A Joint Temperature, Humidity, Ozone, and SST Retrieval Processing System for IASI Sensor Data: Properties and Retrieval Performance Analysis

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Outline

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1. METOP – IASI
   - METOP
   - IASI – Infrared Atmospheric Sounding Interferometer
2. Forward Model and Retrieval
   - The forward model RTIASI
   - The Retrieval
3. Results
   - Retrieval Setup and Channel Selection
   - Results of the Joint Retrieval
4. Summary and Outlook

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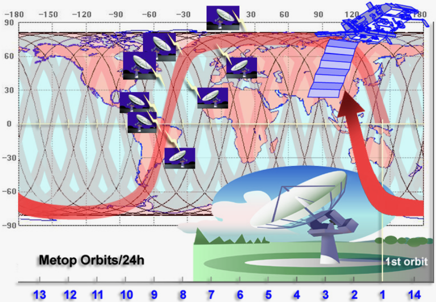
METOP configuration



Source: http://www.esa.int/export/esaME/index.html

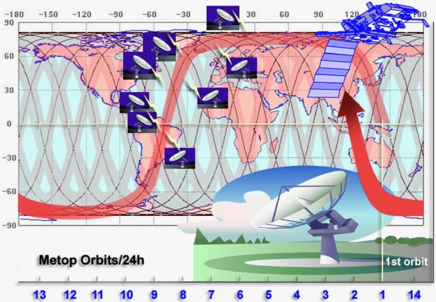
METOP specifications

- size:
  17.6 m $\times$ 6.7 m $\times$ 5.4 m
- mass: 4244 kg
- power: 2010 W (eclipse)

orbit

- inclination: 98.7°
- ALTITUDE: $\sim$830 km
- sun-sync. orbit
  (9:30 local time)
- $>$14 revolutions/day
- repeat cycle: 29 days –
  412 orbits

METOP configuration



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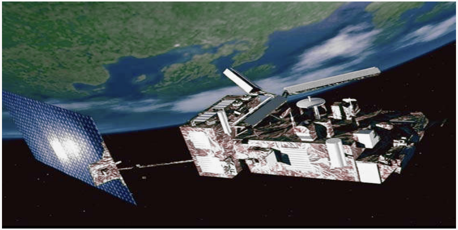
instruments on board of METOP



Source: http://www.space-technology.com/

additional instruments

- A/DCS
- SARP-3
- SARR
- SEM

atmospheric instruments

- IASI
- AMSU - A1, A2
- ASCAT
- AVHRR
- GOME-2
- GRAS
- HIRS
- MHS

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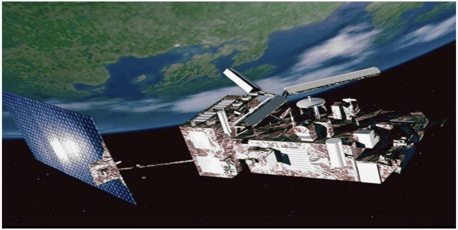
EM-Spetrum

instruments on board of METOP



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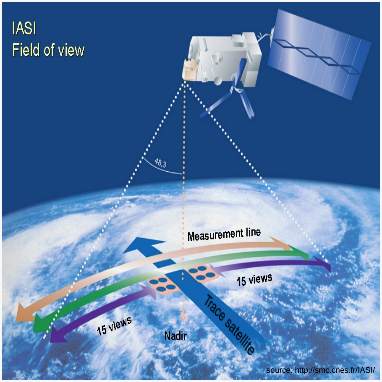
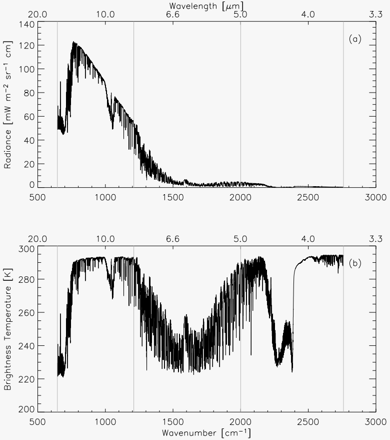
IASI – infrared atmospheric sounding interferometer



