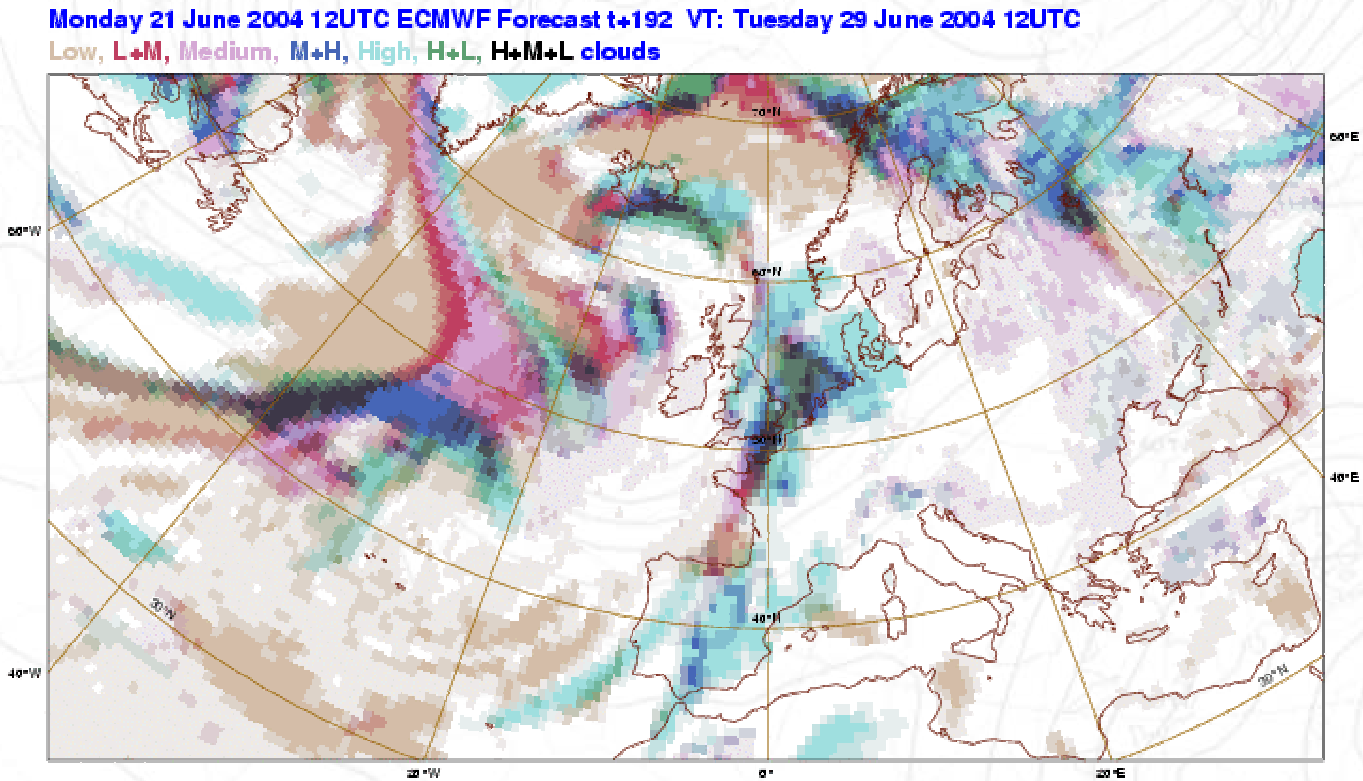
Prospects for assimilating Cloudy radiances from AIRS



Frédéric Chevallier

And …

- Satellite section
  - P. Bauer
  - E. Moreau
  - J.-N. Thépaut
  - P. Watts
  - …
- Physical aspects section
  - M. Janiskova
  - P. Lopez
  - J.-J. Morcrette
  - A. Tompkins

Outline

- Introduction
- Observation operator
- Non-linearity issues
- Illustration with 1D-Var simulations
- Conclusion

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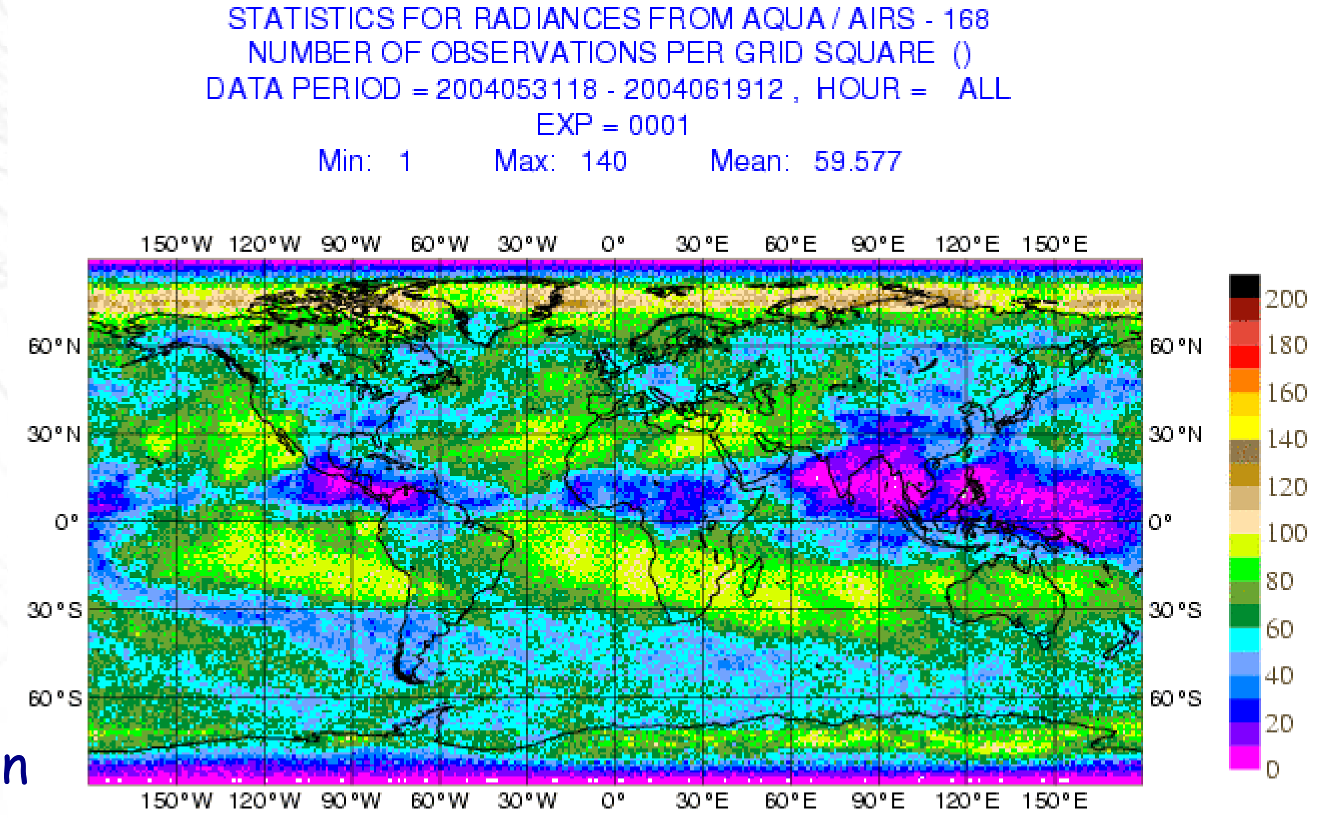
Cloudy AIRS radiances and NWP (1/4)

