A study of the critical processes which determine the severe precipitation events over the Hajar Mountains using observations and model simulations

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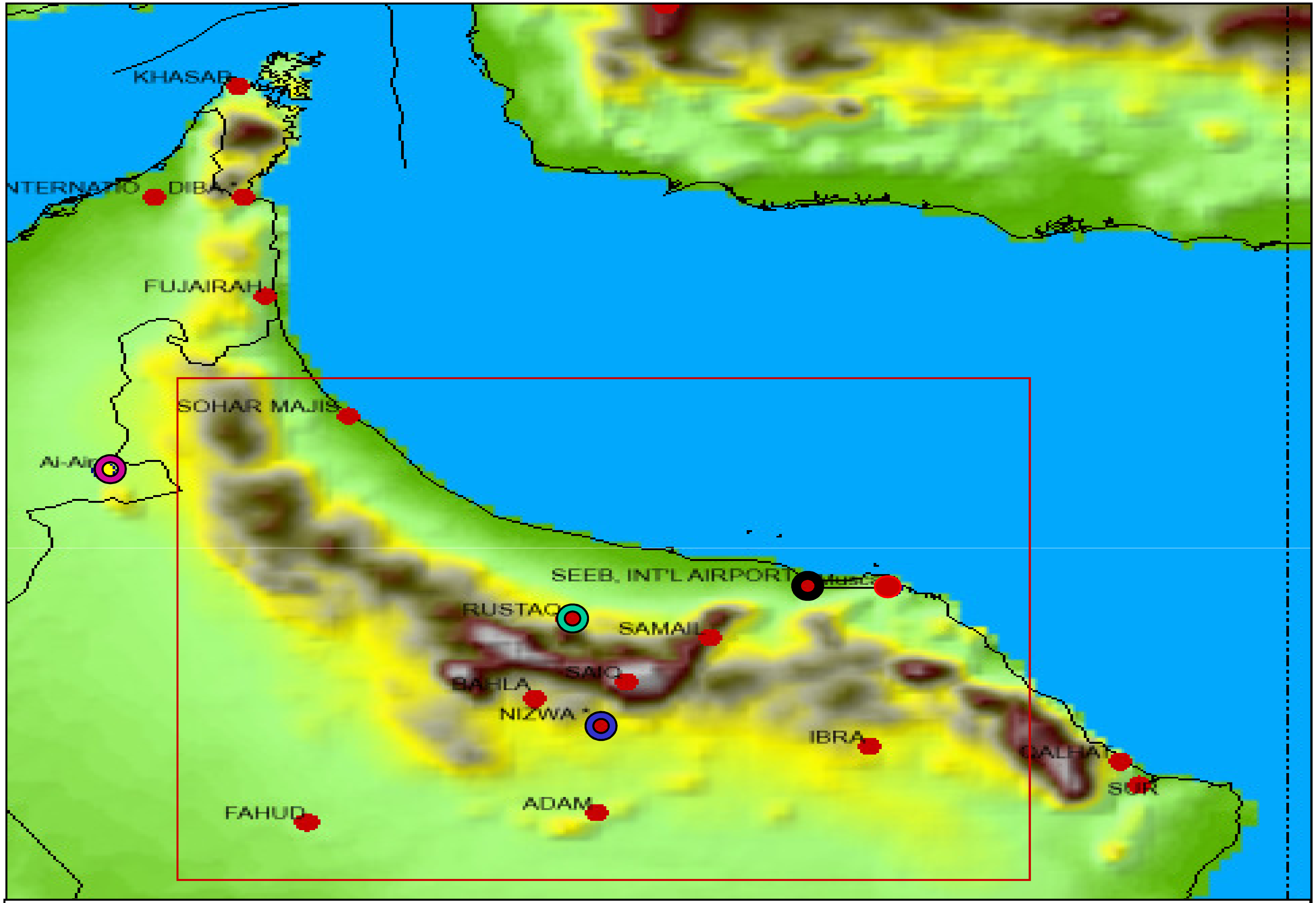


