Synergistic Satellite and Modeling Methods for the Description of Biomass Smoke Dispersion Over Complex Terrain. The FireHub Platform

C. Kontoes, S. Solomos, V. Amiridis and T. Herekakis

Abstract Wildfire smoke properties depend mainly on the severity and type of fire (i.e. smoldering, flaming combustion) and on the local meteorological conditions. The intensity of the fire is characterized by the observed Fire Radiative Power (FRP) and this measurement is also used for the calculation of smoke emissions and initial plume rise. Geostationary (MSG-SEVIRI) and orbital instruments (MODIS, MISR) allow the early and accurate recognition of biomass burning episodes providing also information on the specific characteristics of the fire and smoke properties. Analysis of specific smoke dispersion episodes over Greece are performed with the FIREHUB platform incorporating both satellite and modeling techniques. FIREHUB has been developed at the National Observatory of Athens and combines satellite recognition of the initial hot-spots with high resolution Eulerian and Lagrangian atmospheric tools (FLEXPART-WRF) for the description of smoke dispersion. Comparison of smoke dispersion simulations with satellite data (MISR, MODIS) for the fire events of Peloponnese 2007, Evros 2011 and Agion Oros 2012 shows the ability of the system to reproduce complex dispersion patterns and indicates the increased possibility of long range transport of smoke due to the abrupt changes between marine and land PBL.

1 Introduction

Biomass emissions have a twofold significance for atmospheric science: (i) the dispersion of smoke towards inhabited areas consist a direct threat for human health (e.g. Keramitsoglou et al. 2004; Liu et al. 2009) and (ii) smoke aerosol particles affect radiation and cloud processes (Andreae et al. 1993). The monitoring of active

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T.S. Karacostas et al. (eds.), *Perspectives on Atmospheric Sciences*, Springer Atmospheric Sciences, DOI 10.1007/978-3-319-35095-0_116

fire hot spots and of the related smoke plumes is mainly performed through satellite observations (e.g. MODIS, AIRS, OMI, MSG, VIIRS). Complimentary modeling systems have also been developed to provide forecasts of smoke dispersions (e.g. NAAPS/WFABBA, Reid et al. 2009; SILAM, Sofiev et al. 2009; MACC/GFAS, Kaiser et al. 2012; FIREHUB, Solomos et al. 2015). Such modeling systems rely on satellite sensors for the retrieval of fire hot-spot areas and combine meteorological numerical forecasts to describe the propagation of smoke plumes. In this work we present recent results for three open fire events obtained with the integrated satellite/modeling FIREHUB platform. A short description of the system is provided in Sect. 2, modeling results are shown in Sect. 3 and Sect. 4 includes some concluding remarks and recommendations for the future directions of the system development.

2 Methodology

The FIREHUB system (Kontoes et al. 2013) consists of three main pillars: (i) Retrieval and downscaling of fire hot spots in real time from the MSG/SEVIRI sensor, (ii) Diachronic burn scar archiving over the entire Greek territory and (iii) online forecast of biomass smoke dispersion. In the following sections we focus mainly on the smoke dispersion component.

2.1 Satellite Retrievals

As a first step, downscaling of the SEVIRI hot-spot retrievals from the original pixel size (about 4×4 km) down to subpixel resolutions (500×500 m) is obtained with the use of ancillary landscape evidence and meteorological data (Sifakis et al. 2011). However, what is most important for the timely and accurate forecast of smoke plumes is the high temporal resolution of the retrievals (every 5 min) that allows the assimilation of short term fire variability in the modeling simulations. Additionally, the Fire Radiative Power (FRP) of each measurement is used for the calculation of model emissions rates (E) based on Eq. 1 (Ichoku and Ellison 2014). For the area of Greece we adopt an emission coefficient C = 0.026 kg MJ^{-1}.

$$E\,(\text{kg s}^{-1}) = C\,(\text{kg MJ}^{-1}) \times FRP\,(\text{MJ s}^{-1}), \tag{1}$$

Analysis of FRP for the years 2003–2013 based on MODIS retrievals (Fig. 1) indicates a total of 202 fires with FRP > 1000 (MJ s^{-1}) which would result in emission rates greater than 26 kg s^{-1} of total particulate matter (TPM) for these cases.

