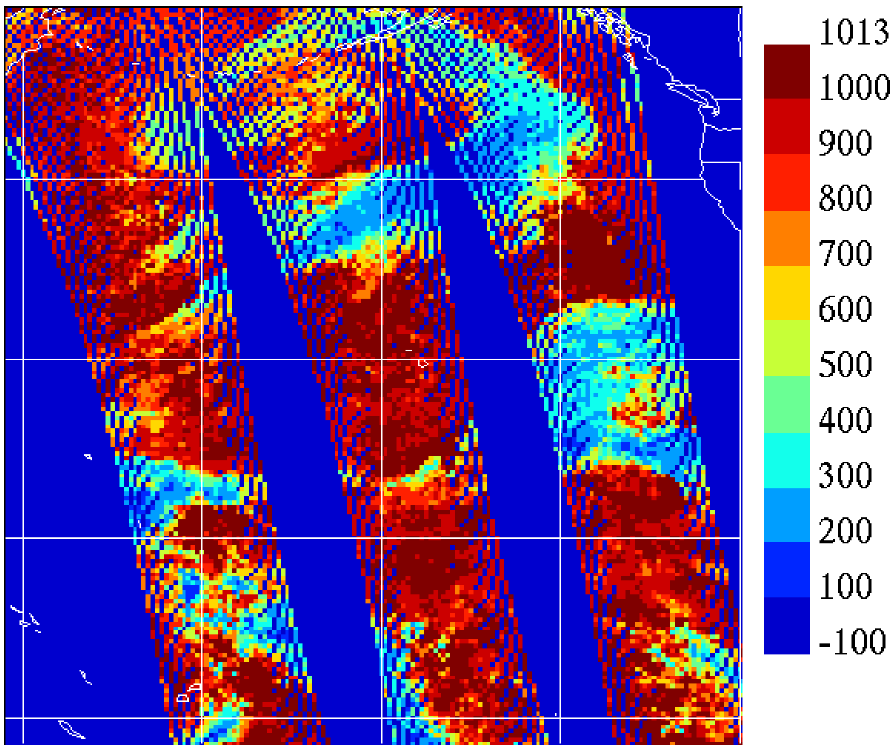
$$Ne = (R_{clr} - R_o) \,/\, (R_{clr} - R_{cp})$$

If no well defined minimum: cp based on window channel BT matched with guess T profile. Ne is then unity.

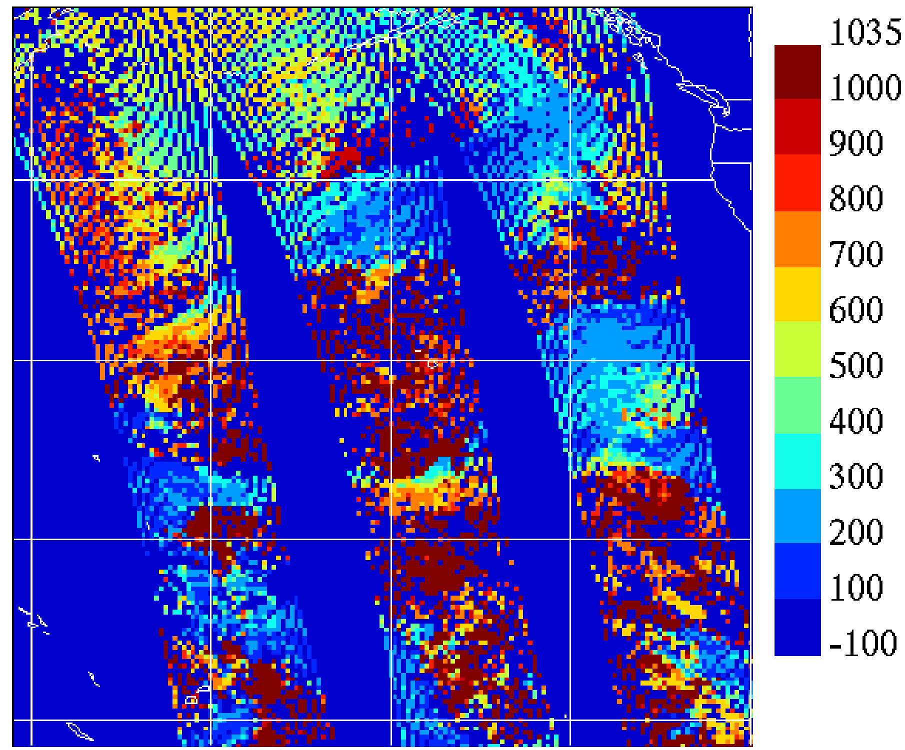
Method allows to obtain equivalent cloud fraction from single FOV

Cloud top inference

Equivalent height from 11 micron

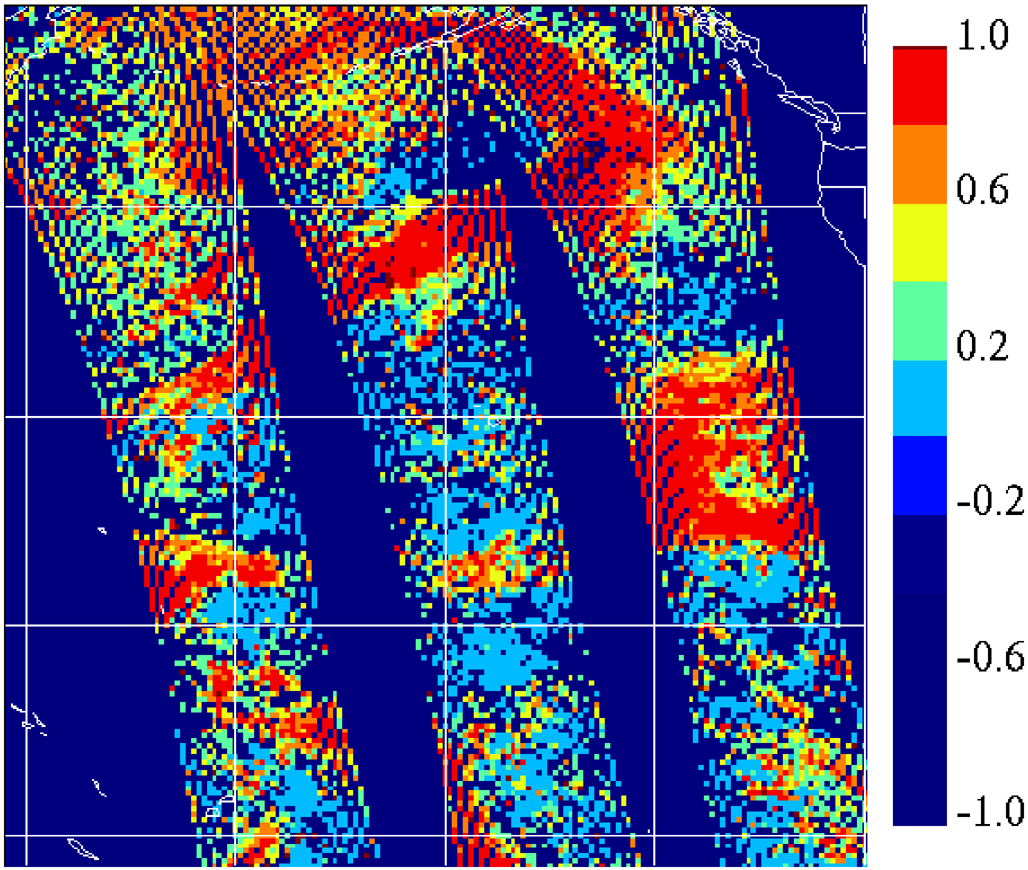


height from CO2 slicing



CO_2 slicing better detects cirrus, low emissivity clouds
+ provides equivalent cloud fraction

Fraction nuageuse effective

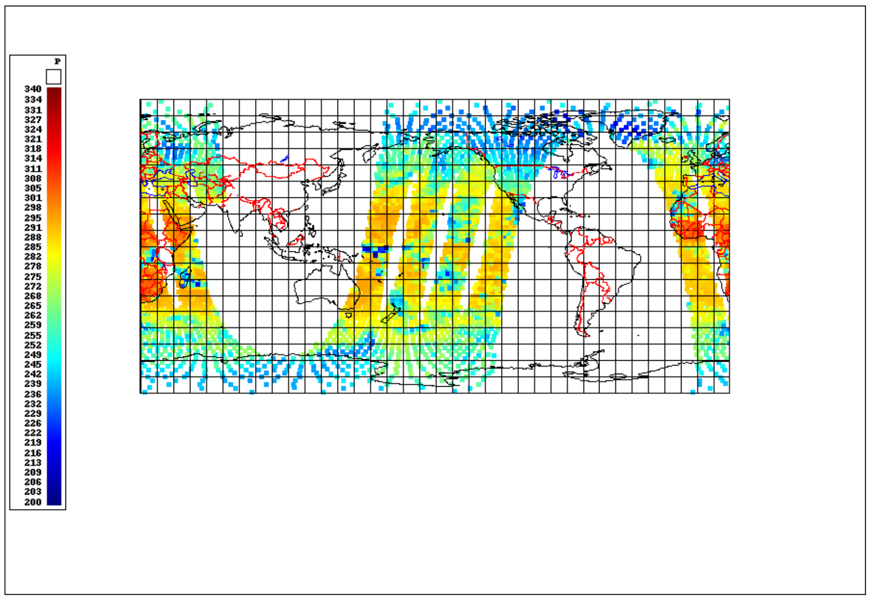


Une archive globale de parametres nuageux sera produite
Aussi champ d'ebauche pour assimilation des radiances nuageuses

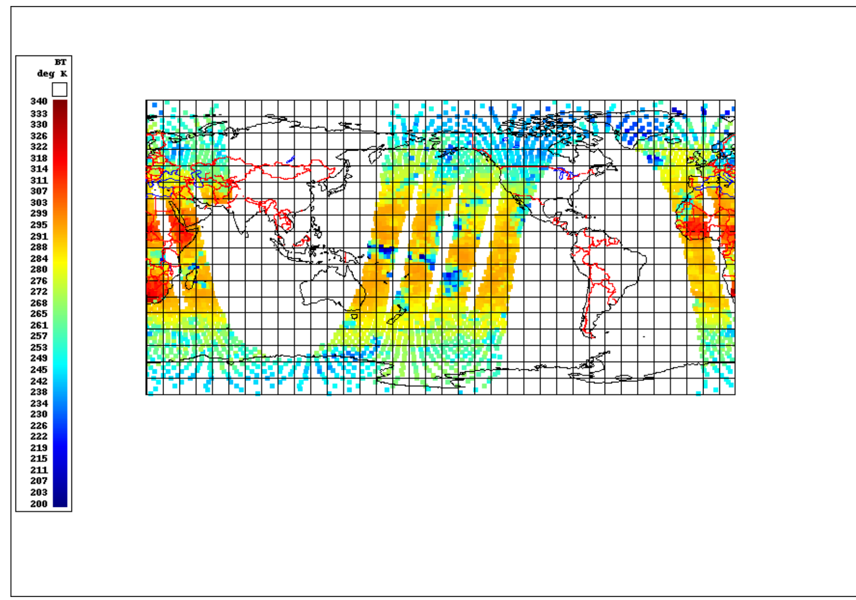
Byproducts: Spectral <u>cloudy</u> radiance validation

BT(calc) from 6-h forecast including cloud water input using RTTOV-CLOUD and corresponding BTobs for a window channel (787)

BTcalc



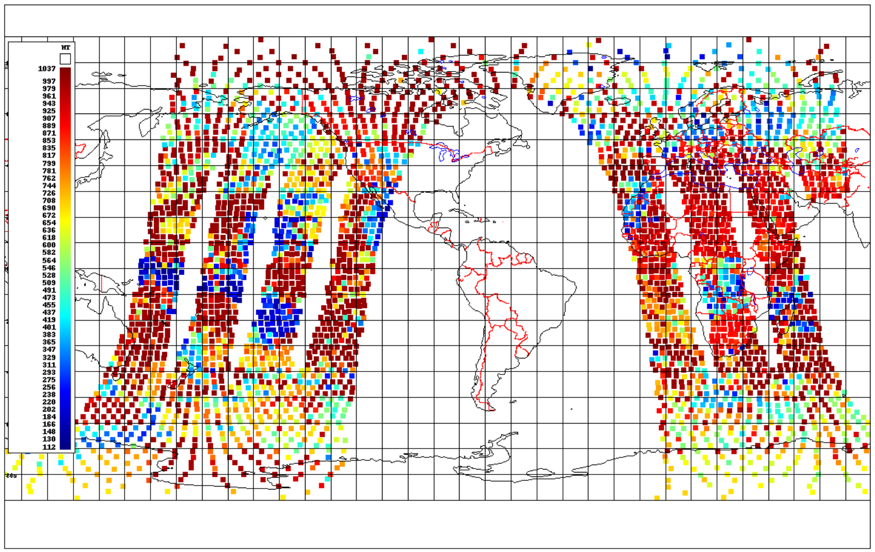
BTobs



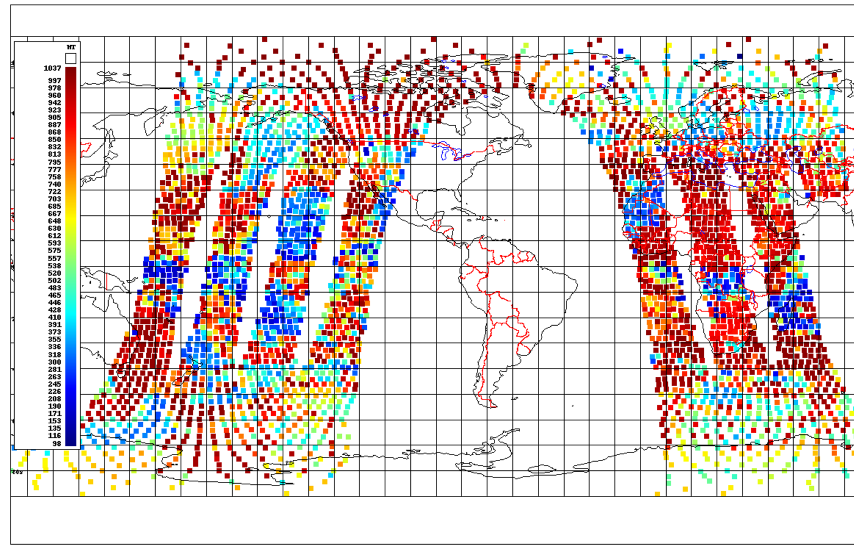
A tool to improve cloud optical properties + spectral surface emissity
Similar validation for effective cloud height and amount
Operational system will provide archive of cloud parameters

Byproducts cloud height/amount validation

Observed cloud height



Model cloud height



Further validation possible with Calipso, notably for polar regions

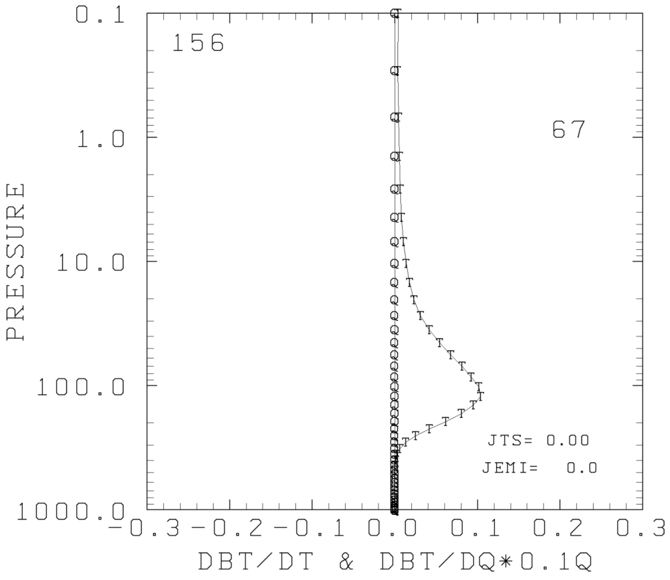
Channel selection

- Good vertical sampling based on response function
- BTs not/weakly affected by ozone or minor gases
- Avoid long stratospheric Jacobian tails

(notably for water vapor ch.): seek localized responses

- Avoid excessive redundancy (notably window channels)
- No significant contribution above model top
- Std of (O-P) well above instrument noise

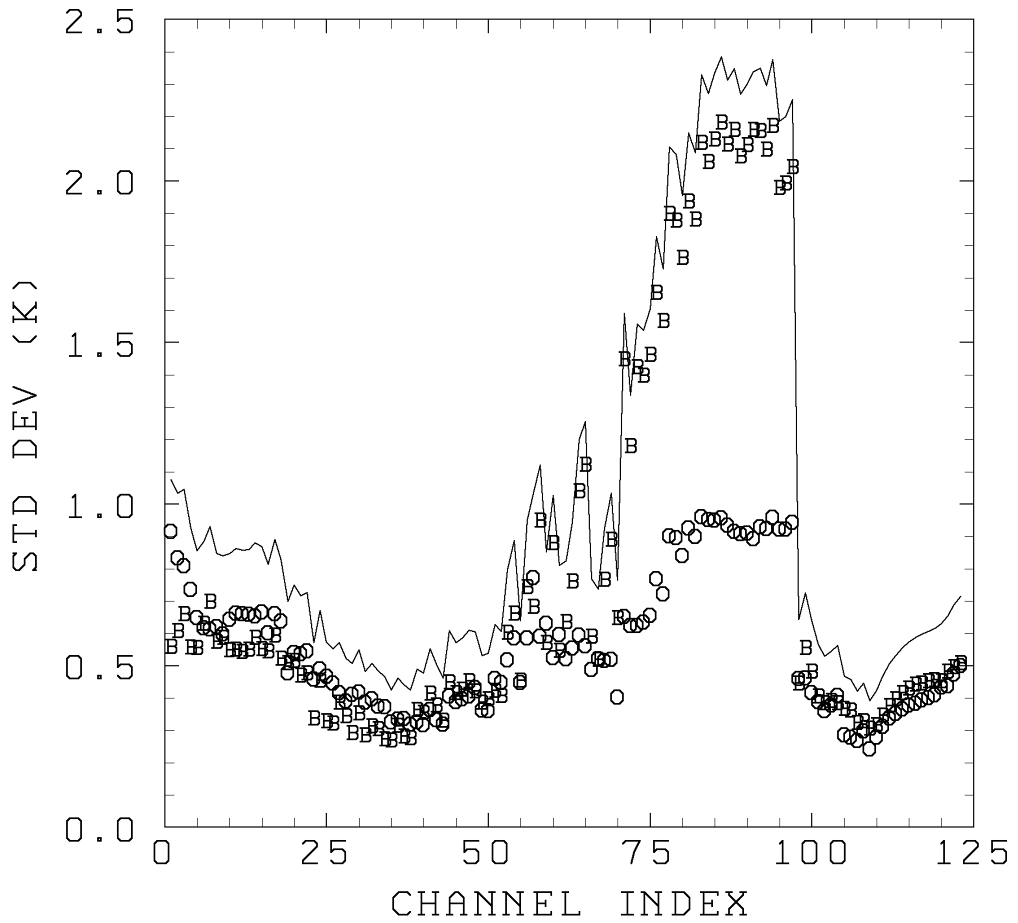
TT Jacobian of highest peaking channel



Other QC criteria

- No shortwave channels in daytime
- No surface channels over land/ice and near coastline
- No surface channels over water if emissivity < 0.90
- No assimilation if Jacobian has a significant contribution above model top
- Background check: $|BT_{obs} – BT_{calc}| > 3$ sigma
- Do not assimilate if reference window channel and alternate reference for cloud detection are both missing. The same applies to reference/alternate for CO2 slicing.

Separating background and obs errors

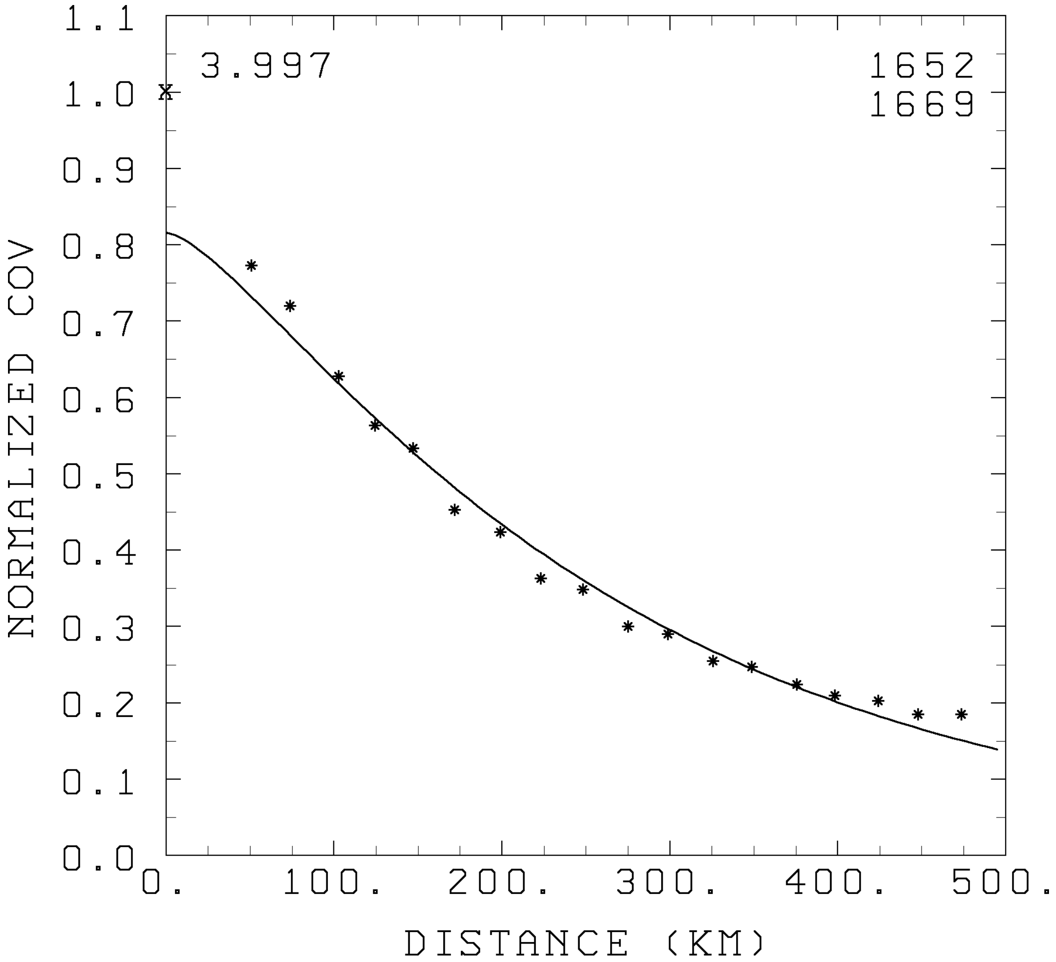


___ Total (O-P)

B: background error
O: observation error

Current practice is to set obs error to total to compensate for inter-channel Error correlation.

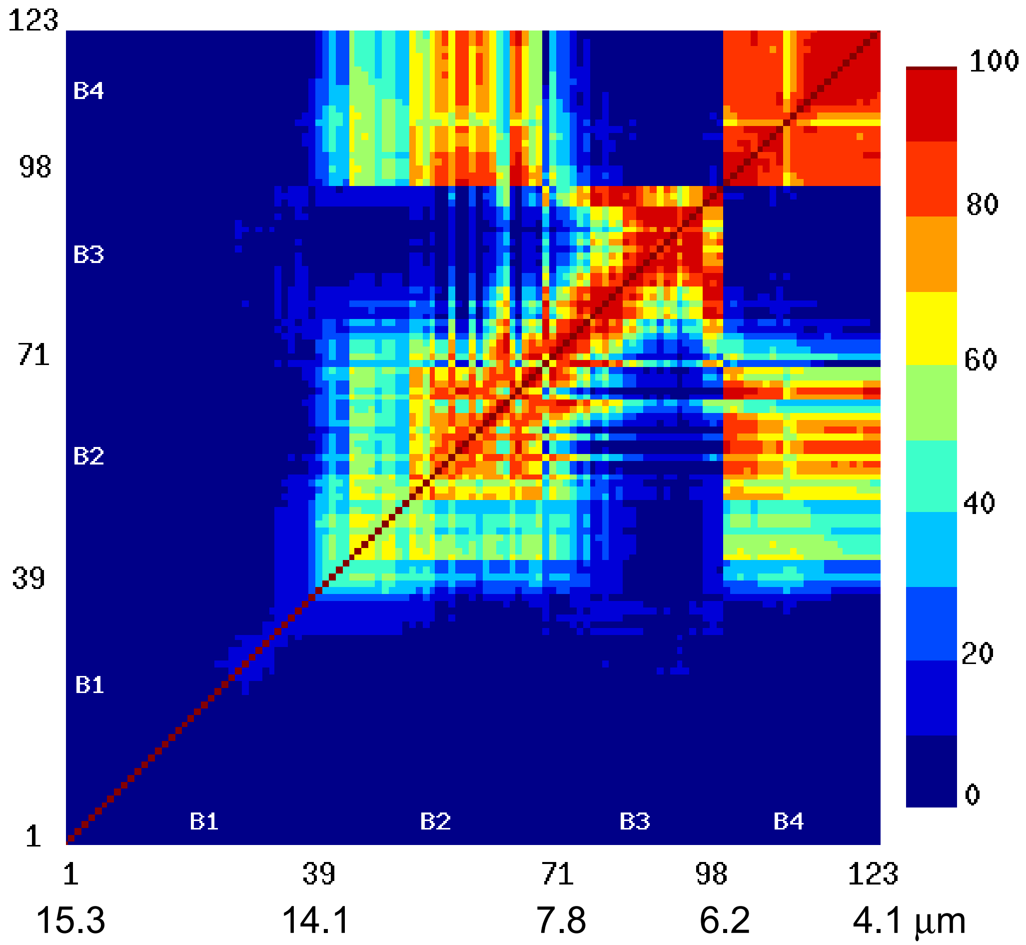
Hollingsworth-Lonnberg error separation



Inter-channel error correlation
Obtained from (O-P)
covariances versus distance

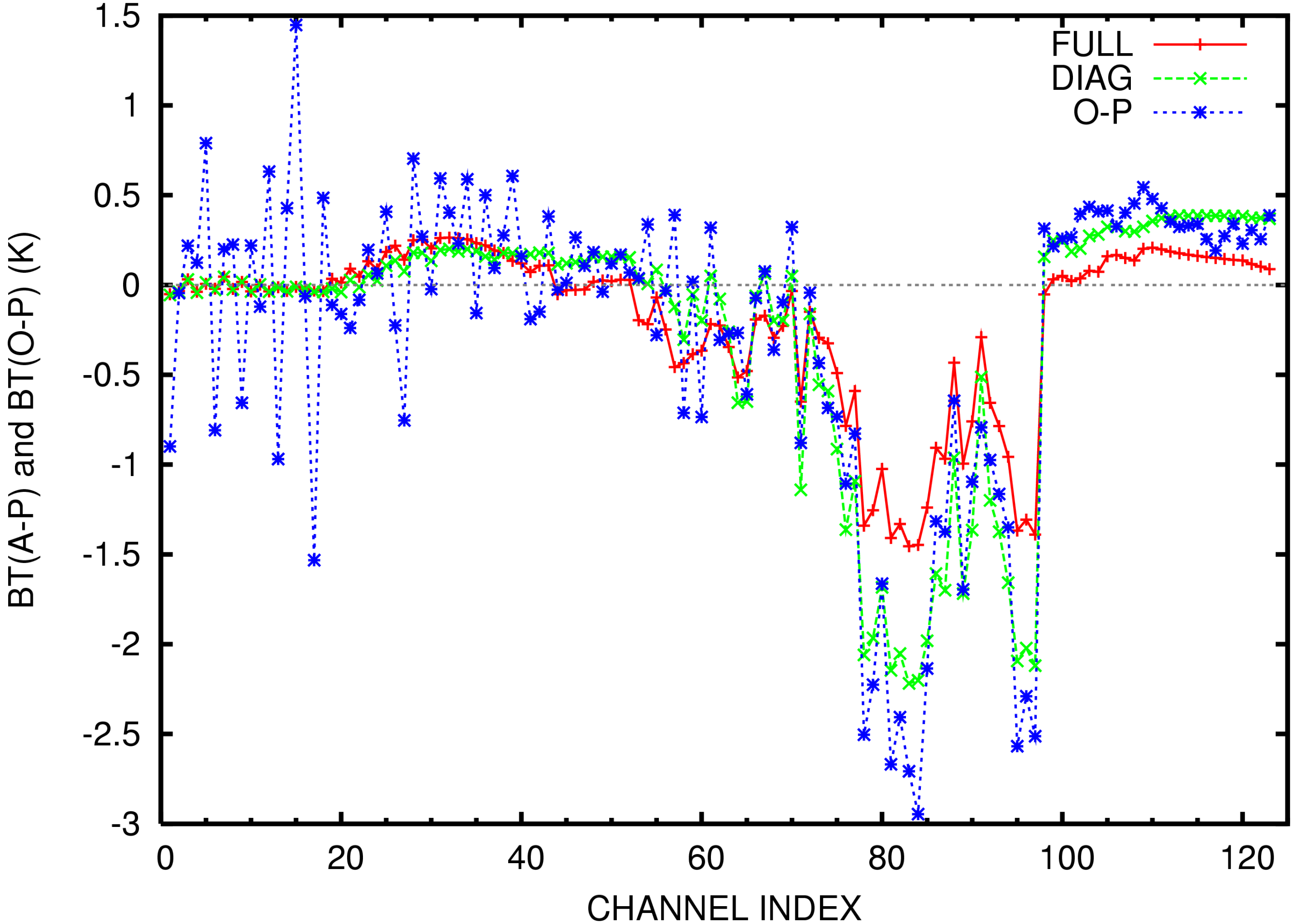
Garand et al, JAMC 2007

Correlation inter-canaux



3Dvar pas code pour tenir compte de cette correlation Toutefois pourrait etre testee dans systeme d'ensembles.

