IASI EOF and ANN Retrieved Total Columnar Amounts Ozone, Compared to Ozone Sonde and Brewer Spectrometer Measurements from the Lindenberg and Sodankylä Validation Campaigns

Olusoji O. Oduleye, Thomas August, Arlindo Arriaga, Xavier Calbet, Peter Schlüssel and Tim Hultberg
EUMETSAT
Aulamo Osmo[1], Rigel Kivi[1], Bernd Stiller[2] Klemens Barfus[2]
[1]Finnish Meteorological Institute, [2]Deutscher Wetterdienst

Abstract

The geophysical parameters retrieved by the operational level 2 PPF (*product processing facility*) of the IASI (*Infrared Atmospheric Sounding Interferometer*) instrument flying on Metop A include total and partial (0-6km, 0-12km and 0-16km) columnar amounts of ozone. The retrieval methods used in the IASI L2 PPF include statistical retrievals and an optimal estimation method based on RTIASI-4 as a forward model and climatology as a priori background. The optimal estimation process is initialised with the results from the statistical retrievals.

Two validation campaigns for IASI measurements were carried out at Lindenberg (14.1° E, 52.2° N) between June and August 2007; and at Sodankylä (26.6° E, 67.4° N) between June and September 2007. During these periods ozone sondes were launched three times per week for each campaign. Here we present the results of IASI L2 processor EOF (*Empirical Orthogonal Functions*) and ANN (*Artificial Neural Network)* retrieved total columnar amounts of ozone with measurements from these campaigns. A further comparison with Brewer spectrometer point-measurements at the campaign sites is carried out.

INTRODUCTION

In addition to an optimally estimated retrieval, the IASI L2 processor implements two statistical retrieval schemes for ozone and other trace gases, they are ANN and EOF retrievals. Currently, the operational IASI Level 2 products contain partial and total columnar amounts ozone from one of the two statistical retrievals.

Two validation campaigns were carried out in 2007, one by the Finnish Meteorological Institute, Artic Research Centre, Sodankylä (67.4 ˚N, 26.6 ˚E) between 4 June 2007 and 5 September 2007; and the other by the Deutscher Wetterdienst Meteorologisches Observatorium, Lindenberg (52.2 ˚N, 14.1 ˚E) between 1 June 2007 and 31 August 2007.

OPERATIONS

Balloon borne measurements of vertical profiles of ozone concentration using Vaisala ECC (*Electrochemical Concentration Cell*) ozone sondes and continuous surface measurements of total columnar amount ozone using Brewer spectrometers were carried out at the two sites during the campaign.

There were three ozone sonde launches per week at the Sodankylä site—a total of forty launches during the entire campaign. All ozone sonde launches were performed in synchronisation with Metop

satellite overpasses on Mondays, Wednesdays and Fridays. The sondes were launched one hour before the satellite's morning overpass. There were three ozone sonde launches per week at the Lindenberg site; the launches were at noon on Mondays, Wednesdays and Fridays. The summaries of ozone sonde launches and total columnar amounts as measured by the sondes for both campaign sites are given in tables 1 and 2 below. The table includes processed cases only. The sondes attained a typical burst height of 5-8 hPa at the Lindenberg campaign site and 6-10 hPa at Sodankylä; this corresponds to about 32 km at both sites.

