A quick look at the Chemistry-Aerosol Mediterranean Experiment (ChArMEx) legacy

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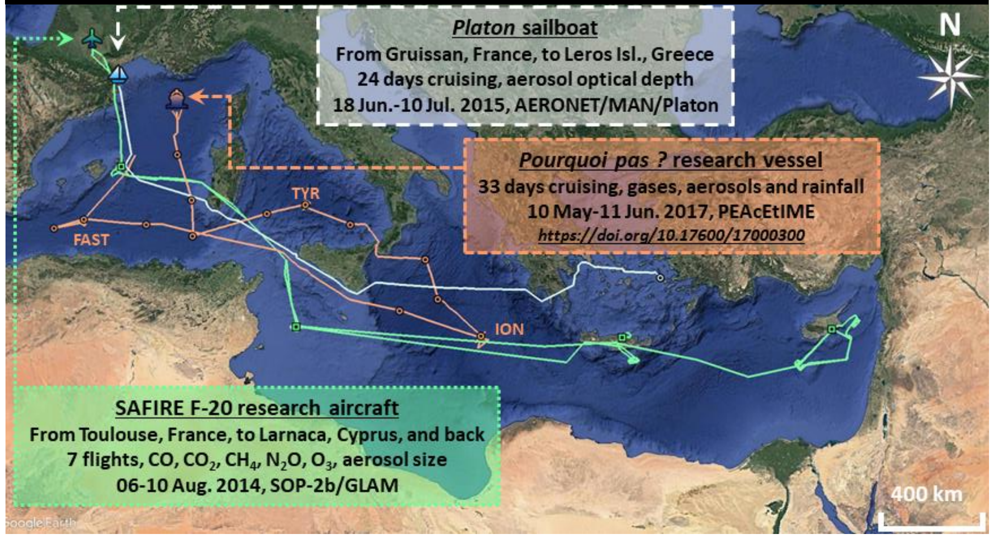
- **The Chemistry-Aerosol Mediterranean Experiment (ChArMEx)** was initiated in 2007 and supported from 2010 to 2020 by the French MISTRALS multidisciplinary research programme on the Mediterranean region and its future inhabitability, itself endorsed by the Union for the Mediterranean.
- **Overarching ChArMEx objective**: An updated assessment of the atmospheric pollution and its impacts in the Mediterranean region, and of their evolution in the next decades.
- **Multiscale observation and modelling integrated strategy**: The project has been primarily driven by several large field campaigns. It also included more local field studies in various specific environments, several years of in situ monitoring efforts, large scale remote sensing analyses, and extensive modelling.
- **Contributions**: ChArMEx has federated efforts from two dozens and several tens of French and foreign labs, respectively.
- **Funding**: ChArMEx-France has raised over 12 M€ (excl. permanent salaries) mainly granted by ADEME, ANR, CEA, CNES, CNRS-INSU, Engineering schools (IMT Lille Douai, ENPC), EU/FP7-Infrastructures, Météo-France, Regions of Corsica, Midi-Pyrénées and PACA, and Universities of Aix-Marseille, Clermont-Auvergne, Corsica, Lille, Paris 7, Toulouse…
- **List of peer-reviewed articles** (~140 incl. 106 in the ChArMEx special issue in ACP and AMT) and PhDs (36): https://www.lsce.ipsl.fr/en/project/charmex /publications.php.
- **Database**: http://mistrals.sedoo.fr/ChArMEx.

