Three-dimensional distribution of desert dust derived from IASI infrared observations

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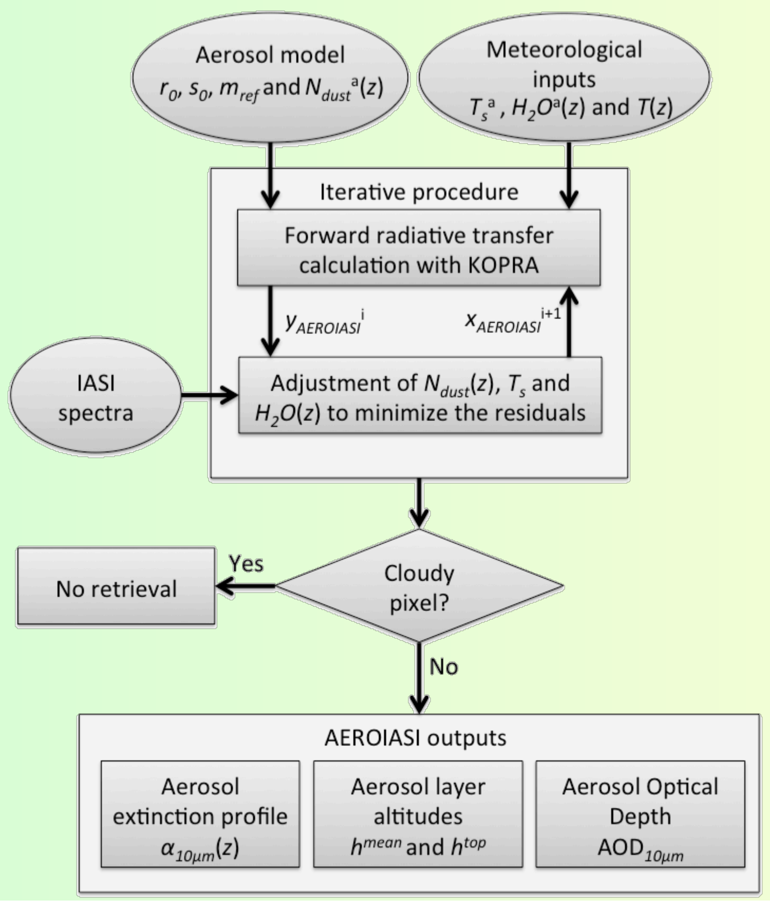
1. Abstract

We describe the daily evolution of the three-dimensional (3D) structure of a major dust outbreak initiated by an extratropical cyclone over East Asia in early March 2008, using new aerosol-related space-borne observations derived from IASI (Infrared Atmospheric Sounding Interferometer). A novel auto-adaptive Tikhonov-Philips-type approach called AEROIASI is used to retrieve vertical profiles of dust extinction coefficient at 10 µm for most clear sky IASI pixels, both over land and ocean. The dust vertical distribution derived from AEROIASI is shown to agree remarkably well with along-track transects of CALIOP space-borne lidar vertical profiles (mean biases less than 110 m, correlation of 0.95 and precision of 260 m for mean altitudes of the dust layers). AEROIASI allows the daily characterization of the 3D transport pathways across East Asia of two dust plumes originating from the Gobi and North Chinese deserts. From AEROIASI retrievals, we provide evidence that (i) both dust plumes are transported over the Beijing region and the Yellow Sea as elevated layers above a shallow boundary layer, (ii) as they progress eastwards, the dust layers are lifted up by the ascending motions near the core of the extratropical cyclone and (iii) when being transported over the warm waters of the Japan Sea, turbulent mixing in the deep marine boundary layer leads to high dust concentrations down to the surface. AEROIASI observations and model simulations also show that the progression of the dust plumes across East Asia is tightly related to the advancing cold front of the extratropical cyclone.

