Lagrangian analysis of the dynamics of Indian summer monsoon break/active events

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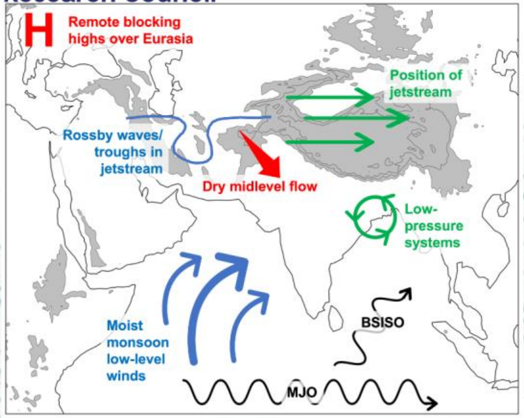
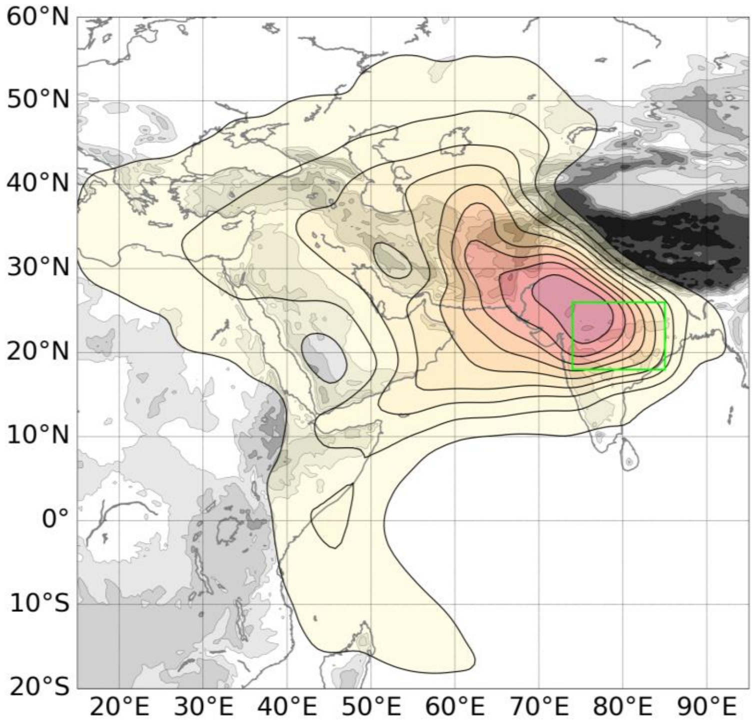
Eighth WMO International Workshop on Monsoons (IWM-8)
18 March 2025

Natural Environment Research Council

MiLCMOP





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OUTBREAK

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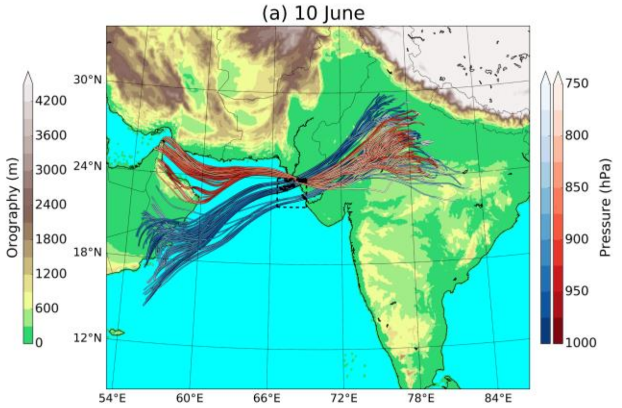
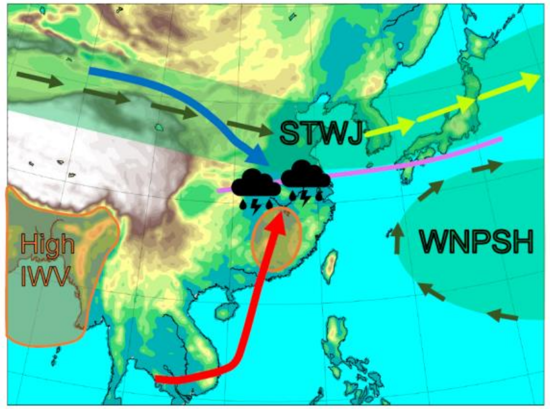
Motivation

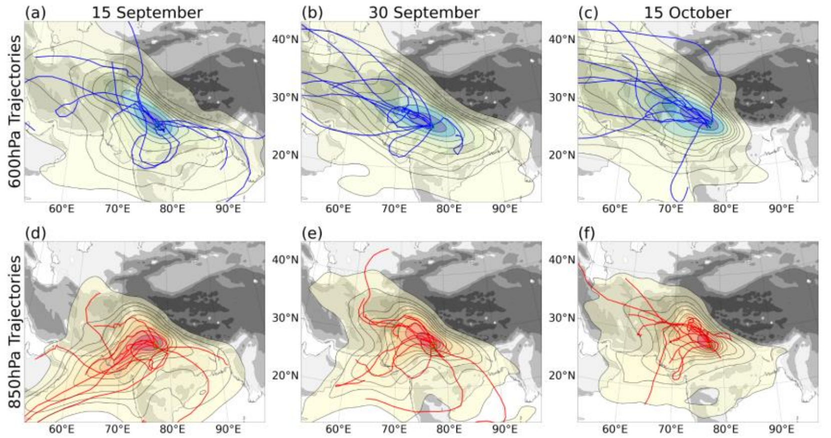
- The Indian summer monsoon (ISM) provides most of the annual rainfall to a region that is home to more than a billion people and its onset caused the decline of the extreme heat of spring.
- Intraseasonal variability drives changes to the onset timing and dramatic variations between active and break conditions in the rains. Accumulated over the whole season, a series of break events can have catastrophic impacts on agriculture and farming.
- In the July 2002 monsoon break, India received only 50% of its usual rainfall. Bhat (2006) revealed the importance of midlevel intrusions of dry air from the Arabian peninsula — rather than moist oceanic air — leading to inversions over the Arabian Sea and suppression of convection over the west coast.
- Krishnamurti et al. (2010) analysed the 2009 extended break and implicated the role of dry air intrusions from W Asia deserts in helping to suppress convection. Further study is needed to unravel the origin of dry air in different break conditions and their contribution to ISM drought (Krishnan et al., 2009).