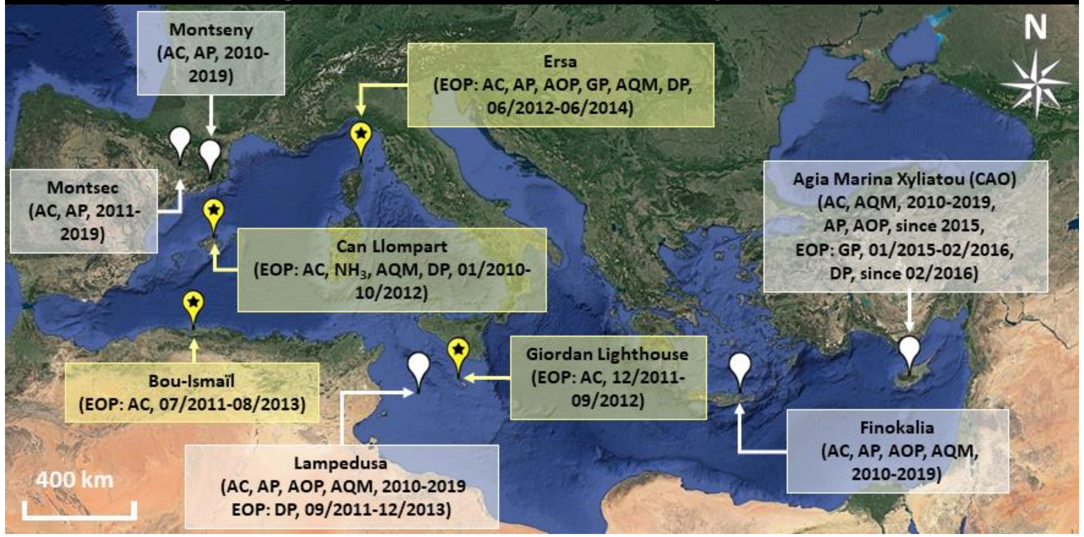
- **These slides highlight a few important facts and results from ChArMEx and introduce an extensive review book in press.**

Illustration of the ChArMEx experimental effort

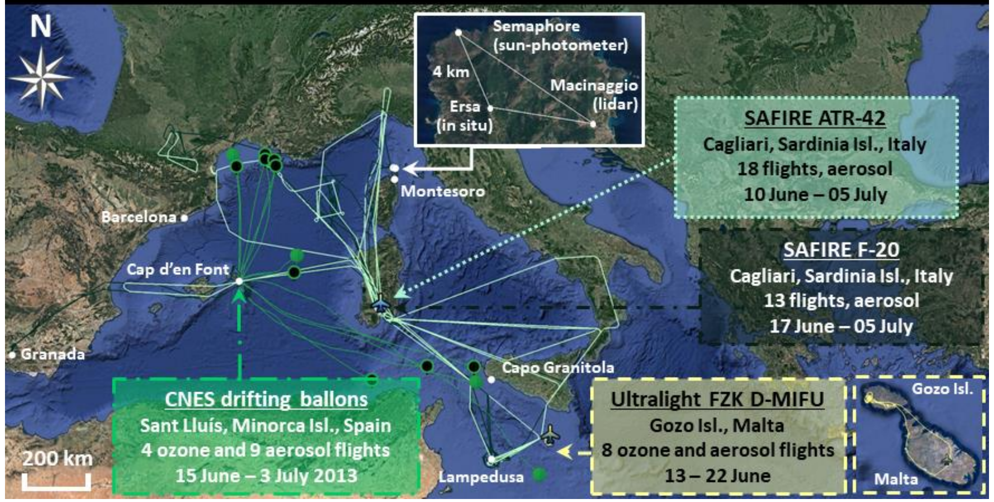
ChArMEx Mediterranean transects



Background aerosol chemistry network



ChArMEx SOP-1a field observations (summer 2013)



ChArMEx-TRANSEMED campaigns in large eastern Mediterranean cities

- 5 regional campaigns with airborne means
- Many other targeted campaigns in selected environments (e.g., Med. forests and large cities)
- Reinforcement of the regional MAN and AERONET photometer networks
- Weekly dust deposition monitoring network
- Etc *(see the Introduction chapter by Dulac, Sauvage, Hamonou and Debevec in Vol. 1 of the forthcoming book shown in slide 7)*

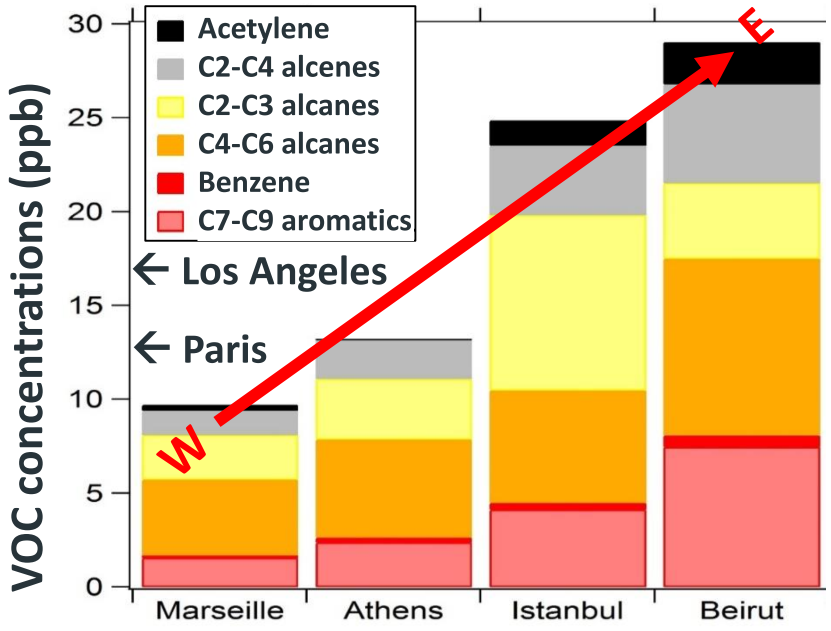
Global anthropogenic emission inventories are highly underestimated for VOCs

