Environment Canada Environnement Canada

Canada

Assimilation of Cloud-Affected Infrared Radiances at Environment-Canada

ECMWF-JCSDA Workshop on Assimilating Satellite Observations of Clouds and Precipitation into NWP models

ECMWF, Reading (UK)

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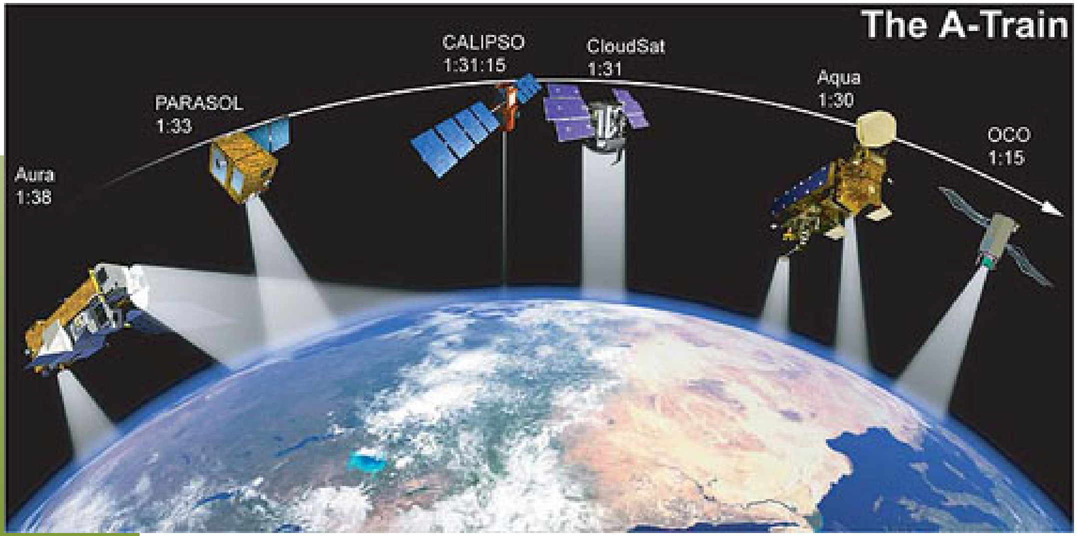
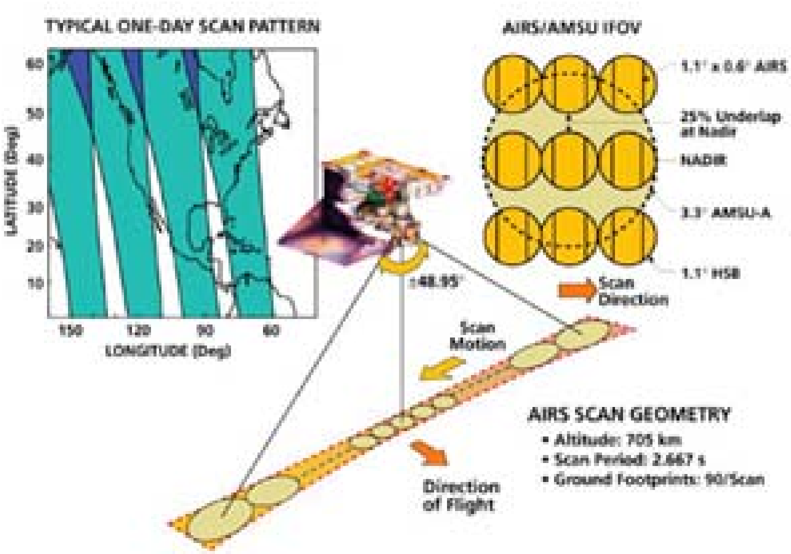
Outline

- Description of the AIRS and IASI instruments
- Assimilation of cloud unaffected IR radiances at EC
- Comparison of approaches using cloud effective parameters
- Assimilation of cloud affected IR radiances at EC
- A first 4D-Var assimilation cycle
- A second 4D-Var assimilation cycle
- Conclusions

Description of the AIRS and IASI Instruments:
AIRS Instrument Overview

- High spectral resolution infrared vertical sounder (grating spectrometer with 2378 channels between 15.5 μm and 3.6μm) onboard AQUA : provides information on temperature, humidity, ozone, etc…)



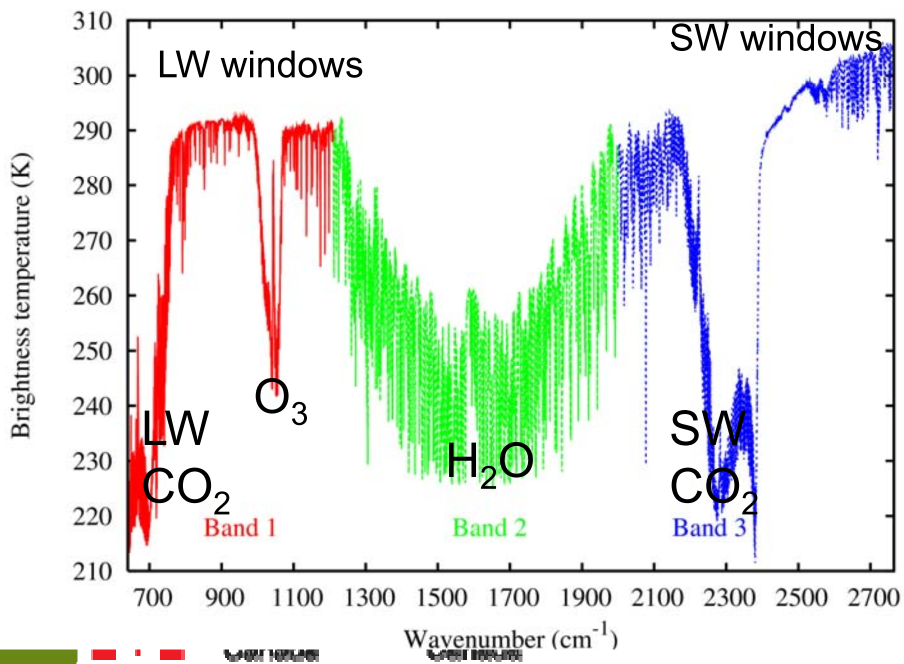


Description of the AIRS and IASI Instruments:

