IASI L2 PPF v6: Validation Report
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## Document Change Record

<table>
<thead>
<tr>
<th>Issue / Revision</th>
<th>Date</th>
<th>DCN. No</th>
<th>Summary of Changes</th>
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<td>V1</td>
<td>10/04/2014</td>
<td></td>
<td>Initial draft version</td>
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<tr>
<td>V1A</td>
<td>25/04/2014</td>
<td></td>
<td>Update with results from off-line monitoring with the Comparomatic</td>
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<tr>
<td>V1B</td>
<td>28/04/2014</td>
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<td>Document Updates</td>
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<td>V1C</td>
<td>28/04/2014</td>
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<td>V2</td>
<td>28/04/2014</td>
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<td>V2A</td>
<td>30/04/2014</td>
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<td>Update after PVRB feed-back and comments</td>
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<td>V3-V3B</td>
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<td>Period of assessment changed and extended from 04-21/04/2014 to 25/04-13/08/2014. Results obtained from monitoring on TCE updated accordingly.</td>
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<td></td>
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<td>Added comparison to sondes from NOAA/NPROVs</td>
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<td></td>
<td>Added comparisons to ARM’s GPS, microwave radiometer, LIDAR and sondes and to SuomiNet GPS validation measurements</td>
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<td>Added comparisons of temperature profiles to COSMIC products</td>
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<td>Added results of monitoring T,q profiles against ECMWF analyses</td>
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<td>Updated the OEM SST assessment</td>
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<td>Updated the Conclusion</td>
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<tr>
<td>V4-V4B</td>
<td>15/09/2014</td>
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<td>Update in view of the OPE PVRB</td>
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<td>Extended the period of validation until 11/09</td>
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<td>In 3.1, 3.2, 3., 4.1, 6.1.5: Comparisons to analyses are the baseline for exhaustive statistics (profiles, histograms, maps) while forecasts were the baseline in V3 of this document). Only vertical profiles of differences to forecasts are shown as a summary now.</td>
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<td></td>
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<td>Include comparison of the retrieval error estimate (OEM) to differences between IASI L2 and ECMWF analyses (4.1). Expanded the presentation and discussion of the retrieval error estimates.</td>
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<tr>
<td></td>
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<td>Added O3 results</td>
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<td>Updated SST monitoring results</td>
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<td></td>
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<td>Updated conclusion section</td>
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<tr>
<td>Issue / Revision</td>
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<td>Summary of Changes</td>
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<tr>
<td>V4C</td>
<td>13/10/2014</td>
<td></td>
<td>Modifications following PVRB OPE meeting, for publication.</td>
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<td>Added example of averaging kernel in the retrieval error estimate section.</td>
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<td></td>
<td>Clarify terminology of products status in the conclusion paragraph.</td>
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1 INTRODUCTION

1.1 Purpose and scope

The latest version of the IASI Level 2 (L2) Product Processing Facility (PPF) is Version 6 (v6) and has been designed following the structure defined in [RD 1]. It has the following main objectives as identified in the products development and implementation plan (PDIP) [AD 1]:

- improve the atmospheric sounding (temperature and humidity) in the lower troposphere;
- include new and state-of-the-art atmospheric composition retrieval algorithms and products;
- increase the yield of L2 products and quality in clear but also in cloudy pixels;
- simplify the processing flags auxiliary information;
- revise the cloud detection and simplify the cloudiness flagging;
- include the full retrieval error estimates, from which the averaging kernels can be derived.

The IASI L2 PPF v6 has been running on the Ground Segment 2 (GS2) since 18 March 2014.

The objective of this document is to support the IASI L2 v6 products commissioning and more specifically to provide the necessary information to the product validation review board (PVRB) to qualify the IASI L2 v6 products as Pre-Operational.

This document compiles assessment and validation results of the IASI Level 2 (L2) products from Metop-A and Metop-B. They are obtained by qualitative and quantitative inspection of the IASI L2 individually and by comparisons with different reference data: numerical models, in situ measurements, and other satellite products. In the summer of 2013, the IASI L2 products v5 underwent a number of detailed validation reviews during the commissioning of Metop-B [RD-2]. The v5 and v6 IASI L2 products are therefore specifically compared here to the same reference data to ensure non-regressions and characterise the improvements.

1.2 Products versions and data description

The analyses presented in this report were performed with the versions 6.0.0 to 6.0.5 of the PPF from off-line reprocessing on the TCE and from routine production on GS2 since the 18/03/2014. The patches 6.0.1 to 6.0.5 were released to fix minor anomalies essentially with meta-information in the L2P SST and in the SND native products. These patches have no impact on the retrieved geophysical parameters forming the IASI L2 products, whose retrieval algorithms have been unchanged.

Both Metop-A and Metop–B products were evaluated. They are presented separately in this document to verify their consistency. Among other innovations, the IASI L2 PPF v6 implements a statistical retrievals (referred to PWLR for piece-wise linear regression) which nominally uses micro-wave (MHS and AMSU) and infra-red (IASI) measurements. Due to the failure of the microwave humidity sounding (MHS) instrument on-board Metop-A between 25 April 2014 and 04 and 20 May 2014, the Metop-A products for during and after this period are also presented separately. In the absence of microwave information the PWLR runs in an infra-red (IASI) only mode, with expected slightly degraded performances of the statistical first guess and of the subsequent retrievals from the optimal estimation method.
1.3 Document structure

Section 1 General information (this section)
Section 2 Self-consistency verifications
Section 3 Temperature and humidity profiles
Section 4 Retrieval error estimates and averaging kernels
Section 5 Analyses of the radiance residuals
Section 6 Surface parameters
Section 7 Cloud products
Section 8 Atmospheric composition products
Section 9 Summary and conclusions

1.4 Applicable Documents

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<tr>
<th>No.</th>
<th>Document Name</th>
<th>EUMETSAT Reference</th>
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<tr>
<td>AD 1</td>
<td>Products development and implementation plan</td>
<td>EUM/STG-SWG/35/13/VWG/07</td>
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<td>AD 2</td>
<td>EPS Programme End User Requirements Document</td>
<td>EUM/EPS/MIS/REQ/93/001</td>
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1.5 Reference Documents

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<td>RD 1</td>
<td>IASI L2 PPF v6 ECPD</td>
<td>EUM/TSS/TEN/14/739182</td>
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<td>RD 2</td>
<td>IASI/Metop-B L2 validation report</td>
<td>EUM/TSS/REP/13/684650</td>
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<td>RD 3</td>
<td>Algorithm Theoretical Basis Document for Land Surface Temperature, LSA-SAF</td>
<td>SAF/LAND/IM/ATBD_LST/1.0</td>
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<td>RD 4</td>
<td>SAF for Land Surface Analysis – Validation Report LST, LSA SAF</td>
<td>SAF/LAND/IM/VR_LST/I_08</td>
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<td>RD 5</td>
<td>Product User Manual – Land Surface Temperature, LSA SAF</td>
<td>SAF/LAND/IM/PUM_LST/2.4</td>
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<td>RD 6</td>
<td>IASI L2 Surface Temperature: PPF v5 Validation Results</td>
<td>EUM/MET/TEN/10/0188</td>
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<td>RD 7</td>
<td>Surface Emissivity within IASI L2 PPF v5</td>
<td>EUM/OPS-EPS/TEN/10/0203</td>
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<td>RD 8</td>
<td>Validation and intercomparison of operational IASI Polar products with CALIOP and Concord Iasi data, EUMETSAT User Conference 2011</td>
<td>EUM/MET/VWG/11/0419</td>
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<td>RD 10</td>
<td>GHRsst data processing specification version 2 revision 5</td>
<td><a href="https://www.ghrsst.org/documents/q/category/ghrssst-data-processing-specification-gds/operational/">https://www.ghrsst.org/documents/q/category/ghrssst-data-processing-specification-gds/operational/</a></td>
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<td>RD 13</td>
<td>OSI-SAF Metop-A IASI sea surface temperature L2P Validation report</td>
<td>EUM/RSP/DOC/14/740547</td>
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<td>RD 15</td>
<td>Assessing the Ability of IR Sounders in Detecting Extreme Weather Events and Predicting Extreme Floods</td>
<td>J.Roman, ITSC 19, Jeju (South-Korea), 2014</td>
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<td>RD 16</td>
<td>IASI on Metop-A: Operational Level 2 retrievals after five years in orbit, JQSRT 2012</td>
<td>August et al, DOI: 10.1016/j.jqsrt.2012.02.028</td>
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<td>RD 17</td>
<td>ANN cloud detection, validation report</td>
<td>EUM/MET/TEN/10/0343</td>
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<td>RD 18</td>
<td>EPS IASI L2 PPF Validation Report: Cloud Top Pressure and Effective Cloud Amount</td>
<td>EUM/MET/REP/09/0698</td>
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<td>RD 19</td>
<td>Assessment of the chi-square method for cloud top pressure and equivalent cloud amount retrievals with measurements from IASI</td>
<td>EUM/MET/TEN/09/0688</td>
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<td>RD 23</td>
<td>Inverse methods for atmospheric sounding: Theory and practice.</td>
<td>C. Rodgers, World Scientific</td>
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<td>RD 25</td>
<td>Validation report</td>
<td>SAF/O3M/ULB/COv20100815</td>
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<td>RD 26</td>
<td>IASI carbon monoxide validation over the Arctic during POLARCAT spring and summer campaigns</td>
<td>Pommier et al, Atmos. Chem. Phys., 10, 10655-10678, doi:10.5194/acp-10-10655-2010, 2010</td>
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<td>RD 29</td>
<td>Hindcast experiments of tropospheric composition during the summer 2010 fires over western Russia</td>
<td>Huijnen et al, Atmos. Chem. Phys., 12, 4341–4364, 2012, doi:10.5194/acp-12-4341-2012</td>
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<td>RD 32</td>
<td>Co-location of GRUAN radiosondes and IASI infrared hyperspectral measurements</td>
<td>Calbet X., EUMETSAT Meteorological Satellite Conference 2014</td>
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<td>RD 33</td>
<td>IASI temperature and water vapor retrievals – error assessment and validation</td>
<td>Pougatchev et al., Atmos. Chem. Phys., 9, 6453-6458, doi:10.5194/acp-9-6453-2009,</td>
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### 1.6 Acronyms Used in this Document

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<td>ANN</td>
<td>Artificial Neural Network</td>
</tr>
<tr>
<td>ARM</td>
<td>Atmospheric Radiation Measurement (US program)</td>
</tr>
<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer, the imager on-board Metop</td>
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<td>CALC</td>
<td>Usually refers to synthetic radiances calculated with a radiative and an atmospheric state vector which may come from the NWP or the L2.</td>
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<tr>
<td>Cal/Val</td>
<td>Calibration / Validation</td>
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<td>ECMWF</td>
<td>European Centre for Medium-Range Weather Forecasts</td>
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<tr>
<td>EPS</td>
<td>EUMETSAT Polar System</td>
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<tr>
<td>EUMETSAT</td>
<td>European Organisation for the Exploitation of Meteorological Satellites</td>
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<tr>
<td>EURD</td>
<td>End User Requirements Document</td>
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<tr>
<td>EOF</td>
<td>Empirical Orthogonal Function</td>
</tr>
<tr>
<td>FG</td>
<td>First Guess</td>
</tr>
<tr>
<td>GCOS</td>
<td>Global Climate Observing System</td>
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<tr>
<td>GHRSSST</td>
<td>Group for High Resolution Sea Surface Temperature</td>
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<td>GRUAN</td>
<td>GCOS Reference Upper-Air Network</td>
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<td>IASI</td>
<td>Infrared Atmospheric Sounding Interferometer</td>
</tr>
<tr>
<td>IASI-A</td>
<td>IASI onboard Metop-A</td>
</tr>
<tr>
<td>IASI-B</td>
<td>IASI onboard Metop-B</td>
</tr>
<tr>
<td>IFOV</td>
<td>Instantaneous Field Of View</td>
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<td>LSA</td>
<td>Land Surface Analysis</td>
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<td>LST</td>
<td>Land Surface Temperature</td>
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<td>L2</td>
<td>Level 2</td>
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<tr>
<td>MACC</td>
<td>Monitoring Atmospheric Composition and Climate</td>
</tr>
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<td>MODIS</td>
<td>Moderate Resolution Imaging Spectroradiometer</td>
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<td>MWR</td>
<td>Microwave radiometer</td>
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<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration (US)</td>
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<td>NPROVS</td>
<td>NOAA Products Validation System</td>
</tr>
<tr>
<td>NRT</td>
<td>Near-Real Time</td>
</tr>
<tr>
<td>NWP</td>
<td>Numerical Weather Prediction</td>
</tr>
<tr>
<td>OBS</td>
<td>Observations (usually refers to L1c radiances)</td>
</tr>
<tr>
<td>OEM</td>
<td>Optimal Estimation Method</td>
</tr>
<tr>
<td>O3M-SAF</td>
<td>Ozone and atmospheric chemistry Monitoring Satellite Application Facility</td>
</tr>
<tr>
<td>OSI-SAF</td>
<td>Ocean and Sea Ice Satellite Application Facility</td>
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<tr>
<td>PC</td>
<td>Principal Components</td>
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<td>PPF</td>
<td>Product Processing Facility</td>
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<tr>
<td>PWV</td>
<td>Precipitable Water Vapour</td>
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<td>PWLR</td>
<td>Piecewise Linear Regression</td>
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<tr>
<td>RMS</td>
<td>Root Mean Square</td>
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<td>SAF</td>
<td>Satellite Application Facility</td>
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<tr>
<td>SEVIRI</td>
<td>Spinning Enhanced Visible and Infrared Imager</td>
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1.7 Regional stratification

The products assessments are performed globally and the statistics presented in this document may be stratified against the following reference geographic classes.