- $L_\nu = h_\nu$ (Temp, Surf, Gas, Cloud, …)
- Removal



14.33 micron

Cloudy AIRS radiances and NWP (2/4)

- $L_\nu = h_\nu$ (Temp, Surf, Gas, Cloud, …)
- Removal
- Partial assimilation
  - $L_\nu = h_\nu^1$ (Temp, Surf, Gas) + h_ν^2 (Temp, Gas) . g_ν (Cloud)
  - g_ν (Cloud) from spatial analysis of observation (e.g. N*), spectral signature + add. information (e.g. CO2-slicing, sink variable in Var, …)

Cloudy AIRS radiances and NWP (3/4)

- $L_\nu = h_\nu$ (Temp, Surf, Gas, Cloud, …)
- Removal
- Partial assimilation
  - $L_\nu = h_\nu^1$ (Temp, Surf, Gas) + h_ν^2 (Temp, Gas) . g_ν (Cloud)
  - g_ν (Cloud) from spatial analysis of observation (e.g. N*), spectral signature + add. information (e.g. CO2-slicing, sink variable in Var, …)
- Full Assimilation
  - Prognostic approach
  - Diagnostic approach

Cloudy AIRS radiances and NWP (4/4)

- Full Assimilation
  - Diag: Optimise cloud variables directly (e.g. using g_ν (Cloud))
    - o Estimation of error statistics for NWP cloud variables
    - o Infinite: nudging (e.g. GEO)
    - o 3/4D-Var: on-going work (e.g. Greenwald et al. 2004)
  - Prog: Optimise standard NWP variables, based on hypothesis:

$$\text{Cloud} = f(\text{Temp}, \text{Gas}) + \varepsilon$$

    - o Filter
    - o Temp and Gas variables have longer spatial and temporal time scales than C ones
    - o How do we build f?

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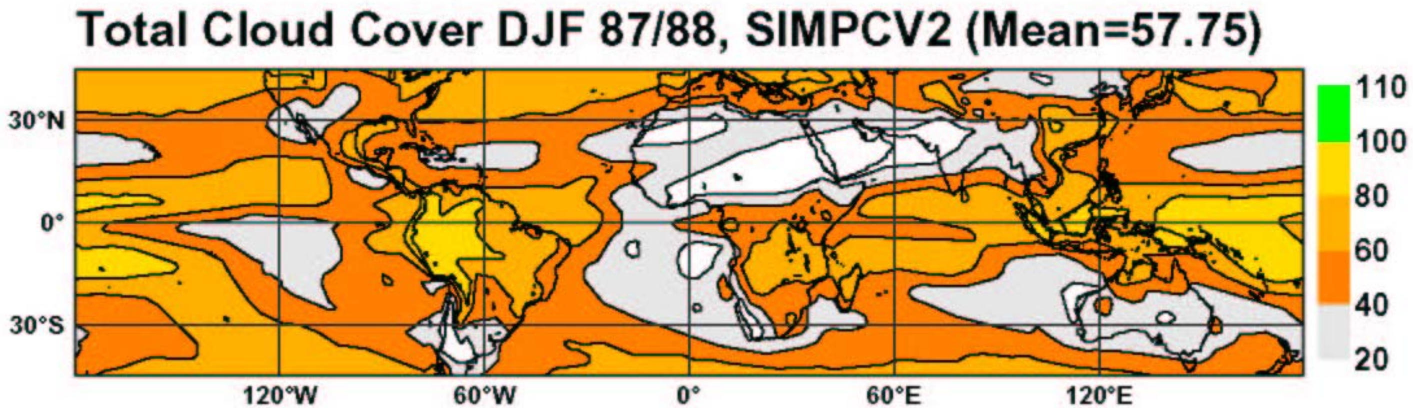
Observation operator (1/4)

- $L_\nu = h_\nu(\text{Temp, Surf, Gas, Cloud})$
  $= R_T \circ \Phi(\text{Temp, Surf, Gas}) + \varepsilon$

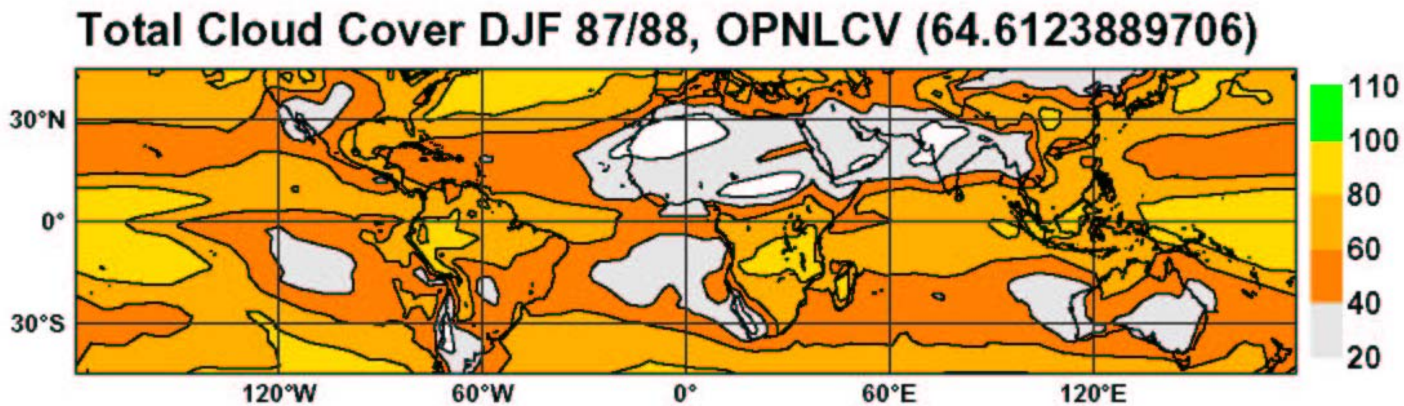
- Φ : Diagnostic cloud scheme
  - Subgrid-scale convection
    (Tiedtke 1989, Lopez and Moreau 2004)

Convection scheme

- Example of validation: 4-month climate runs (%)



Lopez and Moreau (2004)



Tiedtke (1989)

Observation operator (2/4)

