Precipitation Assimilation

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Contents

- Analysis system
- Observation, **y**
- Observation operator, *H* (x), linearity, **H**
- Modelling (representativeness) error, **E** + **F**
- Background error, **B**

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At present, incremental 3D/4D-Var systems represent the only affordable approach for global applications (CMC, Met Office, Météo France, ECMWF, NCEP, JMA, NRL, …).

Dependent of model scale (regional/global) and analysis scheme, the control variable, the regularity/linearity of physical parameterization schemes and the consistency between non-linear and linearized physics are issues that need to be addressed.

Means of making it work: experiment design, length of assimilation window, limited number of included physical processes, spatial resolution, initial conditions, choice of **B**, **E+F**, **y**, **x**, J, *H* vs. **H**, etc., and performance evaluation (what is skill?).

Side-effects: clear-sky observation increments fighting cloud/rain observation increments, too large increments, little impact on dynamics, gravity wave excitation.

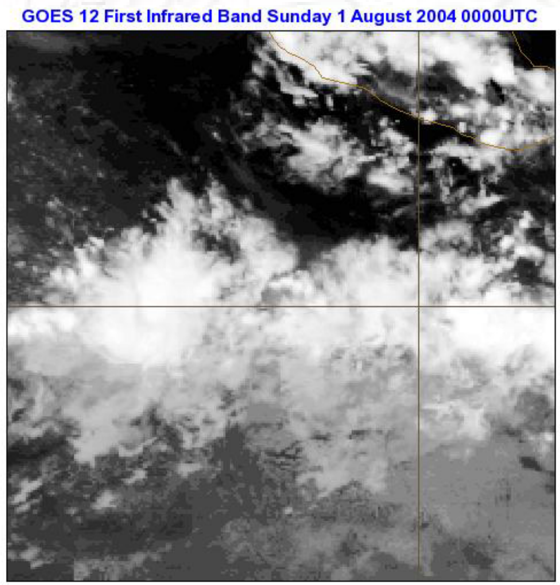
Ideally:

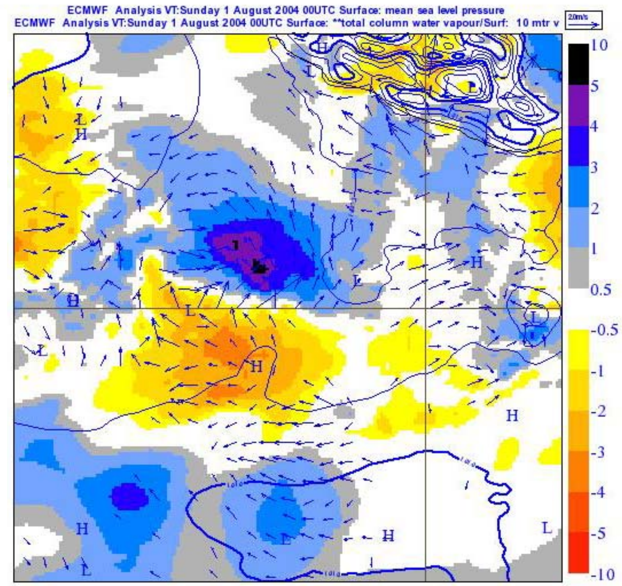
- the system works operationally and is affordable,
- a balance is defined between temperature/moisture and dynamics in the analysis,
- and that this balance is well defined inside and outside precipitation,
- **B** can be specified or, e.g., a choice can be made that **B** is less important (and **Q**?),
- the physical parameterizations used in assimilation system are as consistent as possible (NL, TL, AD),
- the observations (and *H*) have well behaved sensitivity and **E+F** can be specified.

1D-/3D-/4D-Var TCWV/10m-(u,v) increments (DA-Analysis)

20040801
00 UTC

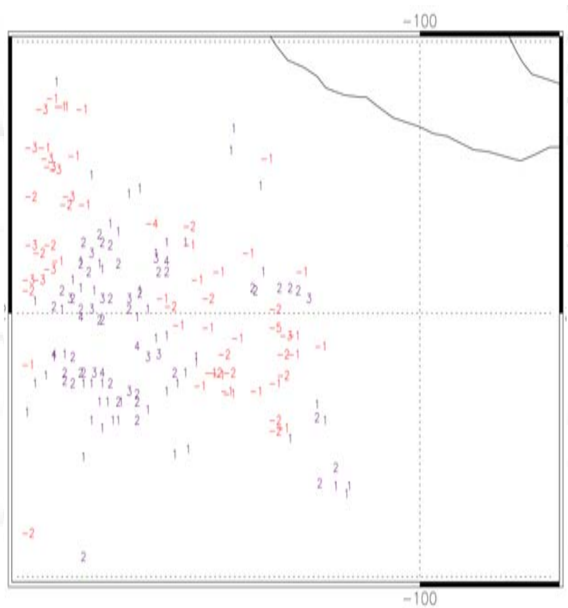
GOES-12
IR TB

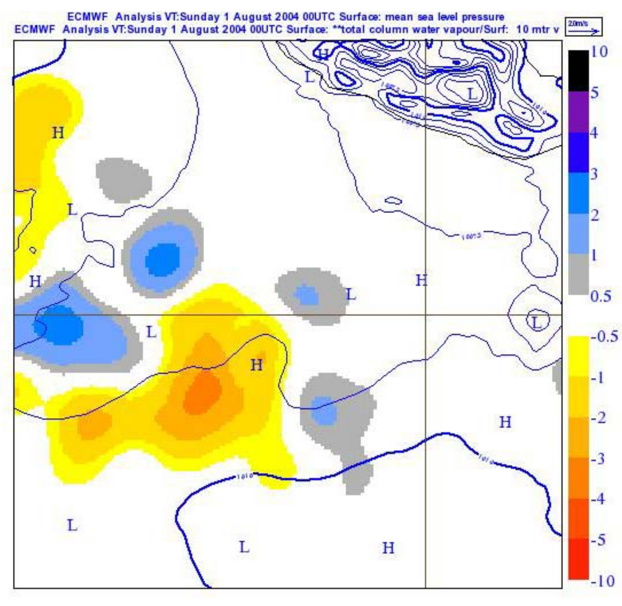




4D-Var
Increment
Differences
(exp-ctrl)

1D-Var
FG-Departures



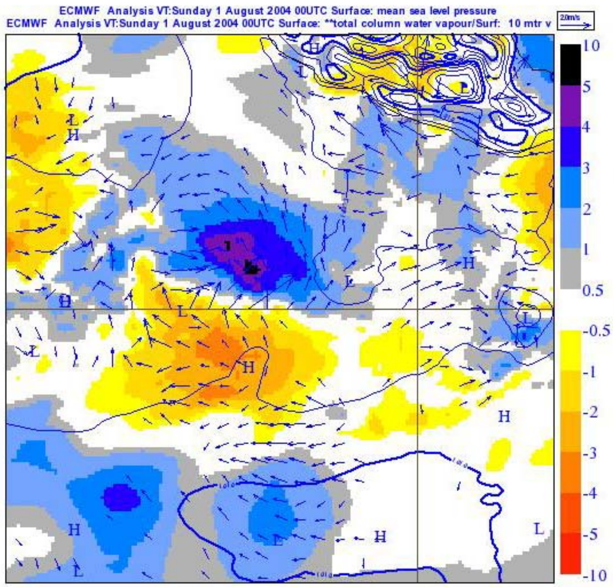


3D-Var
Increment
Differences
(exp-ctrl)

3D-/4D-Var TCWV/10m-(u,v) increments (DA-Analysis): Real vs. fake assimilation of rain affected radiances

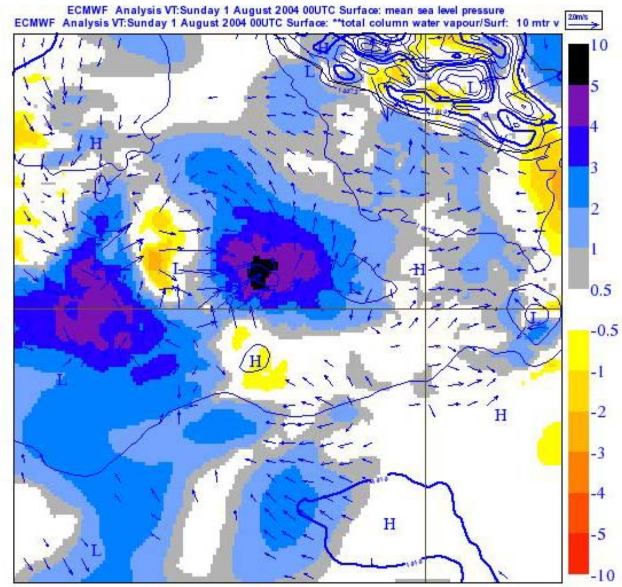
1D+4D-Var:

4D-Var Increment Differences (exp-ctrl)

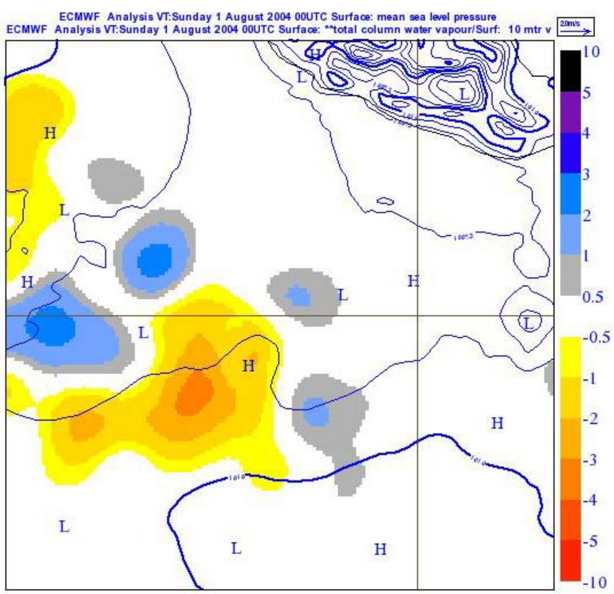


Fake 4D-Var:

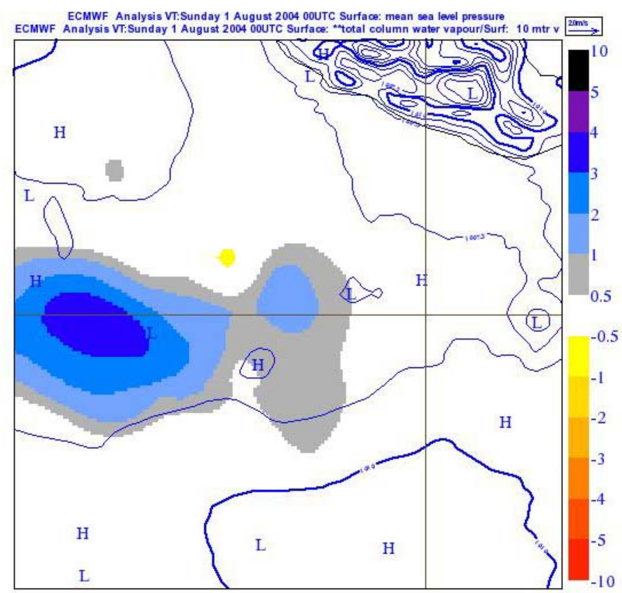
4D-Var Increment Differences (exp-ctrl)



3D-Var Increment Differences (exp-ctrl)



3D-Var Increment Differences (exp-ctrl)



Contents

Observation, **y**, must provide best trade-off between signal vs. noise (sensitivity) and regularity of response:

Rain gauge: point measurement, type-dependent accuracy, no ancillary information on rain type etc. available, measures rain accumulation (possibly DSD), operational.