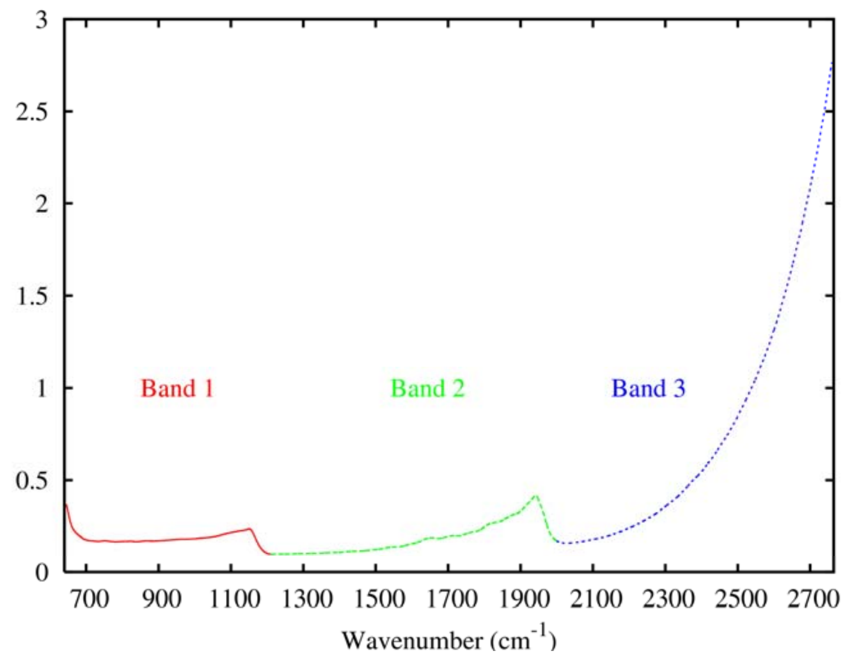
IASI Instrument overview

- Infrared Atmospheric Sounding Interferometer
- Flying onboard the METOP-A European operational satellite (sun-synchronous polar orbit, mean equator crossing time 09.30, descending node)
- Provides high resolution spectra (apodised resolution of 0.5 cm^{-1}) of the infrared radiation emitted by earth/atmosphere between 645 cm^{-1} and 2760 cm^{-1} in 8461 channels

