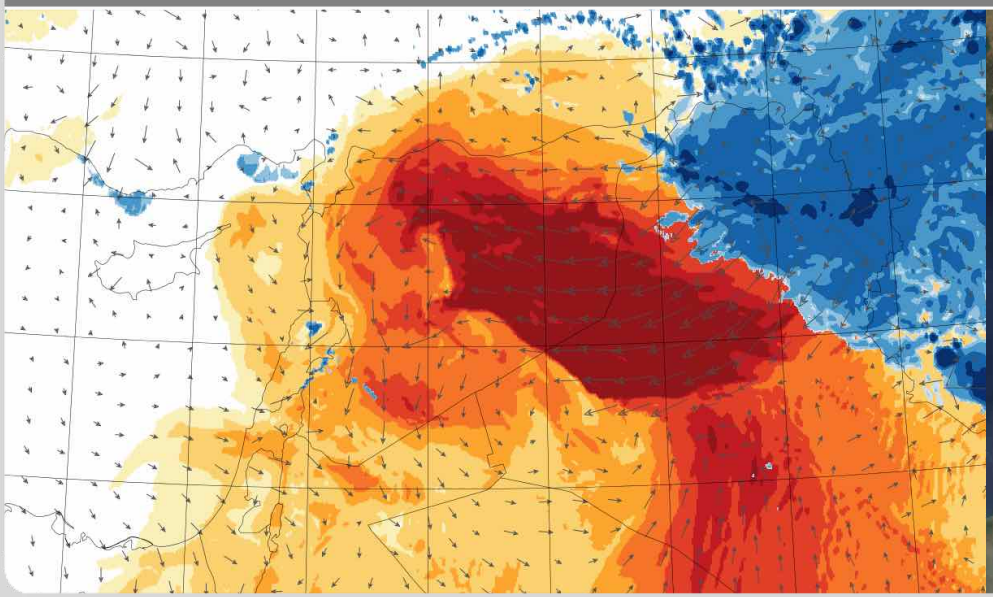
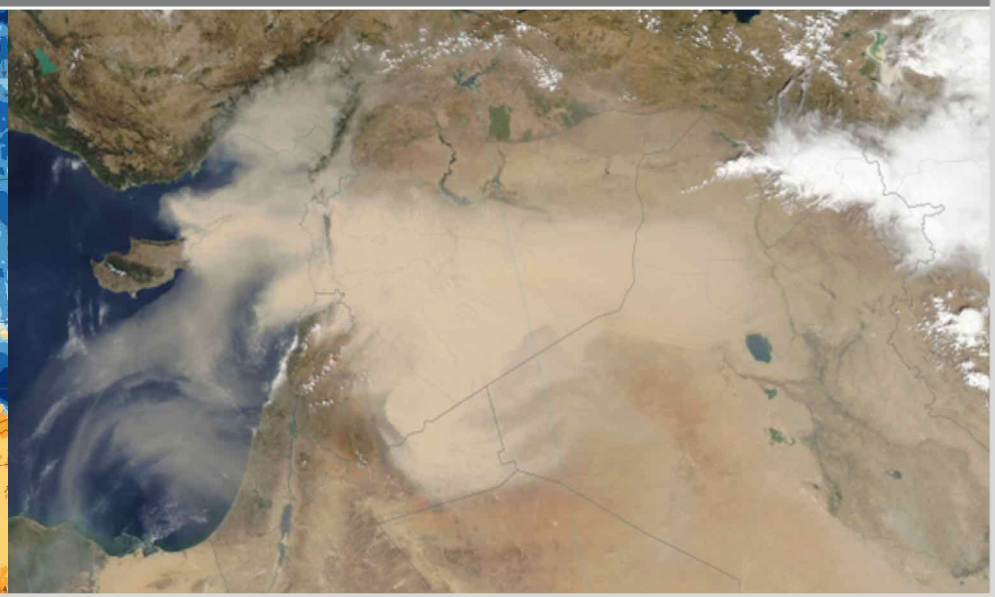
Karlsruher Institut für Technologie

The Role of Moist Convection for Dust Emission

Peter Knippertz

Institute of Meteorology and Climate Research – Troposphere

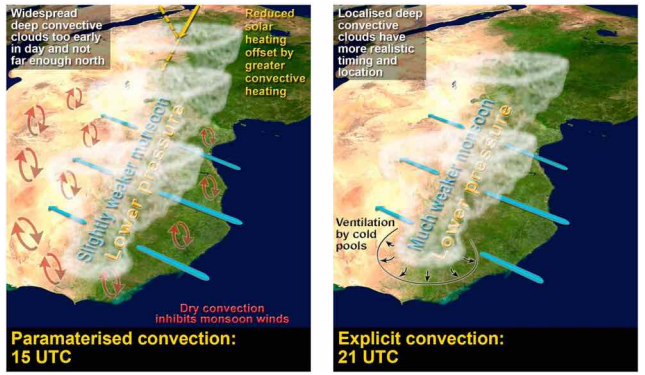




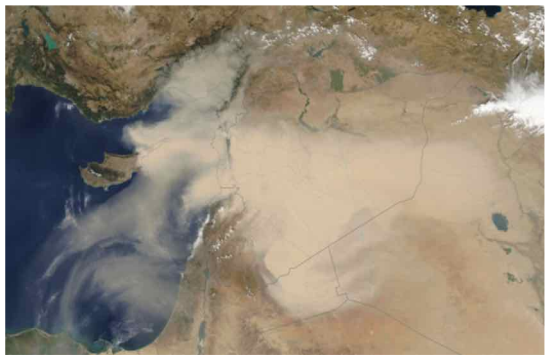
Content / Take-home messages

- Deep convection creates dust-emitting winds through vertical momentum transports and cold pools (haboobs). This is severely underrepresented in models using convective parametrisations.

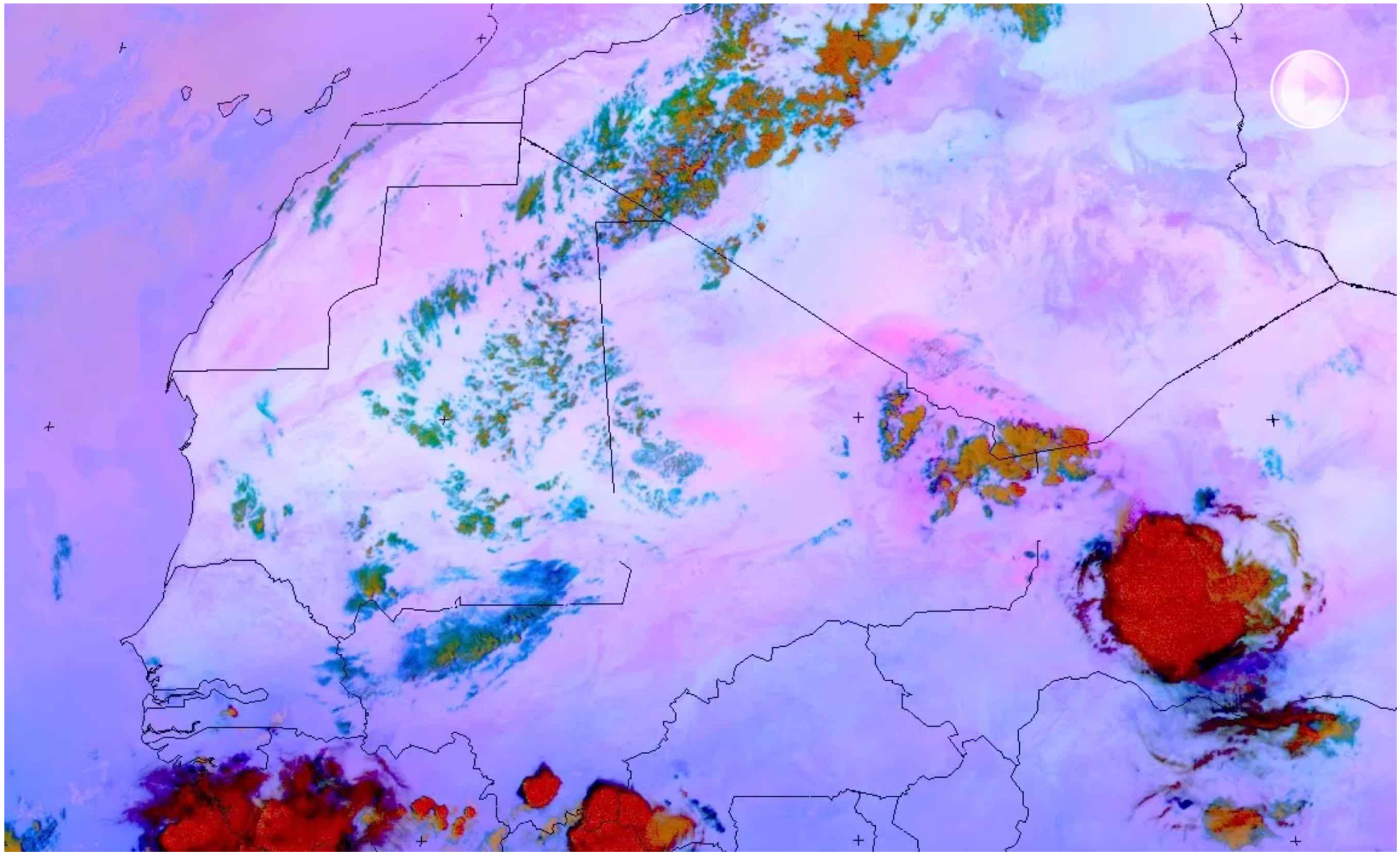
- The misrepresentation of organised convection in models affects the West African monsoon and creates continental-scale wind biases.



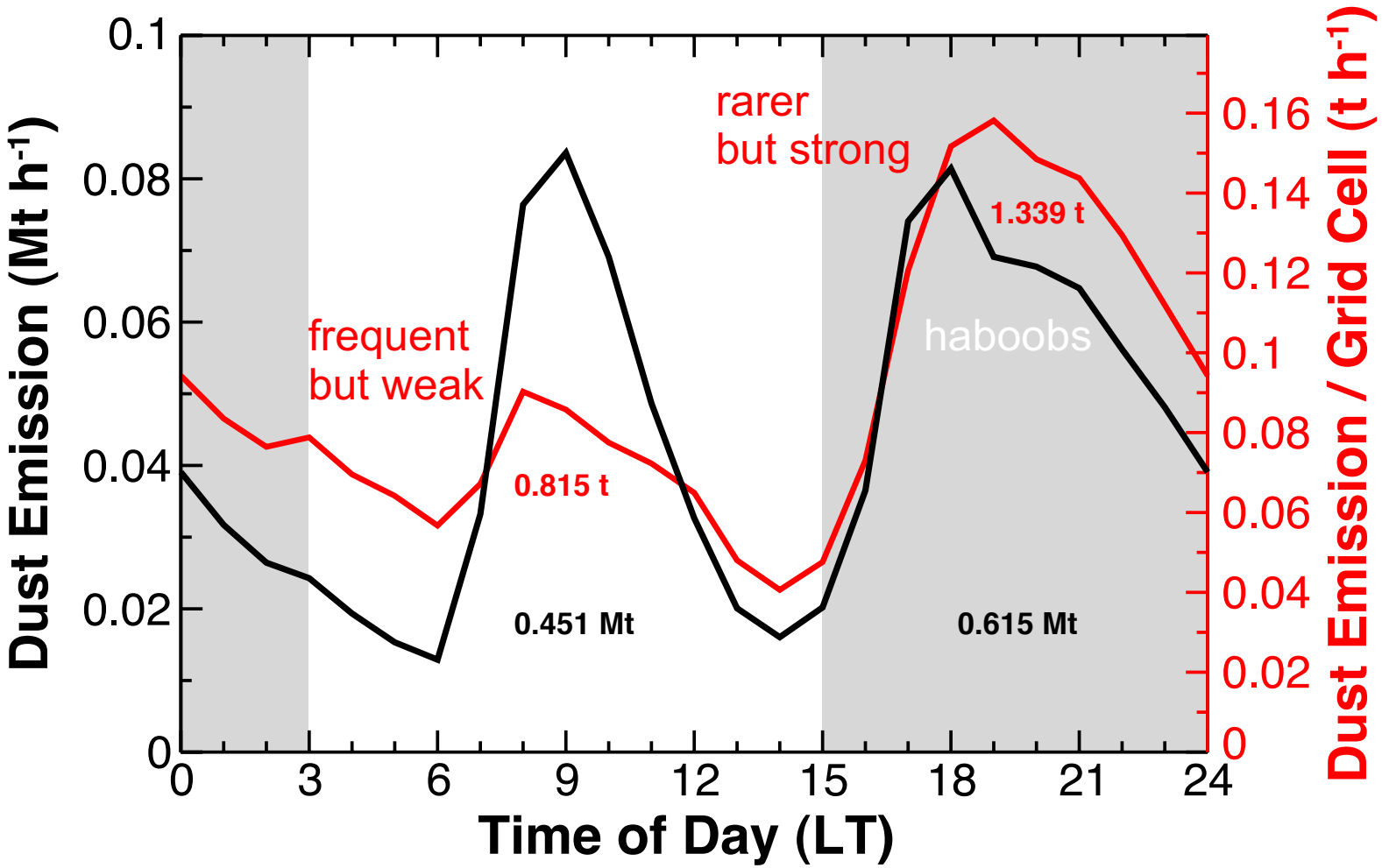
- Convection can interact with larger-scale circulation in complicated ways to create large, long-lasting dust events.



Example of an haboob

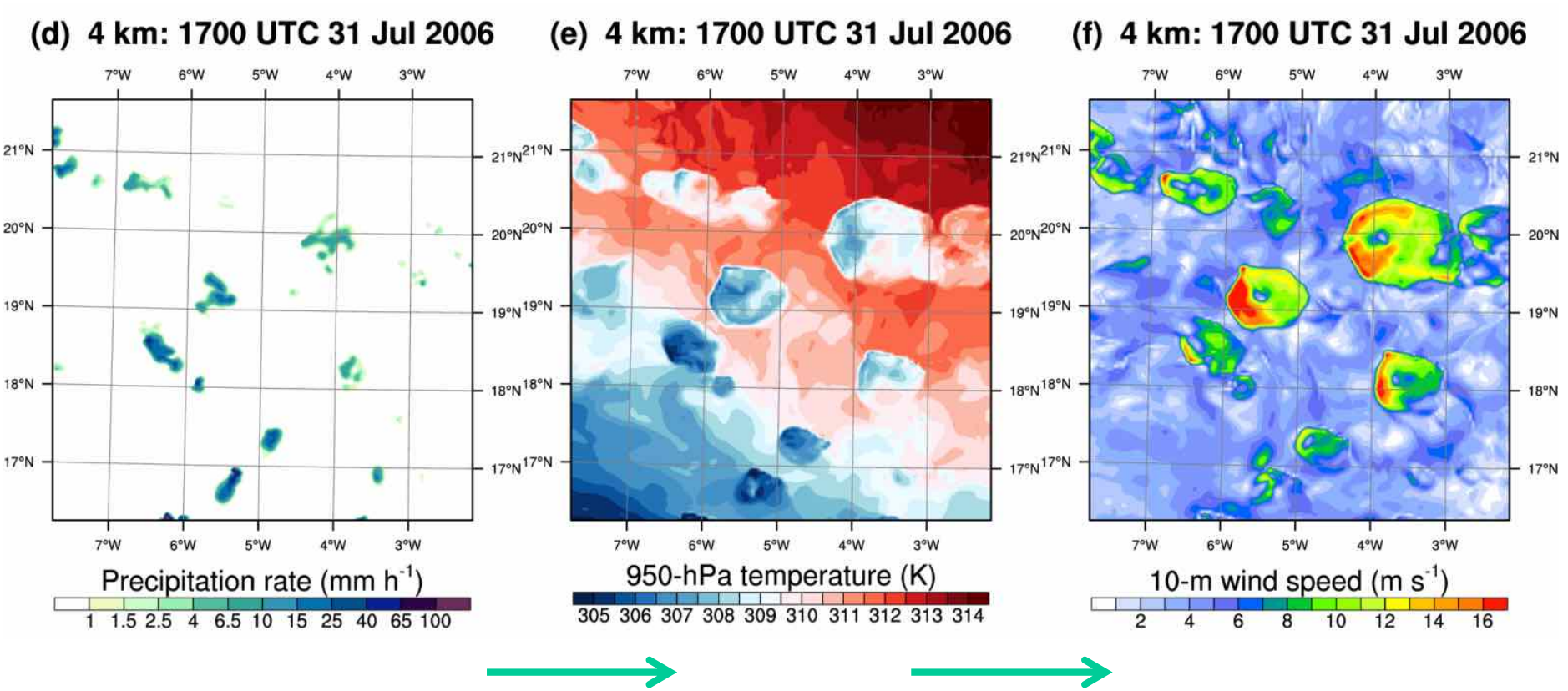


Diurnal cycle of dust emission in 4-km UM



Heinold et al., 2013, JGR

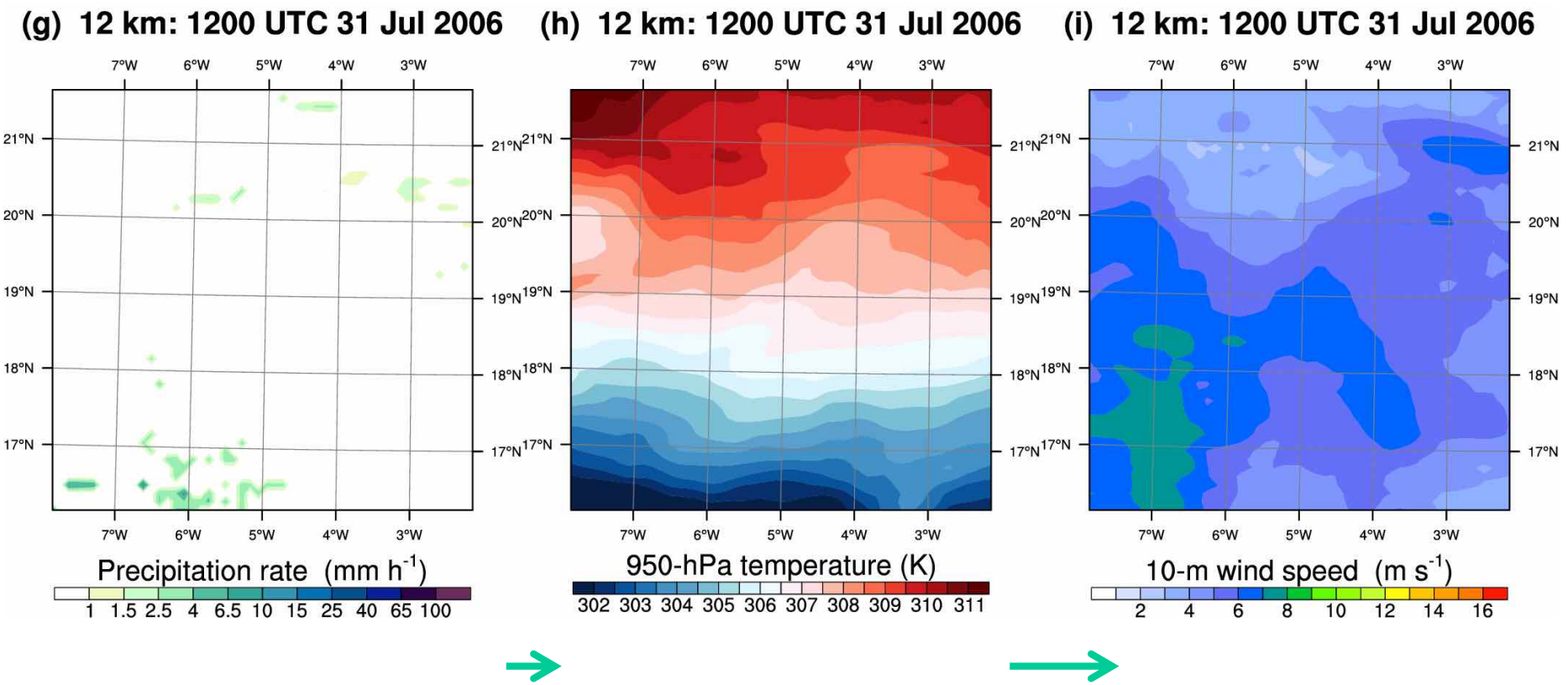
Convective structures at 4 km



from *Pantillon et al., JAS, 2015*

The 4-km run **resolves** convective dust storms
→ reference for the parameterization!

Convective structures at 12 km



from *Pantillon et al., JAS, 2015*

The 12-km run **lacks** convective dust storms
→ test for the parameterization!