<table>
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<th>Label</th>
<th>Surface pressure</th>
<th>Surface type</th>
<th>Latitude</th>
<th>Time</th>
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<tbody>
<tr>
<td>1</td>
<td>North Pole</td>
<td>&lt; 1050 hPa</td>
<td>land and sea</td>
<td>&gt; 60°</td>
<td>day and night</td>
</tr>
<tr>
<td>2</td>
<td>North Sea</td>
<td>&gt; 900 hPa</td>
<td>sea</td>
<td>[30° ; 60°]</td>
<td>day and night</td>
</tr>
<tr>
<td>3</td>
<td>North Land</td>
<td>&gt; 900 hPa</td>
<td>land</td>
<td>[30° ; 60°]</td>
<td>day and night</td>
</tr>
<tr>
<td>4</td>
<td>High Elevation</td>
<td>&lt; 900 hPa</td>
<td>land</td>
<td>[−60° ; 60°]</td>
<td>day and night</td>
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<tr>
<td>5</td>
<td>Intertropic Sea</td>
<td>&gt; 900 hPa</td>
<td>sea</td>
<td>[−30° ; 30°]</td>
<td>day and night</td>
</tr>
<tr>
<td>6</td>
<td>Intertropic Land</td>
<td>&gt; 900 hPa</td>
<td>land</td>
<td>[−30° ; 30°]</td>
<td>day and night</td>
</tr>
<tr>
<td>7</td>
<td>South Pole</td>
<td>&lt; 1050 hPa</td>
<td>land and sea</td>
<td>&lt; -60°</td>
<td>day and night</td>
</tr>
<tr>
<td>8</td>
<td>South Sea</td>
<td>&gt; 900 hPa</td>
<td>sea</td>
<td>[−60° ; 30°]</td>
<td>day and night</td>
</tr>
<tr>
<td>9</td>
<td>South Land</td>
<td>&gt; 900 hPa</td>
<td>land</td>
<td>[−60° ; 30°]</td>
<td>day and night</td>
</tr>
</tbody>
</table>

Table 1: Definition of the validation geographic classes

Figure 1: Geographic classes used in the IASI L2 validation
1.8 Cloudiness stratification

The products assessments are performed globally and the statistics presented in this document may be stratified against the cloudiness classes defined in the flag FLG_CLDNES introduced for the first time in the IASI L2 v6.

Three cloud detection methods are used in combination in the IASI L2 PPF v6. They are based on AVHRR imagery, NWP and IASI measurements. In the latter case, the method implements artificial neural networks (ANN). The various tests may conclude to contradictory clear/cloudy classifications because of different sensitivities and of the uncertainties associated with their respective methodologies (e.g. uncertainties in the a priori surface emissivity and temperature in the NWP test, lack of contrast between snow and clouds for the detection with AVHRR images or in the ANN classification). The different test results are consolidated into the enumerated flag FLG_CLDNES summarising the level of confidence in the clear-sky/cloudiness assessment of the IASI IFOV. This flag controls the choice of the subsequent retrieval methods in the processing chain. It is also created as an answer to several users’ requests for a more concise cloudiness summary.

The flag FLG_CLDNES flag is set as follows:

<table>
<thead>
<tr>
<th>Reason for flagging</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No clouds detected with the NWP, AVHRR and ANN cloud tests</td>
<td>1</td>
</tr>
<tr>
<td>Potential small cloud contamination (at least one cloud test detected a cloud) but no clouds could be characterised with confidence</td>
<td>2</td>
</tr>
<tr>
<td>Cloud detected and characterised. The retrieved equivalent cloud amount is lower than 80%</td>
<td>3</td>
</tr>
<tr>
<td>Cloud detected and characterised. The retrieved equivalent cloud amount is higher than 80%</td>
<td>4</td>
</tr>
</tbody>
</table>

1.9 Acknowledgements

This document characterises and compiles the validation results and discussions prepared by Tim Hultberg, Marc Crapeau, Anne O’Carroll, Marianne Koenig and Thomas August at EUMETSAT.

The validation work involved external reference data as well as analyses and advice provided by the following:

- Folke Olesen and Frank Goettsche (Karslruhe Institute of Technology), experts to the LSA-SAF MSG LST validation activities, did validation of Land Surface Temperature;
- the Ocean and Sea-Ice SAF and the Project Office of NOAA/PMEL performed TAO SST observations, for the validation of the Sea Surface Temperature;
- Cathy Clerbaux, (LATMOS) and Pierre Coheur, Daniel Hurtmans, Rosa Astoreca (ULB) worked on the impact of EUMETSAT IASI L2 products for the atmospheric composition applications and the evaluation of the new products format and content.
- the NOAA/NPROVS system for the comparison of the IASI L2 temperature and humidity against radiosonde measurements—particularly Bomin Sun and Tony Reale, for ingesting the EUMETSAT IASI L2 v6 products in the NPROVS test processing chain.
- Jacola Roman, Bob Knuteson and Michelle Feltz, University of Wisconsin, did the assessment of IASI v6 PWLR temperature and humidity products.
- Tim Trent from University of Leicester for the comparison to sonde measurements.
2 SELF-CONSISTENCY CHECKS

In this section, we present typical results of basic products verification, called self-consistency checks because they involve the IASI L2 v6 products themselves only.

The spatial coherence of large-scale geophysical structures as retrieved from IASI are first inspected and verified daily. Examples are shown below.

2.1 Daily snapshots

2.1.1 Cloud products

Figure 2: Daily maps of the IASI-B L2 cloud fraction on 09/04/2014: Top panel is during daylight, the bottom panel is at night.
Figure 3: Daily maps of the IASI-B L2 cloud top pressure on 09/04/2014. The top panel is daylight, the bottom panel is at night.
Figure 4: Daily maps of the IASI-B L2 cloud top temperature on 09/04/2014. Top panel is during daylight, bottom panel is night.
Figure 5: Daily maps of the IASI-B L2 FLG_CLDNES on 09/04/2014. Top panel is day, bottom panel is night.
2.1.2 Surface Parameters

Figure 6: Daily maps of the IASI-B L2 first-guess surface temperature retrieved on 09/04/2014. The top panel is day, bottom panel is night.
Figure 7: Daily maps of the IASI-B L2 OEM surface temperature retrieved on 09/04/2014. Top panel is day, bottom panel is night.
Figure 8: Daily maps of the IASI-B L2 land surface emissivity at 1071.25 cm⁻¹ on 09/04/2014. Top panel is day, bottom panel is night.
Figure 9: Daily maps of the IASI-B L2 FLG_LANDSEA (0: sea, 1-2: land; 3-4: mixed, 5: sea ice) on 09/04/2014. The top panel is during daylight, bottom panel is at night.
2.2 Interpixel consistency

In this validation test, we verify that the geophysical parameters retrieved on average in the four instrument fields of view (IFOVs) individually do not exhibit significant systematic inter-pixel differences. It is assumed that the atmospheric situations sensed by IASI are not correlated with its detectors and therefore should present very comparable statistics in the four IFOVs when sampled over a sufficiently long time series.

The results in this section are obtained with IASI-B L2 products during the period 11 April 2014 to 25 April 2014.

![Figure 10](image)

Figure 10: Distributions of the IASI L2/Metop-B surface temperatures retrieved with the OEM in each IFOV in the period 11/04/2014 to 25/04/2014. Legend: 1: black 2: blue 3: red 4: green. The legend in the plot details the sample size (#nnnn), the average and the standard deviation (σ) of the OEM retrieved surface temperature in each of the four IFOVs.
Figure 11: Distributions of the IASI L2/Metop-B surface temperatures retrieved with the OEM in each IFOV in the period 11/04/2014 to 25/04/2014. Legend: 1: black 2: blue 3: red 4: green. The legend in the plot details the sample size (#nnnn), the average and the standard deviation (σ) of the first-guess surface temperature in each of the four IFOVs.

Figure 12: Distributions of the IASI L2/Metop-B surface temperatures retrieved with the OEM in each IFOV in the period 11/04/2014 to 25/04/2014. Legend: 1: black 2: blue 3: red 4: green. The legend in the plot details the sample size (#nnnn), the average and the standard deviation (σ) of the retrieval with OEM at 500 hPa.
Figure 13: Distributions of the IASI L2/Metop-B surface temperatures retrieved with the OEM in each IFOV in the period 11/04/2014 to 25/04/2014. Legend: 1: black 2: blue 3: red 4: green. The legend in the plot details the sample size (#nnnn), the average and the standard deviation (σ) of the first guess temperature retrieved at 500 hPa in each of the four IFOVs.

Figure 14: Distributions of the IASI L2/Metop-B surface temperatures retrieved with the OEM in each IFOV in the period 11/04/2014 to 25/04/2014: Legend: 1: black 2: blue 3: red 4: green. The legend in the plot details the sample size (#nnnn), the average and the standard deviation (σ) of the humidity retrieved with OEM at 500 hPa in each of the four IFOVs.
Figure 15: Distributions of the IASI L2/Metop-B surface temperatures retrieved with the OEM in each IFOV in the period 11/04/2014 to 25/04/2014. Legend: 1: black 2: blue 3: red 4: green. The legend in the plot details the sample size (#nnnn), the average and the standard deviation (σ) of the first-guess humidity retrieved at 500 hPa in each of the four IFOVs.

Figure 16: Distributions of the IASI L2/Metop-B surface temperatures retrieved with the OEM in each IFOV in the period 11/04/2014 to 25/04/2014. Legend: 1: black 2: blue 3: red 4: green. The legend in the plot details the sample size (#nnnn), the average and the standard deviation (σ) for total column CO.
2.3 Variation of the retrieved parameters with the viewing angle

Most of the retrieved geophysical parameters are expected to be uncorrelated to the viewing geometry, e.g. total column of O$_3$ or CO, the temperature at 200 hPa. A few parameters, like the surface temperature, may be sensitive to diurnal cycles; therefore they may vary from one swath edge to the other, because the IASI swath of about 2000 km spans different local solar times. This validation procedure assesses the variation of the average retrievals and their standard deviations with the scan angle with IASI-B, from the scan position 1 to the scan position 30—positions 14 and 15 are the near-Nadir views.

**Note:** This task will be completed as part of long-term product monitoring.
3 ASSESSMENT OF TEMPERATURE AND HUMIDITY PROFILES

In this section, we present assessments of the v6 first-guess (PWLR, nearly all-sky) and final (OEM, in clear-sky) retrievals of temperature and humidity profiles. They have been compared to ECMWF forecast (FCT) and analyses (ANA) fields, to sonde measurements and evaluated against Global Navigation Space System Radio Occultation (GNSS-RO) total column water vapour (TCWV) measurements. The retrieved water vapour profiles have been integrated and compared to MSG-SEVIRI TCWV. The global instability index (GII) as computed for the routine SEVIRI product is also derived from the IASI L2 v6 and compared.

The comparisons of IASI L2 to ECMWF profiles are performed in turn for the cloudiness classes 1, 2, 3 and 4 as evaluated with the v6. In this v6 release, the PWLR is attempted in all cloudiness cover and the retrievals are retained unless the corresponding quality indicator is unreasonably high. However, OEM retrievals are only attempted in cloudiness classes 1 and 2, which are probably cloud-free situations, and if the observations and simulated radiances computed with the first guess (PWLR) do not depart too much from each other. In addition, though attempted, the iterative retrieval may not convergence, which explain why the v6 OEM yield may be slightly smaller than with v6 PWLR, as is the case in the Southern Oceans or Lands in Figure 17.

This classification approach did not exist for v5. For comparisons to v6, all available v5 retrievals (OEM and linear regression when OEM was not available in this version) falling in v6 cloudiness categories are gathered and statistics are computed for them. Because v5 processing was based purely on IR measurements, there may be less available retrievals in cloudy IFOVs than for v6 in the observation period. The same applies in clear cases (like FLG_CLDNES 1 and 2) because of the overly-conservative approach for cloud filtering implemented in v5. For instance, the lower v5 yield is observed over tropical clear oceans (see Figure 17) or with cloudy pixels—see cloudiness class 3 and class 4 in Figure 19 and Figure 20.

Comparisons to ECMWF temperature and water vapour fields have been routinely performed against forecasts since April 2014, and against analyses since mid-July 2014.
3.1 Comparisons of Temperature Profiles to ECMWF

3.1.1 Metop-B IASI L2 Temperature versus Analysis

3.1.1.1 Profiles

Figure 17: FLG_CLDNES class 1. IASI-B L2 compared to ECMWF ANA temperatures. The dashed lines are vertical profiles of the mean differences. Solid lines are standard deviation for the period for the period 27/06/2014 to 11/09/2014. Legend: v5 is black, v6 OEM is red, v6 PWLR is blue.
Figure 18: FLG_CLDNES class 2. IASI-B L2 compared to ECMWF ANA temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014.

Legend: v5 is in black, v6 OEM is in red, v6 PWLR is in blue.
Figure 19: FLG_CLDNS class 3. IASI-B L2 compared to ECMWF ANA temperatures. Vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014. Legend: black is v5, blue is v6_PWLR.
Figure 20: FLG_CLDNES class 4. IASI-B L2 compared to ECMWF ANA temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) during the period 27/06/2014 to 11/09/2014. Legend: v5 is black, v6_PWLR is blue.
3.1.1.2 Maps

Figure 21: Map of the mean differences (top) and standard deviation for differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1, Metop-B.
Figure 22: Map of the mean differences (top) and standard deviation of differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2 for Metop-B.
Figure 23: Map of the mean differences (top) and standard deviation of differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1, Metop-B.
Figure 24: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2.
Figure 25: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1, Metop-B.
Figure 26: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2.
Figure 27: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 28: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2.
Figure 29: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 850 hPa during the period 27/06/2014 to 11/09/2014 in FLG_CLDNS class 1. Metop-B
Figure 30: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2.
Figure 31: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 32: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 (OEM) and ECMWF ANA atmospheric temperature at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNS class 2.
3.1.2 Histograms

Figure 33: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue. Metop-B.
Figure 34: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 35: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 36: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 37: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black; v6_OEM is red, v6_PWLR is blue.
Figure 38: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 39: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM v6_OEM is red, v6_PWLR is blue.
Figure 40: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 41: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black; v6_OEM is red; v6_PWLR is blue.
Figure 42: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNESS class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 43: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black; v6_OEM is red, v6_PWLR is blue.
Figure 44: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric temperature at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
3.1.3 Metop-A IASI L2 temperature compared to analysis

Figure 45: IASI-A L2 compared to ECMWF ANA temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNE class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 46: IASI-A L2 compared to ECMWF ANA temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 47: IASI-A. IASI-A L2 compared to ECMWF ANA temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 48: IASI-A. IASI-A L2 compared to ECMWF ANA temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.1.4 Metop-B IASI L2 temperature measured against forecasts