IASI characteristics

- scan type: step and dwell
- scan rate: 8 s
- pixel/views: 4
- views/scan: 30
- IFOV: 3.33°(48 km at nadir)
- swath: ±48.3°(±1026 km)
- lifetime: 5 years
- power: 200 W
- mass: 210 kg
- size: 1.2 m × 1.1 m × 1.1 m

IASI - measurement specifications



(a) radiances and (b) brightness temperatures of IASI simulated by RTIASI for a us.std.midlatitude summer atmosphere.

measurement specifications

- spectral range: 645-2760 cm^{-1}
  15.5-3.6 μm
- spectral res.: 0.35 - 0.5 cm^{-1}
- 8461 channels
  separated into 3 bands
- radiometric res.: 0.25 - 0.5 K
- water vapor: 1250 - 2000 cm^{-1}
- CO_2: near 645 and 2325 cm^{-1}
- additional absorption of
  O_3, CH_4, N_2O, CO, SO_2

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the forward model RTIASI

RTIASI - an overview

- simulation of the IASI measurements at 43 fixed pressure levels between 0.1 and 1013.25 hPa
- calculation of optical depth's via a regression scheme
- calculation of level to space transmittances
- solution of the radiative transfer equation to estimate
- brightness temperatures $\mathbf{T}_B$ (or radiances, respectively).
- tangent linear and adjoint model to calculate jacobians for $\mathbf{T}$, $\mathbf{q}$, $\mathbf{O_3}$, and SST - $\frac{\partial \mathbf{T}_B}{\partial \mathbf{T}}$, $\frac{\partial \mathbf{T}_B}{\partial \mathbf{q}}$, $\frac{\partial \mathbf{T}_B}{\partial \mathbf{O_3}}$, and $\frac{\partial \mathbf{T}_B}{\partial \mathrm{SST}}$

connecting the forward model and the retrieval

the forward model reads

$$\mathbf{y} = \mathbf{f}(\mathbf{x}) + \epsilon \quad (1)$$

- $\mathbf{y}, \mathbf{x}$: measurement and state vector
- $\mathbf{f}$: forward model operator - jacobian matrix $\mathbf{K}$ times $\mathbf{x}$
- ϵ: measurement error vector

the direct inverse reads

$$\mathbf{x}_{retr} = \mathbf{K}^{-g}\mathbf{y} \quad (2)$$

- ill-conditioned problem
- over determined for m>n

the retrieval

optimal estimation algorithm

- incorporates sensibly *a priori* knowledge
- statistically optimal fusion of unbiased measurements and *a priori* data

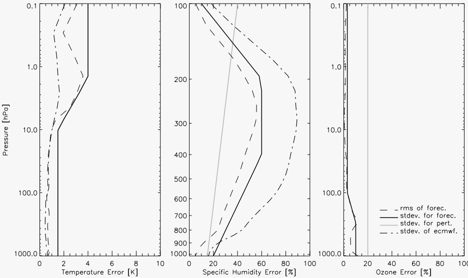
linearized iterative optimal estimation scheme

$$\mathbf{x}_{i+1} = \mathbf{x}_{ap} + \mathbf{S}_i \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \left[(\mathbf{y} - \mathbf{y}_i) + \mathbf{K}_i (\mathbf{x}_i - \mathbf{x}_{ap}) \right] \quad (3)$$

$$\text{with:} \qquad \mathbf{S}_i = \left[\mathbf{S}_{ap}^{-1} + \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \mathbf{K}_i \right]^{-1} . \quad (4)$$

- $\mathbf{S}_i, \mathbf{S}_\epsilon, \mathbf{S}_{ap}$: retrieval, measurement, and *a priori* error covariance matrix
- $\mathbf{x}_{i,i+1}, \mathbf{x}_{ap}$: iterated (iteration index i) and *a priori* profile

the *a priori* error covariance matrix



a priori error covariance matrices for temperature, humidity and ozone.

off diagonal elements

- exponential drop off
- correlation length:

T	6 km
q	3 km
$\mathbf{O_3}$	10 km

the measurement error covariance matrix

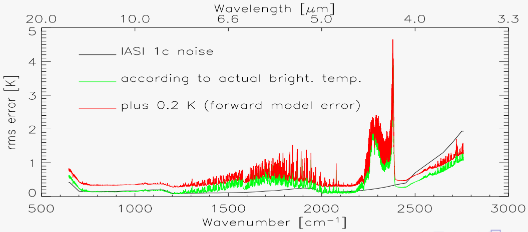
diagonal elements

- IASI level 1c noise values
- adapted to the actual brightness temperature
- +0.2 K forward model error

off diagonal elements

correlation of the three nearest neighbor channels:

1	0.75
2	0.25
3	0.04



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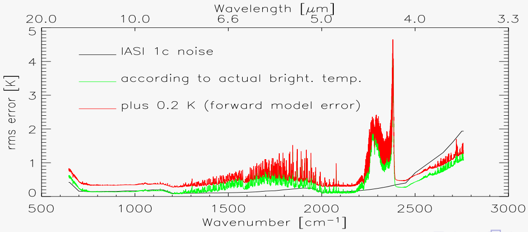

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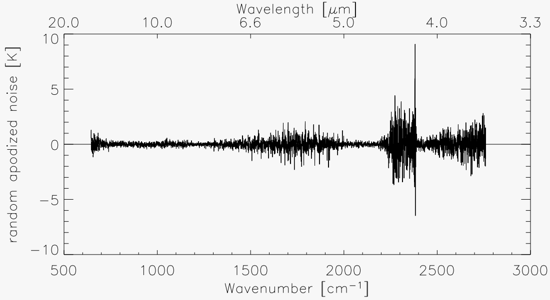
the simulation of the measurement vector

- calculation with the fast radiative transfer model RTIASI
- superposition of radiometric noise $\Delta\mathbf{y}$, consistent with $\mathbf{S}_\epsilon$, according to IASI level 1c noise to get quasi realistic data



channel selection

removal of channel regions

$$\left.\begin{array}{rl} > 2500\ \mathrm{cm}^{-1}: & \text{sun, inst.noise} \\ 1220-1370\ \mathrm{cm}^{-1}: & N_2O, CH_4, SO_2 \\ 2085-2200\ \mathrm{cm}^{-1}: & CO, N_2O \end{array}\right\} \Longrightarrow \sim 6200 \text{ channels} \quad (5)$$

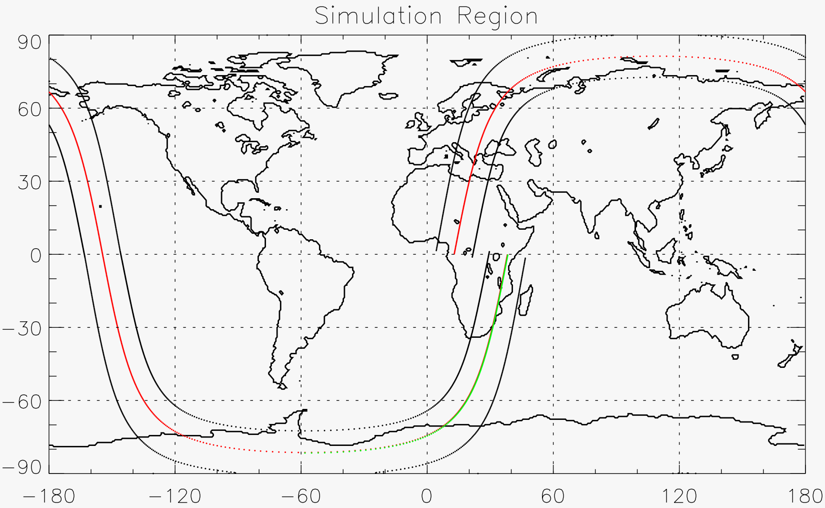
information content theory

$$H_i = \frac{1}{2}\log_2\left|\hat{\mathbf{S}}_i^{-1}\hat{\mathbf{S}}_{i-1}\right|, \quad (6)$$

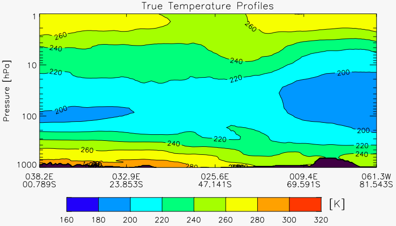
maximum sensitivity approach

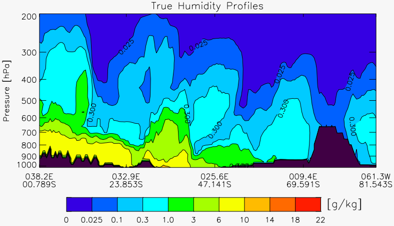
$$\mathbf{H} = \mathbf{S}_\epsilon^{-\frac{1}{2}}\mathbf{K}, \quad (7)$$

