New approach in atmospheric sounding

Wide field INfrared Tomographic Imager (WINTI)

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- **Infrared Atmospheric Tomography**
- **Wide Field INfrared Tomographic Imager: instrument characteristics and RTM simulations**
- **Inversion scheme and results**
- **Way forward**

Infrared Atmospheric Tomography : motivation

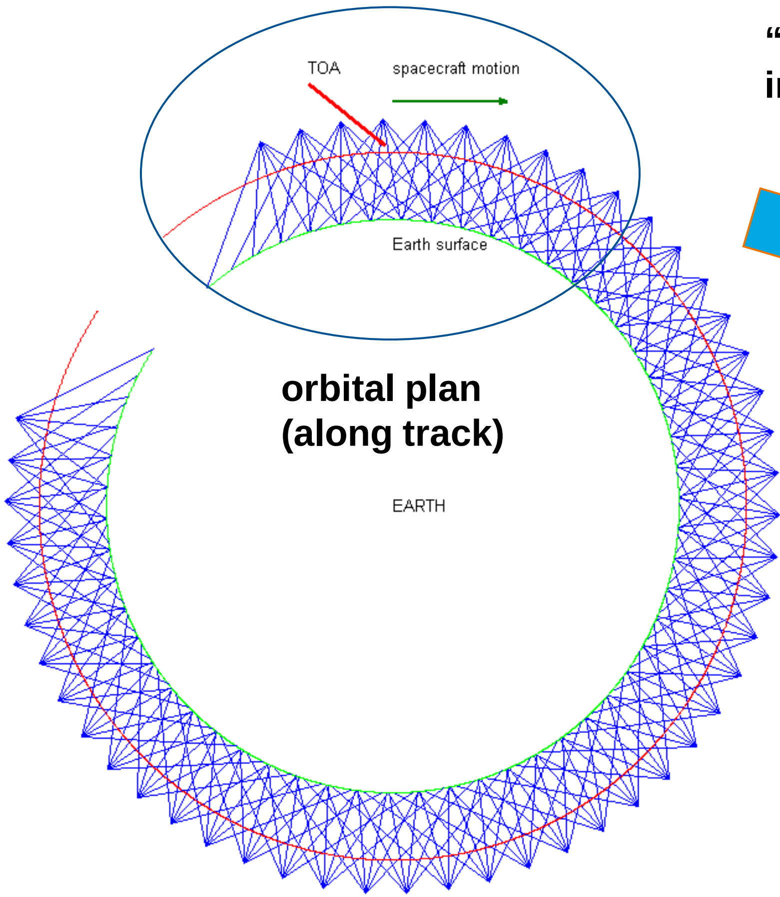
- **This study has been done in the frame of "research & technology" department at CNES in collaboration with the ACRI-ST company and the IPSL/LATMOS research laboratory**

- **Hyperspectral infrared sounders**
  - **Hyperspectral infrared sounders achieve their vertical resolution (5-15 km) thanks to their spectral resolution**
    - **AIRS, IASI, CrIS and IASI-NG are close to the limit imposed by the physics (width imposed by the natural broadening of spectral lines)**
  - **For a LEO mission compatible with actual needs in terms of NedT, the spatial resolution is limited to ~10km (by design)**
  - **The spatial sounding point density is mainly limited by telemetry datarate, on-board processing and detection**

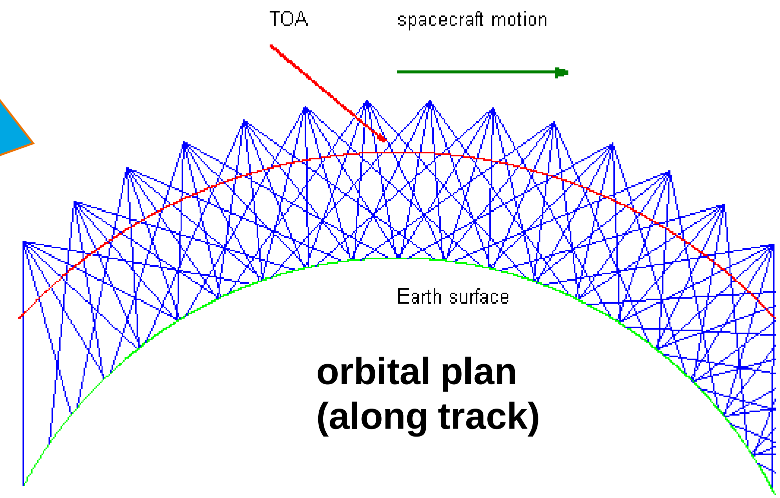
- **Considerations on atmospheric models**
  - **MESO-NH : kilometric spatial and vertical resolution. Validation with observations ?**

- **Objectives of the infrared atmospheric tomography study**
  - **Does an optimal geometry of line-of-sight (LOS) could have the same impact as spectral resolution on the vertical resolution of L2 products (T,H_2O,trace gases) ? Geometry VS Spectral resolution ?**
  - **What are the limits of the tomographic approach ?**
  - **Potential applications NWP, chemistry ?**