Using Lagrangian methods

- Lagrangian trajectories can illustrate origin and path of air masses while highlighting the processes occurring along them. Recently applied to:
- UK Met Office MetUM simulations (including at convection-permitting scale) of 2016 ISM onset, highlighting its non-steady nature and the "tug-of-war" between moist low-level monsoon flow and descending dry air intrusion from NW, influenced by extratropical synoptic-scale dynamics (Volonté et al., 2020)
- E Asian summer monsoon (ERA5 data), stressing the importance of the interaction between tropical and extratropical air masses converging at the monsoon front in driving its progression (Volonté et al., 2022)
- Withdrawal of the ISM (ERA5 data), illustrating the increasing importance of dry mid-level descending air (Deoras et al., 2024)



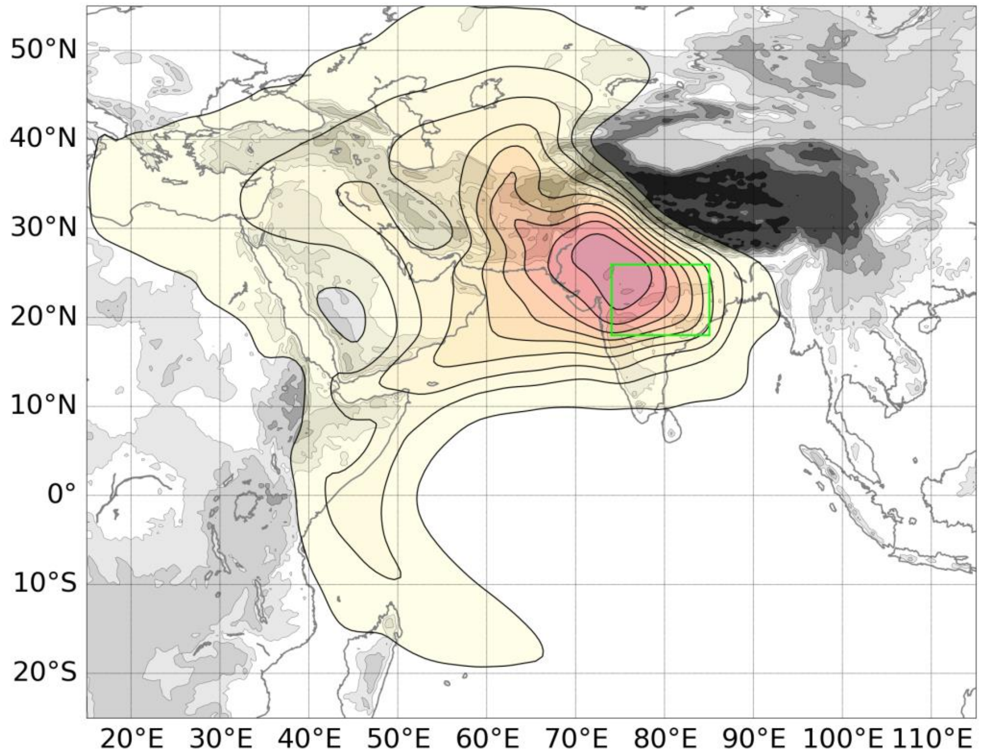




Using Lagrangian methods

- Here we apply the LAGRANTO tool (Sprenger and Wernli, 2015) to 6-hourly ERA5 input data
- We compute 10-day backward trajectories released at 850, 700, 600 and 500hPa from the ISM core zone (green box, 108 starting locations for each level). We release trajectories at 00Z every day from 1 Jun to 30 Sep and from 1940 to 2023
- We create subsets selecting all middle days of break (188) and active (261) events (std precip anomaly beyond ±1 for ≥ 3 consecutive days over the core zone)
- We trace relevant physical quantities, such as pressure and specific humidity and different flavours of potential temperature, along the trajectories to examine variations in properties of the airmasses

Example trajectory density point map (trajectories released at 700 hPa during break events)



