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QUALITY ASSESSMENT OF IASI TOTAL COLUMN AMOUNTS (VERSION 6) THROUGH EUBREWNET

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ACRONYMS

Term	Definition
asl	above sea level
AVK	Averaging Kernel Matrix
DOFs	Degrees of Freedom of the Signal
DU	Dobson Units
EPS	EUMETSAT Polar System
Eubrewnet	European Brewer Network
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GAW	Global Atmosphere Watch
IASI	Infrared Atmospheric Sounding Interferometer
ISSWG	IASI Sounding Science Working Group
IZO	Izaña Atmospheric Observatory
NDACC	Network for the Detection of Atmospheric Composition Change
OEM	Optimal Estimation Method
PWLR	Piece-Wise Linear Regression
RD	Relative Differences
STDV	Standard Deviation
STSM	Short-Term Scientific Missions
SZA	Solar Zenith Angle
TOC	Total Ozone Column
WMO	World Meteorological Organization

1 PURPOSE OF THE STMS

Earth observation data sets are fundamental for investigating the processes driving climate change and thus for supporting decisions on climate change mitigation strategies. Atmospheric remote sounding from space is an essential component of this observational strategy, since it allows for a global coverage. Among the existing thermal infrared space-borne instruments devoted to atmospheric remote sensing, IASI has a special status as it combines the meteorology requirements to weather forecasting (high spatial coverage and a relatively good temporal resolution) and the atmospheric chemistry needs (high spectral resolution thereby allowing for trace gases retrievals). This advanced instrument, based on a Fourier Transform Infrared Spectrometer (Blumstein et al., 2004), combines an excellent horizontal resolution (nadir pixel size of 12 km), a very good signal to noise ratio, with a high spectral resolution (0.5 cm^{-1} between 645 and 2760 cm^{-1}) and a global coverage twice per day. Currently, there are two IASI sensors in orbit operating from the Metop meteorological polar satellites (Metop-A and Metop-B launched in October 2006 and September 2012, respectively) in the framework of EUMETSAT (European Organization for the Exploitation of Meteorological Satellites) Polar System (EPS). Since 2007, IASI provides operational data and its mission is guaranteed until 2020 through the launch of Metop-C in 2018. All these features are very promising for observing highly variable tropospheric gases (e.g., water vapour) or more uniform but less abundant gases (e.g., ozone) with good precision and consistently during many years.

IASI was designed to retrieve operational meteorological sounding (humidity and temperature) with high vertical resolution and accuracy, but also for monitoring atmospheric composition. Among other trace gases, ozone global distributions (total columns, TOC, and vertical profiles) are systematically retrieved from IASI Level 1 radiances and operatively distributed as one of the IASI Level 2 trace gas products by the EUMETSAT Data Centre (www.eumetsat.int/website/home/Data/DataDelivery). For this purpose, since 2007 different approaches have been used: a fast artificial neural network approach from 2007 to 2010 (so-called Version 4, V4, Turquety et al., 2004), and an optimal estimation method, OEM, from 2010 and 2014 (so-called Version 5, V5, August et al., 2012). Recently, the latter has been refined providing the current operational IASI ozone products from 2014 onwards (so-called Version 6, V6, ISSWG, 2014): a statistical vertical profile retrieval referred to PWLR for piece-wise linear regression, and total columns and vertical profiles from OEM. Within V6, diagnostic variables allowing accurate comparison with other data are also provided, such us the full retrieval error estimates, from which the IASI vertical sensitivity (averaging kernel matrices) can be derived.

However, for a correct scientific interpretation of the space-based observational records a continuous documentation of their quality is required. An optimal method is a continuous inter-comparison of the space-based observations to high quality reference observations taken at the Earth's surface, as those recorded by Brewer spectrometers. This technique derives TOC amounts from direct sun, zenith sky or focused moon observations at different wavelengths between 306.3 and 320.1 nm (Gao et al., 2001). It was demonstrated that the precision of this method can be as high as 0.15% (Scarnato et al., 2010), while its absolute accuracy can be further improved, for example, by a proper account of the temperature dependence of the ozone absorption coefficients and for the altitude of the ozone layer (Savastiouk et al., 2005). By using these high-quality TOC observations, the validation of different satellite-derived ozone measurements have successfully already been performed in the last years (Weber et al., 2005; Balis et al., 2007, 2008, 2009; Viatte et al., 2011; Fioletov et al., 2008; Antón et al., 2011; Boynard et al., 2009). These validation activities highlight the potential of Brewer ozone products as a reference for a comprehensive long-term validation of space-based products.

The main tasks of this STSM are to establish and develop a methodology for the operational validation of the IASI TOC products (V6) with ground-based spectrophotometers Brewer belonging to the European Brewer network. Special attention will be put on analyzing the instrumental errors from these measurement techniques as well as those parameters that could affect the comparison of the different datasets (different viewing geometry, different spectral regions used, IASI vertical sensitivity, …). Once the comparison methodology has been established, a comprehensive validation of IASI TOC using different Eubrewnet stations will be addressed for the period October, 2014 to October, 2015.

2 COMPARISON METHODOLOGY

2.1 VALIDATION STRATEGY

The quality assessment and validation methodology described in this work consists of: the characterization of satellite and reference data (including data description studies, collocation studies, and data matching between the difference data sources), the comparison of total ozone columns with ground-based reference data, and the derivation of quality indicators that allow users to evaluate the satellite data. This validation strategy is schematized as a flowchart in Figure 1.

Firstly, it is important to acquire satellite and ground-based reference instruments data from operational networks (NDACC, WMO, Eubrewnet, …) by choosing convenient spatial and temporal collocation criteria. Once the satellite data under validation and reference data are extracted, it is necessary to study data characteristics focusing on the analysis of the atmospheric state data such as distributions, the necessity of filtering measurements, and geographical and temporal coverage for the comparison between both datasets.
In the third place, research and reference total ozone data that obey the spatial and temporal criteria are filtered with the established criteria for each data source.

Next, data statistics are calculated to justify the spatial and temporal collocation criteria between satellite and ground-based coincidences. It is necessary to analyze the difference between both data sources from difference histograms and comparison statistics, such as the mean and the standard deviation of the difference time series, correlation coefficients, bias, etc. Comparison results can be showed as a function of several important parameters as: time, location, solar zenith angle (SZA), cloud fractional cover, and different temporal scales as hourly, daily, annual, etc. Also, it is required quality assessment studies based on the averaging kernel matrix (AVK) of retrieved IASI data for studying how the vertical sensitivity of the satellite data could affect the inter-comparison results.
Finally, user must analyze the obtained results for evaluating the quality assessment and the correct comparison of the satellite data.

In this work, we focus on the IASI TOC retrievals V6 as derived by IASI sensor on-board EUMETSAT/Metop-A as a demonstration and our reference data are ground-based Brewer observations that have been acquired from Eubrewnet network.

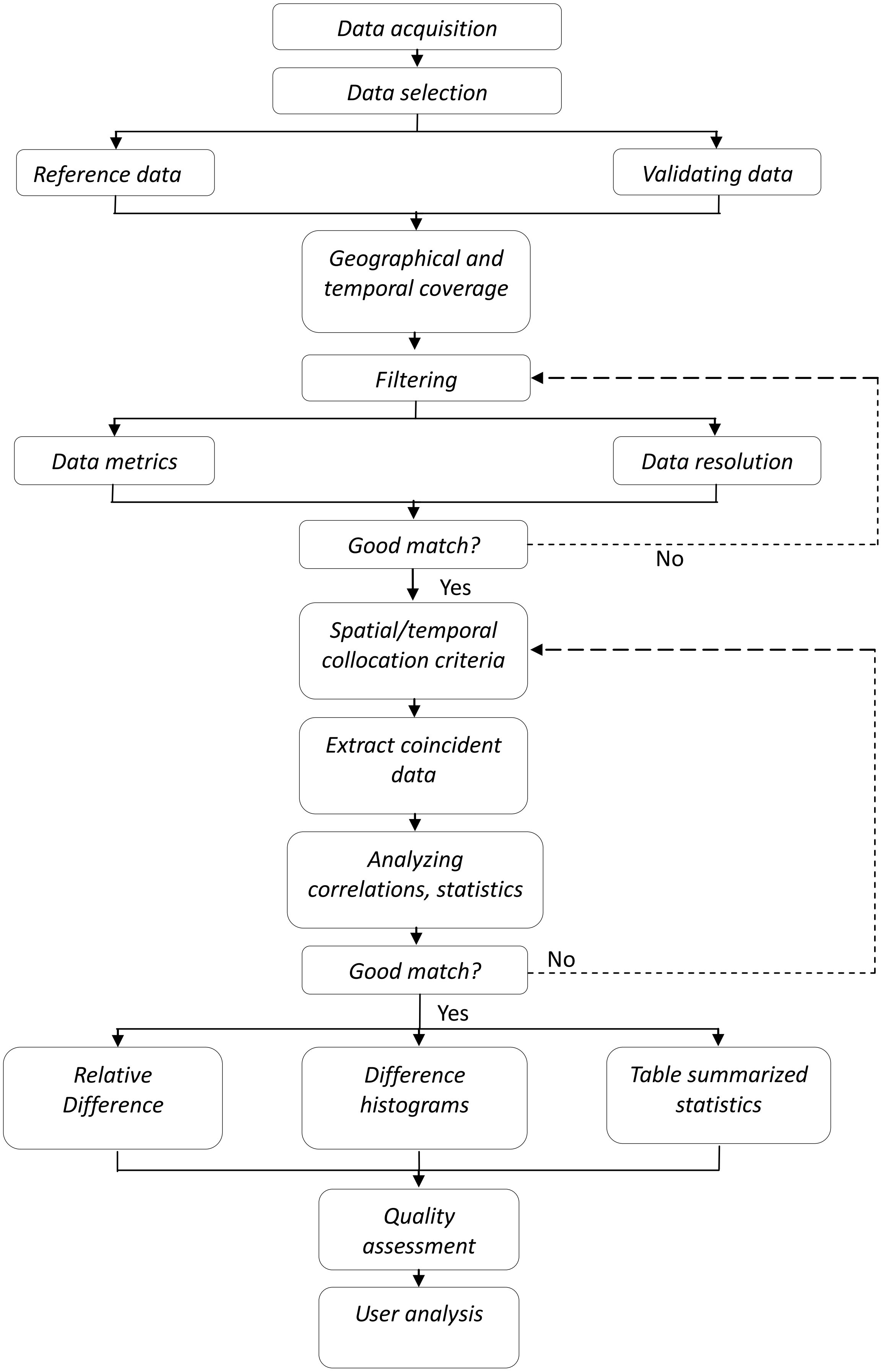

Figure 1 – Flowchart of the quality assessment and validation methodology.

2.2 STUDY AREA

Following the validation strategy described in the previous section and in order to analyze the possible impact of latitude or of different environments, such as urban-industrial or free troposphere, on the IASI products uncertainty, the ground-based stations were selected covering from sub-tropics to polar regions (Figure 2): Izaña Atmospheric Observatory (IZO, Spain), Thessaloniki (Greece), and Sodankylä (Finland).

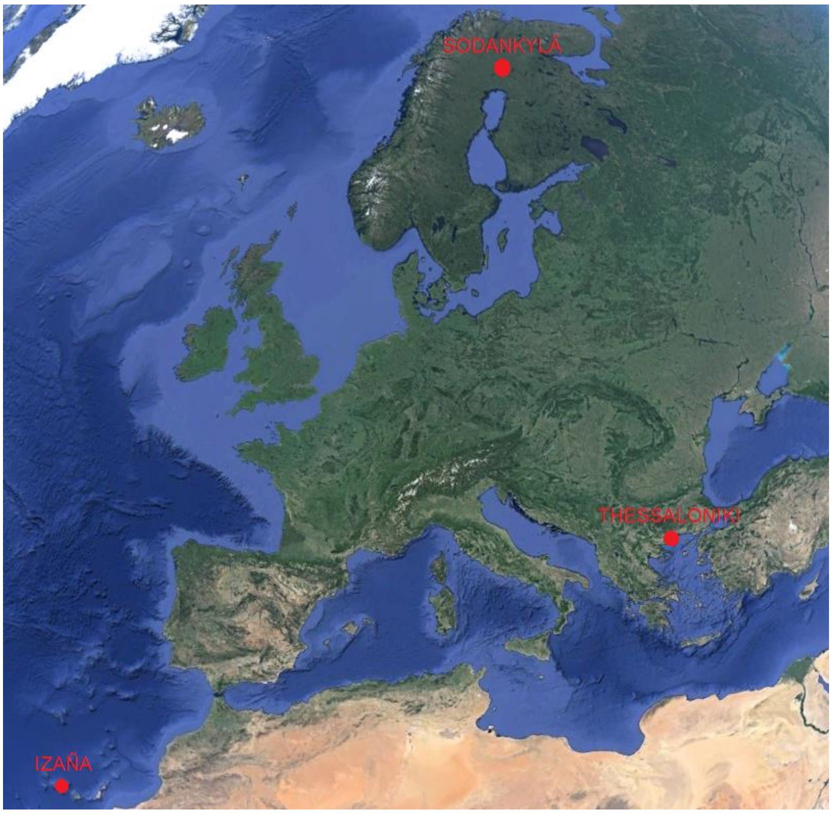

Figure 2 – Map with ground-based instrument stations.

- *Thessaloniki* is a mid-latitude station located in the North of Greece at 40.63º N, 22.96º E, 36 m a.s.l. The Brewer MK II #005 used in this work is being operated and regularly calibrated by the Laboratory of Atmospheric physics of the Aristotle University of Thessaloniki.
- *Izaña Atmospheric Observatory (IZO)* is a sub-tropical station located in the Canary Islands, on the island of Tenerife, Spain, at 28.31º N, 16.50º W, 2367 m a.s.l., run by the Izaña Atmospheric Research Center (IARC, www.izana.aemet.es)-State Agency of Meteorology of Spain (AEMET). Since 2003, IZO is the Regional Brewer Calibration Center for Europe (www.rbcc-e.org) of the World Meteorological Organization (WMO)-Global Atmosphere Watch (GAW) and the Brewer spectrophotometer MK III #185 used in this work is one of the RBCC's reference triad.
- *Sodankylä* observatory is a high-latitude station located in central Lapland, North of the Arctic Circle, Finland, at 67.42°N, 26.59°E, 180 m a.s.l. The Brewer spectrophotometer MK II #037 used in this work is operated by the Finnish Meteorological Institute (FMI) and it is part of the GAW station.

2.3 DATA, COLLOCATION CRITERIA AND IASI VERTICAL SENSITIVITY

The IASI TOC retrievals V6 as derived by IASI on-board Metop-A have been downloaded from EUMETSAT Data Centre (www.eumetsat.int/website/home/Data/DataDelivery), while the ground-based Brewer data Level 1 has been downloaded from Eubrewnet database (http://rbcce.aemet.es/dokuwiki/doku.php?id=start). Brewer data Level 1 are the O_3 recalculations with the standard algorithm from the Direct Sun measures and applying a verified by an operator set of constants. Some considerations:

- The calulations use Brewer Python Module who implement the Standard Algorithm (the BREWER MKIV SPECTROPHOTOMETER OPERATOR'S MANUAL (OM-BA-C231 REV B, August 15, 1999 [Appendix G]).
- Values for O3 and SO2 come from the calculation of the Standard Algorithmn using Raw Counts from the Direct Sun measures and the Temperature from the Direct Sun Summaries.
- with the exception of location of the measurement (Latitude, Longitude and Pressure) the configuration constants and values used in the process come from the Configurations uploaded and validated to the system by the Operators.
- Latitude, Longitude and Pressure are taken from the B inst section of the B file

The process:

- Get the DS and DS summaries measures of the day (coming from B file). If there are not available data, stop process.
- Get the last available configuration with date equal or earlier. If there is not an available configuration, stop process.
- Calulate the O_3 using the Brewer Python Module.
- Group the individual measures in groups of fives and calculate standard deviation.
- Store them into database.

The period analyzed in this work goes from October 1, 2014 to September 30, 2015. From this period, since Brewer instrument only measures during daytime (every 42 seconds), only morning IASI-A observations are considered in the comparison between IASI and Brewer.
As a previous quality control, the Brewer data has been filtered with the stabilized criteria for each data source (Kerr et. al., 1981), taking as wrong values the Brewer measurements with the following criteria:

a) SZA measured by Brewer < 75º
b) Standard deviation for last 5 TOC measurements < 1.5%
c) TOC < 100 DU
d) TOC > 600 DU

IASI-A observations have been filtered taking as wrong values the TOC measurements < 100 and > 600 DU. In addition, an analysis based on the possible presence of clouds on IASI pixels is presented. The fractional cloud cover is evaluated on IASI retrievals against thresholds and used to determine the category the IFOV falls under:

- Flag_CLDNESS=1 ⟶ IASI IFOV is clear
- Flag_CLDNESS=2 ⟶ IASI IFOV is processed as cloud-free but small cloud contamination possible
- Flag_CLDNESS=3 ⟶ IASI IFOV is partially covered by clouds
- Flag_CLDNESS=4 ⟶ High or full cloud coverage

To assess the impact of the collocation criteria on the IASI validation results, different spatial and temporal criteria have been evaluated. For the spatial collocation, we have taken 4 collocation distances: 150 km, 100 km, 50 km and 25 km, taking the closest coincidence between IASI-A and Brewer spectrometer. Regarding temporal collocation, we have paired the daily averages and those coincidences with 1, 2, 3, 4, 5 and 6 hour time difference between the measurements of the two sensors.

The IASI’s response to real atmospheric ozone variability strongly depends on its vertical sensitivity, thereby this information should also be taken into account in the inter-comparison analysis. The vertical structures that are detectable by the IASI remote sensor are given by the averaging kernel matrix (AVKs or A): the maximum sensitivity is given by the peak of the averaging kernels at a given altitude and the vertical resolution of the retrieved profiles can be evaluated through the full width at half maximum of the row averaging kernel (Rodgers, 2000). In addition, the trace of AVKs is an estimator of the number of independent layers contained in the measurements, known as the degrees of freedom for signal (DOFs). Figures 3, 4 and 5 show an example of the ozone row AVKs for typical measurement conditions at the three stations considered, the median of the sum along the row AVKS distinguishing for each season, and the DOFs time series for each station. These figures document that IASI is expected to be sensitive to the maximum O_3 concentrations in the stratosphere and to the upper troposphere/lower stratosphere regions, but with a weak sensitivity in the lower troposphere. Indeed, the median DOFs is 1.8, 1.9 and 1.5 for IZO, Thessaloniki and Sodankylä, respectively. The IASI sensitivity has a seasonal pattern, i.e., maximum DOFs values in spring and summer and minimum values in winter (see Figure 4 and 5 bottom and Table 1). This behavior is clearly observed at Thessaloniki and Sodankylä stations and it is likely due to the seasonal tropopause’s shift: IASI improves its vertical sensitivity when the altitude of tropopause reaches its annual maximum. Note also that the peak-to-peak amplitude of the DOFs annul cycle is more significant at the polar site than at the mid-latitude station. In contrast, at sub-tropical IZO station the IASI sensitivity does not so clearly depend on the time of year and the peak-to-peak of the DOFs annual cycle is almost null.

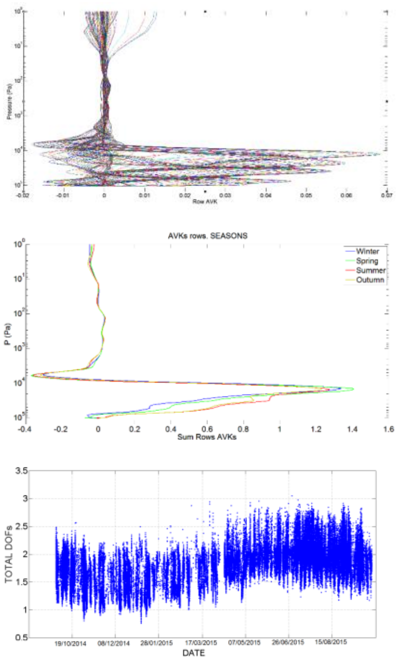

Figure 3 – Top: Row averaging kernels for O_3 profile observed by IASI-A for typical measurement conditions at Thessaloniki. Middle: Median of the sum of row averaging kernels for O_3 profile observed by IASI-A for each season at Thessaloniki. Bottom: Total DOFs time series observed by IASI-A at Thessaloniki.

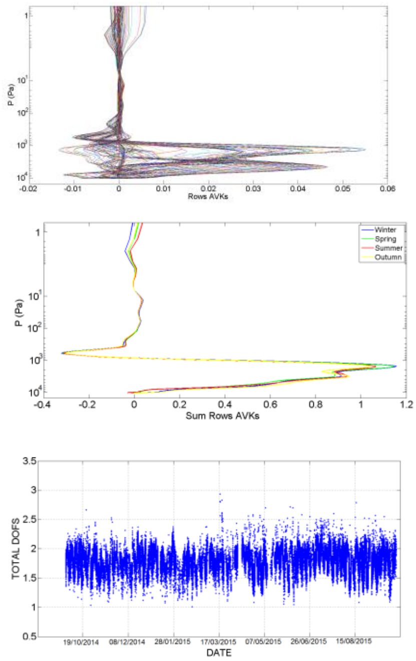

Figure 4 – Row averaging kernels for O_3 profile observed by IASI-A for typical measurement conditions at IZO. Middle: Median of the sum of row averaging kernels for O_3 profile observed by IASI-A for each season at IZO. Bottom: Total DOFs time series observed by IASI-A at IZO.