LINDENBERG 52.21N; 14.12E		
Sonde Launch Time (UTC)	**Overpass Time (UTC)**	**Total Columnar Amount (kg m^{-2})**
2007-06-01_11:19:00	2007-06-01_09:14:58	0.008093
2007-06-04_10:51:00	2007-06-04_09:52:53	0.006979
2007-06-06_10:50:00	2007-06-06_09:11:32	0.007337
2007-06-08_10:47:00	2007-06-08_19:58:01	0.007231
2007-06-13_10:53:00	2007-06-13_19:54:29	0.007908
2007-06-15_10:50:00	2007-06-15_09:25:16	0.007414
2007-06-18_10:49:00	2007-06-18_19:51:01	0.007668
2007-06-20_10:50:00	2007-06-20_09:21:49	0.007335
2007-06-22_10:47:00	2007-06-22_08:40:16	0.007488
2007-06-25_10:54:00	2007-06-25_09:18:21	0.007235
2007-06-27_11:02:00	2007-06-27_20:04:49	0.007665
2007-06-29_10:56:00	2007-06-29_09:35:35	0.007294
2007-07-04_10:53:00	2007-07-04_09:32:07	0.008498
2007-07-06_10:46:00	2007-07-06_08:50:38	0.008340
2007-07-09_11:00:00	2007-07-09_09:28:39	0.006598
2007-07-11_11:06:00	2007-07-11_08:47:09	0.008318
2007-07-13_11:03:00	2007-07-13_09:45:52	0.005050
2007-07-16_10:45:00	2007-07-16_08:43:55	0.006409
2007-07-18_11:05:00	2007-07-18_09:42:40	0.006796
2007-07-20_10:51:00	2007-07-20_09:01:01	0.006530
2007-07-23_10:51:00	2007-07-23_09:39:00	0.006695
2007-07-25_10:52:00	2007-07-25_08:57:34	0.007083
2007-07-27_10:53:00	2007-07-27_09:56:12	0.007214
2007-07-30_10:50:00	2007-07-30_08:54:07	0.008235
2007-08-01_11:23:00	2007-08-01_09:52:46	0.007032
2007-08-03_10:51:00	2007-08-03_09:11:25	0.008469
2007-08-06_11:10:00	2007-08-06_09:49:20	0.006702
2007-08-08_10:59:00	2007-08-08_09:07:58	0.007687
2007-08-13_10:45:00	2007-08-13_09:04:31	0.006409
2007-08-15_10:51:00	2007-08-15_19:51:00	0.006636
2007-08-17_10:49:00	2007-08-17_09:21:48	0.007134
2007-08-22_10:54:00	2007-08-22_09:18:21	0.007216
2007-08-27_10:52:00	2007-08-27_09:14:54	0.006424
2007-08-29_10:50:00	2007-08-29_20:01:22	0.007029
2007-08-31_10:49:00	2007-08-31_09:32:09	0.006990

Table 1: **Summary of ozone sonde launch times, Metop overpass times and total columnar amount ozone as measured by sondes at the Lindenberg campaign site.**

Ozone profiles were measured by ECCs interfaced to Vaisala RS92 PTU (*Pressure Temperature and hUmidity*) radio sondes, thus providing accurate measurement of air pressure, temperature and

humidity synchronised with ozone profile concentration. The ECCs have an accuracy of < 5% in the 16-26 km range; < 10% near the tropopause and < 12 % in the 26-31 km range (Komhyr et al., 1995). The errors in the PTU measurements are as follows ± 0.1 K in the height range surface to 30 hPa, it has a stability of ± 0.2 K in the temperature range 203.16 K to 303.16 K (Vaisala 2004).

Continuous measurement of total columnar amount ozone was provided by a Brewer MKII spectrophotometer. It uses five wavelengths in the range 306.3 to 320.1 nm for standard ozone retrieval and has an accuracy of ± 1% for direct-sun total ozone retrieval (Kyro E 1993).

SODANKYLA 67.37N; 26.63E		
Sonde Launch Time (UTC)	**Overpass Time (UTC)**	**Total Columnar Amount (kg m^{-2})**
2007-06-04_07:08:02	2007-06-04_08:08:00	0.006036
2007-06-06_08:06:38	2007-06-06_09:06:51	0.006994
2007-06-08_07:25:18	2007-06-08_08:25:19	0.006777
2007-06-13_09:02:05	2007-06-13_10:02:04	0.007957
2007-06-18_08:59:52	2007-06-18_09:58:37	0.008241
2007-06-20_08:17:14	2007-06-20_09:17:14	0.000651
2007-06-22_07:35:43	2007-06-22_08:35:42	0.007928
2007-06-25_08:13:44	2007-06-25_09:13:46	0.006898
2007-06-27_07:32:12	2007-06-27_08:32:13	0.007819
2007-06-29_08:31:14	2007-06-29_09:31:02	0.007321
2007-07-02_07:28:44	2007-07-02_08:28:44	0.006839
2007-07-04_08:27:55	2007-07-04_09:27:34	0.007117
2007-07-06_07:46:03	2007-07-06_08:46:04	0.006771
2007-07-09_08:24:08	2007-07-09_09:24:06	0.006913
2007-07-11_07:46:45	2007-07-11_08:42:35	0.006209
2007-07-16_07:39:10	2007-07-16_08:39:12	0.006324
2007-07-27_07:12:22	2007-07-27_08:11:21	0.006840
2007-07-30_07:49:32	2007-07-30_08:49:32	0.006963
2007-08-01_08:48:15	2007-08-01_09:48:15	0.003958
2007-08-07_08:26:13	2007-08-07_09:24:07	0.005626
2007-08-08_08:03:24	2007-08-08_09:03:23	0.005600
2007-08-10_09:02:03	2007-08-10_10:02:02	0.006120
2007-08-13_07:59:58	2007-08-13_08:59:56	0.006001
2007-08-15_08:59:56	2007-08-15_09:58:36	0.006332
2007-08-17_08:17:12	2007-08-17_09:17:14	0.006106
2007-08-20_08:55:28	2007-08-20_09:55:09	0.006644
2007-08-24_07:32:14	2007-08-24_08:32:14	0.006388
2007-08-27_08:10:50	2007-08-27_09:10:19	0.006618
2007-08-29_07:28:54	2007-08-29_08:28:46	0.002349
2007-08-31_08:27:35	2007-08-31_09:27:35	0.007208
2007-09-03_07:26:05	2007-09-03_08:25:17	0.006484
2007-09-05_08:24:10	2007-09-05_09:24:08	0.006098

