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Atmospheric hazards monitoring and forecasting

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Abstract

Monitoring and forecasting of atmospheric hazards is one of the major research branches inside the BEYOND Center of Excellence. In this framework several satellite products for aerosol characterization have been developed incorporating advanced satellite retrieval algorithms utilizing CALIPSO and MODIS data. New methodologies based on lidar ratio correction, decomposition of pure dust from dust mixtures and optimized averaging allow the derivation of aerosol climatology over North Africa and Europe. Collocated satellite observations of CALIOP and MISR instruments are used for the identification of fire smoke plumes and the description of their spatial and temporal characteristics. This information is implemented in the atmospheric dispersion model FLEXPART and the simulated evolution of smoke plumes is discussed with regards to satellite observations. We present specific applications and recent findings of the above methodologies and we discuss the capabilities of the atmospheric component of BEYOND as well as future developments.

Keywords: atmospheric hazards; dust; CALIPSO; lidar ratio; MISR; smoke; FLEXPART

1. INTRODUCTION

Observations of the Earth system and its atmosphere from ground and space play an important role in understanding and forecasting atmospheric hazards. These phenomena include wildfires and associated smoke dispersion, natural and anthropogenic aerosols outbreaks, volcanic ash and severe weather. The range of these events may be from local to regional and even global scale. Such phenomena are of particular interest at the greater S. Europe and N. Africa area. Mediterranean is a unique region with significant importance for climate change issues, since it is characterized by complex water/land terrain, complicated weather patterns and also by various mixtures of particulate matter in the atmosphere. In the framework of BEYOND, specific activities have been designed for the monitoring of aerosol and cloud properties in the greater Mediterranean area as well as on forecasting air quality related episodes such as dust outbreaks and smoke dispersion. A synergistic remote sensing / modelling approach is necessary for examining the role of aerosol (e.g. dust, smoke) particles in radiative transfer and cloud processes in the greater Mediterranean area. This combined effort - incorporating both modeling and remote sensing techniques - provides a valuable benchmark for developing robust aerosol climatology for the area and improving our understanding on relevant physical processes. In this context we present recent findings and developments in the framework of BEYOND that are related to atmospheric hazards. More specifically we present a new optimization method for decomposing dust from CALIPSO space-

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borne observations and recent developments on the identification and simulation of smoke plumes from wild fire episodes.

2. BEYOND CENTER OF EXCELLENCE FOR MONITORING ATMOSPHERIC HAZARDS

Both passive (MODIS, MISR) and active satellite sensors (CALIPSO) are routinely used for the interpretation of airborne particle properties. The spatio-temporal evolution of aerosol load is continuously monitored over the area (MODIS). Ground-based cal-val activities within BEYOND offer a validation bed for all these data and daily optimization. These facilities include two lidar stations in Athens and Crete and sun photometric instruments for monitoring aerosol and trace gases abundances in the atmosphere. Such synergies benefit the decomposition of climatic impacts from anthropogenic and natural causes. The Saharan dust AOD is obtained for both over sea and land from CALIPSO data with a bias of 0.02 compared to AERONET AOD and a monthly climatology of this product is provided online http://lidar.space.noa.gr:8080/livas.

Assimilating such observations in atmospheric models improves the accuracy of natural hazards forecasting. Regarding fire smoke dispersion, an automatic modeling system has been developed in the framework of BEYOND (Figure 1). The system is composed of an atmospheric model (WRF) providing daily simulations at 4x4 km resolution over Greece, coupled with a Lagrangian dispersion model (FLEXPART). Simulations are triggered from the online fire monitoring service of NOA (http://ocean.space.noa.gr/seviri/fend_new/index.php). First results indicate a satisfactory agreement between modeled and observed smoke plumes. More work is undergoing on the description of injection heights over sources incorporating comparisons with MISR 3-D smoke profiles. A similar setup is also in experimental use regarding the development of an early warning system for volcanic ash dispersion, taking into account all active volcanoes and their potential for particle emissions. Continuous comparison of modeling results with satellite data is important for improving the representation of aerosol-atmosphere interactions in the models. These interactions include the effects of aerosols on radiative transfer (direct effect) and the effects of aerosols on clouds (indirect effect). Understanding the vertical distribution of the particles is a very important step towards untangling some of these interactions.