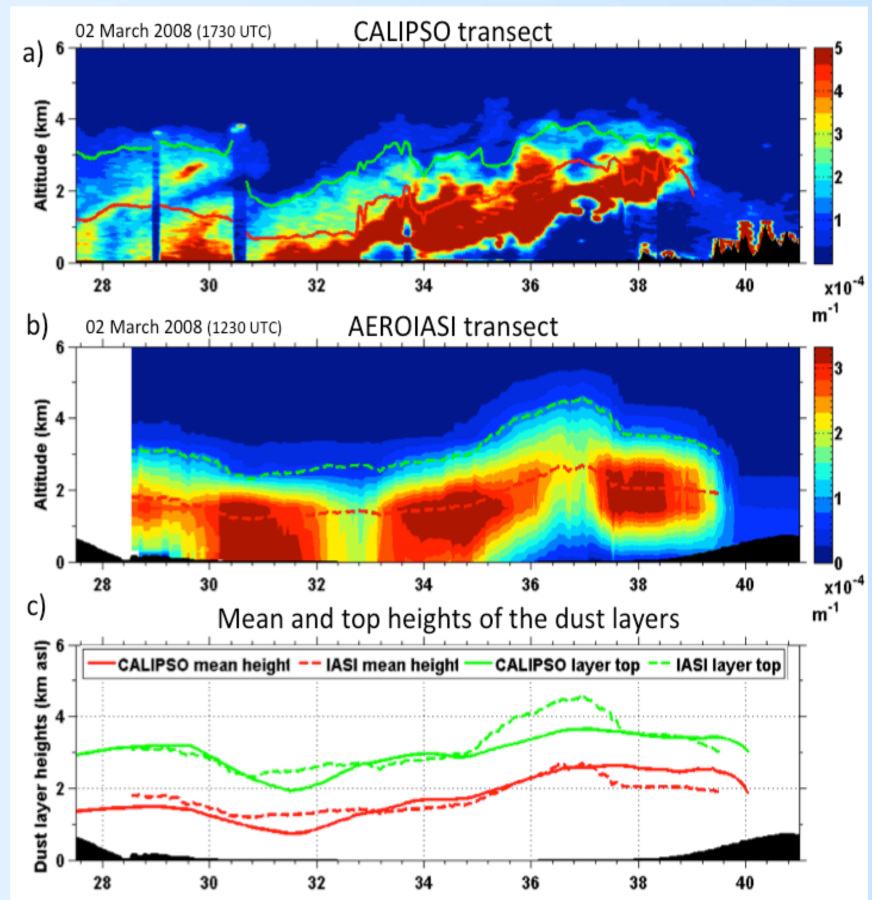
2. AEROIASI Approach

The AEROIASI algorithm follows the sequence of steps presented in the flowchart. First, a desert dust model (including dust microphysical properties) and meteorological profiles are provided as inputs to the radiative transfer model. Then, a thermal infrared radiance spectrum is simulated and compared to the one measured by IASI, for selected spectral micro-windows. In order to minimize the spectral residuals, the method adjusts iteratively the radiative transfer inputs (e.g. the aerosol vertical profile) until reaching convergence (i.e. a minimum of the spectral residuals). Next, a series of cloud screening tests are performed. Then, the final outputs of AEROIASI are calculated for individual unscreened pixels. Each of these steps is detailed in the following paragraphs.



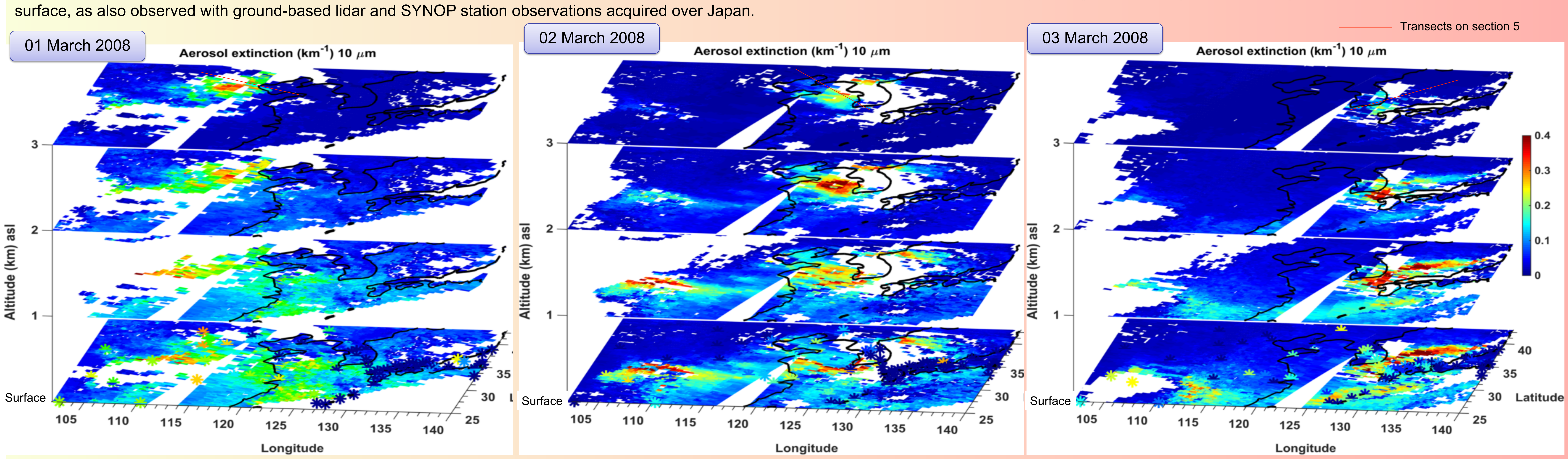
3. Validation of AEROIASI dust profiles against CALIOP