Table 2: **Summary of ozone sonde launch times, Metop overpass times and total columnar amount ozone as measured by sondes at the Sodankylä campaign site.**

PROCESSING

Due to incomplete information about the ozone profile above the burst height, profiles from Numerical Weather Prediction (*NWP*) analysis of the European Centre for Medium Range Weather Forecast

(*ECMWF*) have been employed to complement the ozone information at higher altitudes. Figure 1 below shows a typical ozone profile as measured by ozone sonde compared with a NWP ozone profile for 20070609 at Sodankylä.

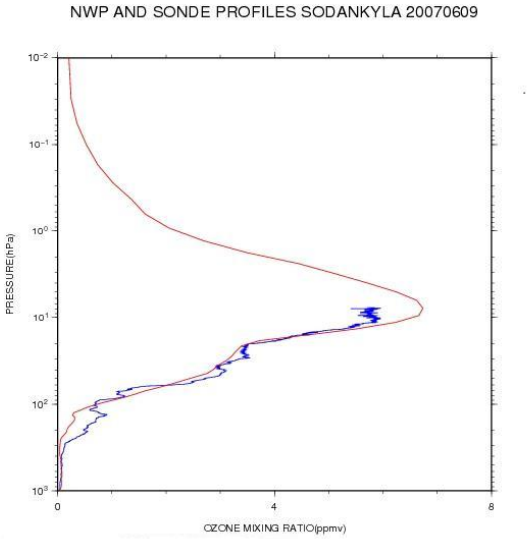

Figure 1: **Sonde vertical profile ozone concentration compared with NWP analysis vertical ozone profile measured at Sodankylä on 20070609.**

The sonde profile has a much higher vertical resolution than the NWP profile and it contains higher frequency components owing to its much higher sampling rate— one sample every two seconds. The total sonde flight time is approximately two hours; the burst height is around 10 hPa, close to the maximum of the ozone concentration.

Smoothing

In order to obtain the total columnar amount of ozone the sonde profile needs to be smoothed and then extended to the top of the atmosphere (*TOA*). Two methods were considered for the extension of the profiles: the first method, the Constant Mixing Ratio (*CMR*) method, assumes a constant ozone mixing ratio from the burst height to the TOA; the second method complements the sonde profile with a NWP analysis profile. The NWP profile is obtained by interpolating available analysis profiles to the sonde launch time. The latter method has been used in this study. The CMR method has been used by Kivi et al, 2008 to obtain a Brewer/sonde total ozone ratio of 0.989 ± 0.024 for the campaign measurements at Sodankylä.

Filtering

The filtering method adopted consists of passing the sonde profile through a suitable low pass filter and rejecting high frequency components not present in the NWP profile and then resampling and interpolating the data onto the NWP vertical pressure grid, thereby harmonising the vertical resolutions of the two data sets. The resulting profile is the integrated to obtain the total columnar amount, which is then compared to IASI retrieved amounts.

.

