Tomographic retrievals for high spatial resolution measurements of the PREMIER Infrared Limb Sounder

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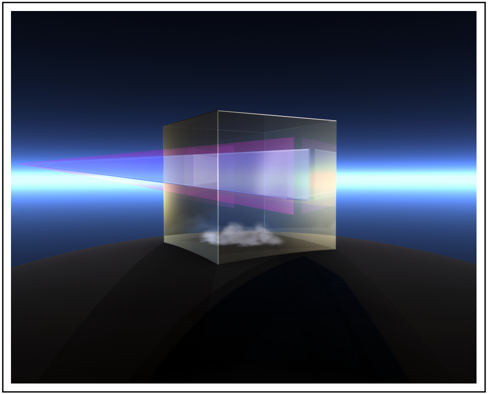
Outline

1. PREMIER Infrared Limb Sounder
2. Simulation of ‘dynamics mode’ measurements
3. Results of retrieval studies (temperature, H_2O, O_3)
4. Summary

PREMIER Mission Concept

PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation



(Image credit: ESA)

- **Main objective:** To observe atmospheric composition for a better understanding of chemistry-climate interactions.
- **A specific topic:** First measurements of gravity wave momentum flux components.

PREMIER Mission Concept

PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation

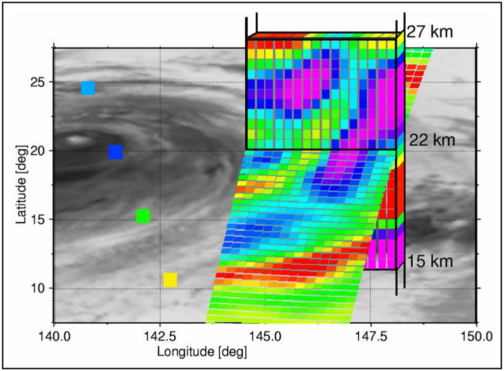
- **Instrumentation:**

  Infrared Limb Sounder (IRLS),

  Microwave Limb Sounder (MWLS)

- **Limb Imaging:**

  Combine FTIR spectrometer with 2D detector arrays to achieve high spatial sampling.