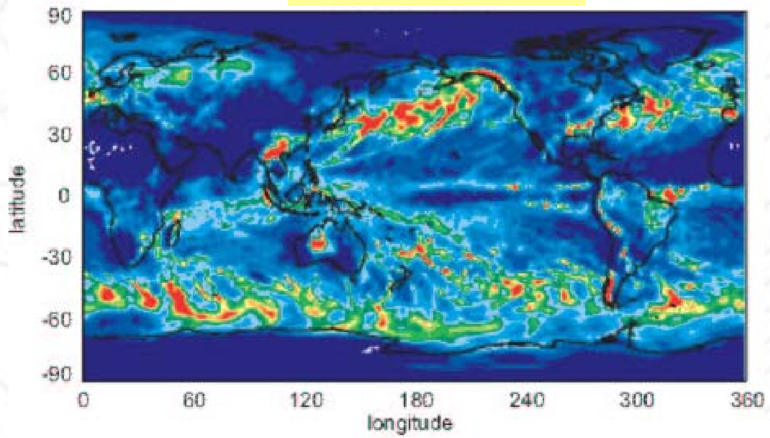
- $L_\nu = h_\nu$ (Temp, Surf, Gas, Cloud)
  $= R_T \circ \Phi$ (Temp, Surf, Gas) $+ \varepsilon$

- Φ : Diagnostic cloud scheme
  - Subgrid-scale convection (Tiedtke 1989, Lopez and Moreau 2004)
  - Large-scale (Tompkins and Janiskova 2004)

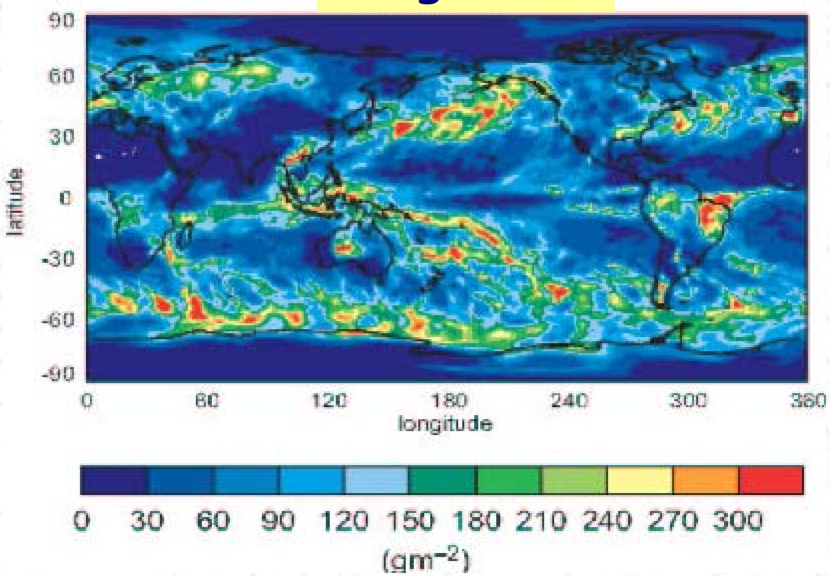
Large-scale cloud scheme

- Example of validation: Total column water (liquid+ice) averaged over 19 forecasts at the 12-hour forecast range. First two weeks of March 2003, L60T159 resolution.

Prognostic



Diagnostic



Tiedtke 1993

Tompkins and Janiskova (2004)

Observation operator (3/4)

- $L_\nu = h_\nu$ (Temp, Surf, Gas, Cloud)
  $= R_T \circ \Phi$ (Temp, Surf, Gas) + ε

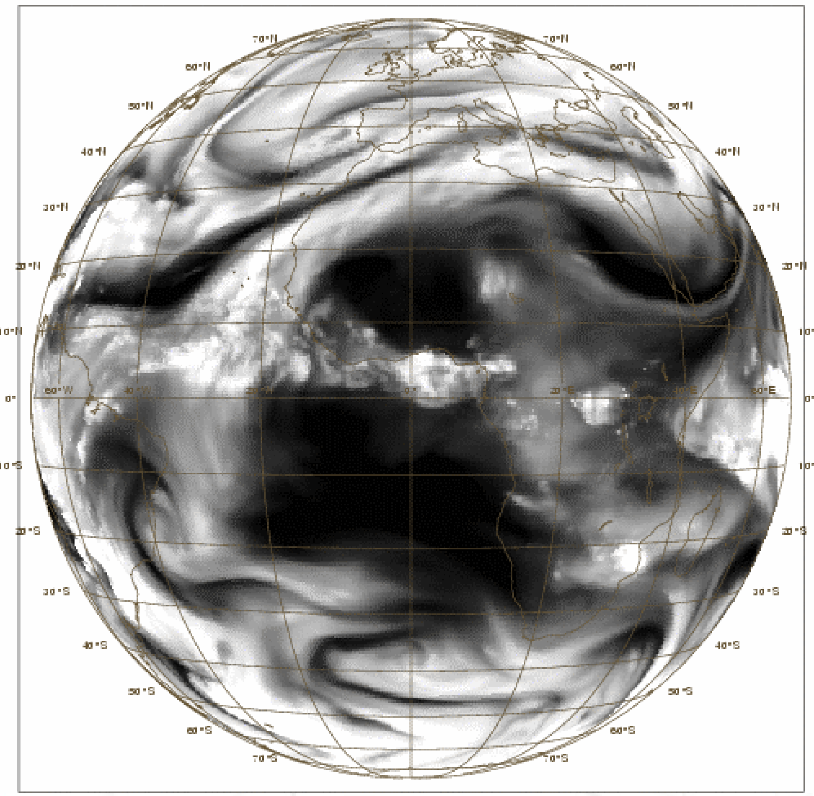
- Φ : Diagnostic cloud scheme
  - Subgrid-scale convection
    (Tiedtke 1989, Lopez and Moreau 2004)
  - Large-scale (Tompkins and Janiskova 2004)

- R_T: Radiation model
  - Cloud extension of RTTOV (Eyre 1991; Chevallier et al. 2001, 2002; Saunders et al. 2002)
  - IR: Multilayer cloud overlap assumption (Raisanen 1998)
  - MW: scattering (Moreau et al 2003)

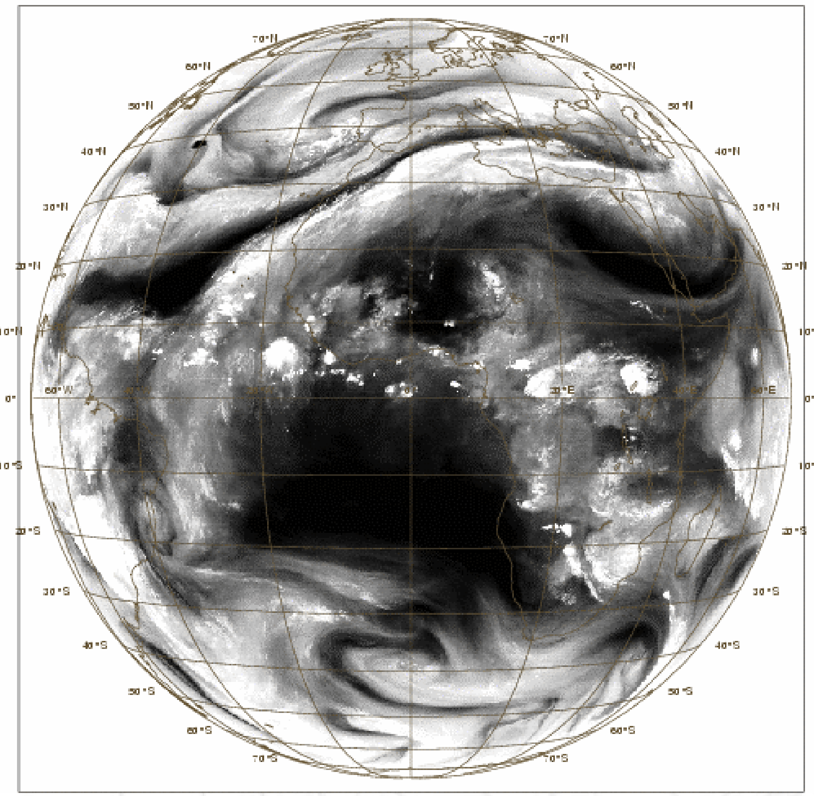
Forecasted imagery: WV

- 42-hour forecast vs. observed

Saturday 25 October 2003 12UTC ECMWF Forecast t+42 VT:Monday 27 October 2003 06UTC
Satellite Image, Water vapour