Figure 49: IASI-B L2 compared to ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 50: IASI-B. IASI-B L2 compared to ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) during the period 25/04/2014 to 11/09/2014 in FLG_CLDNS class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 51: IASI-B L2 compared to ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 52: IASI-B. IASI-B L2 compared to ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 11/09/2014 in FLG_CLDINES class 4. Legend: v5 is black, v6_PWLR is blue.
3.1.5 Metop-A IASI L2 temperature compared to forecasts

3.1.5.1 IR-mode, during MHS failure

Figure 53: IASI-A L2 and ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 05/05/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 54: IASI-A (IR-only). IASI-A L2 and ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 05/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 55: IASI-A (IR-only). IASI-A L2 and ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 05/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 56: IASI-A (IR-only). IASI-A L2 and ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) during the period 25/04/2014 to 05/2014 in FLG_CLDNESS class 4. Legend: v5 is black, v6_PWLR is blue.
3.1.5.2 Nominal synergistic production, after MHS recovery

Figure 57: IASI-A L2 and ECMWF FCT (with AMSU/MHS) temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 58: IASI-A (with AMSU/MHS). IASI-A L2 and ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) during the period 22/05/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 59: IASI-A (with AMSU/MHS). IASI-A L2 and ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) during the period 22/05/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 60: IASI-A (with AMSU/MHS). IASI-A L2 and ECMWF FCT temperatures, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 11/09/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.2 Comparisons of Specific Humidity profiles to ECMWF

3.2.1 Metop-B IASI L2 Humidity compared to analysis

3.2.1.1 Profiles

Figure 61: IASI-B L2 and ECMWF ANA water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 62: IASI-B L2 and ECMWF ANA water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNEs class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 63: IASI-B. IASI-B L2 and ECMWF ANA water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 64: IASI-B. IASI-B L2 and ECMWF ANA water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
### 3.2.1.2 Maps

[Map Image]

**Figure 65:** Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 66: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2, Metop-B.
Figure 67: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 68: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Metop-B.
Figure 69: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1, Metop-B.
Figure 70: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Metop-B.
Figure 71: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 72: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2, Metop-B.
Figure 73: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1, Metop-B.
Figure 74: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2.
Figure 75: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 76: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Metop-B.
3.2.1.3 Histograms

Figure 77: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_PWLR is blue. Metop-B.
Figure 78: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 79: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 80: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 81: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 82: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 83: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 84: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 85: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue. Metop-B.
Figure 86: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 87: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 88: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric specific humidity at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
3.2.2 Metop-A IASI L2 Humidity and Analysis

Figure 89: IASI-A L2 and ECMWF ANA water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 90: IASI-A (IR-only). IASI-A L2 and ECMWF ANA water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2 Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 91: IASI-A (IR-only). IASI-A L2 and ECMWF ANA water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 92: IASI-A (IR-only), IASI-A L2 and ECMWF ANA water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.2.3 Metop-B IASI L2 Humidity and Forecasts

Figure 93: IASI-B L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 94: IASI-B. IASI-B L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 95: IASI-B. IASI-B L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 96: IASI-B. IASI-B L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.2.4 Metop-A IASI L2 Humidity and Forecasts

3.2.4.1 IR-mode, during MHS failure

Figure 97: IASI-A L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 20/05/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 98: IASI-A (IR-only). IASI-A L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 20/05/2014 in FLG_CLDNEs class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 99: IASI-A (IR-only). IASI-A L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 20/05/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 100: IASI-A (IR-only). IASI-A L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 20/05/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.2.4.2 Nominal synergistic production, after MHS recovery

Figure 101: IASI-A L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 13/08/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 102: IASI-A (with AMSU/MHS). IASI-A L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 13/08/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 103: IASI-A (with AMSU/MHS), IASI-A L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 13/08/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 104: IASI-A (with AMSU/MHS), IASI-A L2 and ECMWF FCT water vapour profiles, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 13/08/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.3 Comparisons of Relative Humidity Profiles to ECMWF Data

3.3.1 Metop-B IASI L2 Actual Relative Humidity and Forecasts

3.3.1.1 Profiles

Figure 105: IASI-B L2 and ECMWF ANA relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 106: IASI-B. IASI-B L2 and ECMWF ANA relative humidity, vertical profiles of the mean departures (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDYES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 107: IASI-B L2 and ECMWF ANA relative humidity, vertical profiles of the mean departures (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 108: IASI-B, IASI-B L2 and ECMWF ANA relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNS class 3. Legend: v5 is black, v6_PWLR is blue.
3.3.1.2 Maps

Figure 109: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 110: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Metop-B.
Figure 111: Map of the mean differences (left) and standard deviation differences (right) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 112: Map of the mean differences (left) and standard deviation differences (right) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2, Metop-B.
Figure 113: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 114: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Metop-B.
Figure 115: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 116: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Metop-B.
Figure 117: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 118: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2, Metop-B.
Figure 119: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Metop-B.
Figure 120: Map of the mean differences (top) and standard deviation differences (bottom) between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2, Metop-B.
3.3.1.3 Histograms

Figure 121: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 122: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 50 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 123: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNS class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 124: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 200 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 125: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue. Metop-B.
Figure 126: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 500 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 127: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 128: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 700 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 129: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 130: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 850 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 131: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 132: Histograms of the differences between IASI-B L2 and ECMWF ANA atmospheric relative humidity at 980 hPa for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue. Metop-B.
3.3.2 Metop-A IASI L2 Relative Humidity compared to analysis

Figure 133: IASI-A L2 and ECMWF ANA relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 134: IASI-A (IR only). IASI-A L2 and ECMWF ANA relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 135: IASI-A (IR only). ECMWF ANA relative humidity, vertical profiles of the mean (dashed lines) differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNS class 3. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 136: IASI-A (IR only), ECMWF ANA relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 27/06/2014 to 11/09/2014 in FLG_CLDNE5 class 4. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
3.3.3 Metop-B IASI L2 relative humidity compared to forecasts

Figure 137: IASI-B L2 and ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 138: IASI-B and ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 139: IASI-B and ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 140: IASI-B. ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 11/09/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.3.4 Metop-A IASI L2 relative humidity compared to forecasts

3.3.4.1 IR-mode, during MHS failure

Figure 141: IASI-A L2 and ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 20/05/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 142: IASI-A (IR only). IASI-A L2 and ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 20/05/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 143: IASI-A (IR only). ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 20/05/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 144: IASI-A (IR only). ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 25/04/2014 to 20/05/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.3.4.2 Nominal synergistic production, after MHS recovery

Figure 145: IASI-A L2 and ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 146: IASI-A (IR only). IASI-A L2 and ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: v5 is black, v6_OEM is red, v6_PWLR is blue.
Figure 147: IASI-A (IR only). ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 11/09/2014 in FLG_CLDNES class 3. Legend: v5 is black, v6_PWLR is blue.
Figure 148: IASI-A (IR only). ECMWF FCT relative humidity, vertical profiles of the mean differences (dashed lines) and standard deviation (solid lines) for the period 22/05/2014 to 11/09/2014 in FLG_CLDNES class 4. Legend: v5 is black, v6_PWLR is blue.
3.4 Comparisons to Sonde Measurements

3.4.1 Temperature and humidity assessment at NOAA/NPROVS

The NOAA Products Validation System (NPROVS) routinely compiles daily datasets of collocated radiosonde, dropsonde and appended numerical weather prediction (NWP) data for the pressure levels not reached by the sondes. The system uses a number of satellites and sounding (temperature and moisture) product suites, including the IASI L2 products generated at EUMETSAT. The comparison of in-situ measurements to satellites products is performed routinely, allowing punctual assessments and long-term monitoring of the remote-sensing products.

The match-up criteria for the results presented hereafter are as follows: a three-hour time span and 100 km in distance. The following figure presents the location of the in-situ measurements collocated to the IASI L2 products from both Metop-A and Metop-B in the test period used for the assessment. The vertical profiles of mean departures and standard deviation are shown in the Figures 150 and 153.

Figure 149: Global location of radio-sounding points collocated with IASI-A and IASI-B L2 products from 7 June to 11 August 2014.
**Figure 150:** Mean (solid line) and root mean square (dashed line) difference between IASI L2 and in-situ atmospheric temperature evaluated at NOAA/NPROVS between 7 June and 11 August 2014. LEGEND: red, IASI L2 v5: red(IASI-A)/orange(IASI-B), v6: cyan(IASI-A)/green(IASI-B). Data courtesy of Bomin Sun.

**Figure 151:** Mean (solid line) and root mean square (dashed line) difference between IASI L2 and in-situ atmospheric humidity evaluated at NOAA/NPROVS between 7 June and 11 August 2014. IASI L2 v5: red(IASI-A)/orange(IASI-B), v6: cyan(IASI-A)/green(IASI-B). Data courtesy of Bomin Sun.
Figure 152: Mean (solid line) and root mean square (dashed line) difference between IASI L2 and in-situ atmospheric temperature evaluated at NOAA/NPROVS between 7 June and 11 August 2014. The time window extended to 6-hours from sondes time. IASI L2 v6 first guess (PWLR): brown (IASI-A)/Orange (IASI-B), optimal estimation: cyan (IASI-A)/green (IASI-B). Data courtesy of Bomin Sun.

Figure 153: Mean (solid line) and root mean square (dashed line) difference between IASI L2 and in-situ atmospheric humidity evaluated at NOAA/NPROVS between 7 June and 11 August 2014. Time window extended to 6-hours from sondes time. LEGEND: IASI L2 v6 first guess (PWLR): Brown (IASI-A)/Orange (IASI-B), optimal estimation: Cyan (IASI-A)/Green (IASI-B). Data courtesy of Bomin Sun.
3.4.2 Assessment of water vapour profiles with GRUAN data

GCOS Reference Upper-air Network (GRUAN) aims for high-quality humidity measurements, through standardised launch processes and sonde measurements, calibration and processing [RD 14]. Preliminary comparisons have been carried out by Tim Trent (University of Leicester) for the sonde site in Barrow (Alaska).

Figure 154: Collocation of atmospheric soundings (PWLR) from IASI-A and IASI-B (disks). The red triangle is the GRUAN launch site at the station of Barrow.

Figure 155: Comparison of atmospheric soundings (PWLR) from IASI-A and IASI-B (green), ERA interim profiles (red) with the GRUAN sonde measurements (blue) from Barrow, Alaska station. Left panel: humidity, right panel: temperature.
3.5 Evaluation of the humidity products with MSG TPWV and GII products

Here, we make a qualitative comparison of the operational total precipitable water vapour (TPWV) and global instability index (GII) products derived from SEVIRI/MSG [RD 20] with the same quantities computed from IASI PWLR profiles. This preliminary analysis was prepared by M. Koenig (EUMETSAT).

The figures Figure 156 to Figure 161 illustrate the remarkable consistency of the two products obtained from independent platforms and instruments as well as the complementarities of the GEO VIS/IR and LEO MW/IR systems with the additional spatial coverage enabled at GEO limb views by the LEO and in overcast situations enabled by the microwave and infrared synergistic LEO soundings.
Figure 156: TPWV from SEVIRI on 02/09/2013 at 21:00UTC.

Figure 157: TPWV from IASI (PWLR) on 02/09/2013 at 21:00UTC.

Figure 158: IASI TPWV overlaid on SEVIRI product.
Figure 159: GII from SEVIRI on 02/09/2013 at 21:00UTC.

Figure 160: GII from IASI (PWLR) on 02/09/2013 at 21:00UTC

Figure 161: IASI GII overlaid on SEVIRI product.
3.6 Evaluation of the humidity and temperature profiles by the University of Wisconsin

The water vapour and temperature products assessed here are the PWLR, using the micro-wave and infrared measurements for all-sky retrievals. The work presented in this section is the contribution to the IASI L2 products validation from the team lead by Bob Knuteson at the University of Wisconsin (Madison, Wisconsin, USA). The team included Jacola Roman, who worked at EUMETSAT as a visiting scientist, and Michelle Feltz. The evaluation of these IASI L2 retrievals is performed against comprehensive correlative temperature and water vapour datasets provided by the ARM (Atmospheric Radiation Measurement) and UCAR (University Corporation for Atmospheric Research) SuomiNet programs in the USA. The total column water vapour (TCWV) or precipitable water vapour (PWV) is compared to ground-based Global Navigation Satellite System Radio Occultation (GNSS-RO) and microwave radiometer measurements routinely performed at and around Darwin. This Darwin region is referred to as Temperate Western Pacific (TWP) in this study. Also the region of Lamont is referred to as South Great Plains, SGP, which is a SuomiNet ARM site. The temperature and humidity profiles are compared to in situ radiosonde measurements at those two sites and, in addition, to ground-based LIDAR measurements at Darwin (TWP). The PWV and profiles assessments cover the entire IASI mission period ranging from 2007 through mid-2014 for IASI/Metop-A and from April 2013 through July 2014 for IASI/Metop-B. In addition, the IASI L2 temperature profiles from both Metop-A and Metop-B are compared to GNSS-RO satellite dry temperature retrievals in the lower stratosphere, using UCAR COSMIC and GRAS products from July 2013 and May 2012, for Metop-A only.