Principle and geometry of the measure

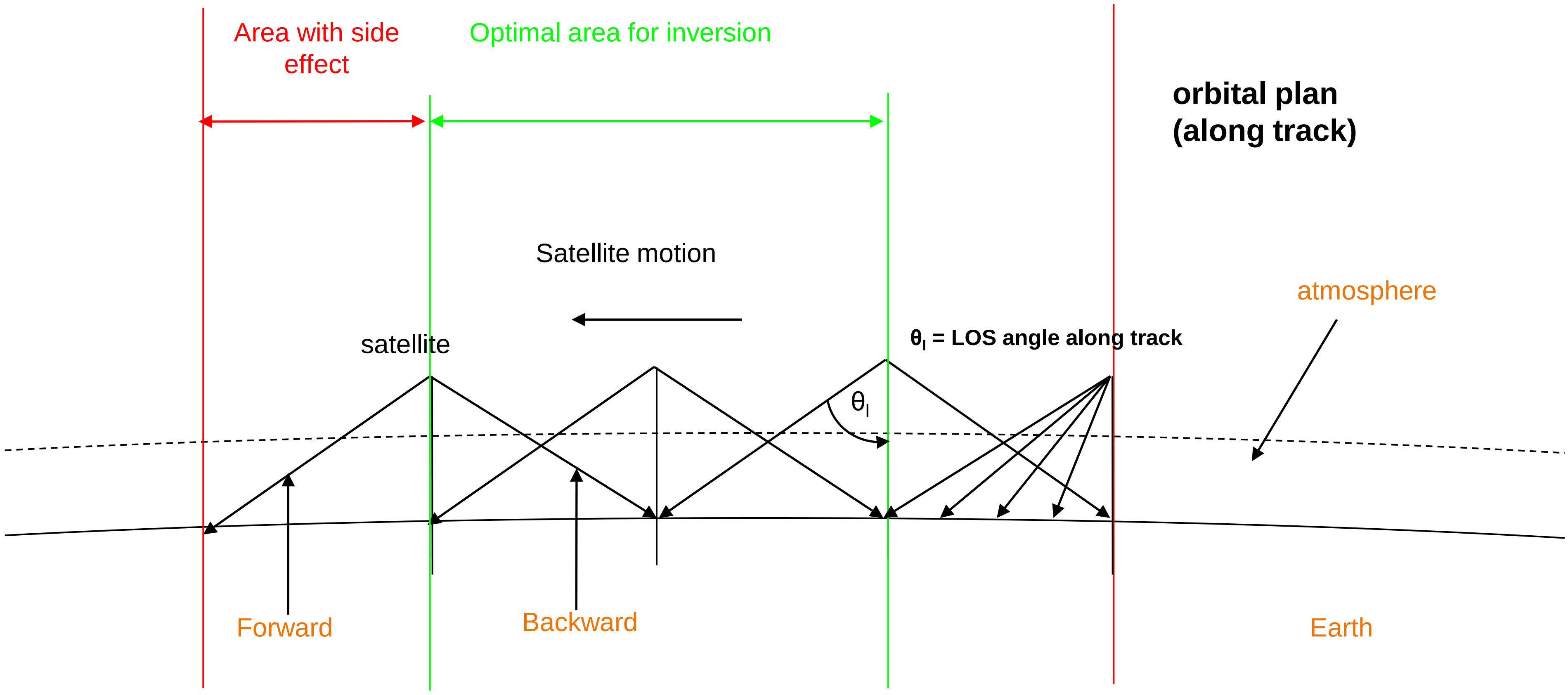


"Nadir line-of-sight" (max LOS angle 50°)
in the orbital plan using an array detector

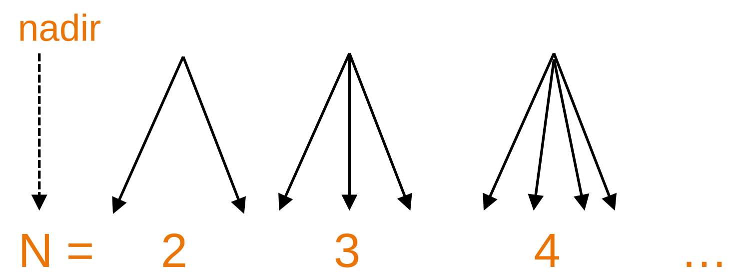


LOS Network (2D-3D, depending on the array detector you use)

Principle and geometry of the measure



LOS density:



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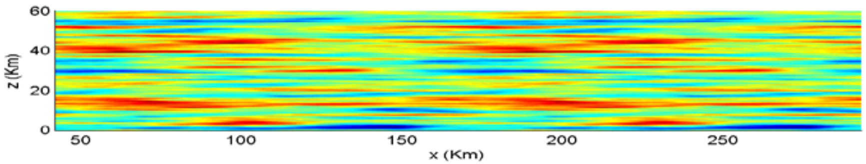
WINTI instrument characteristics

- **LEO orbit**
- **Detectors: Wide field IR 2D-array detectors providing a total field of 500x500km with spatial resolution of 1km**
- **Spectral resolution: 30-200 cm^{-1} depending on channel (this is compatible with current imager specifications)**
- **Typical NedT@280K = 0.1- 0.2 K**
- **Channels**
  - **10-20 IR channels for temperature and water vapour sounding**
  - **1-3 IR channels for the inversion of one atmospheric gas you may be interested in**

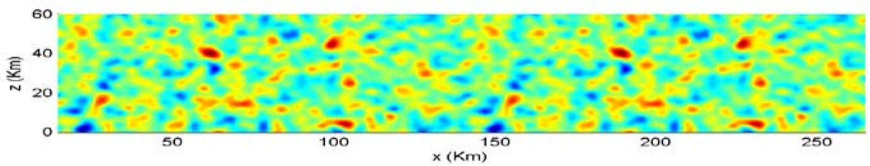
Atmospheric scenes considered

- **3 atmospheric states have been simulated and studied**
  - **"Gurvich" : anisotropic (stable and stratified atmosphere)**



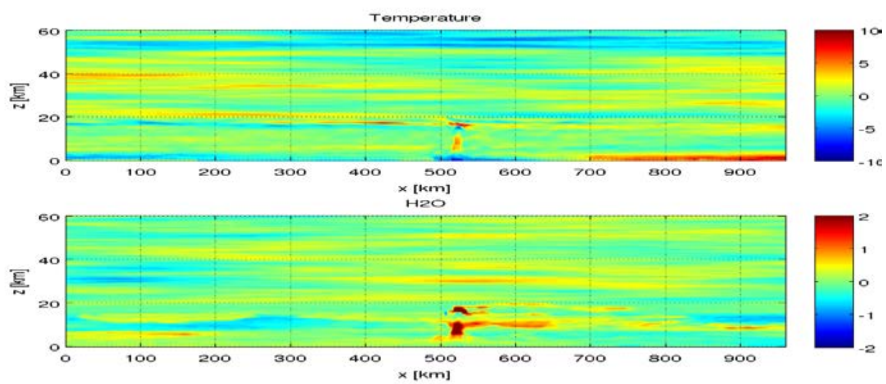
Temperature anomaly field
Anisotropy coefficient = 30
-10 K<DT<10 K

  - **"Gaussian" : isotropic (unstable atmosphere) – typical structure size 3km**



Temperature or H_2O anomaly field.
σ_T=3 K with -10 K<DT<10 K,
σ_{H2O}/H2O=0.25 with -0.8<DH2O/H20<0.8

  - **"Meso-NH" : realistic from Meso-NH model, Lomé-Niamey June 13th, 2006**



- **RTM : 4A/OP (LMD, NOVELTIS, CNES)**

- Infrared Atmospheric Tomography
- Wide Field INfrared Tomographic Imager: instrument characteristics and RTM simulations
- **Inversion scheme and results**
- Way forward

Inversion scheme

● **Forward model:** d = g(p) + noise where g = RT forward model; d = data vector and p = parameter vector (T, $H2O$, Ts or concentration of one trace gas)

● **Inverse problem:** find p estimator and p error knowing d, g and noise statistic.

● **Classical approach:** Maximum Likelihood (ML). If g is linear and if the noise follows a Gaussian law, then the parameter estimators are unbiased.