Impact of error correlation in 1D-var

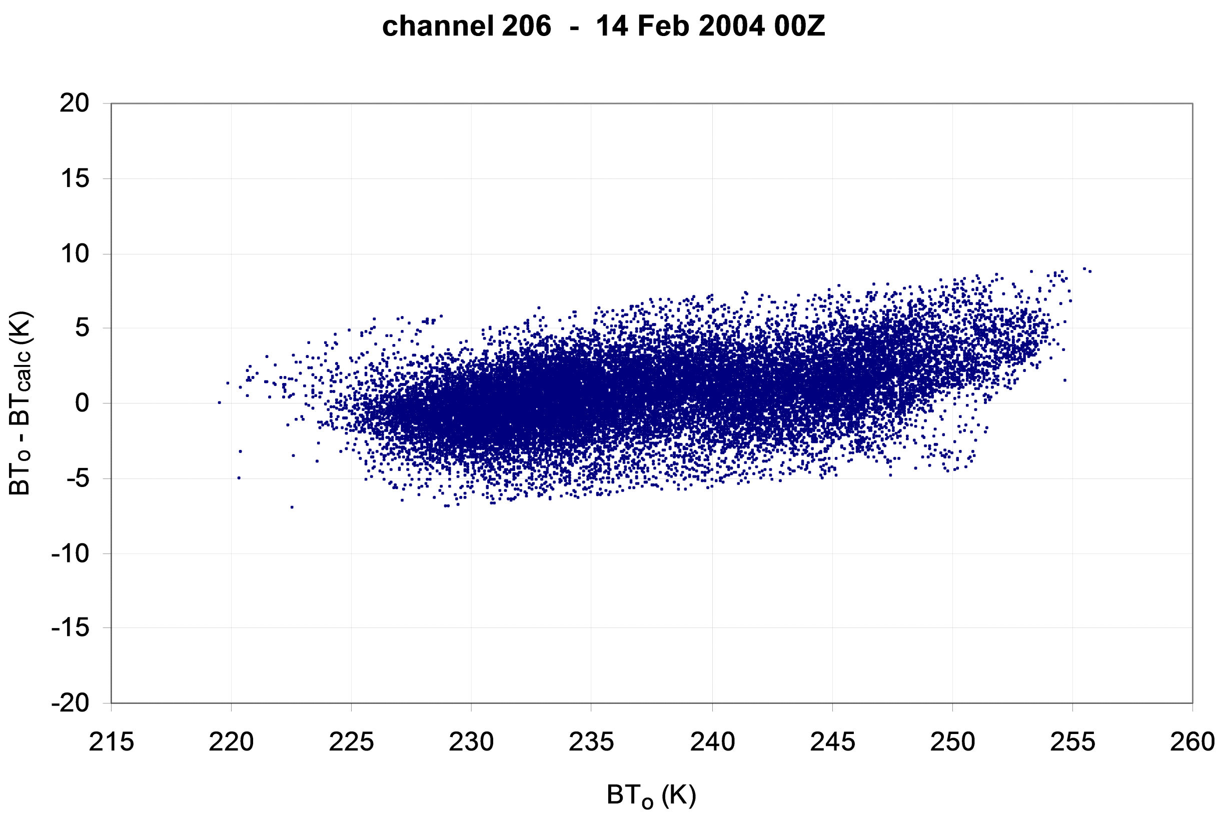


A-P full
A-P diag
O-P

More weight to observations for diagonal matrix vs full

Correction de biais choisie: lineaire

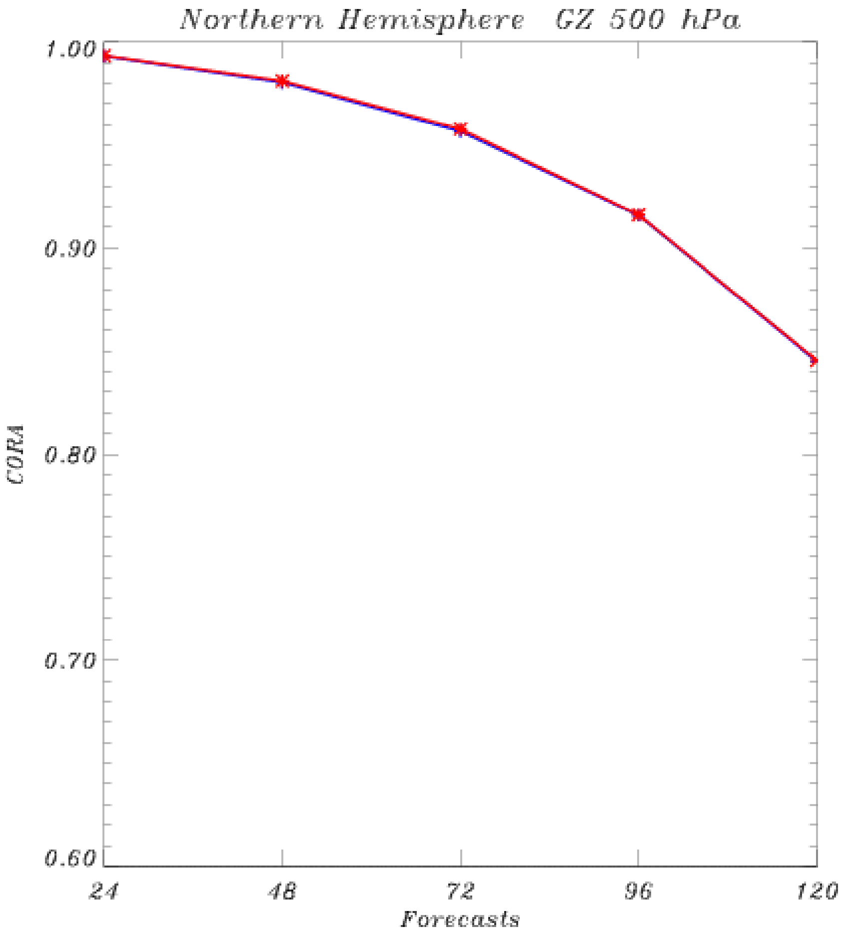
Index 206 : AIRS 1783 (1555.6 cm-1)

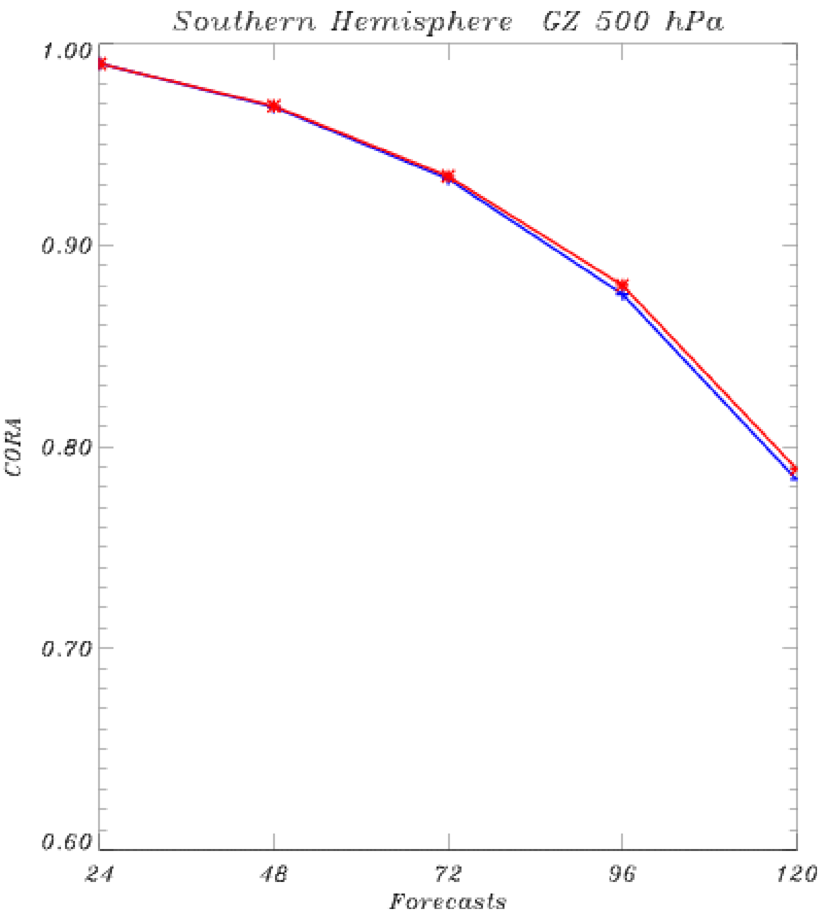


$$\text{Biais} = a\ BT_{obs} + c$$

Flat versus linear bias correction

14-29 Feb 2004 assimilation

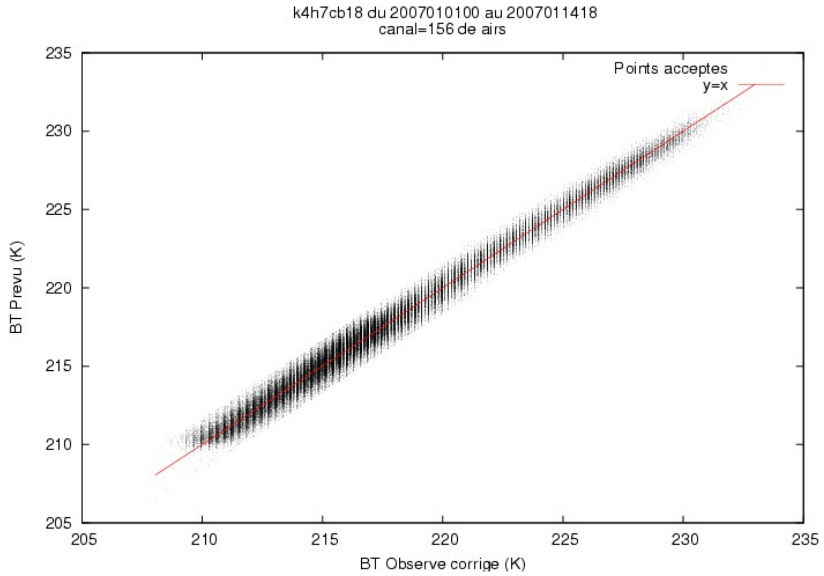




Linear bias correction slightly superior in southern hemisphere

Examples de correction de biais

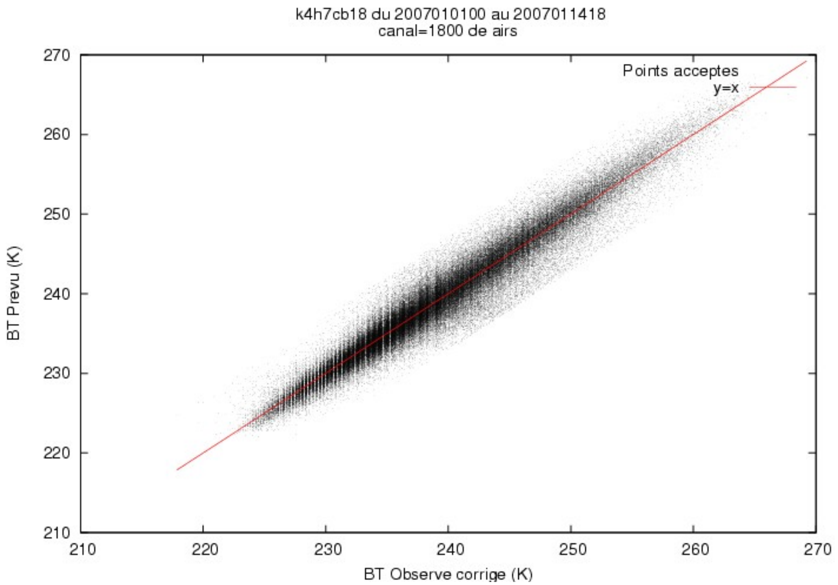
BTcalc vs BTobs (corrigé)



Ch 156 (14.4 μm)

$$bias = (BT_{obs} - BT_{calc}) = aBT_{obs} + c$$

$$BT_{cor} = BT_{obs} - bias$$

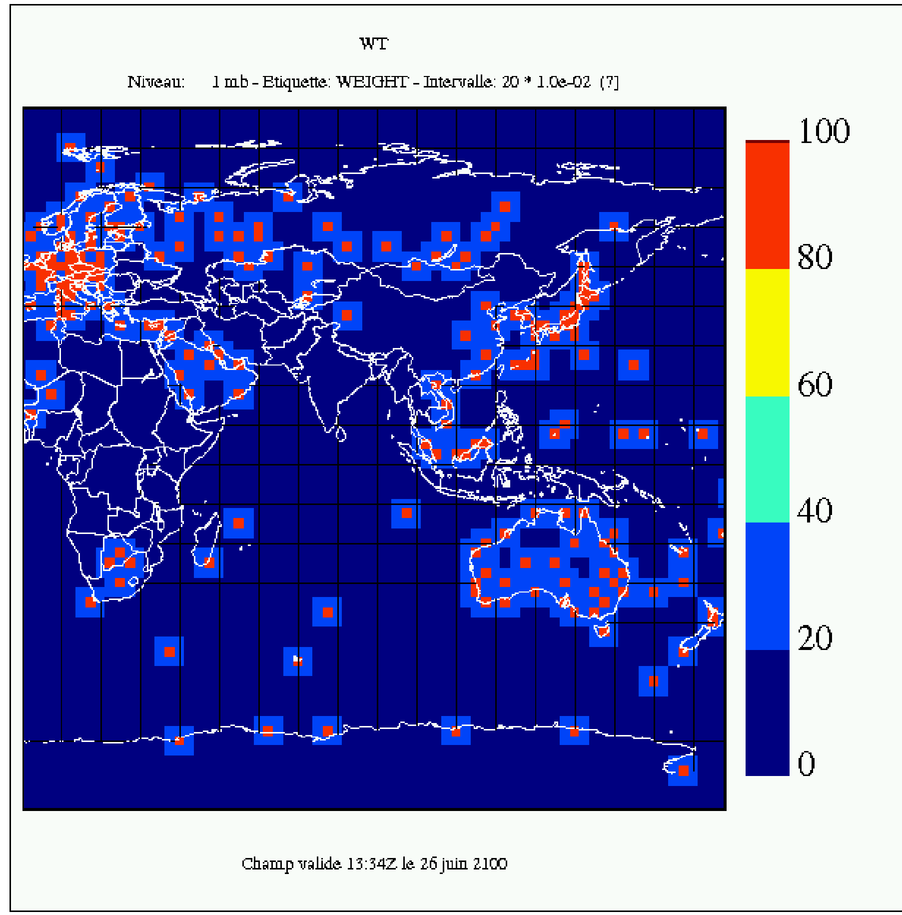


Ch 1800 (6.38 μm)

➡ Correction satisfaisante pour toutes valeurs de BT

Masque raob 2.5 deg pour radiances

Poids:	local	global
Pixel raob:	1.0	25%
Voisins:	0.21	25%
Ailleurs:	0.08	50%



Code de correction de biais

Generalise a N predicteurs

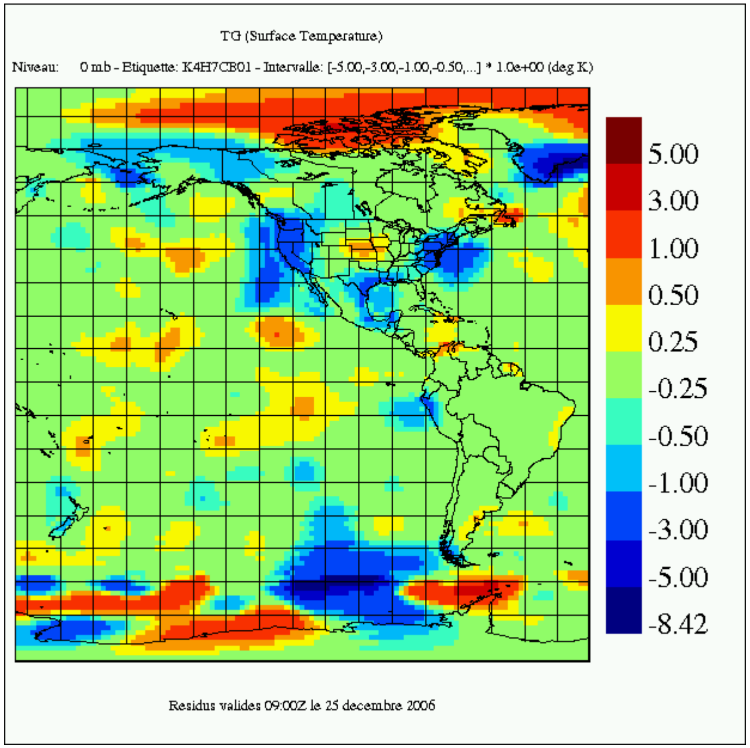
(2 nouveaux extraits 1-10 hPa et 5-50 hPa)

+ possibilite de poids

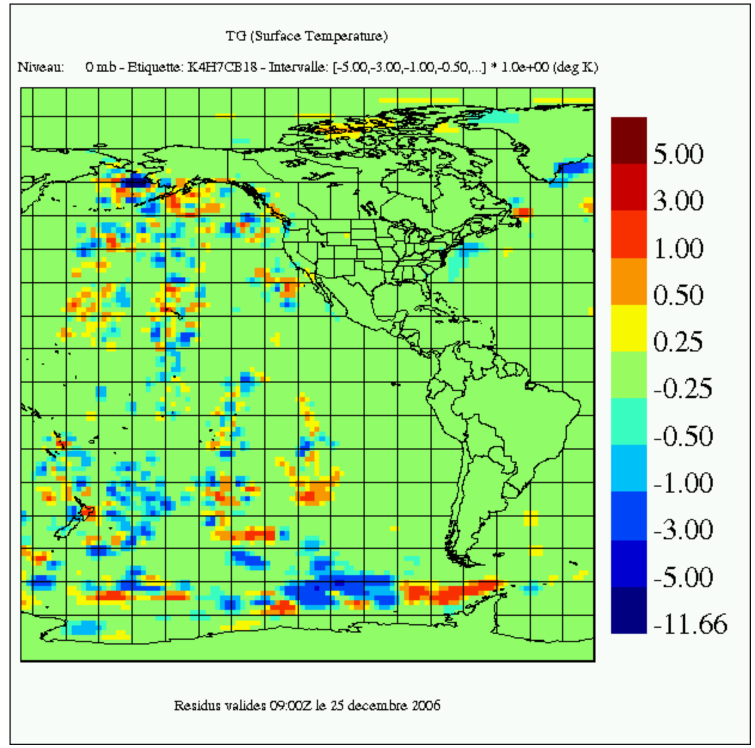
Sera teste dans GEM-strato. Impact faible dans meso.

Modification to TG horizontal length scale

L = 500 km, no AIRS



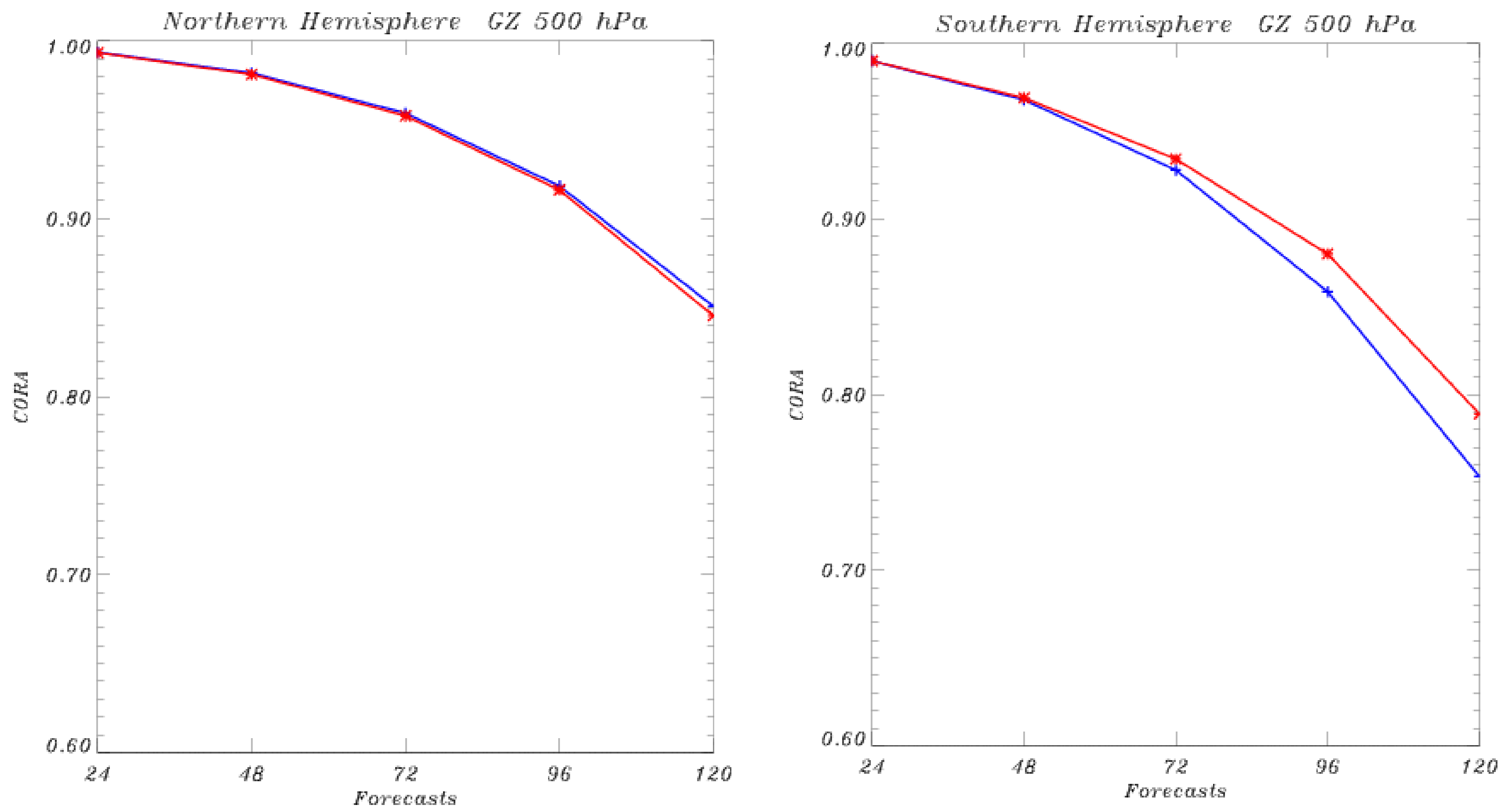
L = 100 km with AIRS



Current TG increments are much too broad. Change needed
To better assimilate surface sensitive channels. Also TG error of 4K
Over land reduced to 3K.

First results with AIRS assimilation (3D-Var)

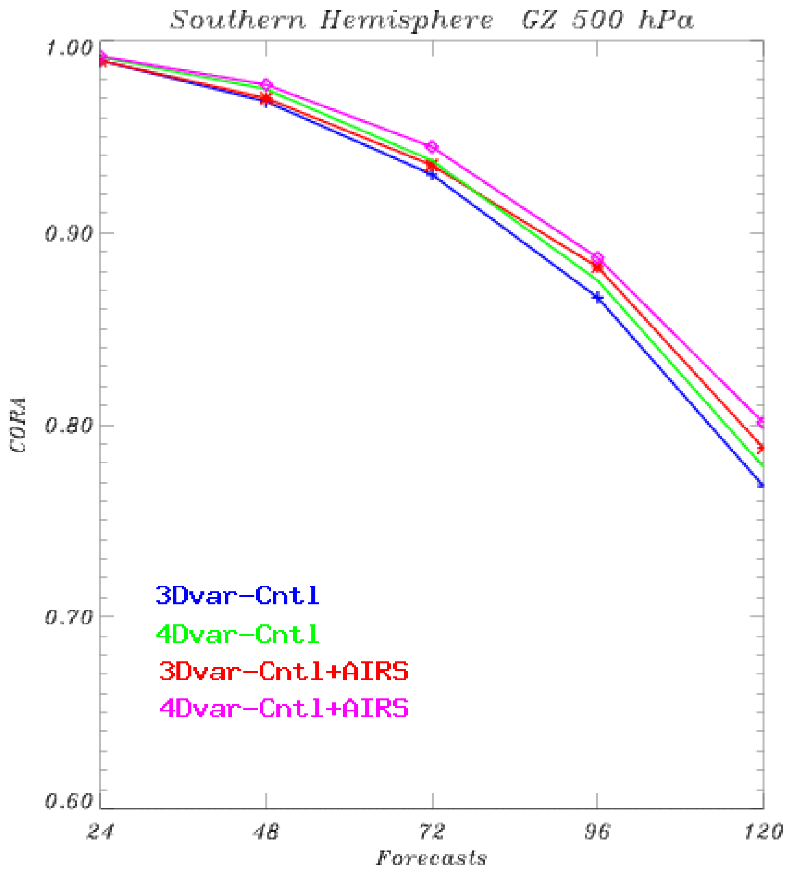
CONTROL CONTROL+AIRS 14-29 Feb 2004



Clear positive impact in southern hemisphere

AMSU-A from AQUA not assimilated

First 4D-var results, 100 channels



JCSDA Newsletter, March 2006
GEM 28 levels

Impact of AIRS similar or larger than that of 4Dvar vs 3Dvar

On passe a GEM-meso … et le ciel nous tombe sur la tete!

Dérive au toit du modele, refroissement de 25 degrés + au cercle polaire a 10 mb !

Identification du probleme: les canaux dans la bande a 14 μm,
avec faible sensibilite au-dessus de 10 mb créent de forts incréments.
Dilemme: ces canaux sont connus pour avoir le plus d'impact en NWP…

Combinaison de facteurs causant increments TT élevés:

8. Erreur de background TT élevées (~5 K)
9. Correlation d'erreur de TT (10 mb, autres) significative
10. Effet cumulatif sur increments TT dus a l'adjoint de l'extrapolateur

Solution "compromis": réduire le nombre de canaux de 100 a 87, ne conservant que 4 canaux avec sensibilite au-dessus de 10 mb. De plus: ces 4 canaux ne sont pas Utilises aux latitudes 60-90N/S, zone d'incréments les plus forts a 10 mb.

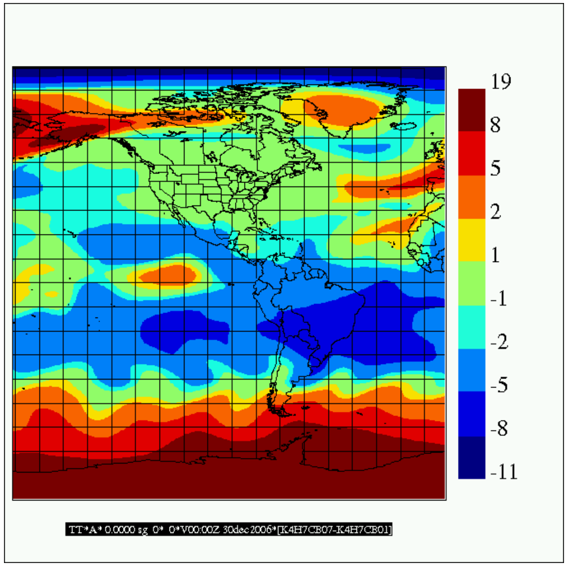
Autre solution: éliminer adjoint d'extrapolateur + localisation correlation TT, forcer Increments de TT zero a 10 hPa. N'a pu etre testé dans cycles.

