Experimental assimilation of cloud radar and lidar observations at ECMWF

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Introduction

- New possibilities for model improvement to be explored through assimilation of data related to clouds from active and passive sensors.
- Observations providing 3D-information on clouds from space-borne active instruments on board of CloudSat & CALIPSO already available and new ones, such as EarthCARE should appear in the near future.
- To study the impact of the new observations on 4D-Var analyses and subsequent forecasts, a 1D+4D-Var technique has been selected.

Methodology:

– 1D-Var + 4D-Var approach built on experience of using such technique for operational assimilation of precipitation related observations. *(Bauer et al. 2006 a, b)*

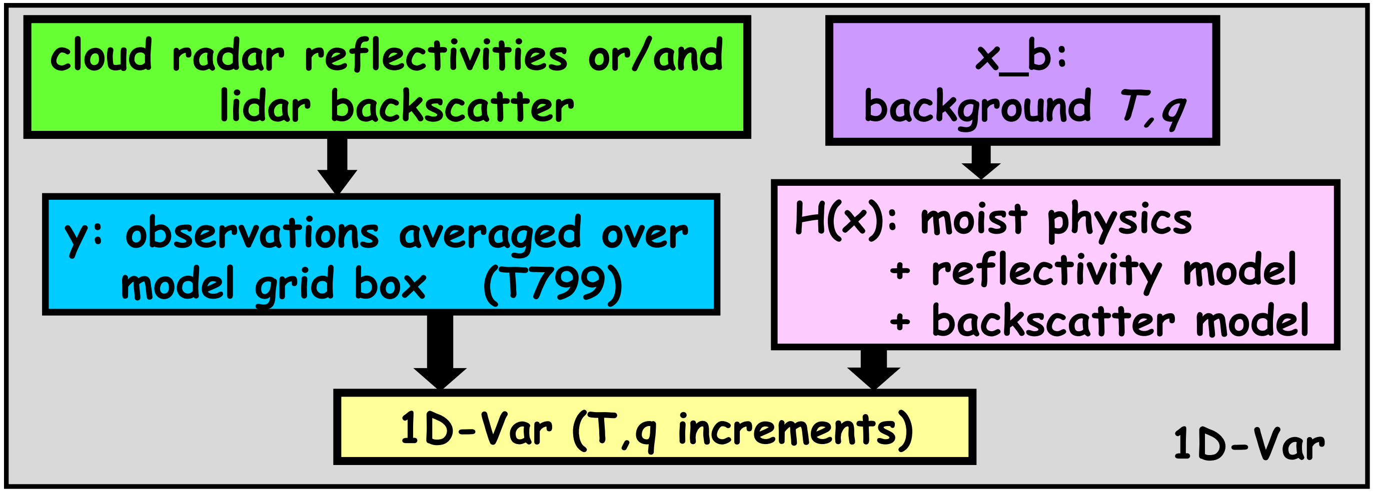
– In 2-step 1D-Var + 4D-Var approach used for cloud radar reflectivity *(Janisková et al. 2011)* or/and lidar backscatter:

  – 1D-Var retrieval first run on the set of observations to produce pseudo-observations of temperature *T* and specific humidity *q* *(based on evaluation of T and q increments both variables are modified by the assimilation of cloud related observations)*,

  – modified *T* and *q* profiles then assimilated in the ECMWF 4D-Var system.

1D-Var – One-Dimensional Variational assimilation
4D-Var – Four-Dimensional Variational assimilation

1D-Var assimilation of cloud radar and lidar observations



Flowchart describing 1D-Var technique:

- For a given observation y^o, 1D-Var searches for the model state $x=(T,q_v)$ that minimizes the cost function:

$$J(\mathbf{x}) = \underbrace{\frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b)}_{\text{Background term}} + \underbrace{\frac{1}{2}(H(\mathbf{x})-\mathbf{y}^o)^{\mathrm{T}}\mathbf{R}^{-1}(H(\mathbf{x})-\mathbf{y}^o)}_{\text{Observation term}}$$

B = background error covariance matrix
R = observation and representativeness error covariance matrix

***H* = nonlinear observation operator (model space → observation space)**

- Moist physics *(cloud and convection scheme)*
- Radar reflectivity operator *(multiple scattering not considered for assimilation studies)*
- Lidar backscatter operator *(simple parametrization for multiple scattering)*

Data selection tools

Quality control :

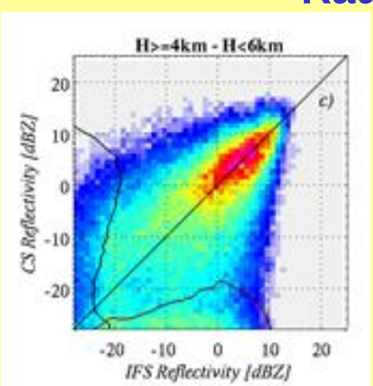
- excluding situations when discrepancies between observations and model equivalents are large → *based on statistics of first-guess (FG) departures*

Bias correction:

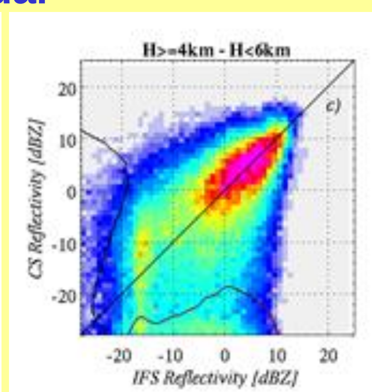
- Statistics based on the comparison of model FG with observations
  → *temperature and altitude used as predictors, separately over seasons and geographical regions*
- Applying correction → more Gaussian distribution of FG departures