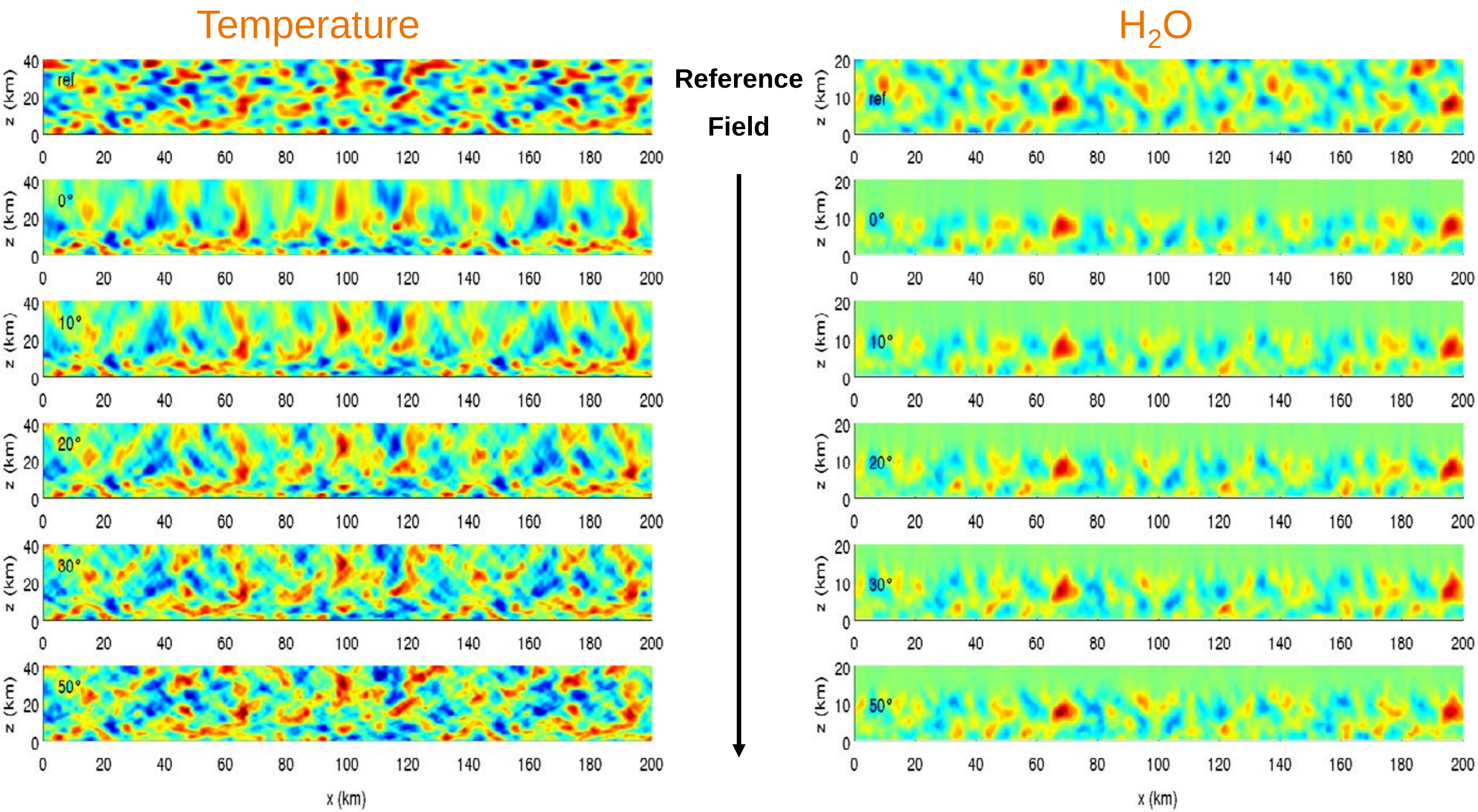
However, in our case, **ML cannot be used because the inverse problem is ill-conditioned**.

● **SOLUTION: use regularization** (Bayes, maximum entropy method, Lanczös decomposition, Tikhonov regularization …).

Bayesian approach allows regularizing ill-conditioned problems. Advantage : It is a statistical approach.

Inversion using classical minimization see Tarantola & Valette, 1982; Rodgers, 1981

NWP application: T and H_2O retrievals for an "isotropic" atmosphere



Maximum LOS angle along track (θ_{max}) increase from 0° to 50°

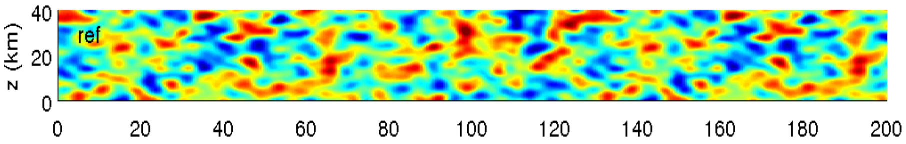
- The accuracy of the restitution increases as the angular aperture
- Saturation

