Satellite Monitoring of Ash and Sulphur Dioxide for the mitigation of Aviation Hazards: Part I. Validation of satellite-derived Volcanic Ash Levels.

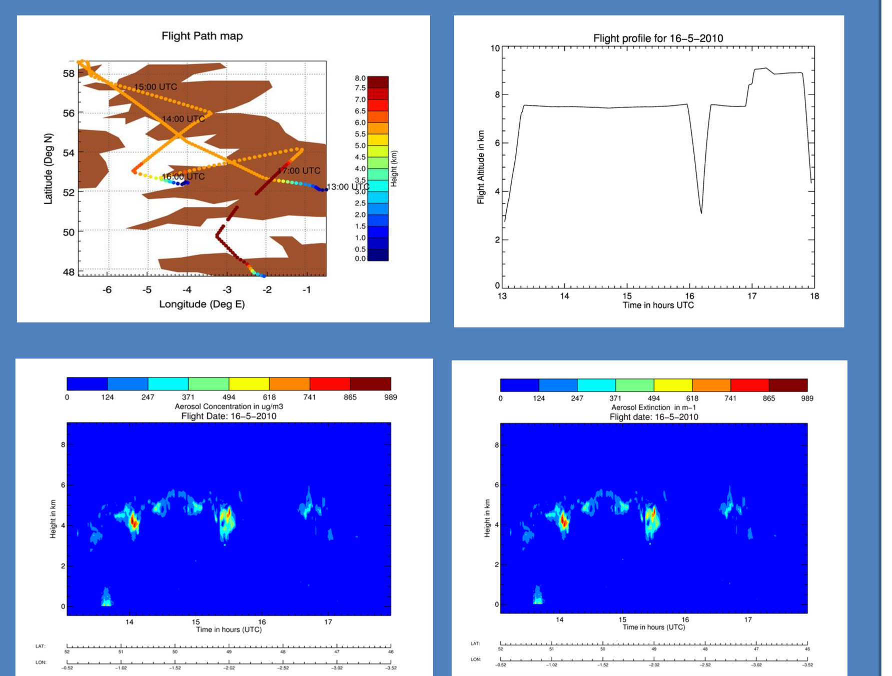
Koukouli, M. E.[1*], Balis, D. S.[1], Dimopoulos, S.[1], Siomos, N. [1], Clarisse, L.[2], Carboni E.[3], Wang, P.[4], Siddans, R. [5], Marenco, F.[6], Mona, L.[7], Pappalardo, G.[7], Spinetti C.[8] , Theys, N.[9], Tampelini, L.[10], Zehner, C.[11]

1 Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Greece.
2 Université Libre de Bruxelles, Brussels, Belgium.
3 University of Oxford, Atmospheric, Oceanic & Planetary Physics Clarendon Laboratory, Oxford, UK.
4 Royal Netherlands Meteorological Institute, De Bilt, The Netherlands.
5 Rutherford Appleton Laboratory, Oxford, U.K.
6 Observational Based Research, Met Office, U.K.
7 Istituto di Metodologie per l'Analisi Ambientale, Potenza, Italy.
8 Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy.
9 Belgian Institute of Aeronomie, Brussels, Belgium.
10 Compagnia Generale per lo Spazio, Milano, Italy.
11 European Space Agency – ESRIN, Frascati, Italy.

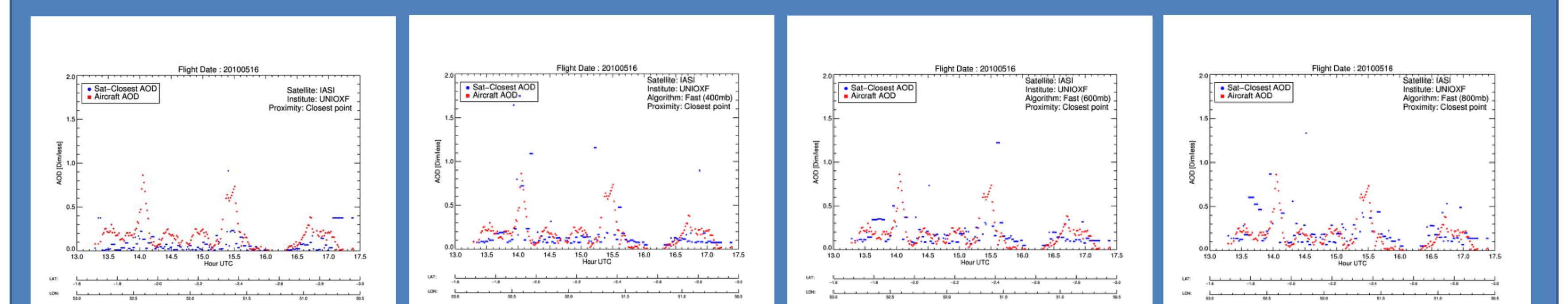
*corresponding author e-mail: mariliza@auth.gr