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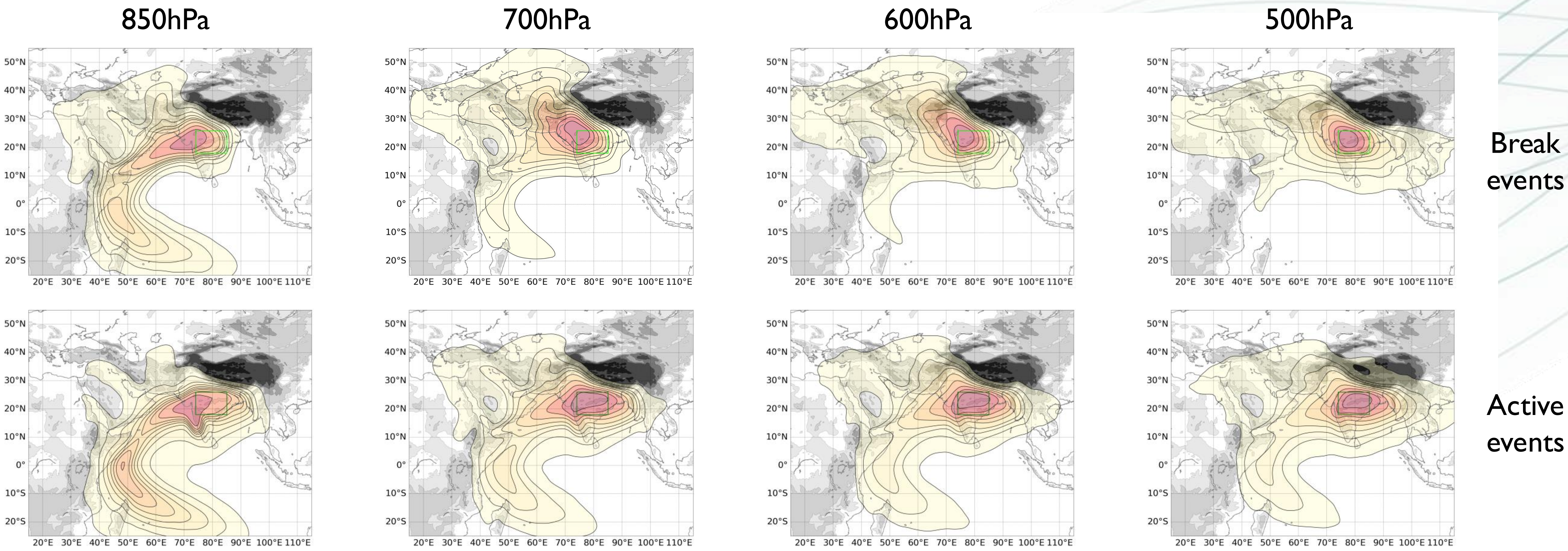
Trajectory maps

Dramatic differences in path and evolution of airmasses arriving at the monsoon core zone in active vs break events.

Air of mid-latitude origin, including zonal flow from remote regions is more dominant in break events, particularly above the low-levels. Terrain gaps have a key role in allowing the passage of air from Central Asia to the Indian Subcontinent.



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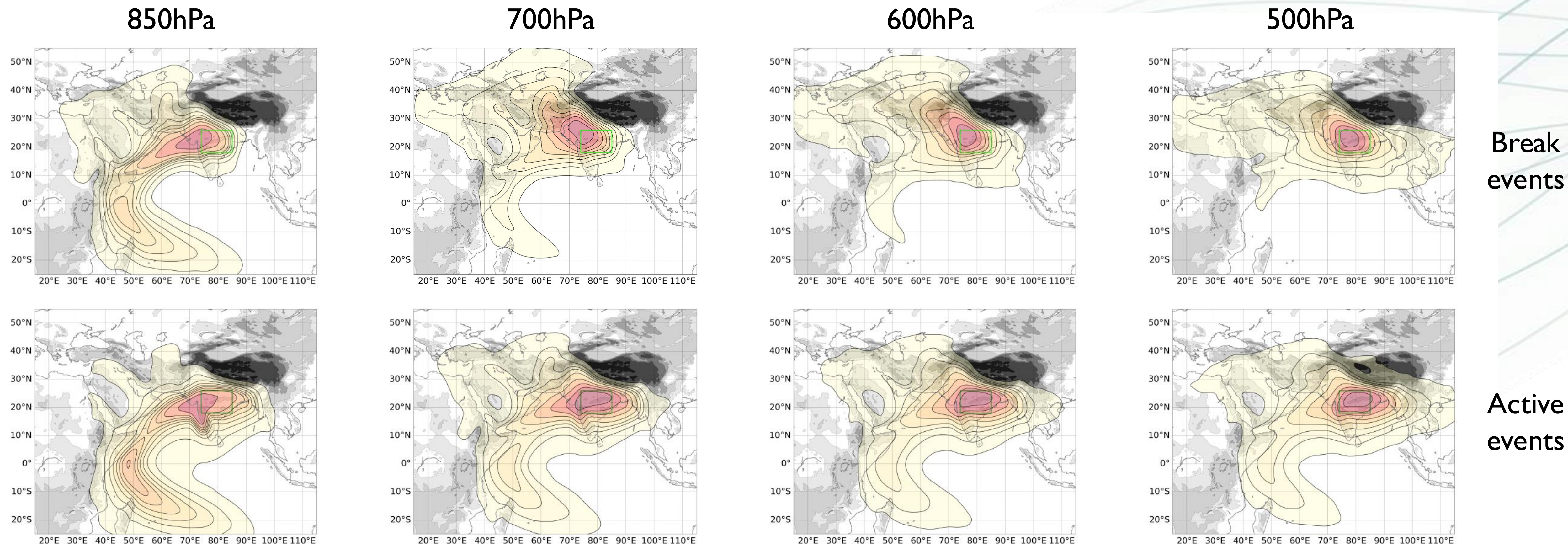

