

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

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May 24 – 31, 2005



# Outline

- 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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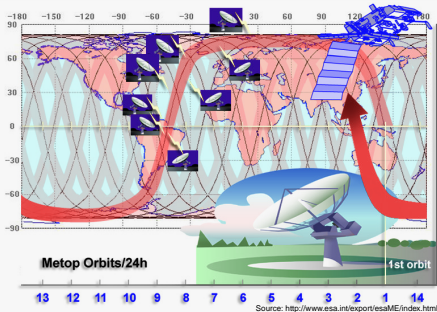
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# METOP configuration



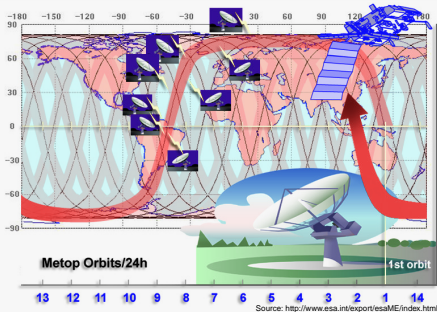
## METOP specifications

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

## orbit

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

# METOP configuration



## orbit

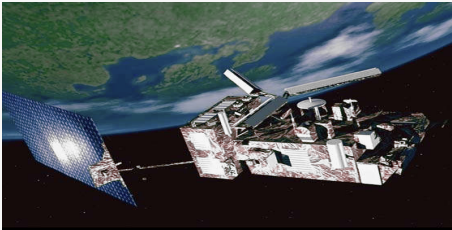
- inclination:  $98.7^\circ$
- ALTITUDE:  $\sim 830$  km
- sun-sync. orbit  
(9:30 local time)
- $> 14$  revolutions/day
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412 orbits

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 $17.6 \text{ m} \times 6.7 \text{ m} \times 5.4 \text{ m}$
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# instruments on board of METOP



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

## additional instruments

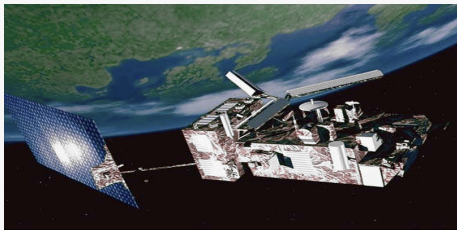
- A/DCS
- SARP-3
- SARR
- SEM

## atmospheric instruments

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

▶ EM-Spektrum

# instruments on board of METOP



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

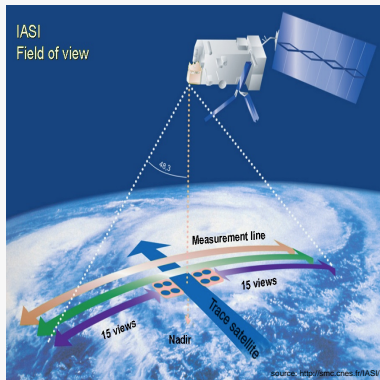
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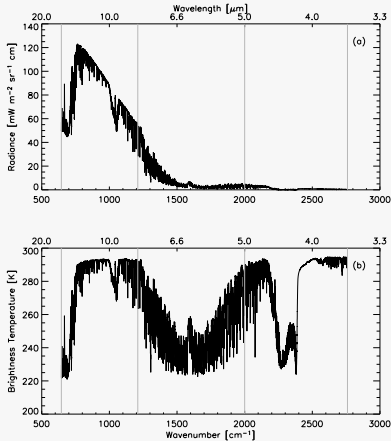
# IASI – infrared atmospheric sounding interferometer



## IASI characteristics

- scan type: step and dwell
- scan rate: 8 s
- pixel/views: 4
- views/scan: 30
- IFOV:  $3.33^\circ$  (48 km at nadir)
- swath:  $\pm 48.3^\circ$  ( $\pm 1026$  km)
- lifetime: 5 years
- power: 200 W
- mass: 210 kg
- size: 1.2 m  $\times$  1.1 m  $\times$  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<sup>-1</sup>  
15.5-3.6 μm
- spectral res.: 0.35 - 0.5 cm<sup>-1</sup>
- 8461 channels  
separated into 3 bands
- radiometric res.: 0.25 - 0.5 K
- water vapor: 1250 - 2000 cm<sup>-1</sup>
- CO<sub>2</sub>: near 645 and 2325 cm<sup>-1</sup>
- additional absorption of  
O<sub>3</sub>, CH<sub>4</sub>, N<sub>2</sub>O, CO, SO<sub>2</sub>