Satellite Image Monday 27 October 2003 0500UTC

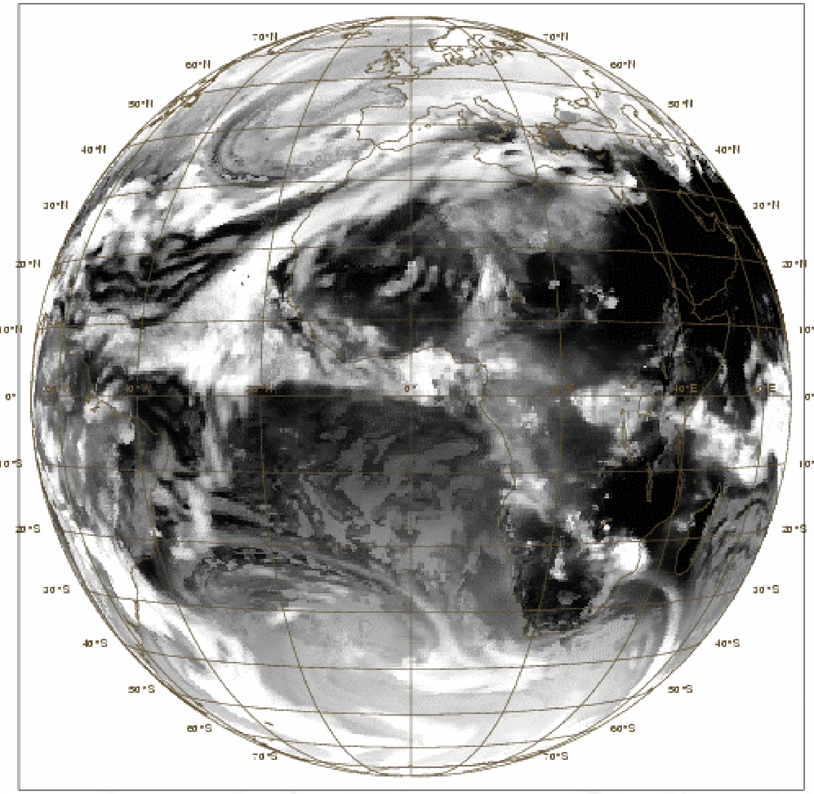


Different grey scales

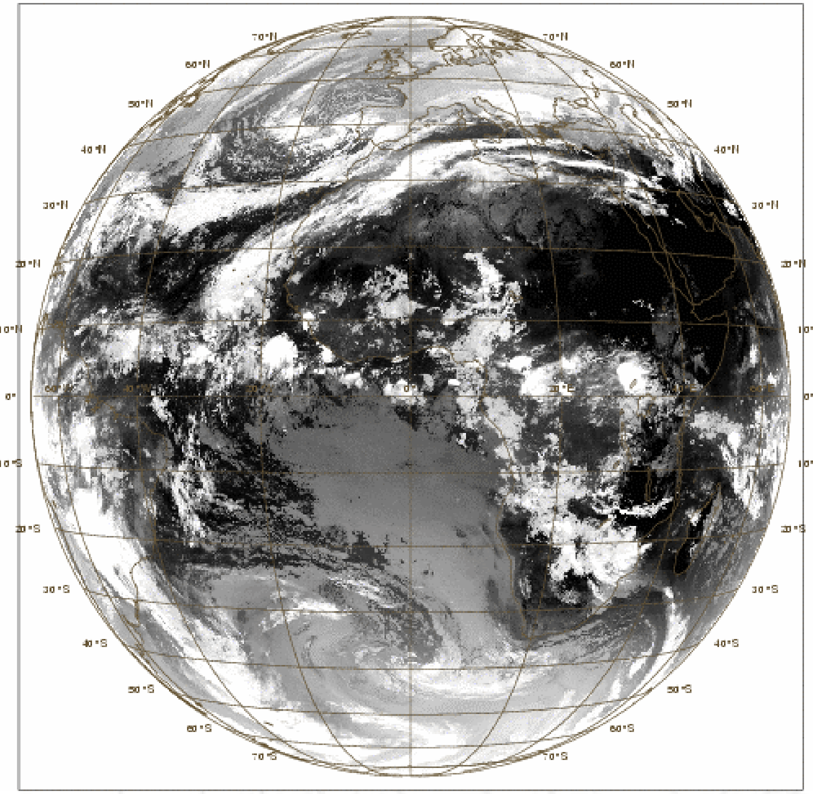
Forecasted imagery: IR

- 42-hour forecast vs. observed

Saturday 25 October 2003 12UTC ECMWF Forecast t+42 VT:Monday 27 October 2003 06UTC
Satellite Image, First infrared band



Satellite Image Monday 27 October 2003 0600UTC



Different grey scales

Observation operator (4/4)

- $L_\nu = h_\nu$ (Temp, Surf, Gas, Cloud)
  $= R_T \circ \Phi$ (Temp, Surf, Gas)

- Φ : Diagnostic cloud scheme
  - Subgrid-scale convection
    (Tiedtke 1989, Lopez and Moreau 2004)
  - Large-scale (Tompkins and Janiskova 2004)

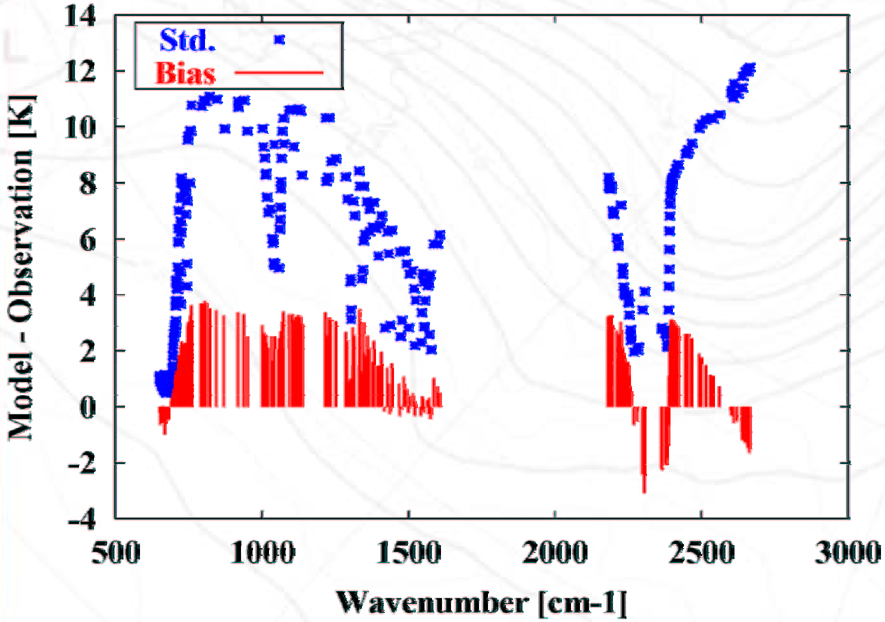
- R_T: Radiation model
  - Cloud extension of RTTOV (Eyre 1991; Chevallier et al. 2001, 2002; Saunders et al. 2002)
  - IR: Multilayer cloud overlap assumption (Raisanen 1998)
  - MW: scattering (Moreau et al 2003)