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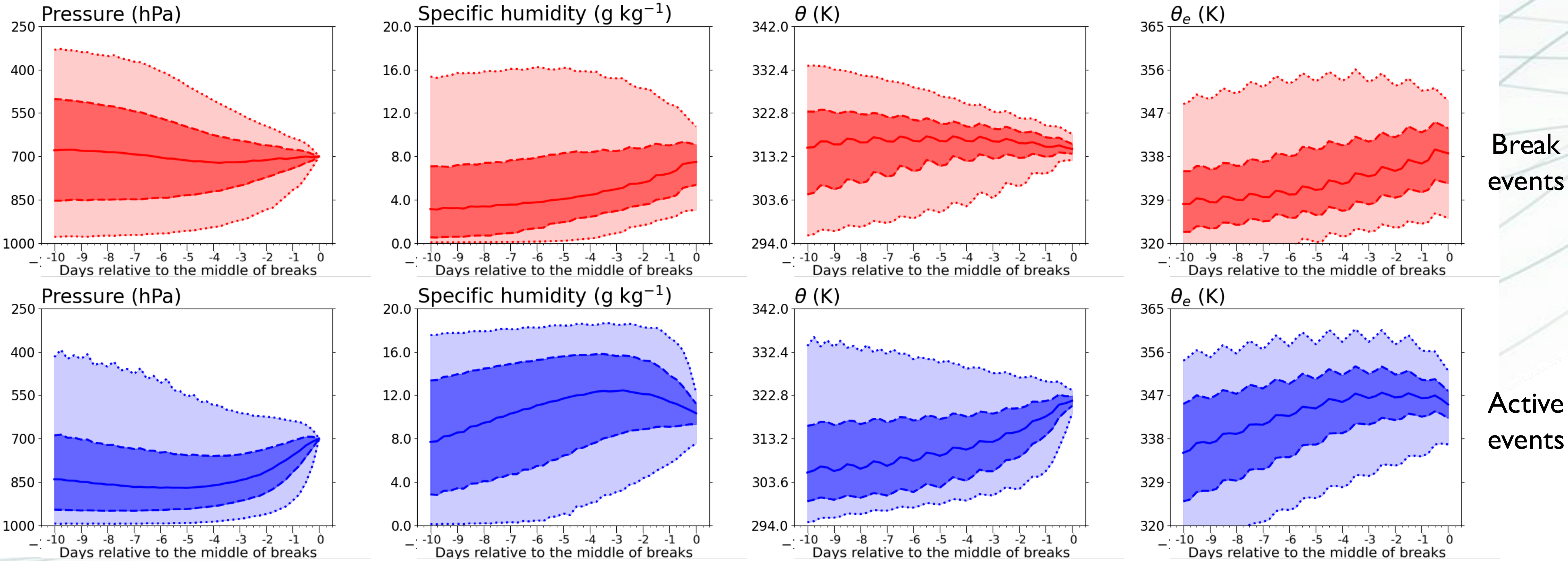
Trajectory profiles

The evolution of pressure, specific humidity and dry and equivalent potential temperatures (only shown for 700hPa trajectories in this slide) is consistent with the clear differences in the regions and heights of travel of the airmasses.

Break events trajectories have a much more limited moisture content and uptake and mixing with near-sea-surface warm air.



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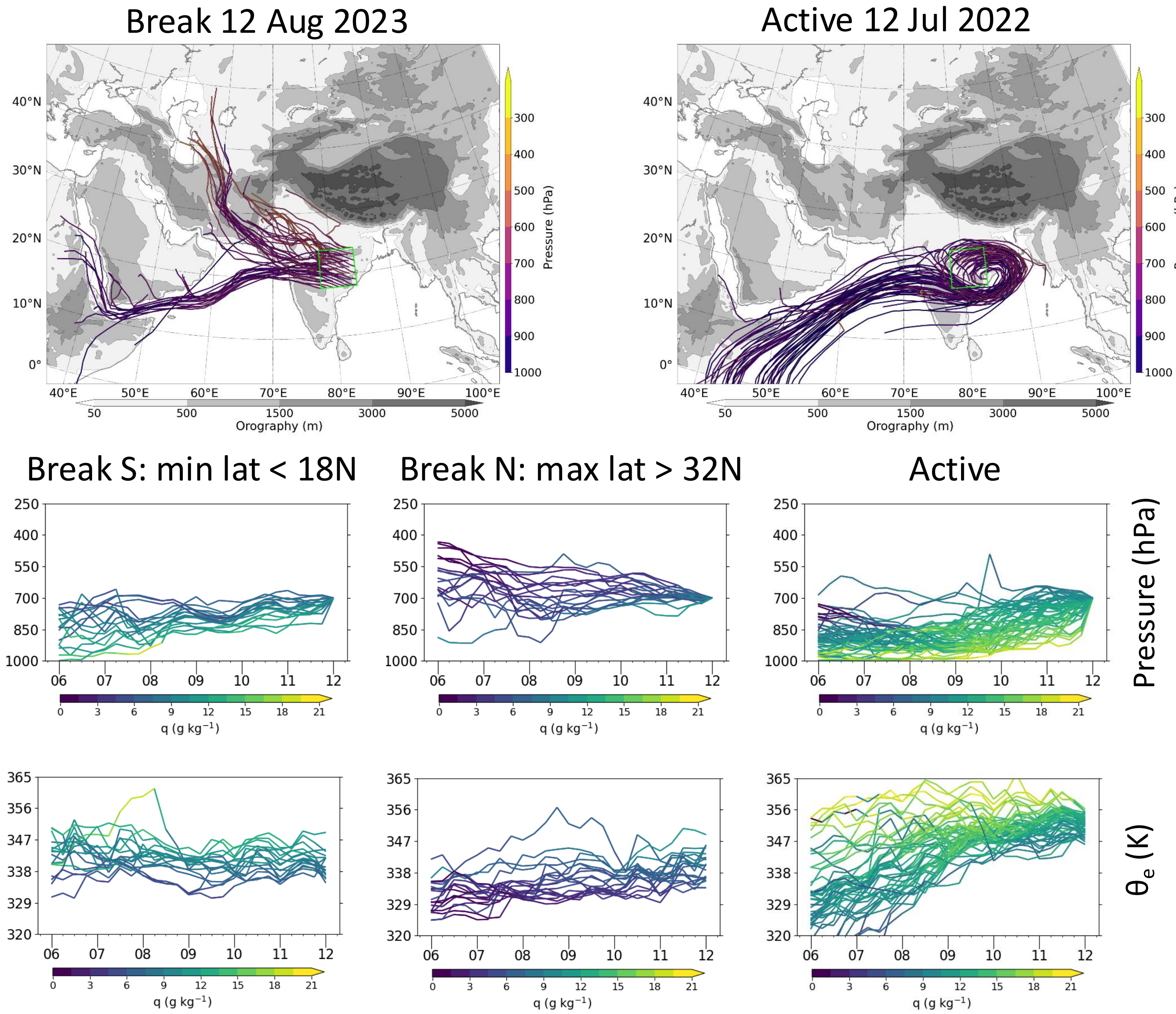
Case studies



Case studies can be used to highlight these differences and to reveal detailed airmass behaviour in active and break events.

