Large-scale forcing of extreme African dust storms by double Rossby wave breaking

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Motivation and content

- Upper-level troughs penetrating equatorward over North Africa may result in heavy precipitation events and the formation of dust storms
- Frequent trough amplification and thinning accompanying equatorward RWB
- Area with complex topography, low-level baroclinicity

⇨ Three dust storm case studies with strong impact over the Iberian Peninsula (IP)

- **Double Rossby wave breaking in the Polar Jet** is the common large-scale precursor that organizes a favorable environment for:

  1. dust storm formation over deflatable areas in North Africa, and
  2. restructuring of upper-level air flows for transport of dust poleward to the IP

- Substantial differences between the three cases in location and geometry of key upper- and low-level features following RWB#2

⇨ One case study of dust advected SW towards the eastern Atlantic

- How relevant is this process? Started a climatological analysis of the secondary RWB amplification

Motivation and content

Amplification of the second RW in the Polar Jet by nonlinear energy reflection

⇩

PV-rich and very cold air penetrating into low latitudes over North Africa

- Dynamic lifting (jet streak secondary circulations)
- Reduction of the static stability ahead of the cyclonic side

Low-level convergence of moisture in most cases

Destabilizes the lower troposphere

Orza et al (2020), Atmos. Environ. 237, 117688

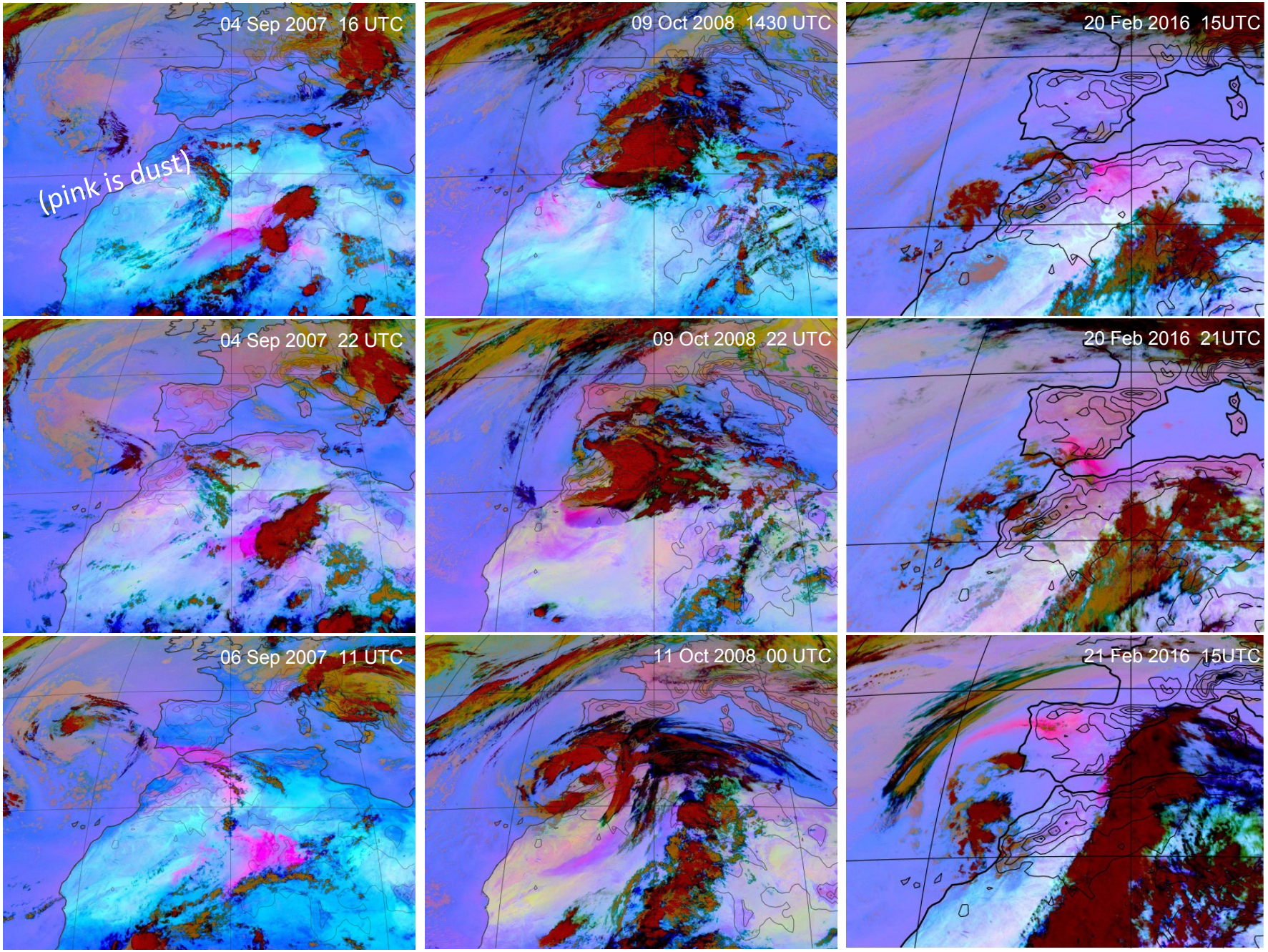
⇨ Observations and ERA-Interim/ERA5 reanalysis data

LLJ, moist convection and different topographically-induced circulations (downslope winds, density current-like cold fronts, undular bores, barrier jets, hydraulic jumps, and mesoscale internal gravity waves),
strengthen TKE in the ABL, leading to dust ablation and entrainment

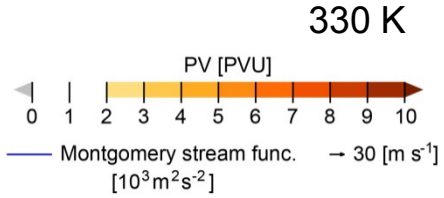
⇨ WRF CHEM high-res simulations

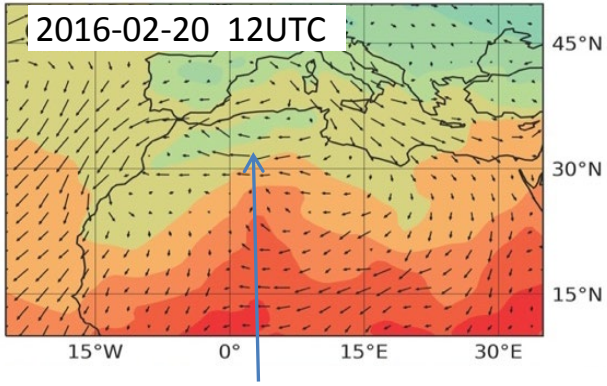
Dhital et al (2020), J. Geophys. Res. Atmos. 125, e2020JD032975
Dhital et al (2021), Atmos. Environ. 261, 118574
Dhital et al (under revision)