Instantaneous Field of View (*IFOV*) Selection

Several sophisticated cloud detection algorithms are implemented operational IASI level 2 processor, the results of these are indicated by flags in the operational level 2 product. Only those IASI IFOVs which are identified as cloud free by all cloud tests are included in the analysis.

RESULTS

Variability in Total Columnar Amount Ozone

Figure 2 below show the wide variation in total columnar amount ozone over the Lindenberg site during the entire campaign. The variation is between 0.0064 and 0.0075 kg m^{-2} (299 – 350 DU) for clear IASI IFOVs only.

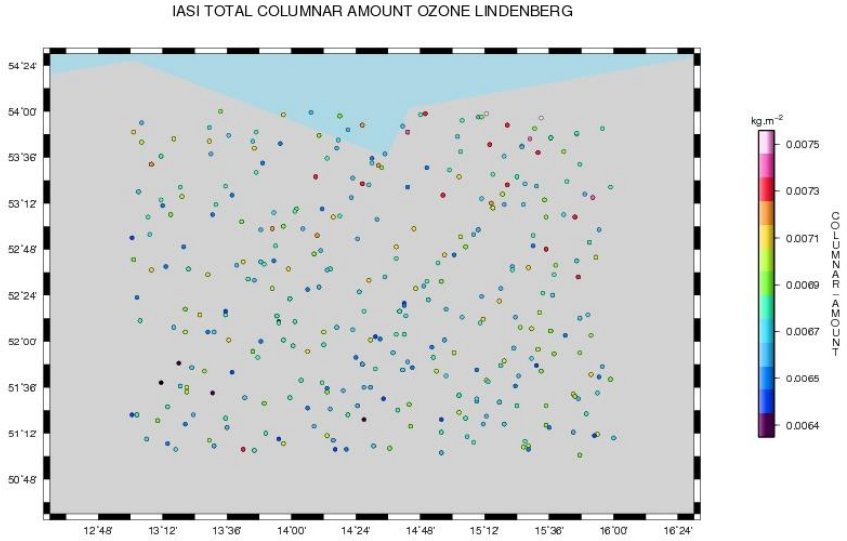

Figure 2: **Variation in total columnar amount of ozone over Lindenberg between 20070601 and 20070831**

Figure 3 below show the wide variation in total columnar amount ozone over the Sodankylä site during the entire campaign. The variation is between 0.0069 and 0.0079 kg m^{-2} (322- 370 DU) for clear IASI IFOVs only.

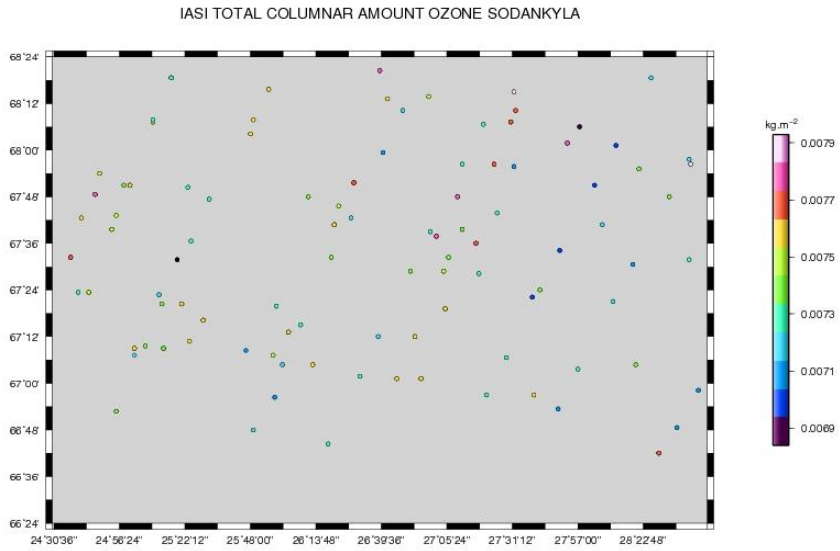

***Figure 3*: Variation in total columnar amount of ozone over Sodankylä between 20070604 and 20070905**

For both sites the criterion for 'clear' has been based on IASI L2 cloud detection only. Data from auxiliary surface instruments such as microwave profilers, GPS, Ka-band radar, Global Surfaced Observing Network (*GSN*) and Automatic Weather Stations (*AWS*) have not been used to determine the cloudiness of the sky.

