Effects of cloud variability on TROPOMI molecular and cloud property products

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Outline

Motivation

- The design of spectrometers aboard spaceborne platforms:
  - trade-off between spectral and spatial resolutions
  - guarantee of high signal-to-noise ratios
- Land/ocean optical imagers favor spatial over spectral resolution
  - designed to highly resolve surface properties
- Atmospheric composition sensors favor spectral over spatial resolution
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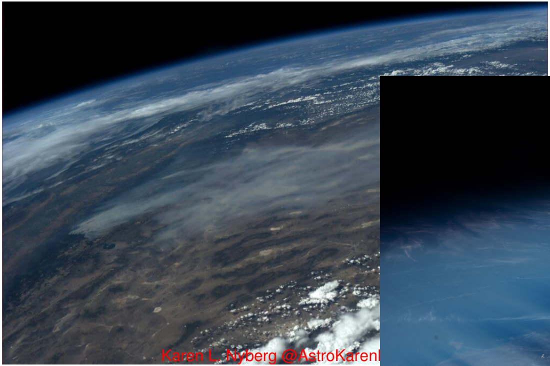

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  - 1-dimensional (1D) horizontally homogeneous radiative transfer (RT) models

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- Models do not account for inside-pixel variability
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- Models do not account for photon horizontal transport
  - 1-dimensional (1D) horizontally homogeneous radiative transfer (RT) models
- variability and 3D RT effects:
  - bias modelled radiances
  - bias retrieved atmospheric products
  - ...but, by how much?

Outline

Inside-pixel variability effects – Components

- heterogeneous cloud field
  - PaLM – A PArallelized Large-Eddy Simulation Model for Atmospheric and Oceanic Flows [Heinze et al. (2012)]
  - 6.4×6.4 km^2 domain
  - $10 \times 10 \times 10$ m^3 cells of liquid water content (LWC)

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  - spatial resolution: 7×7 km^2 ground pixel
  - instrumental slit function
    - ⋆ Ozone fitting window FWHM: 0.54 nm
    - ⋆ O2 A-band window FWHM: 0.38 nm

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$\Longrightarrow$ radiance spectrum of a heterogeneous scene as seen by TROPOMI

Inside-pixel variability effects – Study

Goal

- Study the impact of non-resolved in-scene variability on:
  - simulated radiance spectra
  - molecular and cloud products

Design

- Select a high-resolved $10 \times 10 \times 10$ m^3 PaLM cumulus field embedded in a 6.4x6.4km^2 domain
- Coarsen n-fold the original 3D LWC field at 9 different horizontal resolutions:
  - $10 \times 10 m^2$, $20 \times 20 m^2$, $40 \times 40 m^2$, $80 \times 80 m^2$, $160 \times 160 m^2$, $320 \times 320 m^2$, $640 \times 640 m^2$, $1280 \times 1280 m^2$, $6400 \times 6400 m^2$
- Calculate spectra at each spatial resolution by
  - averaging over the whole spatial pixel domain
  - convolving the LBL RT calculations with the TROPOMI ILS

Outline

cloud property retrieval – Setup

- Observer at TOA = 60 km
- Viewing zenith angle: 15°
- Solar zenith angle: 0°, 30°, 60°
- Relative azimuth angle: 45°
- Surface height: 0 km
- Surface albedo = 0.1
- US standard atmosphere
- O2 LBL absorption coefficients
- Rayleigh scattering
- Cloud PSD:
  - Gamma: N_c=100, α=7
- Mie scattering
  - full cloud phase function

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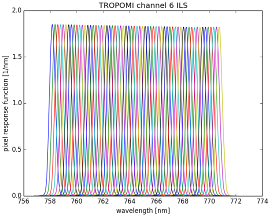
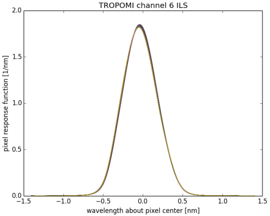
- TROPOMI channel 6 spectral sampling and resolution