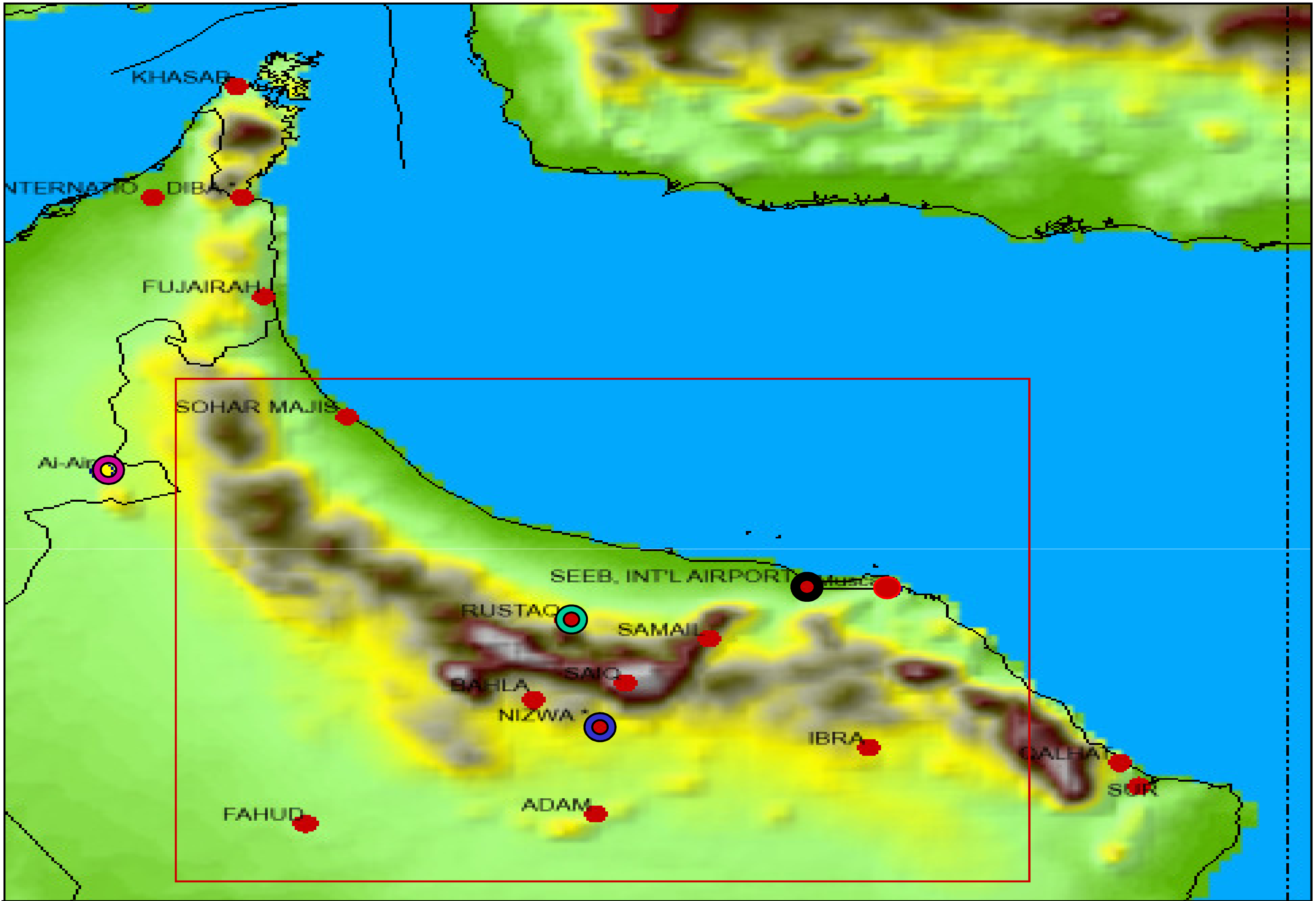
Fig 1. Map of the Hajar Mountains, ◎ ◎◎ sodar locations, ◎ radar, and (red circles) - met. observing stations. Red box represents the model domain

