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Impacts of atmospheric rivers on the hydrometeorology of the Euphrates-Tigris Basin in the snowmelt season*

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*Bozkurt, D., Sen, O. L., Ezber, Y., Guan, B., Viale, M., Caglar, F., 2021. Influence of African Atmospheric Rivers on Precipitation and Snowmelt in the Near East's Highlands. JGR-Atmospheres, in press, https://doi.org/10.1029/2020JD033646.

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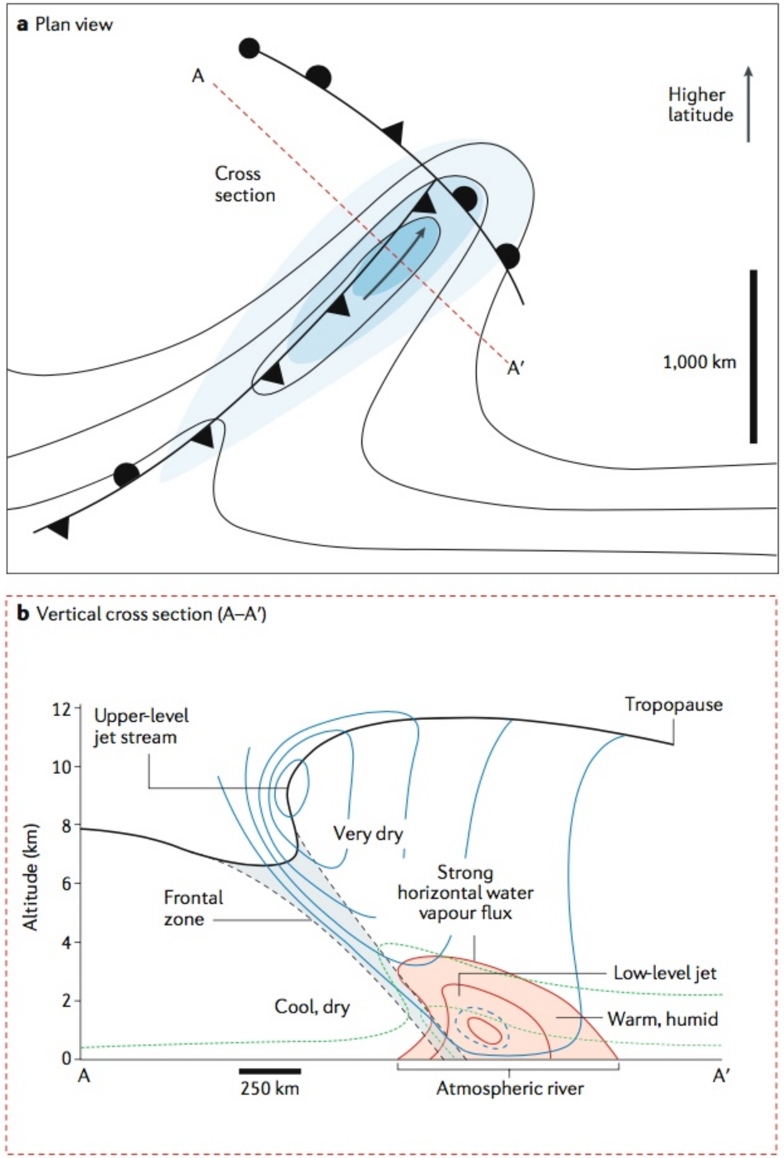


AMS American Meteorological Society | Glossary of Meteorology

Atmospheric rivers (ARs)

A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone. The water vapor in atmospheric rivers is supplied by tropical and/or extratropical moisture sources.

$$IWV = \frac{1}{g}\int_{1000}^{300} q\,dp$$

Integrated water vapor

kg m^{-2}, mm

$$IVT = \sqrt{\left(\frac{1}{g}\int_{1000}^{300} qu\,dp\right)^2 + \left(\frac{1}{g}\int_{1000}^{300} qv\,dp\right)^2}$$

Integrated vapor transport

kg m^{-1} s^{-1}

Payne, A. E., Demory, M., Leung, L. R., Ramos, A. M., Shields, C. A., Rutz, J. J., & Ralph, F. M. (2020). Responses and impacts of atmospher- ic rivers to climate change. Nature Reviews Earth & Environment, 1(3), 143–157. https://doi.org/10.1038/s43017-020-0030-5

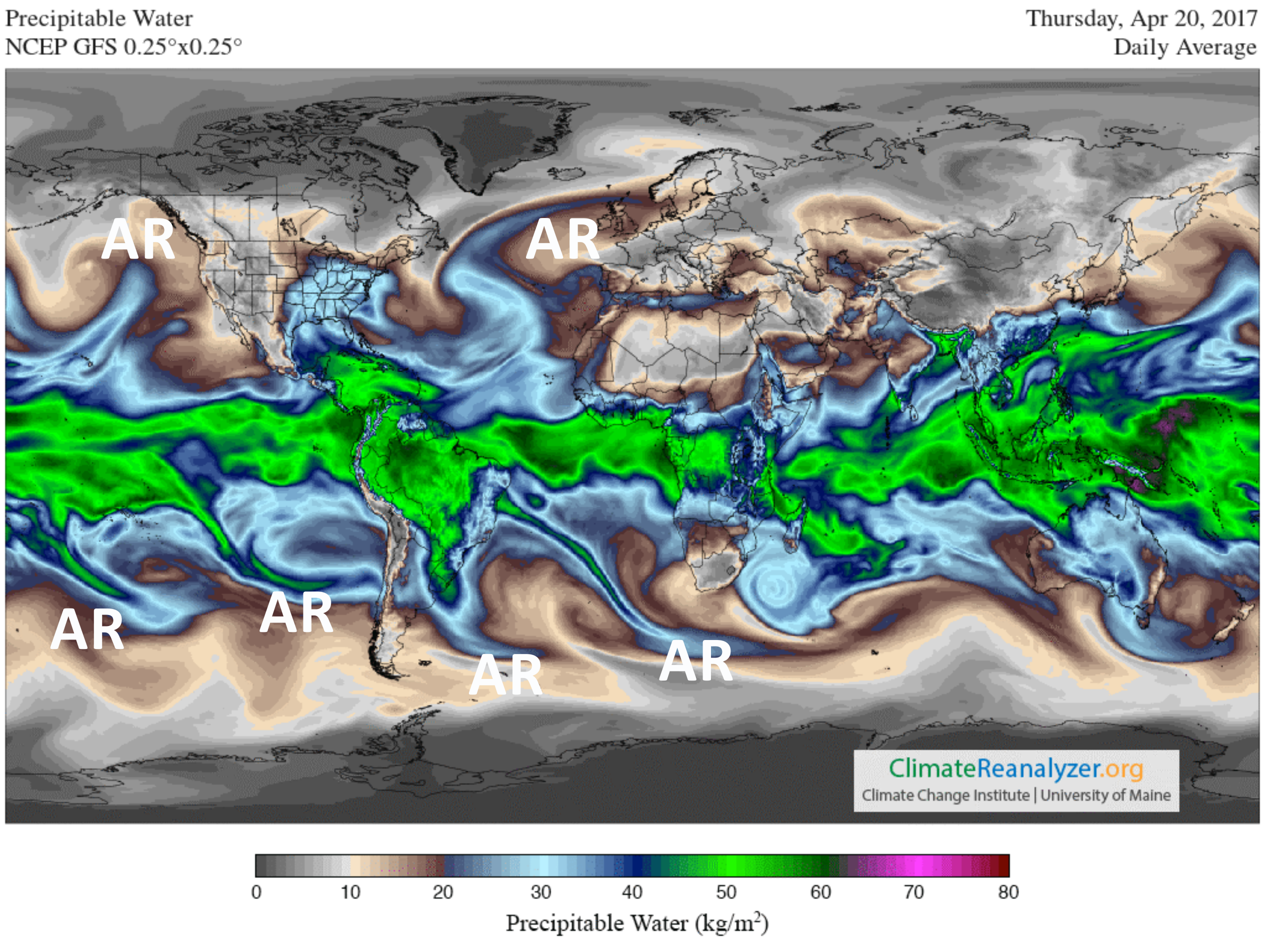
Most common thresholds:

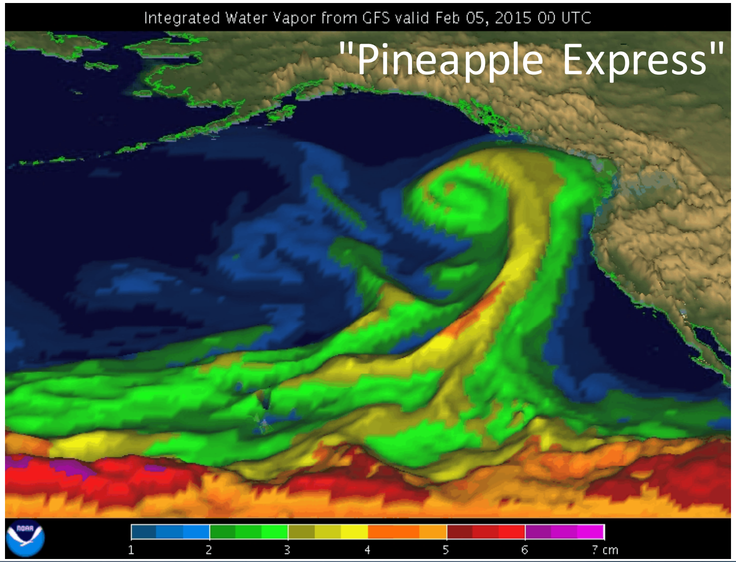
Intensity: IVT> 85th percentile

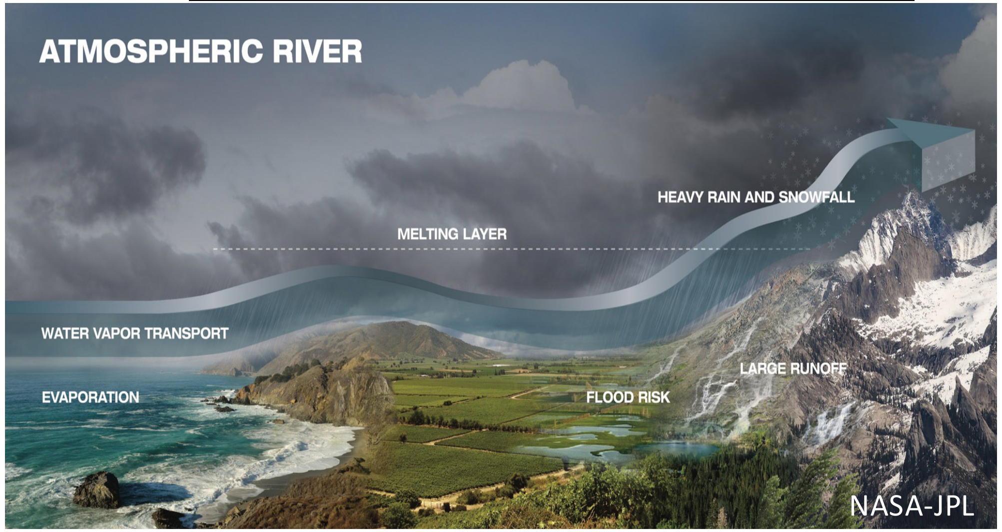
Length: > 2000 km

Length/Width: > 2

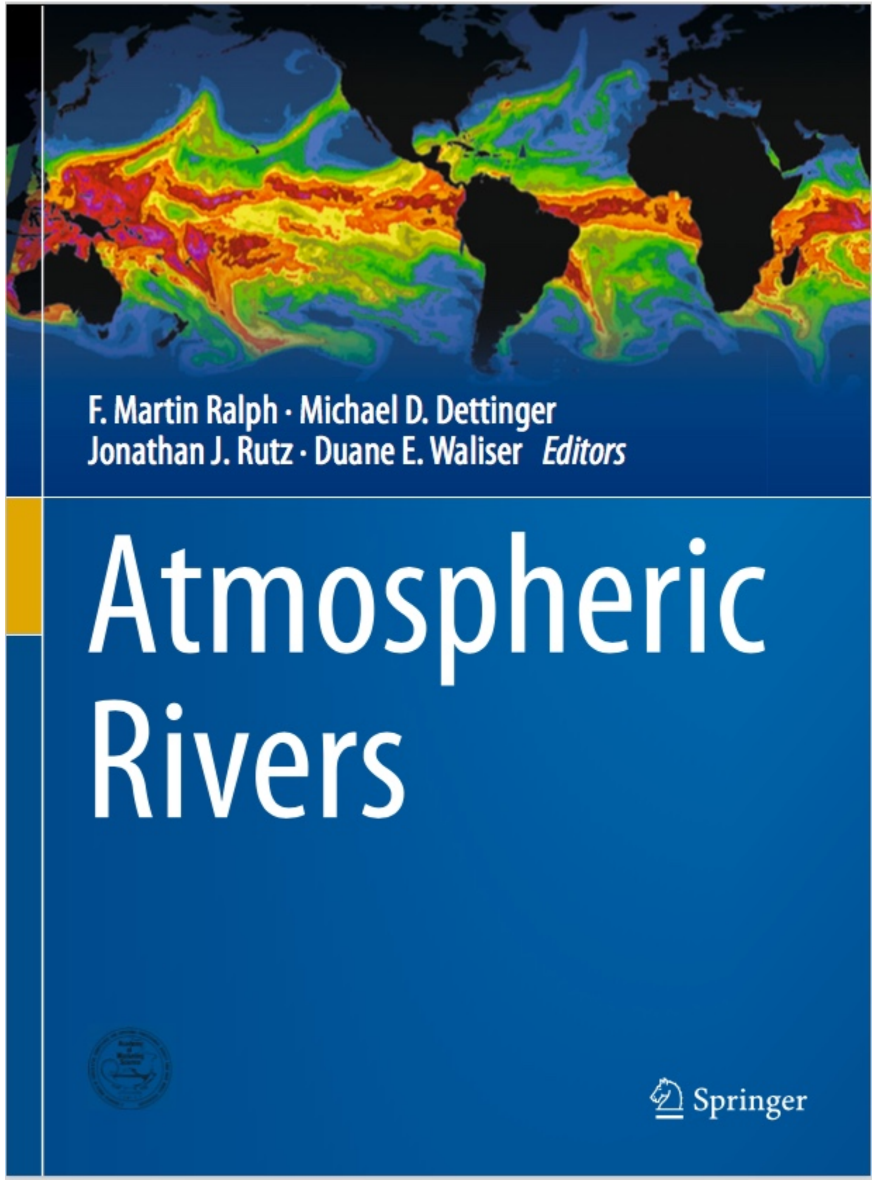
Direction: >50 kg m^{-1} s^{-1} poleward component



