THE ANALYSIS OF A COMPLEX FIRE EVENT USING MULTI-SPACEBORNE OBSERVATIONS

Simona Andrei[1]*, Emil Carstea[1], Luminita Marmureanu[1], Dragos Ene[1], Ioannis Binietoglou[1], Doina Nicolae[1], Dimitra Konsta[2], Vassilis Amiridis[2], Emmanouil Proestakis[2]

[1]National Institute of R&D for Optoelectronics, Bucharest-Magurele, 077125, Romania,
**Email:simona.andrei@inoe.ro*
[2]National Observatory of Athens, Athens, Greece

ABSTRACT

This study documents a complex fire event that occurred on October 2016, in Middle East belligerent area. Two fire outbreaks were detected by different spacecraft monitoring instruments on board of TERRA, CALIPSO and AURA Earth Observation missions. Link with local weather conditions was examined using ERA Interim Reanalysis and CAMS datasets. The detection of the event by multiple sensors enabled a detailed characterization of fires and the comparison with different observational data.

1 INTRODUCTION

Oil and sulfur fires have a major deleterious impact on the environment and human health. Crude oil burns produce smoke containing carbon dioxide, carbon monoxide, sulfur dioxide, oxides of nitrogen, volatile organic hydrocarbons, ozone, acidic aerosols, soot, droplets of unburned oil and PM_{10}. Sulfur fires generate fumes of sulfur dioxide and sulfur trioxide, and when these react with moisture they produce sulfurous and sulfuric acids [1]. Sulfur dioxide (SO_2), in particular, is an important pollutant gas with significant impact on the environment. It is a precursor of sulfate aerosols that can affect air quality and climate. Although SO_2 has a relatively short atmospheric lifetime, sizable transient SO_2 plumes can travel into remote oceanic areas [2].

Sulfur fires were documented as some of the largest sources of SO_2 fumes released into the atmosphere. In June 2003, a fire at a sulfur mine and processing facility near Mosul, Iraq, released about 600 kilotons of SO_2, making it the largest non-volcanic release of SO_2 that has ever been observed with satellites [3].

Major oil fires were reported in the 1990s, in the Persian Gulf War, when Iraqi troops ignited over 700 oils well in Kuwait and consumed roughly 4.6 million barrels of oil a day. Similar events occurred over several months in 2016, periodic oil fires being recorded by satellite imagery. These events produced a thick, dark smoke [4].

On October 2016, a complex fire event was registered, combining fires at the Al-Mishraq sulfur plant (the same that produced the event in 2003) and at the nearby Qayyarah oil field, when ISIS forces that retreated from Mosul torched the plants. The complex event lasted for 6 days and spread a sulfur plume across northern Iraq, Syria and Turkey [5], [6] exposing the local population to substantial risks [7].

Taking into consideration the negative effects of oil and sulfur fires it is highly important to study the events using state of the art satellite data. The present study is focused on the analysis of a prolonged fire event occurred during 20th and 25th of October, 2016 over the belligerent area of Mosul-Iraq (35.99°N, 43.34°E). Using different spacecraft monitoring instruments onboard of TERRA satellite, two distinct fire outbreaks have been spotted: one with dark plume due to oil wells burning and one with white plume coming from a burning sulfur plant (Fig.1).

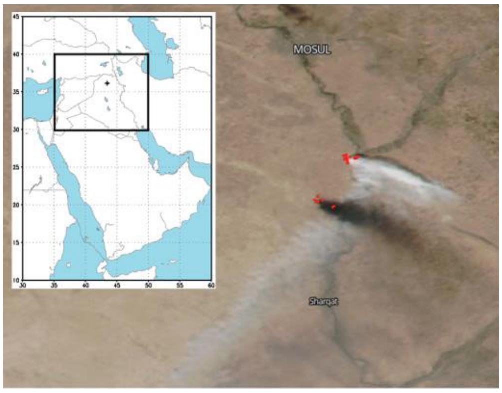

Figure 1 Satellite image of fire event on 22nd October 2016, (https://worldview.earthdata.nasa.gov/)

2 METHODOLOGY

The analysis has implied the use of multiple data from the following instruments: Multi-angle Imaging SpectroRadiometer (MISR), Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), Ozone Monitoring Instrument (OMI). The link with the local weather conditions has been examined by the use of Copernicus Atmosphere Monitoring Service (CAMS) datasets.