Examples of flash flooding in Oman, November 2011

Background

The Hajar Mountain range is a key factor in inducing a significant amount of rainfall during summer months. These steep mountains have peaks of approximately 10,000 feet, and run parallel to the coast of Gulf of Oman (see Figure 1). Convective clouds form over the mountains creating a regular occurrence of showers and thunderstorms over a limited area in northern Oman. The active weather is generally of short duration, quite intense and is occasionally accompanied by hail and strong downdrafts. In addition to orographic forcing, the synoptic pattern shows that the advection of moisture and large scale lifting are important factors in determining wet days from dry days. As well as moisture from the adjacent sea, another important source of moisture is a tropical monsoonal flow from the south-western parts of the Arabian Sea. In order to understand this orographic convection, various observational data was collected during June/July 2004. Simultaneously, the EULAG meso-scale non-hydrostatic model with a horizontal resolution of 2 km was used to simulate the orographic convection. The model was initialised with a single morning profile from the hydrostatic model.

Results and analysis from the field observations and preliminary model results will be presented.



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Observational Experiment.

Objectives: -

- To obtain as many observations as possible in order to validate the model's ability to predict orographic convection.
- To understand the important factors that enhances convection under certain conditions and suppresses it in others.

Fig. 1 shows positions of:

- two sodars that were deployed just for this study (the sodars were alternated between 3 locations).
- radiosondes that were launched from Seeb International Airport at 00,06, and 12 UTC on selective days.
- a Doppler radar located at Al-Ain in the United Arab Emirates which covers the western part of the model domain. (To complement radar data, imagery from geostationary satellite was used).
- meteorological observing stations.

In addition, products from other NWP models were used MM5 (30km res.), and a hydrostatic limited area model (7km res.) run at the Omani Met Department (based on the German HRM model).

Modelling Experiment

Eulag model was used as defined (Grabowski & Smolarkiewicz, 2002 MWR, 130, 939-956)

- Non-hydrostatic, Eulerian time-stepping (in this case), with cfl condition limiting time step. Anelastic equation set (Lipps & Hemler 1982,J. of Atmos. Sci., 113, 1117-1140).
- Non-staggered A grid structure.
- Terrain following vertical coordinates. (Gal-Chen and Somerville 1975, J. Comp. Phys., 17, 209-228).
- Turbulence closure. (Smagorinsky 1963, MWR, 49, 2082-2096).
- Bulk microphysics (q_v, q_c, q_r, q_i)
- The model has been used for a variety of problems including convective clouds, gravity wave, oceanic flow, and canyon flow at Leeds and this formulation was utilised.

Model / Case formulation:

- Open boundary conditions with no relaxations
- Grid-box of 192 x 150 x 50 for dx=dy=2km and dz=400m, dt=4 sec.
- Simulations were for 17 hours starting 4 am local, dumping every 10 minutes.
- An idealised surface heat flux forcing was introduced after 2 hours of model run

Experimental design

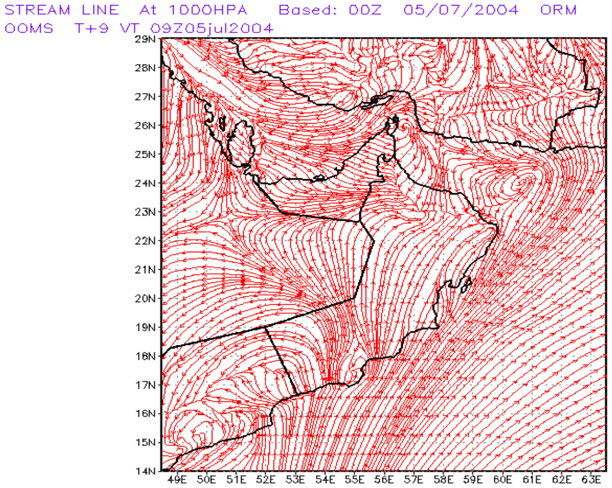
Table 1. Case studies and sensitivity tests. C is the profile for the control run. M1, M2, M3 represent change in moisture. W1, W2, W3 represents change in wind. H is the control heat flux, as defined in the text, and NH represents zero heat flux. A3 represents a change in temperature. A12 is a case with reduced orography. H* represents heat flux started immediately. C2* and C3 represents profiles for the light rain day and dry day, respectively