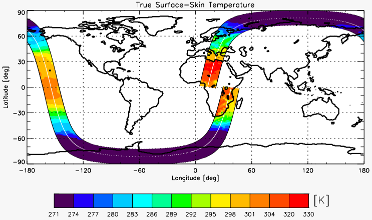
the simulation region

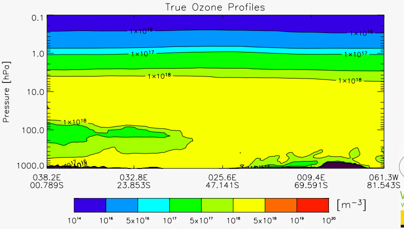


true fields









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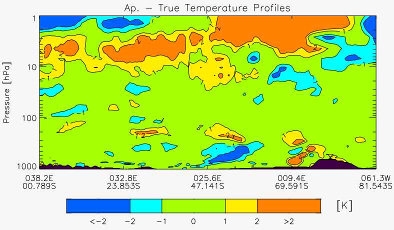
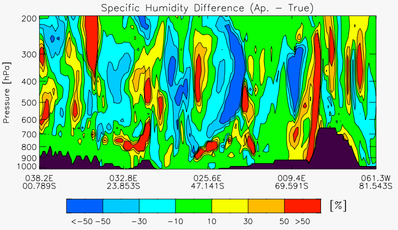
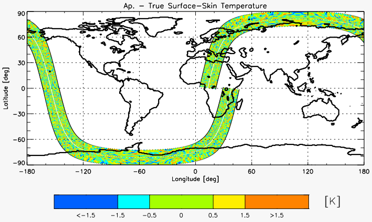
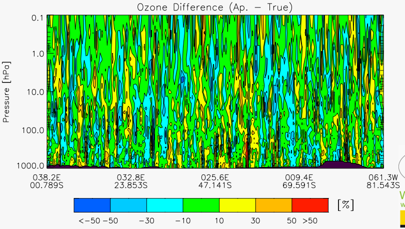
a priori minus true – 24h forecast









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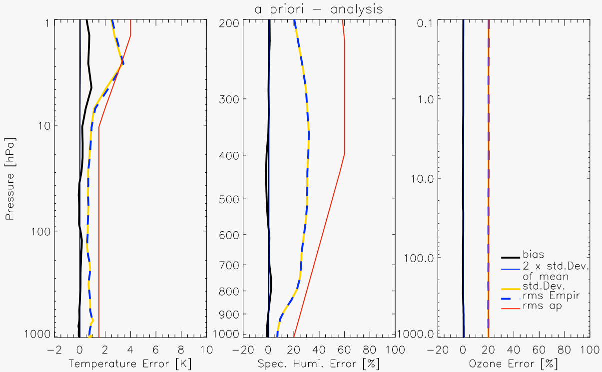
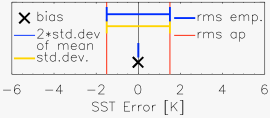
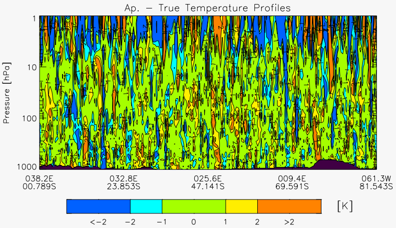
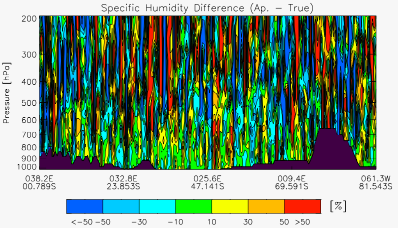
a priori minus true – 24h forecast/ error data