Parametrisation: conceptual model

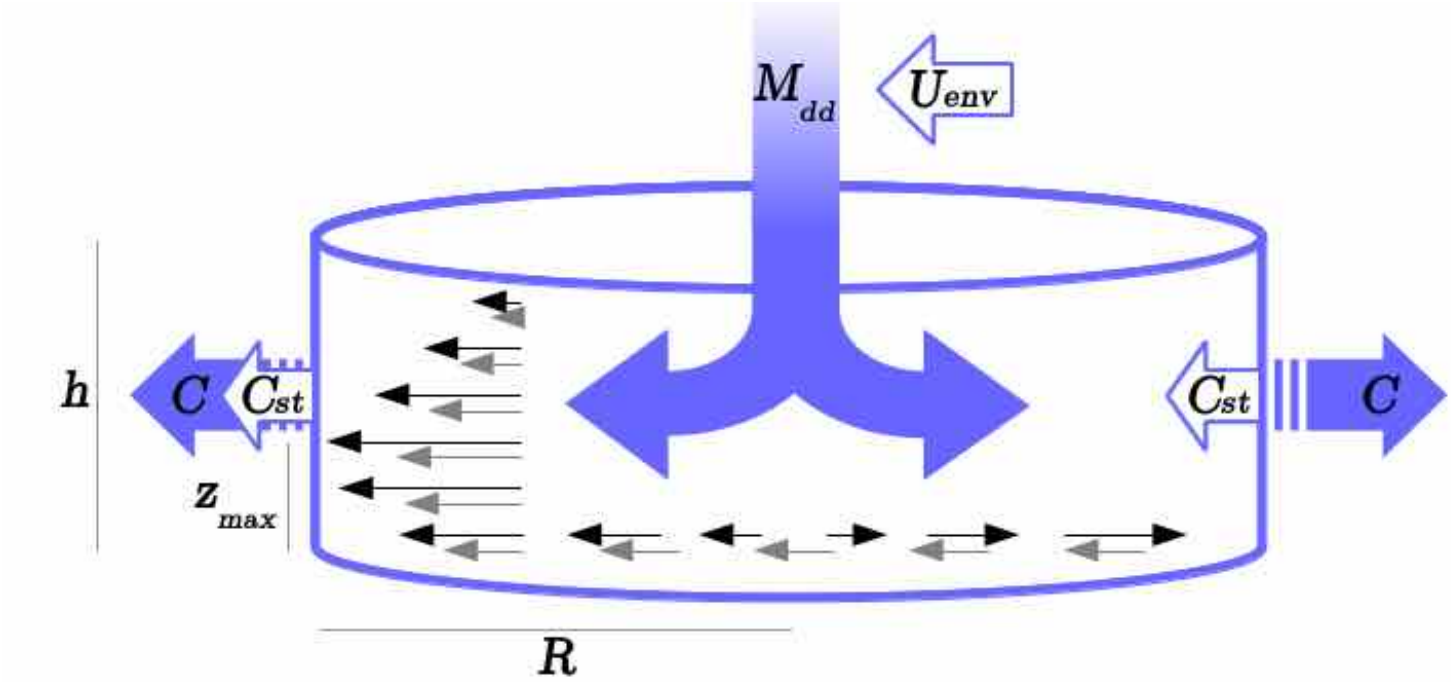
The parameterization is based on the **downdraft mass flux** M_{dd}

M_{dd} spreads out radially in a cold pool of radius R and height h

The cold pool propagates with radial speed $C = M_{dd} / 2\pi\rho Rh$

The radial wind increases linearly with radius and peaks at height z_{max}

The cold pool is steered with speed $C_{st} = 0.65\ U_{env}$



from *Pantillon et al., JAS, 2015*

Results: geographical distribution

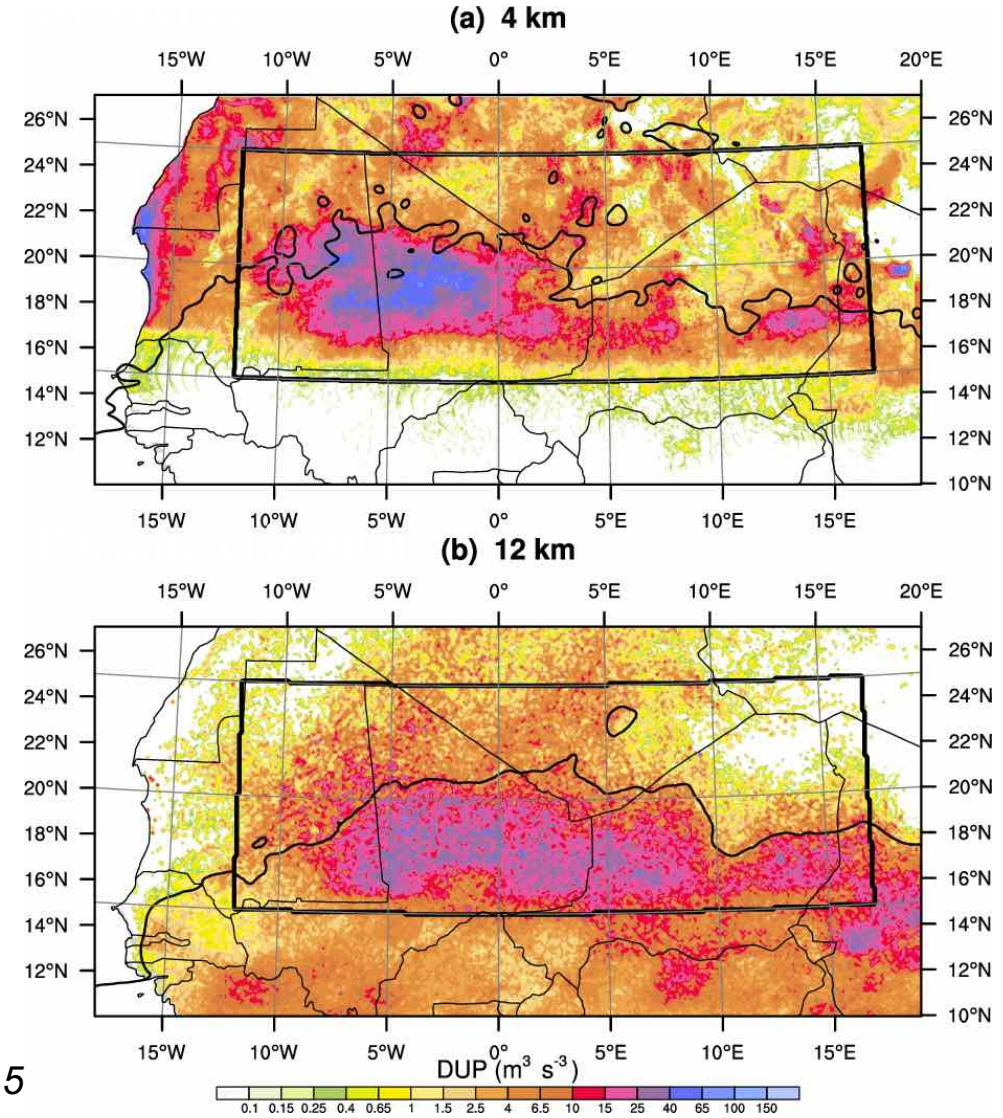
Dust proxy in reference 4-km run

Highest over South Sahara:
successfully captured by parameterization
although shifted eastward with monsoon flow

High near mountain ranges:
missed by parameterization
due to relative lack of convection

High along the Atlantic coast:
not related to convection

Weak over Sahel:
missing in reference run!?



from *Pantillon et al., JAS, 2015*

Results: diurnal cycle

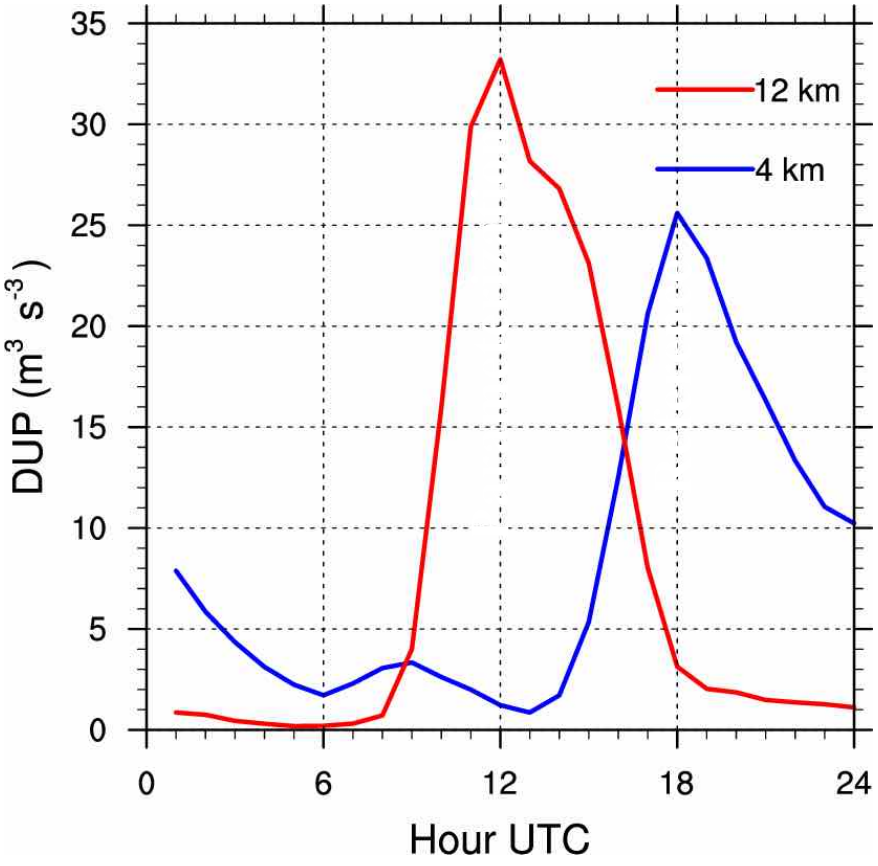
Dust proxy in reference 4-km run

Strong amplitude:
captured by parameterization

Triggering in the afternoon:
too early in parameterization
like parameterized convection

Long-lasting peak:
too short in parameterization
like parameterized convection

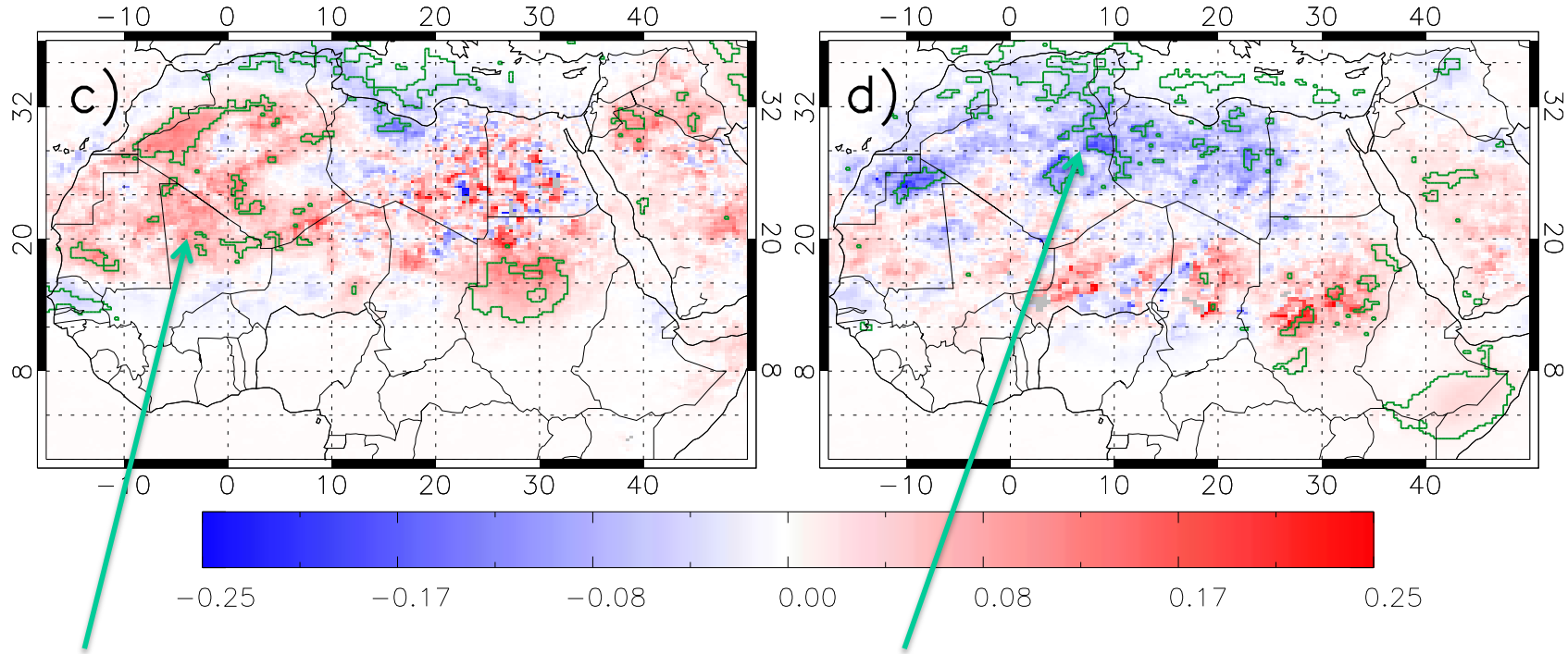
Main biases in parameterization
due to **biases in convection scheme**



from *Pantillon et al., JAS, 2015*

Can this repair a systematic model error?

UK Met Office AOD data assimilation increments after rainfall detection



DA adds dust in summer;
lack of haboobs?!

DA takes out dust in winter;
frontal systems?!

from *Pope et al. (2016, GRL)*

Impact of organized convection on West African monsoon

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 1843–1849, doi:10.1002/grl.50347, 2013

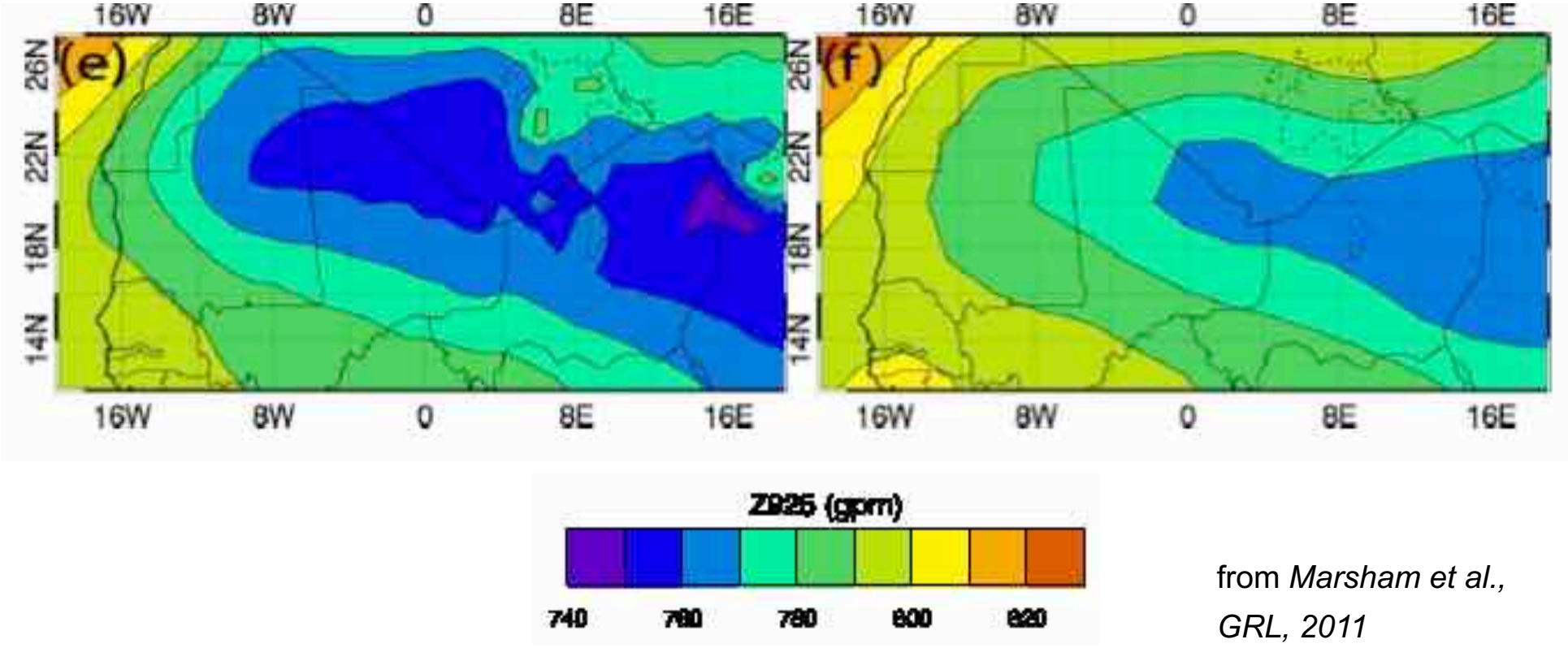
The role of moist convection in the West African monsoon system: Insights from continental-scale convection-permitting simulations

John H. Marsham,[1,2] Nick S. Dixon,[2] Luis Garcia-Carreras,[2] Grenville M. S. Lister,[1,3] Douglas J. Parker,[2] Peter Knippertz,[2] and Cathryn E. Birch[2]

