IASI Level 2 Processing

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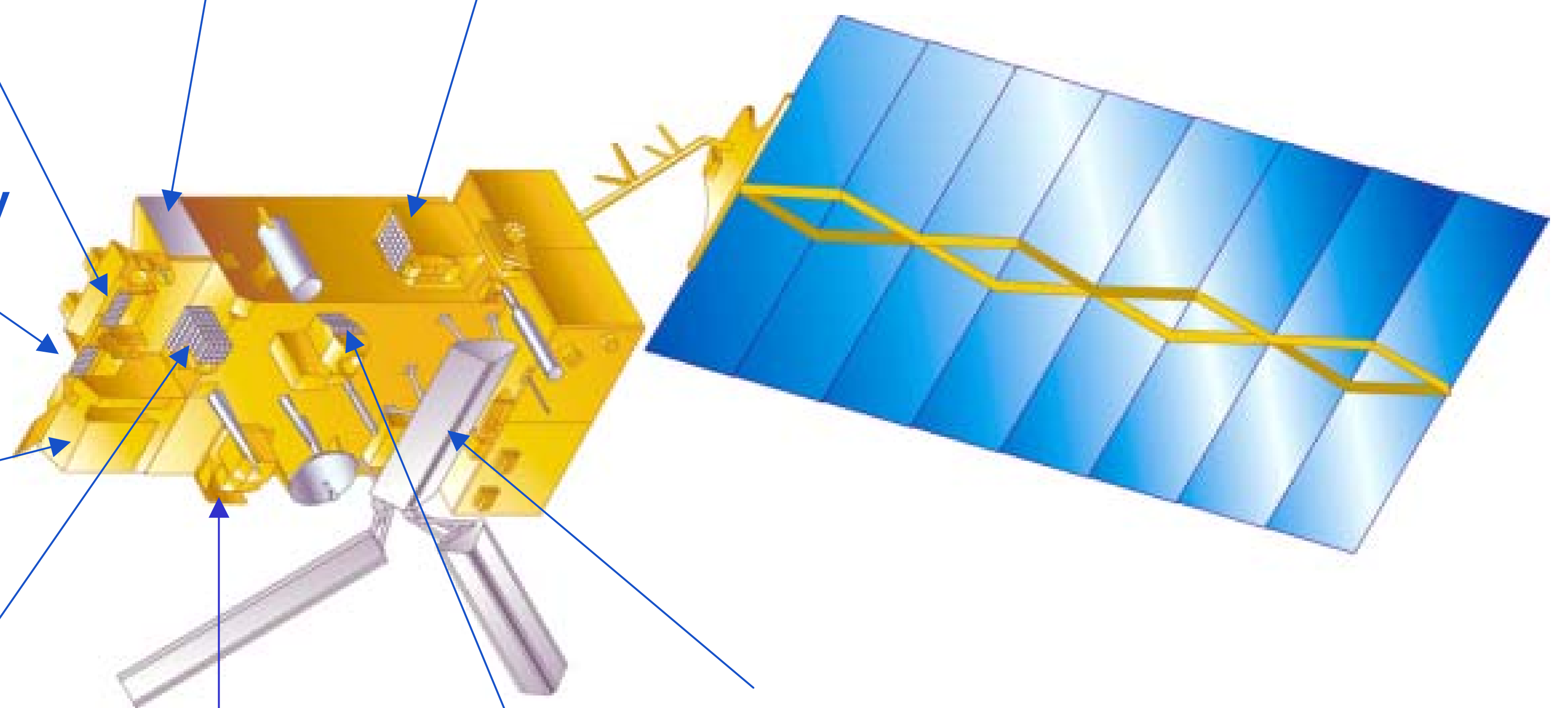
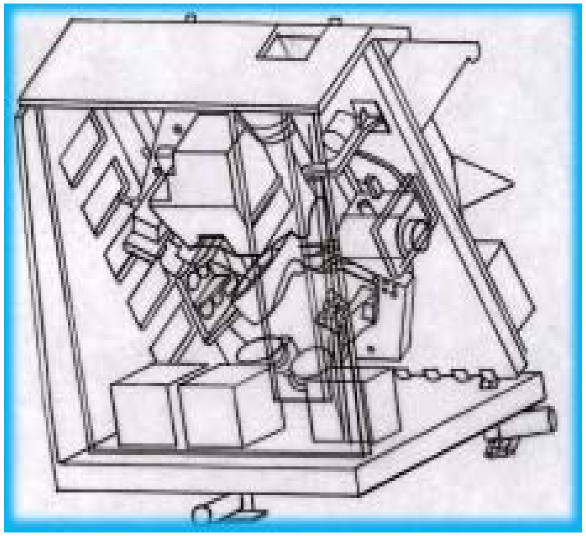
Outline

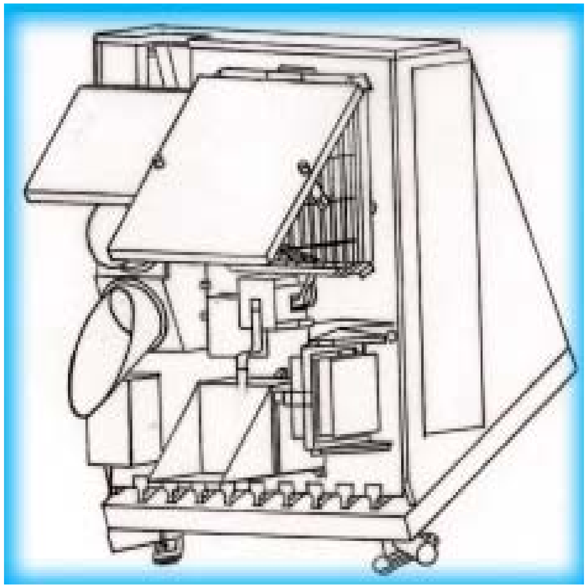
- IASI instrument properties
- IASI Level 2 processor overview
- IASI Level 2 physical retrieval

Metop: Satellite and Instruments



IASI Instrument Overview





• Pixel diameter	12 km at nadir
• Sampling interval	25 km at nadir
• Field of view	±48.33°
• Spectral range	645 to 2,760 cm^{-1}
• Spectral resolution	0.35 to 0.5 cm^{-1}
• Radiometric resolution	0.25 to 0.5 K
• Design lifetime	5 years
• Power consumption	200 W
• Dimensions	1.2 m x 1 m x 1.1 m
• Mass	211 kg
• Data rate	1.5 Mbit/s