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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  $T_B$  (or radiances, respectively).
- tangent linear and adjoint model to calculate jacobians for  $\mathbf{T}$ ,  $\mathbf{q}$ ,  $\mathbf{O}_3$ , and SST -  $\frac{\partial T_B}{\partial \mathbf{T}}$ ,  $\frac{\partial T_B}{\partial \mathbf{q}}$ ,  $\frac{\partial T_B}{\partial \mathbf{O}_3}$ , and  $\frac{\partial T_B}{\partial \text{SST}}$

## connecting the forward model and the retrieval

### the forward model reads

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

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

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

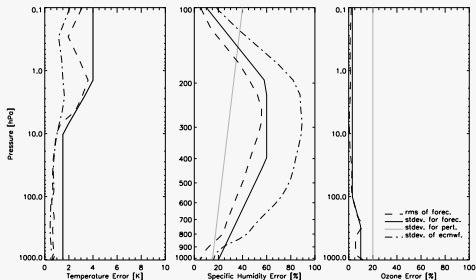
$$\text{with: } \mathbf{S}_i = \left[ \mathbf{S}_{ap}^{-1} + \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \mathbf{K}_i \right]^{-1}. \quad (4)$$

- $\mathbf{S}_i, \mathbf{S}_\epsilon, \mathbf{S}_{ap}$ : 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

**O<sub>3</sub>** 10 km



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# the measurement error covariance matrix

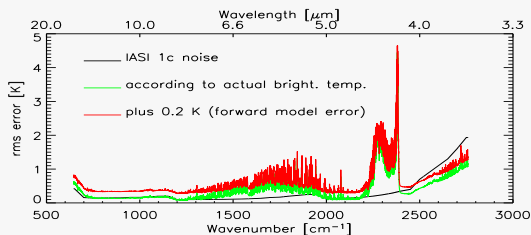
## diagonal elements

- 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



# the measurement error covariance matrix

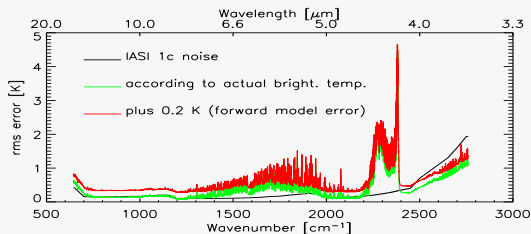
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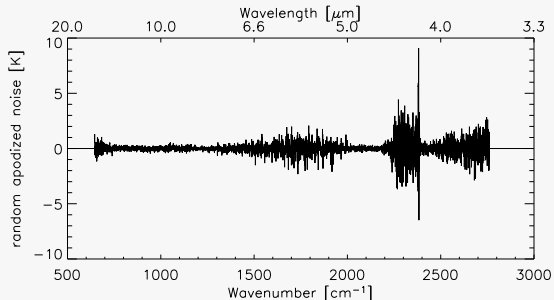


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# the simulation of the measurement vector

- 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

$$\left. \begin{array}{l} > 2500 \text{ cm}^{-1} : \text{ sun, inst.noise} \\ 1220 - 1370 \text{ cm}^{-1} : \text{ N}_2\text{O, CH}_4, \text{ SO}_2 \\ 2085 - 2200 \text{ cm}^{-1} : \text{ CO, N}_2\text{O} \end{array} \right\} \Rightarrow \sim 6200 \text{ channels} \quad (5)$$