In these examples break and active airmasses display entirely different evolutions, with the absence of transitional trajectories.

The dry air in the break event is shown to belong to two distinct branches, having either a mid-level central Asia origin or travelling at low levels over the Red Sea before zonally crossing the Arabian Sea.

In both break subsets, the non-mixing and limited-moisture nature of the airmass is clear.

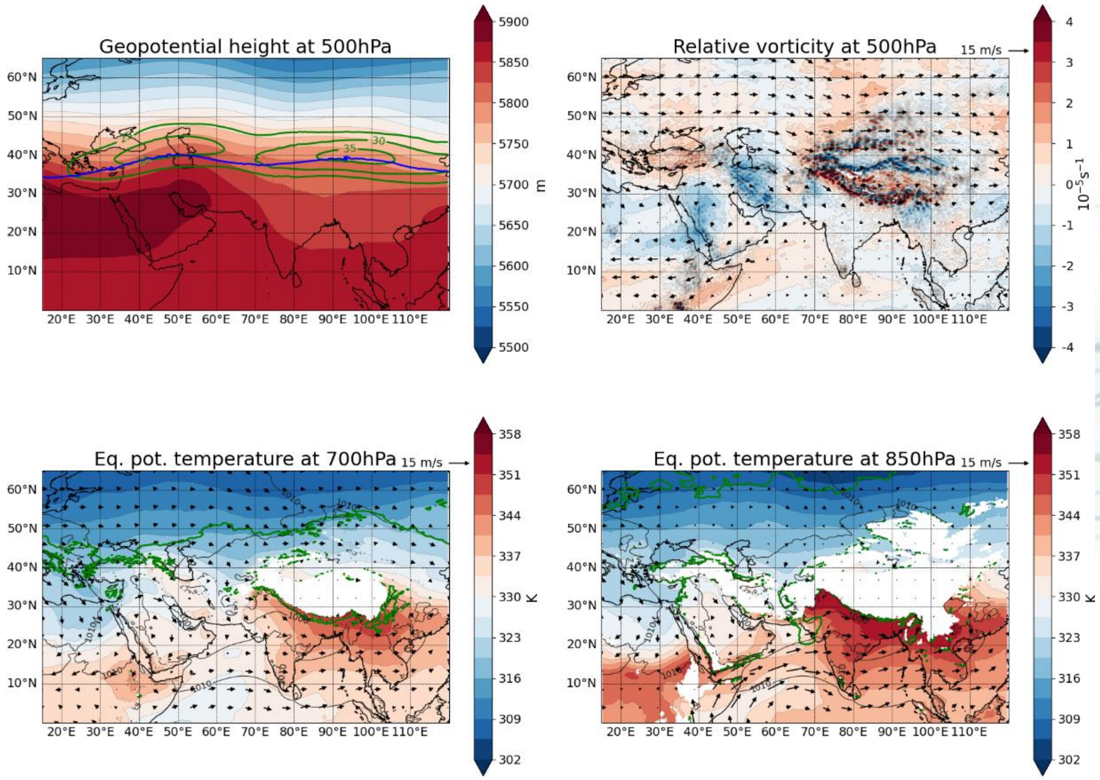
Despite the low-level origin and (orography-constrained) path of the Break S trajectories, their moisture content is still substantially lower than in active event trajectories.

Large-scale flow

A preliminary Eulerian examination of flow patterns across Asia complements the analysis.

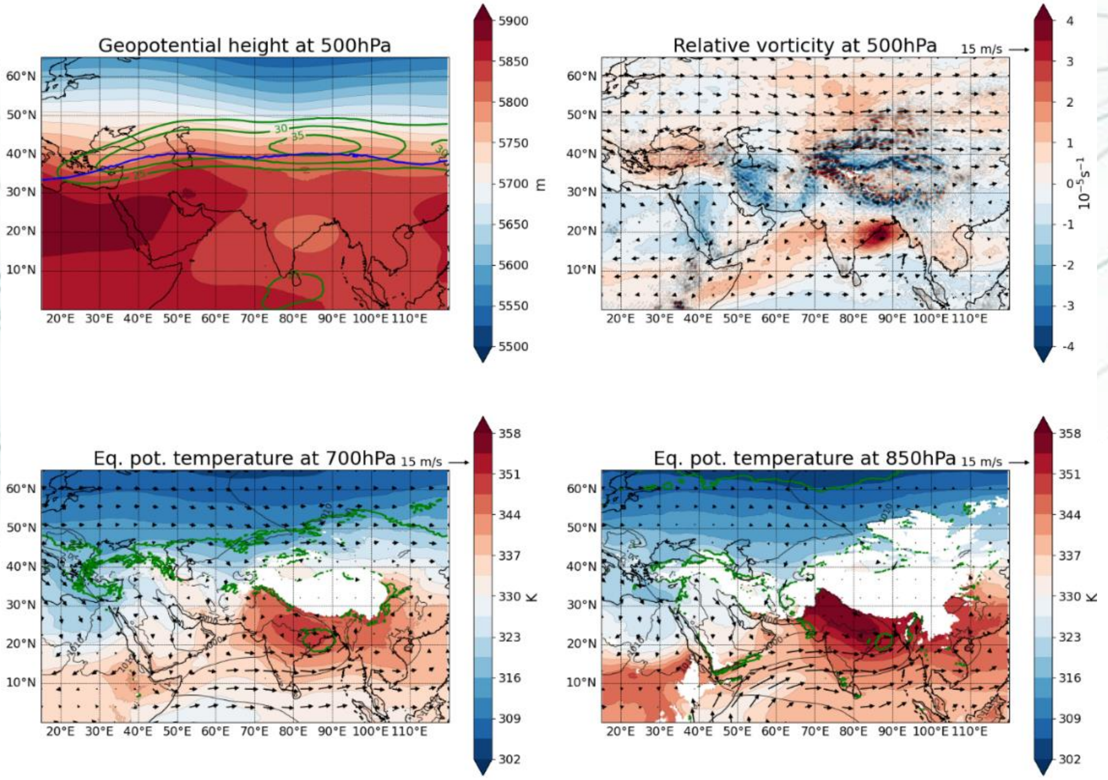
Consistent with the Lagrangian results, it shows that the arrival of dry air over the monsoon core zone is more favoured during break events and that this is associated with a greater anticyclonic tendency over west Asia.