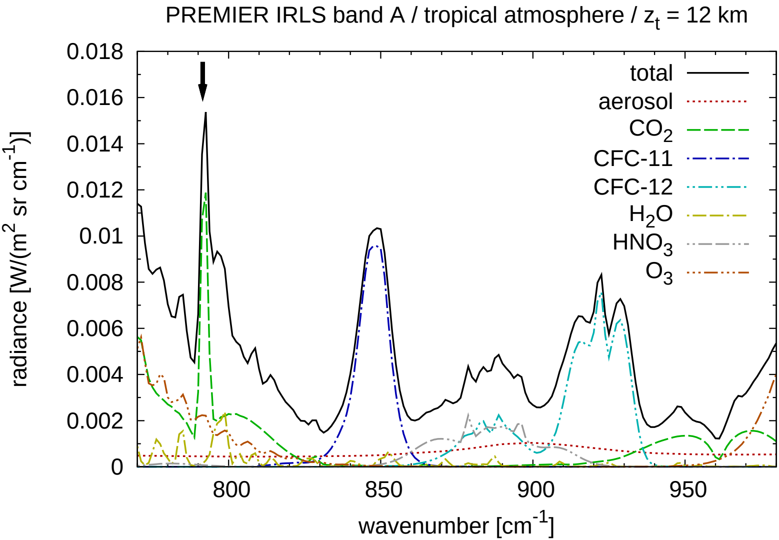


PREMIER Infrared Limb Sounder

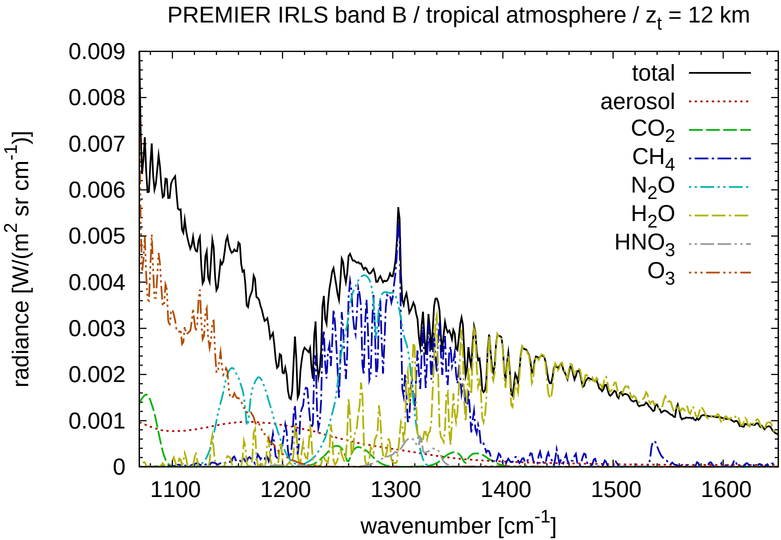
- **Characteristics or IRLS measurements:**
  - Vertical coverage: $3 - 58$ km
  - Horizontal coverage: 320 km
  - Spectral coverage: $770 - 1650\,\mathrm{cm}^{-1}$
- **Different measurement modes:**
  - Atmospheric Chemistry Mode:
    good spectral sampling ($\Delta\nu = 0.2\,\mathrm{cm}^{-1}$),
    moderate spatial sampling ($2\,\mathrm{km} \times 100\,\mathrm{km} \times 80\,\mathrm{km}$)[1]
  - Atmospheric Dynamics Mode:
    moderate spectral sampling ($\Delta\nu = 1.25\,\mathrm{cm}^{-1}$),
    high spatial sampling ($0.5\,\mathrm{km} \times 50\,\mathrm{km} \times 25\,\mathrm{km}$)
  - Cloud Imaging Mode:
    low spectral sampling ($\Delta\nu = 10\,\mathrm{cm}^{-1}$),
    highest spatial sampling ($0.5\,\mathrm{km} \times 8\,\mathrm{km} \times 4\,\mathrm{km}$)

[1] vertical × along-track × across-track

Dynamics Mode Radiance Spectra



Dynamics Mode Radiance Spectra



Forward Model and Retrieval Studies

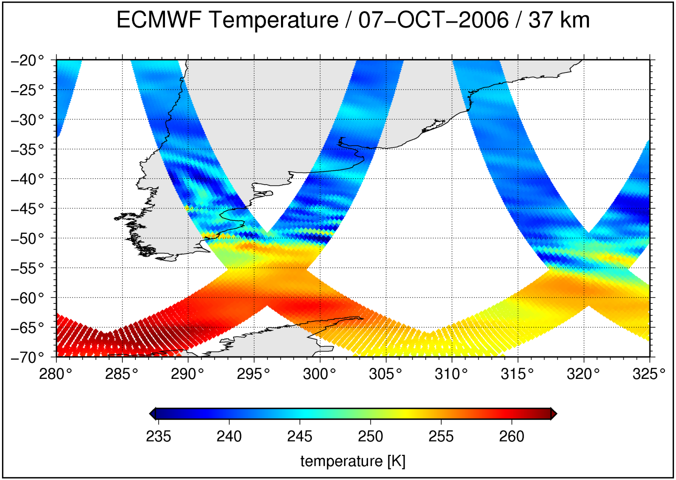
- **High data rates of dynamics mode:**
  - About 12,000 limb images per day!
  - About 15,000,000 radiance spectra per day!

- **Juelich Rapid Spectral Simulation Code (JURASSIC):**
  - Fast radiative transfer calculations:
    - look-up tables, EGA, CGA, regression
    - about 10 ms to simulate single atmospheric ray path
    - about 1% accuracy
  - Flexible raytracing routine:
    - 1D, 2D, or 3D regular or irregular atmospheric data
    - any kind of measurement geometry
  - Retrieval processor:
    - optimal estimation approach
    - Levenberg-Marquardt or Gauss-Newton (*m*- or *n*-form)
    - regularization by means of first-order autoregressive model
  - Projects and references:
    https://jurassic.icg.kfa-juelich.de/JURASSIC

