Airmass analysis of the processes driving the progression of the Indian summer monsoon

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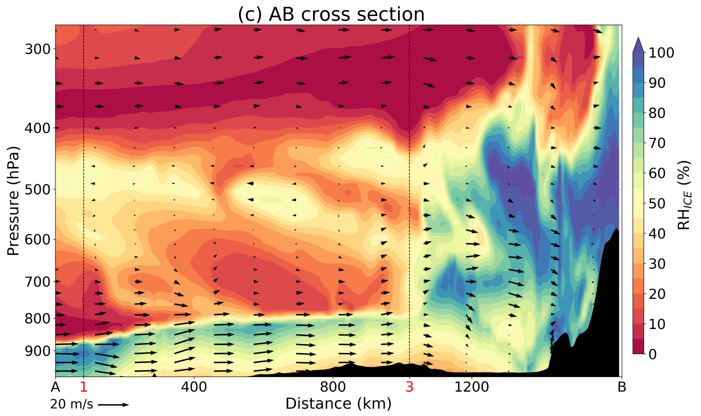
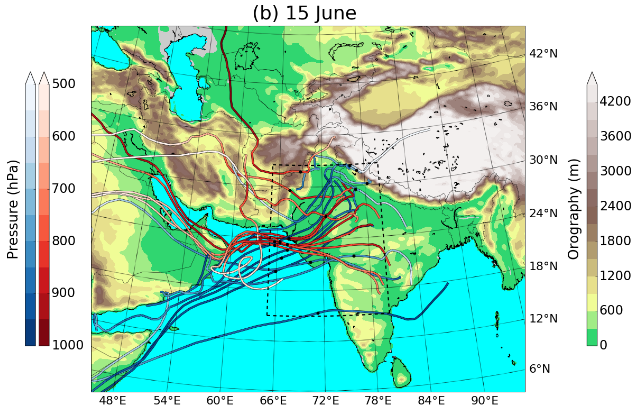
Volonté et al. (2020): https://doi.org/10.1002/qj.3700





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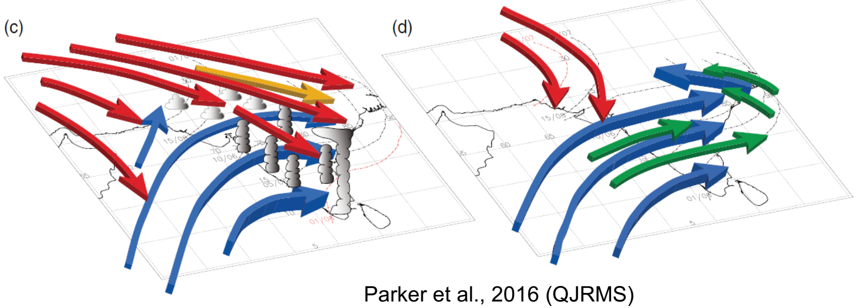
Intro: Indian summer monsoon (ISM) progression

- 2-layer model (Parker et al., 2016)
  - erosion of NW-ly dry air by moist low-level SW-ly flow underneath
  - explains SE→NW ISM progression although monsoon flow is from SW

- Link between heavy monsoon rainfall and mid-latitude troughs
  - e.g. Pakistan and Uttarakhand floods (Martius et al., 2013; Vellore et al., 2016)

- Link between NW-ly dry advection towards India and major ISM droughts
  - e.g. 2002 and 2009 seasons (Bhat, 2006; Krishnamurti et al., 2010)
  - associated with blocking over W Asia (Krishnamurti et al., 2010) and anomalies in the subtropical jet (Fletcher et al., 2018)



Parker et al., 2016 (QJRMS)

Research questions

- Is ISM progression a steady process?

gradual erosion of the dry layer or “bursts-like” progression?
(as for the Australian monsoon, see Berry and Reeder, 2016)

- How is ISM progression linked with extratropical circulation?

- What is the importance of diabatic processes in the 2-layer model?

