Physically-based simultaneous retrieval for CO, CO_2, CH_4, HNO_3, NH_3, OCS and N_2O from IASI observations and inter-comparison with in situ observations and AIRS, GOSAT, OCO-2 satellite products

Applied Spectroscopy

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Rationale

- The Infrared Atmospheric Sounder Interferometer (IASI) onboard of MetOp polar platforms has been largely used for meteorological applications. However, with a coverage from 645 to 2760 cm^{-1}, and a spectral sampling of 0.25 cm^{-1} it can be used for the retrieval of minor and trace gases.
- Most of the procedures used to retrieve such parameters from IASI spectra are based on the exploitation of narrow spectral regions, which prevents to use the full information content embedded in IASI radiances, and both the retrievals and the related uncertainties are biased. This aspect is common to many present retrieval schemes for other satellite missions.
- We have developed a new Level 2 (L2) processor for the retrieval of surface and atmospheric state from IASI radiances. The inversion procedure works with the full IASI spectral interval (645-2760 cm^{-1}), and simultaneously retrieves:
  - *Surface Temperature and Emissivity (spectrum),*
  - *Atmospheric Profiles of Temperature, H_2O, O_3, HDO, CO_2, N_2O, CO, CH_4, SO_2, HNO_3, NH_3, OCS, CF_4*

Random Projections

$$\mathbf{c} = \Phi \mathbf{R}$$

where the elements of the matrix Φ are identically distributed random variables from a Gaussian density probability function with zero mean and variance 1/M, where M is the number of elements of the radiance R.

The transform has the restricted isometry property, and preserves the information content in the spectrum.

$$1-\eta \le \frac{||\Phi \mathbf{R}||}{||\mathbf{R}||} \le 1+\eta$$

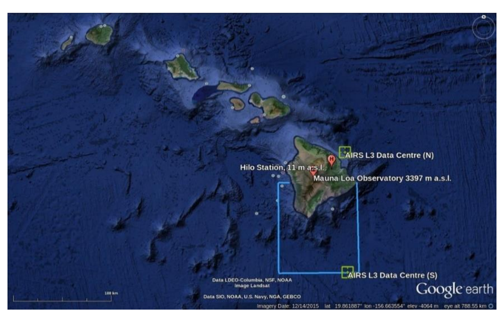
Usual equations for Optimal Estimation are transformed accordingly

$$(\mathrm{S}_a^{-1} + \tilde{\mathrm{K}}^t \tilde{\mathrm{S}}_o^{-1} \tilde{\mathrm{K}})\mathbf{x} = \tilde{\mathrm{K}}^t \tilde{\mathrm{S}}_o^{-1} \tilde{\mathbf{y}} \qquad \tilde{\mathbf{y}} = \Phi \mathbf{y}; \quad \tilde{\mathrm{K}} = \Phi \mathrm{K}; \quad \tilde{\mathrm{S}}_o = \Phi \mathrm{S}_o \Phi^t$$