- Volatile organic compounds are precursors of major secondary pollutants such as ozone and fine particles.

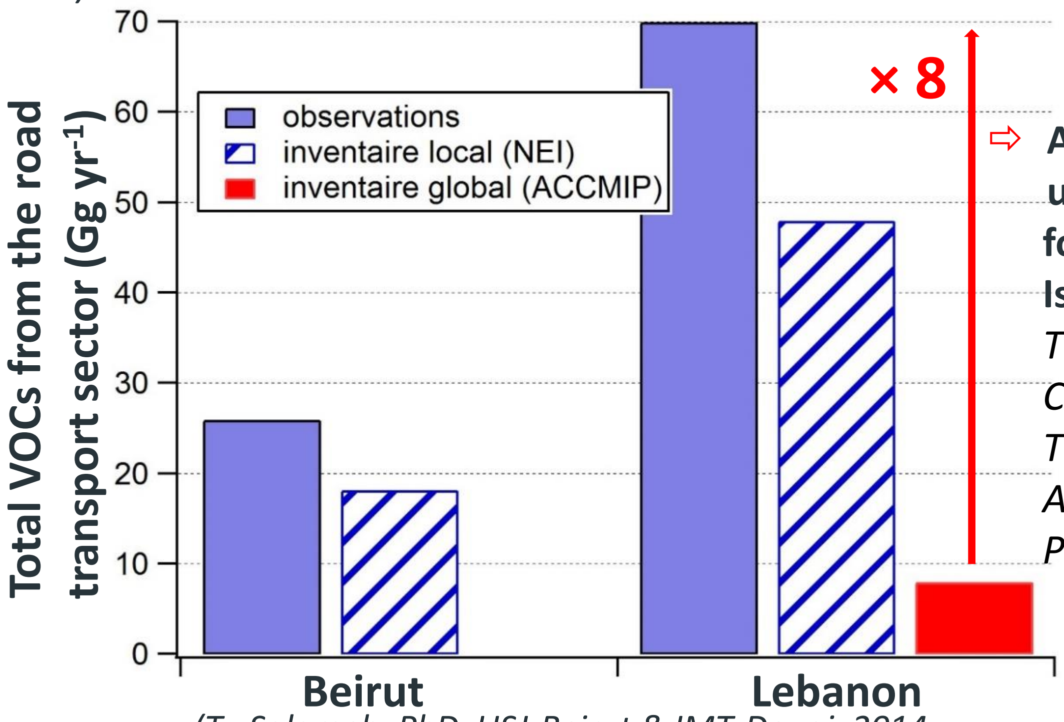
⇨ **Since 1980, anthropogenic emissions decreased by 2 in Europe and America but increased by 50% in the Middle East, and a strong W to E gradient is observed in the urban pollution in VOCs** *(Salameh et al., ACP, 2017)*.

⇨ **In eastern Med. cities, VOC emissions are generally controlled by the road transport sector, incl. fuel evaporation** *(A. Panopoulou, PhD, IMT-Douai and NOA-Athens, 2019; Salameh et al., ACP, 2016)*.

⇨ **Whereas observations are compatible (±30%) with local emission inventories, large scale inventories appear under-estimated by one order of magnitude, which questions global atmospheric modelling** *(Salameh et al., ACP, 2017)*.