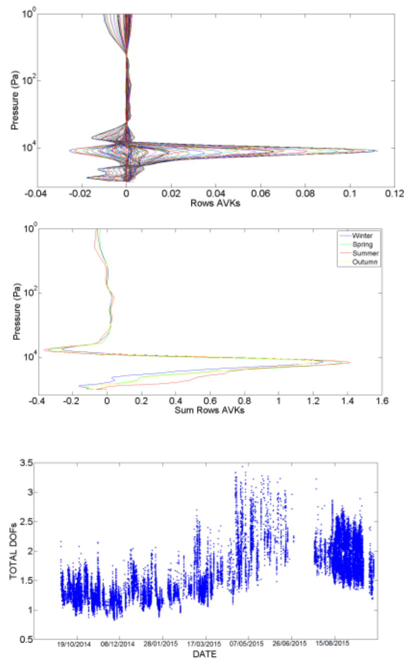

Figure 5 – Top: Row averaging kernels for O_3 profile observed by IASI-A for typical measurement conditions at Sodankylä. Middle: Median of the sum of row averaging kernels for O_3 profile observed by IASI-A for each season at Sodankylä. Bottom: Total DOFs time series observed by IASI-A at Sodankylä.

The table below summarizes the mean of the DOFs for each season at Thessaloniki, IZO, Sodankyä for the study period of time:

SEASON	Typical DOFs		
	THESSALONIKI	IZO	SODANKYLÄ
Winter	1,5	1,8	1,2
Autumn	1,7	1,8	1,3
Summer	2	1,8	2
Spring	1,8	1,7	1,5

Table 1 – Median of the DOFs for each season at Thessaloniki, IZO and Sodankylä.

2.4 METRICS

As statistic estimators for TOC inter-comparison the correlation between IASI-A and Brewer spectrophotometer (Pearson correlation coefficient) has been calculated as well as the mean and the standard deviation (STDV) of the relative differences (RD). The RD are calculated as:

$$RD_i(\%) = 100 \cdot \frac{(IASI_i - Brewer_i)}{Brewer_i} \qquad (1)$$

and the Mean and STDV as

$$\mathbf{Mean} = \frac{1}{N}\sum_{i=1}^{N}(RD_i) \qquad (2)$$

$$\mathbf{STDV} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[(RD]_i - Mean_i)^2} \qquad (3)$$

where N is the number of the coincident observations between IASI and Brewer spectrophotometer data.

The BIAS error has been calculated with the equation:

$$\mathbf{BIAS} = \frac{1}{N}\sum_{i=1}^{N}[(IASI]_i - Brewer_i) \qquad (4)$$

where N is the number of the coincident observations between IASI and Brewer spectrophotometer data. In addition, it has been calculated the observed ozone daily variability for spectrophotometer Brewer data, with the equation:

$$O_3\ \mathbf{Brewer\ variability}\ (\%) = 100 \cdot \frac{\mathbf{STDV\ Brewer_i}}{\mathbf{Mean\ Brewer_i}} \qquad (5)$$

where:

$$\mathbf{Mean\ Brewer_i} = \frac{1}{N}\sum_{i=1}^{N}(Brewer_i) \qquad (6)$$

$$\mathbf{STDV\ Brewer_i} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[(Brewer]_i - Mean_i)^2} \qquad (7)$$

3 RESULTS

The inter-comparison results for each station are presented separately on section 3.1, 3.2 and 3.3 for Thessaloniki, IZO, and Sodankyä, respectively.

3.1 THESSALONIKI

In the following we show the quality assessment performed for a maximum collocation distance between IASI-A and Brewer of 150 km, as example, in Thessaloniki since the results are very similar for all the spatial/temporal criteria tested, but distinguishing by the IASI-A cloudiness flag.

Figures 5, 6, 7, and 8 show the TOC time series as observed by IASI and Brewer and the comparison between both datasets for each flag cloudiness value. From October 1, 2014 to about June 16, 2015 there is much dispersion on data comparison than on later months. It is because on June 16, 2015 Brewer spectrophotometer from Thessaloniki was re-calibrated, whereby the agreement between both datasets significantly improves.

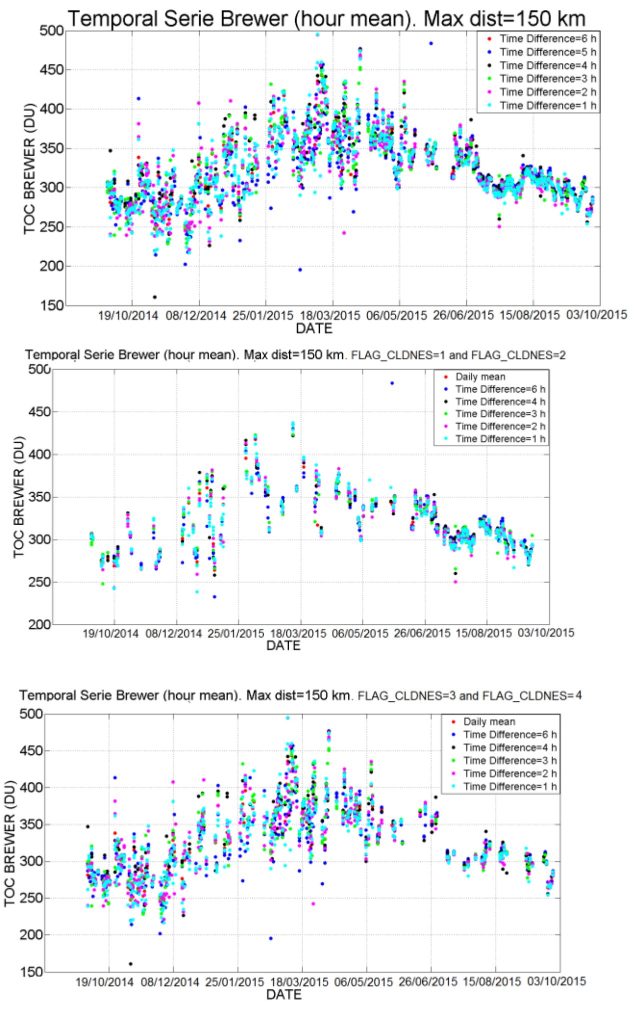

Figure 6 – Top: Time series for Brewer TOC measurements in Thessaloniki with a max collocation distance of 150 km for each studied time difference, with all IASI flag cloudiness (1= clear with high confidence, 2= presumably clear, 3= partly cloudy, 4= cloudy). Middle: Time series for Brewer TOC with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Time series for Brewer TOC with IASI flag cloudiness 3 and 4 at Thessaloniki.

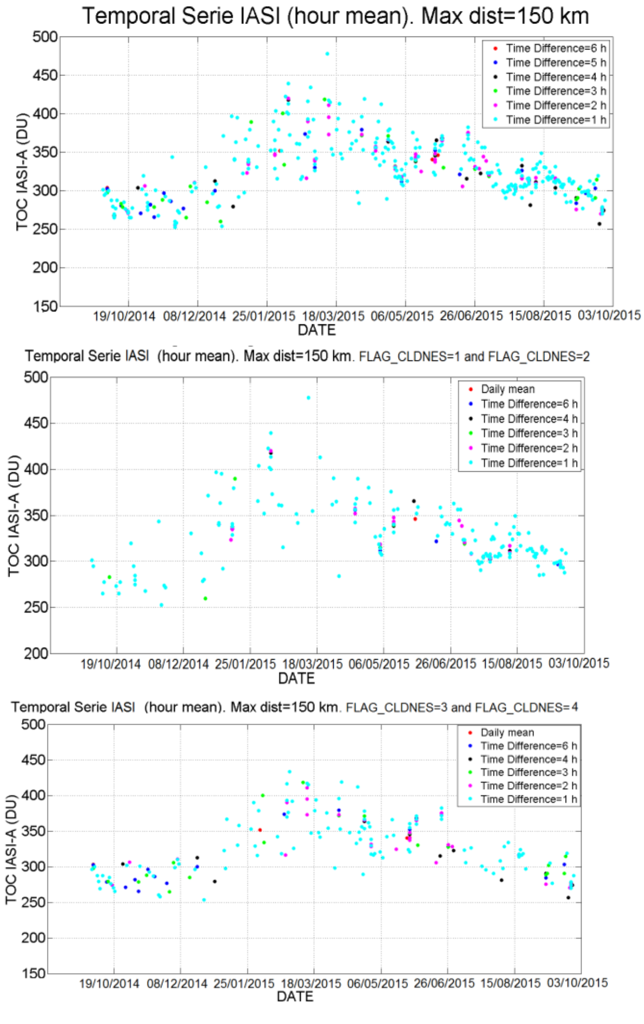

Figure 7 – Top: Time series for IASI-A TOC measurements with a max collocation distance of 150 km for each studied time difference with a max collocation distance of 150 km for each studied time difference, with all IASI flag cloudiness (1= clear with high confidence, 2= presumably clear, 3= partly cloudy, 4= cloudy) at Thessaloniki. Middle: Time series for IASI-A TOC measurements with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Time series for IASI-A TOC measurements with IASI flag cloudiness 3 and 4 at Thessaloniki.

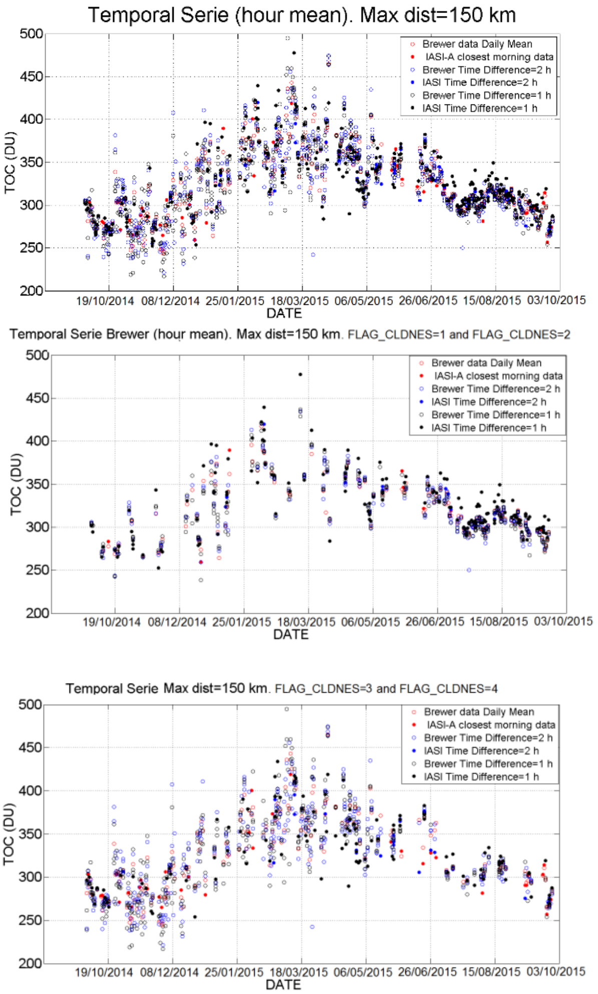

Figure 8 –Top: Time series for Brewer and IASI-A TOC measurements in Thessaloniki with a max collocation distance of 150 km for daily mean and for 1h and 2h time difference between both datasets, with all IASI flag cloudiness. Middle: Time series for Brewer and IASI-A TOC measurements with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Time series for Brewer and IASI-A TOC measurements with IASI flag cloudiness 3 and 4 at Thessaloniki.

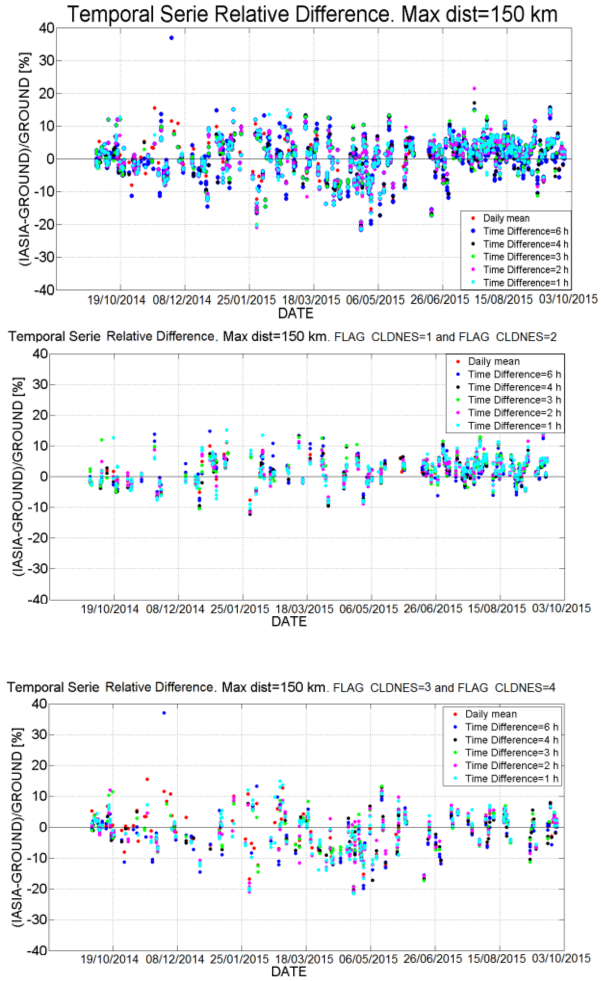

Figure 9 – Top: Time series of the relative difference between Brewer and IASI-A TOC measurements in Thessaloniki with a max collocation distance of 150 km for each studied time difference with all IASI flag cloudiness. Middle: Time series of RD between Brewer and IASI TOC with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Time series of RD between Brewer and IASI TOC with IASI flag cloudiness 3 and 4 at Thessaloniki.

On the next graphics it is shown the scatter plot of the coincident total ozone columns with the correlation coefficient and the number of coincidences between Brewer and IASI-A for the studied time period in Thessaloniki for a max collocation distance of 150 km. Also, it has been shown the relative difference between IASI-A and Brewer coincidences for each time difference versus the daily variability as observed by the Brewer spectrometer (Eq. 5), documenting that the IASI-A and Brewer differences do not depend on the observed variability. Also, it can be observed as inter-comparison results show a larger agreement for IASI-A retrievals filtering by cloudiness flag values of 1 and 2 (cloud-free scenes) than for all flag cloudiness values and for values of 3 or 4 (cloudy pixels). Note that the daily total ozone column variability is, on average, about 3.3%, slightly larger than at sub-tropics IZO station.

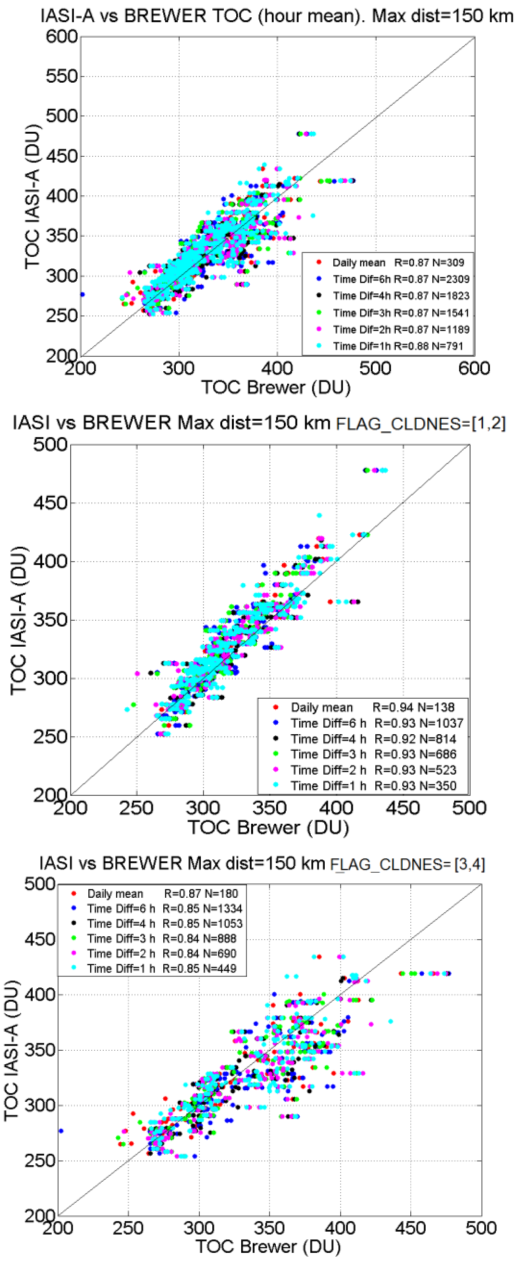

Figure 10 – Top: Scatter plot between IASI-A and Brewer TOC measurements for each time difference. On the legend it is shown the correlation coefficient and the number of coincidence between both datasets for each hourly mean. The solid black line corresponds to the diagonal (x=y) with all IASI flag cloudiness at Thessaloniki. Middle: Scatter plot between IASI-A and Brewer TOC measurements with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Scatter plot between IASI-A and Brewer TOC measurements with IASI flag cloudiness 3 and 4 at Thessaloniki.

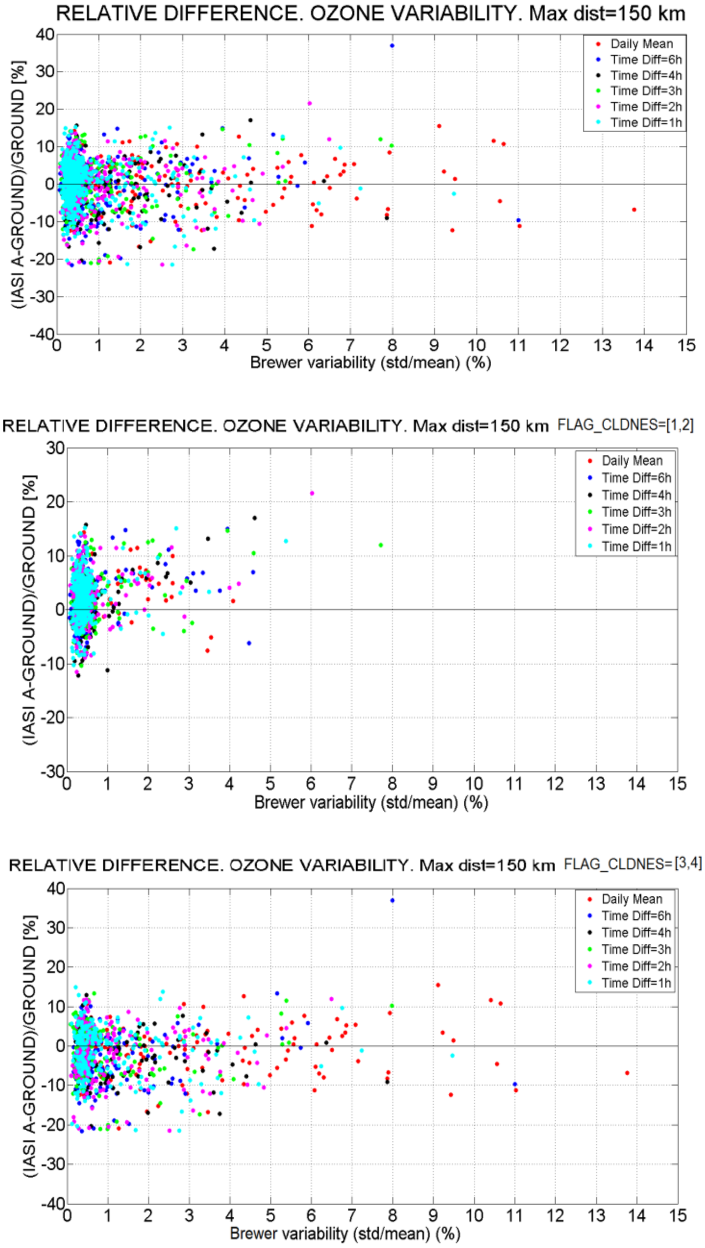

Figure 11 – Top: Brewer total ozone daily variability study for IASI-A and Brewer coincidences for each time difference in Thessaloniki for the period of time between October 1, 2014 and September 30, 2015 with all IASI flag cloudiness. Middle: Brewer total ozone daily variability study for IASI-A and Brewer coincidences with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Brewer total ozone daily variability study for IASI-A and Brewer coincidences with IASI flag cloudiness 3 and 4 at Thessaloniki.

On the next histograms, it is shown the daily relative and the absolute difference of Brewer and IASI-A coincidences for all the period of study:

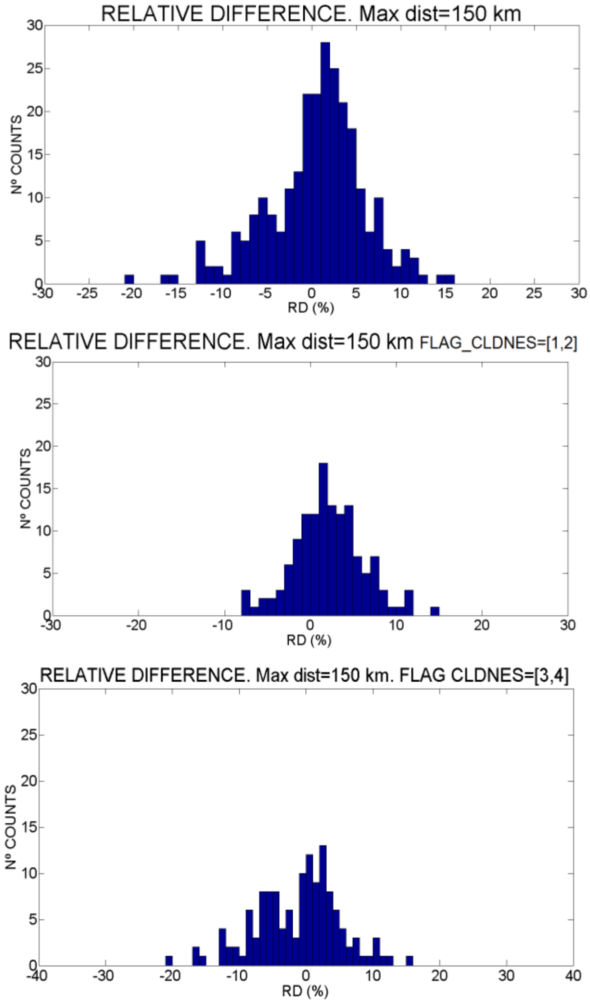

Figure 12 –Top: Daily relative difference of Brewer and IASI-A coincidences in Thessaloniki from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness values. Middle: Daily relative difference of Brewer and IASI-A coincidences with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Daily relative difference of Brewer and IASI-A coincidences with IASI flag cloudiness 3 and 4 at Thessaloniki.