Poleward transport of dust MSG SEVIRI – Dust RGB imagery



The February 2016 event





Barrier jet

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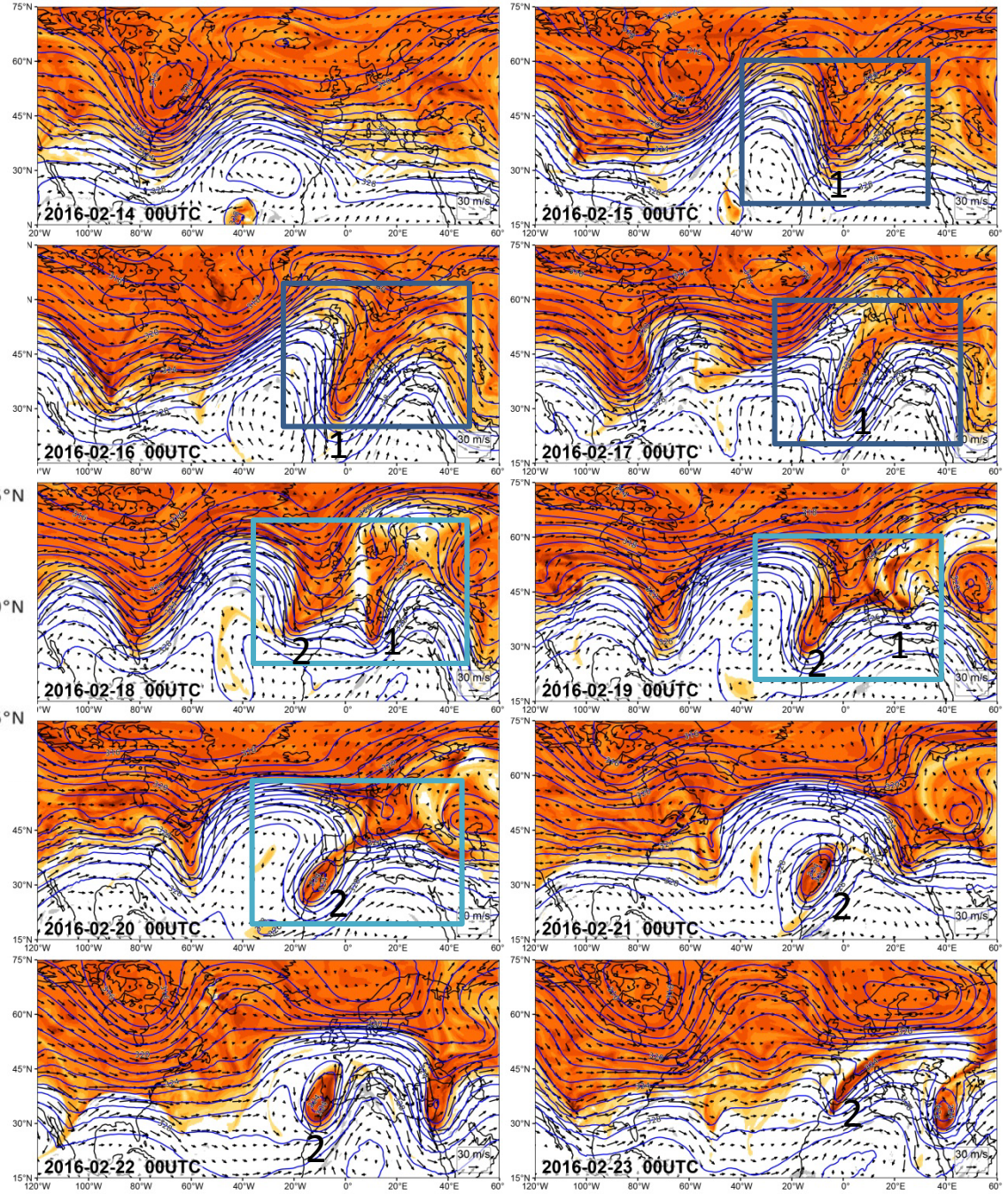
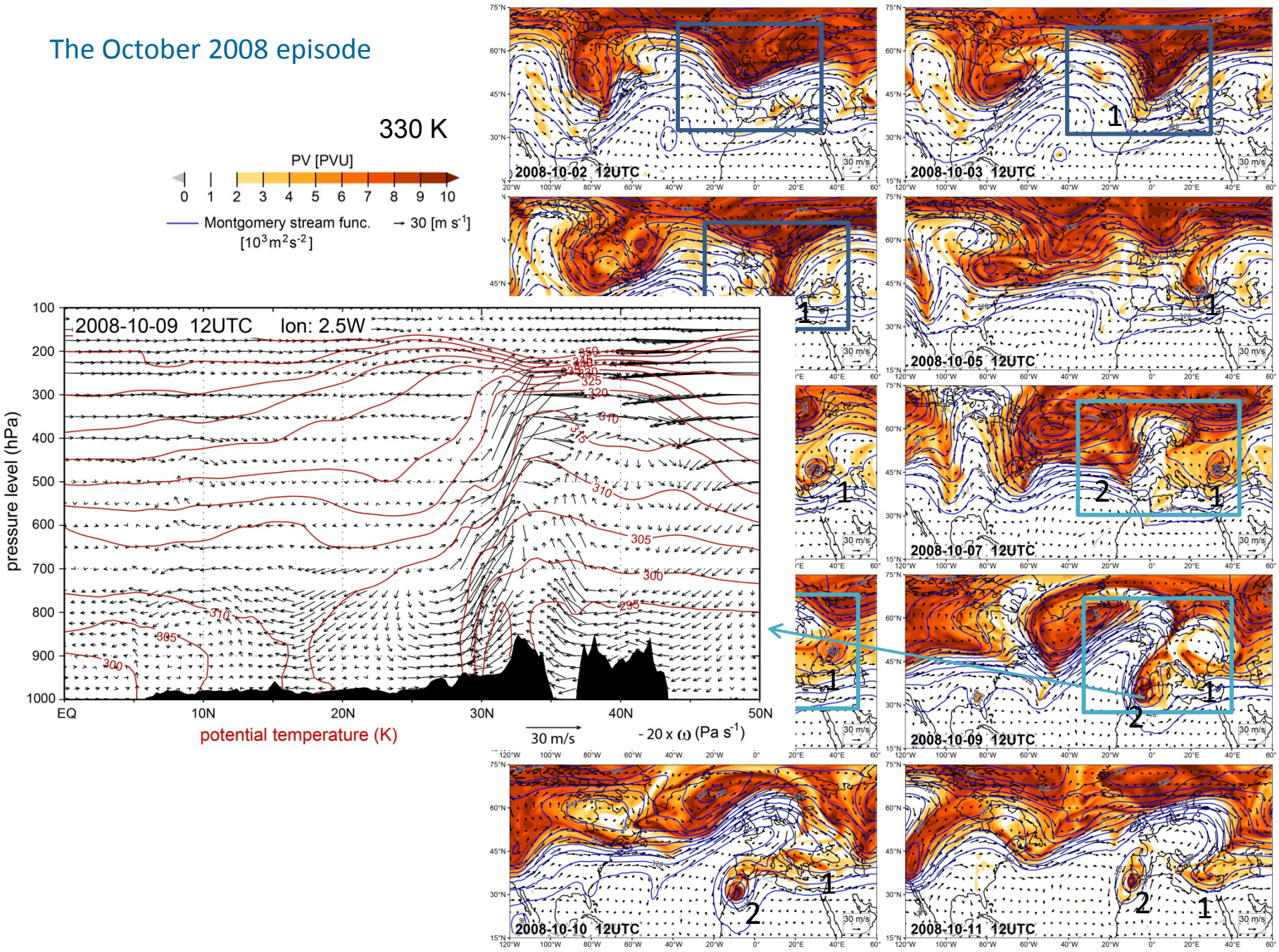
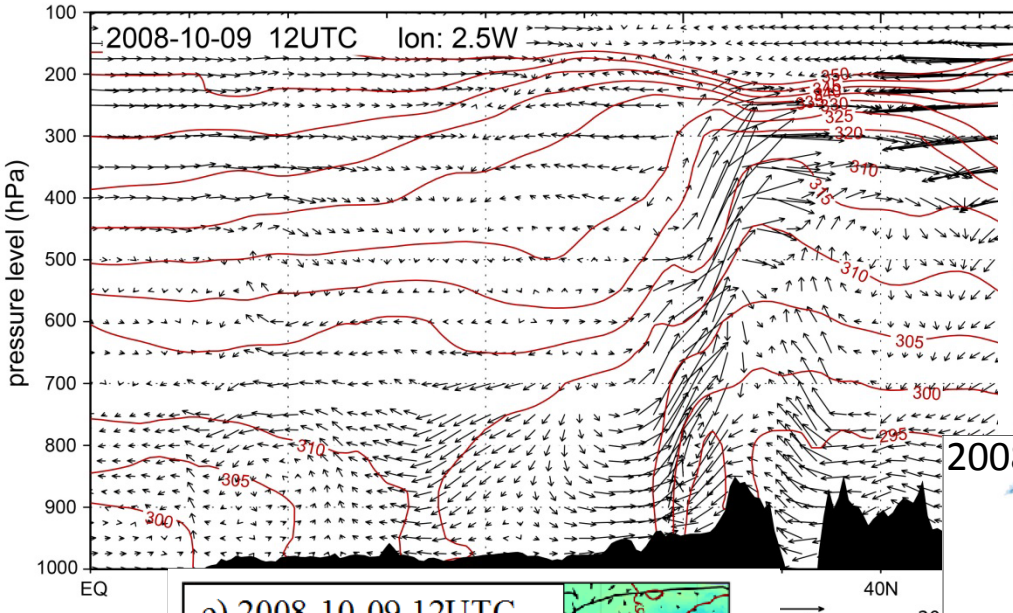
Differential heating in the Saharan Atlas:
Mountain Plain Solenoidal circulations