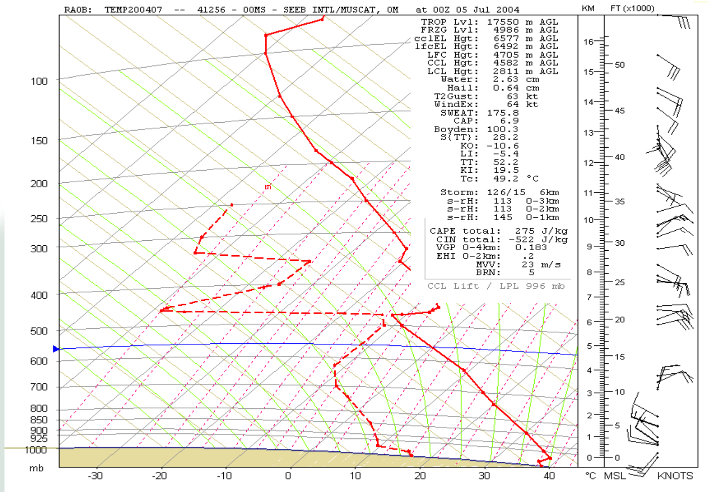
Index	Horizontal Resolution	Vertical Resolution	Levels	Time step	Profile	Heat flux
Wet day (Control run)						
A	1 km	250 m	80	3 seconds	C	H
Sensitivity test (moisture)						
A1	1 km	250 m	80	3 seconds	M1	H
A2	1 km	250 m	80	3 seconds	M2	H
A3	1 km	250 m	80	3 seconds	M3	H
Sensitivity test (wind)						
A4	1 km	250 m	80	3 seconds	W1	H
A5	2 km	250 m	80	3 seconds	W2	H
A6	2 km	250 m	80	3 seconds	W3	H
Sensitivity test (vertical resolution)						
A7	2 km	250 m	80	3 seconds	C	H
A8	2 km	160 m	125	3 seconds	C	H
A9	2 km	400 m	50	3 seconds	C	H
Sensitivity test (horizontal resolution), case A10, A7, and A						
A10	3 km	250 m	80	3 seconds	C	H
Sensitivity test (others)						
A11	2 km	400 m	50	3 seconds	C	NH
A12	2 km	400 m	50	3 seconds	C	H
Light rain east of the mountains						
A13	1 km	250 m	80	3 seconds	C2*	H
Dry day						
A14	1 km	250 m	80	3 seconds	C3	H*

The aim of this talk is to present two cases (dry and wet).

In the dry-case, streamlines (produced by the Oman regional model) show that the dry north-westerlies converge (over the mountains) with the sea-breeze (setting rather late) from the Gulf of Oman. The streamlines pattern is confirmed by the sodar observations (at Nizwa) showing northwesterly winds. In the wet-case, the sea-breeze converges with moisture flow advected from the Arabian Sea. This flow was also confirmed by sodar observations. Surface observations of dew-point temperature and wind speed and direction for Adam station and for Seeb station are also in agreement with the streamlines and the sodar winds. Examining various case studies indicated that the position of the heat low and its depth determine the direction and type of winds that converge over the mountains. A dry desert air (even when flowing over the Arabian Gulf) will lead to moist convection being suppressed, whereas moist air advected from the Arabian Sea will enhance moist convection.