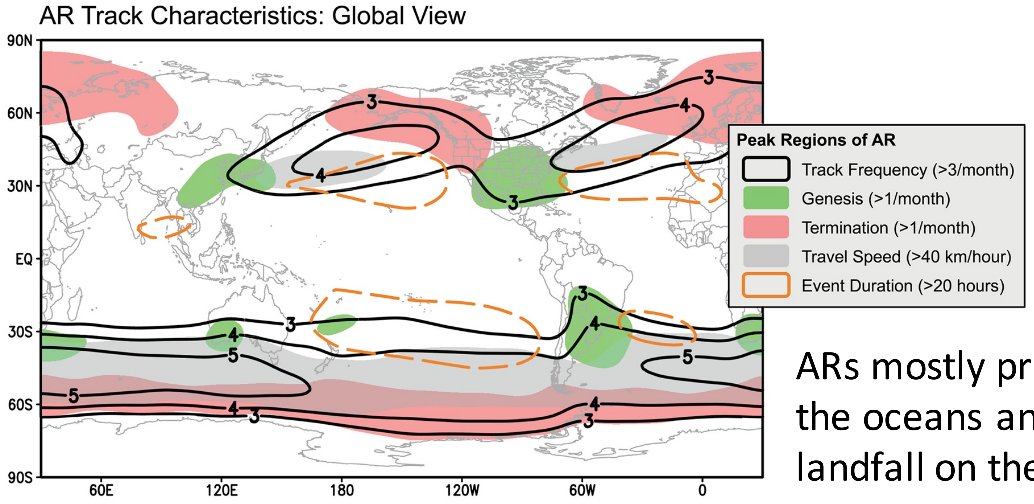




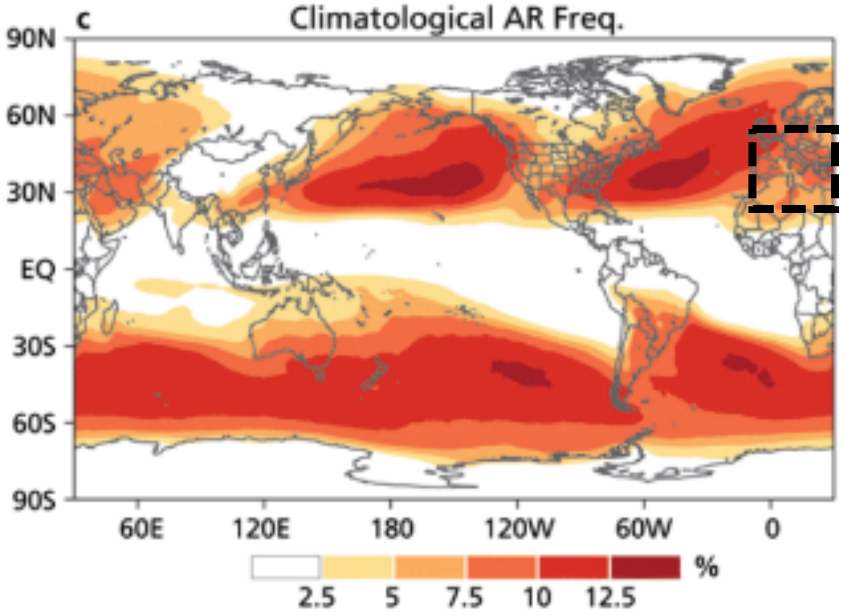
Atmospheric rivers horizontally transport large quantities of water vapor (on average, more than double the flow of the Amazon River) and can cause extreme precipitation events on west coasts of major landmasses due to orographic lift over mountainous topography.



Atmospheric Rivers. Ralph, F. M., Dettinger, M. D., Rutz, J. J., Waliser, D. E. (eds) Springer Nature. Springer, Cham. https://doi.org/10.1007/978-3-030-28906-5



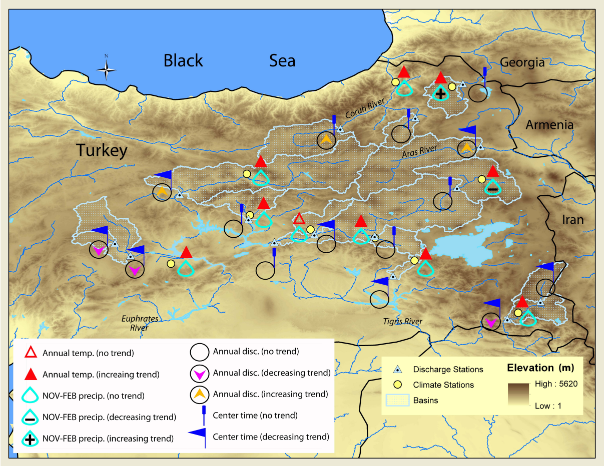
ARs mostly prevail over the oceans and primarily landfall on the western coasts of the midlatitude continents as a result of westerly flow of the midlatitudes.

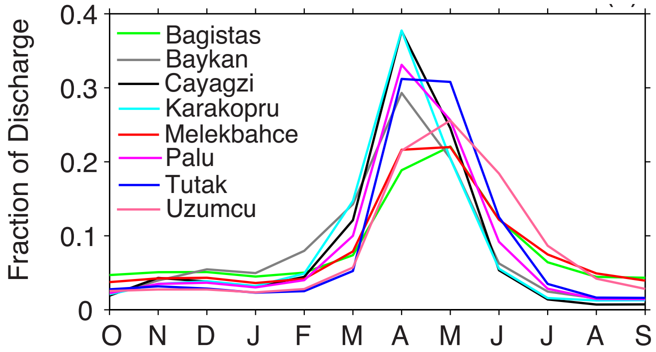


Apart from the large ocean basins, certain ARs can develop and propagate over continents (e.g., North Africa and Middle East), which has received less scientific attention.

Euphrates-Tigris Basin

- Major water resources of the Middle East, covering areas in five countries (Turkey, Iraq, Syria, Iran and Kuwait)
- Approximately total area of 766,000 km^2
- Two main rivers: Euphrates (annual total flow around 30 billion cubic meters) Tigris (annual total flow around 50 billion cubic meters
- Eastern Anatolia: Headwaters of the basin. High elevation (> 2500 m), so covered with snow in winter
- Both rivers are snowfed
- 60 – 80 % of their total annual flows occur in March-June period





Sen, O.L., Unal, A., Bozkurt, D., Kindap, T., 2011. Temporal changes in the Euphrates and Tigris discharges and teleconnections. Environmental Research Letters, 6 024012 DOI:10.1088/1748-9326/6/2/024012.

