The total IASI level 2 processor τ²IP: Seven-years of IASI sea surface temperature, CO_2, CH_4, N_2O retrievals for the Arctic Ocean during the summer season

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Abstract

- This paper describes the level 2 processor that we developed for IASI. This processor, called τ²IP (total level 2 processor for IASI [1,2,3]), uses the whole IASI spectral coverage, therefore making it possible to exploit the full information content of the spectra. τ²IP also uses a random projections approach to reduce the dimensionality of the data space.
- The Infrared Atmospheric Sounder Interferometer (IASI) onboard the 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 many minor and trace gases.
- τ²IP retrieves surface and atmospheric properties from IASI spectral radiances. The inversion procedure works with the full IASI spectral interval (645-2760 cm^{-1}), and is simultaneously retrieving:
  - *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

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

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.

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

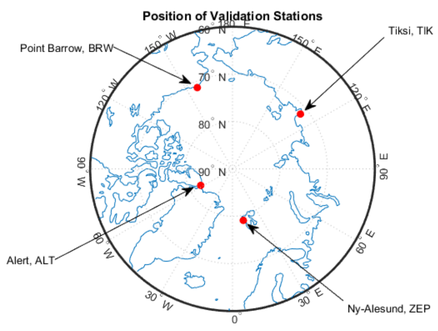
Usual equations for Optimal Estimation are transformed accordingly

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

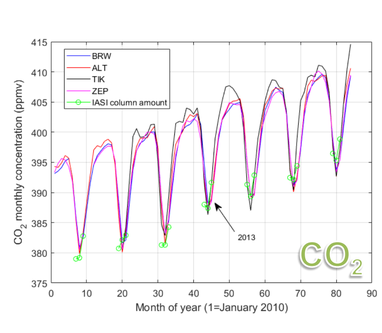
Random projections provide

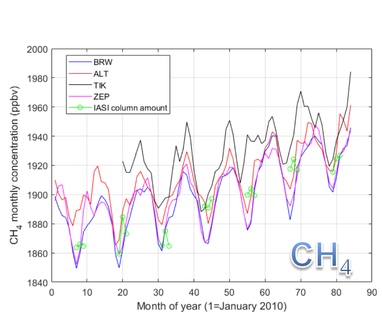
a) an unified and consistent treatment of systematic and random errors;
b) a compression tool, which reduces the dimensionality of the data space (in our application the compression ratio is 7:1);
c) a noise model which is truly Gaussian making it rigorously applicable to Optimal Estimation without further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

Validation with 4 Arctic stations

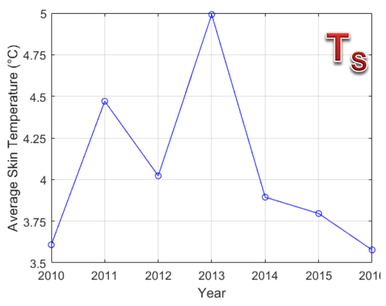


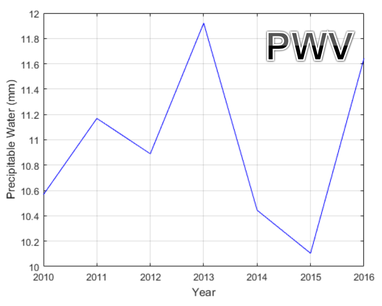
- Data: IASI-A
- Period: June, July, August 2010-2016,
- Target area, Arctic Sea
- Ground based stations:
  - Point Barrow (BRW)
  - Alert (ALT)
  - Tiksi (TIK)
  - Ny-Alesund (ZEP)





The Figures above show time series of monthly mean IASI retrievals for CO_2 and CH_4 averaged over the Arctic region (open circles) and their comparison with ground based validation stations (solid lines).
IASI is capable to capture the increase of CO_2 and CH_4 of about, respectively, 2.2 ppmv/year and 10 ppbv/year in the seven years period. For CO_2, the 2013 grow rate has reached the largest value on record of about 7 ppmv (15 ppbv for CH_4). The CO_2 jump in 2013 (Figures below) is paralleled by an increase in skin temperature (SST) and water vapour content (the main natural greenhouse gas). The data shown in the plots below have been averaged over the whole Arctic ocean (sea water) and over the summer season (July, August, September).