### information content theory

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

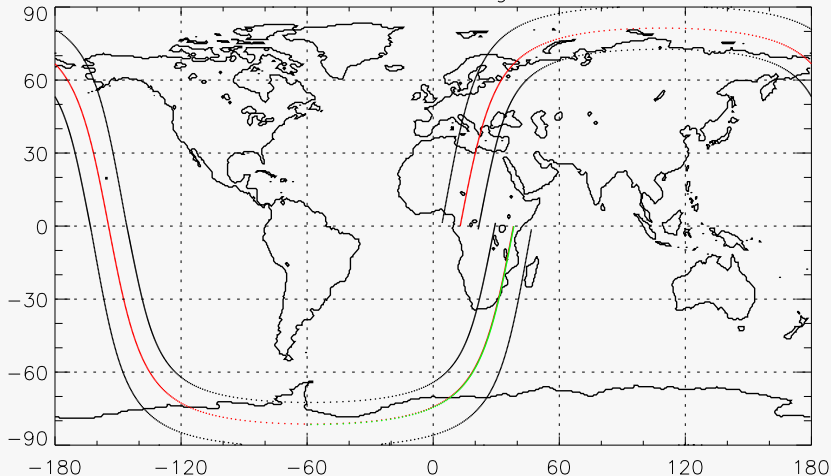
### maximum sensitivity approach

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



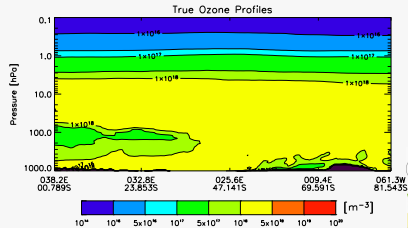
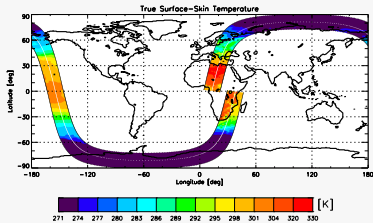
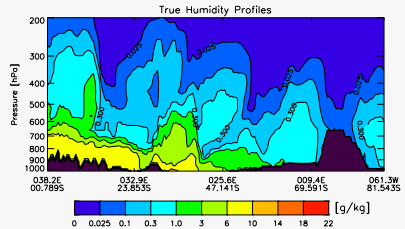
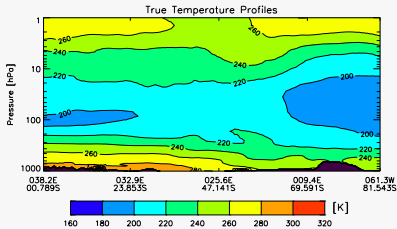
# the simulation region

Simulation Region



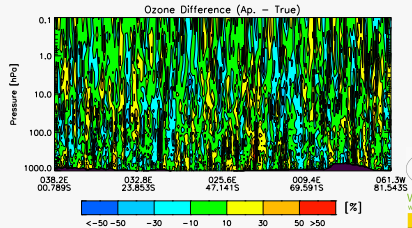
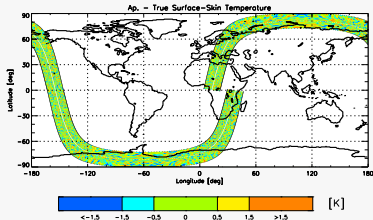
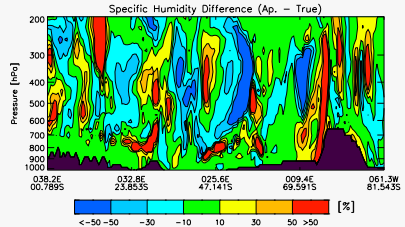
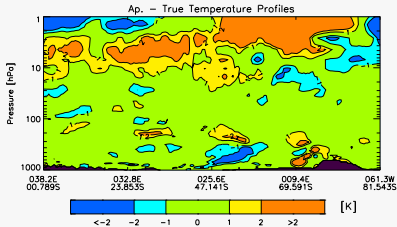
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# true fields

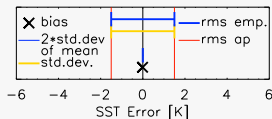
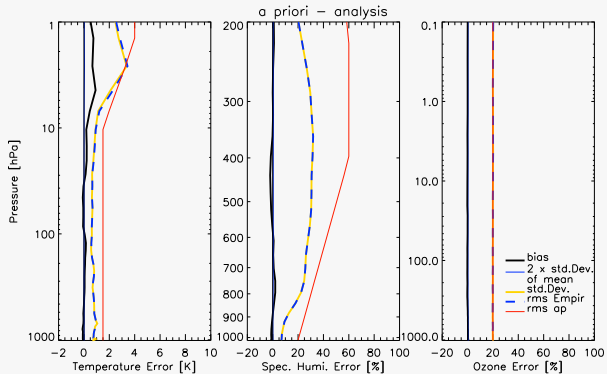