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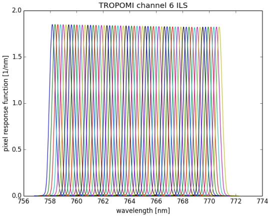
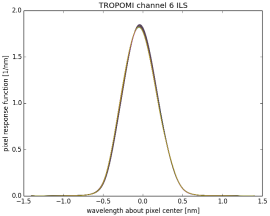
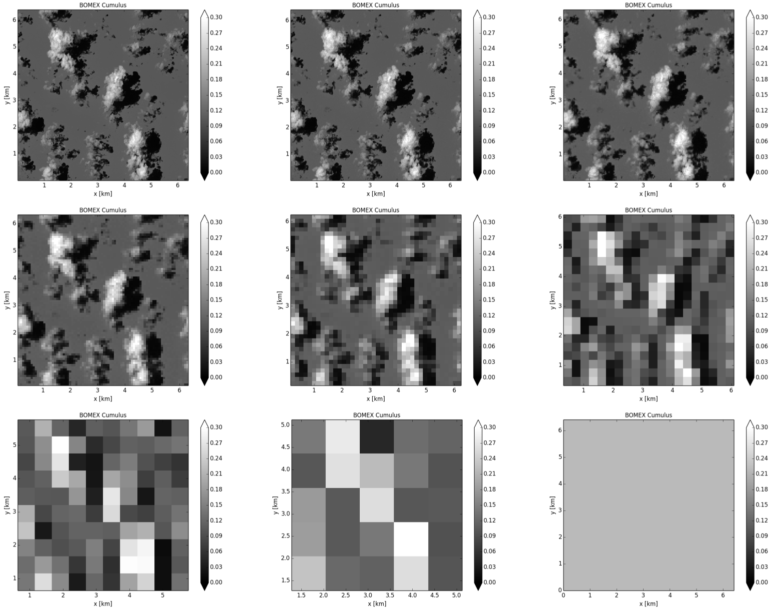
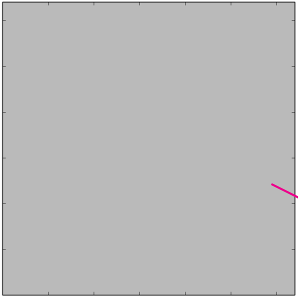


