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Role of friction and orography in the Asian-African monsoonal system

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Objectives of this study

i. The westwards influence by the South Asian monsoon (SAM) on the West African monsoon (WAM) via planetary waves

ii. WAM's eastwards influence on the SAM via Kelvin waves

iii. The impact of the Ekman pumping on the monsoonal circulation

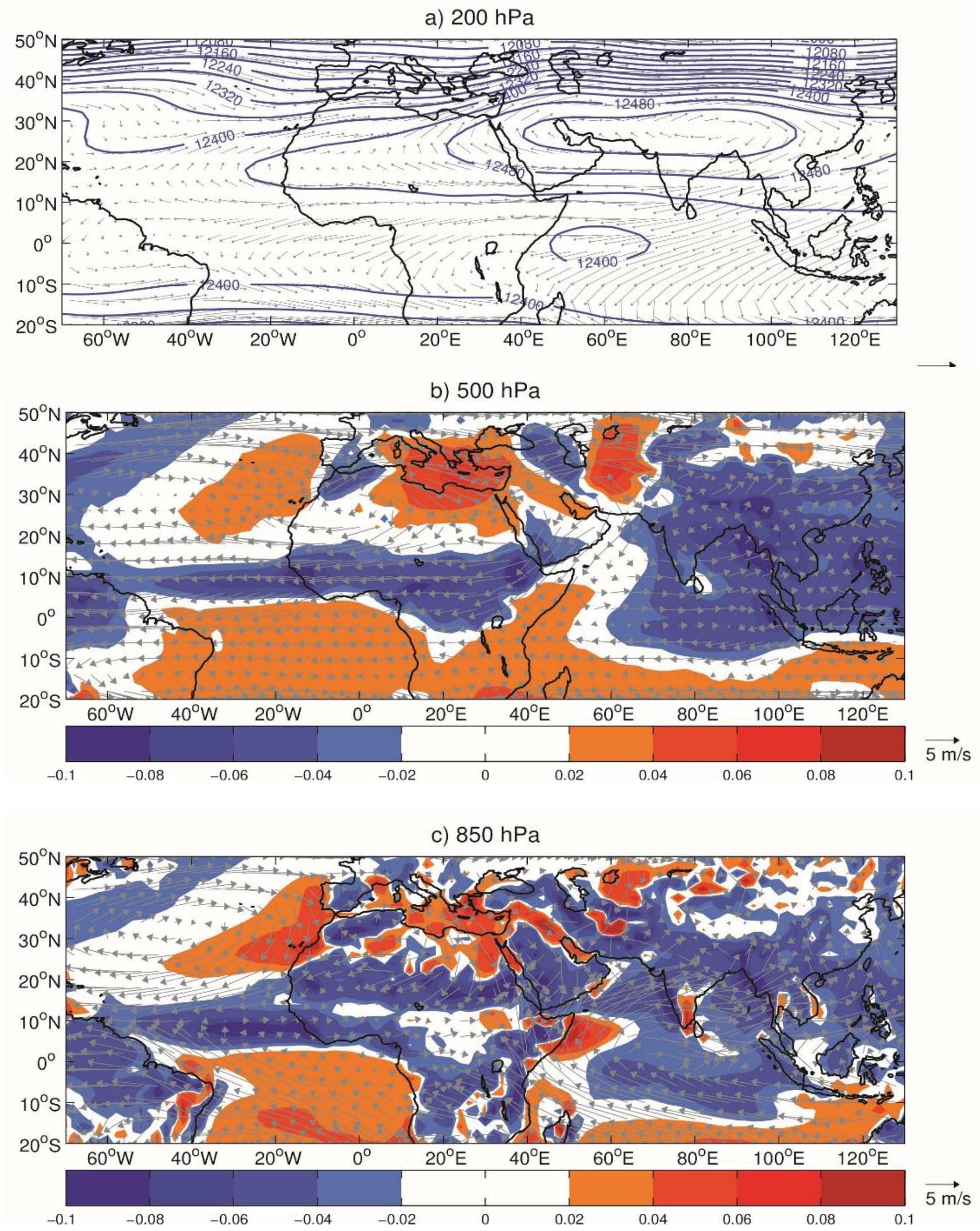
iv. The role of the South Asia and East Africa mountains in shaping the monsoonal winds

v. The role of the Mascarene high in expanding SAM catch basin to the winter hemisphere

