AIRS stratospheric temperature retrievals at full horizontal resolution

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1 Motivation
Why do we need temperature data at full horizontal resolution?

2 Forward modelling for AIRS
Brief description of the JURASSIC forward model.
Model optimization and validation.

3 Stratospheric temperature retrievals
Brief description of the optimal estimation approach.
Retrieval parameter studies and characteristics.

4 First results and summary
Retrieved temperature data for selected AIRS granules.
AIRS radiance measurements provide information about stratospheric gravity waves on small horizontal scales...

(Typical horizontal wavelength in this area: $\lambda_x \sim 100$ km)
Motivation

Example of gravity waves produced by deep convection...

12–JAN–2003, 16:44 UTC, near Darwin, Australia

⇒ Loss of horizontal resolution in operational temperature retrieval (20 km → 60 km; cloud-clearing) is a drawback for gravity wave studies...
Forward Modelling for AIRS

- **Juelich Rapid Spectral Simulation Code (JURASSIC)**

- Fast radiative transfer model for the mid-infrared spectral region (4...15 micron, LTE, no scattering, no surface).

- **Approximations** for fast radiative transfer calculations:
  - Band Transmittance Approximation
  - Emissivity Growth Approximation
  - Independent Gas Approximation
  - Look-up tables for spectral mean emissivity

- Flexible handling of different types of observation geometry and atmospheric data:
  - Interpolation of 1D, 2D or 3D atmospheric data (single profiles, satellite track, model output)
  - Observer within or outside atmosphere
  - Nadir, sub-limb, limb or zenith viewing
Modelling of instrument effects:
- Spectral filter functions (ILS, SRF,...)
- Vertical field of view (FOV)
- Offset and gain calibration

Retrieval interface:
- Definition of state and measurement vector \((x, b, y)\)
- Jacobians by numerical perturbation \((z, p, T, q_i, k_j, c_0, c_1)\)

Optimization studies and validation studies:
- Optimized ray-tracing step length
- Optimized emissivity look-up tables
- Comparisons against MIPAS RFM
- Comparisons against AIRS SARTA

Documentation and download:
https://jurassic.icg.kfa-juelich.de
⇒ CPU-time for forward calculation is about 20 msec on a normal PC. Reduction by a factor 1000 compared to line-by-line reference calculations.
Reference model output is reproduced within AIRS noise. Results for 4 micron channels are similar.
Good agreement! 4 micron kernels are rather broad (due to broad SRFs), i.e. provide less information on vertical distribution, but help to reduce noise.
Optimal estimation approach: Find optimal estimate (i.e. MAP solution) of retrieval targets $x$ for given measurements $y$ by minimizing a cost function:

$$J(x) = (y - F(x))^T S_\varepsilon^{-1} [y - F(x)] + (x - x_a)^T S_a^{-1} (x - x_a)$$

where:

- $x = \text{atmospheric state}$
- $y = \text{radiance measurements}$
- $S_\varepsilon = \text{measurement error covariance}$
- $F(x) = \text{simulated observations (forward model)}$
- $x_a = \text{a priori state}$
- $S_a = \text{a priori covariance}$
Stratospheric Temperature Retrievals

- Retrieval grid:
  - 1D case: homogeneously stratified atmosphere
  - Fixed altitudes: 3 km below 60 km, 5 km up to 90 km
  - Retrieve only T, get p from hydrostatic equilibrium.

- Measurement error covariance:
  - Consider only noise (uncorrelated).

- A priori data:
  - Use AIRS operational retrieval results as a priori state (inter/extrapolate data gaps).
  - Use a priori uncertainty of $\sigma_i = 20$ K, correlations from first-order autoregressive model:
    \[
    S_{ij} = \sigma_i \sigma_j \exp(-\Delta z / c_z)
    \]
  - Correlation length $c_z$ is an important tuning parameter!
⇒ Exclude all channels where tropospheric fraction of kernel functions ($z_{trop} = 17.5$ km) exceeds 1% to minimize influence of clouds...
Varying the a priori profile by ±20 K causes differences below ±1.5 K in the retrieved profile at 20...55 km altitude.
⇒ We use an a priori vertical correlation length of 50 km to reduce the retrieval error due to noise: The resulting error is 1 . . . 2 K at 20 . . . 55 km.
⇒ For 50 km a priori vertical correlation length the vertical resolution is 7...11 km at 20...55 km.
Full resolution retrieval results resemble operational data, but gravity wave amplitudes are larger.
Gravity waves produced by deep convection...

⇒ Retrieval at full horizontal resolution reveals small-scale structures!
Warm bias (about 3...5 K) in full resolution retrievals at the stratopause.
We use the fast radiative transfer model JURASSIC to simulate AIRS measurements:
- The fast model helps to reduce CPU-time by a factor 1000.
- Reference calculations are reproduced within AIRS noise.

We use the optimal estimation approach to retrieve temperature data for the stratosphere:
- Altitude Range: 20...55 km
- Vertical resolution: 7...11 km (about 6 dfs)
- A priori information: less than 5%
- Retrieval error (due to noise): 1...2 K

First retrieval results for selected granules look promising: The full resolution data much better reveal the horizontal small-scale structures caused by gravity waves.