Onboard of TERRA, the Multi-angle Imaging SpectroRadiometer instrument uses 9 push-broom cameras, which allow the system to image every scene at 9 viewing zenith angles in line with the ground track of the satellite in 7 minutes. [8]. The instrument has been used to access the magnitude and variability of smoke plume heights.

The retrievals from MISR have been validated by/compared with the spaceborne lidar retrievals coming from CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations).

CALIPSO carries the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), which provides vertical resolved aerosol and cloud observations. CALIOP measures the backscatter signal at 532 nm and 1064 nm, and polarization at 532 nm. Cloud and aerosol layers are identified using the level 2 retrievals and through the cloud aerosol discrimination algorithm, based on the probability distribution functions of altitude–and-latitude dependent parameters (integrated colour ratio, layer-integrated volume depolarization ratio, mean attenuated backscatter coefficient) [9].

The Ozone Monitoring Instrument (OMI) has been used to detect the concentration of SO_2 over the plume. OMI, onboard NASA Earth Observing System Aura satellite, observes aerosols and trace gases, including SO_2. Data from the first and last 10 cross-track positions were excluded from the analysis to limit the across-track pixel width to about 40 km [10], [11].

Weather conditions during the event were examined using ERA Interim Reanalysis and Copernicus Atmosphere Monitoring Service (CAMS) datasets [12], [13]. Boundary layer height, obtained from the European Centre for Medium-Range Weather Forecast (ECMWF), was compared with the injection height measured & computed by MISR [8]. Concentration of SO_2 from OMI was compared/validated using SO_2 from CAMS.

3 RESULTS

The cameras of Multi-angle Imaging SpectroRadiometer have detected the fire event on October 21st, 2016. Digitized plumes (Figure 2 a, b) indicate the dispersion along W-NW air circulation within the troposphere.

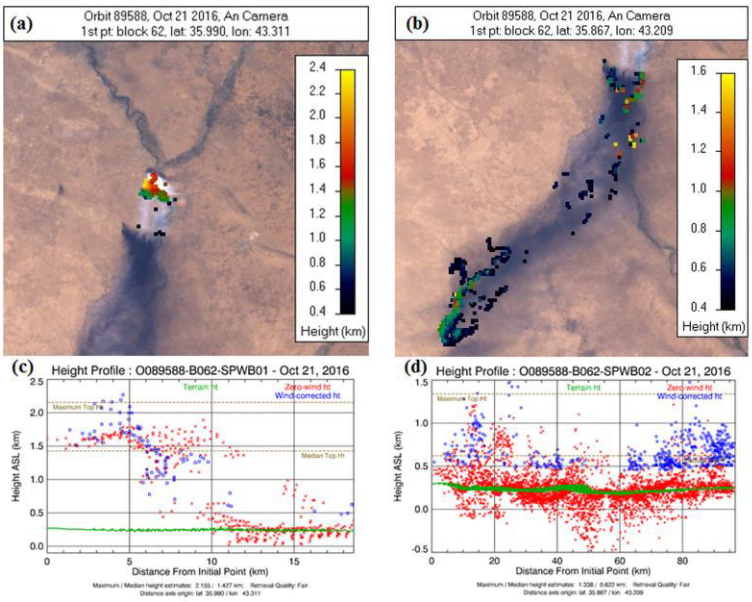

Figure 2 Digitized plumes of SO_2 (a), and oil well (b) in nadir view, height profile of SO2 plume (c), and height profile of oil plume (d) detected with MISR, on October 21st, 2016

The corresponding plumes height generated by MINX are shown in Figure 2 c, d. Red points represent zero-wind heights, blue points wind-corrected heights, and the green line represents the terrain heights with sea level as references.

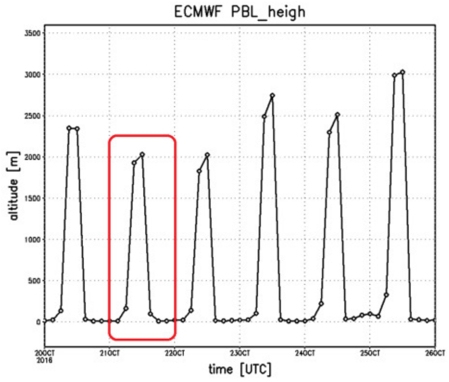

Figure 3 Time series of PBL height from ECMWF during the fire event

Time series of planetary boundary layer (PBL) height from ECMWF (Figure 3) shows that the maximum value of PBL on October 21st has reached 2 km at the afternoon hours. Comparing the altitude where the smoke particles were detected by MISR (Figure 2 c, d) with the PBL height values corresponding to the morning hours (06UTC) when TERRA overpassed Mosul area, it is obvious that the smoke injection dispersed within the free atmosphere and affected a large area, as it was mentioned by WHO reports.