3.6.1 Reference Data description

3.6.1.1 Radiosondes

The sondes at the ARM sites for this time period are the Vaisala RS92 sensors using the Vaisala processing software. No H2O corrections are applied to the sonde measurements exploited here. http://www.arm.gov/instruments/sonde

The location of the launch is collocated with the Raman LIDAR and the MWR, although once released it drifts away by a range of up to 100 km. In the boundary layer however, the sonde does not average over the natural spatial at the scale of the IASI footprint. It does not provide information on the temporal variability either, unlike the ground-based LIDAR and MWR. A total of four launches per day was still organised in the first part of the intercomparisons, which was reduced to two launches per day for the most recent years. The sonde data are encapsulated in the Raman LIDAR product files used for this study. They have been interpolated to the 10-minute intervals in time and the height levels of the Raman LIDAR. Because the purpose of many radio sondes in this dataset was to validate AIRS products, the coincidence in time is not optimised with IASI overpasses, with only seven match-ups within 1 hour for instance in SGP. The sonde data gathered within three hours of a IASI overpass are retained in this study.
3.6.1.2 The Raman LIDAR products

The Raman LIDAR products used here are so-called Value Added products from the ARM project created by Dr. David Turner (NOAA, Norman, Oklahoma).

http://www.arm.gov/instruments/rl

Unlike the DIAL LIDAR, the water vapour Raman LIDAR uses the principle of stimulated emission by sending a laser signal directly upward in a narrow pencil-like beam. This beam stimulates H₂O molecules to enter an excited state. When the molecules slow to their ground state, they send photons down to the ground; there, they are collected by a telescope and recorded using photomultiplier tubes, which count the number of photons. By pulsing the LIDAR and measuring the return, the photons can be traced back to vertical height range bins measured in meters. Setting a ratio for the number of H₂O stimulated photons to the density of air gives a direct measurement of mixing ratio. By stimulating the Raman frequency using the laser, the return frequency is well known and thus the LIDAR receiver can be tuned to exclude all other frequencies. During hours of darkness, there are no other sources of signal at the H₂O Raman frequency, this allows for a good signal-to-noise ratio that extends up to about 8-10 km above the surface of the earth, however, when clouds are present, the laser signal is attenuated due to scattering and absorption from water droplets. This limits the vertical extent of the Raman LIDAR signal in daylight hours. The relative accuracy of the Raman Mixing ratio profiles is very high; however, there is no absolute calibration. Following Dave Turner’s approach, the Raman LIDAR absolute calibration is tied to the microwave radiometer at the site which does have good absolute calibration but only provides an integrated column H₂O estimate. The Raman LIDAR does provide good vertical profile shapes, but with an uncertainty in the absolute calibration—this uncertainty can be represented as a scale factor times the profile. To some extent, the LIDAR can see through thin clouds, but is blocked by thick clouds. This is purely a signal-to-noise issue and does not introduce any biases. The other problem is the scattering of sunlight into the LIDAR antennae from aerosols (suspended particles) in the column of air above the LIDAR. Since the sun is such a strong source, and the Raman return signal is so small, the LIDAR height profiles are limited in daylight to the lower atmosphere, which includes the boundary layer up to about 5 km. With these limitations, it was decided to use the MWR for ARM site validation of satellite sounder PWV, and the Raman WV mixing ratio profiles for validation of sounder water vapour vertical mixing ratio profiles, although not for the PWV. The same layer-averaging done with sondes (3.6.1.1) is applied to LIDAR profiles before comparison to the PWLR temperature and humidity retrievals.

3.6.1.3 The microwave-radiometer

The ARM microwave-radiometer (MWR) is a two-channel microwave radiometer that uses the 22-GHz H₂O emission line (on and off) as a measure of the total column water vapour. This is similar to the infrared sounder in that it requires adjusting the atmospheric state vector for fitting the observed brightness temperatures with calculated ones. This is a ground-based instrument and views only a narrow beam in the vertical. See this website for more detailed information.

http://www.arm.gov/instruments/mwr

The unique value of this sensor is demonstrated in the well-known spectroscopy of the 22-GHz line, which can be measured using the Zeeman effect. Unlike many other microwave channels, the radiative transfer for this channel has a very low uncertainty. See the document here for specifications:

http://www.jcsda.noaa.gov/documents/meetings/wkshp2008/1/PayneAER.pdf
However, the measured brightness temperatures do need to be calibrated. Thanks to the careful calibration done at the ARM sites using cold targets and Langley plots, the ARM MWR sensors are well established and trusted for long-term monitoring. The overall uncertainty is thought to be about 3%, when the sensors are at full capacity. However, when the sensor is covered with rain, dust or snow, it can go out of calibration for a period of time. This will cause some outliers to appear in our MWR/Sounder statistics.

3.6.1.4 SuomiNet GPS network

Full details on this network can be found on this web site.

http://www.suominet.ucar.edu/

The SuomiNet network of ground-based GPS receivers is completely independent of the ARM network. One advantage of the UCAR SuomiNet system is that a single consistent algorithm is being used to analyze all the station data. Another advantage of GPS in general is that the "signal" is transmitted to all the GPS satellites at the same time—so the time delay that is measured by each receiver has a very high relative accuracy as explained in [RD 21] and [RD 22]. Also important is that the PWV is sampled by the GPS-RO on a volume of atmosphere that is more similar to satellite products with a large footprint, unlike the Raman and MWR instruments. IASI is 12 km at nadir. Rather than a thin vertical beam like the Raman and MWR, the receiver is designed to lock onto a GPS satellite as it comes up over the horizon and tracks it until the signal is lost on the opposite horizon. Then it locks on to the next GPS satellite, which crosses the sky on a different path, because it is in a different orbit. A composite of multiple satellite data is used to deduce the time delay caused by the presence of water vapour in the atmosphere compared to what the time delay would be for a dry atmosphere. In practice, a cut-off in the elevation angle (approximately 15 degrees) is applied for tracking the satellites; this avoids radio signals that bounce off the surface and other surface interferences. Most of water vapour molecules are in the lowest two km of atmosphere, so a the cut-off point of 15 degrees elevation translates into an approximate 15 km diameter circle around the station.

3.6.1.5 UCAR COSMIC and GRAS L2 temperature profiles (cited from Feltz 2014, RD 31)

For this study, GPS RO data from the US/Taiwan Constellation Observing System for Meteorology, Ionosphere & Climate (COSMIC) network and Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS) instruments are used. COSMIC 10 is also known as Taiwan’s Formosa Satellite Mission #3 (FORMOSAT-3). This mission consists of six radio receivers in distinct satellite orbits with different orbit crossing times. The COSMIC network produces about 1000–2000 profiles per day, though samples in the tropic latitudes are fewer. In contrast, GRAS instruments are onboard the Metop series of operational weather satellites in a sun-synchronous late morning orbit (Klaes et al., 2007). This will be an important distinction when considering how to match up dataset sample sizes in statistical comparisons.

To use a consistent processing approach, all GPS RO data in this study are obtained from the University Corporation for Atmospheric Research (UCAR) COS20 MIC Data Analysis and Archive Center. The post-processed dry temperature products, identified by the label atmPrf, are used. Specifically, the COSMIC data used are version 2010.2640 and the Metop-A GRAS data used are version 2011.2980. There are some known differences in these product versions that are likely to have the biggest impact on the results shown. These are found in the excess phase processing where the COSMIC data 25 are processed in a single-difference mode and Metop-A data are processed in a
zero-difference mode due to the high stability of the GRAS clock. One difference in the processing done by each version is when excess phase data are used to compute bending angle and, subsequently, the refractivity profiles. This affects the open-loop data processing, which in turn only impacts the lower troposphere, which is not considered in this study. This was verified by private communication with UCAR.

### 3.6.2 Selected results in the southern Great Plains

The subsections hereafter present a selection of key figures from the intercomparisons performed between IASI products and ground-based GPS-RO, LIDAR and radiosondes measurements in the South Great Plains (SGP) region, around the ARM site at Lamont [Latitude: 36° 36’ 18.0” N; Longitude: 97° 29’ 6.0” W]. The period under study extends from June 2007 through June 2014 for IASI/Metop-A and from April 2013 through July 2014 for IASI/Metop-B. The LIDAR measurements available for this station have not been exploited yet and are still subject to analyses. More detailed discussions and additional results will be presented at the EUMETSAT Users Conference 2014 in Geneva and will be available in a dedicated communication.

![Figure 162: Location of the UCAR SuomiNet GPS stations network (black squares), the ARM site Lamont (red star) and the SGP region considered in this study (black box)](image)

### 3.6.2.1 Precipitable water vapour assessment

The total column water vapour retrieved with IASI are compared to measurements from the GPS station GS01, the MWR and sondes operated at the ARM site in Lamont, and to all SuomiNet GPS stations within the SGP region (Figure 162). Data from a total of 29 SuomiNet GPS stations were matched to data from IASI products. The collocation criteria are the following:

- GPS or MWR measurements are within one hour of the overpass
- Sound measurements are within three hours of overpass
- The nearest IASI IFOV whose centre is within 1° radius of the station or launch site is retained.

In addition, a quality control on the GPS PWV is applied. This control excludes measurements where the error provided by SuomiNet operators exceeds 5% of the actual total column water vapour reported. For MWR data, the records with more than 100 mm water vapour are discarded.
Figure 163: Correlation figures between the IASI (y-axis) and ground-based and in-situ measurements (x-axis) at Lamont (right column) and in the SGP region (left column).
Figure 164: Top panel, PDFs of PWV from IASI-A (black lines) and GPS-RO (green lines) for all SuomiNet stations within the SGP region. Bottom panel, PDFs of PWV from IASI (black), SG01 (green), MWR (red) and sonde (blue) at Lamont.
Figure 165: Time series of the IASI (blue) and GPS (black) PWV (above) and of their differences (bottom panel) for IASI-A at SG01, Lamont.
Figure 166: PDFs of PWV differences between IASI (top: IASI-A, bottom: IASI-B) and GPS-RO for all SuomiNet stations within SGP (black), SG01 (green), MWR (red) and sonde (blue) at Lamont.
Figure 167: Relative accuracy (plotted in points) and its uncertainty (error bars) between IASI and GPS at SG01 (blue) and with all SuomiNet stations within SGP (red) calculated for 5 mm bins.
Figure 168: For all SuomiNet GPS stations within SGP, the plots show the difference in PWV (IASI-A - GPS) as a function of GPS PWV (a), IASI quality indicator for water vapour (b), IASI-GPS time difference (c), distance between GPS station IASI IFOV centre (d), IASI-GPS surface pressure (e). (f) shows the correlation between the surface pressure recorded at the GPS stations and the value inferred for the IASI footprints.
3.6.2.2 Water-vapour profiles assessment

The vertical profiles measured by the radiosondes launched at Lamont are compared to the profiles retrieved from space with IASI, using the following comparison criteria:

- The nearest IASI IFOV whose centre is within 1° radius of the sonde launch site is retained.
- The sonde launch must be within three hours of IASI overpass.

No additional QC filtering is performed on the sonde data, they are used as provided in the ARM database. No LIDAR data have been exploited yet for Lamont. They are still being analysed. LIDAR data could however be exploited already for the Darwin site. See Section 3.6.3.2.

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**Figure 169:** Histograms of the time difference (left) and distance in degrees (right) between the sonde launch and the IASI-A overpass/IFOV centre.

We acknowledge that the three-hour threshold on the time difference with sondes does likely imply a significant contribution of the collocation error to the uncertainty budget evaluated for the IASI products. This is almost inevitable as only seven sonde measurements are found within 1 hour of IASI overpass—323 are within 2 hours and 510 are within 3 hours.

The radio sounding and LIDAR profiling offer a much higher vertical resolution than the IASI products vertical resolution sampling—101 static pressure levels—and *a fortiori* than the actual instrument vertical resolution, which is typically one km for temperature and two km for water vapour. The LIDAR data is not yet available yet for SGP, but is exploited at TWP as detailed in Section 3.6.3.2). LIDAR and sonde profiles are therefore smoothed by averaging the quantities in the layers defined by the IASI products grid and by averaging them at a two-km resolution before comparison to the IASI humidity profiles. This method was preferred to applying the averaging kernels of the retrievals to the sonde profiles—as shown in Section 4.1—for practical reasons and also because it is assumed that the remaining smoothing error that is ignored with the slab layering is small and negligible in comparison to the collocation errors. The collocation errors are due to the relatively large time differences between the sonde measurements and the IASI overpass on one hand, and to the fact that the sonde is doing a single point measurement while IASI senses large regions with its footprint of 12 km at nadir.

The effect on the variance by representation of the Sonde humidity profiles at different vertical resolution is shown in the Figure 170. The variance of the humidity measured by the sondes is closer
to that of the IASI water vapour products when averaged in two km layers, but the IASI products underestimate it by 0.2 to 0.5 g/kg in the lower troposphere.

Figure 170: Average water vapour profiles (solid line) in the match-up sonde (black), and IASI-A (red) records. Their variability (standard deviation) is plotted with the dashed line. They are calculated at the nearest pressure level of the 101-level IASI products grid (top), by averaging in the IASI products grid layers (centre) and smoothed in 2 km layers (bottom panel).
Figure 171: Vertical statistics of the differences between IASI-A and sonde specific humidity at different vertical resolutions: nearest grid level, IASI products grid layers, two-km slab layering.

Figure 172: Vertical statistics of the differences between IASI-A and sonde relative humidity at different vertical resolutions: nearest grid level, IASI products grid layers, two-km slab layering.
Figure 173: PDF of the water vapour mixing ratio at 700 hPa (top panel) and 900 hPa (bottom panel) in the sondes (blue) and IASI (red) products.
Figure 174: PDF of the IASI and sondes differences in water vapour content at 700 hPa (top) and 900 hPa (bottom panel).
Figure 175: IASI and sondes differences in water vapour content at 700 hPa (top) and 900 hPa (bottom) measured against the time difference between the sonde launches and IASI-A overpasses at Lamont.
3.6.3 Selected results in TWP

The subsections that follow present a selection of key figures from the intercomparisons performed between IASI products and ground-based GPS-RO, MWR, LIDAR and radiosonde measurements in the TWP region, around the ARM site at Darwin, Australia [Latitude: 12° 25' 28.56" S ; Longitude: 130° 53' 29.75" E]. The time periods and instruments used are as follows:

<table>
<thead>
<tr>
<th>Instrument(s)/data</th>
<th>Time period covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>IASI/Metop-A</td>
<td>June 2007 through June 2014</td>
</tr>
<tr>
<td>IASI/Metop-B</td>
<td>April 2013 through June 2014</td>
</tr>
<tr>
<td>LIDAR, MWR and sonde data</td>
<td>December 2010 through June 2014</td>
</tr>
</tbody>
</table>

More detailed discussions and additional results will be presented at the EUMETSAT Users Conference in Geneva, October 2014 and will also be available in exclusive communication to the user community.

Figure 176: Location of the UCAR SuomiNet GPS stations network (squares), the ARM site Darwin (red star) and the TWP region considered in this study (black box)
3.6.3.1 Precipitable water vapour assessment

The total column water vapour retrieved with IASI are compared to measurements from the two GPS stations, the MWR, the LIDAR and the sondes operated at the ARM site in Darwin, Australia. The collocation criteria are the following:

- GPS, LIDAR or MWR measurements are within one hour of the overpass.
- Sound measurements are within three hours of overpass.
- The nearest IASI IFOV whose centre is within 1° radius of the station or launch site is retained.

In addition, a quality control on the GPS PWV is applied as follows:

- measurements where the error provided by SuomiNet operators exceeds 5% of the actual total column water vapour reported are excluded.
- for MWR data, records with more than 100 mm water vapour are excluded.