EXAMPLE

Radar

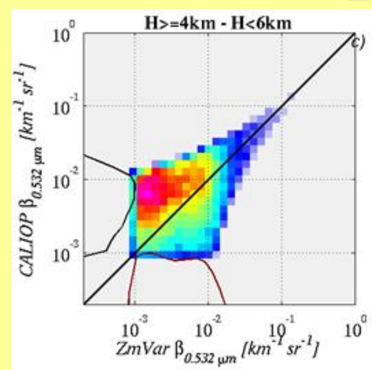


before

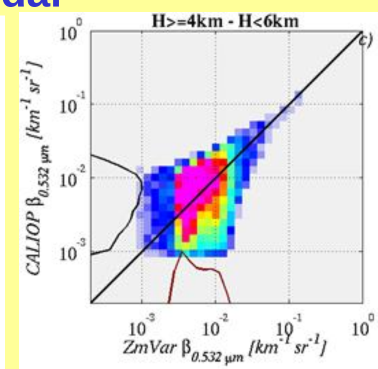


after bias correction

Lidar



before



after bias correction

Observation errors

Observation error = instrument error + forward modelling error + representativity error

Instrument error:

- CloudSat instrument random error $$\Delta Z_{dB} = \frac{4.343}{\sqrt{M}}\left(1 + \frac{1}{SNR}\right)$$
- CALIOP instrument errors evaluated from Level-1 data (background signal power st.dev. and NoiseScaleFactor) according to Liu *et al.* (2006).

Forward modelling error:

- Approach: – error expressing uncertainty in microphysical assumption
  – evaluation through differences between perturbed state and reference configuration
- Reflectivity/backscatter standard deviation expressed as percentage of the simulated radar reflectivity/backscatter separately for different ranges of temperature

Representativity error:

- Flow dependent error estimated based on statistical approach using the Structure Function Maximum (SFM) defined for different altitudes and geographical regions (Stiller 2010)

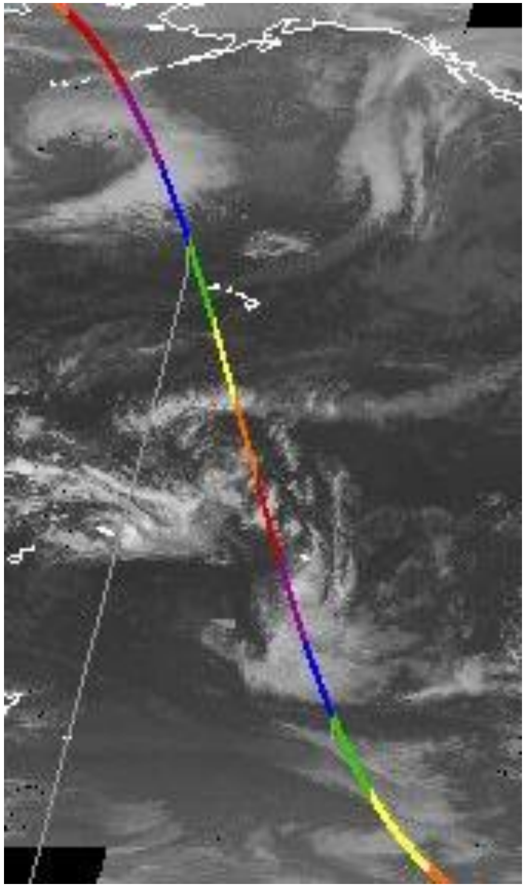
1D-Var assimilation experiments

- Assimilating different observations:
  - *cloud radar reflectivity* (R)
  - *cloud lidar backscatter* (L)
  - *cloud radar reflectivity + lidar backscatter* (C)

- Observations averaged in the grid-box using:
  - *full error definition*
  - *quality control and bias correction*

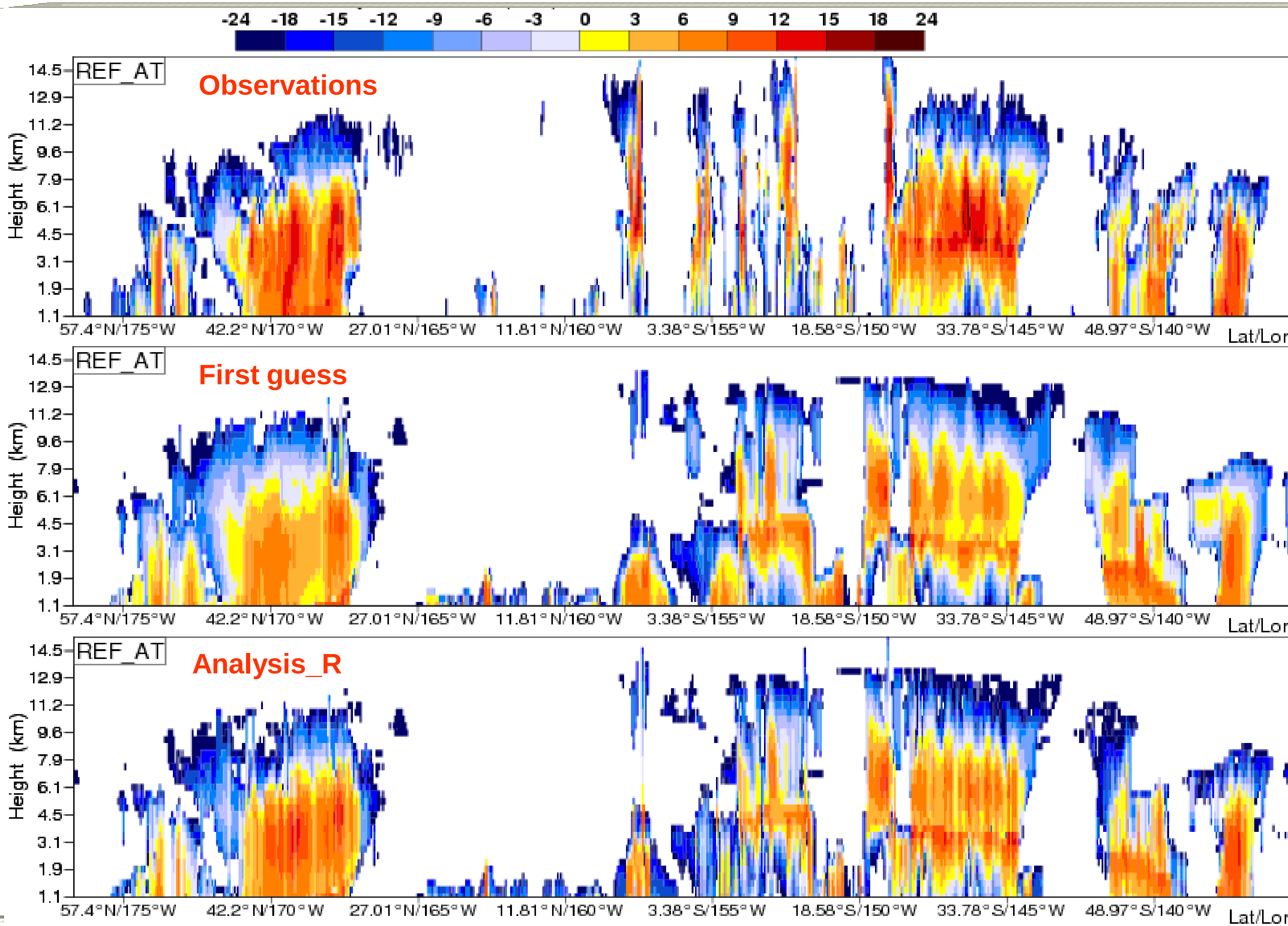
- Performance of 1D-Var verified using independent observations:
  - *cloud optical depth from MODIS*
  - *radar reflectivity or lidar backscatter when not assimilated*