Typical full resolution spectrum



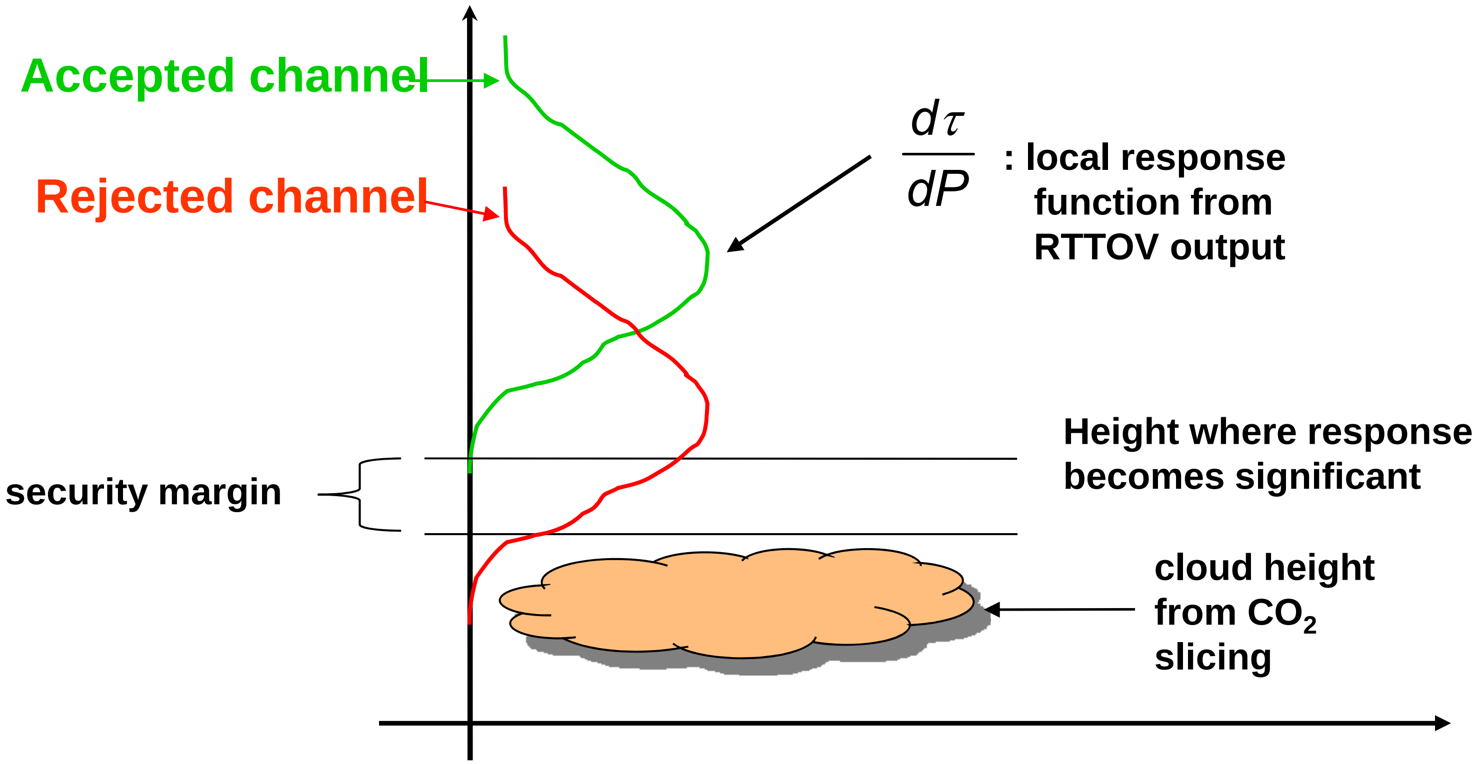
Radiometric noise characteristics



Description of the AIRS and IASI Instruments:
AIRS and IASI Channels Selected for Assimilation at EC

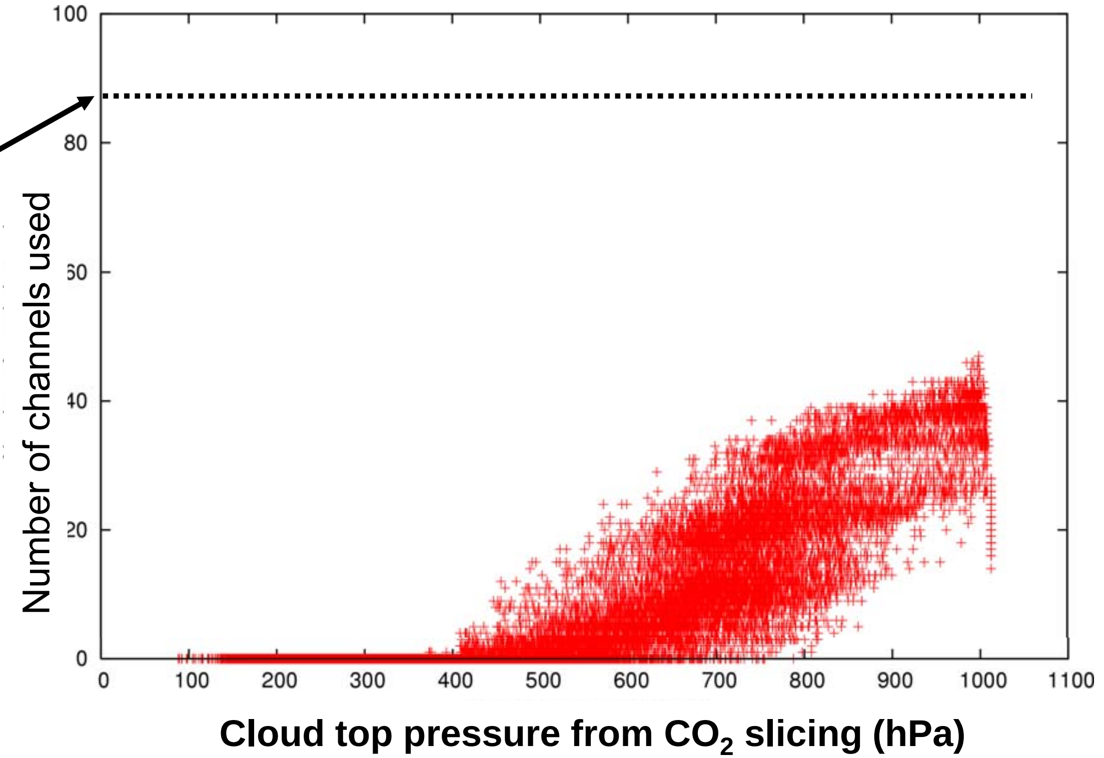
	LW T channels (15 μm)	Boundary layer channels (above sea only)	Ozone channels	H_2O channels (6.3 μm)	SW T channels	Total
Operational	20	10		33	24	87
Control 1	20/43	10/19		33/66	24	87/128
Exp1. when cloud-affected	20/43	10/19		33/66		53/128
Control 2	55/53	10/19		33/10	24	122/82
Exp2. when cloud-affected	55/53					55/53

Assimilation of Cloud Unaffected IR Radiances at EC



Assimilation of Cloud Unaffected IR Radiances at EC : Severe Limitation in the Number of Assimilated Radiances

87 AIRS channels assimilated in **clear sky** case over ocean



No AIRS channel assimilated for P_c < 400 hPa

Comparison of Approaches Using Effective Parameters (1/2)

	UKMET	Meteo-France	ECMWF	CMC
Background value for cloud parameters	From *1Dvar* initialized by minimum residual (9 channels) method with big background errors	*CO_2 slicing* (124 pairs with the same reference channel at 979.13 cm^{-1})	*Minimum residuals* (using 2 or 3 channels)	*CO_2 slicing* (13 pairs of channels with different reference channels)
Variable cloud parameters in 4D-Var ?	no	no	yes	yes
Cloud parameters	$P_c, N\varepsilon$	$P_c, N\varepsilon$	$P_c, N\varepsilon$ (only Pc is variable)	P_c, δ, r_e, D_e (only the 2 first are variable)

Comparison of Approaches Using Effective Parameters (2/2)

	UKMET	Meteo-France	ECMWF	CMC
Conditions for cloudy assimilation	Above sea Radiances weakly affected by clouds	Above sea. 600 hPa<P_c<950 hPa Nε >0.1	Above sea 100 hPa<P_c<900 hPa Overcast cloud	Above sea. 250 hPa<P_c<P_s-100 hPa Nε >0.75
Cloud ε modeling	no	no	no	yes
Obs. error for cloud params.	0	0	5 hPa for Pc 0 for Nε	from CO_2 slicing estimates
Implemented operationally ?	yes	yes	yes	no
Assimilated channels	92 AIRS for 1D-Var pre-processing In 4D-Var ?	54 in the CO_2 15 μm band (AIRS)	Same as cloud unaffected cases except for SW channels	15 μm CO_2 only