![Graphs showing correlation between IASI and ground-based measurements](image)

Figure 177: Correlation figures between the IASI (y-axis) and ground-based and in-situ measurements (x-axis) at Darwin.
Figure 178: Top panel, PDFs of Precipitable Water Vapour (PWV) from IASI-A (black) and GPS-RO (green) for all SuomiNet stations within the TWP region. Bottom panel, PDFs of PWV from IASI (black), SG01 (green), MWR (red) and sonde (blue) at Darwin.
Figure 179: Time series of the IASI (blue) and GPS (black) precipitable water vapour (top) and of their differences (bottom) for IASI-A at station SA39, Darwin.
Figure 180: Probability Density Function s of PWV differences between IASI (top): IASI-A, bottom panel: IASI-B) and GPS-RO for the two SuomiNet stations within TWP (black), SA39 (green), MWR (red) and sonde (blue) at Lamont.
Figure 181: Relative accuracy (points) and its uncertainty (error bars) between IASI and GPS at SA39 (blue) and with the two SuomiNet stations within TWP (red) calculated for 5 mm bins.
Figure 182: For all SuomiNet GPS stations within SGP, the plots show the difference in PWV (IASI-A - GPS) as a function of GPS PWV (a), IASI quality indicator for water vapour (b), IASI-GPS time difference (c), distance between GPS station IASI IFOV centre (d), IASI-GPS surface pressure (e). (f) shows the correlation between the surface pressure recorded at the GPS stations and the value inferred for the IASI footprints.
3.6.3.2 Water-vapour profiles assessment

The vertical profiles measured by the radiosondes and retrieved from ground with a Raman-LIDAR at Darwin are compared to the profiles retrieved from space with IASI, using the following comparison criteria:

- The LIDAR measurements are within one hour of the IASI overpass.
- The nearest IASI IFOV whose centre is within 1° radius of the LIDAR and sonde station is retained.
- The sonde launch is within three hours of IASI overpass.

Figure 183: Histograms of the time difference (top) and distance in degrees (bottom) between the sonde launch and the IASI-A overpass/IFOV centre.
Figure 184: Average water vapour profiles (solid line) in the comparison sonde (black), LIDAR (blue) and IASI-A (red) records. Their variability (standard-deviation) is plotted with a dashed line. They are calculated at the nearest pressure level of the 101-level IASI products grid (top), by averaging in the IASI products grid layers (centre) and smoothed in 2 km layers (bottom panel).
Figure 185: Vertical statistics of the differences between IASI-A and sonde specific humidity at different vertical resolutions. Nearest grid level, IASI products grid layers, 2 km slab layering.

Figure 186: Vertical statistics of the differences between IASI-A and sonde relative humidity at different vertical resolutions. Nearest grid level, IASI products grid layers, 2 km slab layering.
Figure 187: Probability Density Function (PDF) of the water vapour mixing ratio at 700 hPa (top) and 900 hPa (bottom). Sonde products are black, IASI are red.
Figure 188: PDF of the IASI and sondes differences in water vapour content at 700 hPa (top) and 900 hPa (bottom).
Figure 189: IASI and sonde differences in water vapour content at 700 hPa (top panel) and 900 hPa (bottom panel) measured against the time difference between the sonde launches and IASI-A overpasses at Darwin.
3.6.4 Summary of the statistics for IASI-A and IASI–B at Lamont and Darwin

<table>
<thead>
<tr>
<th>Area</th>
<th>SGP</th>
<th>Lamont</th>
<th>Darwin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instruments</td>
<td>SuomiNet</td>
<td>GPS SG01</td>
</tr>
<tr>
<td>Sample size</td>
<td>55822</td>
<td>3772</td>
<td>1320</td>
</tr>
<tr>
<td>mean</td>
<td>–0.8493</td>
<td>–0.5757</td>
<td>–1.5904</td>
</tr>
<tr>
<td>median</td>
<td>–0.4266</td>
<td>–0.1849</td>
<td>–0.9109</td>
</tr>
<tr>
<td>1st percentile</td>
<td>–14</td>
<td>–14</td>
<td>–16</td>
</tr>
<tr>
<td>5th percentile</td>
<td>–10</td>
<td>–10</td>
<td>–10</td>
</tr>
<tr>
<td>95th percentile</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>99th percentile</td>
<td>8</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>mode</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.9502</td>
<td>0.9484</td>
<td>0.9567</td>
</tr>
<tr>
<td>Slope</td>
<td>0.842</td>
<td>0.8357</td>
<td>0.8304</td>
</tr>
<tr>
<td>Intercept</td>
<td>2.5766</td>
<td>2.6892</td>
<td>1.9975</td>
</tr>
</tbody>
</table>

Table 2: Statistics summary of the PWV differences in mm between IASI-A and validation data.

<table>
<thead>
<tr>
<th>Area</th>
<th>SGP</th>
<th>Lamont</th>
<th>Darwin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instruments</td>
<td>SuomiNet</td>
<td>GPS</td>
</tr>
<tr>
<td>Sample size</td>
<td>4838</td>
<td>645</td>
<td>180</td>
</tr>
<tr>
<td>mean</td>
<td>–1.2322</td>
<td>–1.0741</td>
<td>–2.1345</td>
</tr>
<tr>
<td>median</td>
<td>–0.8005</td>
<td>–0.476</td>
<td>–1.5764</td>
</tr>
<tr>
<td>1st percentile</td>
<td>–14</td>
<td>–14</td>
<td>–18</td>
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<td>5th percentile</td>
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<td>–10</td>
<td>–12</td>
</tr>
<tr>
<td>95th percentile</td>
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</tr>
<tr>
<td>99th percentile</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>mode</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.9389</td>
<td>0.9425</td>
<td>0.9575</td>
</tr>
<tr>
<td>Slope</td>
<td>0.8506</td>
<td>0.8454</td>
<td>0.8329</td>
</tr>
</tbody>
</table>

Table 3: Statistics summary of the PWV differences in mm between IASI-B and validation data.
3.6.5 Assessment of the stratospheric temperature products with GNSS-RO satellite products

In this section, we highlight the preliminary results of a comparison of IASI-A/IASI-B temperature profiles with COSMIC products for the month of July 2013. The nominal vertical range for COSMIC products extends between 10 hPa and 200 hPa. Measurements above 10 hPa have uncertainties in COSMIC that are known to be larger. This is due to ionospheric effects not fully modelled. In addition, the dry temperature assumption is no longer valid for altitudes where the water vapour becomes a significant component of the atmospheric refractivity, typically below 200 hPa.

The COSMIC vertical temperature profiles are averaged in 1 km layers before comparison to the IASI temperature profiles. Biases of opposite sign in COSMIC temperature profiles in the two hemispheres have been identified [RD 31], which can be seen again here in the IASI-COSMIC statistics.
Figure 190: Comparison of IASI-A/IASI-B temperature profiles with COSMIC products for the month of July 2013. a) 60N_90N  b) 30N_60N  c) 30S_30N  d) 30S_60S  e) 60S_90S  f) Global
Legend: black Metop-A bias, blue Metop-B bias.
3.6.6 A global intercomparison of satellite and model precipitable water vapour for climate

The IASI L2 v6 products were analysed in the context of assessing the potential of satellite sounder products for the analyses of severe weather events, their societal impact, and their evolution with climate changes. Preliminary results were presented at the International TOVS Study Conference ITSC-19. See J. Roman [RD 15].

The EUMETSAT IASI, National Center for Environmental Prediction (NCEP) Reanalysis, the ECWMF ERA Interim and Atmospheric Infrared Sounder (AIRS) daily TPWV products are computed and compared on a 1° × 1° grid. In order to isolate and characterise the atmospheric moisture features better, a climatological mean is subtracted from the daily TPWV products. This is illustrated in Figure 191, which shows both the moist and dry “anomalies” as observed by AIRS and IASI and modelled at ECMWF and NCEP, whereas IASI products show a qualitative good agreement with the AIRS satellite products and with the models.
Figure 191: Total PWV (mm) for 01/08/2013 as per ERA-Interim (top left), NCEP Reanalyses (top right), AIRS L3 v6 (bottom left), IASI-B v6 (bottom right).
Figure 192: Total PWV anomalies (mm) for 01/08/2013 in ERA-Interim (top left), NCEP Re-analyses (top right), AIRS L3 v6 (bottom left), IASI-B v6 (bottom right), computed from an ECMWF climatological mean.
4 RETRIEVAL ERROR ESTIMATE

The IASI L2 v6 products contain the full retrieval error estimate—full retrieval error covariance matrix—for temperature, humidity and ozone profiles. This information is compressed in the principle components of the atmospheric state profiles. The retrieval error estimates are compared to the differences between the IASI L2 v6 products and reference profiles ECMWF analysis as shown in Section 4.1. The retrieval error estimates for temperature range between 0.5 K in the mid-troposphere and between 0.8 K to 1 K (standard deviation) in the lower and upper troposphere. They are slightly lower than the random component of the differences between ECMWF analyses and the IASI L2 products, which typically range from 0.8 K to 1 K on sea and to 1.5 K on land. These differences obviously contain the satellite products errors but also the collocation uncertainties, both spatial and temporal differences between IASI and ECMWF fields, the effect of IASI vertical resolution (or smoothing error) as discussed below, and the ECMWF model errors themselves. The process of separating these components and assessing the errors due to non-exact and simultaneous collocation is a long-term activity which has started [RD 32] and will require further developments. The standard deviation differences between the retrieval error estimate and the differences with ECMWF analyses are found to be compatible with the elements of the overall uncertainty budget listed previously. In such case, the retrieval error estimate for temperatures seems to be a realistic representation of their precision. The same considerations apply to water vapour products, with the estimated precision of between 0.5 and 1.5 g/kg in the lower troposphere, and to the differences to ECMWF analyses, which range between 1 and 2 g/kg. These departures are much more important than those for temperatures. This is consistent with the assumption that the uncertainties in NWP models are larger for water vapour than for temperature and with the fact that water vapour content varies rapidly in short range time and space [RD 33], which yields larger collocation errors.

In the IASI L2 products, the temperature, humidity and ozone profiles are provided on a fixed vertical grid of a much finer sampling (101 levels) than the resolution of the profiles themselves. This is true also for the other hyperspectral sensors. The actual vertical resolution achieved with IASI is approximately 1 km for temperature and 2 km for water vapour in the troposphere. The vertical sensitivity varies also with the scene being sensed. In general, sounding in the lowest layers is favoured by a good contrast between the surface and the air temperature, a concept called thermal contrast. The vertical resolution and vertical sensitivity information is contained in the so-called averaging kernels (AK). The AKs can be reconstructed from the full retrieval error estimate and the observation error covariance matrices used in the OEM. Plots in Section 4.2 show the effect of applying the averaging kernels to the reference profiles before comparison to the IASI L2 v6 products and display examples of maps of the degrees of freedom for temperature, humidity and ozone.

Mathematically, the degrees of freedom for signal are the trace of the averaging kernel matrix. They express the number of independent pieces of information that have been extracted from the measurements to generate the retrieved profiles. Full details of the mathematics and of the retrieval and error estimate theory behind the optimal estimation can be found in [RD 23]. In this IASI v6, we typically identify up to ten independent pieces of information for temperature, up to seven for water vapour and from three to three and a half for ozone. As a general rule, the higher the number of degrees of freedom, the better resolution for the profile. Maps of degrees of freedom are created and monitored a shown in Section 4.3. As expected, more degrees of freedom are usually observed in the warmer areas and at daytime than in hours of darkness. See Figure 204 to Figure 211.
The PWLR method does not provide yet similar information on the vertical resolution and sensitivity. However, it has been trained to return a quality indicator that relates to the absolute retrieval error. These quality indicators for temperature, surface temperature, humidity and ozone can be used by the products’ user base as filtering data, depending on their applications. They are also monitored as the product’s quality control that ensures stability and spatial consistency. Examples of maps of PWLR quality indicators are shown in Section 4.4.

Figure 193: Averaging kernels for temperature (left) and water vapour (right) profiles for a mid-latitude oceanic location on 12/09/2014.
4.1 Mean retrieval error estimates compared to differences with ECMWF analyses

Figure 194: IASI-A L2 v6 and ECMWF ANA temperatures differences during the period 06/09/2014 to 11/09/2014. FLG_CLDNES classes 1 and 2. Legend: vertical profiles of the mean (dashed lines) and standard deviation (solid lines) are in blue. In green, the mean retrieval error estimate (dashed line) for temperature (diagonal of the error covariance matrix) and its standard deviation (solid line).
Figure 195: In blue, vertical profiles of the mean (dashed lines) and standard deviation (solid lines) of the IASI-A L2 v6 and ECMWF ANA differences in humidity during the period 06/09/2014 to 11/09/2014 in clear IFOVs (FLG_CLDNES classes 1 & 2). In green, the mean retrieval error estimate (dashed line) for temperature (diagonal of the error covariance matrix) and its standard deviation (solid line).
4.2 Application of the AK before comparisons to ECMWF fields

4.2.1 Temperature profiles

4.2.1.1 Metop-B

Figure 196: IASI-B L2 and ECMWF ANA temperature, vertical profiles of the mean differences (dashed line) and standard deviation (solid lines) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 1. Legend: Red: v6_OEM without smoothing, green: v6_OEM with averaging kernel smoothing.
Figure 197: IASI-B. IASI-B L2 and ECMWF ANA temperature, vertical profiles of the mean differences (dashed line) and standard deviation (solid lines) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: red: v6_OEM without smoothing, green: v6_OEM with averaging kernel smoothing.
4.2.1.2 Metop-A

Figure 198: IASI-A L2 and ECMWF ANA temperature, vertical profiles of the mean differences (dashed line) and standard deviation (solid lines) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNE class 1. Legend: red: v6_OEM without smoothing, green: v6_OEM with averaging kernel smoothing.
Figure 199: IASI-A. IASI-A L2 and ECMWF ANA temperature, vertical profiles of the mean differences (dashed line) and standard deviation (solid lines) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: red: v6_OEM without smoothing, green: v6_OEM with averaging kernel smoothing.
4.2.2 Specific Humidity profiles

4.2.2.1 Metop-B

Figure 200: IASI-B L2 and ECMWF ANA specific humidity, vertical profiles of the mean differences (dashed line) and standard deviation (solid line) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNS class 1. Legend: red: v6_OEM without smoothing, green: v6_OEM with averaging kernel smoothing.
Figure 201: IASI-B, IASI-B L2 and ECMWF ANA specific humidity, vertical profiles of the mean differences (dashed line) and standard deviation (solid line) during the period 27/06/2014 to 11/09/2014 in FLG_CLDNES class 2. Legend: red: v6_OEM without smoothing, green: v6_OEM with averaging kernel smoothing.
Figure 202: Comparison of IASI-A L2 and ECMWF ANA specific humidity, vertical profiles of the mean differences (dashed line) and standard deviation (solid lines) during the period 27/06/2014 to 13/08/2014 in FLG_CLDNES class 1. Legend: red: v6_OEM without smoothing, green: v6_OEM with averaging kernel smoothing.
Figure 203: IASI-A. IASI-A L2 and ECMWF ANA specific humidity, vertical profiles of the mean departures (dashed line) and standard deviation (solid lines) during the period 27/06/2014 to 13/08/2014 in FLG_CLDNES class 2. Legend: red: v6_OEM without smoothing, green: v6_OEM with averaging kernel smoothing.
4.3 Maps of degrees of freedom

4.3.1 Atmospheric Temperature

Figure 204: IASI-B L2 degree of freedom for atmospheric temperature during the period 25/04/2014 to 11/09/2014 for day pixels only

Figure 205: IASI-B degree of freedom for atmospheric temperature during the period 25/04/2014 to 11/09/2014 night pixels only
4.3.2 Atmospheric specific humidity

Figure 206: IASI-B L2 degree of freedom for atmospheric specific humidity for the period 25/04/2014 to 11/09/2014 for day pixels only.