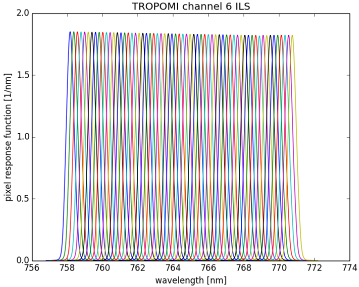


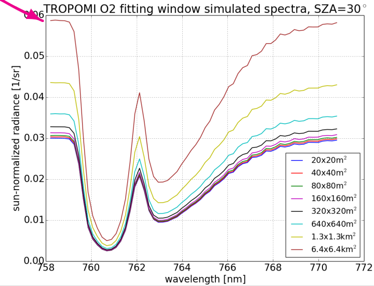
Spatially resolved radiances @ 758 nm



O2 A-band spectra







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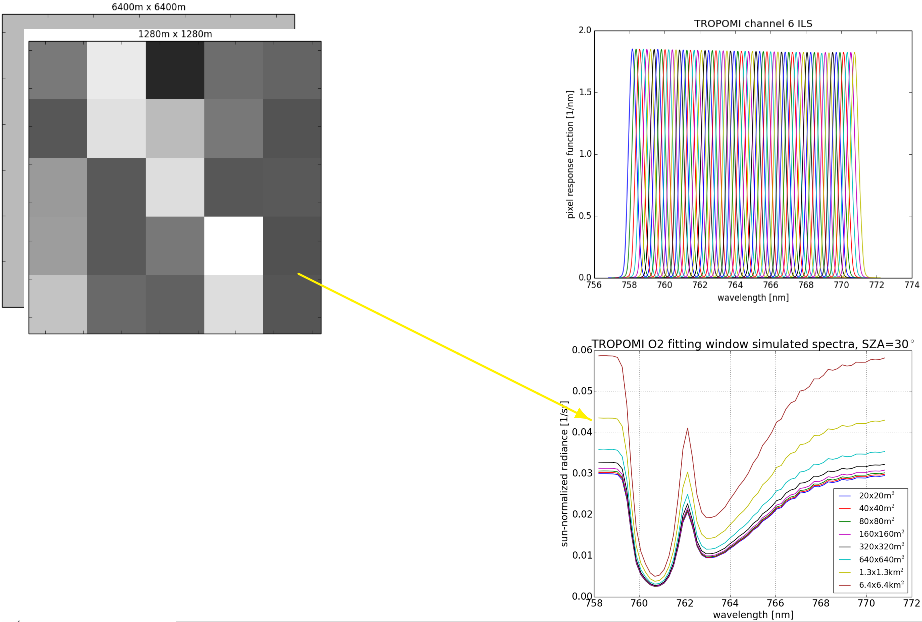

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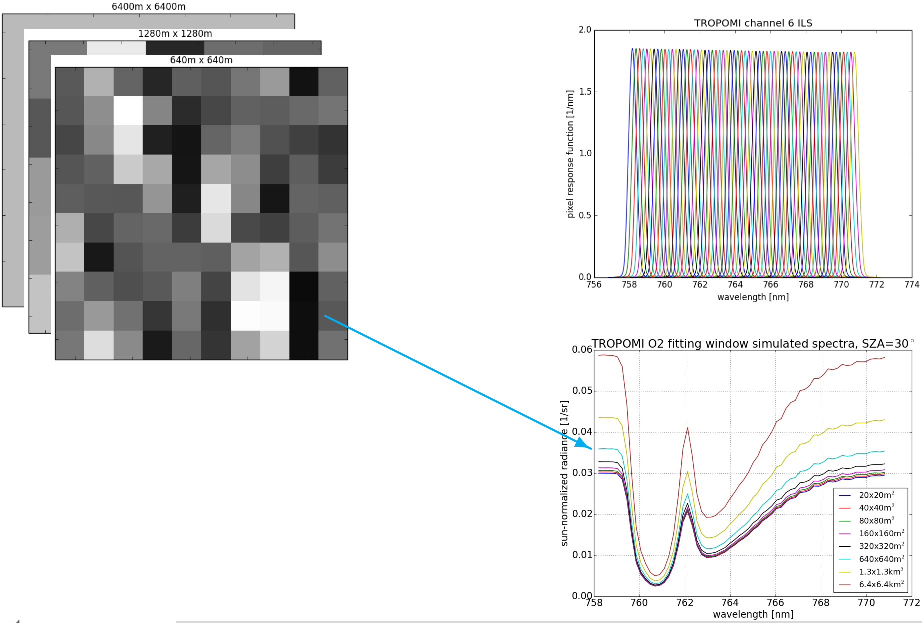

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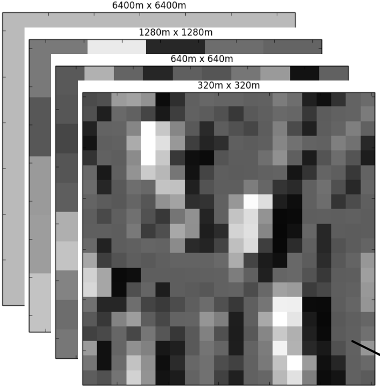