# *a priori* minus true – 24h forecast

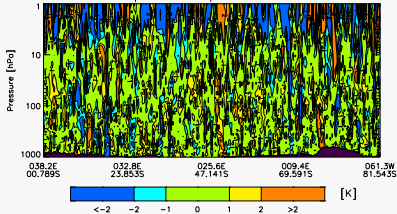


# *a priori* minus true – 24h forecast/ error data

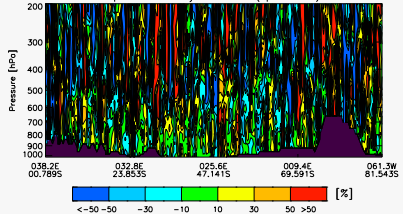


# *a priori* minus true – true perturbed

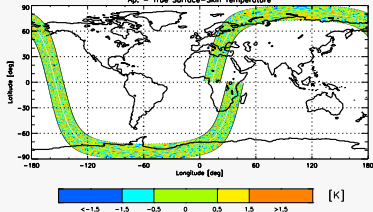
Ap. – True Temperature Profiles



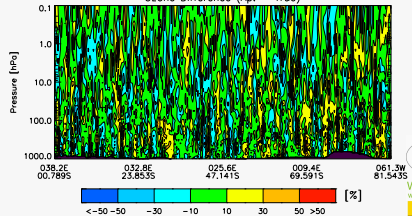
Specific Humidity Difference (Ap. – True)



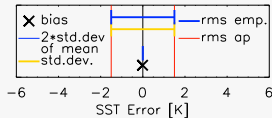
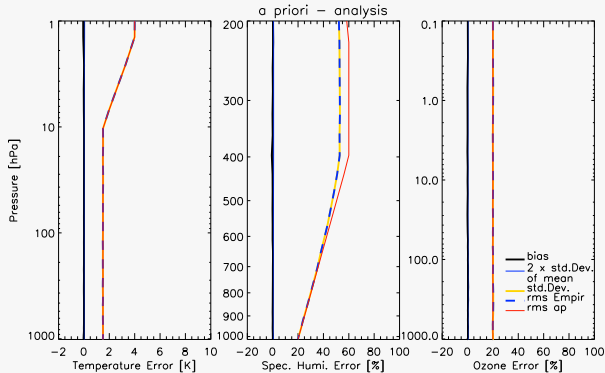
Ap. – True Surface-Skin Temperature



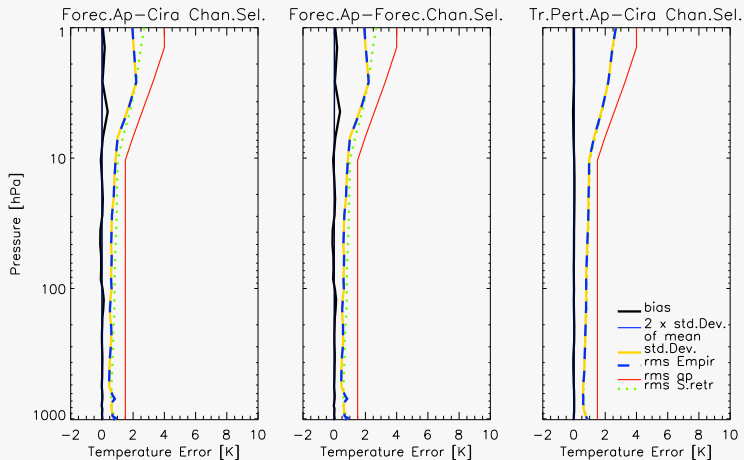
Ozone Difference (Ap. – True)