- Full AD and TL codes of Φ and R_T have been developed for use in a variational context

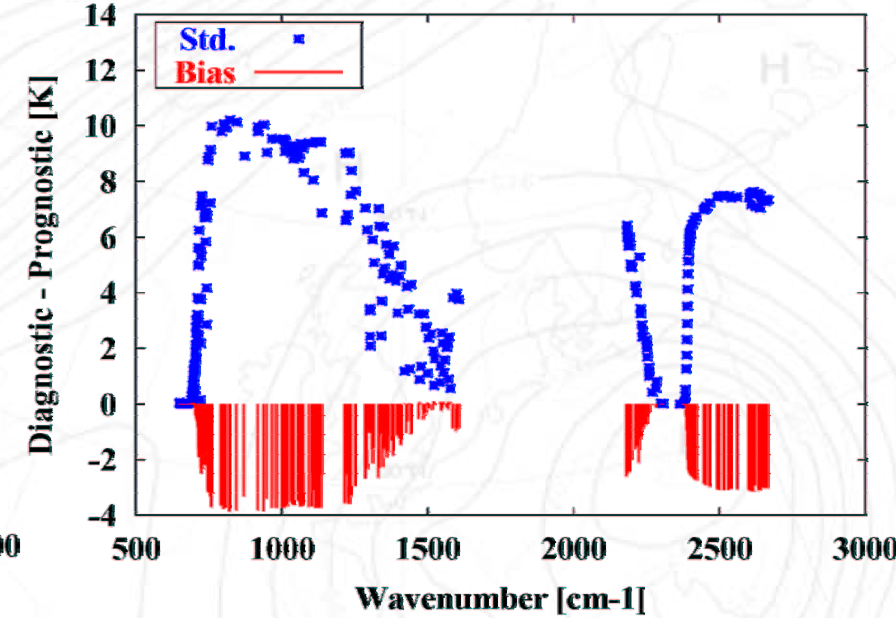
Observation operator: AIRS

- $L_\nu = h_\nu$ (Temp, Surf, Gas, Cloud)
  $= R_T \circ \Phi$ (Temp, Surf, Gas)

PROG -AIRS



DIAG (h_ν) - PROG



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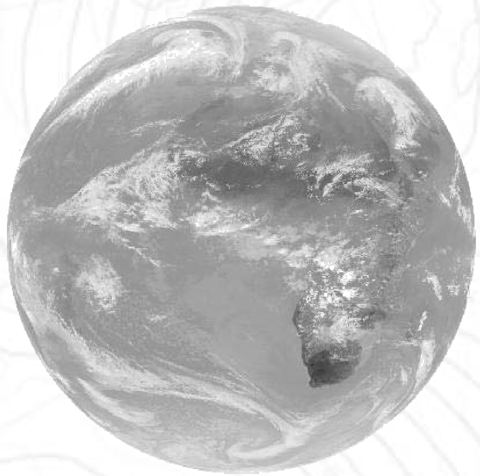
Non-linearity: so what?

- Over the NWP space/time scales, cloud processes are prone to non-linearity
- Current 3/4D-Var systems are based on linearity and Gaussianity hypotheses
- Handling strong non-linearity may be very costly (e.g. Monte Carlo)
- Strong non-linearity makes the error statistics non-Gaussian
  - High-order moments of the error pdf should be taken into account…
  - … but are difficult to estimate
- Are we sentenced to nudging?
  - Is there any useful cloud observation that is not affected by strong non-linearities?

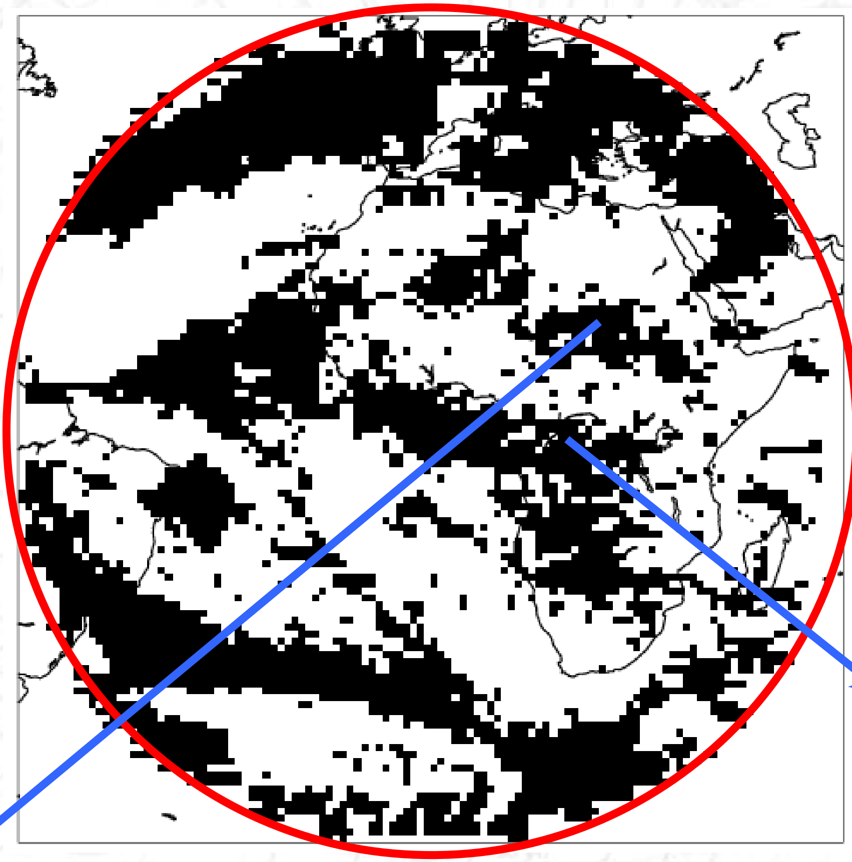
Linearity of H: method (1/2)