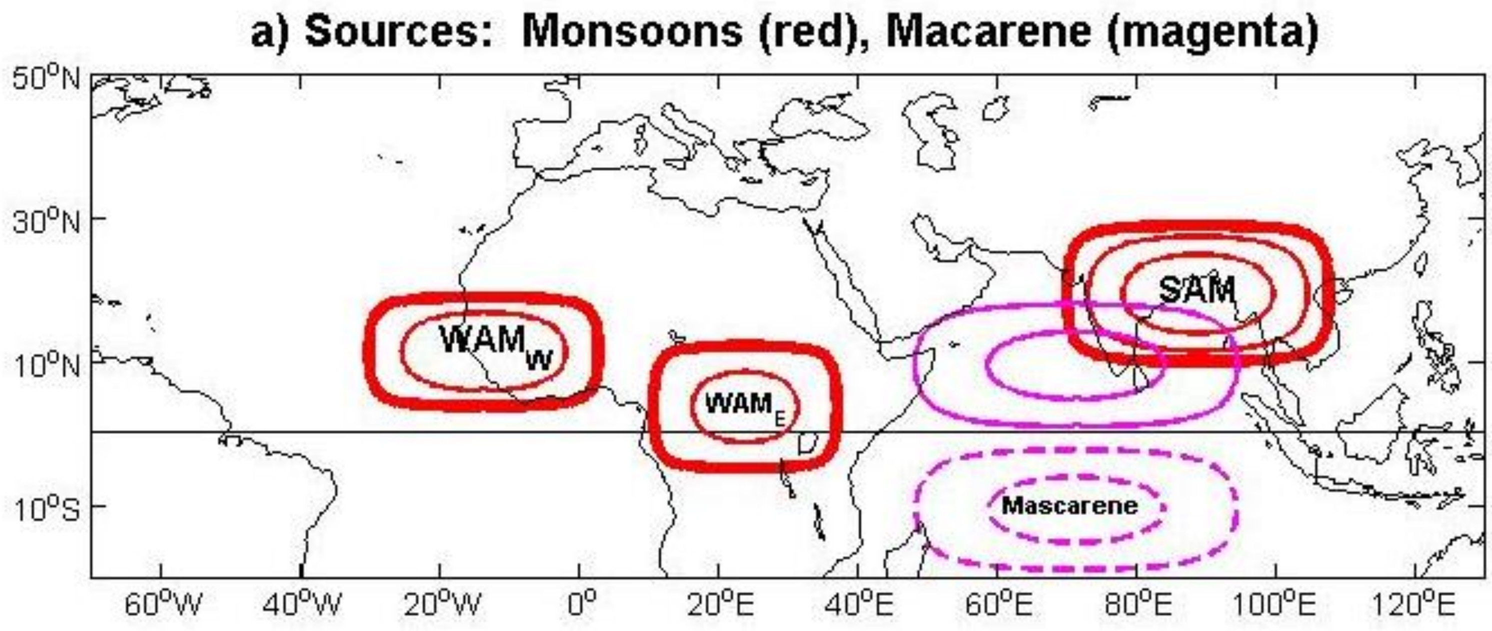
Keywords: Asian-African monsoon; Himalayas, Indian Ghats and Somali Mountains; Mascarene high.

Asian-African monsoon system in ECMWF reanalysis

- In the upper-troposphere, a single anticyclone encircles both monsoon systems (Fig. a).
- At the mid-tropospheric level, the large upward vertical velocity (negative omega) over the monsoonal regions is balanced by a vast region of weak downwelling (positive omega) over the Atlantic, the African deserts and the eastern Mediterranean (Fig. b).
- In the lower-half of the atmosphere, the circulation is cyclonic, with an increasing longitudinal separation of the SAM circulation from the WAM circulation with decreasing altitude (Fig. c).
- Upwelling at 850 hPa level and below is seen where downwelling is located at 500 hPa (see Fig. b and c).