Surface radar: limited volume measurement, measures Z (possibly polarization, Doppler-spectrum), operational, accuracy of RR-retrieval depends on rain gauge calibration.

Satellite radar: profile/narrow swath measurement, calibration rather good, measures Z, experimental.

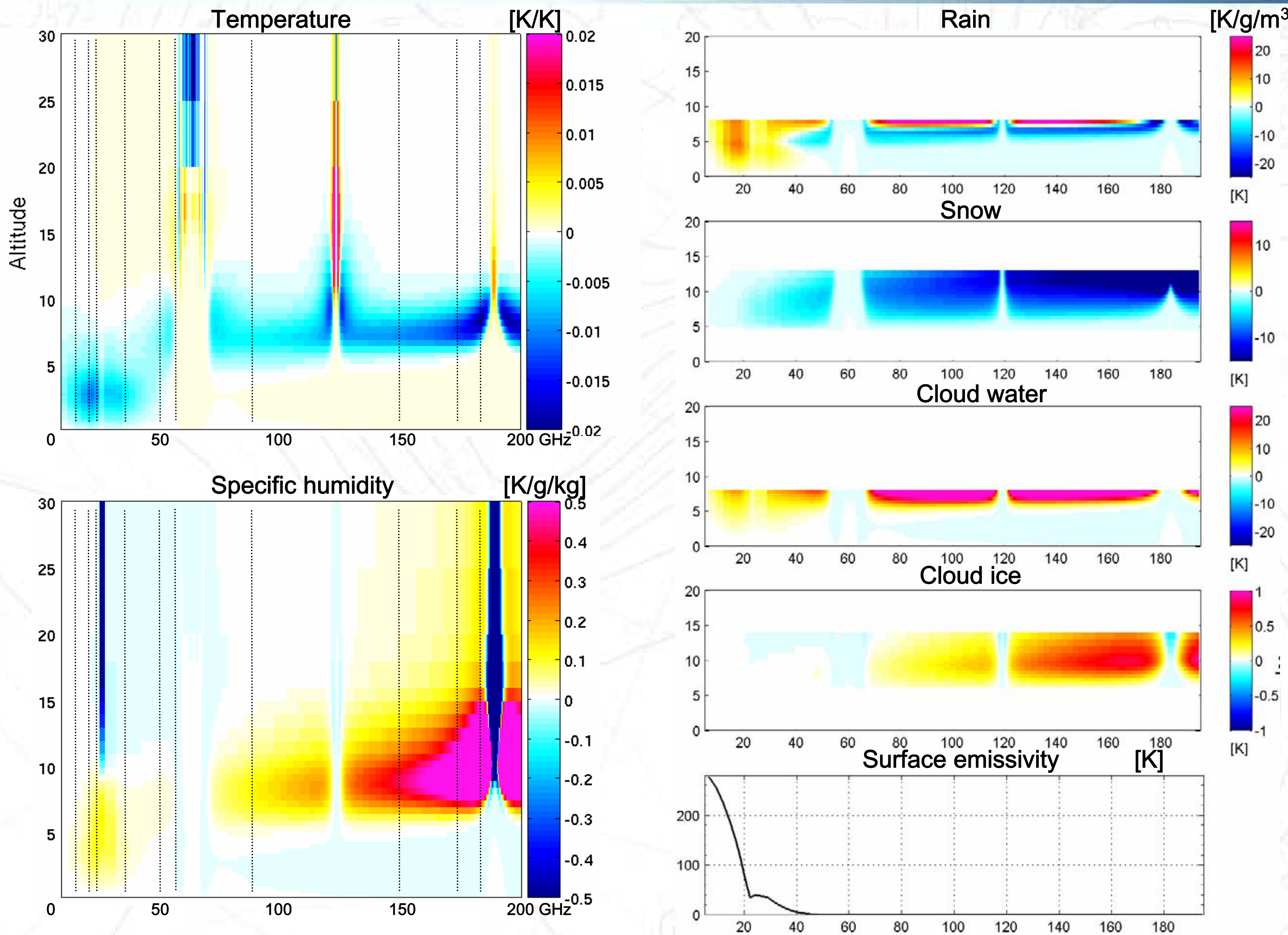
Satellite radiometer: wide swath measurement, calibration good, measures TB that is sensitive to T, q, hydrometeors, (surface emissivity,) channel selection rather flexible, operational.

Surface measurements provide less constraints than profile/column measurements.

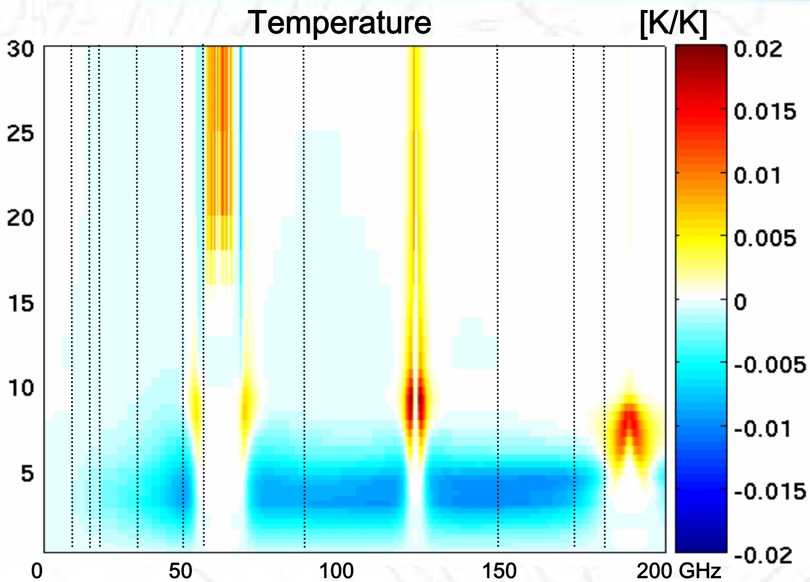
Rain rate measurements constrain condensation/convection less than simultaneous measurement of rain, cloud water (cover) and moisture.

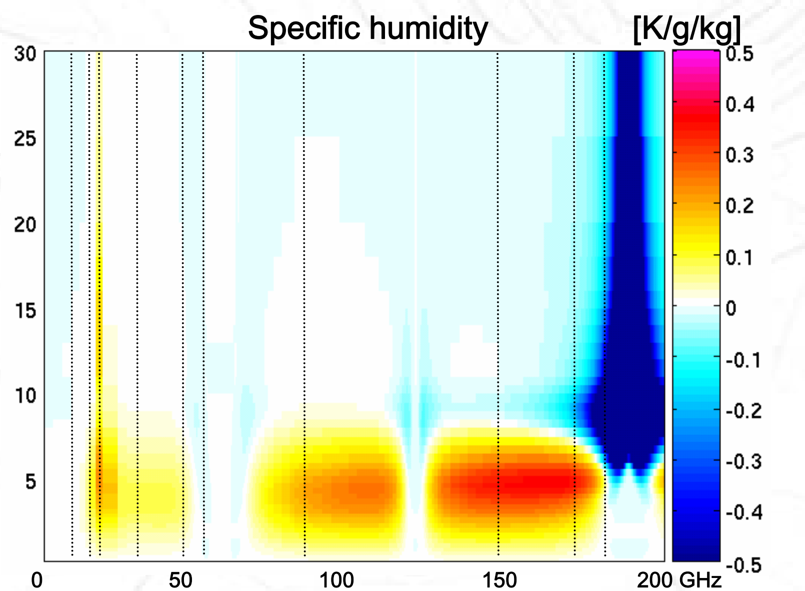
Rain rate measurements suffer from irregularity (pdf) and 0-value problem (no sensitivity where FG has no rain); derived rain rates suffer from incoherent algorithm performance and mostly unknown error properties.