Model data used in the study for 2016 ISM season:
(validated with observations)

- Regional analysis:

17km UKMO global operational forecast

- Local analysis:

4.4km convection-permitting UKMO LAM
(INCOMPASS seasonal run)

All info and results in:
Volonté et al., 2020 (QJRMS), https://doi.org/10.1002/qj.3700

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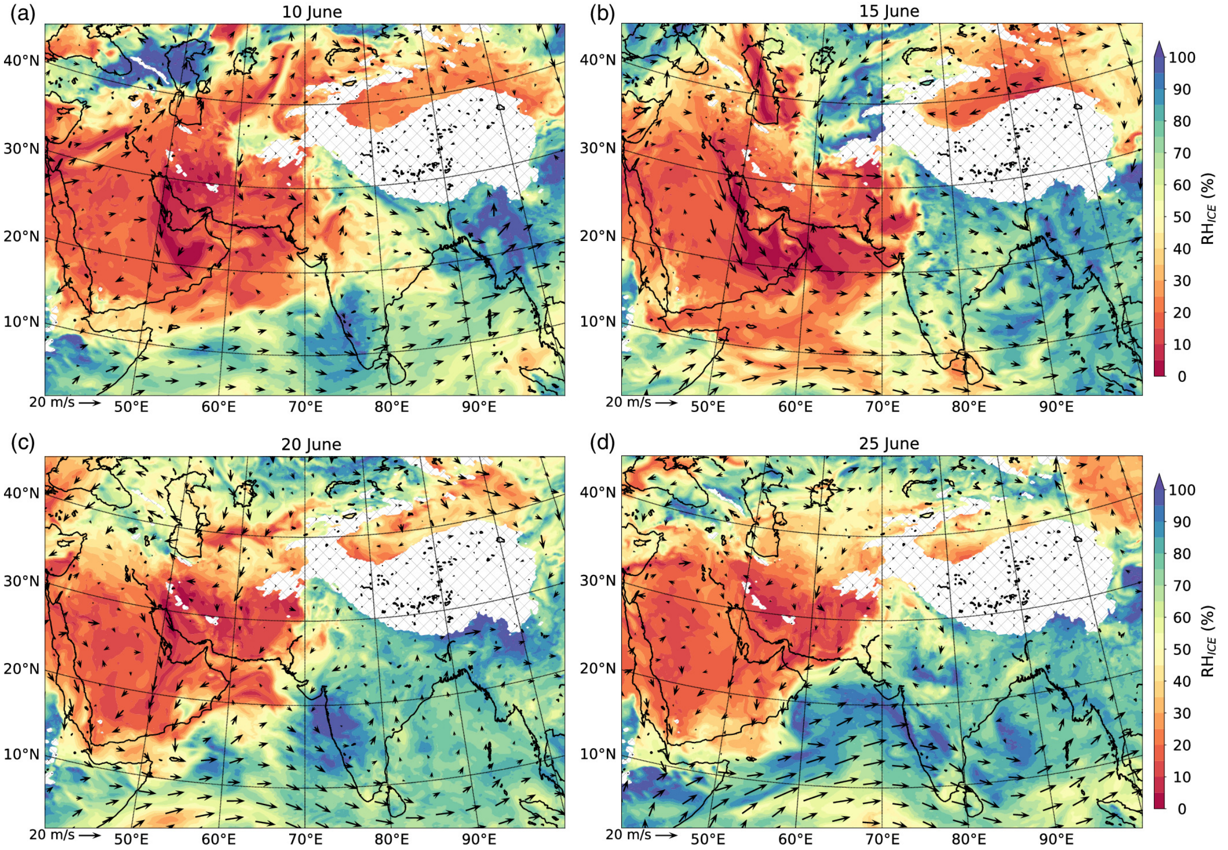
ISM progression: 2016 season
Regional analysis

1. Observation of nonlinear time evolution of relative humidity
(RH at 760 hPa):

Overall, 25 June (d) vs 10 June (a):
- net reduction in dry-air area
- expansion and deepening of moist monsoon flow, particularly over NW India

However, evolution is nonlinear:
- max southward expansion of dry air occurs on 15 June (b)
- cyclonic flow in Arabian Sea separates dry and moist air on 20 and 25 June (c,d)

➢ What are the drivers of these irregularities in the evolution of dry-air extension?



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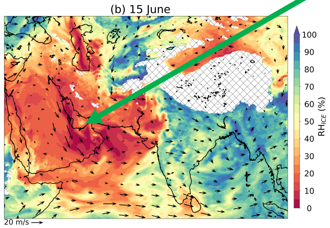
ISM progression: 2016 season
Regional analysis

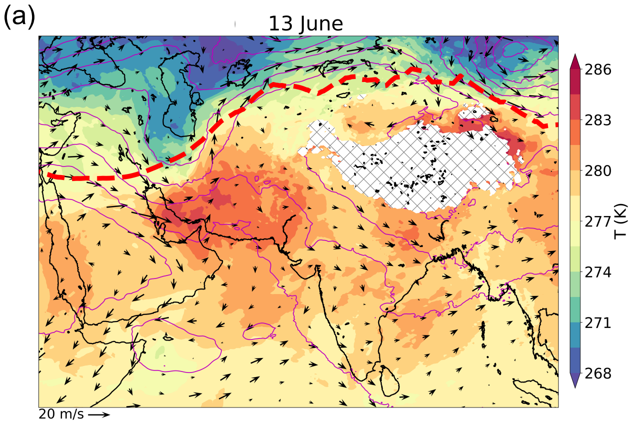
2. Passage of a mid-latitude trough
(T & GPH at 625 hPa + upper-level jet):