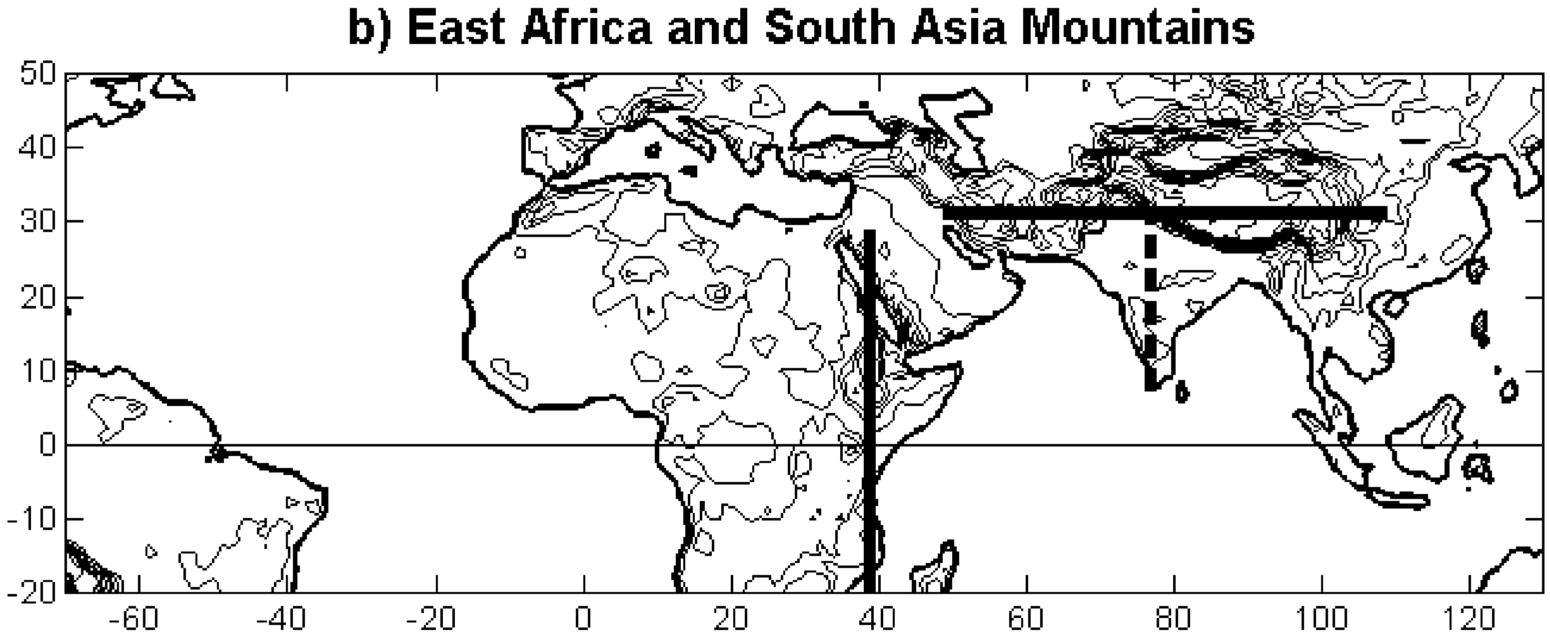


Adopted monsoonal sources and Mascarene high



- The adopted sources are as in Rodwell and Hoskins (2001), but in a simplified geometrical form shown in Fig. a.
- The Mascarene winds are driven in the model by a prescribed temperature anomaly in the Indian ocean, positive to the north of the equator and negative to its south.

South Asia and East Africa mountains as barriers



Black segments indicate the position of the barriers

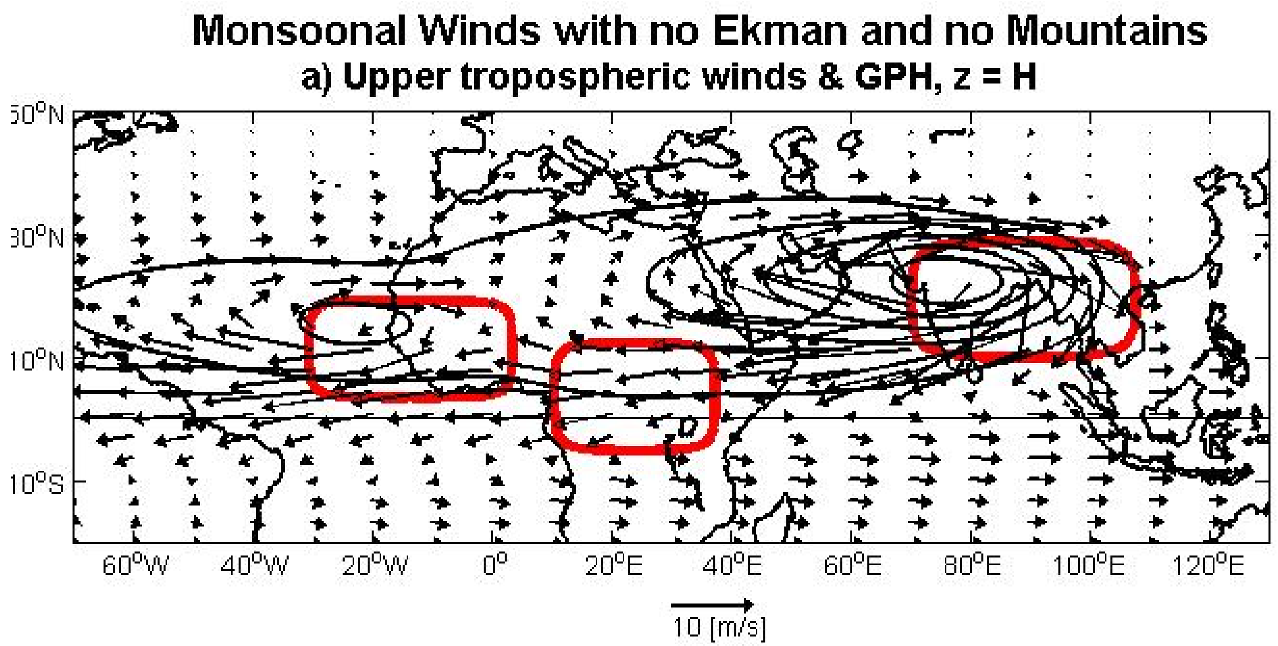
- The Himalayas and Iran and Pakistan mountains are the east-west barrier at 32°N as deep as the model.
- The Somali and Arabian Peninsula Mountains are the north-south barrier to the Ekman winds at 42°E.
- The Indian Ghats are the semi-permeable north-south barrier to the Ekman winds at 78°E.