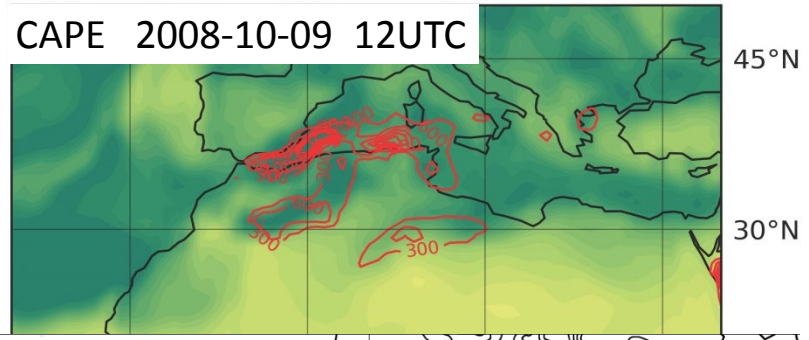


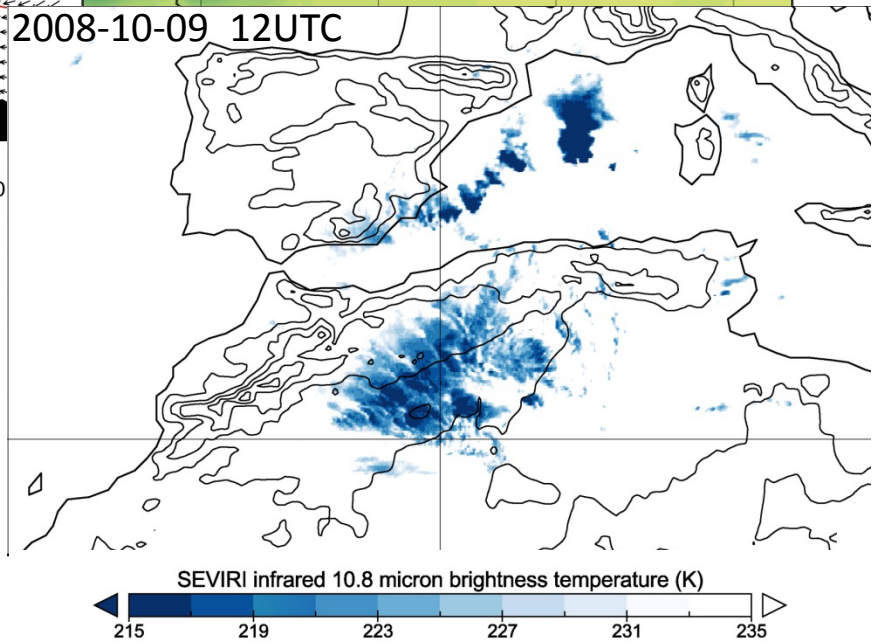
The October 2008 episode

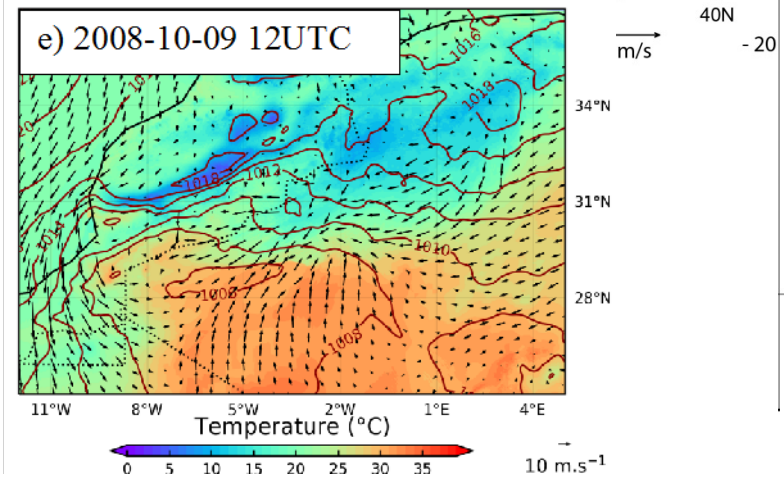


The October 2008 episode





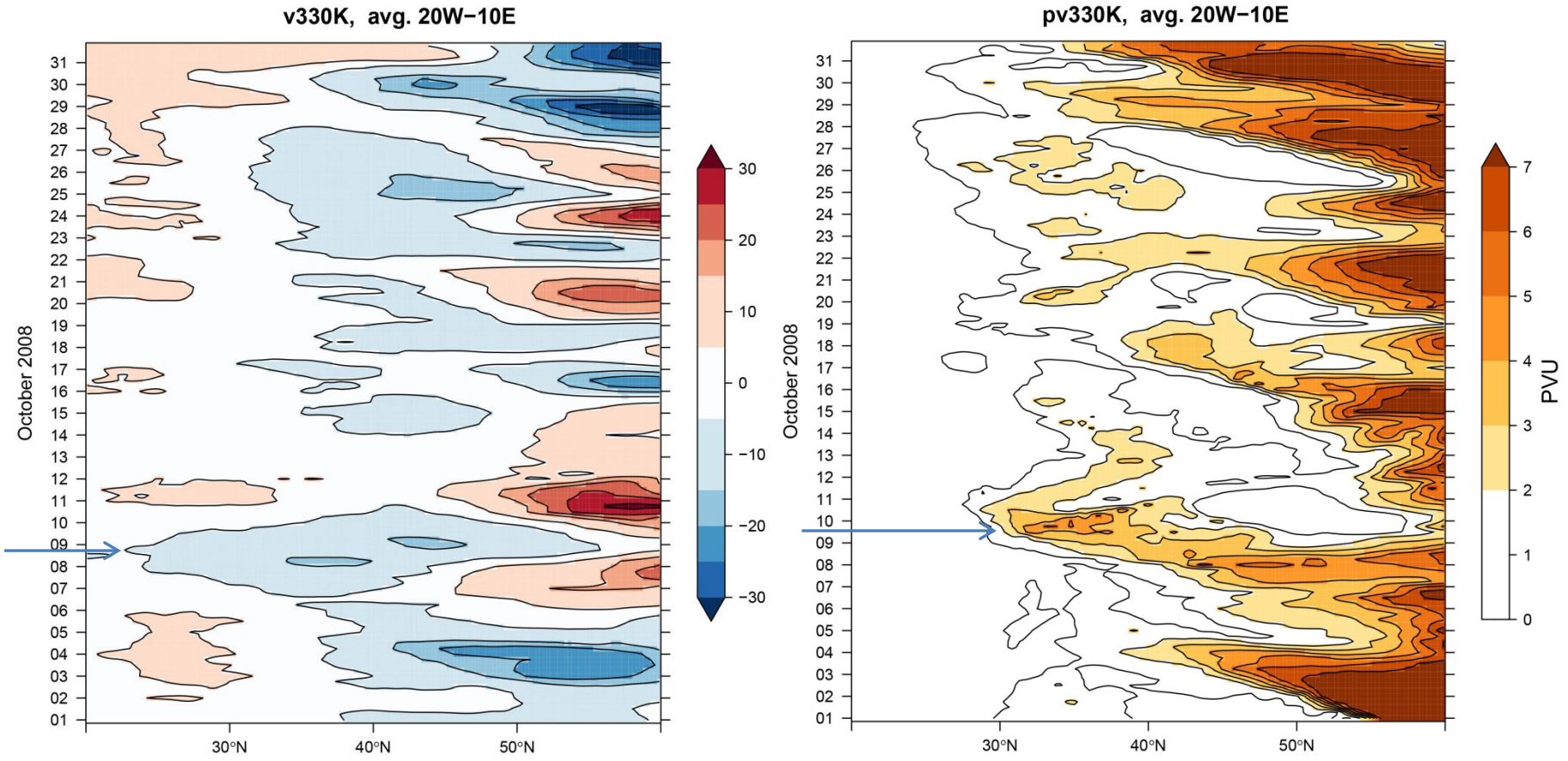




Cold convective cloud tops as observed by BT at 10.8 μm. The ascent realizes the potential instability and results in moist convection, cold pool and haboob development