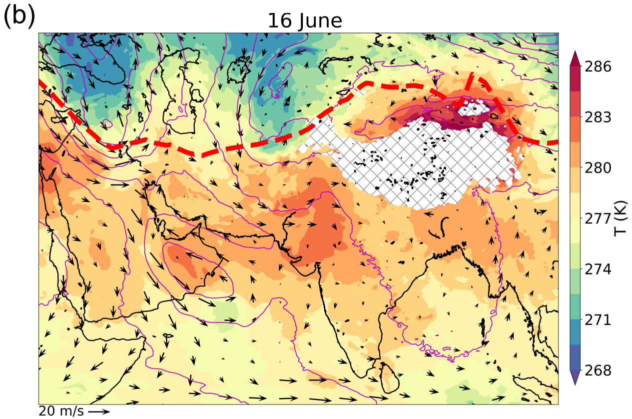
Synoptic ingredients associated with southward advection of dry air over the Arabian sea around 15 June



- Passage of mid-latitude trough on 13 June (a)
- Formation of cyclonic circulation over the Arabian Sea on 16 June (b)

➢ Are these two features linked?





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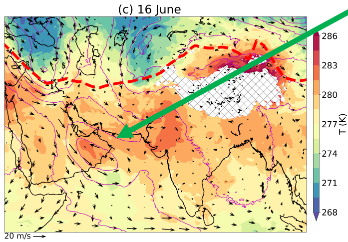
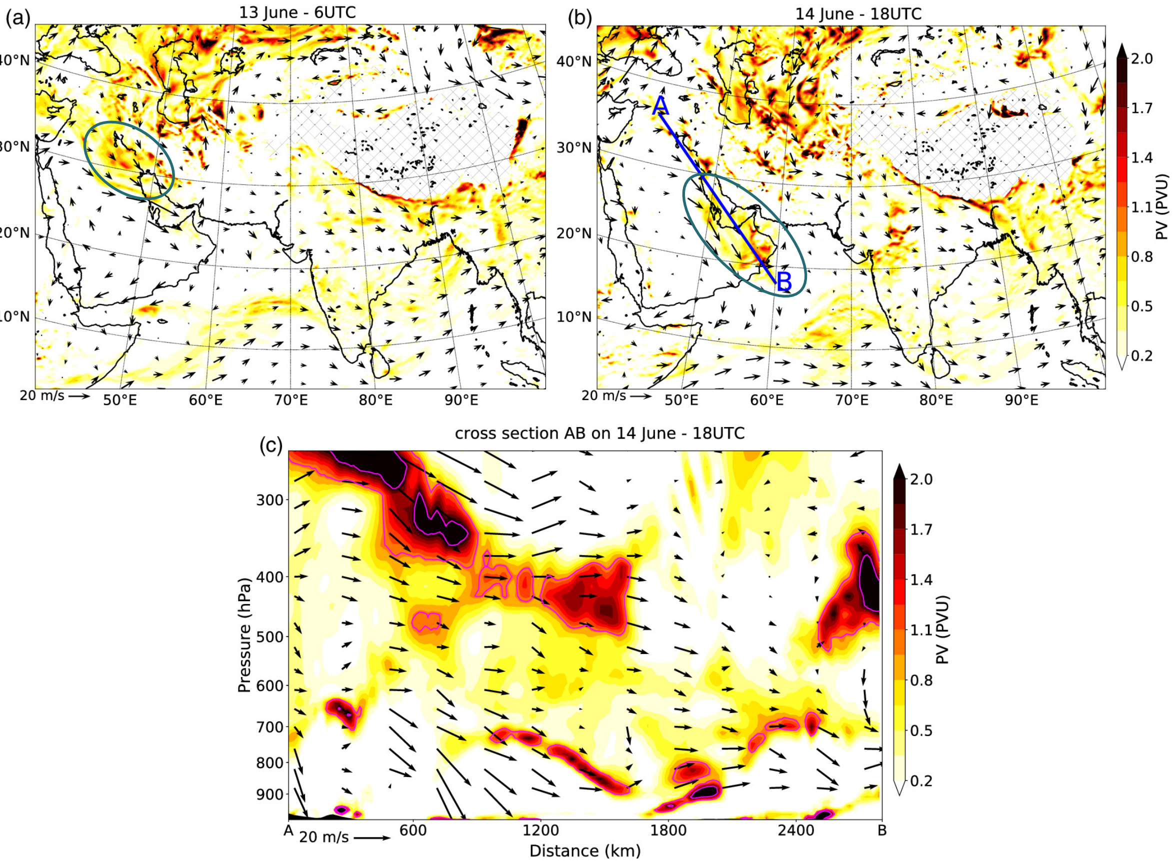
ISM progression: 2016 season
Regional analysis