Assimilation of Cloud Affected IR Radiances at EC: Simplified Cloudy Radiance Modeling With Effective Cloud Parameters (1/2)

- Simplified description of the cloud radiative effect for a cloud located at P_c with cloud emissivity spectrum $N\varepsilon(\nu)$:

$$I_{cld}(\nu) = N\varepsilon(\nu) I_{ovc}(\nu, P_c) + (1 - N\varepsilon(\nu)) I_{clr}(\nu)$$

$I_{cld}(\nu)$: Cloudy radiance

$N\varepsilon(\nu)$: Cloud effective emissivity

$I_{ovc}(\nu, P_c)$: Cloudy overcast radiance

$I_{clr}(\nu)$: Clear radiance

Assimilation of Cloud Affected IR Radiances at EC: Simplified Cloudy Radiance Modeling With Effective Cloud Parameters (2/2)

- Cloud emissivity model:

$$N\varepsilon(\nu) = 1 - \exp\left[-k_{cld}(\nu, r_e, D_e)\delta\right]$$

r_e : effective radius for liquid phase (set to 12 μm)
D_e : effective diameter for ice phase (set to 55 μm)
δ : effective cloud water path

- Up to date optical properties of liquid and solid (ice) water are used
- Scattering is accounted for approximately
- ***It is implicitly assumed that the cloud covers the whole field of view***
- First guess and background values determined from CO_2 slicing for δ (via retrieved $N\varepsilon$) and P_c

Assimilation of Cloud Affected IR Radiances at EC : Proposed 3D/4D-Var Assimilation

- Addition to the state vector **x** of a *local* estimate of the 4 cloud parameters at each AIRS observation location

$$\mathbf{x} \rightarrow \tilde{\mathbf{x}} = (\mathbf{x}, \mathbf{z})$$ State augmentation

x: model fields

$\mathbf{z}$: vector of local effective parameters :

$$z = (\underbrace{P_{c1}, \delta_1, r_{e1}, D_{e1}}_{\text{obs.1}}, \ldots\ldots, \underbrace{P_{ci}, \delta_i, r_{ei}, D_{ei}}_{\text{obs.i}}, \ldots\ldots, \underbrace{P_{cn}, \delta_n, r_{en}, D_{en}}_{\text{obs.n}})$$

Dim(**x**)~10^6-10^7
Dim(**z**)=4N_{obs}~10^4

$$J_c(\tilde{\mathbf{x}}) = \left\{ \underbrace{(\mathbf{x}-\mathbf{x_b})^t \mathbf{B}^{-1} (\mathbf{x}-\mathbf{x_b})}_{\text{Background term}} + \underbrace{(\mathbf{z}-\mathbf{z_b})^t \mathbf{C}^{-1} (\mathbf{z}-\mathbf{z_b})}_{\text{Cloudy background term}} + \underbrace{(\mathbf{H}_c(\tilde{\mathbf{x}})-\mathbf{y})^t \mathbf{O}^{-1} (\mathbf{H}_c(\tilde{\mathbf{x}})-\mathbf{y})}_{\text{Observation term with cloud}} \right\}$$

z_b : cloud background state from CO_2 slicing and climatology

H_c cloudy observation operator combining **RTTOV 8.7** and the cloud emissivity model

Assimilation of Cloud Affected IR Radiances at EC : Preconditioning of 4D-Var Assimilation

- Minimization of the cost function more difficult in 4D-Var mode than it was in 3D-Var mode

→Need for a preconditioning with the diagonal of the hessian Matrix for cloud parameters

$$z \longrightarrow Z = C(z - z_b)$$

Where z is a cloud parameter

with $$C = \sqrt{\frac{1}{\sigma_c^2} + \sum_{\text{channels}\, i} \left(\frac{1}{\sigma_{oi}} \frac{\partial H_i}{\partial z} \right)^2}$$ Instead of $$C = \frac{1}{\sigma_c}$$

σ_c represents the error associated with the cloud parameter z
σ_{oi} represents the observation error of channel i
H is the radiative transfer operator

A First 4D-Var Assimilation Cycle : Description of the 4D-Var Experiments

- Background error for cloud parameters :

$$\sigma_{b\,P_c} = \frac{2.0}{\left(\frac{\partial BT_{window}}{\partial P_c}\right)} \qquad \sigma_{b\,\delta} = \frac{2.0}{\left(\frac{\partial BT_{window}}{\partial \delta}\right)}$$

Description of the model

- GEM global model
- 800x600 grid
- 80 vertical hybrid levels with a top at 0.1 hPa

A First 4D-Var Assimilation Cycle: Quality Control Criteria for Cloud-affected Radiances Experiment 1

- Assimilation of cloudy radiances above sea only
- No assimilation of AIRS shortwave channels
- **250 hPa < P_c < P_s-100 hPa**
- **Restriction to near overcast situations ($N\varepsilon$>0.9)**
- Exclusion of situations with temperature inversion leading to an ambiguous solution for the CO_2 slicing algorithm
- Restriction to situation where the solution of the CO_2 slicing is well defined (σ_{Pc}<50 hPa, $\sigma_{N\varepsilon}$<0.1)
- To limit the impact of uncertainty on cloud phase:

$$\left| \left(\varepsilon_{ice} - \varepsilon_{liquid} \right) \frac{\partial T_B}{\partial \varepsilon} \frac{1}{\sigma_{obs}} \right| \leq \frac{1}{4}$$