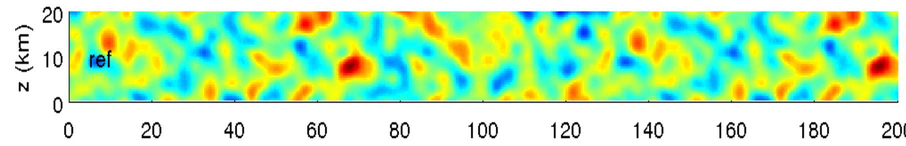
Comparison with IASI

Temperature

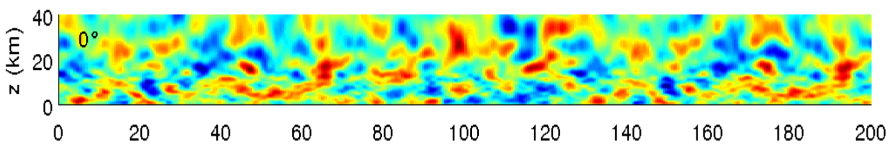
H_2O

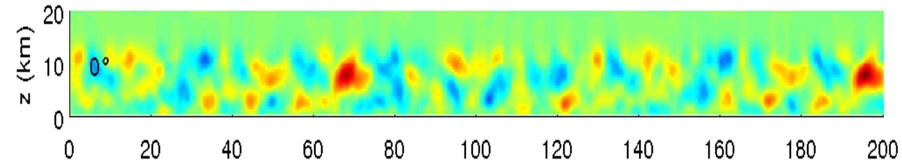
Reference



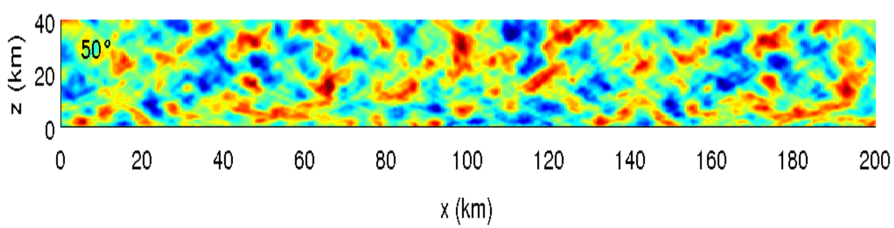


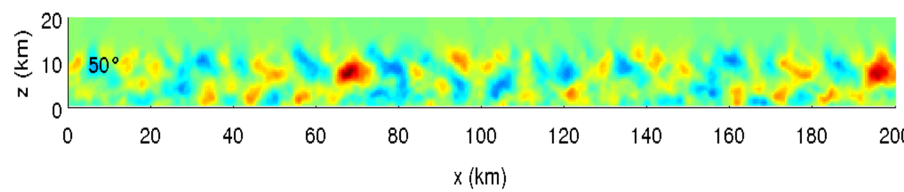
IASI (hyperspectral nadir, “classical” sounding channels)





WINTI (broad channels tomographic with θ_{max}=50°)

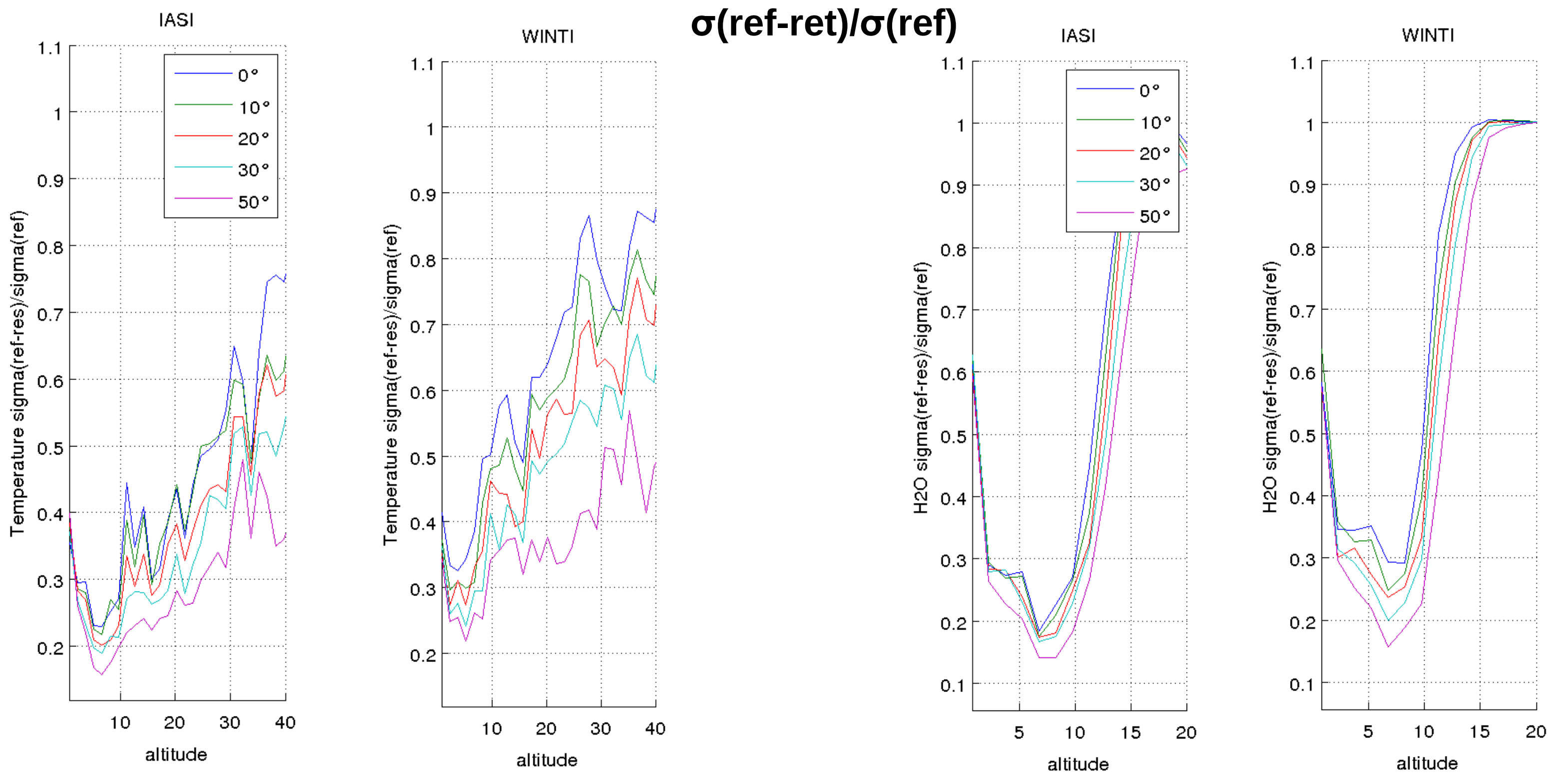




- in the tomographic approach, vertical and horizontal resolution are given by crossing point density, along track angular aperture and angular diversity

Comparison with IASI : σ a posteriori

Temperature H_2O

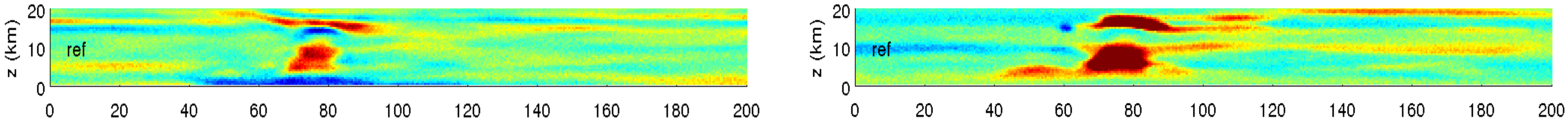


- for an "isotropic" atmosphere with typical structures of 3 km
  - WINTI 50° (24 Channels) > IASI Nadir for T retrieval
  - equivalent performances for H_2O retrieval