3. Role of a potential vorticity streamer
(PV at 700 hPa + vertical cross-section):

High-PV air is advected towards SE behind the trough (a-b):

- vertical cross-section shows the presence of a descending PV streamer (c)
- this streamer moves on top of low-level high-PV air ("PV tower", Čampa and Wernli, 2012)
- this helps the formation of a cyclonic system in the northern Arabian Sea





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ISM progression: 2016 season
Regional analysis

4. Lagrangian trajectories of the cores of dry and moist air masses:

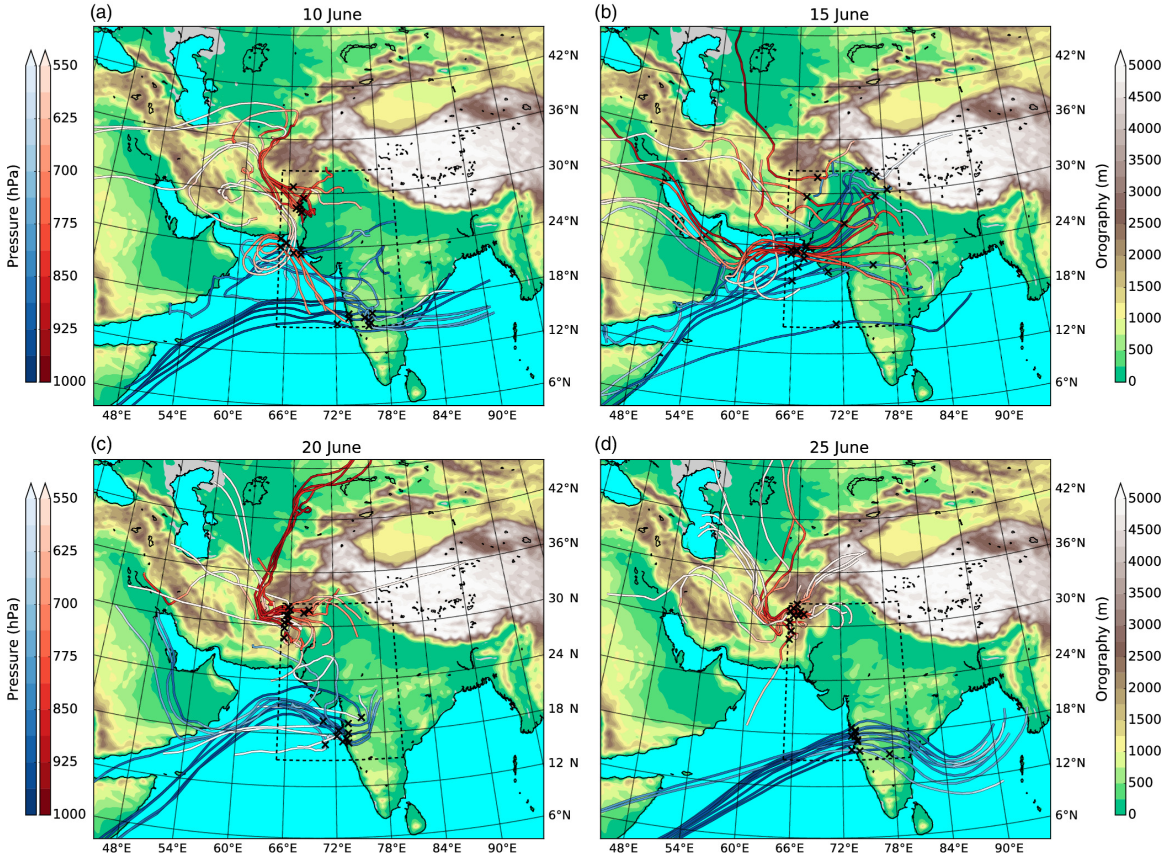
Focus on origin and path of different air masses

- core of moist air (blue): “classic” Somali Jet path towards India

- core of dry air (red): partly descending, advected from W-NW

10-15 June (a-b):
- dry air flows over N Arabian Sea
- close interaction with moist flow