The October 2008 episode

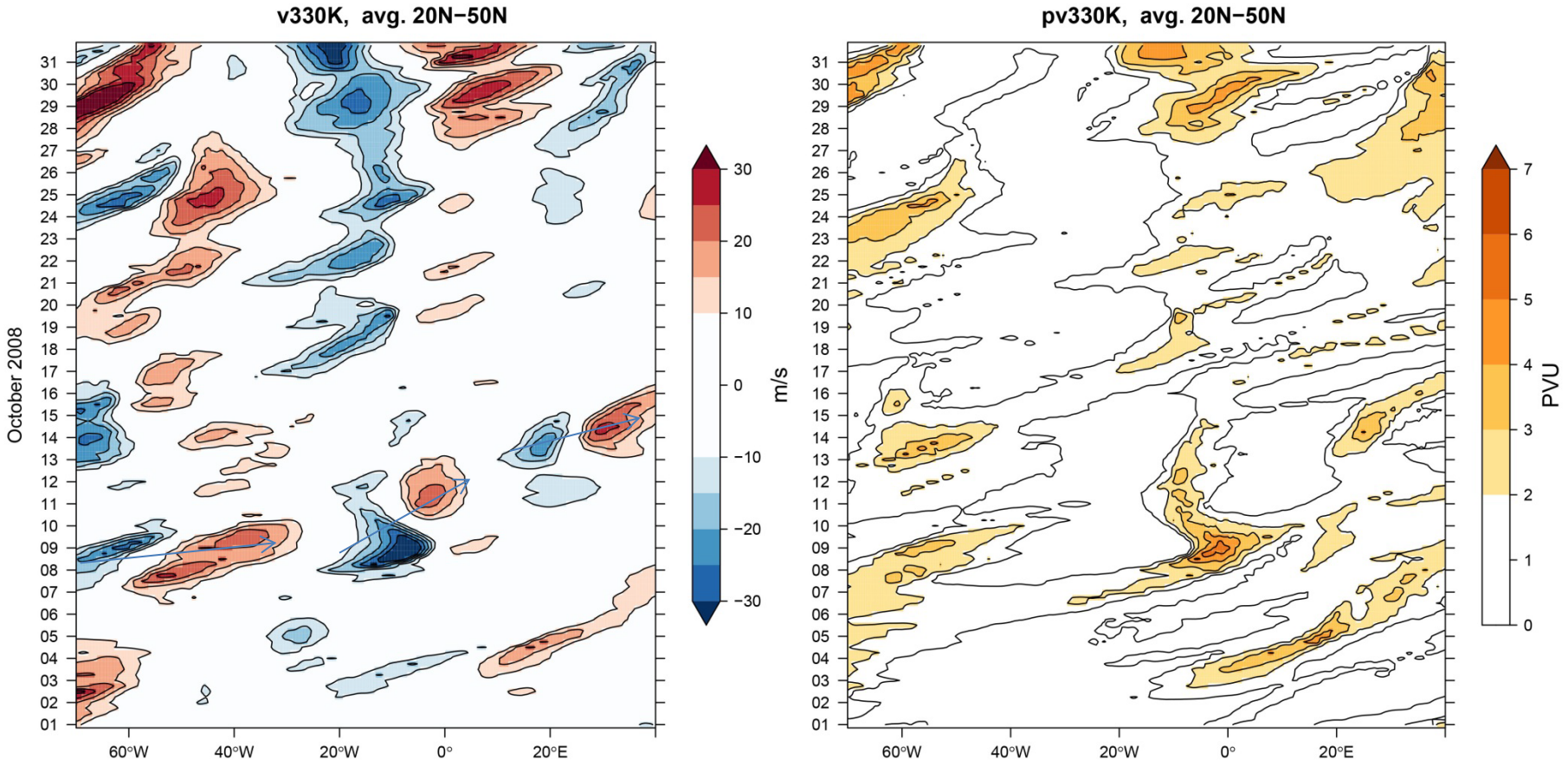
Latitudinal Hovmöller plots



RWB#2 penetrates further equatorward than RWB#1

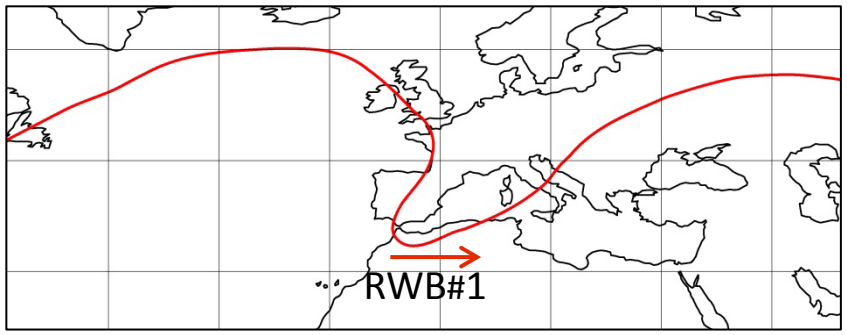
The October 2008 episode

Longitudinal Hovmöller plots



The double anticyclonic RWB in the Polar Jet. Conceptual depiction

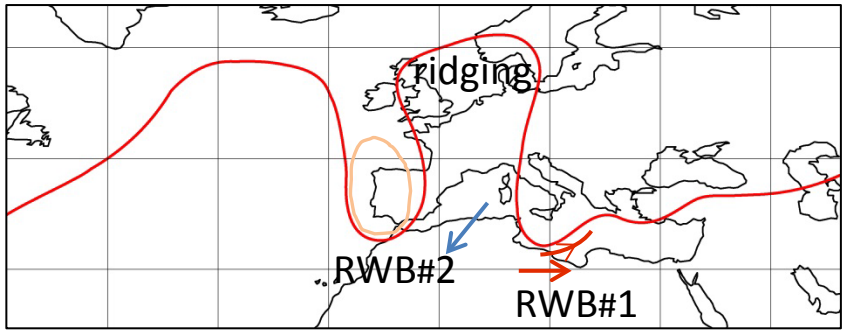
RWB#1: IPV reversal ~10 days before dust arrives Iberia



When RWB#2 develops, RWB#1 drifts slowly eastward (no downstream wave propagation)

RWB#1 induces low-level NE/E cold flows and blocks downstream propagation of pressure systems

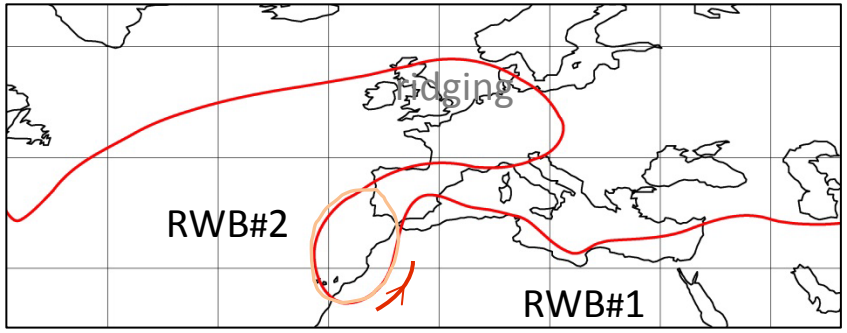
Energy from RWB#1 is nonlinearly reflected poleward and upstream; it amplifies RWB#2



RWB#2: 3-5 days after RWB#1. Results in a cut-off vortex or fortifies an offshore preexisting upstream vortex

Vortex locates over NW Africa, jet streak with SW momentum intensifies on its forward flank