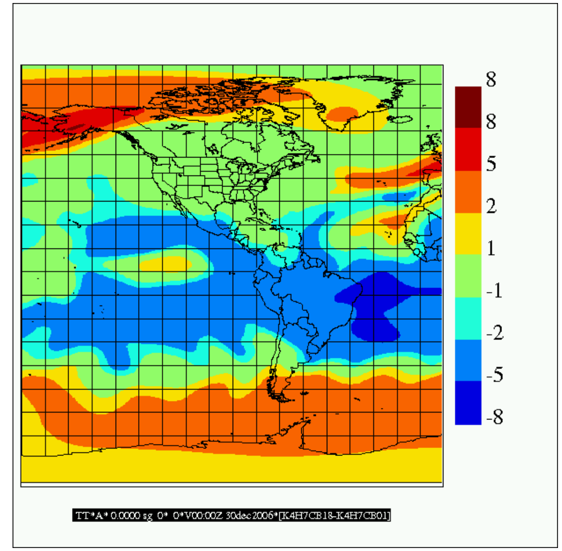
Difference d’analyses apres 10 jours

AIRS_87 – NOAIRS

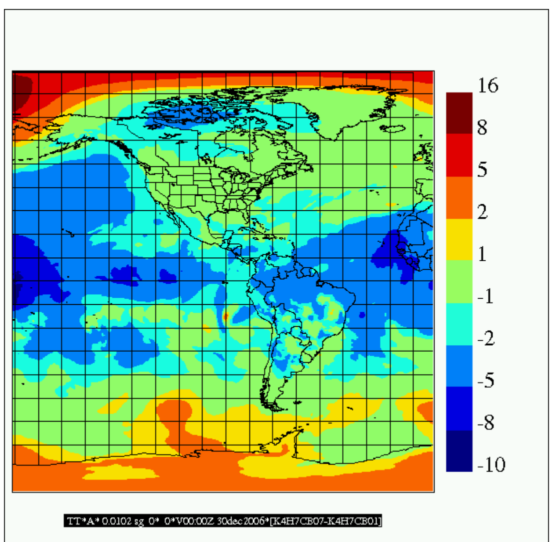
AIRS_87_83 – NOAIRS

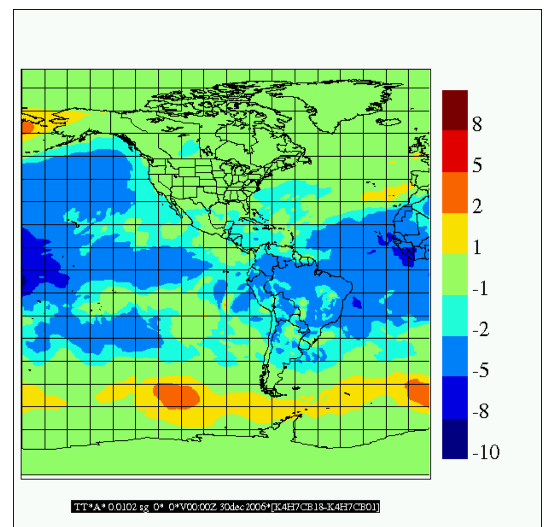
Niv 1
10 mb





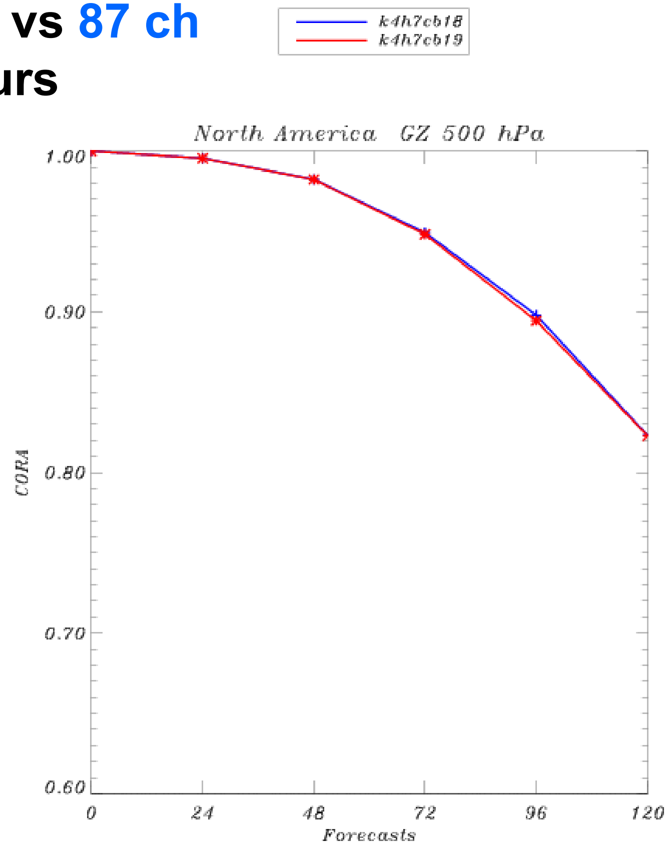
Niv 2
20 mb

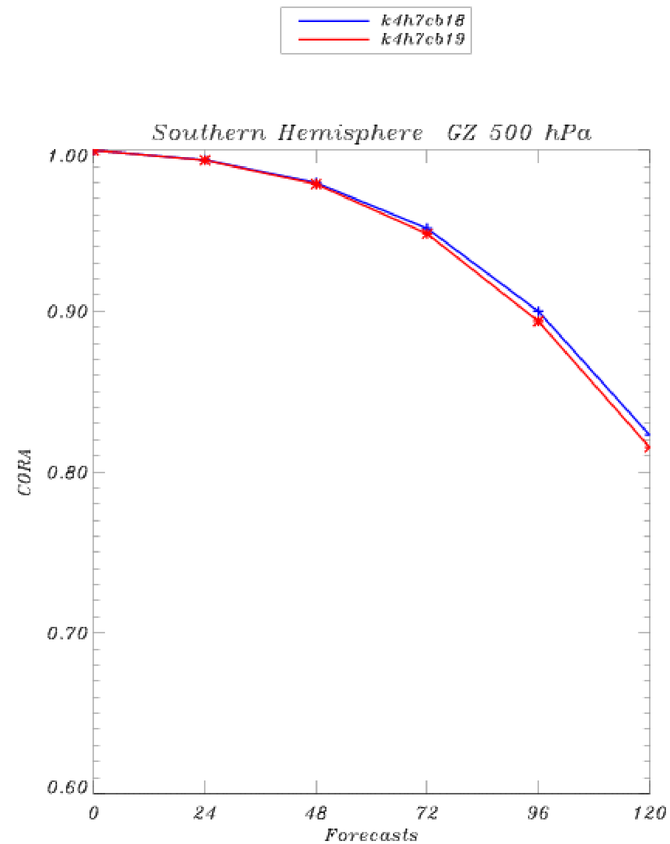




Impact des 4 canaux CO_2 avec contribution partielle au-dessus du toit

83 ch vs **87 ch**
35 jours





CO_2 channels in 15 µm band are known to be the most important
For impact in NWP. Raising model top + using more channels
Should have a significant additional positive impact

Composantes considérees et retenues pour la passe ajout d'observations

- <u>L'équipe:</u> D. Anselmo, J. Aparicio, A. Beaulne, J.-M. Bélanger, M. Buehner, G. Deblonde, L. Garand, J. Hallé, S. Laroche, P. Koclas, J. Morneau, R. Sarrazin, N. Wagneur, E. Lapalme, Y. Rochon

  – RTTOV7 → RTTOV8 (plusieurs améliorations, nécessaire pour IASI)
  – estimation/correction de biais dynamique (données de radiance)
  – nouvel interpolateur pour RTTOV (importantes avec analyse à 58 niveaux)
  – données AMSU supplémentaires (extreme scan angles)
  – nouvelles statistiques (background et observations)
  – SSM/I (+ élimination de AMSU-A ch3 et filtre de nuage pour AMSU-B)
  – QuikScat
  – AIRS
  – GPS-RO
  – augmentation volume de données conventionnelles:
    - UA (43 niveaux au lieu de 28)
    - AI (plus haut résolution dans le verticale)
    - SW (3.9 micron, seulement pendant la nuit et à bas niveaux)
    - P_{sfc} (toutes les 3 heures)
  – diffusion des vents réels dans la couche-éponge (M. Roch)

"Package de Jacques"

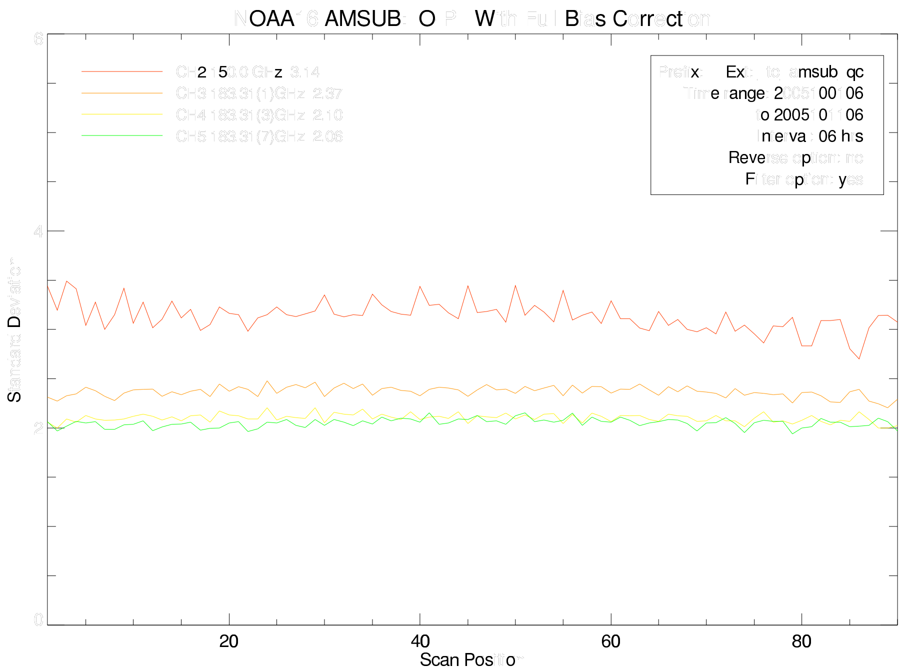
25/07/07,dernier jour au CMC!

- RTTOV-8 (recodage majeur, types derivés), incluant multitasking
  16 CPU (découpage en bandes de 10 deg lat) + open-mp (8 "threads")
- Nouvel interpolateur vertical pour RTTOV
- Correction de biais dynamique pour AMSU, SSM/I (15 derniers jours)
- Ajout des données AMSU-A-B aux bouts du balayage (+25 %)

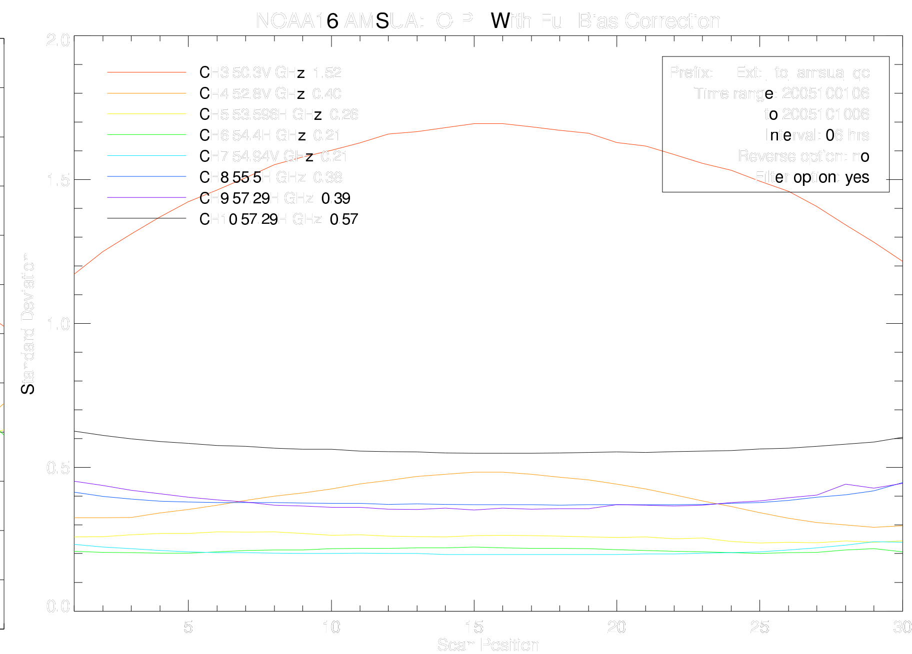
→ **Ce package a servi de base pour tester les nouvelles données**

Ajout AMSU-A-B aux bouts du balayage
(Ecmwf Bias Estimation Workshop, 2005)

STD AMSU-B



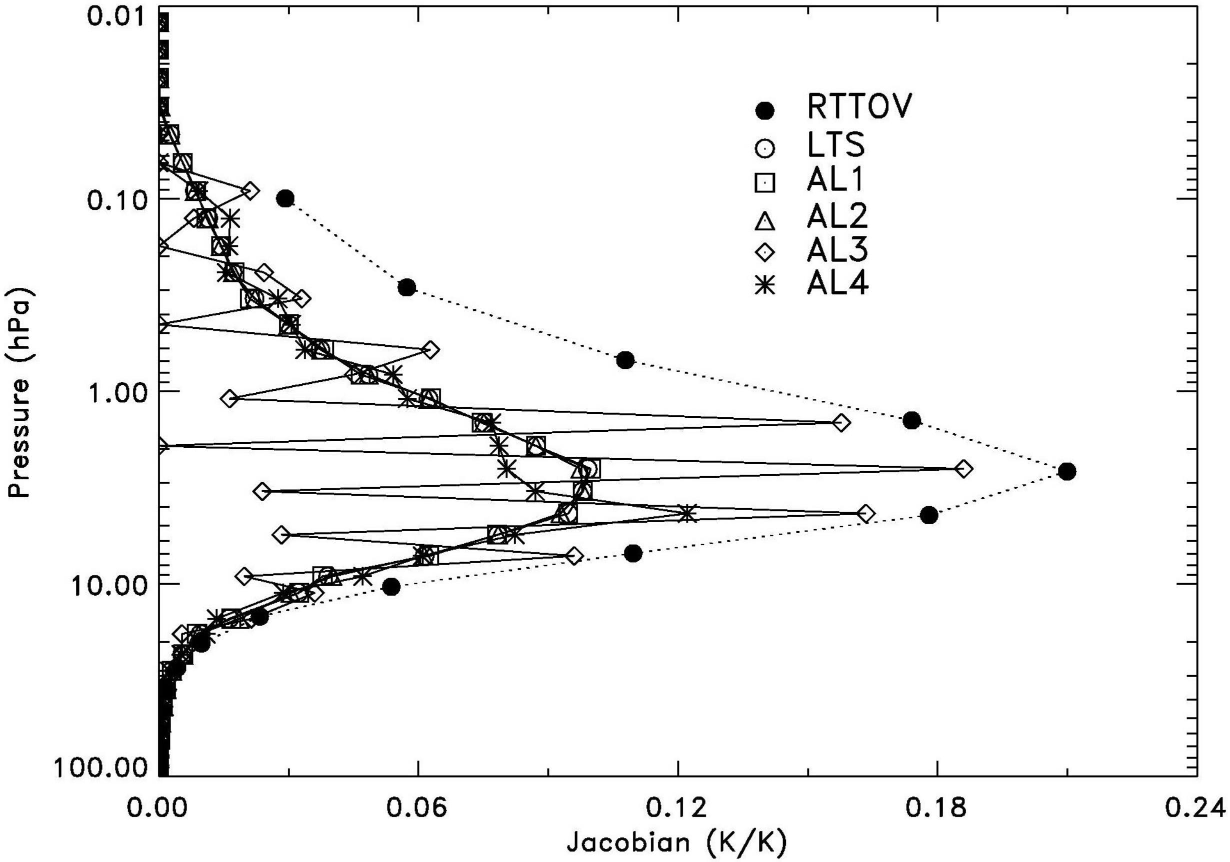
STD AMSU-A



Eliminer bout du scan non justifie
STD plus eleve au nadir Ch 3-4 du a sensibilite a Ts

New vertical interpolator

NWP to RTTOV coordinates: forward BTs,Jacobians then remapped on NWP coordinate



Rochon at al, QJRMS 2007,

Implemented in

RTTOV-9

Example of T Jacobian

Remapping for AMSU-A channel 40

Nearest-neighbor log-linear AL3 introduces noise in remapped Jacobians because not all NWP inputs are used in interpolation to RTTOV

Strategie des cycles

- CNTL = systeme operationnel
- Cycles de 2.5 mois, hiver 06/07 (80 jours), ete 06 (78 jours)
- Composantes individuelles testees 1 mois sauf AIRS avec CNTL+ “package de Jacques”
- NEW: CNTL + tout sauf AIRS
- AIRS: NEW + AIRS teste sur les 2 mois
- AIRS: max 87 canaux, thinning 250 km

→ Resultats presentes: **OPE**-**NEW**-**AIRS**

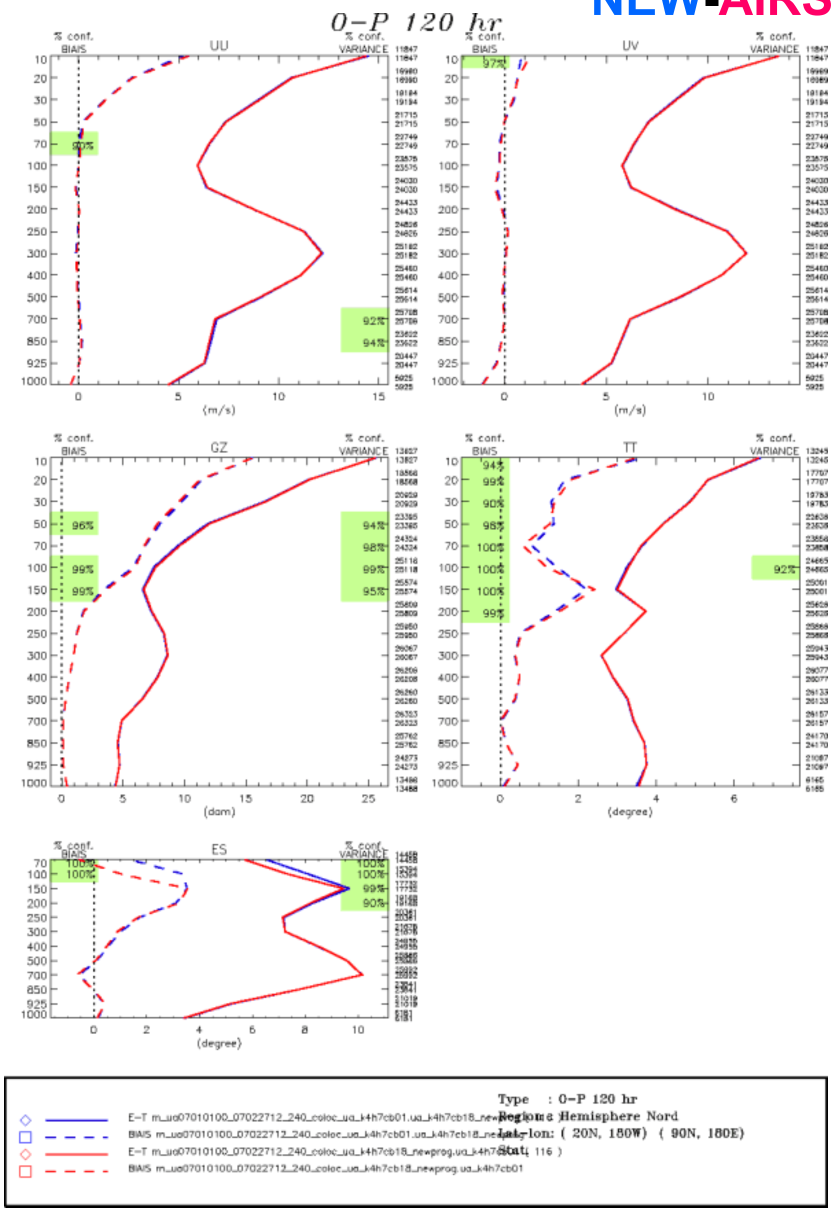
Volume des données

Système opérationnel		Nouvelles données	
RAOBS	50000	SSMI	14000
Aircraft	55000	QuikScat	10000
Profilers	8000	AIRS	75000
Surface	13000		
GOES	5000		
SatWind	40000	SatWind	1500
AMSU-A	50000	AMSU-A	14000
AMSU-B	20000	AMSU-B	5000
Total	~240000	Total	~120000

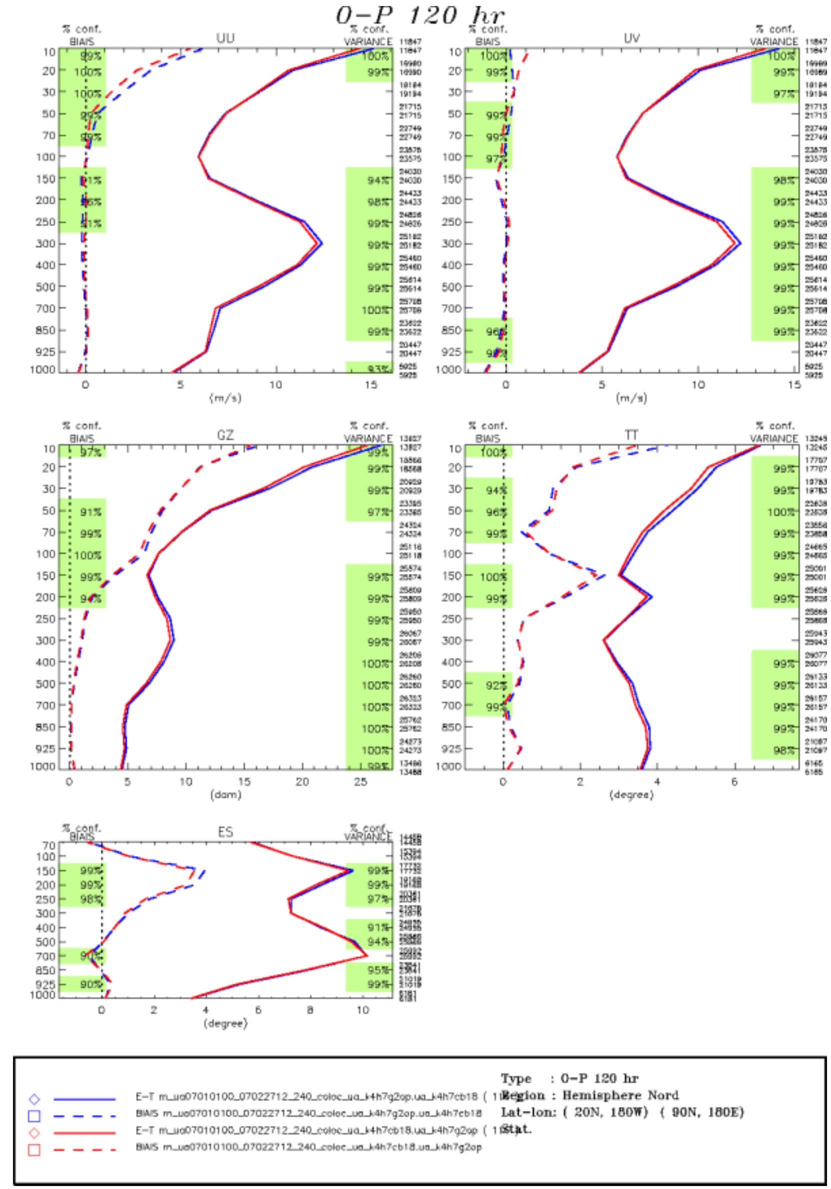
Augmentation des données assimilées de ~50%

