Impacts of aerosol particle episodes on cloud physical properties and precipitation

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Introduction

Clouds play a key role in climate as they strongly affect the Earth's radiation balance (IPCC, 2013). The atmospheric aerosols have also significant effects on climate and weather modulation, e.g. by modifying cloud properties (Flossmann and Wobrock, 2010). During aerosol episodes the magnitude of aerosol effects is expected to increase. The present work aims at determining the relative impact of the aerosol episode-associated: (i) increased CCN and (ii) modified lapse rate due to aerosol absorption of solar radiation and consequent heating, on the basis of an aerosol episode occurring in the broader Mediterranean basin.

Methodology - Model

For this study, the simulations of clouds and precipitation were performed with the 1.5D bin resolved microphysics Detailed Scavenging Model (Leroy et. al, 2006). The model was initialized using aerosol properties (CCN and AOD) from MODIS Aqua satellite observations and the atmospheric lapse rate of the episode day (06/02/2004) from the University of Wyoming Upper Air database. Three scenarios were examined with DESCAM, concerning the (i) non – episode conditions, (ii) the episode conditions, accounting for both modified CCN and lapse rate (dCCN+dT) and (iii) the episode conditions accounting for only the modified CCN. The factor of CCN increase was found to be 108%.The aerosol atmospheric heating has been calculated by the SBDART radiation transfer model.