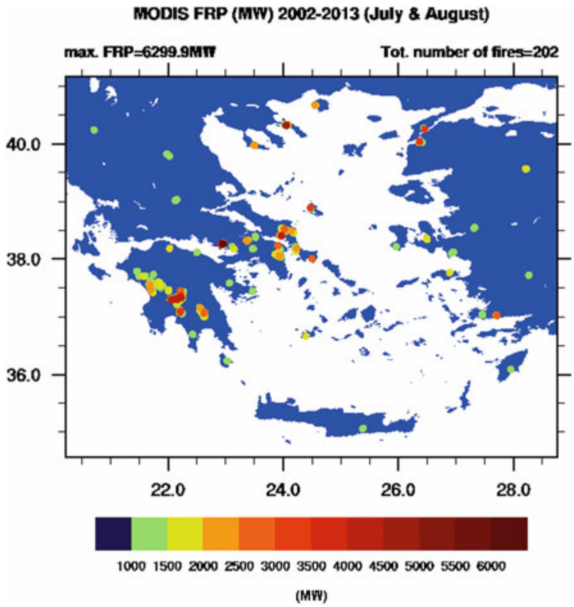

Fig. 1 MODIS FRP values exceeding 1000 MJ s^{-1} during the period 2002–2013

2.2 *Dispersion Modeling*

For the simulation of smoke transport we adopt the offline coupling of the Lagrangian dispersion model FLEXPART (Brioude et al. 2013) with the atmospheric model WRF (Skamarock et al. 2008). The simulations are driven by hourly WRF atmospheric data at a horizontal resolution of 4 × 4 km over Greece and a total of 10,000 TPM particles are released for each detected hot spot. The model runs in sequential warm start cycles and the updated hot-spot locations are assimilated every hour into the model based on the most recent FIREHUB retrievals. In this approach we include short term variations of fire activity in our modeling calculations.

3 Results

In this section we present FIREHUB results for three complex patterns of smoke dispersion over Greece namely: (i) Evros 25 August 2011; (ii) Agion Oros 9 August 2012; (iii) Peloponnese 25–26 August 2007 and we derive the specific characteristics of biomass burning emissions over the area.

3.1 Evros Fire, 25 August 2011

This rather simple event of smoke transport (Fig. 2a) provides a typical example of vertical plume divergence due to wind shear and gives also a clear picture of how the planetary boundary layer (PBL) affects the fate of smoke plumes. As detected from the MISR satellite sensor (red stars) in Fig. 2b, the smoke plumes are constrained by the land PBL (continuous line). However as the smoke travels towards the sea, the PBL depth is significantly lower (dashed line in Fig. 2b). As a result, the plume slides over the marine PBL into the free troposphere thus enabling long range transport. Additionally, as seen in Fig. 2c, the strong vertical wind shear inside the marine PBL (dashed line) results in veering of the lower parts of the plume towards NW. This divergence of smoke is also evident in Fig. 2a. Moreover, the wind speed is higher over the sea (dashed line in Fig. 2c) than over land (solid line in Fig. 2d) favoring also the transport of smoke towards Samothrace.

3.2 Agion Oros Fire, 9 August 2012

The fire event that occurred at Agion Oros Peninsula on 9 August 2012 was accompanied by convective activity over the area and the satellite imagery (Fig. 3a) indicates widespread smoke plumes all over Chalkidiki, Thermaikos Gulf and even at the city of Thessaloniki. A detailed modeling and satellite based analysis of this event by Solomos et al. 2015 showed that in fact the particles first traveled at lower heights (<1.5 km) from Agion Oros towards Thermaikos [1], then elevated to higher tropospheric layers (>2.5 km) through convection [2] and afterwards recirculated towards the east [3]. The MODIS aerosol optical depth (AOD) during this

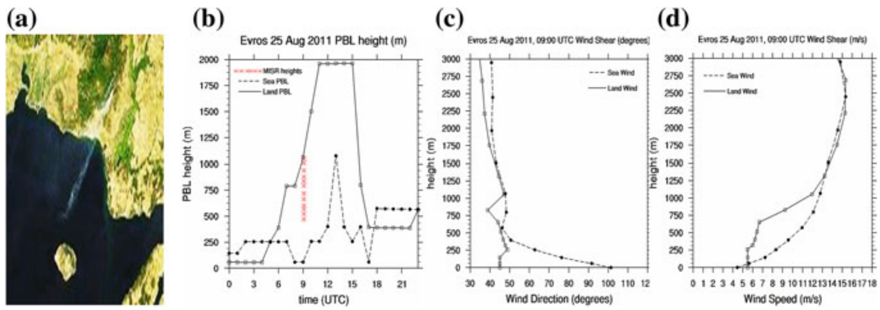

Fig. 2 **a** MODIS image of the smoke advection from the Evros area towards the island of Samothrace, 25 August 2011. **b** Modeled PBL height close to the fire hot spots (Land PBL), off the coast (Sea PBL) and MISR observed smoke heights over the emission sources; **c** Modeled vertical profiles of wind direction (degrees) near the sources (Land Wind) and off the coast (Sea Wind); **d** Modeled vertical profiles of sea and land wind speed (m s^{-1}) (**b**, **c** and **d** figures taken from Solomos et al. 2015)