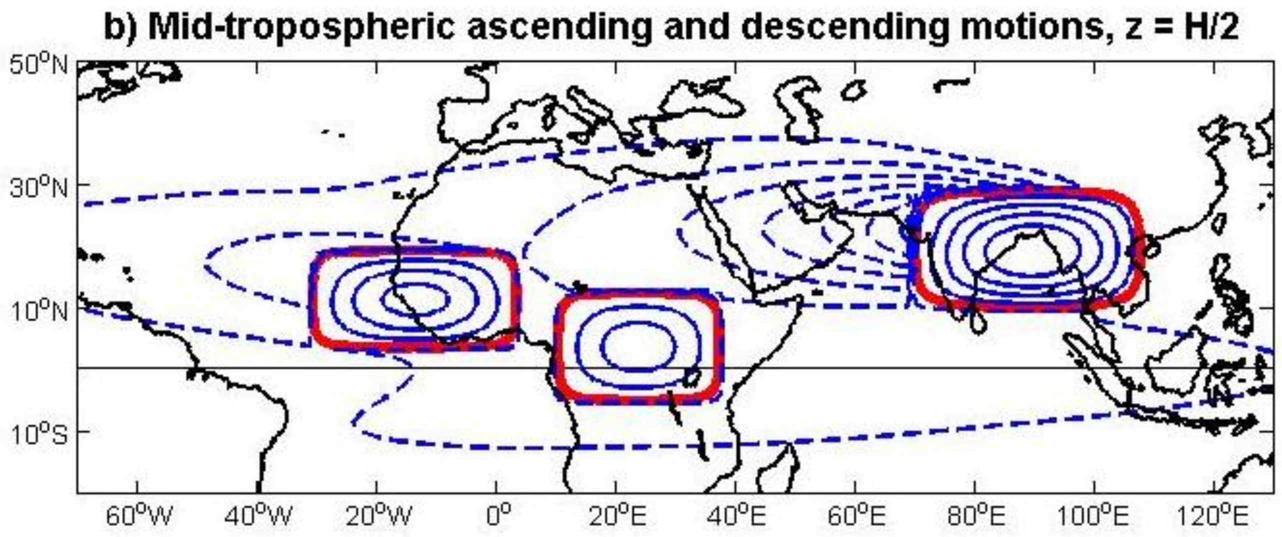
Monsoonal flow in the upper half of the atmosphere (1/1)

Monsoonal flow with no mountains and no Ekman layer

- A single anticyclone encircles the Asian-African monsoon in the upper troposphere (Fig. a).

- The prevailing subsidence is in the summer hemisphere, over North Africa, over the eastern Atlantic and over the Indian Ocean (Fig. b).