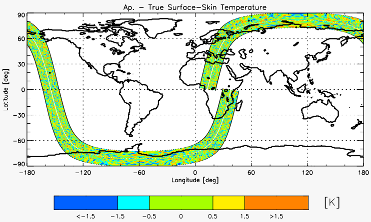


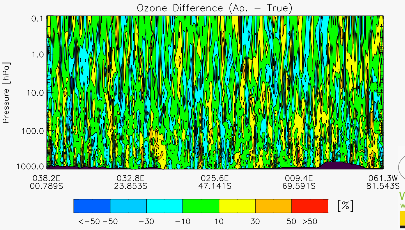


a priori minus true – true perturbed









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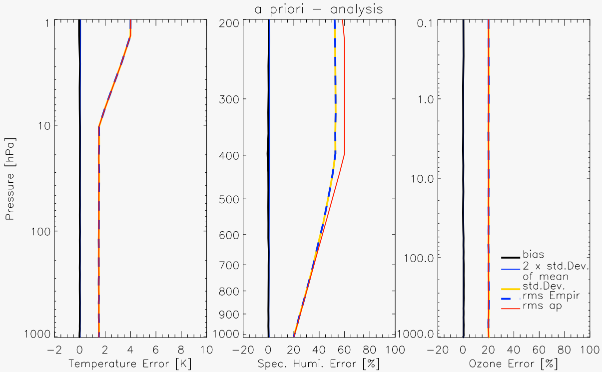
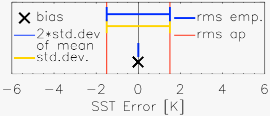
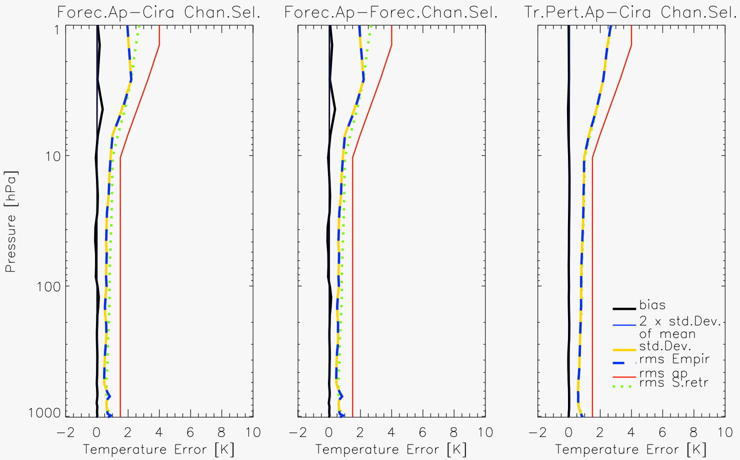
a priori minus true – true perturbed/ error data