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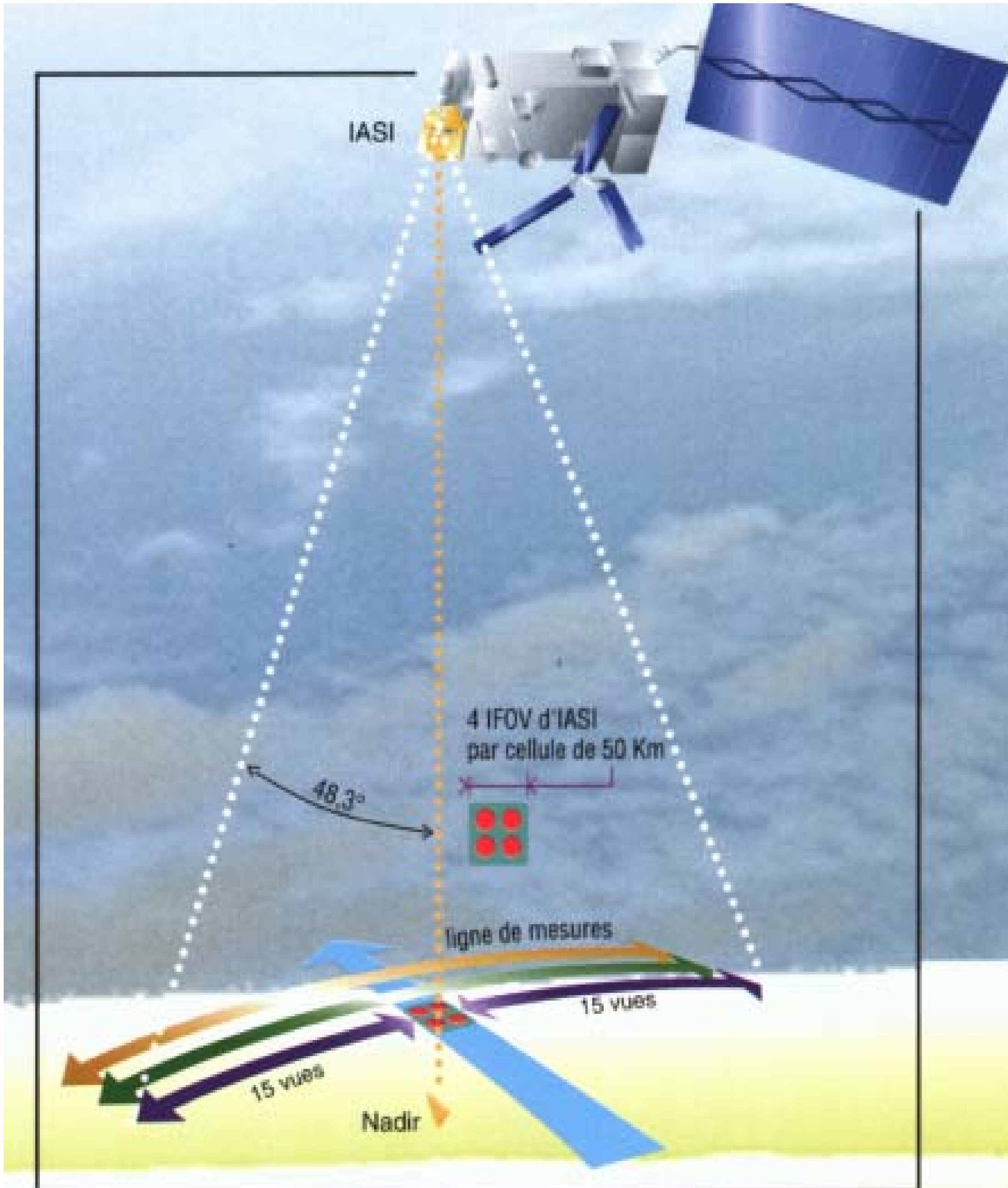
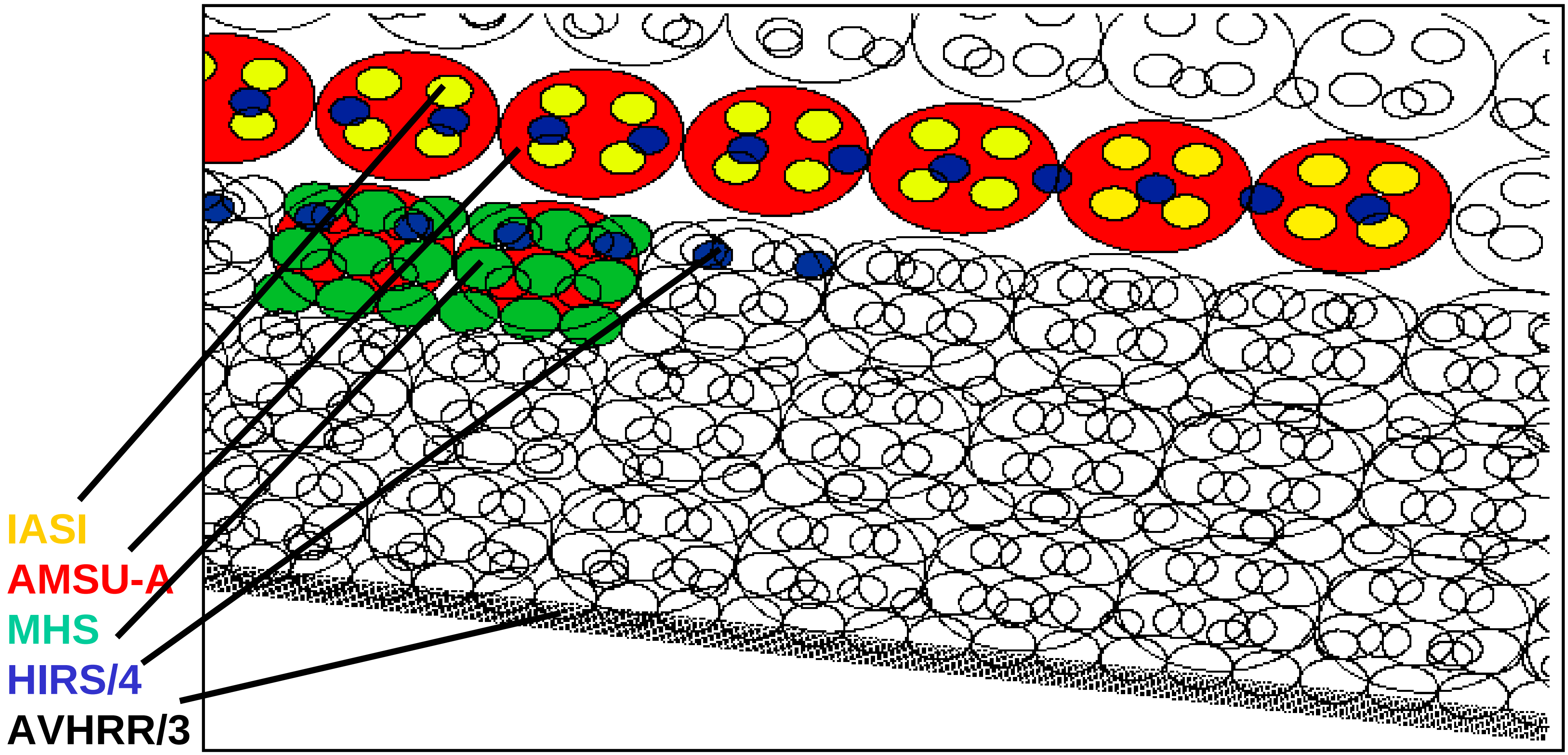
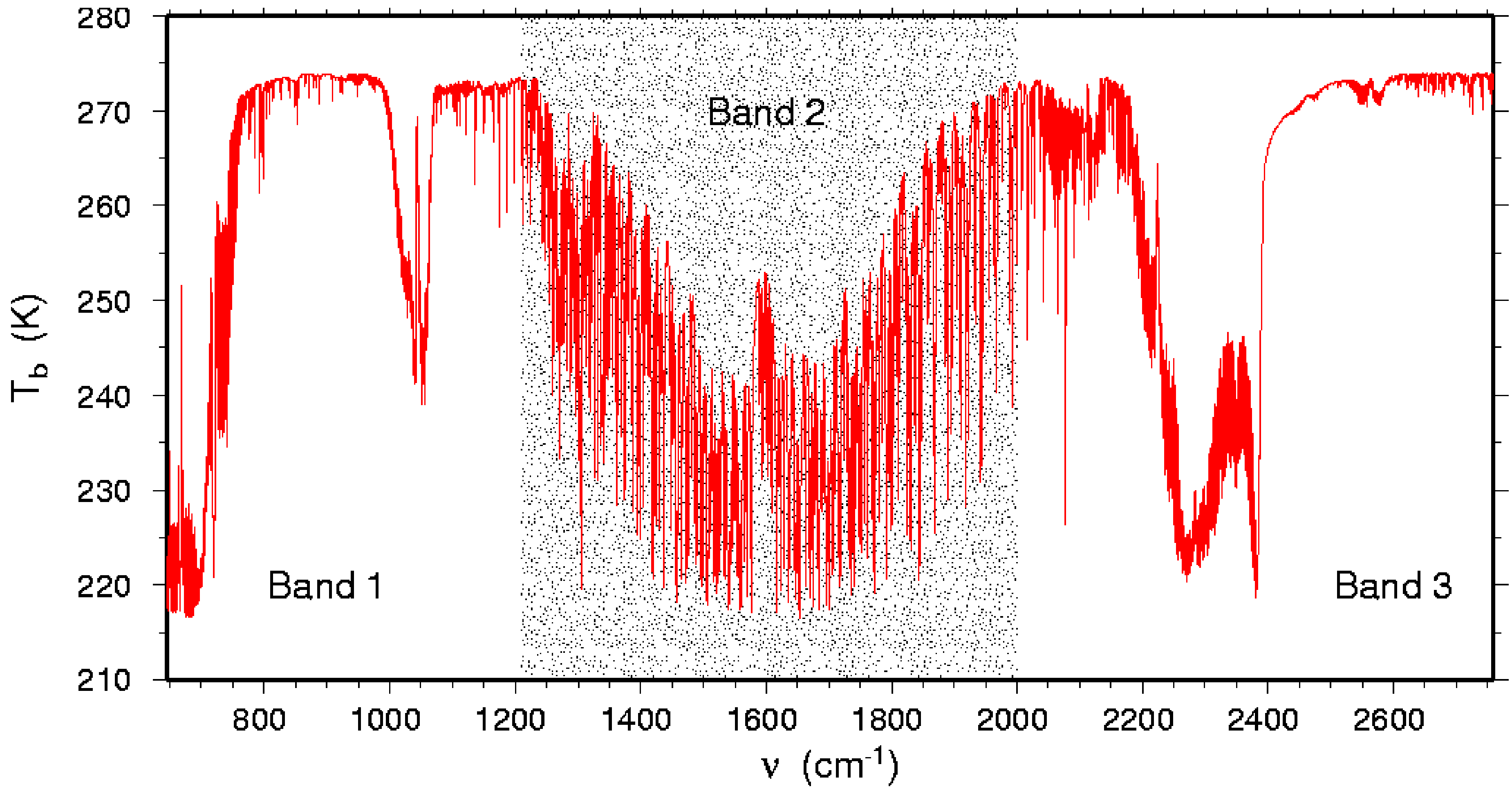