20-25 June (c-d):
- dry air blocked NW of India
- separation between the two air masses



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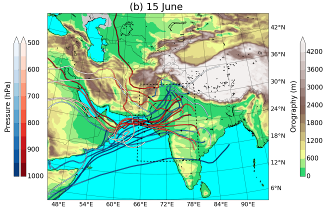
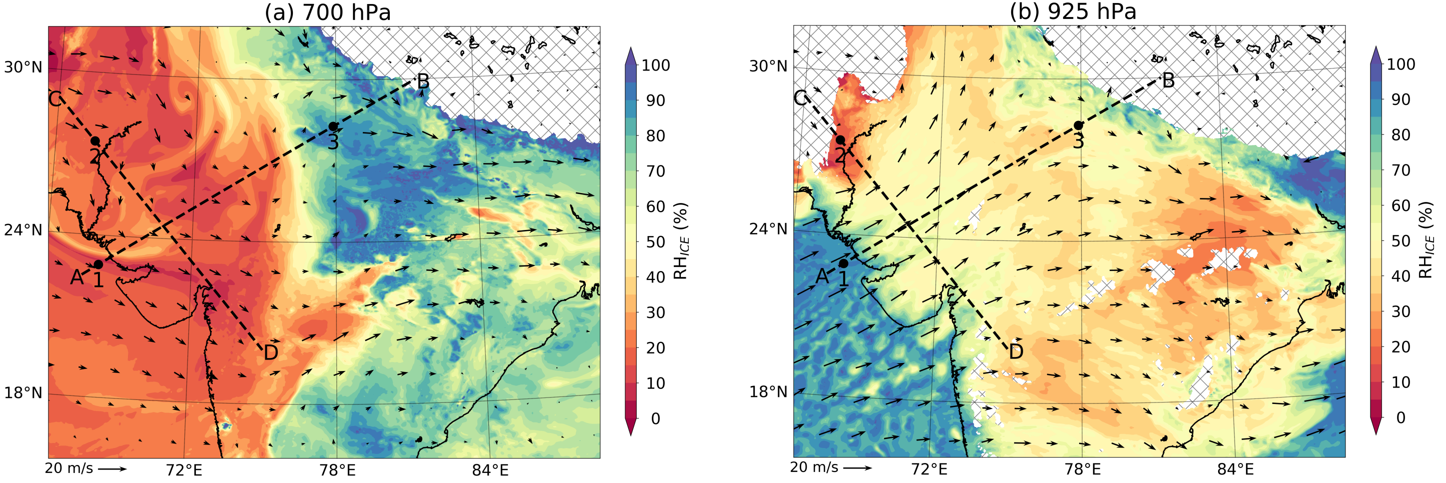
ISM progression: 2016 season
Local analysis

1. 2-layer structure – horizontal maps
(RH at 700 - 925 hPa):



Fully explicit 4.4.km LAM simulation:

- focus on the region of the interaction between the two different air masses (e.g. on 15 June)
- 2-layer structure confirmed with dry NW-ly advection (a) above moist SW-ly flow (b)



4.4km convection-permitting UKMO LAM (INCOMPASS seasonal run)