(Marseille: M. Dufresne, on-going PhD, IMT-Lille-Douai & ADEME; Athens: A. Panopoulou, PhD, IMT-Douai and NOA-Athens, 2019; Istanbul: B. T. P. Thera, on-going PhD, LaMP-Clermont-Ferrand; Beirut: T. Salameh, PhD, USJ-Beirut & IMT Douai, 2014)



(T . Salameh, PhD, USJ-Beirut & IMT-Douai, 2014; Salameh et al., Atmos. Chem. Phys., 2016)

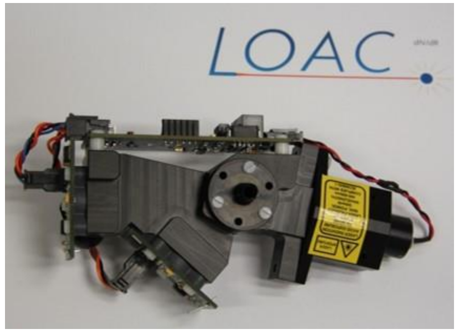
⇨ **Also a factor 10 underestimate for total VOCs in Istanbul** *(B. T. P. Thera, PhD, LaMP-Clermont-Ferrand; Thera et al., Atmos. Chem. Phys., 2019)*.

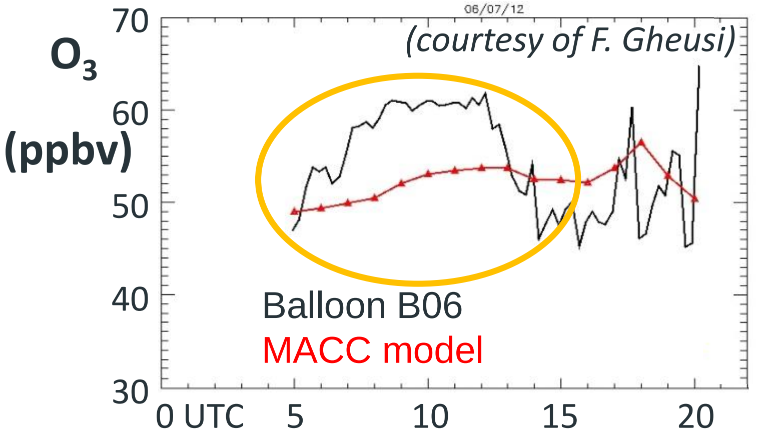
Challenging results from a still unique experiment using long-range drifting instrumented balloons

- **Balloons make possible in situ Lagrangian monitoring, a key issue for studying processes during transport**

- 30 (2.5-m or 2.6-m diam.) drifting balloons.
- Ceiling altitude: between 0.3 up to 3.4 km.
- Some launches by pair at 2 ceiling altitudes.
- Range: up to 33 h and 1000+ km.
- Basic payload: GPS, P, T, U, and downward broadband solar flux, + satellite comm.
- **Plus ozone sonde or aerosol counter/sizer.**

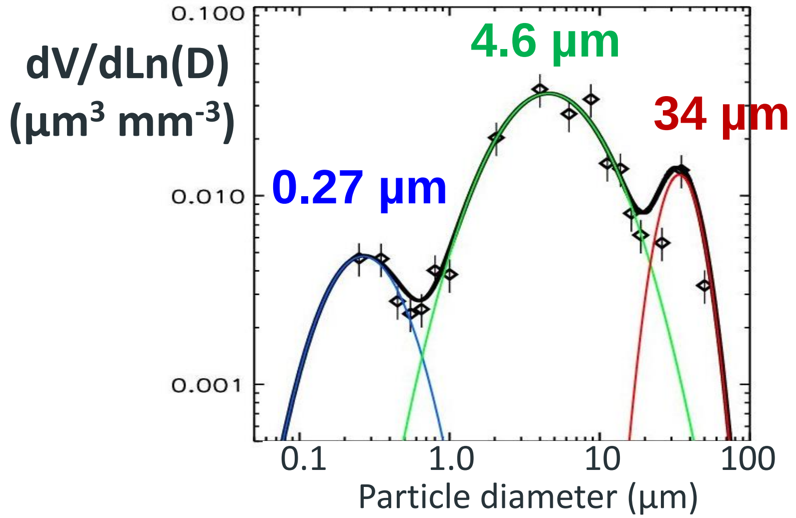
- **Instrumental developments:**
- Adaptation of the commercial O_3 ECC sonde *(Gheusi et al., AMT, 2016).*
- Development of a mini OPC with particle speciation capability *(Renard et al., AMT, 2016).*





⇨ **Intensity of photochemical increase in O_3 at sunrise (net prod. rate of 1.5 to 2 ppbv h^{-1}) and quick afternoon decrease missed here by the European air quality forecast model MACC**