Study case

DSS (Dust-Sea-Salt) aerosol episode: *06/02/2004*, over sea

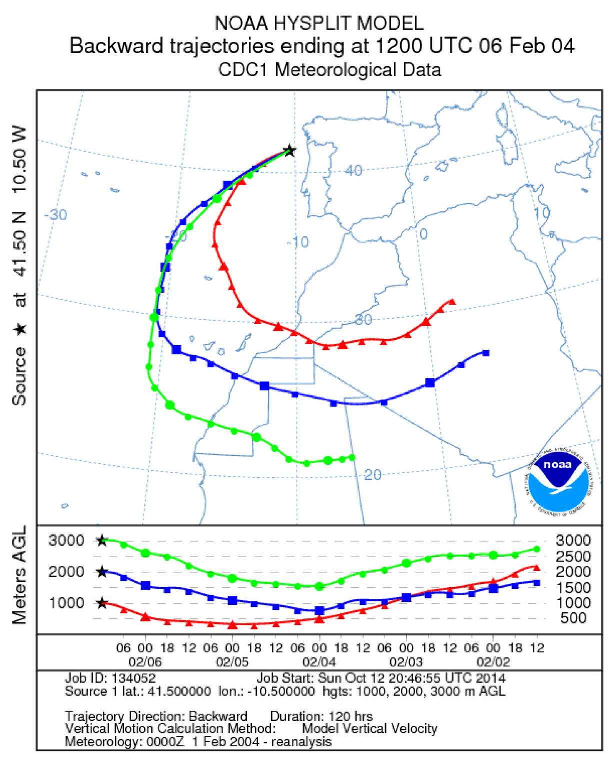


Fig. 1

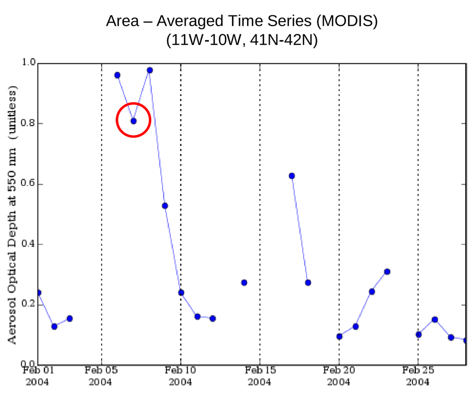


Fig. 2

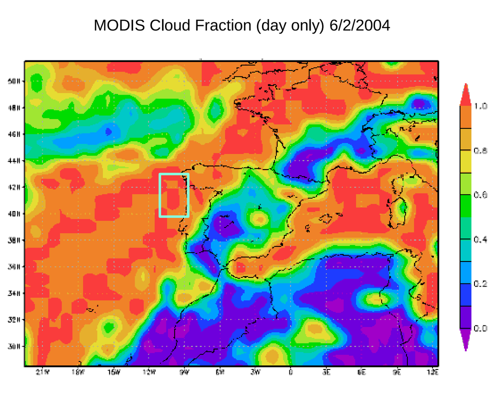


Fig. 3

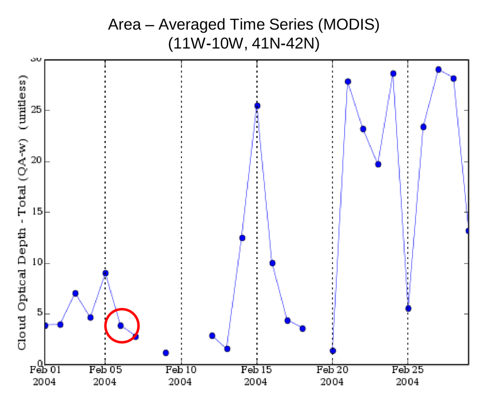


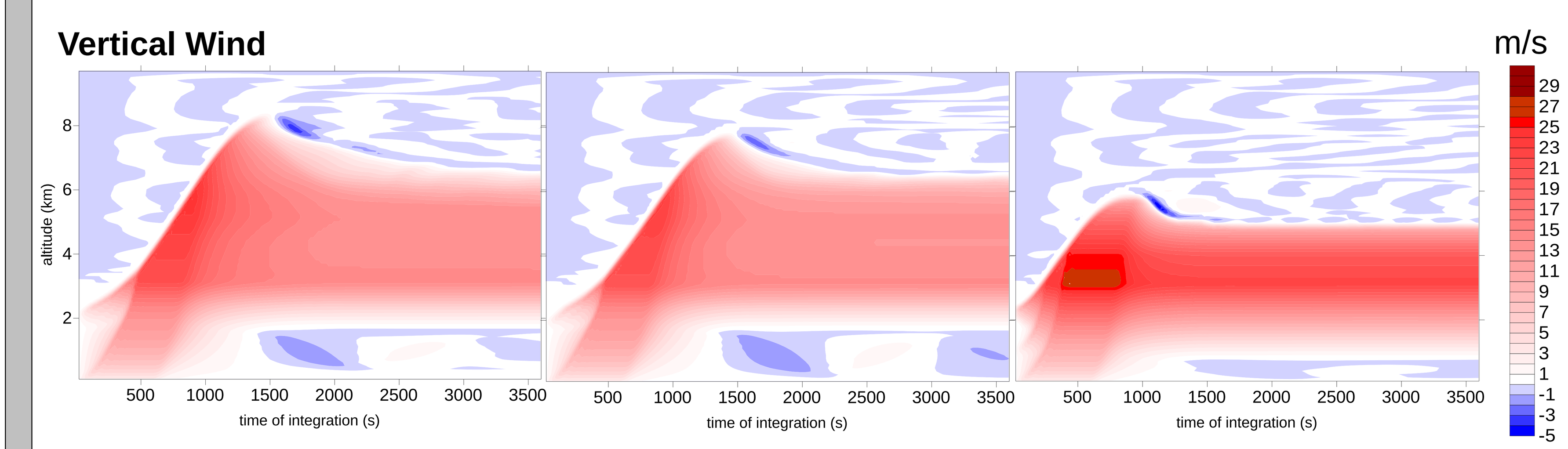
Fig. 4

- Origin of air masses (Fig.1): northwestern Africa
- Air masses enriched with sea-salt during their journey over Atlantic ocean (Fig.1)
- Large AOD (≈0.8) area-averaged value (Fig.2) at 6/2/2004 over the episode location
- Cloud cover: 100% over the episode pixel (Fig.3)
- Thin clouds detected, small (≈4) cloud optical depth (Fig.4)

Warm Cloud Simulation Results

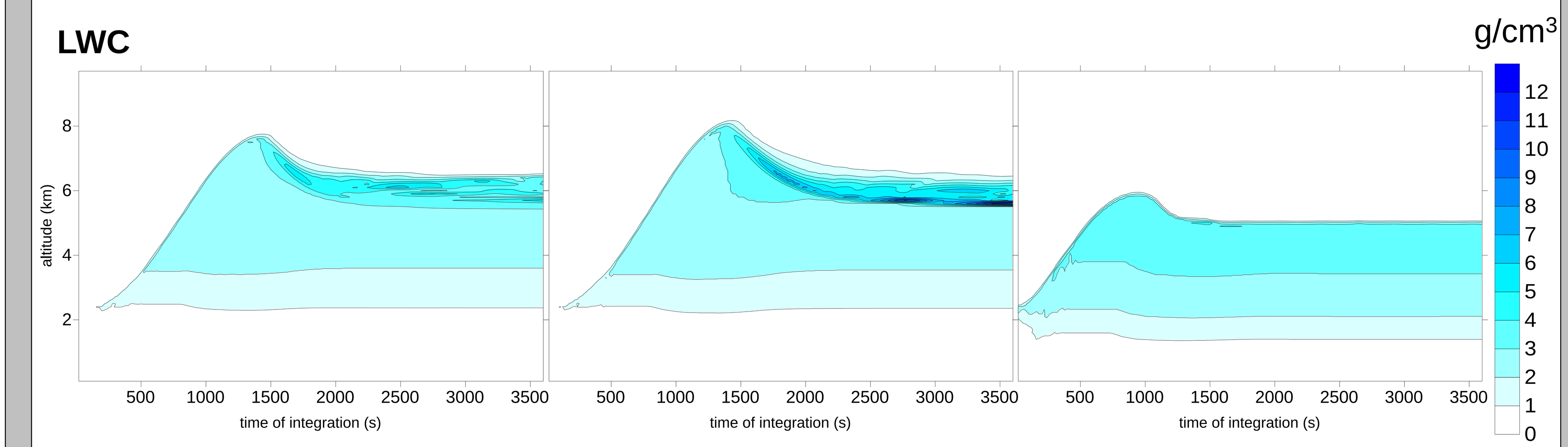
Non - Episode | Episode (dCCN+dT) | CCN increase only