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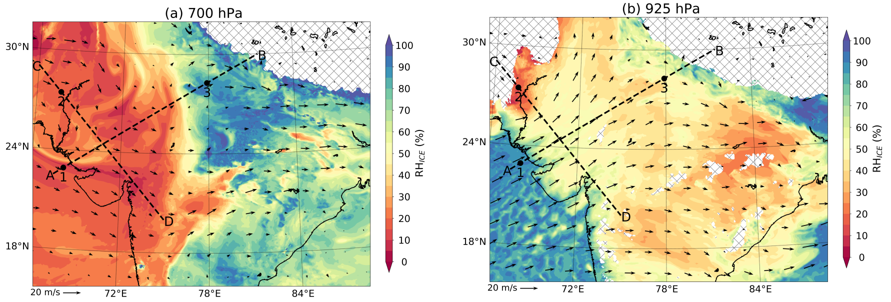
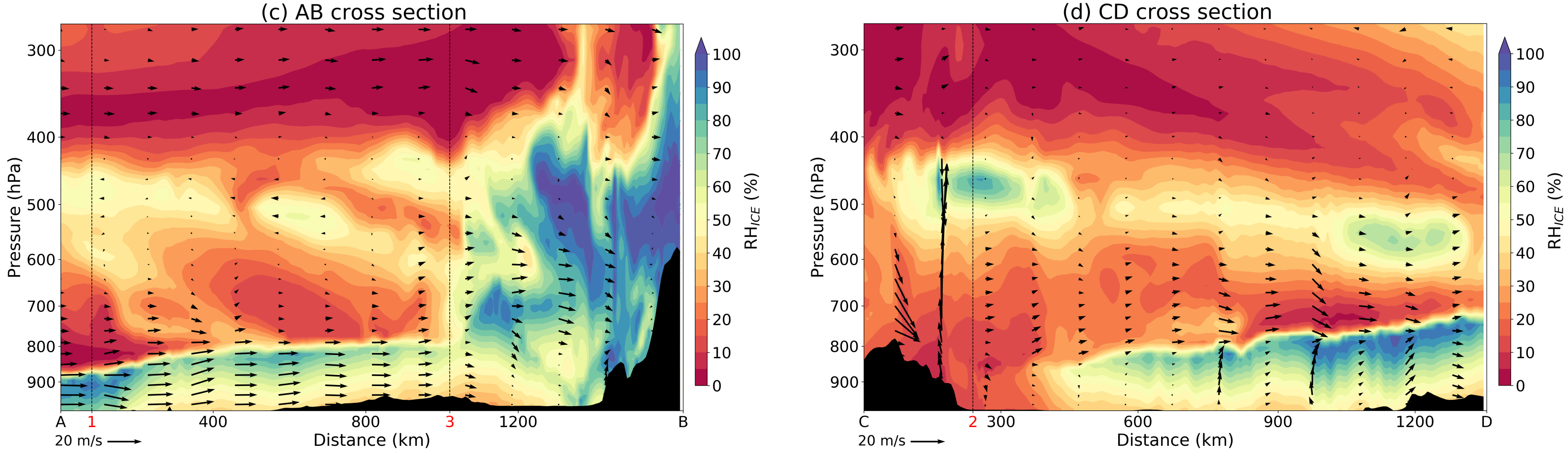
ISM progression: 2016 season
Local analysis

2. 2-layer structure – vertical cross-sections:



Vertical cross-sections show:

- 2 layers: SW-ly moist below (c), NW-ly dry above (d)
- sharp boundary between the 2 air masses at 850 hPa (c-d)
- occurrence of deep convection prevented by the dry layer (d)



4.4km convection-permitting UKMO LAM (INCOMPASS seasonal run)

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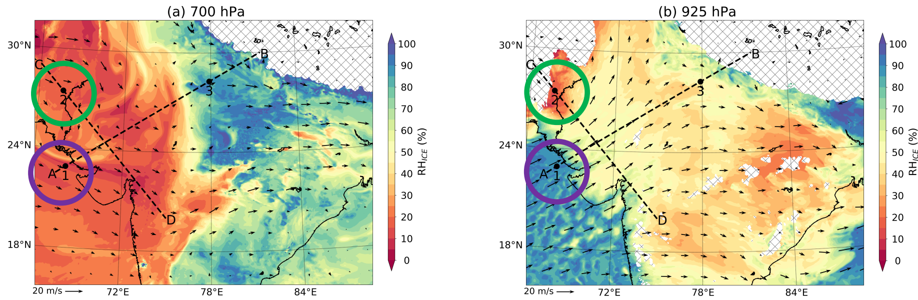
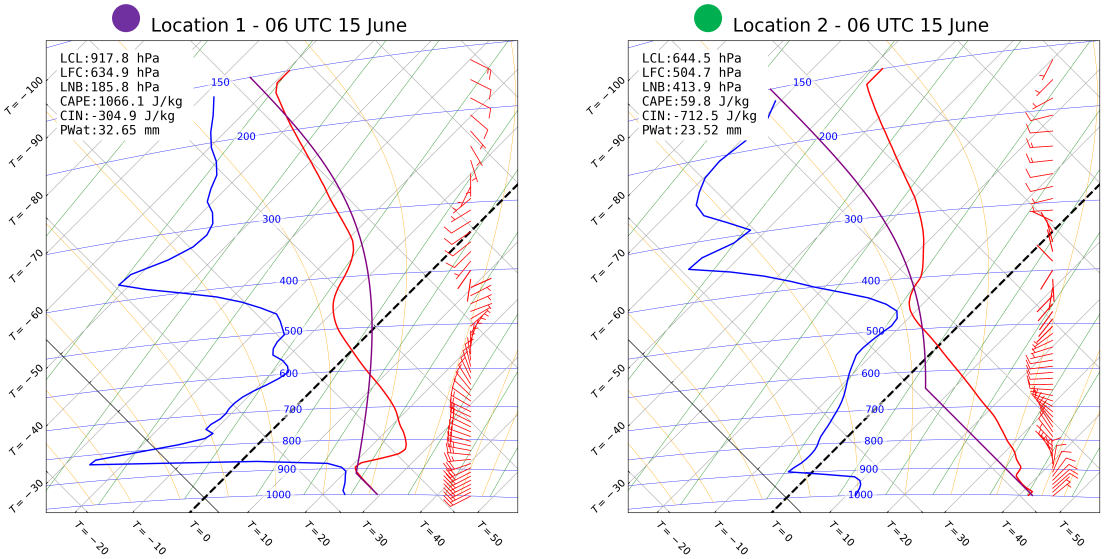
ISM progression: 2016 season
Local analysis