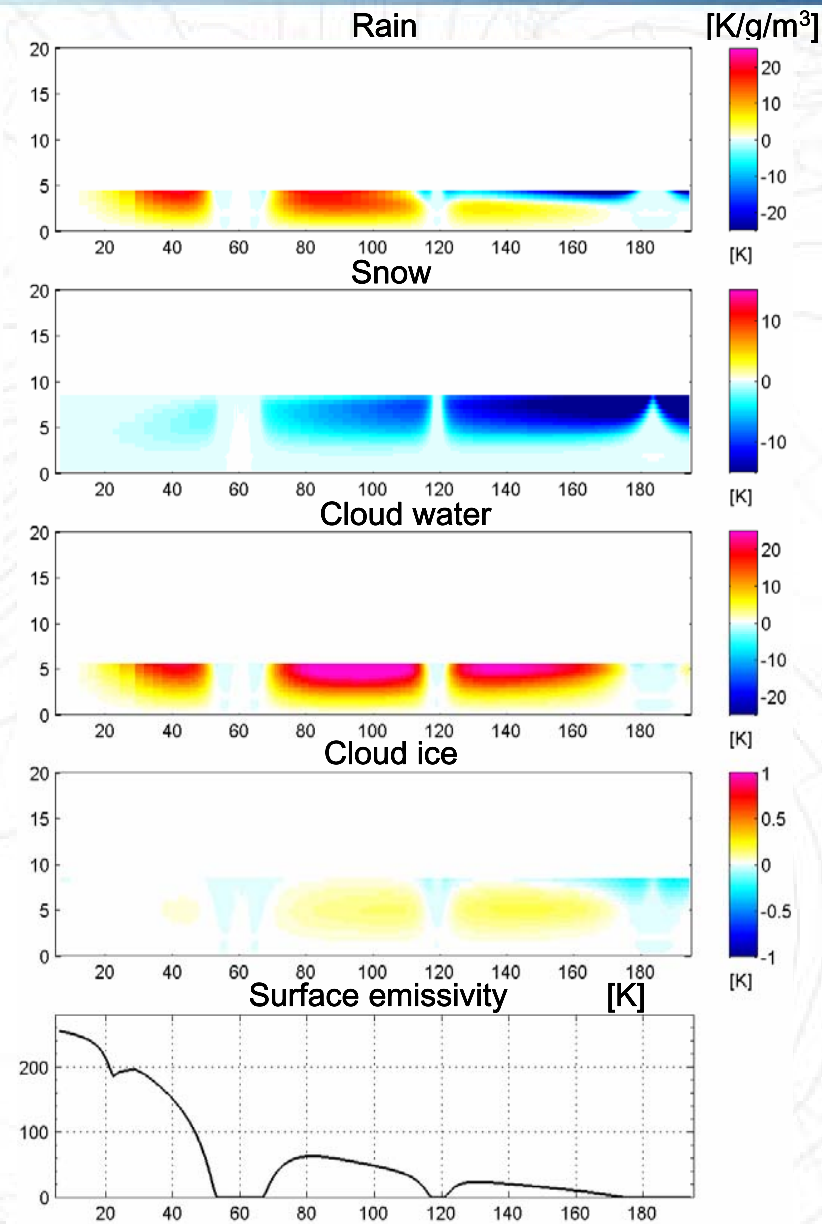
Microwave TB-Jacobians over ocean



Microwave TB-Jacobians over land

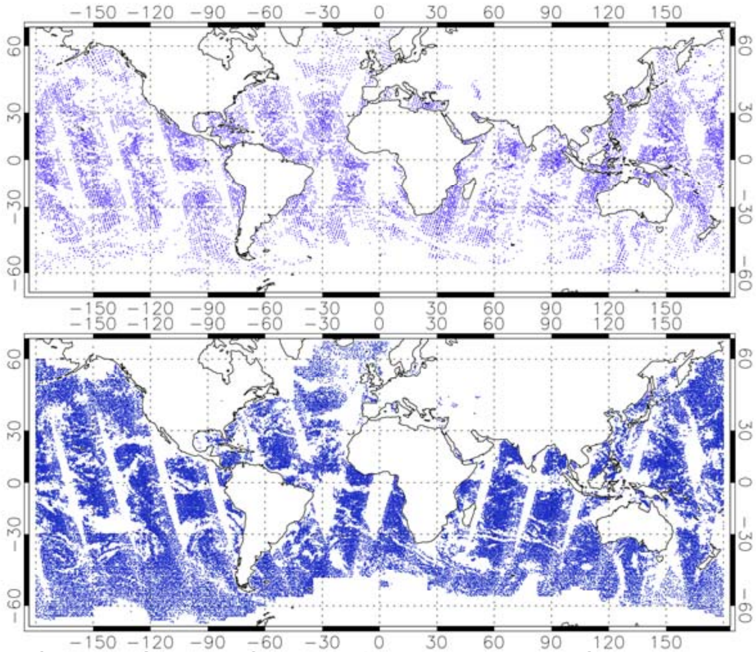






International Workshop on the Assimilation of Satellite Cloud and Precipitation Observations in NWP Models, Peter Bauer (ECMWF)

FG SSM/I Radiance Departures (03/08/2004 00 UTC)



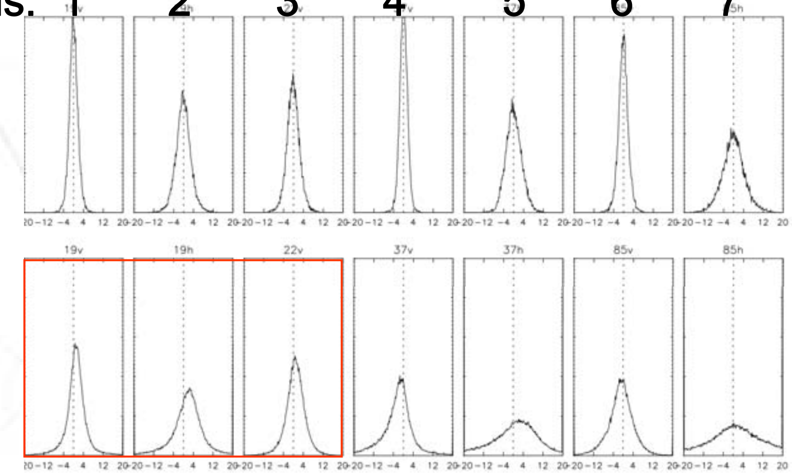
SSM/I clear-sky radiance data coverage

DCDA:	70,000 observations/cycle
DA	50,000 observations/cycle

SSM/I precipitation TCWV data coverage

DCDA:	50,000 observations/cycle
DA	25,000 observations/cycle

SSM/I Channels: 1 2 3 4 5 6 7

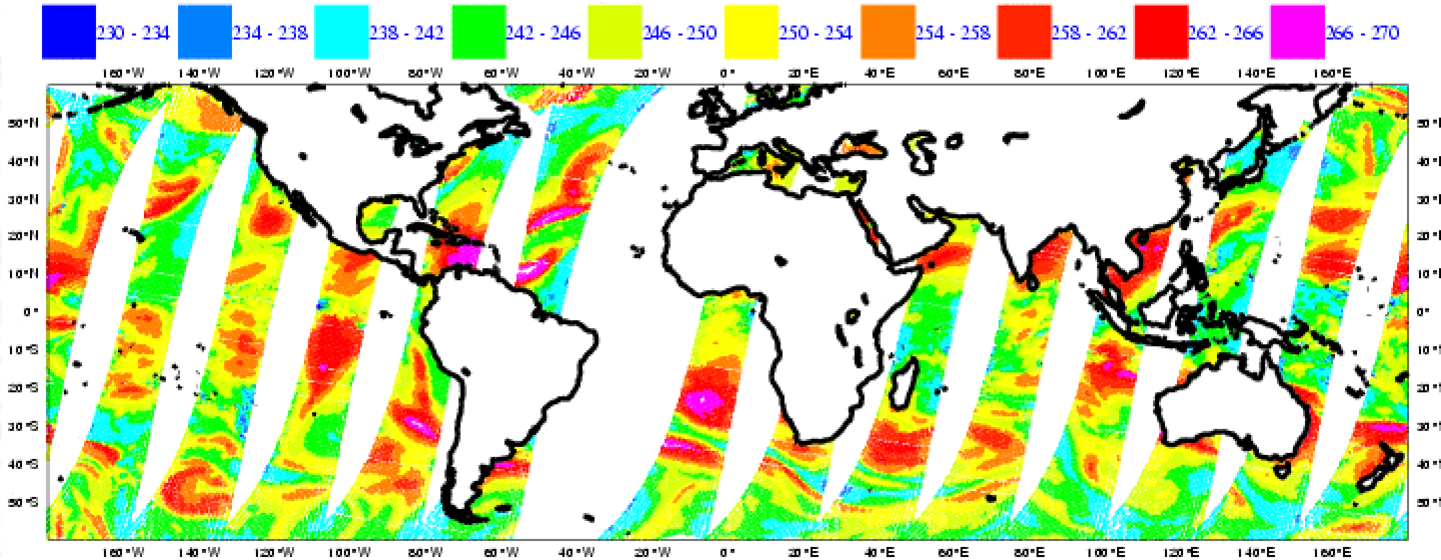


SSM/I clear-sky FG radiance departure pdf's

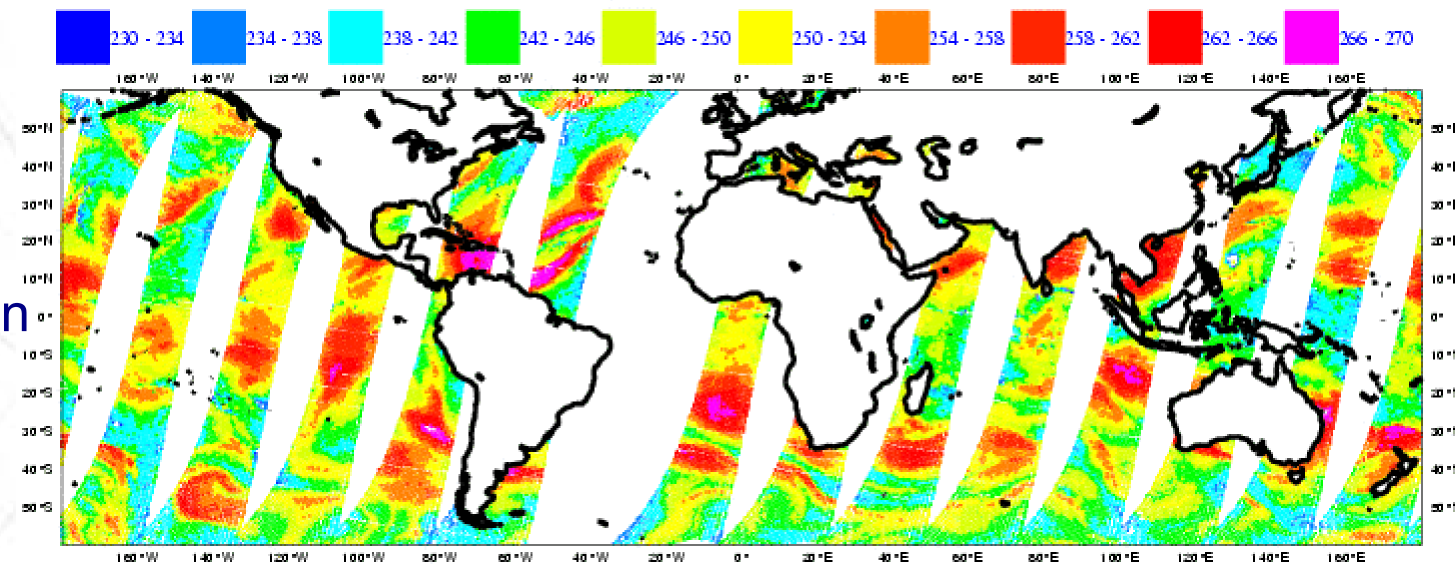
SSM/I precipitation FG radiance departure pdf's