Vertical Wind



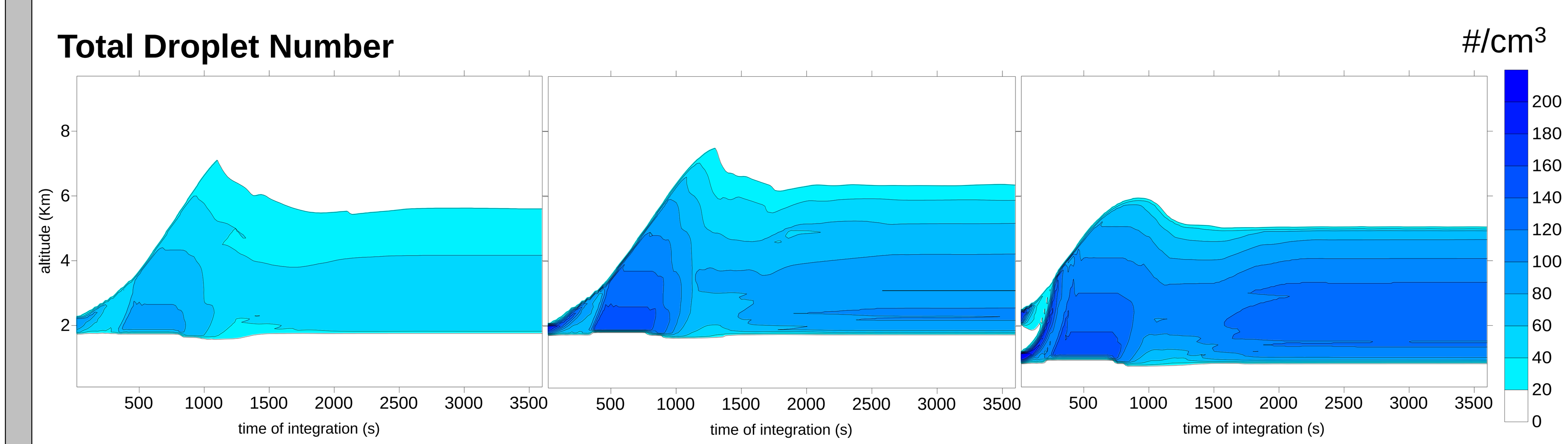
- Suppression of convection when episode occurs, caused by increased CCN (dCCN) and extenuated by aerosol heating (dT).
- Increasing CCN and enhanced atmospheric solar heating due to aerosols are counterbalancing, resulting in small changes of cloud base height, though cloud forms faster and its base is lower when only the increase of the CCN takes place.

LWC



- Small differences in total LWC amount between the aerosol episode and non-episode cases.
- Maximum LWC: 50% less during the episode case compared to the non – episode one.
- LWC decreases under increased CCN conditions and partly recovers due to aerosol heating.

Total Droplet Number



- More droplets are formed when the aerosol episode occurs, attributed to the CCN increase.