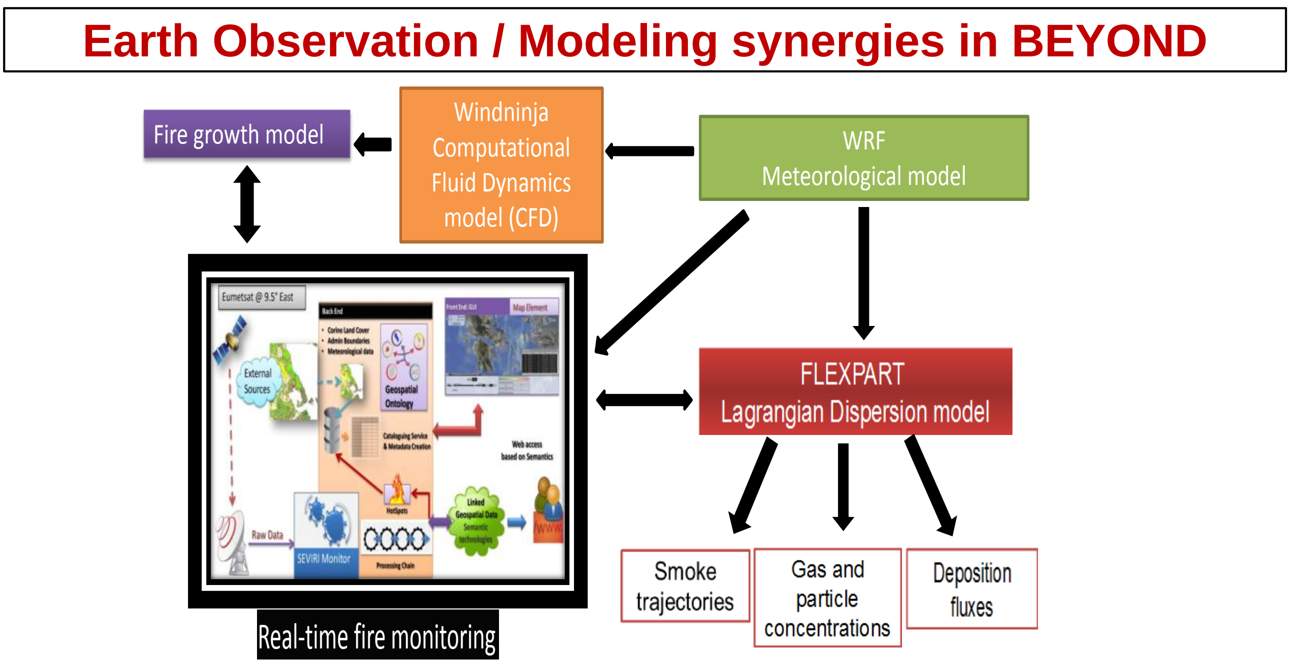

Figure 1. Flowchart of interdependencies between the specific BEYOND components that are involved in atmospheric hazards related to wildfires

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3. APPLICATION EXAMPLES

A brief presentation of recent atmospheric applications in the framework of BEYOND Center of Excellence is given in this section.

3.1 The extreme wildfire episode of Peloponnese, 25-27 August 2007

On 25 August 2007, the combination of a deep high pressure system over central Mediterranean and a low pressure system over Turkey (Figure 2) results in sharp pressure gradients over Greece and in strong NE winds with gusts exceeding 20 m/s at the area of Peloponnese (Figure 3a). Temperatures over 40^{o} C and very low relative humidity (Figure 3b) especially over western Peloponnese favor the rapid development of severe wild fires in this area. The prevailing N and NE winds during this day favored the advection of smoke from Greece towards Mediterranean.

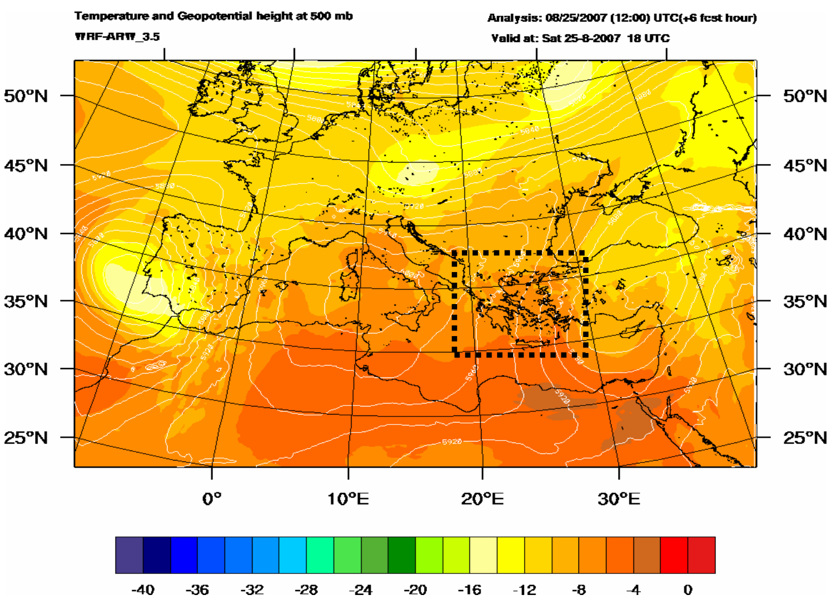

Figure. 2. Temperature and geopotential height at 500mb.The dashed rectangular indicates the location of the nested model grid.