Saharan heat low in analysis data

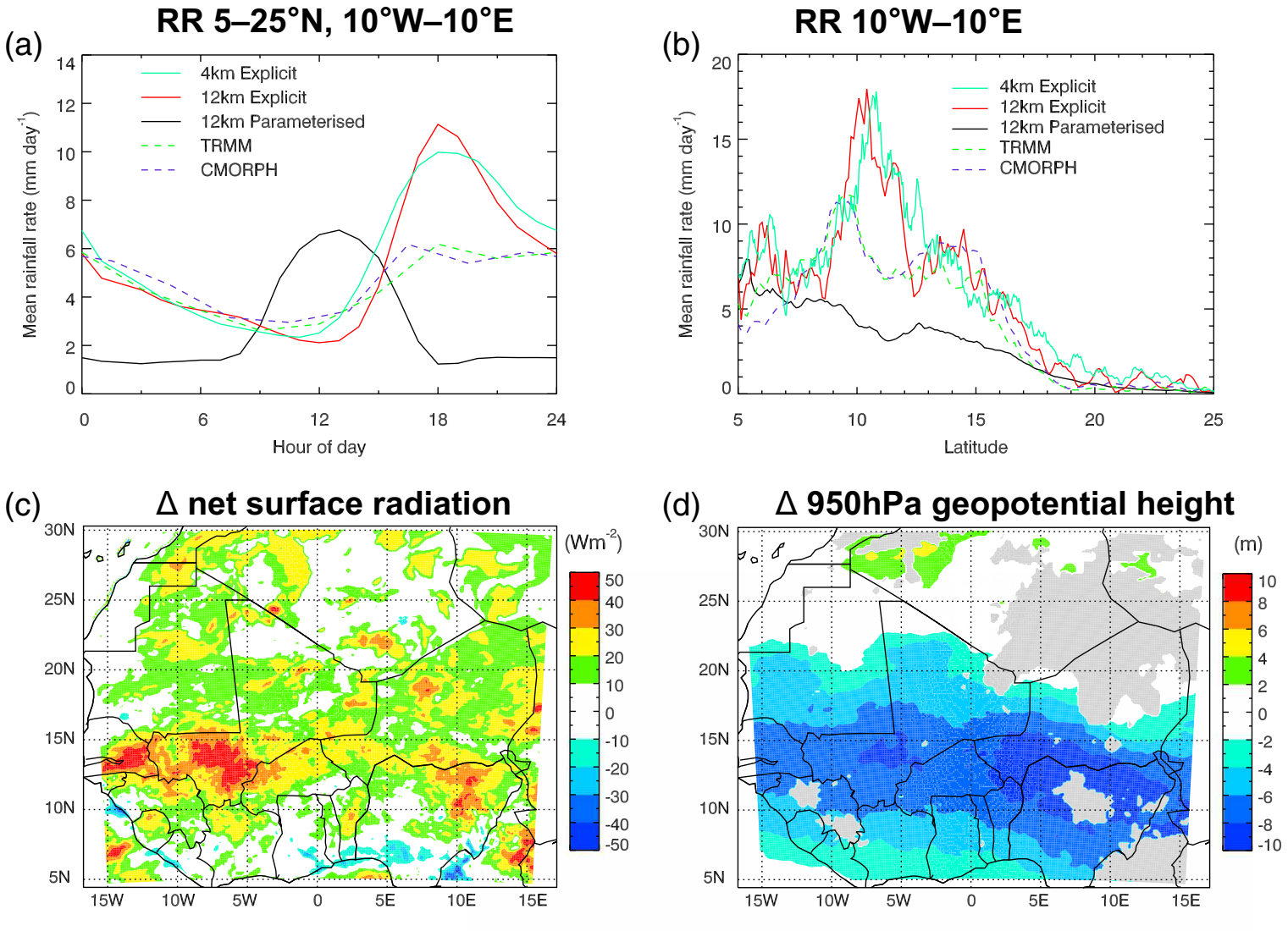
Z925 – 25 July – 03 Aug. 2006

ECMWF **NCEP**



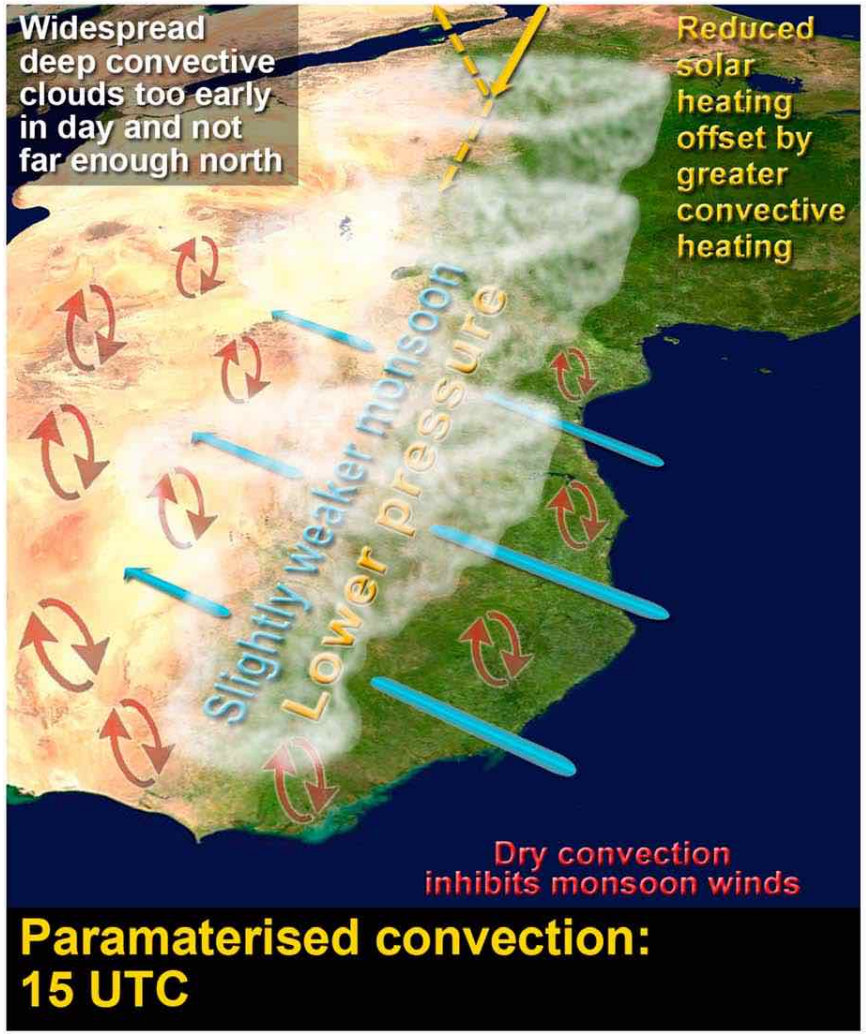
from *Marsham et al., GRL, 2011*

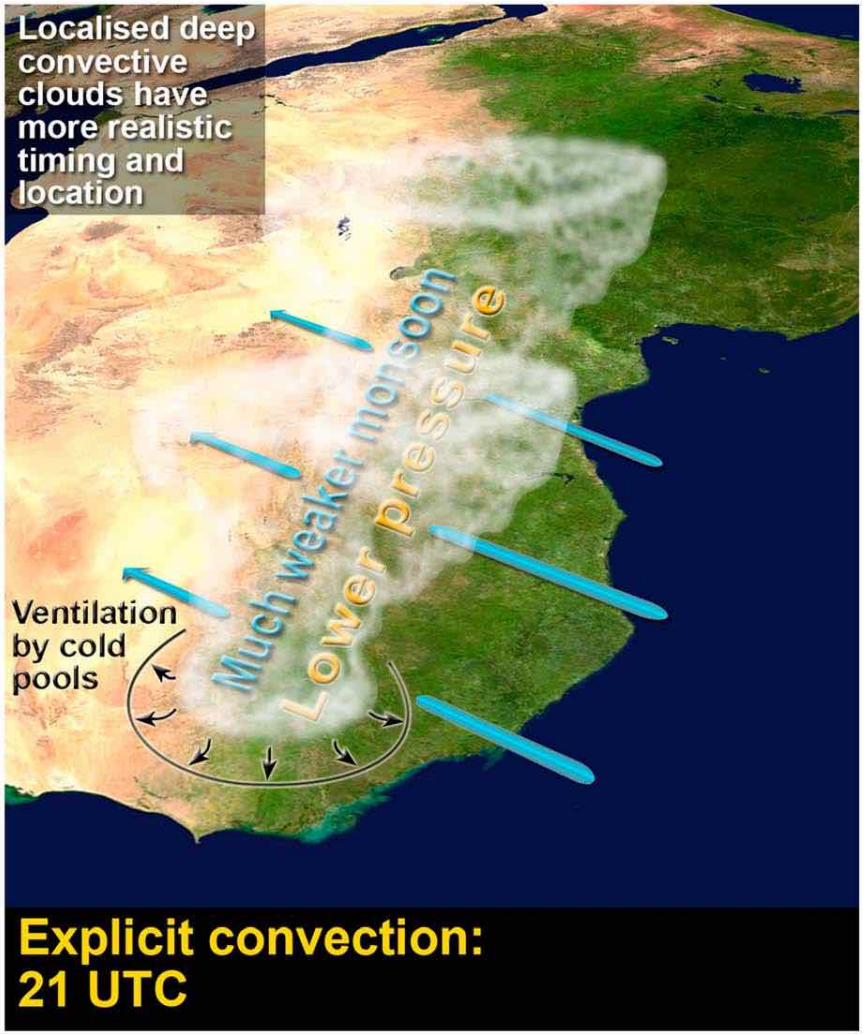
Explicit versus parametrised convection



from *Marsham et al., GRL, 2013*

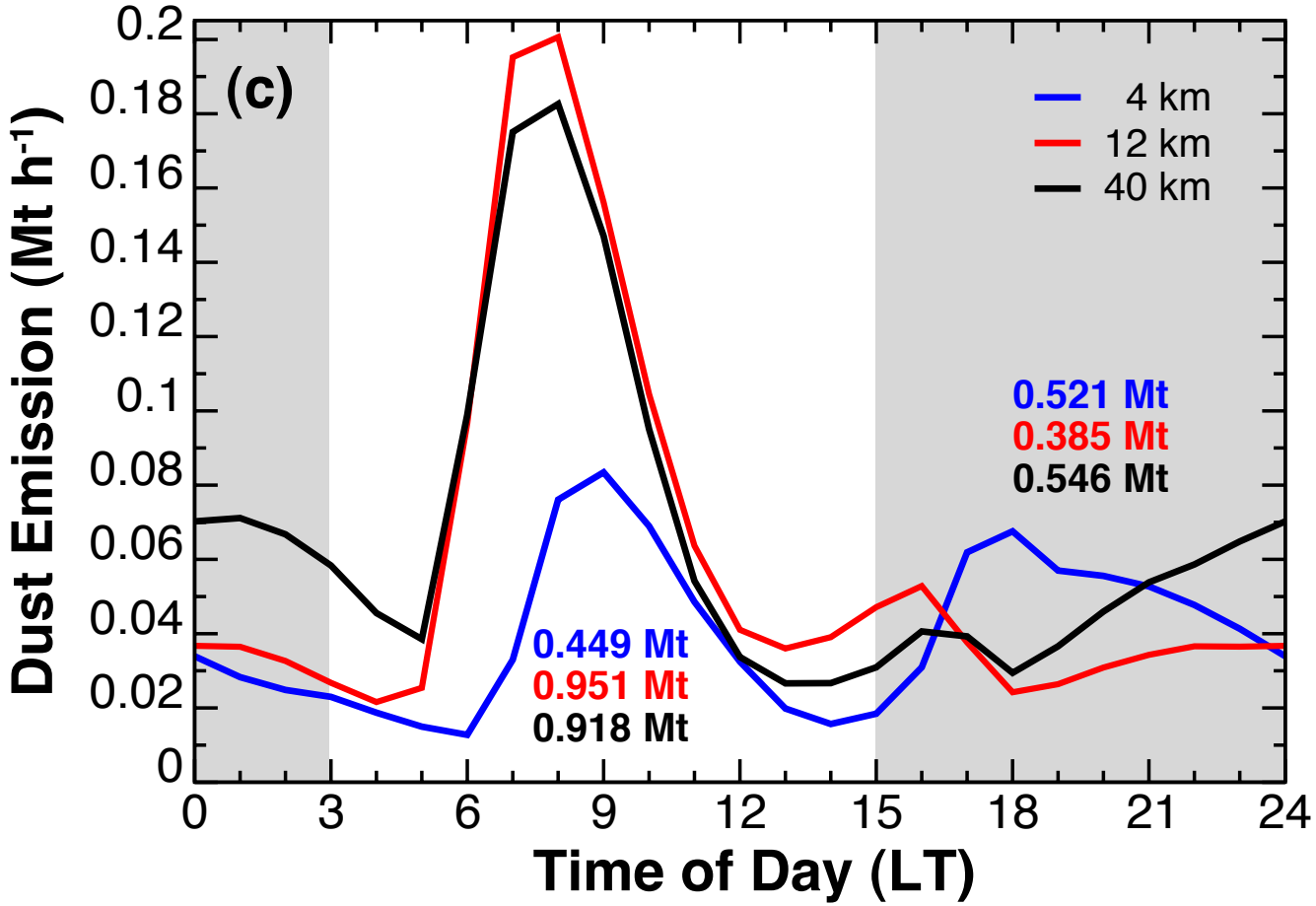
Convection schemes change heat low





from *Marsham et al., GRL, 2013*

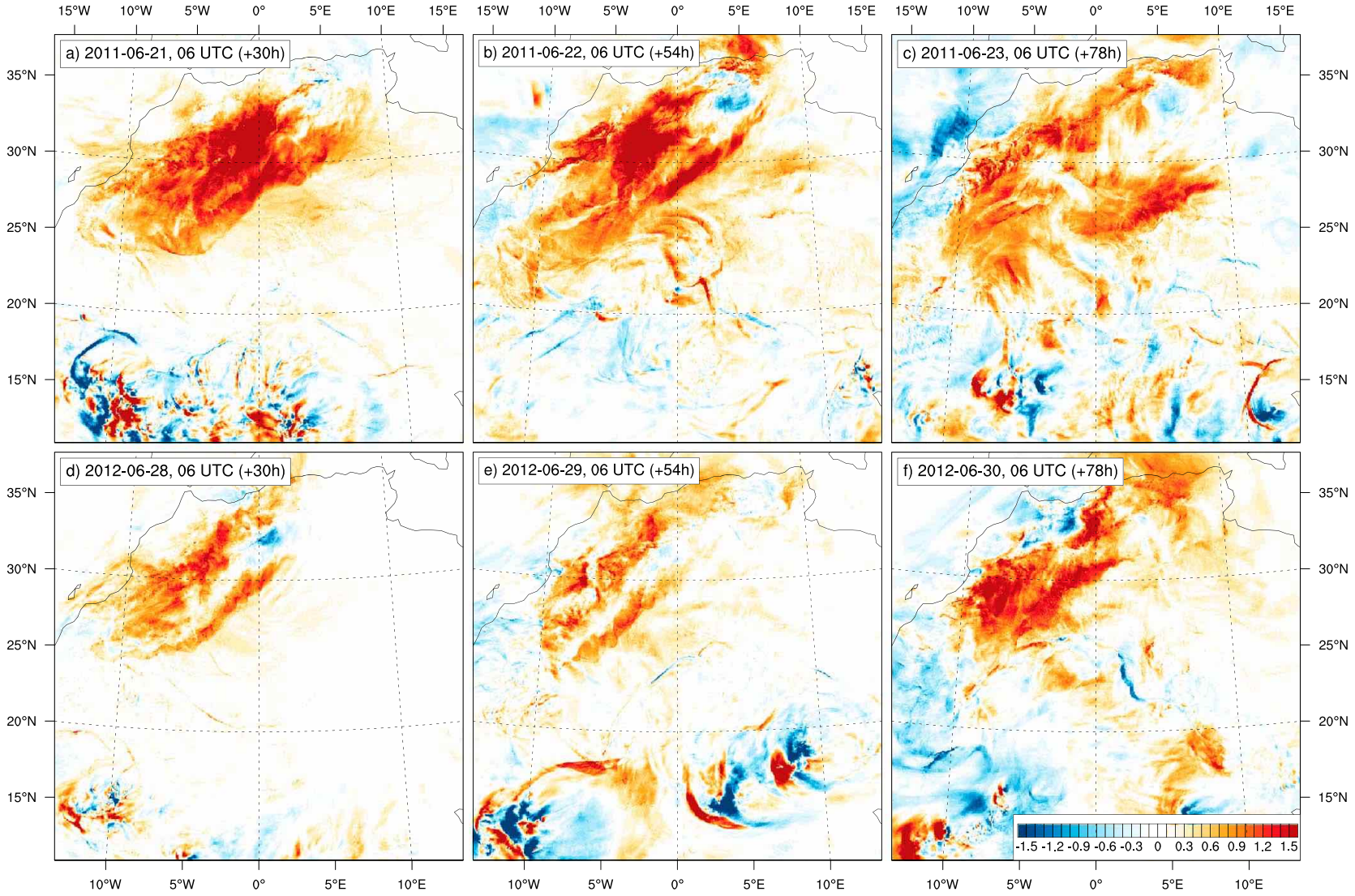
Impact of heat low strength on dust



Heinold et al., 2013, JGR

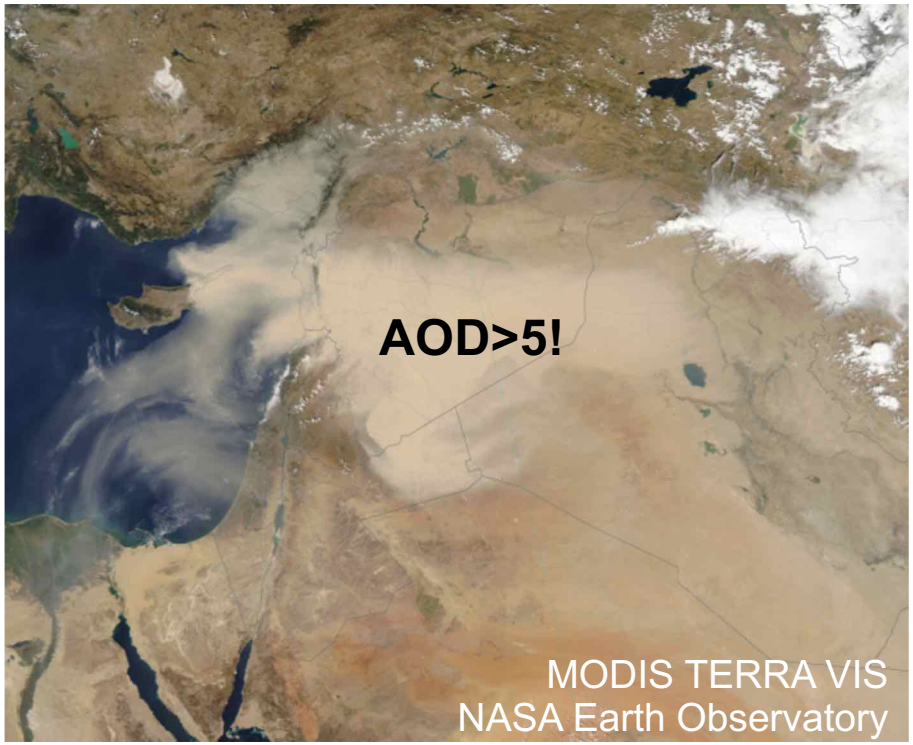
- 4km run has about 30% less dust than the coarse resolution runs.
- Larger contribution from haboobs, but morning peak is less than half.

Impact on heat low when suppressing cold pools



Redl et al., 2016, JGR

Extreme Middle Eastern dust storm in Sept. 15



7 September 2015

10 UTC

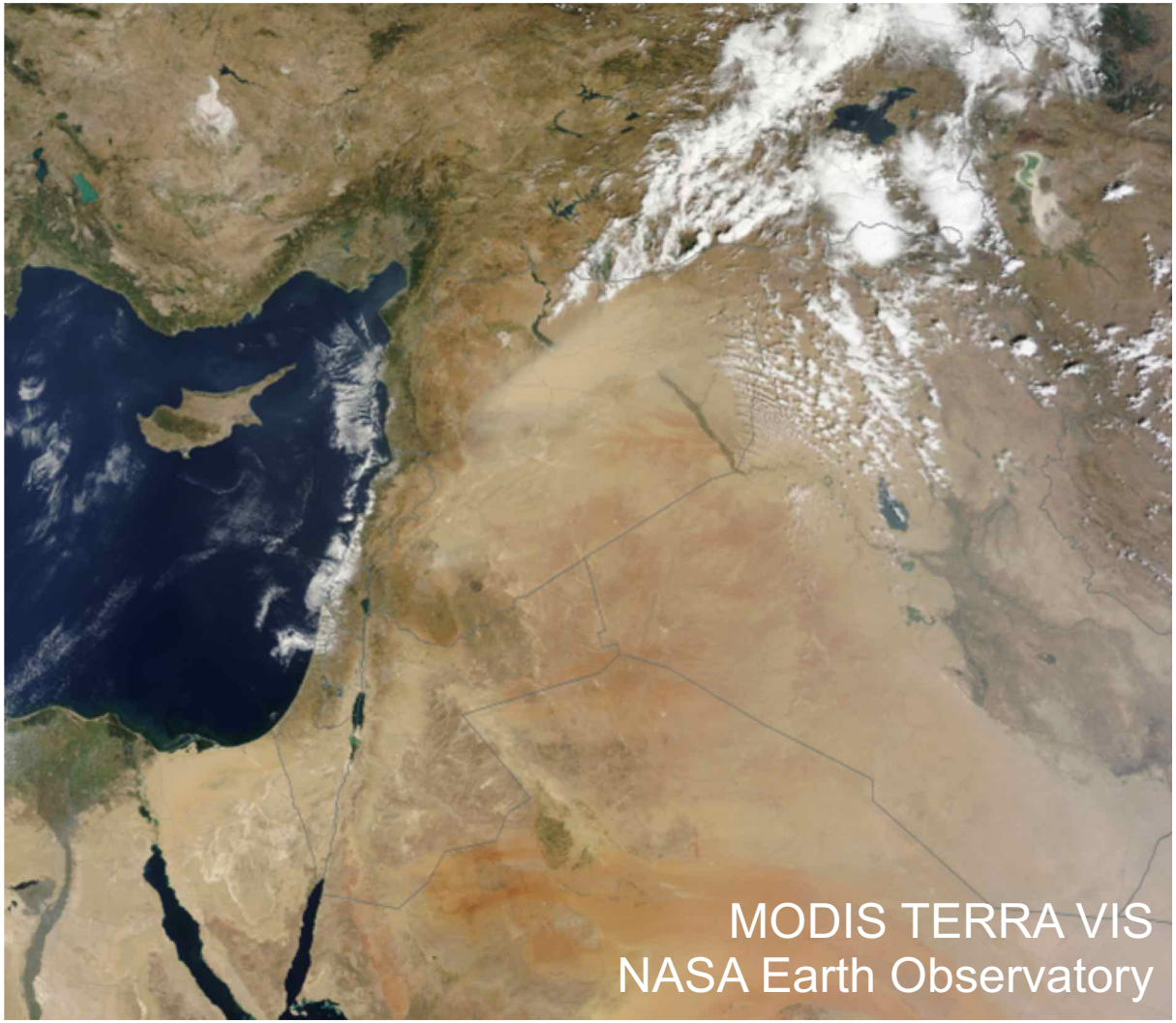
Atmospheric Chemistry and Physics Open Access EGU

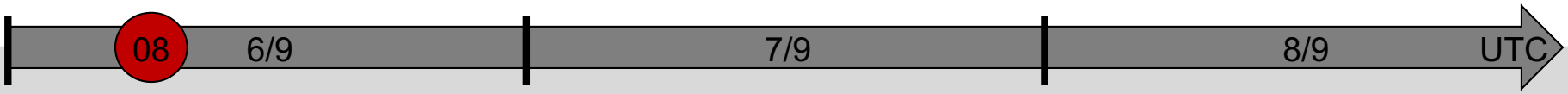
Revealing the meteorological drivers of the September 2015 severe dust event in the Eastern Mediterranean

Philipp Gasch[1], Daniel Rieger[1,a], Carolin Walter[1], Pavel Khain[2], Yoav Levi[2], Peter Knippertz[1], and Bernhard Vogel[1]

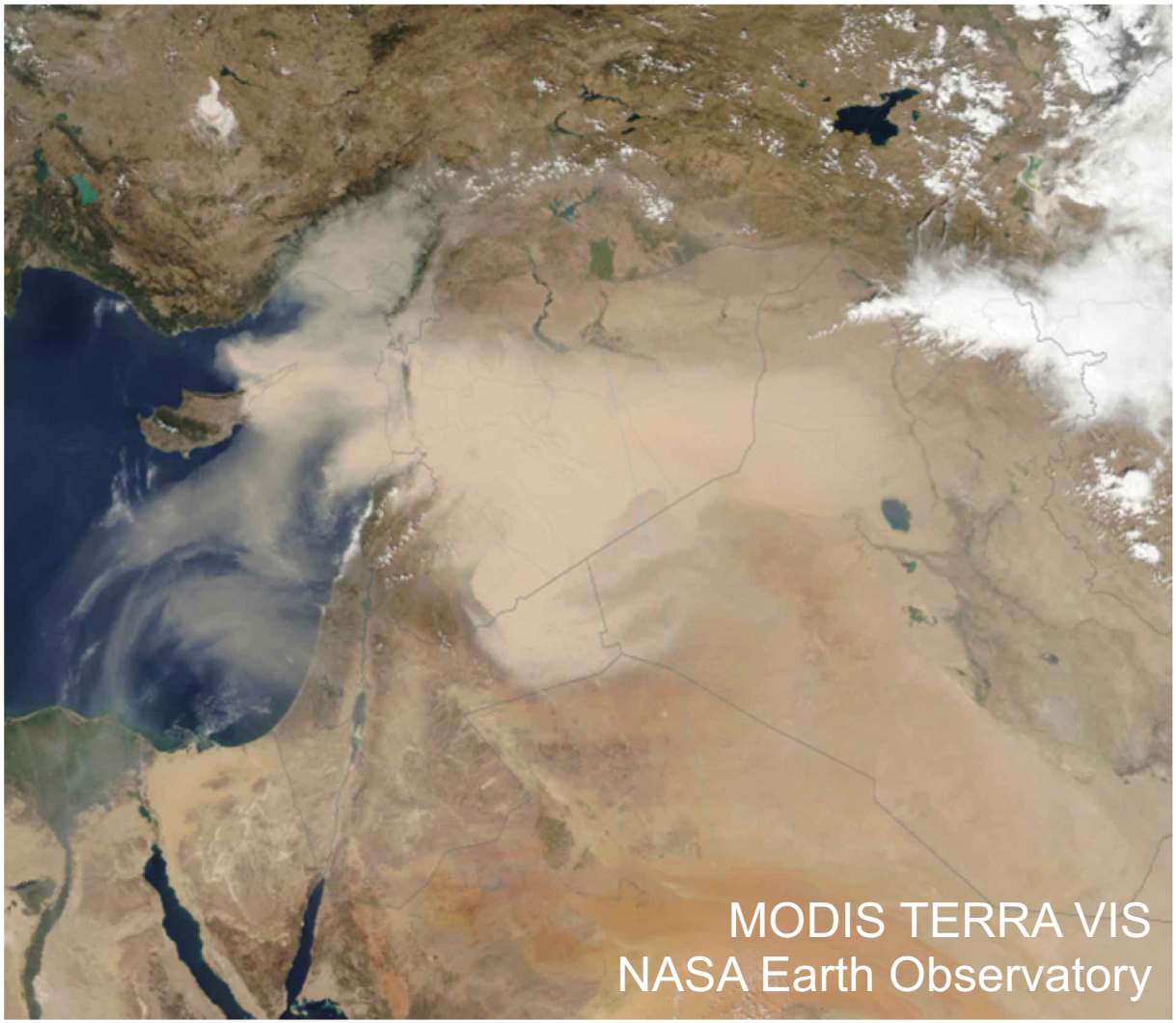
[1]Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Karlsruhe, Germany
[2]Israel Meteorological Service, Bet Dagan, Israel
[a]now at: Deutscher Wetterdienst, Frankfurter Str. 135, 63067 Offenbach, Germany