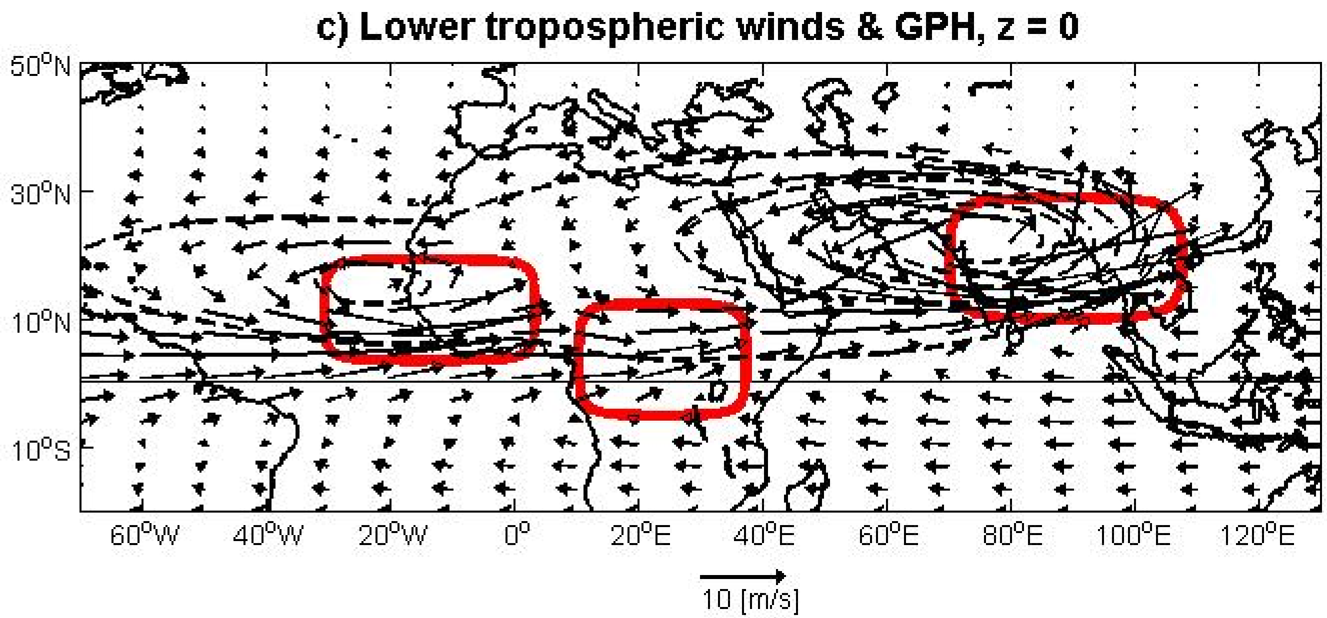


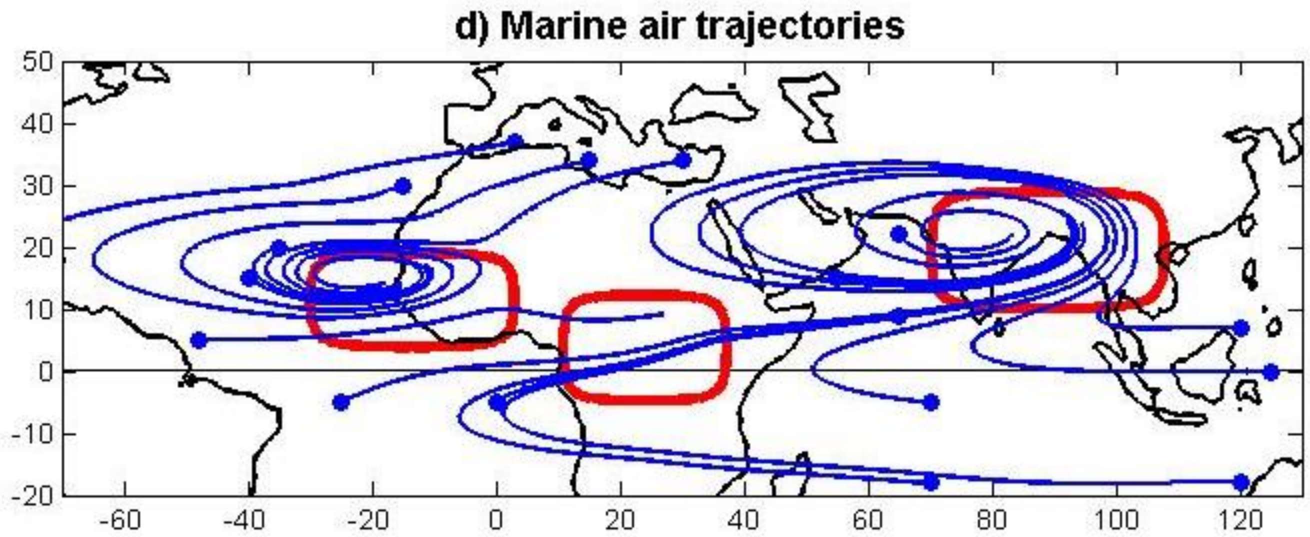
Monsoonal flow in the lower atmosphere (2/2)

Monsoonal flow with no mountains and no Ekman layer

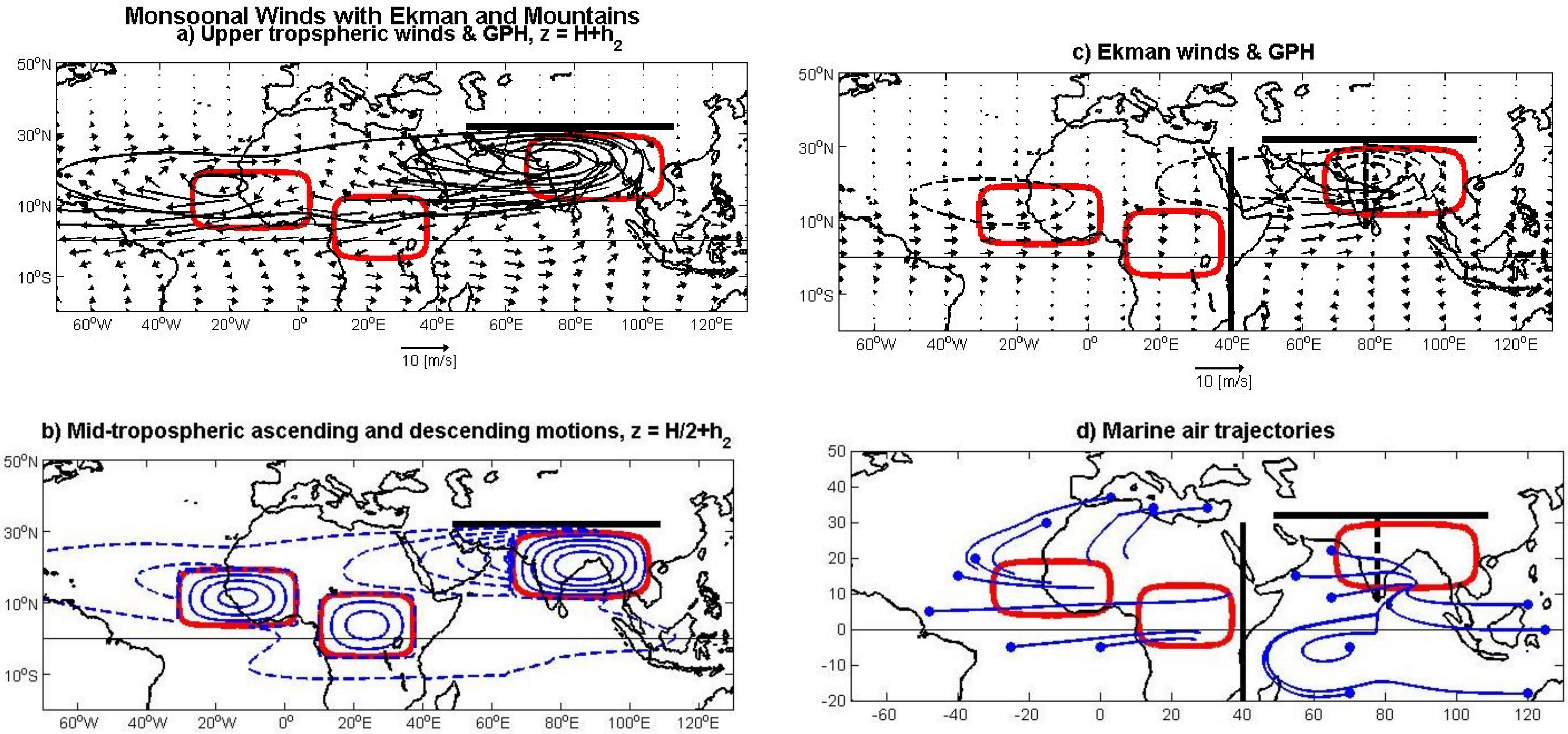
- With no Ekman layer a single specular symmetric cyclone encircles the Asian-African monsoon (Fig. c).
- The strengthening of the winds to the south of this system is due to the equatorial β-plane.