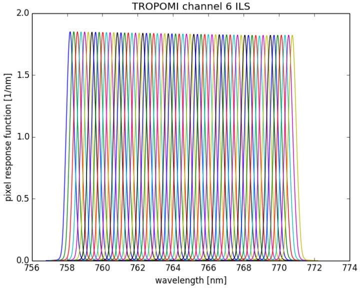

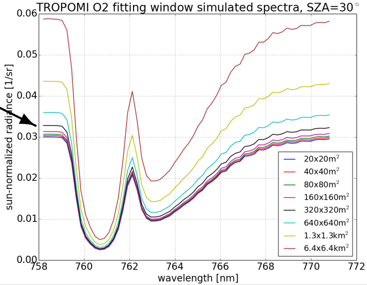

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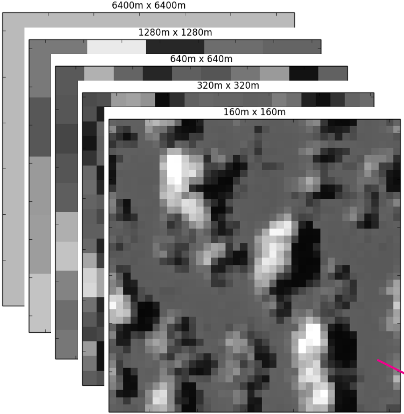

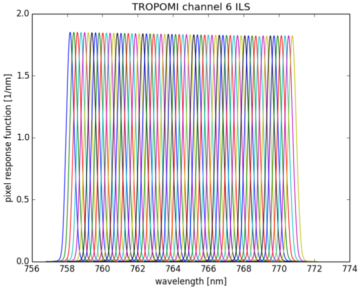

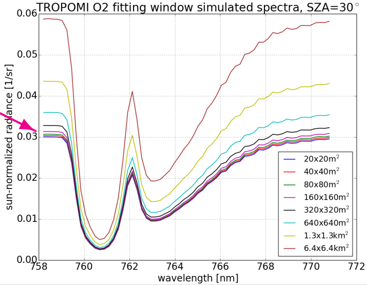

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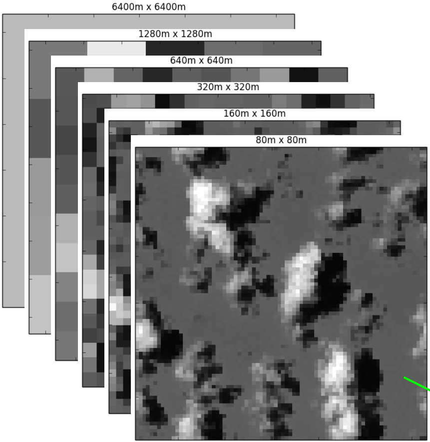

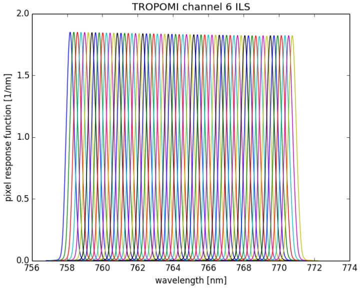

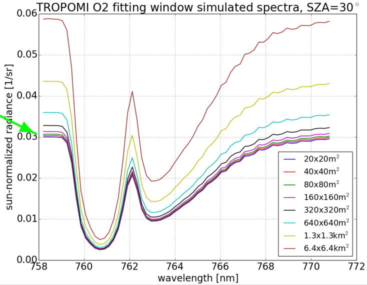

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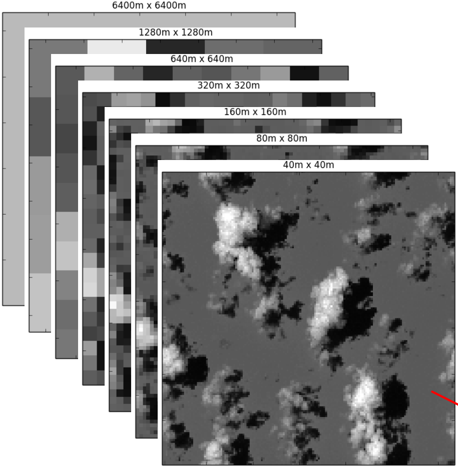