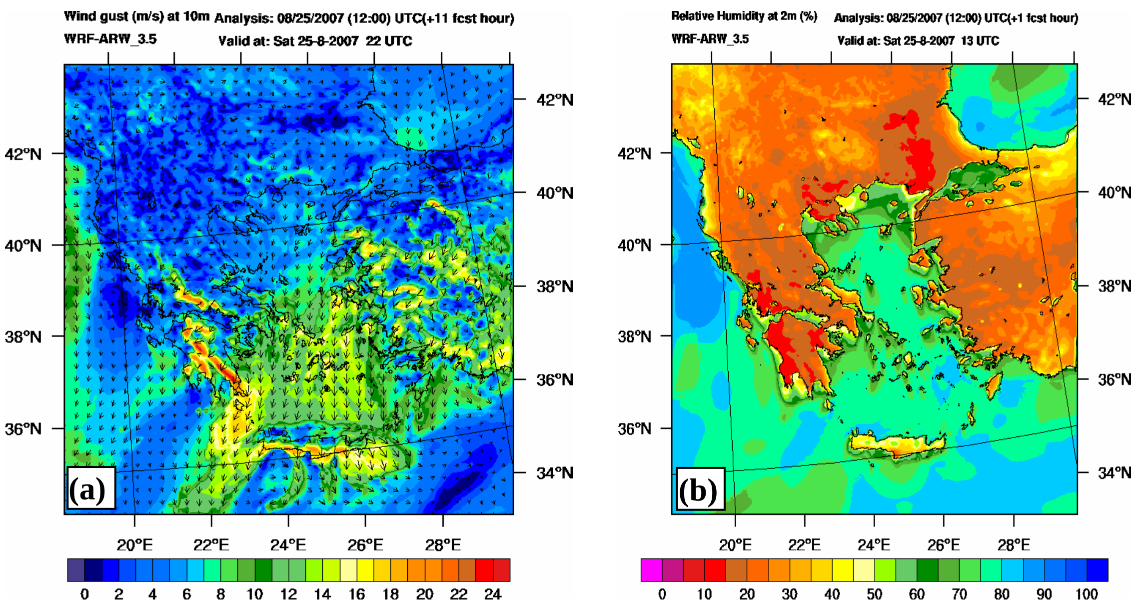

Figure. 3. a) Wind gust at 10m (m/s). b) Relative humidity (%) at 2 m, WRF model, 25 August 2007,12:00 UTC

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TERRA satellite passed over Greece the second day of the episode (26 August 2007). Post processing of MISR fire plume observations (Sofiou et al., 2013) using the MISR interactive explorer tool (MINX) indicated a significant variability in plume heights as indicated in Figure 4a. Particles were mostly identified at a range 0.5 – 3 km while particles higher than 3 km were mostly found at the SW plume parts. The plume height retrievals are computed from the animations of the nine MISR cameras following the methodology of Val Martin et al., (2010). The location and duration of fire hot spots is obtained from NOA-MSG SEVIRI database and MISR observations are used to constrain initial injection heights in FLEXPART. The simulated dispersion of smoke (Figure 4b) indicates a satisfactory agreement with available observations (Figure 4a). Elevation of smoke above 3 km in the atmosphere is probably related to a deepening of mixing layer during midday hours and to injection of particles above the atmospheric boundary layer (ABL) near the sources.