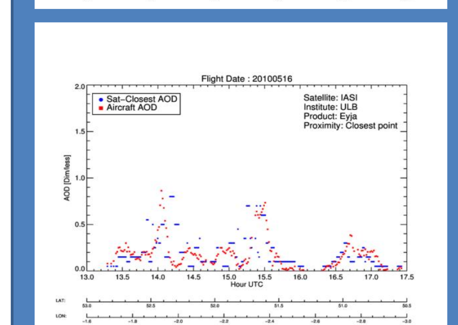
Satellite to aircraft-borne LIDAR comparisons

Research flights, over the United Kingdom and surrounding sea regions, were conducted during the Eyjafjallajokull May 2010 eruption from the UK's Bae-146-301 Atmospheric Research Aircraft managed by the Facility for Airborne Atmospheric Measurements. Lidar measurement variables from the 14th, 16th and 17th of May on a per flight basis are analyzed. The values of these variables were compared with the satellite product values of aerosol Optical Depth and aerosol Layer Height over a cross-section of variable radius from 50km to 200km. The closest point value in terms of spatial proximity for every path location was also found and presented. Since most of the satellite data overpass around 10:00 L.T., in order to have co-locations, only spatial criteria where used.



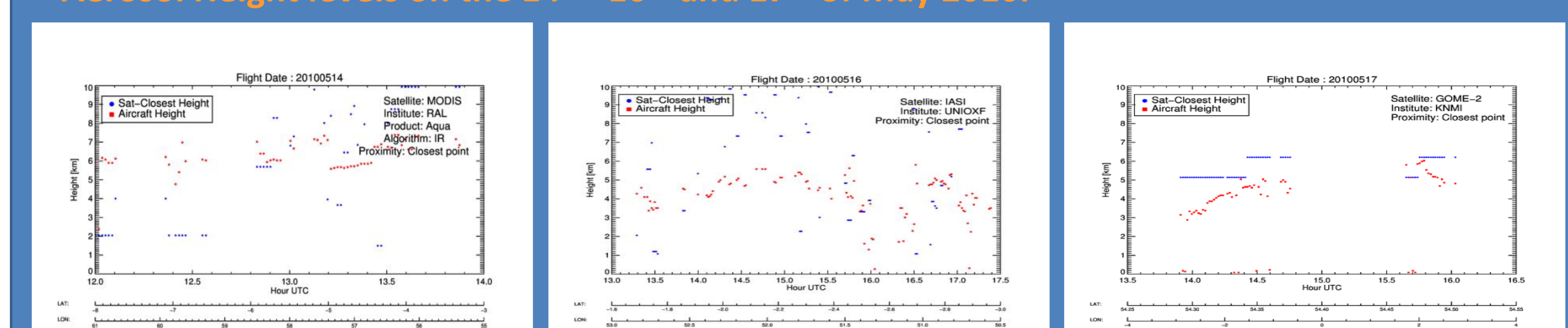
AOD levels on the 16th of May 2010. Details of the flight are shown in the panels above.





In this composite of figures we are comparing the Aerosol Optical Depth between satellite and aircraft-born LIDAR. Upper panel, leftmost: the Oxford/IASI optimal estimation algorithm, followed by: the Oxford/IASI Fast algorithm for a plume at 400mbars, a plume at 600mbars and a plume at 800mbars. Lower panel: the ULB/IASI algorithm. A very promising comparison for all three algorithms.

Aerosol Height levels on the 14th, 16th and 17th of May 2010.



Left panel: RAL/MODIS-Aqua estimates of the ash plume height. Middle panel: Oxford/IASI optimal estimation algorithm height estimate and Right panel: KNMI/GOME2 height estimate.

Table 1. Summary of mean satellite and aircraft AOD level estimates, as well as their mean difference.