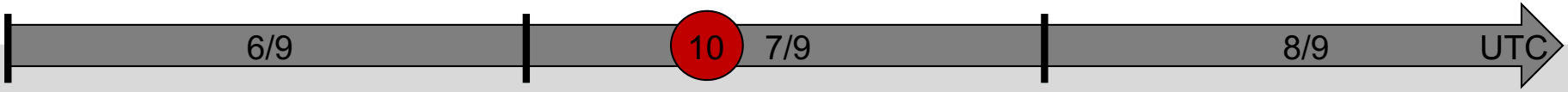
Spatial extent and temporal evolution



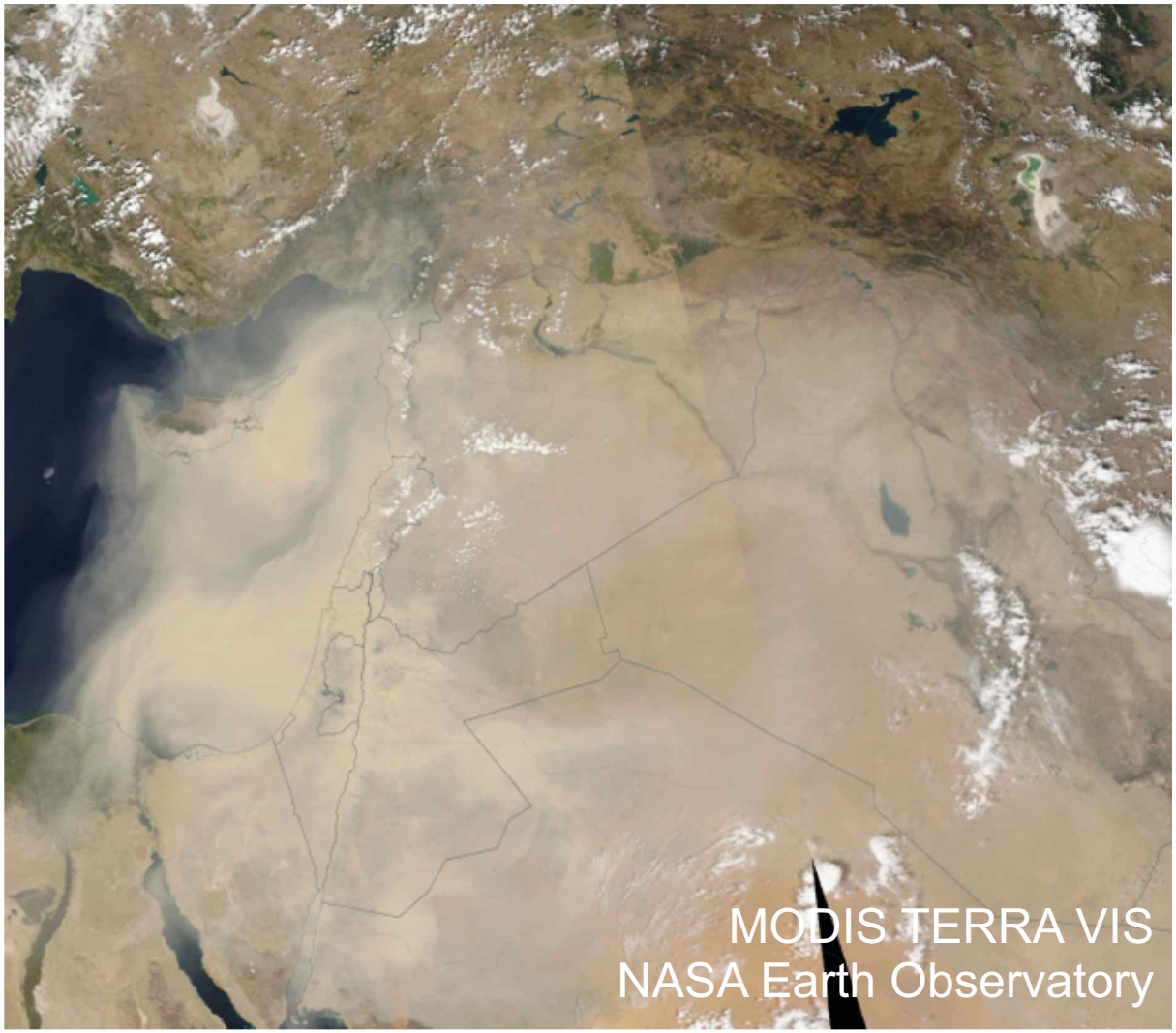


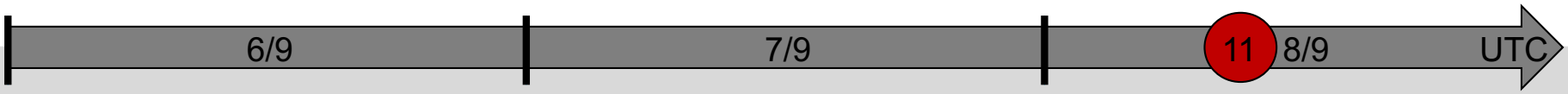
Spatial extent and temporal evolution



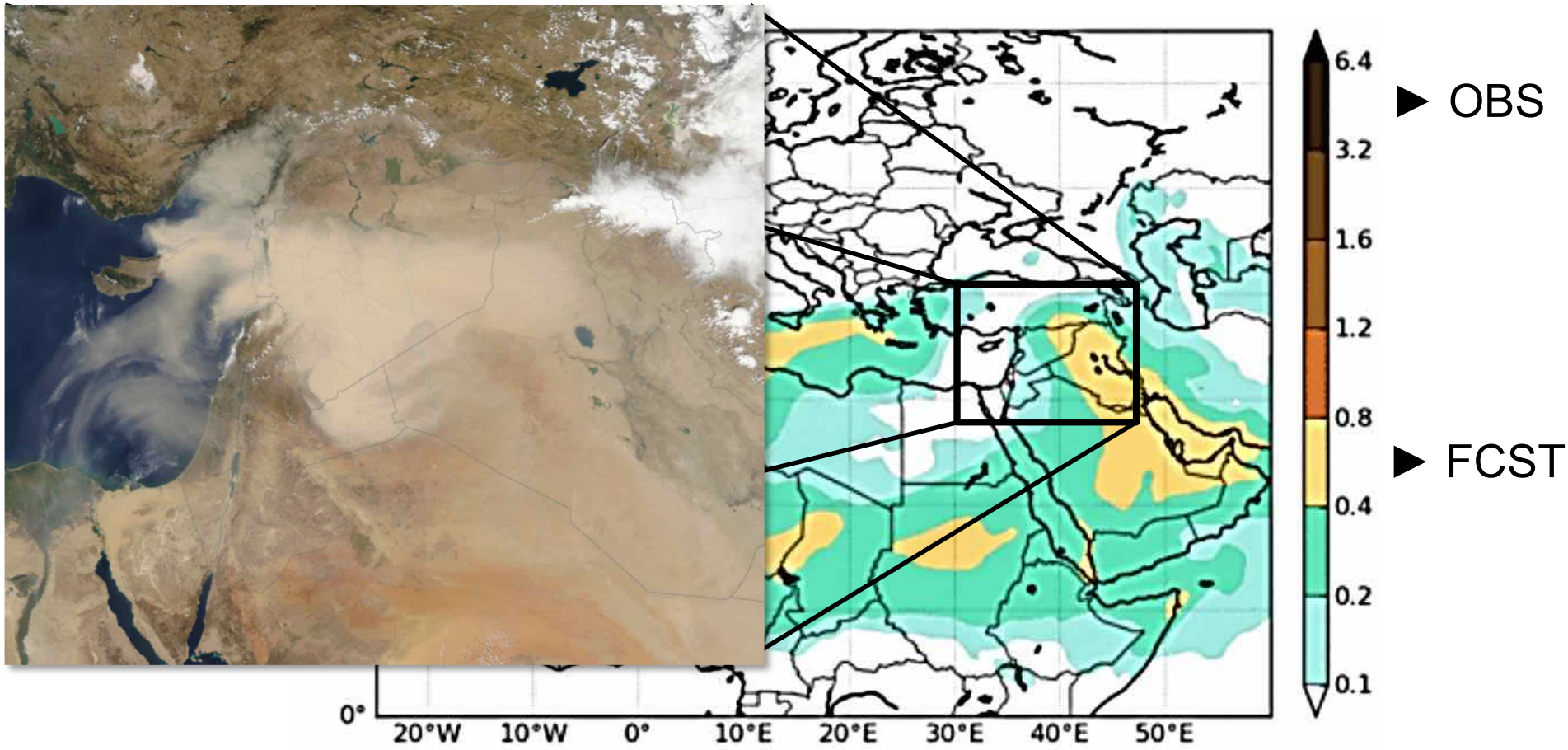


Spatial extent and temporal evolution



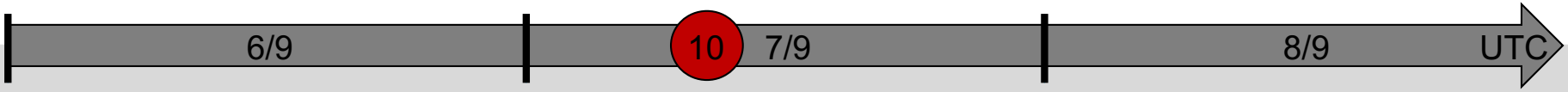


Forecast failure of operational models

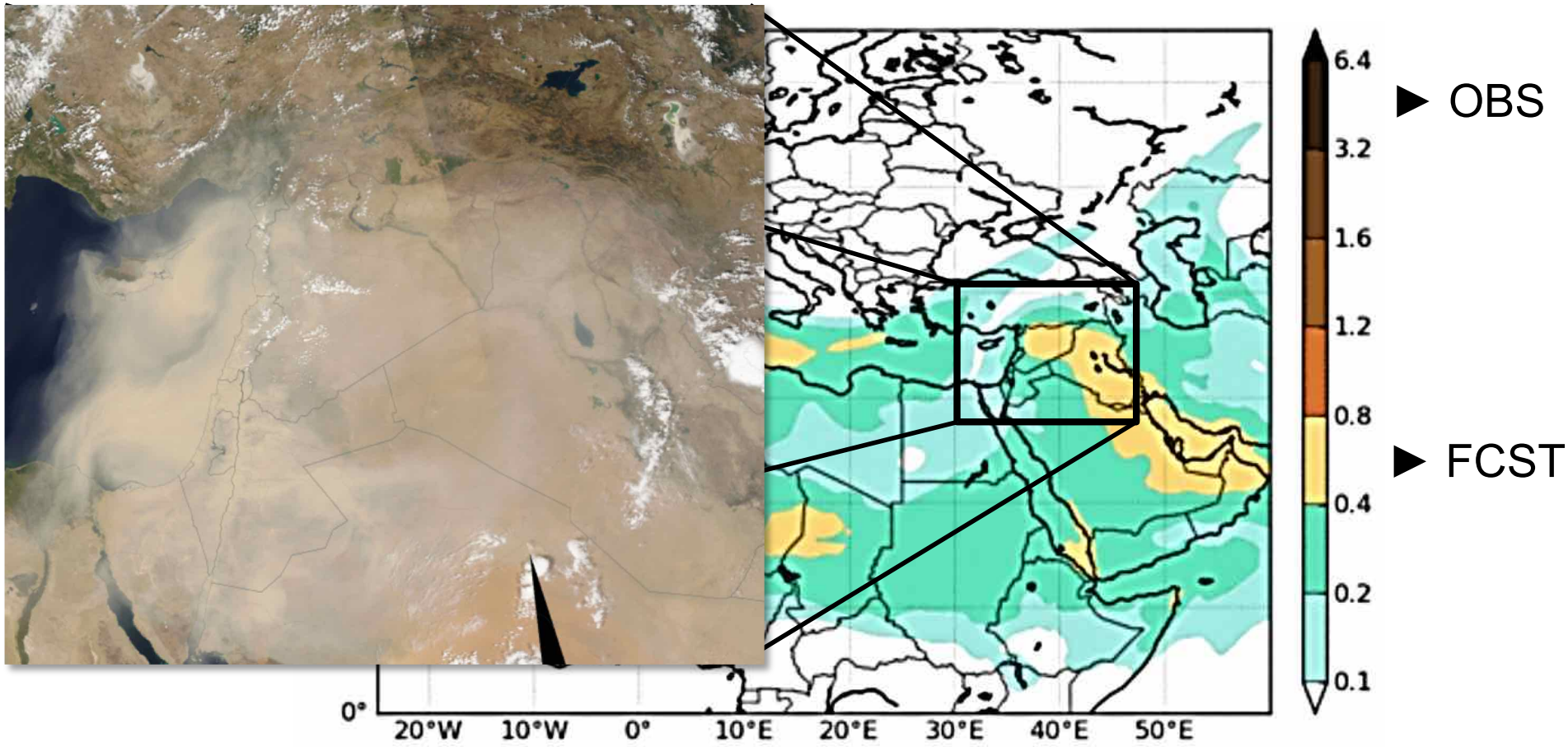


Multi-model mean dust optical depth

Obtained from WMO Model intercomparison project at http://sds-was.aemet.es

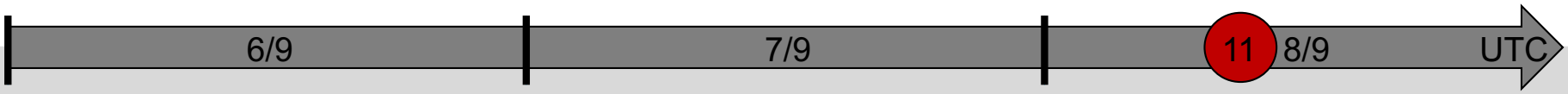


Forecast failure of operational models



Multi-model mean dust optical depth

Obtained from WMO Model intercomparison project at http://sds-was.aemet.es

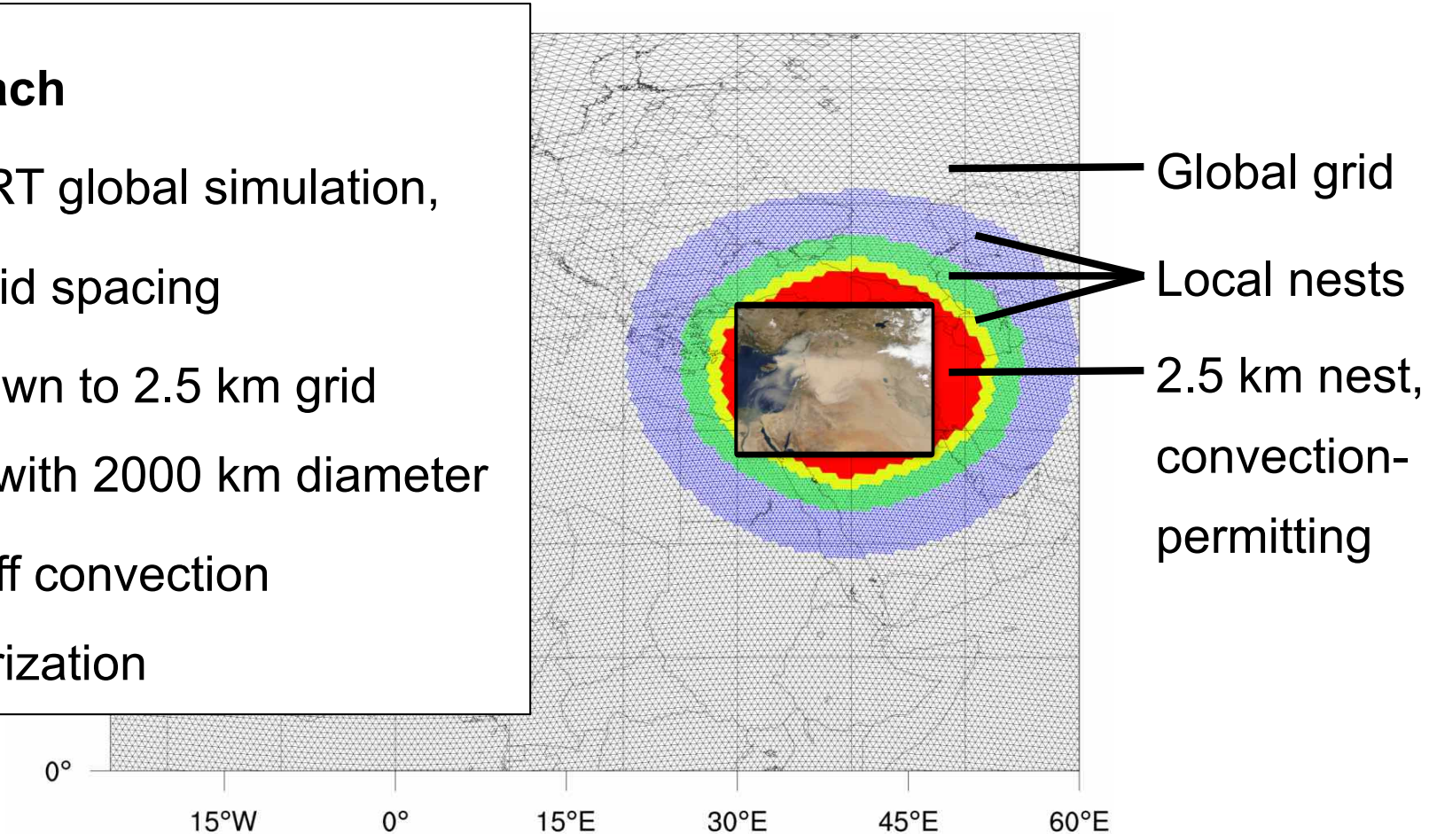


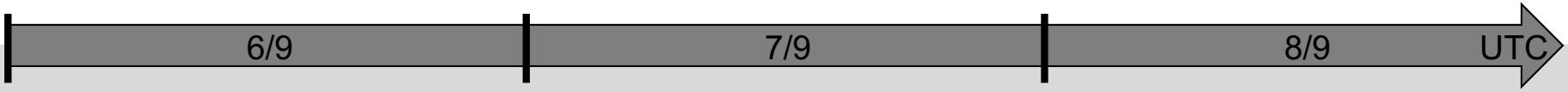
Forecast failure of global models

Our approach

- ICON-ART global simulation, 40 km grid spacing
- Nests down to 2.5 km grid spacing with 2000 km diameter

→ Switch-off convection parametrization

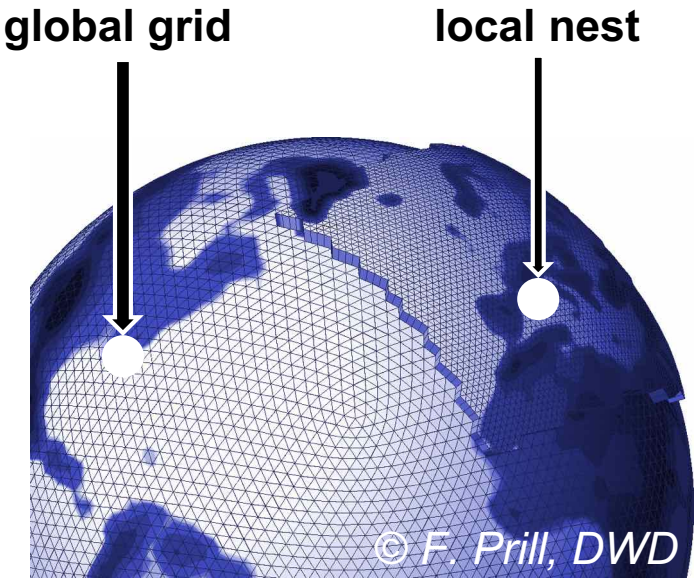


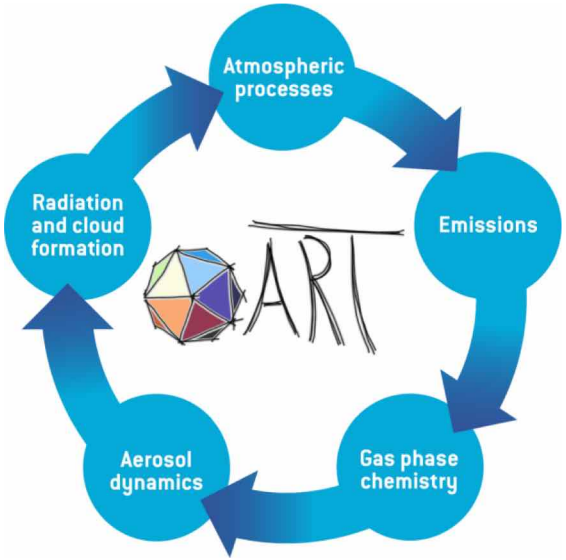


ICON-ART

ICON

- Developed by DWD and Max-Planck
- Non-hydrostatic global model
- Mass consistent tracer transport
- 2-way nesting capabilities





Rieger et al. (2015), Geosci. Mod. Dev.