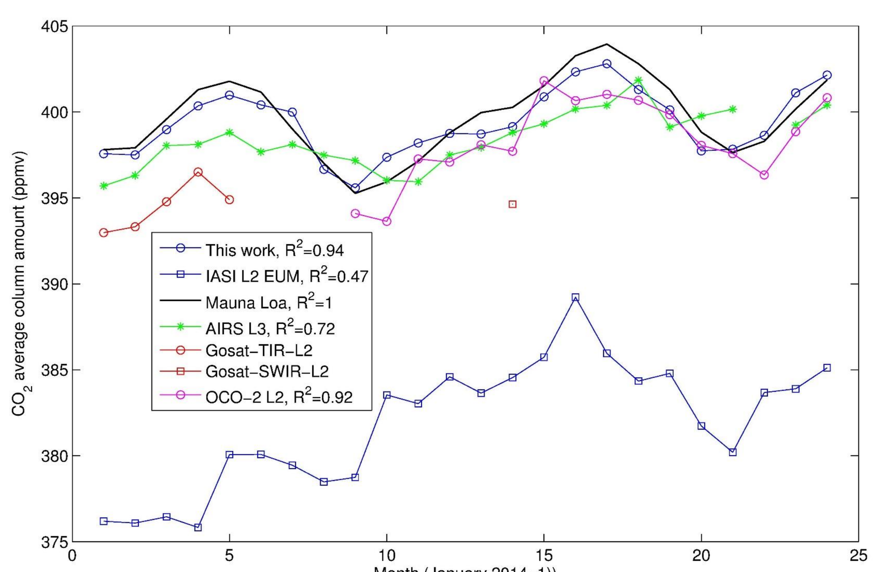
Random Projections Provide

a) an unified and coherent treatment of systematic and random errors;
b) a compression tool, which reduces the dimensionality of the data space (in our application the compression ratio is 7:1);
c) a noise model which is truly Gaussian making it possible to rigorously applicable without further adjustments to Optimal Estimation, and derive the correct retrieval error;
d) a simplified treatment of the inverse algebra to get to the final solution.

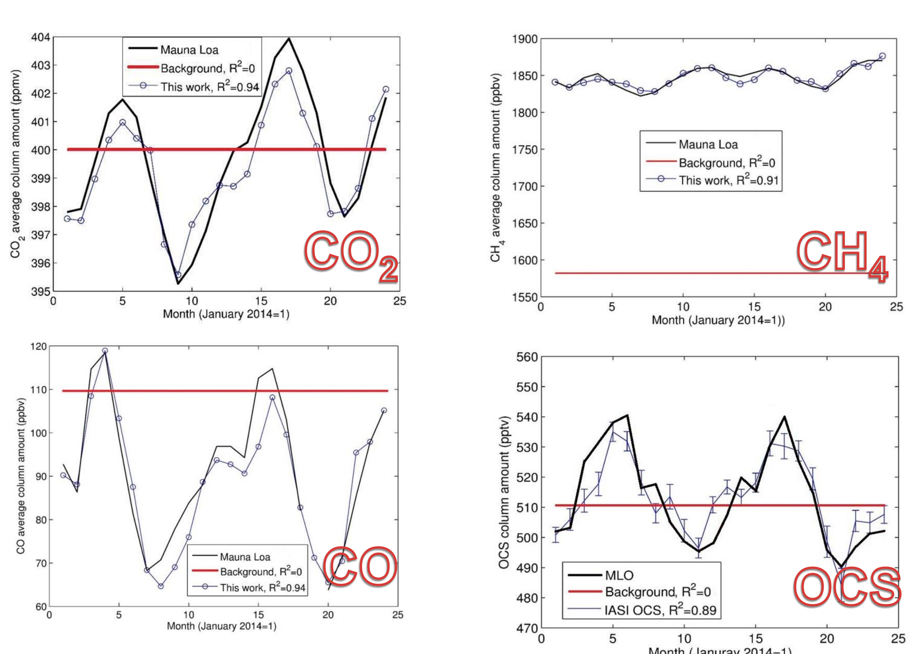
Validation study based on a two-years long record of IASI observations



- Data: IASI-A-B
- Period: Jan 2014 to Dec 2015,
- Target Area, Hawaii close to Mauna Loa (MLO) validation station.
- Total IASI spectra analyzed: 43842



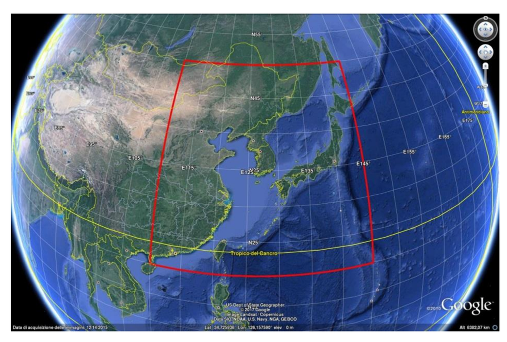
In the Figure above, IASI retrieval for CO_2 are compared to operational products from different satellites and instruments. These include AIRS (Atmospheric Infrared Radiometer Sounder), GOSAT (Greenhouse Gases Observing Satellite), OCO-2 (Orbiting Carbon Observatory-2). Results show that our retrieval methodology is by far superior to the widely algorithms applied to IR radiances (IASI, AIRS, GOSAT). Comparison with OCO-2 shows similar results, but in our methodology much less a-priori information is introduced than with OCO-2.