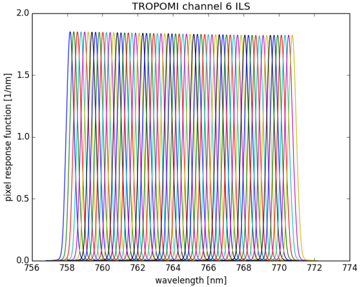

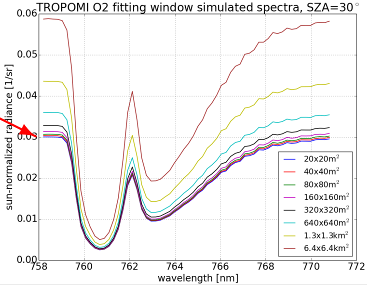

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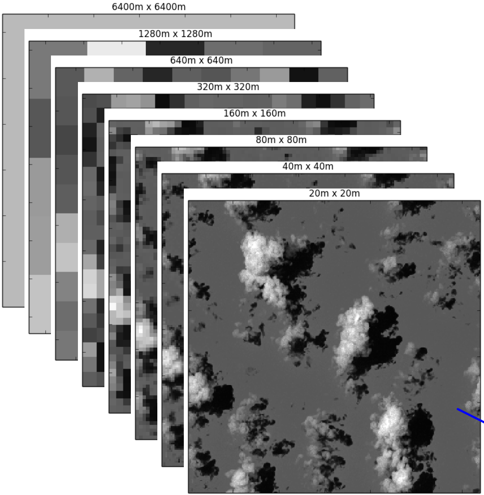

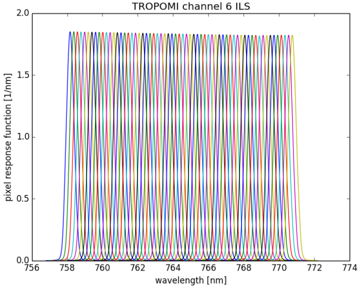

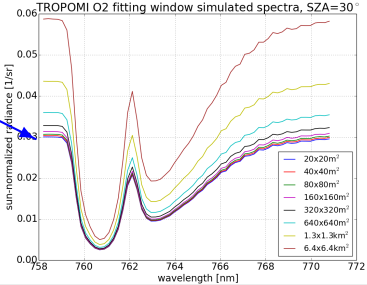

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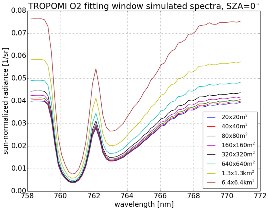