Impact dans le modele global HN 120h Hiver

NEW-AIRS

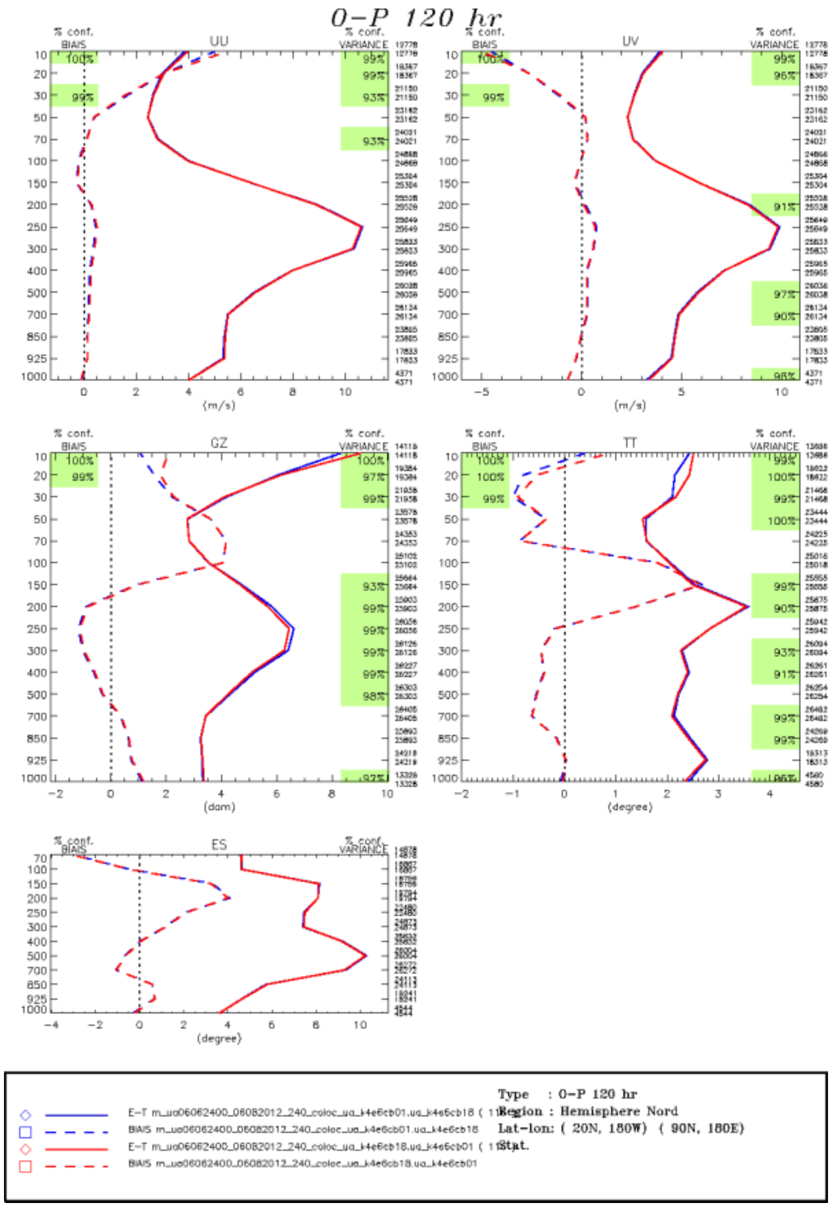


CNTL-AIRS

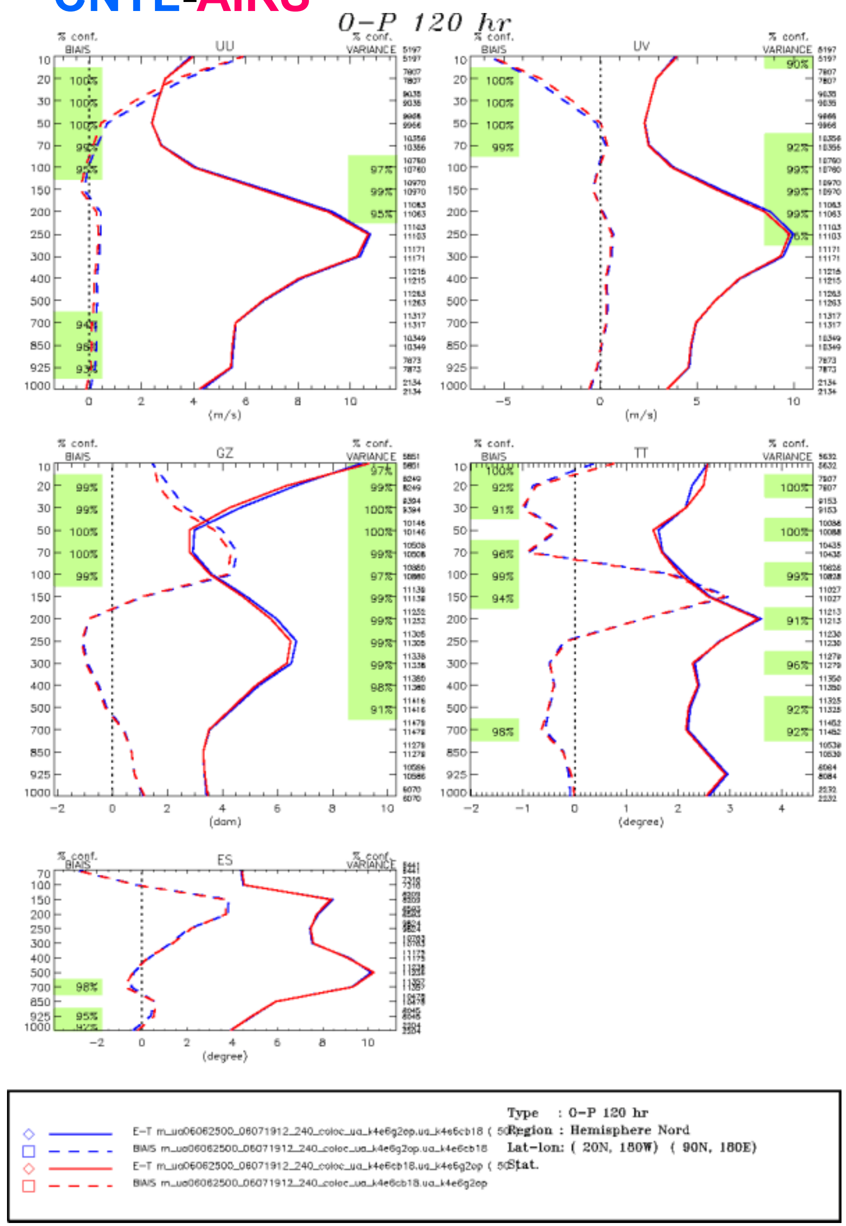


Impact dans le modele global HN 120h ete

NEW-AIRS

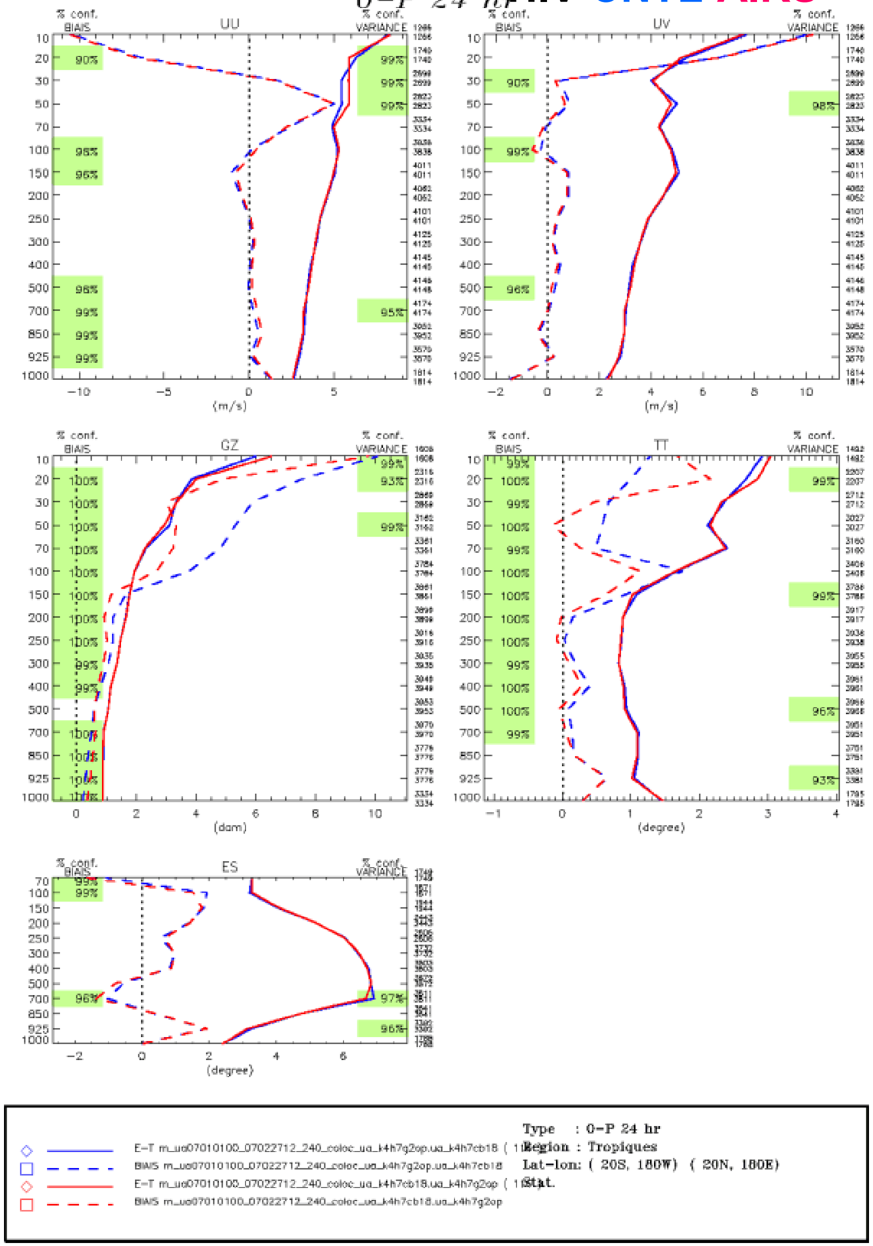


CNTL-AIRS

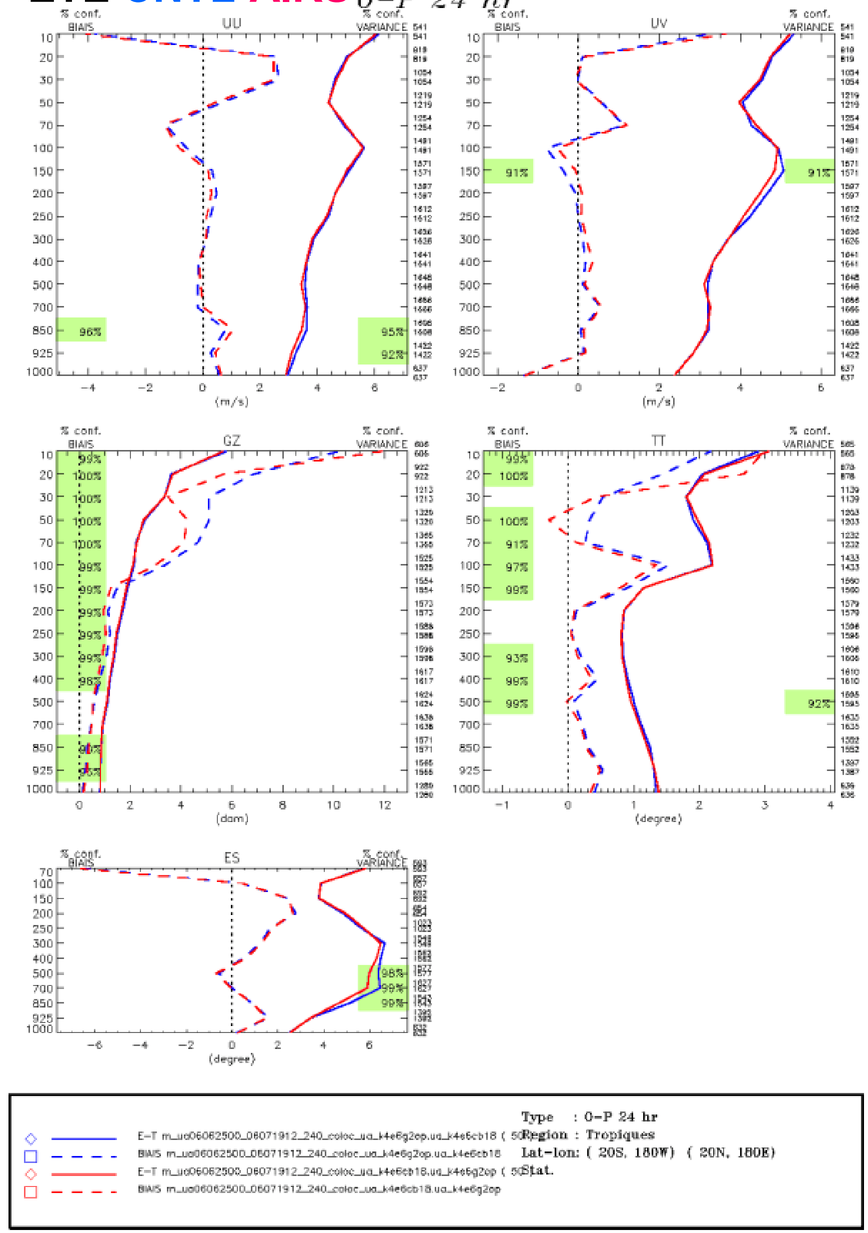


Impact dans le modele global TRO 24h

HIV CNTL-AIRS

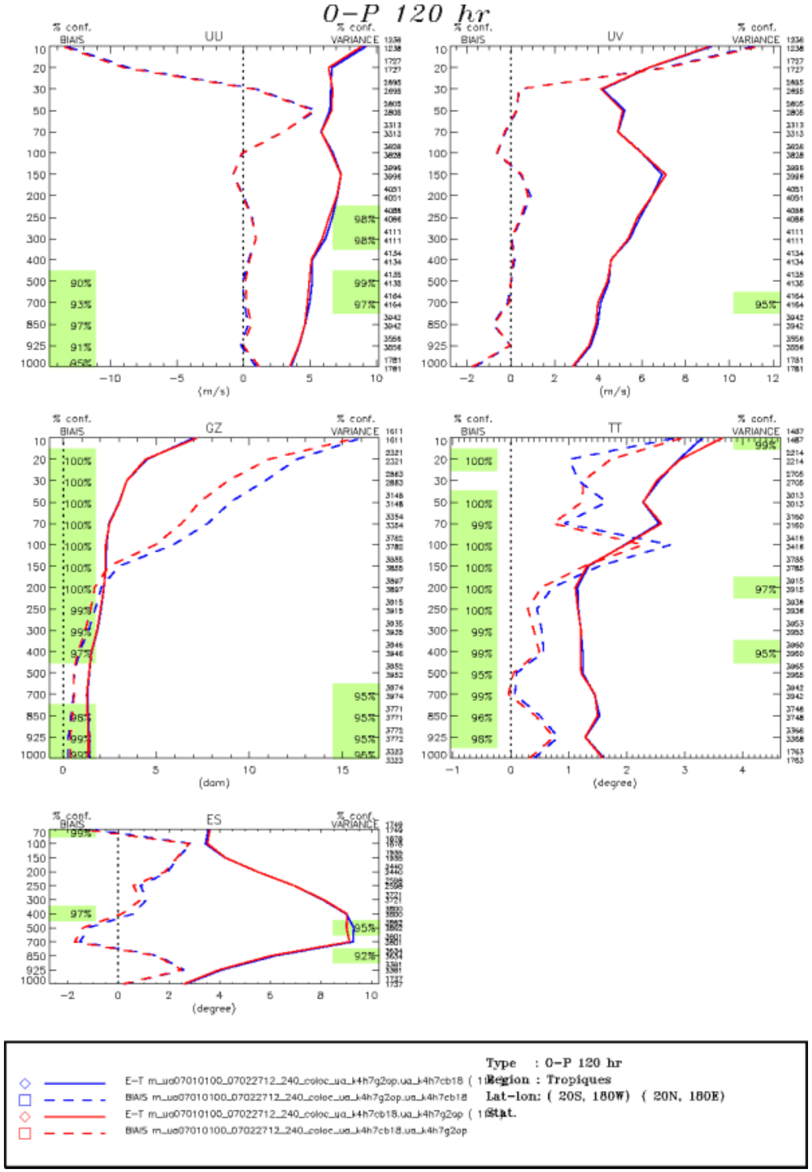


ETE CNTL-AIRS

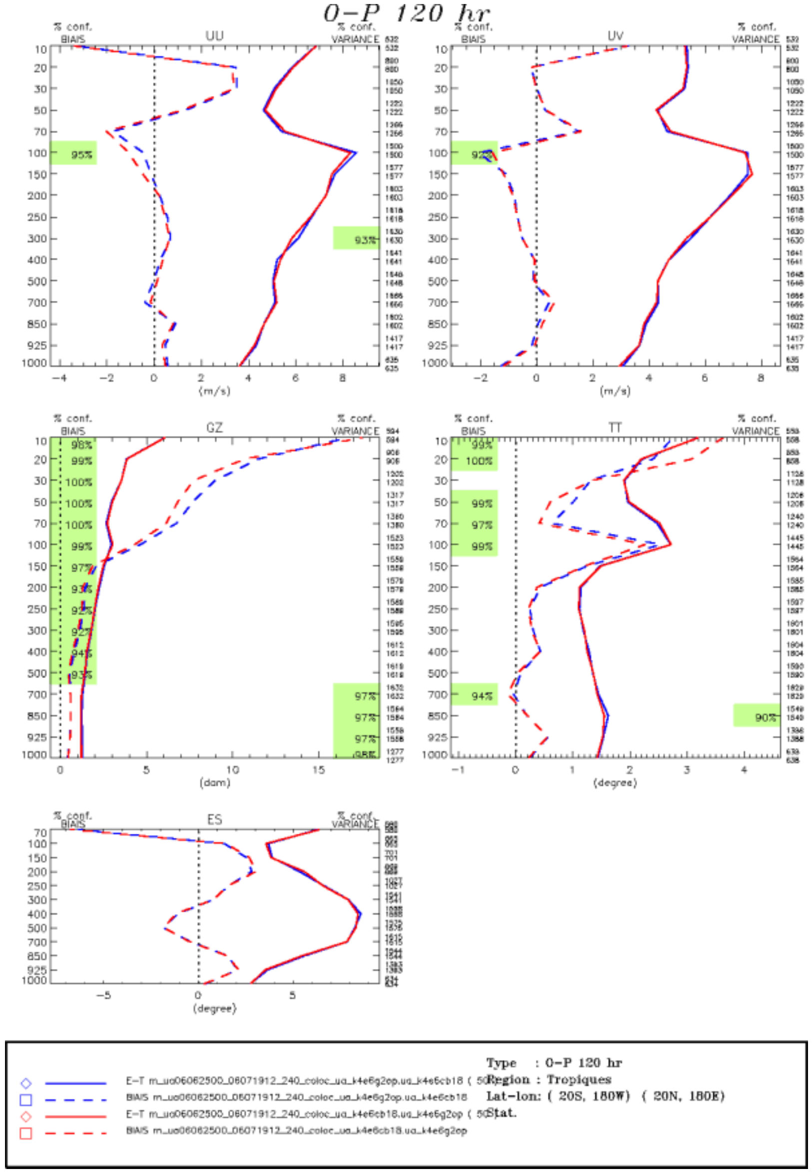


Impact dans le modele global TRO 120h

HIV CNTL-AIRS

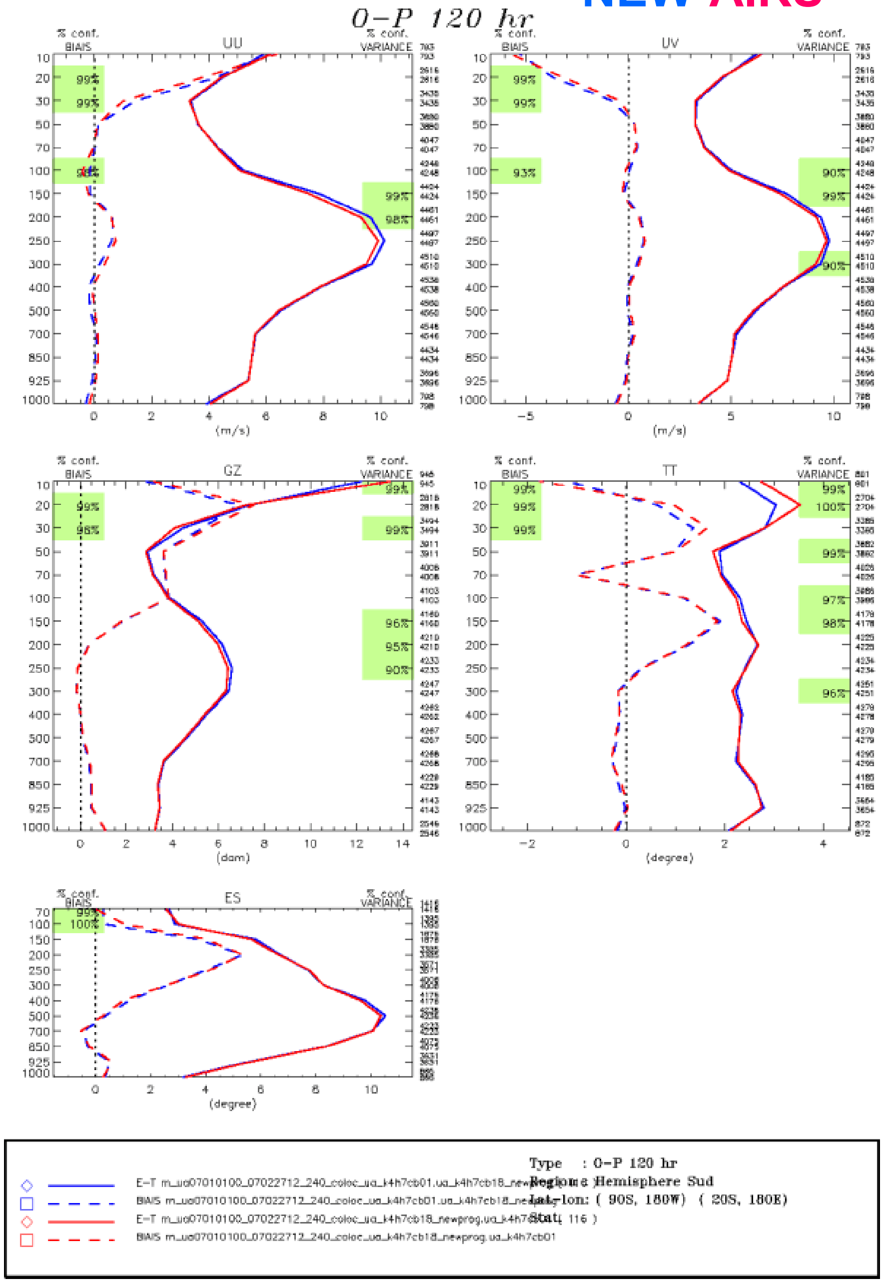


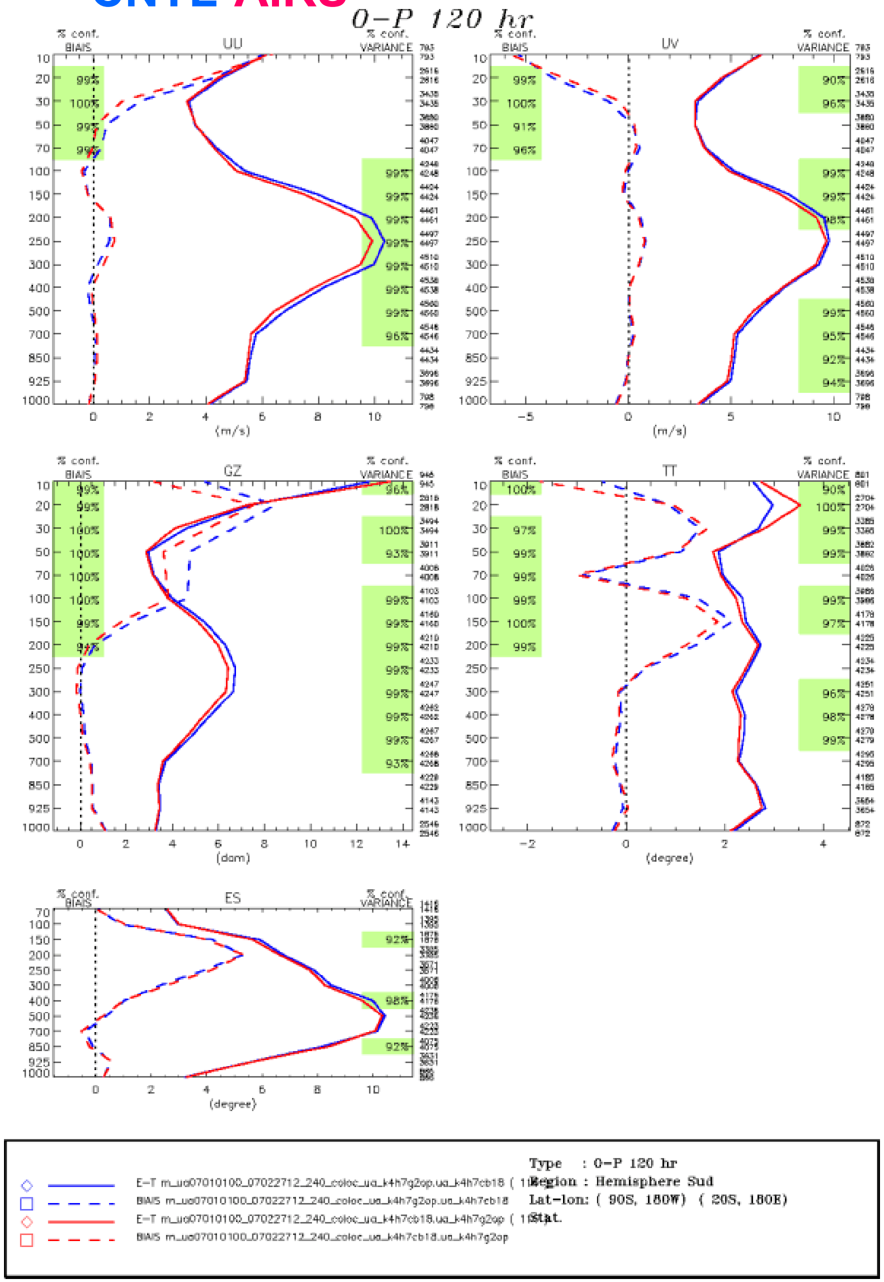
ETE CNTL-AIRS



Impact dans le modele global HS 120h Hiver

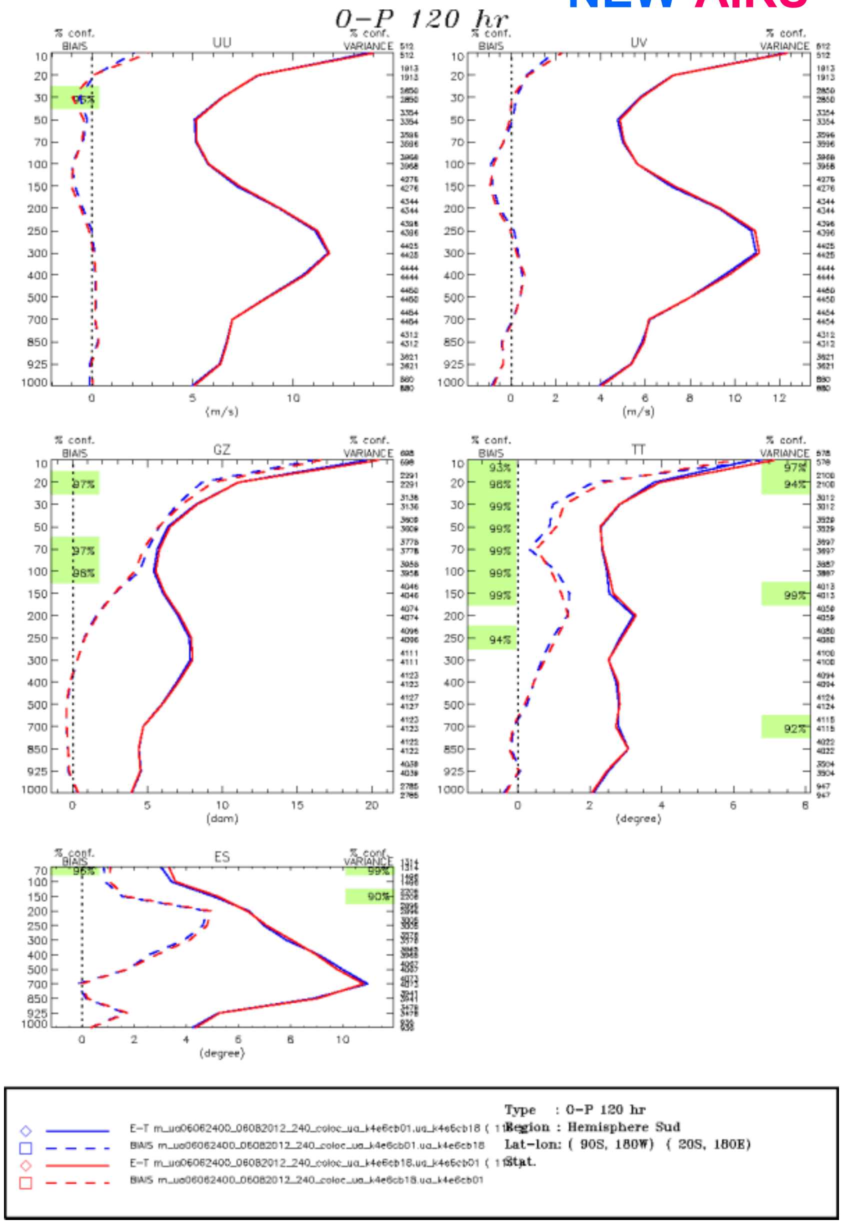
NEW-AIRS **CNTL-AIRS**



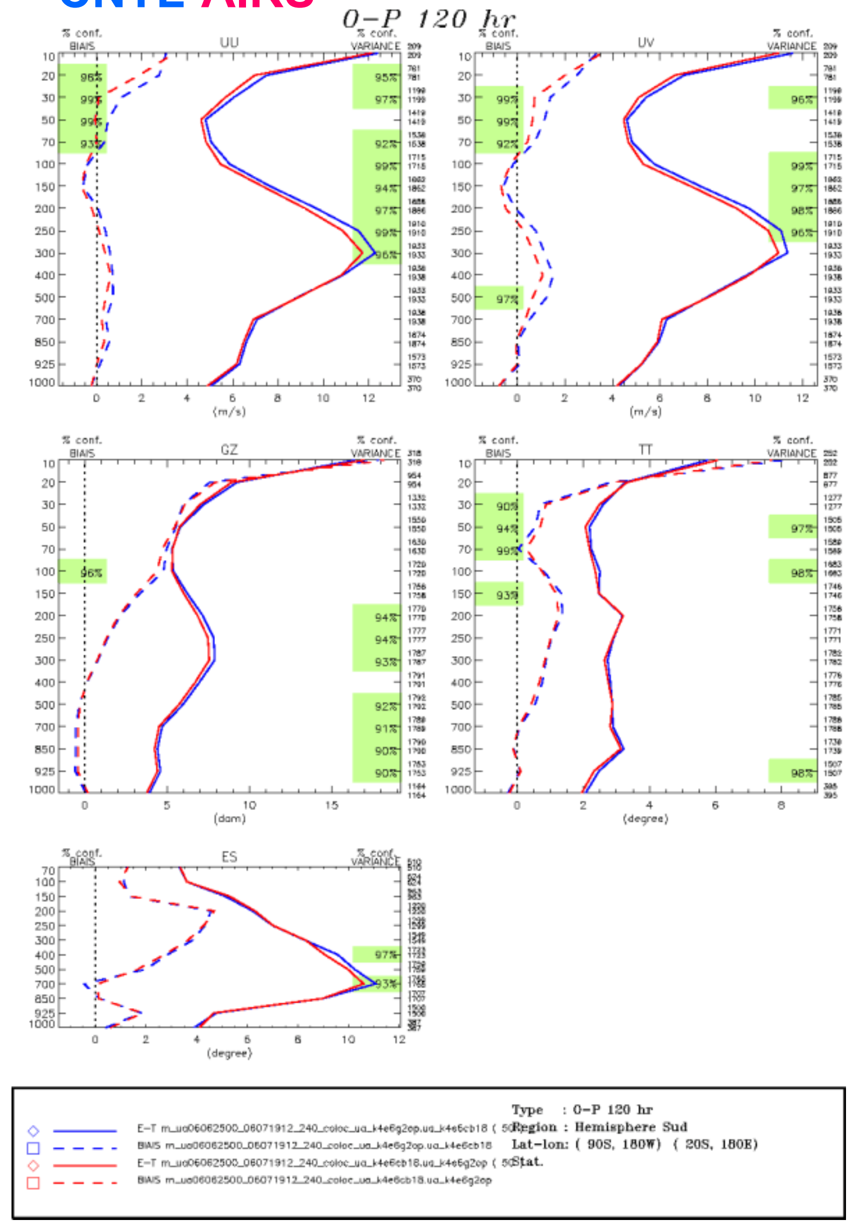


Impact dans le modele global HS 120h ete

NEW-AIRS



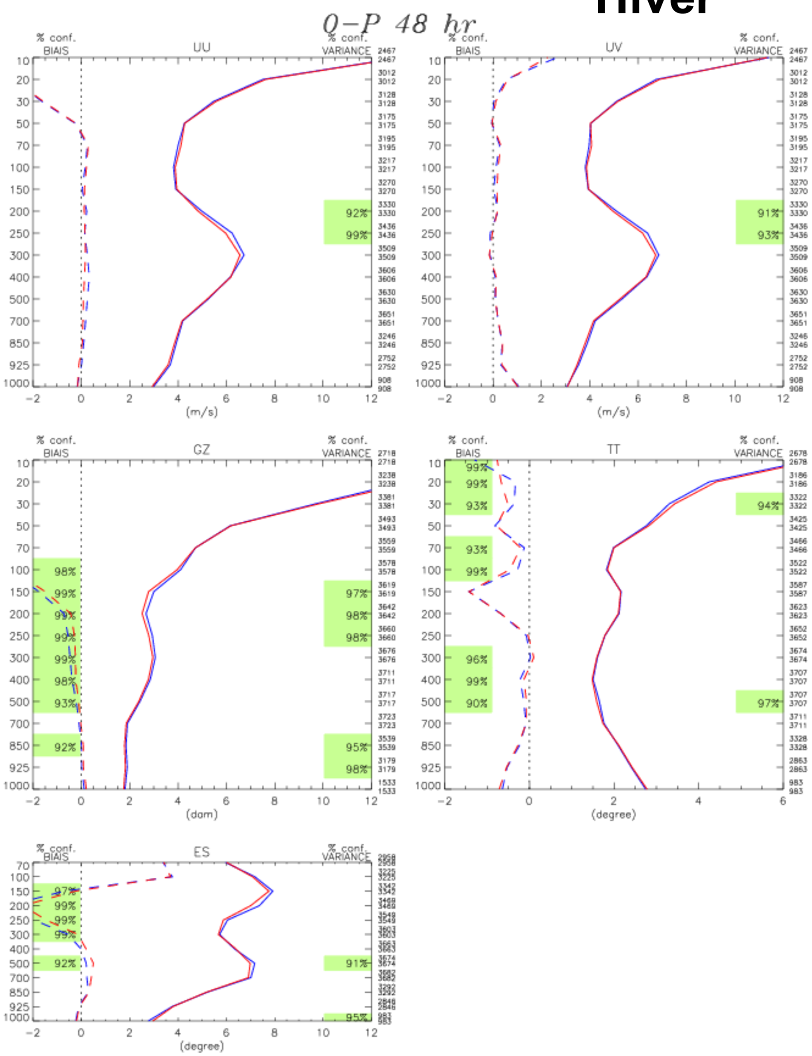
CNTL-AIRS



Impact dans le regional AN+ 48h

CNTL-AIRS

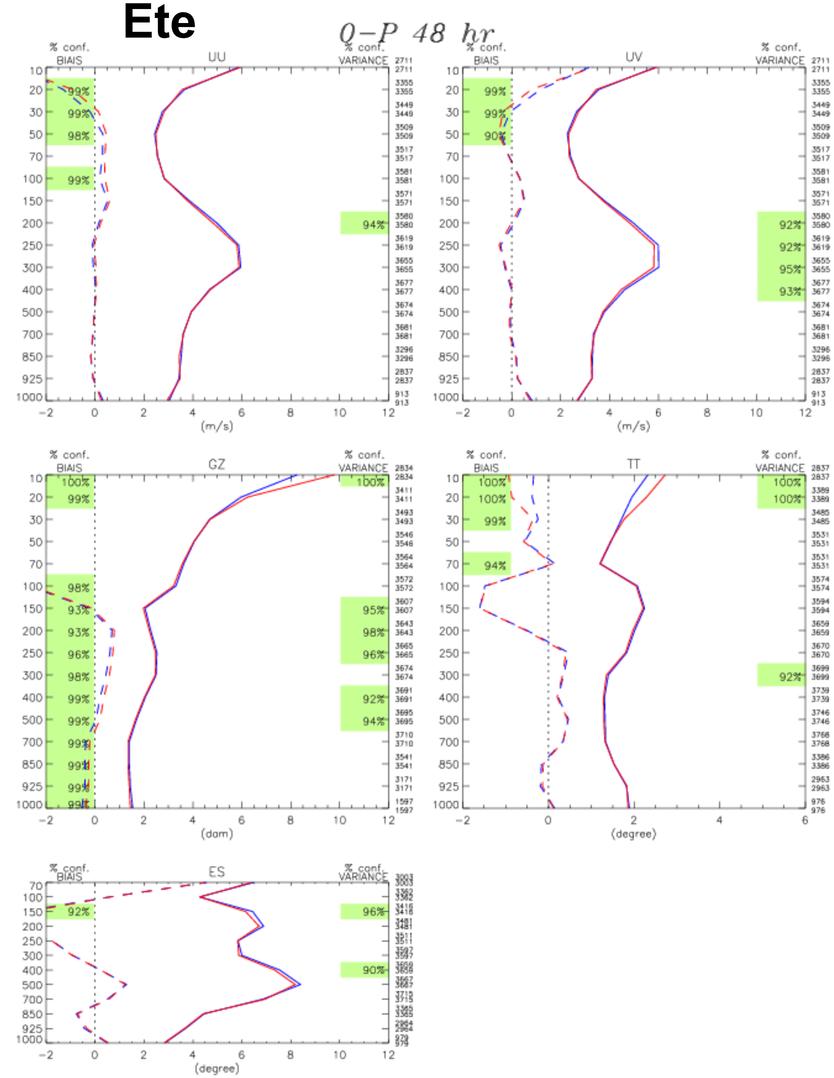
Hiver



EQM m_ua_048_ugj12 (40)
BIAIS m_ua_048_ugj12
EQM m_ua_048_ugjbh (40)
BIAIS m_ua_048_ugjbh