IASI
4 IFOV d'IASI
par cellule de 50 Km
48,3°
ligne de mesures
15 vues
15 vues
Nadir

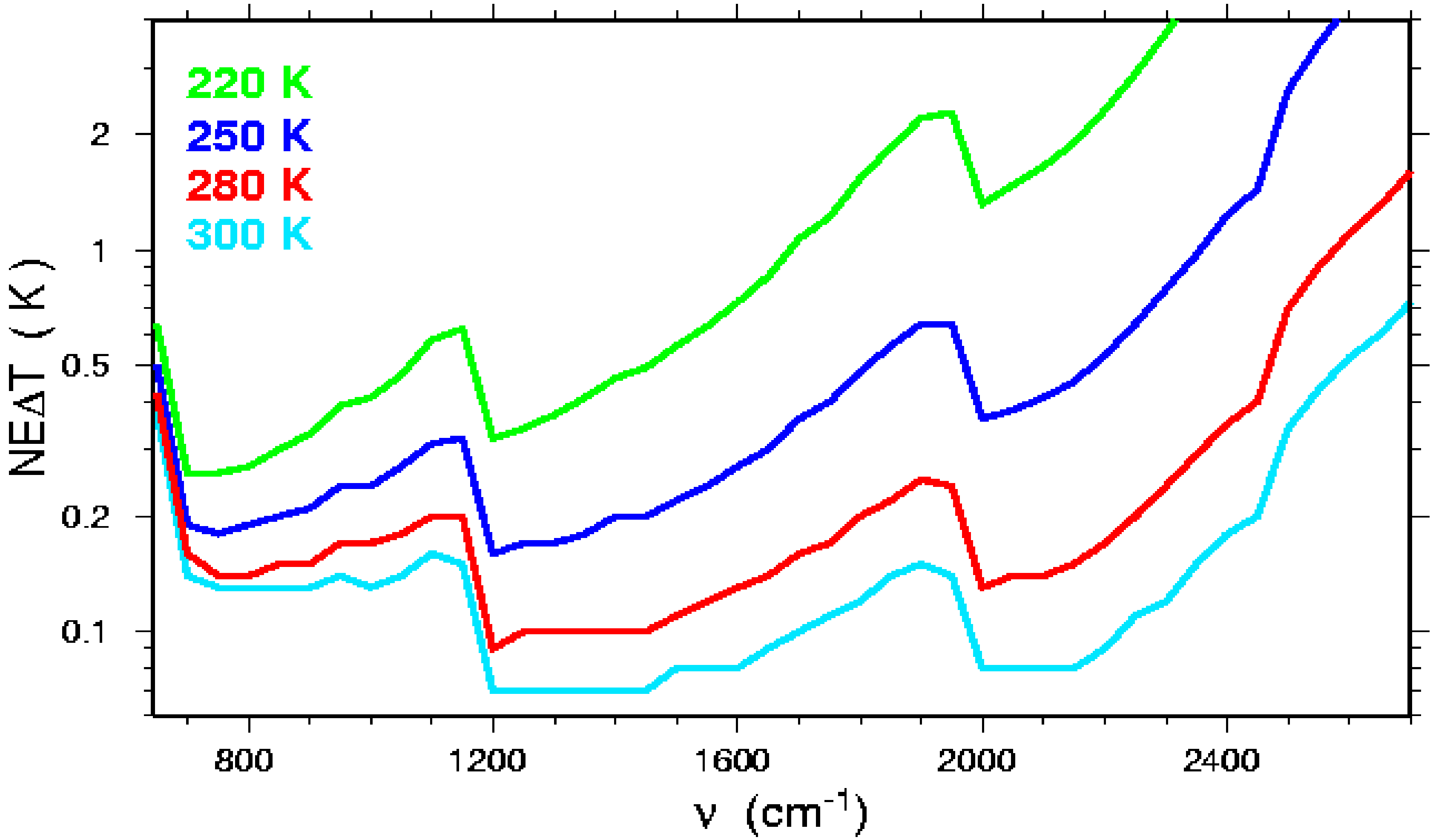
Instruments' Fields of View



IASI Spectral Bands



Instrument Noise at Different Temperatures



Operational IASI Level 2 Processor

- The IASI Level 2 product processing facility (PPF) is being built by industry in the frame of the EPS Core Ground Segment development, according to specifications given by EUMETSAT