Total Columnar Amount Ozone: IASI vs. Sondes

In figures 4 and 5 below each bunch of IASI IFOVs has been matched to single sonde launch. The criteria for matching is that the IFOVs lie within a square of sides ±100 km (this being the range over which an ozone sonde can drift over its two-hour flight) centred around the launch site and that the sonde launch time is within two hours of the satellite overpass.

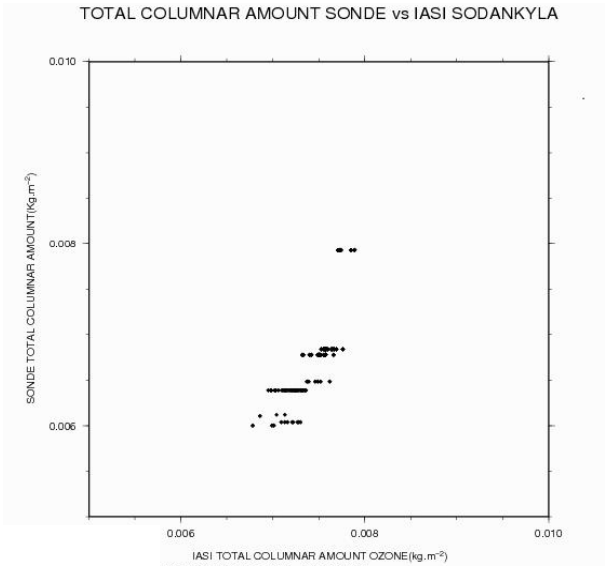

Figure 4: **Total columnar amount ozone sonde vs. IASI Sodankylä**

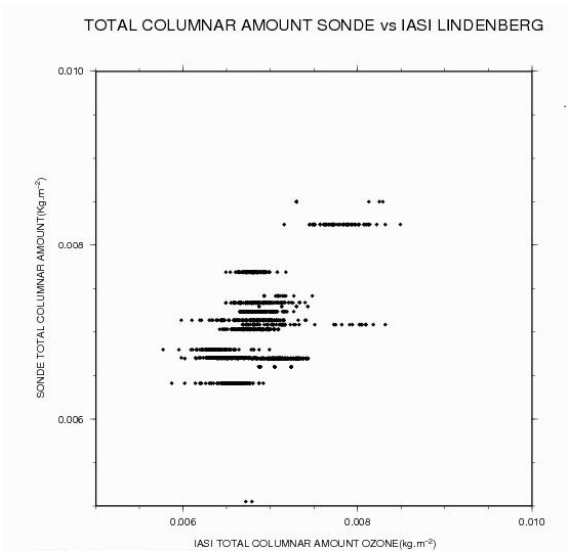

Figure 5: **Total columnar amount ozone sonde vs. IASI Lindenberg**

Total Columnar Amount Ozone: IASI vs. Brewer Spectrometer

Depending on weather conditions continuous Brewer spectrometer measurements were carried out at both sites throughout the campaigns. Figures 6 and 7 below show a good correlation between total columnar amounts as measured by IASI and Brewer spectrometer at the two sites, but also systematic deviations consisting of an overestimation of low ozone amounts by IASI.