STJ strengthens equatorward and downstream by the two RWBs ⇨ Jet streak secondary circulations



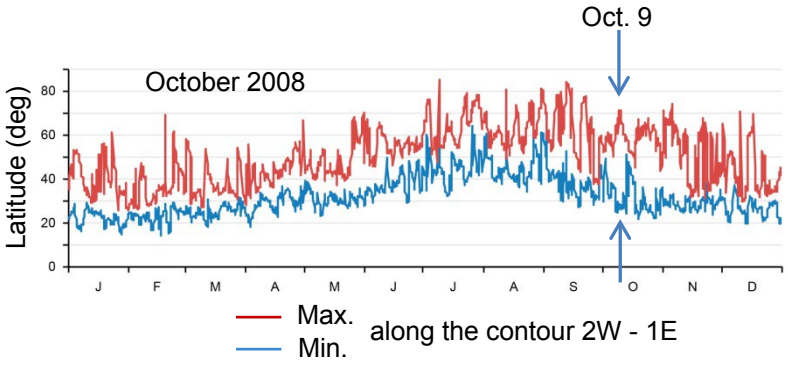
- The equatorward transport of mass and momentum is enhanced by the succesive RWBs linked by nonlinear wave reflection. This creates a more favorable low-level environment for dust storm genesis over North Africa.
- The amplification and location of the upstream RWB#2, together with the blocking of zonal airflows, key to the poleward transport towards the IP.
- Not all dust storms form this way

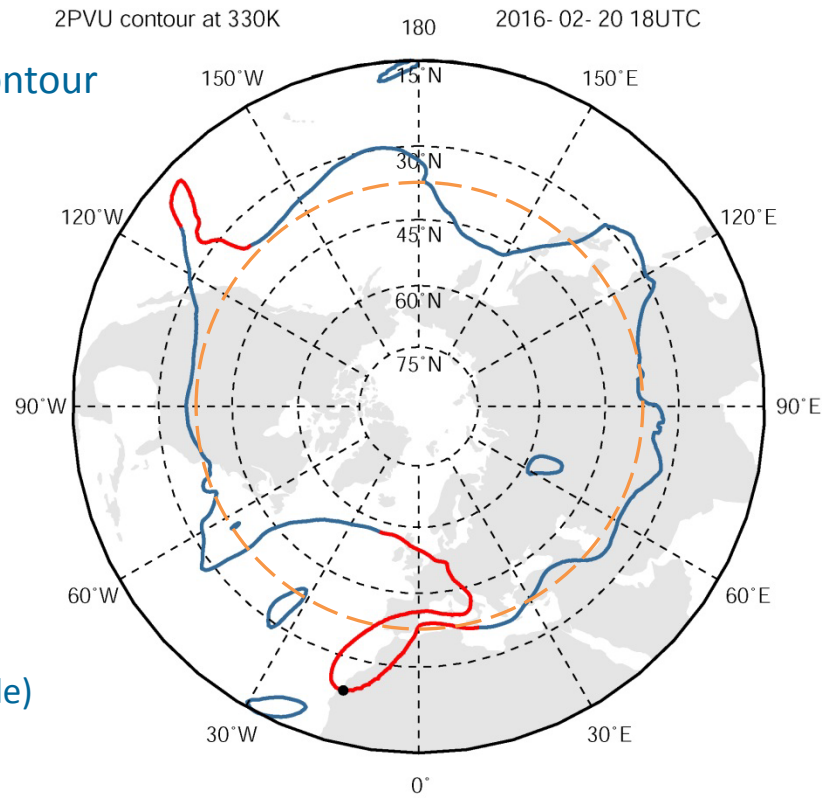
- Abatzoglou and Magnusdottir (2006) found non-linear reflection in a large fraction of RWBs in the subtropical tropopause.
- How relevant is the secondary RWB process in the polar stream?
  - Large scale forcing of strong cold flow over North Africa
  - Amplified ridging, connection with other extreme weather episodes