Motivation, data and methods

Motivation:

- In this respect, this study aims to show how overland African ARs developing in the snowmelt season can influence the Near East's (NE) highlands, which are essential for satisfying the water need of Euphrates-Tigris Basin and Mesopotamia that are potentially at risk of water scarcity and conflicts.

Data and Methods:

- AR Catalog (Guan and Waliser, 2019)
- Reanalysis (ERA-Interim, ERA5-Land)
- Stations (Meteorological, Streamflow)
- Analysis Period: March-April snowmelt season (1979-2017)
- The AR frequency is expressed in units of days (i.e., one 6-hour AR step = 0.25 day). Additionally, AR events correspond to the days when AR is presented at any of the four 6-hour steps within detected AR shape boundaries

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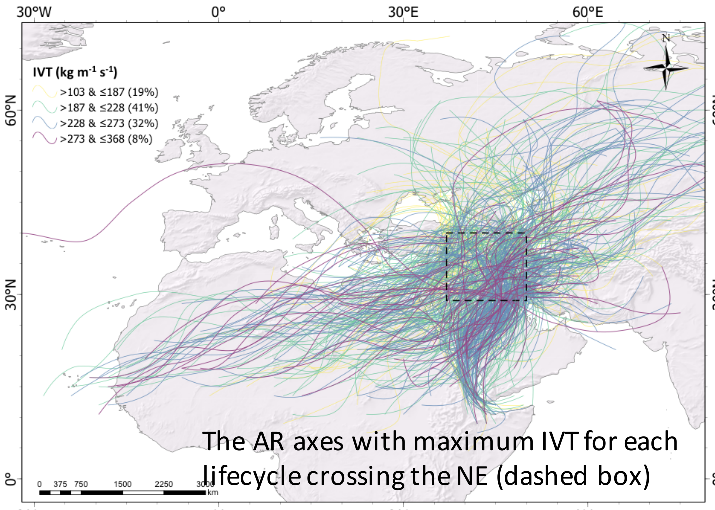
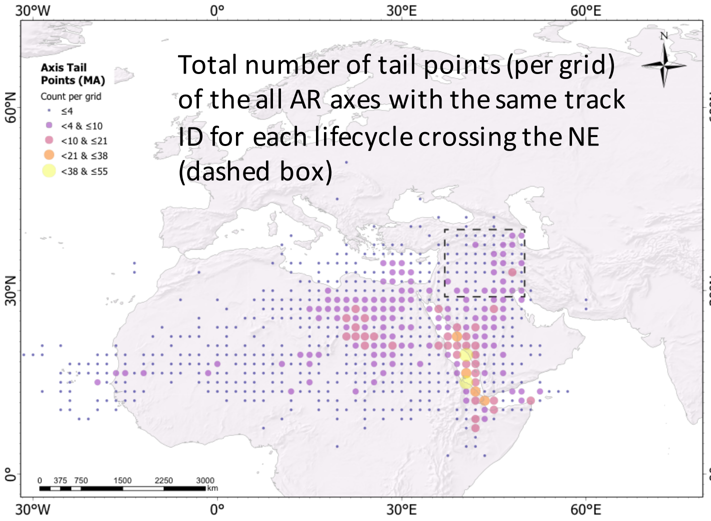
AR climatology

a)

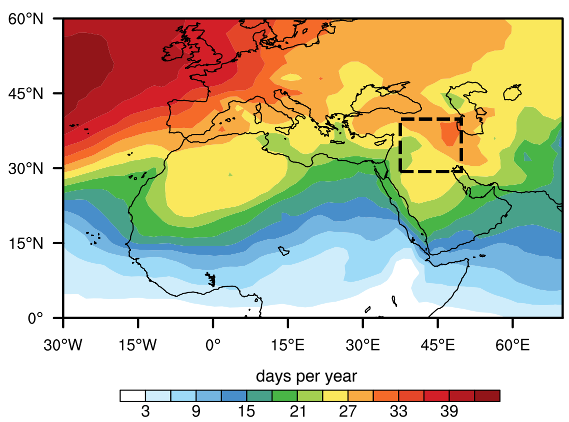


b)

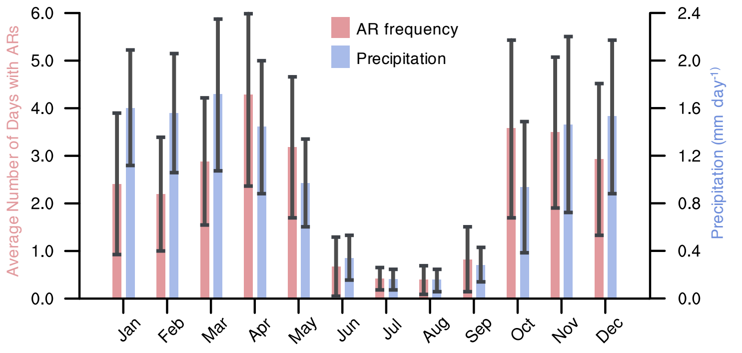


- More than half of the ARs crossing the NE are weak. Strong ARs (>~ 275 kg m−1 s−1) are relatively rare (~8%) over Africa.
- The Red Sea tends to be a major source region of the ARs, yet, northeast Africa also exhibits considerable tail points of the ARs hitting the highlands of the NE.

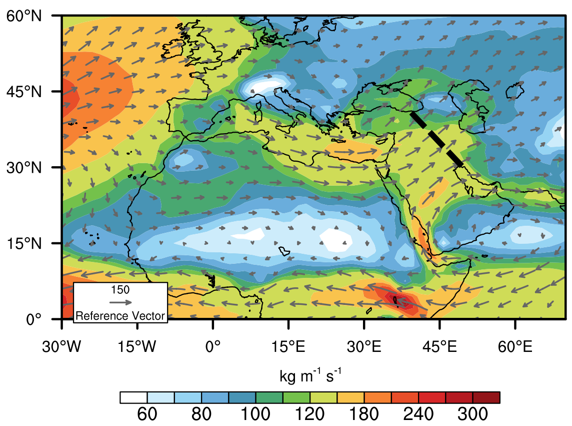
a) AR frequency



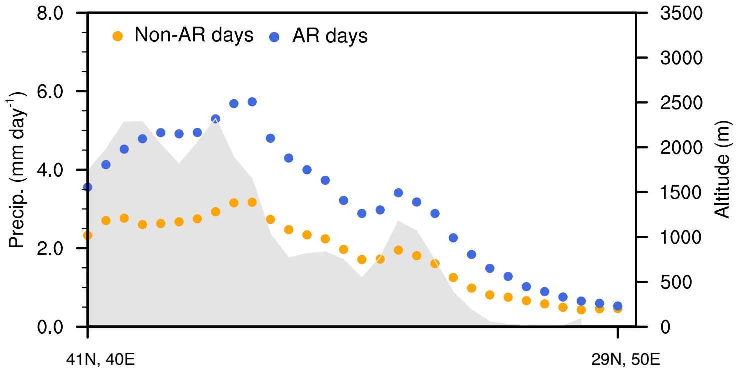
b) Annual cycle of AR frequency and precipitation



c) Mean IVT on AR days



d) Precipitation transect on AR days vs. non-AR days



- Long-term mean AR frequency exhibits that April has the most AR days in a year (~ 4 days per month) and March also has relatively frequent AR days (~ 3 days per month).