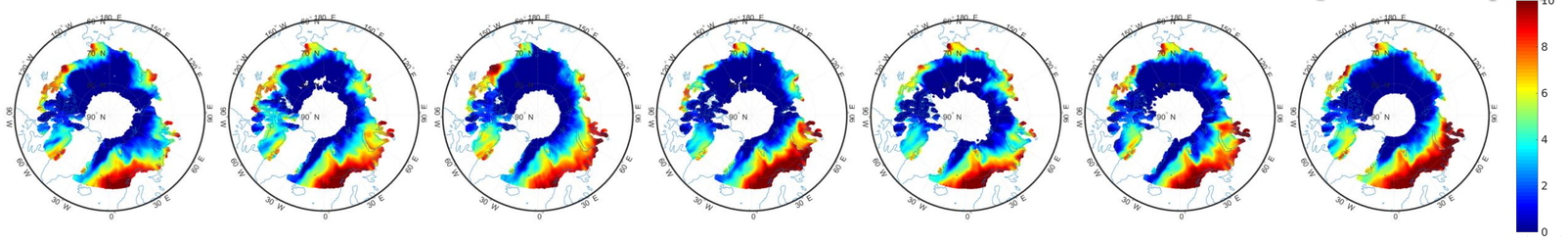
Results: Summer Season Maps

- **Data: IASI-A**
- **Period: June, July and August 2010-2016**
- **Target area, lat-lon range [65°,90°] × [-180°,180°]**
- **Total IASI spectra analyzed: ~ 4 millions clear sky, sea surface soundings.**

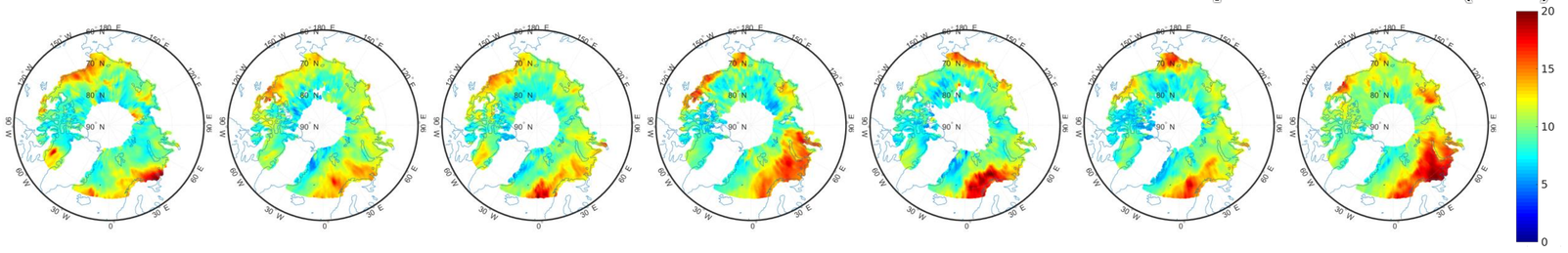
- IASI (Infrared Atmospheric Sounder Interferometer) observations for the years 2010 to 2016 over the Artic Sea during the summer season have been processed for the simultaneous retrieval of skin temperature (SST), methane, nitrous oxide and carbon dioxide.

- The analysis has considered clear sky, sea water, IASI soundings for a latitude greater than 65°, which has allowed us to derive maps covering the whole Arctic sea.
- Results have been rendered with maps of grid spacing of 1°×1°, which show a wealth of spatial structures.
- These findings are unexpected, mostly for CO_2, and could be used to tune and validate transport models.