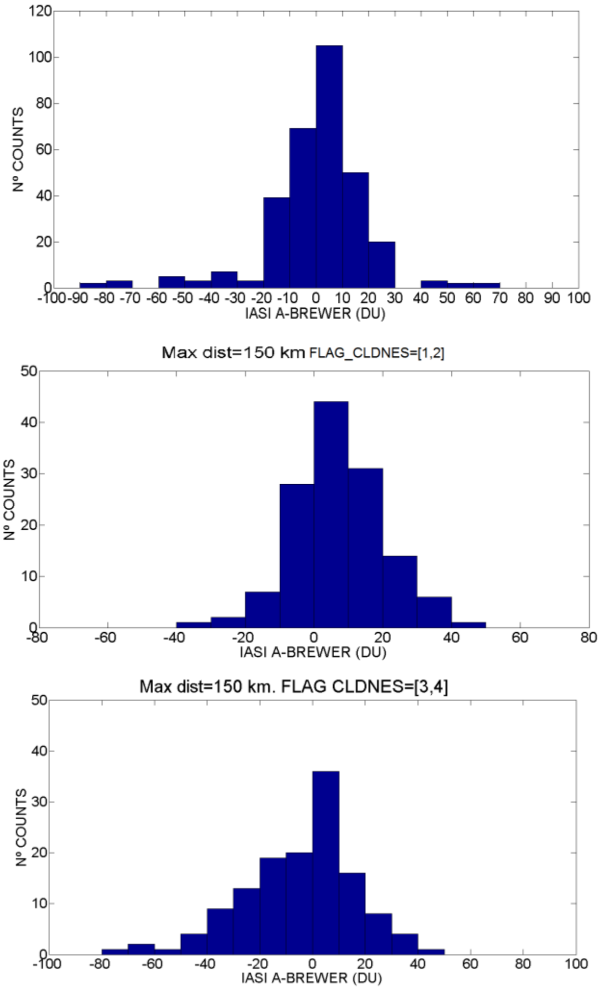

Figure 13 – Top: Daily absolute difference between Brewer and IASI-A total ozone measurements coincidences in Thessaloniki from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness values. Middle: Daily absolute difference between Brewer and IASI-A total ozone measurements coincidences with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Daily absolute difference between Brewer and IASI-A total ozone measurements coincidences with IASI flag cloudiness 3 and 4 at Thessaloniki.

The same results have been extracted for the rest of interest collocation distances: 100 km, 50 km and 25 km. The IASI-A and Brewer measurements have a high agreement with a high correlation coefficient and a low mean and standard deviation of RD, whatever the spatial and temporal criteria adopted, even it is taken the closest IASI-A measurement. The following tables (Table 2, 3, 4, and 5) summarize the calculated statistics for each collocation distance and for each time difference between both datasets, and highlight the similarity between the results. In addition and in order to analyze the effect of cloud presence on the inter-comparison results, it has been calculated the statistics for IASI-A and Brewer inter-comparison coincidences distinguishing by IASI cloudiness flag for the two extreme collocation distances: 150 and 50 km. It has been obtained very similar results independently the spatial and temporal criteria, but with a larger agreement for IASI-A observations with flag cloudiness values of 1 and 2 than for other cases.

Statistics for coincidences with IASI retrievals with all flg_cldness

150 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,88	40,1	0,6	5,5	1,1	309
6 h	0,87	44,6	0,5	5,6	0,7	2309
4 h	0,87	38,9	0,6	5,5	0,9	1823
3 h	0,87	39,0	0,6	5,6	1,0	1541
2 h	0,87	40,0	0,7	5,6	1,1	1189
1 h	0,88	40,3	0,8	5,5	1,5	791

Statistics for coincidences with IASI retrievals with flg_cldness=[1,2]

150 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,94	57,2	2,2	4,0	6,0	138
6 h	0,93	56,3	2,1	4,3	6,5	1037
4 h	0,92	50,5	2,1	4,3	6,6	814
3 h	0,93	48,8	2,2	4,3	6,8	686
2 h	0,93	44,6	2,2	4,3	6,7	523
1 h	0,93	45,9	2,3	4,3	6,8	350

Statistics for coincidences with IASI retrievals with flg_cldness=[3,4]

150 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,87	18,6	-1,2	6,4	-2,1	180
6 h	0,85	28,2	-2,1	6,6	-4,1	1334
4 h	0,85	25,2	-1,9	6,4	-3,8	1053
3 h	0,84	27,8	-1,8	6,5	-3,6	888
2 h	0,84	36,7	-1,8	6,6	-3,5	690
1 h	0,85	39,3	-1,4	6,4	-2,8	449

Table 2 – Top: Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 150 km in Thessaloniki. It is shown the Pearson Correlation Coefficient and the offset for each collocation time difference as well as the mean and standard deviation of the RD between IASI with all IASI flag cloudiness. Also it is shown the number of coincidences between two sensors, N. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

100 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,88	43,3	0,6	5,6	1,2	309
6 h	0,86	51,2	0,5	5,6	0,9	2533
4 h	0,87	42,6	0,6	5,6	1,0	1803
3 h	0,87	43,4	0,7	5,6	1,1	1517
2 h	0,87	44,2	0,7	5,6	1,2	1166
1 h	0,87	43,2	0,8	5,5	1,5	761

Table 3 – Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 100 km in Thessaloniki. The Pearson Correlation Coefficient and the offset for each collocation time difference as well as the mean and standard deviation of the RD between IASI-A is shown, with the number of coincidences between two sensors, N.

Statistics for coincidences with IASI retrievals with all flg_cldness

50 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,88	44,3	0,6	5,6	1,2	309
6 h	0,86	49,0	0,5	5,7	0,8	2289
4 h	0,87	43,1	0,7	5,6	1,1	1782
3 h	0,87	43,6	0,8	5,6	1,3	1498
2 h	0,88	44,0	0,8	5,5	1,4	1148
1 h	0,88	42,7	0,9	5,5	1,7	744

Statistics for coincidences with IASI retrievals with flg_cldness=[1,2]

50 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD(%)	BIAS (DU)	N
Daily mean	0,94	57,6	2,2	4,1	6,0	138
6 h	0,92	56,9	2,1	4,3	6,6	1033
4 h	0,92	50,8	2,2	4,4	6,7	805
3 h	0,93	49,4	2,3	4,3	6,9	673
2 h	0,93	45,5	2,2	4,2	6,7	510
1 h	0,93	46,2	2,3	4,3	6,8	335

Statistics for coincidences with IASI retrievals with flg_cldness=[3,4]

50 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,86	39,0	-1,0	6,5	-1,8	175
6 h	0,84	26,7	-1,9	6,8	-3,7	1283
4 h	0,85	35,7	-1,7	6,6	-3,3	995
3 h	0,84	38,7	-1,5	6,7	-2,9	8,39
2 h	0,85	45,6	-1,4	6,5	-2,6	647
1 h	0,85	44,4	-1,3	6,4	-2,4	412

Table 4 – Same as Table 1, but for max collocation distance of 50 km.

25 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,88	43,1	0,7	5,6	1,5	287
6 h	0,87	47,4	0,7	5,7	1,2	2133
4 h	0,87	41,3	0,8	5,6	1,4	1663
3 h	0,87	41,7	0,9	5,5	1,6	1401
2 h	0,88	42,0	0,9	5,4	1,7	1072
1 h	0,88	41,7	1,0	5,3	2,0	687

Table 5 – Same as Table 3, but for max collocation distance of 25 km.

Since the inter-comparison results are no dependent on the spatial-temporal collocation criteria established, in the following we only show the analysis for the IASI-A and Brewer coincidences on a daily basis and for a 150 km validation box. The inter-comparison results are analysed as a function of several important parameters as: season, observing geometry, and cloud fractional cover.

Next, it is shown the seasonal Brewer total ozone daily mean variability study and the scatter plot for each different season with the calculated statistics:

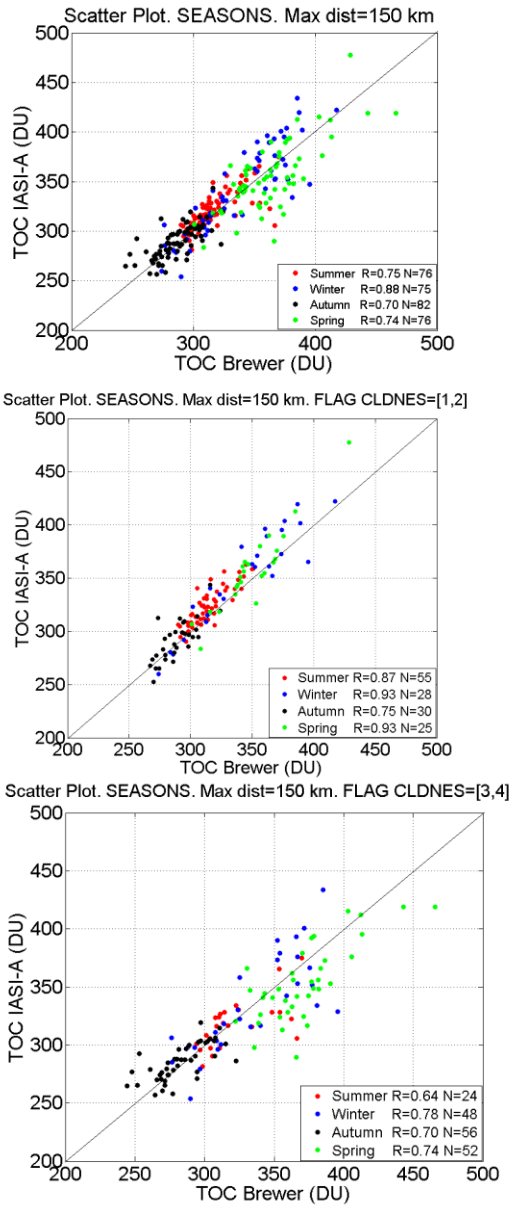

Figure 14 – Top: Scatter plot between IASI-A and Brewer TOC daily mean measurements for each season. On the legend it is shown the correlation coefficient and the number of coincidence measurements with all IASI flag cloudiness at Thessaloniki. Middle: Scatter plot between IASI-A and Brewer TOC with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Scatter plot between IASI-A and Brewer TOC with flag cloudiness 3 and 4 at Thessaloniki.

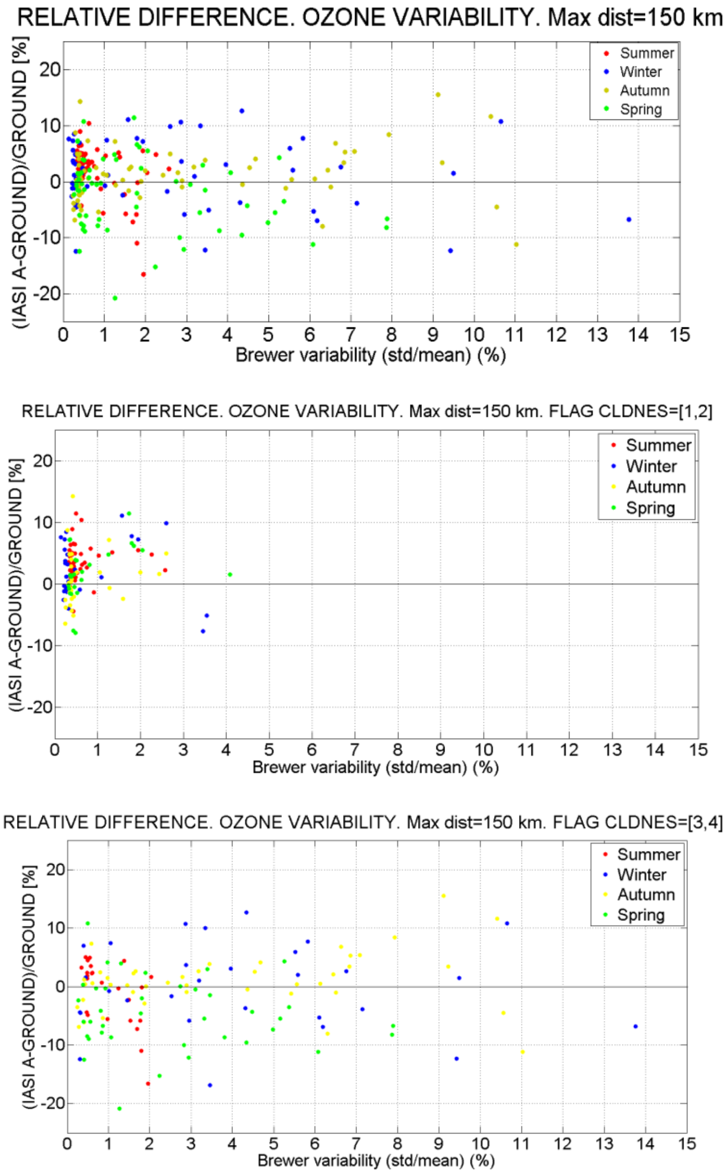

Figure 15 – Top: Brewer total ozone daily variability study for IASI-A and Brewer coincidences for each season in Thessaloniki for the period of time between October 1, 2014 and September 30, 2015 with all IASI flag cloudiness. Middle: Brewer total ozone daily variability study for IASI-A and Brewer coincidences for each season with flag cloudiness 1 and 2 at Thessaloniki. Bottom: Brewer total ozone daily variability study for IASI-A and Brewer coincidences for each season with flag cloudiness 3 and 4 at Thessaloniki.

The following table summarizes the calculated statistics for each season with a max collocation distance of 150 km:

Statistics for coincidences with IASI retrievals with all flg_cldness

SEASON	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,75	91,0	1,6	4,0	4,9	76
Winter	0,88	79,1	1,4	6,2	3,5	75
Autumn	0,70	83,7	1,1	4,8	2,3	82
Spring	0,74	134,5	-2,2	6,5	-6,6	76

Statistics for coincidences with IASI retrievals with flg_cldness=[1,2]

SEASON	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,87	75,3	2,9	2,9	9,1	55
Winter	0,93	64,4	2,5	4,9	8,0	28
Autumn	0,75	126,7	0,9	4,5	2,7	30
Spring	0,93	117,6	2,0	4,5	7,2	25

Statistics for coincidences with IASI retrievals with flg_cldness=[3,4]

SEASON	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,64	94,5	-1,1	5,5	-4,1	24
Winter	0,78	113,1	0,1	7,4	-0,2	48
Autumn	0,70	46,7	1,0	4,9	-1,7	56
Spring	0,74	131,3	-4,8	6,5	-13,1	52

Table 6 – Top: Statistics for max collocation distance of 150 km for each season, between IASI-A TOC retrievals and Brewer TOC measurements with all IASI flag cloudiness at Thessaloniki. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Comparison between IASI-A and Brewer shows a high agreement between two sensors for all seasons with all IASI-A observation cloudiness conditions. The agreement between two datasets is high with correlation coefficient of 0.75 in summer, 0.88 in winter and 0.70 and 0.74 in autumn and spring, respectively. But the agreement for the inter-comparison with filtered IASI-A observations for flag cloudiness values between 1 and 2 is higher (0.87 in summer, 0.93 in winter, 0.75 in autumn and 0.93 in spring), while for filtered IASI-A observations for flag cloudiness values between 3 and 4 results show a lower agreement between two sensors measurements with a coefficient correlation of 0.64 in summer, 0.78 in winter, 0.70 in autumn and 0.74 in spring. In addition, standard deviation is not higher than 6.5 % for any season for the inter-comparison between Brewer and IASI-A observations with all cloudiness conditions, and the bias shows that IASI-A total ozone column retrievals overestimate Brewer measurements by 4.9 DU (~1.6%) in summer, 3.5 DU (~1.1%) in winter and 2.3 DU (~0.8%) in autumn, but in spring IASI-A underestimates Brewer data by 6.6 DU (~2.2%). While for filtered IASI-A observations with flag cloudiness value between 1 and 2 standard deviation is not higher than 4.9 and the bias shows a larger overestimation than for all IASI-A retrievals with all flags cloudiness values. On the other side, IASI-A observation with flag cloudiness values between 3 and 4 show a higher standard deviation in all seasons than for the other two cases and the bias shows an underestimation of total ozone columns measures by IASI-A retrievals regarding Brewer spectrophotometer. Note also that the high variability observed in the Brewer measurements is likely due to the presence of clouds, according to the IASI cloudiness flags (recall Figure 15).

The next graphic shows the analysis of the relative difference between IASI-A and Brewer spectrophotometer coincidences as function of Brewer TOC measurements for all cloudiness conditions:

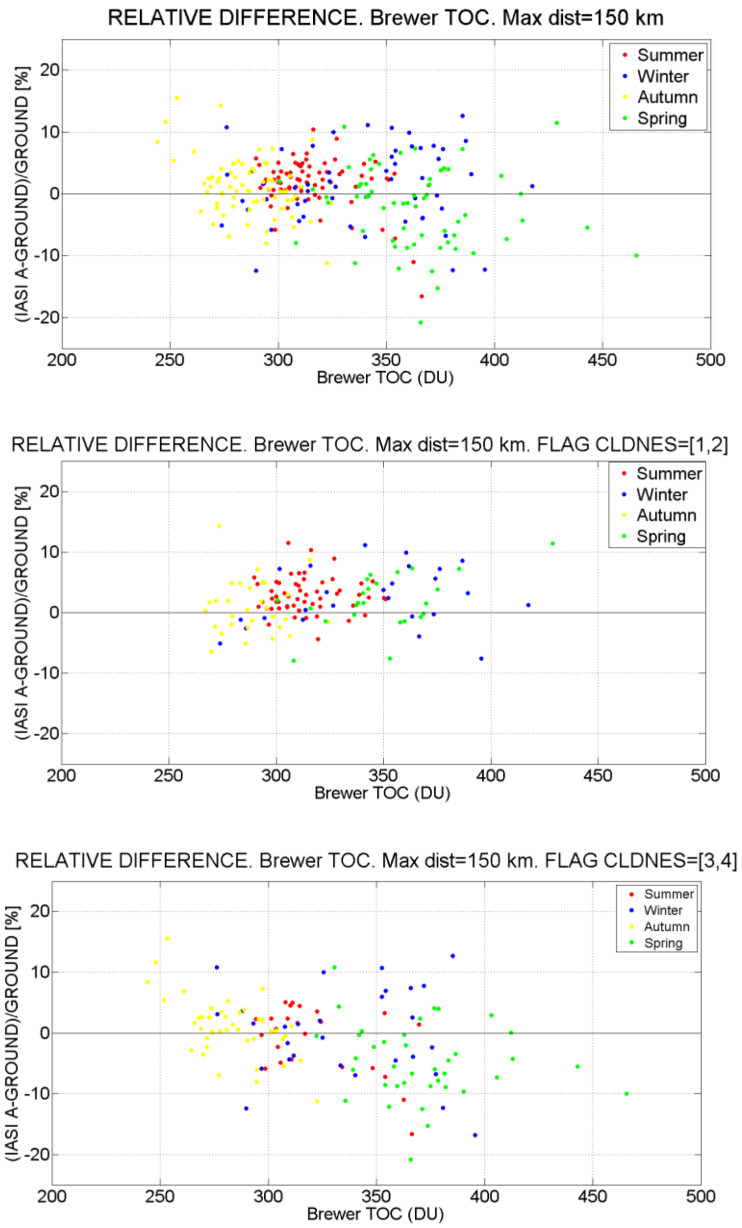

Figure 16 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of Brewer TOC data at Thessaloniki with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Figure 16 shows as on spring TOC values measured by Brewer spectrophotometer are higher at Thessaloniki than for the rest of seasons.

Next, it is shown the seasonal variations for the solar zenith angle measured by both sensors and the IASI-A viewing zenith angle:

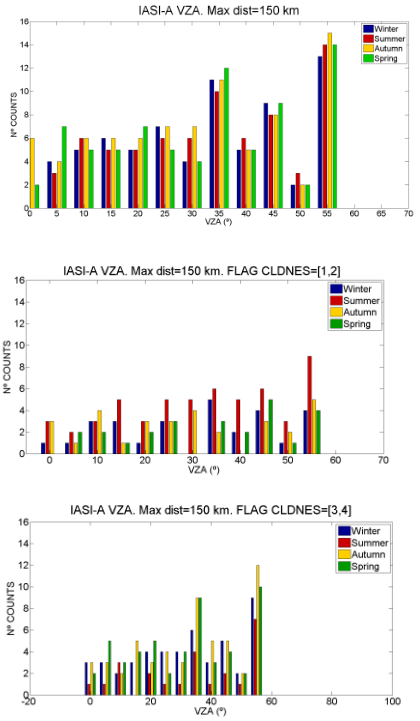

Figure 17 – Top: IASI-A viewing zenith angle measured in Thessaloniki for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: IASI-A viewing zenith angle measured in Thessaloniki with IASI flag cloudiness 1 and 2. Bottom: IASI-A viewing zenith angle measured in Thessaloniki with flag cloudiness 3 and 4.