ART – Aerosols and Reactive Trace gases

- Developed at KIT
- Mineral dust module
- Emission, transport, dry and wet deposition
- Online radiation interaction

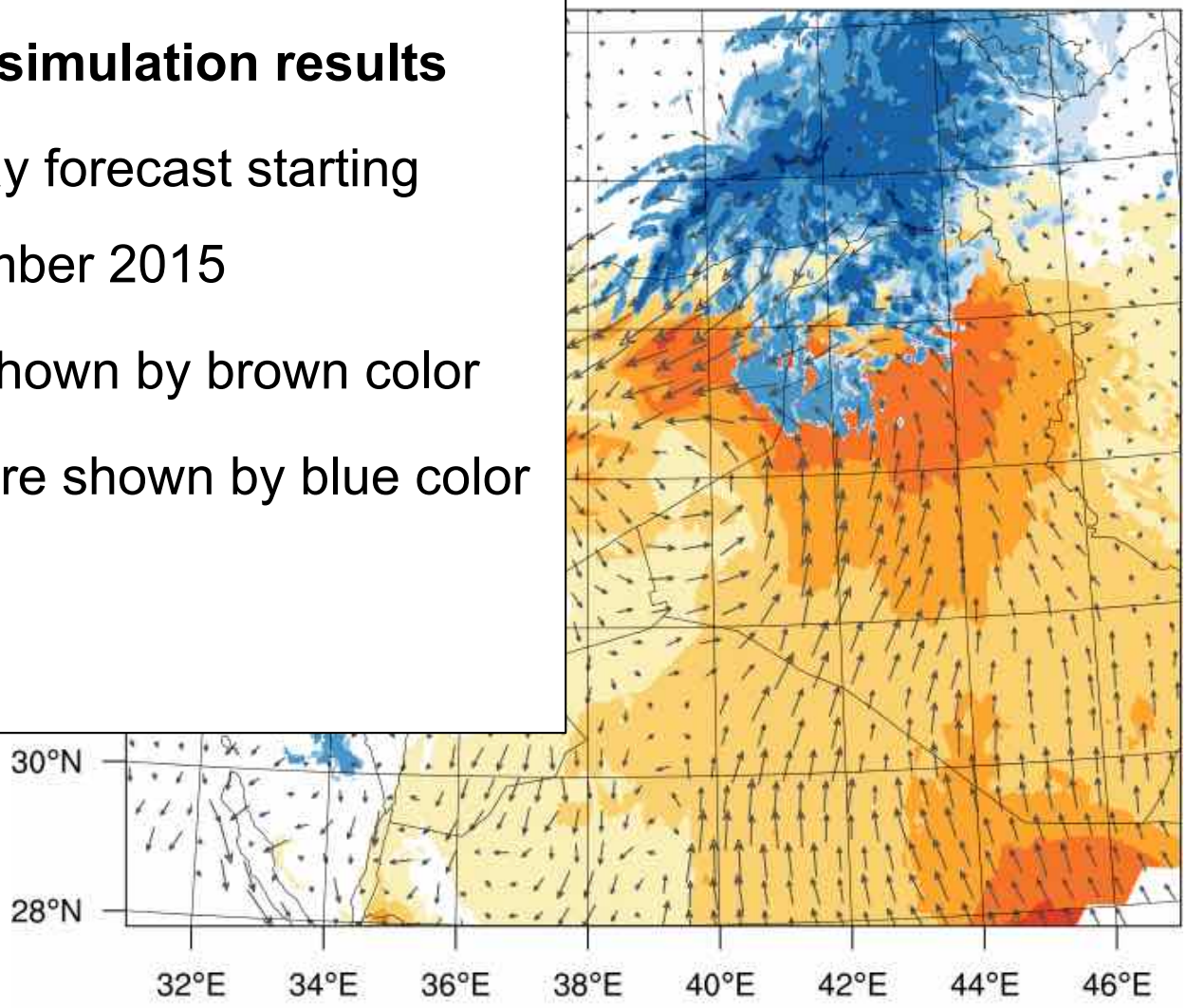
Course of event

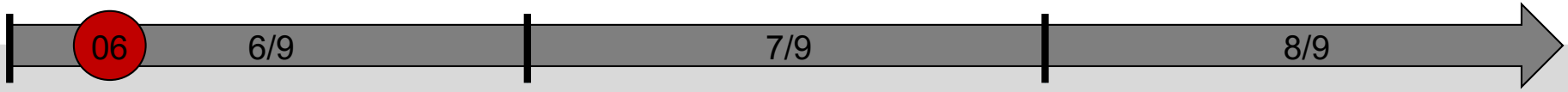
ICON-ART simulation results

- Three day forecast starting

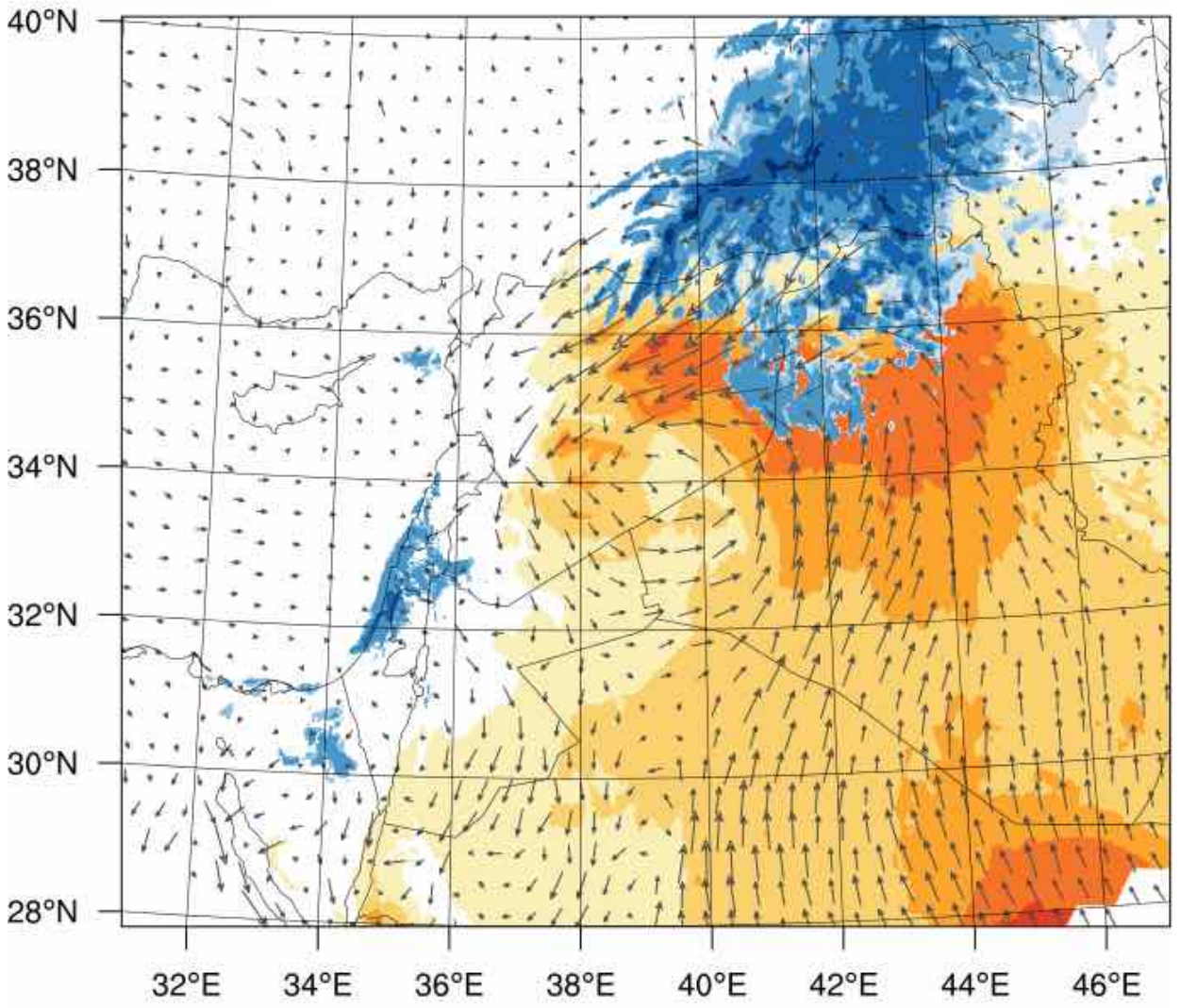
  6 September 2015

- Dust is shown by brown color
- Clouds are shown by blue color



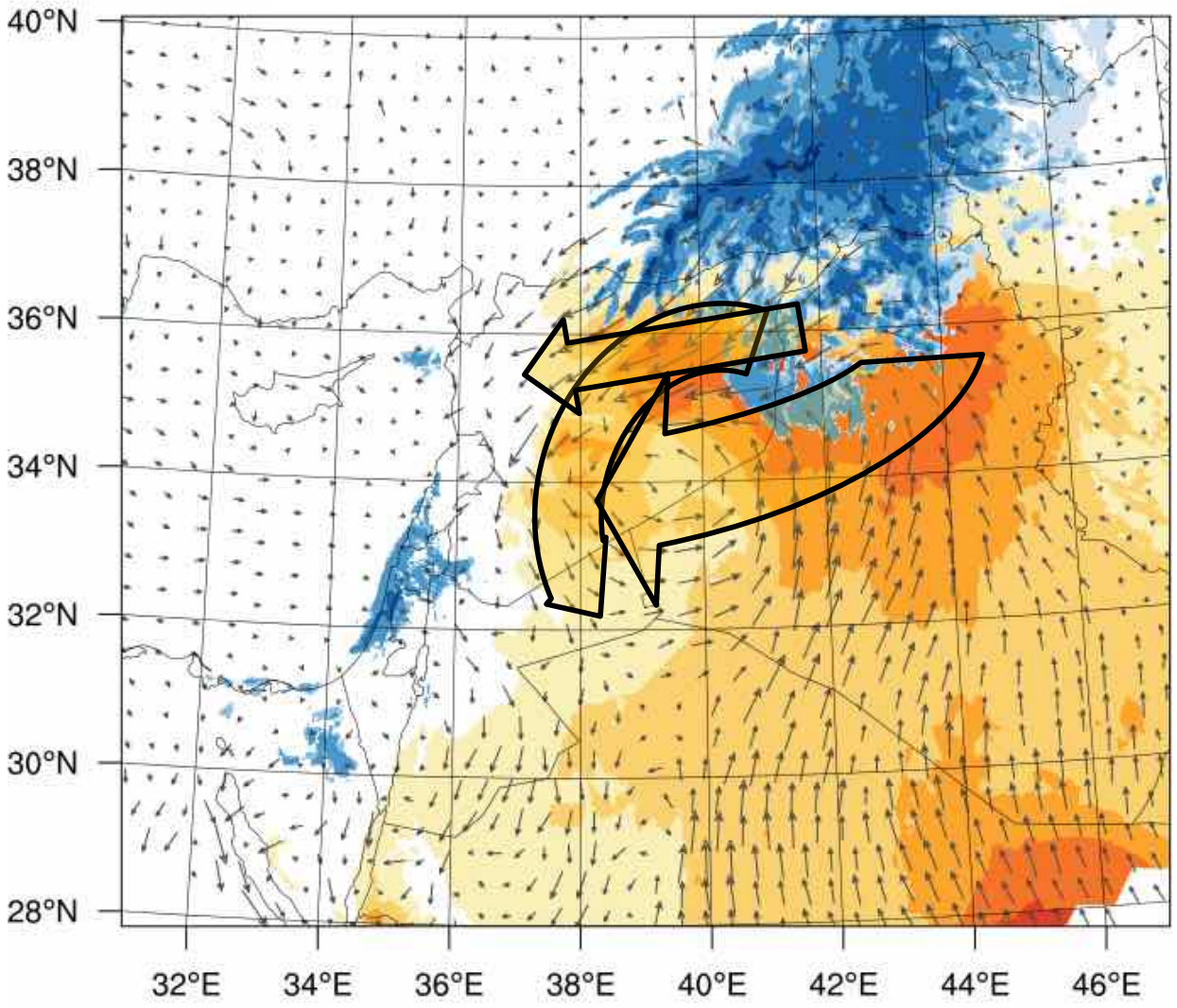


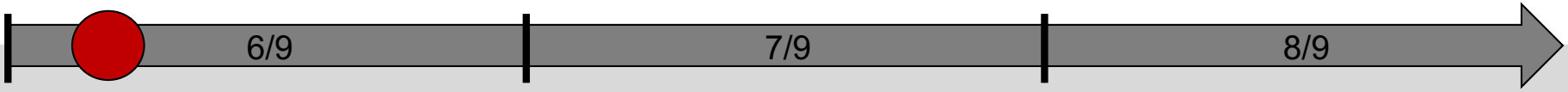
Course of event



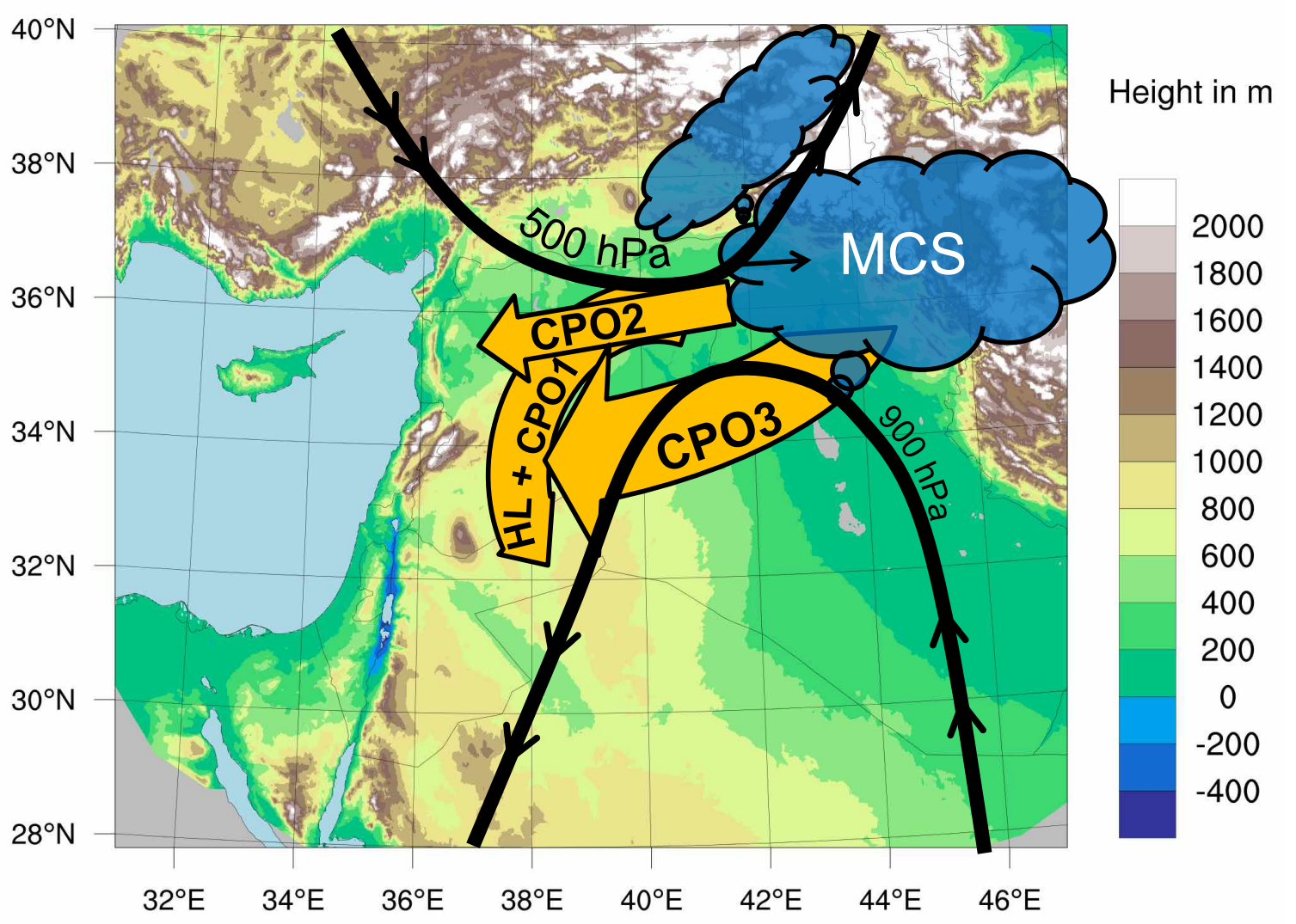
06 | 6/9 | 7/9 | 8/9

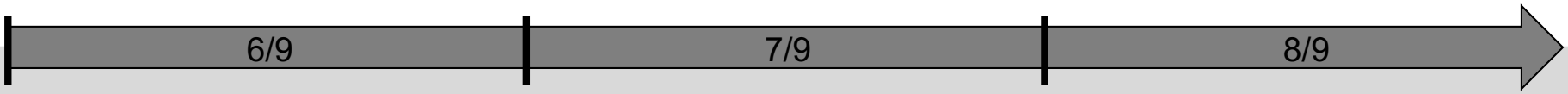
Course of event





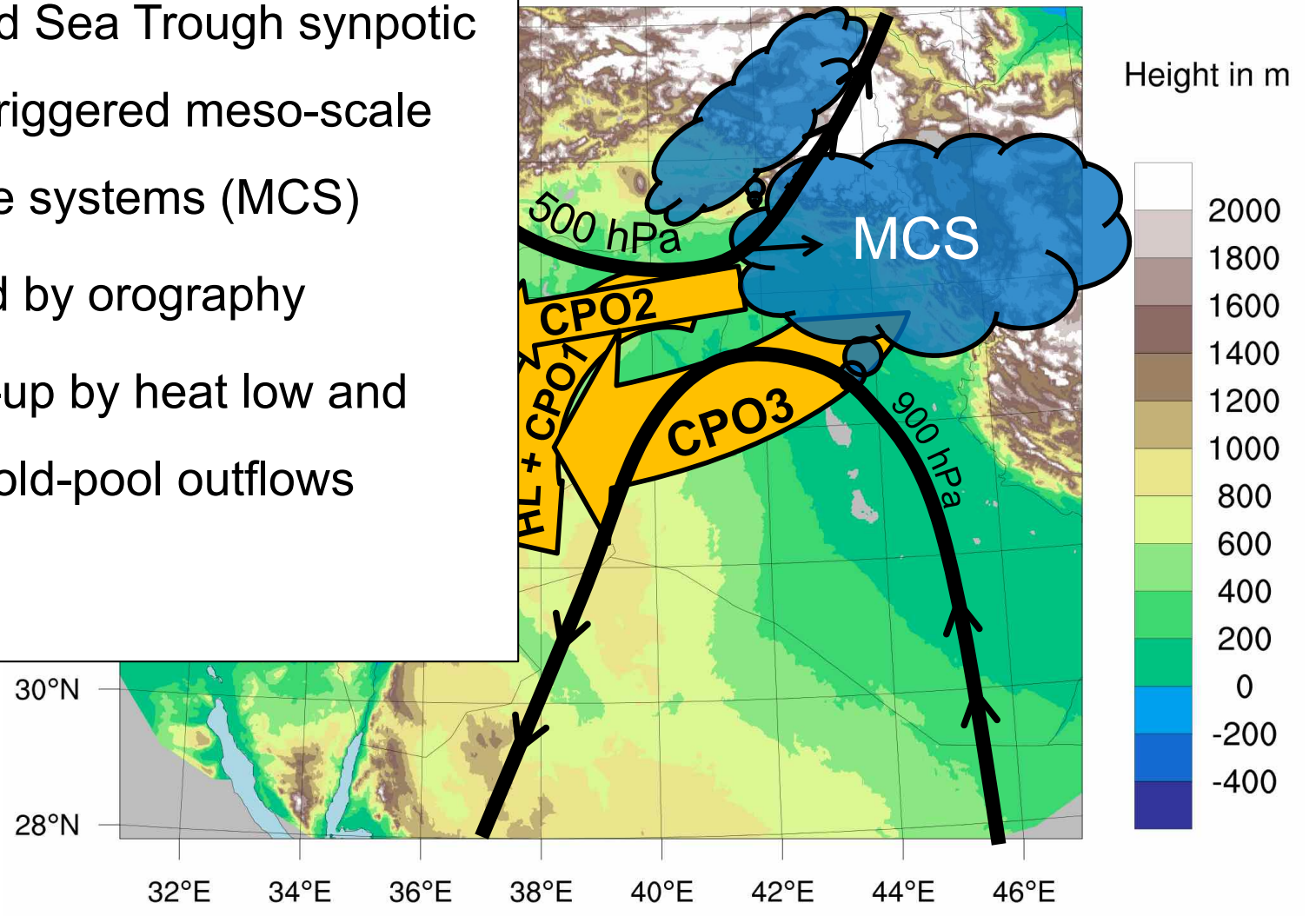
Synoptic situation





Synoptic situation

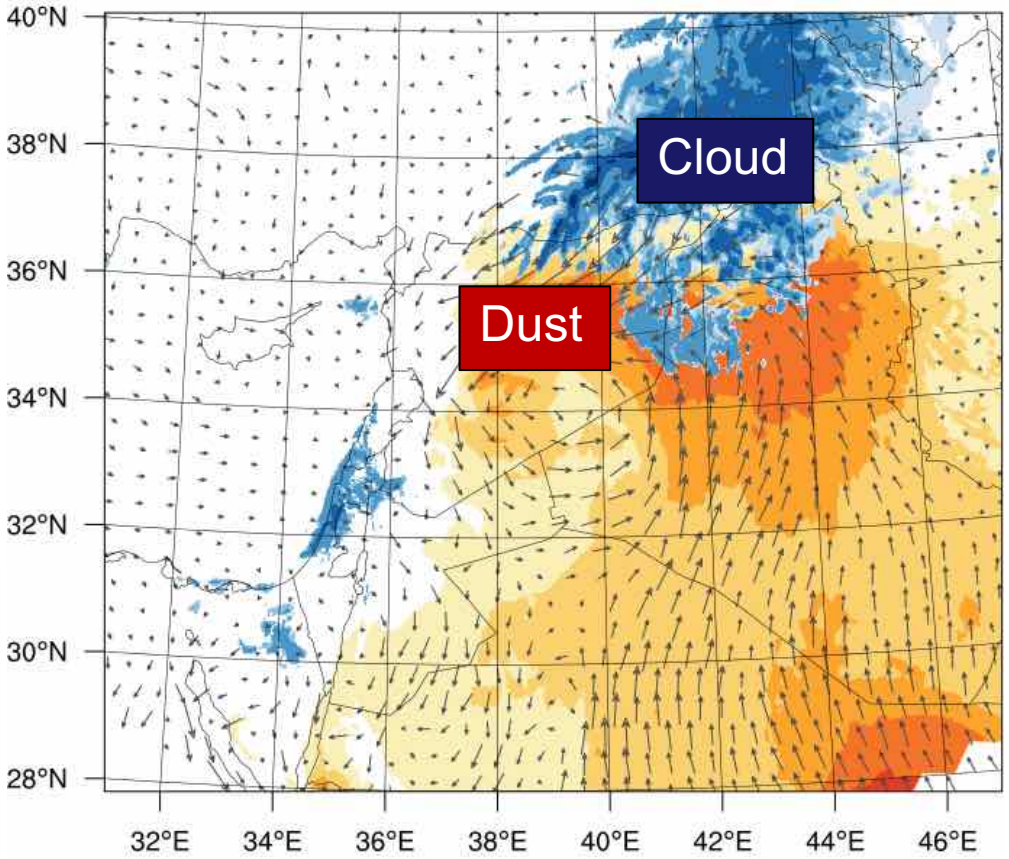
- Active Red Sea Trough synpotic situation triggered meso-scale convective systems (MCS)
- Supported by orography
- Dust pick-up by heat low and multiple cold-pool outflows (CPO)