Figure 207: IASI-B degree of freedom for atmospheric specific humidity for the period 25/04/2014 to 11/09/2014 for night pixels only.
4.3.3 Atmospheric Ozone

Figure 208: IASI-B L2 degree of freedom for atmospheric ozone for the period 25/04/2014 of 11/09/2014 for day pixels only.

Figure 209: IASI-B degree of freedom for atmospheric ozone for the period 25/04/2014 of 11/09/2014 for night pixels only.
4.3.4 All retrievals

Figure 210: IASI-B L2 degree of freedom for all the retrievals (temperature and specific humidity and ozone) during the period 25/04/2014 to 11/09/2014 for day pixels only.

Figure 211: IASI-B L2 degree of freedom for all the retrievals (temperature and specific humidity and ozone) during the period 25/04/2014 to 11/09/2014 for night pixels only.
4.4 PieceWise Linear Regression-retrieval (PWLR) quality indicator

4.4.1 Atmospheric Temperature

![Figure 212: IASI-B L2 PWLR quality indicator for atmospheric temperature during the period 25/04/2014 to 11/09/2014 for day pixels only.](image1)

![Figure 213: IASI-B PWLR quality indicator for atmospheric temperature during the period 25/04/2014 to 11/09/2014 for night pixels only.](image2)
4.4.2 Atmospheric Specific Humidity

Figure 214: IASI –B L2 PWLR quality indicator for atmospheric specific humidity for the period 25/04/2014 to 11/09/2014 for day pixels only.

Figure 215: IASI-B PWLR quality indicator for atmospheric specific humidity for the period 25/04/2014 to 11/09/2014 for night pixels only.
5  INSPECTION OF THE RADIANCE RESIDUALS

This is another way to analyse retrieved profiles: evaluate how well they reproduce the observed radiances (OBS) by calculating (CALC) simulated radiances with a radiative transfer model. These OBS-CALC differences are also referred to as residuals and can be computed with atmospheric profiles derived from satellite observations or from numerical models.

In Figure 216 to Figure 218, we compare the residuals—standard deviations from 17/01/2014—computed with ECMWF forecasts (red) and analyses (blue) to the residuals computed with IASI L2 v6 PWLR profiles, which are plotted in green. The simulated radiances are computed with RTTOV 10.2 as a forward model. The residuals obtained with IASI L2 v6 PWLR profiles are significantly smaller than those obtained with ECMWF forecasts in the complete spectral range, except for the short wavelength in Band 3 where errors due to non-correctly modelled solar radiations are assumed to be dominant. This exercise illustrates the merits of satellite products for near-real time applications in comparison to numerical model predictions.

While the residuals from IASI L2 PWLR and from ECMWF analyses are comparable in the entire IASI spectral domain, the PWLR better fit the observations in the ozone and water vapour regions. This is remarkable. The PWLR is a linear regression and is not based on residuals minimisation, unlike the assimilation process that yields the analyses at ECMWF or in the OEM in the IASI L2 processor. For this, the residuals are shown in Figure 219; they prove to be much smaller than those obtained with ECMWF forecasts. In this case, small residuals are not a guarantor for the L2 products quality but a sanity quality check that the retrieval system is converging properly. Remember the minimisation process that occurs naturally in the OEM. Now that the final surface temperature and humidity profiles in the IASI Level 2 products come from the OEM in v6, you will notice that the values in OBS-CALC (IASI L2) are much smaller in v6 than in v5, where only the temperature profiles originated in the OEM. This is due to the humidity profiles and surface parameters being retrieved with statistical methods.
Figure 216: Standard deviation of the residuals computed on 17/04/2014 with IASI observations and simulations computed with ECMWF forecasts (red), analyses (blue) and with IASI L2 PWLR profiles (green) in IASI band 1 for clear-sky oceans.

Figure 217: Standard deviation of the residuals computed on 17/04/2014 with IASI observations and simulations computed with ECMWF forecasts (red), analyses (blue) and with IASI L2 PWLR profiles (green) in IASI band 2 for clear-sky oceans.
Figure 218: Standard deviation of the residuals computed on 17/04/2014 with IASI observations and simulations computed with ECMWF forecasts (red), analyses (blue) and with IASI L2 PWLR profiles (green) in IASI band 3 for clear-sky oceans.

Figure 219: Standard deviation of the residuals computed on 25/02/2014 with IASI observations and simulations computed with ECMWF forecasts (black), and with IASI L2 OEM profiles (red) for clear-sky oceans.
6 SURFACE PARAMETERS

6.1 Sea-Surface Temperature

This section summarises the assessment of the first-guess all-sky (PWLR) and of the clear-sky OEM retrieved SSTs by comparison to in-situ buoys measurements, the AVHRR SST products, and numerical SST model data from ECMWF.

In Section 6.1.1 and Section 6.1.2, we present the initial validation results of the PWLR sea surface temperature using IASI L2 data analysed over the period July 2013 to December 2013. In Section 0, we present initial validation results from 1D-VAR SST over the period 18 March to 31 August 2014. In addition, the methodology and results for the Sensor Specific Error Estimates (SSES) are discussed in Section 6.1.3. They form part of the Group for High Resolution SST (GHRSST) Data Specification Version 2 in [RD 10].

6.1.1 PWLR SST assessment with in-situ buoys measurements

The Version 6 SSTs have been compared with daily matchup datasets of collocated drifting buoy and AVHRR SSTs supplied by the OSI-SAF. These are the same matchup datasets that are used in RD-3, and more information is given in that document. The collocation criteria for PWLR and the buoy SSTs is as follows:

- Time collocation is one hour between drifting buoy and IASI SSTs.
- A conservative collocation in space of 12 km nadir.
- Night and daytime analyses are considered separately.
- Only drifting buoys are selected.

Some collocations were classified as high QC, and had these additional criteria:

- the uncertainty of SST_IASI was less than 0.3 K.
- the AVHRR inhomogeneity parameter was less than 0.025 for night-time only.

The SST_IASI values in v6 of the IASI processor are accompanied by a value of the observational uncertainty in SST (Q_SST_IASI). See [RD-1]. For IASI skin SSTs to be able to be compared to buoy SSTs, the IASI skin SSTs were converted to an IASI sub-skin SST by the addition of 0.17 K The specification and formula are presented in [RD 11].

The results in Table 4 show the global statistics of the comparisons between SST_IASI and drifting buoy SSTs. During darkness hours (Metop-01) there is a cool bias of –0.18K; this is similar to the v5 IASI validation results presented in [RD-3]. During daytime, when diurnal variations in surface temperature influence the bias, this reduces to –0.04K. The highest quality results are selected where the uncertainty of the SST_IASI (Q_SST_IASI) is less than 0.3 K and only low values of AVHRR inhomogeneity over the IASI field of view are used to reduce the effects of the possibility of residual cloud. For these cases, the cool bias on SST_IASI is –0.22 K, with a standard deviation of 0.3K. Very similar results are observed for Metop-02.
<table>
<thead>
<tr>
<th>IASI-buoy (K)</th>
<th>Metop-01</th>
<th>Metop-02</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bias</td>
<td>stdev</td>
</tr>
<tr>
<td><strong>Night</strong></td>
<td>−0.18</td>
<td>0.45</td>
</tr>
<tr>
<td><strong>Day</strong></td>
<td>−0.04</td>
<td>0.46</td>
</tr>
<tr>
<td><strong>High QC</strong></td>
<td>−0.22</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*Table 4: Global statistics of SST_IASI minus drifting buoy SST over the period July 2013 to December 2013, using 3-sigma statistics to remove outliers.*

The graphs displayed in Figure 220 indicate that the biases are fairly constant both latitudinally and longitudinally; however, there are larger uncertainties at higher latitudes. This observation is consistent with that observed for the plot of Q_SST_IASI measured against latitudes, where the higher uncertainties are at higher latitudes. A slight scan angle effect is observed for SST_IASI, this effect is due to the zenith angle being greater than 60 degrees. Figure 221 shows how this uncertainty increases for higher latitudes.
Figure 220: The top four panels are binned plots of SST_IASI minus buoy SST during darkness: SST versus latitude, SST versus longitude, satellite zenith angle, and the uncertainty of the SST_IASI versus latitude for Metop-01. The bottom four panels are the same sequence for Metop-02. These cover the period July 2013 to December 2013.
Figure 221: Global maps of uncertainty of SST_IASI over the period July 2013 to December 2013. Metop-01 is the panel on top, Metop-02 is the bottom panel.
6.1.2 PWLR SST 3-way assessment with AVHRR and buoys data

Table 5 lists the global standard deviation of uncertainty for each observation type in the preceding comparisons: for SST_IASI (PWLR), for AVHRR and for drifting buoy SSTs. These use the method described in [RD 12]. The uncertainty on Metop-01 SST_IASI is 0.25 K, AVHRR is 0.2 K and for drifting buoys is 0.16 K. Very similar results are observed for Metop-02.

<table>
<thead>
<tr>
<th></th>
<th>SST_IASI (K)</th>
<th>AVHRR (K)</th>
<th>Drifting buoy (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metop-01</td>
<td>0.25</td>
<td>0.20</td>
<td>0.16</td>
</tr>
<tr>
<td>Metop-02</td>
<td>0.24</td>
<td>0.17</td>
<td>0.18</td>
</tr>
</tbody>
</table>

*Table 5: Global standard deviation of uncertainties for SST_IASI, AVHRR and drifting buoy SSTs for the high QC criteria.*

The histograms of the differences are shown in Figure 222, for high QC cases only. These indicate that the standard deviations vary between 0.34 K and 0.41 K, with a slight cool bias observed for the cases of SST_IASI minus the drifting buoy.
Figure 222: The top four panels show these histograms: AVHRR minus SST_IASI, drifting buoy minus AVHRR SST, SST_IASI minus drifting buoy SST, and SST_MWIR minus drifting buoy SST for Metop-01. The bottom four panels show the same for Metop-02. All use a high-QC criteria of uncertainty less than 0.3K and homogeneity of the AVHRR scene to be less than 0.025. The time period is July 2013 to December 2013.
6.1.3 Initial Sensor Specific Error Estimates based on PWLR

Using the analyses in the previous section, a new Sensor Specific Error Estimate (SSES) scheme has been derived. This scheme uses the information contained in Q_SST_IASI. Therefore, the GHRSST Quality Levels are defined as followed:

- Quality Level 2: Q_SST_IASI greater than 0.7 K.
- Quality Level 3: Q_SST_IASI between 0.5 to 0.7 K.
- Quality Level 4: Q_SST_IASI between 0.3 to 0.5 K.
- Quality Level 5: Q_SST_IASI less than 0.3 K.

The values for the SSES Look Up Table (LUT) as shown in Table 6 were determined by examination of collocations with drifting buoys over the period July 2013 to December 2013. Only night-time observations were used along with a 3-sigma standard deviation test. The standard deviations are in line with the values for the Q_SST_IASI. Slightly different biases are observed across the quality levels.

<table>
<thead>
<tr>
<th>IASI-buoy (K)</th>
<th>METOP-01 bias</th>
<th>METOP-01 st dev</th>
<th>METOP-02 bias</th>
<th>METOP-02 st dev</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>QL2</td>
<td>0.01</td>
<td>0.96</td>
<td></td>
<td>0.03</td>
<td>0.97</td>
</tr>
<tr>
<td>QL3</td>
<td>-0.13</td>
<td>0.66</td>
<td>416</td>
<td>-0.05</td>
<td>0.65</td>
</tr>
<tr>
<td>QL4</td>
<td>-0.17</td>
<td>0.44</td>
<td>1570</td>
<td>-0.16</td>
<td>0.44</td>
</tr>
<tr>
<td>QL5</td>
<td>-0.22</td>
<td>0.30</td>
<td>2433</td>
<td>-0.22</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Table 6: SSES bias and standard deviation, computed over the period July to December 2013.