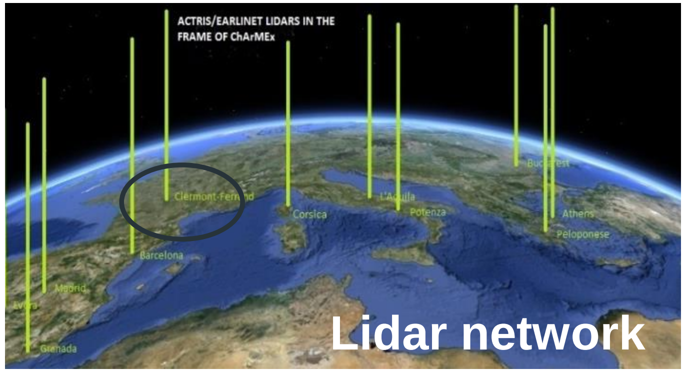
⇨ **Many other forecast overestimations**

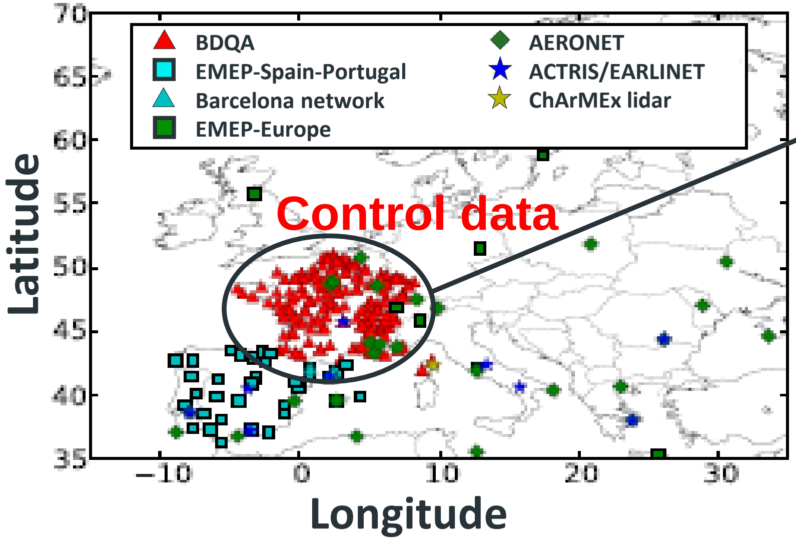


⇨ **Saharan dust showed a persistent mode at about 30 µm in diameter despite its high (>6 km d^{-1}) theoretical gravitational settling velocity** *(Renard et al., ACP, 2018)*

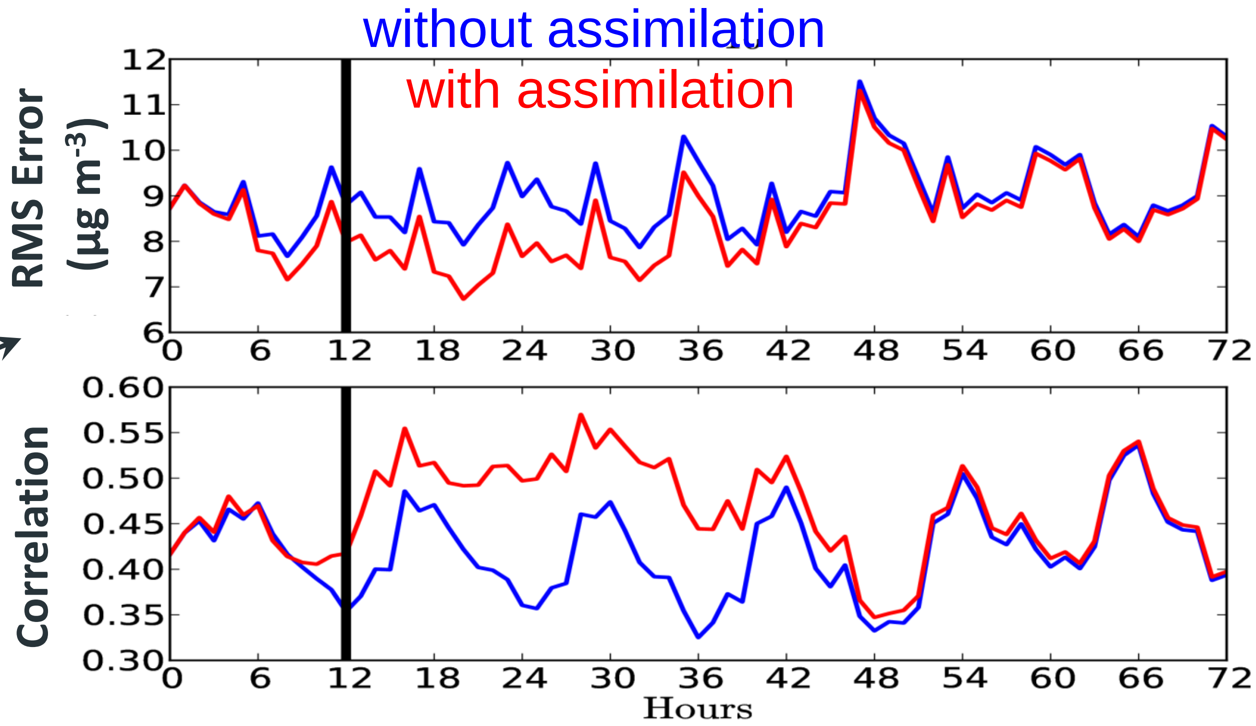
An original demonstration of aerosol model forecast improvement by lidar obs. assimilation