- Checking increments of system control variables (temperature *T* and specific humidity *q*)



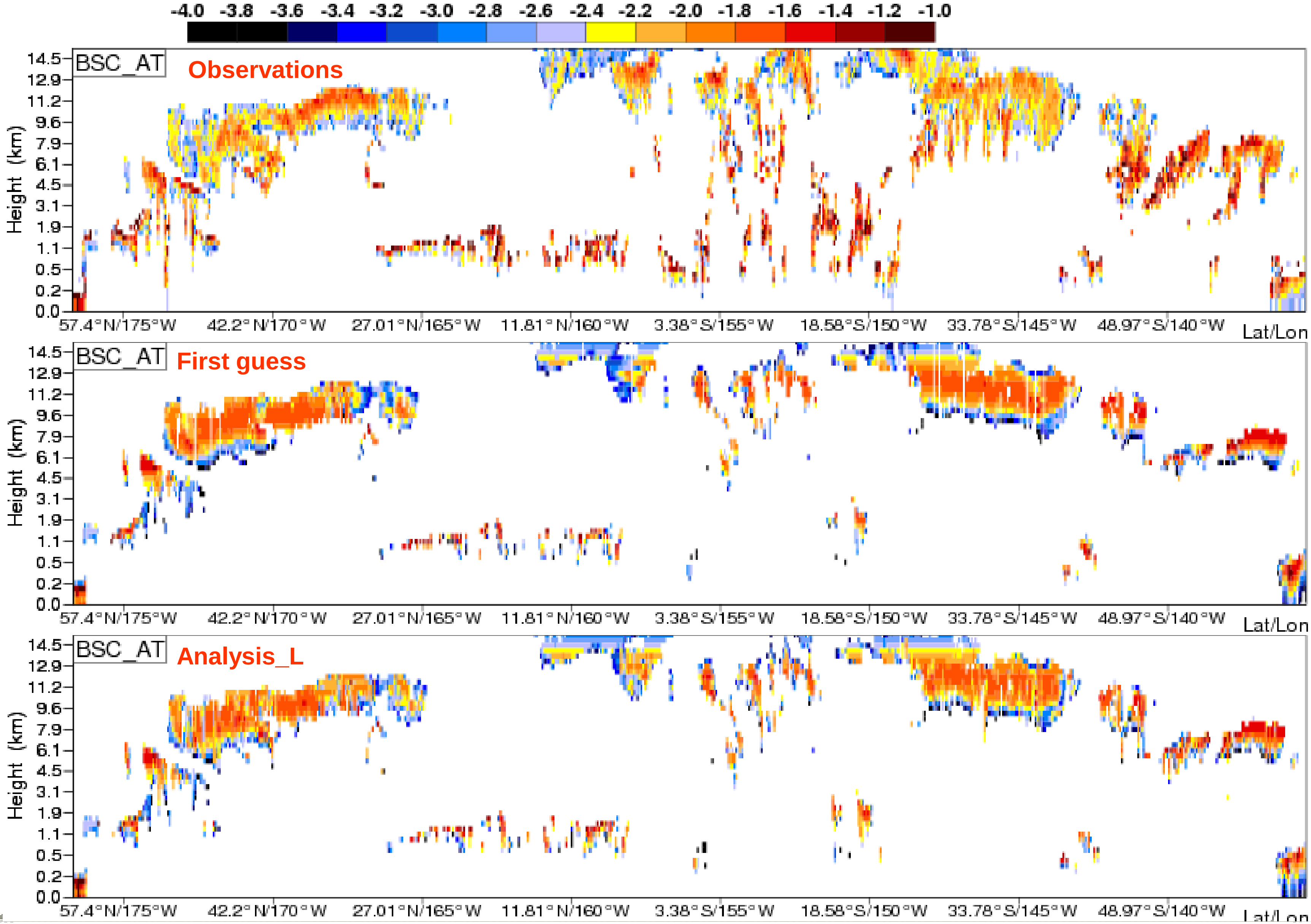
Presented example for: 2007012400 over Pacific