Simulated vs. observed AMSU-B 183±7 GHz TB's

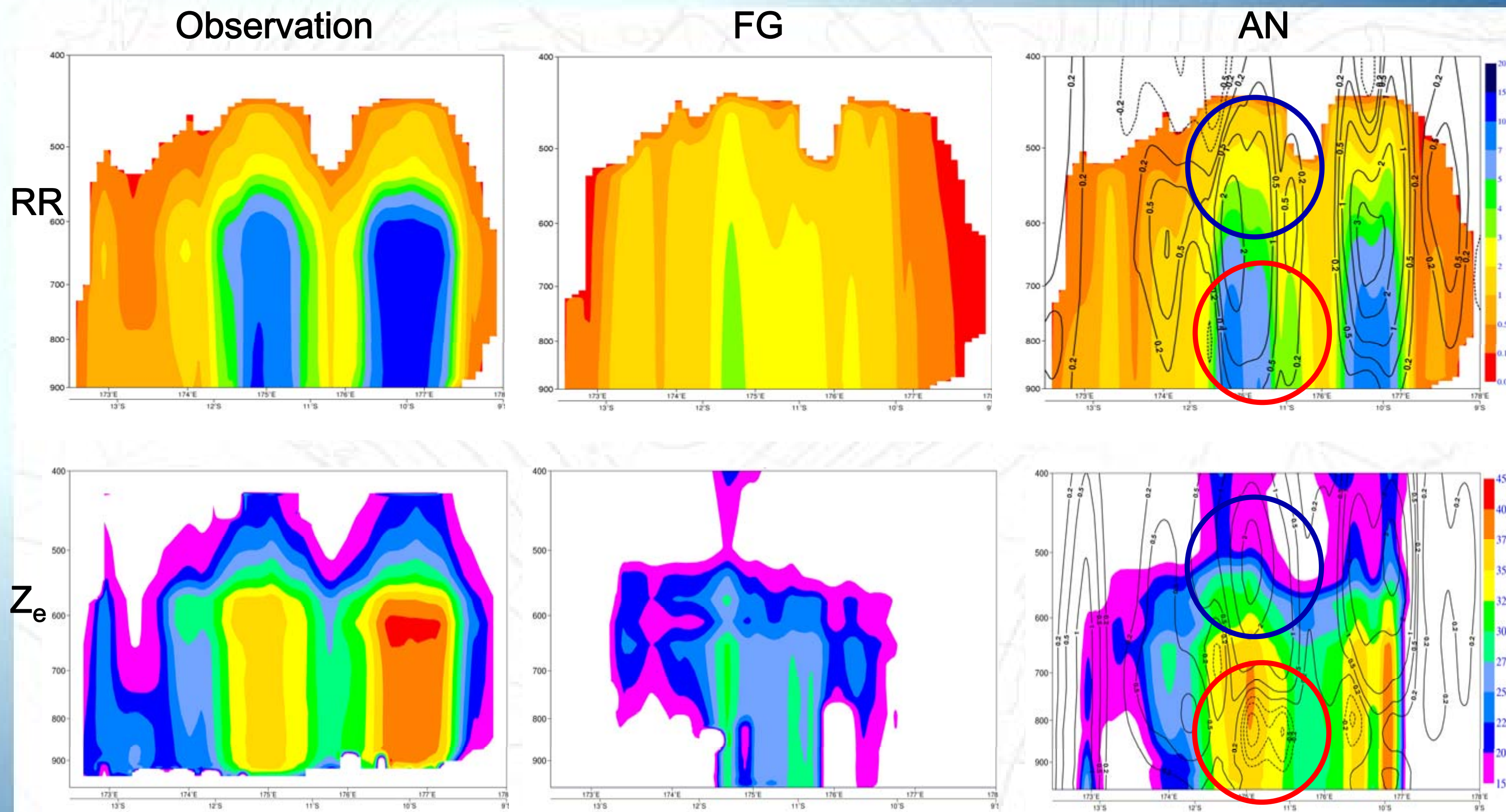
Model



Observation



1D-Var Assimilation of TRMM PR RR vs. Z_e



Tropical Cyclone Zoe (26 December 2002 @1200 UTC)

Vertical cross-section of rain rates (top, mm h^{-1}) and reflectivities (bottom, dBZ), observed (left), background (middle), and analyzed (right).
Black isolines on right panels = 1D-Var specific humidity increments [g/kg].

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Observation operator: Moist Physics (convection)

Linearized parameterization of convection:

- based on Tiedtke (1989)
- single closure assumption based on CAPE
- uncoupling of formulation for convective mass flux and updraft
- unified entrainment/detrainment formulation
- forward/tangent-linear/adjoint models

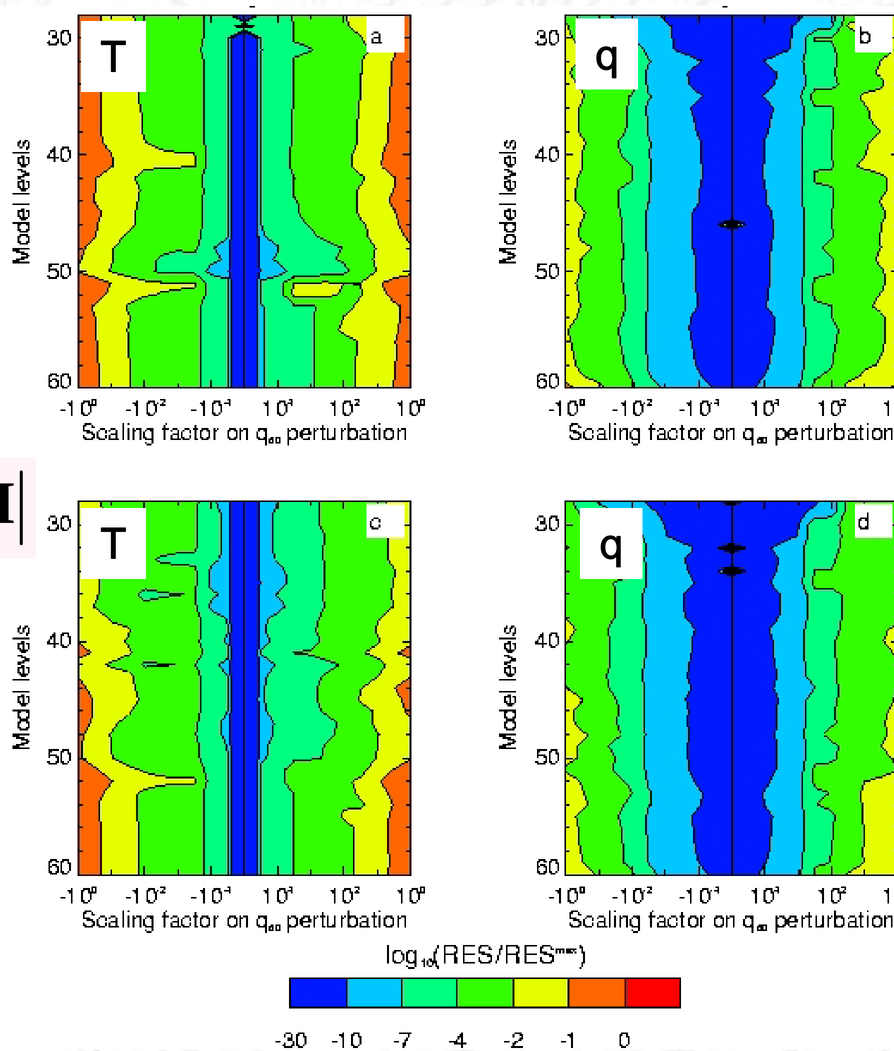
Issues: Linearity

$$RES = \left| H(\mathbf{x} + \lambda\delta\mathbf{x}) - H(\mathbf{x}) - \lambda\delta\mathbf{x}\mathbf{H} \right|$$

H:	non-linear observation operator
H:	TL of H
x:	state vector
δ**x**:	perturbation
λ:	scaling factor

Response of (T,**q**)-tendencies to perturbations of **q**:

Operational Non-linear | Linearized



Lopez and Moreau (2005)

Observation operator: Radiative Transfer

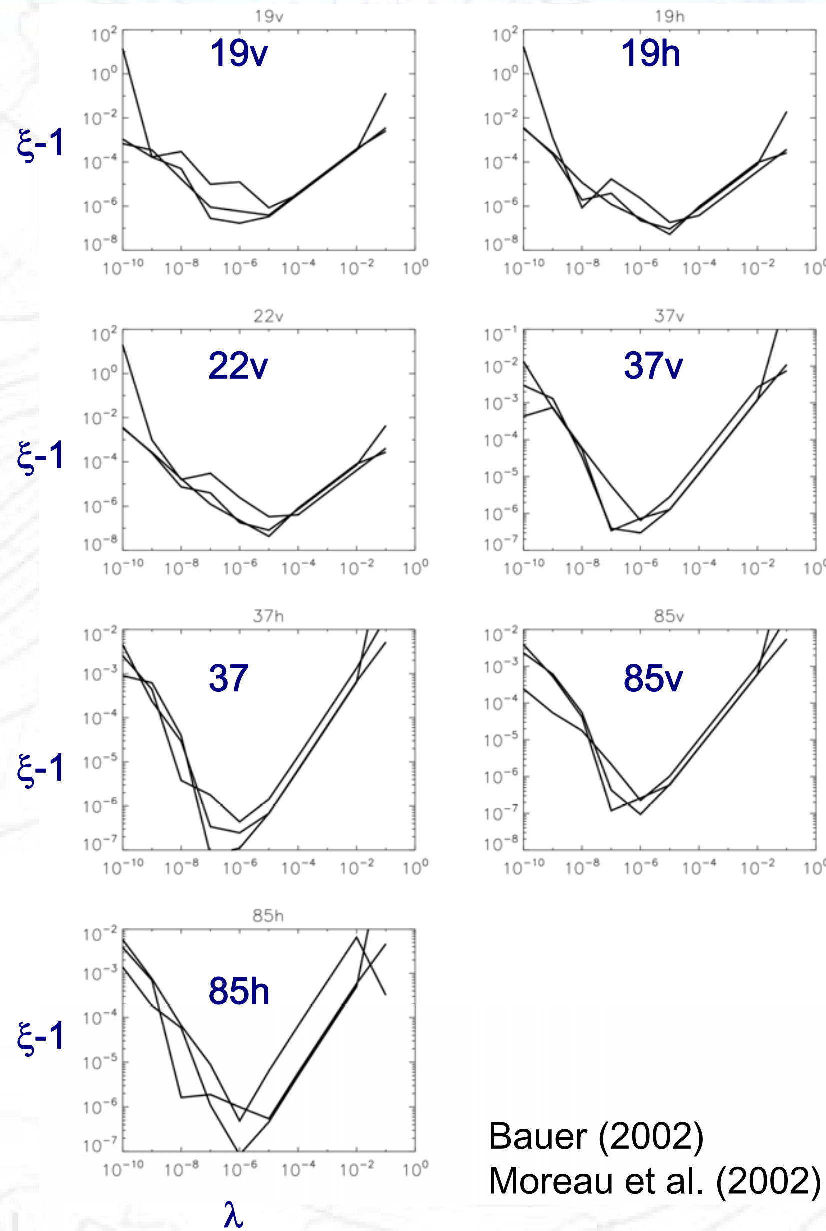
Multiple scattering radiative transfer:

- δ-Eddington solution (Eddington's 2nd approximation)
- plane-parallel with clear and cloud/rain column
- forward/tangent-linear/adjoint models
- part of NWP-SAF RTTOV-8 package
- atmospheric absorption / surface emission from RTTOV

Issues: Linearity

$$\xi - 1 = \frac{H(\mathbf{x} + \lambda\delta\mathbf{x}) - H(\mathbf{x})}{\lambda\delta\mathbf{x}\mathbf{H}}$$