Institute	Instrument & algorithm	Mean Satellite AOD levels	Mean Aircraft AOD levels	Mean difference	Number of common observations
KNMI	GOME2	0.42 0.03	0.231 0.15	-0.19 0.18	64
Oxford	IASI Optimal Estimation	0.09 0.09	0.22 0.18	0.13 0.17	600
Oxford	IASI Fast 400mbars	**0.24 0.33**	**0.22 0.17**	-0.03 0.32	586
Oxford	IASI Fast 600mbars	0.29 0.32	0.21 0.17	-0.08 0.28	550
Oxford	IASI Fast 800mbars	0.38 0.44	0.21 0.17	-0.17 0.39	542
ULB	IASI	**0.22 0.15**	**0.25 0.17**	0.03 0.22	463

Abstract – Project description

The 2010 eruption of the Icelandic volcano Eyjafjallajökull attracted the attention of the public and the scientific community to the vulnerability of the European airspace to volcanic eruptions. Major disruptions in European air traffic were observed for several weeks surrounding the two eruptive episodes, which had a strong impact on the everyday life of many Europeans as well as a noticable economic loss of around 2-3 billion Euros in total. The eruptions made obvious that the decision-making bodies were not informed properly and timely about the commercial aircraft capabilities to ash-leaden air, and that the ash monitoring and prediction potential is rather limited. After the Eyjafjallajökull eruptions new guidelines for aviation, changing from zero tolerance to newly established ash threshold values, were introduced.

Within this spirit, the European Space Agency project Satellite Monitoring of Ash and Sulphur Dioxide for the mitigation of Aviation Hazards, called for the creation of an optimal End-to-End System for Volcanic Ash Plume Monitoring and Prediction . This system is based on improved and dedicated satellite-derived ash plume and sulphur dioxide level assessments, as well as an extensive validation using auxiliary satellite, aircraft and ground-based measurements. The validation of volcanic ash levels extracted from the sensors GOME2/MetopA, IASI/MetopA and MODIS/Terra and MODIS/Aqua is presented in this work with emphasis on the ash plume height and ash optical depth levels. Co-located aircraft flights and as well as European Aerosol Research Lidar Network [EARLINET] measurements were compared to the different satellite estimates for the those two eruptive episodes. The validation results are extremely promising with most satellite sensors performing quite well and within the estimated uncertainties compared to the comparative datasets.

Main Findings - Conclusions

As far as the ash AOD is concerned:

- The KNMI/GOME2 AOD over-estimates the ground-based values, showing quite high values for cases where the LIDAR see a low AOD range.
- The Oxford/IASI optimal estimation algorithm shows an acceptable correlation with the ground values, with coefficients ranging between 0.6 and 0.85, and, even though it provides rather low values, these are of the same order of magnitude as the LIDAR ones.
- The Oxford/IASi Fast algorithm also provides same order of magnitude AOD estimates as the ground with a correlation ranging between 0.7 for the 400 mbars product to 0.8 for the 800 mbars product.
- The ULB/IASI Eyjafjallajökull refractive index AOD estimates are also quite promising, with correlations ranging between 0.74 and 0.94, the highest yet.
- The RAL MODIS/Terra & /Aqua AOD show high values for the Terra instrument compared to the ground-based LIDAR and moderate over-estimation for the Aqua instrument.

As far as the ash plume height is concerned:

The Oxford nominal IASI algorithm ash plume height comparisons are quite satisfactory with similar mean estimated height and spread in values.

The RAL MODIS/Terra & MODIS/Aqua ash plume height estimates are moderately satisfactory; the MODIS/Terra products shows a high spread in values with the MODIS/Aqua product showing more correlation to the ground-based estimates.

References

- Clarisse, L., F. Prata, J.-L. Lacour, et al. (2010), A correlation method for volcanic ash detection using hyperspectral infrared measurements, Geophys. Res. Lett., 37, L19806, doi:10.1029/2010GL044828.
- Clerbaux, C., Boynard, A., Clarisse, L., et al., (2009), Monitoring of atmospheric composition using the thermal infrared IASI/MetOp sounder, Atmos. Chem. Phys., 9, 6041-6054, doi:10.5194/acp-9-6041-2009.
- Marenco F., B. Johnson, K. Turnbull, et al., Airborne lidar observations of the 2010 Eyjafjallajokull volcanic ash plume, J. Geophys. Res., 116, D00U05, doi:10.1029/2011JD016396, 2011.
- Pappalardo et al., Four-dimensional distribution of the 2010 Eyjafjallajokull volcanic cloud over Europe observed by EARLINET, Atmos. Chem. Phys., 13, 4429-4450, doi:10.5194/acp-13-4429-2013
- Rix, M., Valks, P., Hao, N., et al. (2012): Volcanic SO_2, BrO and plume height estimations using GOME-2 satellite measurements during the eruption of Eyjafjallajokull in May 2010, J. Geophys. Res., 117, D00U19, doi:10.1029/2011JD016718.
- van Gent, J., Spurr, R., Theys, N., et al., (2014), Towards operational retrieval of SO_2 plume height from GOME-2 radiance measurements, manuscript in preparation for Atmos. Meas. Tech., 2014.