RWB climatology in the polar stream, with nonlinear wave reflection assessment

First step ⇨ Identification of polar stream RWBs by the irreversible overturning of the 2PVU contours on the 330K isentropic surface

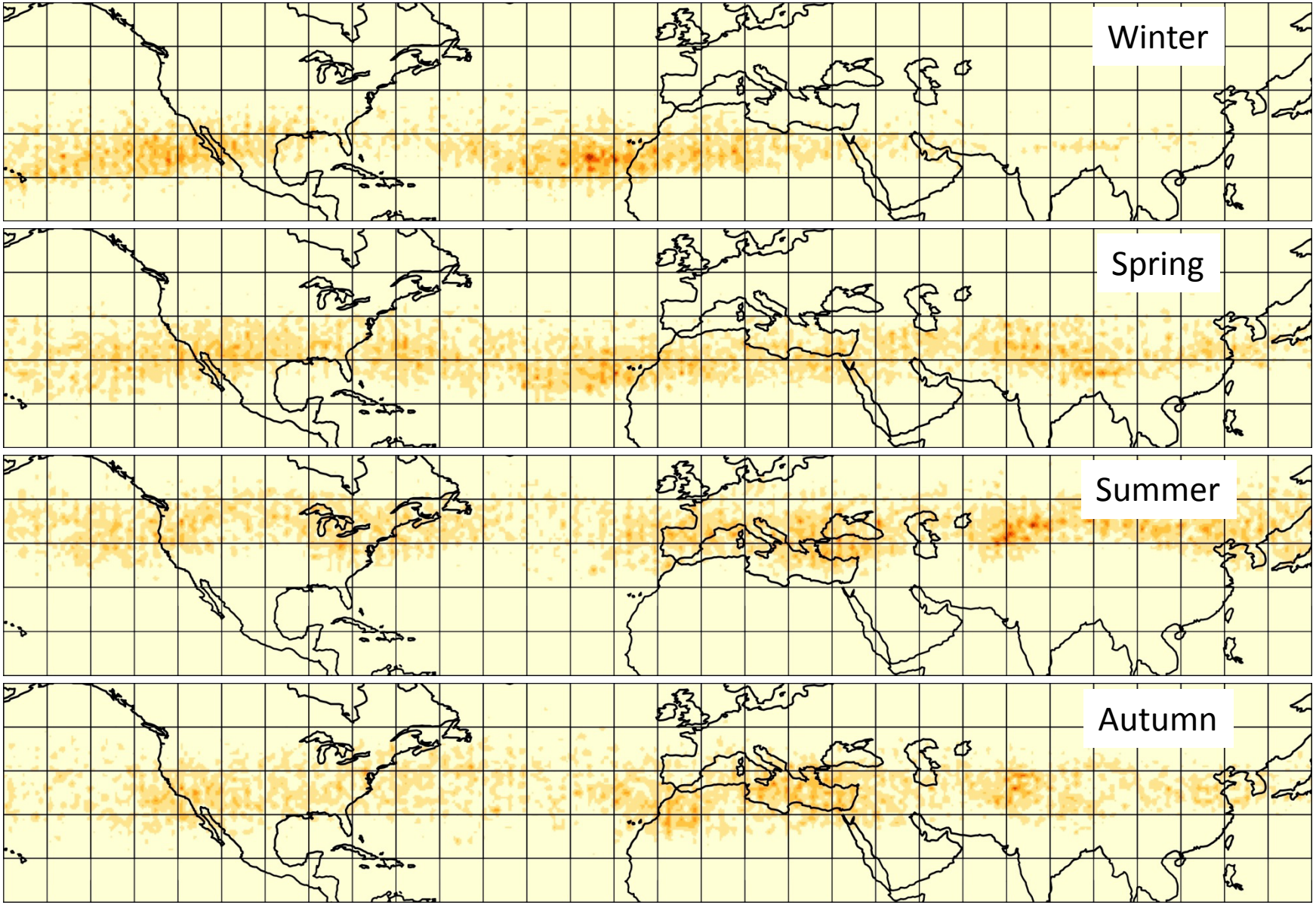
- Preferred locations and times for wave breaking and penetration equatorward
- Geometrical analysis of the longest 2PVU contours
  - Equivalent latitude
  - Great circle length of the 2PVU contour
  - Regional analysis



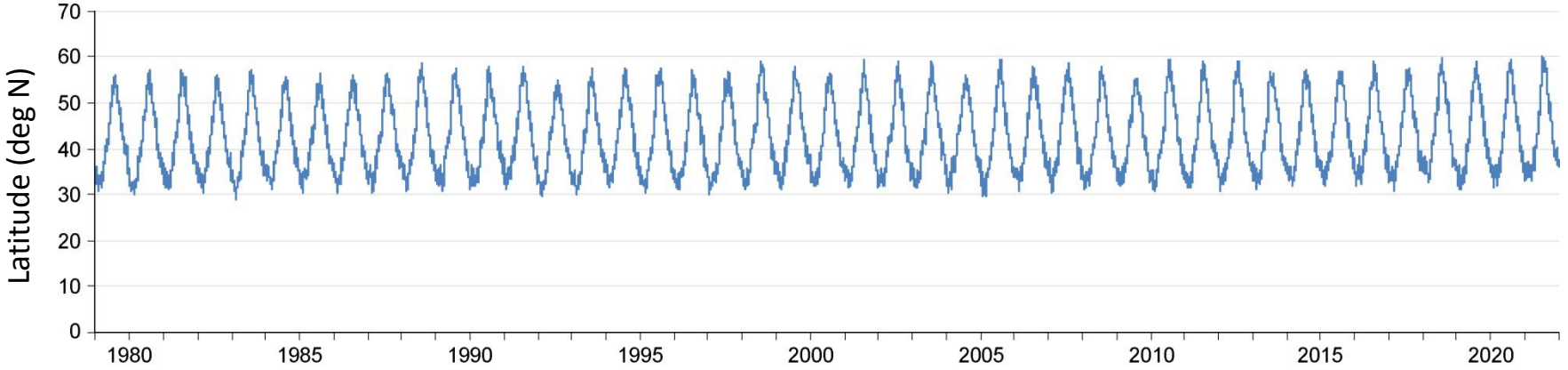


(Febr. 2016 dust episode)