- The specifications have been written according to current scientific knowledge as expressed in literature, results from scientific studies, heritage of AIRS, and input from review by ISSWG and IFCT

- Document: “EPS Ground Segment: IASI Level 2 Product Generation Specification” (current release: Issue 5, Rev. 4)

Properties of the Operational IASI L2 Processor

- Combined use of IASI, AVHRR, AMSU-A, MHS, and ATOVS Level 2
- Optional inclusion of NWP forecast is possible
- Flexibility due to steering of the processing options by configuration settings (86 configurable auxiliary data sets) allows for optimisation of PPF during commissioning
- Online quality control supports the choice of best processing options in case of partly unavailable or corrupt data
- Besides error covariances a number of flags are generated steering through the processing options and giving quality indicators (42 flags are specified), which are part of the product

Properties of the Operational IASI L2 Processor (cont.)

- All IASI “channels” can be used in the retrieval to maximise the retrieved information

$$\nu_k = 645.00 + (k+1) \times 0.25\,\mathrm{cm}^{-1}, k = 1, \ldots, 8461$$

- PPF supports nominal and degraded instrument modes (e.g. failure of single detectors)

- Bias control by radiance tuning via configuration

IASI Level 2 Product Generation
High Level Break-Down Structure

IASI Level 1

AVHRR Cloud Mask and S/CTT

Configurable Databases

ATOVS Level 2

AMSU-A Level 1

MHS Level 1

NWP Forecast

Pre-Processing

Cloud Processing

Geophysical Parameters Retrieval

Monitoring Information

Level 2 Product

Quality Information

Geophysical Parameters Retrieval
State Vector to be Retrieved

$$\mathbf{x} = (T_1,\ldots,T_{N_T}, W_1,\ldots,W_{N_W}, O_1,\ldots,O_{N_O}, C_{N2O}, C_{CO}, C_{CH4}, C_{CO2},$$
$$T_{S1}, T_{S2}, \varepsilon_1,\ldots,\varepsilon_{N_\varepsilon},$$
$$\alpha_1,\alpha_2,\alpha_3,\varepsilon_1^{cld},\varepsilon_2^{cld},\varepsilon_3^{cld}, T_{C1}, T_{C2}, T_{C3}, p_{C1}, p_{C2}, p_{C3}, \phi)$$

Geophysical Parameters Retrieval
First Retrieval

- EOF regression for temperature and water-vapour, and ozone profiles, surface temperature, and surface emissivity

- Artificial neural network (multi-layer perceptron) for trace gases (optionally also for temperature, water-vapour and ozone, depends on configuration setting)

- The results from the first retrieval may constitute the final product or may serve as input to the final, iterative retrieval, the choice depends on configuration setting and on quality of the first retrieval results

EOF Regression Retrieval

$$T_n^{'} = \overline{T_{n,m}} + \sum_{i=1}^{L} R_{n,i,m}(s_{i,m} - \overline{s_{i,m}})$$

$$s_{i,m} = \sum_{k=1}^{K} (T_{bk,m} - \overline{T_{bk,m}}) E_{k,i,m}$$

- T'_n = retrieved deviation from mean temperature profile (incl. surface temperature), $R_{n,i,m}$ = covariance operators at level n, eigenvector i, and surface type m, $s_{i,m}$ = principal component scores, $T_{bk,m}$ = measured IASI brightness temperature spectrum, $E_{k,i,m}$ = pre-calculated eigenvectors
- Analogue expressions for water vapour, ozone, emissivity
- Pre-calculated operators, eigenvectors and mean quantities are configurable

Artificial Neural Network for Trace Gas Columns

$$C = \left\{ \sum_{k=1}^{S_2} w_{1k} \, f\left(\sum_{j=1}^{S_1} w_{kj} \, f\left(\sum_{i=1}^{N_{RTr}} w_{ij} R''(i) + \sum_{i=N_{RTr}+1}^{N_{RTr}+M} w_{ji} T'(i - N_{RTr}) + C_j \right) + C_k \right) + C_1 \right\}$$

$$f(z) = \tanh(z)$$

- Retrieval of columnar trace gas amounts from a sub-set of $N_{RTr} \leq 200$ IASI radiances $R(i)$ and a coarse temperature profile $T(i - N_{RTr})$, defined on $M \leq 10$ levels, using a multi-layer perceptron with S_1 and S_2 neurons in the first and second hidden layers, respectively

- Weights and number of neurons are configurable

- The coarse temperature profile will be taken from the first retrieval

Physical Retrieval

- Simultaneous iterative retrieval, seeking maximum probability solution by Marquardt-Levenberg method (combination of steepest descent and Newtonian iteration), using a subset of IASI channels, combined to super-channels

- Initialisation with results from first retrieval

- Other choices of initialisation may be selected, depending on configuration setting (e.g. NWP forecast, climatology)

- Background state vector from climatology, ATOVS, adjacent retrieval, or NWP forecast, depending on configuration

- State vector to be iterated depends on cloud conditions and configuration setting (clear, cloudy, variational cloud clearing)

Geophysical Parameters Retrieval
State Vector in Clear and Cloudy Cases

- Clear case, single IFOV

$$\mathbf{x} = (T_1,\ldots,T_{N_T}, W_1,\ldots,W_{N_W}, O_1,\ldots,O_{N_O}, C_{N2O}, C_{CO}, C_{CH4}, C_{CO2}, T_{S1}, T_{S2}, \varepsilon_1,\ldots,\varepsilon_{N_\varepsilon})$$

- Cloudy retrieval, single IFOV

$$\mathbf{x} = (T_1,\ldots,T_{N_T}, W_1,\ldots,W_{N_W}, O_1,\ldots,O_{N_O}, C_{N2O}, C_{CO}, C_{CH4}, C_{CO2}, T_{S1}, T_{S2}, \varepsilon_1,\ldots,\varepsilon_{N_\varepsilon}, \alpha_{C1}, \alpha_{C2}, \alpha_{C3}, \varepsilon_1^{cld}, \varepsilon_2^{cld}, \varepsilon_3^{cld}, T_{C1}, T_{C2}, T_{C3}, p_{C1}, p_{C2}, p_{C3})$$

- Variational cloud clearing, IFOV quadruples

$$\mathbf{x} = (T_1,\ldots,T_{N_T}, W_1,\ldots,W_{N_W}, O_1,\ldots,O_{N_O}, C_{N2O}, C_{CO}, C_{CH4}, C_{CO2}, T_{S1}, T_{S2}, \varepsilon_1,\ldots,\varepsilon_{N_\varepsilon}, \eta_1, \eta_2, \eta_3)$$