3. 2-layer structure – thermodynamic profiles:



Profile 1: sharp transition between air masses at 850 hPa
- winds change from SW-ly to W-NW-ly
- sudden drop in moisture content
- dry layer provides inhibition preventing convection

Profile 2: dry air at all heights
- profile located too far NW, no moist flow
- very dry air at low levels
- stable profile



4.4km convection-permitting UKMO LAM (INCOMPASS seasonal run)

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ISM progression: 2016 season
Local analysis

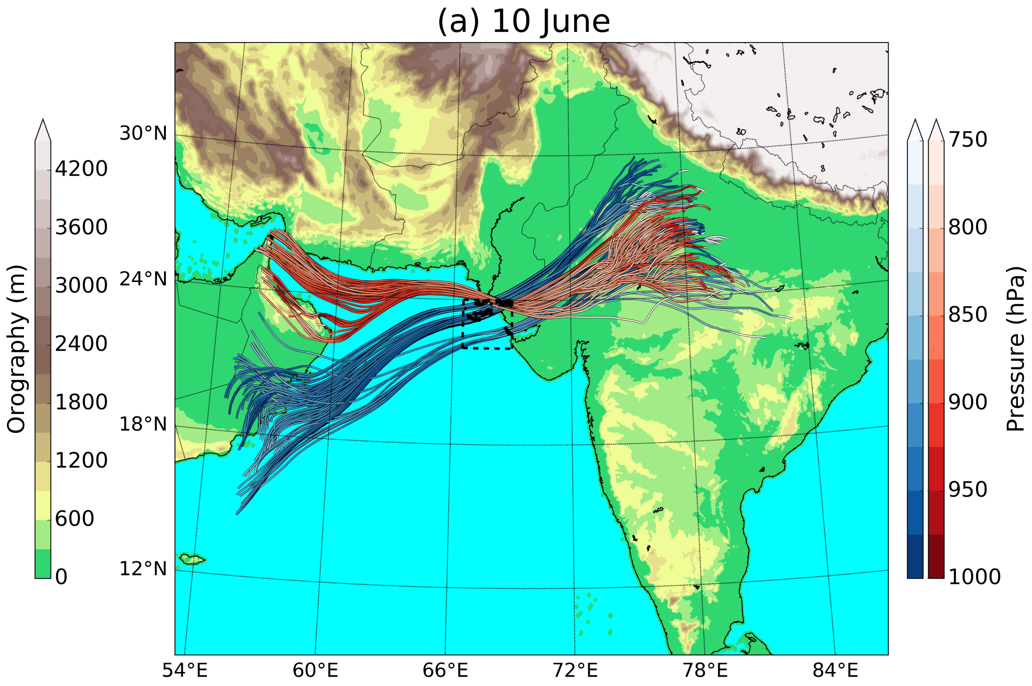
4. Lagrangian trajectories of the cores of dry and moist air masses:

Starting points for forward + backward trajectories selected between surface and 700 hPa on 10 June at 06z:

- 100 highest values of RH in dashed square (blue)
- 100 lowest values of RH in dashed square (red)

- these sets represent the cores of the two air masses
- trajectories flow along similar paths over Arabian Sea
- they then converge when moving inland

➤ What can we say about the dynamics of these airstreams?