Forward Model and Retrieval Studies

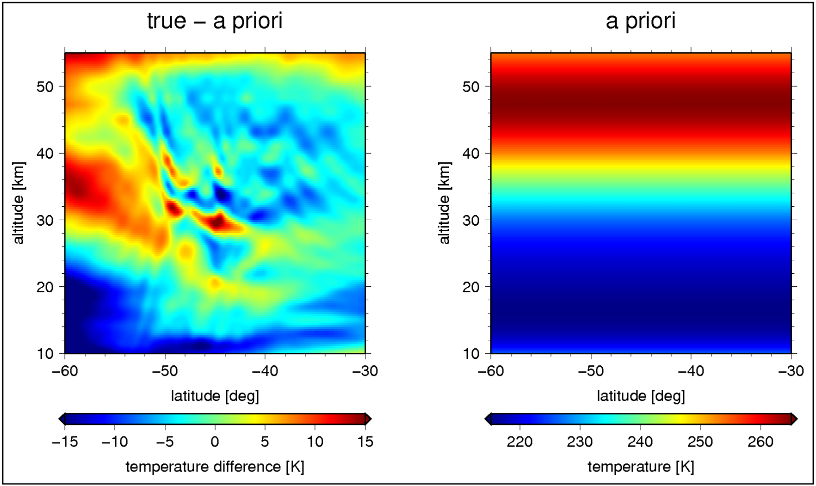
- **We applied JURASSIC for 2D non-linear retrieval simulations for the PREMIER IRLS Dynamics Mode**:
  1. Selection of scenarios from atmospheric models:
     - Stratospheric gravity wave observations (ECMWF)
     - Transport processes in the UT/LS region (CLaMS)
  2. Retrieval simulations:
     - Retrieval of 2D cross-sections (Geofit-approach)
     - $1-2$ radiance channels per target (maximize Shannon IC)
     - Retrieval grid: 1 km $\times$ 50 km (vertical $\times$ along-track)
     - A priori state / first guess: 1D climatology
     - A priori covariance: first-oder autoregressive model (sigmas from climatology, correlations: 2 km $\times$ 500 km)
     - Measurement grid: 0.5 km $\times$ 50 km
     - Measurement covariance: noise, $\sim$1 nW/(cm^2 sr cm^{-1})
  3. Analysis of retrieval diagnostics:
     - Comparison of model data ('truth') and retrieval results
     - Resolution (information density) and retrieval noise

Stratospheric Gravity Wave Observations



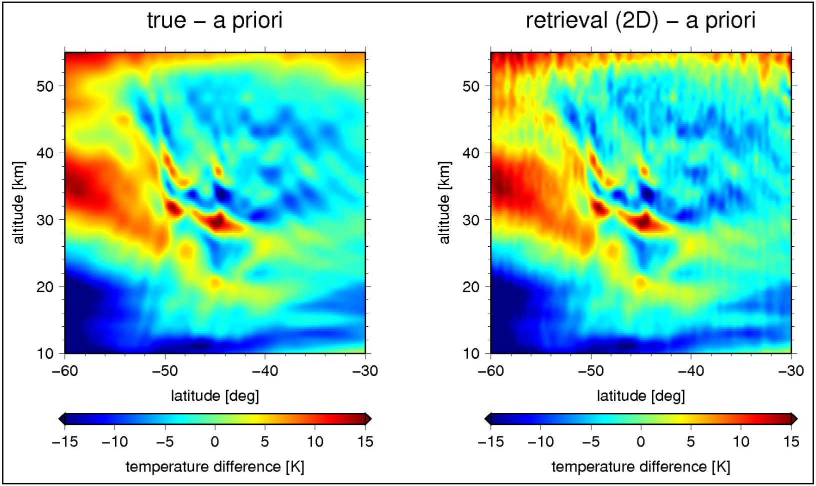
- ECMWF temperature data sampled on PREMIER IRLS Dynamics Mode measurement tracks.
- Select measurement tracks over South America for retrieval studies as they show gravity wave structures (mountain waves + other sources).