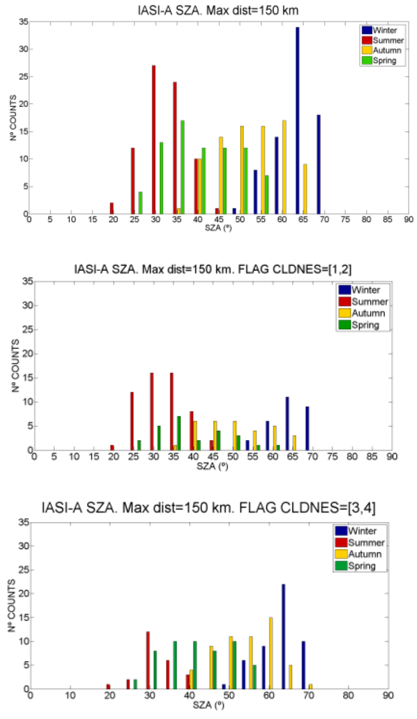

Figure 18 – Top: IASI-A solar zenith angle measured in Thessaloniki for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: IASI-A solar zenith angle measured in Thessaloniki with IASI flag cloudiness 1 and 2. Bottom: IASI-A solar zenith angle measured in Thessaloniki with flag cloudiness 3 and 4.

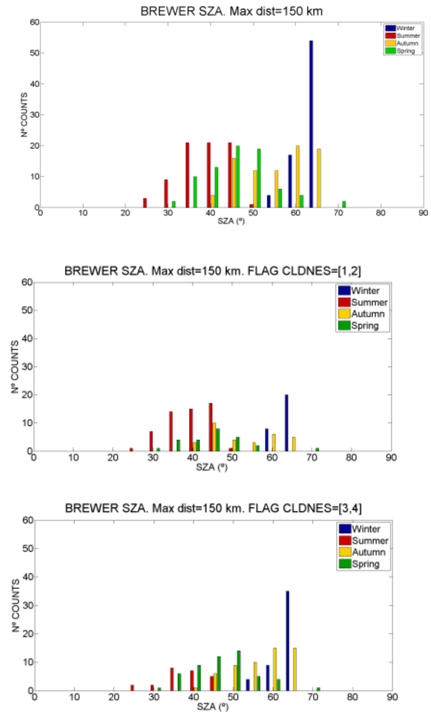

Figure 19 – Top: Brewer solar zenith angle measured in Thessaloniki for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: Brewer solar zenith angle measured in Thessaloniki with IASI flag cloudiness 1 and 2. Bottom: Brewer solar zenith angle measured in Thessaloniki with flag cloudiness 3 and 4.

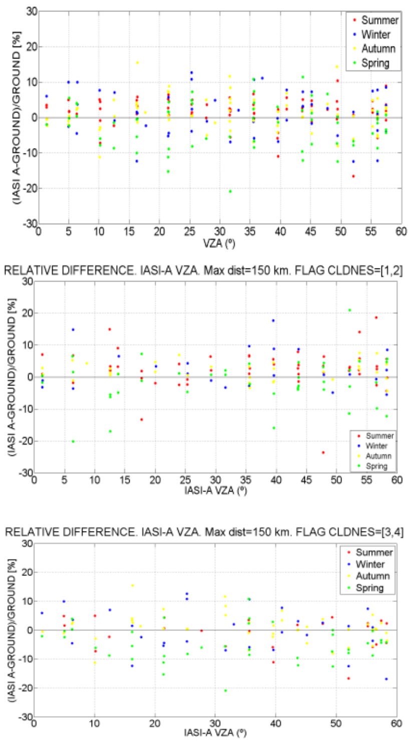

Figure 20 –Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of IASI-A viewing zenith angle with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4 at Thessaloniki.

Figure 21 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of IASI-A solar zenith angle with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4 at Thessaloniki.

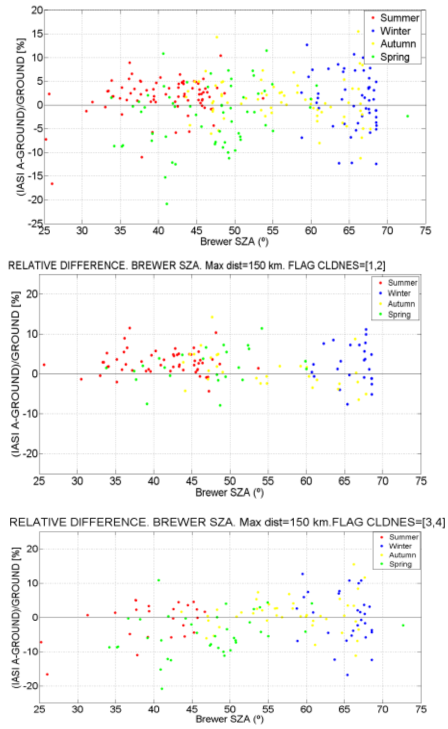

Figure 22 –Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of Brewer solar zenith angle. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4 at Thessaloniki.

As shown Figure 17, 18, 19, 20, 21 and 22 the bigger discrepancies IASI-A and Brewer data are found in spring. In addition, the relative differences between two sensors ozone data have its maximum of 15% for high SZA and low SZA. And the minimum difference between two datasets is found for angles between 40º and 55º, where it is no higher than 7%.

Finally, it is shown the seasonal study of the clouds parameters of interest for the satellite validation: cloud fraction and cloud top pressure:

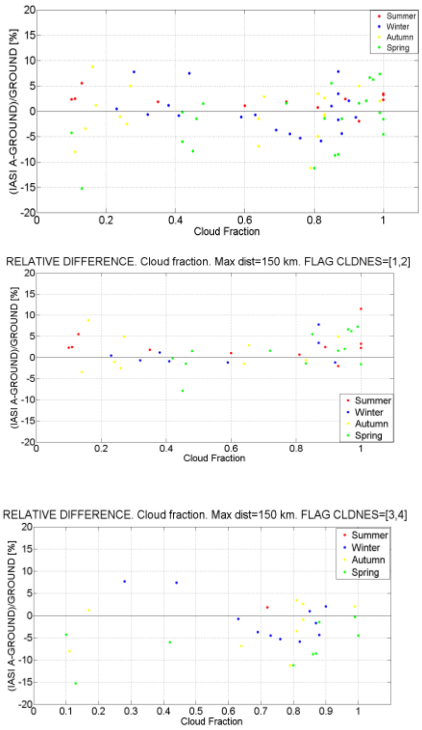

Figure 23 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of cloud fraction cover with all IASI flag cloudiness in Thessaloniki. Middle: Same as Top, but with IASI flag cloudiness 1 and 2 in Thessaloniki. Bottom: Same as Top, but with flag cloudiness 3 and 4 at Thessaloniki. Where: 0=transparent and 1=opaque.

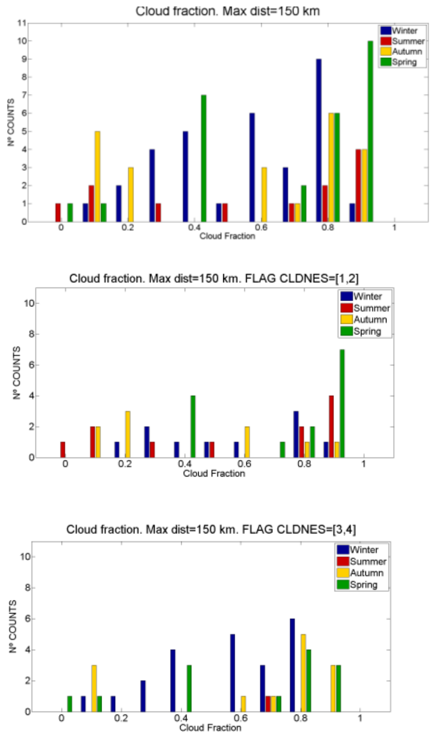

Figure 24 – Cloud fraction measured by IASI-A in Thessaloniki for October 1, 2014 to September 30, 2015. Where: 0=transparent and 1=opaque. Top: Cloud fraction measured by IASI-A with all IASI flag cloudiness in Thessaloniki. Middle: Cloud fraction measured by IASI-A with IASI flag cloudiness 1 and 2 in Thessaloniki. Bottom: Cloud fraction measured by IASI-A with flag cloudiness 3 and 4 at Thessaloniki.

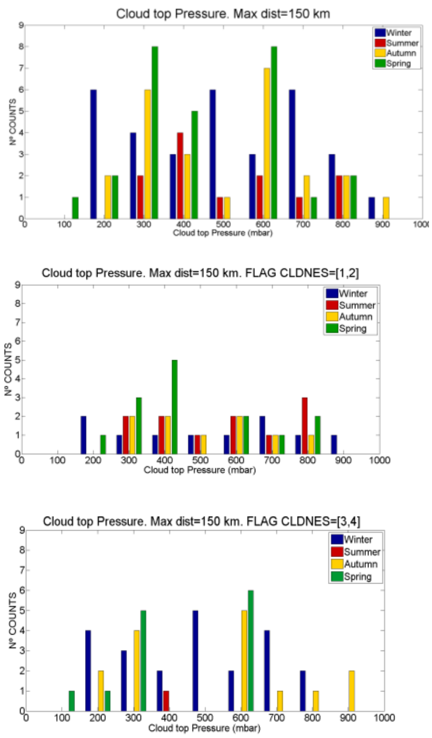

Figure 25 – Cloud top pressure measured by IASI-A in Thessaloniki for October 1, 2014 to September 30, 2015. Top: Cloud top pressure measured by IASI-A with all IASI flag cloudiness in Thessaloniki. Middle: Cloud top pressure measured by IASI-A with IASI flag cloudiness 1 and 2 in Thessaloniki. Bottom: Cloud top pressure measured by IASI-A with flag cloudiness 3 and 4 at Thessaloniki.

Histograms of the characteristics of the clouds for the whole studied year by seasons are shown on Figure 23, 24 and 25. It is important to know this information, because the presence of clouds could be the cause of the discrepancies between the datasets comparison.

3.2 IZAÑA

For IZO we follow the same procedure that in Thessaloniki: IASI/Metop-A TOC retrievals has been analyzed by comparing to ground-based Brewer spectrometer observations for the period October 1, 2014-September 30, 2015. The next graphics show the TOC time series of each sensor for a max collocation distance between IASI-A and Brewer spectrophotometer of 150 km, and the calculated RD between two sensor observations for all studied period. Note that the IZO Brewer spectrophotometer measured several extreme TOC values on March 20, 2015 and May 27, 2015 (TOC > 400 DU), not recorded by IASI-A. Although these values passed the quality control established in this study and can not be considered as outliers, they are very unusual TOC values at IZO. These cases were not discarded from our analysis, but they could slightly alter our statistics.

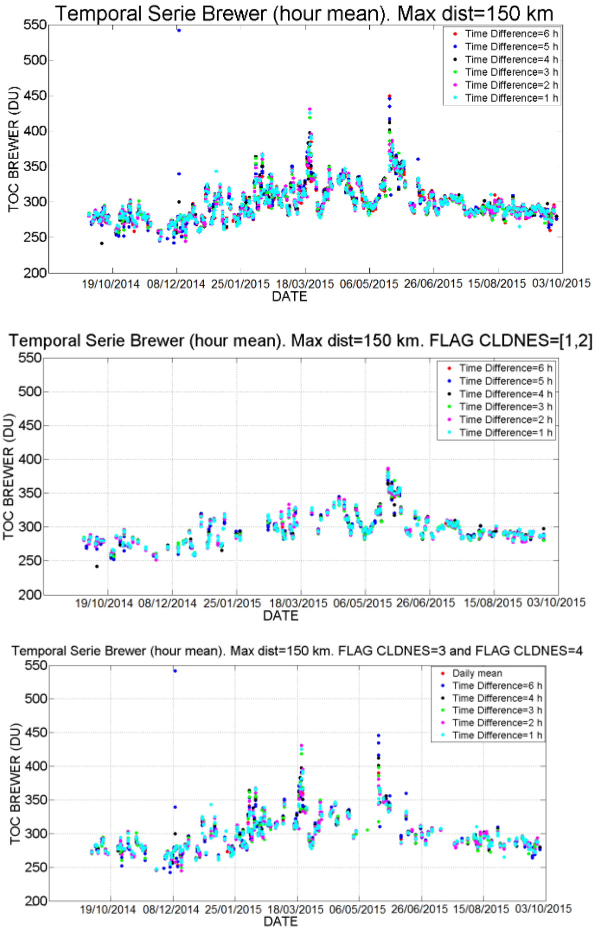

Figure 26 – Top: Time series for Brewer TOC measurements in IZO with a max collocation distance of 150 km for each studied time difference with all IASI flag cloudiness. Middle: Time series for Brewer TOC with IASI flag cloudiness 1 and 2. Bottom: Time series for Brewer TOC with IASI flag cloudiness 3 and 4.

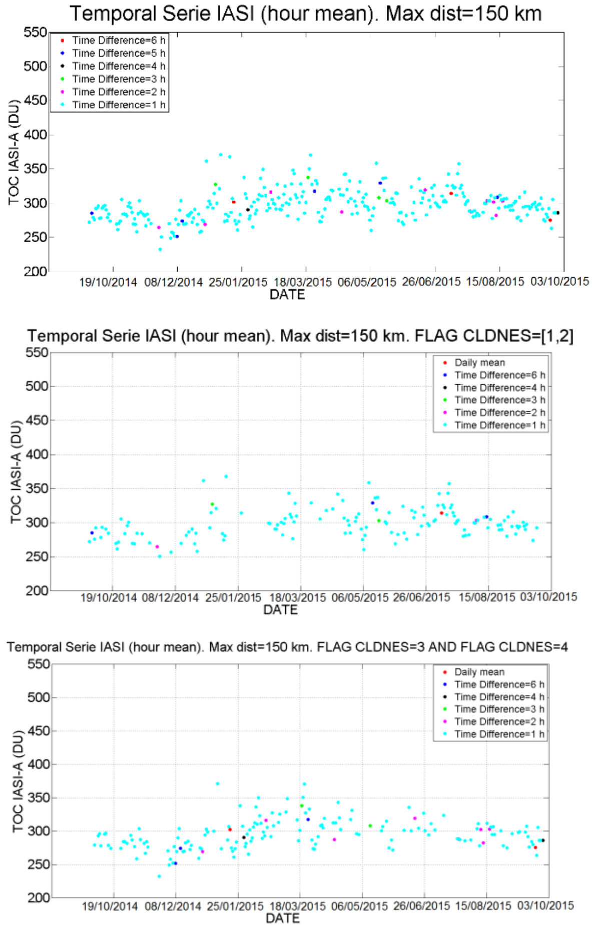

Figure 27 – Top: Time series for IASI-A TOC retrievals in IZO with a max collocation distance of 150 km, for each studied time difference with all IASI flag cloudiness. Middle: Time series for Brewer TOC with IASI flag cloudiness 1 and 2. Bottom: Time series for Brewer TOC with IASI flag cloudiness 3 and 4.

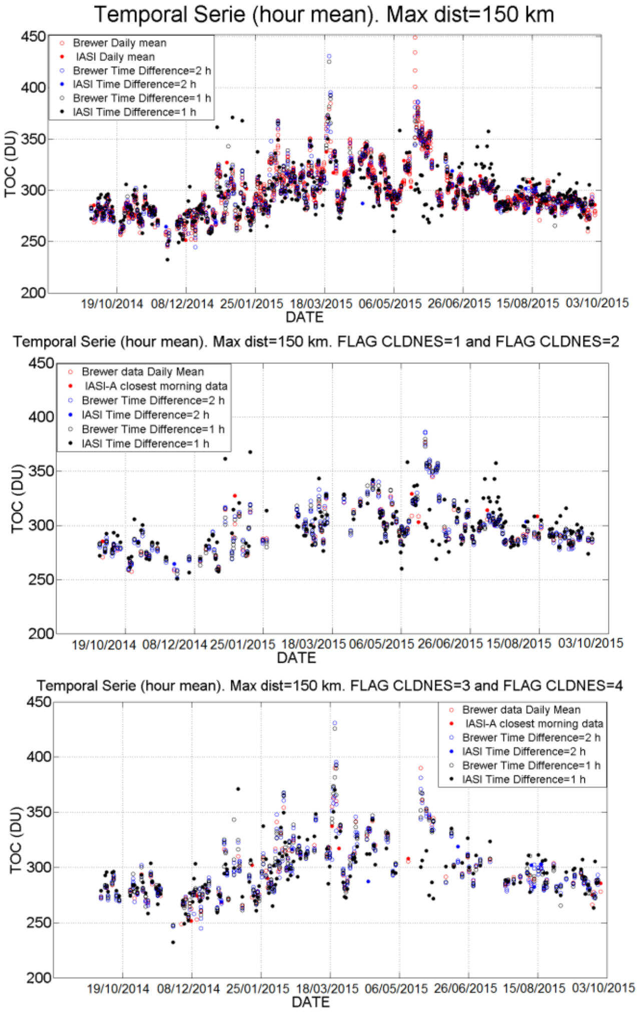

Figure 28 – Top: Time series for Brewer and IASI-A TOC measurements with a max collocation distance of 150 km, for daily mean and for 1h and 2h time difference between both datasets with all IASI flag cloudiness at IZO. Middle: Time series for Brewer and IASI-A TOC measurements with IASI flag cloudiness 1 and 2. Bottom: Time series for Brewer and IASI-A TOC measurements with IASI flag cloudiness 3 and 4.

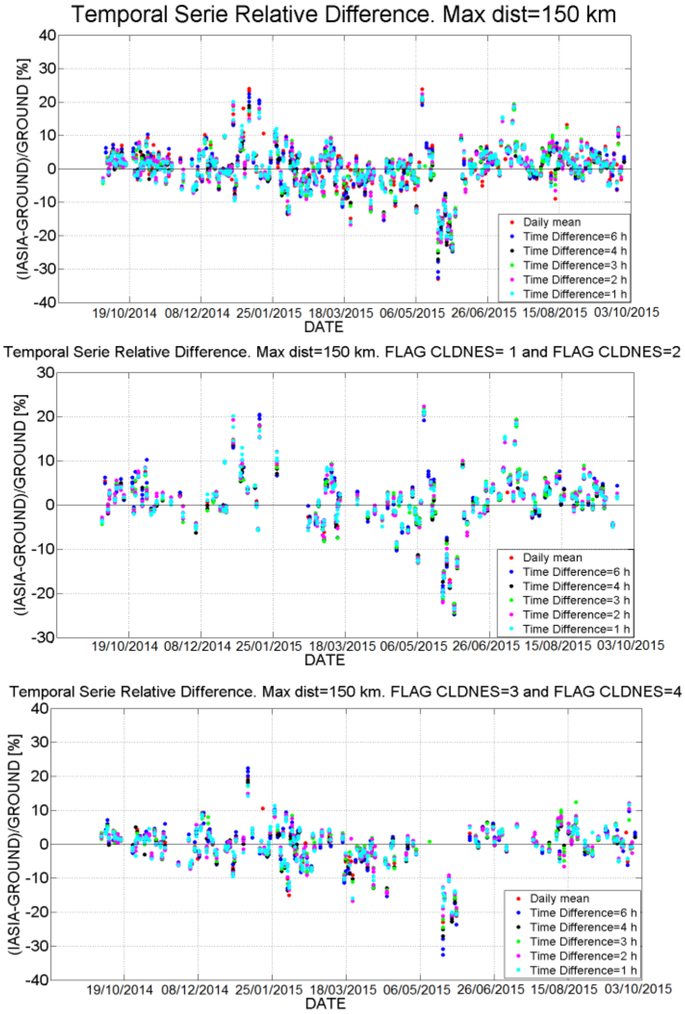

Figure 29 – Top: Time series of the relative difference between Brewer and IASI-A TOC measurements with a max collocation distance of 150 km, for each studied time difference with all IASI flag cloudiness at IZO. Middle: Time series of RD between Brewer and IASI-A TOC measurements with IASI flag cloudiness 1 and 2. Bottom: Time series of RD between Brewer and IASI-A TOC measurements with IASI flag cloudiness 3 and 4.

Next graphics show the scatter plot of the coincident TOC values and the relative differences between IASI and Brewer observations as a function of the daily ozone variability as well as the occurrence histograms of the absolute and relative differences. As for Thessaloniki, the differences are not sensitive to the observed ozone variability.