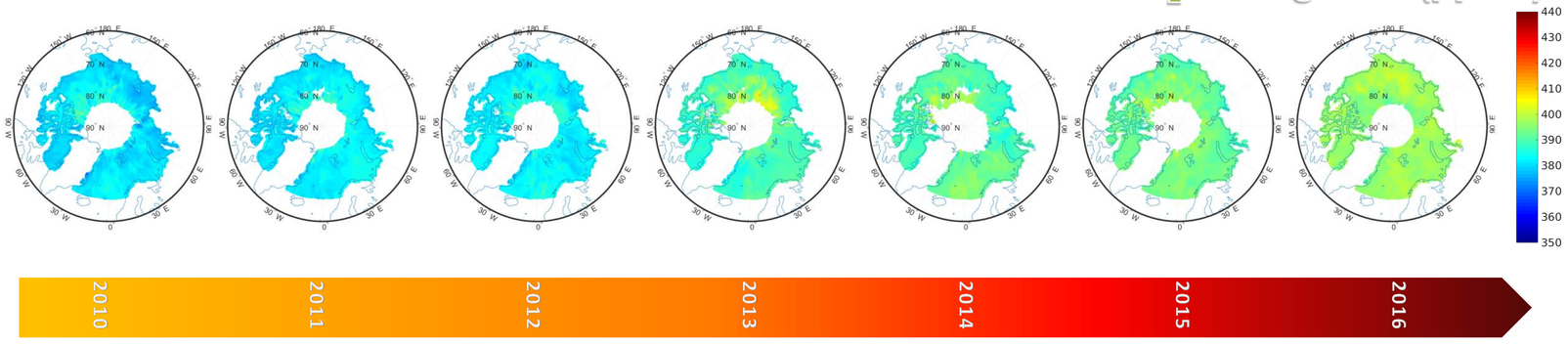
Skin Temperature (°C)



Precipitable Water (mm)



CO_2 mixing ratio (ppmv)



References

1. C Camy-Peyret, G Liuzzi, G Masiello, C Serio, S Venafra, SA Montzka (2017) *Assessment of IASI capability for retrieving carbonyl sulphide (OCS).* Journal of Quantitative Spectroscopy and Radiative Transfer 201, 197-208
2. G Liuzzi, G Masiello, C Serio, S Venafra, C Camy-Peyret (2016) *Physical inversion of the full IASI spectra: Assessment of atmospheric parameters retrievals, consistency of spectroscopy and forward modelling.* Journal of Quantitative Spectroscopy and Radiative Transfer 182, 128-157
3. C Serio, G Masiello, G Liuzzi (2016) *Demonstration of random projections applied to the retrieval problem of geophysical parameters from hyper-spectral infrared observations.* Applied optics 55 (24), 6576-6587

Conclusions

- We have analyzed seven years (2010-2016) of IASI data for the Arctic Basin (ice free sea water) during the summer season.
- Greenhouse gases dry air column average mixing ratios have been simultaneously retrieved with skin temperature (SST) and water vapor.
- The analysis allowed us to derive CO_2 and CH_4 growth rate for a region, where SWIR-based instrument operated in the sun-glint mode are not efficient. In effect, satellite observations of greenhouse gases in the Arctic region are rather rare.
- We have found a dramatic increase of CO_2 in 2013 which is also evidenced by *in situ* observations in four validation stations.
- An increase has been also seen in skin temperature and precipitable water which could be the sign of regional global warming.
- The uniqueness of this analysis is the simultaneous retrieval of several key geophysical parameters which minimizes possible artifacts due to space and time co-location differences of separate/independent retrievals as well as possible biases originating from the impact of interfering species or parameters.

See also the poster A1.3 of IWGGMS14 by S. Payan et al. on the same topic, but using GOSAT/TANSO-FTS spectra