Preparation of Variational Cloud Clearing

- Inclusion of cloud-clearing parameters η_ι^0 in variational retrieval, allowance for up to three cloud formations
- Retrieval for combination of IFOV-quadruples in an EFOV

$$\begin{pmatrix} R_1^{clr} - R_{1,1} \\ R_2^{clr} - R_{2,1} \\ \vdots \\ R_{N_C}^{clr} - R_{N_C,1} \end{pmatrix} = \begin{pmatrix} R_{1,1} - R_{1,2} & R_{1,1} - R_{1,3} & R_{1,1} - R_{1,4} \\ R_{2,1} - R_{2,2} & R_{2,1} - R_{2,3} & R_{2,1} - R_{2,4} \\ \vdots & \vdots & \vdots \\ R_{N_C,1} - R_{N_C,2} & R_{N_C,1} - R_{N_C,3} & R_{N_C,1} - R_{N_C,4} \end{pmatrix} \begin{pmatrix} \eta_1^0 \\ \eta_2^0 \\ \eta_3^0 \end{pmatrix}$$

- First guess of clear radiances from RT calculations based on ATOVS profiles

Maximum Probability Solution
Formulation of Cost Function

- Minimisation of cost function

$$J = (\mathbf{y}(\mathbf{x}) - \mathbf{y}^{\mathbf{m}})\mathbf{E}^{-1}(\mathbf{y}(\mathbf{x}) - \mathbf{y}^{\mathbf{m}})^{\mathbf{T}} + (\mathbf{x} - \mathbf{x}^{\mathbf{b}})\mathbf{C}^{-1}(\mathbf{x} - \mathbf{x}^{\mathbf{b}})^{\mathbf{T}}$$

- $\mathbf{x}$ = atmospheric state vector as calculated iteratively
- $\mathbf{x}^{\mathbf{b}}$ = atmospheric state vector from background field
- $\mathbf{C}$ = the error covariance matrix associated with the background
- $\mathbf{y}^{\mathbf{m}}$ = measurement vector
- $\mathbf{E}$ = combined measurement and forward model error covariance matrix
- $\mathbf{y}(\mathbf{x})$ = forward model operator for given state vector $\mathbf{x}$
- $\mathbf{K}_{\mathbf{x}}$ = partial derivatives of $\mathbf{y}$ with respect to the elements of $\mathbf{x}$ (Jacobians)

Maximum Probability Solution
Minimisation of Cost Function

- Increment after each iteration step

$$\delta \mathbf{x} = -(\mathbf{J}'' + \xi\, \mathbf{I})^{-1} \mathbf{J}'$$

- with

$$\mathbf{J}' = \mathbf{K}_{\mathbf{x}}^{\mathbf{T}} \mathbf{E}^{-1} (\mathbf{y}(\mathbf{x}_{\mathbf{i}}) - \mathbf{y}^{\mathbf{m}}) + \mathbf{C}^{-1} (\mathbf{x}_{\mathbf{i}} - \mathbf{x}^{\mathbf{b}})$$

$$\mathbf{J}'' = \mathbf{K}_{\mathbf{x}}^{\mathbf{T}} \mathbf{E}^{-1} \mathbf{K}_{\mathbf{x}} + \mathbf{C}^{-1}$$

- Error covariance of the iterated solution

$$\mathbf{S}_{\mathbf{n}} = (\mathbf{C}^{-1} + \mathbf{K}_{\mathbf{x}}^{\mathbf{T}} \mathbf{E}^{-1} \mathbf{K}_{\mathbf{x}})^{-1}$$

Maximum Probability Solution
Constraints on Iteration and Convergence

- Super-saturation only within the error bounds of the temperature profile
- Super-adiabatic layering only within the error bounds of the temperature profile
- Iteration step is only accepted if cost function decreases
- Termination of iteration according to following criteria or after given number of iterations

$$\left|(J_n - J_{n-1}) \big/ J_{n-1}\right| < t_{\chi,1} \quad \text{or} \quad \left\| J_n^{'} \right\| < t_{\chi,2} \quad \text{or} \quad \frac{\left\| \mathbf{x}_n - \mathbf{x}_{n-1} \right\|}{\left\| \mathbf{x}_{n-1} \right\|} < t_{\chi,3}$$

- The termination threshold and the maximum number of iterations are configurable

Parameters Steering the Physical Retrieval Control Parameter ξ

- Initialised by mean diagonal of covariance matrix, multiplied by a constant factor
- Updated according to convergence criteria:
  - If cost function increases, step is not taken
    - ξ is changed towards steeper descent
  - If cost function decreases, step is taken
    - If change is greater than a threshold ξ is changed towards more Newtonian
    - If change is smaller than a threshold ξ is kept constant

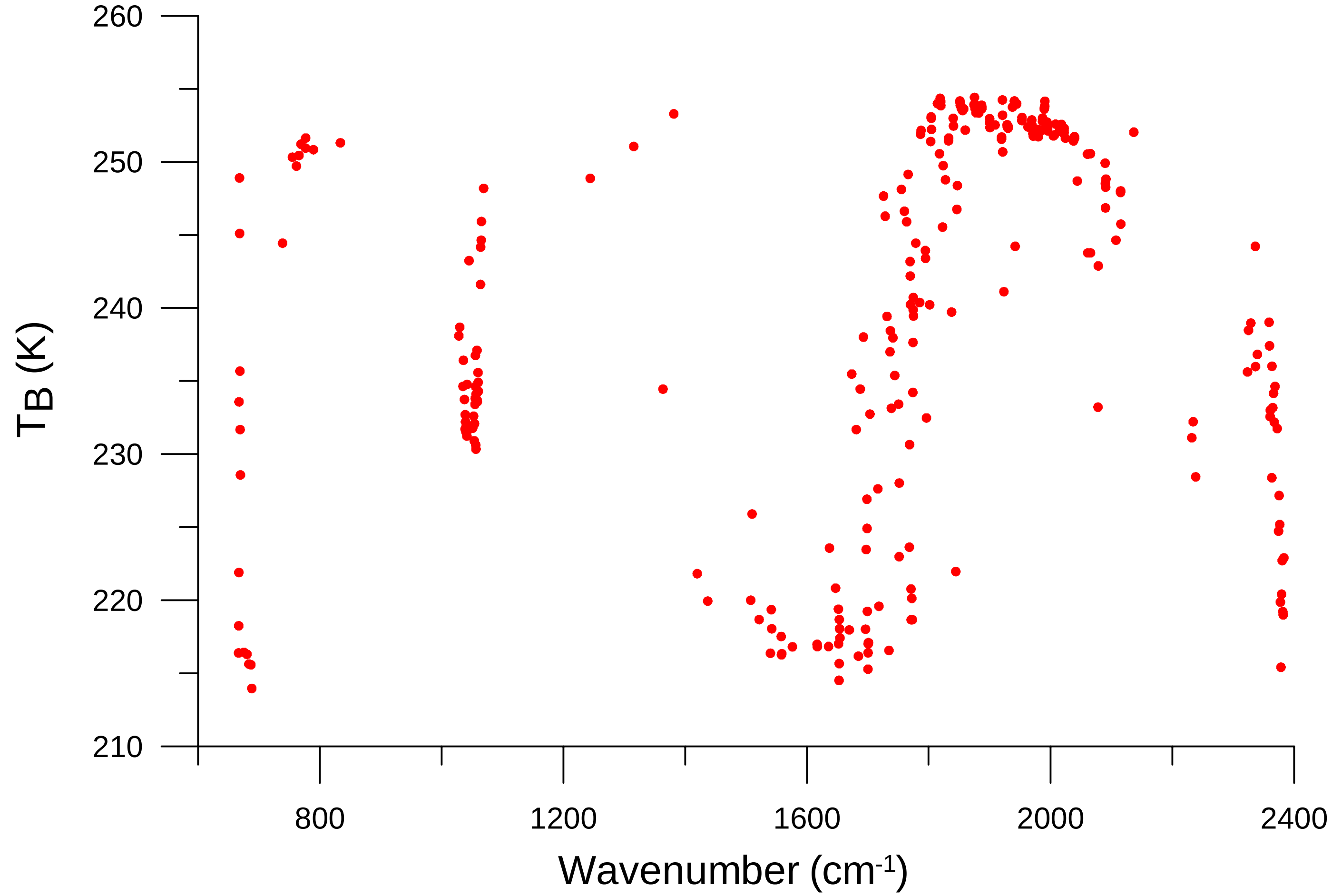
Parameters Steering the Physical Retrieval Background Vector and Covariance