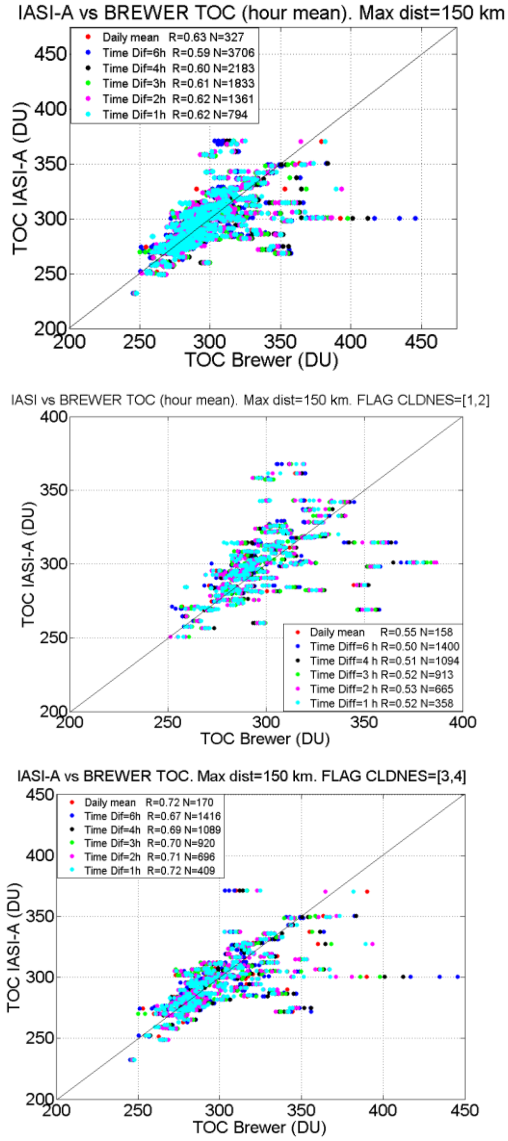

Figure 30 –Top: Scatter plot between IASI-A and Brewer TOC measurements for each time difference with all IASI flag cloudiness at IZO. On the legend it is shown the correlation coefficient and the number of coincidence between both datasets for each hourly mean. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

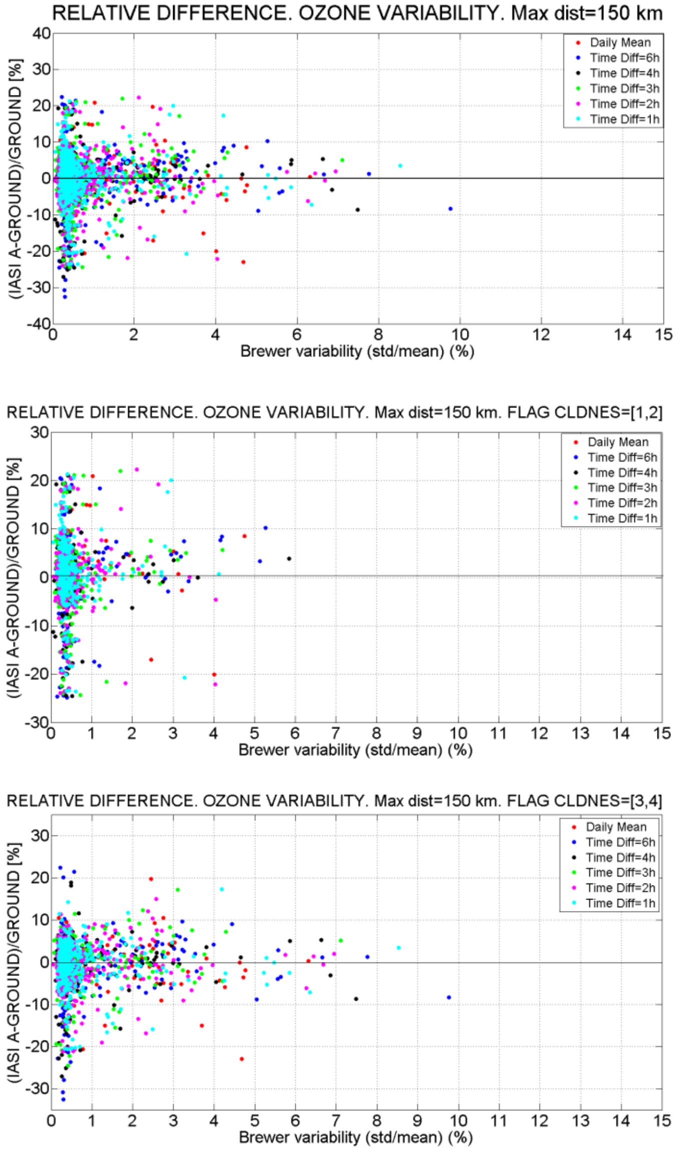

Figure 31 – Top: Brewer total ozone daily variability study for IASI-A and Brewer coincidences for each time difference in IZO for the period of time between October 1, 2014 and September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

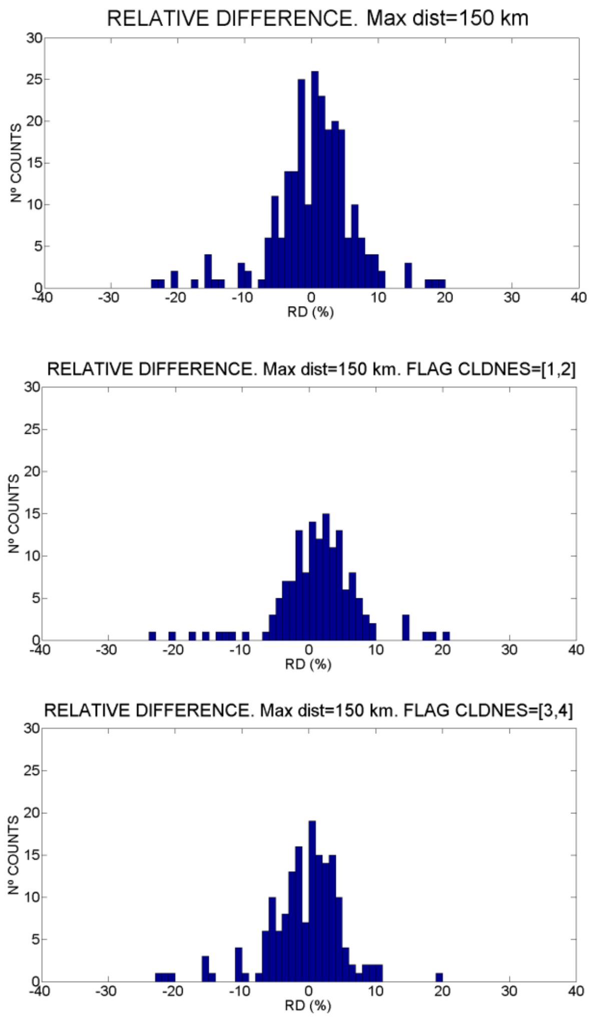

Figure 32 – Daily relative difference of Brewer and IASI-A coincidences in IZO for October 1, 2014 to September 30, 2015. Top: Daily relative difference of Brewer and IASI-A coincidences with all IASI flag cloudiness at IZO. Middle: Daily relative difference of Brewer and IASI-A coincidences measurements with IASI flag cloudiness 1 and 2 at IZO. Bottom: Daily relative difference of Brewer and IASI-A coincidences with IASI flag cloudiness 3 and 4 at IZO.

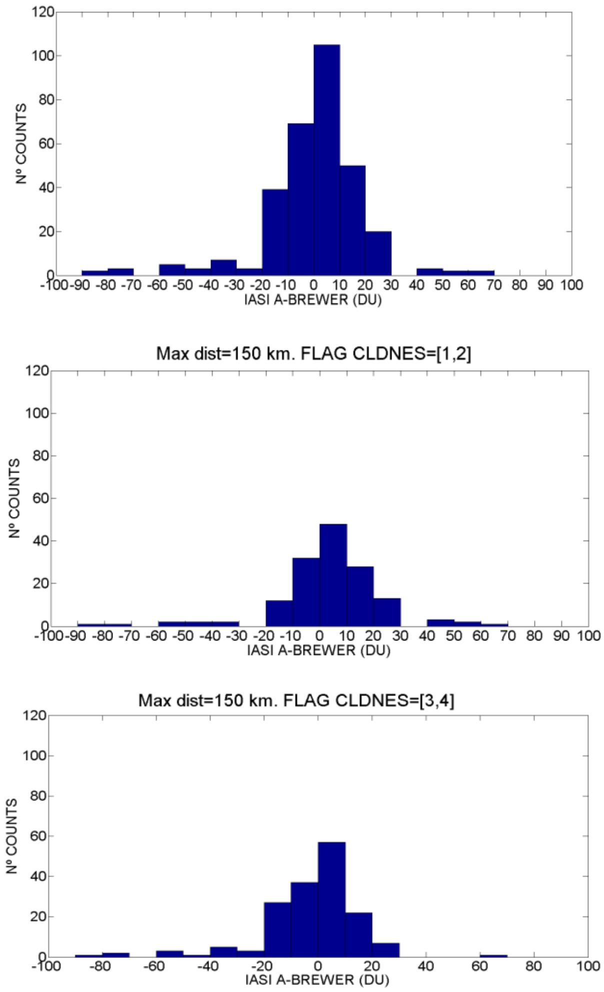

Figure 33 – Daily absolute difference between Brewer and IASI-A coincidences in IZO for October 1, 2014 to September 30, 2015. Top: Daily absolute difference between Brewer and IASI-A coincidences with all IASI flag cloudiness at IZO. Middle: Daily absolute difference between Brewer and IASI-A coincidences with IASI flag cloudiness 1 and 2 at IZO. Bottom: Daily absolute difference between Brewer and IASI-A coincidences with IASI flag cloudiness 3 and 4 at IZO.

The same results have been calculated for the rest of interest collocation distance (see Table 7-10): 100 km, 50 km and 25 km and, as for Thessaloniki, the obtained results are very similar for any collocation criteria for all coincidences between Brewer and IASI-A observations despite cloudiness conditions. It is important to note that Brewer TOC values miss the partial column below 2.4 km (IZO altitude). Thereby, the BIAS found underestimates the real one by about 10 DU (estimation from ozone sondes climatology at IZO). But, the scatter estimators are not expected to be affected since, as shown Figure 4, IASI has a weak sensitivity in the lower troposphere leading to the variability of the partial columns missed by Brewer not being crucial for the IASI-Brewer comparison.

Statistics of coincidences for all IASI retrievals

150 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,63	97,4	0,3	6,0	-0,2	327
6 h	0,59	115,0	0,1	6,2	-0,3	3706
4 h	0,60	113,1	0,1	6,1	-0,3	2183
3 h	0,61	109,7	0,2	6,0	-0,1	1833
2 h	0,62	105,3	0,1	5,9	-0,2	1361
1 h	0,62	107,1	0,1	6,0	-0,2	794

Statistics of coincidences for filtering IASI retrievals with flg_cldness=[1,2]

150 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD(%)	BIAS (DU)	N
Daily mean	0,55	145,2	1,3	6,2	1,5	158
6 h	0,50	154,9	1,0	6,5	2,0	1400
4 h	0,51	153,8	0,9	6,4	1,9	1094
3 h	0,52	151,1	1,0	6,4	2,1	913
2 h	0,53	146,2	0,9	6,3	2,0	665
1 h	0,52	151,0	0,9	6,5	2,0	358

Statistics of coincidences for filtering IASI retrievals with flg_cldness=[3,4]

150 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD(%)	BIAS (DU)	N
Daily mean	0,72	50,3	-0,6	5,7	-1,3	170
6 h	0,67	71,1	-0,7	5,7	-2,6	1416
4 h	0,69	65,9	-0,7	5,6	-2,6	1089
3 h	0,70	61,3	-0,6	5,4	-2,3	920
2 h	0,71	60,8	-0,7	5,3	-2,3	696
1 h	0,72	60,9	-0,7	5,4	-2,3	409

Table 7 – Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 150 km in IZO. Top: Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 150 km in Thessaloniki with all IASI flag cloudiness at Thessaloniki. Middle: Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 150 km in Thessaloniki with IASI flag cloudiness 1 and 2 at Thessaloniki. Bottom: Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 150 km in Thessaloniki flag cloudiness 3 and 4 at Thessaloniki.

100 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,65	91,5	0,4	6,0	0,5	305
6 h	0,59	112,8	0,3	6,2	0,2	2999
4 h	0,61	107,8	0,2	6,1	-0,1	2035
3 h	0,62	103,9	0,3	5,9	0,2	1711
2 h	0,63	100,5	0,2	5,9	0,1	1268
1 h	0,64	101,7	0,2	5,9	0,1	736

Table 8 – Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 100 km in IZO.

Statistics of coincidences for all IASI retrievals

50 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,65	92,1	0,4	6,0	0,4	303
6 h	0,60	113,1	0,2	6,2	0,1	2609
4 h	0,61	110,8	0,2	6,1	-0,1	2022
3 h	0,62	106,1	0,3	5,9	0,2	1700
2 h	0,63	102,8	0,2	5,9	-0,1	1259
1 h	0,64	105,2	0,2	5,9	0,1	730

Statistics of coincidences for filtering IASI retrievals with flg_cldness=[1,2]

50 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD(%)	Standard Deviation RD(%)	BIAS (DU)	N
Daily mean	0,56	140	1,3	6,2	1,5	154
6 h	0,509	150,0	1,0	6,4	2,1	1364
4 h	0,52	148,7	0,9	6,4	2,0	1066
3 h	0,53	146,0	1,0	6,3	2,2	890
2 h	0,54	141,0	1,0	6,3	2,1	648
1 h	0,53	145,6	0,9	6,4	2,1	374

Statistics of coincidences for filtering IASI retrievals with flg_cldness=[3,4]

50 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD(%)	Standard Deviation RD(%)	BIAS (DU)	N
Daily mean	0,73	47,6	-0,6	5,7	-1,1	149
6 h	0,69	66,1	-0,6	5,7	-2,3	1245
4 h	0,71	64,0	-0,6	5,6	-2,4	956
3 h	0,72	58,1	-0,5	5,4	-2,0	810
2 h	0,73	57,9	-0,6	5,4	-2,2	611
1 h	0,74	57,9	-0,6	5,4	-2,1	356

Table 9 – Same as Table 7, but for a max collocation distance of 50 km in IZO.

25 km	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,64	91,6	0,3	6,2	0,3	261
6 h	0,60	110,3	0,2	6,2	-0,1	2250
4 h	0,61	108,5	0,2	6,1	-0,1	1739
3 h	0,62	104,5	0,2	5,9	0,1	1465
2 h	0,63	101,3	0,2	5,9	-0,1	1084
1 h	0,64	102,6	0,2	5,9	-0,1	628

Table 10 – Same as Table 8, but for a max collocation distance of 25 km in IZO.

In the following it is shown the analysis on a seasonal basis (Figure 34 and 35 and Table 11). The results obtained are very consistent with those found for Thessaloniki station: the agreement for season ranges from about 70% to 80%, except for spring (R of 47%). During these season, as it has been discussed above, the IZO Brewer registered unusual extreme values that could explain the low correlation observed and also the high STD of RD. In addition, the BIAS is also consistent with Thessaloniki results: the IASI-A TOC retrievals overestimate Brewer measurements in all the season, except for spring, where IASI-A underestimates Brewer data. Note that at IZO the inter-comparison results show poorer agreement than the other stations, but this could be in part due to the orography of the Tenerife island, thereby we are mixing IASI pixels with low and high altitude and sea/land scenes.

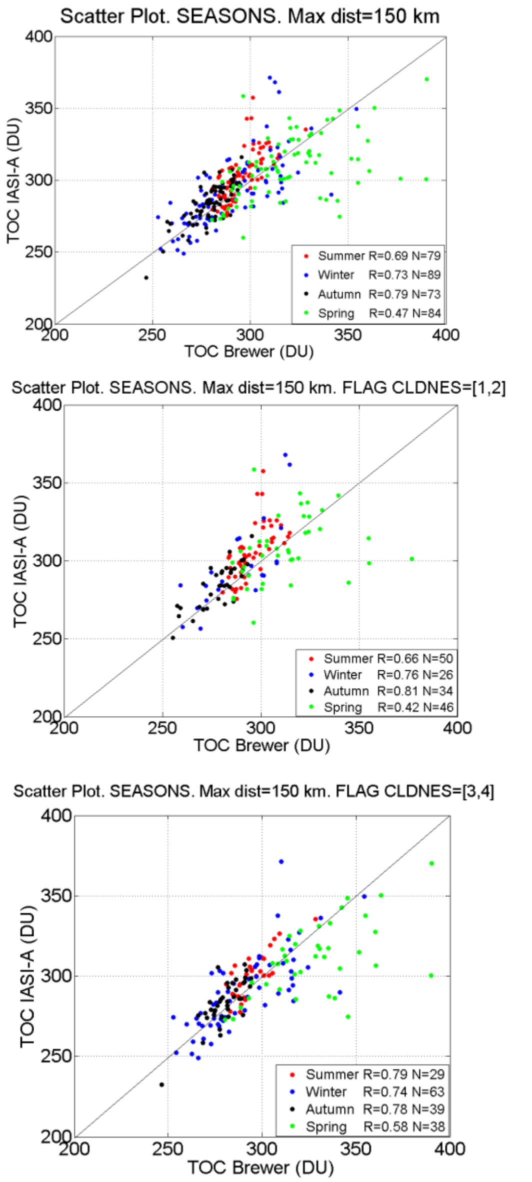

Figure 34 – Top: Scatter plot between IASI-A and Brewer TOC measurements for each time season with all IASI flag cloudiness at IZO. On the legend it is shown the correlation coefficient and the number of coincidence between both datasets for each hourly mean. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

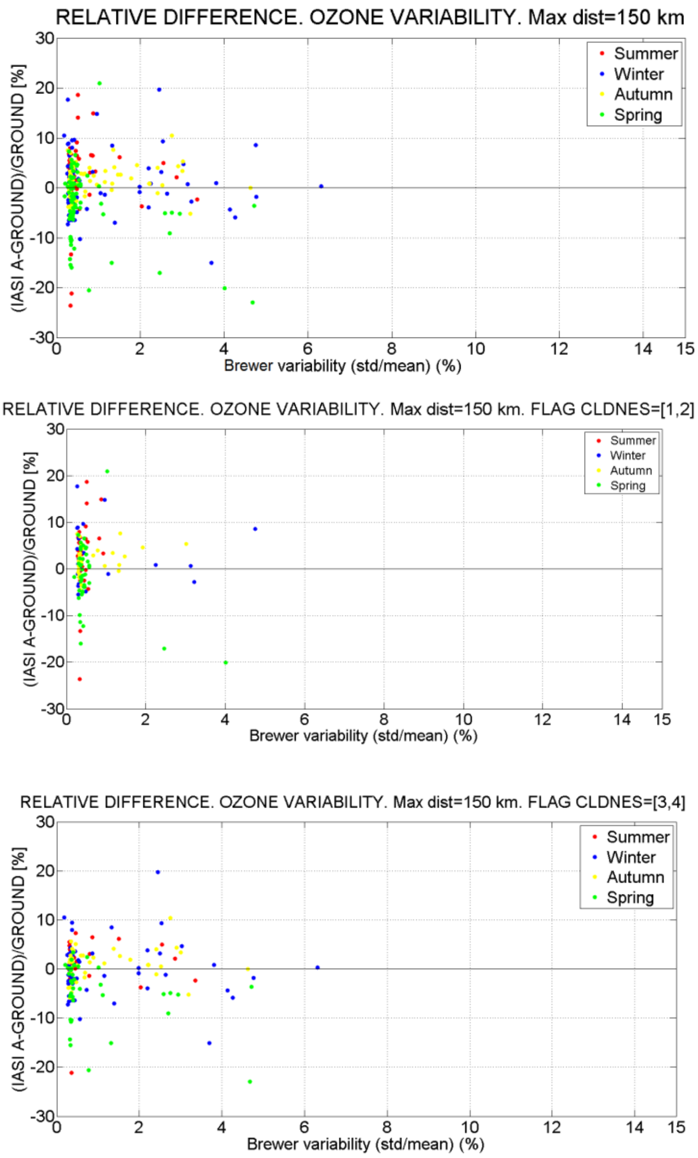

Figure 35 – Top: Brewer total ozone daily variability study for IASI-A and Brewer coincidences for each season in IZO for the period of time between October 1, 2014 and September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Statistics for coincidences with IASI retrievals with all flg_cldness

SEASON	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,69	175,6	2,0	5,9	8,3	79
Winter	0,73	114,3	0,7	5,9	1,7	89
Autumn	0,79	121,8	1,6	3,1	4,5	73
Spring	0,47	158,1	-3,2	7,0	-10,4	84

Statistics for coincidences with IASI retrievals with flg_cldness=[1,2]

SEASON	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,66	194,5	2,5	6,3	9,6	50
Winter	0,76	148,9	2,7	6,3	7,0	26
Autumn	0,81	105,1	2,1	2,9	5,8	34
Spring	0,32	216,2	-1,5	7,4	-4,9	46

Statistics for coincidences with IASI retrievals with flg_cldness=[3,4]

SEASON	Correlation Coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,79	122,6	1,3	5,1	6,1	29
Winter	0,74	91,6	-0,1	5,6	-0,4	63
Autumn	0,78	135,1	1,2	3,2	3,4	39
Spring	0,58	118,6	-4,9	6,2	-17,1	38

Table 11 – Top: Statistics for max collocation distance of 150 km for each season, between IASI-A TOC retrievals and Brewer TOC measurements at IZO. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

On Figure 35 and 35 it is shown the total ozone column differences measured by IASI-A and Brewer spectrophotometer in IZO for October 1, 2014 to September 30, 2015.