Stratospheric Gravity Wave Observations



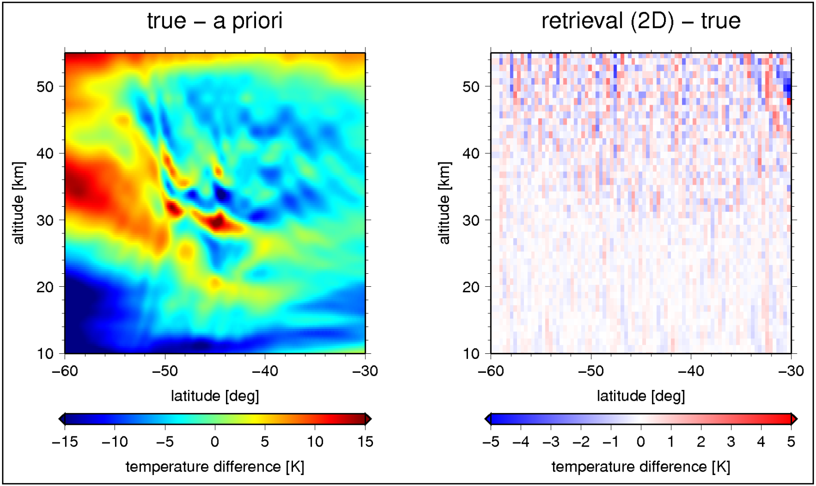
- Comparison of ECMWF data for single measurement track (true) with a priori (and first guess) used for retrievals.
- Constant climatological data used to avoid introducing structures through a priori and for testing convergence in non-linear iterations.

Stratospheric Gravity Wave Observations



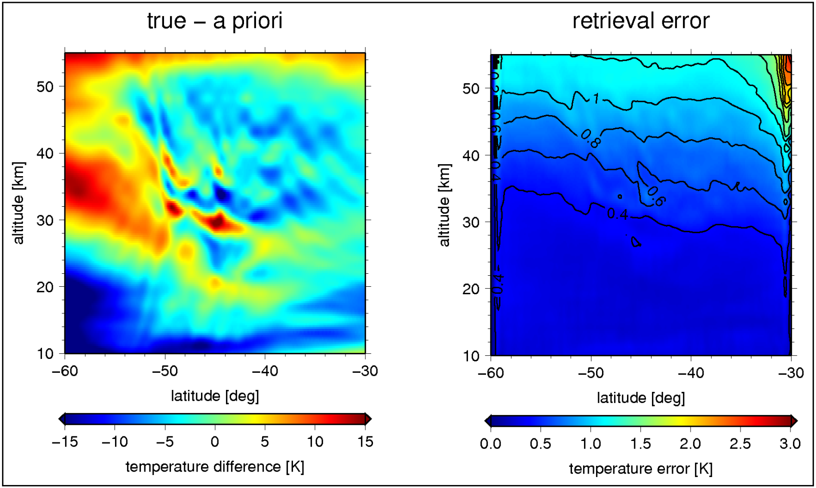
- Comparison of true data (ECMWF) with 2D retrieval results.
- Good overall agreement of true and retrieved structures.

Stratospheric Gravity Wave Observations



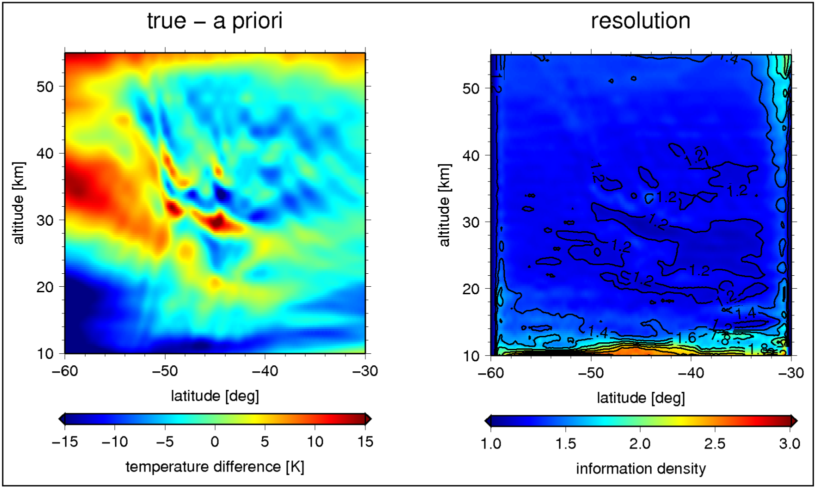
- Comparison of true data (ECMWF) with 2D retrieval results.
- Differences mainly due to noise added to simulated observations.