Break events



Averages computed 2 days before the middle day of each break/active event

Active events



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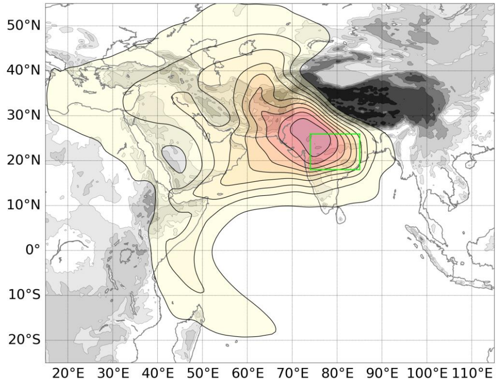
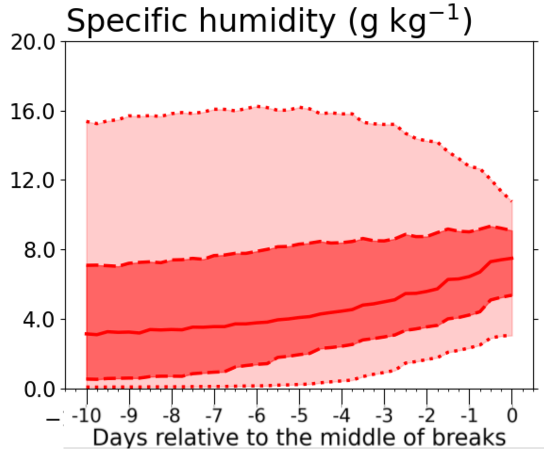
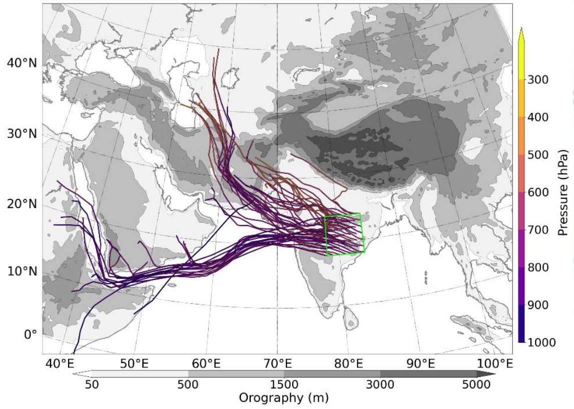
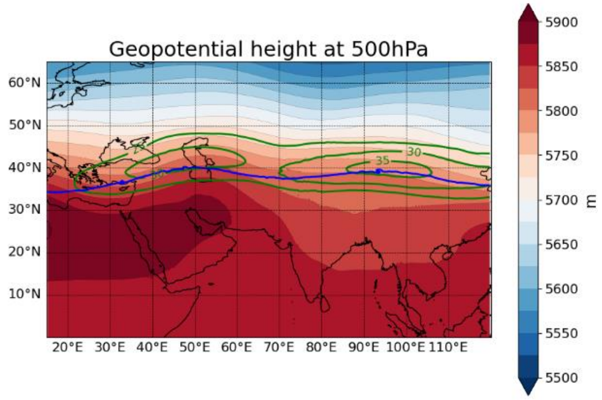
Conclusions

- Overall, these interim results clearly highlight the differences in the evolution of the airmasses arriving at the monsoon core zone during active vs break events.
- Further analysis will be conducted to fully detail the drivers and processes behind these differences, with particular focus on the intrusion of dry air during break events.