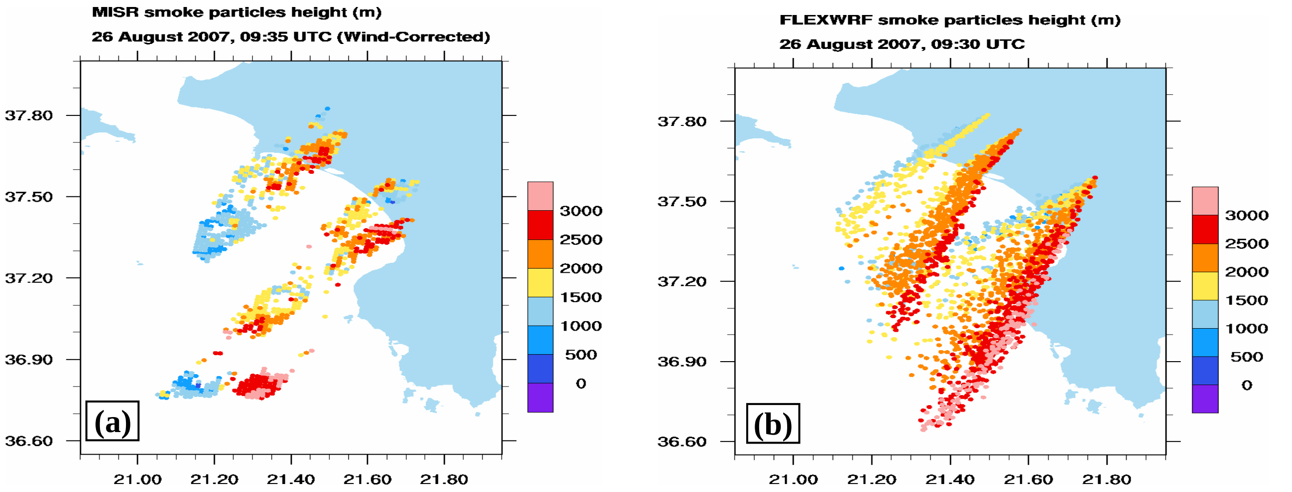

Figure 4. Smoke heights: a) MISR retrievals b) FLEXWRF simulation

Previous modeling studies of the same event (not shown here) were based on the assumption of a homogeneous injection height for all smoke plumes inside the modeling domain. The use of satellite information for constraining the dispersion model improved the representation of plume structure. For example, smoke particles elevate higher than 3 km as the plumes move towards southwest while the northern plumes show weaker advection and reach lower altitudes. These results indicate also the complexity of the physical processes involved in smoke dispersion and the unique properties of each fire event. The main factors that are crucial for this type of applications are:

1. Correct source information in time and space (retrieved from MODIS and SEVIRI data)
2. Detailed information on the plume injection height (retrieved from MISR multi angle observations)
3. Source emission rates (depending on fire power and fuel properties)

Assimilating all the above information into the model results in a good representation of fire smoke dispersion compared to MODIS observations (Figure 5). However, wildfire smoke dispersion is a dynamically evolving phenomenon and it is difficult to extract generic results from comparisons with satellite snapshots.

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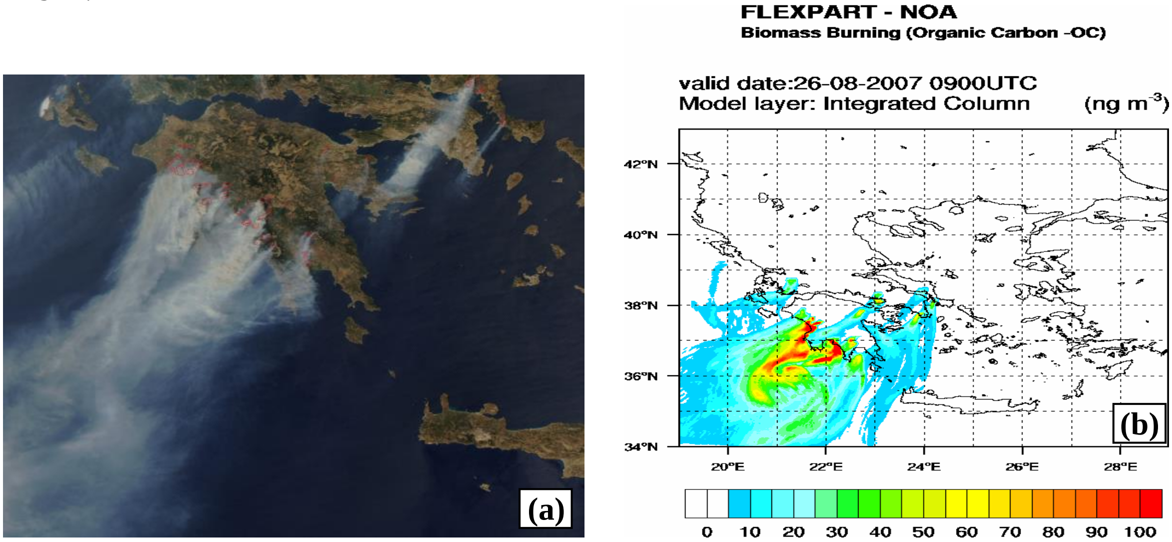