1D-Var of cloud radar reflectivity



2007012400 over Pacific

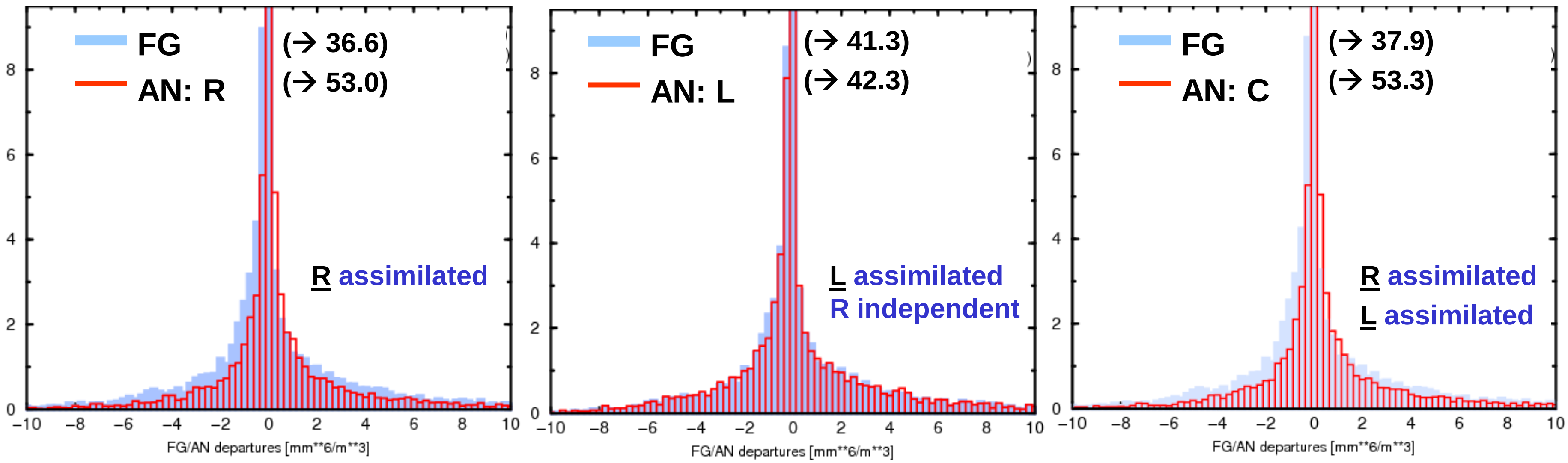
1D-Var of cloud lidar backscatter



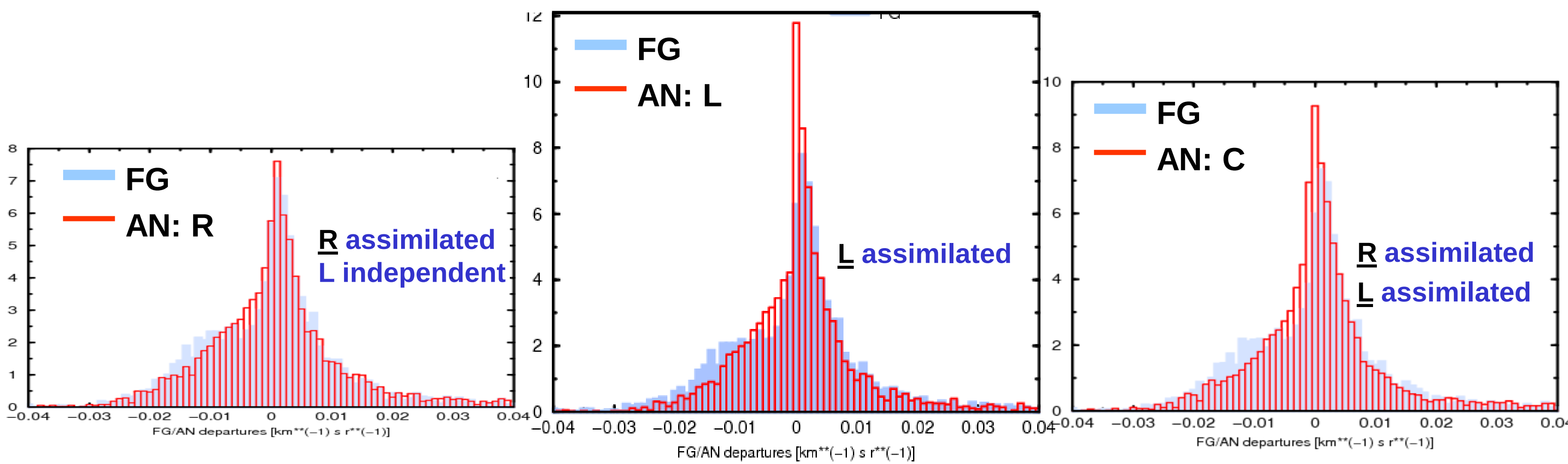
2007012400 over Pacific

PDF of first-guess vs. analysis departures

Cloud radar reflectivity



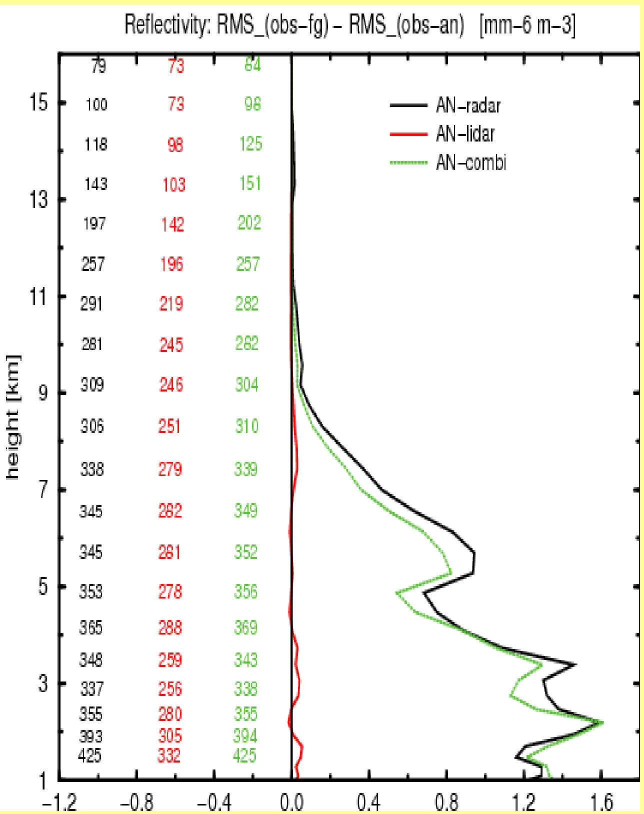
Cloud lidar backscatter