CALIOP is rarely able to detect specific targets such as aerosol source due to its narrow field-of-view [14]. However, by the time of the event CALIPSO overpass the area of Mosul and an aerosol layer can be seen in the PBL, using the CALIOP Vertical Feature Mask on October 21st 2016, 23:15 UTC (Fig.4). The layer is localized between near surface and 2.5 km altitude and is classified as a mix of dust and pollution, (2= dust, 5=polluted dust) with traces of smoke (6 = smoke) [15].

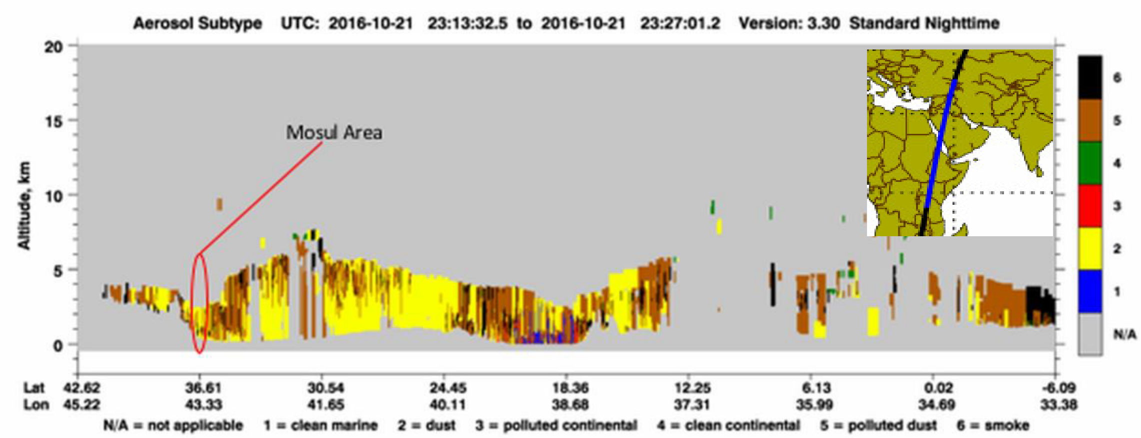

Figure 4 Vertical Feature Mask of aerosol layers detected with CALIOP over Mosul, Iraq

OMI was used to detect the column integrated SO_2 over the dispersion area. The data measured by OMI from 20 to 25 Oct 2016 reveals an average maximum value of 7 DU (Figure 5 a). CAMS analysis (Figure 5 b) emphasizes the initiation of the fire event, showing an injection of SO_2 throughout the atmospheric column.

4 CONCLUSIONS

The detection of smoke by multiple instruments has enabled the detailed characterization of the fire event and the comparison between different observational datasets. CALIOP was able to detect the vertical details of the aerosol layers highlighting both the dust and smoke pollution. Complementary data from the OMI quantitatively estimated the SO_2 released in the atmospheric column.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from ANCS Core program, project no. 16.40.01.01 and the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement no 692014 – ECARS.

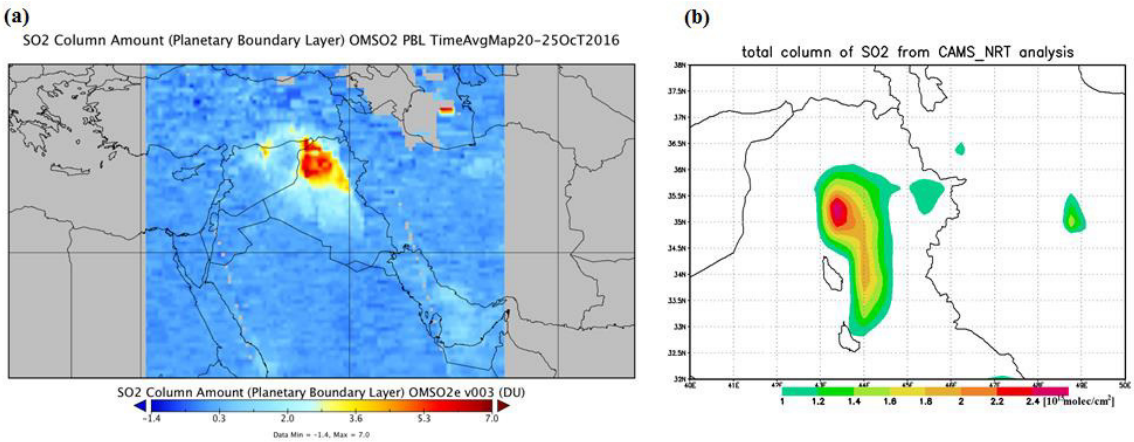

Figure 5 Time averaged map of SO_2 detected with OMI (a), SO_2 total column derived from CAMS (b)

