Cross-equatorial dry intrusions and their impact on Indian summer monsoon-associated water cycle

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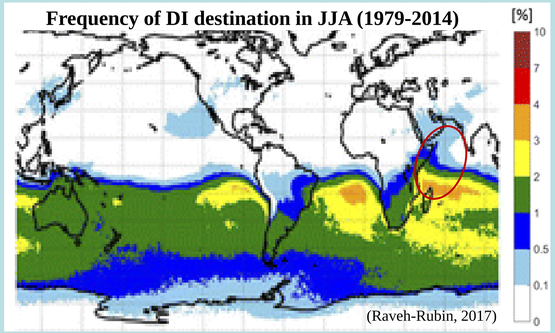
ABSTRACT

Dry intrusion (DI) is the slantwise descent of dry air from the extratropical upper troposphere to the mid/lower troposphere of the lower latitudes. When reaching the tropical regions, DIs substantially change the overall amount of available moisture, ocean surface fluxes into the atmosphere, as well as the atmospheric stability to vertical motion and the 3-dimensional flow and associated dynamics. However, the occurrence of such events has not been quantified systematically. Here, we quantify the climatological occurrence of DIs that extend from the extratropics to tropical regions. Specifically, we focus on events that host subsequent cross-equatorial (CE) flow. Using 6-hourly ERA-Interim reanalysis data with a Lagrangian approach, we show that during the summer monsoon season (June to September) about 25% DIs could enter the tropical region. Although CE DIs are rare (~2%), a hotspot of such DIs is evident in the Indian Ocean, having a potential role for Indian summer monsoon (ISM) water cycle. The dominance of the ISM for the annual rainfall over India implies that small changes in the evaporation and moisture pathways may influence the ISM precipitation downstream significantly. Indeed, we demonstrate the connection between ISM rainfall and the preceding water-cycle interaction under DI conditions. Further, DIs entering the Indian subcontinent modify the low-level jets, ocean evaporation distribution and moisture transport towards the Indian coast .

BACKGROUND



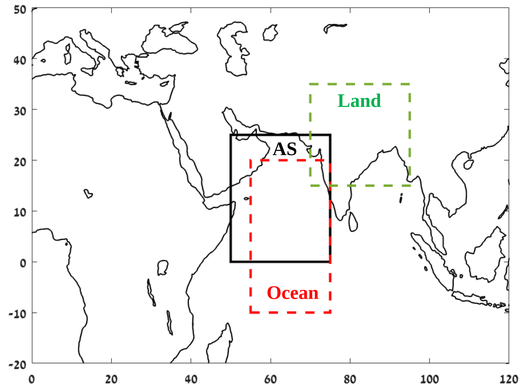
OBJECTIVES

Arrival of extratropical DIs to lower latitudes are associated with dry and cold lower-tropospheric anomalies, and consequently induced ocean evaporation and sensible heat flux into the atmosphere. Therefore the objective of this study is to investigate

a) the influence of CE DIs on the CE flows (e.g. Somali jets)
b) the role of CE DIs in the moisture transport (CE flows are an important conveyers of moisture between winter and summer hemisphere)
c) the coupling of CE DIs to the ISM precipitation variability

METHOLODOGY

- Global atmospheric data from the ECMWF interim reanalyses (ERA-Interim; Dee et al. 2011) are used for the years 1979–2018.
- The Lagrangian analysis tool (LAGRANTO), version 2.0 (Sprenger and Wernli 2015), is used to diagnose DIs where trajectories descending at least 400 hPa during 48 h (Raveh-Rubin, 2017)
- Only DIs entered within Arabian Sea (AS; 0-25 N and 50-75 E) at 120 hour from the start of their descent are selected for further investigation.



DIs entering the tropics (15 S–15 N), AS and CE during JJAS

- <25 % of the global DIs could reach to the tropics
- <2.5 % of the global DIs are CE DIs
- About 1.5 % of the global DIs are CE DIs into the AS

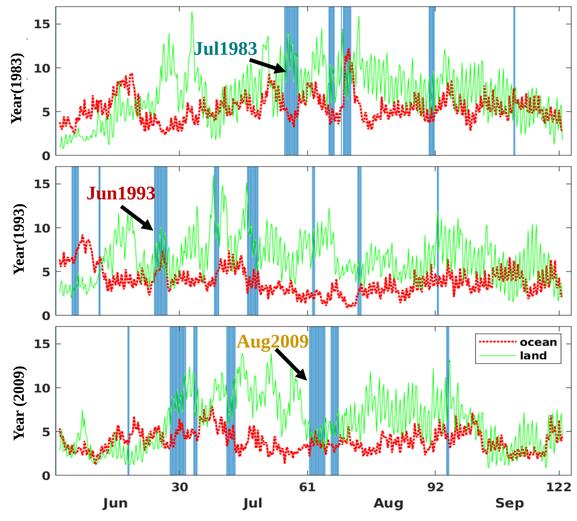
Selected cases

Selected cases represent different possible responses in terms of flow, moisture transport and precipitation variability. Precipitation variability is examined both locally (ocean; 10 S-20N, 55-75 E) and downstream (land; 15-35 N, 70-95 E). While domain average, land and ocean are masked for evaluation of rain rate over ocean and land respectively.