H:	non-linear observation operator
H:	TL of H
x:	state vector
δ**x**:	perturbation
λ:	scaling factor



Bauer (2002)
Moreau et al. (2002)

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E+F = modelling (representativeness) error + measurement error covariance:

- magnitude and quantifiability depends crucially on choice of **y** (*H*, and *H* vs. **H**)
- moist physical parameterizations may constitute biggest contribution:
  - multi-model ensembles, ensemble analysis, EnKF
  - single-column model forecasts with IC/BC from (accurate) observations
- bias-correction

SSM/I

		19v	19h	22v	37v	37h	85v	85 h
Clear-sky	*Clear sky:*							
	Mean FG-departure	0.2	0.2	0.1	0.1	0.3	0.0	0.2
	FG-Departure standard deviation	1.8	3.1	2.7	1.6	3.1	2.1	4.6
	Mean AN-departure	0.1	0.1	-0.1	0.1	0.2	0.0	0.1
	AN-Departure standard deviation	1.3	2.0	1.9	1.2	2.4	1.7	3.6
	Observation error : E+F	3.0	4.5	4.0	3.5	4.0	4.0	6.0
	Mean background error : HBH^T	1.7	3.1	2.7	1.4	2.7	1.7	4.0
Clouds + precipitation	*Precipitation:*							
	Mean FG-departure	0.3	0.5	0.5	0.4	0.8	0.5	1.1
	FG-Departure standard deviation	4.2	7.7	3.9	6.4	13.3	5.8	13.0
	Mean AN-departure	0.1	0.1	0.1	0.1	0.0	0.3	-0.2
	AN-Departure standard deviation	1.0	1.7	1.1	3.0	5.9	4.9	9.1
	Observation error : E+F	4.0	6.0	4.0	-	-	-	-
	Mean background error : HBH^T	4.1	7.5	4.8	-	-	-	-

$$\sigma^2_{E+F} \neq \sigma^2_{\Delta FG} - \sigma^2_{HBH^T}$$

Observational Method

Hollingsworth and Lönnberg (1986):

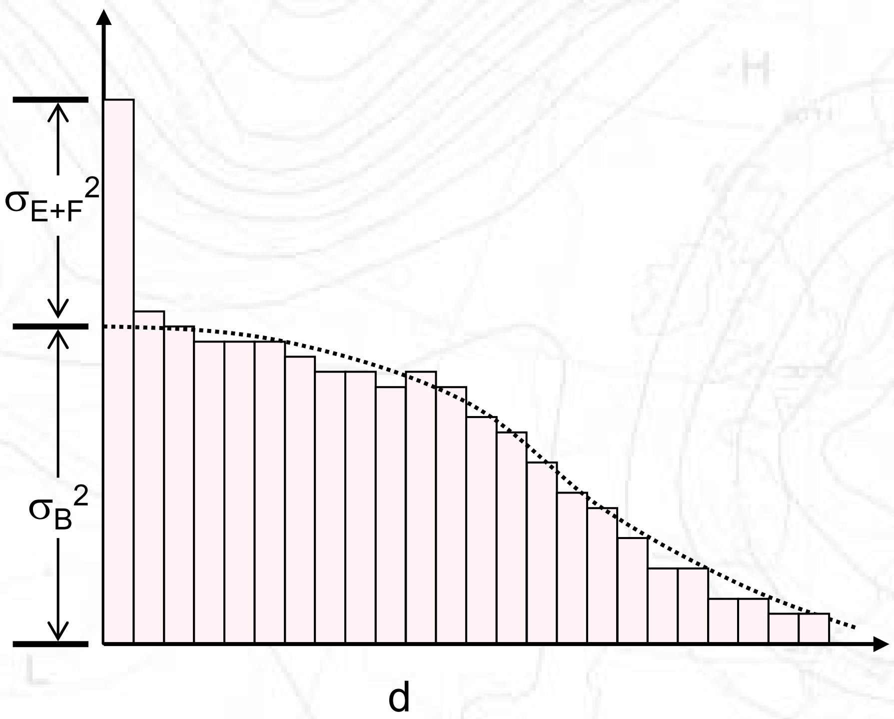
Estimation of σ_B vs. σ_{E+F} from spatial covariance structure of first-guess departures

Assumptions:

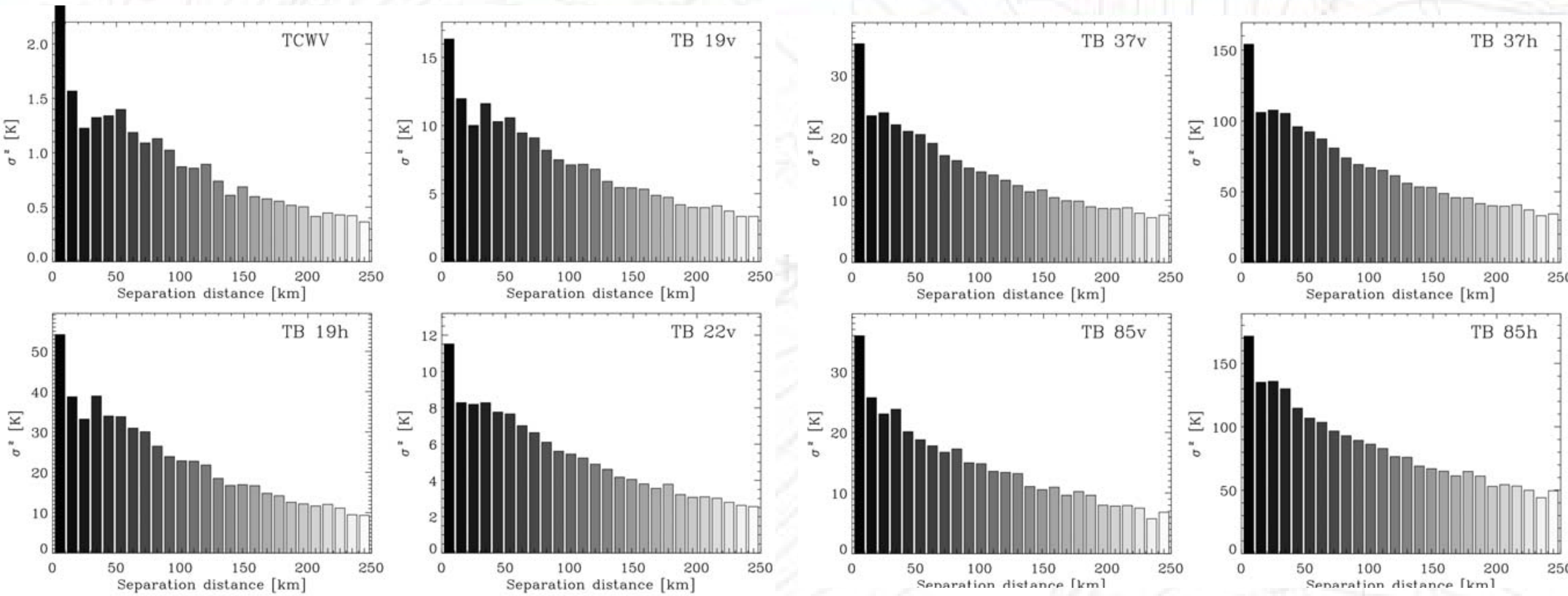
- observation network is rather dense
- observations are spatially uncorrelated (and discrete)

Conclusions:

- at 0-separation distance, the variance is $\sigma_B^2 + \sigma_{E+F}^2$
- at >0-separation distance, the variance is covariance σ_B^2 (d)



Observational Method: TCWV/TB in Precipitation



	σ_B	σ_{E+F}	
TCWV	1.5	1.5	kg/m²
TB 19v	3	2.5	K
TB 19h	6	4.5	K
TB 22v	3	2	K
TB 37v	5	3	K
TB 37h	10	7	K
TB 85v	5	3.5	K
TB 85h	11	6	K

$$\sigma_{E+F}^2 = \sigma_{\Delta FG}^2 - \sigma_{HBH^T}^2$$

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B determines:

- weight of background,
- structure of increments,
- interaction between temperature/moisture and, e.g., dynamics.

Profile of increments $\neq$ observation (weighting function) [x moist physics] sensitivity

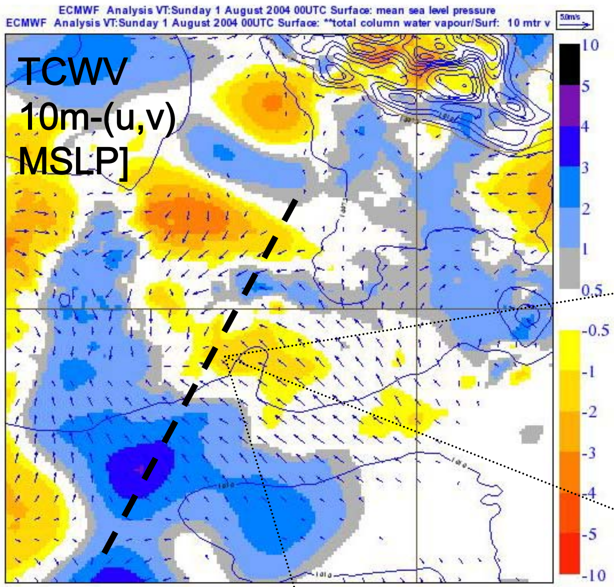
Shape of **B** is not precipitation specific:

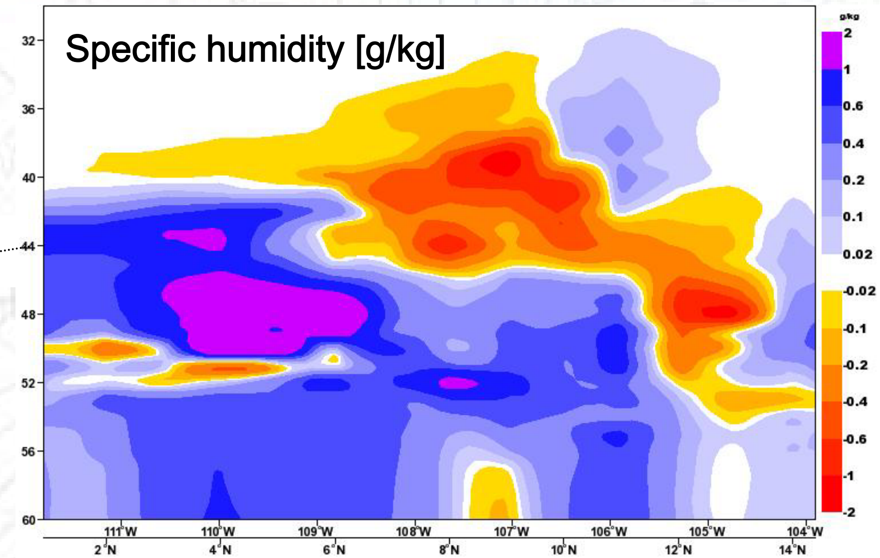
- σ_b profile drives increments similarly inside/outside precipitation
- spread of information due to horizontal structure functions may be disproportional