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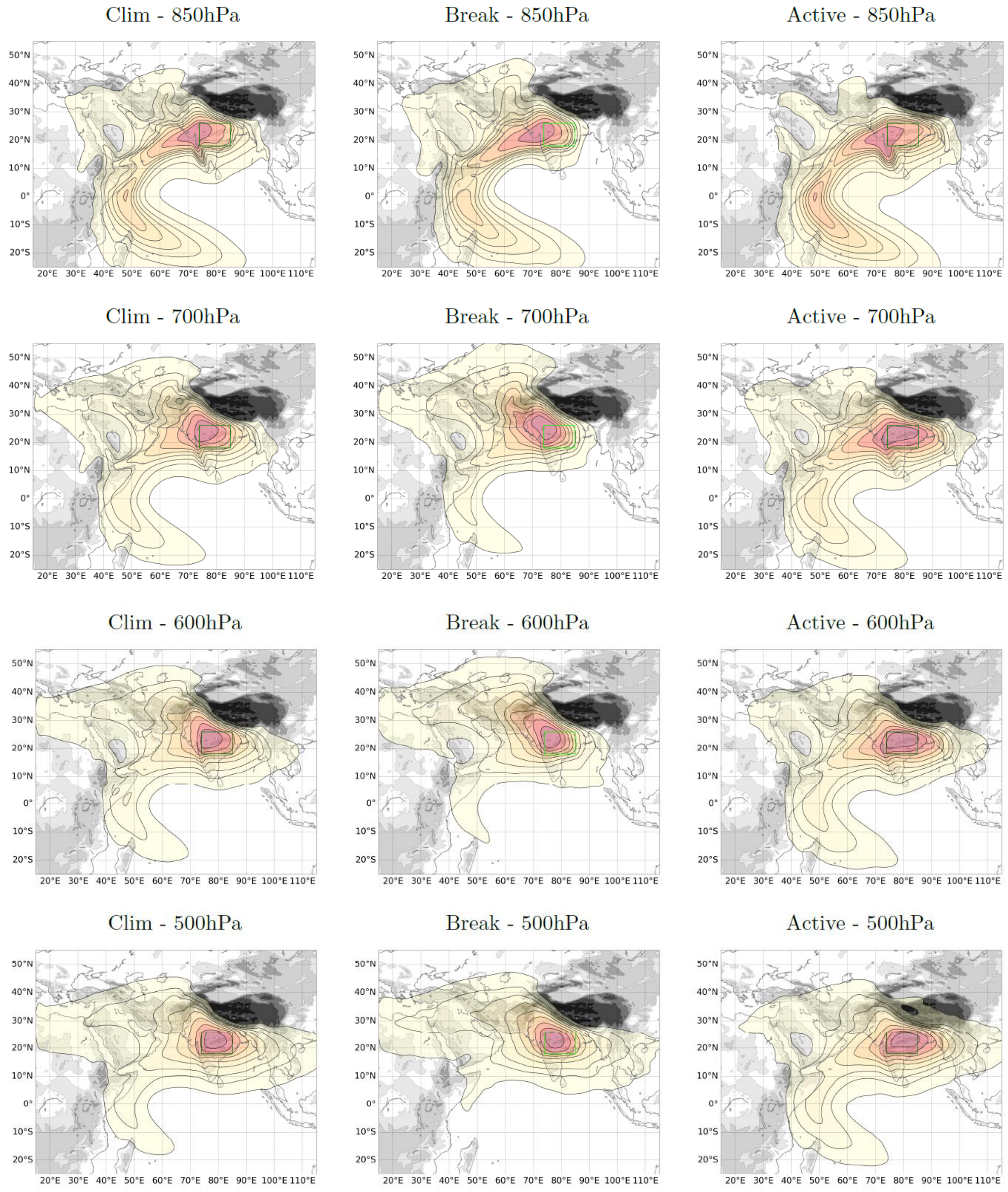
Extra slides



Context:

Lagrangian overview of climatological break and active events

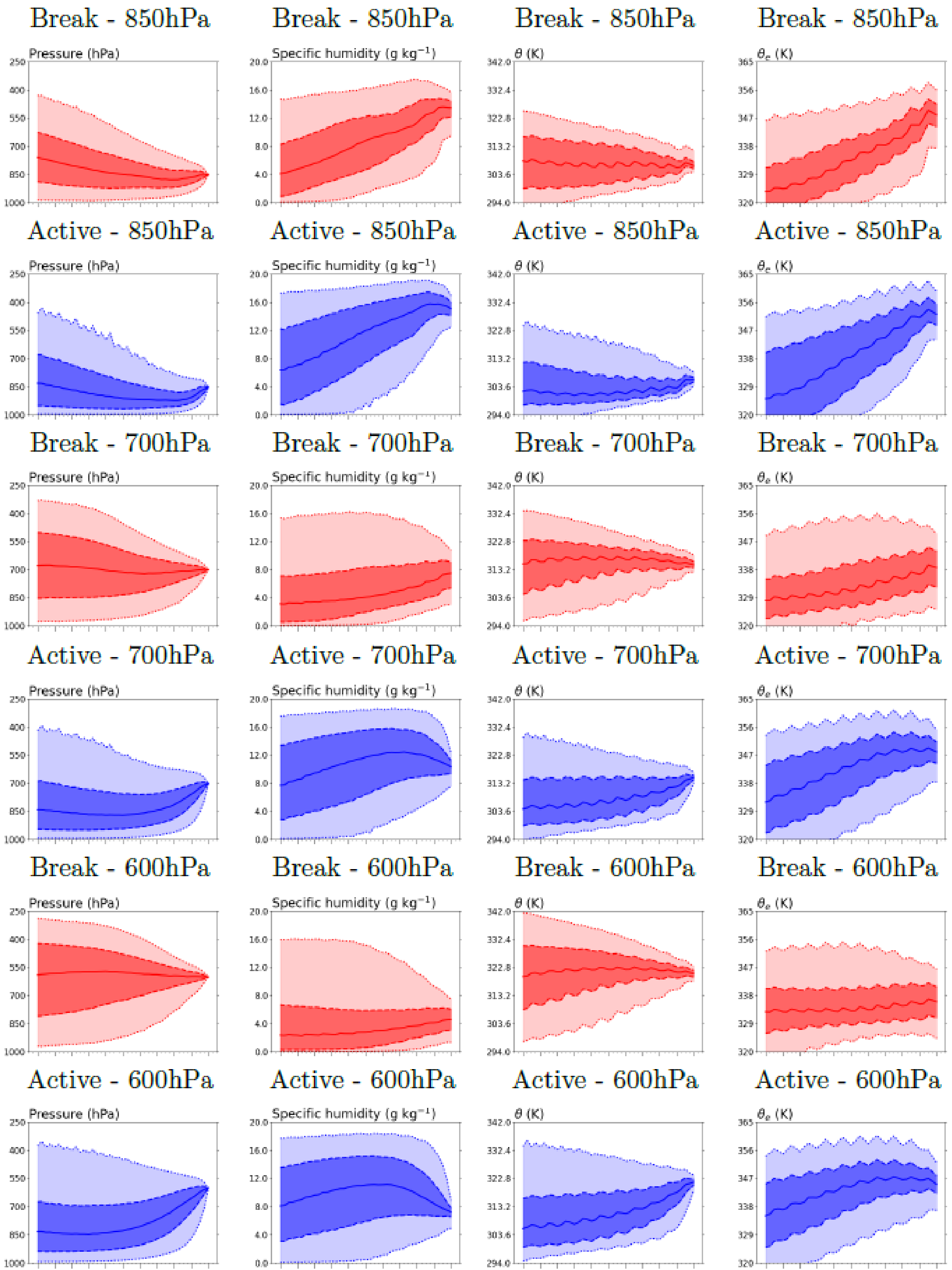
- Lagrangian 10-day-lon backward Lagrangian trajectories released from the monsoon core zone at 4 different pressure levels available for all days in JJAS 1940-2023.