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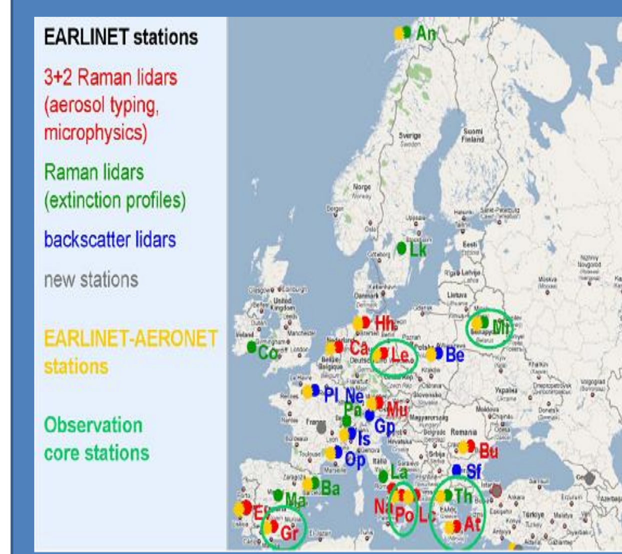
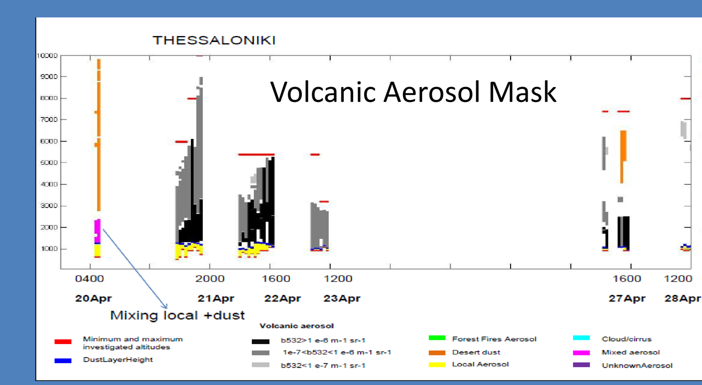
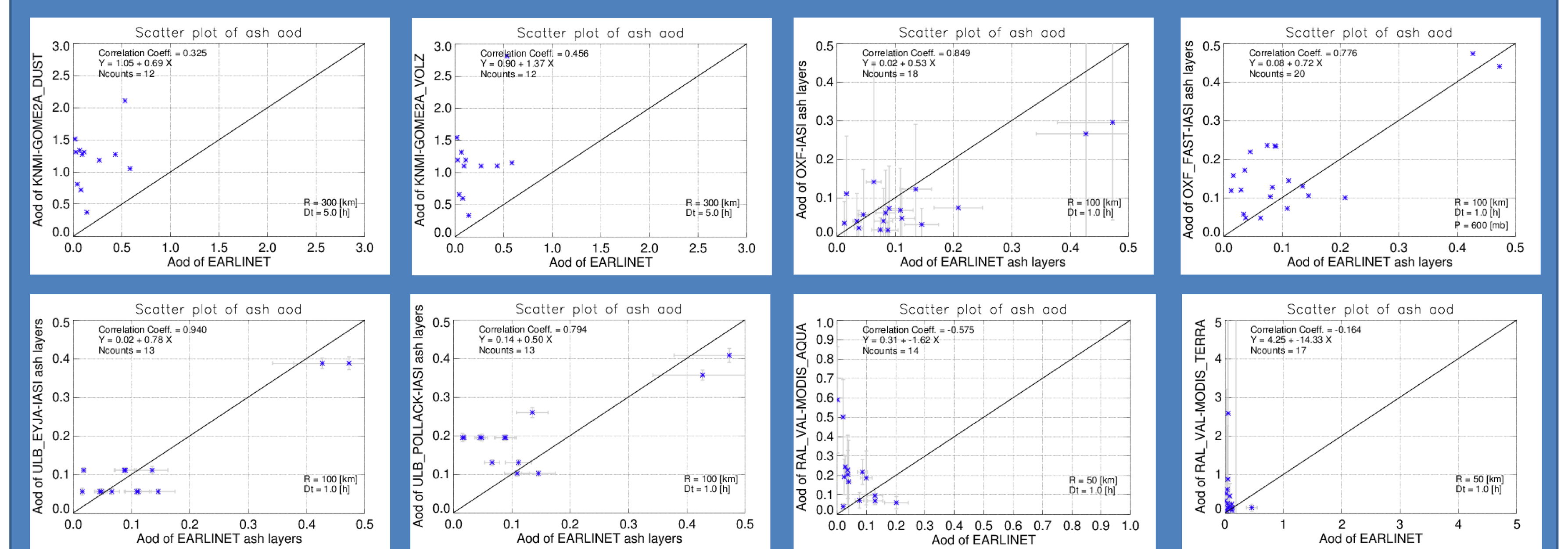
Satellite to ground-based LIDAR comparisons