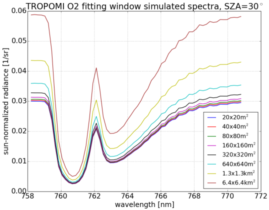

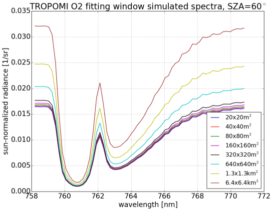

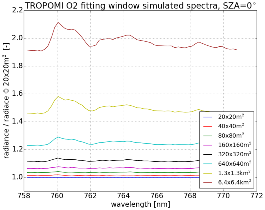

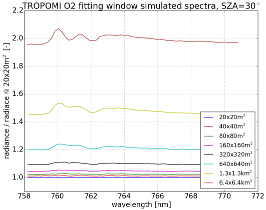

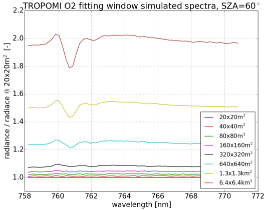

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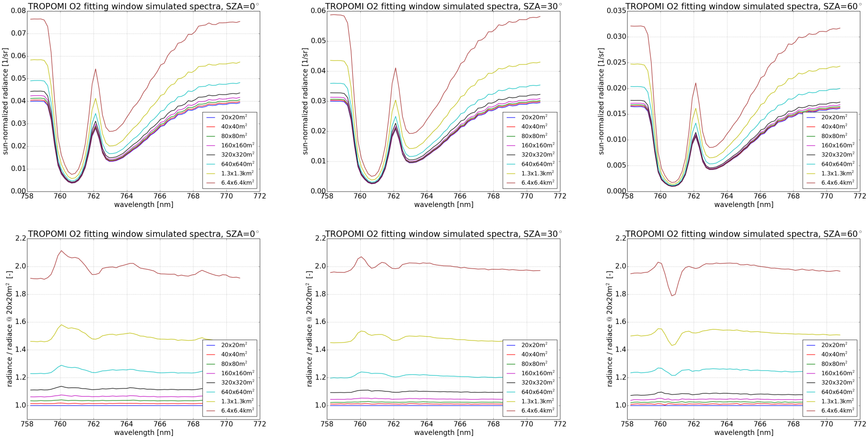

- Coarser cloud fields bias the radiances to higher values

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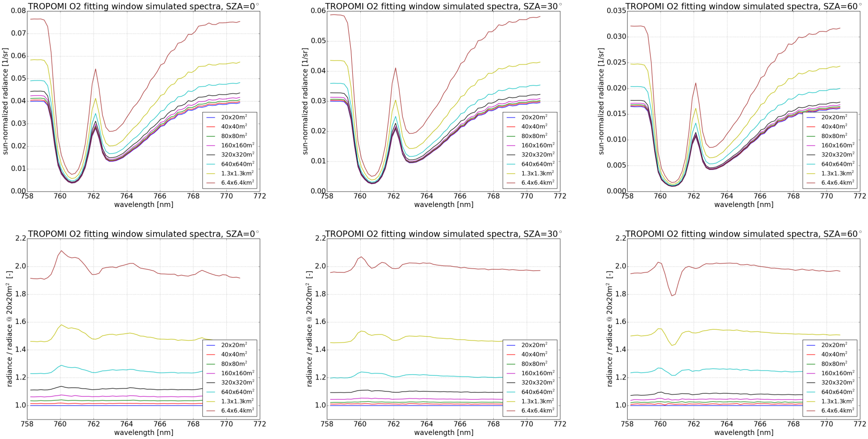


- Coarser cloud fields bias the radiances to higher values
- The spectral shape also depends on spatial resolution

Cloud property retrieval – Forward model

- Independent pixel approximation:
  - cloudy and clear sky contributions
- Clouds and surface treated as Lambertian reflectors
- Rayleigh scattering
- O_2 absorption
- geometrical cloud fraction
  - portion of vertical columns where cloud optical thickness is greater than 0

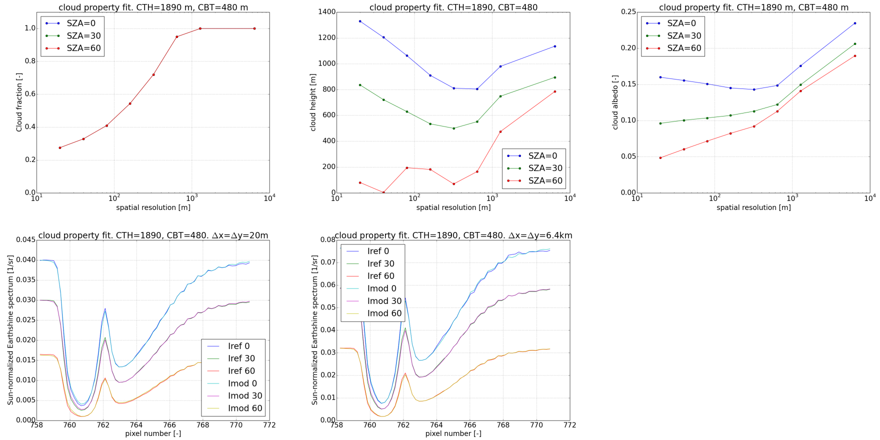
$$I(CH, CA, CF) = CF\ I_{cld}(CH, CA) + (1 - CF)\ I_{clr}(SH, SA)$$