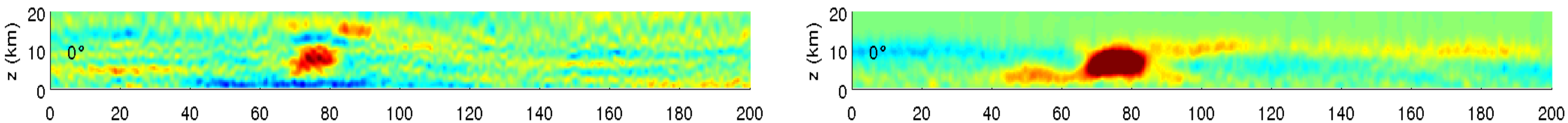
NWP application: T and H_2O retrievals for “MESO-NH” atmosphere (WINTI vs IASI)

Temperature | H_2O

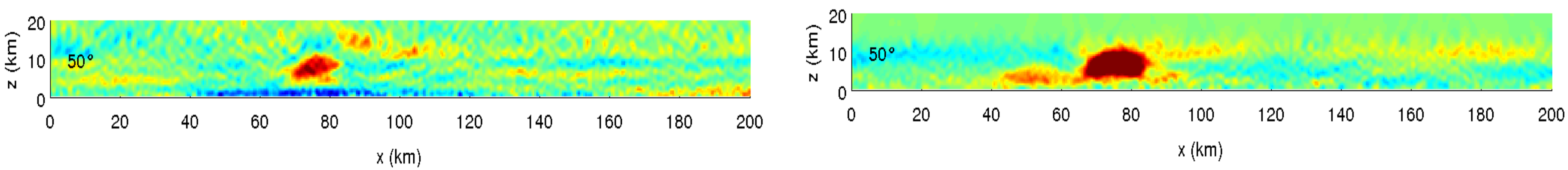
Reference



IASI (hyperspectral nadir, “classical” sounding channels)

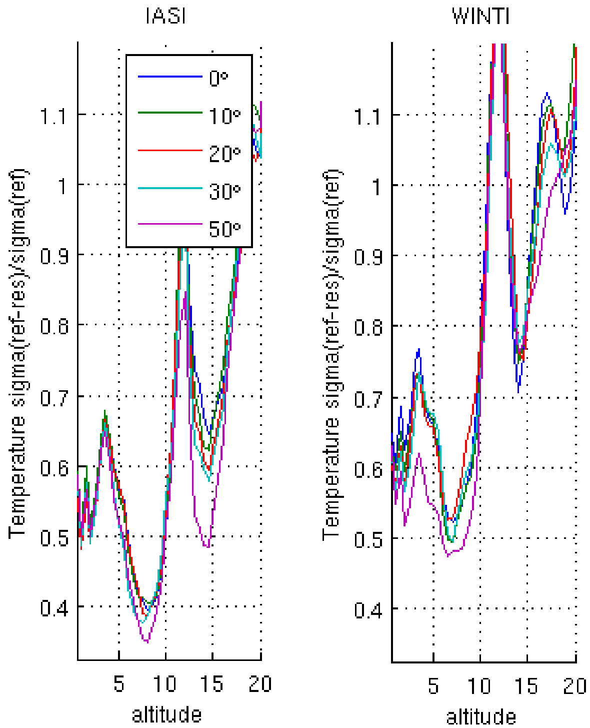


WINTI (broad channels tomographic with θ_{max}=50°)

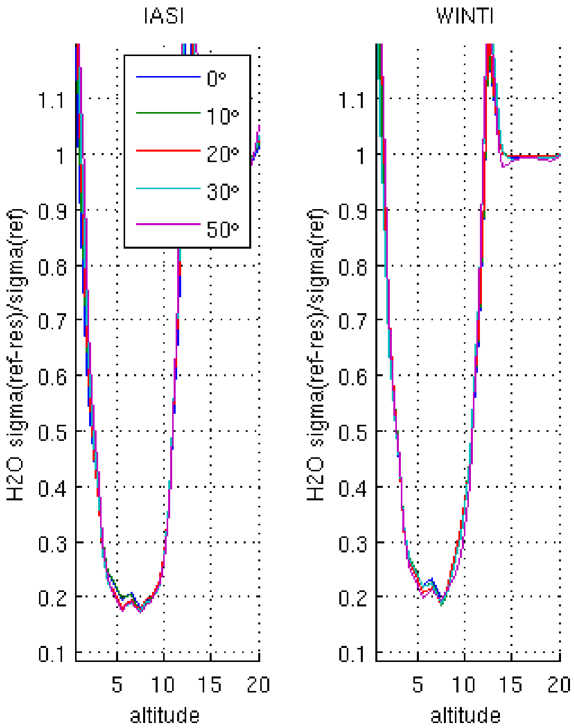


Comparison with IASI : σ a posteriori

Temperature



H_2O

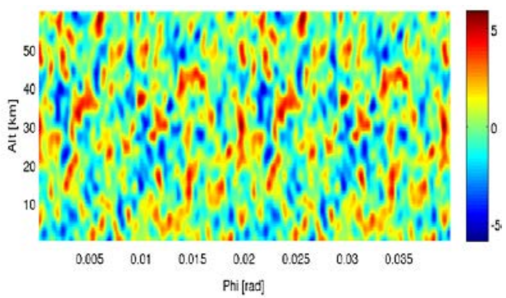


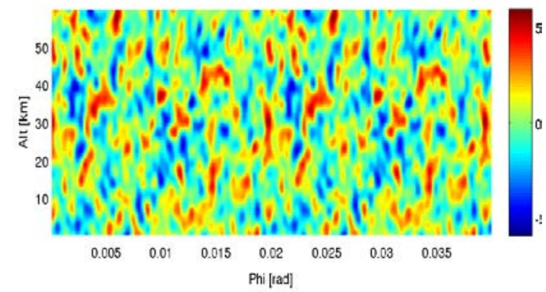
- for a stratified atmosphere with typical vertical structure of 3 km
  - WINTI 50° (24 Channels) < IASI Nadir for T retrieval
  - equivalent performances for H_2O retrieval