- Climatology is taken as background constraint as NWP forecast is not desired in retrieval
- Problem: climatology imposes strong constraint with respect to vertical correlation, relaxation on the vertical correlation will be necessary

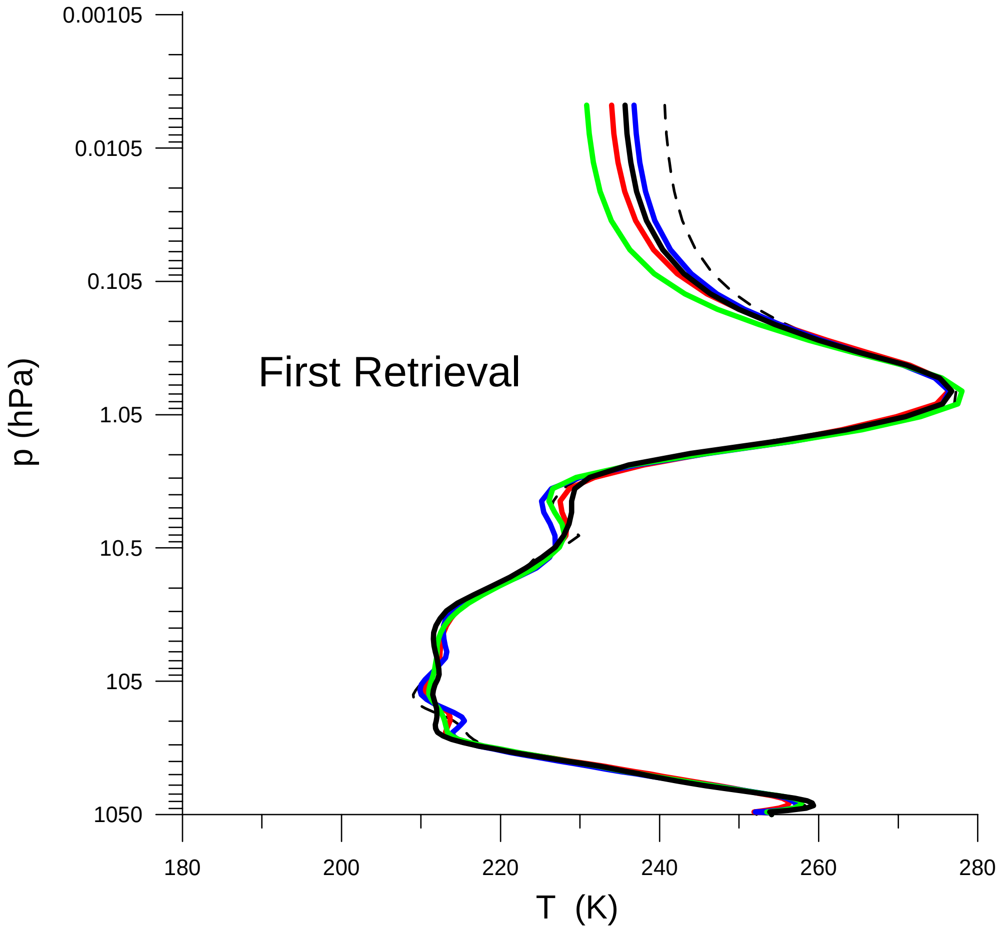
Retrieval Experiments

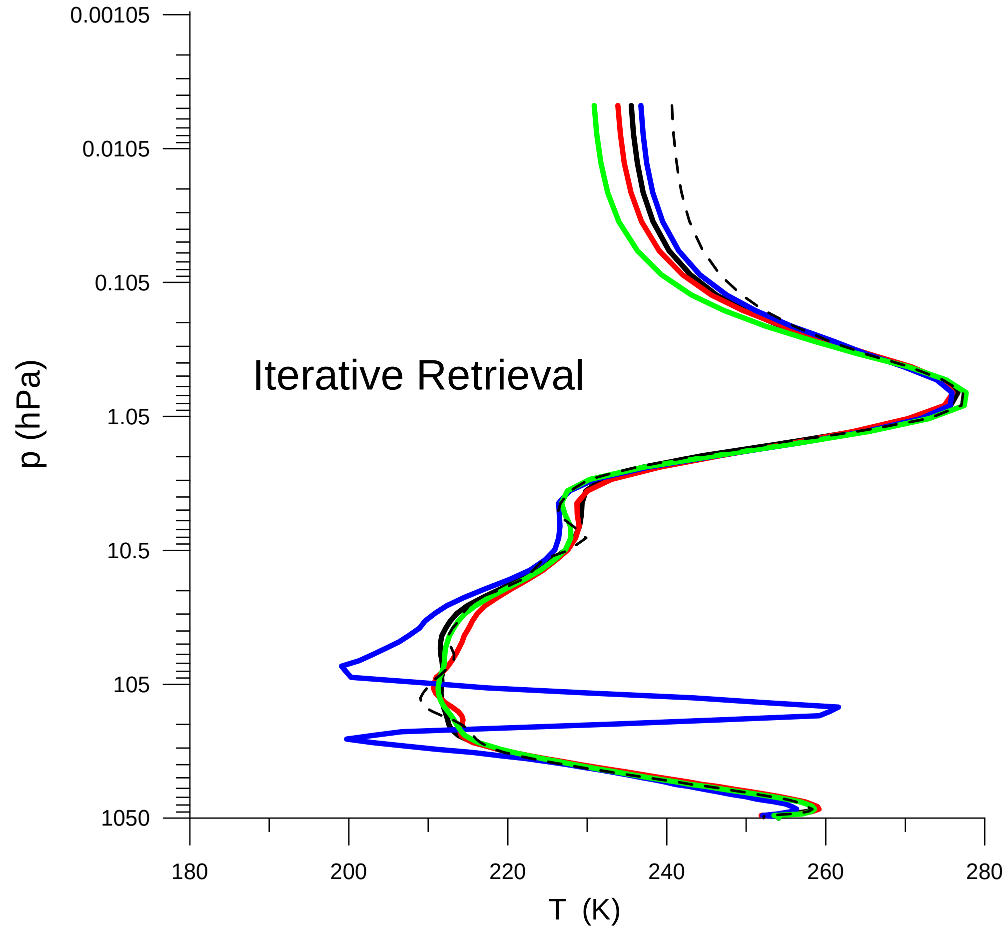
- Choice of 295 IASI channels with well distributed weighting functions, representing the atmospheric state to be retrieved
- Level 2 product shall be independent of NWP forecast
  - Regularisation by climatology or related smoothness-function
- Physical retrieval is started with a first guess from an EOF regression retrieval using all IASI channels

Selection of 295 IASI Channels



Same Atmospheric Situation Measured in 4 IASI IFOVs with Different NEΔT from Same distribution





Problem 1

- A small perturbation in the first guess profile is strongly amplified by the physical retrieval, leading to an unrealistic result
- How to cure?
  - Tighten the a priori constraint (e.g. apply further constraints such as no super-saturation and no super-adiabatic layering)
  - Chose better representation of state vector (e.g. deep layer means)
  - Improve initial choice of ξ: right balance between steepest descent and Newtonian iteration
  - Removal of components in/near null space
  - Relax measurement noise in early iteration steps (cost is too high)
- What is useful for high-resolution sounding?