References

[1] http://www.emro.who.int/images/stories/eha/WHO_health_advice_oil_and_sulphur_fires.pdf?ua=1.

[2] Li, C., Joiner, J., Krotkov, N. A., Bhartia, P. K., 2013: A fast and sensitive new satellite SO2 retrieval algorithm based on principal component analysis: Application to the ozone monitoring instrument, *Geophys. Res. Lett.*, **40**, 6314–6318.

[3] Carn, S.A, Krueger, A.J., Krotkov, N.A., Gray, M. A., 2004: Fire at Iraqi sulfur plant emits SO2 clouds detected by Earth Probe TOMS, *Geophys. Res. Lett.*, **31**, L19105.

[4] http://earthobservatory.nasa.gov/IOTD/view.php?id=88666.

[5] http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=88994.

[6] http://reliefweb.int/sites/reliefweb.int/files/resources/mosul_env_health_hazards_report_final_8nov.pdf.

[7] http://www.emro.who.int/irq/iraq-news/who-and-ministry-of-health-manage-over-1000-cases-of-suffocation.html.

[8] Nelson, D. L., Chen, Y., Kahn, R. A, Diner D. J., Mazzoni, D., 2008: Example applications of the MISR INteractive eXplorer (MINX) software tool to wildfire smoke plume analyses, *Proc. SPIE*, **7089** 708909-2.

[9] Gkikas, A., Basart, S., Hatzianastassiou, N., Marinou, E., Amiridis V., Kazadzis, S., Pey, J., Querol, X., Jorba, O., Gassó, S., Baldasano, J.M., 2016: Mediterranean intense desert dust outbreaks and their vertical structure based on remote sensing data, *Atmos. Chem. Phys.*, **16**, 8609–8642.

[10] Fioletov, V. E., McLinden, C. A., Krotkov, N., Yang, K., Loyola, D. G., Valks, P., Theys, N. Van Roozendael, M., Nowlan, C. R., Chance, K., Liu, X., Lee, C., Martin, R. V., 2013: Application of OMI, SCIAMACHY, and GOME-2 satellite SO_2 retrievals for detection of large emission sources, *J. Geophys. Res. Atmos.*, **118**, 11399-11418.

[11] Fioletov, V. E., McLinden, C. A., Krotkov, N, Li, C., 2015: Lifetimes and emissions of SO_2 from point sources estimated from OMI. *Geophys. Res. Lett.* **42**, 1969–1976.

[12] Dee DP, Uppala SM, Simmons AJ, Berrisford P, Poli P, Kobayashi S, Andrae U, Balmaseda MA, Balsamo G, Bauer P, Bechtold P, Beljaars ACM, van de Berg L, Bidlot J, Bormann N, Delsol C, Dragani R, Fuentes M, Geer AJ, Haimberger L, Healy SB, Hersbach H, H´olm EV, Isaksen L, K°allberg P, K¨ohler M, Matricardi M, McNally AP, Monge-Sanz BM, Morcrette J-J, Park B-K, Peubey C, de Rosnay P, Tavolato C, Th´epaut J-N, Vitart F. 2011. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Q. J. R. Meteorol. Soc*. **137**: 553–597.

[13] https://atmosphere.copernicus.eu/sites/default/files/repository/SPP%20November%202016_2.pdf.

[14] Winker, D. M., W. H. Hunt, and C. A. Hostetler, 2004: Status and Performance of the CALIOP lidar, *Proc. SPIE*, **5575**, 8-15.

[15] Omar, A., D. Winker, C. Kittaka, M. Vaughan, Z. Liu, Y. Hu, C. Trepte, R. Rogers, R. Ferrare, R. Kuehn, and C. Hostetler, 2009: The CALIPSO Automated Aerosol Classification and Lidar Ratio Selection Algorithm, *J. Atmos. Oceanic Technol.* **26**, 1994-2102.