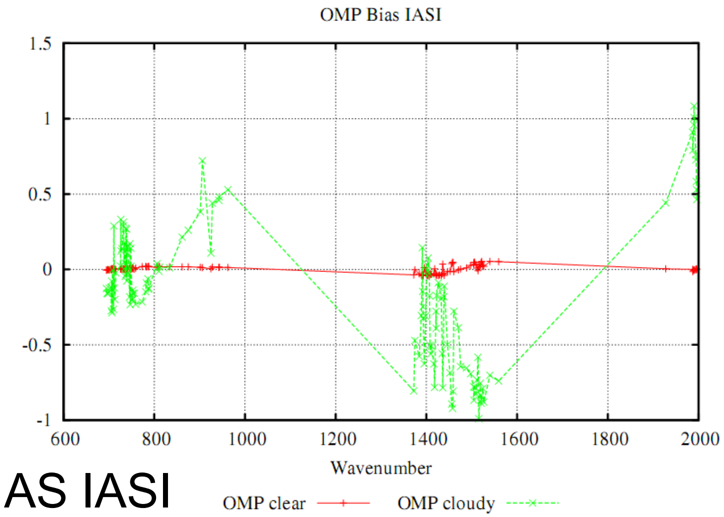
A First 4D-Var Assimilation Cycle : Description of the 4d-var Experiment 1

From 12/15/2008 to 01/08/2009 (25 days).

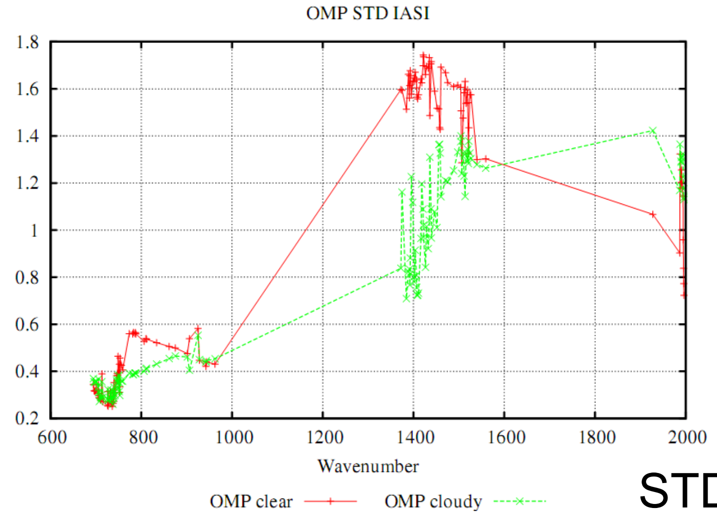
- **Control 1 experiment**:
  - Conventional data (radiosondes, etc…).
  - Quickscat winds.
  - AMSU-A and AMSU-B microwave radiances.
  - SSM-I and SSM-I-S microwave radiances.
  - ***GEORAD radiances.***
  - AIRS infrared radiances (87 channels).
  - ***IASI infrared radiances (128 channels).***
  - GPS radio-occultation (refractivity profiles).
  - ***Humidity from planes.***
- **Cloudy 1 test experiment**: same as above + AIRS and IASI in cloudy mode with bias correction represented by a constant (instead of A*BT+B in the control run).

A First 4D-Var Assimilation Cycle : IASI Obs-first Guess Statistics 6h Period

	CONTROL1	CLOUDY1	INCREASE
AIRS	2997 FOVS 66189 rad.	3185 FOVS 71939 rad.	+6% FOVS +8% RAD.
IASI	3958 FOVS 155696 rad.	4258 FOVS 183042 rad.	+7% FOVS +17% RAD.