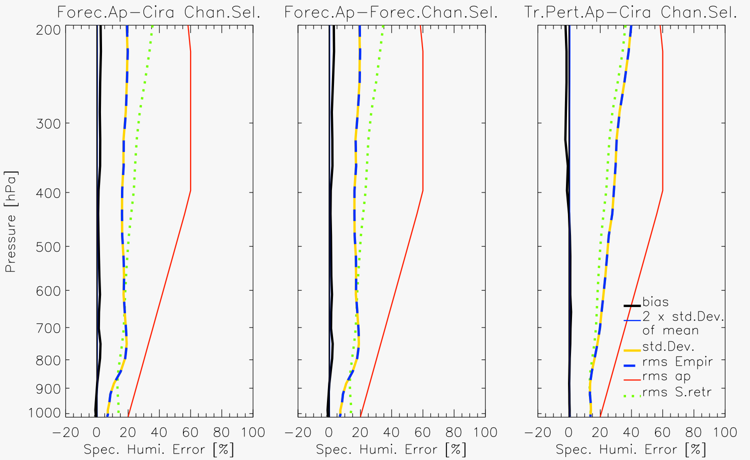




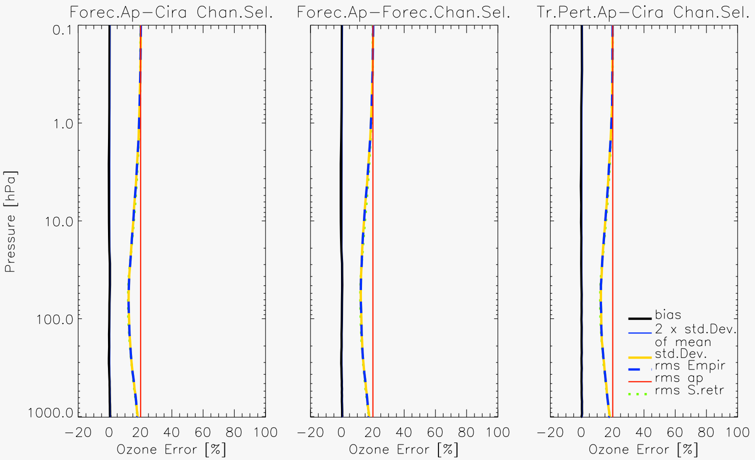
temperature profiles – error analysis



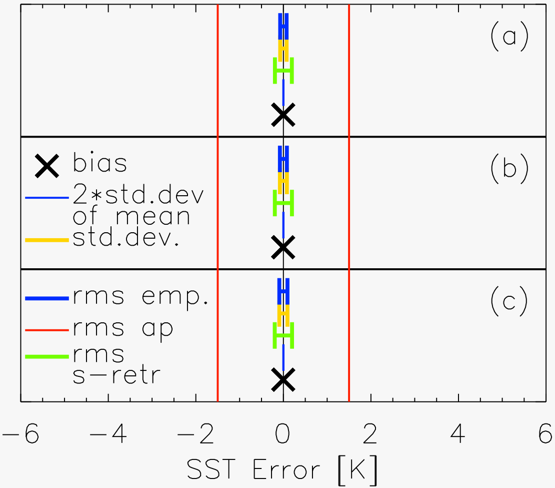
humidity profiles – error analysis



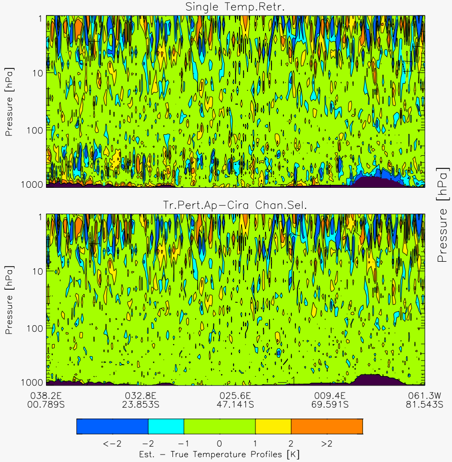
ozone profiles – error analysis

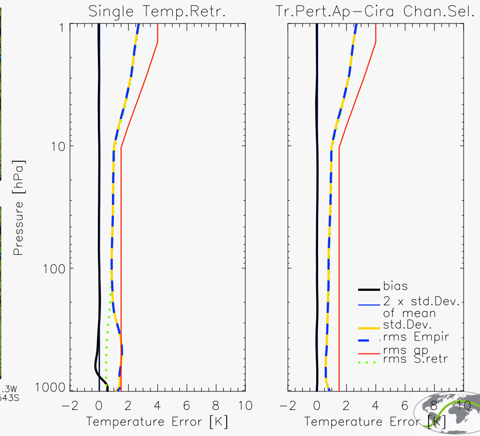


SST – error analysis

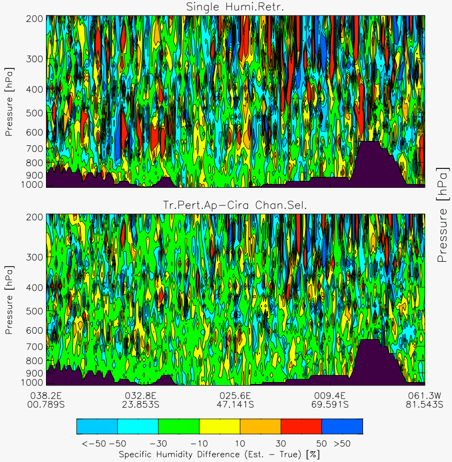


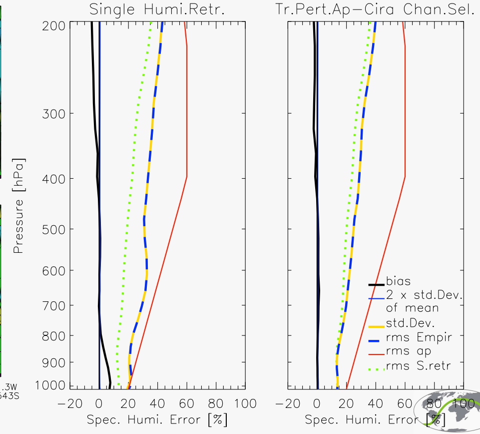
single parameter retrieval – temperature