Warm vs. Mixed-phase Cloud Results

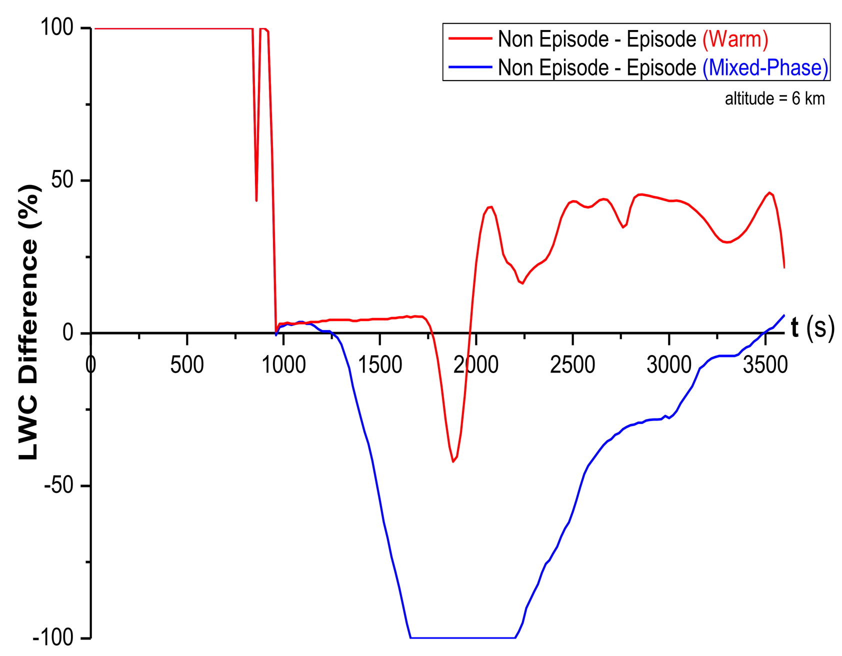


Fig. 5: LWC difference (%) between Non-Episode and Episode case for warm and mixed-phase cloud at 6 km height

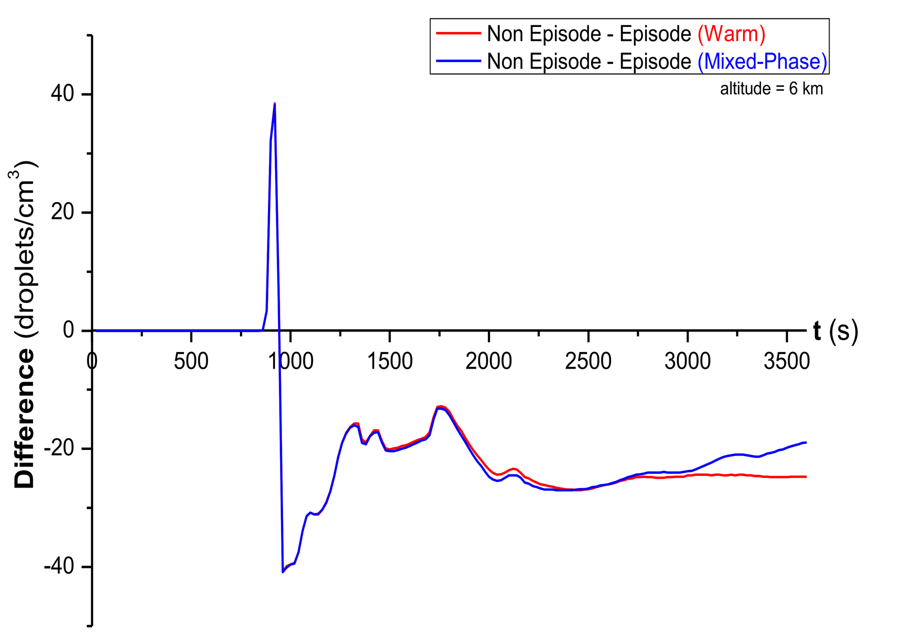


Fig. 6: Total droplet number absolute difference between Non-Episode and Episode case for warm and mixed-phase cloud at 6 km height

Conclusions

- Aerosol episodes lead to a generally small reduction of LWC at the top of the cloud.
- When only d(CCN) is considered, this results in a strong suppression of convection and significantly reduces the vertical development and top height of cloud (by about 2 km) while increasing the droplet number with respect to the non-episode case. It also significantly reduces LWC throughout the cloud lifetime, while it accelerates the formation and development of the cloud.
- The atmospheric heating (dT) due to aerosol solar absorption has effects on updrafts, cloud base height, LWC and total droplet number, which are counteracting with those induced by dCCN, but are slightly smaller.
- In overall, the combined effect of aerosol episodes, due to both dCCN and dT, is smaller than the single separate effects, consisting in a slight suppression of convection, reduction of LWC and increase of cloud droplet number.
- Small and reasonable differences are found between warm and mixed – phase cloud formation.
- The amount of LWC is generally bigger for warm clouds than for mixed-phase clouds and it is also found in higher altitudes in warm clouds.
- Finally, a slightly stronger suppression of the convection takes place when the ice phase is being taken into account. According to the indicative comparisons (Fig.5 and 6), the aerosol episode seem to impact more a mixed-phase cloud than a warm cloud.

Perspectives

- Study the impacts of aerosol episodes on cloud optical properties and radiative effects (indirect effect).
- Examine other similar cases of aerosol episodes (possibly of other types, e.g. soot).
- Repeat the study in a more complete dynamic framework, namely with a 3-D model.

References

- *Flossmann, A. and Wobrock, W.: A review of our understanding of the aerosol–cloud interaction from the perspective of a bin resolved cloud scale modelling, Atmos. Research, 97, 478-497, 2010.*
- *IPCC: Summary for Policymakers, in: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Stocker, T. F., Qin, D., Plattner, G.-K. et al., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.*

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