Opaque clouds : altitude 12km, spatial extension 3km

θ_{max}=0° (nadir) | θ_{max}=50°

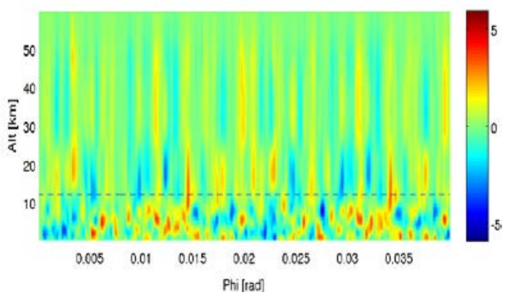
Reference

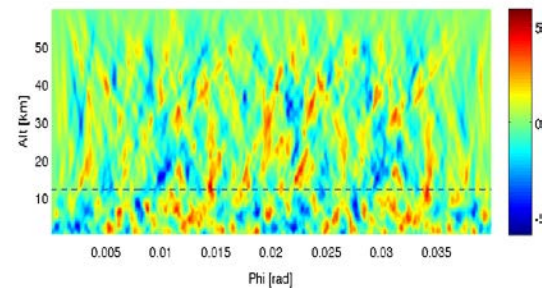




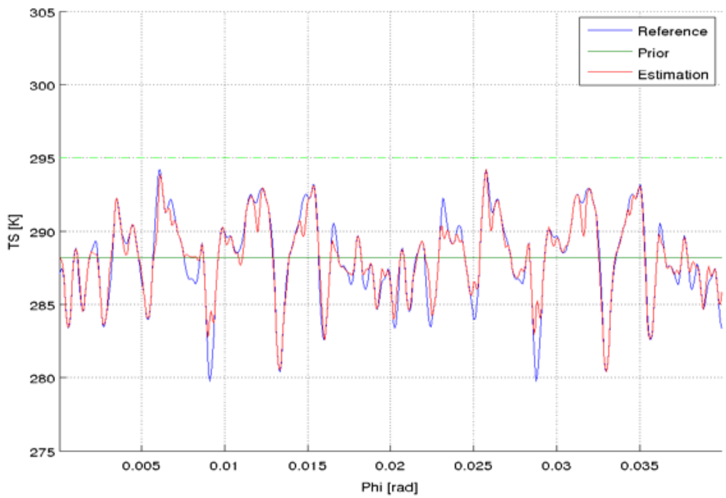
Temperature

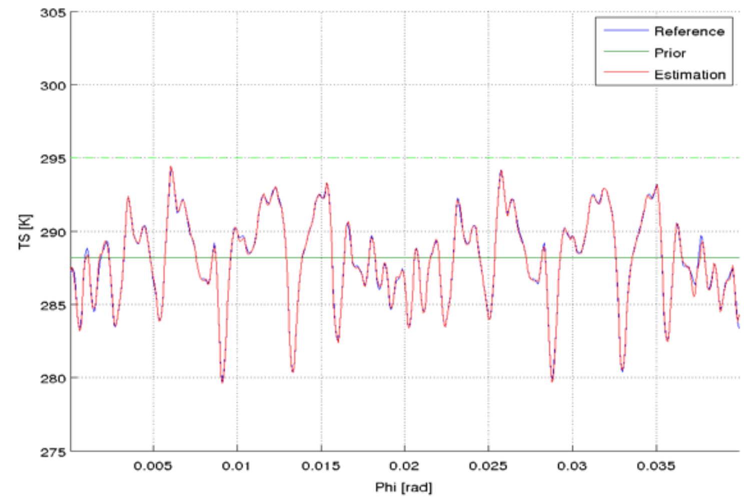
Restitution





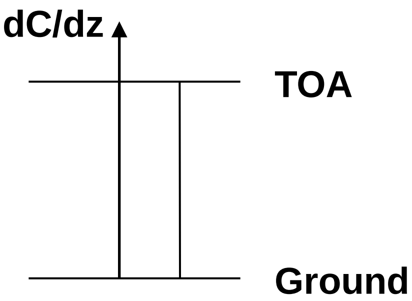
Ts





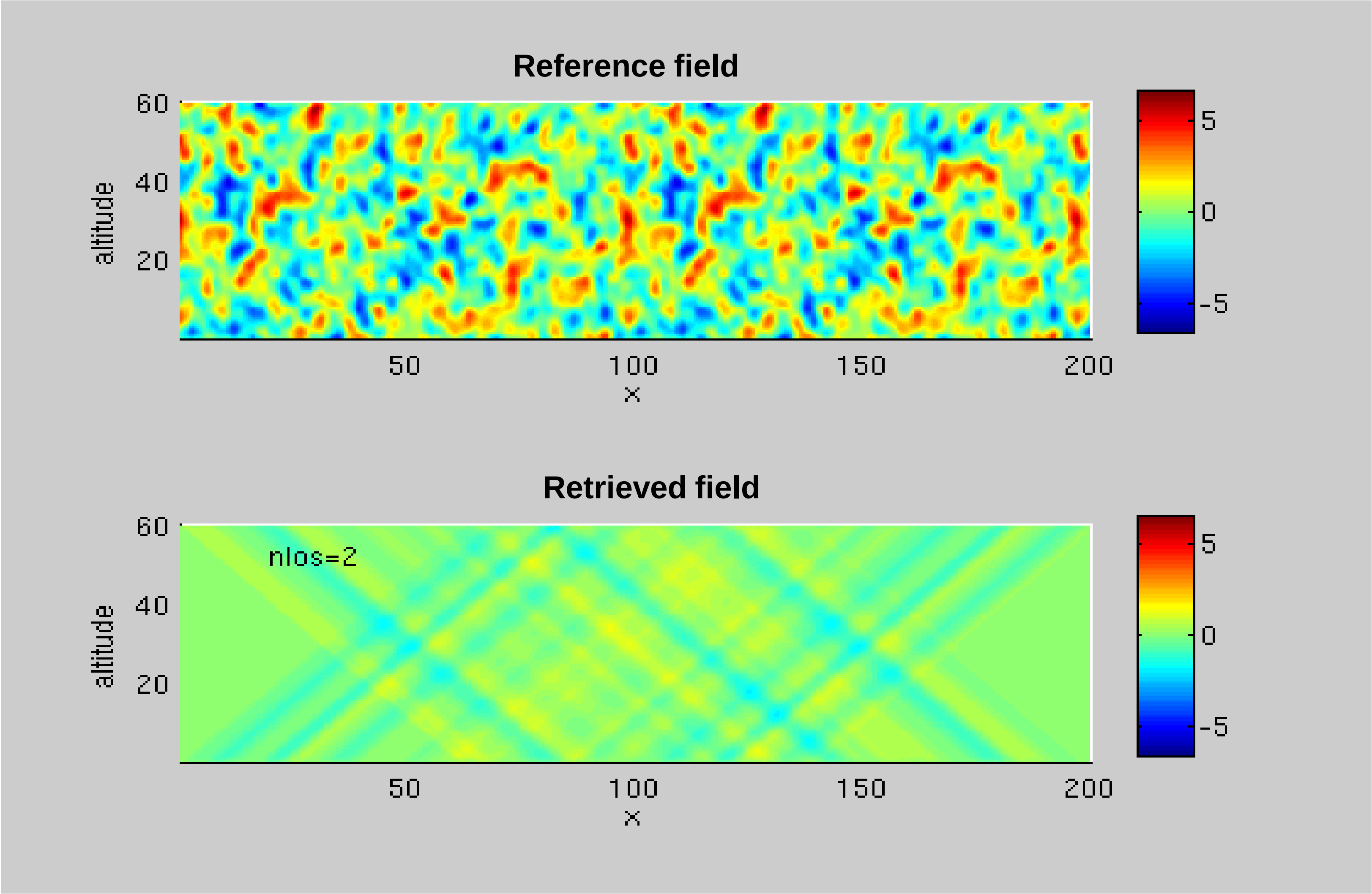
Chemistry application

- An experiment have been done using a single channel with a “theoretical” flat (constant) jacobian along the LOS → simulating 1 degree of freedom