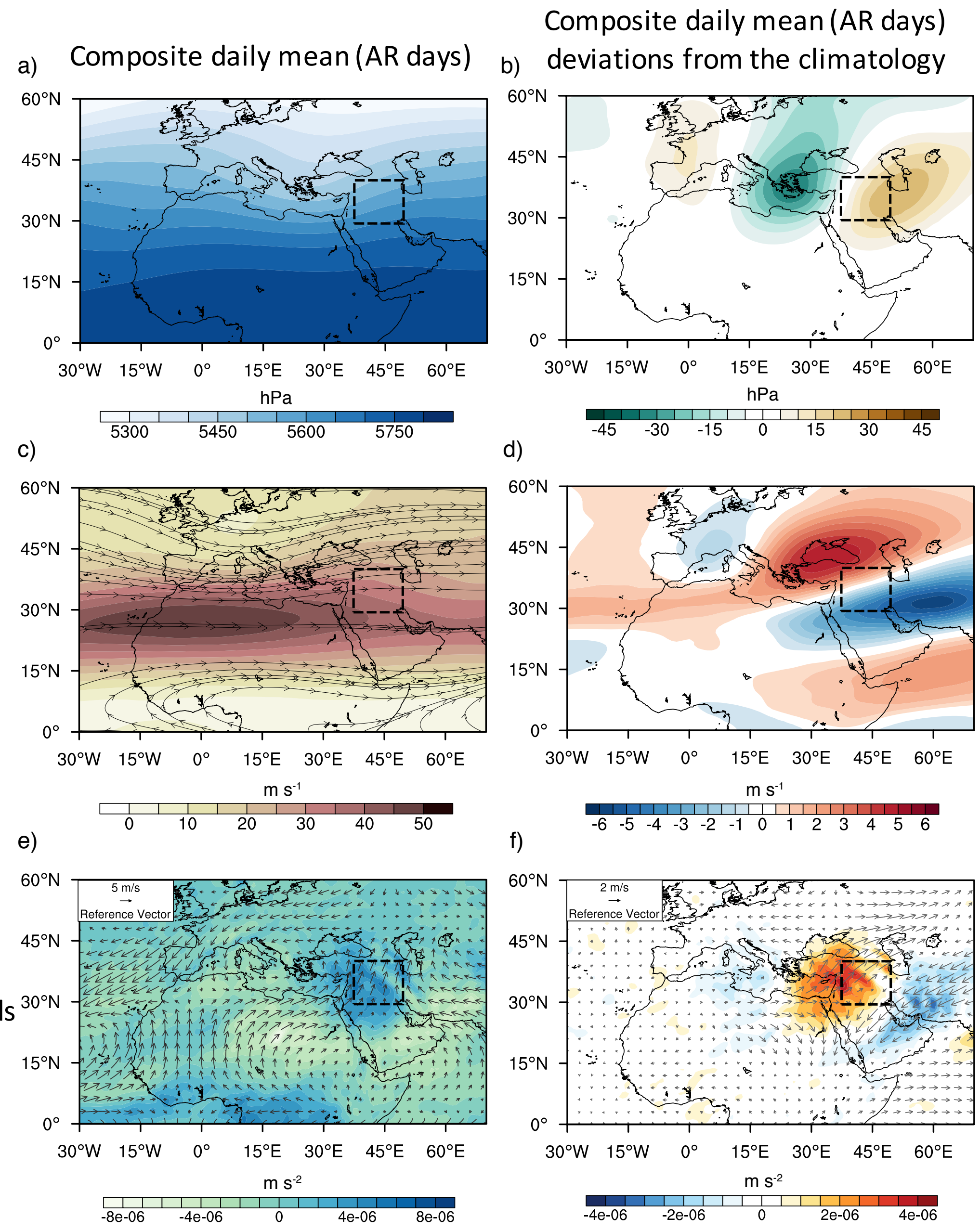
- Orographically enhanced precipitation (ERA-Int) over the highlands with AR conditions.

Synoptic conditions during the AR events

500 hPa
HGT

200 hPa
Jet stream

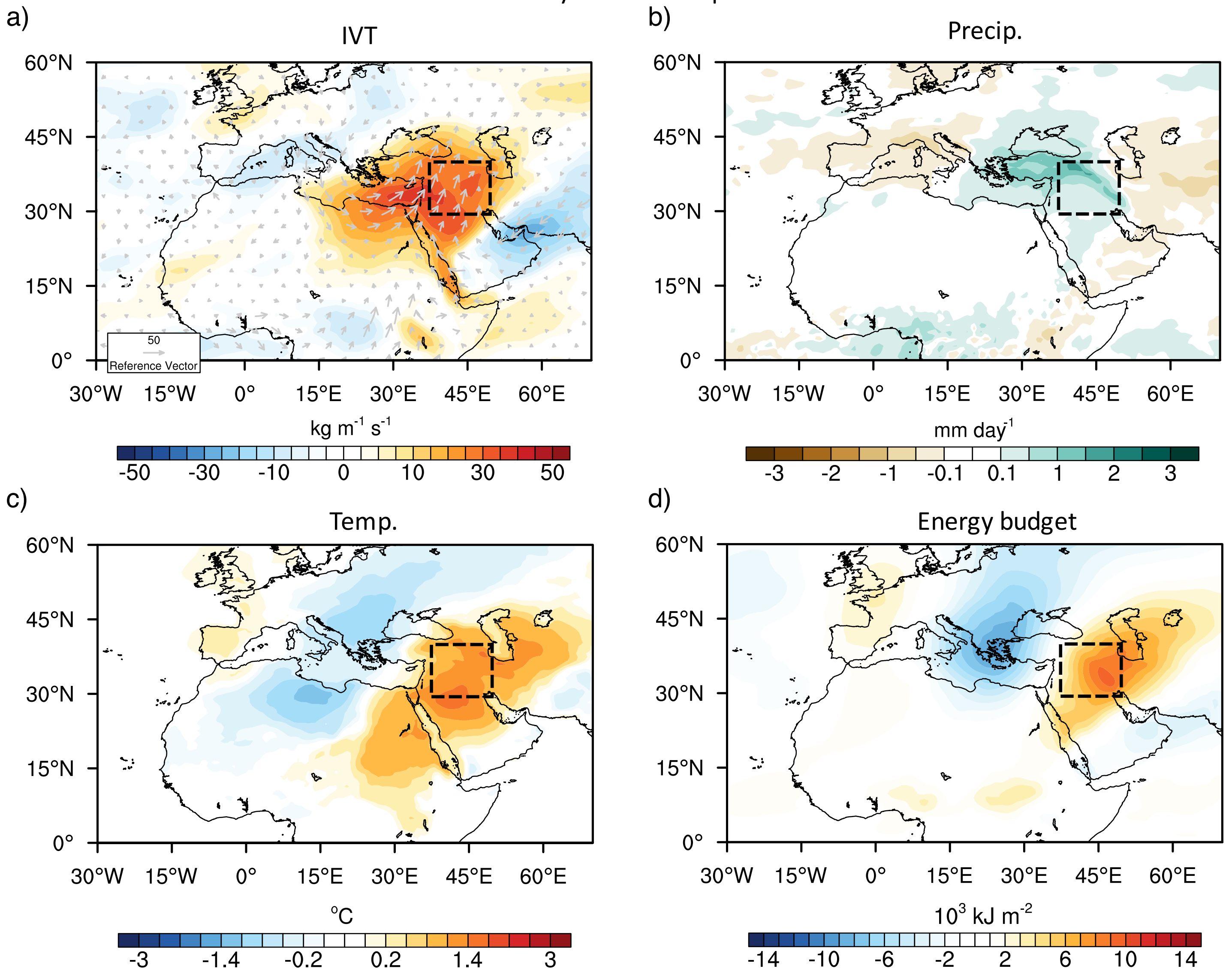
200 hPa
divergence fields
and divergent
wind vectors