Moisture advection from the Arabian Sea in a column of at least 1 km depth is required for proper convection. The stronger the flow from the Arabian Sea and the deeper the column of the moist air, the heavier the precipitation. Results from the anelastic model show that the model is able to simulate cloud development and precipitation reasonably well, but the model seems to precipitate 2-3 hours earlier than observed. The model also shows that clouds develop over the mountain peaks and dissipate as they move west, which agrees well with radar and satellite imagery





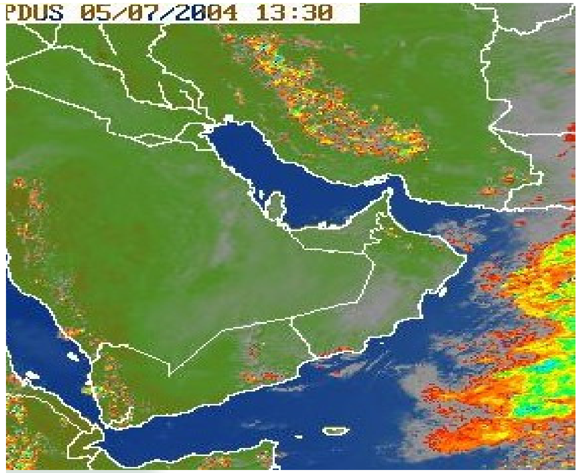
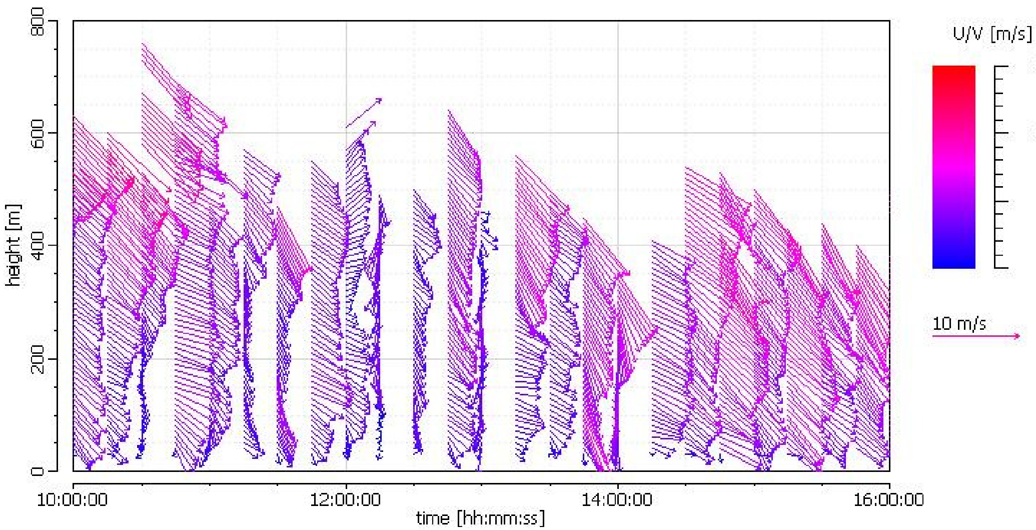
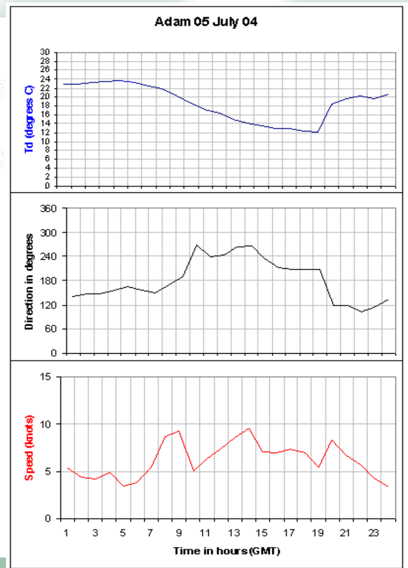
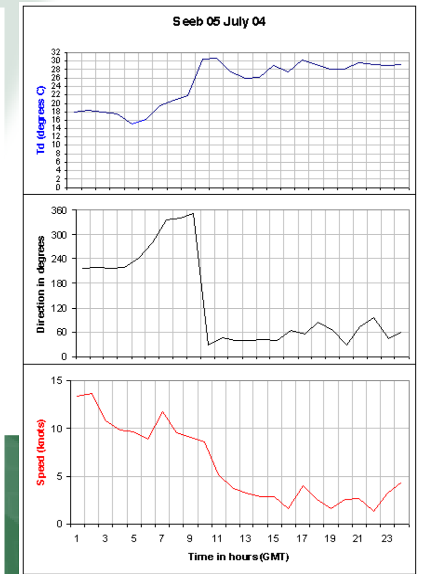