- We want to investigate the linearity of the observation operator ($h_\nu = R_T \circ \Phi$) for the 324 nrt AIRS channels
- Linearity is studied with respect to T and q perturbations about the size of analysis increments (from ECMWF background error matrix)
- Model data are taken at cloud location based on Meteosat WV mask
- At each model grid point we compute the correlation between linear increments ($H_\nu.\delta x$) and non-linear increments ($h_\nu (x+\delta x) - h_\nu(x)$) using Monte-Carlo perturbations δx

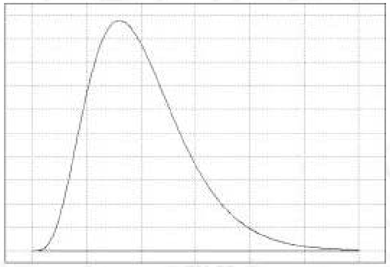
Linearity of H: method (2/2)



30 November 2002
12 UTC
Meteosat WV cloud mask



Correlation (x,y)

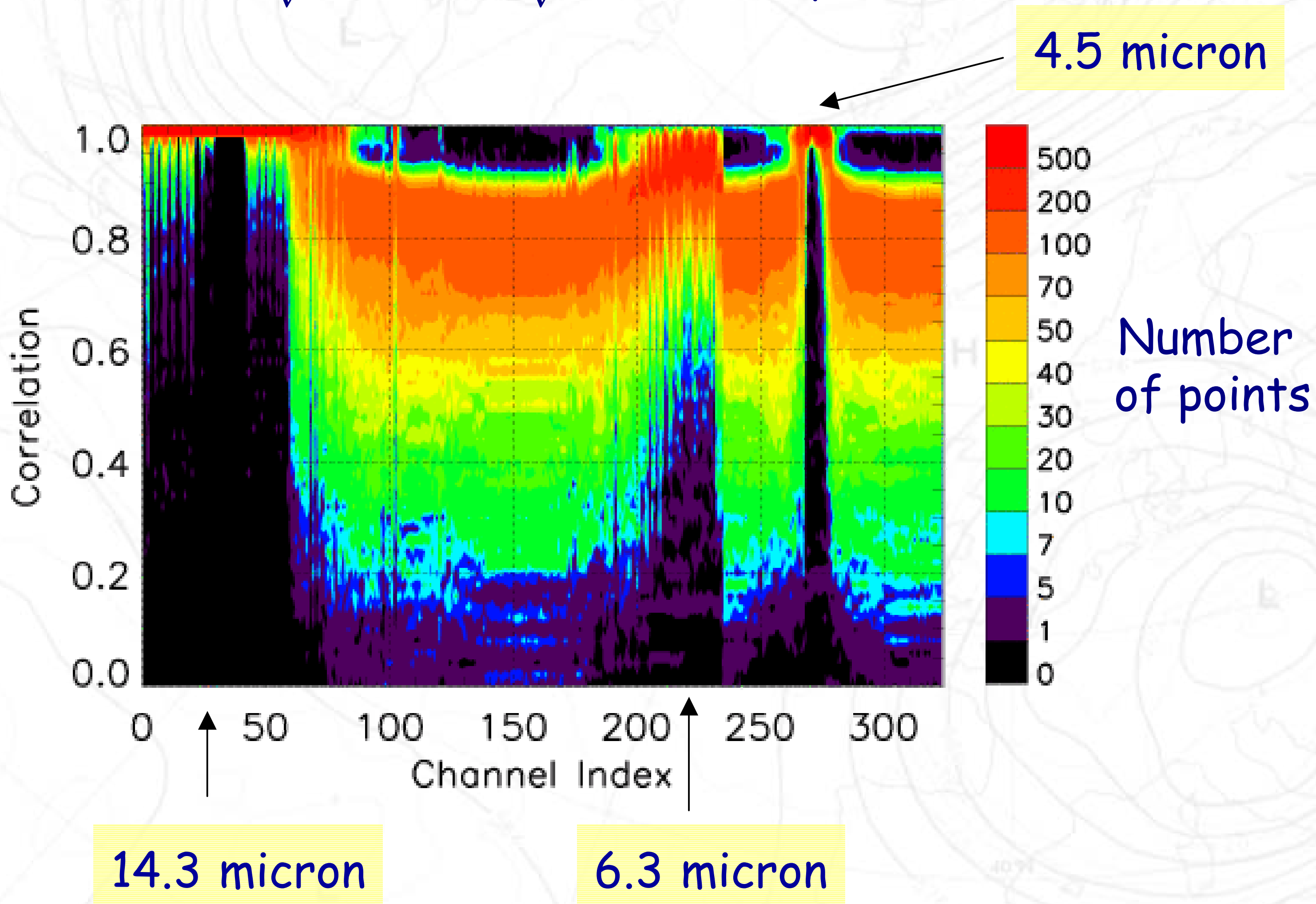


0 = NL

1 = L

Linearity of H : results (1/2)

- Correlation between linear increments ($H_{\nu}.\delta x$) and non-linear increments ($h_{\nu}(x+\delta x) - h_{\nu}(x)$). Hemispheric data.



Linearity of H : results (2/2)

- Near-linear channels @ 4.5, 6.3 and 14.3 micron
  - Results marginally improved if q standard deviations are devided by 2
  - Results hardly changed if correlations are performed on radiances rather than on brightness temperatures
- Tough check
  - Uses Meteosat WV cloud mask
  - Near-linear channels may be found for lower-peaking channels in the absence of high clouds

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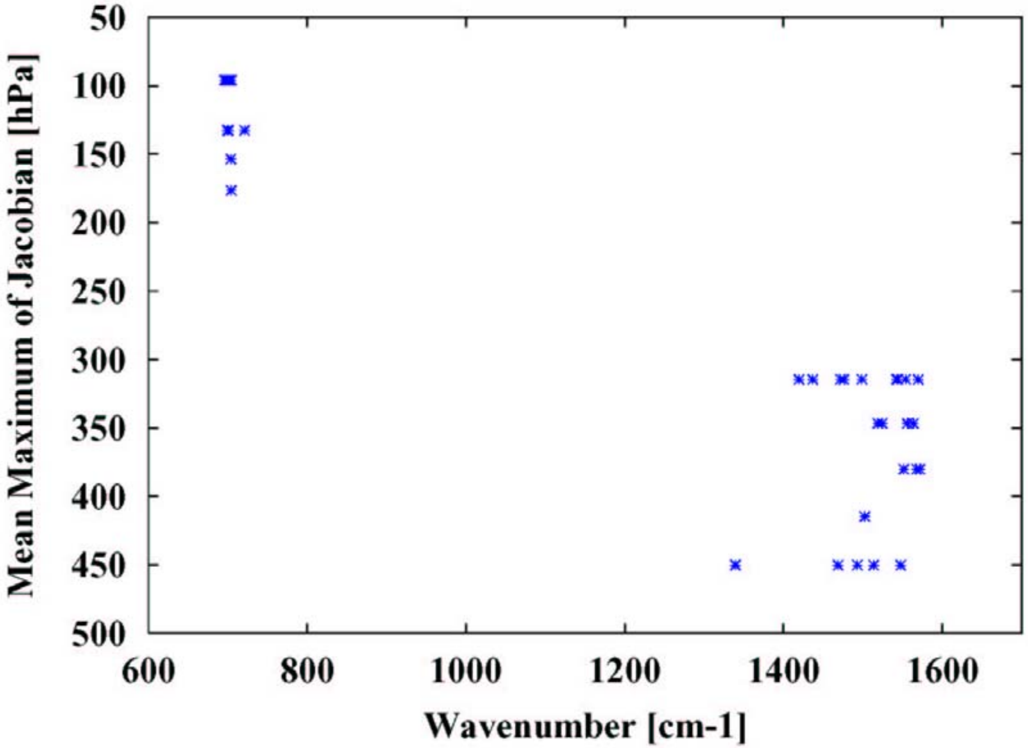
1D-Var: method (1/2)