Location of the minimun latitude in the 2PVU overturning contours (*anticyclonic* RWBs)
(2000 – 2009)



Equivalent latitude of 2PVU contours at 330K (1979 – 2021)



Small displacement poleward,… is the polar signal weakening?

monthly means ⇨ 0.069 deg/yr

seasonal means ⇨ 0.23 deg/Summer

0.13 deg/Winter

(Theil-Sen slope estimator)

Further analysis needed

Thank you for your attention

- We thank ECMWF for making available the ERA5 and ERA-Interim datasets and EUMETSAT for the MSG-SEVIRI data.
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FRESA Project

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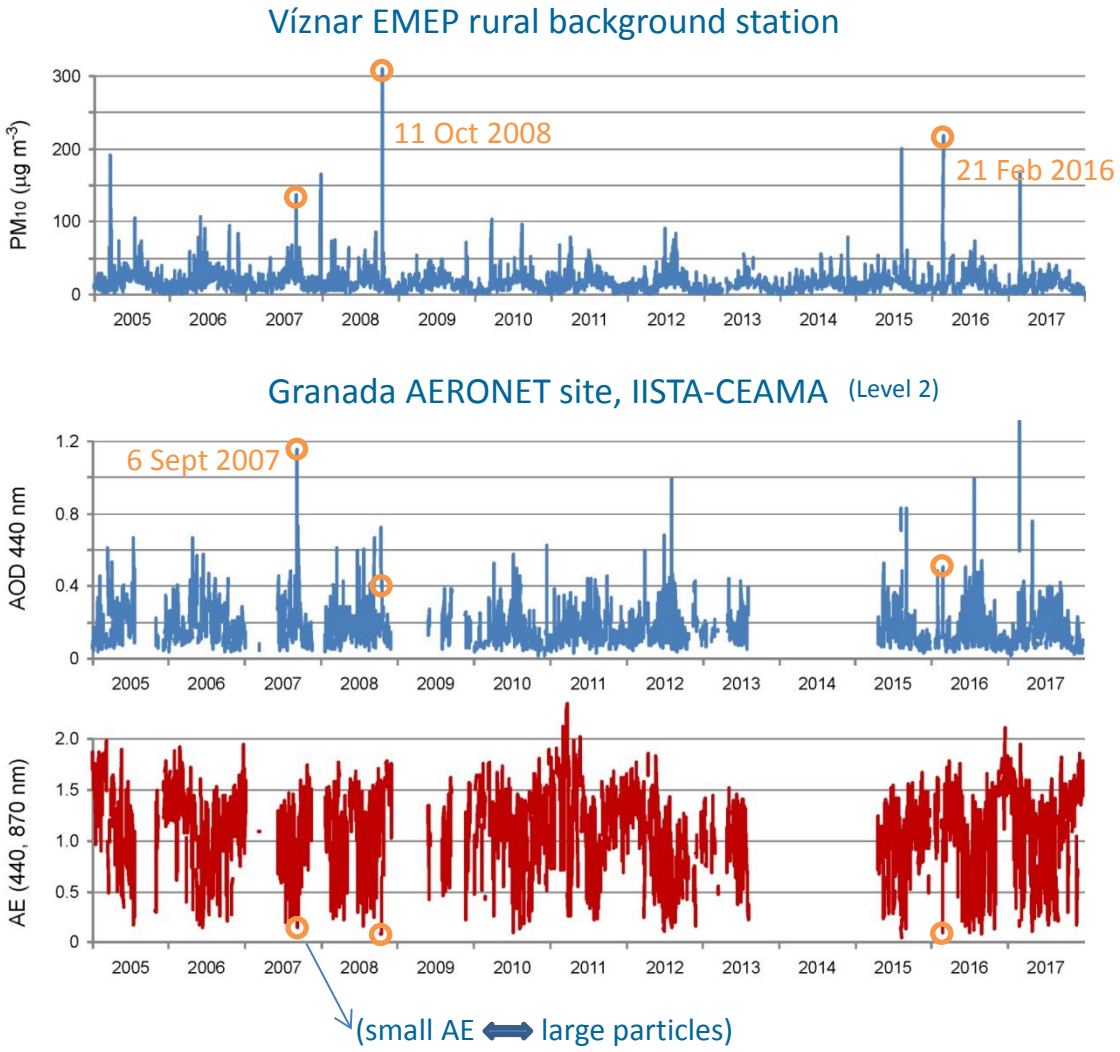
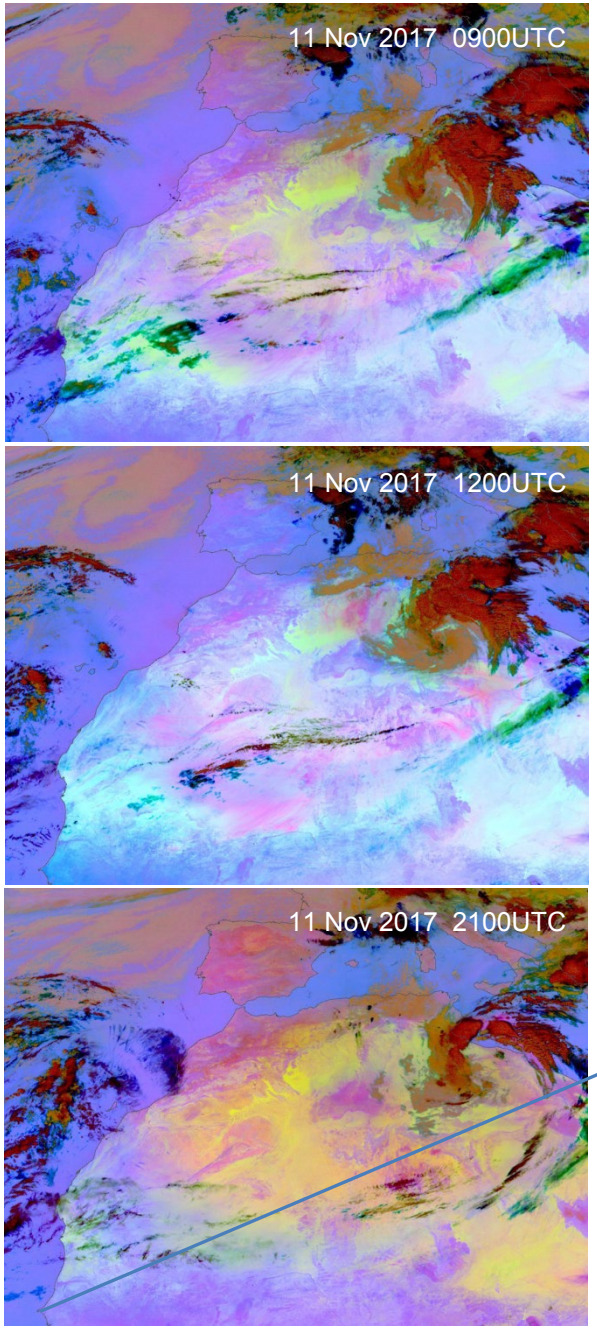
Strong impact of the three events over Iberia