4.4km convection-permitting UKMO LAM (INCOMPASS seasonal run)

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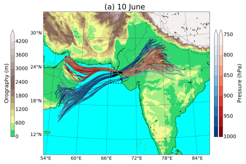
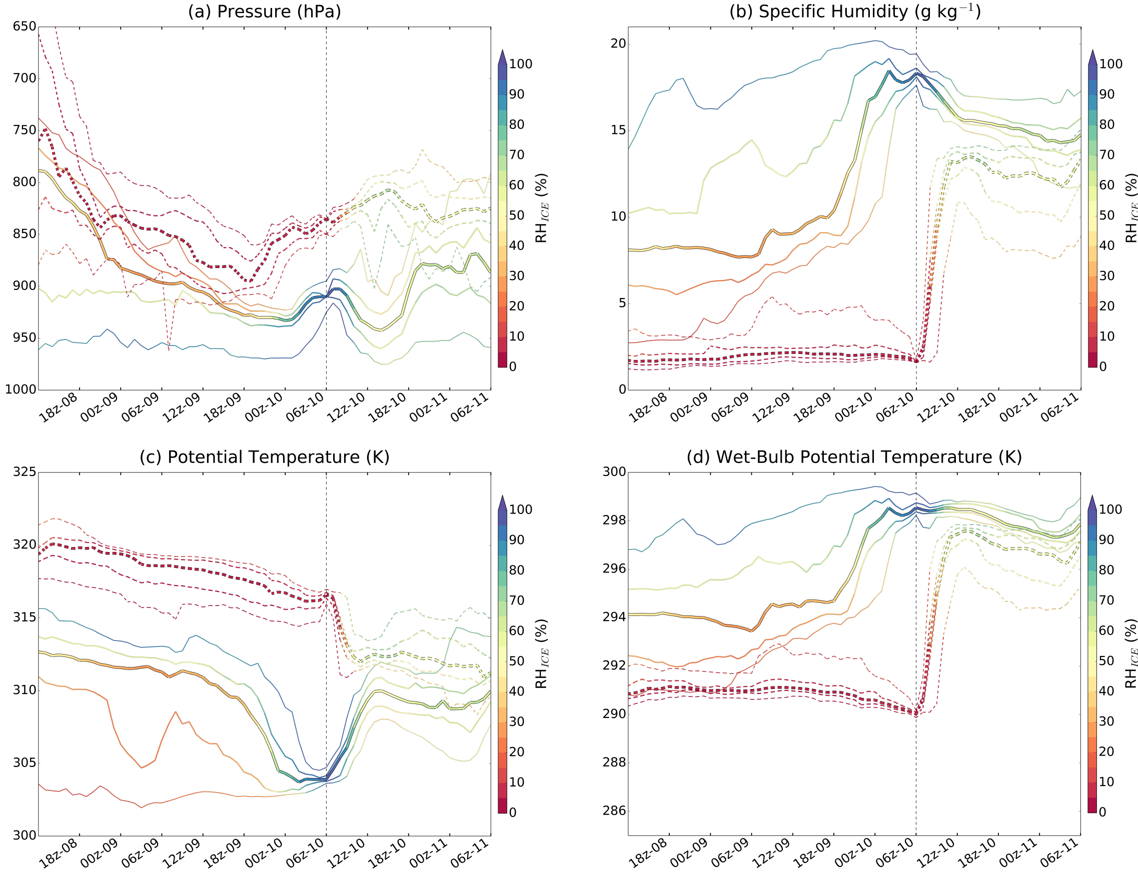
ISM progression: 2016 season
Local analysis

5. Time series of relevant physical quantities on trajectories:

Dashed lines for quantiles of dry trajectories (median in bold) and solid lines for moist trajectories selected on 10 June





- gradual descent of dry airstream and part of moist airstream while over the Arabian Sea (a)
- moist airstream receives a substantial part of its moisture content when over Arabian Sea (b)
- strong mixing occurs over land when the two airstreams interact (b-c-d)
- moist processes + mixing change markedly the thermodynamic properties of airstreams (c-d)

4.4km convection-permitting UKMO LAM (INCOMPASS seasonal run)

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Summary

1. Regional Analysis:

- Progression of the ISM towards NW India is a **non-steady** process
- 2-layer model: "tug-of-war" between SW-ly monsoon flow and NW-ly dry-air incursion
- Balance between these airstreams can be influenced by synoptic-scale dynamics at higher latitudes

2. Local Analysis:

- Close interaction between cores of dry and moist airstreams at times during ISM onset and progression
- Importance of diabatic processes, particularly over the Arabian Sea, on airstreams' properties

Possible future steps:

- Evaluation of equatorial vs mid-latitude influences on dry-air incursion strength and monsoon "bursts"
  (e.g. using vorticity fluxes in reanalysis datasets, see Narsey et al. (2017) for Australian monsoon)
- Analysis of moisture and surface fluxes associated with the evolution of the airstreams
  (focus: identifying which diabatic processes are at play)
- Lagrangian analysis of sources and transport of moisture towards ISM core region
  (focus: assess the role of local and remote evaporation/precipitation along the airstreams)

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