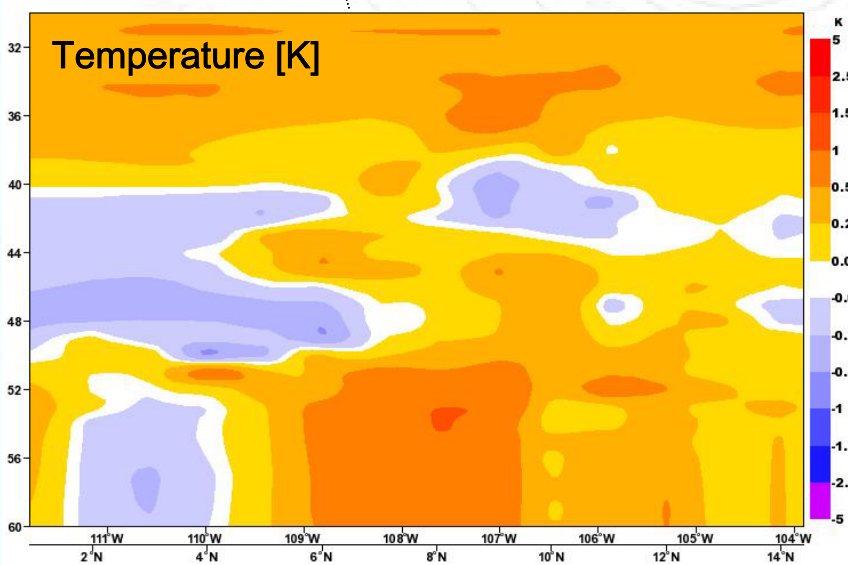
Definition of **B** may include other mechanisms (e.g. limitation of increments in dry environments)

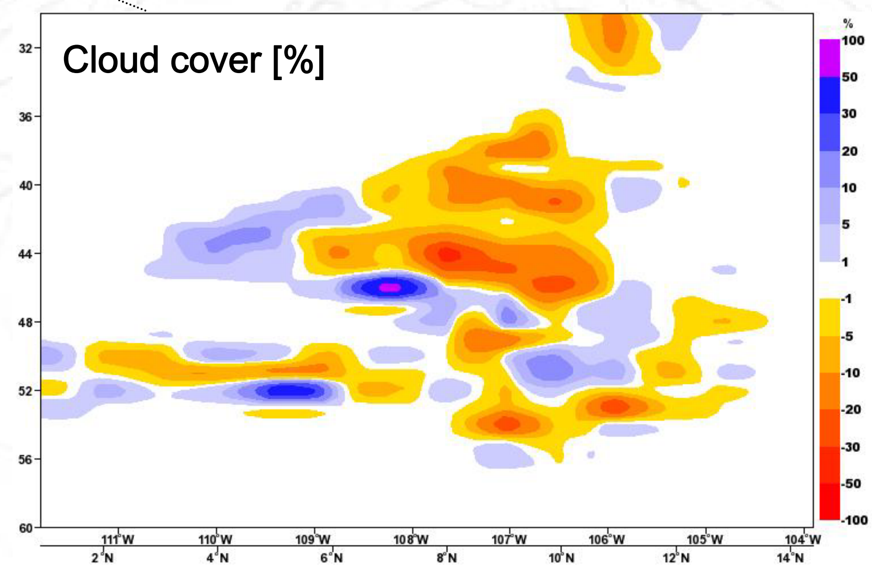
Development of more specific formulations required: wavelets, ENKF etc.

4D-Var increment cross-section (DA-Analysis)



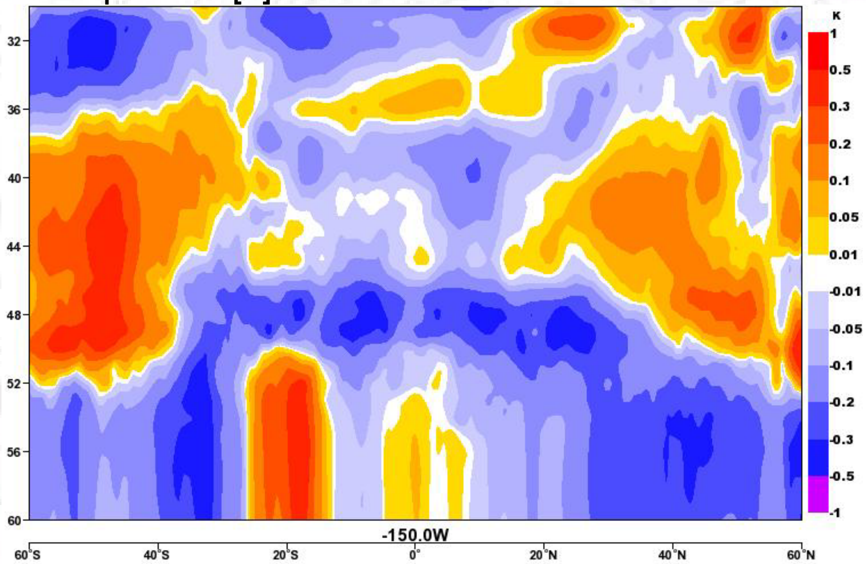




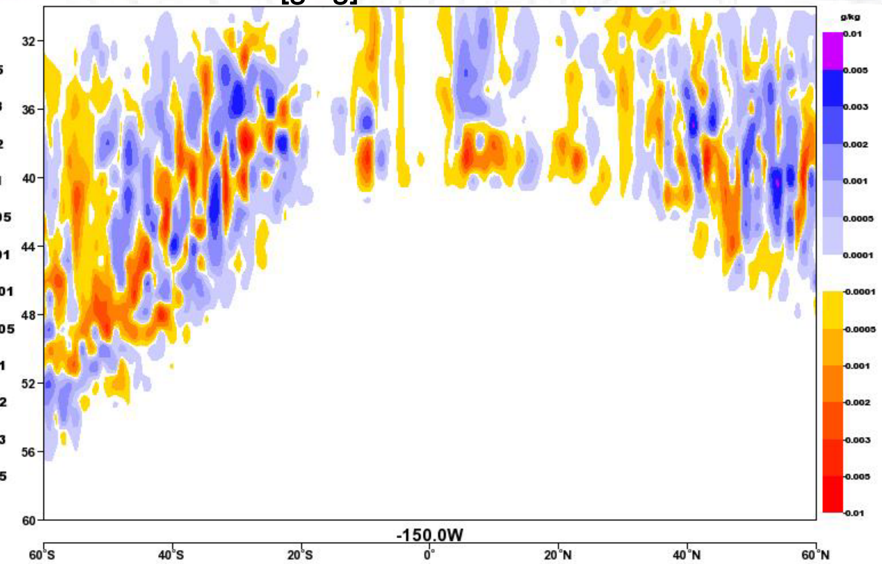


4D-Var mean increment cross-section (DA-Analysis)
200408 - 150° W

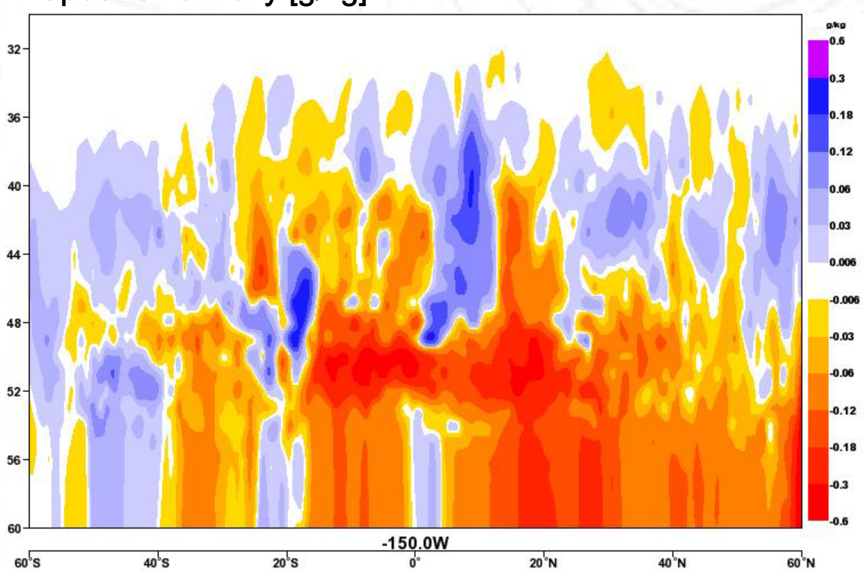
Temperature [K]



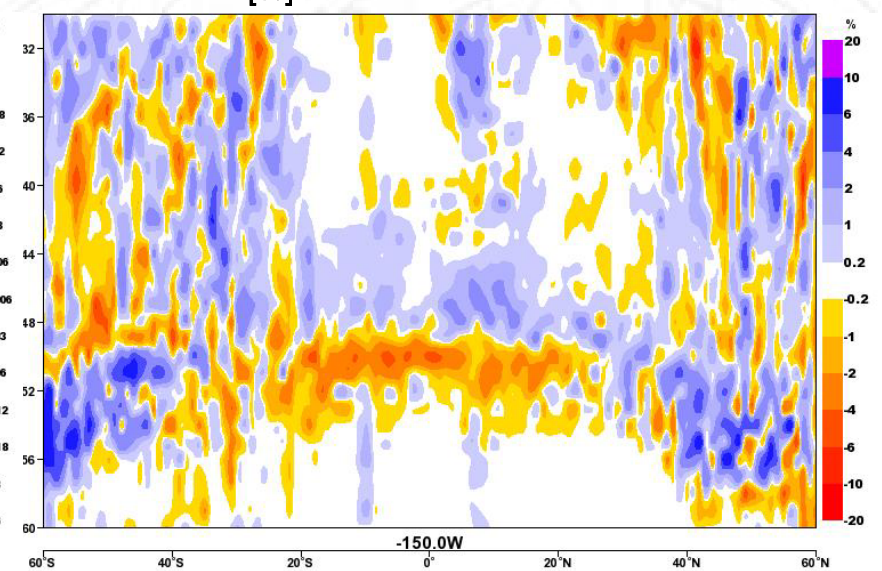
Cloud water/ice [g/kg]



Specific humidity [g/kg]

