Using the full IASI spectrum for the physical retrieval of temperature, H_2O, HDO, O_3, minor and trace gases

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Using the Full IASI Spectrum for the Physical Retrieval of Temperature, H_2O, HDO, O_3, Minor and Trace Gases

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Abstract. IASI (Infrared Atmospheric Sounder Interferometer) is flying on the European MetOp series of weather satellites. Besides acquiring temperature and humidity data, IASI also observes the infrared emission of the main minor and trace atmospheric components with high precision. The retrieval of these gases would be highly beneficial to the efforts of scientists monitoring Earths climate. IASI retrieval capability and algorithms have been mostly driven by Numerical Weather Prediction centers, whose limited resources for data transmission and computing is hampering the full exploitation of IASI information content. The quest for real or nearly real time processing has affected the precision of the estimation of minor and trace gases, which are normally retrieved on a very coarse spatial grid. The paper presents the very first retrieval of the complete suite of IASI target parameters by exploiting all its 8461 channels. The analysis has been exemplified for sea surface and the target parameters will include sea surface temperature, temperature profile, water vapour and HDO profiles, ozone profile, total column amount of CO, CO_2, CH_4, N_2O, SO_2, HNO_3, NH_3, OCS and CF_4. Concerning CO_2, CH_4 and N_2O, it will be shown that their colum amount can be obtained for each single IASI IFOV (Instantaneous Field of View) with a precision better than 1-2%, which opens the possibility to analyze, e.g., the formation of regional patterns of greenhouse gases. To assess the quality of the retrieval, a case study has been set up which considers two years of IASI soundings over the Hawaii, Manua Loa validation station.

INTRODUCTION

In this paper we present an original retrieval methodology, which exploits the full IASI (Infrared Atmospheric Sounder Interferometer, [1]) information content in order to estimate the atmospheric parameters. These include the main contributors to the formation of the Earth infrared emission spectrum: surface parameters (emissivity ϵ) and surface temperature (T_s), vertical profiles of temperature (T), of water vapour mixing ratio (Q), of ozone mixing ratio (O), of HDO mixing ratio (D) and average column abundances of CO_2, CO, CH_4, N_2O, HNO_3, SO_2, NH_3 OCS and CF_4. Exploiting the forward/inverse methodology developed and presented in [2, 3, 4, 5, 6, 7, 8], we perform a combined retrieval, which estimates all atmospheric parameters simultaneously. The strategy allows a consistency assessment of the spectroscopic modelling of different species and of the different spectral ranges where they are contributing. The analysis presented here provides the possibility to examine retrieval products, precision and bias, by comparison with *in situ* correlative data and we have chosen those from the Mauna Loa validation station.

DATA AND METHODS

The data set used in the present analysis consists of a two-year period (January 2014 to December 2015) of IASI observations acquired on sea surface over the target area shown in Fig. 1. IASI [1] has been developed in France by CNES and is flying on board the Metop platforms. These are satellites of the EUMETSAT European Polar System (EPS). IASI level 1 product (L1C) consists in a continuous spectrum covering the domain 645 cm^{-1} to 2760 cm^{-1}. The

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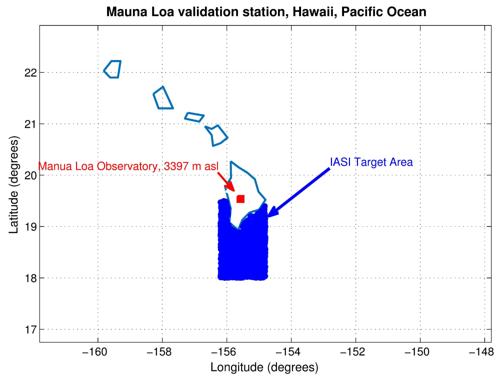

FIGURE 1. IASI target area showing the location of the Mauna Loa validation station. The retrieval target area shows the IASI footprints for the month of July 2014.

target area (see Fig. 1) is intentionally close to the Mauna Loa validation station (19.5362 N, 155.5763 W, 3397.00 m asl) in Hawaii (UTC = Local Time + 10 hr) and has a size of approximately 1.5°×1.0°, which corresponds to a box of size ≈50 km. The number of IASI soundings within the target area are some 2000 per month, after cloud screening they reduce to some 400-500 of which some 200-300 correspond to night-time. We have considered night-time soundings only to avoid the effect of non-LTE (non Local Thermal Equilibrium) in the core of CO_2 ν_3 spectral region. Cloud detection has been performed using the methodology developed in [9]. In addition to IASI data, we have used *in situ* observations (monthly means) of CO_2 and CH_4 [10] recorded at Mauna Loa observatory. For the target area shown in Fig. 1, the ECMWF (European Centre for Medium Range Weather Forecasts) analysis, at the four canonical hours, has been used to initialize the retrieval scheme. The surface and atmospheric parameters have been directly downloaded from the ECMWF MARS (Meteorological Archival and Retrieval System) archive and consist of surface temperature and pressure, profiles of temperature, water vapour and ozone. The ECMWF analysis is available on a horizontal grid mesh of 0.125°×0.125°. The atmospheric profiles are obtained on 137 pressure levels. The ECMWF analysis was time and space interpolated and co-registered with IASI soundings. *The retrieval scheme* with its forward and inverse modules have been fully described in [11, 12]. Here we briefly limit ourselves to a brief decscription of the basics aspects. *The forward model* embedded in the retrieval scheme is called σ-IASI [2]. This is a monochromatic forward module using a look-up table for the optical depth. The look-up table is derived from LBLRTM (Line-by-Line Radiative Transfer Model) model (e.g., [13]). The latest version of σ-IASI uses LBLRTM version 12.2. The forward module is based on 60 pressure layers, spanning the atmosphere from the ground level to the top level assumed to be at 0.005 hPa. The model computes spectral radiances and analytical Jacobian derivatives of any surface and/or atmospheric parameter. IASI radiances are obtained through convolution with the IASI Instrumental Spectral Response Function (ISRF). *The inverse mathematical scheme* we use in this analysis is the so-called δ-IASI inverse module [3], which implements an iterative algorithm for the optimal estimation of the thermodynamic state of the atmosphere. The retrieval algorithm follows Rodgers optimal estimation method [14] and uses an additional regularization parameter which improves the retrieval accuracy and convergence rate of the inverse scheme [8]. The state vector is simultaneously retrieved and it is made up by T_s, ε, atmospheric profiles for T, Q, D, O, and minor and trace gas mixing ratio profiles for CO_2, N_2O, CO, CH_4, SO_2, HNO_3, NH_3, OCS and CF_4. The atmospheric profiles are specified on a pressure grid of N_L = 60 layers, spanning the range 1050 to 0.005 hPa [2]. The nine minor and trace gas profiles are parameterized with a single scaling factor. The emissivity spectrum is parameterized with 20 Principal Component scores (e.g., see [12]).