- With no East Africa mountains, marine air masses end up in the WAM catch basin or in the SAM catch basin, transiting from the Atlantic to the Indian ocean, and vice versa (Fig. d).





Monsoonal flow with Ekman friction and mountains (1/1)



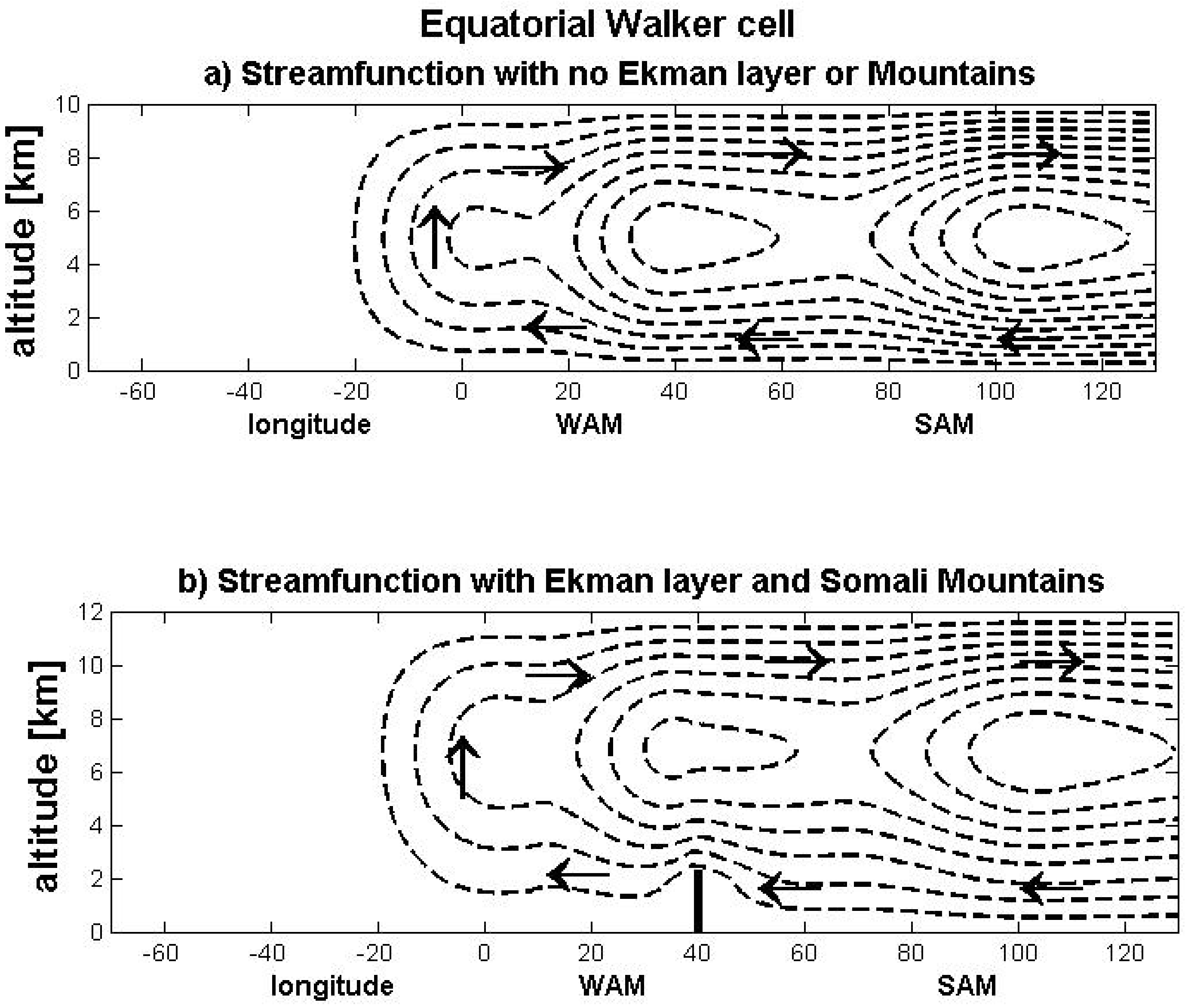
Monsoonal flow with Ekman friction and mountains (2/2)