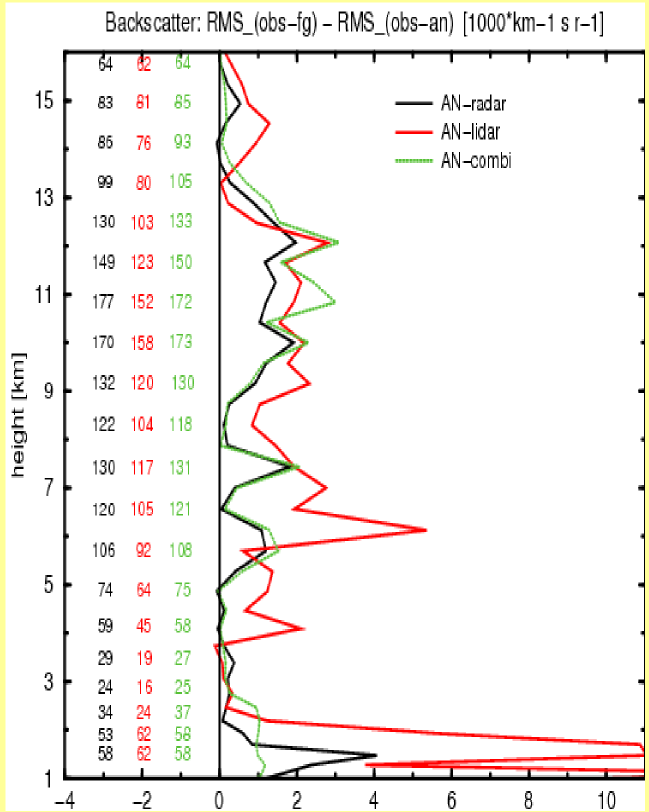
Improvement from assimilation of cloud radar and lidar observations

RMS (OBS – FG) – RMS (OBS – AN)

Cloud radar reflectivity

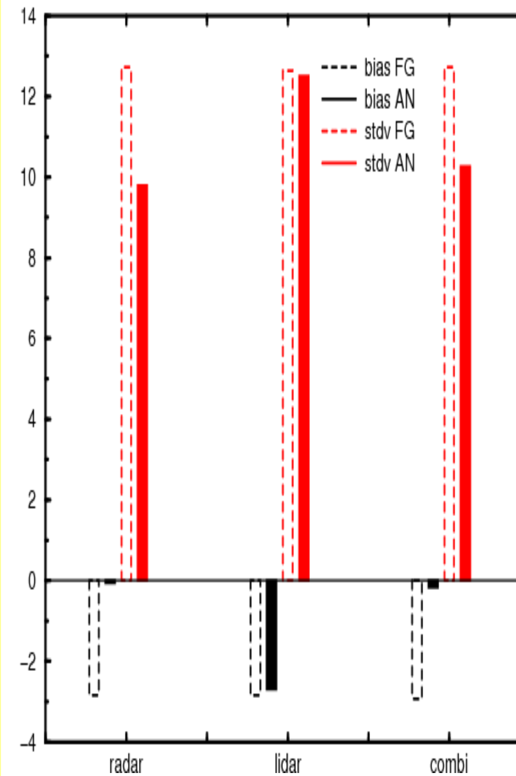


Cloud lidar backscatter

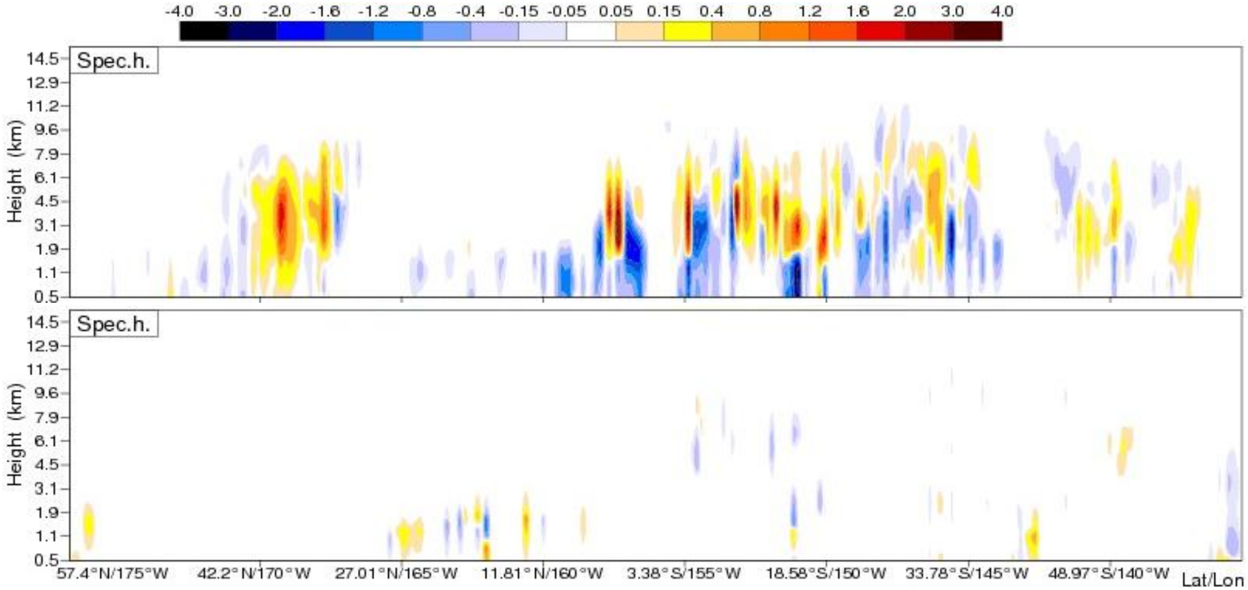


AN – radar (R)
AN – lidar (L)
AN – combi (C)