CF: Cloud fraction

CH: Cloud height, CA: Cloud albedo

SH: Surface height, SA: Surface albedo

Cloud property retrieval – Results



- Overall good convergence, independently of spatial resolution
- CA increases for decreasing spatial resolution
- CH well bellow geometrical cloud top height
  - for high solar inclination (SZA=60°), CH bellow cloud bottom height

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Ozone retrieval – Setup

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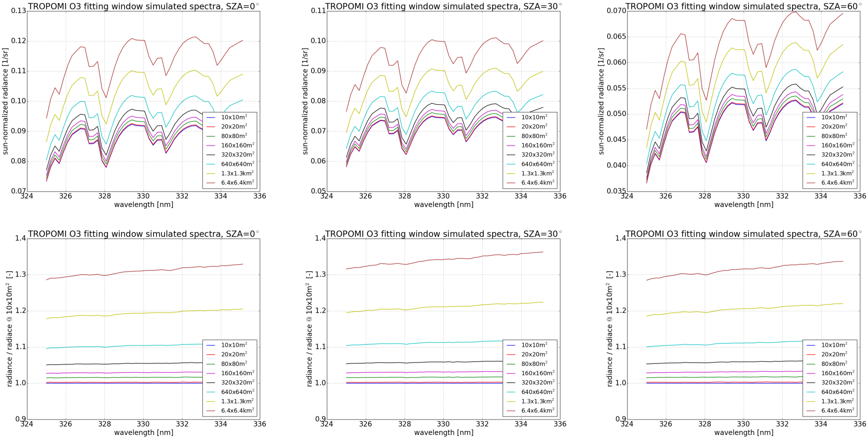
- Relative azimuth angle: 45°
- Surface height: 0 km
- Surface albedo = 0.1
- US standard atmosphere
- O3 cross sections [Brion]
- NO2 cross sections [Vandaele]
- CSs interpolated at all atm. levels
- Rayleigh scattering
- No Raman scattering

- Cloud PSD:
  - Gamma: N_c=100, α=7
- Mie scattering
  - full cloud phase function
- TROPOMI channel 3:
  - Gaussian slit function
  - Spectral sampling: 0.22 nm
  - Spectral resolution (FWHM): 0.54 nm

Ozone fitting window spectra



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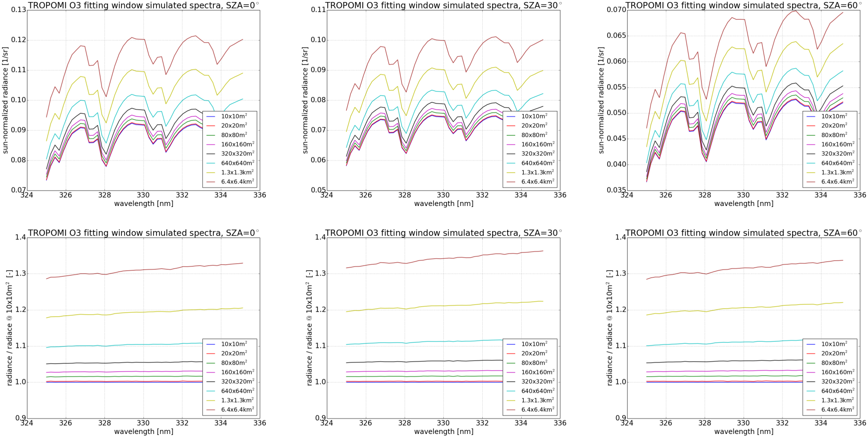