- The Himalayas strengthen the SAM winds by tightening the isobars (Fig. a).
- The Somali Mountains split the Ekman cyclone in two cyclones, dividing the eastern Atlantic air masses from the Indian ocean air masses (Fig. c).
- Friction slows the Ekman winds and the motion of the marine air masses (Fig. c).
- The Ekman pumping makes the lower cyclone deeper and more compact than the upper anticyclone (see Fig. a and Fig. c).
- The Mediterranean and the north-eastern Atlantic marine particles fall into the east flank of the WAM catch basin (Fig. d).
- The Gulf of Guinea particles fall into the west flank of the WAM catch basin (Fig. d).
- The Indian ocean particles fall into the SAM catch basin (Fig. d).
- The Indian Ghats deflect the trajectories of the air mass trajectories towards the Bengal Bay (Fig. d).

Equatorial Walker cell

a) In the absence of an Ekman layer, the lower branch of this cell is as deep as the upper branch.

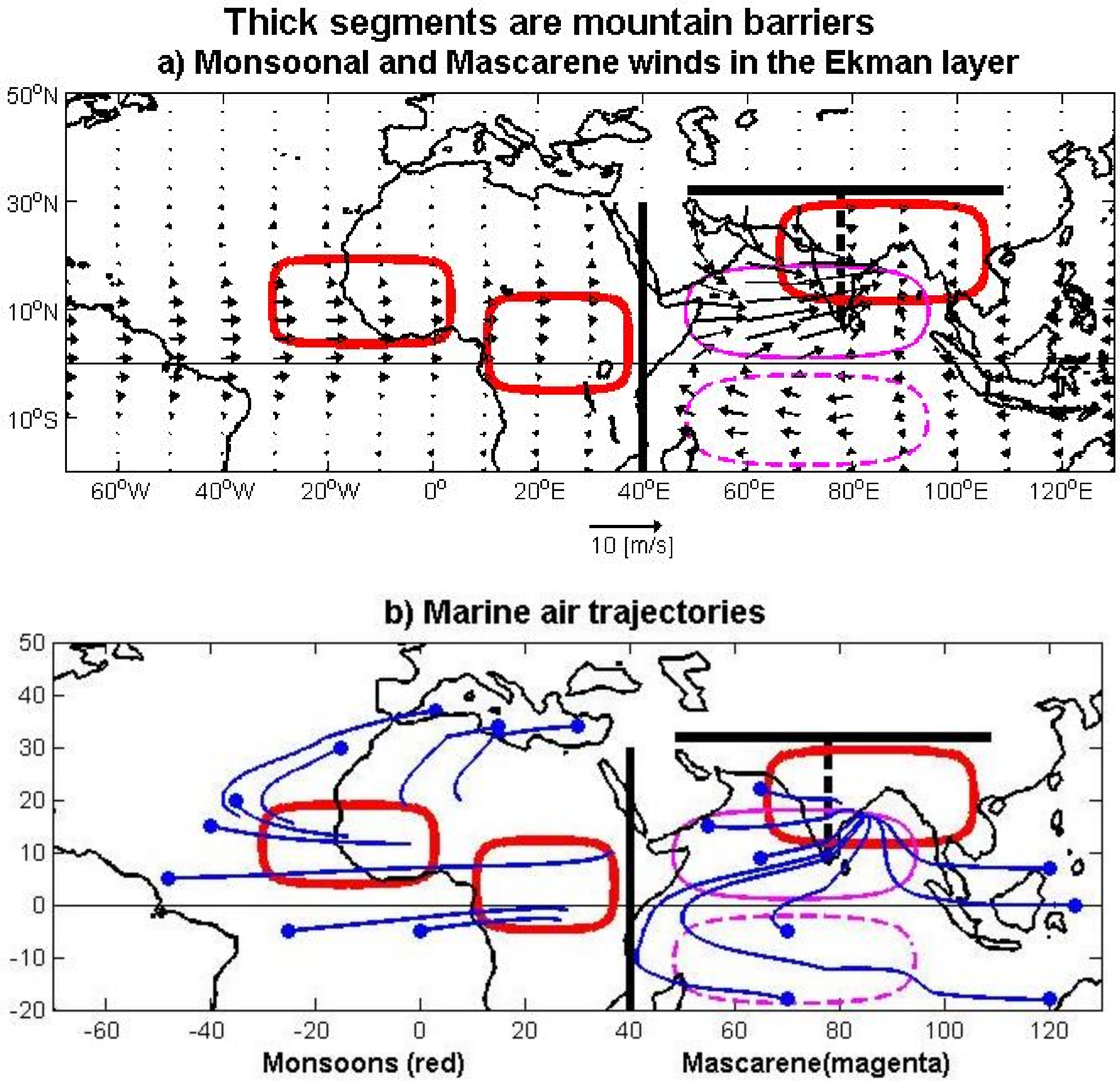
b) In the presence of an Ekman layer, the lower branch of this cell is deeper than the upper branch, the former overtakes the East Africa mountains by compressing its streamlines.