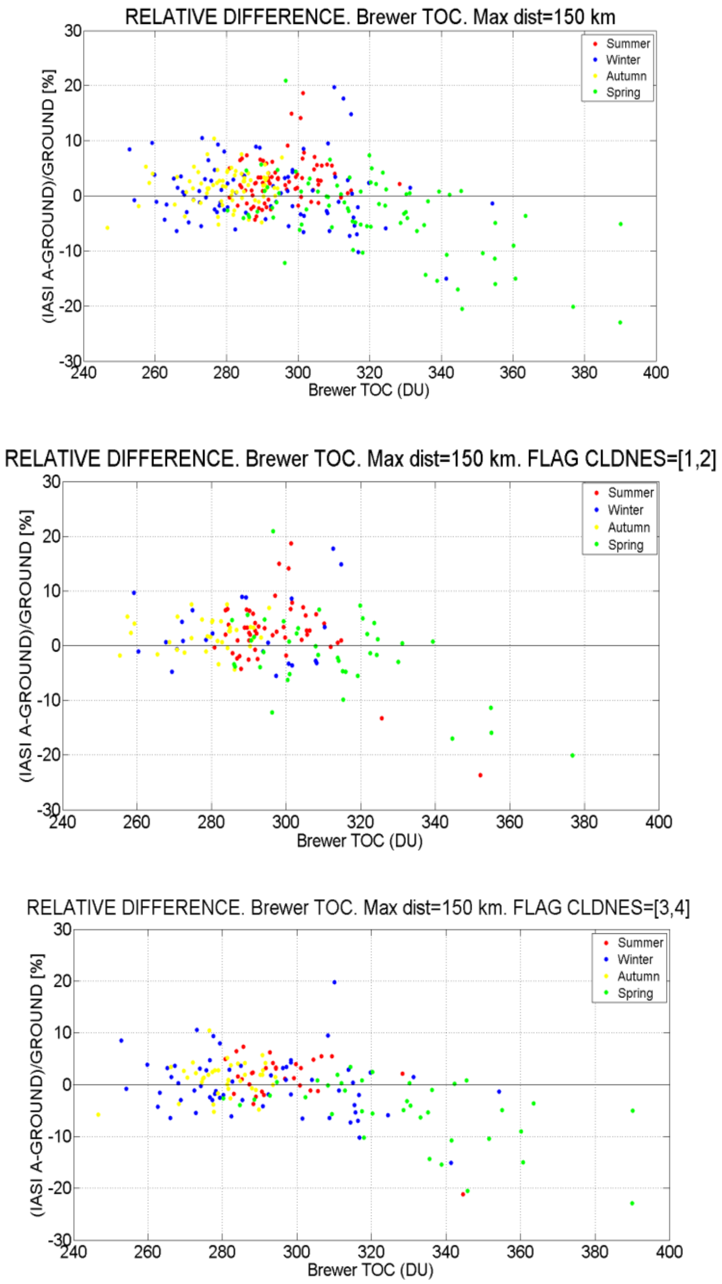

Figure 36 –Top: Evolution of the relative differences between TOC data retrieved by IASI-A and Brewer spectrophotometer as function of Brewer TOC measurements at IZO with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Figure 36 shows, as for Thessaloniki station, on spring TOC values are higher than for the rest of seasons at IZO.

Next, it is shown the seasonal variations for the solar zenith angle measured by both sensors and the IASI-A viewing zenith angle and the RD as a function of the observing geometry. As for Thessaloniki, the RD are large for extreme SZA (about ±20%), while the minimum RD are found for angles between 40º and 55º, where they are no higher than 10%.

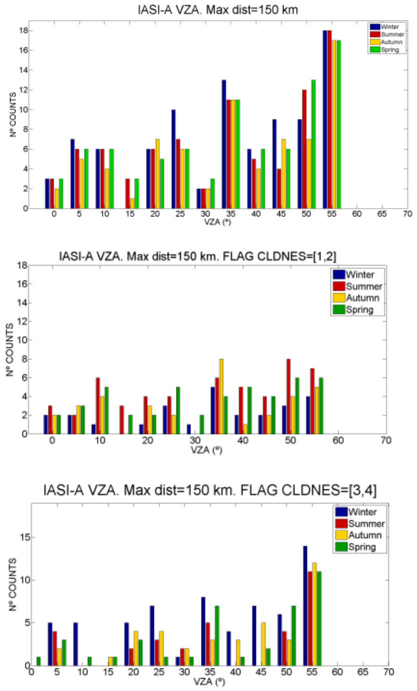

Figure 37 – Top: IASI-A viewing zenith angle measured in IZO for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

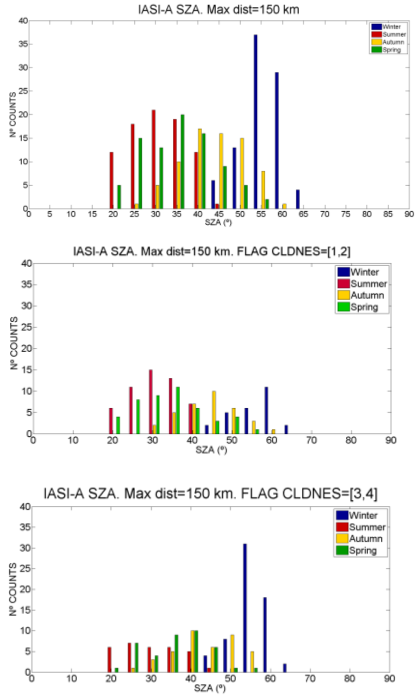

Figure 38 – Top: IASI-A solar zenith angle measured in IZO for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

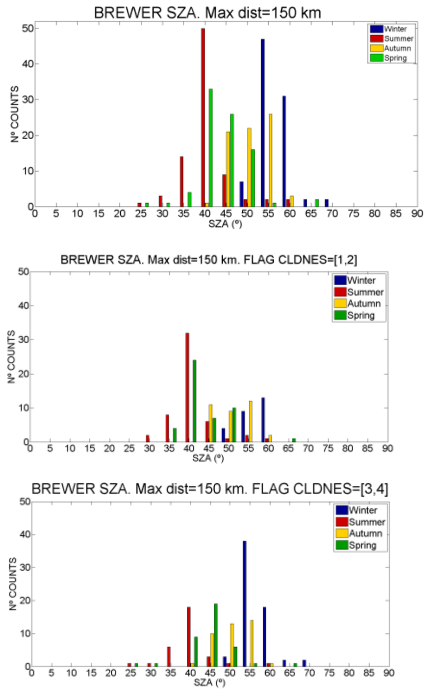

Figure 39 – Top: Brewer solar zenith angle measured in IZO for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness at IZO. Middle: Same as Top, but with IASI flag cloudiness 1 and 2 at IZO. Bottom: Same as Top, but with flag cloudiness 3 and 4.

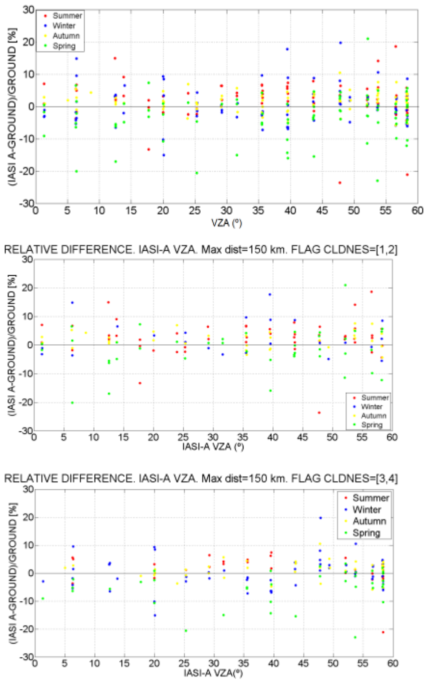

Figure 40 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of IASI-A viewing zenith angle, with all IASI flag cloudiness at IZO. Middle: Same as Top, but with IASI flag cloudiness 1 and 2 at IZO. Bottom: Same as Top, but with flag cloudiness 3 and 4 at IZO.

Figure 41 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of IASI-A solar zenith angle, with all IASI flag cloudiness at IZO. Middle: Same as Top, but with IASI flag cloudiness 1 and 2 at IZO. Bottom: Same as Top, but with flag cloudiness 3 and 4 at IZO.

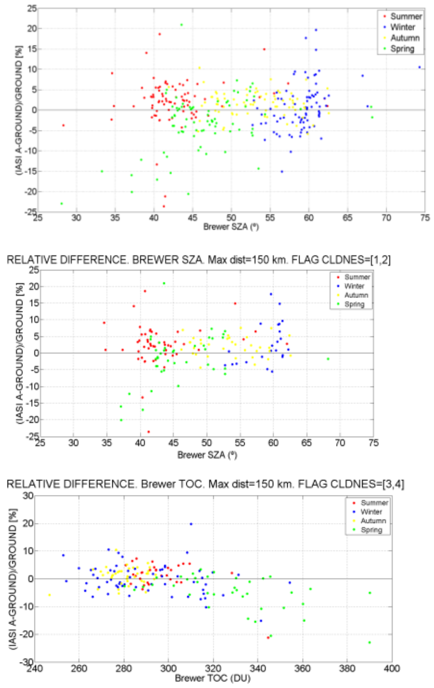

Figure 42 –Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of Brewer solar zenith angle, with all IASI flag cloudiness at IZO. Middle: Same as Top, but with IASI flag cloudiness 1 and 2 at IZO. Bottom: Same as Top, but with flag cloudiness 3 and 4 at IZO.

Finally, it is shown the seasonal study of the clouds parameters of interest for the satellite validation: cloud fraction and cloud top pressure:

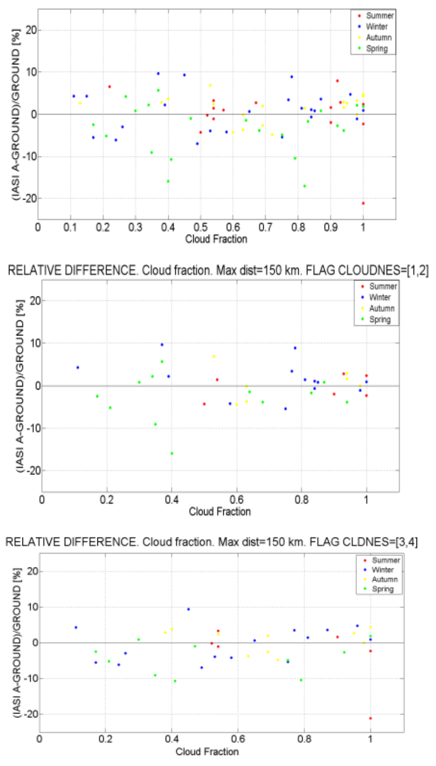

Figure 43 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of cloud fraction cover. Middle: Same as Top, but with IASI flag cloudiness 1 and 2 at IZO. Bottom: Same as Top, but with flag cloudiness 3 and 4 at IZO. Where: **0=transparent and 1=opaque.**

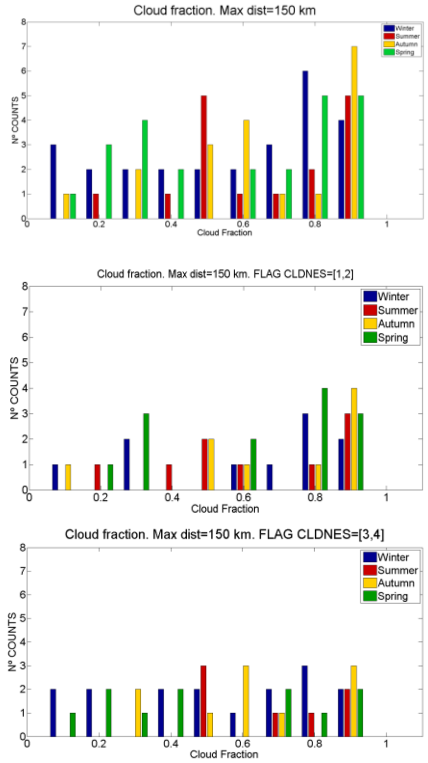

Figure 44 – Cloud fraction measured by IASI-A in IZO for October 1, 2014 to September 30, 2015. Top: Cloud fraction measured by IASI-A with all IASI flag cloudiness at IZO. Middle: Same as Top, but with IASI flag cloudiness 1 and 2 at IZO. Bottom: Same as Top, but with flag cloudiness 3 and 4 at IZO. Where: 0=transparent and 1=opaque.

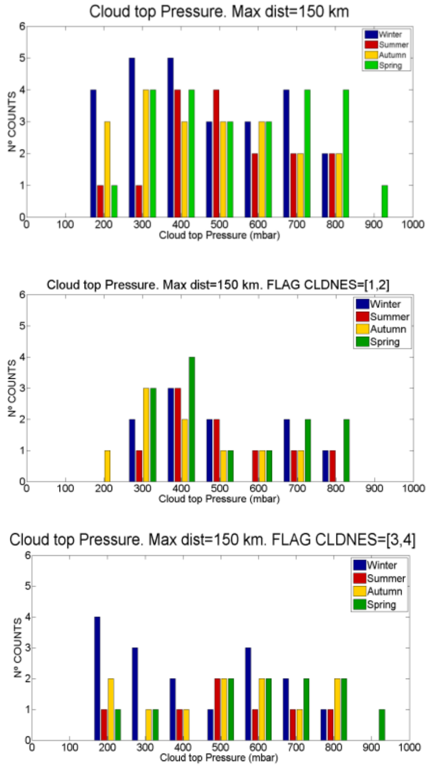

Figure 45 – Cloud top pressure measured by IASI-A in IZO for October 1, 2014 to September 30, 2015. Top: Cloud top pressure measured by IASI-A with all IASI flag cloudiness at IZO. Middle: Same as Top, but with IASI flag cloudiness 1 and 2 at IZO. Bottom: Same as Top, but with flag cloudiness 3 and 4 at IZO.

2.2 SODANKYLÄ

For Sodankylä we follow the same procedure that in Thessaloniki and IZO: IASI/Metop-A TOC retrievals has been compared to ground-based Brewer spectrometer observations for the period October 1, 2014-September 30, 2015. In the following analysis we show the TOC time series of each sensor for a max collocation distance between IASI-A and Brewer spectrophotometer of 150 km, as example, and the calculated RD between two sensor observations for all studied period, since the results are very similar for all the spatial/temporal criteria tested despite IASI-A retrievals flag cloudiness results, as it will be shown later.

Figures 45, 46, 47, and 48 show the TOC time series as observed by IASI and Brewer and the comparison between both datasets for each flag cloudiness value.

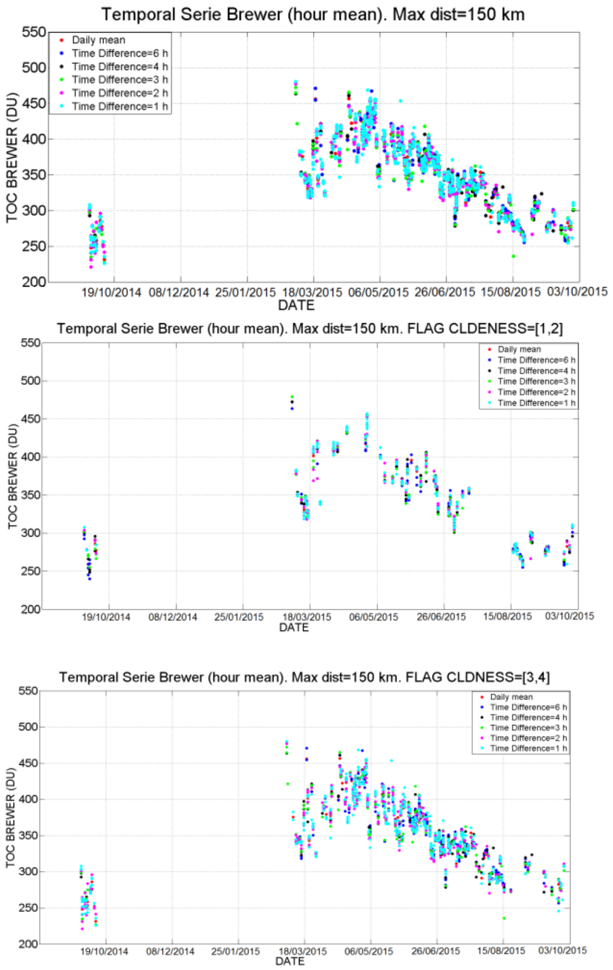

Figure 46 – Top: Time series for Brewer TOC measurements in Sodankylä with a max collocation distance of 150 km for each studied time difference, with all IASI flag cloudiness (1= clear with high confidence, 2= presumably clear, 3= partly cloudy, 4= cloudy). Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

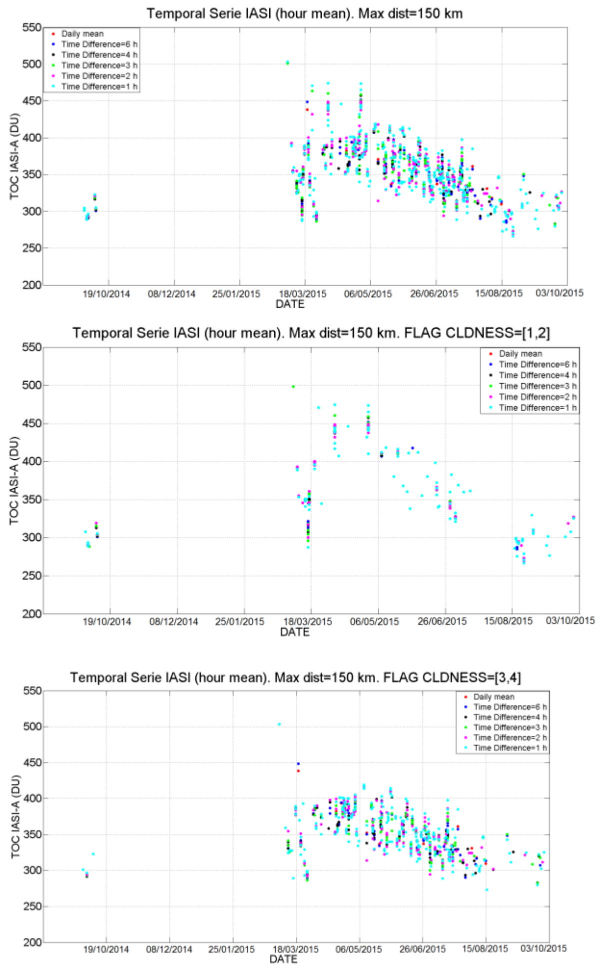

Figure 47 – Top: Time series for IASI-A TOC measurements with a max collocation distance of 150 km for each studied time difference with a max collocation distance of 150 km for each studied time difference, with all IASI flag cloudiness at Sodankylä. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

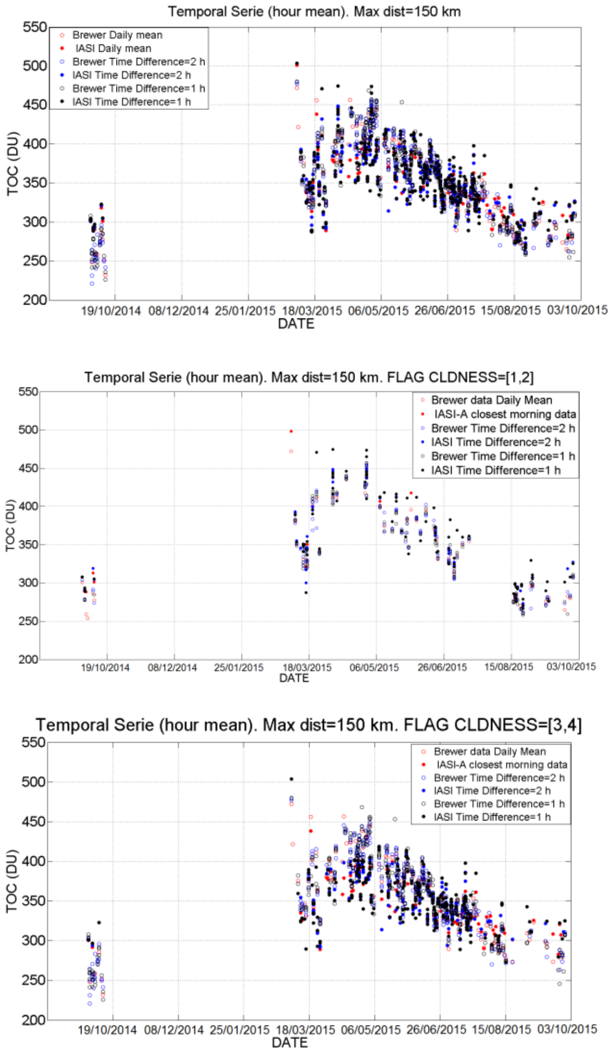

Figure 48 –Top: Time series for Brewer and IASI-A TOC measurements in Sodankylä with a max collocation distance of 150 km for daily mean and for 1h and 2h time difference between both datasets, with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

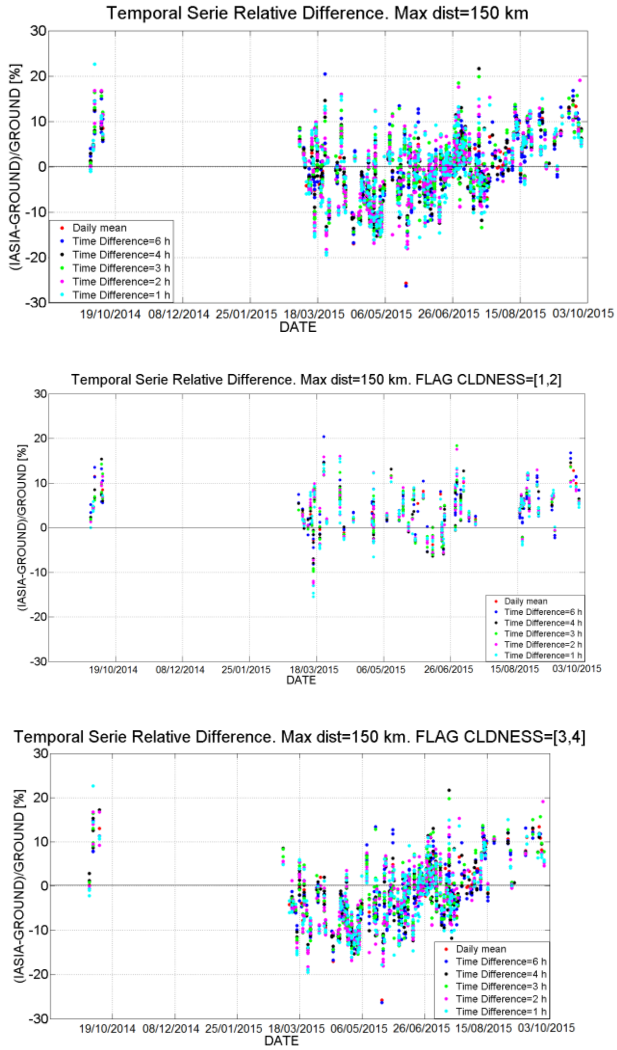

Figure 49 – Top: Time series of the relative difference between Brewer and IASI-A TOC measurements in Sodankylä with a max collocation distance of 150 km for each studied time difference with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

We haven't found no coincidences between IASI-A and Brewer spectrophotometer measurements in winter possibly because, the cloud cover is abundant in Finland, particularly in the autumn and winter. The number of cloudy days with at least 80% of the sky covered with clouds is usually higher every month than that of days with clear skies (at most 20% of the sky covered by cloud) or partly cloudy days. The number of days with clear skies is highest in May-June, and lowest in November-December.