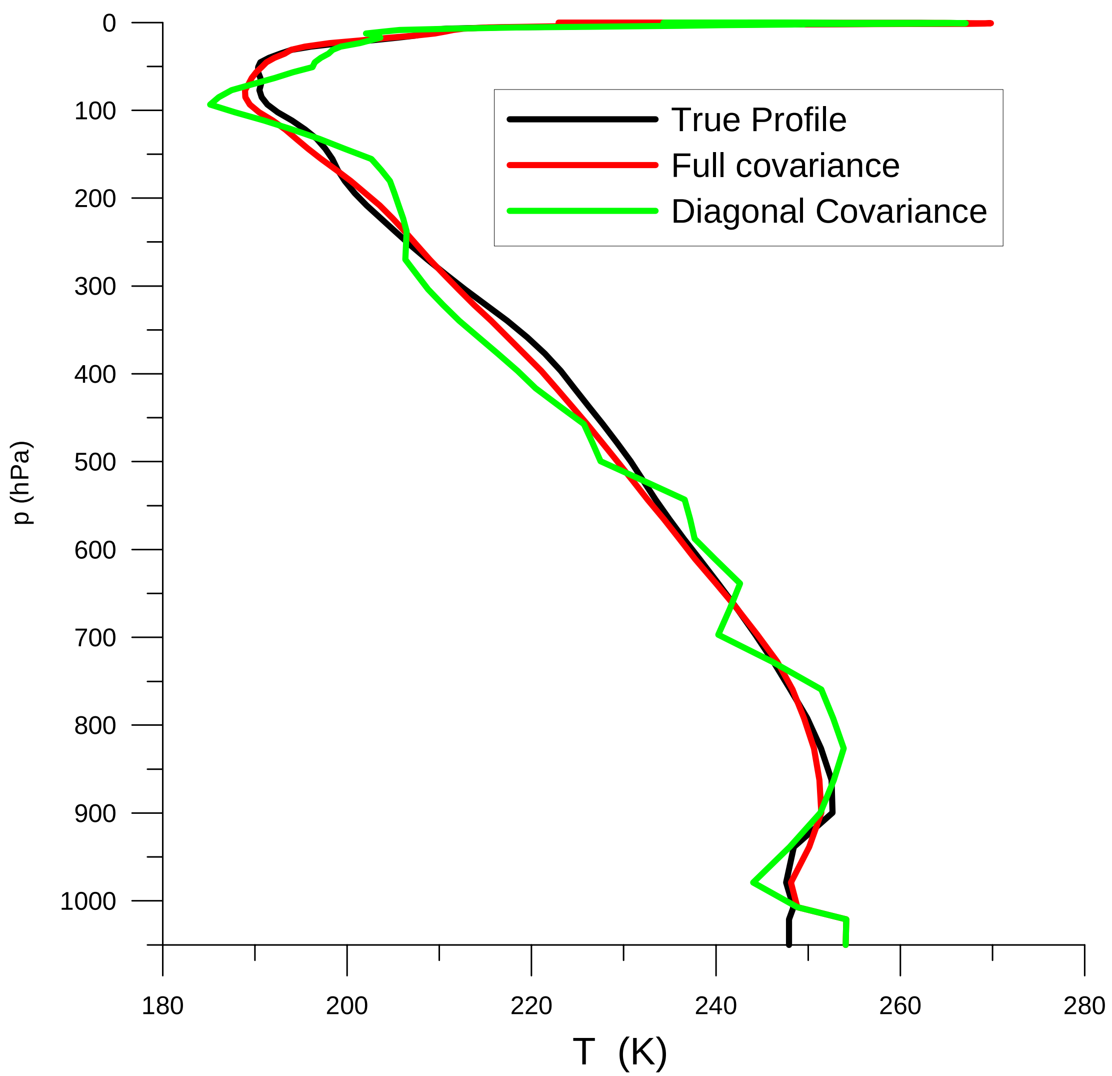
Uniqueness

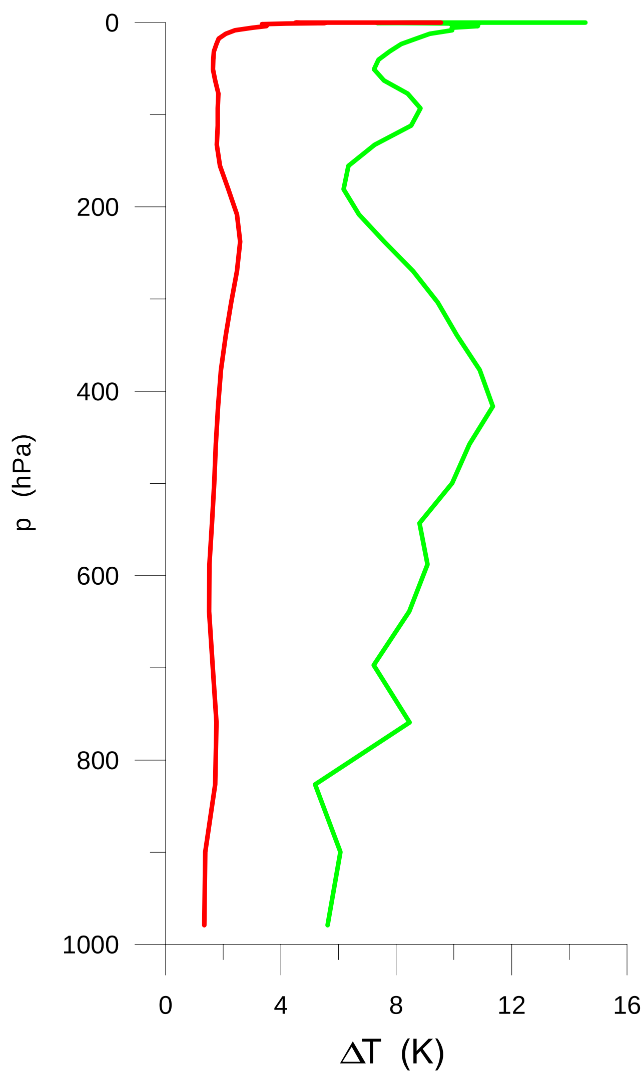
- Components of the state which are in the row space are likely to be measured well
  - Little a priori constraint necessary
  - example: surface temperature measured with window channels
- Components of the solution which are in the null space or near-null space cannot be retrieved from the measurements
  - Removal of such components as far as possible
  - Introduction of strong a priori constraint where unavoidable
  - example: high-resolution profiles
- If components which lie in the null space are included the retrieval and are not strongly constrained by a priori will produce non-unique results