- In general, ARs hitting the highlands of the NE are associated with the eastern Mediterranean trough over the Balkan Peninsula and a blocking anticylone on the eastern flank of the trough, over the NE-Caspian Basin.
- By increasing the amplitude of the midlatitude upper layer trough, this blocking anticyclone causes the extension and penetration of the northerly cold air masses to the subtropical regions.
- This pattern then triggers and accelerates westerly/southwesterly tropical humid air flow towards the NE.

Hydroclimatological impacts of the AR events

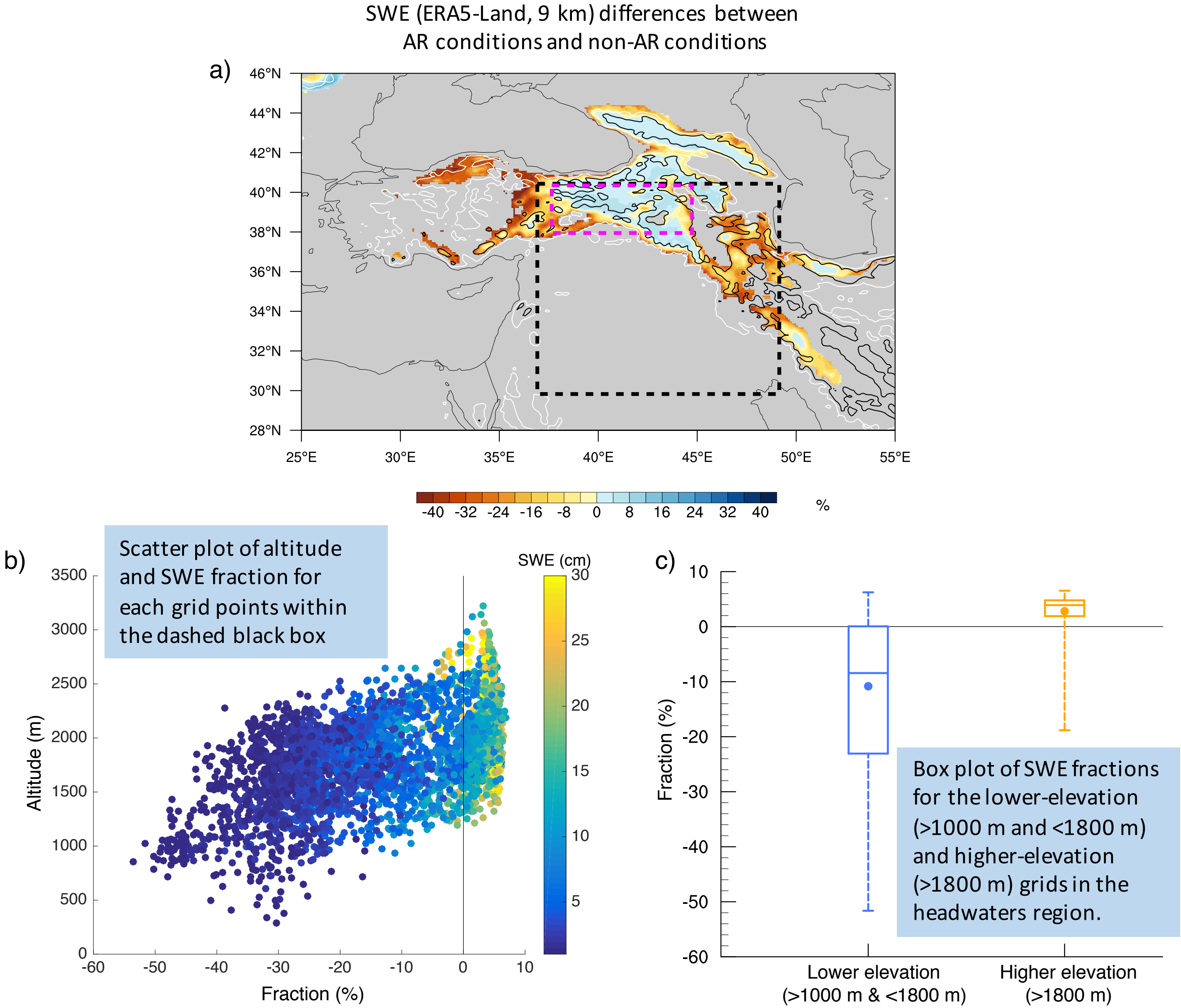
Composite daily mean deviations from the climatology (ERA-Int, 1979-2017) for AR days in March-April season



The Near East is wetter (up to +2 mm day^{-1}) and warmer (up to +1.5°C) on AR days compared to all-day climatology.

- Enhanced IVT over the eastern Mediterranean.
- Following the anomalous IVT pattern, the eastern Mediterranean region shows a general increase in precipitation, in particular, over the Taurus and Zagros mountains.
- Warmer temperature anomalies (up to +1.5◦C) take place over the NE and northeast Africa, whereas cooler anomalies exist (~ −1◦C) over the central Mediterranean and Europe.

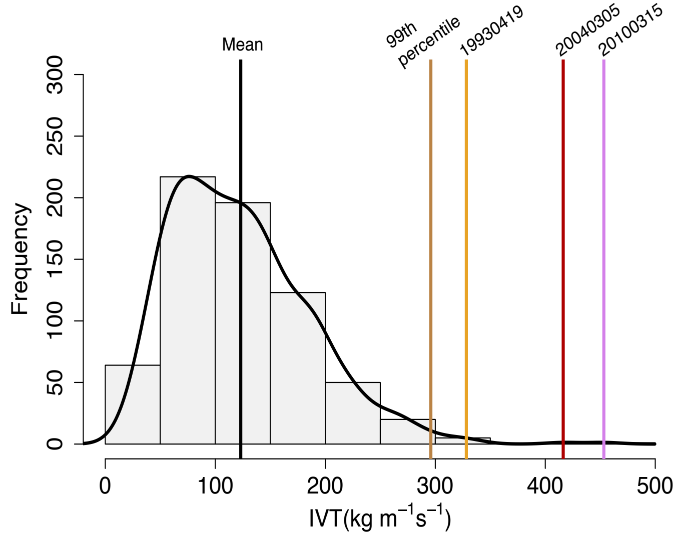
Hydroclimatological impacts of the AR events