Type : O−P 48 hr
Region : Amerique du Nord plus
Lat−lon: (25N, 170W) (85N, 40W)
Stat. communes/inversees

Ete

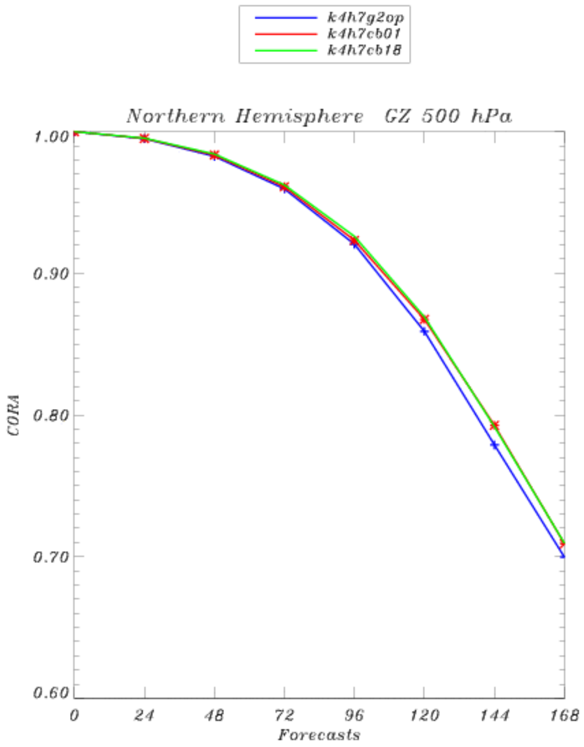


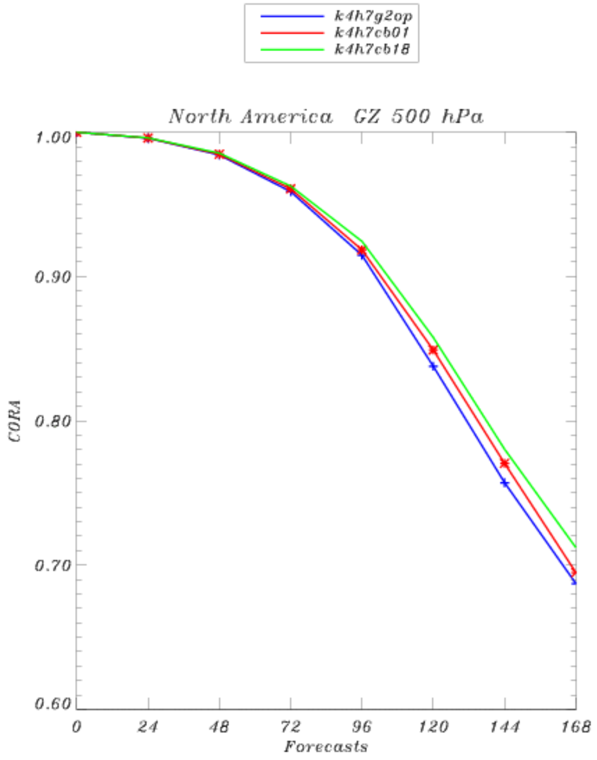
EQM m_ua_048_ugj22 (40)
BIAIS m_ua_048_ugj22
EQM m_ua_048_ugjbe (40)
BIAIS m_ua_048_ugjbe

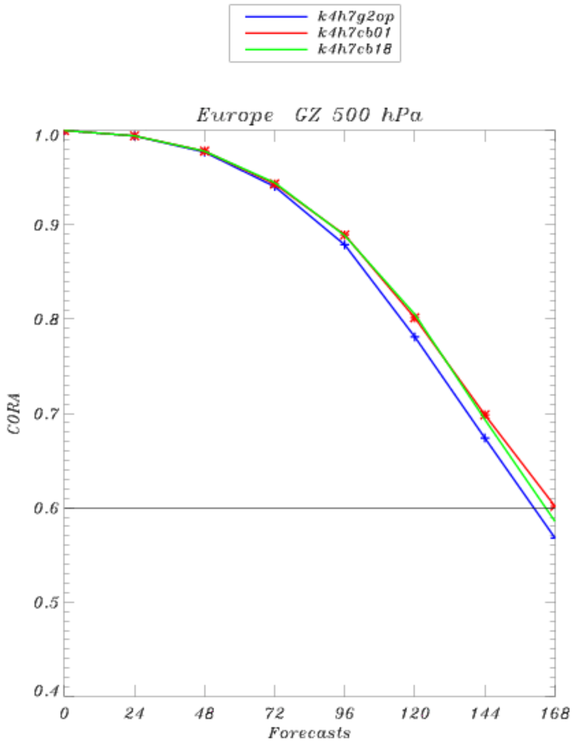
Type : O−P 48 hr
Region : Amerique du Nord plus
Lat−lon: (25N, 170W) (85N, 40W)
Stat. communes/inversees