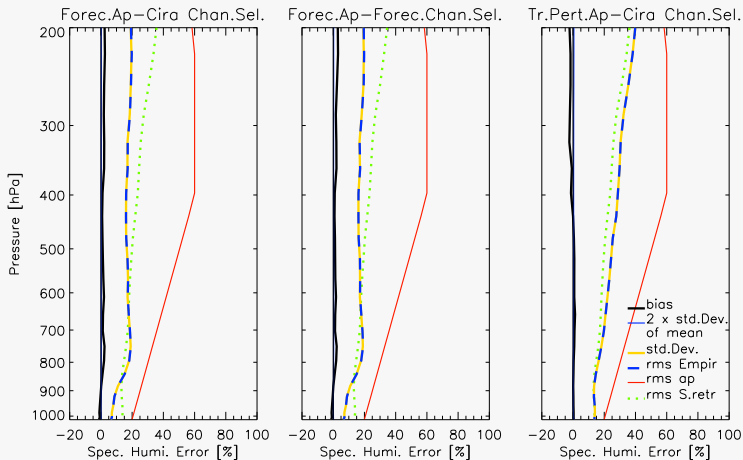
# *a priori* minus true – true perturbed/ error data



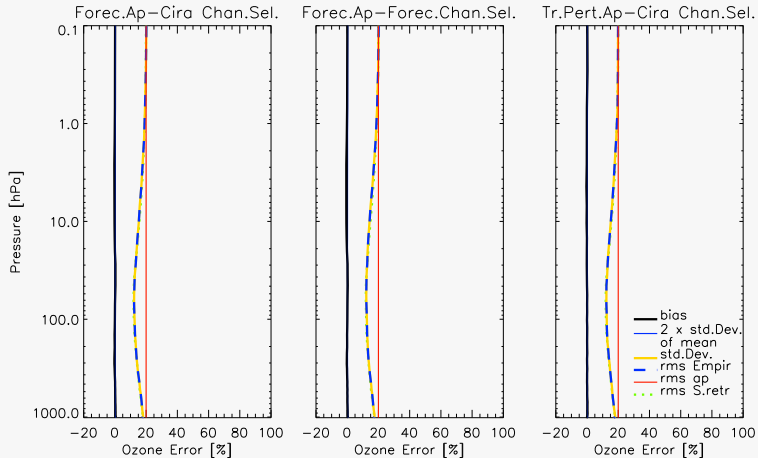
# temperature profiles – error analysis



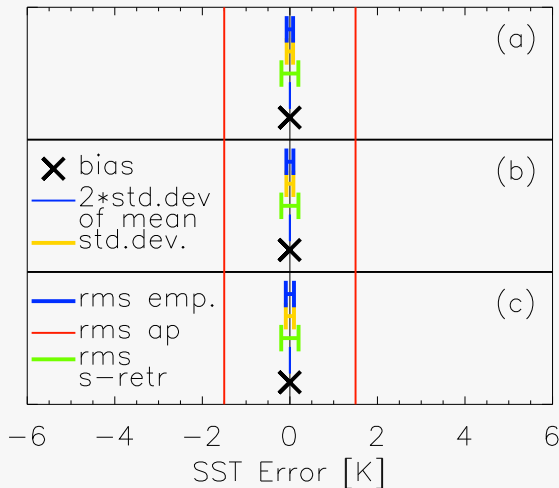
# humidity profiles – error analysis



# ozone profiles – error analysis

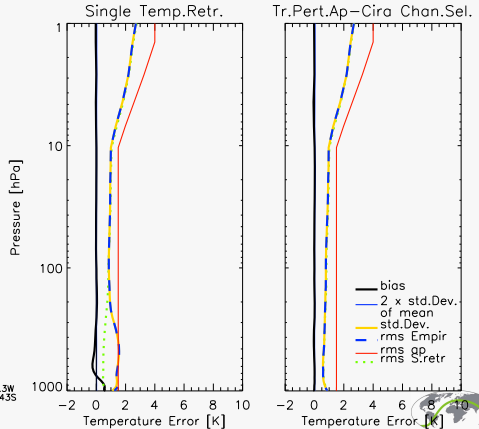
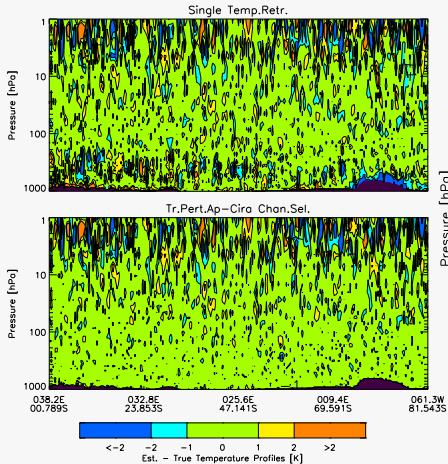