- Selection of 35 near-linear tropospheric AIRS channels, exempt of solar effects

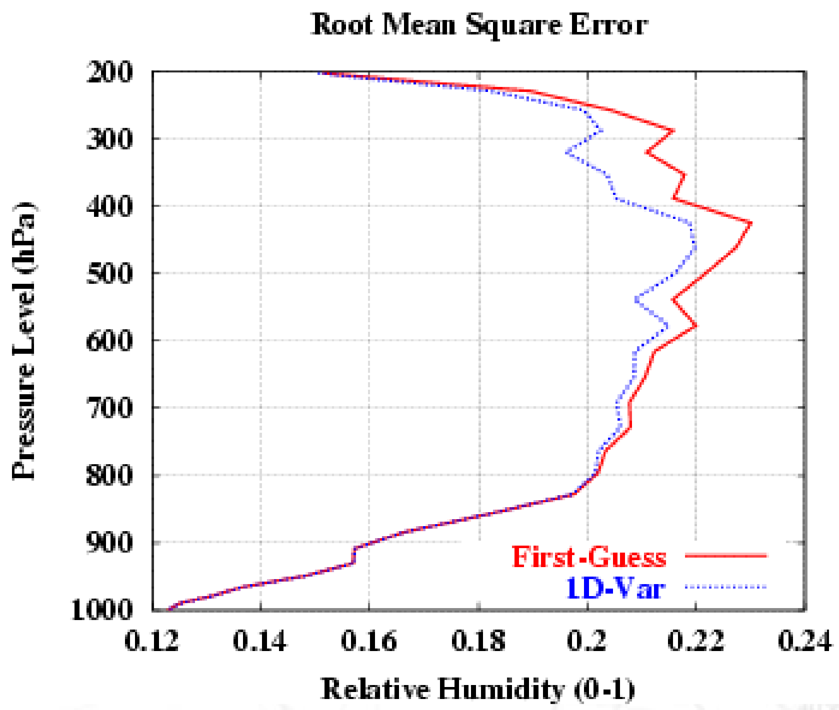


1D-Var: method (2/2)

- Real AIRS observations during Nov 2002 and Feb 2003 over Europe
- Cloud detection from the McNally and Watts (2003) scheme
- Observations rejected if clouds in less than 22/35 channels
- Bayesian linear retrieval of T and q
  - T and q error statistics from ECMWF oper. (Holm et al. 2002)
  - Observation errors std. = [model – obs] std.
  - Observation error correlations = 0.8
  - Bias-correction based on departure mean bias on 30/11/2002
- Validation against 00 and 12 UTC radiosondes

1D-Var: AIRS results (1/2)

- 1D-Var vs. European radiosondes, Nov 2002 and Feb 2003
- If T<243K use Vaisala RS90 only
  - ~ 250 matches in upper troposphere
  - ~ 2300 matches in lower troposphere

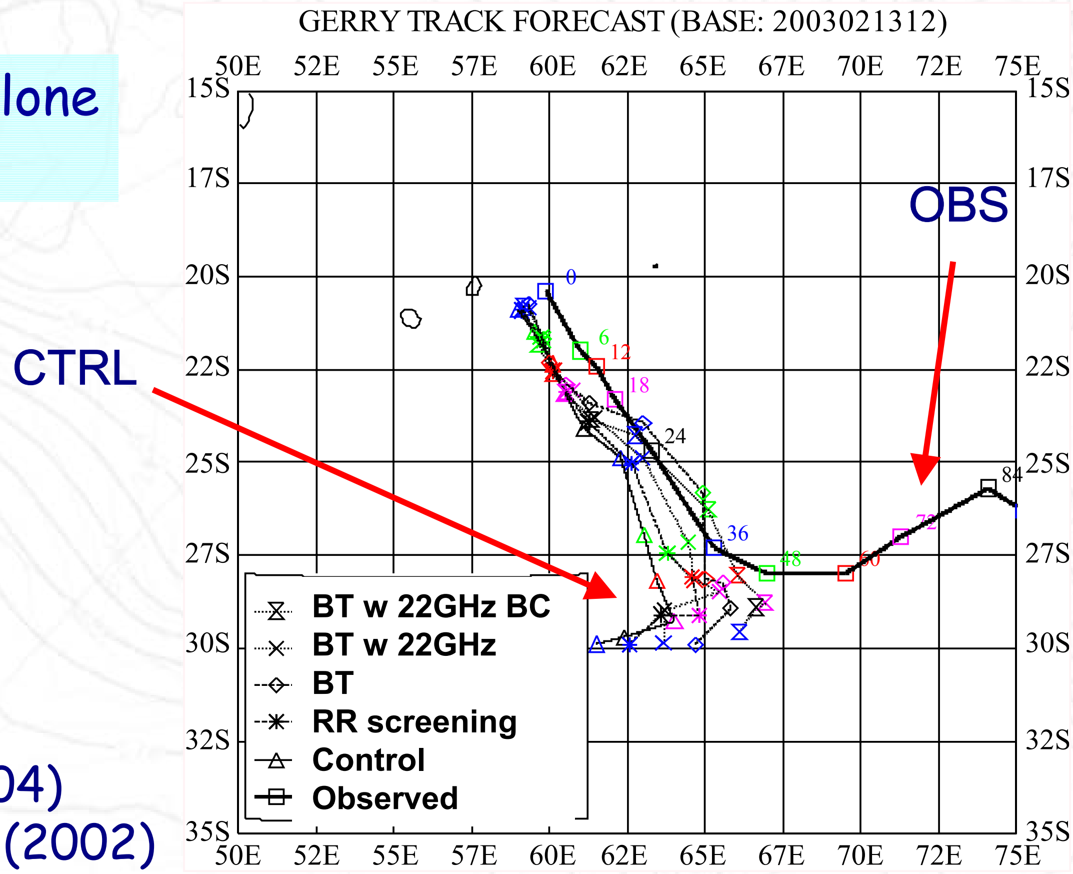


1D-Var: AIRS results (2/2)

- Degree of freedom for signal (e.g. Rodgers 2000):
  - ~ 0.2 for T
  - ~ 1.0 for q
- Average self-sensitivity for observation (e.g. Cardinali et al. 2003):
  - ~ 6% at 6.3 micron
  - ~ 1% at 14.3 micron

1D-Var+4D-Var: TMI results

FC track for cyclone 'GERRY'



Moreau et al. (2004)
Marecal and Mahfouf (2002)