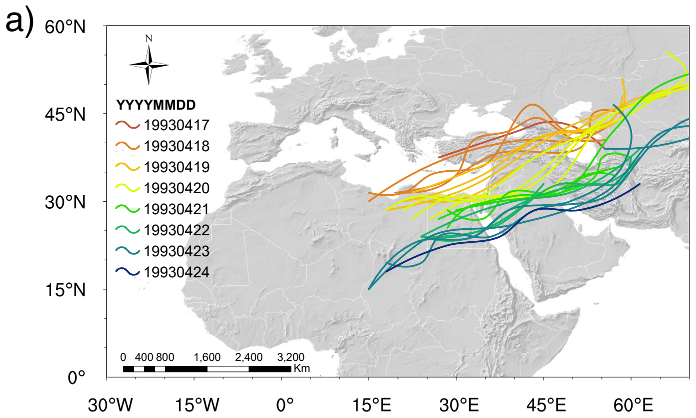
- On AR days, while snowpack tends to decrease (up to 30%) in the Zagros Mountains, it can show decreases or increases in the Taurus Mountains depending largely on elevation.
- Box plot analysis exhibits a notable decrease in SWE for the lower-elevation grids (mean value is −11%) with a large variability (between ~−50% and ~+6%). On the other hand, snow water equivalent (SWE) tends to increase at grids mostly above 1800 m (black contour) on AR days (mean value is ~3%) in the headwaters region.

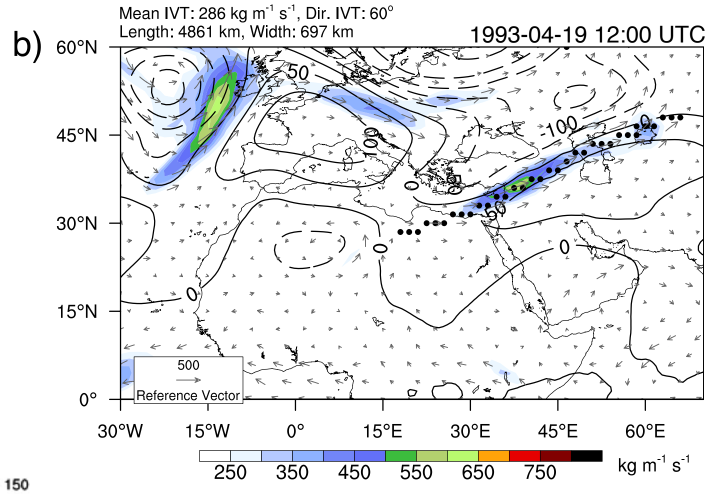
Extreme AR cases

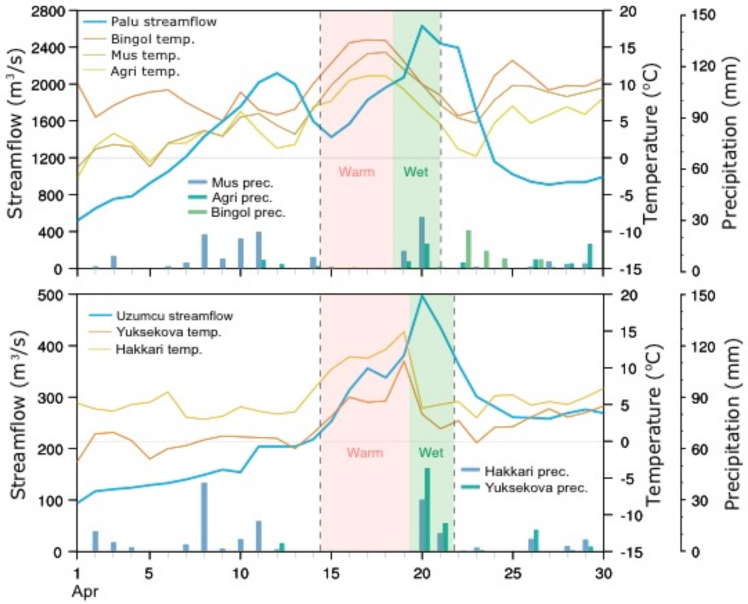
April 1993 case

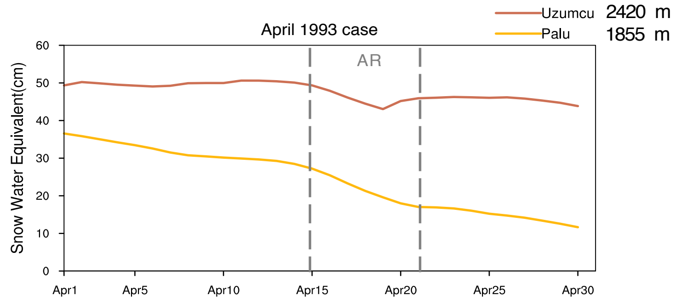


Long-term (1979-2017) frequency analysis of daily mean IVT for AR days in MA season for a region covering the headwaters of the Euphrates and Tigris rivers. The vertical black and orange lines correspond to the long-term mean and **99th percentile**, respectively. The yellow, red, and violet lines correspond to the extreme case of **19 April 1993**, **5 March 2004** and **15 March 2010**, respectively.