Fig. 2: Dry case 05 July 2004. From left to right, streamlines chart for 0900 UC; profile of T (solid), Td (dashed) and wind barbs for Seeb at 00 UTC; Meteosat visible image at 1330 UTC (1730 local time) where the colour palette represent cloud reflectivity; sodar winds for 1000-1600 hours local time at Nizwa; surface Td, wind direction and speed for Adam station (south of the mountains); and Seeb (north of the mountains). The general wind pattern recorded by Nizwa sodar and by Adam surface station which are both south of the mountains, indicate that dry north-westerlies prevented the development of clouds despite the onset of sea-breeze at Seeb.







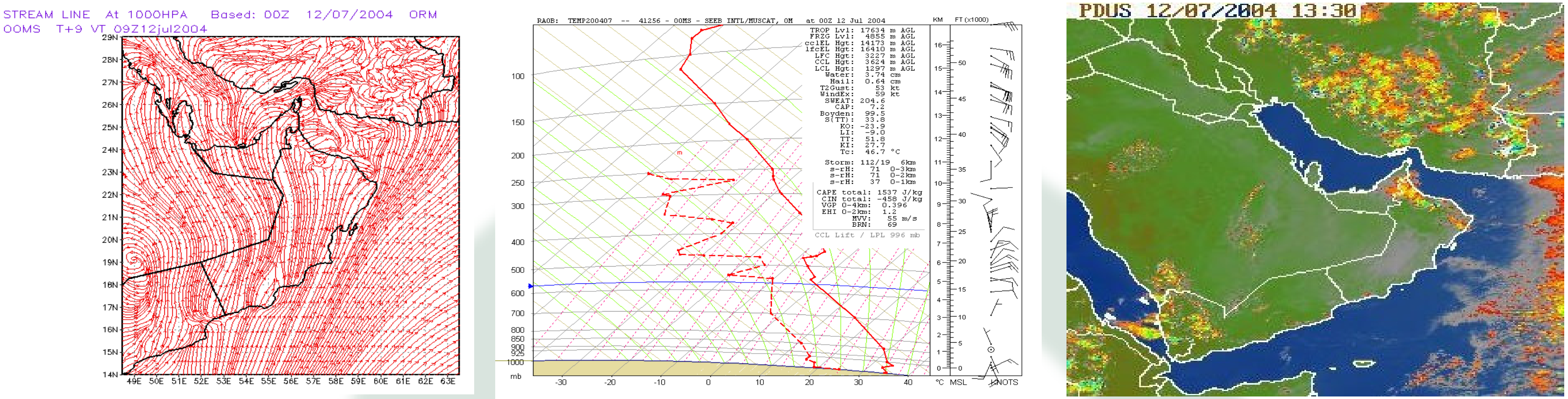
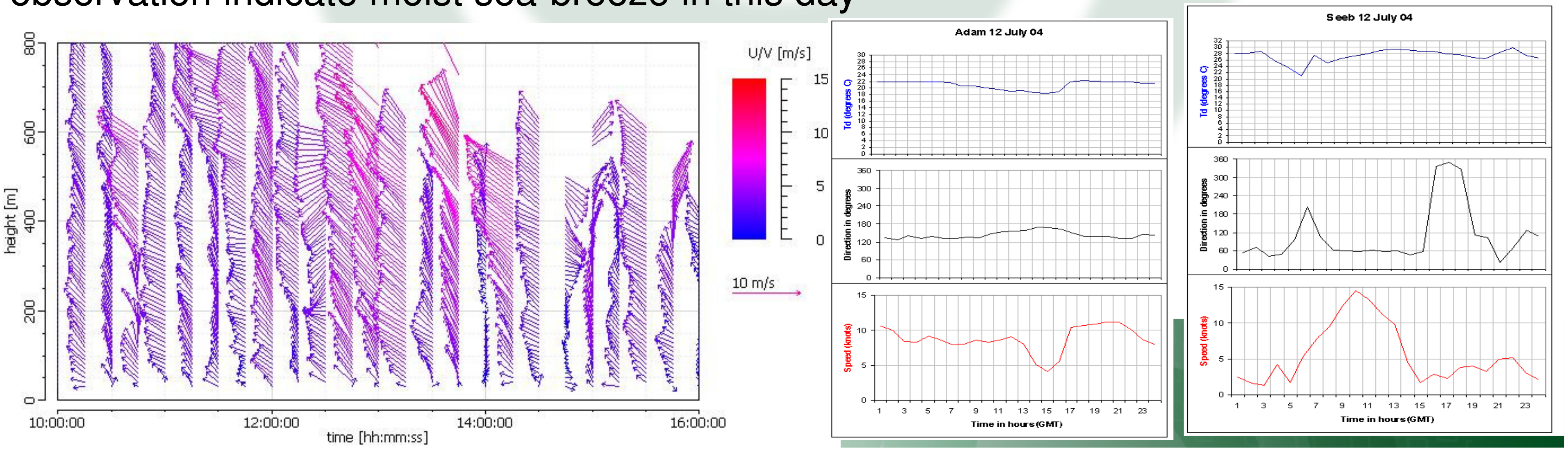