RESULTS

An error analysis has been performed using all the IASI channels (8461) and the typical precision achieved for the colum amount of gas species is shown in Tab. 1. A full account of the results is beyond the scope of this paper. Here we limit ourselves to show some salient aspects of the analysis regarding gas species. The reader is referred to [12]for a detailed account of methodology and results. For the main green-house gases the analysis is quite sta-

TABLE 1. Precision derived from the error analysis and background average column amount of the target gases. The values in brackets are the percentage errors.

Gas	Precision	Background average column amount
CO	1.36 ppbv (1.24%)	109.65 ppbv
CO_2	0.70 ppmv (0.17%)	397 ppm
N_2O	1.14 ppbv (0.38%)	296.52 ppbv
CH_4	7.23 ppbv (0.46%)	1582 ppbv
SO_2	209 pptv (156%)	134 pptv
HNO_3	37.60 pptv (7.95%)	473 pptv
NH_3	108 pptv (51.5%)	211 pptv
OCS	33.89 pptv (6.36%)	510 pptv
CF_4	9.0 pptv (10.151%)	88.80 pptv

ble and compare very well with in situ observations. Figure 2 shows the case of methane. It is seen that, although we initialize the scheme with a constant background, the retrieval (monthly means in Fig. 2) shows a good correlation with in situ observations, which testifies the ability of the scheme to consistently reproduce the seasonal CH_4 cycle. Another interesting example is obtained for SO_2. Form Tab. 1 we see that SO_2 is characterized by a large error. However, this poor precision corresponds to a background of 134 pptv. For the case at hand, we know that the continuous activity of the Kilauea volcano injects large amount of SO_2 in the atmosphere. In fact, the retrieval for this gas (see Fig. 3) shows concentrations, which are 10-20 times larger than the background values. The monthly means shown in the left panel of Fig. 3 show a peak activity for June 2014. The detail of the daily values (Fig. 3, right panel) exhibits a large peak on June 2014, the 20th. From the US Geological Survey we know that June 2014 was characterized by an intense activity, which culminated with *the June 27th lava flow* (see e.g. http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=84472).

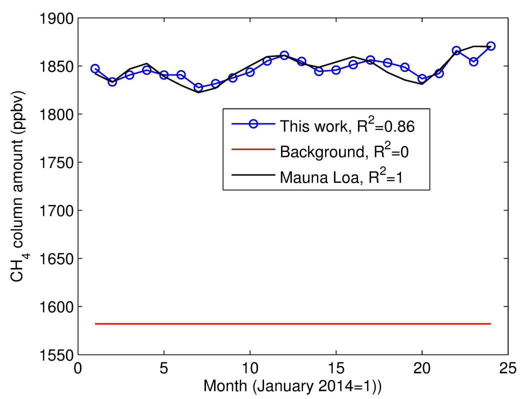

FIGURE 2. Retrieved monthly average column mixing ratio for methane and comparison with in situ observations. Retrievals have been spatially averaged over the target area shown in Fig. 1. The correlation coefficient, R^2 is computed with respect to *in situ* observations.

CONCLUSIONS

We have shown that the simultaneous retrieval of the whole IASI spectrum for surface and atmospheric parameters is feasible and yields column amounts of minor and trace species with unprecedented precision. Greenhouse gases

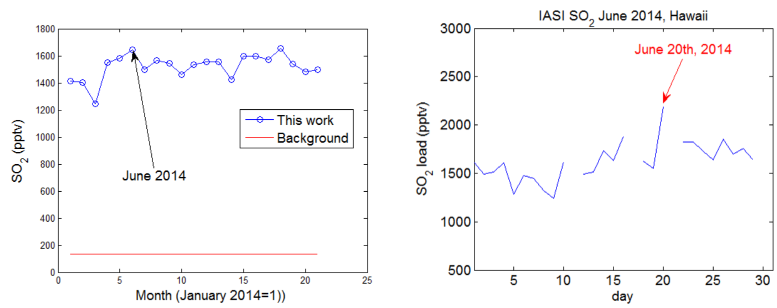

FIGURE 3. Left: retrieved monthly average column mixing ratio for SO_2. Right: daily average for June 2014. Retrievals have been spatially averaged over the target area shown in Fig. 1.

(CO_2, N_2O and CH_4) can be estimated at the level of an individual IASI sounding with a precision better than 1%. In addition, volcanic SO_2 plumes can be easily detected and their evolution followed with high accuracy.

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