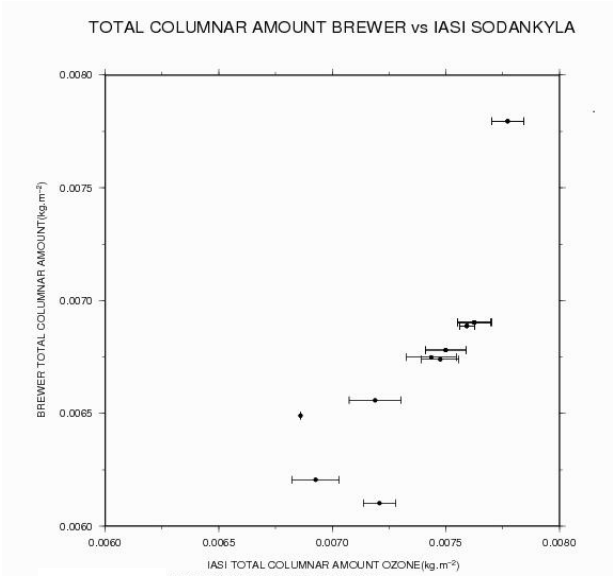

Figure 6: **Total columnar amount ozone Brewer Spectrometer vs. IASI Sodankylä**

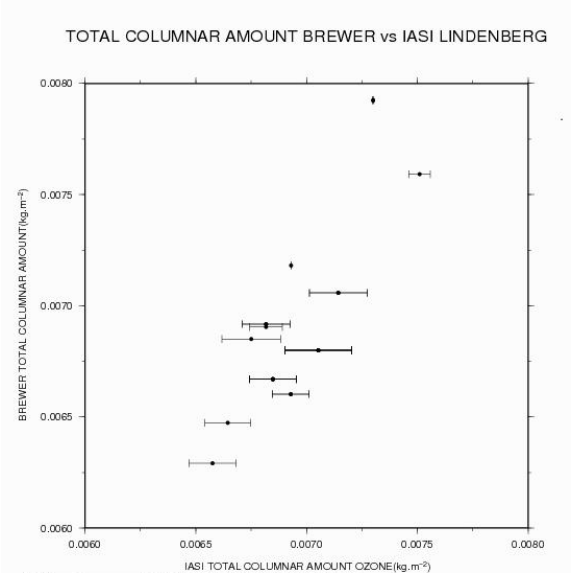

Figure 7**: Total columnar amount ozone Brewer Spectrometer vs. IASI Lindenberg**

DISCUSSION, CONCLUSIONS AND FUTURE WORK

Inter-comparisons of IASI EOF and ANN retrieved total columnar amount ozone, ozone sondes and Brewer spectrometers have been carried out for two validation campaigns carried out at Lindenberg between June and August 2007 and at Sodankylä between June and September 2007. Over these periods high variability in the measured total columnar amounts was observed at the two sites. IASI IFOVs were screened so that only those deemed clear by the processing facility's cloud detection algorithms were selected. Cloud information from auxiliary surface based instruments has not been used in this work.

While the results show good correlations between sonde and IASI as well as Brewer and IASI measurements, IASI is seen to overestimate low ozone amounts. Owing to the burst heights of the sondes a bias is seen between the sonde and IASI measurements for the two methods of extending the sonde profiles to the TOA. The typical mean difference between IASI and Brewer spectrometer measurements is 7 $x10^{-4}$ kg m^{-2} (32 DU) with a typical standard deviation of 7 $x10^{-5}$ kg m^{-2} (3.2 DU).

Future work will include expanding the analysis to the 0-6 km, 0-12 km, and 0-16 km ozone sub-columns; and also to columns derived from GOME2-retrived ozone profiles; OMI and SCIAMACHY data.

REFERENCES

Kivi R E, Kyro E, Turunen T, Harris N R P, von der Gathen P, Rex M, Andersen S B and Wohltmann I, 2007, Ozonesonde observations in the Artic during 1989-2003: Ozone variability and trends in the lower stratosphere and free troposphere, J. Geophysical Research, 112, D08306, doi:1029/2006JD007271

Kivi R E, 2008, Private communication (e-mail)

Komhyr W D, Barnes R A, Brothers G B, Lathrop JA and Oppermann D P, 1995, Electrochemical concentration cell ozonesonde performance evaluation during STOIC 1989, J. Geophysical Research, 100, 9231-9244

Kyro E, 1993, Intercomparison of total ozone data from Nimbus 7 TOMS, the Brewer UV spectrophotometer at high latitudes observatory, Sodankylä, Geophysical Research Letters, 20, 571-574

The Deutscher Wetterdienst Meteorologisches Observatorium (*DWD*), Lindenberg, 2007 Campaign Plan EUMETSAT Polar System Programme

The Finnish Meteorological Institute (*FMI*), Artic Research Centre, Sodankylä, 2007 EUMETSAT Polar System Atmospheric Sounding Campaign Final Report, EUM.EPS.FMI.FR1

Tsou J J, Connor B J, Parrish A, McDermid I S and Chu W P, 1995, Ground-based microwave monitoring of middle atmosphere ozone: Comparison to lidar and stratospheric aerosol and Gas Experiment II satellite observations, J. Geophysical. Research 100(D2):3005-3016.

Vaisala, 2004, Digital Radiosonde RS92-AGP Users Guide M210 502en-B