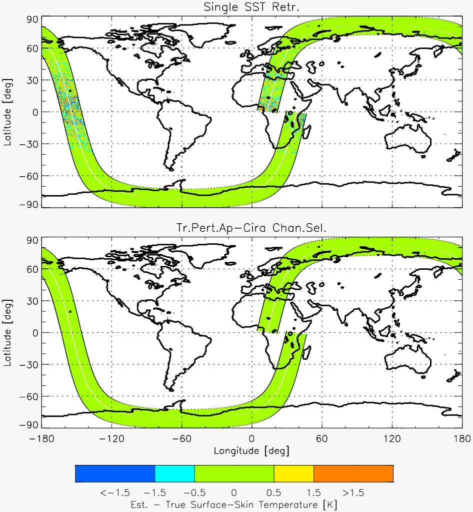


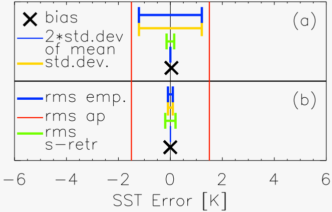
single parameter retrieval – humidity



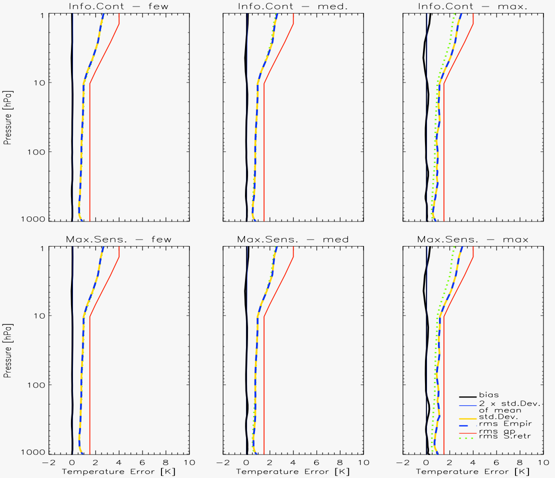


single parameter retrieval – SST





channel selection – a comparison



numerical efficiency

a) IC – ∼300 chan.
b) IC – ∼900 chan.
c) IC – ∼1800 chan.
d) MS – ∼300 chan.
e) MS – ∼900 chan.
f) MS – ∼1800 chan.

numerical efficiency

set	IC	MS
300	1.00	0.98
887	3.74	4.25
1808	11.25	13.13

Outline

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Summary

Summary (1)

- IASI is the most advanced infrared sounder to be launched in the near future
- the IC based channel reduction makes the retrieval efficient –
  reduction from $>$8400 to $\sim$3.5% ($\sim$300)
- retrieval accuracy:

temperature:	1 K	at 1-3 km
humidity:	15-20%	at 1-3 km
SST:	$\sim$0.1 K	
ozone:	improvements in the stratosphere in heights with high concentration of O_3	

Summary

Summary (2)

- *a priori* data exhibit important influence from the tropopause upwards
- the joint algorithm shows an clearly improved performance compared to more specific retrieval setups
- temperature, humidity, and SST results are quite independent from the initial guess of ozone (a few 10% uncertainty level)

Outlook

Outlook

- **Improvements:**
  - statistical model of the *a priori* error covariance matrices, e.g., direct use of the relevant ECMWF *a priori* covariance matrices for **T** and **q**
  - usage of the newest forward model RTIASI
- **next steps:**
  - application of the algorithm to AIRS data is planned

Thank You!

Outline

5 Anhang
- EM-Spectrum

measured spectrum

Source: http://www.giangrandi.ch/optics/ spectrum/spectrum.shtml

GOME-2 AVHRR AMSU-A1,A2

HIRS ASCAT

IASI GRAS

MHS

Return

International TOVS Study Conference, 14th, ITSC-14, Beijing, China, 25-31 May 2005. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2005.