Stratospheric Gravity Wave Observations



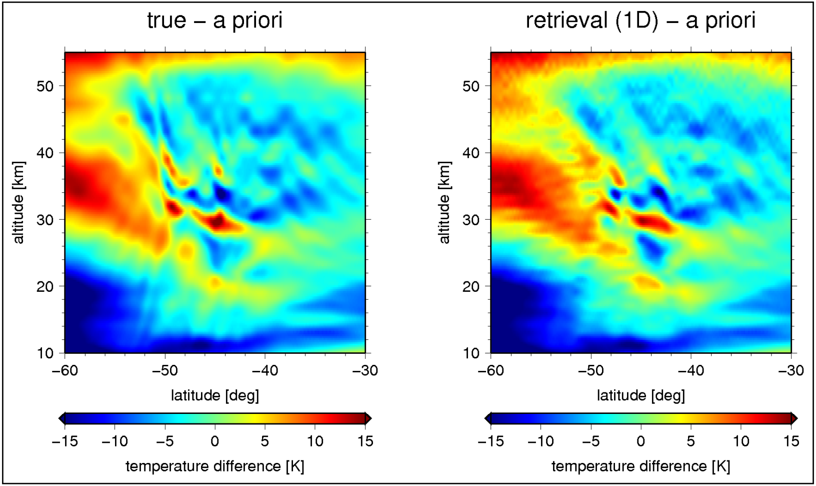
- Comparison of true data (ECMWF) with 2D retrieval results.
- Retrieval noise increases from 0.4 to 1.2 K from 10 to 55 km altitude.

Stratospheric Gravity Wave Observations



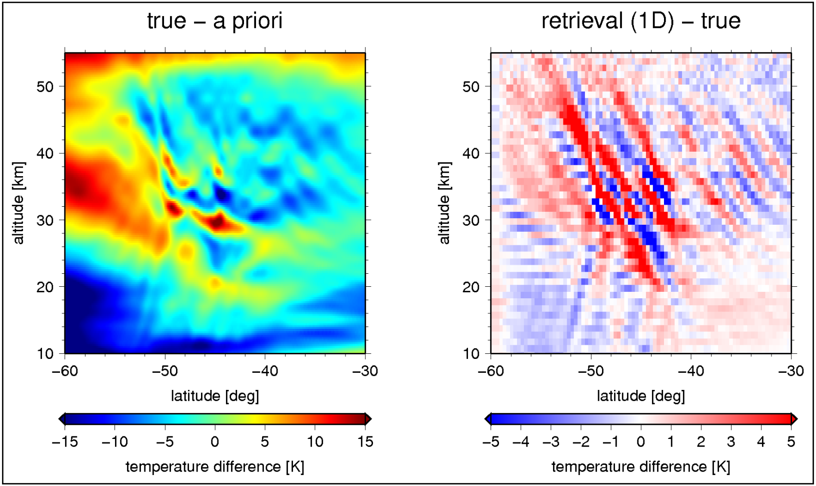
- Comparison of true data (ECMWF) with 2D retrieval results.
- Averaging kernels indicate resolution of 1.2 to 1.4 grid boxes / dfs.

Stratospheric Gravity Wave Observations



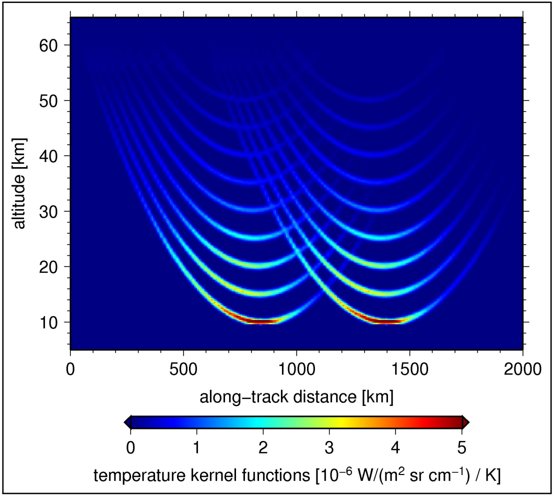
- Comparison of true data (ECMWF) with 1D retrieval results.
- 1D retrieval less sensitive to noise (about 0.4 K), but does not reproduce small-structures of true temperature field correctly.