Better track (up to 48h)
and MSLP minimum forecast
with the linear assimilation of 22GHz BT's

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Summary (1/2)

- Forthcoming operational assimilation of hydrometeors in the ECMWF 4D-Var
  - Focus on q (and T) information
- Restriction to near-linear satellite channels
  - ‘Only’ technical changes in operational 4D-Var
  - Reduced computational burden
  - Better/easier handling of errors (biases, std. dev.) in Bayesian framework
  - Small increments

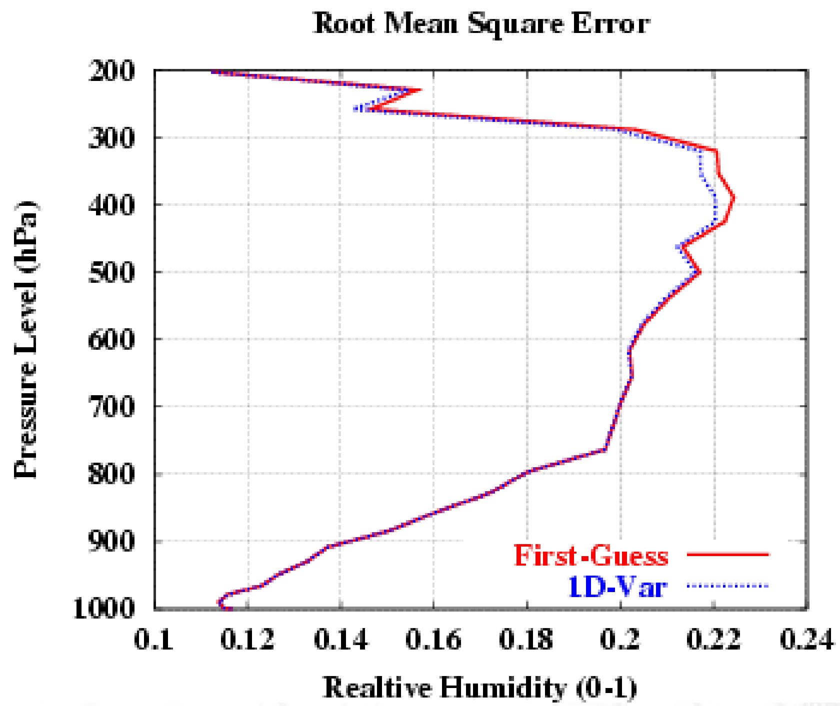
Summary (2/2)

- MW: 22 GHz (water cloud+rain)
  - In good shape
  - Re-organization of 4D-Var observation operator

- Plans for extension to IR: 4.5, 6.3 and 14.3 micron
  - AIRS (ice clouds)
    - … or sink variable (T. McNally's talk)?
    - … or both?
  - 6.3 micron from geostationary satellites (ice clouds)

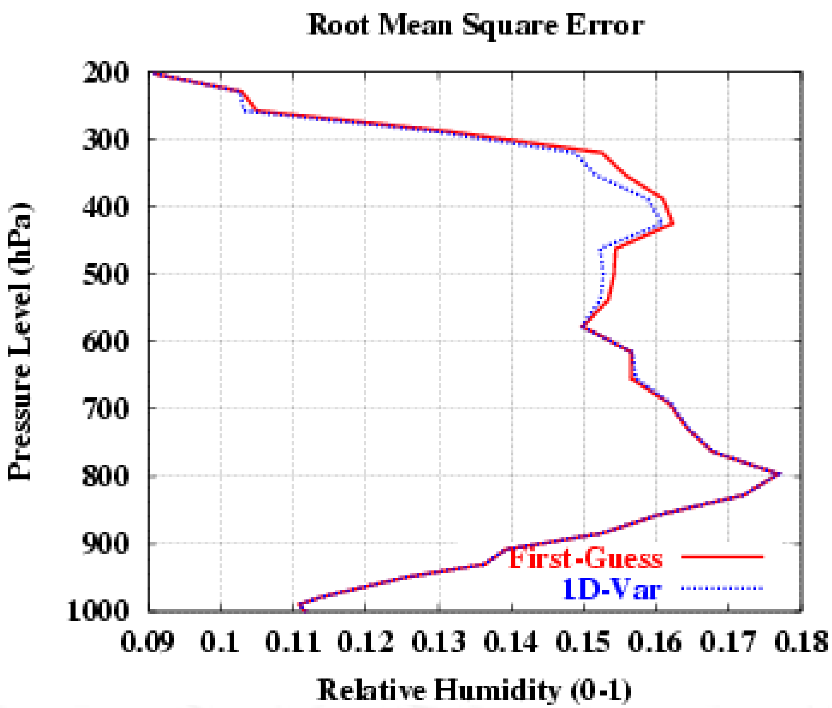
1D-Var: Meteosat results (1/2)

- Observations = cloudy Meteosat WV
- 1D-Var vs. European radiosondes, Nov 2002 and Feb 2003



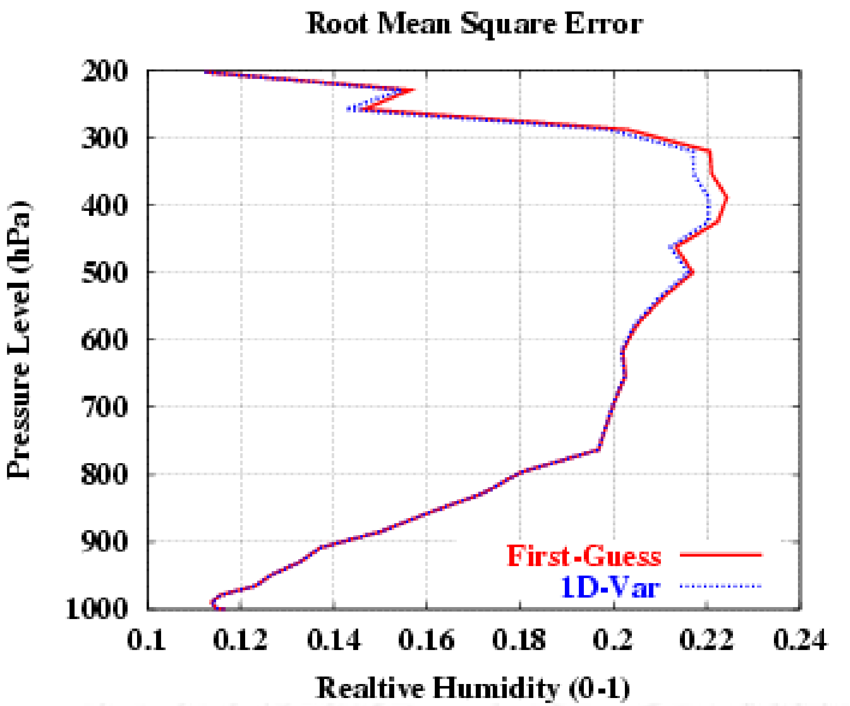
1D-Var: Meteosat results (2/2)

Clear quadrants



~ 250 matches in UT
~ 1500 matches in LT

Cloudy quadrants



~ 200 matches in UT
~ 1400 matches in LT