## SST – error analysis

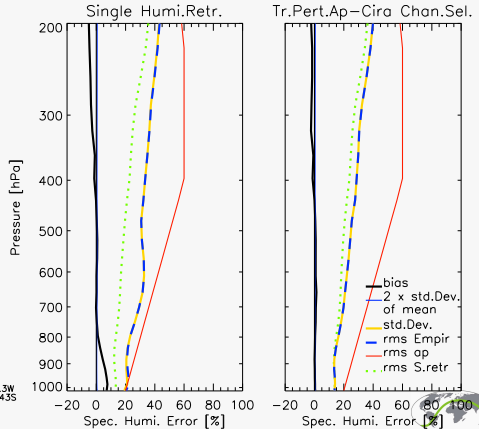
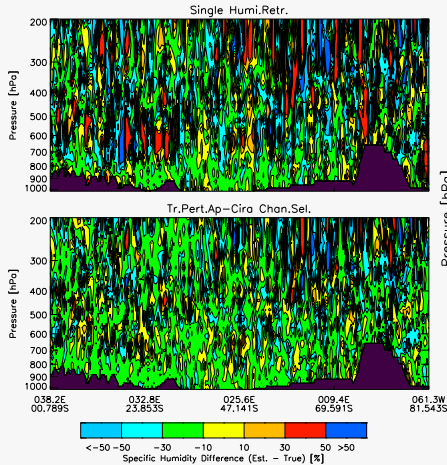




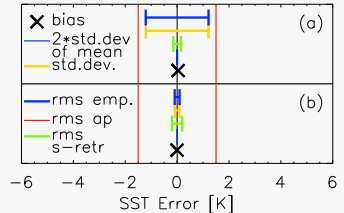
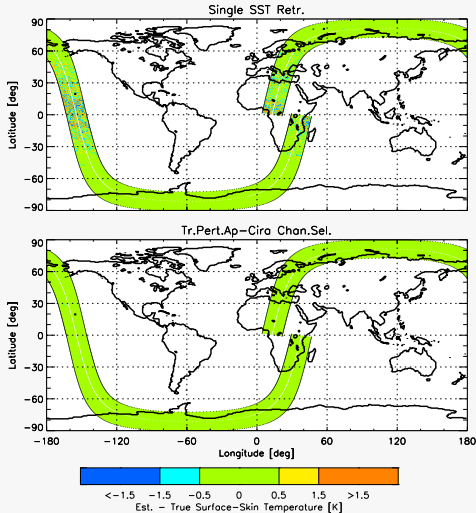
# single parameter retrieval – temperature



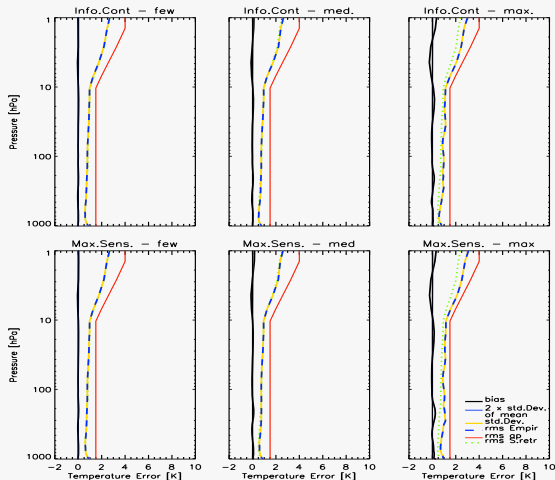
# single parameter retrieval – humidity



# single parameter retrieval – SST



# channel selection – a comparison



## numerical efficiency

- a) IC –  $\sim 300$  chan.
- b) IC –  $\sim 900$  chan.
- c) IC –  $\sim 1800$  chan.
- d) MS –  $\sim 300$  chan.
- e) MS –  $\sim 900$  chan.
- f) MS –  $\sim 1800$  chan.

## numerical efficiency

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

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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  
HIRS  
IASI

AMSU-A1,A2  
ASCAT  
GRAS  
MHS

Return