Stratospheric Gravity Wave Observations



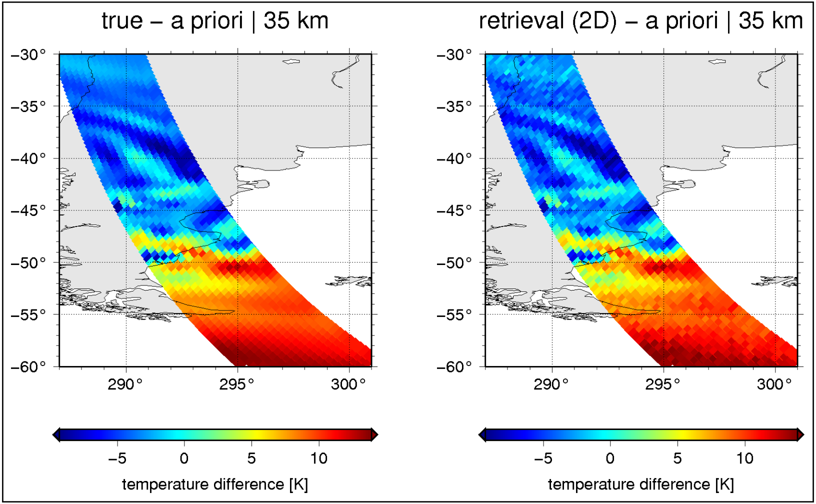
- Comparison of true data (ECMWF) with 1D retrieval results.
- Difference plots indicates phase shifts in 1D retrievals.

Stratospheric Gravity Wave Observations



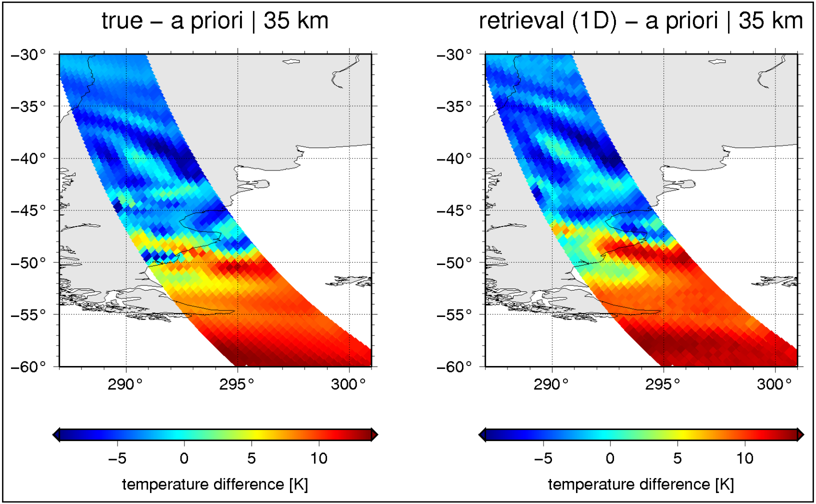
- Temperature kernel functions on 0.25 km × 12.5 km atmospheric grid.
- Peaks of weighting functions shifted towards instrument (40 – 140 km).
- Note: Real measurement grid 10 × 10 finer than shown. (Tomography!)

Stratospheric Gravity Wave Observations



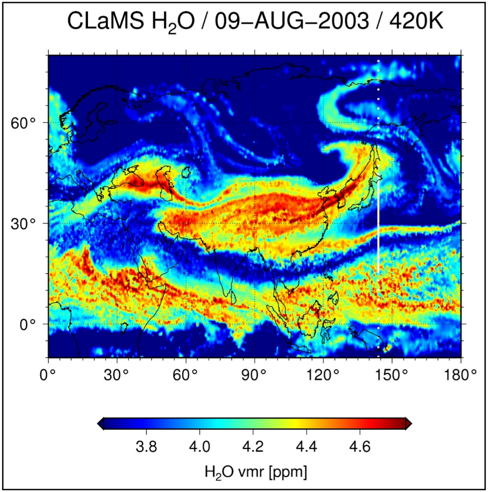
- 3D temperature fields obtained by combining 2D retrieval results.
- Consistent picture of retrieved horizontal temperature structures. PREMIER provides full 3D view of stratospheric gravity waves.

