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Reply on RC1

Simon Whitburn et al.

Author comment on "A CO_2-independent cloud mask from Infrared Atmospheric Sounding Interferometer (IASI) radiances for climate applications" by Simon Whitburn et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2022-127-AC1, 2022

We would like to thank the reviewer very much for its constructive feedback on the paper and its useful comments and suggestions, which all have been answered or addressed and significantly improved the paper. Point-by-point responses are provided below.

This manuscript describes a new algorithm to discriminate cloudy versus cloud-free scenes in IASI pixels. It uses a neural network approach, trained to reproduce the current last version of the EUMETSAT IASI level 2 cloud product, and ends up indeed with similar results as that training product, with the benefit that it can easily be processed along the whole IASI time series and provide therefore a homogeneous cloud mask time series, while the EUMETSAT IASI cloud product undergoes a number of discontinuities during the whole IASI time period. This data will be useful for all other types of climate data records reprocessing based on IASI data, all requiring cloud-free scenes.

The paper is well organized, well written, well presented, and the scientific work is sound and well described. To my point of view, it will be suitable for publication after the following comments are addressed.

Major comments

- The IASI-related bibliographic references should be made a bit larger than citing work from the co-authors and their teams. This is especially obvious in the introduction, lines 29 to 32, where discussing in general trace gas, aerosols and radiation retrieval/work (not even specifically from IASI) and citing only 3 papers, all from the team(s) authoring the current manuscript. I also quickly scanned the full bibliographic list: all cited papers containing the word “IASI” (except 2, one on IASI assimilation and one on AVHRR within IASI pixels) contain co-authors from the current manuscript. This feels weird.

It is true that even if the paper describes a cloud mask algorithm specifically dedicated to the IASI measurements, we could have emphasized more the work from other teams working with other instruments, especially for the discussions not especially related to IASI. We have now added the following references to the manuscript:

Lines 27-33: *Besides their importance for modeling the Earth’s climate, accurate detection of cloud-free (clear) scenes from satellite measurements is also an essential* *preprocessing step for most climate and atmospheric satellite applications. This is especially the case in most trace gas (e.g.* ***Warner et al., 2013****; Van Damme et al., 2017) and dust retrieval schemes (e.g.* ***DeSouza-Machado et al., 2010; Capelle et al., 2018;*** *Clarisse et al., 2019) or to derive the Earth Outgoing Longwave Radiation (OLR) budget (e.g.* ***Loeb et al., 2003; Chen and Huang, 2016****; Whitburn et al., 2020), […].*

Concerning the remark on the predominance of the co-authors in the IASI cited papers, the reason is that the co-authors of this paper belong to three large teams (EUMETSAT, ULB/SQUARES, LATMOS/IPSL) that are deeply implicated in the development of the IASI retrieval algorithms since the beginning of the IASI/Metop mission (including all the official IASI L2 products).

References:

- Warner, J., Carminati, F., Wei, Z., Lahoz, W., and J.-L. Attié (2013). Tropospheric carbone monoxide variability from AIRS under clear and cloudy conditions. *Atmos. Chem. Phys., 13*, 12469-12479, https://doi.org/10.5194/acp-13-12469-2013
- DeSouza-Machado, S.G., Strow, L. L., Imbiriba, B., McCann, K. K., Hoff, R. M. Hannon, S. E., & Torres, O. (2010). Infrared retrievals of dust using AIRS: Comparisons of optical depths and heights derived for a North African dust storm to other collocated EOS A-Train and surface observations. *Journal of Geophysical Research, 115*, D15201. https:///doi.org/10.1029/2009JD012842
- Capelle, V., Chédin, A., Pondrom, M., Crevoisier, C., Armante, R., Crepeau, L., & Scott, N. (2018). Infrared dust aerosol optical depth retrieved daily from IASI and comparison with AERONET over the period 2007–2016. *Remote Sensing of Environment, 206*, 15–32. https://doi.org/10.1016/j.rse.2017.12.008
- Chen, X., and X. Huang (2016). Deriving clear-sky longwave spectral flux from spaceborne hyperspectral radiance measurements: A case study with AIRS observations. *Atmos. Meas. Tech., 9*, 6013-6023, https://doi.org/10.5194/amt-9-6013-2016
- Loeb, N. G., N. M. Smith, S. Kato, W. F. Miller, S. K. Gupta, P. Minnis, and B. A. Wielicki (2003). Angular distribution models for top-of-atmosphere radiative flux estimation from the Clouds and the Earth's Radiant Energy System instrument on the Tropical Rainfall Measuring Mission satellite. Part I: Methodology. *J. Appl. Meteor., 42*, 240–265, https://doi.org/10.1175/1520-0450(2003)042<0240:ADMFTO>2.0.CO;2