The figure shows comparisons between AEROIASI and CALIOP co-located transects (altitude vs. latitude) of particle extinction coefficient profiles at 10 µm and 532 nm, respectively. It is an example of elevated dust layers mostly over the Yellow Sea on the 2 March. A very good agreement between AEROIASI and CALIOP transects is obtained, both in terms of the dust layers vertical distribution and their horizontal location along the CALIPSO track. Both AEROIASI and CALIOP show a dense dust layer reaching the surface between 30 and 32°N, near the ground but slightly elevated at 34°N and ascending northwards up to similar altitudes (mean altitudes around 2.5 km agl) while being detached from the surface from 35 to 38°N. Around 29°N, an elevated southern dust plume not reaching the ground is as well captured by both instruments. A good quantitative agreement can be noted, with low mean biases for both altitudes of about 100 to 150 m and a precision of 250 m and 350 m for the mean and top altitudes, respectively.



4. 3D distrubion of dust from AEROIASI

The major dust outbreak over East Asia described by AEROIASI originates from strong surface winds associated to an extratropical cyclone crossing over the Mongolian and North Chinese deserts. Ahead of the cold fronts associated with the cyclone, a first major dust plume is lifted over the Gobi desert. On 1 March 2008, AEROIASI shows how dust travels over the Mongolian plateau and the Taihang Mountains, and then overpasses the Beijing region at the same altitude as over the mountains. A second major dust front is emitted near the Loess plateau. On 2 March 2008, both dust plumes form a very large dust belt extending from southeast to northeast across most East Asia, with highest AOD values over the Yellow Sea. According to AEROIASI, this dense dust layer is mixed down to the sea surface only over the southern Yellow Sea, where warm sea surface temperatures enable the development of a deep marine mixing layer entraining into the dust layer. Over the northern Yellow Sea, the dust layer remains elevated at ~2.5 km (mean altitude) over shallower marine boundary layers due to cooler sea surface temperatures than further south. This dust layer is lifted even higher while approaching the low-pressure system core, likely due to the associated ascending motions. On 3 March 2008, the major dust plume, previously transported as elevated layers over the northern Yellow Sea, encounters a deep mixing boundary layer over the Japan Sea, which mixes it down to the surface, as also observed with ground-based lidar and SYNOP station observations acquired over Japan.