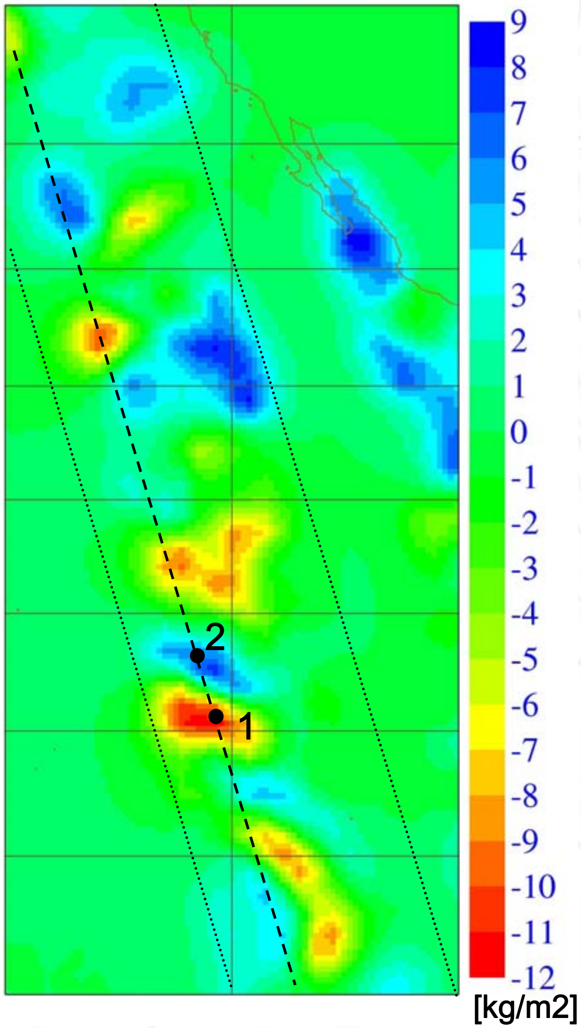


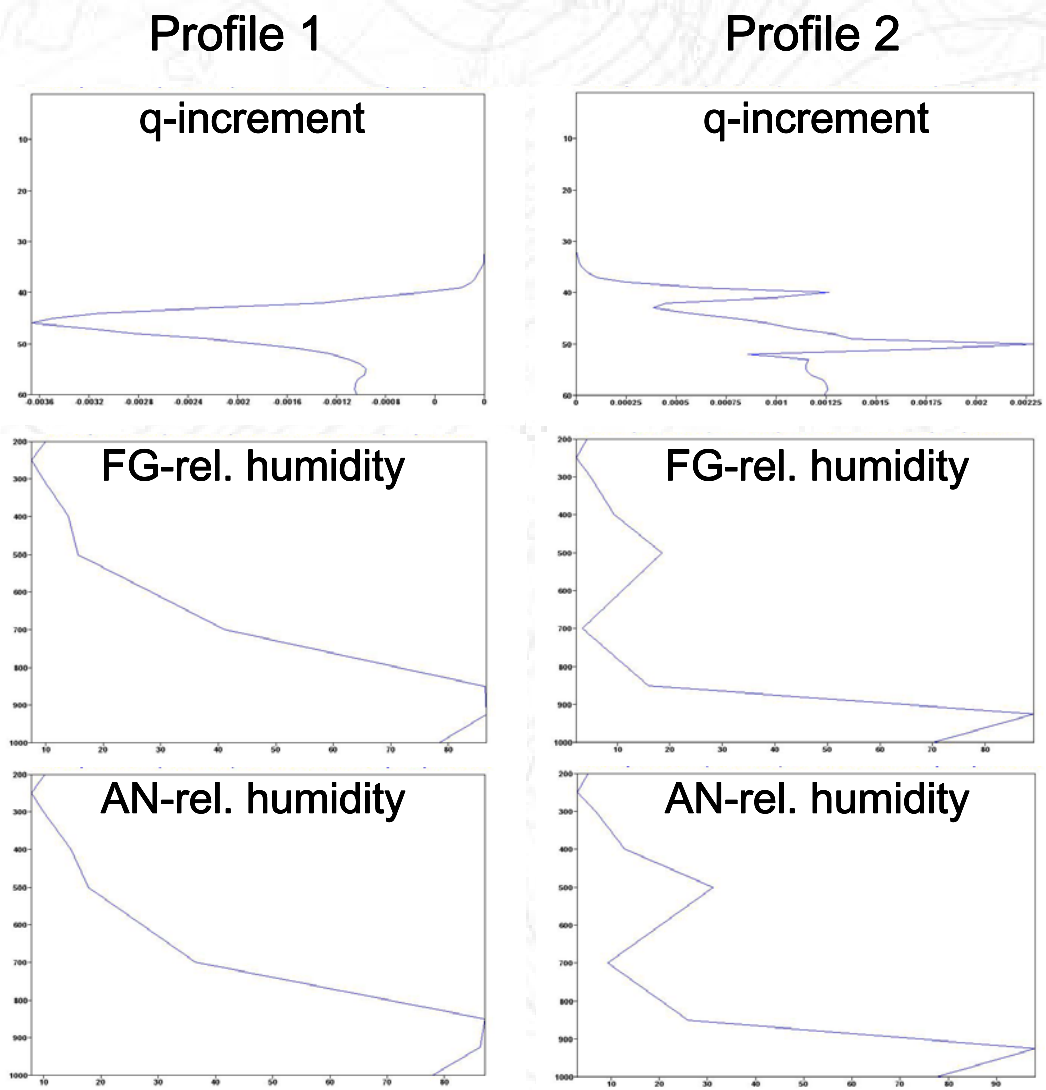
Cloud cover [%]



Example q-increment profiles

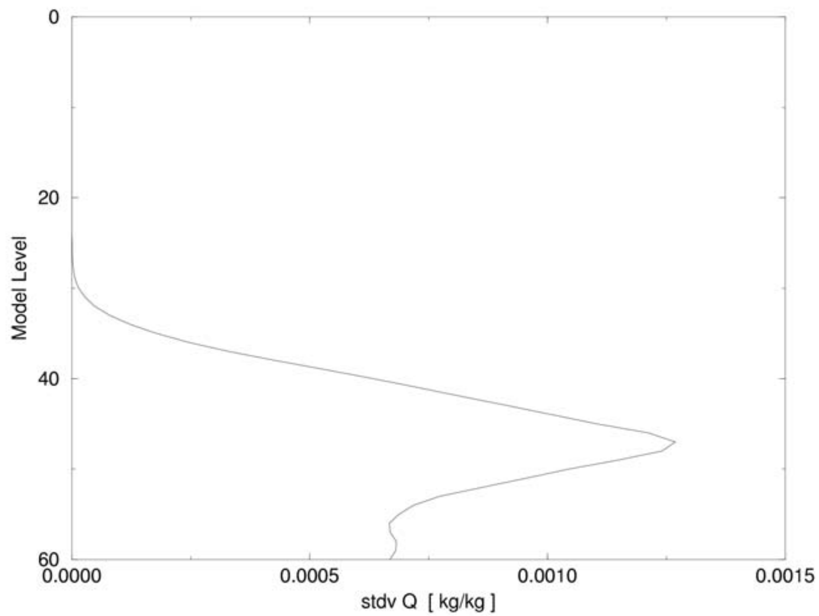
SSM/I 3D-Var TCWV increments from SSM/I clear-sky radiance assimilation