Problem 2

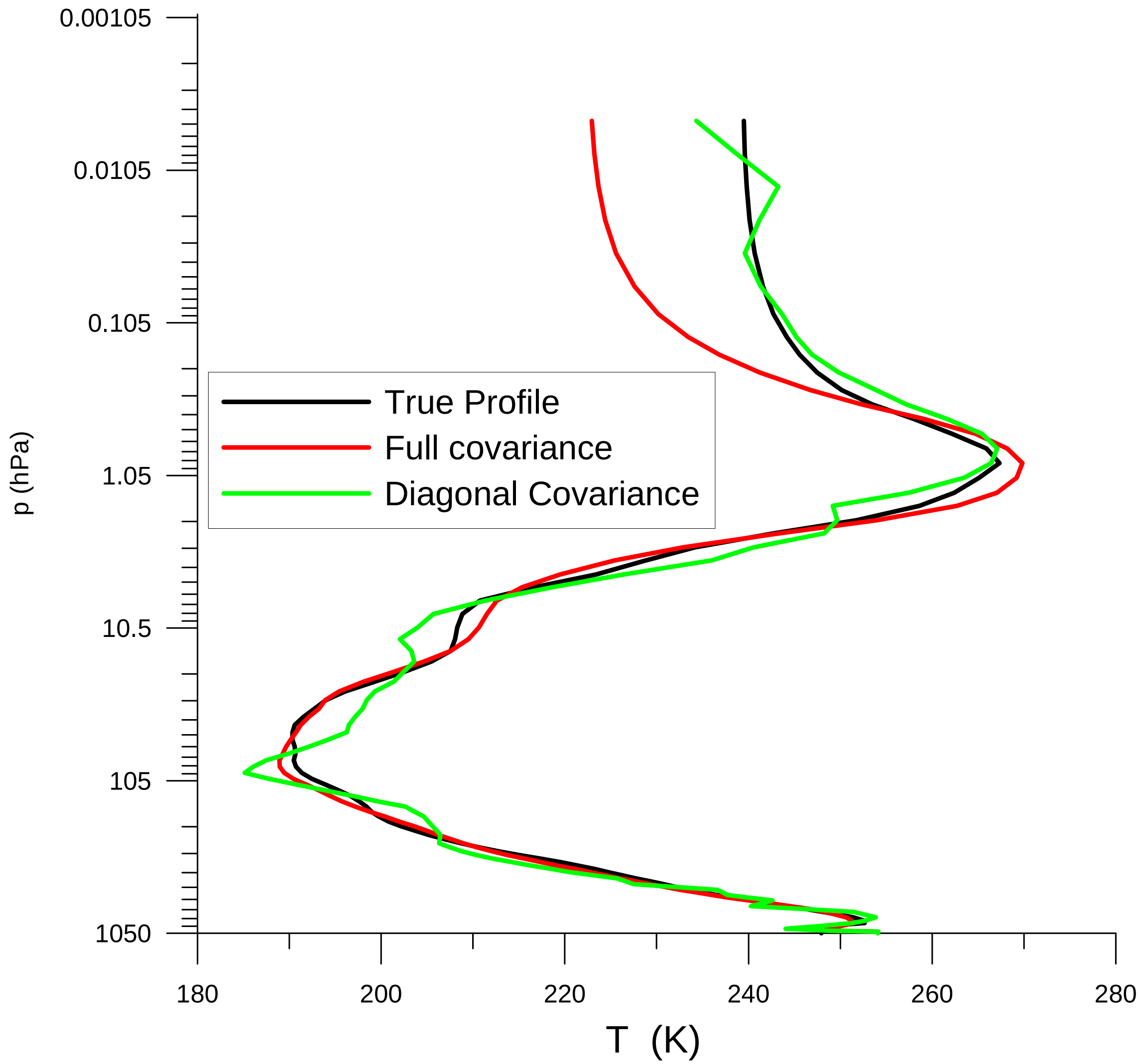
- Application of strong constraints like climatology prevent the physical retrieval from observing fine-scale structures in the profiles
  - If fine structure is present in the first guess it will be taken up by the physical retrieval and can be modified according to the measurements
  - Lacking fine structure in the first guess is not recovered by the physical retrieval if the background constraint prescribes close correlation between adjacent or distant layers
- Way forward
  - Relax background constraint at the cost of increased retrieval errors
  - Profile will show much fine-structure
  - User will need full covariance matrix to assimilate such profiles, which do not look realistic

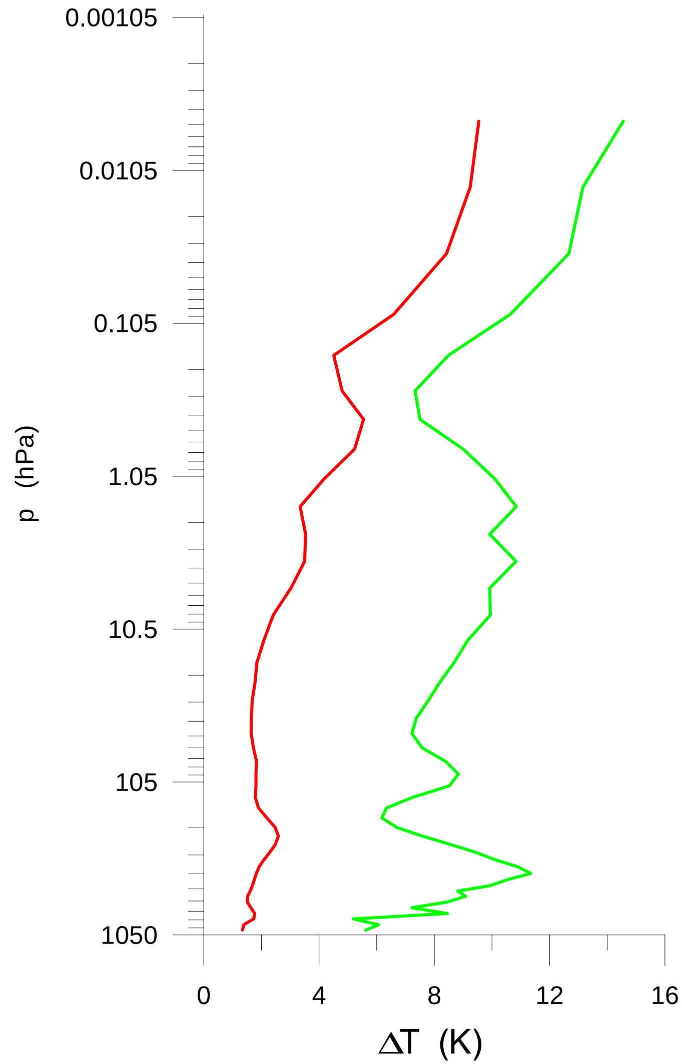
Effect of a priori Constraint





Effect of a priori Constraint





General Observations

- The physical retrieval improves over the statistical retrieval (used as first guess)
- Fine structure is rarely added by the physical retrieval if climatological background is used
- Strong background/a priori constraint tends to suppress fine structure which was in the first guess