Fig. 3: Wet-case 12th July 2004. From left to right, streamlines chart for 0900 UTC; profile of T (solid), Td (dashed) and wind barbs for Seeb at 00 UTC; Meteosat visible image at 1330 UTC (1730 local time) where the colour palette represent cloud reflectivity; sodar winds for 1000-1600 hours local time at Nizwa; surface Td, wind direction and speed for Adam station and Seeb. The general wind pattern recorded by Nizwa sodar and Adam surface station which are both south of the mountains, indicate that moist south-easterly flow from the Arabian Sea is dominating. Seeb surface observation indicate moist sea-breeze in this day



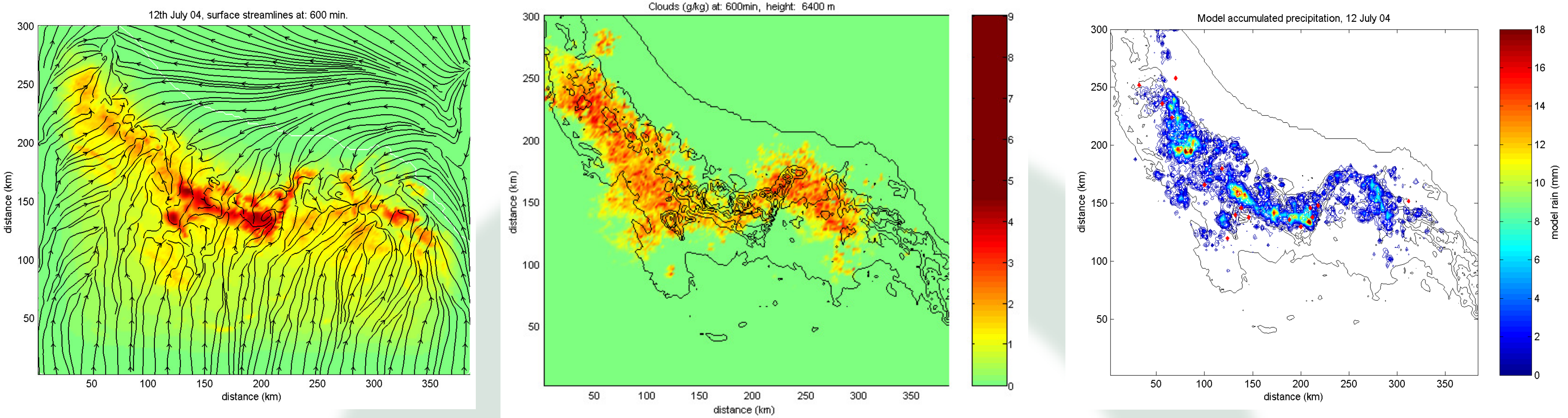
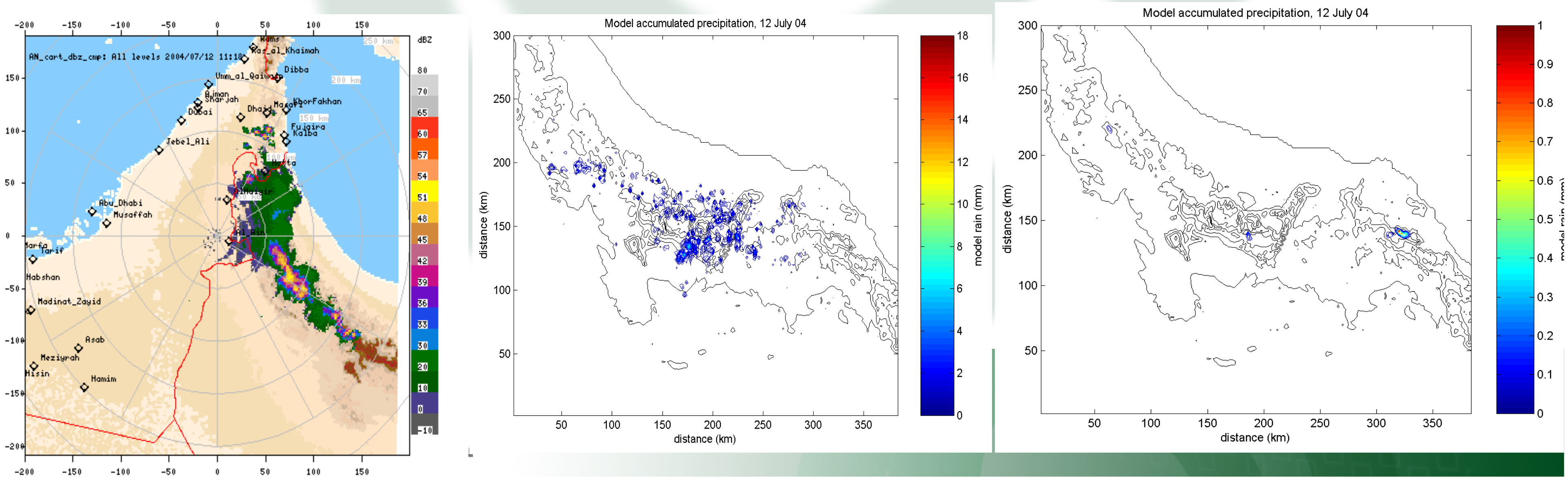


Fig. 4: Model results & radar image, wet-case 12 July 04: From left to right, surface streamlines at 600 min model time; clouds (g/kg) at 600 min at a height of 6.4 km; model accumulated total precipitation (mm) where red dots indicate rain-gauges with precipitation; radar reflectivity (dBZ) at 1118 GMT, radar covers only the western part of the domain; model accumulated total precipitation with reduced orography (peak 200 m); model accumulated precipitation with heat flux switched off. Maximum rainfall observed by a rain-gauge was 28mm.



Conclusions

- Sea-breeze, orographic forcing, moisture advection (and the depth of the moist column) from the Arabian Sea, and convergence are key factors in convective cloud development over the Hajar Mountains.

- The position of the thermal low and its depth determined whether the flow towards the mountains was dry desert or moist air from the Arabian Sea. Moisture advection from the Arabian Sea was the main ingredient for convection.

- The model demonstrated its ability to simulate the convergence of winds and cloud (development and movement) well. Model total precipitation was also in agreement with observations.