- Lines 54-56 Could you add a reference to support your statement (last sentence of the paragraph) and maybe mention what was the IASI-CIRS developed for, if not for cloud masking in satellite retrievals?

We have adapted the manuscript as follows:

Lines 55-58: *However, the product is not strict enough to be used in the cloud removal preprocessing phase in satellite data retrieval schemes of geophysical variables. It was also never designed for this purpose but rather for establishing global climatologies of cloud properties (Stubenrauch et al., 2017).*

- Line 187: what are those "emissivity features associated with a lower sensitivity" and why does it only affect night-time data?

The emissivity features observed in Figure 3 likely reflect inhomogeneities in the land surface properties. These particular cases, more visible at night because of the lower surface temperature, can easily be confused with clouds and are difficult to train with the neural network as they only represent a very small percentage of all the IASI measurements.

Is this also present in the other IR cloud retrievals?

Yes, as for the false cloud detections reported over the high mountain ranges, the emissivity features are also observed in the distribution from other cloud retrieval algorithms (even on daytime distributions, as seen on Figure 4).

We now mention this in the manuscript:

Lines 200-205: […] *or to the heterogeneity of the topography within the IASI pixel which make the distinction between clear and cloudy pixels more difficult. In addition, for the nighttime distribution, patches of slightly higher cloud coverage are observed over deserts, in particular for the Sahara Desert, which probably reflect emissivity features due to inhomogeneity in the land surface properties associated with a lower sensitivity.* ***These patterns over the high mountain ranges and deserts are also observed in the distributions derived from other cloud products (see Sect. 4).***

- For the intercomparison, I find a bit problematic to have all data from 2016 except two. I understand the reasons to have the IASI-L2 from 2020 but then why not all data for 2020? – for AMSU it is impossible, then obviously you should keep 2015, but then I would have a second plot for 2015 with AMSU and IASI NN. In any case, comparing yearly averages for different years does not make much sense, except if you can prove that those yearly averages do not change over time.

The reason for choosing the year 2016 is that not all datasets are available until 2020 so far. For example, the CIRS-LMD and the CLARA-A2 products are available until 2019, and the ESA Cloud_cci until 2016. We believe it is fair to compare different years as we are not performing here a validation against other products but simply an intercomparison to illustrate the strengths and weaknesses of the existing products. Moreover, at global scale and on average, the variability in the cloud amount and in the cloud distribution is relatively limited for the main features that are discussed in the manuscript. This can be observed when comparing the daily averaged NN cloud distribution (2008-2020) (Figure 3) and the cloud distribution for 2016 on Figure 5a and the time series of the mean fraction of cloud free scenes for the NN on Fig. 6.

- In the intercomparison with IASI-L2: when comparing the year 2020, which was used for the training, could you specify which percentage of the full year data was used in the training, and if it is small enough that the comparison is not skewed towards being "perfect" because it was the training set?

The training was performed with 54 000 L2 clear and 54 000 cloud scenes. These represent only a very small percentage of the total number of IASI observations over one year (more than 1.2 million data per day, so less than 0.025%).

- Is there any way to assess which algorithm makes a better job (IASI-L2 or IASI-NN) in the cases where they do not agree? For example, select a number of specific cases and compare with MODIS Terra as is done for the dust aerosols? That would be a great addition to the paper, I think, being able to discern if the NN makes a better job than its training data, or if it is "only" similarly good but with easy long time series consistent processing.