For the validation of the ash plume height as well as the optical depth of the ash plume, LIDAR data from the EARLINET network will be used in this section [http://www.earlinet.org/] EARLINET is the first aerosol LIDAR network on a continental scale with the main goal to provide data for the aerosol distribution over Europe at 25 participating stations.



A relational database, containing the output of the 4-D analysis of EARLINET data related to the volcanic eruption of 2010, is freely available. Comparisons were performed for the 532/550 nm wavelengths and collocation criteria vary between 1-5 h and 50-500km.



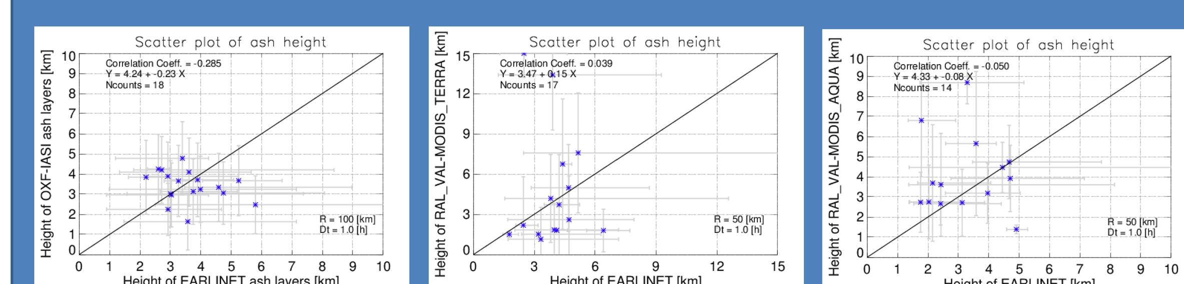
Scatter plots between the different satellite AOD estimates during the 2010 Eyjafjallajökull eruptive periods [y-axis] and co-located ground-based LIDAR stations around Europe [x-axis] depending on different collocation criteria given in each plot, bottom right corner. In the top left corner, some statistics are given.

Top row, from left to right: KNMI/GOME2 *dust* algorithm; KNMI/GOME2 *volz* algorithm; Oxford/IASI optimal estimation algorithm and Oxford/IASI Fast algorithm with a plume height at 600mbars.

Bottom row, from left to right: ULB/IASI Eyja algorithm; ULB/IASI Pollack algorithm; RAL/MODIS-Aqua and RAL/MODIS-Terra algorithms. Note the different scale in the different plots.

Table 2. Summary of mean satellite and ground-based AOD level estimates.

Product	Spatiotemporal criteria	EARLINET mean AOD and standard deviation	Satellite mean AOD and standard deviation
Oxford nominal	100km & 1h	0.12 0.12	0.08 0.08
Oxford fast 400mbars	100km & 1h	0.12 0.12	0.10 0.04
Oxford fast 600mbars	100km & 1h	0.12 0.12	0.17 0.12
Oxford fast 800 mbars	100km & 1h	0.12 0.12	0.32 0.38
KNMI *dust*	300km & 3h	0.19 0.22	1.29 0.48
KNMI *volz*	300km & 3h	0.19 0.22	1.32 0.69
RAL MODIS/Terra	50km & 1h	0.09 0.11	3.00 9.30
RAL MODIS/Aqua	50km & 1h	0.06 0.06	0.20 0.16
ULB Eyja	100km & 1h	0.14 0.14	0.12 0.12



Product	Spatiotemporal criteria	EARLINET mean and standard deviation [km]	Satellite mean and standard deviation [km]
Oxford nominal	100km & 1h	3.63±0.95	3.40±0.78
RAL MODIS/Terra	50km & 1h	3.81±1.15	4.01±4.42
RAL MODIS/Aqua	50km & 1h	3.23±1.16	4.01±1.91

The comparison of the ash plume height between three satellite products and collocated ground-based stations. The figured follow the same format as those above for AOD. The associated statistics are given in the Table below.

From left to right: the Oxford/IASI optimal estimated ash height; the RAL/MODIS-Terra and the RAL/MODIS-Aqua estimated ash height. Note the different scales in the axes between the different plots.