- **First hindcast aerosol modelling exercise with assimilation of measurements from an aerosol lidar network in continuous operation for 3 days (9-12 July 2012) in cooperation with ACTRIS/EARLINET.**





Model comparison to independent observations of surface PM_{10} in France



⇨ **The impact of 12-h assimilation of lidar observations between 1 and 3.5 km in altitude significantly improves particulate air quality (and AOD) forecasts up to 36 h in advance.**

(Wang et al., Atmos. Chem. Phys., 2014)

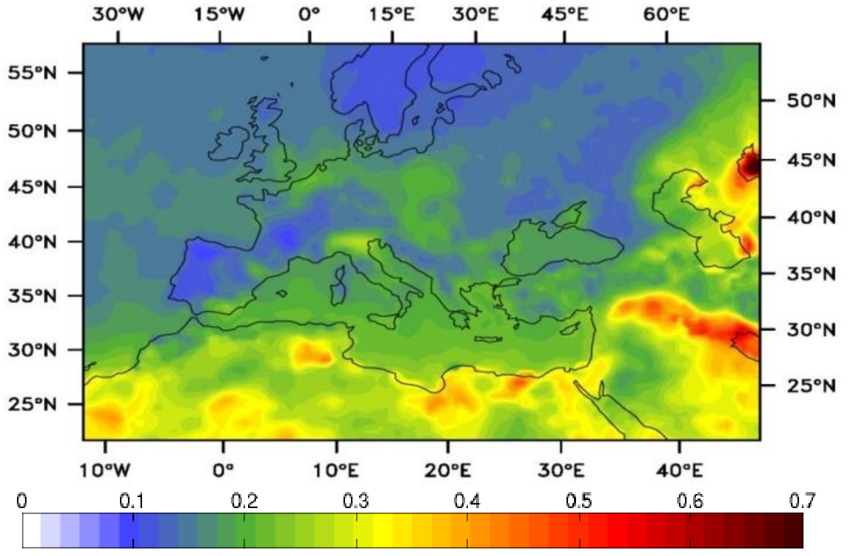
A strong positive feedback of the direct aerosol radiative impact on decreasing precipitation

- By reducing solar radiation, aerosols contribute to a decrease in surface temperature and evaporation.