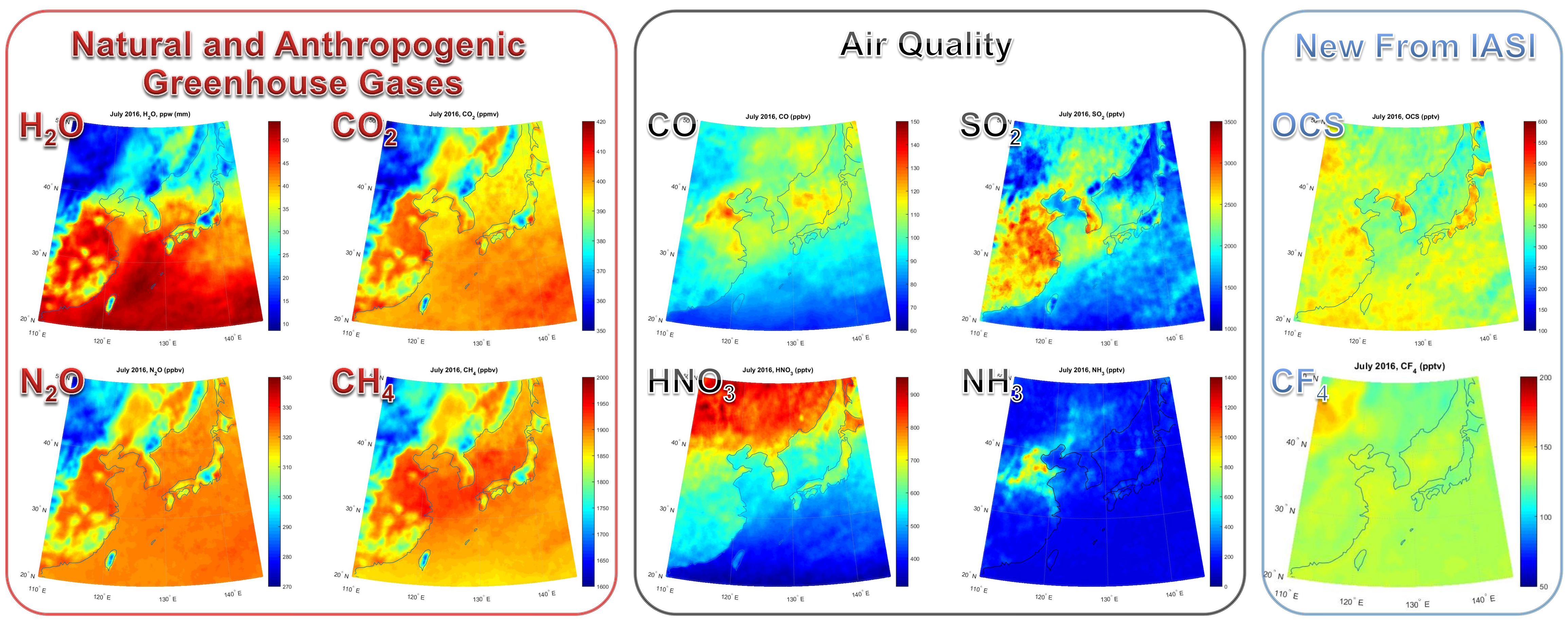
Retrieval of CO_2, CH_4, CO and OCS compared with in situ measurements (in black). Red lines show the background values we used in our methodology. The a-priori we use is a flat line.

Random Projections combined with a wide spectral coverage (such as that provided, e.g., by IASI) enable the greenhouse and trace gases retrieval based on data alone.