- Subsets of trajectories released on central day of each of the 1940-2023 break/active events are also available.

- Trajectory density maps show that the C-shape Somali Jet circulation is dominant in the climatology and in both active and break event composites. However, low-level flow flows through gaps in the orography near Hindukush, Persian Gulf and Red Sea is visible, particularly in the break composite.

- For trajectories released at 700hPa the Somali Jet is still dominant in the active composite, while in the break composite flow coming from W and NW has greater importance.

- At mid-levels the westerly flow from remote regions becomes dominant, particularly in the break event composite.

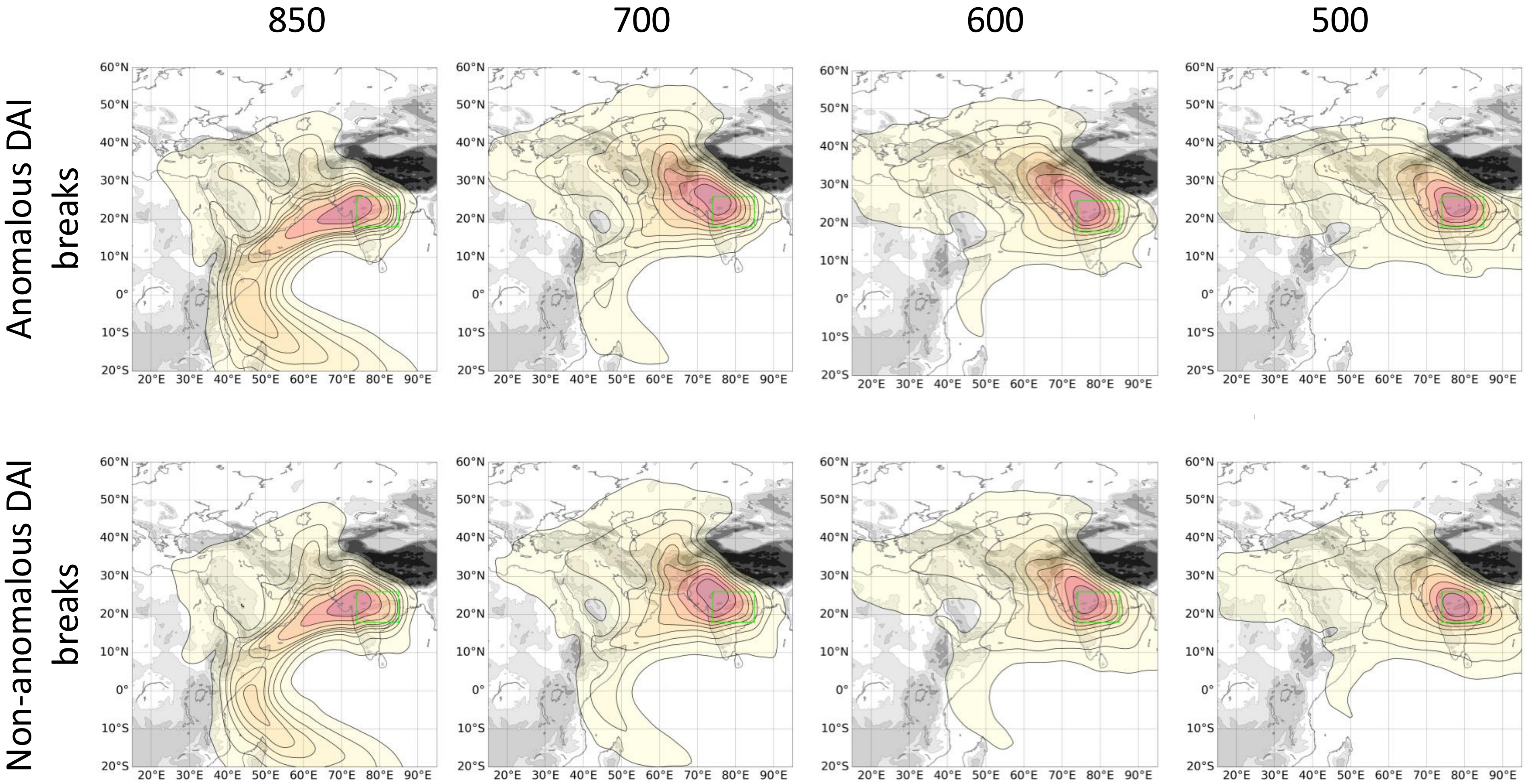


Context:

Lagrangian overview of climatological break and active events

- Timeseries of pressure, specific humidity, dry and equivalent potential temperature along the trajectories are shown here for the break and active composites.
- Both composites show low-level air steadily increasing its moisture content as it travels over the sea and mixes with warmer air.
- At 700hPa the difference between break and active composite are more pronounced as in break event the flow sees a limited moisture increase travelling horizontally, as opposed to the active composite flow, which ascends from low-level where it acquired a larger amount of moisture.
- Similar behaviour is shown by mid-level flow (500hPa profiles not included in the slide) with the flow in break events being considerably drier, consistent with the different region of origin and path towards the monsoon core zone.

Lagrangian analysis of dry-intrusion-mediated break events: composite picture



- Breaks associated with dry intrusions are characterised by a more important role of westerly flow
- While the main picture doesn't change, in those breaks we see a higher density of trajectory points over the Persian Gulf and Middle East at low-levels and over Iran and towards the E Mediterranean at mid-levels

- 79 dry-intrusion-mediated break events: with standardised VIMDF anomaly >1.5 on any day between day -5 and day -1
- 109 non- dry-intrusion-mediated break events, where the condition above is not met