Comparison for:
FG, AN against MODIS OBS ≤ 50
Cloud optical depth (independent OBS)



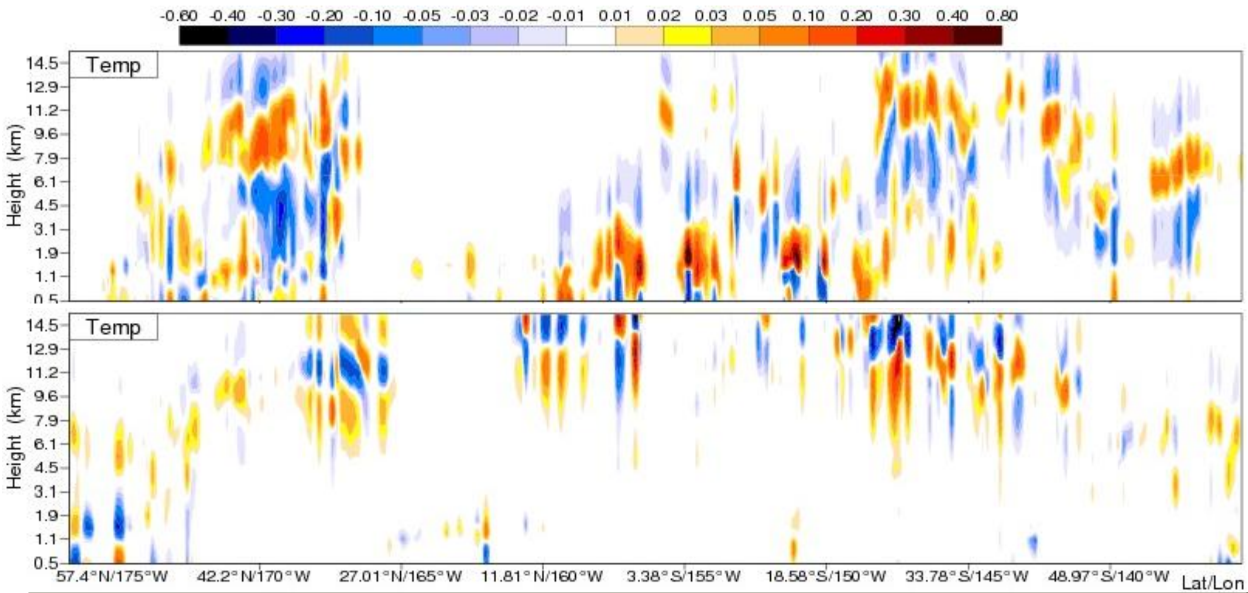
Increments of T and q from 1D-Var



Specific humidity [g/kg]

1D-Var - radar

1D-Var - lidar

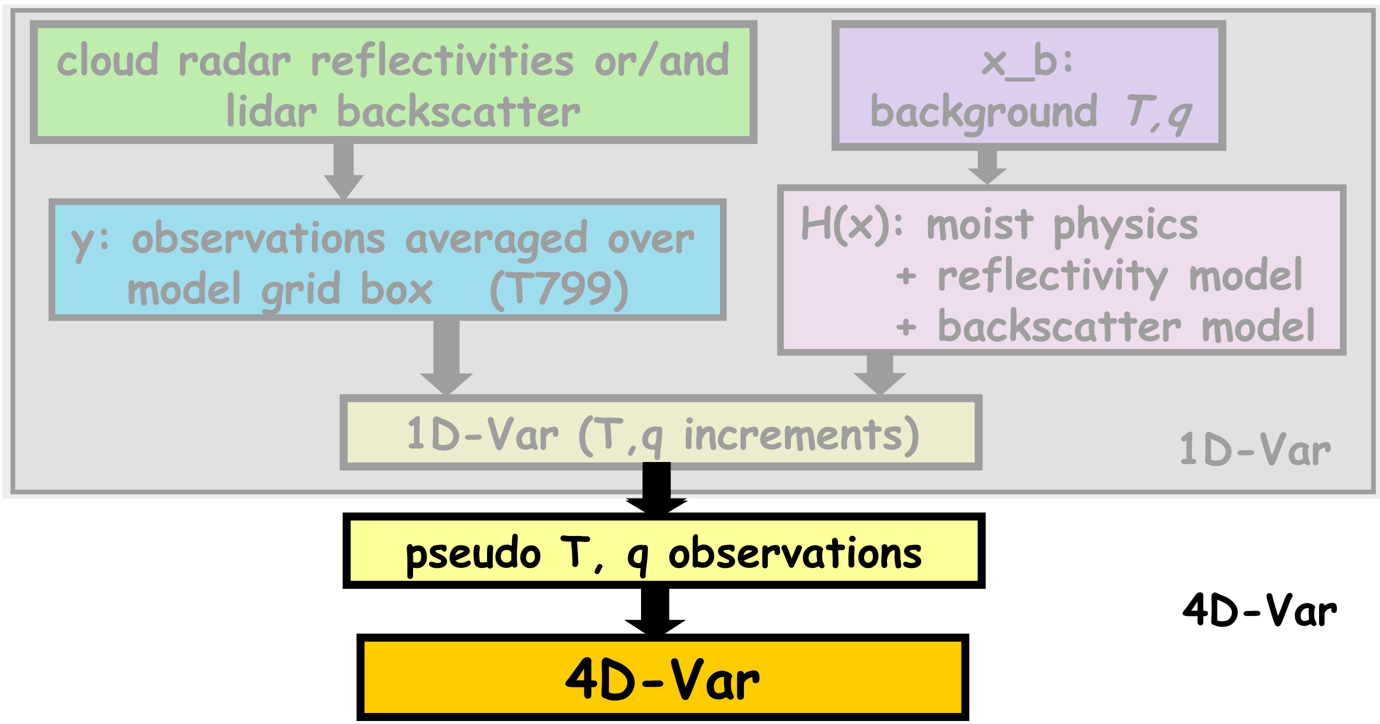


Temperature [K]