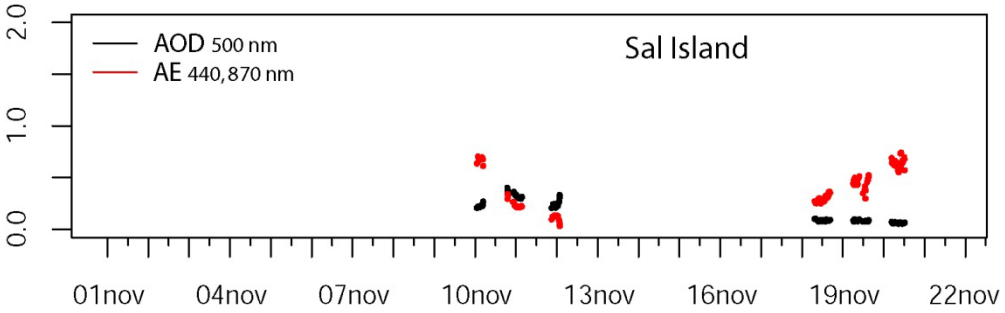
Mean daily values in SE Spain

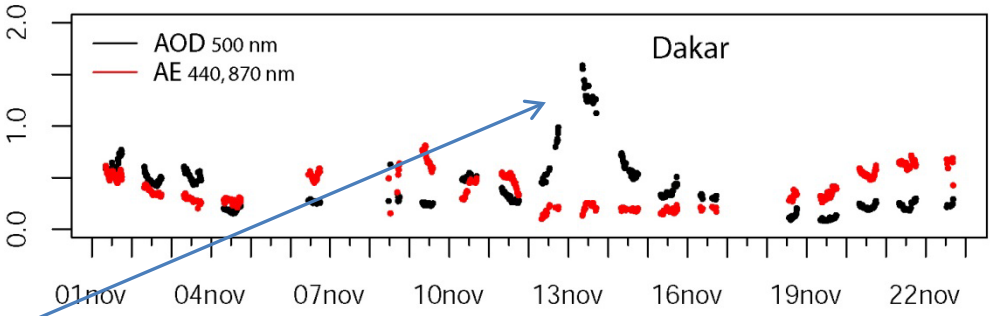


Southwestward transport of dust

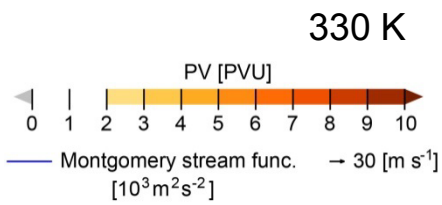
MSG SEVIRI – Dust RGB imagery

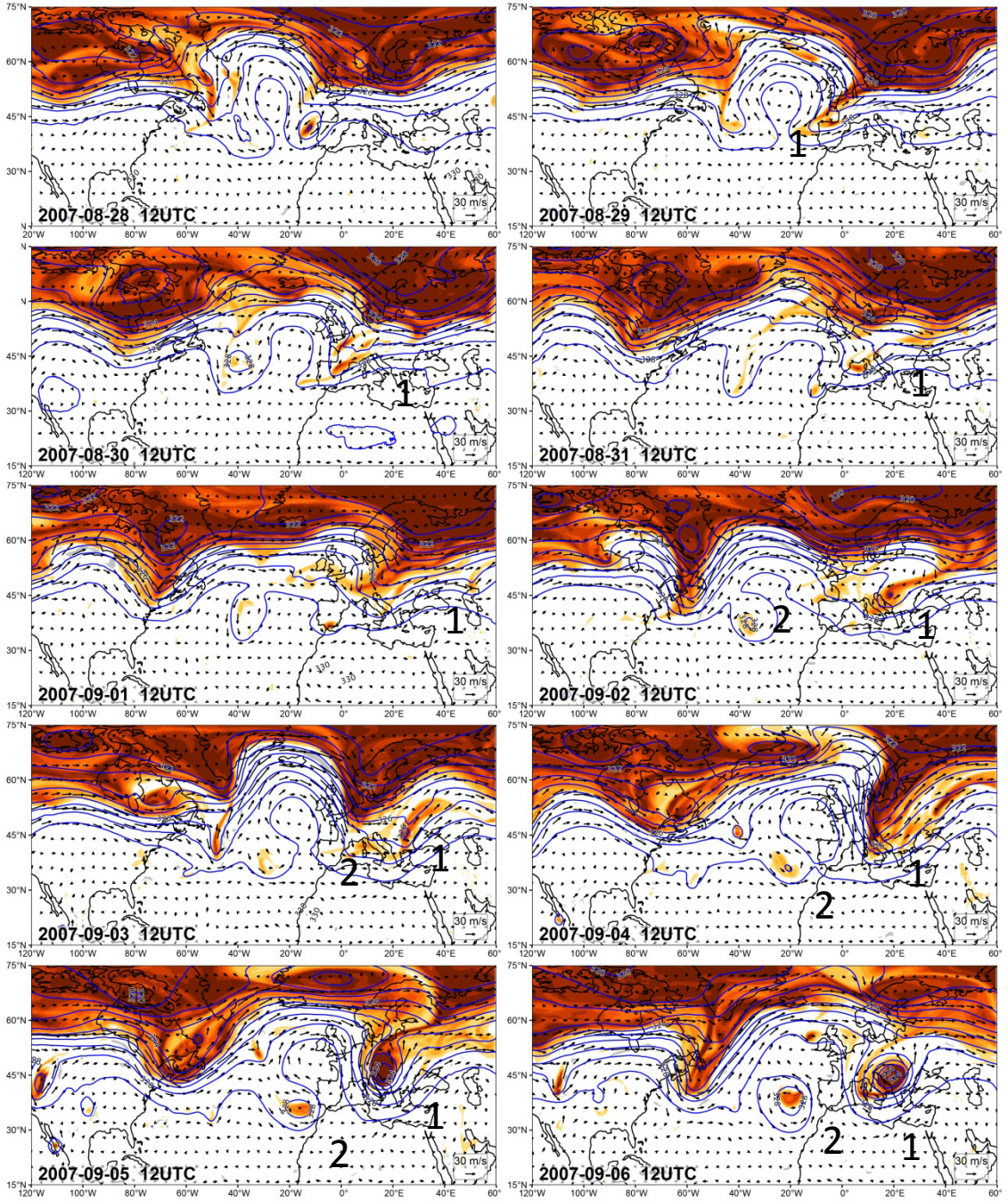




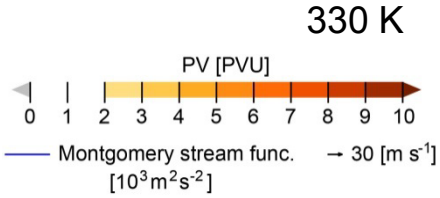


The September 2007 episode





The November 2017 episode



Initiates as a cold surge