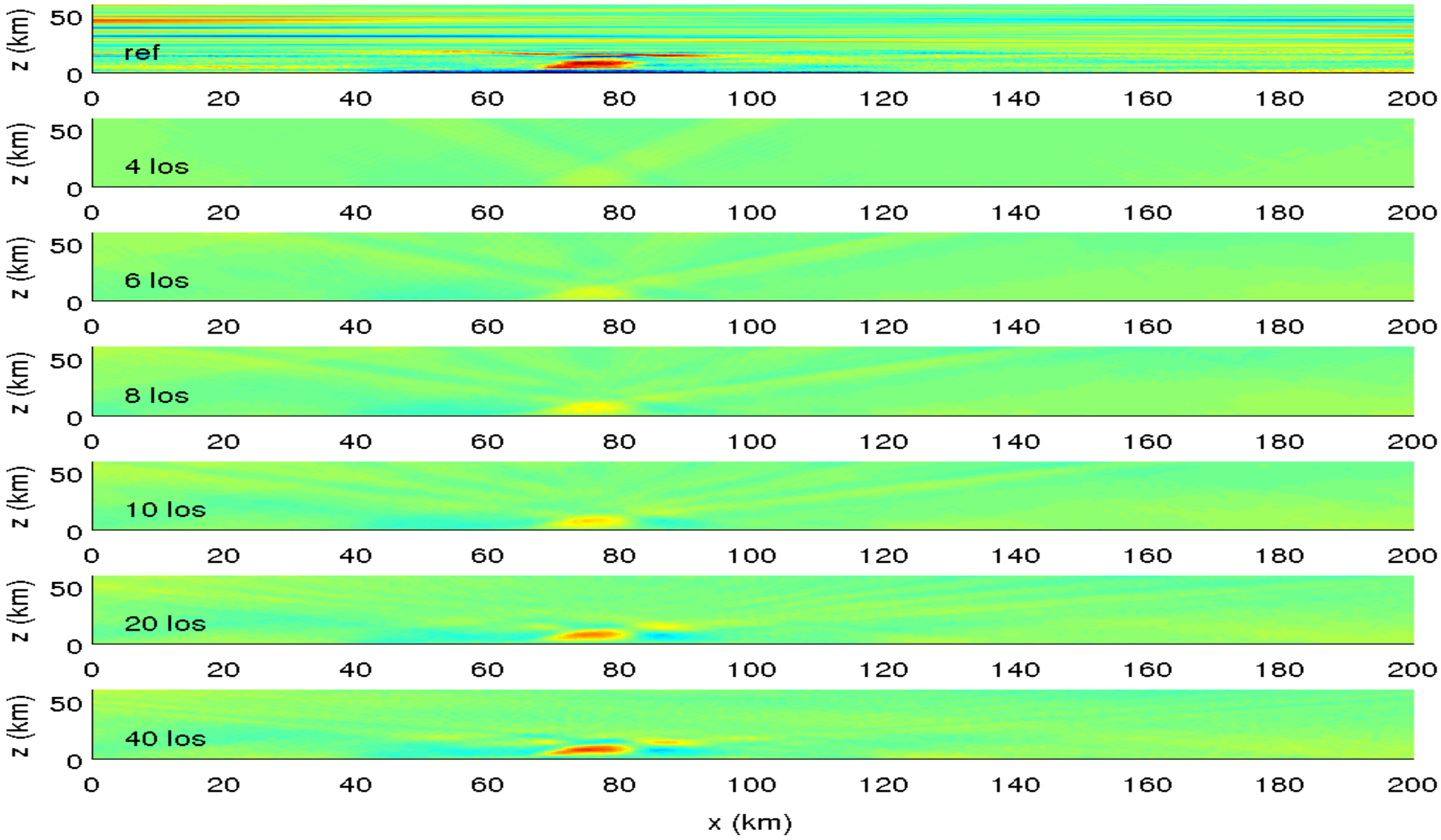


- From instrument design point of view, using large band is a very interesting approach
  - SNR increases
  - Instrument, detection and on-board processing complexity + size/mass (an imager with a limited number of spectral bands VS an interferometer)

A single channel with a flat jacobian (θ_{max}=50°)