Histograms of SST_IASI minus drifting buoy SST are shown in Figure 223 for each of the quality level cases. These plots indicate that the bias and standard deviations of the IASI SSTs for quality levels 3 to 5 are of good quality. We recommend that these levels be used for the product. Figure 224 and Figure 225 indicate the geographic spread of SST_IASI for each quality level.
Figure 223: The top four panels show histograms of SST_IASI minus drifting buoy SST for SSES Quality Levels 2, 3, 4 and 5 for Metop-01. The bottom four show the same sequence for Metop-02. These cover the period July 2013 to December 2013.
Figure 224: Global night time maps of Metop-01 SST_IASI minus drifting buoy SST: From top panel: SSES Quality level 2, SSES Quality level 3, SSES Quality level 4 and SSES Quality level 5 (bottom panel).
Figure 225: Global night time maps of Metop-02 SST, IASI minus drifting buoy SST. From top panel: SSES Quality level 2, SSES Quality level 3, SSES Quality level 4 and SSES Quality level 5 (bottom panel).
6.1.4 Optimal Estimation Method (OEM) SST assessment with *in-situ* buoys measurements

This section presents the initial validation results of the 1D-VAR sea surface temperature using IASI L2 data analysed over the period 18 March to 31 August 2014. Due to an error in copying data, there is a gap in IASI SST availability for these dates:
- 1 April to 6 April,
- 23 to 31 May,
- 1, 2, and 5 June

Also, drifting buoy SSTs are missing on 23 April. Finally, there are some extra dates lacking data for Metop-B:
- 9 April to 21 April
- 23 April
- 3 and 6 June

The v6 1D-VAR SSTs have been compared with daily matchup datasets of collocated drifting buoy and AVHRR SSTs supplied by the OSI-SAF. The collocation between 1D-VAR and the buoy SSTs has the following criteria:
- Time collocation is two hours between drifting buoy and IASI SSTs.
- Nighttime and daytime analyses are considered separately.
- Only drifting buoys are selected.
- Only AVHRR observations with a quality level greater than or equal to three are used.
- The IASI skin SSTs are converted to an IASI *sub-skin* SST by the addition of 0.17 K.

Table 7 describes differences between IASI and drifting buoy SSTs, and Table 8 shows similar results taken from AVHRR and IASI comparisons. When compared to drifting buoy SSTs, the IASI SSTs display a minor cool bias of about \( -0.16 \) K for both Metop-A and Metop-B during night-time. This is reduced during daytime due to diurnal warming. A similar IASI cool bias is confirmed by the AVHRR comparisons.
Table 7: Global IASI and drifting buoy SST statistics over the period 18 March to 31 June 2014.

Table 8 shows the statistics per quality level, with the lowest biases observed in the highest quality results (QL5), along with the lowest standard deviation of 0.33 K for Metop-A and 0.35 K for Metop-B. The QC matchup criteria is equivalent to the third row in tables 1 and 2, where IASI QL ≥ 3, AVHRR QL ≥ 3. Metop-A has a higher number of matchups than Metop-B. Similar yields of data and quality control are passed into the collocation process. This higher number is due to number of collocations which pass the further collocation criterion. The OSI-SAF MDB was not operational for Metop-B, resulting in fewer AVHRR SST observations of quality level 3 or above. Analysis of only the QL5 results using a three-way uncertainty analysis returns an overall global standard deviation of uncertainty as follows:

- 0.27 K (0.29 K) for IASI SST
- 0.18 K (0.20 K) for AVHRR SST
- 0.20 K (0.20 K) for drifting buoy SST (Metop-A and Metop-B).

Table 8: Global AVHRR-IASI SST statistics over the period 18 March to 31 August 2014.
6.1.5 Sensor-Specific Error Estimates (SSES) based on OEM for operational release

Table 9 specifies the SSES based on OEM and six months of monitoring. It will be used for operational release and configuration of the IASI L2P SST products.

<table>
<thead>
<tr>
<th>Quality Level</th>
<th>Metop-A</th>
<th></th>
<th></th>
<th>Metop-B</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (K)</td>
<td>St. Dev. (K)</td>
<td>N</td>
<td>Mean (K)</td>
<td>St. Dev. (K)</td>
<td>N</td>
</tr>
<tr>
<td>QL2</td>
<td>-0.27</td>
<td>0.52</td>
<td>187</td>
<td>-0.28</td>
<td>0.46</td>
<td>137</td>
</tr>
<tr>
<td>QL3</td>
<td>-0.27</td>
<td>0.46</td>
<td>207</td>
<td>-0.34</td>
<td>0.41</td>
<td>138</td>
</tr>
<tr>
<td>QL4</td>
<td>-0.17</td>
<td>0.40</td>
<td>724</td>
<td>-0.18</td>
<td>0.39</td>
<td>457</td>
</tr>
<tr>
<td>QL5</td>
<td>-0.09</td>
<td>0.33</td>
<td>628</td>
<td>-0.08</td>
<td>0.35</td>
<td>485</td>
</tr>
</tbody>
</table>

Table 9: Nighttime IASI and buoy SST global mean differences for each quality level (Sensor Specific Error Statistics), over the period 18 March to 31 August 2014. These are calculated using the criteria equivalent to where both IASI and AVHRR QL ≥ 3.

Figures 226 to 228 show an analysis of IASI minus drifting buoy differences over the validation period. The histograms show almost no cool tails suggesting that any residual cloud contamination in the IASI SSTs is very limited. Figure 227 shows the variation of bias with latitude, satellite zenith angle and wind-speed. There is some variation with latitude, although Figure 228 indicates that there are fewer matchups in the equatorial regions with most being in the mid-latitudes. No obvious variation with satellite zenith angle is observed. The plot of bias against wind speeds indicates that the IASI SSTs are warmer during daytime, as shown by the dashed line. This is as expected.

The global maps plotting IASI minus buoy SST difference over the period indicate that most of the differences are close to zero, but higher values exist in these regions:

- the Arabian Sea—this is probably due to desert dust aerosol
- the gulf stream—this is probably due to higher collocation uncertainties linked to increased SST gradients
- tropical regions such as the Indian Ocean where the IASI SSTs are warmer—this is probably due to diurnal warming

Further regional analysis is necessary when more matchups have been obtained.
Figure 226: Histograms of nighttime IASI and drifting buoy, AVHRR and IASI and AVHRR and drifting buoy for 18 March to 31 August 2014. Metop-A is the top row of panels. Metop-B is the bottom. Equivalent to IASI and AVHRR QL ≥ 3.
Figure 227: Binned plots of IASI and drifting buoy versus latitude, satellite zenith angle and ECMWF 10m wind speed for 18 March to 30 June 2014, where Metop-A is the top row of panels and Metop-B is the bottom row. On the far right panel in both rows, the solid line is night, and the dotted line day.
Figure 228: Global maps of IASI and drifting buoy SST differences for 18 March to 31 August 2014. The top panel is Metop-A, the bottom panel is Metop-B. Equivalent to IASI and AVHRR QL ≥ 3.
Figure 229: Time-series of global IASI and drifting buoy SST differences for 18 March to 30 June 2014. Metop-A is the top series of panels, Metop-B is the bottom sequence. Equivalent to IASI and AVHRR QL $\geq 3$. IASI SSTs have been converted to a ‘sub-skin’ SST for direct comparison with the drifting buoy and AVHRR sub-skin SSTs.
6.1.6 Summary

- IASI SSTs from PPF v6 continue to be of good quality compared to drifting buoys and AVHRR SSTs.
- Both Metop-A and Metop-B IASI SSTs have similar cool biases, with the highest quality results having a cool bias of –0.09 K for Metop-A and –0.08 K for Metop-B.
- The overall global standard deviation of uncertainty for IASI SST is 0.27 K (0.29 K), for AVHRR SST is 0.18 K (0.20 K), and for drifting buoy SST is 0.20 K (0.20 K) for both Metop-A and Metop-B.
- Some larger differences are observed in some regional areas: aerosol regions, regions of high spatial SST variation, and tropical regions (diurnal warming).
- Bias and standard deviation values for the GHRSST SSES look-up tables are presented, with almost six months of v6 data analysed.
6.1.7 SST assessment with ECMWF model analyses

6.1.7.1 Metop-B

Figure 230: Map of the mean differences between IASI-B L2 and ECMWF ANA sea surface temperature for the period 25/04/2014 to 13/08/2014 for OEM retrievals during day only
Figure 231: IASI-B Map of the mean differences between IASI-B L2 and ECMWF ANA sea surface temperature for the period 25/04/2014 to 13/08/2014 for OEM retrievals for night pixels only.
Figure 232: Histograms of the differences between IASI-B L2 and ECMWF ANA sea surface temperature for the period 27/06/2014 to 13/08/2014 in FLG_CLDNES class 1 (left) to 4 (right). Legend: black is v5, red is v6_OEM, blue is v6_PWLR.
6.1.7.2 Metop-A

Figure 233: Map of the mean differences between IASI-A L2 and ECMWF ANA sea surface temperature for the period 25/04/2014 to 13/08/2014 for OEM retrievals during day only.
Figure 234: IASI-A. Map of the mean departure between IASI-A L2 and ECMWF ANA sea surface temperature during the period 25/04/2014 to 13/08/2014 for OEM retrievals for night pixels only.
Figure 235: Histograms of the departures between IASI-A L2 and ECMWF ANA sea surface temperature during the period 27/06/2014 to 13/08/201 in FLG_CLDNS class 1 (left) to 4 (right). Legend: black: v5, red: v6_OEM, blue: v6_PWLR.
6.1.8 Conclusions and future work on SST

This report presents validation results with buoys from the PWLR IASI SST (SST_IASI) over the period July 2013 to December 2013 for version 6 of the IASI operational processor. A new SSES scheme is presented, based on PWLR, using the uncertainty information for SST_IASI. The SST field for version 6 will be that derived using 1D-VAR. The amount of 1D-VAR SST data from version 6 collocated to in situ measurements is increasing through the off-line monitoring. An update of the SSES based on at least 6 months of systematic products analysis is planned by Q4-2014. The results already show that the new retrieval for the SST_IASI continues to give good quality SST observations, as previously shown for version 5.

Future work is planned to examine in more detail the cool bias observed on the IASI SSTSs, and to look at a retrieval particular for sea surface temperatures, including improved use of the training dataset on the PWLR retrieval. In addition, the inclusion of the Q_SST_IASI field to the IASI L2Pcore product will be considered for inclusion as an ‘experimental field’ allowed by the GDS2 specification.

Although not as accurate as the in situ buoys, the comparison of IASI v6 SST with ECMWF analyses SST from April to August 2014 shows a significant improvement in the yield and confirms the accuracy of this upgraded product as compared to v5.

6.2 Land Surface Temperature

6.2.1 Evaluation with Land-SAF LST products from SEVIRI

The Land Surface Analysis Satellite Application Facility (LSA SAF) generates an operational Land Surface Temperature (LST) product based on the Spinning Enhanced Visible and Infrared Imager (SEVIRI) measurements acquired from the Meteosat Second Generation (MSG) satellites. The retrieved physical parameter is the radiative skin temperature over land and is available under clear sky conditions only. Derived from thermal infrared measurements, it is directly comparable to the IASI LST. Its computation involves a generic split window (GSW) algorithm described in [RD 3] with two adjacent window channels—IR10.8 μm and IR12.0 μm—to correct for the atmospheric absorption. The spatial resolution is approximately 3 km at the sub-satellite point, equal to that of the SEVIRI images in a nominal mode. Coverage includes all of Europe and Africa, along with a portion of South America. See Figure 236.
The periodicity of these products is 15 minutes, which allows a very close temporal coincidence with the successive Metop overpasses and their associated IASI LST retrievals. Each LSA LST comes with a quality flag [RD 5] that indicates the degree of confidence and the error associated with the retrieval. For this study, we only kept the products with “above nominal” and nominal” quality for both the LST and surface emissivity parameters. This corresponds to uncertainties of less than 1 K and between 1 K and 2 K. See [RD 4] and the following web site:

http://landsaf.meteo.pt/

Differences (LSA SAF minus IASI) are computed for each match-up where at least four good LSA LST retrievals can be found within the IASI field of view. The matching SEVIRI points are averaged and only used if their standard deviations remain lower than 5 K; this avoids scenes that are too heterogeneous. The intercomparisons are performed for cloud-free IFOVs only, as identified with the flag IASI (FLG_CLDNES = 1 or 2) and SEVIRI, and for daytime and nighttimes separately. Indeed, some differences are expected due to shadow effects coming from the relative Metop/MSG to Sun to Surface viewing and illumination geometry. The latter explains the angular variation of the SEVIRI-IASI LST with IASI scan angle as reported at daytime in Figure 238 and Figure 239, as IASI observes more shadows at the beginning than at the end of the swath, on average. The statistics are computed globally with the exclusion of the Sahara, where satellite LST retrievals usually present very large differences, especially during daytime. The African Sahara and the Arabian Peninsula, presenting specific bare soil types, are therefore isolated and the statistics repeated
separately. It can be noted here too that the OEM is generally not attempted over the Sahara because of excessive OBS-CALC differences before the first iteration, especially in the spectral window regions. This is because the surface emissivity comes from static atlases and may be inaccurately describing the real consistency of these soils, because the surface emissivity is a fixed-state vector parameter in the OEM. Therefore the retrievals of atmospheric profiles and surface parameters in this region come solely from the statistical method PWLR. The specific assessment of the LST retrieved with the statistical method (first guess) in these circumstances will form part of forthcoming validation report updates, which will be for both pre-operational and operational release.

Figure 237: Comparison of LSA-SAF (SEVIRI) and IASI L2 LST mean differences (top left) and standard deviation (top right) for the period 28/03/2014 to 09/04/2014 at night time (left panel) and daytime (right panel) for Metop-B.
Figure 238: LSA-SAF(SEVIRI) and IASI LST products correlation (a), variations of the differences with latitude (b) and scan angle (c), their departures distributions (d) and at night time and day times (left and right panels, respectively) and for Metop-B in the period 28/03/2014 to 09/04/2014, Sahara excluded.

Figure 239: LSA-SAF(SEVIRI) and IASI LST products correlation (a), variations of the differences with latitude (b) and scan angle (c), their departures distributions (d) and at night- and daytime (left and right panels, respectively) and for Metop-B in the period 28/03/2014 to 09/04/2014 for Sahara only.
6.2.2 Validation against surface temperature ground based measurements

This will be done as part of long-term monitoring and validation.