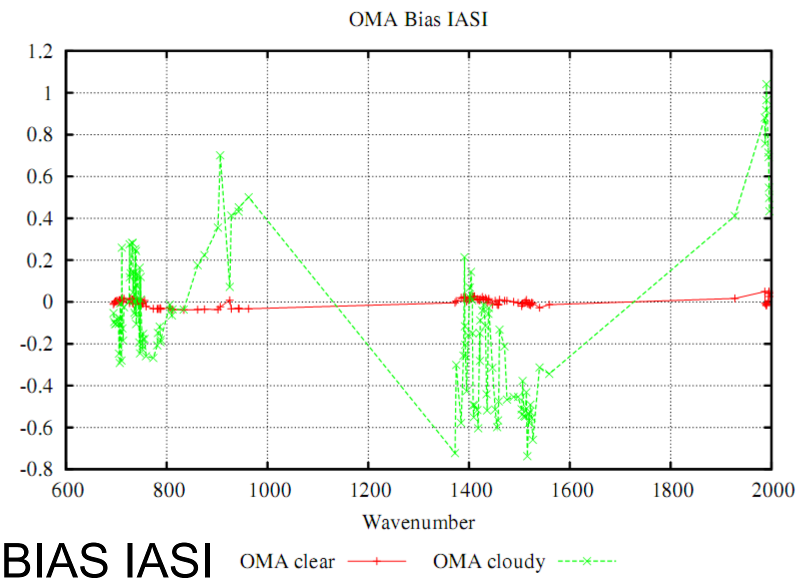
BIAS IASI



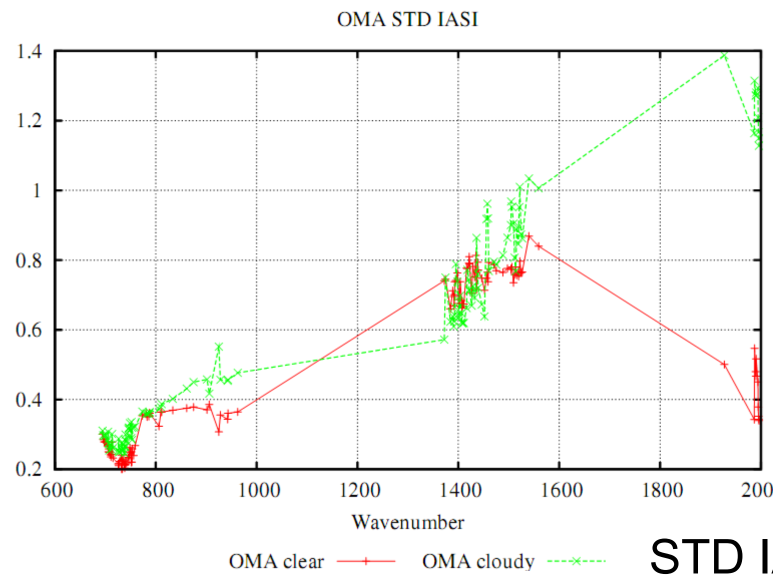
STD IASI

- **Residual bias for cloudy radiances not negligible**
- **Cloudy standard deviation lower for water vapor sensitive channels**
- **Very similar standard deviation for temperature channels**

A First 4D-Var Assimilation Cycle: IASI Obs-analysis Statistics 6h Period



BIAS IASI

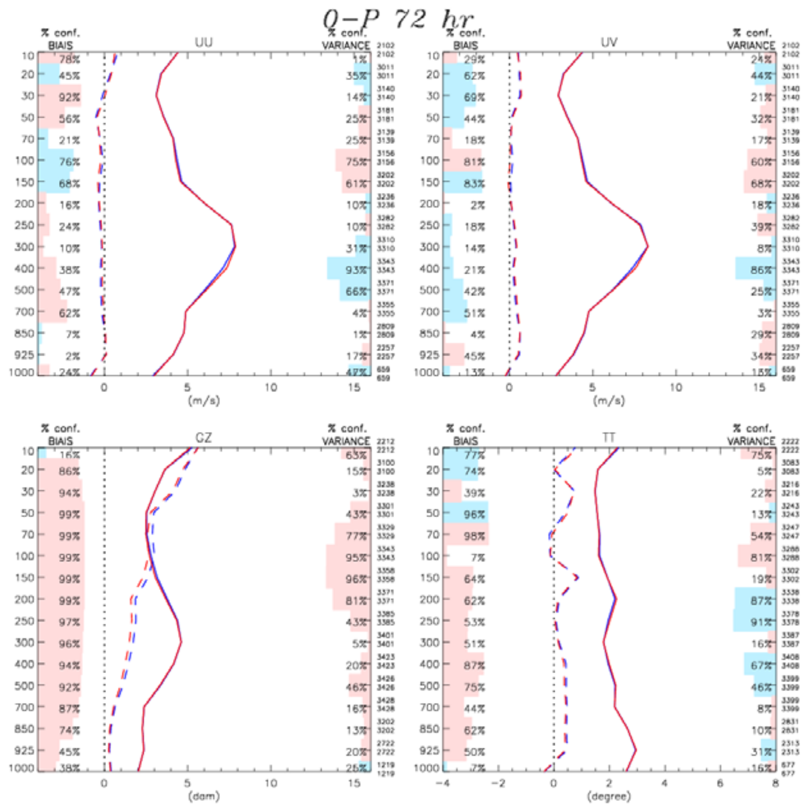


STD IASI

- Persistant residual bias for cloudy radiances
- Similar standard deviation after assimilation except for channels close to 2000 cm^{-1}

A First 4D-Var Assimilation Cycle : Validation of Forecasts Against Radiosondes: North America 72 H

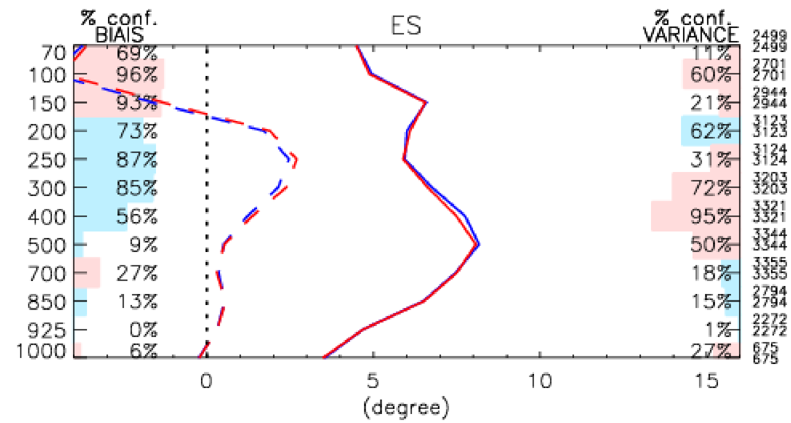
Wind



Geopotential height

Temperature

Dew point depression



38 cases

Legend:

Control is better

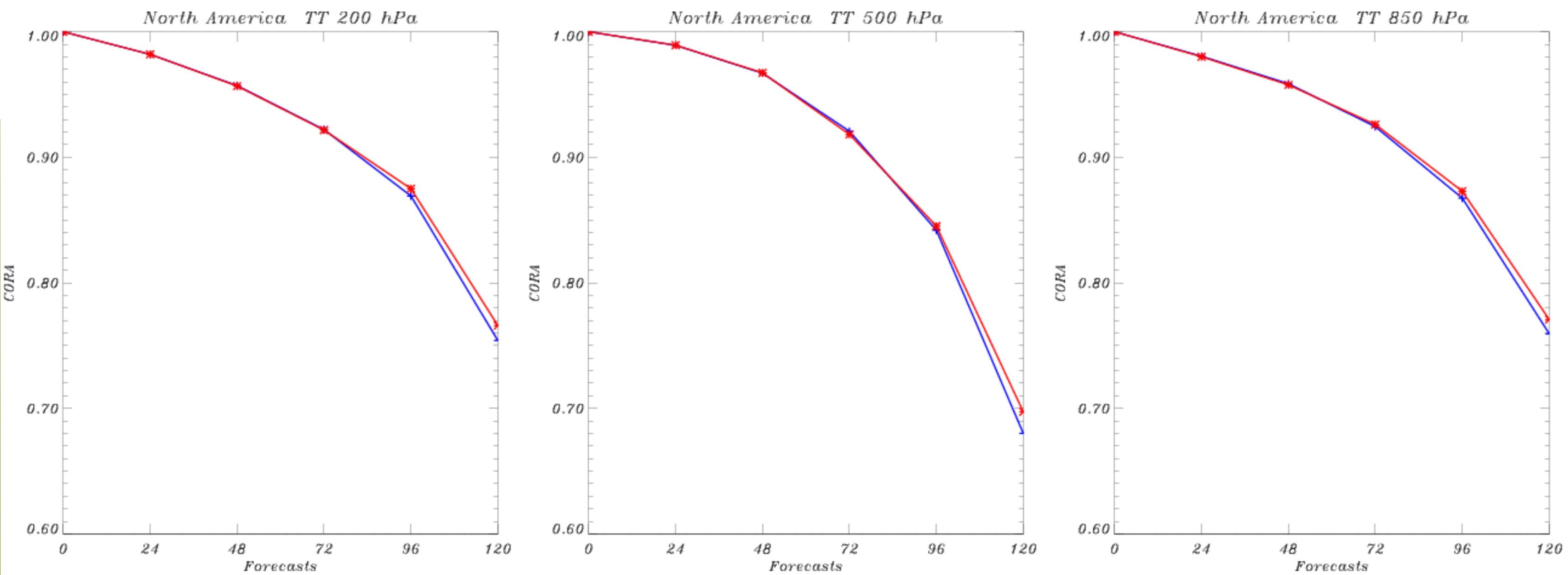
Test is better

A First 4D-Var Assimilation Cycle : Validation Against Analyses North America Temperature Anomaly Correlation

Control

Experiment

200 hPa 500 hPa 850 hPa

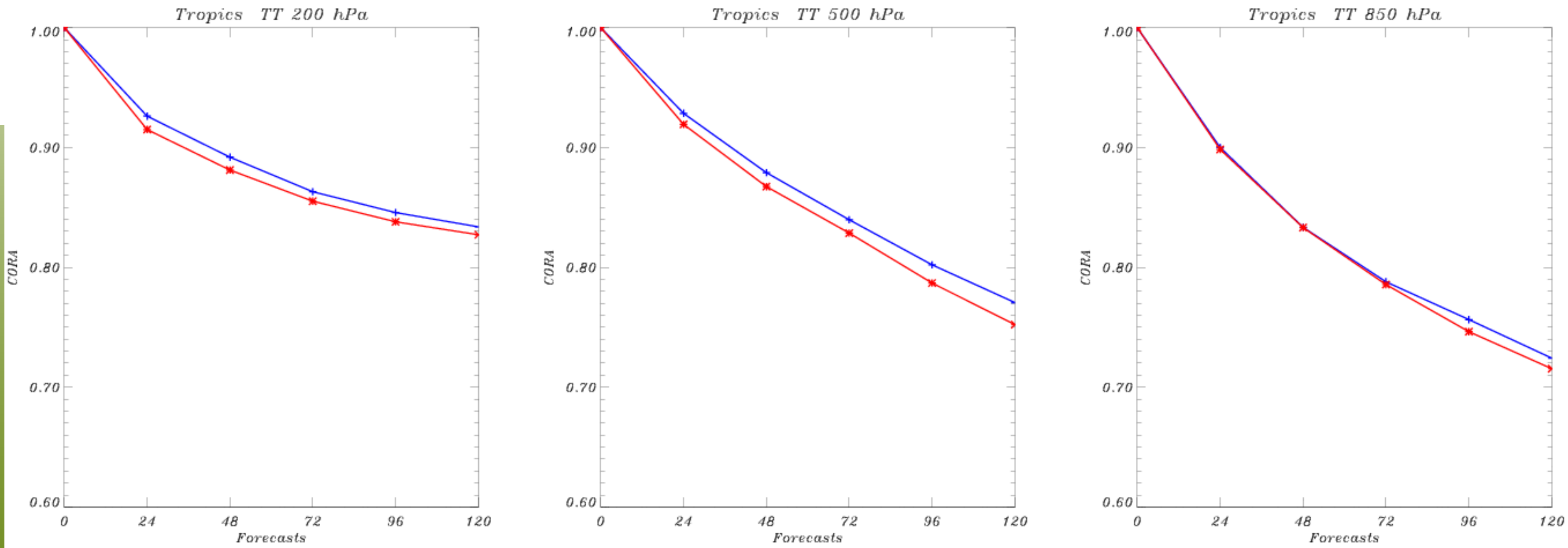


A First 4D-Var Assimilation Cycle Validation Against Analyses Tropics Temperature Anomaly Correlation

Control

Experiment

200 hPa   500 hPa   850 hPa



A First 4D-Var Assimilation Cycle : Lessons Learned From First 4dvar Experiment (and Others)

- A positive impact was demonstrated locally in North America.
- Some channels selected in both control and test experiments (extra stratospheric channels and IASI water vapor channels) are problematic and could be responsible for some of the observed problems.
- The constant bias correction used in the cloudy experiment 1 is sub-optimal. Furthermore a air mass predictor based bias correction was shown to improve our clear radiance assimilation and is also suitable for cloudy radiances.
- Some channels far (spectrally) from the 15 μm CO_2 band seem to be problematic from their O-F and O-A statistics.
- The extra data volume was relatively small and could be increased by decreasing our threshold on cloud effective fraction from 0.9 to 0.75.