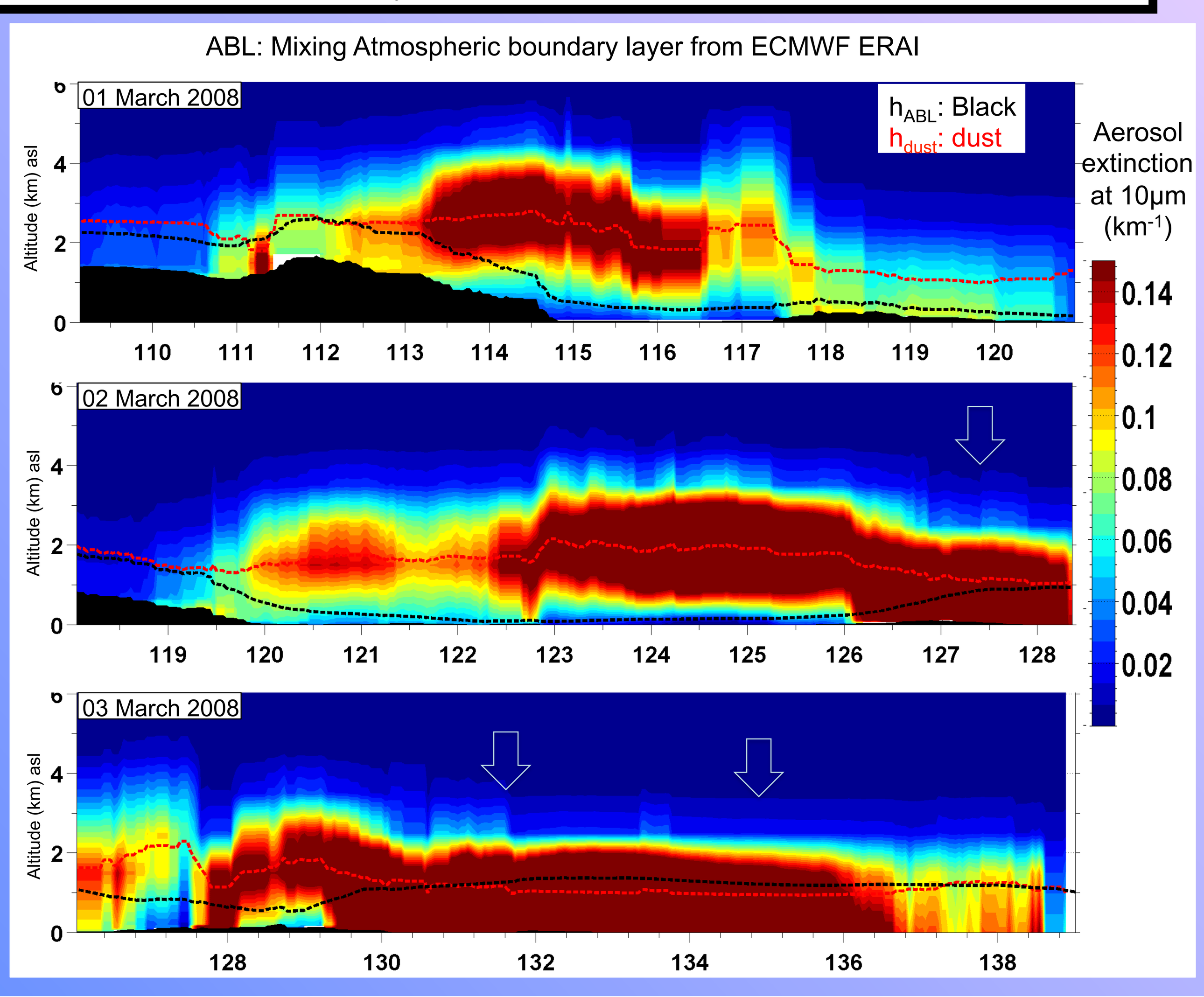


5. Transects of the main dust plume from AEROIASI

When reaching the Beijing region, the main dust layer is transported as an elevated layer over a shallow mixing layer

Then, dust are transported over the Yellow Sea as elevated layers when the mixing layer is shallow. Only it is mixed down to the surface, when reached a deeper marine boundary layer over warmer water.

Over the Japan Sea, the mixing boundary layer is developed up to 2 km of altitude and it reaches the dust layer, mixing it down to the surface



6. Summary

- ✓ AEROIASI: A new and unique method to observe the 3D distribution of dust from IASI spaceborne measurements, both over land and ocean under clear-sky conditions
  - ➙ *Cuesta et al., J. Geophys. Res. 2015 (in revision)*
- ✓ First analysis of the evolution of the 3D transport pathways of dust plumes from satellite observations : link to atmospheric dynamics, air quality, etc.
- ✓ Good validation results
  - ➢ Transects on the CALIPSO tracks: very similar structures, mean bias of mean altitude of the dust layers < 110m and linear correlation R of 0.95
  - ➢ AOD vs. AERONET (coarse): low mean bias (< 1%) and good correlation (0.76)
  - ➢ Structures of dust plumes similar to those observed by MODIS