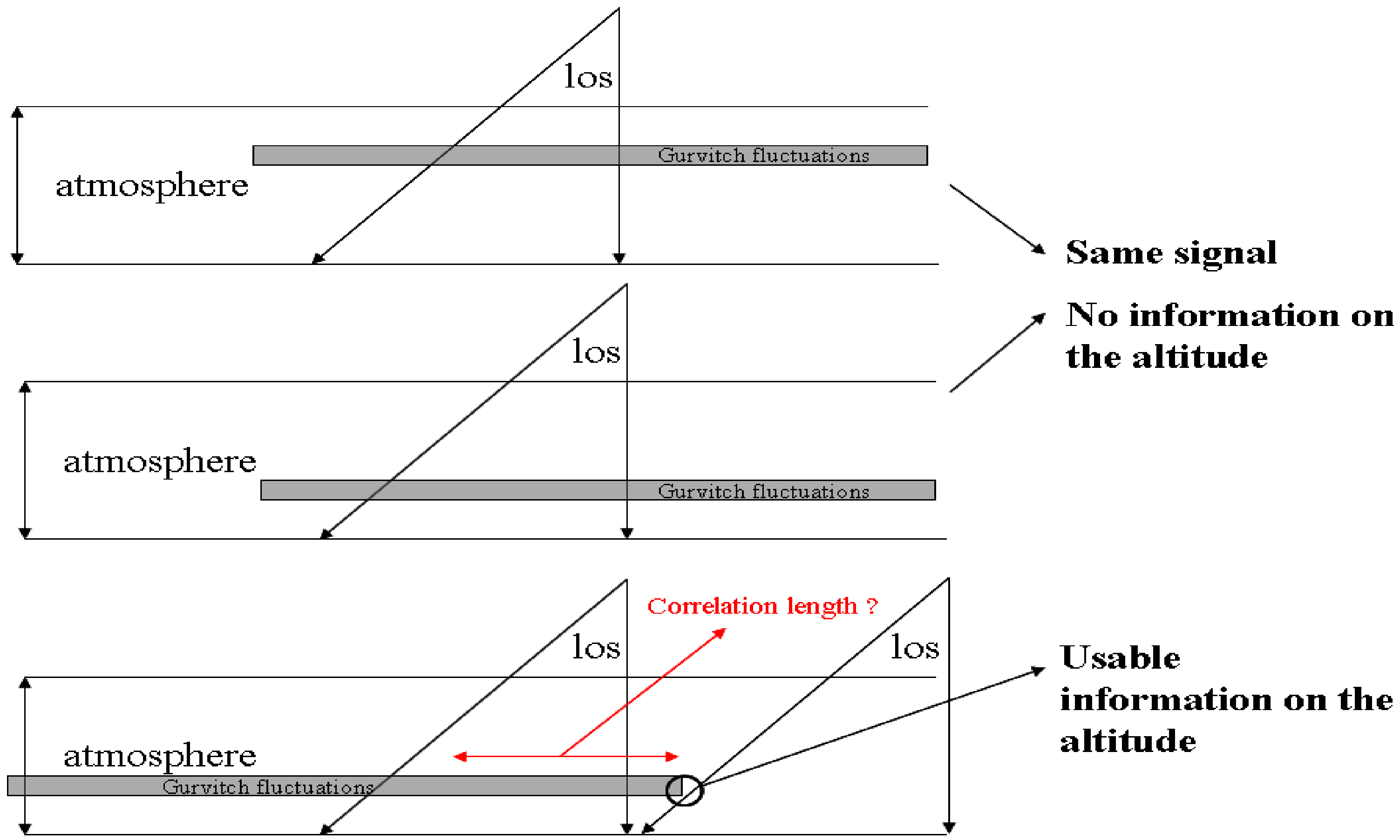


Flat jacobians (θ_{max}=70°) on « MESO-NH » atmosphere



- OK to retrieve convective structures
- NOK to retrieve stratified structures

Flat jacobian limitation : stratified structure vertical position is difficult to constrain



- Limb views should help in stratified atmosphere case (which is the most common case !)

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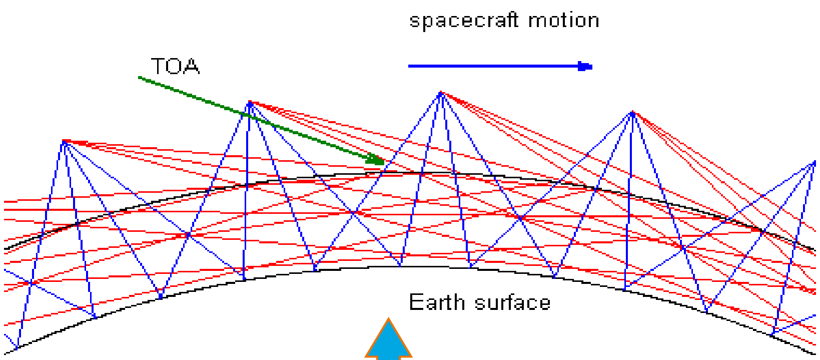
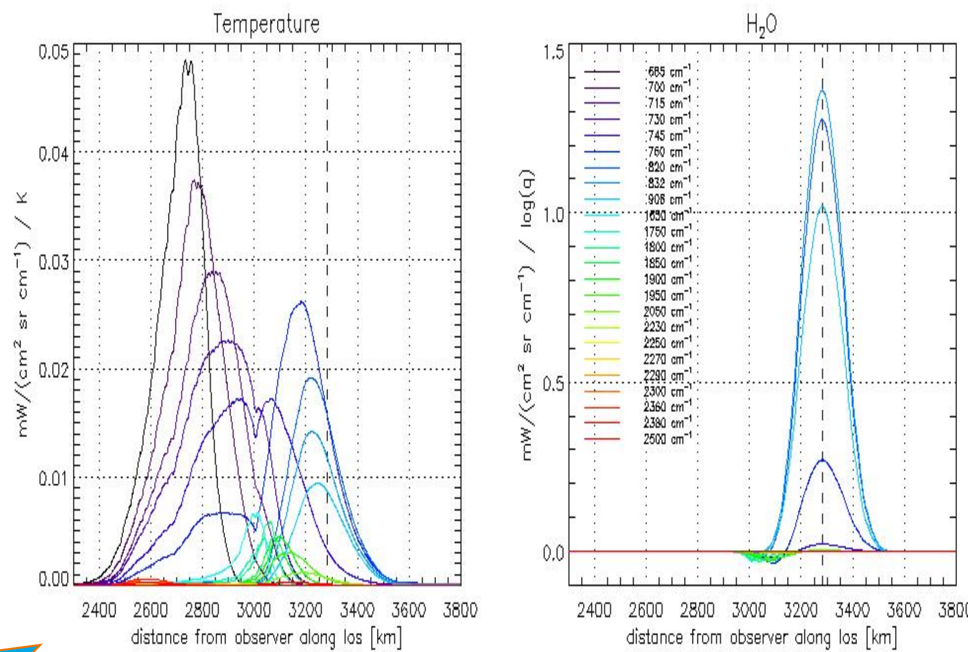
Way forward

Nadir and forward LOS

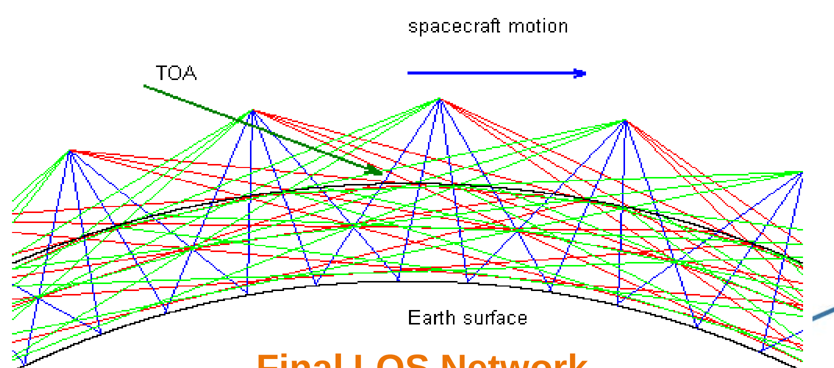


Adding limb forward LOS



Warning: jacobians are shifted wrt the tangent point !!

=> Solution : forward and backward limb LOS



Final LOS Network

Way forward

- **Limb and nadir views at the same time**

- **Decrease as much as possible the number of channels using an optimal geometry (including limb LOS)**
  - **decrease instrument complexity (optics, detection, on-board processing)**
  - **size/mass/power are reduced**
  - **broader channels (SNR increase)**