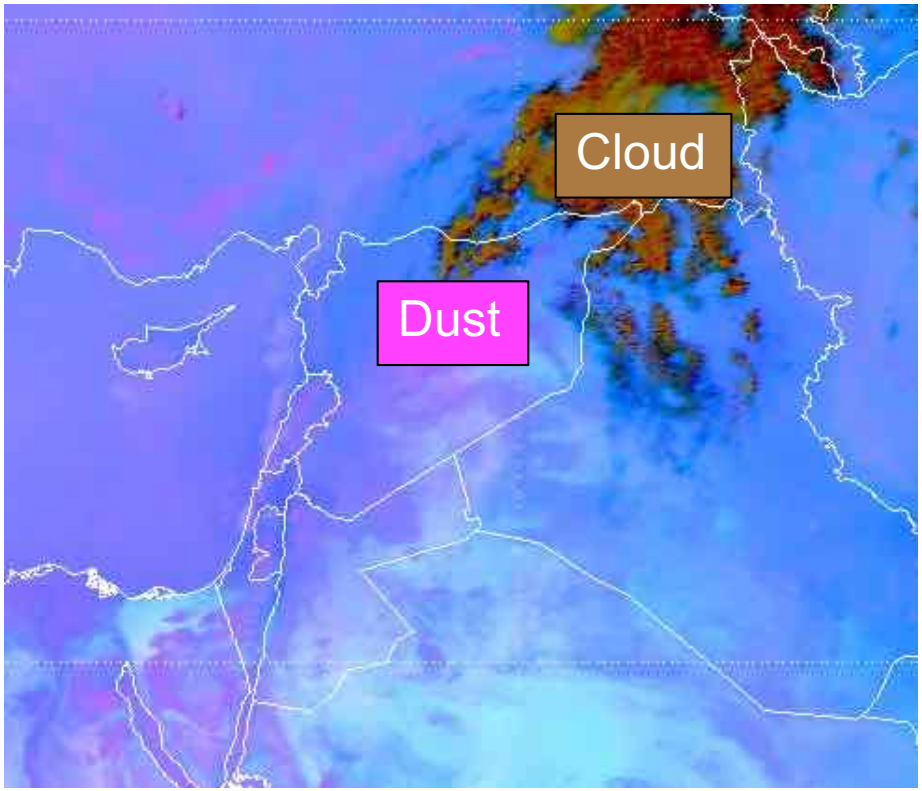
6/9 7/9 8/9

Validation of ICON-ART

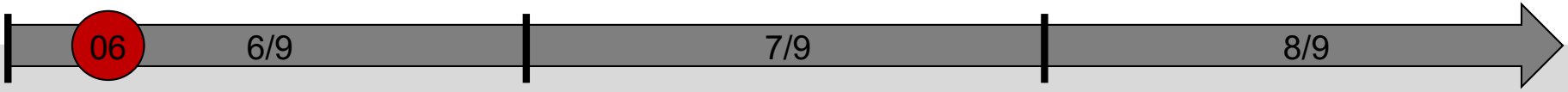
ICON-ART model



EUMETSAT satellite

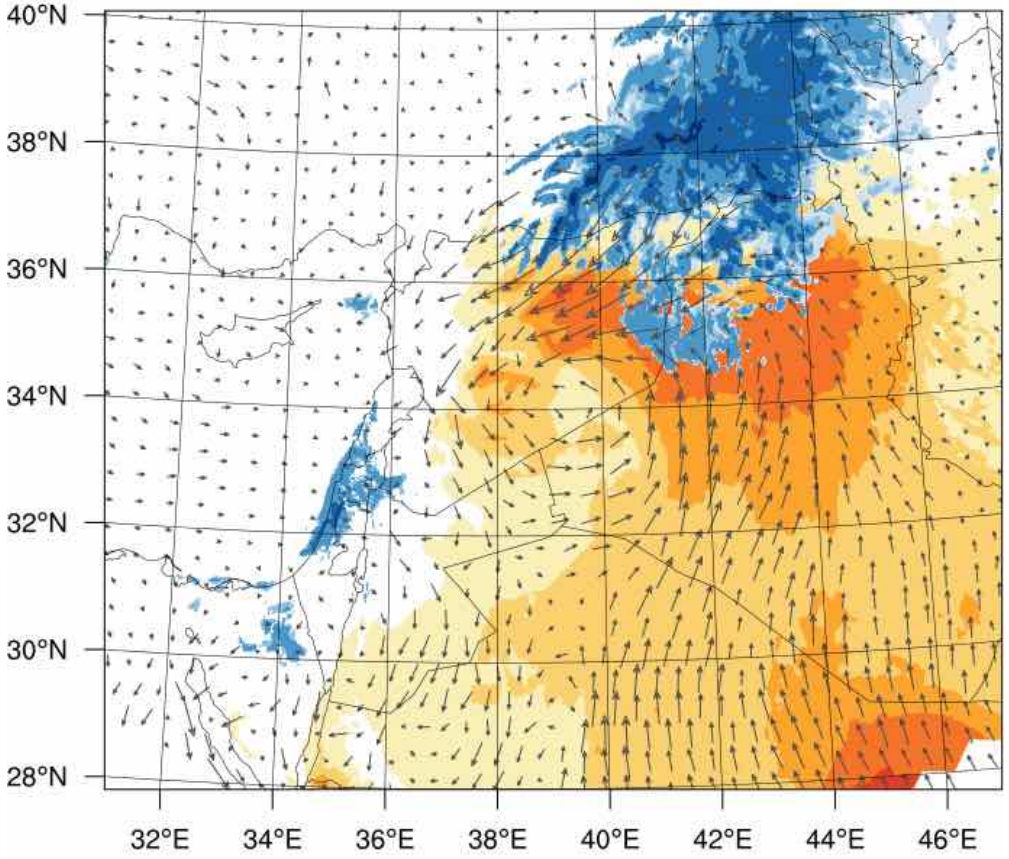


SEVIRI Dust RGB Product
provided by and thanks to
J. Kerkman, S. Lancaster, H. Roesli

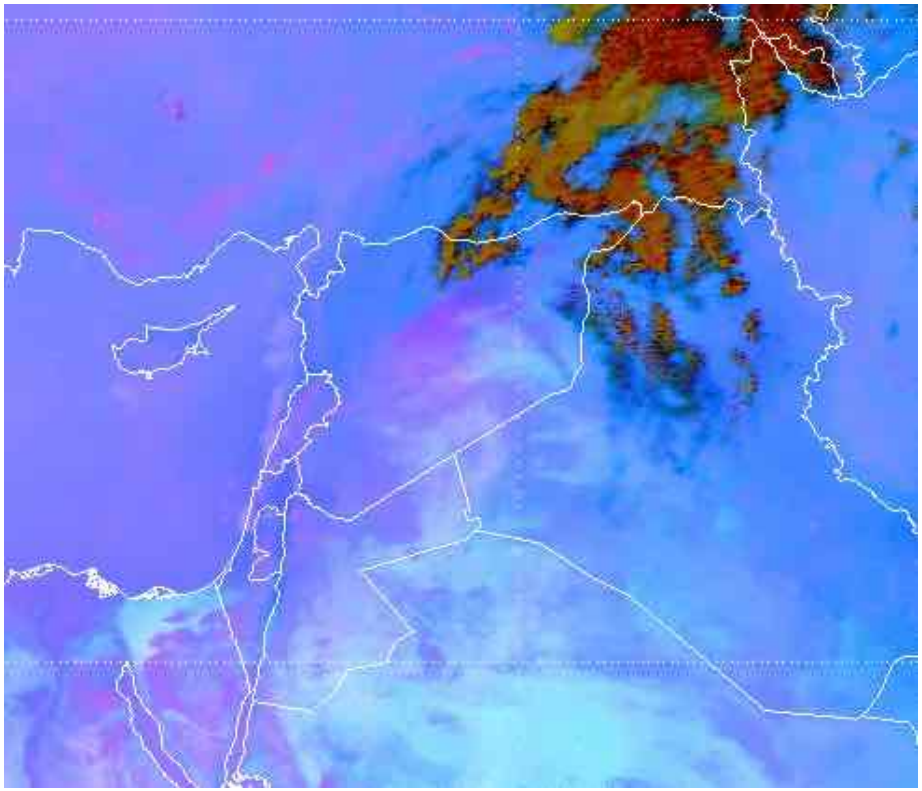


Validation of ICON-ART

ICON-ART model



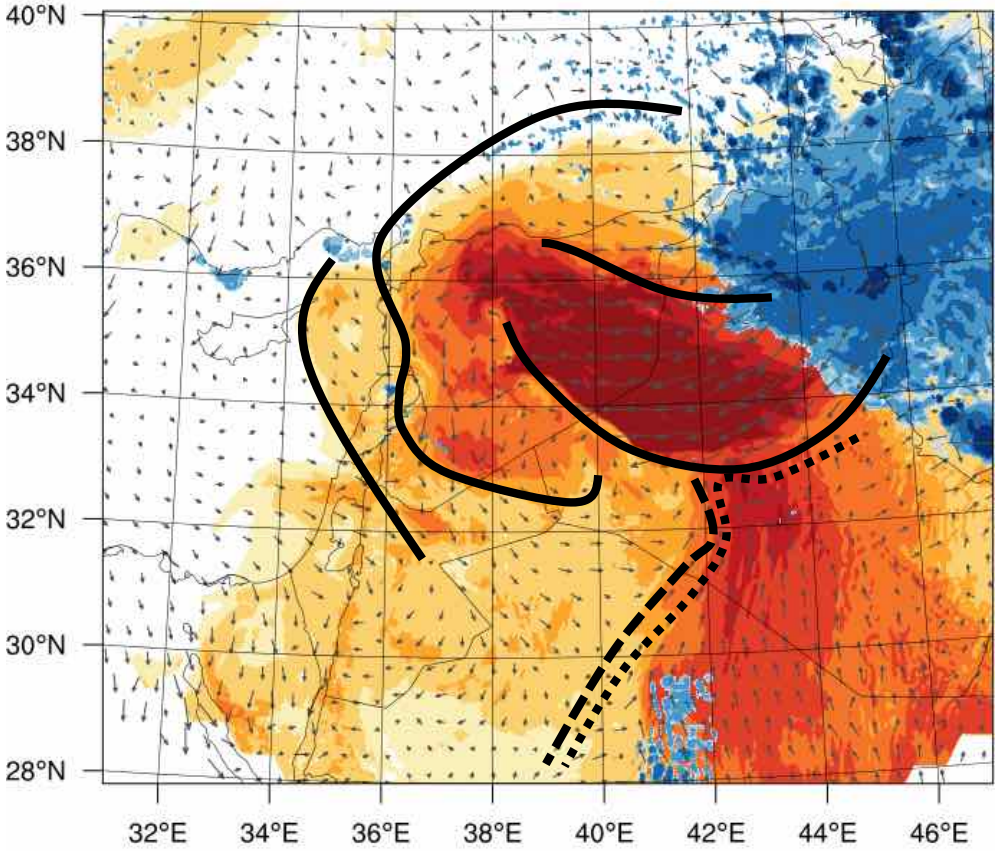
EUMETSAT satellite



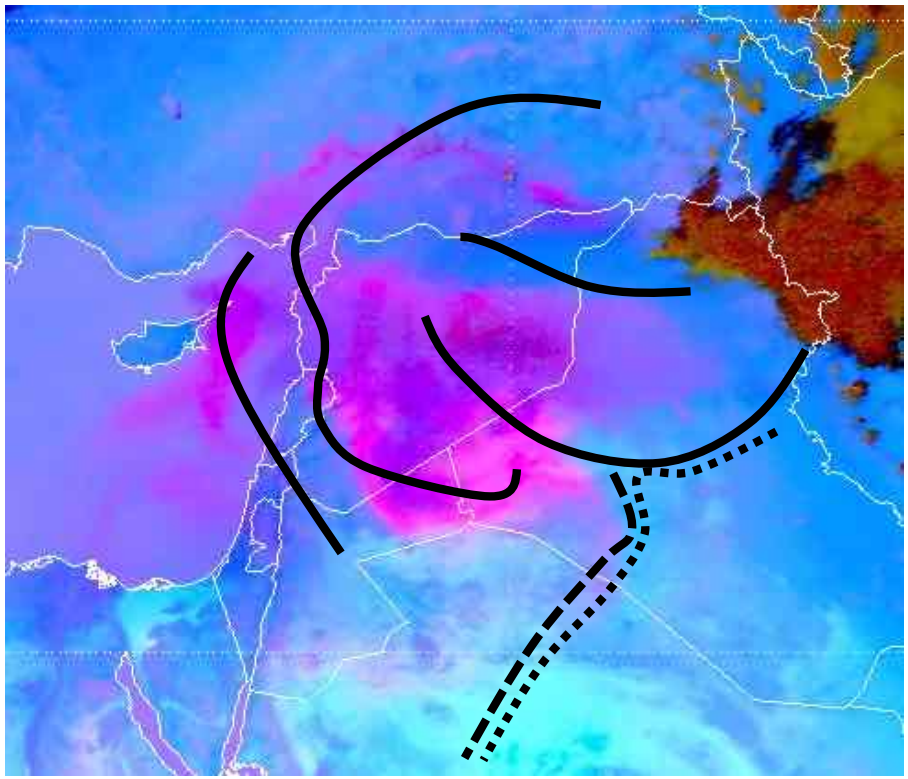
6/9 7/9 8/9

Validation of ICON-ART

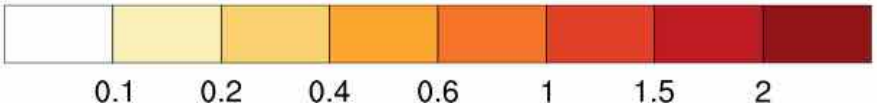
ICON-ART model

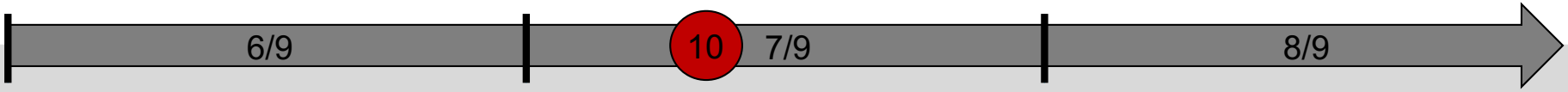


EUMETSAT satellite



Dust optical depth @550 nm

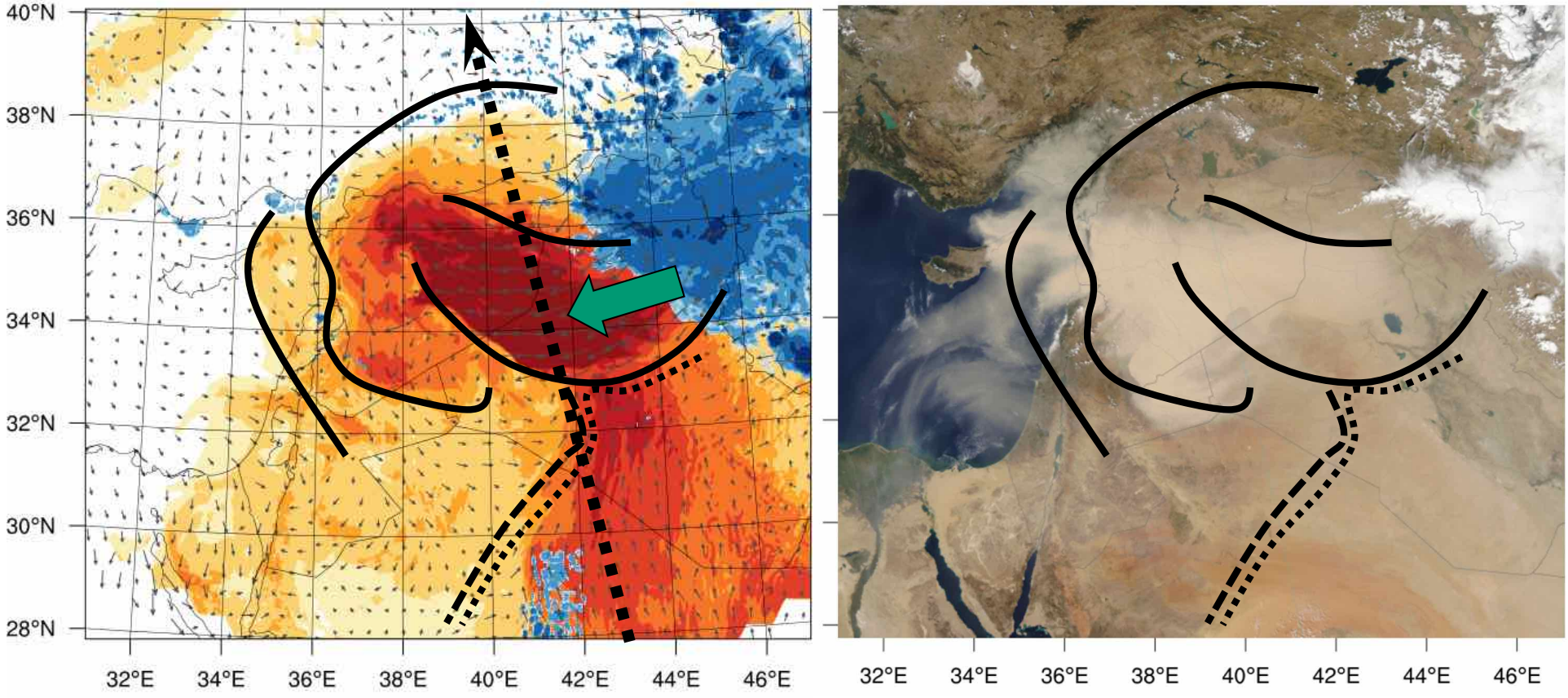


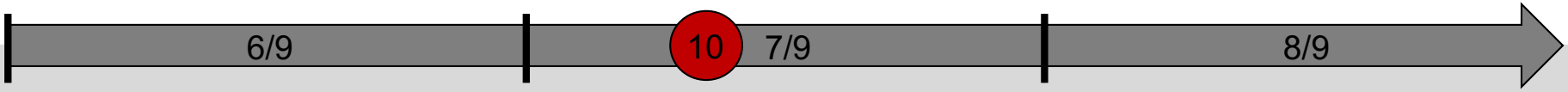


Validation of ICON-ART

ICON-ART model

MODIS TERRA VIS satellite





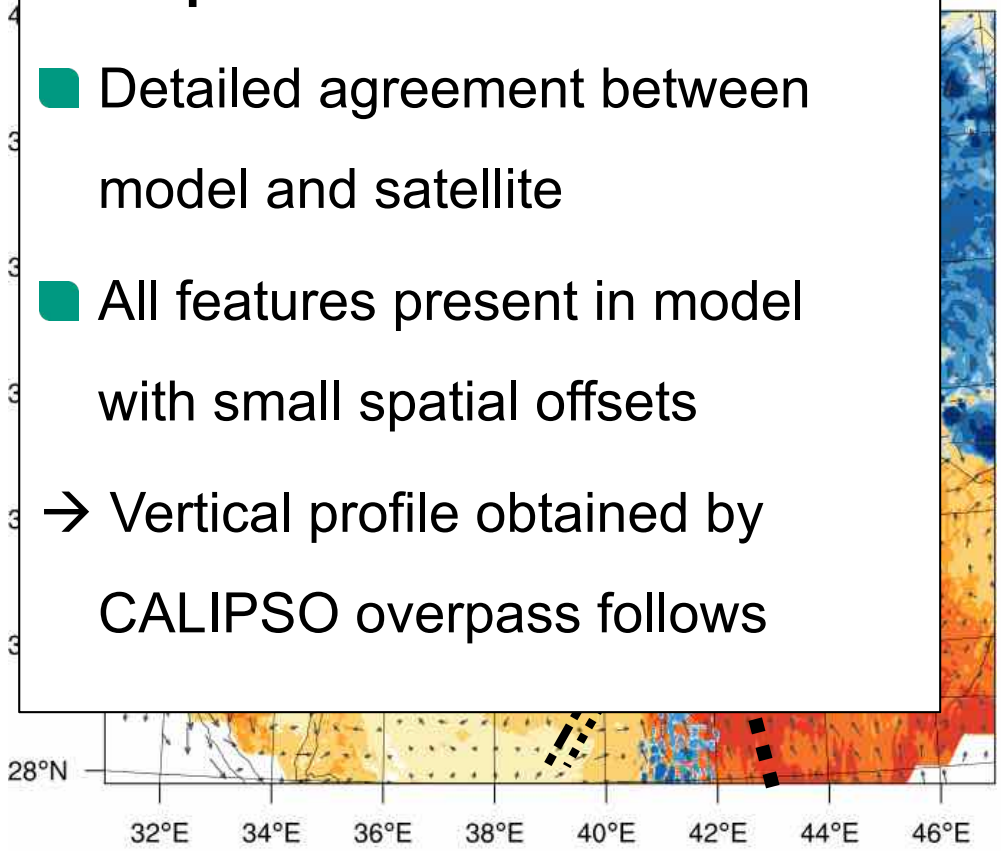
Validation of ICON-ART

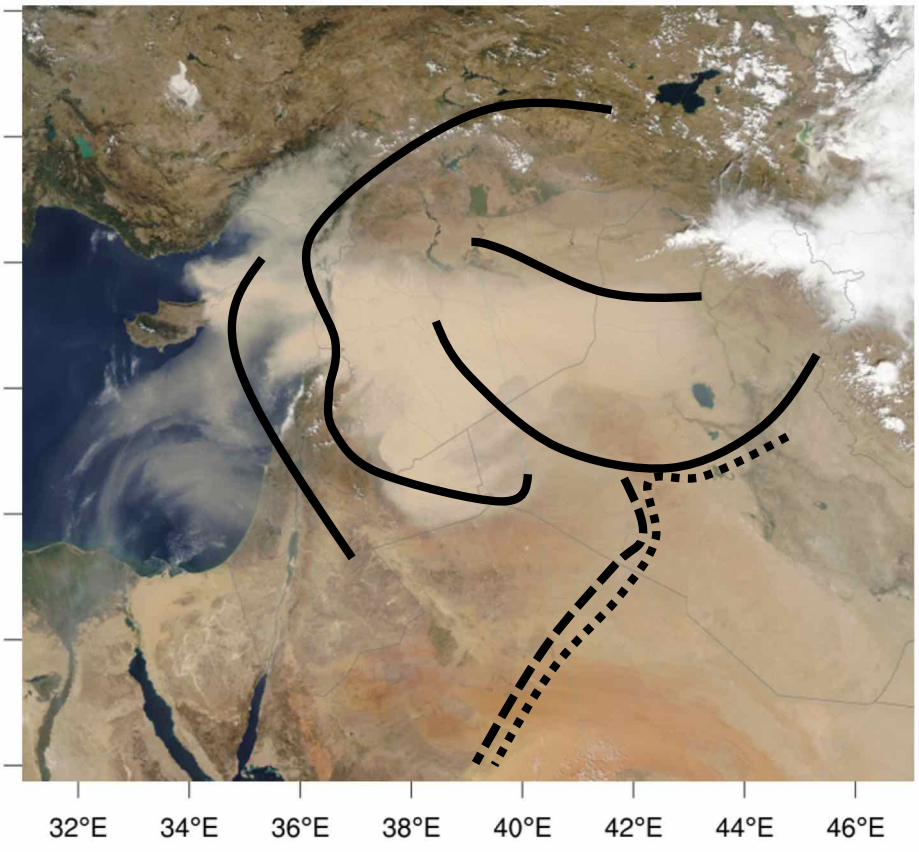
07 Sep ’15 – 10 UTC

- Detailed agreement between model and satellite
- All features present in model with small spatial offsets

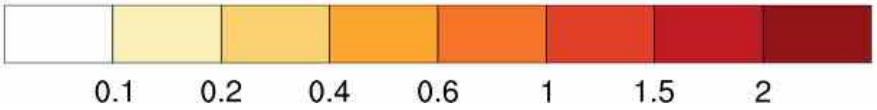
→ Vertical profile obtained by CALIPSO overpass follows