Stratospheric Gravity Wave Observations



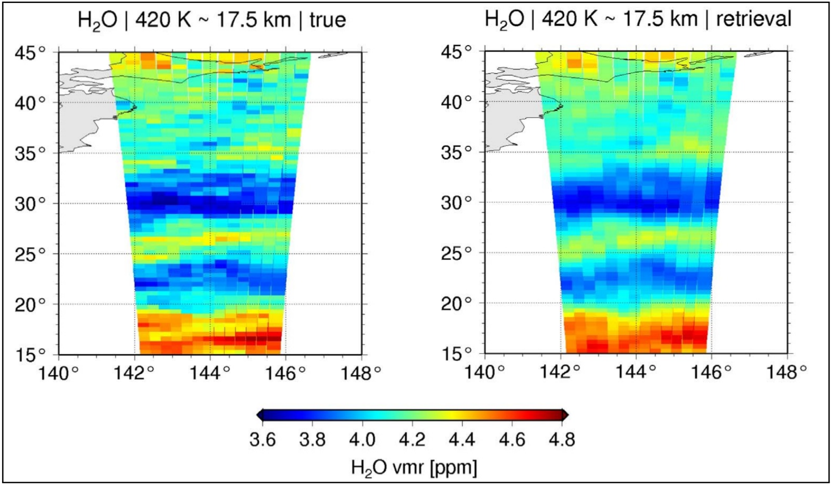
- 3D temperature fields obtained by combining 1D retrieval results.
- Assumption of homogeneously stratified atmosphere in 1D retrievals introduces artificial small-scale structures and phase shifts.

Transport Processes in UT/LS Region



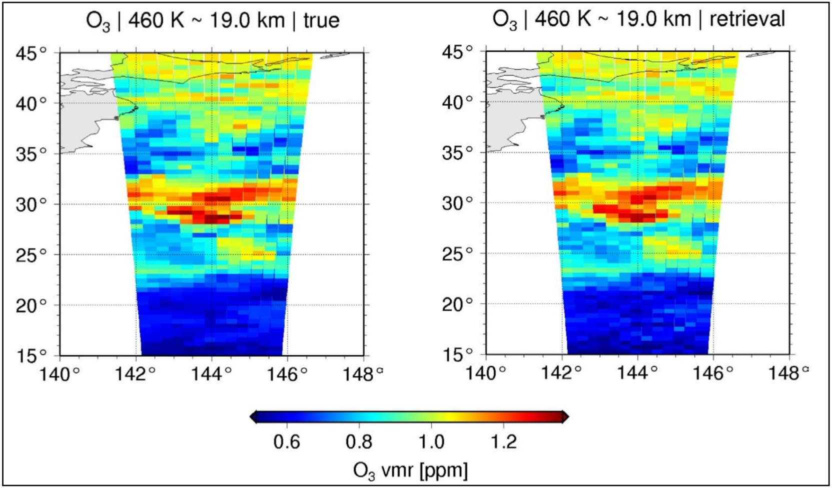
- **CLaMS simulation:** Study of transport and mixing of air masses in the UT/LS region in the vicinity of the Asian monsoon.
- **Retrieval studies:** Trace gas cross-sections (H_2O, O_3, CFC-11) for measurement tracks near 144°E.

Transport Processes in UT/LS Region



- Comparison of H_2O distributions obtained from CLaMS model (true) and corresponding retrieval results.
- Small-scale structures reproduced by 2D retrievals. Some loss of resolution for low stratospheric H_2O vmr becomes evident.

Transport Processes in UT/LS Region



- Comparison of O_3 distributions obtained from CLaMS model (true) and corresponding retrieval results.
- Small-scale structures reproduced by 2D retrievals. PREMIER data will become excellent tool to validate atmospheric models like CLaMS.

Summary

- PREMIER will take the technique of infrared limb sounding to its extreme (instrument and data processing).
- We optimized JURASSIC to simulate PREMIER IRLS measurements and to carry out 2D non-linear retrieval simulations for different scenarios.
- PREMIER will be capable of resolving horizontal structures on considerably finer scales than earlier limb-emission sounders, thereby filling observational gaps in scales between satellites and aircraft instruments.