Anomaly correlation winter NH-NA-EUR

CNTL-NEW-NEW+AIRS



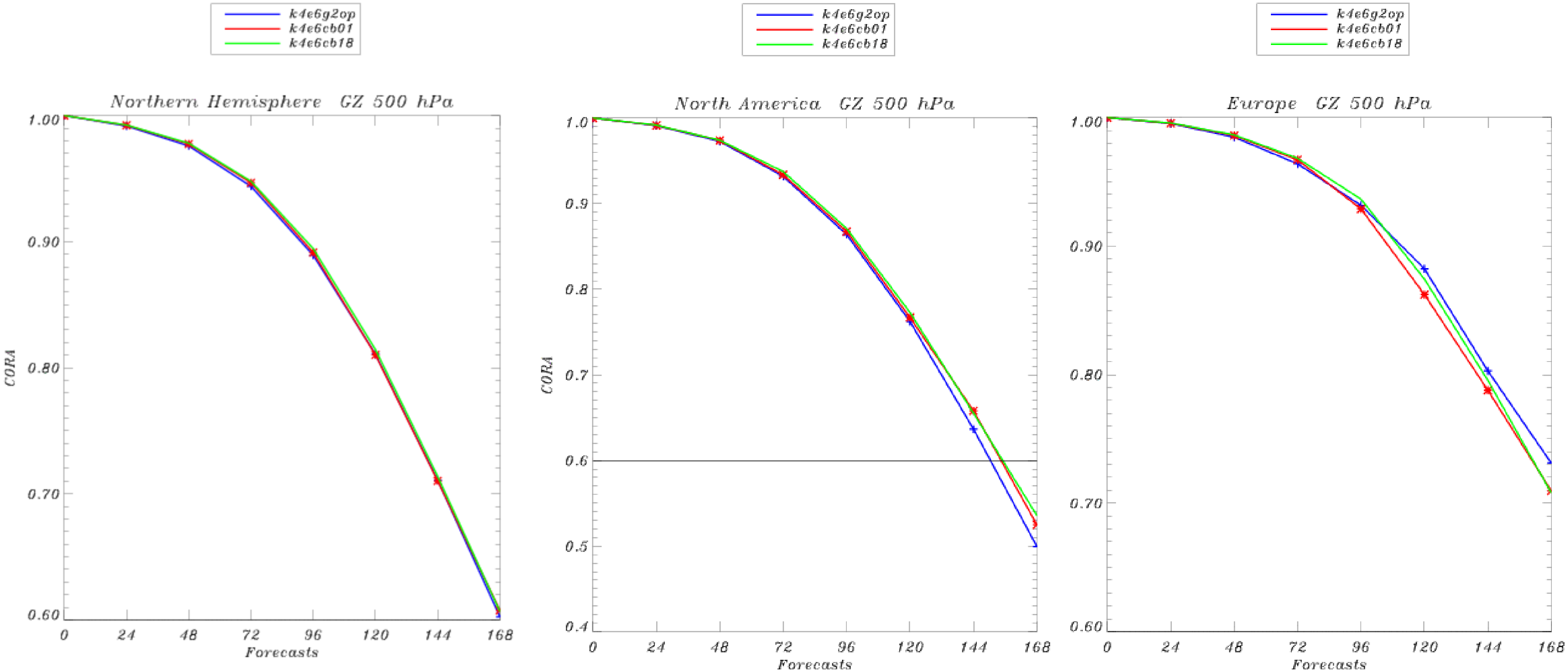




WINTER = 15 dec 2006- 10 mar 2007

Anomaly correlation summer NH-NA-EUR

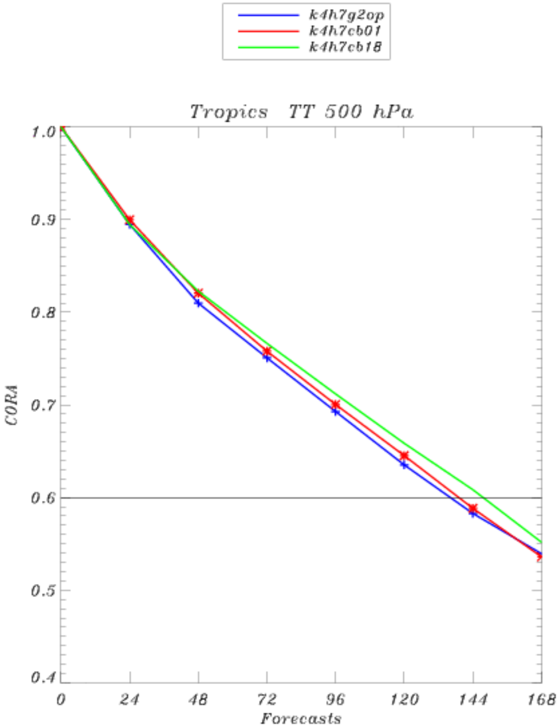
CNTL-NEW-NEW+AIRS

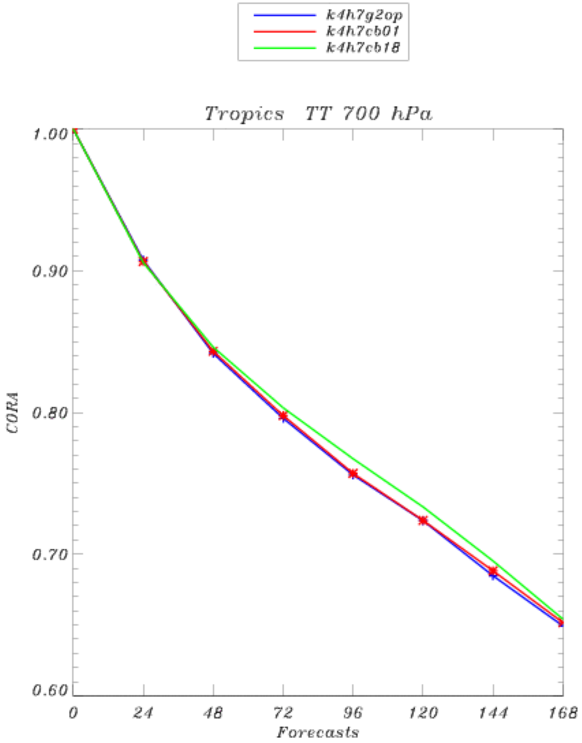


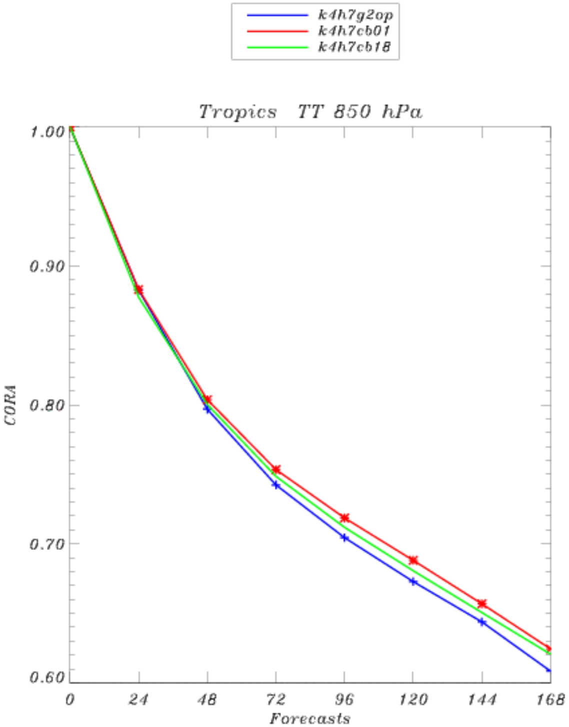
Summer = 15 june – 30 aug 2006

TT Anomaly correlation winter TRO

CNTL-NEW-NEW+AIRS

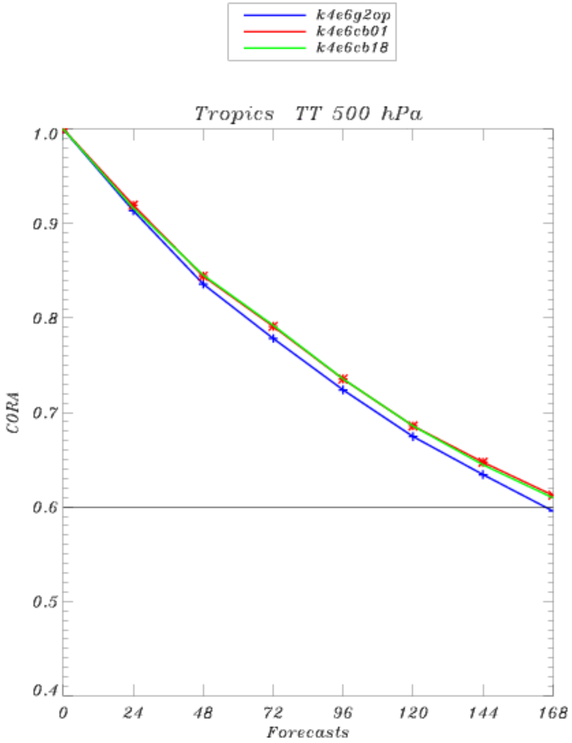


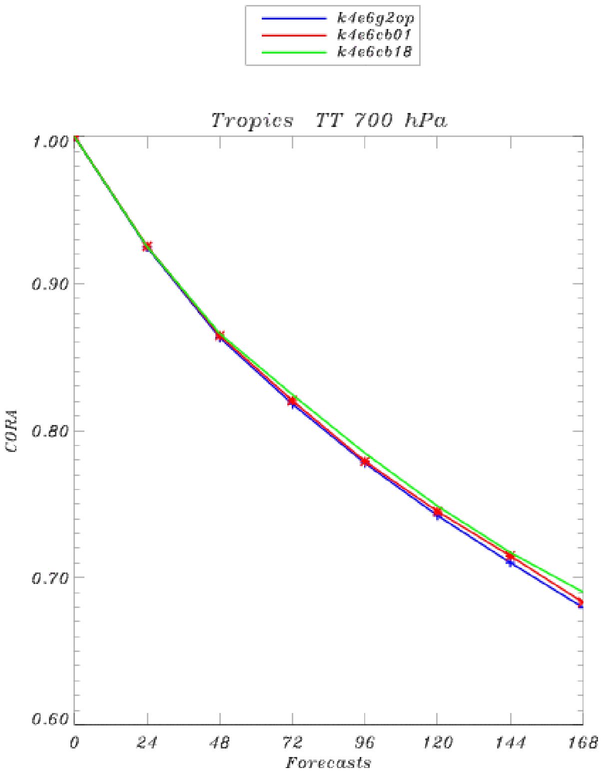


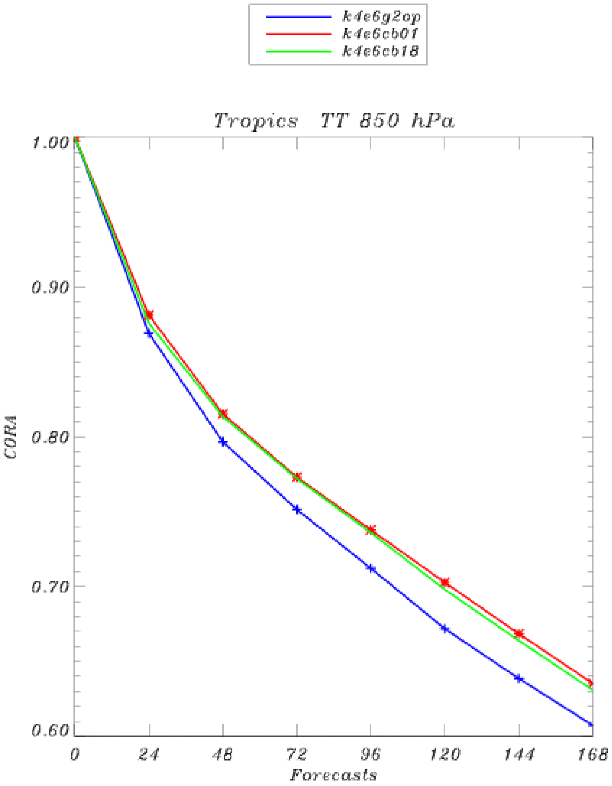


TT Anomaly correlation summer TRO

CNTL-NEW-NEW+AIRS

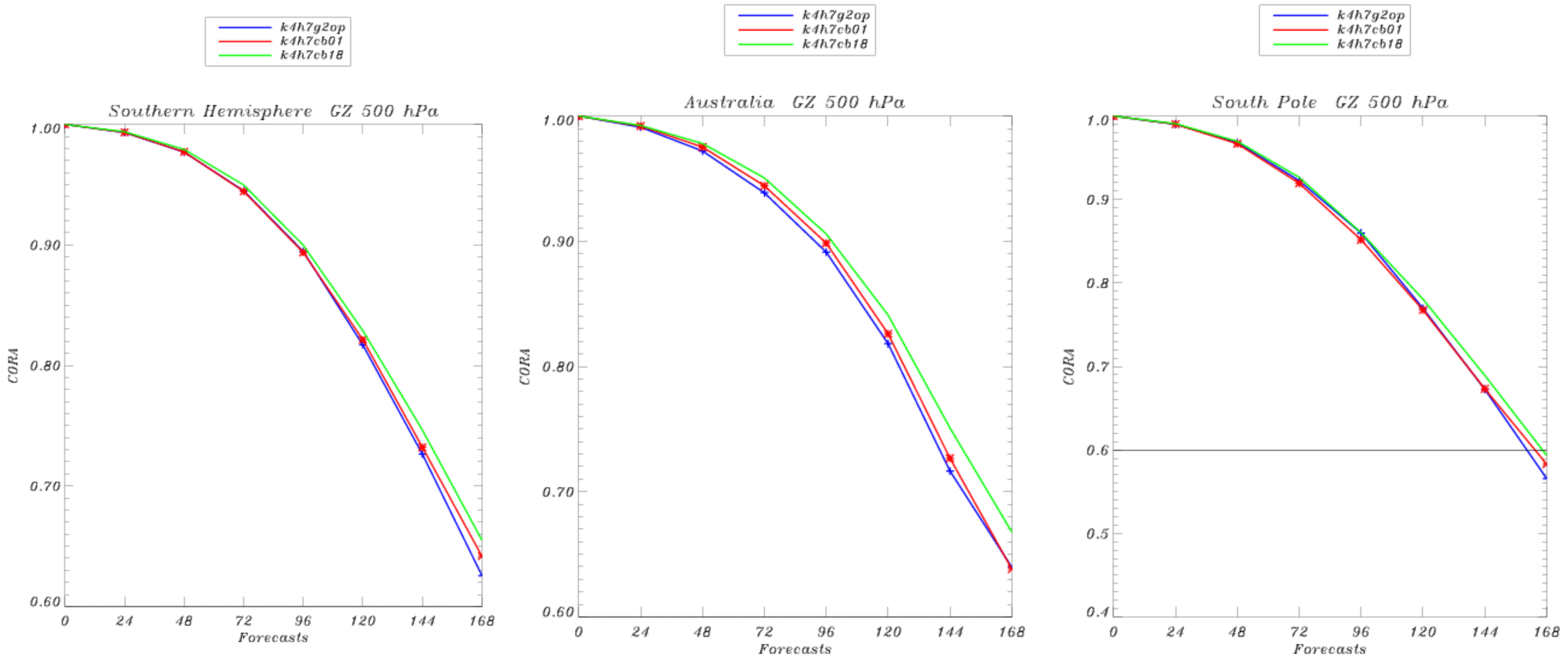






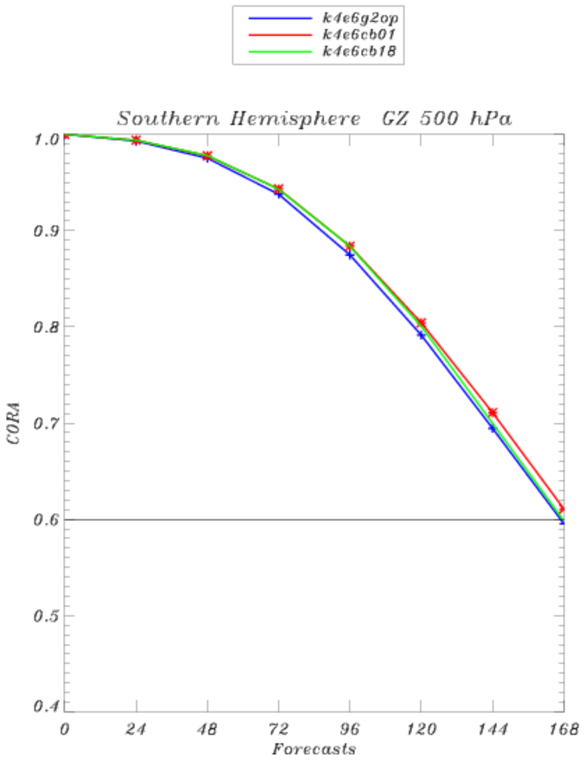
Anomaly correlation winter SH-AUS-SP

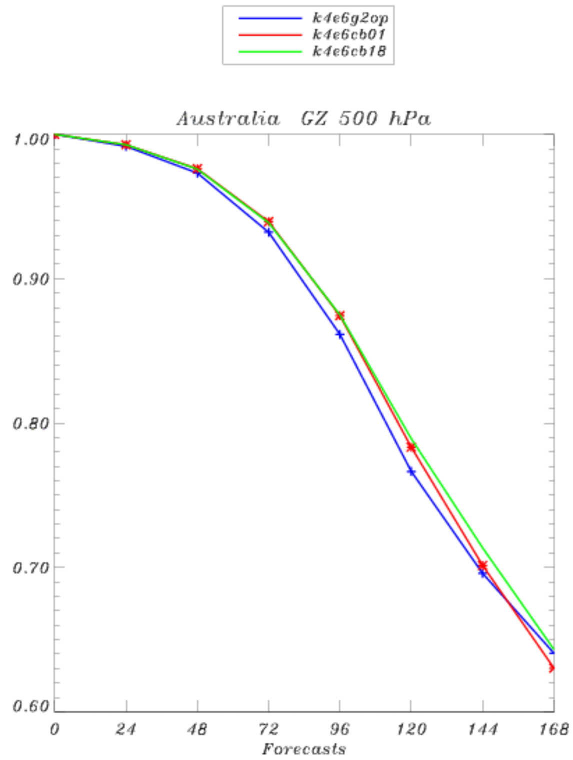
CNTL-NEW-NEW+AIRS

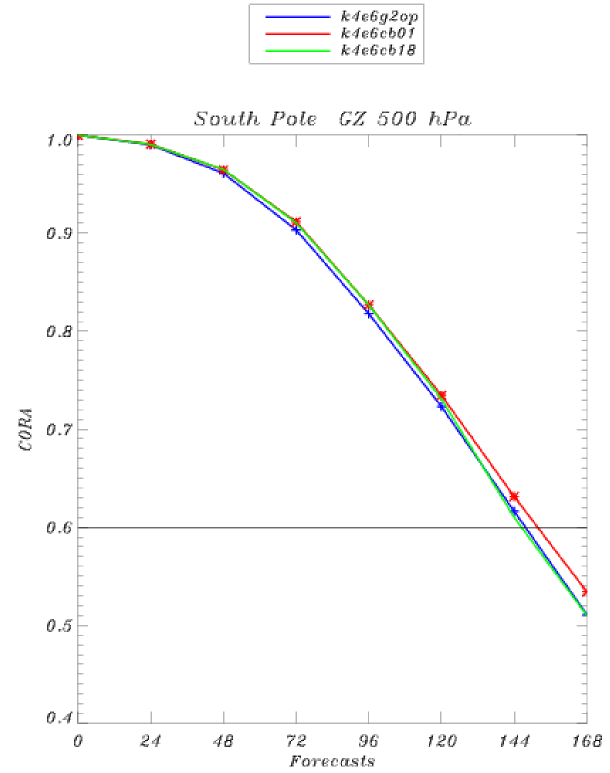


Anomaly correlation summer SH-AUS-SP

CNTL-NEW-NEW+AIRS





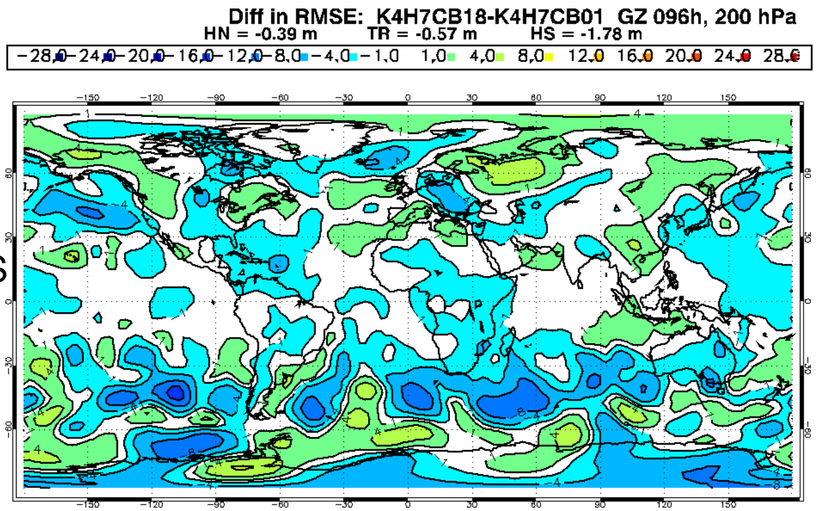


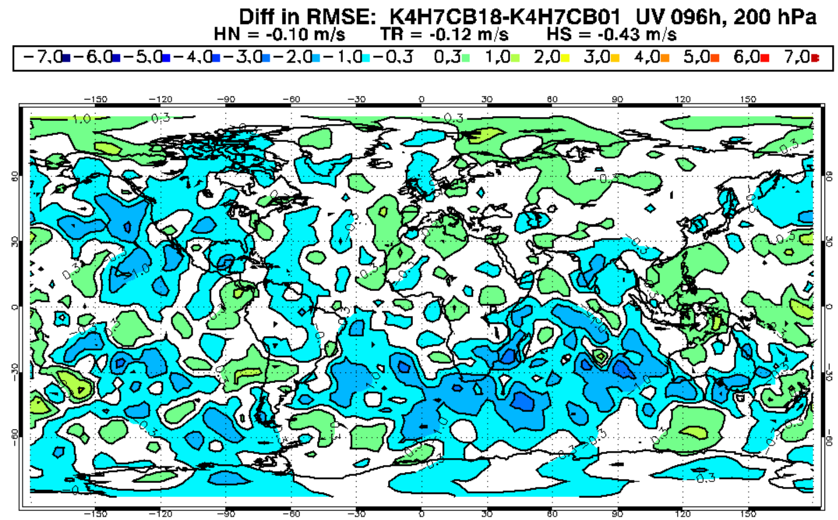
RMS DIFFERENCES 96-h 200 hPa hiver

GZ

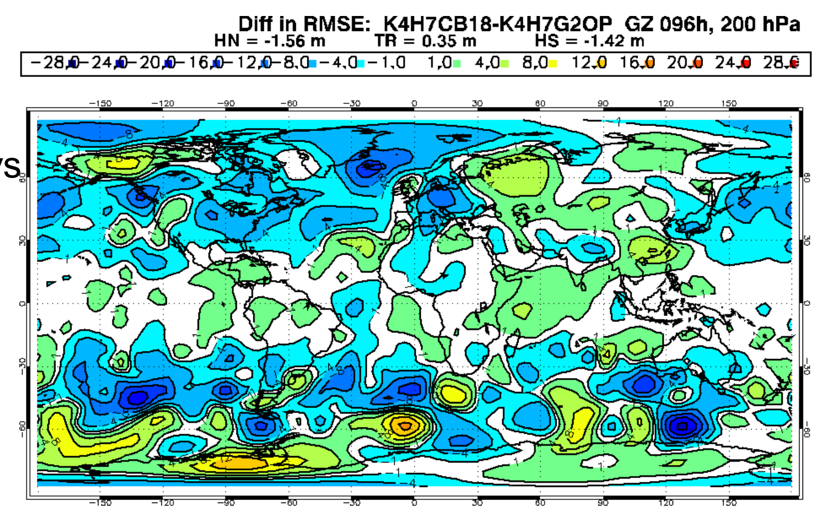
UV

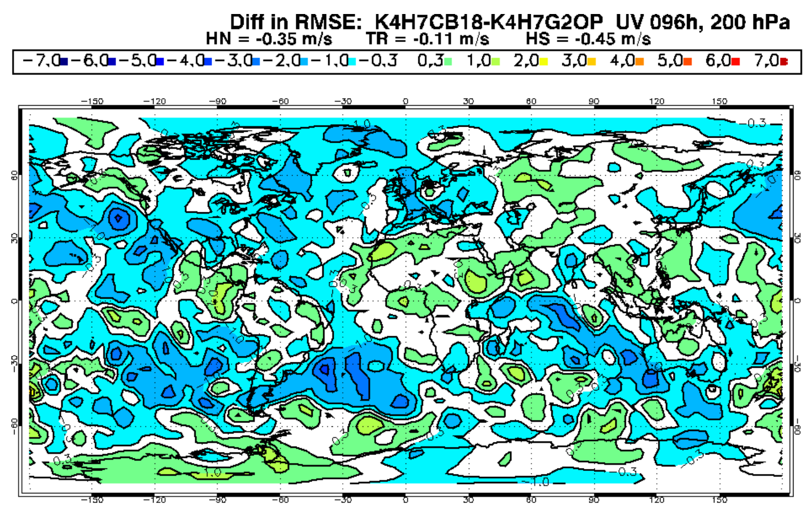
AIRS vs NOAIRS





AIRS vs OPE



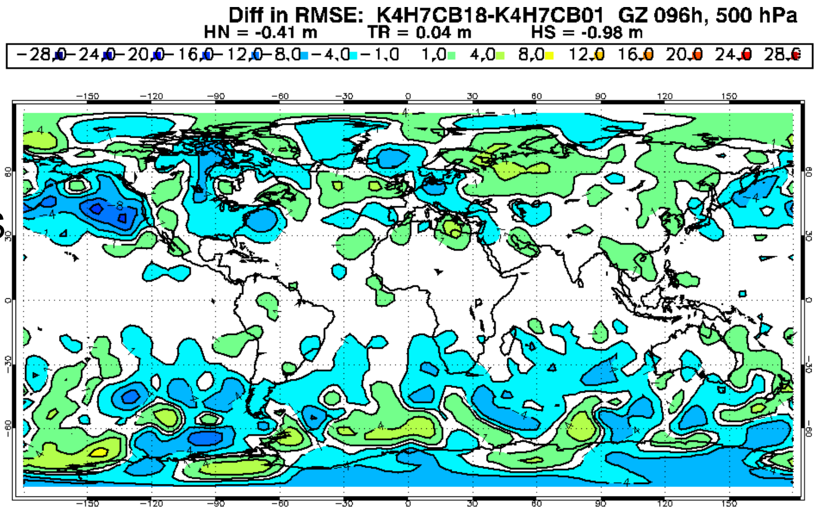


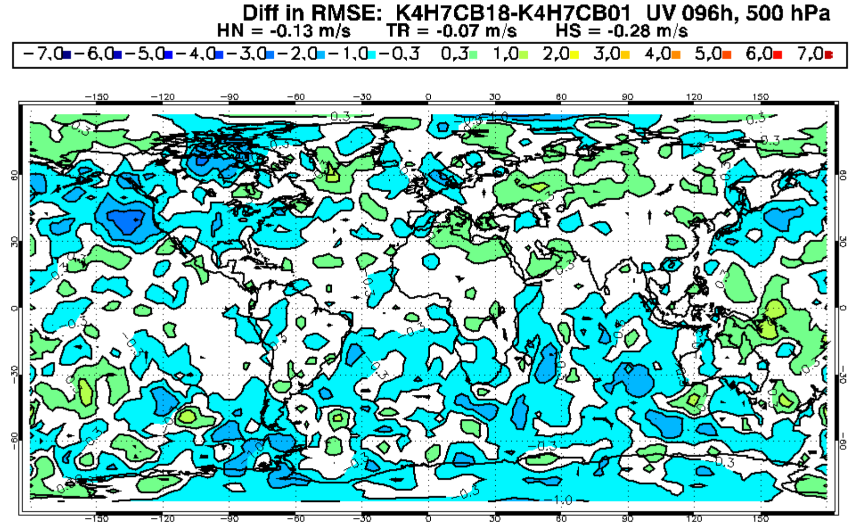
RMS DIFFERENCES 96-h 500 hPa hiver

GZ

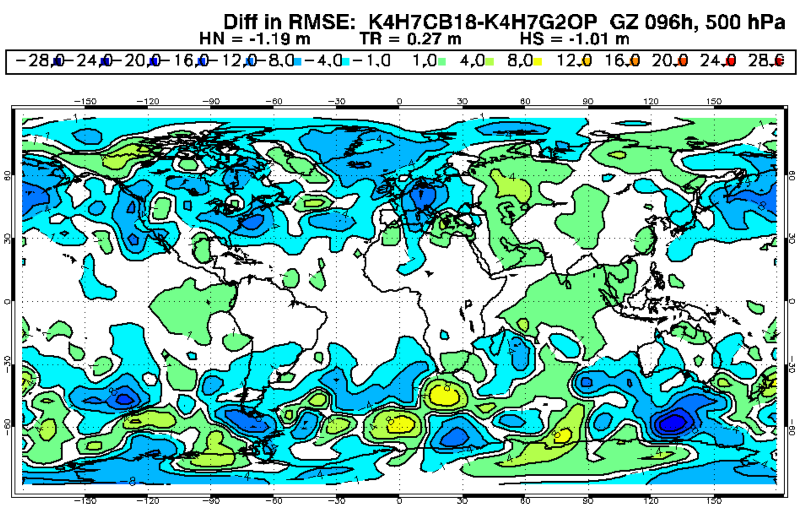
UV

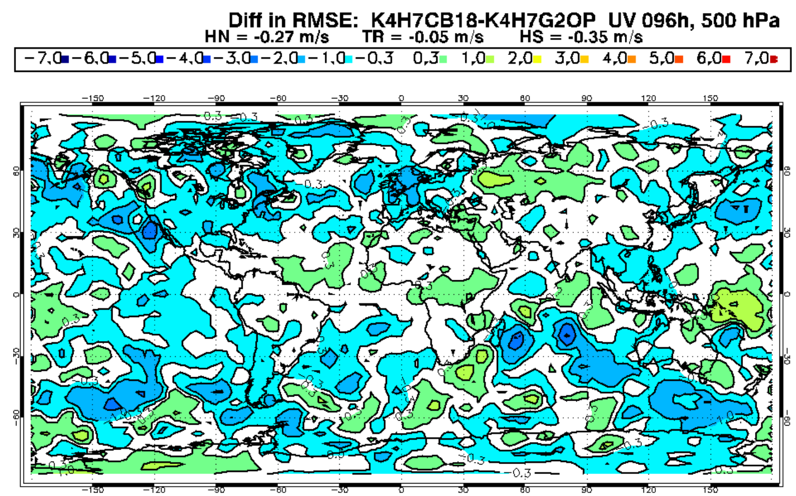
AIRS vs NOAIRS





AIRS Vs OPE



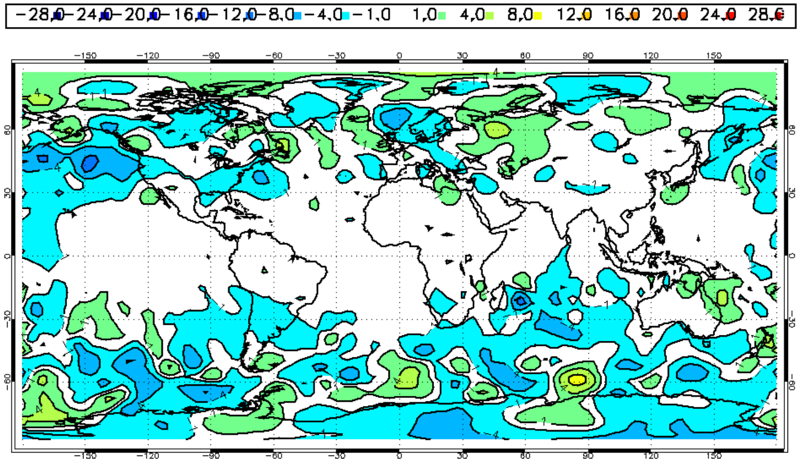


RMS DIFFERENCES 96-h 850 hPa hiver

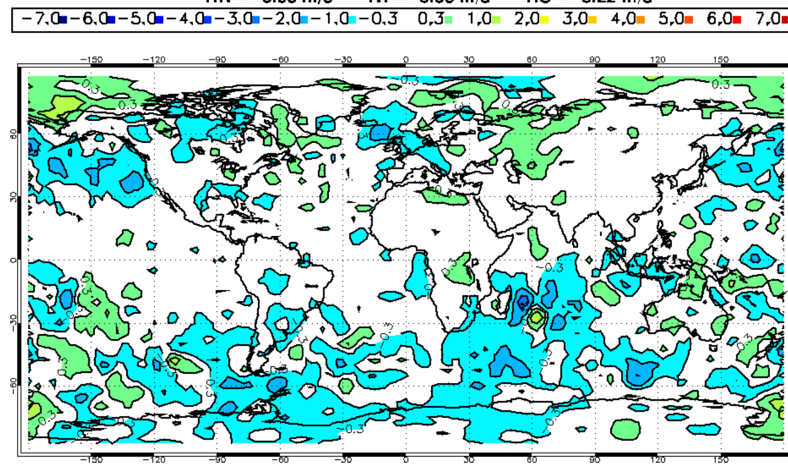
GZ | UV

AIRS vs NOAIRS

Diff in RMSE: K4H7CB18-K4H7CB01 GZ 096h, 850 hPa
HN = -0.46 m TR = -0.26 m HS = -0.95 m

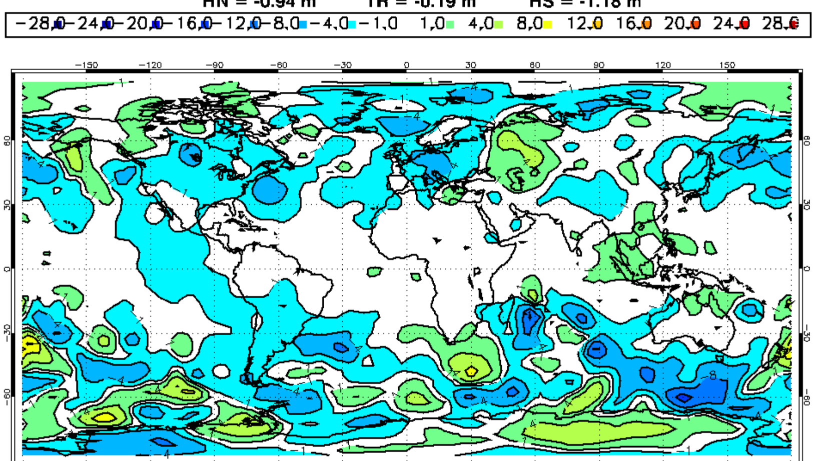


Diff in RMSE: K4H7CB18-K4H7CB01 UV 096h, 850 hPa
HN = -0.06 m/s TR = -0.06 m/s HS = -0.22 m/s

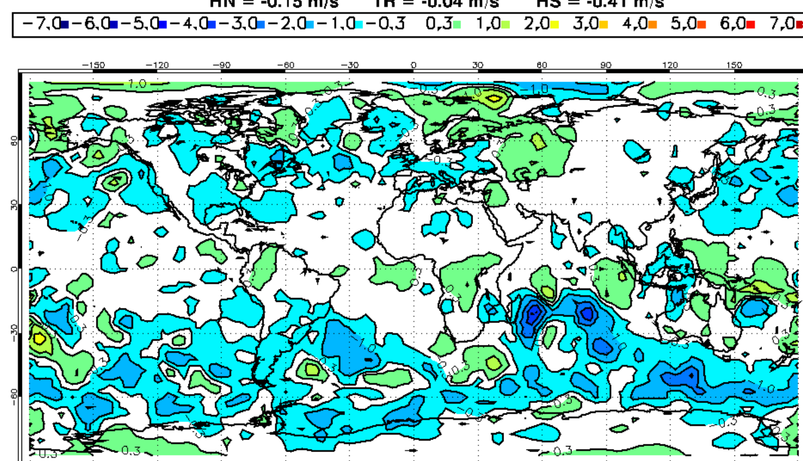


AIRS Vs OPE

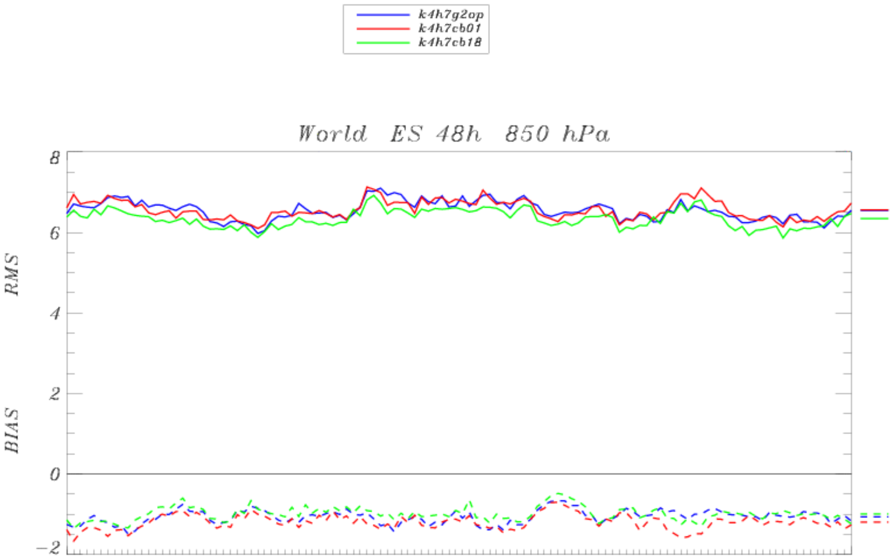
Diff in RMSE: K4H7CB18-K4H7G2OP GZ 096h, 850 hPa
HN = -0.94 m TR = -0.19 m HS = -1.18 m

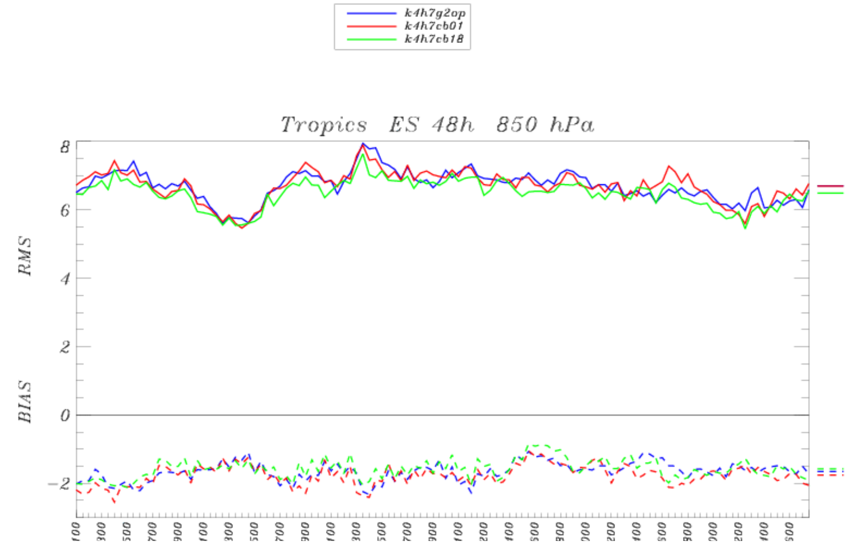


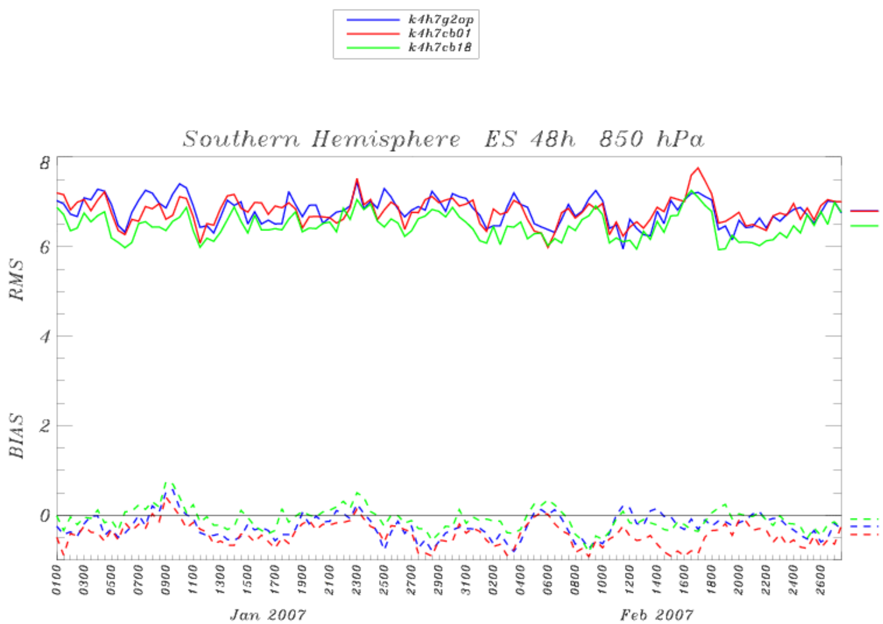
Diff in RMSE: K4H7CB18-K4H7G2OP UV 096h, 850 hPa
HN = -0.15 m/s TR = -0.04 m/s HS = -0.41 m/s

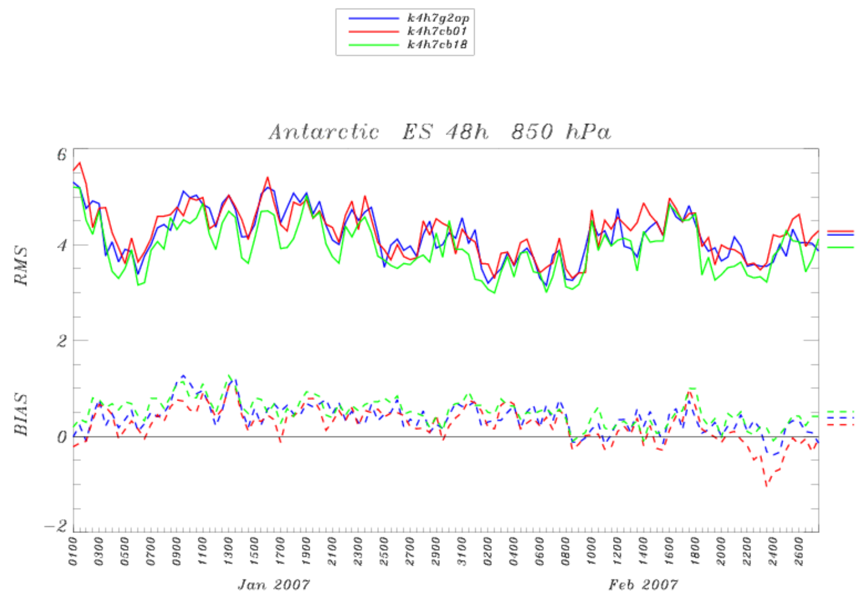


850 hPa Humidite 48-h hiver OPE NEW NEW+AIRS



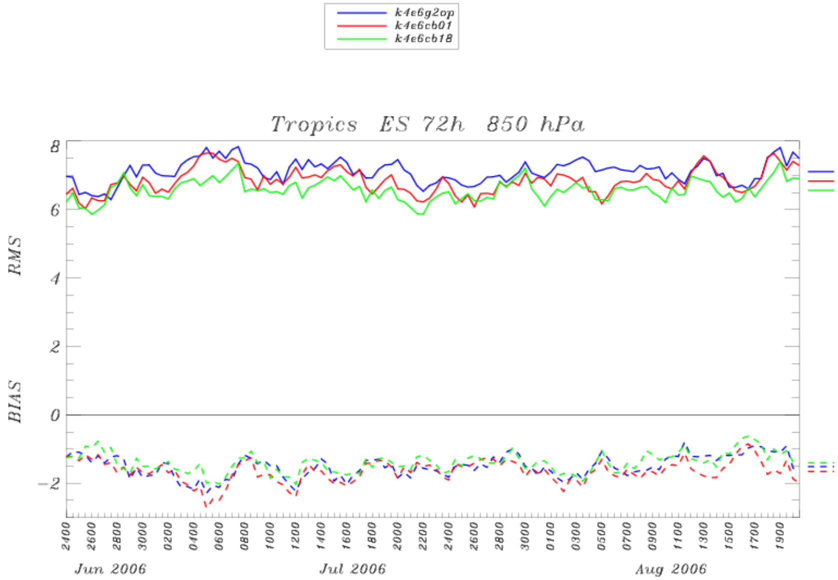


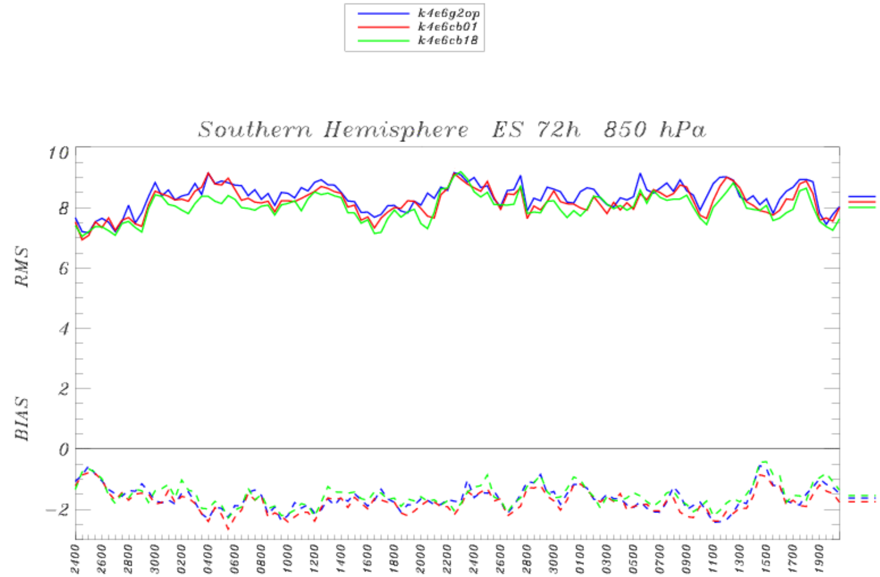




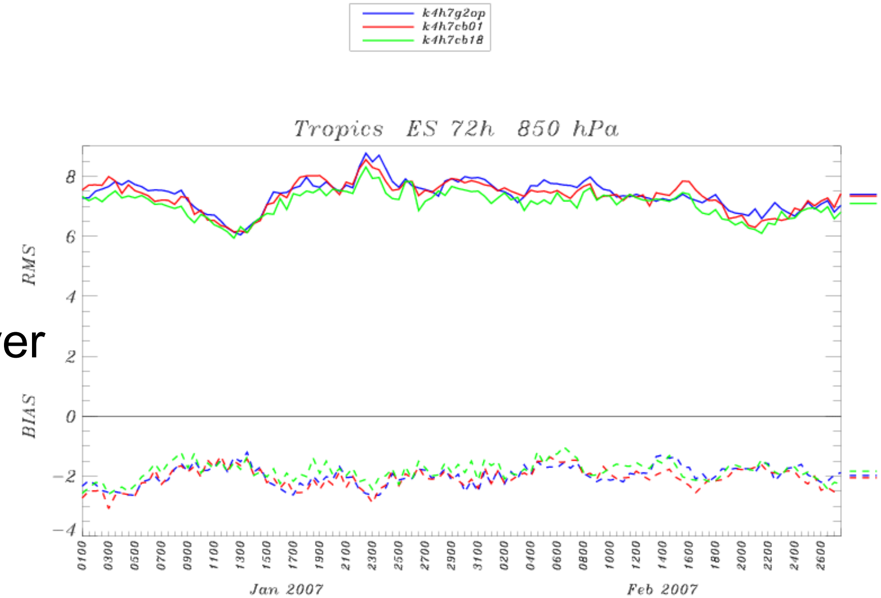
Humidite 850 hPa CNTL-NEW-NEW+AIRS

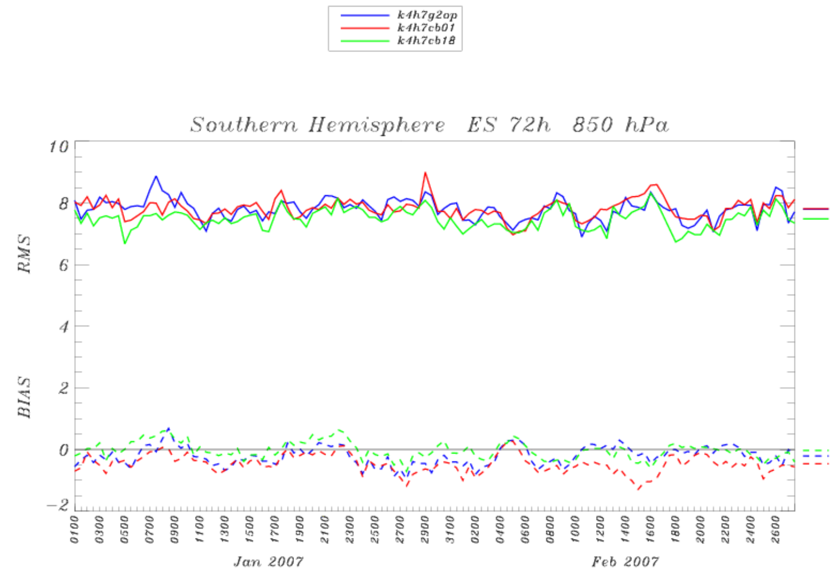
Ete



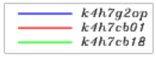


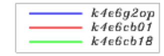
Hiver





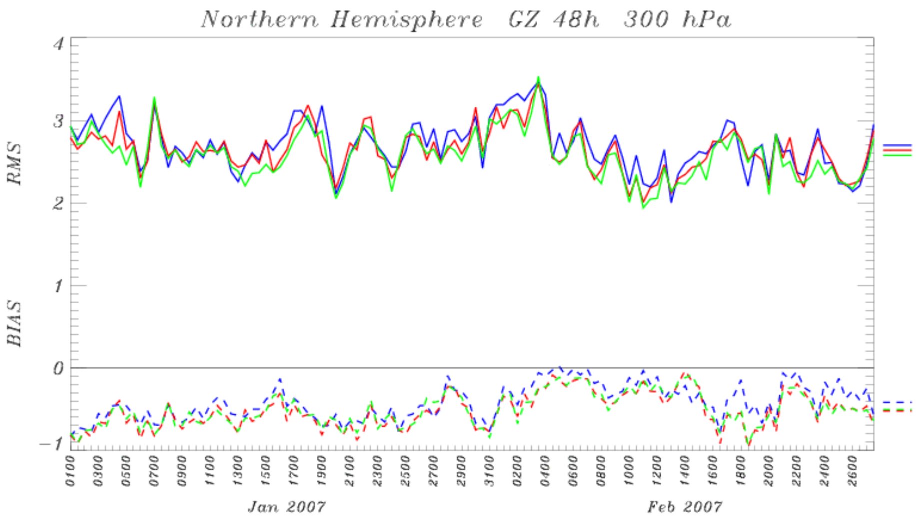
Serie temporelle GZ 48h 300hPa **OPE** **NEW** **NEW+AIRS**