Contribution by the Mascarene winds

a) The Mascarene high strengthens the flow towards the Somali mountains over the southern Indian ocean, increasing the cross-equatorial flow to the east of Somalia. These mountains redirect the flow towards the Indian subcontinent over the north-western Indian ocean.

b) The Mascarene high expands SAM's catch basin to the southern Indian ocean.



Summary of results *(1/2)*

Results show that the West African monsoon (WAM) has an eastwards influence over the Tropical Indian ocean via eastward propagating Kelvin waves, and that the South Asian monsoon (SAM) has an influence over North Africa via westward propagating planetary waves. The introduction of a lower frictional layer and orography substantially disrupts the regional circulation. Friction slows the Ekman winds. The Ekman pumping makes the lower cyclone deeper and more compact than the upper anticyclone by transferring tropospheric vorticity into the EFL.

Summary of results *(2/2)*

- The Himalayas strengthen the SAM winds by tightening the isobars.
- The East Africa and the Arabian Peninsula mountains divide the Atlantic marine air masses from those of the Indian ocean.
- The West African monsoon is fuelled by Atlantic air, while the South Asian monsoon is only fuelled by Indian ocean air.
- The Indian Ghats deflect the marine air masses towards the Bay of Bengal, strengthening the SAM south-eastern flank.
- In the absence of an Ekman friction and of the East Africa mountains, in addition to the Indian ocean marine air, the SAM catch basin collects marine air originating in the Gulf of Guinea.

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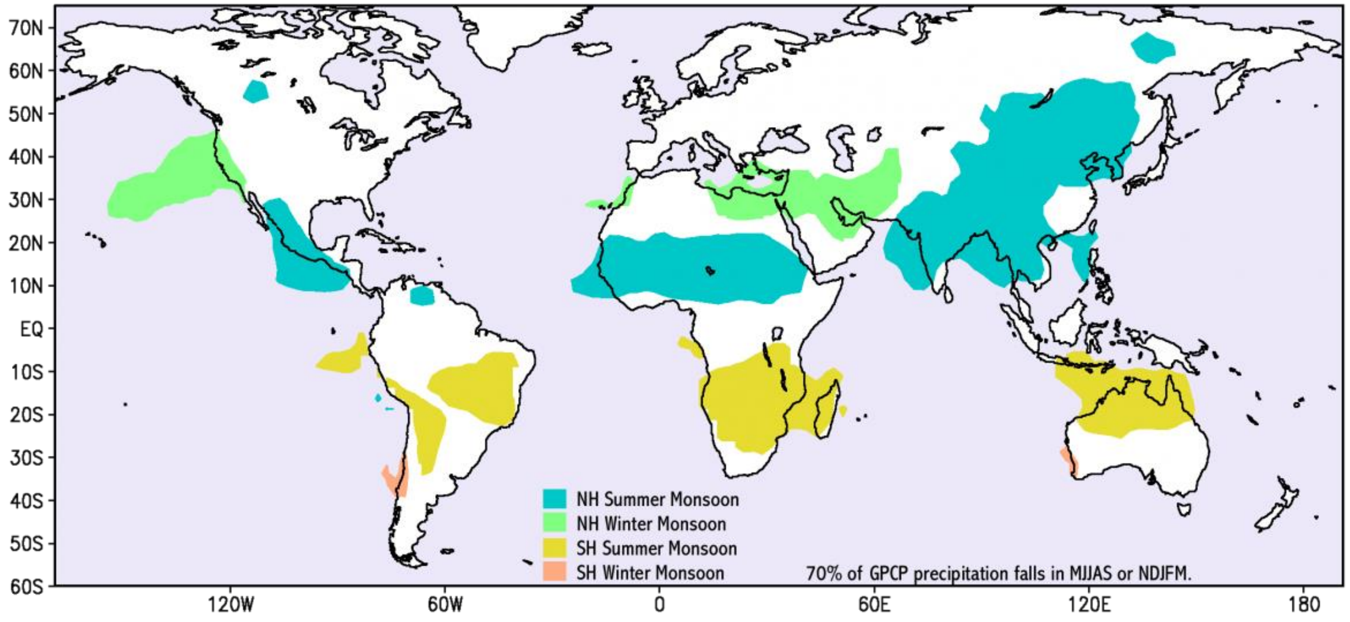
Thank you !



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