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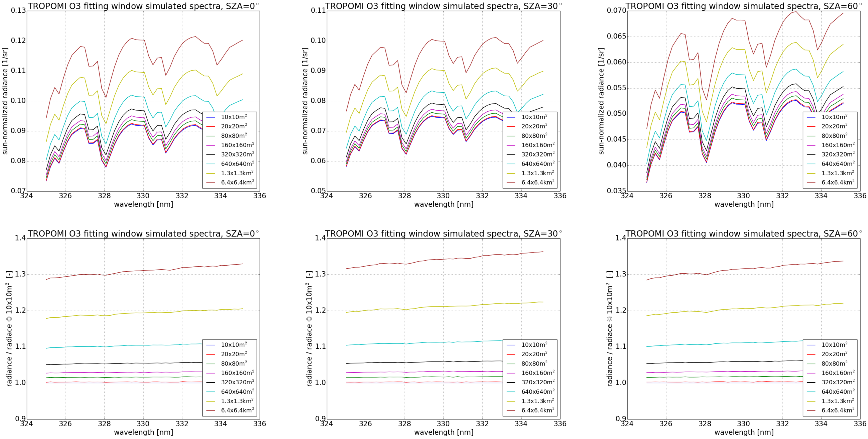
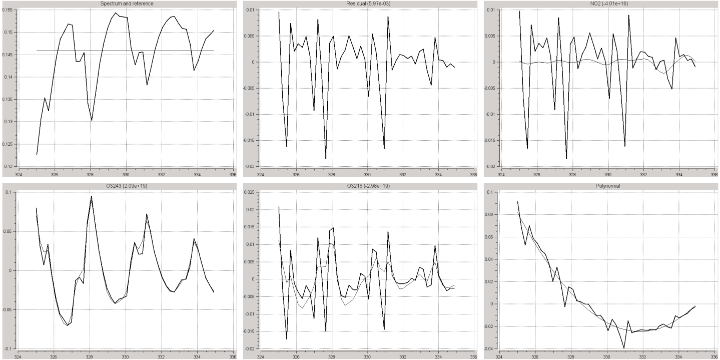


- Coarser cloud fields bias the radiances to higher values
- The spectral shape slightly depends on spatial resolution

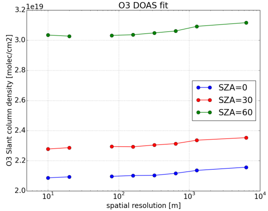
Ozone retrieval

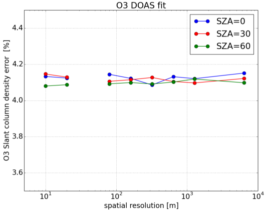
- Differential optical absorption spectroscopy (DOAS)
- QDOAS software package developed @ BIRA
- Results presented as O3 slant column densities (SCD)

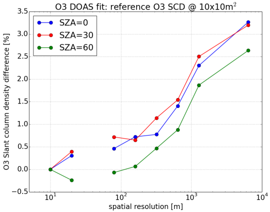


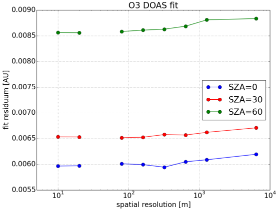
- Overall good convergence, independently of spatial resolution and illumination
- low residua

Ozone retrieval – Results









- Ozone SCD increases for decreasing spatial resolution
- Impact of scene heterogeneity on ozone SCDs is relatively small, bellow the fit error (4%)
- However, the effect can be remarkable for tropospheric ozone

Outline

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- optical variability and 3D RT effects have a large impact on radiance spectra
  - The coarser the sub-pixel resolution, the higher the radiances
  - Sub-pixel resolution also affects absorption features due to changes in photon path lengths
- Cloud property retrieval

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  - We also expect the heterogeneity effects to be larger for tropospheric gases: H2O, CO, CH4, ...

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