6.3 Land Surface emissivity

The surface emissivity retrieval is performed with the same algorithm as in v5, this being the linear regression in the EOF radiance and emissivity domains as designed by Dan Zhou (NASA). In v6, the underlying training base was updated with latest surface emissivity spectra and fixes an ongoing issue with silicate signatures in the Antarctica. In the section that follows, we present qualitative comparisons of v5 and v6 emissivity maps. The final validation of such products is still subject to further study and product development.
Figure 240: IASI-B L2 land surface emissivity 765.5 cm⁻¹ for PPF v6 (left) and PPF v5 (right) for daylight (upper panel) and night (lower panel) for the period 04/04/2014 to 21/04/2014.
Figure 241: IASI-B L2 land surface emissivity 900 cm$^{-1}$ for PPF v6 (left) and PPF v5 (right) for daylight (upper panel) and night (lower panel) during the period 04/04/2014 to 21/04/2014.
Figure 242: IASI-B L2 land surface emissivity 991 cm$^{-1}$ for PPF v6 (left) and PPF v5 (right) for daylight (upper panel) and night (lower panel) during the period 04/04/2014 to 21/04/2014.
Figure 243: IASI-B L2 land surface emissivity 1071.25 cm⁻¹ for PPF v6 (left) and PPF v5 (right) for daylight (upper panel) and night (lower panel) during the period 04/04/2014 to 21/04/2014.
Figure 244: IASI-B L2 land surface emissivity 1160.25 cm$^{-1}$ for PPF v6 (left) and PPF v5 (right) for daylight (upper panel) and night (lower panel) during the period 04/04/2014 to 21/04/2014.
Figure 245: IASI-B L2 land surface emissivity 1228 cm\(^{-1}\) for PPF v6 (left) and PPF v5 (right) for daylight (upper panel) and night (lower panel) during the period 04/04/2014 to 21/04/2014.
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7 CLOUD PRODUCTS

7.1 Cloud detection

The cloud detection involves three independent methods:

- the NWP test, based on Numerical Weather Predictions
- the AVHRR test, based on the Advanced Very High Resolution Radiometer, the imager on board Metop
- the ANN test, based on Artificial Neural Networks processing IASI and collocated AVHRR measurements

Their descriptions and the individual performance assessments are detailed in [RD 1] and [RD 2].

Those tests have already been implemented in the version 5 of the IASI L2 PPF with the difference that the ANN test was only used for monitoring and did not contribute the operational cloud mask. The information coming from this cloud test is directly used to infer the cloudiness in v6. A second innovation is in the way those concurrent tests are used in synergy. In v5, the strategy was very conservative. An IFOV was declared cloud-free only if all tests agreed on this. If the three cloud tests give contradicting results in v6, a cloud is suspected and its properties (cloud fraction and top temperature) are tentatively retrieved with the CO₂-slicing and Chi² methods. See [RD 16]. If no firm clouds can be characterised, then the scene is considered potentially to be free of clouds and the clear-sky retrievals as in OEM apply. The validation of the additional cloud was performed and documented already in [RD 17]. In this section, we are present examples of the resulting cloudiness classification.
7.2 Cloudiness classification

Figure 252: IASI-B L2 cloudiness classification (FLG_CLDNES) for day (top) and night (night) during the period 04/04/2014 to 21/04/2014.
Figure 253: Metop-A IASI-A cloudiness classification (FLG_CLDNES) for day (top) and night (night) for the period 04/04/2014 to 21/04/2014.
7.3 Cloud fraction

The cloud parameters are retrieved in v6 with the same algorithms as in v5. However, their configurations vary slightly by the surface emissivity used as input to the radiative transfer model. The validation of the v6 cloud products is therefore done by verification of their consistency with the v5 products. Please refer to the cloud products validation reports for more detailed figures and comparisons to external references, see documents [RD 8], [RD 18], and [RD 19].

![Cloud fraction distribution graphs](image)

*Figure 254: Distributions of the global differences between v6 and v5 IASI L2 cloud fraction for the period 04/04/2014 to 21/04/2014.*
Figure 255: Map of the mean differences between v6 and v5 IASI L2 cloud fraction for the period 04/04/2014 to 21/04/2014.

Figure 256: Map of the differences standard deviation between v6 and v5 IASI L2 cloud fraction for the period 04/04/2014 to 21/04/2014.
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Figure 257: Distributions of the global differences between v6 and v5 IASI L2 cloud top pressure for the period 04/04/2014 to 21/04/2014.
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Figure 261: Map of the mean differences between v6 and v5 IASI L2 cloud top temperature for the period 04/04/2014 to 21/04/2014.

Figure 262: Map of the differences standard deviation between v6 and v5 IASI L2 cloud-top temperature for the period 04/04/2014 to 21/04/2014.
8 ATMOSPHERIC COMPOSITION PRODUCTS

8.1 CO profiles

Another major innovation with the IASI L2 PPF v6 is the retrieval of CO profiles and the provision of their averaging kernels. Previous product releases retrieved only the total column CO. The CO product is generated with the FORLI-CO algorithm, developed at ULB/LATMOS [RD 24], which has been delivered by the O3M-SAF as part of the CDOP-2 activities and integrated into the IASI L2 processor v6 for operation in the central application facility.

A number of verifications were made which confirmed that the integration of FORLI-CO in the overall IASI L2 processor operated at EUMETSAT matches the stand-alone implementation at ULB/LATMOS. Since the retrieval software is delivered as a library, most of the verification focused on feeding the two implementations with the exact same inputs and analysing the consistency of the respective outputs. The two implementations returned the exact same results, within the numerical precisions of the machines, for almost all pixels processed. In very few exceptions—the occurrence rate is a fraction of a percent—the differences are measurable but still small, leading to differences in CO total column below 2%, which is well below the retrieval error for this parameter, which is typically 10% to 15%.

The CO product developed at ULB/LATMOS has a long record and had been evaluated in a number of studies [RD 25], [RD 26], [RD 27]. This product was routinely monitored and assimilated at ECMWF in MACC [RD 29], [RD 30]. Further validation and qualification of its integration in the IASI L2 PPF is being carried out by the O3M-SAF with on-going reviews and will be documented in separate reports.

8.2 O3 profiles and total column

It is planned in the near future to integrate the FORLI-O3 products in the IASI L2 processor, as part of the CDOP-2. This will include comprehensive validation work and documentation. The evaluation of the interim IASI L2 O3 products is therefore limited to verifying the spatial coherence and performing qualitative comparisons to external total column fields from models assimilating GOME-2 products, namely part of the TEMIS project. See the website:

www.temis.nl

In Figure 263 and Figure 264, maps of IASI O3 total column (TC) products are shown for 15/09/2014. These combine IASI-A and IASI-B products for the morning and afternoon overpasses separately. The TEMIS field shows the modelled O3TC at 12:00UTC that day, resulting from the assimilation of Metop-B/GOME-2 products.
Figure 263: Maps of the $O_3$ total column on 15/09/2014 from IASI-A and -B L2 v6. Top panel shows nighttime overpass. The bottom shows daytime overpass. From TEMIS, the middle panel shows model at 12 UTC.
8.3 $\mathrm{N}_2\mathrm{O}$, $\mathrm{CH}_4$, $\mathrm{CO}_2$

These green-house trace gas products have been experimental products in v5 and remain so in v6, where the exact same algorithms and configurations are implemented. New developments toward upgraded operational products are ongoing for $\mathrm{CH}_4$. Retrievals of $\mathrm{N}_2\mathrm{O}$ and $\mathrm{CO}_2$ from IASI are in general still in the research and development stage. Therefore, these products are not specifically evaluated further in the context of the v6 release.
9 SUMMARY, OUTLOOK AND RECOMMENDATION

The Level 2 products routinely generated on GS3 and then GS2 with the IASI measurements from Metop-A and -B have been undergoing an extended series of assessments with data starting in January 2014. The core objective is to characterise improvements with the IASI L2 processor version 6 as compared to the version 5. This is for instance established by assessment and routine monitoring against ECMWF model data and in-situ measurements (NOAA NPROVs) for temperature and water vapour sounding. The absolute characterisation of the IASI L2 products accuracy and precision is a continuous activity. Some most recent selected results are reported and discussed in this document, including ground-based and in situ independent measurements of SST (buoys), of the total column water vapour (GPS-RO, microwave radiometers, sondes) and of temperature and water vapour profiles (sondes, COSMIC and GRAS).

The visual inspection of daily products confirms the good qualitative spatial coherence of the large-scale atmospheric structures like for instance the cloud formations, temperature fields or humidity patterns etc. The atmospheric structures derived from IASI agree well with other satellite products or numerical models.

Quantitatively, no evidences of systematic interpixel differences have been found with this v6 release. The quantities retrieved in each individual field of view agree with each other in mean and standard deviation over the studied period. However, for the SST, the retrieval accuracy of the first guess shows slight variations at very large viewing angle. These are likely retrieval artefacts and are currently under investigations. More work to confirm the consistency of other retrieved parameters with the viewing angle will be performed for the next validation reviews (pre-operational and operational). The consistency of IASI-A and IASI-B L2 products is also confirmed in the many studies performed and documented here, as in the University of Wisconsin and ECMWF models.

The IASI L2 products have been compared to external reference data of different types: numerical models, external satellite products and in-situ measurements. The retrieved temperature profiles in clear sky agree for instance with the ECMWF analyses and forecasts to less than 1 K not only in the mid in upper troposphere, as was the case with v5, but also now in the upper and lower parts. The bias is significantly reduced to below 0.2 K on average. Larger discrepancies are still observed toward the surface and especially over land, where however the accuracy of the numerical model itself can be discussed.

It is important to recall too here, that the cloud classification of v6 increases the yield of OEM (with IASI measurements only) retrieved pixels by nearly a factor two in comparison to v5, with same or better overall performances. The use of microwave measurements in synergy with the infrared in v6 allows nearly all-sky retrievals with statistical methods, namely the PWLR. The accuracy and precision of these products, distributed in addition to the clear-sky OEM, prove very robust to cloud contamination, with constant statistics for temperature: of the order of 1 K standard deviation between 300 hPa and 800 hPa over oceans and biases below 0.1 K in general. The yield with this method reaches 95%.

The precision of humidity retrievals improves by nearly a factor two in the boundary layer as compared to the version 5 products. The standard deviation of differences with sondes and ECMWF fields is usually below 1 g/kg in temperate latitudes to 1.5 g/kg in the tropics or between 10 % and 15% in relative humidity. The version 6 fixes the problem of accuracy in v5 humidity products.
Biases as assessed against ECMWF analyses and forecasts fields are now well below 0.3 g/kg or 4% relative humidity on average, for both OEM (clear-sky) and PWLR (nearly all-sky) products. These numbers are verified against sonde in-situ measurements and ground-based retrievals using GPS-RO, LIDAR and micro-wave radiometer instruments. The total column water vapour retrieved with the PWLR seems to be underestimating the most humid atmospheres, which originates in dry biases of the retrieved profiles in the boundary layer with extremely moist atmospheres. The root cause is still under investigation and further work will be needed to verify if this affects the OEM clear-sky products too. However, the retrieval of dry and mean water vapour profiles is free of this bias issue.

The retrievals in IR-mode, i.e. in the absence of microwave information, are characterised with IASI-A products during the MHS failure. It is found that the accuracy and precision in clear-sky (FLG_CLDINES classes 1 and 2) of the IR-only version 6 improves as compared to the v5 and are comparable to the results for v6 using microwave and infrared information (MW+IR). As expected, the IR-mode show poorer performances in partly cloudy situations (FLG_CLDINES = 3) as compared to the MW+IR mode and is of a very degraded quality in overcast situations (FLG_CLDINES = 4), where there use is not recommended. We can point out that the characteristics of the IASI-A L2 products after MHS recovery are similar to the characteristics of the IASI-B L2 products.

The sea and land surface temperature show improvements in v6 as compared to v5. The bias is improved by 0.15 K to 0.2K in v6 for SST with a constant precision of 0.3 K to 0.4 K. The accuracy and precision seems having improved too for LST in v6. The agreement with the SEVIRI LSA-LST products has dropped down to 0.5 K in bias and 1.5 K standard deviation at daytime and even below 1 K at nighttime.

The overall quality of the IASI L2 v6 parameters is reflected also in the radiance domain, where observations can be much better reproduced with v6 than with v5. IASI L2 v6 also better fits the observations than numerical weather predictions and in some spectral areas than the numerical weather analyses. Longer periods will be required for analysing the stability of the IASI L2 v6 products over time and characterising any potential inter-annual trend or seasonal variations.

Another innovation with v6 is the provision of the full retrieval error estimate (OEM) and of quality indicators (PWLR) together with the retrievals, for better use of the products in further scientific applications and for validation. The application of the averaging kernels to ECMWF profiles before inter-comparison with IASI L2 is removing the smoothing error from the uncertainty budget and brings the differences to about 0.5 K in standard deviation for temperatures throughout the vertical profiles and 0.5 g/kg for humidity in the boundary layers, which is consistent with the expected theoretical retrieval errors.

It is not discussed in this report, but the IASI L2 PPF v6 also includes a state-of-the-art CO profile retrieval, namely FORLI-CO, which had been successfully tested in assimilations in MACC. The FORLI-CO products are generated in the Central Application Facility with the IASI L2 processor. They will follow an independent validation cycle coordinated with the O3M-SAF as part of the CDOP-2 activities. The integration of these products has been verified and they can already be disseminated for testing at MACC and by other IASI CO users. Also part of CDOP-2, it is planned to integrate the FORLI-O3 in the operational processor. Meanwhile an interim O3 product is maintained, retrieved simultaneously with the temperature and humidity profiles.
To concluded this assessment, we find that the IASI L2 v6 products are a significant improvement over the v5 products, especially for humidity and temperature in the boundary layers. In areas where the v5 products were already of high quality, like in the mid troposphere and upper troposphere for temperature as well as for surface temperatures on both land and sea, we find that v6 preserves the precision and further improves their accuracy in some places. The IASI L2 v6 processor generates sounding products meeting the requirements expressed in the EPS EURD [AD 2]. It is therefore recommended to proceed with the operational release of the IASI L2 v6 and with the routine dissemination of the IASI L2 v6 products in replacement of the v5. The L2PCore SSES shall be configured with the statistics reported in 6.1.5. The following table summarises the recommended products status.

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<tr>
<th>Parameter</th>
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<th>Status</th>
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<td>Operational</td>
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<tr>
<td>Cloud fraction &amp; height</td>
<td>CO₂-slicing, Chi²</td>
<td>Operational</td>
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<tr>
<td>Cloud phase</td>
<td>BT difference</td>
<td>Demonstrational</td>
</tr>
<tr>
<td>T profiles</td>
<td>OEM (clear-sky)</td>
<td>Operational</td>
</tr>
<tr>
<td>q profiles</td>
<td>OEM (clear-sky)</td>
<td>Operational</td>
</tr>
<tr>
<td>O₃ profiles</td>
<td>OEM (clear-sky)</td>
<td>Pre-Operational</td>
</tr>
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<td>SST / LST</td>
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<td>T profiles</td>
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