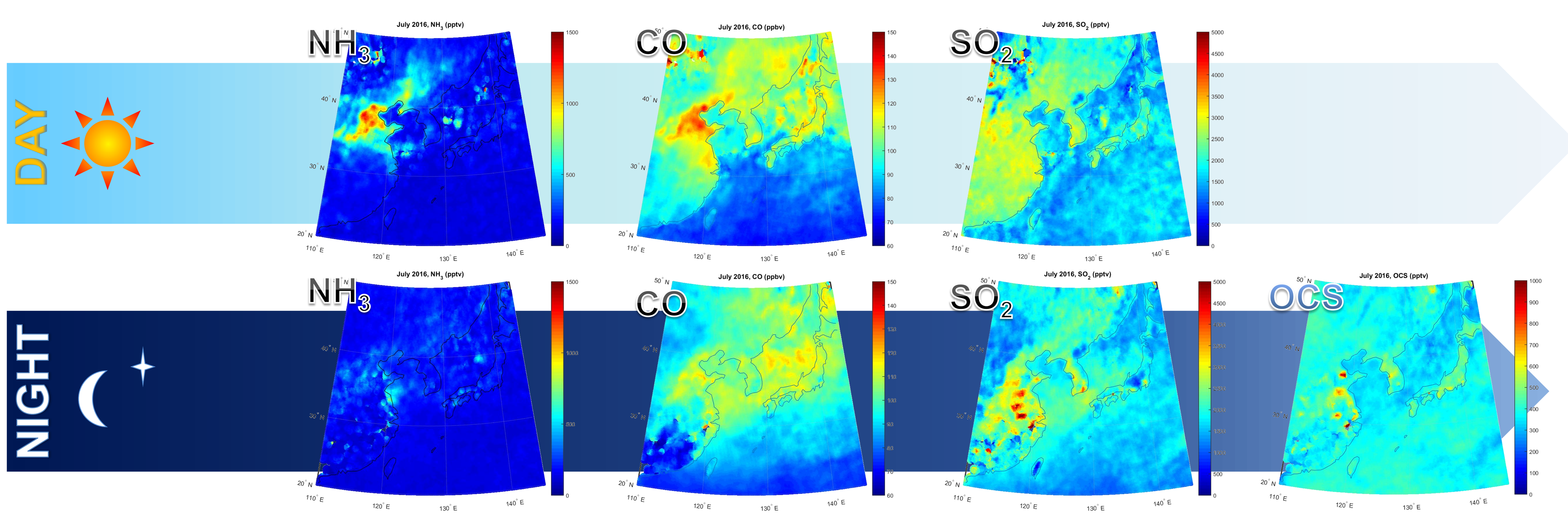
Application Eastern China and Japan



- Data: IASI-A-B
- Period: July 2016
- Target Area, lat-lon range [20°,50°]×[110°,145°]
- Total IASI spectra analyzed: 1,325,222 of which clear sky, 304,829 (~23%).



Monthly average maps. Retrieval results have been obtained for the clear sky spectra and averaged over a grid 0.5°×0.5° (~50 km × 50 km)



Differentiating Day and Night. These maps show the monthly average differentiating Day from Night observations. Ammonia (NH_3) and Carbon Monoxide (CO) values are higher during the day related to the anthropic activities. Intense hotspots of SO_2, OCS during the night indicate the Carbon power plant activities.

References

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Conclusions

- Combining a forward model with a Random Projections algorithm, we have shown that the exploitation of the whole IASI spectral coverage works and yields results of unprecedented accuracy. Our scheme is unique. Being physically based it does not need ad-hoc constraints, which can heavily bias the final products.
- Because of random projections, the typical time of a single run is ≈ 7 s considering a platform with an IntelCore i7-2600CPU3.50 GHz. This time can be optimized because at present our software is based on a hybrid Matlab–Fortran architecture. Since IASI reaches the global coverage in 12 h, during which the instrument records about 650,000 spectra, of which some 20% in clear sky, with a commercial work station equipped with some 50–100 CPUs, our inverse scheme can easily run in real time even in its present non-optimized software architecture.
- We conclude that Random Projections combined with a wide spectral coverage (such as that provided, e.g., by IASI) enable the concept of greenhouse and trace gases retrieval based on data alone.
- An application has been shown to Eastern China and Japan, showing that we can retrieve with a wealth of details greenhouse gases and trace species, which directly impacts Air Quality.
- In effect, we have found that Eastern China is a source of carbon, sulphate and nitrate aerosols.