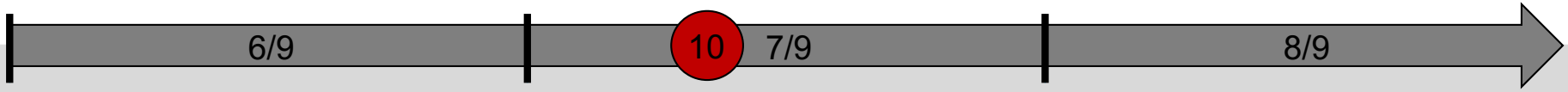
MODIS TERRA VIS satellite





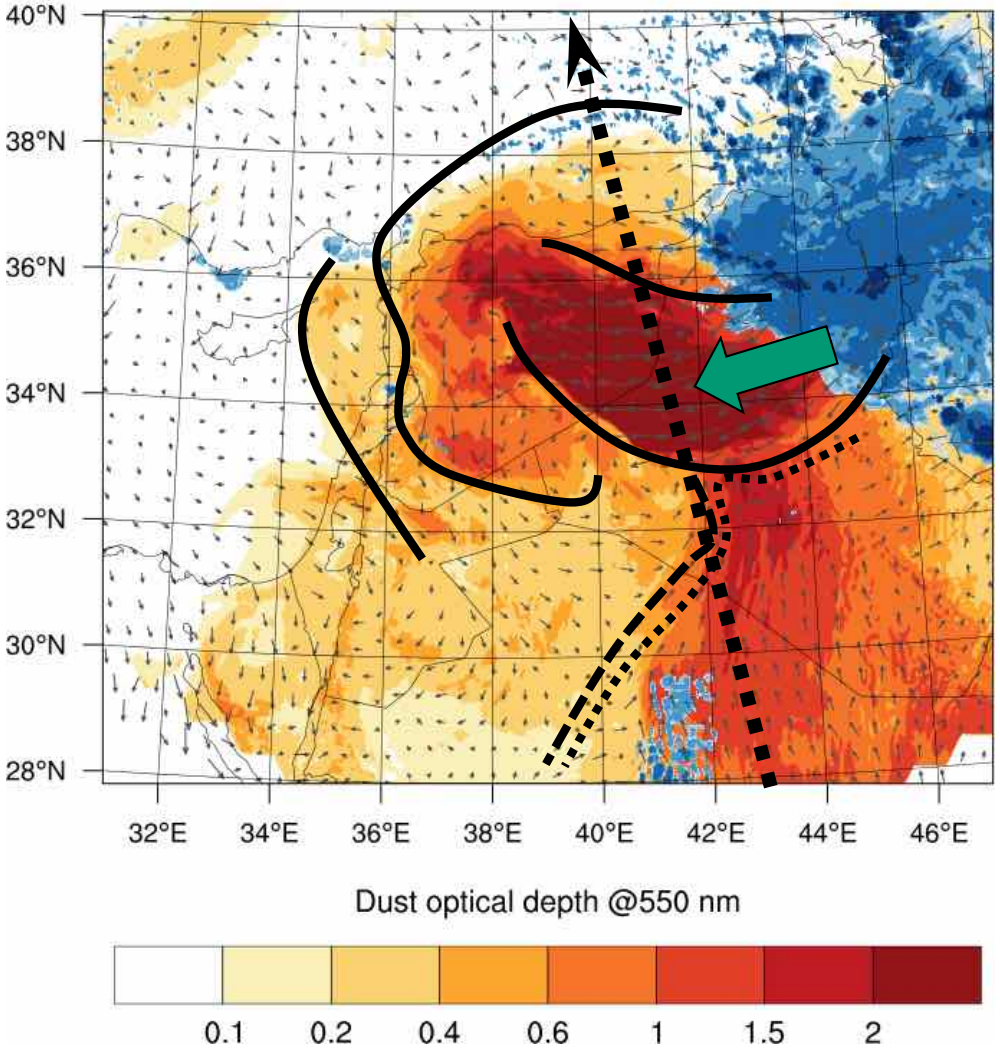
Dust optical depth @550 nm



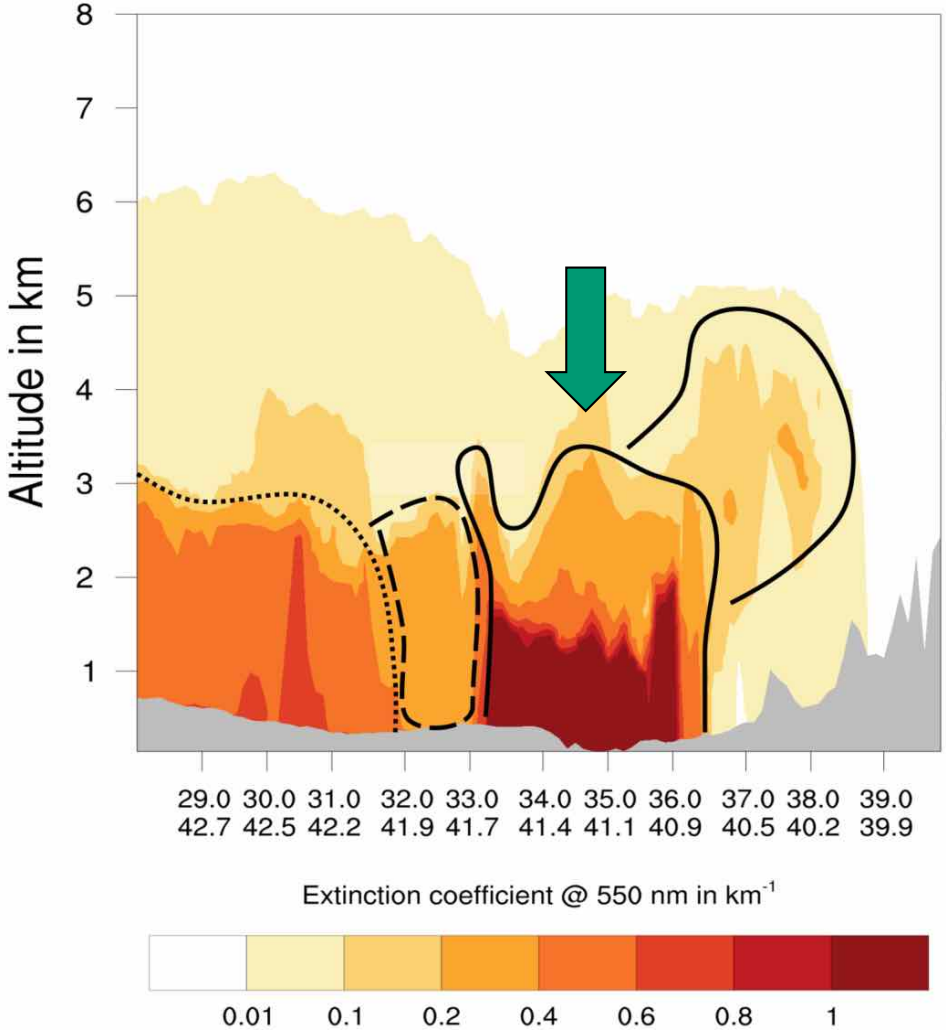


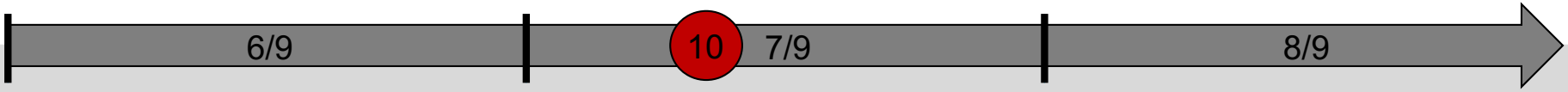
Validation of ICON-ART

ICON-ART model



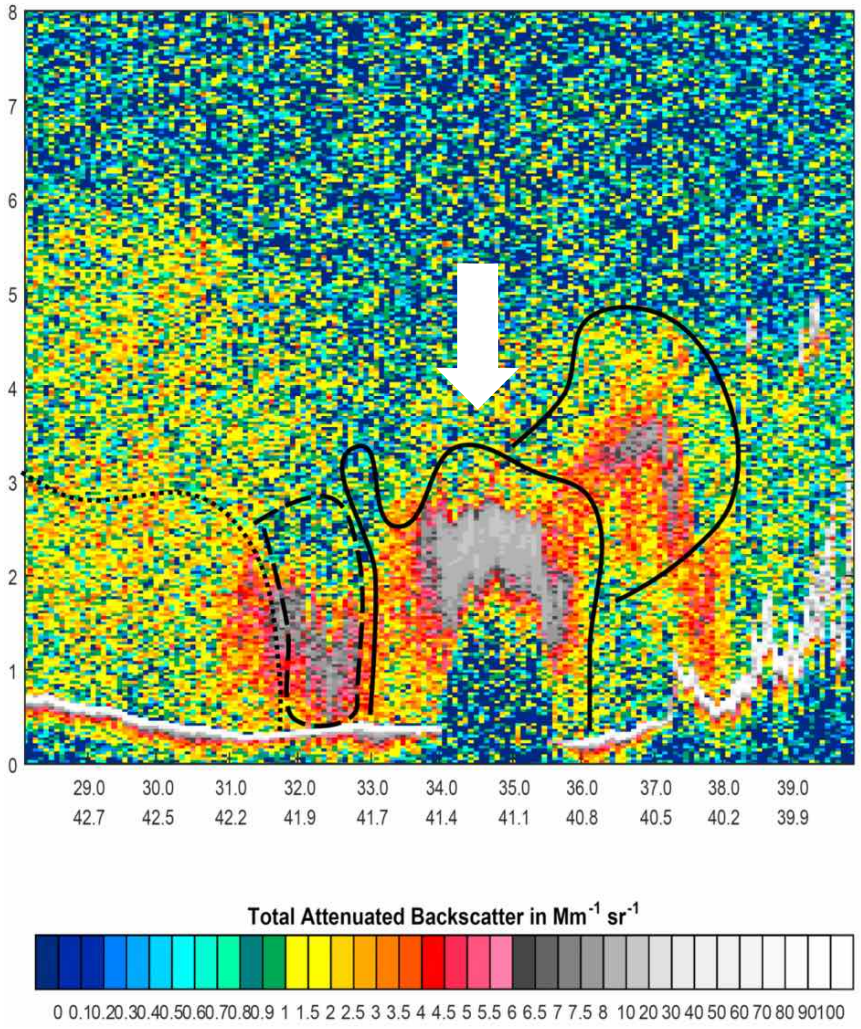
ICON-ART X-Z model



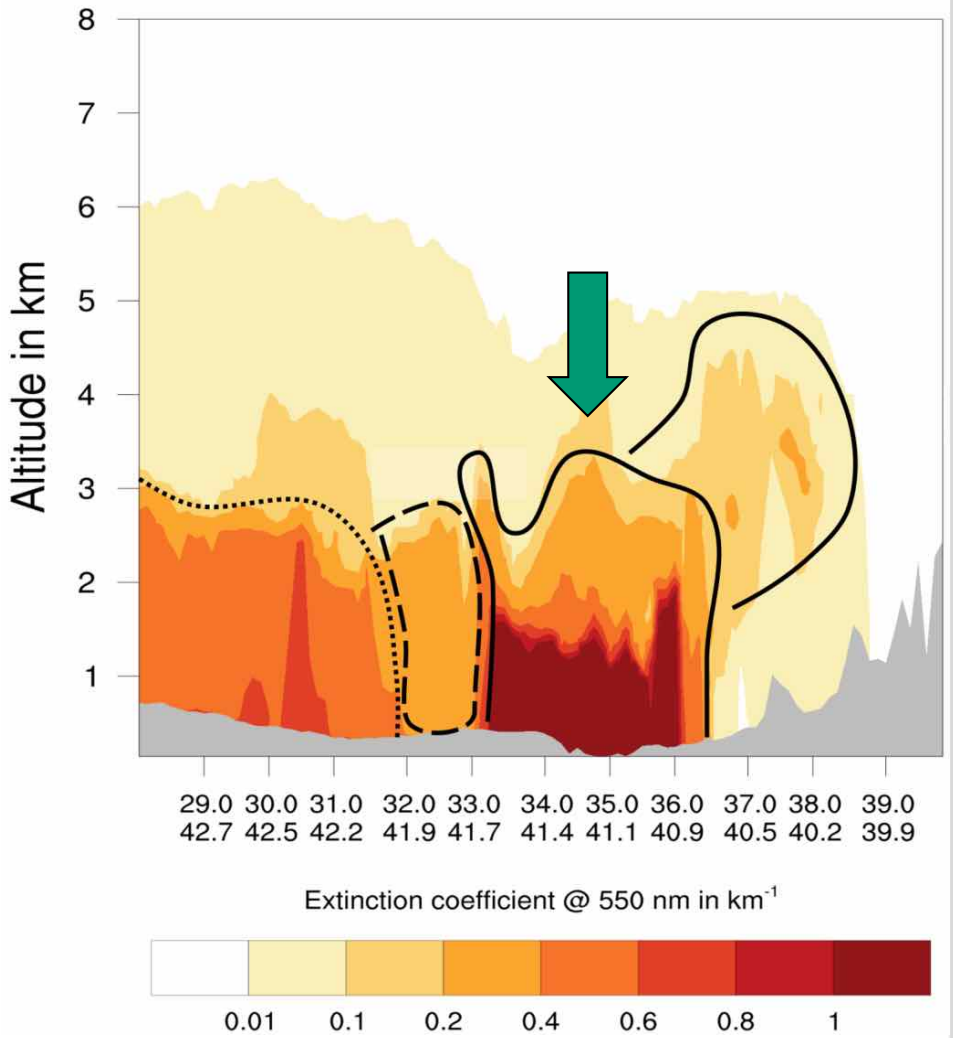


Validation of ICON-ART

CALIPSO X-Z satellite



ICON-ART X-Z model



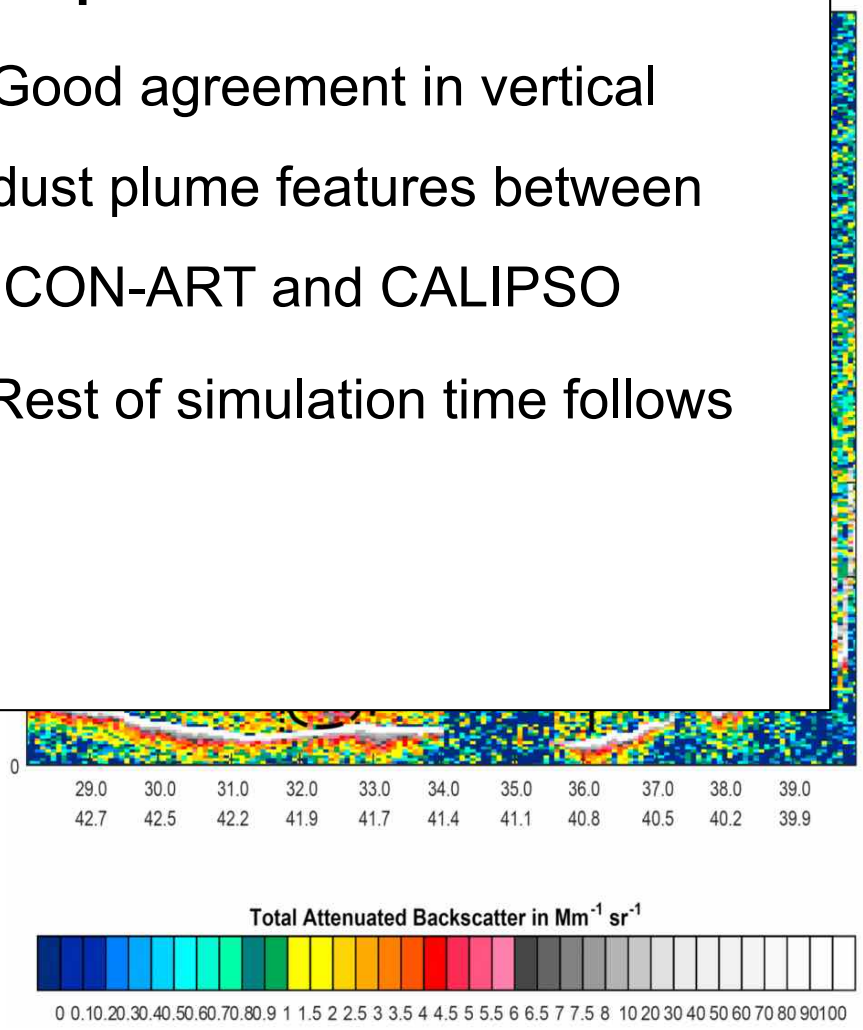
6/9 — 10 — 7/9 — 8/9

Validation of ICON-ART

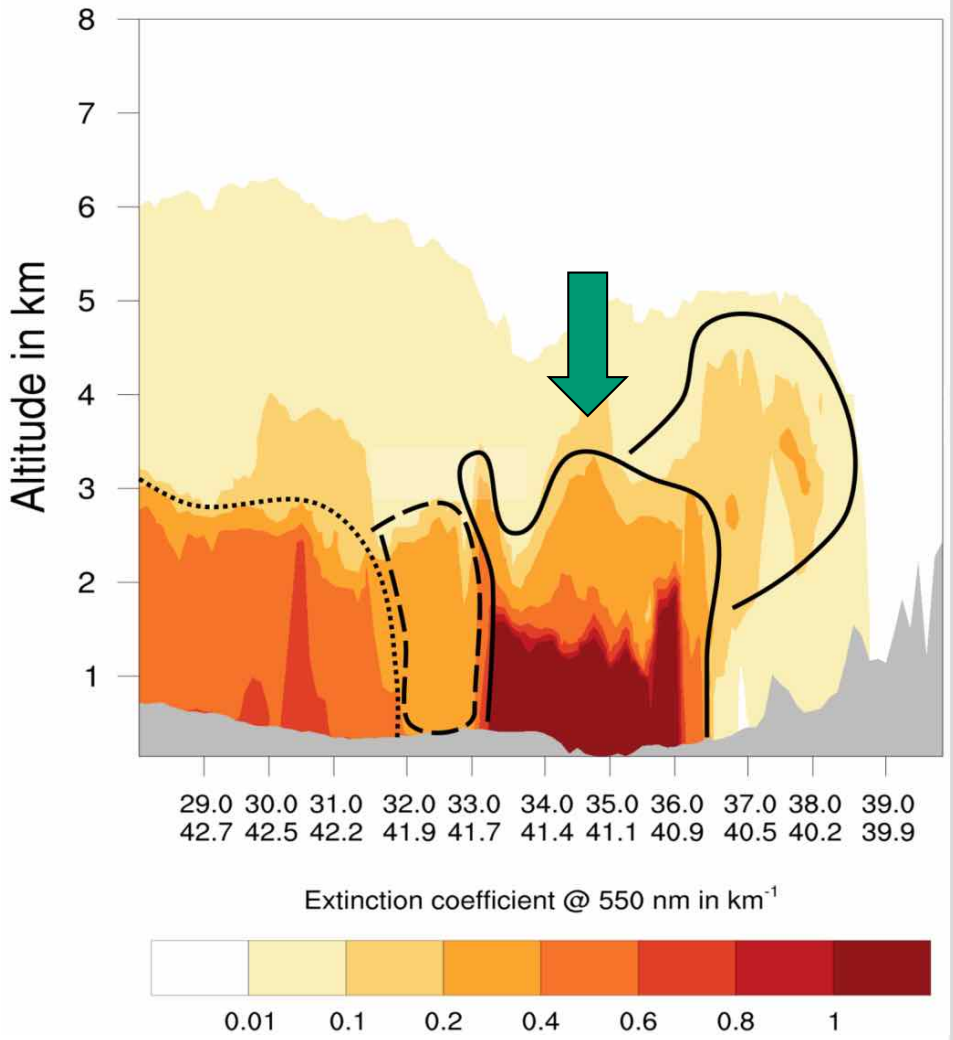
07 Sep ’15 – 10 UTC

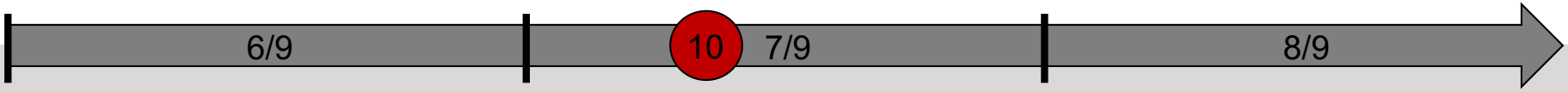
- Good agreement in vertical dust plume features between ICON-ART and CALIPSO