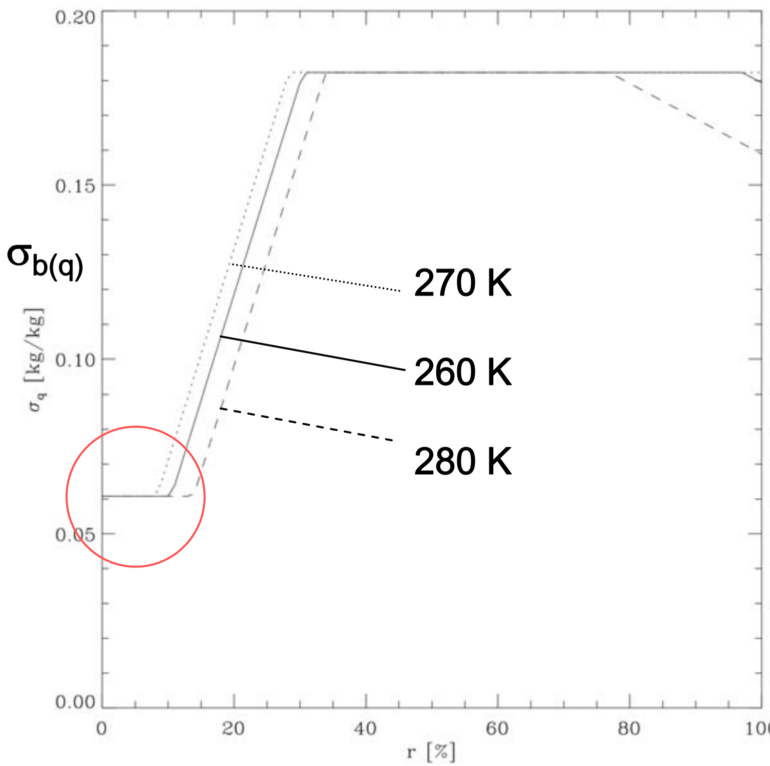


Increments vs. Background errors

Typical σ_b profile

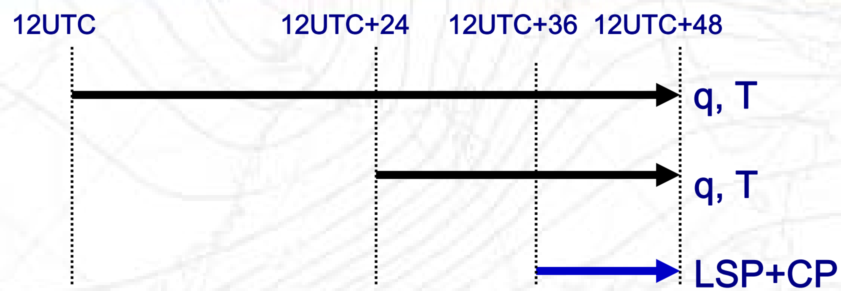


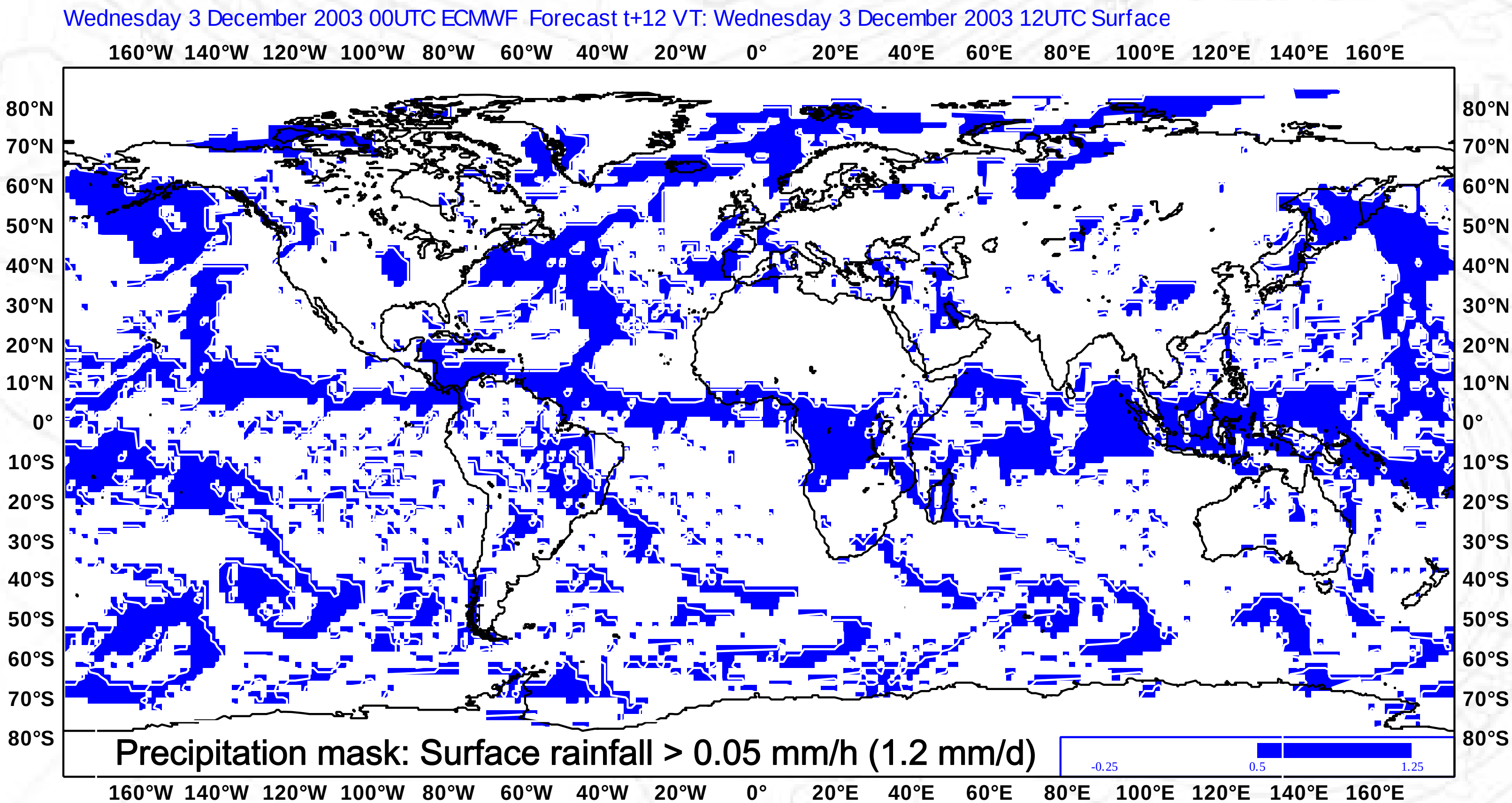
σ_b (RH, T) formulation



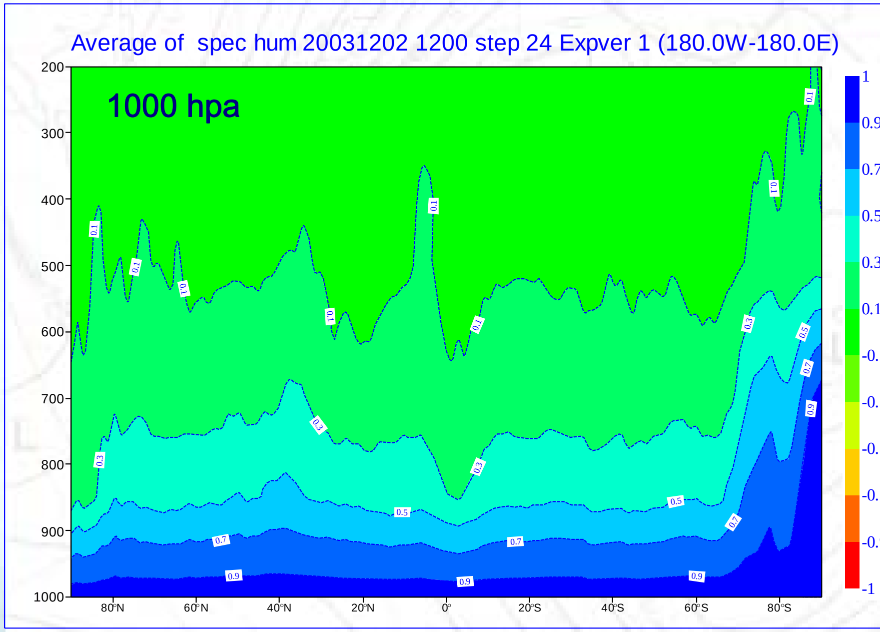
BG-error vertical correlations and error standard deviations

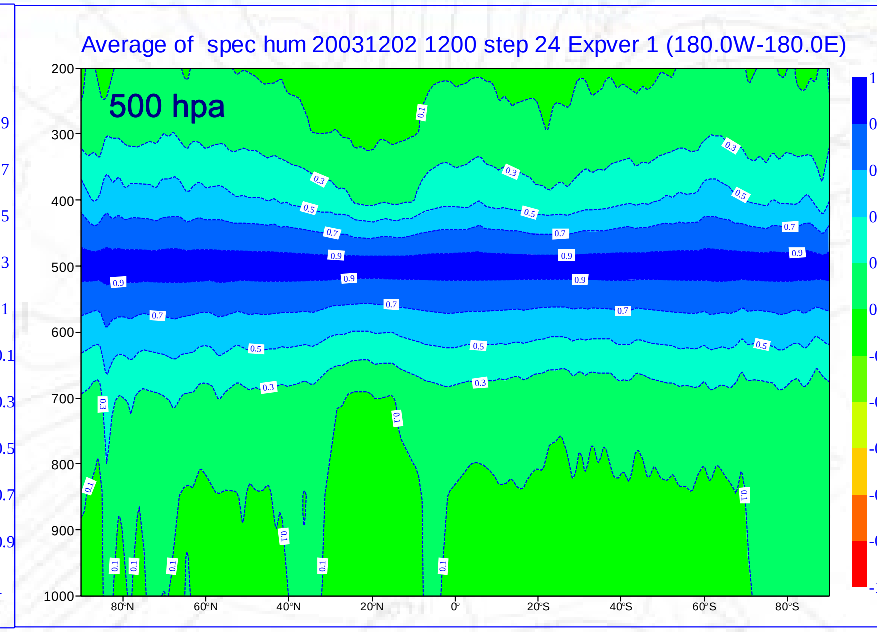
NMC-method:
Statistically, the difference between 48h and 24h forecasts corresponds to forecast errors, I.e. FG-errors of next forecast

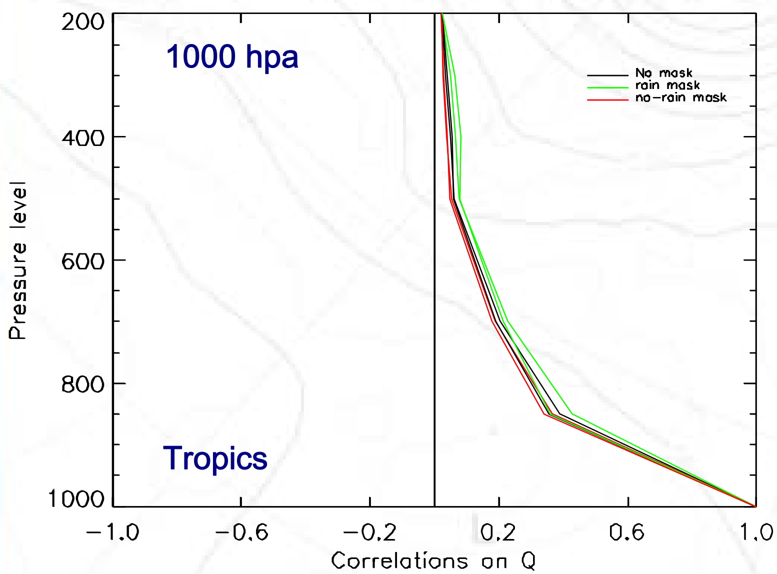


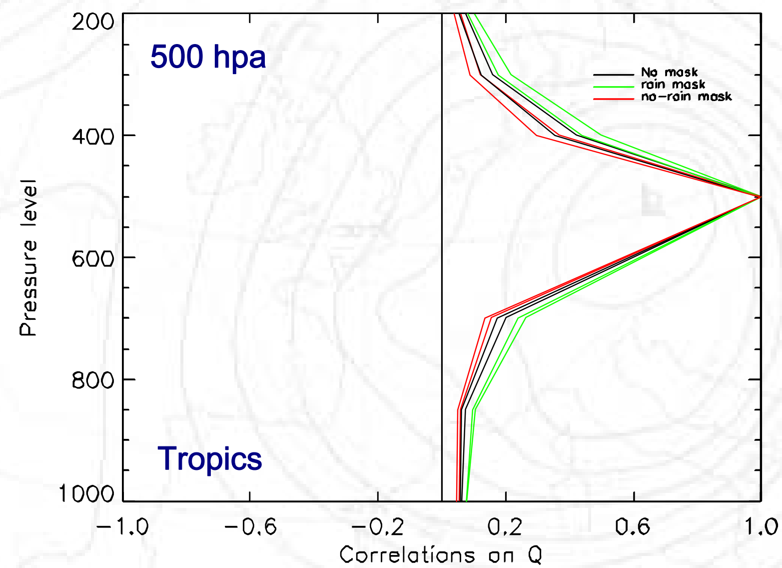


Zonal means of vertical correlations for specific humidity (DJF 2004, global)









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Issues for Discussion

In view of the importance of departure-pdf's (and error pdf's) what is the optimum choice of control variable (e.g. total water content) and precipitation-related observation (e.g. microwave TB)?

Biases: how can systematic model (observation operator) errors be reduced (1^{st} choice: bias-correction schemes) and separated from observation biases?

Non-linearity of observation operators/convergence - how non-linear is it and can we produce criteria for avoiding the problematic situations?

How can (moisture) background errors be defined in precipitation (this includes horizontal structure functions)? Longer-window 4D-Var to reduce importance of B for analysis (loss of memory but model error contribution, **Q**, increases)? Ensemble Kalman Filter, i.e., perturb f/c's for cloud profiles to have more specific adaptation of local conditions?

Design experiment for quantifying representativeness error (E+F).

How can the link between moisture analysis and dynamics be improved (through B and/or 4D-Var and/or otherwise)?

Experiment evaluation - Since we deal with variable, inhomogeneous, synoptic-system-rather-than-large-scale-wave-pattern parameters, do we need other ways of scoring precipitation assimilation performance?