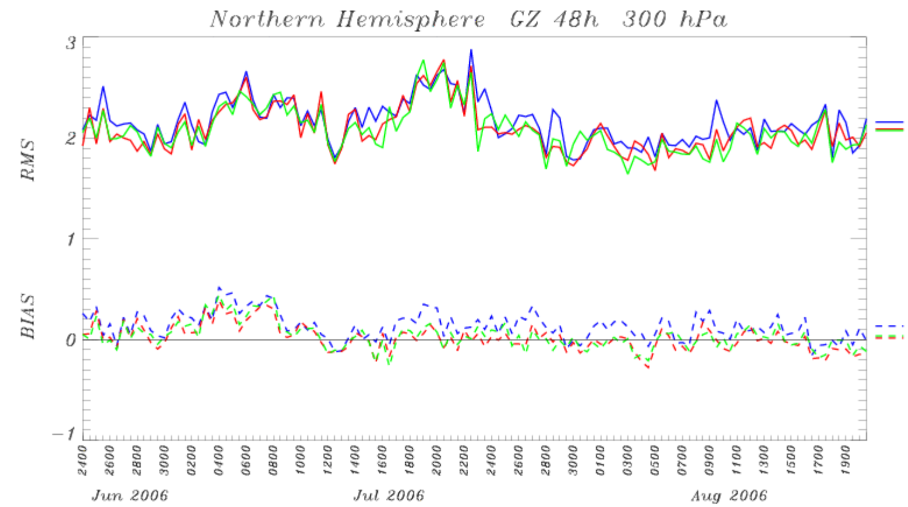


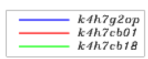


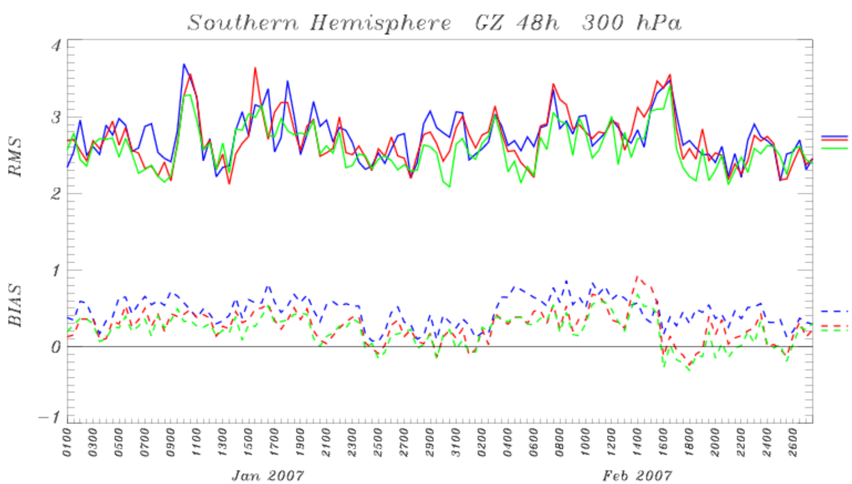
Hiver

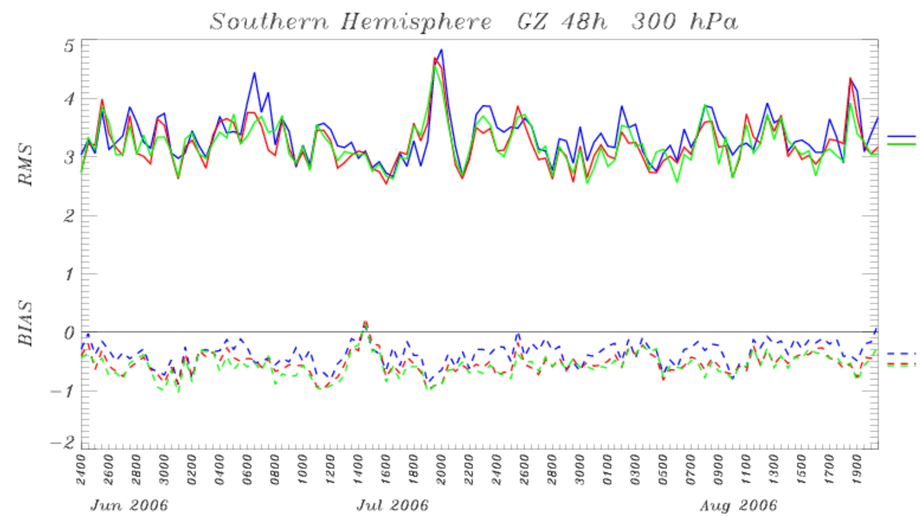
Ete







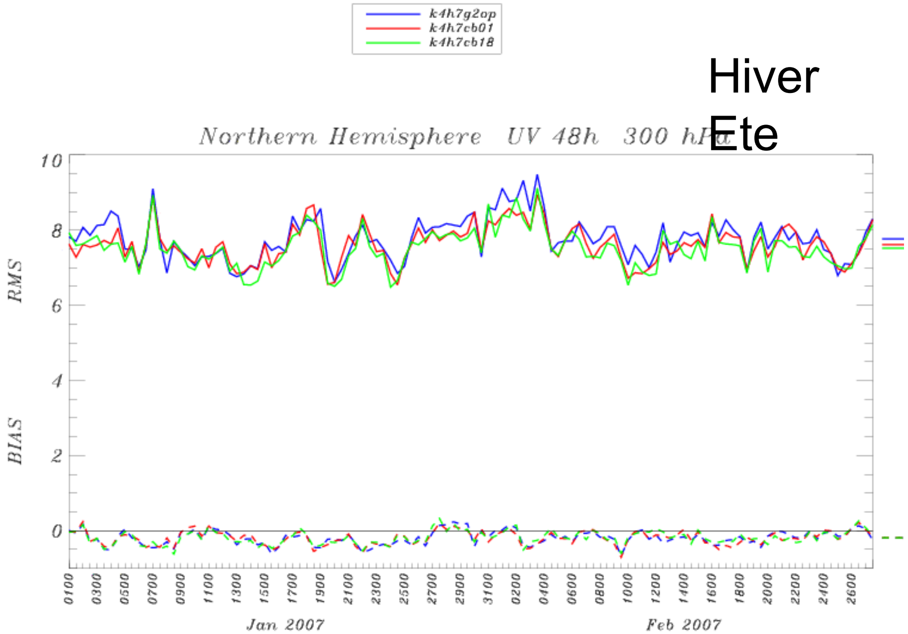


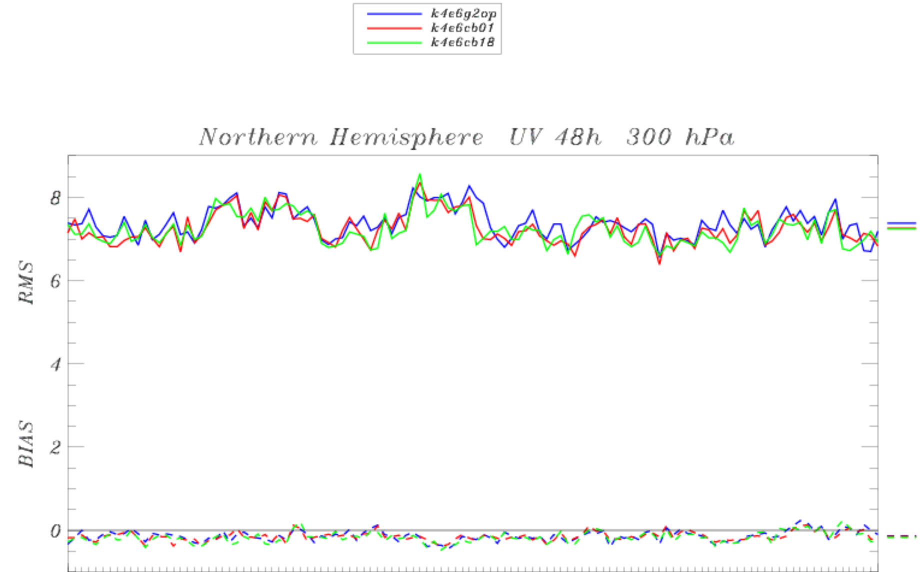


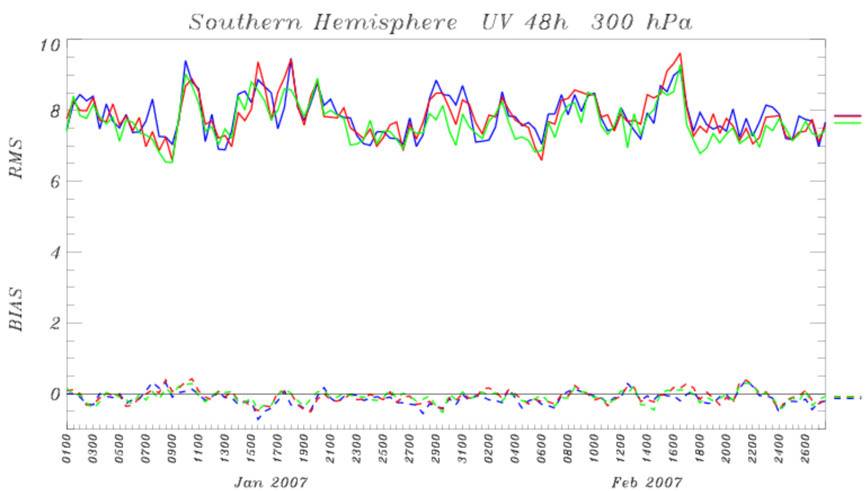
Serie temporelle UV 48h 300hPa OPE NEW NEW+AIRS

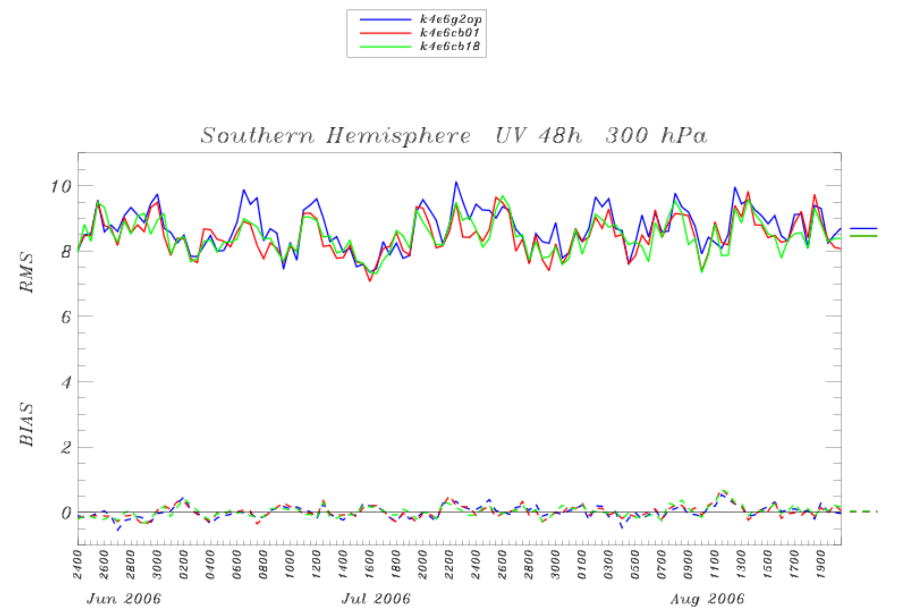
Hiver

Ete



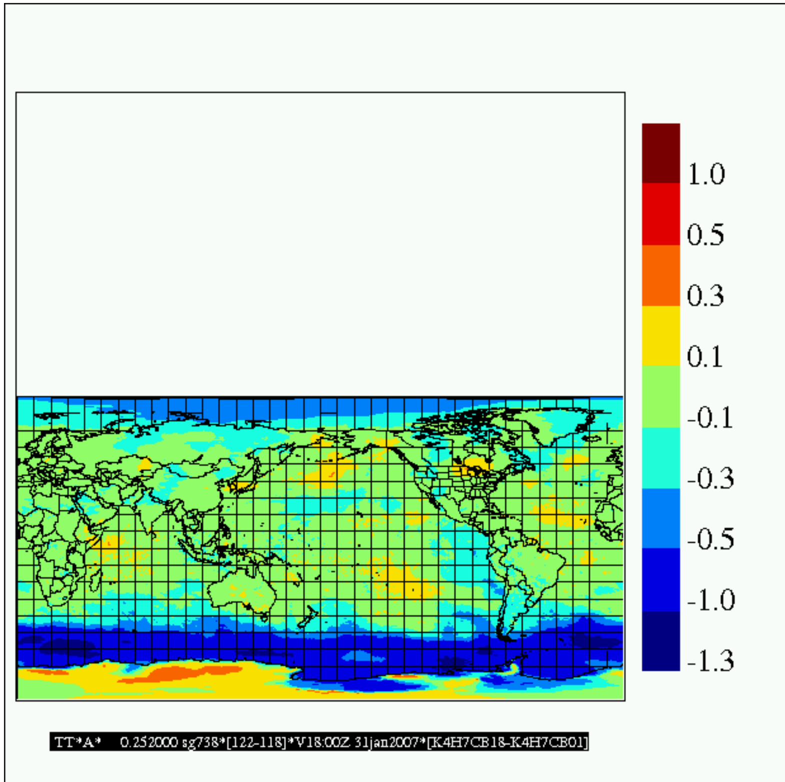




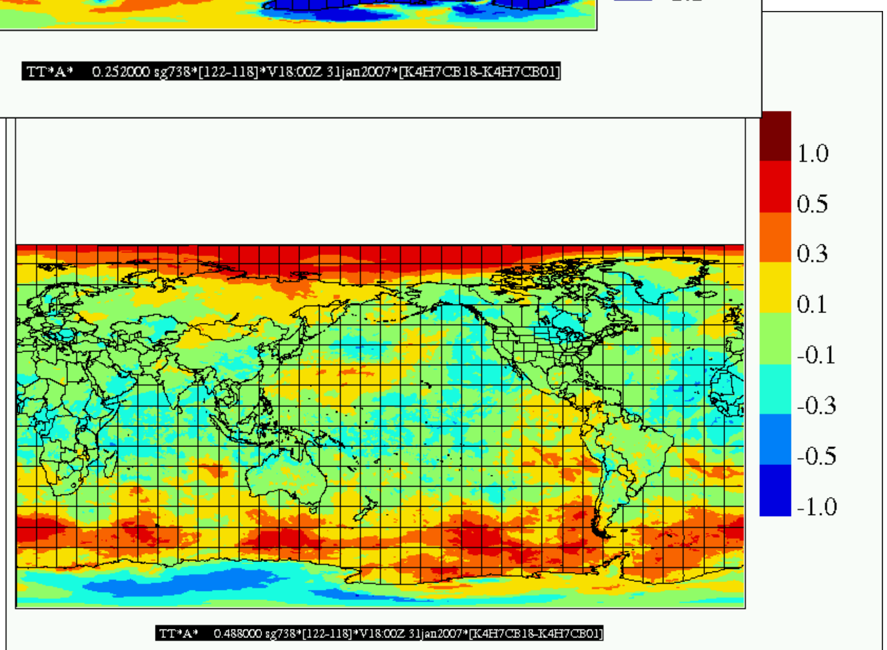


Change to thermal structure: mean jan 07 TT (with – without AIRS)

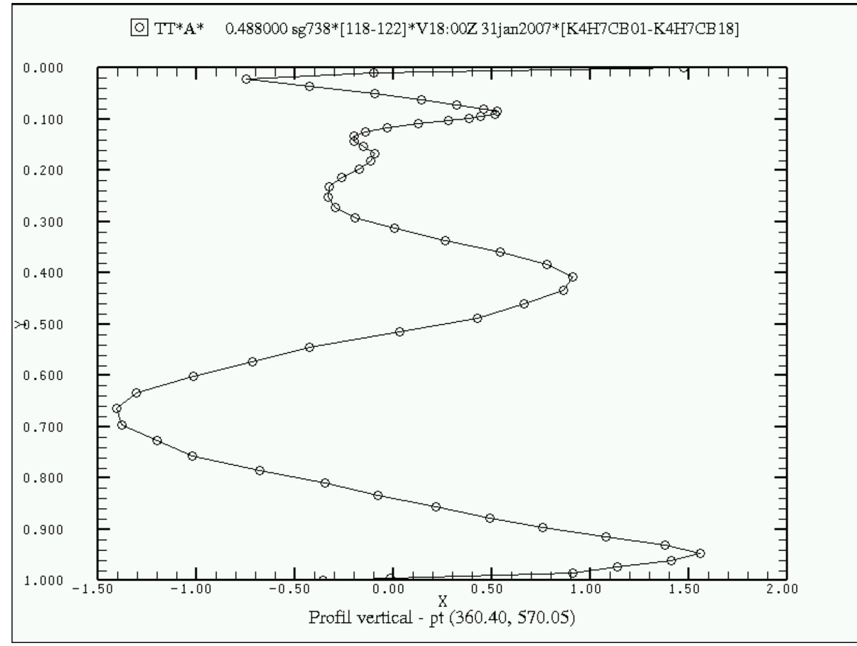
250 hPa



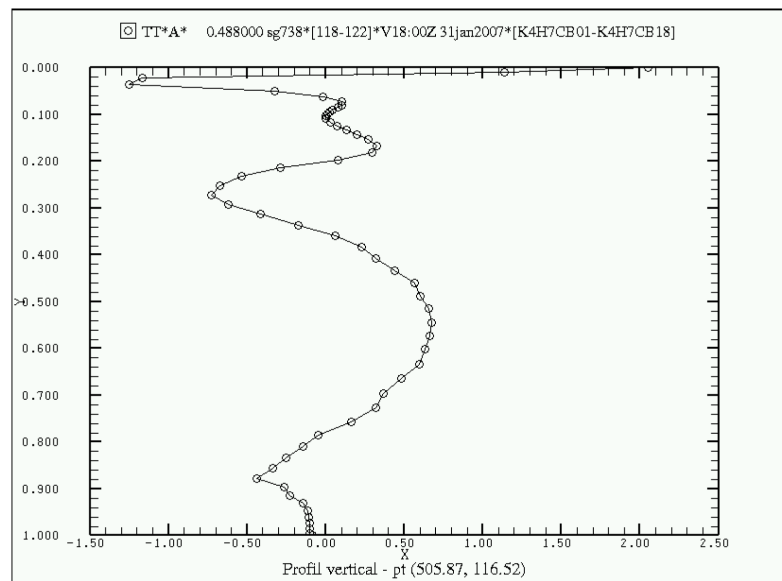
500 hPa



Point near north Pole

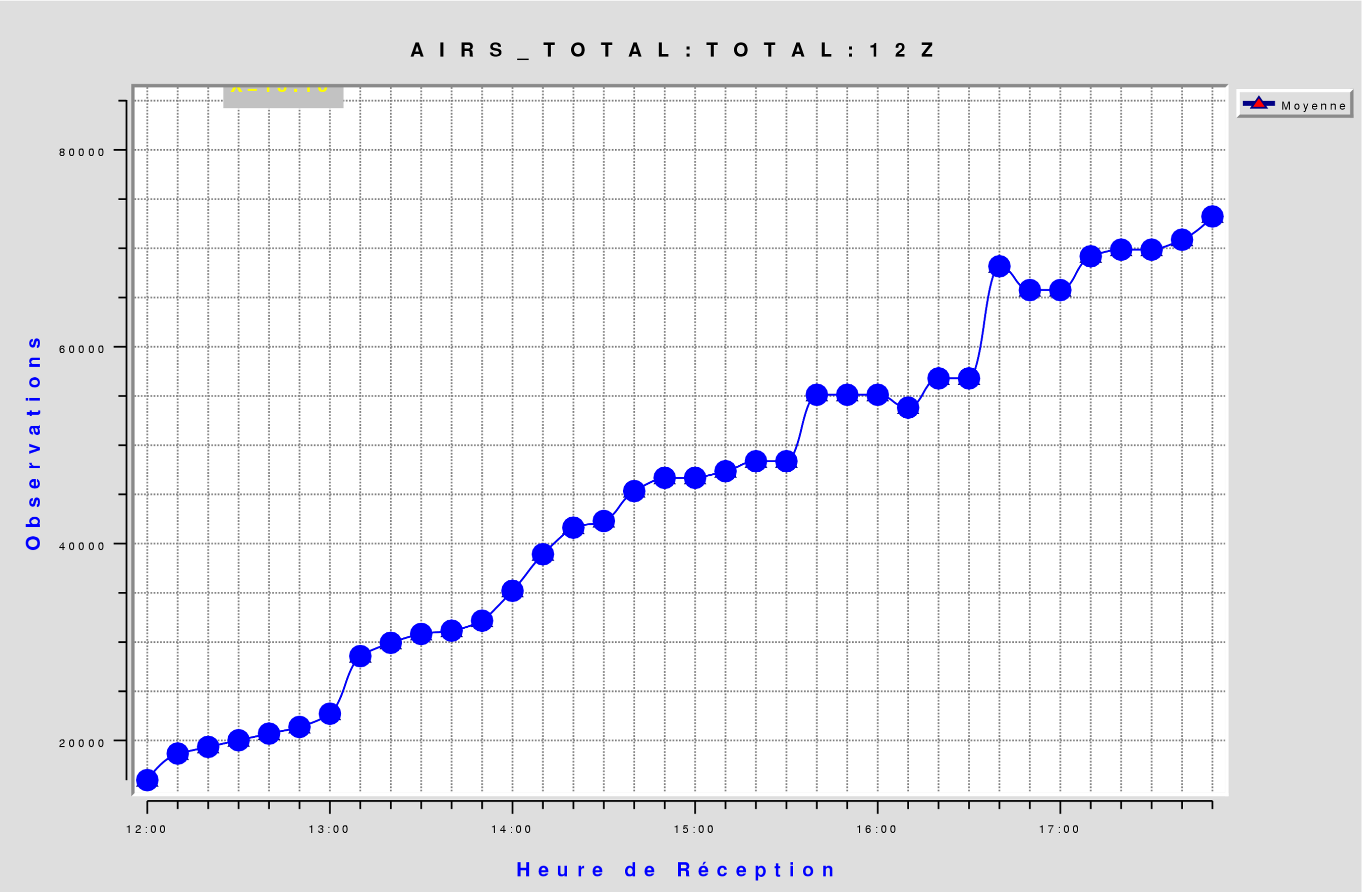


Point near 60 S, 130 W



Réception des données AIRS

12 UTC Moyenne sur 10 jours

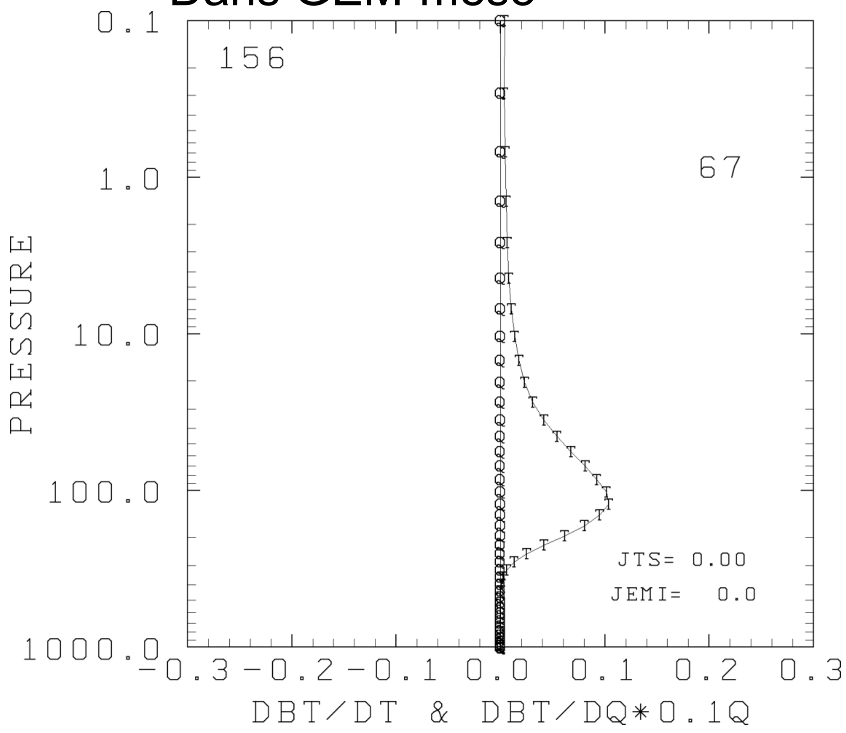


Max: 81000 points/6h, disponible pour G1: ~47000 (58 %), pour G2/trial: complet

Vers Gem-Strato, canaux additionnels

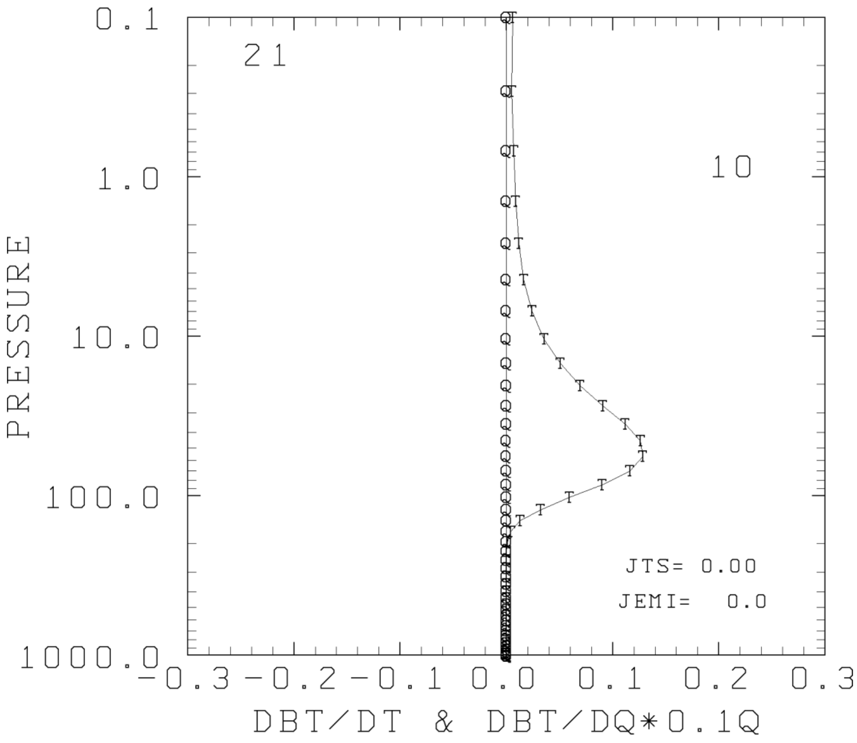
Max 120 hPa: le plus haut

Dans GEM-meso



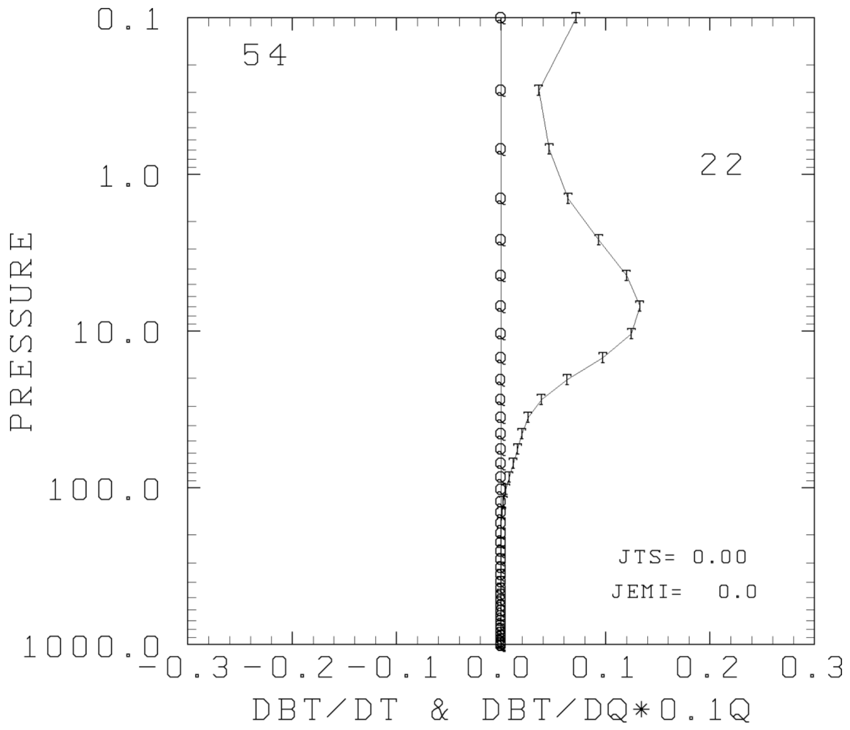
Max 50 mb: acceptable

pour GEM-strato

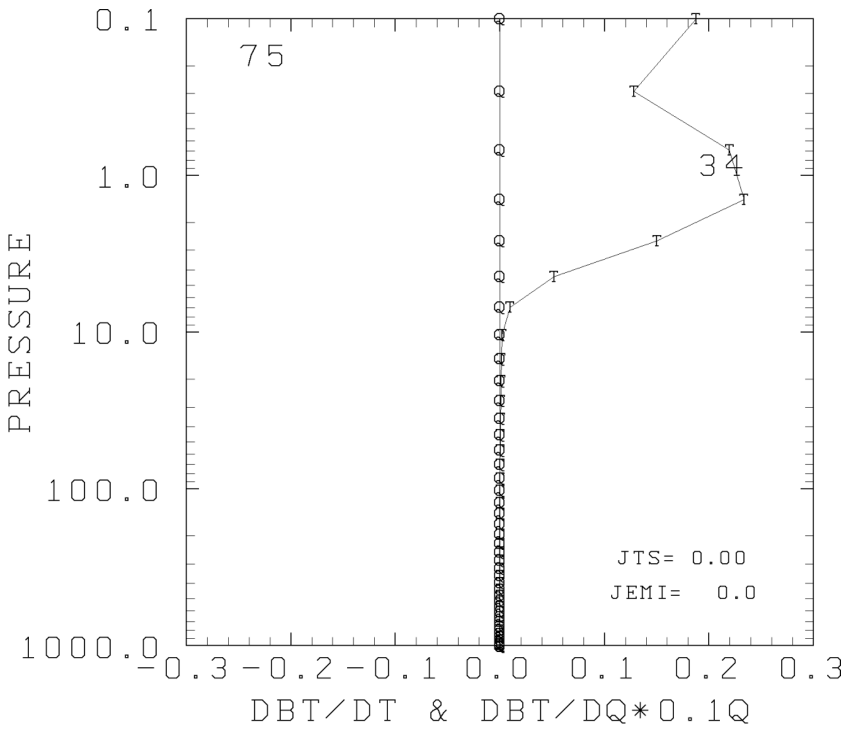


Assimilable dans GEM-strato?