On the next graphics it is shown the scatter plot of the coincident total ozone columns with the correlation coefficient and the number of coincidences between Brewer and IASI-A for the studied time period in Sodankylä for a max collocation distance of 150 km. Also, it has been shown the relative difference between IASI-A and Brewer coincidences for each time difference versus the daily variability as observed by the Brewer spectrometer (Eq. 5), documenting that the IASI-A and Brewer differences do not depend on the observed variability. As can be observed results show a larger agreement for IASI-A retrievals filtered by flag cloudiness values between 1 and 2 than for all flag cloudiness values and for values between 3 and 4.

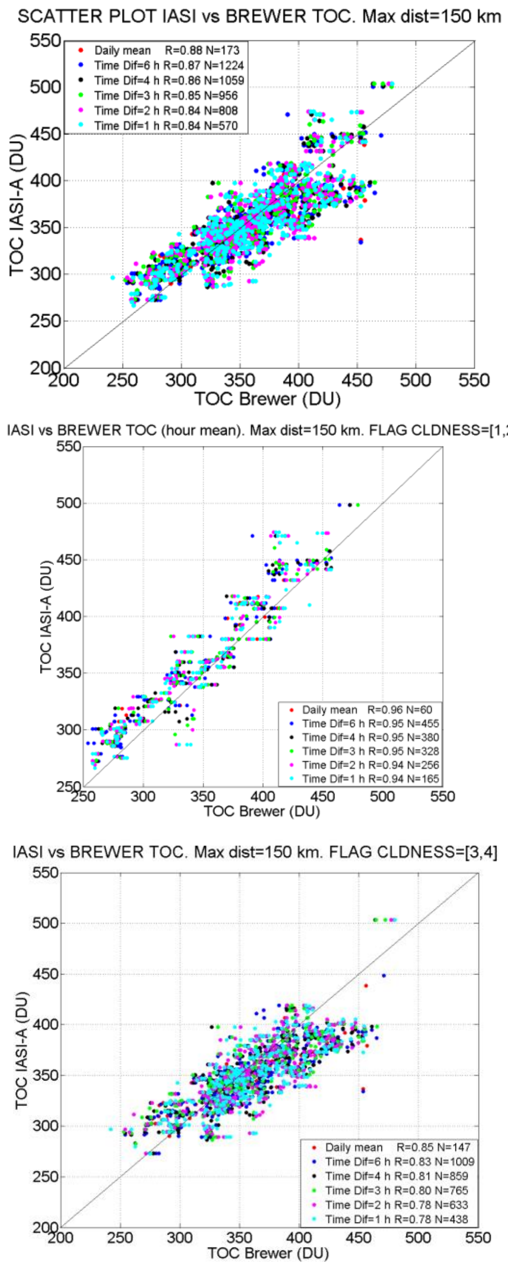

Figure 50 – Top: Scatter plot between IASI-A and Brewer TOC measurements for each time difference. On the legend it is shown the correlation coefficient and the number of coincidence between both datasets for each hourly mean. The solid black line corresponds to the diagonal (x=y) with all IASI flag cloudiness at Sodankylä. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

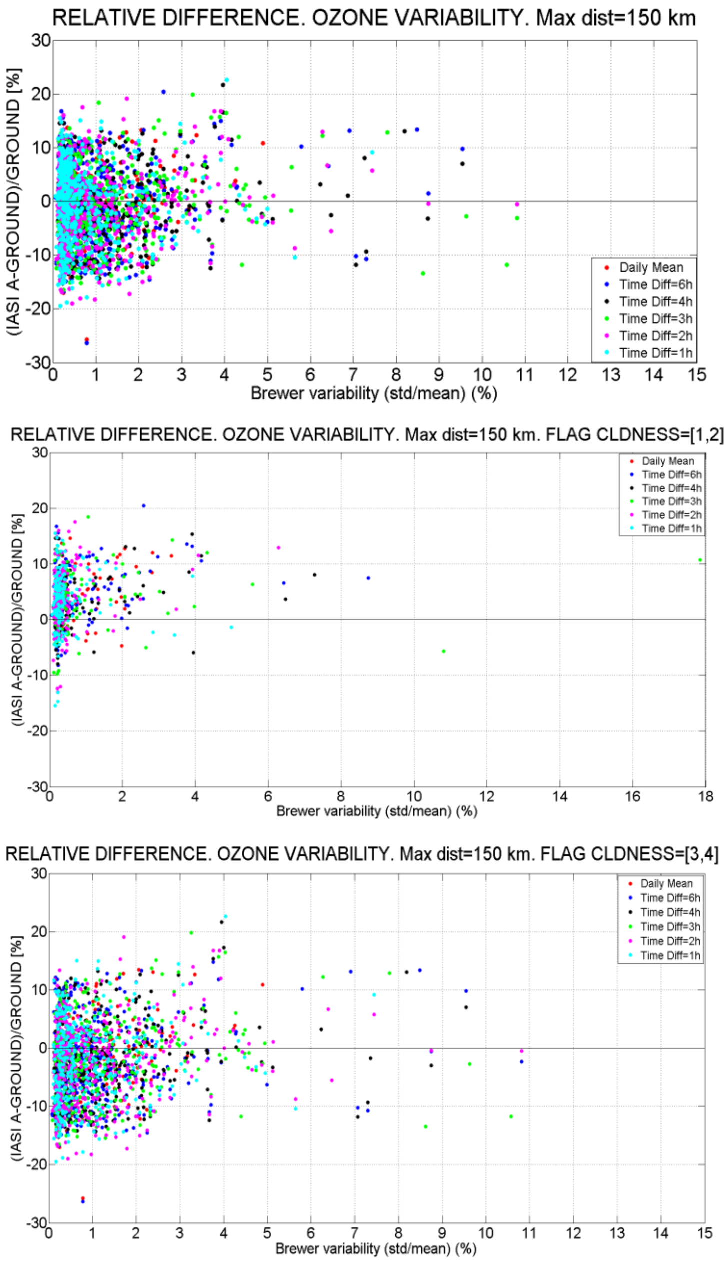

Figure 51 – Top: Brewer total ozone daily variability study for IASI-A and Brewer coincidences for each time difference in Sodankylä for the period of time between October 1, 2014 and September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

On the next histograms, it is shown the daily relative and the absolute difference of Brewer and IASI-A coincidences for all the period of study:

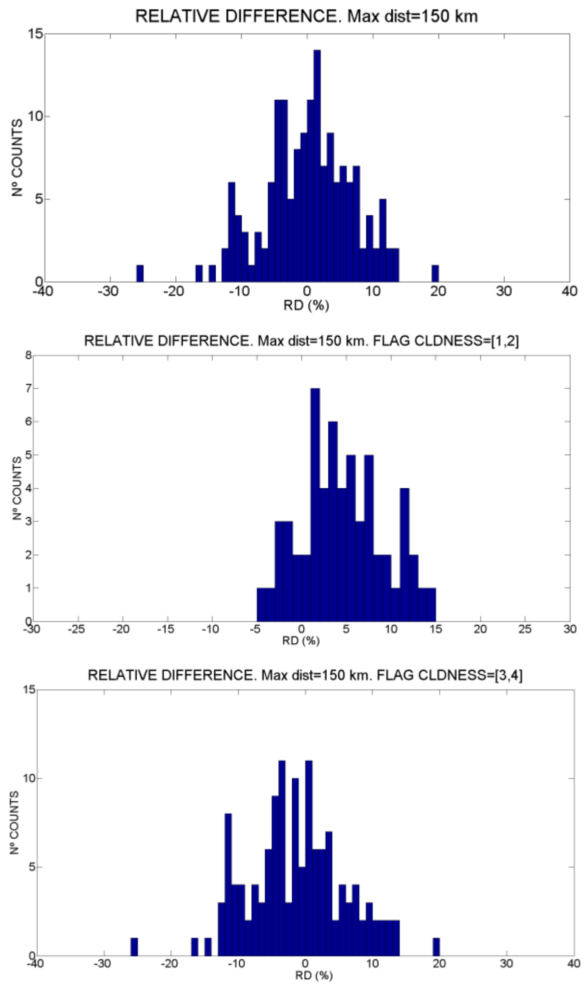

Figure 52 –Top: Daily relative difference of Brewer and IASI-A coincidences in Sodankylä from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness values. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

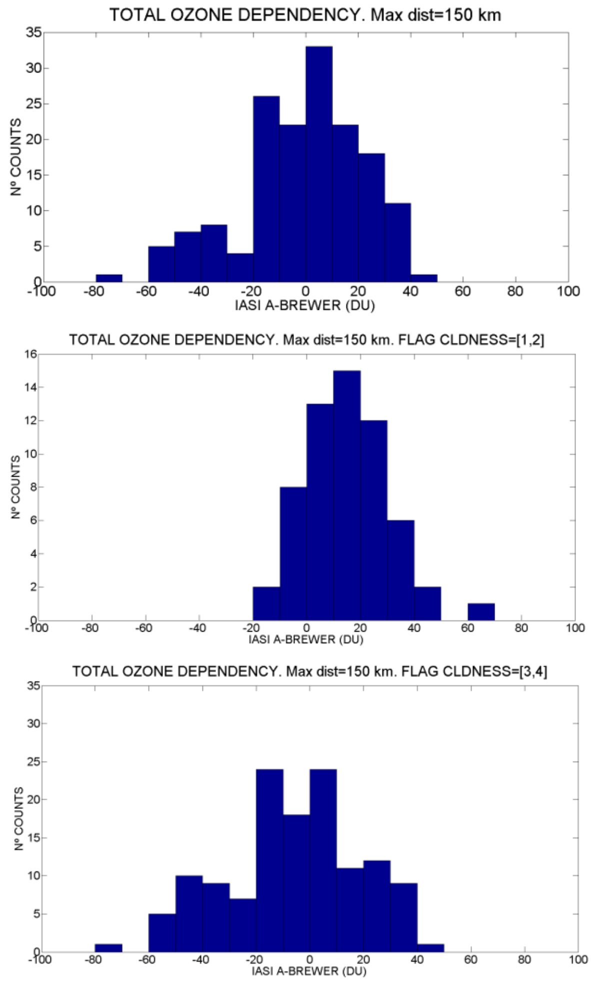

Figure 53 – Top: Daily absolute difference between Brewer and IASI-A total ozone measurements coincidences in Sodankylä from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness values. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with IASI flag cloudiness 3 and 4.

The same results have been extracted for the rest of interest collocation distances: 100 km, 50 km and 25 km, but the obtained results are very similar. The IASI-A and Brewer measurements have a high agreement with a high correlation coefficient and a low mean and standard deviation of RD, whatever the spatial and temporal criteria, even it is taken the closest IASI-A measurement. The following tables (Table 12, 13, 14, and 15) summarize the calculated statistics for each collocation distance and for each time difference between both datasets. In addition, as for the other stations, has been calculated the statistics for IASI-A and Brewer inter-comparison coincidences for IASI-A retrievals with flag cloudiness values between 1 and 2, and between 3 and 4 for a max collocation distance criteria of 150 and 50 km, also obtaining very similar results independently the spatial and temporal criteria, but with a larger agreement for IASI-A observations with flag cloudiness values between 1 and 2, than for other cases.

Statistics of coincidences for all IASI retrievals

150 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,88	-51,8	0,1	6,9	-1,2	173
6 h	0,87	-27,1	-0,1	6,5	-2,0	1224
4 h	0,86	-18,3	-0,2	6,6	-2,3	1059
3 h	0,85	-6,0	-0,2	6,8	-2,2	956
2 h	0,84	11,6	-0,4	6,9	-2,7	808
1 h	0,84	21,2	-0,5	7,0	-2,7	570

Statistics for coincidences with IASI retrievals with flg_cldness=[1,2]

150 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,96	1,4	4,5	4,7	3,3	60
6 h	0,95	4,2	3,9	4,8	11,9	455
4 h	0,95	5,0	3,8	4,8	11,3	380
3 h	0,95	5,7	3,7	4,9	11,3	328
2 h	0,94	11,1	3,7	5,2	11,3	256
1 h	0,94	19,2	3,7	3,7	11,5	165

Statistics for coincidences with IASI retrievals with flg_cldness=[3,4]

150 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,85	-63,5	-1,3	7,2	-3,6	147
6 h	0,83	-35,5	-1,9	6,6	-7,2	1009
4 h	0,81	-25,3	-2,1	6,8	-7,7	859
3 h	0,80	-13,5	-2,1	7,0	-7,7	765
2 h	0,78	5,5	-2,3	7,0	-8,2	633
1 h	0,78	8,8	-2,4	7,0	-8,1	438

Table 12 – Top: Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 150 km in Sodankylä. It is shown the Pearson Correlation Coefficient and the offset for each collocation time difference as well as the mean and standard deviation of the RD between IASI with all IASI flag cloudiness. Also it is shown the number of coincidences between two sensors, N. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Statistics for coincidences with IASI retrievals with all flg_cldness

100 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,88	-50,3	0,3	6,9	-0,9	173
6 h	0,88	-36,1	0,2	6,3	-1,1	1349
4 h	0,86	-17,6	-0,1	6,6	-2,0	1030
3 h	0,85	-6,7	-0,1	6,8	-1,8	916
2 h	0,84	11,1	-0,2	6,9	-2,0	757
1 h	0,83	22,4	-0,3	7,0	-2,2	529

Table 13 – Statistics for max collocation distance between IASI-A TOC retrievals and Brewer measurements of 100 km in Sodankylä. The Pearson Correlation Coefficient and the offset for each collocation time difference as well as the mean and standard deviation of the RD between IASI-A is shown, with the number of coincidences between two sensors, N.

Statistics for coincidences with IASI retrievals with all flg_cldness

50	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,88	-48,1	0,3	7,0	-0,9	172
6 h	0,88	-27,2	0,1	6,4	-1,3	1190
4 h	0,87	-17,7	0,1	6,5	-1,5	1007
3 h	0,86	-9,0	0,1	6,6	-1,3	888
2 h	0,85	6,4	-0,1	6,8	-1,6	710
1 h	0,84	20,4	-0,2	7,2	2,0	498

Statistics for coincidences with IASI retrievals with flg_cldness=[1,2]

50	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,96	-3,5	4,4	4,5	3,0	55
6 h	0,95	-1,7	4,0	4,6	12,20	420
4 h	0,95	-2,4	3,9	4,6	11,9	349
3 h	0,96	-2,7	3,9	4,5	12,1	300
2 h	0,95	0,7	4,1	4,6	12,5	231
1 h	0,95	6,0	4,2	4,5	13,2	150

Statistics for coincidences with IASI retrievals with flg_cldness=[3,4]

50	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,84	-48,3	-1,2	7,5	-3,5	143
6 h	0,82	-21,1	-1,8	6,7	7,0	950
4 h	0,82	-14,1	-2,0	6,8	-7,3	787
3 h	0,81	-7,3	-2,0	6,9	-7,2	686
2 h	0,80	9,6	-2,1	6,9	-7,6	541
1 h	0,78	16,9	-2,4	7,1	-8,1	370

Table 14 – Same as Table 12, but for max collocation distance of 50 km.

25 km	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Daily mean	0,88	43,1	-1,7	7,2	-3,5	158
6 h	0,87	-23,1	-1,7	6,7	5,2	1083
4 h	0,87	-11,1	-1,8	6,6	-7,4	956
3 h	0,87	-3,3	-1,9	6,5	-7,1	798
2 h	0,88	5,6	-1,9	6,4	-7,3	659
1 h	0,88	12,9	-2,0	6,3	-7,9	413

Table 15 – Same as Table 13, but for max collocation distance of 25 km.

Since the inter-comparison results are no dependent on the spatial-temporal collocation criteria established, in the following we only show the analysis for the IASI-A and Brewer coincidences on a daily basis and for a 150 km validation box for each season.

Next, it is shown the seasonal Brewer total ozone daily mean variability study and the scatter plot for each different season with the calculated statistics:

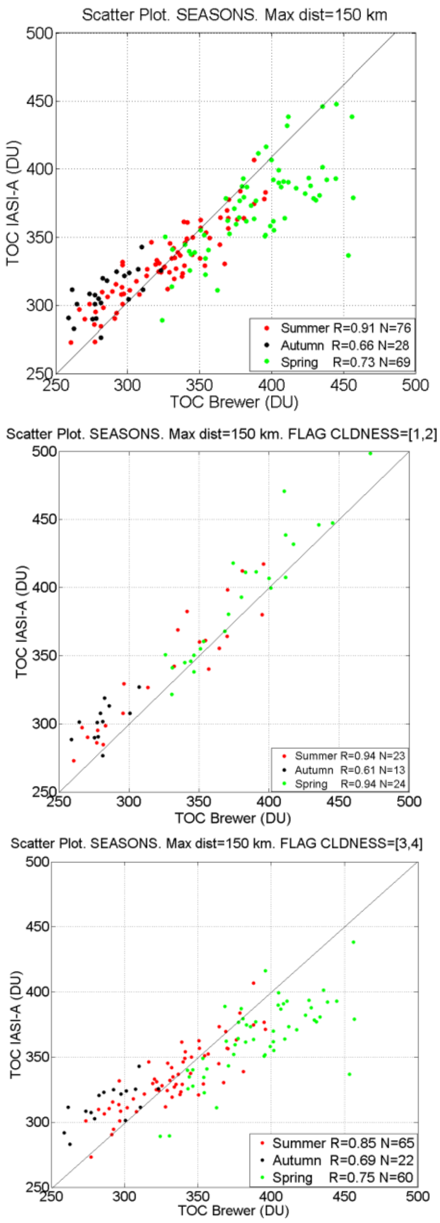

Figure 54 – Top: Scatter plot between IASI-A and Brewer TOC daily mean measurements for each season. On the legend it is shown the correlation coefficient and the number of coincidence measurements with all IASI flag cloudiness at Sodankylä. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

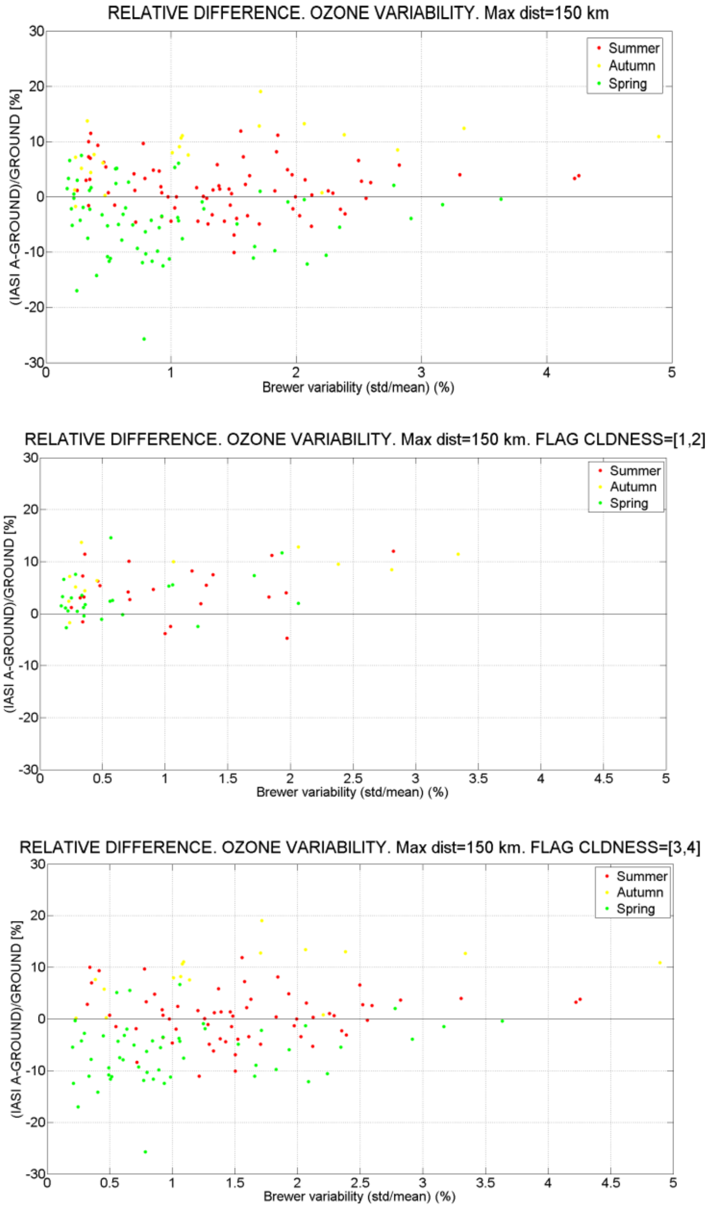

Figure 55 – Top: Brewer total ozone daily variability study for IASI-A and Brewer coincidences for each season in Sodankylä for the period of time between October 1, 2014 and September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