1D-Var - radar

1D-Var - lidar

1D+4D-Var for CloudSat and CALIPSO observations



Flowchart describing 1D+4D-Var technique:

Observations :

- modified profiles of *T* a *q* from 1D-Var retrievals used as pseudo-observations in 4D-Var

Observation errors :

- Observation errors for *T* and *q* pseudo-observations:
  - derived from 1D-Var analysis error covariance matrix

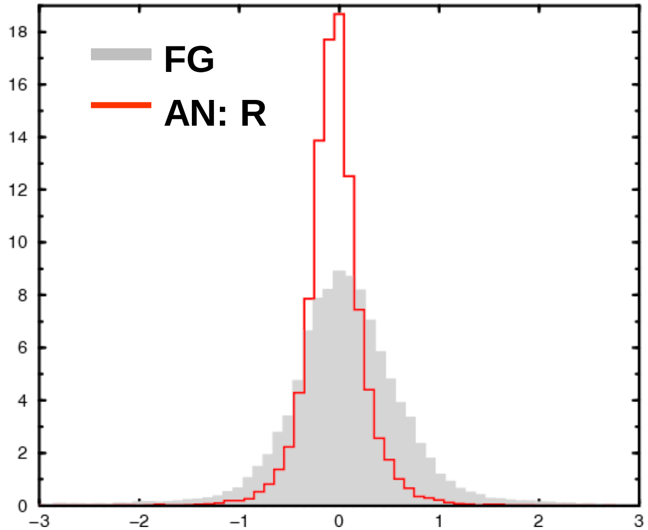
$$\mathbf{A} = \left[\mathbf{B}^{-1} + \mathbf{K}^{T}(\mathbf{x})\ \mathbf{R}^{-1}\ \mathbf{K}(\mathbf{x})\right]^{-1} \quad \text{where} \quad \mathbf{K} = \left[\frac{\partial H(\mathbf{x})}{\partial \mathbf{x}}\right]$$

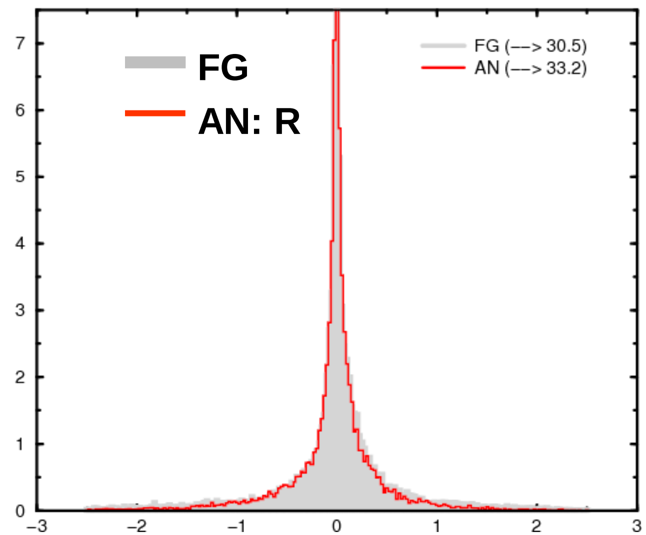
  - or twice *(2err)* as large as computed *(i.e. closer to the errors for radiosonde T and q)*

1D+4D-Var of T,q pseudo-observations

PDF of FG vs. AN departures

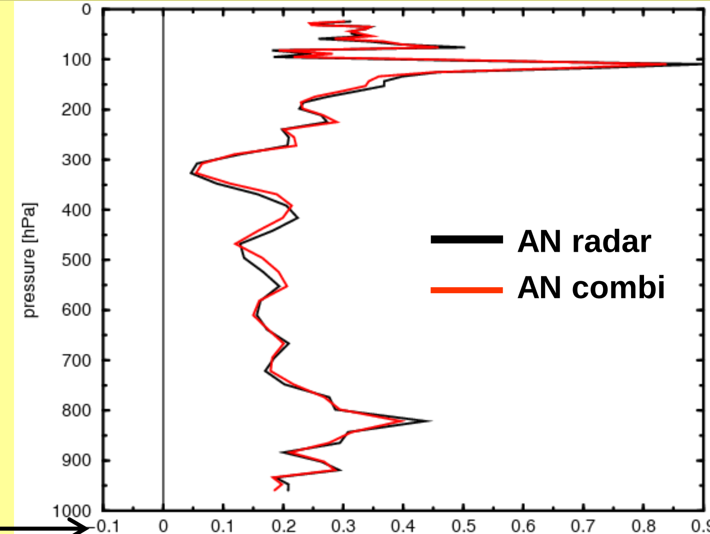
T,q pseudo-obs from 1D-Var of radar

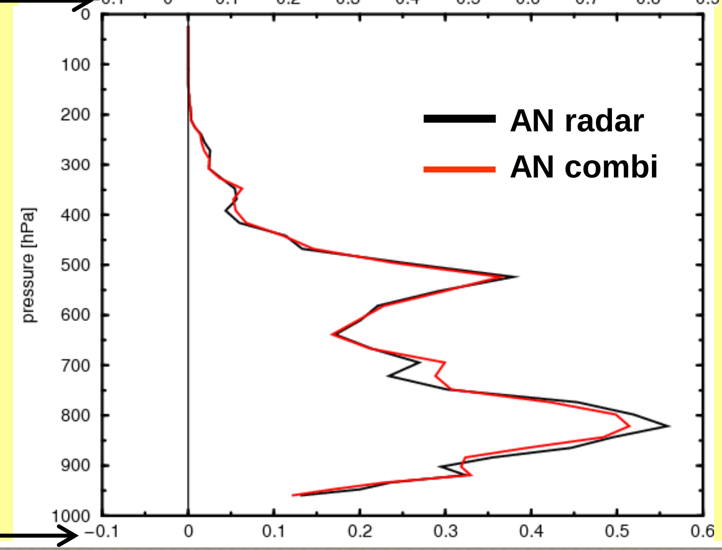




Improvement from assimilation of radar/lidar obs

RMS (OBS – FG) – RMS (OBS – AN)