It was relatively easy to evaluate the ability of the NN and the L2 cloud products to distinguish clouds from dust by comparing with MODIS images because we could select large and homogeneous dust plumes transported over apparent cloud free regions (also relying on a dust index developed for IASI measurements). However, apart from these very specific cases, it would be very

difficult to determine which product works better based on the comparison with MODIS. Cloud amount and cloud cover can evolve rapidly (due to transport and/or evaporation), especially in the case of thin cirrus or sparse clouds. Given the difference in the overpass time (9.30 vs 10.30) between IASI and MODIS and that the main differences observed between the L2 and the NN are generally found on the cloud edges, it would therefore be very complicated to draw conclusions.

In our opinion, based on the comparison we have done, the NN is doing as good as the L2 in most of the cases (which was the goal of the proposed algorithm) but seems to perform slightly better at differentiate cloud from dust plumes. This is mentioned in the manuscript at lines 245-246.

We have clarified the limits of the comparison between MODIS and IASI for identifying cloud scenes:

Lines 160-165: […] *The MODIS Terra corrected reflectance imagery for the same day is shown as well. An excellent correspondence is found for the large structures of high opaque clouds and the cloud-free regions (e.g. the North and South Africa, the Arabian Peninsula, …). For the regions characterized by sparse cumulus or thin cirrus clouds, the comparison is more difficult because of the different overpass time of the two instruments (10.30 AM/PM for MODIS Terra and 9.30 AM/PM for IASI) as the spatial distribution of clouds can evolve very rapidly (due to evaporation, precipitation and transport).*

- In the comparisons, the NN with the double threshold compares better to some other products. There is no discussion afterwards which threshold should be retained for the IASI-NN mask. I guess it is the "non doubled", but I think it is worth a sentence or two.

Indeed, to be used as cloud removal preprocessing phase in satellite data retrieval schemes, we recommend using the 'non-doubled' threshold as this is the one that matches the best the IASI L2 cloud product which was used as a reference dataset. However, for other applications the user is free to set the thresholds that seem the most appropriate. We have clarified this in the manuscript:

Line 146-150: […] *A separate threshold, of respectively 0.175 (± 0.020) and 0.275 (± 0.015), was defined for land and for sea measurements. Those are recommended when the NN cloud product is used for cloud removal preprocessing phase in satellite data retrieval schemes. However, as we demonstrate in Sect. 4.1, this threshold can be adjusted depending on the application. The uncertainty on the thresholds is estimated by evaluating the change in the threshold for a 1% increase in the difference between the L2 and the NN.*

- In the time series, it is clear that the IASI-L2 sea undergoes a "drop" at the launch of v6.5; however, I am surprised to see that the CIRS-LMD matches quite nicely the IASI-L2 before v6.5 from 2013 onwards (before that, anyone would agree that the IASI-L2 has issues); so has it been proved that the latest IASI-L2 yields better results than the prior versions? If not, maybe the IASI-NN should be trained with the prior IASI-L2 version 6.4? And if yes, maybe the CIRS-LMD team could be consulted to try to understand why their (independent) data matches better the previous IASI version?

Validation against CALIOP data is part of a routine monitoring of the L2 cloud product since 2019. Public monitoring reports are available at https://www.eumetsat.int/iasi-level-2-geophysical-products-monitoring-reports. **The long-term statistics are updated each month, by appended new matchups into the evaluation. The current version of the cloud product is the result of many**

years of improvement to reach a quite mature state today. As it can be seen on Fig. 2.3 of the last report (August 2022), the release of the version 6.5 has brought a significant improvement in the cloud detection against version 6.4. Hanssen Kuiper's skill score and the Percent Correct comparing the L2 cloud mask and CALIOP have increased of about 35% and 15%, respectively (to reach about 75% and 87%). This has been emphasized in the manuscript:

Lines 96-102: *The goal of the proposed algorithm is to produce a sensitive and consistent (unbiased) cloud mask over the entire IASI lifespan using as a reference dataset the version 6.5 (v6.5) of the operational IASI L2 cloud product (August et al., 2012). The latter shows a clear improvement over the previous version (v6.4) when compared to the cloud products from the Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP) onboard the Cloud-Aerosol LiDAR and Infrared Pathfinder Satellite Observation (CALIPSO, Winker et al., 2007), as reported in the CALIOP-CALIPSO IASI Level 2 geophysical products monitoring reports available at https://www.eumetsat.int/iasi-level-2-geophysical-products-monitoring-reports (accessed online on August 10, 2022). The retrieval method presented here is based on a supervised NN relying on the IASI radiance spectra only, […].*

- About the specific "dust training set" (17 selected dust storms), could you confirm that the events taken to analyse the performance, in Fig 7, were not part of these 17 events used to select the best NN training with respect to dust?

We think there might be a misunderstanding here. There is no specific dust training set. The training set was composed of a large set of clear and cloud scenes (according to the IASI L2 cloud product) taken randomly over one year (2020). The best training was then selected by, among others, analyzing its performance over 17 dust plume events. The events used to illustrate the performance of the IASI NN cloud mask over dust plumes (Fig. 7) are taken from these set of 17 dust storms. Note however that none of the observations of these 17 events were used for the training.

- In data availability, please be more specific about which data will be available: the cloud mask, or the output of the NN (and then the user has to decide of the threshold, as line 137 mentions that "this threshold can be adjusted depending on the application" – but then, except the double sea threshold for comparisons, no threshold depending on application is ever discussed).

This has been clarified in the data availability section:

Line 368-370: *The daily IASI NN outputs will be made freely available for all users through the IASI-FT website: https://iasi-ft.eu/. For using as cloud removal preprocessing phase in satellite retrieval, we recommend adopting the thresholds mentioned in the manuscript for land and sea observations, but these can also be adjusted depending on the application.*

Typos and small corrections

Thank you for pointing out the typos and small corrections. All have been corrected.

- Line 37 – at 9.30 AM and PM -> maybe add that this is local solar time and not UTC?
- Line 75 "algorithm that retrieveS" (s is missing)
- Figures 2 and 7: could you add the lat/lon as in Fig 3?

For these two figures, we decided not to show the geographic coordinates as

they were not helping for the interpretation and were reducing their effective width of the figures.

- Line 152 providing a computational time without the technical information on the machine is a bit weird; I understand that the goal is to show it is pretty fast, without having to describe technically a system, but you could just mention "on a typical personal computer" or "on a type xxx HPC machine"
- Line 166 exhibit (remove the s)
- Figure 4 caption: missing the last)
- Table 2, first line: could you provide the start date of the version 6.5?
- Line 248 typo in "together"
- Figure 6: the y axis title says it is in %, while the numbers are clearly not in %
- Figure 7: the days in the caption do not match the days written on the plots; maybe also mention it is day-time data (9:30 AM)?
- Line 315: "dust" (without the s) or "dust aerosols"
- Line 406 (biblio) the IASI l2 PG citation would need some kind of number version, DOI, or weblink and access date, I think.

Thoughts and suggestions – entirely left to your appreciation

- The title is slightly misleading (at least to me), as if maybe the cloud mask worked only in the absence of CO2 (which makes no sense), or does not contain CO2 (again, not much sense); I would suggest maybe using something like "CO2-independent" instead of "free"?

This is indeed a good suggestion. Thank you.

- In the cloud mask plots, I find it counter-intuitive to have the clouds in yellow, especially when discussing the dust (which will usually call the colour yellow/orange in people's minds). Obviously, white would not be a good choice, but what about some kind of grey?

We had the same feeling, but we have tried many color combinations and none of them were satisfactory (in terms of contrast, because the cloudy pixels are much more numerous than the clear-sky ones). The advantage here is that the pixels with and without clouds are clearly identifiable (even if the choice of the color is a bit counter-intuitive).

- Lines 156 to 159 why have 3 different words for the same concept? It is good to mention they mean the same thing, but I think it would be even better to use consistently the same term.

We think that using the three terms helps to lighten the text for the reader.

- Often, I find the figures come a bit late with respect to the text addressing them, but I guess this is anyway dealt with during the final preparation by the journal crew.

This is true, we will take care that the figures are properly placed in the final revision before publication.