Max 8 hPa: risque



Max 1hPa: non assimilable



Conclusion

- L’impact d’ajout d’obs sur la prévisibilité a 5 jours est de l’ordre de 3 heures (anomalie GZ 500 hPa). L’impact de AIRS correspond typiquement a 40-50 % du total avec variations dépendant de la variable, du niveau ou de l’ écheance.
- L’impact du systeme complet est essentiellement positif partout.
- EC est clairement pénalisé par le toit a 10 mb. On a du sacrifier plusieurs canaux AIRS dans bande a 14 μm reconnus comme importants pour l’impact. On s’attend donc a un impact additionnel dans GEM-Strato (été 2008) avec ~25 canaux en sus.
- Le systeme d’assimilation des radiances est grandement amélioré avec nouvelles données + RTTOV-8 + biais dynamique + parallélisation
- Le passage a IASI (300 canaux) devrait pouvoir etre réalisé en un an.

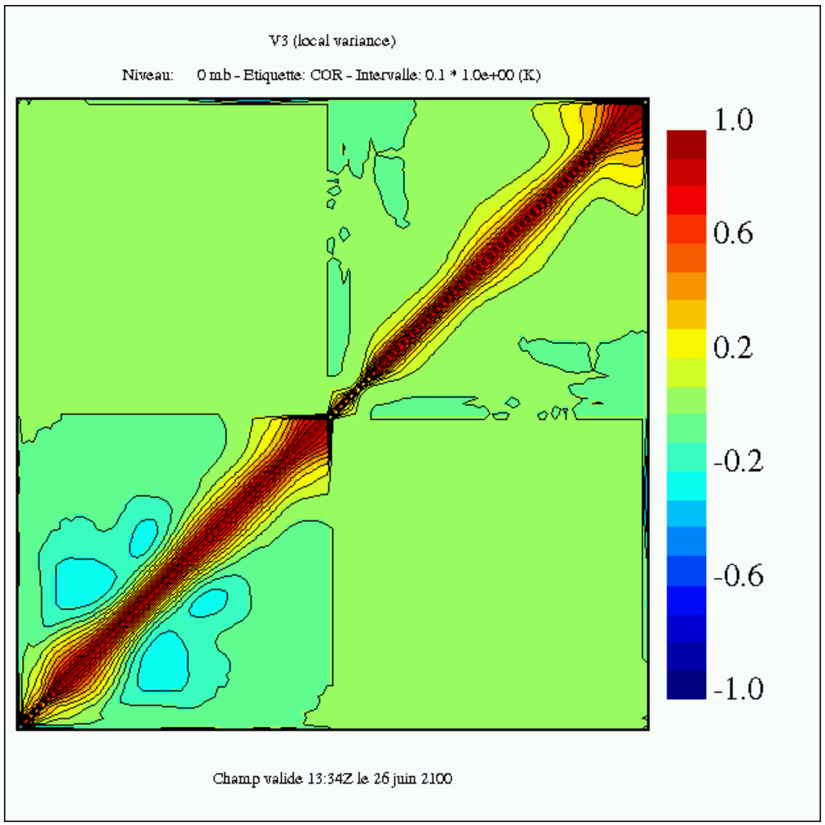
Comparing AIRS impact …

500 Hpa GZ anomaly correlation
Predictability gain in hours at day 5

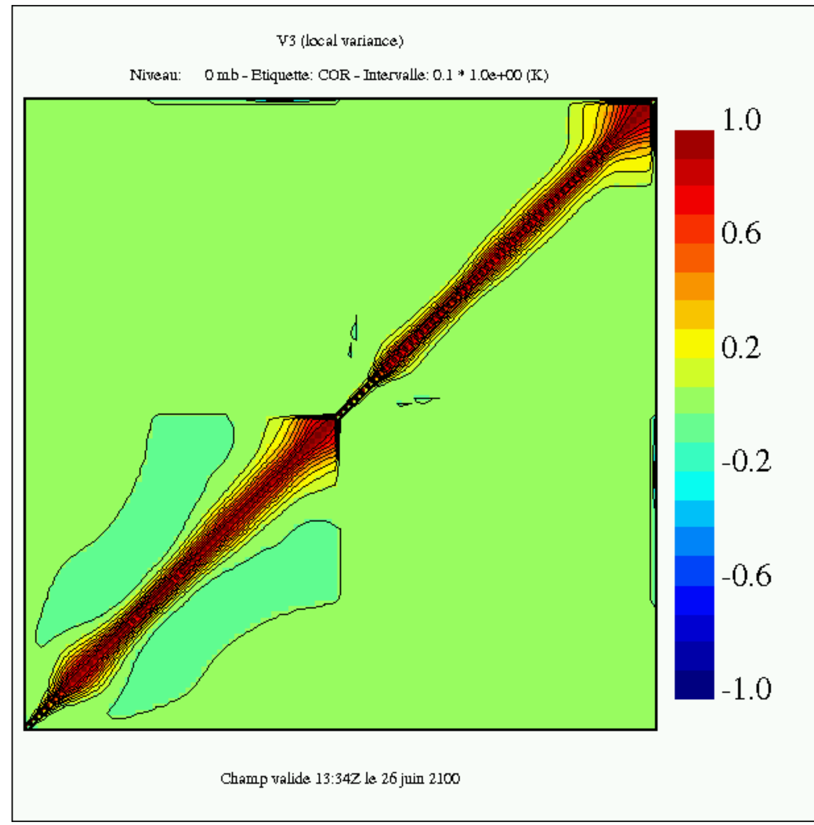
		Ndays	NH	SH	Source
ECMWF	WIN	100	2	1	McNally et al., QJRMS 2006
	SUM	70	1	3	~170 channels
NCEP	WIN	27	3	4	LeMarshall et al., BAMS 2006
					~250 channels
CMC	WIN	80	1 (3)	3 (4)	Garand et al., 2007, 87 channels
	SUM	78	1 (1)	0 (2)	AIRS alone (full package)

Effet de localisation sur correlation T, lnq

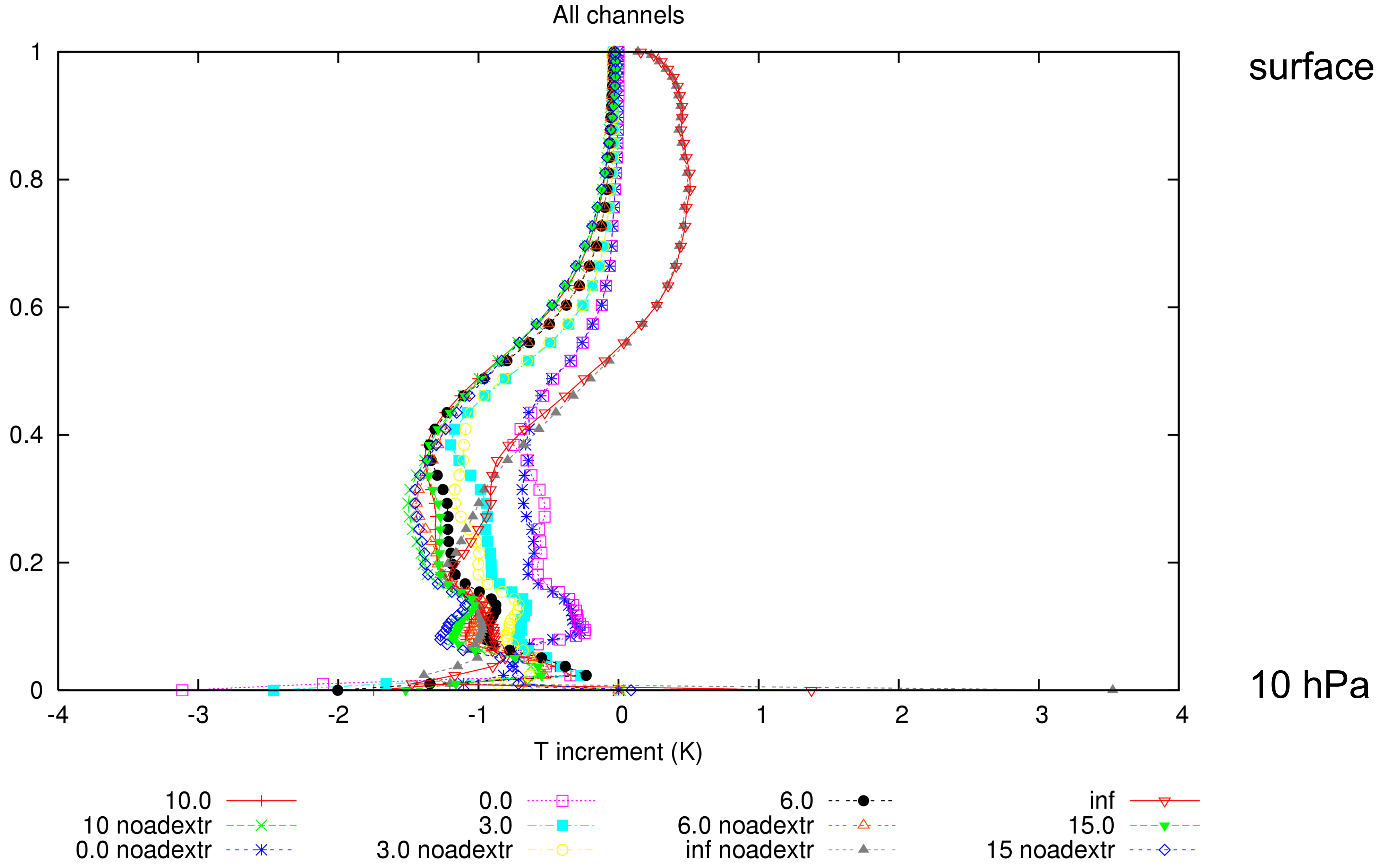
Nominal COR matrix



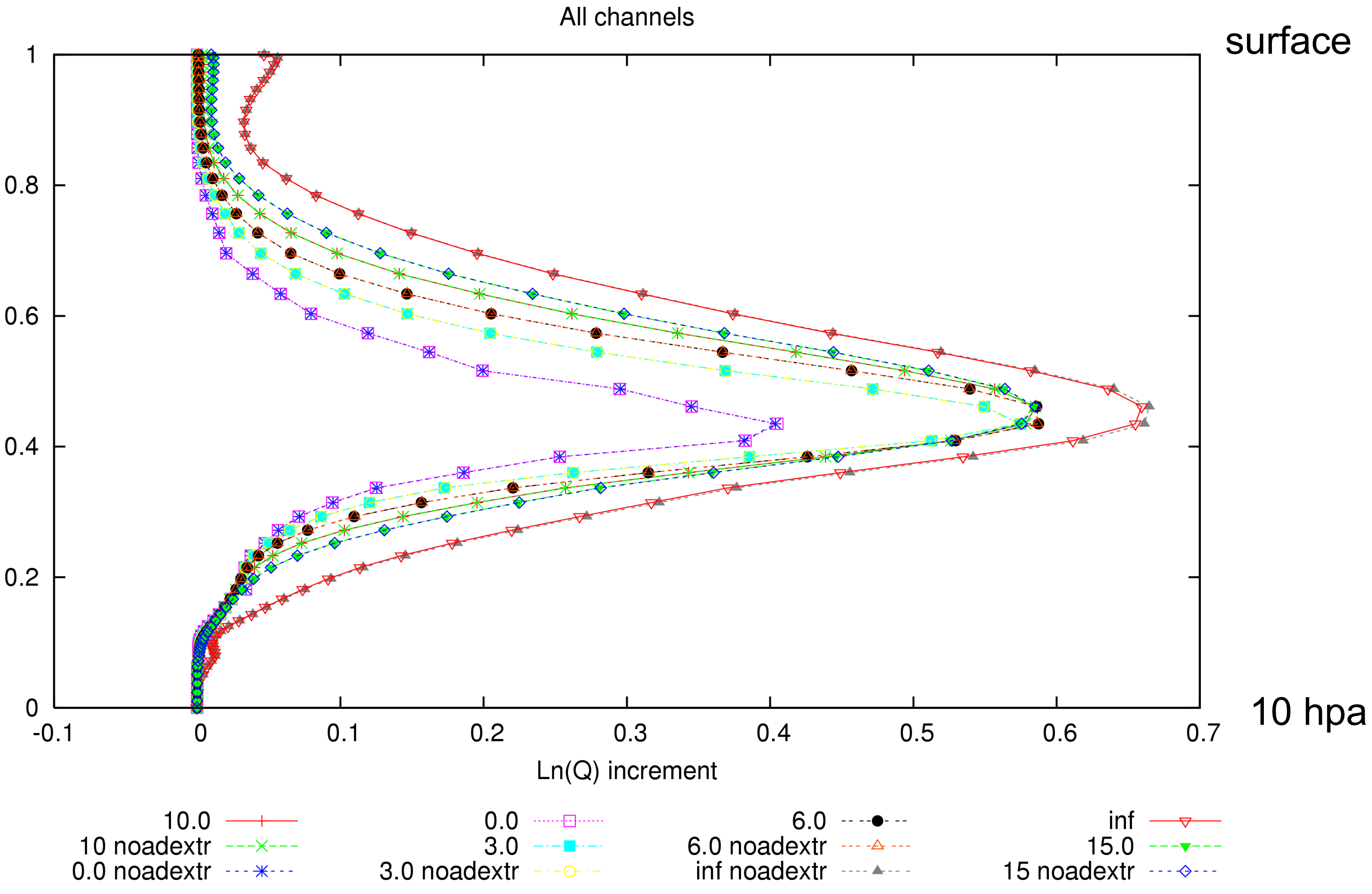
COR matrix with L=10



Temp increment vs L, adj_extrap

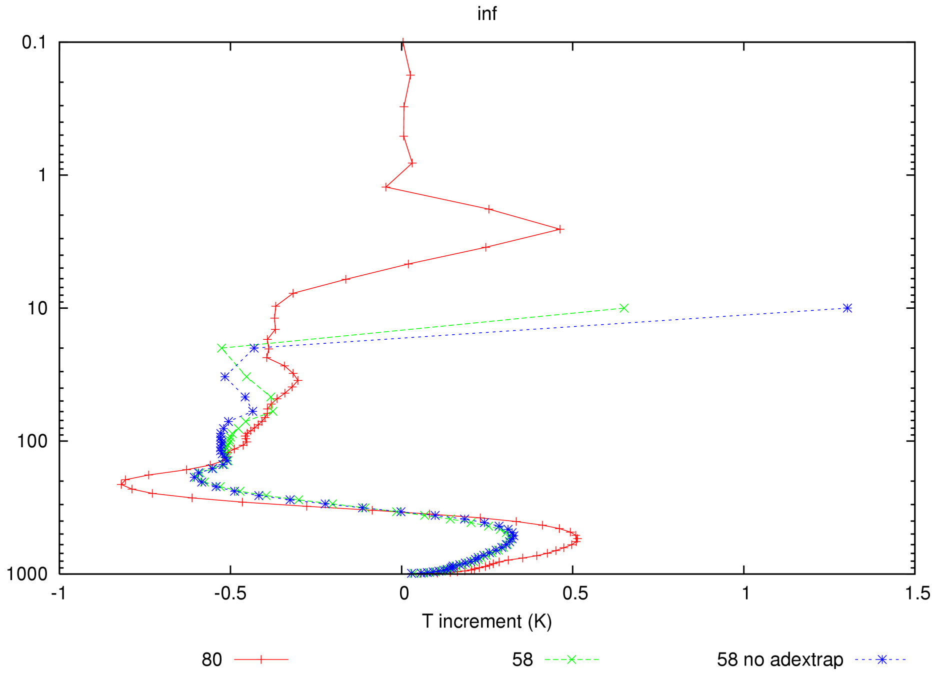


Increment lnq

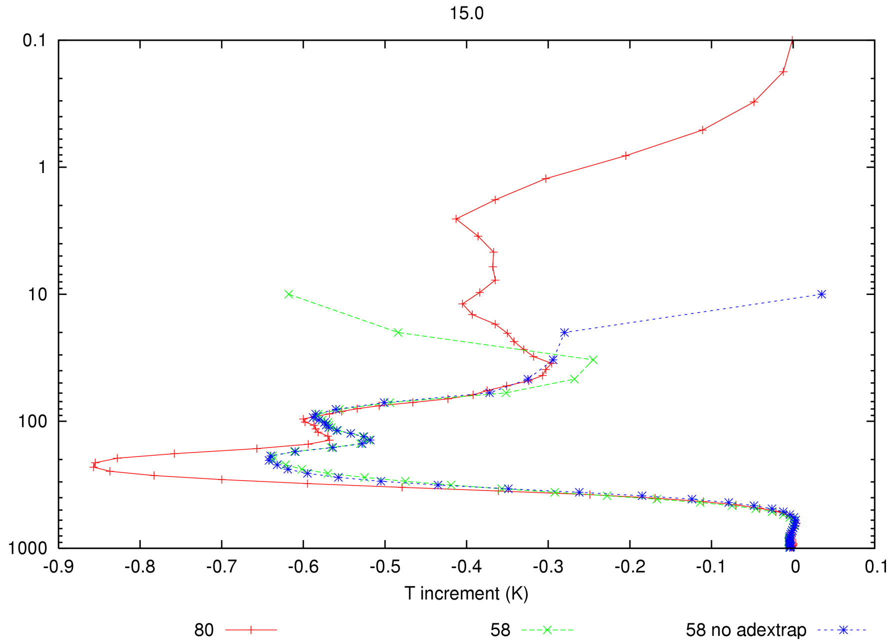


Ch 156 TT increments: 80 lev vs 58 lev

Original B matrix

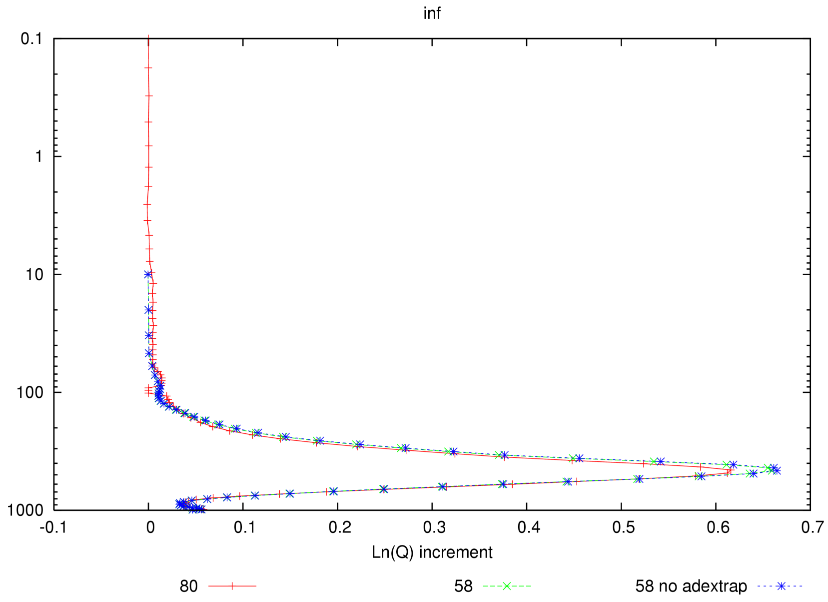


Localized B matrix

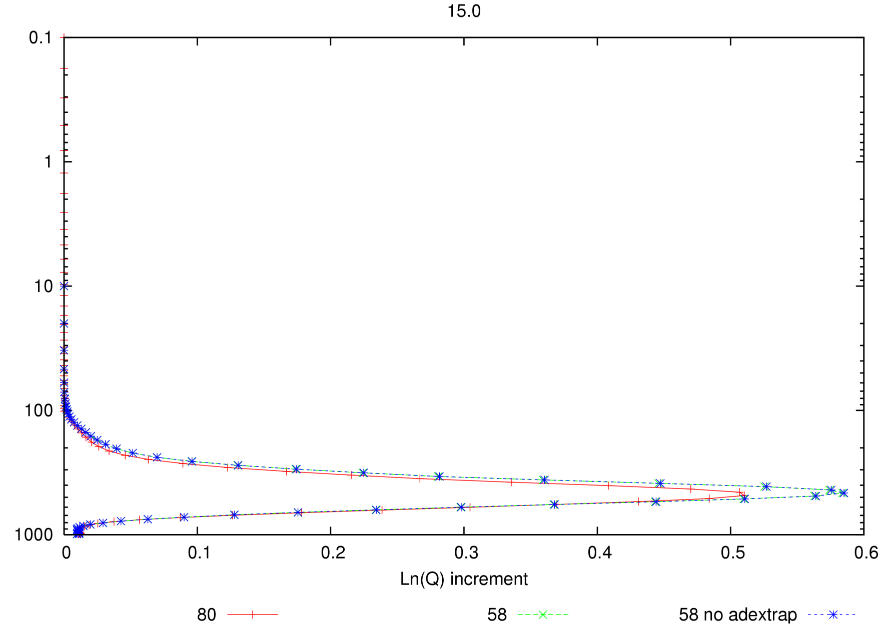


Lq inc all channels 58 vs 80 levels

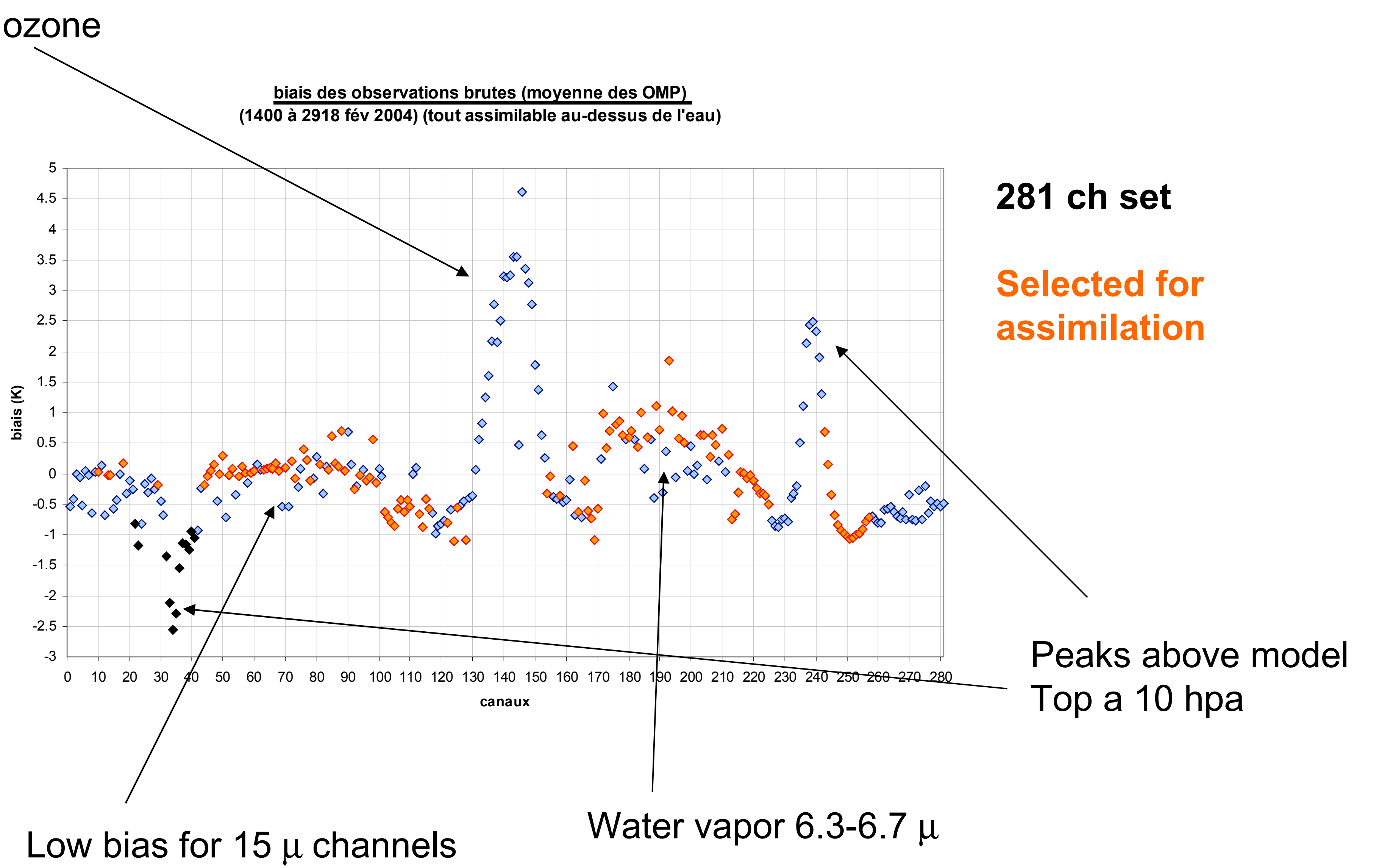
Original



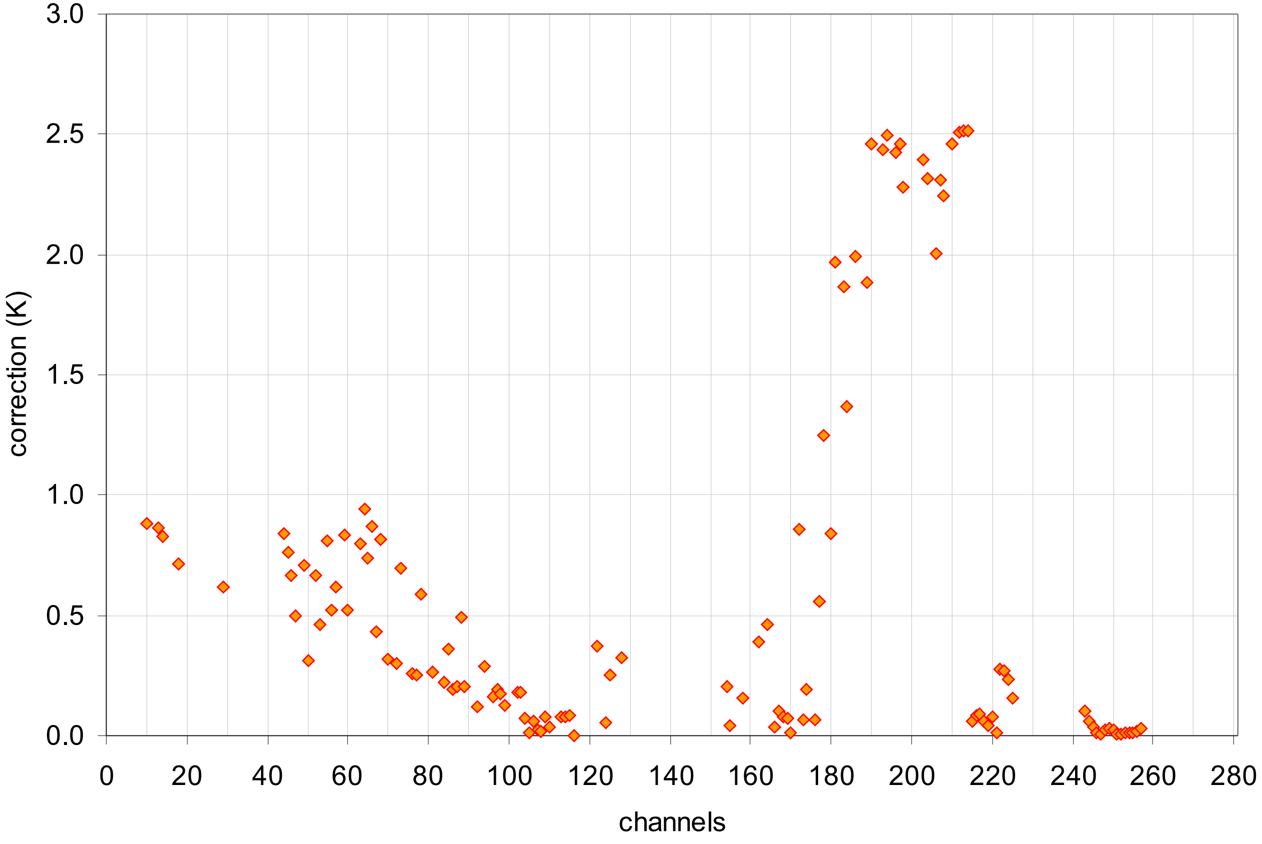
localized



AIRS (O-P) bias spectrum



Maximum departure (K) from flat bias (3σ)



Up to 2.5K departure from flat bias in water vapor channels.
These largest departures are seen in dry air masses