A Second 4D-Var Assimilation Cycle: Quality Control Criteria for Cloud-affected Radiances Assimilation Experiment 2

- Assimilation of cloudy radiances above sea only (slightly revised criteria)
- ***Restriction of the assimilation of cloud-affected radiances to the 15 μm longwave temperature sounding channels***
- **P_s-100 hPa< P_c < 250 hPa**
- ***Restriction to close to overcast situations ($N\varepsilon$>0.75)***
- Exclusion of situations with temperature inversion leading to an ambiguous solution for the CO_2 slicing algorithm
- Restriction to situation where the solution of the CO_2 slicing is well defined (σ_{Pc}<50 hPa, $\sigma_{N\varepsilon}$<0.1)
- Criteria on cloud phase related to emissivity model lo longer necessary if cloudy assimilation is restricted 15 μm channels

A Second 4D-Var assimilation cycle: Description

Winter 2008/2009

- Bias correction from A*BT+B to air mass predictors
- ***Reduced Spatial thinning (250 km →150 km)***
- **Control 2 experiment** ad before except for:
  - AIRS infrared radiances (122 channels)
  - ***IASI infrared radiances (82 channels)***
- **Test 2 experiment**: same but with assimilation of AIRS and IASI in cloudy mode

Conclusions

- EC assimilation system is extended to assimilate cloudy radiances in 4D-Var mode
- The assimilation is robust and the additional computational cost is modest
- The system takes into account the spectral variation of cloud optical properties
- Results of first 4D-Var assimilation experiments (3 weeks) indicate a mix of slightly positive and negative impacts
- New assimilation experiments currently running

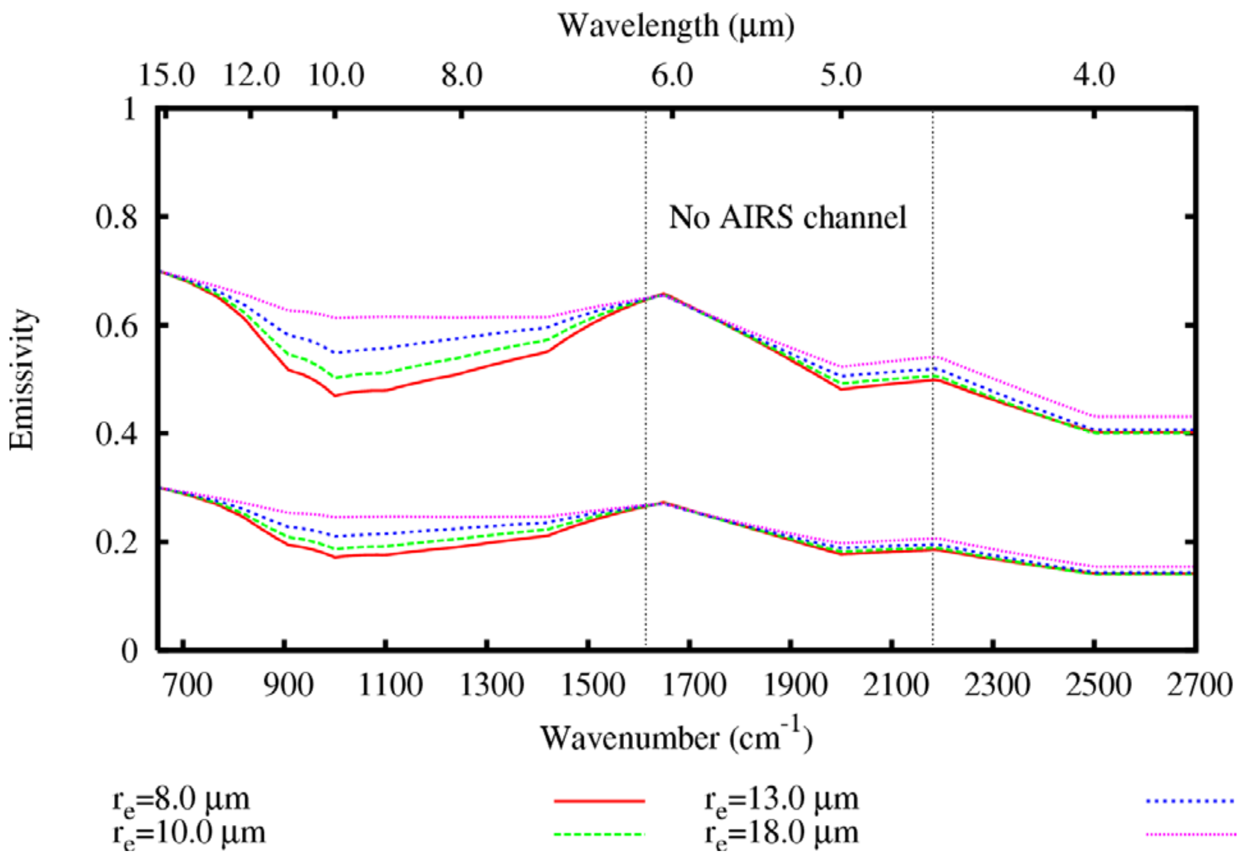
SPARE SLIDES

Details of AIRS and IASI Channels Selected for Assimilation

cm^{-1}	Spectral bands	AIRS	IASI
650 – 770	Temperature Sounding (CO2 Band)	20 + 37	65
770 – 980	Surface and cloud properties	6	19
1000 – 1070	Ozone sounding	0	0
1070 – 1150	Surface and cloud properties	4	0
1210 – 1650	Water vapor temperature sounding	33	55
1650 – 2100	Water vapor temperature sounding	0	11
2100 – 2150	CO column amount	0	0
2150 – 2250	Temperature sounding	9	0
2350 – 2420	Temperature sounding (CO2 Band)	15	0
2420 – 2700	Suface and cloud properties	0	0

Examples of Cloud Emissivity Spectra

μ δ



Examples of Cloud Emissivity Spectra

μ δ