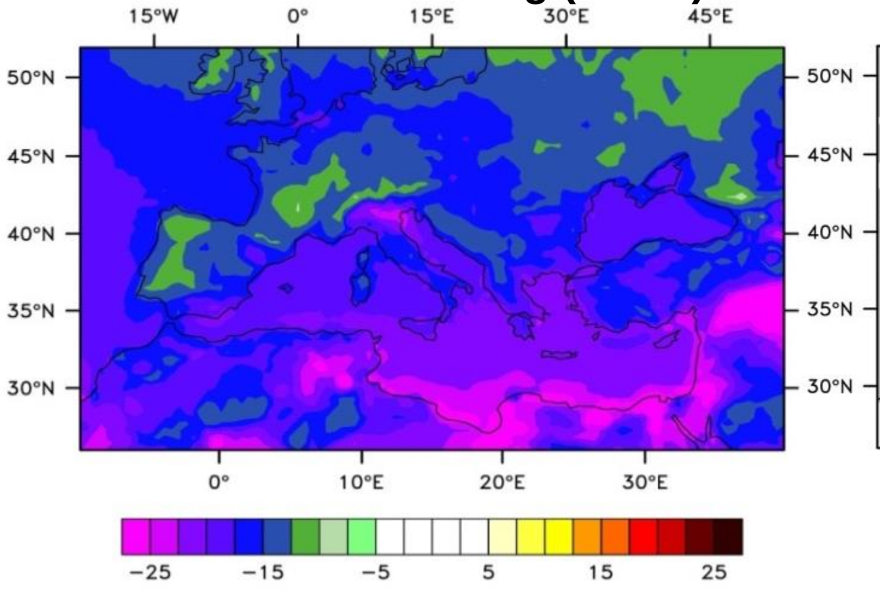
⇨ **Anthropogenic sulphate reduction explains observed trends in surface solar radiation** *(Nabat et al., Geophys. Res. Lett., 2014)* **and 20-25% of the warming over the period 1980-2007** *(Nabat et al., Clim. Dyn., 2015)***.**

⇨ **Coupled atmosphere-ocean modelling is requested to reproduce the 0.3-0.6°C sea surface T decrease, and shows a 10% decrease in annual precipitation over the Med. Basin** *(Nabat et al., Clim. Dyn., 2015)***.**

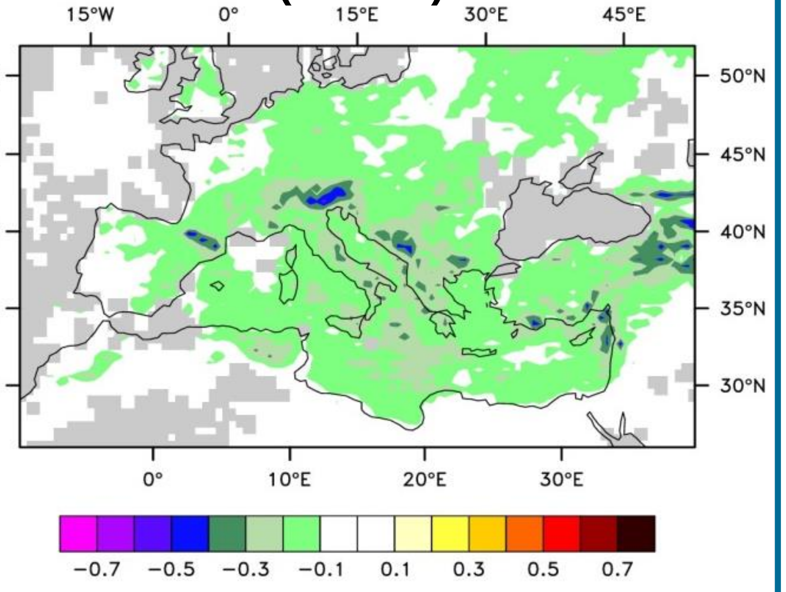
Aerosol Optical Depth at 500 nm



Surface shortwave direct radiative forcing (W m^{-2})



Aerosol impact on precipitation (mm d^{-1})



2003-2009 averages, CNRM-RCSM4 model

(P. Nabat, PhD, CNRM-Toulouse, 2014; Nabat et al., Clim. Dyn., 2015)

A forthcoming review book on atmospheric pollution in the Mediterranean region

- The ChArMEx community has produced a peer-reviewed book in 2 volumes *(F. Dulac, S. Sauvage and E. Hamonou Eds. ; foreword J. Lelieveld)*, including 10 sections and 41 chapters co-authored by 100 scientists from 15 different countries, synthesizing several decades of research on atmospheric chemistry and its impacts in the Mediterranean region, and issuing recommendations for future research :
- **Introductions to volumes 1 and 2**
- **Part I: The Mediterranean atmospheric chemistry hotspot**
- **Part II: Synoptic and dynamical conditions affecting pollutant concentrations**
- **Part III: Aerosol concentrations and variability**
- **Part IV: Reactive gas concentrations and variability**
- **Part V: Emissions and sources**
- **Part VI: Recent progress on chemical processes**
- **Part VII: Mediterranean aerosol properties**
- **Part VIII: Atmospheric deposition**
- **Part IX: Impacts of air pollution on precipitation chemistry and climate**
- **Part X: Impacts of air pollution on human health and ecosystems**
- **Conclusions and recommendations for future research**