The following table summarizes the calculated statistics for each season with a max collocation distance of 150 km:

Statistics for coincidences with IASI retrievals with all flg_cldness

SEASONS	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,91	-42,5	1,6	4,6	4,0	76
Winter	-	-	-	-	-	0
Autumn	0,66	59,7	8,2	5,1	17,9	28
Spring	0,75	119,1	-4,3	6,4	-16,3	69

Statistics for coincidences with IASI retrievals with flg_cldness=[1,2]

SEASONS	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,94	1,4	4,4	4,7	13,5	23
Winter	-	-	-	-	-	0
Autumn	0,69	110,2	7,5	4,5	19,2	13
Spring	0,94	69,2	3,1	4,2	12,2	24

Statistics for coincidences with IASI retrievals with flg_cldness=[3,4]

SEASONS	Correlation coefficient	OFFSET (DU) y-intercepts	Mean RD (%)	Standard Deviation RD (%)	BIAS (DU)	N
Summer	0,85	-21,4	0,6	4,8	1,0	65
Winter	-	-	-	-	-	0
Autumn	0,61	8,1	8,9	5,3	18,1	22
Spring	0,73	113,0	-6,5	5,7	-23,5	60

Table 16 – Top: Statistics for max collocation distance of 150 km for each season, between IASI-A TOC retrievals and Brewer TOC measurements with all IASI flag cloudiness at Sodankylä. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Comparison between IASI-A and Brewer shows a high agreement between two sensors for all seasons with all IASI-A observation cloudiness conditions. The agreement between two datasets is high with correlation coefficient of 0.91 in summer, 0.73 in spring and 0.66 in autumn and a standard deviation of relative differences of 4.6% in summer, 6.4% in spring and 5.1% in autumn. But the agreement for the inter-comparison with filtered IASI-A observations for flag cloudiness values between 1 and 2 is higher (correlation coefficient and standard deviation of relative differences of 0.94 and 4.7%, respectively in summer, 0.94 and 4.2% in spring and correlation coefficient of 0.69 and standard deviation of RD of 4.5% in autumn) while for filtered IASI-A observations for flag cloudiness values between 3 and 4 results show a lower agreement between two sensors measurements with a coefficient correlation of 0.85 and standard deviation of RD of 4.8 in summer, 0.75 and 5.7% in spring and 0.61 and 5.3 in autumn. So in seasons where the cloudiness is higher as in autumn and spring agreement between two sensors measurements can be improve filtering IASI retrievals by cloudiness conditions. Note that the BIAS shows a clear seasonal pattern: during the spring IASI underestimates the actual observations, while for the rest of year we observe the contrary behaviour. Although the IASI sensitivity increase during the spring/summer, it is not good enough to capture the annual increase of ozone amounts during these seasons.

The next graphic shows the analysis of the relative difference between IASI-A and Brewer spectrophotometer coincidences as function of Brewer TOC measurements for all cloudiness conditions:

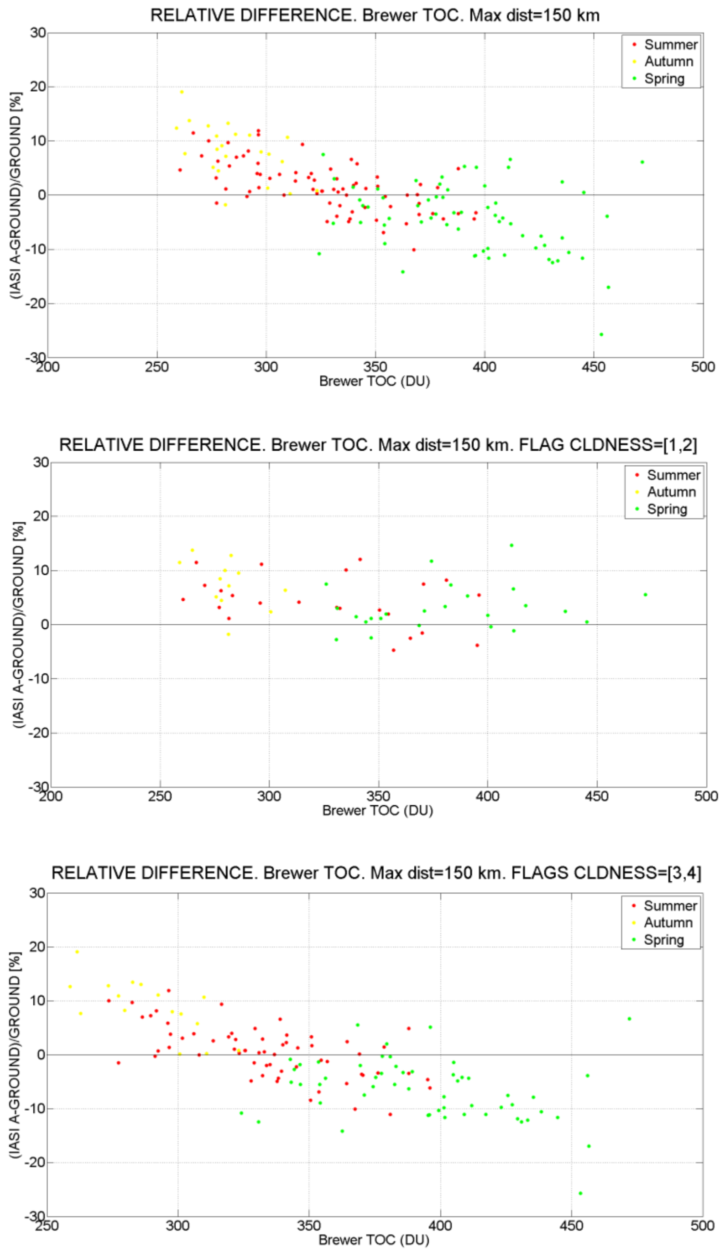

Figure 56 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of Brewer TOC data at Sodankylä with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Figure 56 shows as on spring TOC values measured by Brewer spectrophotometer are higher at Sodankylä than for the rest of seasons, again, the same result as for Thessaloniki and IZO.

Next, it is shown the seasonal variations for the solar zenith angle measured by both sensors and the IASI-A viewing zenith angle:

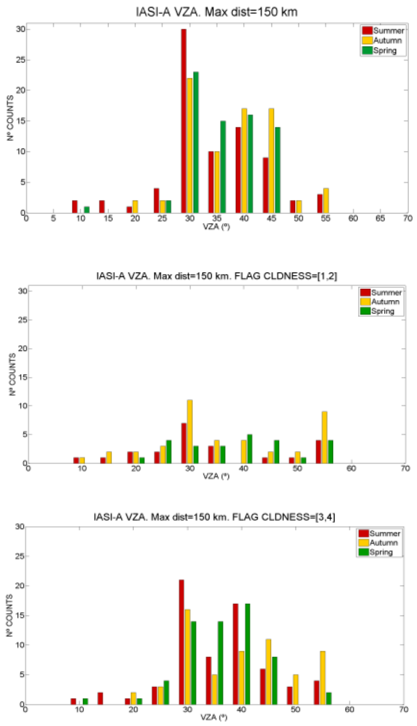

Figure 57 – Top: IASI-A viewing zenith angle measured in Sodankylä for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

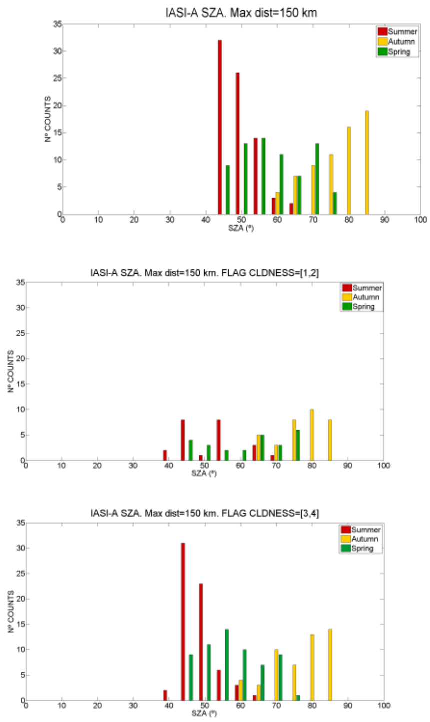

Figure 58 – Top: IASI-A solar zenith angle measured in Sodankylä for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

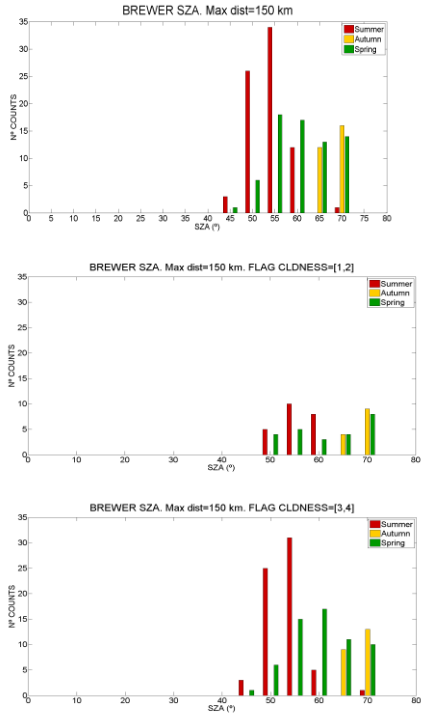

Figure 59 – Top: Brewer solar zenith angle measured in Sodankylä for the period of time from October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Figure 60 –Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of IASI-A viewing zenith angle with all IASI flag cloudiness in Sodankylä. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

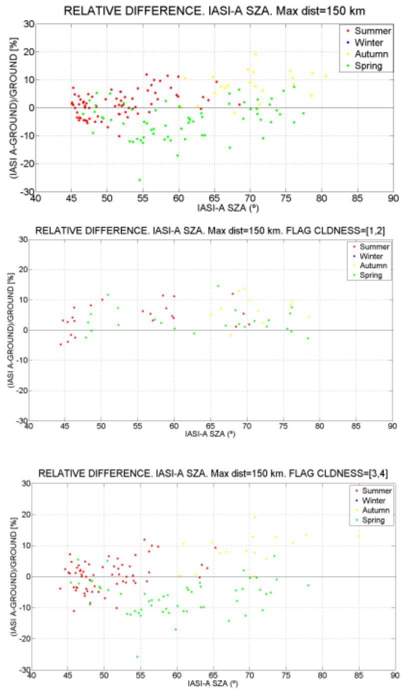

Figure 61 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of IASI-A solar zenith angle with all IASI flag cloudiness in Sodankylä. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Figure 62 –Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of Brewer solar zenith angle in Sodankylä. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

As shown Figure 57, 58, 59, 60, 61 and 62 the bigger discrepancies IASI-A and Brewer data are found in spring and autumns when the cloudiness is higher. In addition, the relative differences between two sensors ozone data have its maximum of 10% for low SZA and 20% for high SZA founding the higher discrepancies when the cloudiness is higher, so, discrepancies are higher for IASI-A retrievals with flag cloudiness between 3 and 4 than for retrievals with flag cloudiness between 1 and 2.

Finally, it is shown the seasonal study of the clouds parameters of interest for the satellite validation: cloud fraction and cloud top pressure:

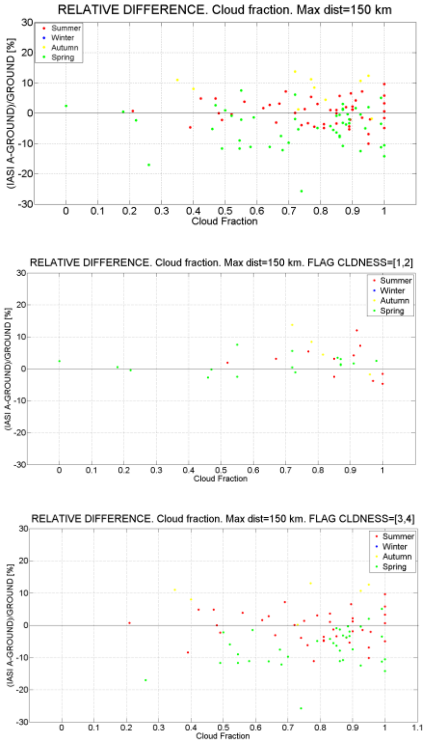

Figure 63 – Top: Evolution of the relative differences between total ozone column data retrieved by IASI-A and Brewer spectrophotometer as function of cloud fraction cover with all IASI flag cloudiness in Sodankylä. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4. Where: 0=transparent and 1=opaque.

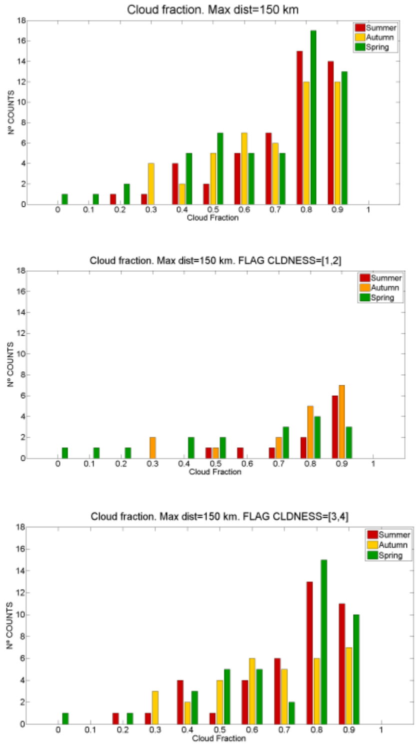

Figure 64 – Top: Cloud fraction measured by IASI-A in Sodankylä for October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Where: 0=transparent and 1=opaque. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

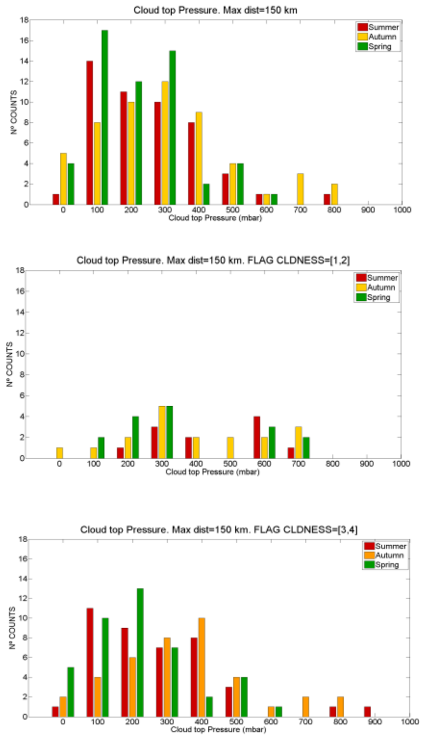

Figure 65 – Top: Cloud top pressure measured by IASI-A in Sodankylä for October 1, 2014 to September 30, 2015 with all IASI flag cloudiness. Middle: Same as Top, but with IASI flag cloudiness 1 and 2. Bottom: Same as Top, but with flag cloudiness 3 and 4.

Histograms of the characteristics of the clouds retrieved by IASI-A in Sodankylä for the coincidences between two sensor for whole studied year by seasons are shown on Figure 63, 64 and 65.

4 SUMMARY TABLE

GROUND-BASE STATION CHARACTERISTICS							ALL FLAG CLDNESS					FLAG CLDNESS=[1,2]					FLAG CLDNES=[3,4]				
STATION	Lat. (º)	Lon. (º)	Elevation (m a.l.s)	Nº Brewer	Spatial collocation	Temporal collocation	Correlation coefficient	Mean RD (%)	STD RD (%)	BIAS (DU)	N	Correlation Coefficient	Mean RD (%)	STD RD (%)	BIAS (DU)	N	Correlation Coefficient	Mean RD (%)	STD RD (%)	BIAS (DU)	N
Thessaloniki	40.63º N	22.96ºE	36	#005	150 km	Daily mean	0,88	0,6	5,5	1,1	309	0,94	2,2	4,0	6,0	138	0,87	-1,2	6,4	-2,1	171
IZO	28.31º N	16.50ºW	2367	#185	150 km	Daily mean	0,63	0,3	6,0	-0,2	327	0,55	1,3	6,2	1,5	158	0,72	-0,6	5,7	-1,3	169
Sodankylä	67.42°N	26.59°E	180	#037	150 km	Daily mean	0,88	0,1	6,9	-1,2	173	0,96	4,5	4,7	3,3	60	0,85	-1,3	7,2	-3,6	123

GROUND-BASE STATION CHARACTERISTICS								ALL FLAG CLDNESS					FLAG CLDNESS=[1,2]					FLAG CLDNES=[3,4]				
STATION	Lat. (º)	Lon. (º)	Elevation (m a.l.s)	Nº Brewer	Spatial collocation	Temporal collocation	SEASON	Correlation coefficient	Mean RD (%)	STD RD (%)	BIAS (DU)	N	Correlation Coefficient	Mean RD (%)	STD RD (%)	BIAS (DU)	N	Correlation Coefficient	Mean RD (%)	STD RD (%)	BIAS (DU)	N
Thessaloniki	40.63º N	22.96º E	36	#005	150 km	Daily mean	Summer	0,75	1,6	4	4,9	76	0,87	2,9	2,9	9,1	55	0,64	-1,1	5,5	-4,1	24
							Winter	0,88	1,4	6,2	3,5	75	0,93	2,5	4,9	8,0	28	0,78	0,1	7,4	-0,2	48
							Autumn	0,70	1,1	4,8	2,3	82	0,75	0,9	4,5	2,7	30	0,7	1	4,9	-1,7	56
							Spring	0,74	-2,2	6,5	-6,6	76	0,93	2	4,5	7,2	25	0,74	-4,8	6,5	-13,1	52
IZO	28.31º N	16.50º W	2367	#185	150 km	Daily mean	Summer	0,69	2,0	5,9	8,3	79	0,66	2,5	6,3	9,6	50	0,79	1,3	5,1	6,1	29
							Winter	0,73	0,7	5,9	1,7	89	0,76	2,7	6,3	7,0	26	0,74	-0,1	5,6	-0,4	63
							Autumn	0,79	1,6	3,1	4,5	73	0,81	2,1	2,9	5,8	34	0,78	1,2	3,2	3,4	39
							Spring	0,47	-3,2	7	-10,4	84	0,32	-1,5	7,4	-4,9	46	0,58	-4,9	6,2	-17,1	38
Sodankylä	67.42°N	26.59°E	180	#037	150 km	Daily mean	Summer	0,91	1,6	4,6	4	76	0,94	4,4	4,7	14,0	23	0,85	0,6	4,8	1,0	65
							Winter	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0
							Autumn	0,66	8,2	5,1	17,9	28	0,69	7,5	4,5	19,0	13	0,61	8,9	5,3	18,1	22
							Spring	0,75	-4,3	6,4	-16,3	69	0,94	3,1	4,2	12,0	24	0,73	-6,5	5,7	-23,5	60

5 CONCLUSIONS

In this work we present an operational methodology to validate space-based total ozone column (TOC) retrievals using coincident observations from ground-based Brewer spectrophotometers belonging to the European Brewer network Eubrewnet. As a demonstration, we have used the EUMETSAT IASI/Metop-A Version 6 TOC data for the mid-latitude Thessaloniki station (Greece), the sub-tropics Izaña Atmospheric Observatory (Spain) and high latitude Sodankylä station (Finland) during the 1-year period from October 1, 2014 to September 30, 2015.

In summary, the TOC comparison as retrieved by IASI-A v6 to coincident ground-based Brewer observations show very consistent results at three stations, thereby a latitudinal dependence of the IASI precision might be regretted. Furthermore, the inter-comparison results are shown not to be dependent on the collocation criteria used: results are very similar for 150 km and daily mean than for 25 km and 1 hour of time difference between two datasets. This is likely due to the TOC daily variability is not so high in three stations (in general lower than 5%). Regarding the impact of observing geometry, we found that the relative differences between both instruments could be maxima for extreme solar zenith angles, while the minimum differences are observed for intermediate SZA (40º-55º). Finally, it has been shown that both techniques reveal very similar annual seasonality, with the exception of spring, when large discrepancies are found for three stations, founding in Sodankylä larger discrepancies in autumn too probably because high cloudiness conditions. Also, the IASI behavior in spring is the opposite to that observed during the rest of year: IASI overall overestimates the Brewer TOC values except in spring for all of three stations considered. Nevertheless, further analysis would be needed to extract robust conclusions, such as analyzing topography and the surface type (land/water) using a larger period of time.

Finally, we would like to remark that Brewer spectrometers have proved to be a very useful tool to validate any space-based TOC products with a high precision.

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