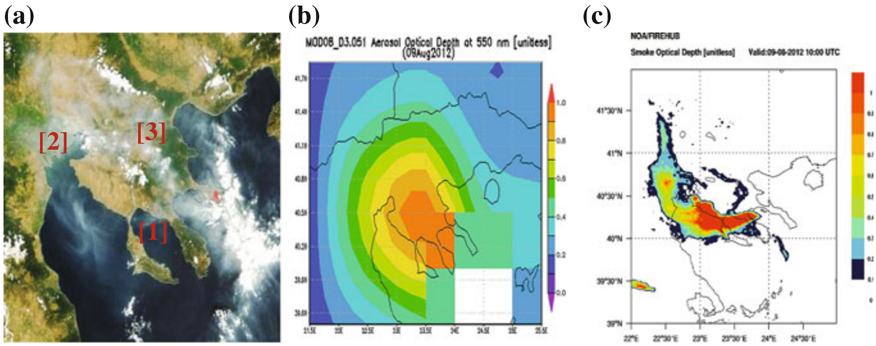

Fig. 3 **a** MODIS visible channel; **b** MODIS AOD; **c** FIREHUB AOD, 9 August 2012

event is close to 1 (Fig. 3b) indicating also the severity of smoke emissions. Similar AOD values are found by FIREHUB model (Fig. 3c) indicating also the capability of the system to reproduce such complex events.

3.3 Peloponnese Fires, 25–26 August 2007

The most devastating fire events in recent Greek history occurred on 25 and 26 of August 2007 over western Peloponnese, Evvoia and western Greece. Description of this extremely complex event is an ultimate challenge for FIREHUB platform taking into account that the total number of recorded hot-spots during these two days was 11,033. As seen in Fig. 4a the smoke plumes were advected towards long distances over the Mediterranean due to the prevailing strong NE winds. Both satellite retrievals (Fig. 4b) and model results (Fig. 4c) indicate high AOD values at the area due to the smoke layers. However the AOD from the Evvoia plumes may be overpredicted by the model ($AOD_{MODEL} \approx 0.3$ while $AOD_{MODIS} \approx 0.14$).

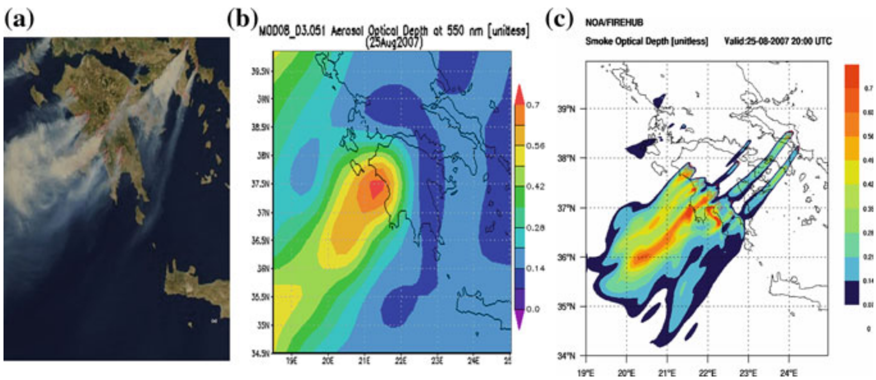

Fig. 4 **a** MODIS visible channel; **b** MODIS AOD; **c** FIREHUB AOD, 25 August 2007

4 Conclusions

We analyze the behavior of smoke plumes from open fire episodes over Greece. The main factor that enables long range transport of these particles is the complex coastline and the associated interchanges between land and marine PBL. While the smoke from inland fires is quickly diluted and deposited inside the turbulent mixing layer, smoke from coastal and island fires is favorably injected above the marine PBL into the free troposphere and these plumes have longer lifetimes and cover distances of several hundred kilometers downwind. Satellite retrievals and high resolution simulations with FIREHUB platform indicate AOD values exceeding 1 during severe smoke dispersion episodes. Future plans include the continuous improvement of retrieval and modeling algorithms and the extension of the FIREHUB domain to cover the entire MSG-SEVIRI disc.

Acknowledgments The publication was supported by the European Union Seventh Framework Programme (FP7-REGPOT-2012-2013-1), in the framework of the project BEYOND, under Grant Agreement No. 316,210 (BEYOND—Building Capacity for a Centre of Excellence for EO-based monitoring of Natural Disasters, http://ocean.space.noa.gr/BEYONDsite).

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