Figure 5. Dispersion of smoke: a) MODIS 26 August 2007 09:30 UTC b) FLEXWRF 26 August 2007 09:00 UTC

3.2 Optimization of CALIPSO dust product

Although CALIPSO dust retrievals may appear to be self-consistent, comparisons with AERONET ground-based retrievals revealed a relative bias of CALIPSO equal to −13% when dust is present and −3% when dust is not present (Schuster et al., 2012). Statistical analysis of pure dust elevated layers found in multi-year EARLINET Raman lidar ground-based observations show considerable discrepancies with respect to the LR at 532 nm, from 40 sr to 58 ± 8 sr for CALIPSO and ground-based lidars, respectively (Wandinger et al., 2010). The LR value of ~58 sr is also supported by the calculations Schuster et al. (2012) using AERONET data.

In Amiridis et al., (2013) we investigated the possible improvement of CALIPSO dust retrievals by appropriately filtering CALIPSO Level 2 data and applying the LR value of 58 sr to CALIPSO backscatter retrievals. Moreover, we examined potential improvements on Level 3 climatological monthly means when accounting for pure dust only, applying the method introduced by Tesche et al. (2009), by separating pure dust from both “polluted dust” and “dust” CALIPSO subtypes based on depolarization observations. We apply our methodology to collocated and synchronized CALIPSO-AERONET measurements of homogeneous dust columns and we see that the agreement in AOD is improved (see Figure 7). The domain of our application is North Africa and Europe, and we wish to note that this methodology cannot be applied to mineral dusts different from those advected from the Sahara desert.

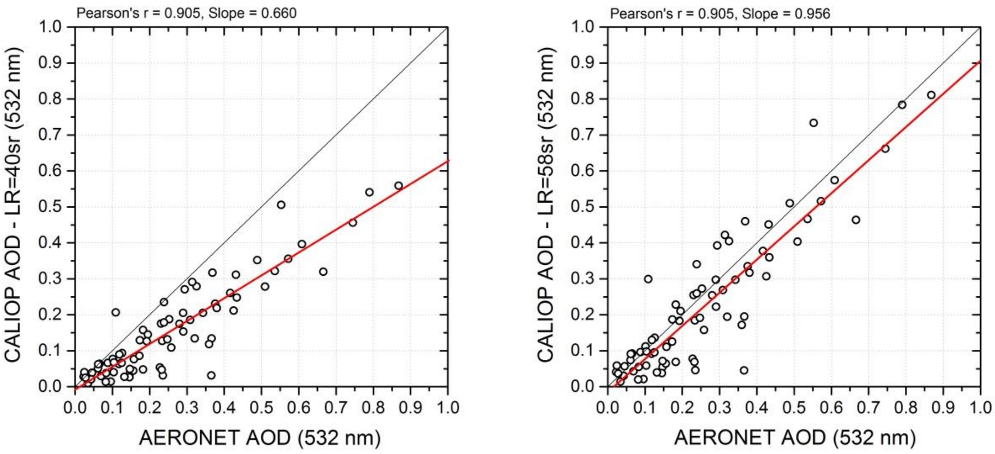

Figure 7. Comparison of CALIPSO AOD versus collocated AERONET measurements when LR is equal to 40 sr (left) and when LR is equal to 58 sr (right).

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4. CONCLUSIONS

Application of an off-line Lagrangian dispersion model for the computation of wildfire smoke trajectories indicated the ability to adequately simulate such events. Several issues were raised during this experiment regarding mainly the sensitivity of smoke properties towards emission heights. Comparison of model output with satellite derived products of vertical plume structure is encouraging when the plumes are initialized at the observed heights. However satellite observations of this type are very sparse resulting in significant uncertainty in the detection of smoke plume rise. More work is underway on the implementation of a plume rise module for wildfire smoke in order to estimate injection heights based on fuel properties and atmospheric processes. Inclusion of discrete emissions with accurate locations and duration of the fires as provided by the MSG SEVIRI database increased the detail of the model. Using a lidar ratio of 58 sr instead of 40 improved CALIPSO retrievals for Saharan dust. Assimilating this information in dust models can improve our understanding and forecasting of dust processes in the atmosphere. Since the lidar ratio seems to vary significantly for different dust areas (e.g. Atlantic, Middle East, China) the need for a different dust modeling approach for different areas is prominent.

Acknowledgement

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