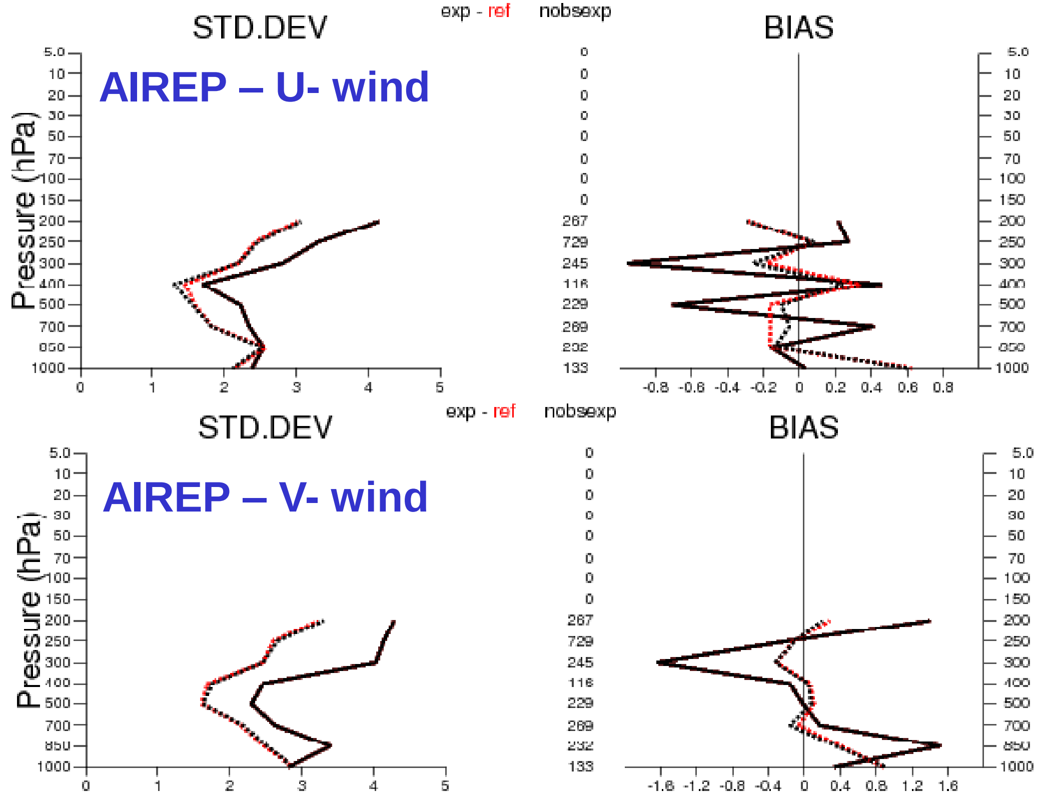


Temperature [K]

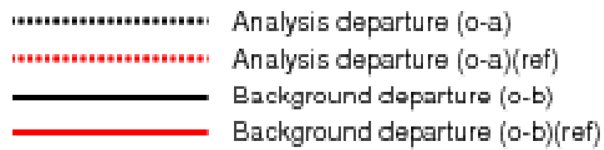
Specific humidity [g/kg]

FG – First Guess AN – Analysis OBS - Observations

Verification of assimilation runs against other assimilated observations

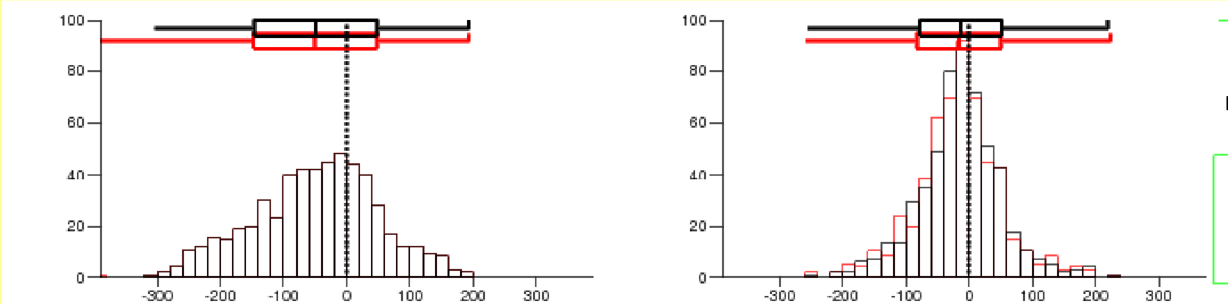


4D-Var assimilating *T*, *q* pseudo-obs retrieved from 1D-Var with radar and lidar



area NSEW = 65/-65/-130/-180
2007012400

SYNOP – Ps (Pa)



Background departure (o-b)

nb=	544 (ref=	545)	rms=	109.	(	110.)
mean=	-49.4	(-50.1)	std=	97.2	(	97.9)
min=	-304.	(-403.)	max=	193.	(	193.)

Analysis departure (o-a)

nb=	544 (ref=	545)	rms=	66.2	(	68.5)
mean=	-13.4	(-16.1)	std=	64.8	(	66.6)
min=	-256.	(-258.)	max=	220.	(	223.)

Summary and perspectives

- 1D-Var assimilation experiments performed using observations:
  - cloud radar reflectivity
  - lidar backscatter
  - combination of cloud radar reflectivity and lidar backscatter

- information on T and q retrieved from 1D-Var of cloud radar and/or lidar data used as pseudo-observations in the 4D-Var system

- Obtained results indicate:
  - 1D-Var analysis gets closer to assimilated and also independent observations
  - impact of cloud radar reflectivity larger than of lidar backscatter
  - 1D+4D-Var analysis reduces analysis departures for T, q pseudo observations
  - small impact observed in FG and AN departure statistics when verified against other observation types assimilated in 4D-Var
  - getting more impact from the new data would require to carefully tune their usage in the assimilation system

- More experiments to be performed:
  - for different situations
  - for refining data control and error definition usage