→Rest of simulation time follows



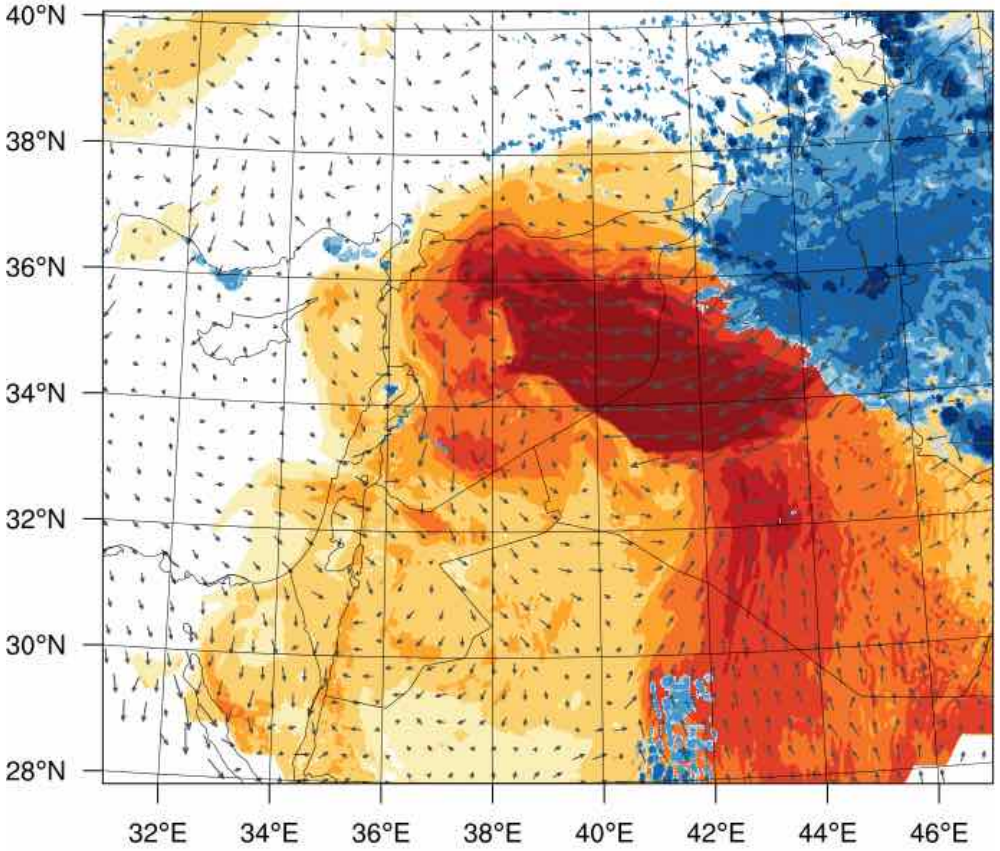
ICON-ART X-Z model



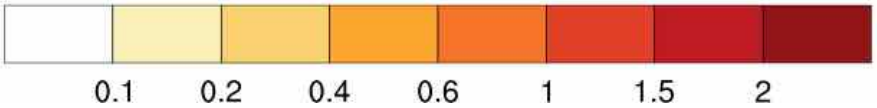


Forecast improvement

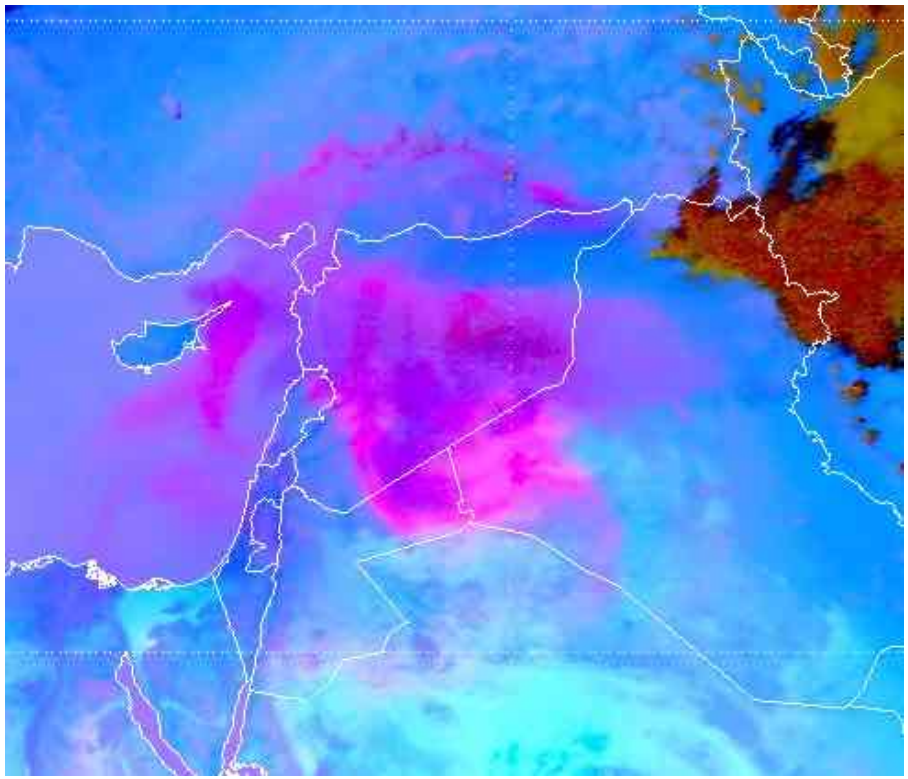
ICON-ART model

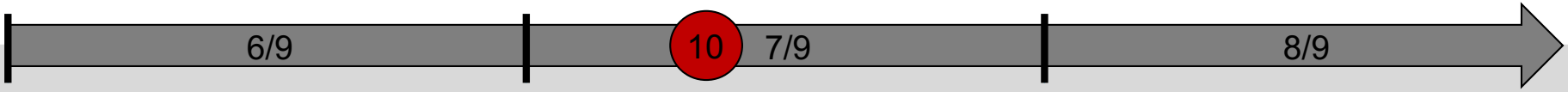


Dust optical depth @550 nm



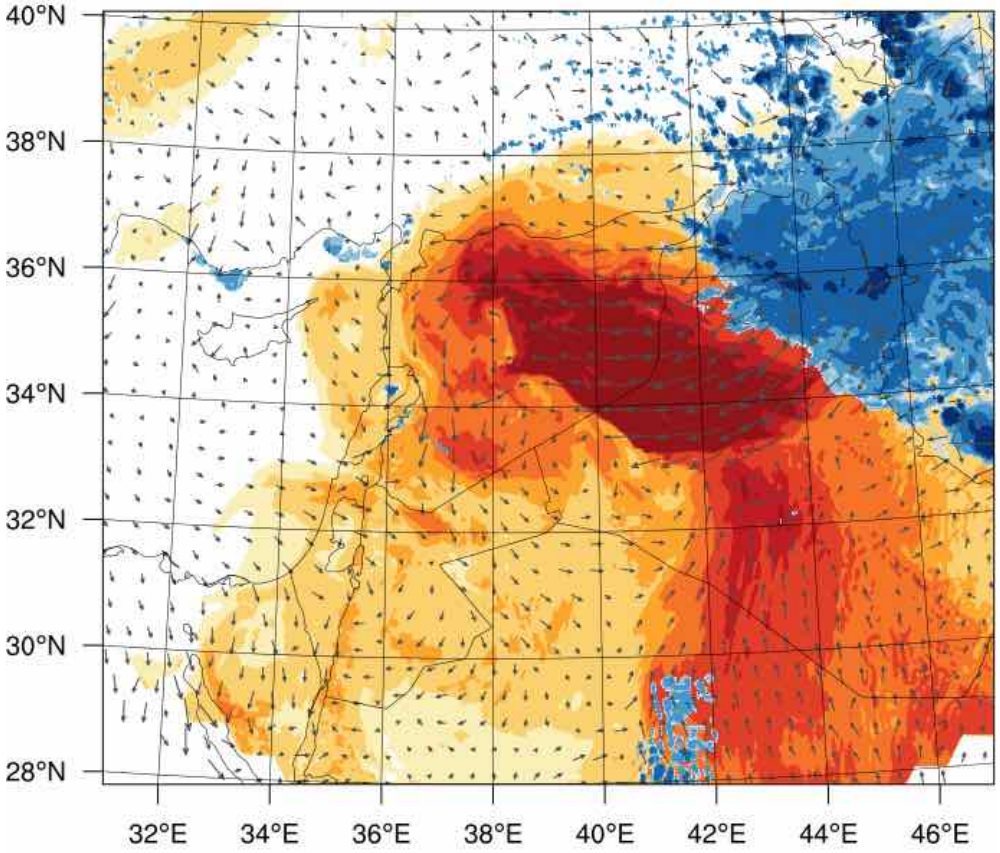
EUMETSAT satellite



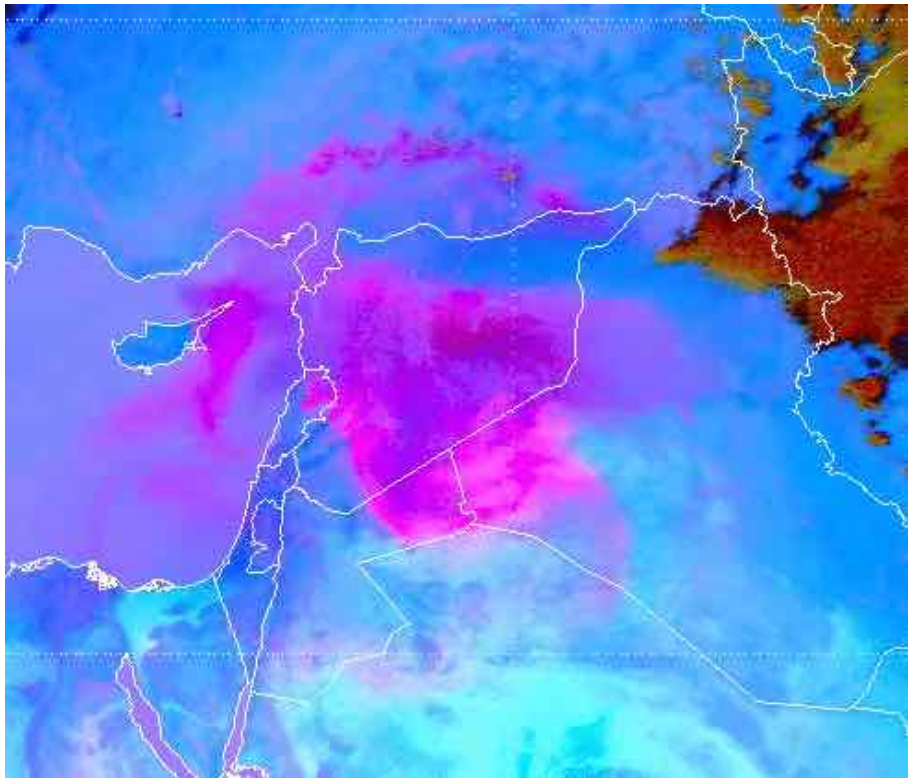


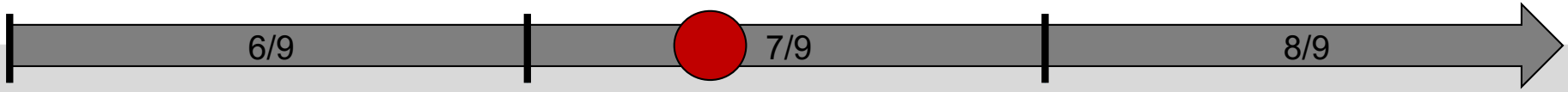
Forecast improvement

ICON-ART model



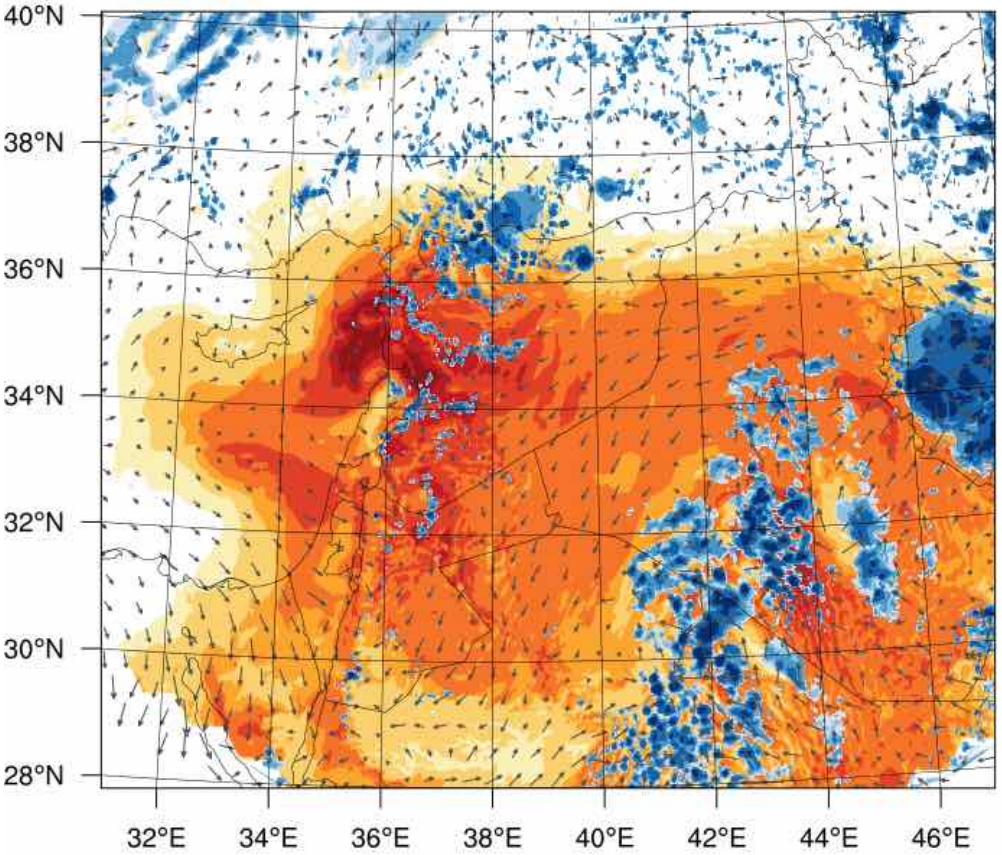
EUMETSAT satellite



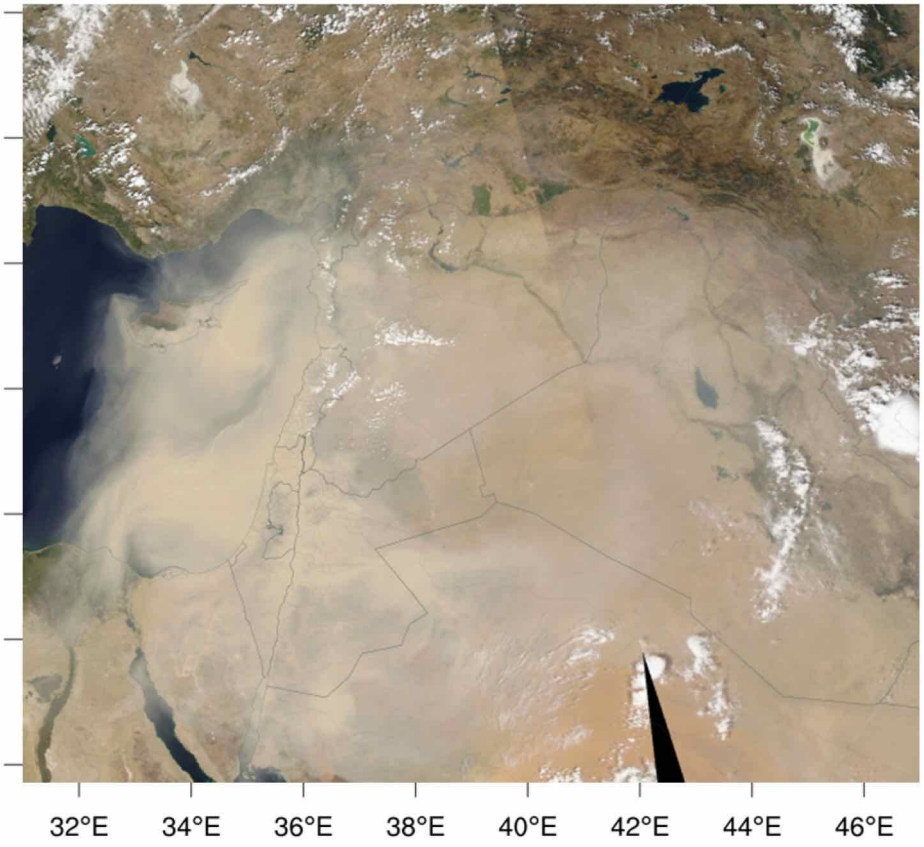


Forecast improvement

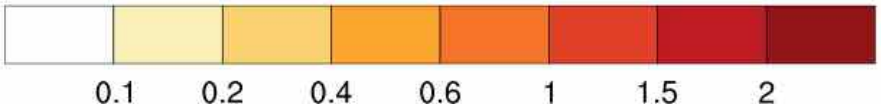
ICON-ART model

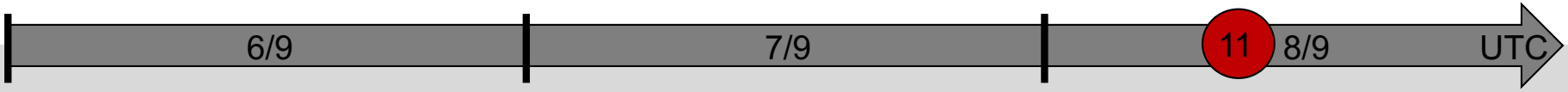


MODIS AQUA VIS satellite



Dust optical depth @550 nm



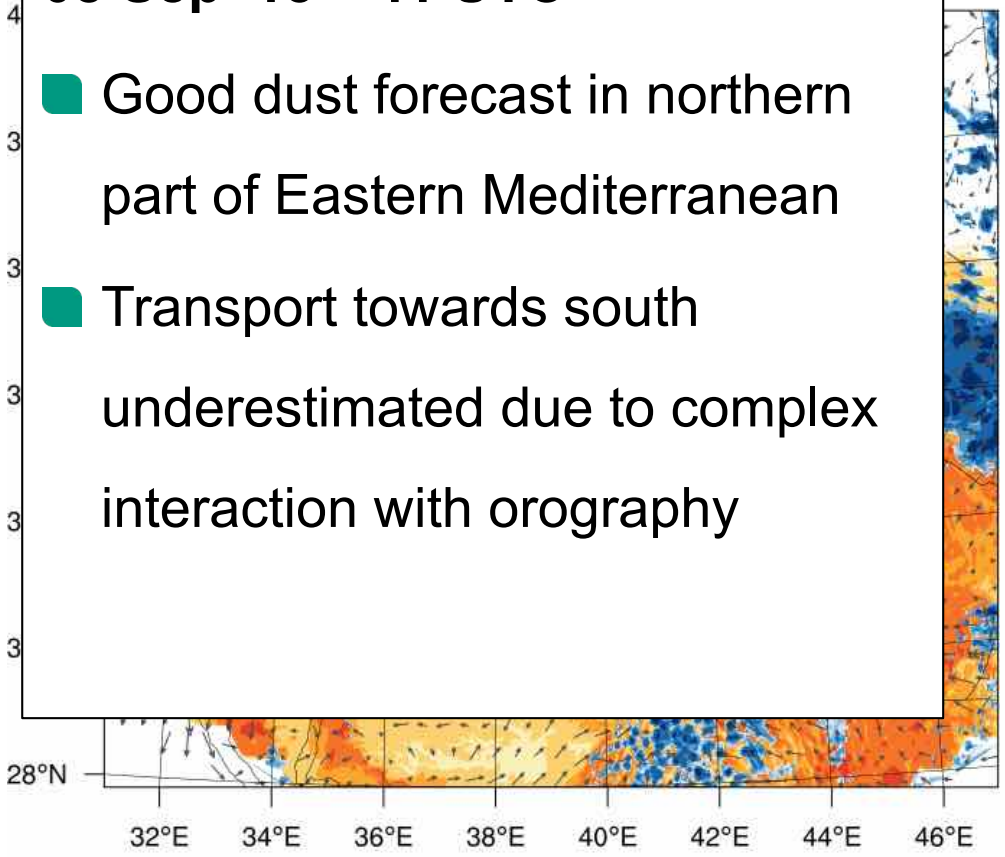


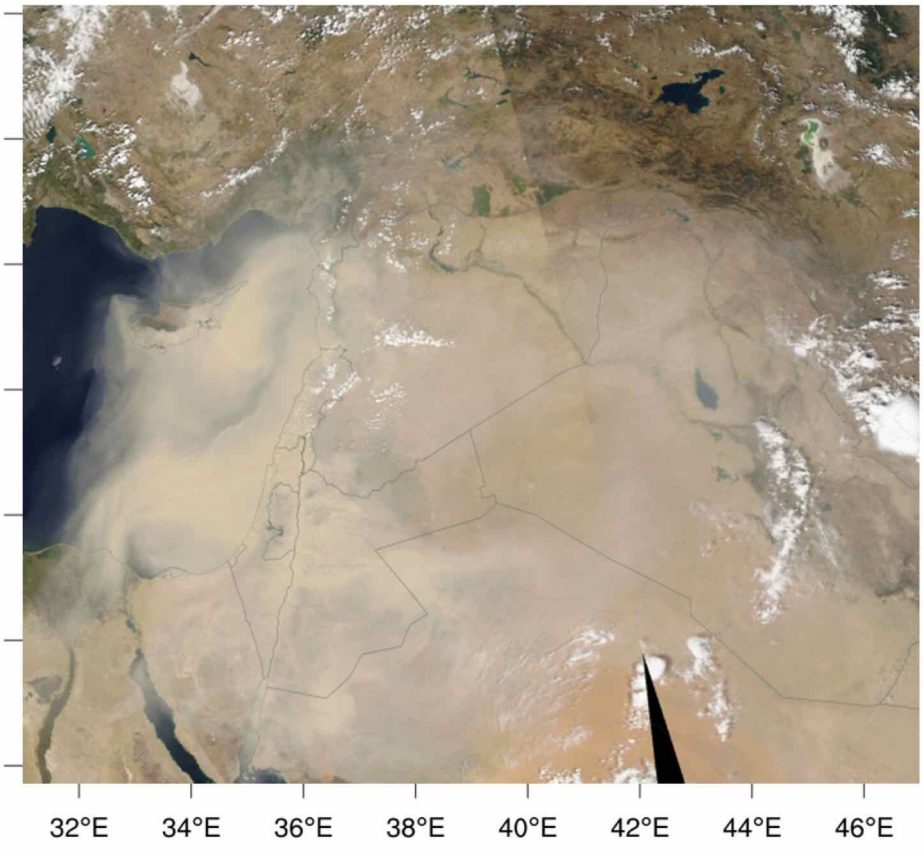
Forecast improvement

08 Sep ’15 – 11 UTC

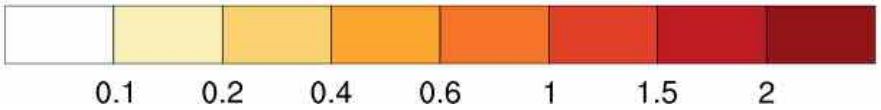
- Good dust forecast in northern part of Eastern Mediterranean
- Transport towards south underestimated due to complex interaction with orography

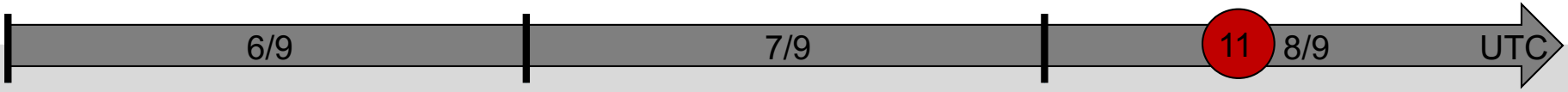
MODIS AQUA VIS satellite





Dust optical depth @550 nm





Conclusions

- Haboobs can create locally severe dust storms but also interact with the regional scale circulation to create large and long-lasting events.
- Using parametrised convection can lead to spectacular mis-forecasts.
- Pantillon et al. parametrisation can emulate effect of haboobs statistically but not for single events.
- We should thus aim for explicitly resolving haboobs in forecast models, at least in sensitive areas such as the Middle East.
- Particularly for the West African monsoon, mis-representation of convection in models can create large continental-scale wind biases.