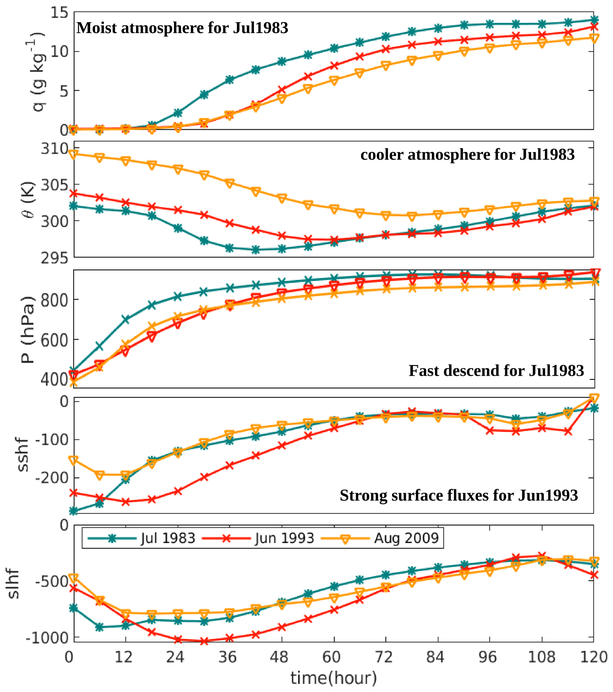
Case	Duration	Property	No. of DIs
Jul1983	12 UTC 25 July−18 UTC 28 July 1983	rain rate over the land (↑) and ocean (↓) are out of phase	1200
Jun1993	00 UTC 24 June−00 UTC 27 June 1993	rain rate over the land (↑) and ocean (↑) are in same phase	364
Aug2009	12 UTC 31 July−06 UTC 4 August 2009	rain rate over the land and ocean do not change	665

RESULTS

Variation in rain-rate (mm day^{-1}) over land and ocean and occurrence of DIs

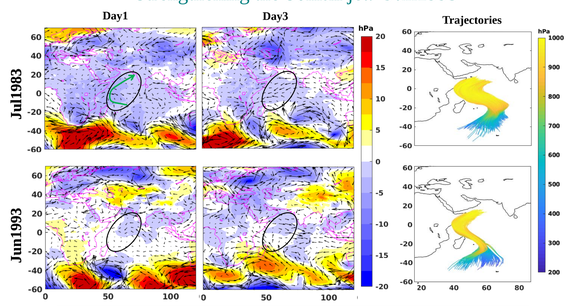


Mean variables along DI trajectory



Impact of DIs on monsoonal features

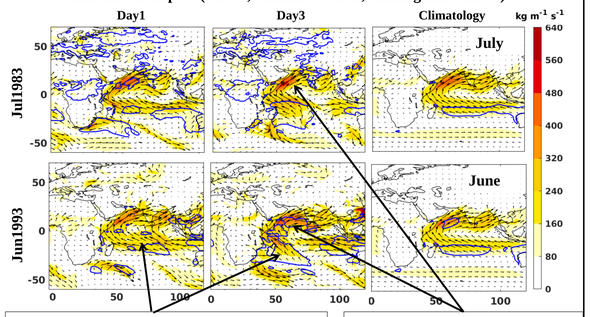
- **Somali jet:** provide most of the water vapor for the ISM
  Weakening the Somali jet: **Jul1983**; Aug2009
  Strengthening the Somali jet: **Jun1993**



Wind vector anomaly (850 hPa); SLP anomaly (shading); climatological location of the Somali jet (green arrow)

Moisture properties

Surface latent heat flux (SLHF; -200 W m^{-2} contour); vertically integrated moisture transport (VIMT; surface-850 hPa; shading and vectors)



Following DI trajectories, westerly VIMT at Day1 shifts to southerly at Day3 in southern hemisphere

VIMT follows DI trajectory with weak/strong SLHF for weak/strong Somali jet

CONCLUSIONS

- Although CE DIs are rare (<2%), when they occur, they modulate the strength of the Somali jets
- Weak/strong Somali jets are associated with weak/strong SLHF and locally less/more rain respectively.
- Low-level moisture transport follows the DI trajectory path
- After 2-days of DI initiation, southern Indian Ocean plays as a major additional source of moisture
- Since CE DIs have potential role for ISM water cycle, dynamical mechanisms governing CE DIs and modulating the CE flows needs to be investigated further.

REFERENCES

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- Sprenger, M., and H. Wernli, *Geosci. Model Dev.*, **8**, 2569–2586 (2015)