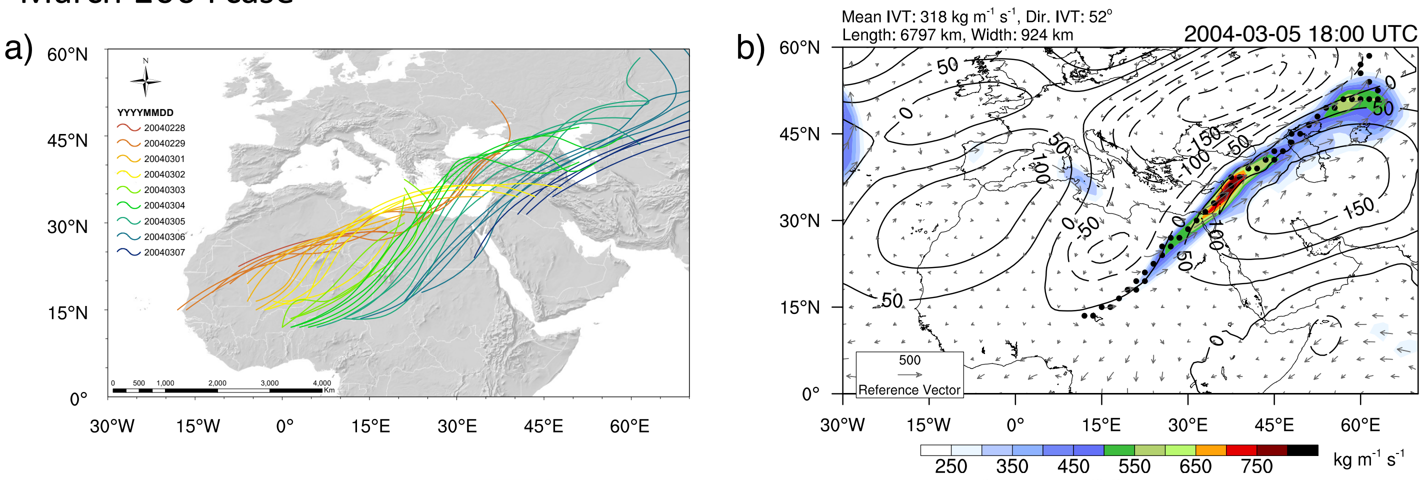


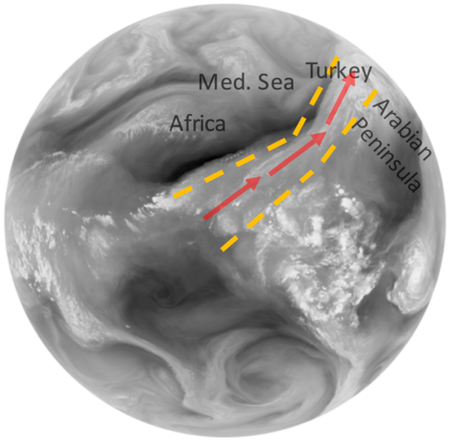


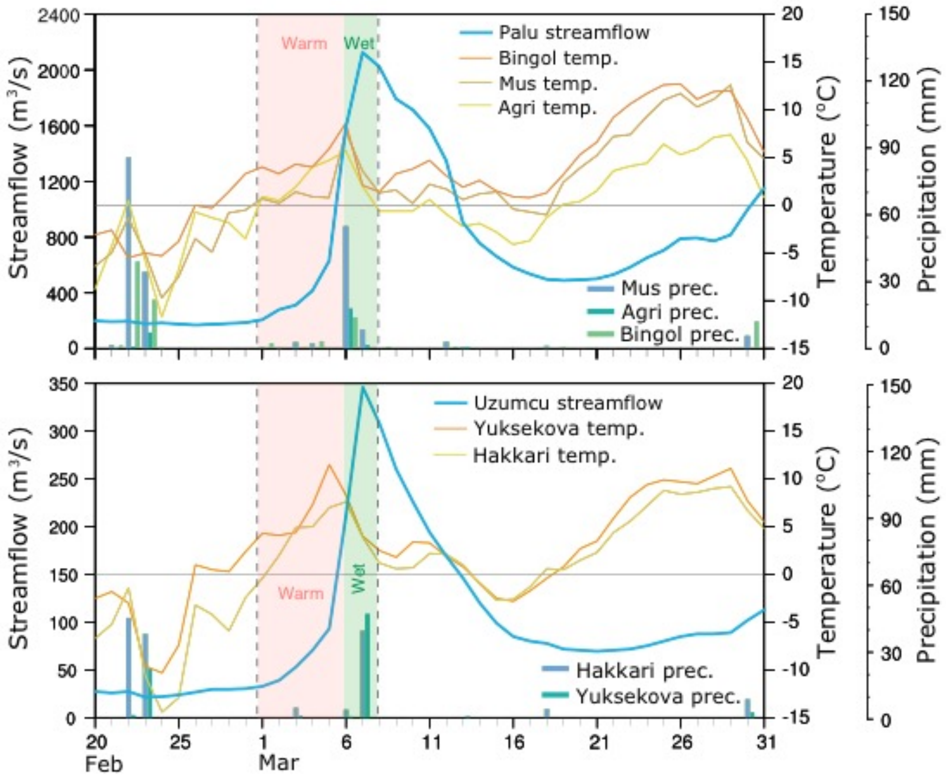


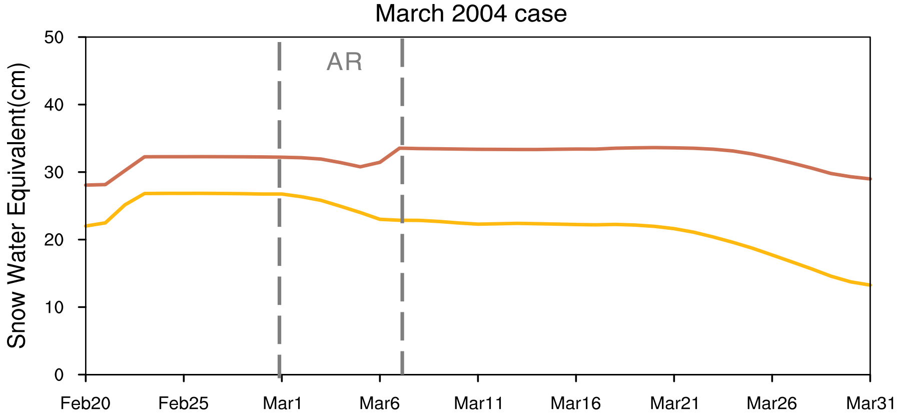
- During the AR period, stations exhibited a dry and warm period accompanied with snowmelt, and increases in discharge. When the AR hit the mountainous region with the largest IVT, surface stations recorded precipitation (up to 50 mm day^{-1}), causing the discharges to make a peak.
- During the height of the event, SWE decreased in the relatively low-elevation Palu Basin, indicating the contribution of rain-on-snow precipitation to the snowmelt. On the other hand, it slightly increased in the higher-elevation Uzumcu Basin.

March 2004 case





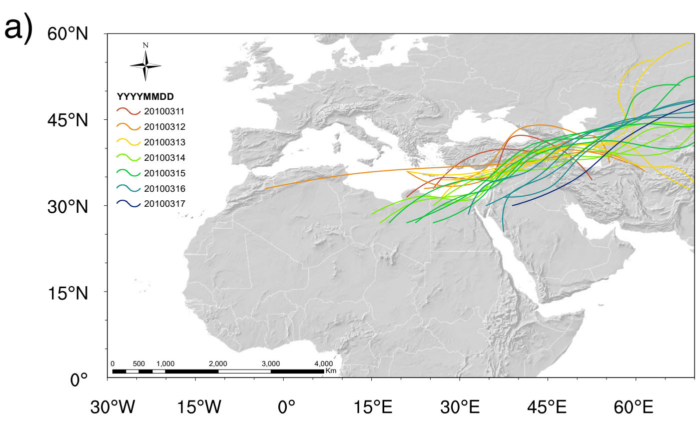


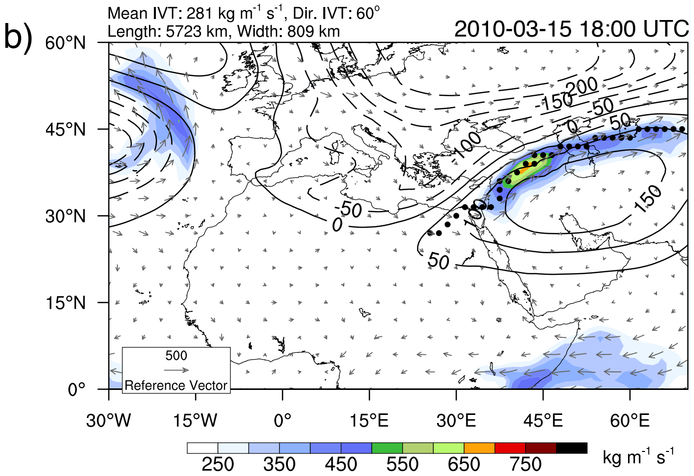


- The event notably exhibited an anomalous deepening of the Mediterranean trough toward central Africa resulting in a relatively long fetch of moisture transport.
- Combined effect of snowmelt during the warm period and precipitation events resulted in unprecedented snowmelt runoff amounts in the Euphrates and Tigris basins.

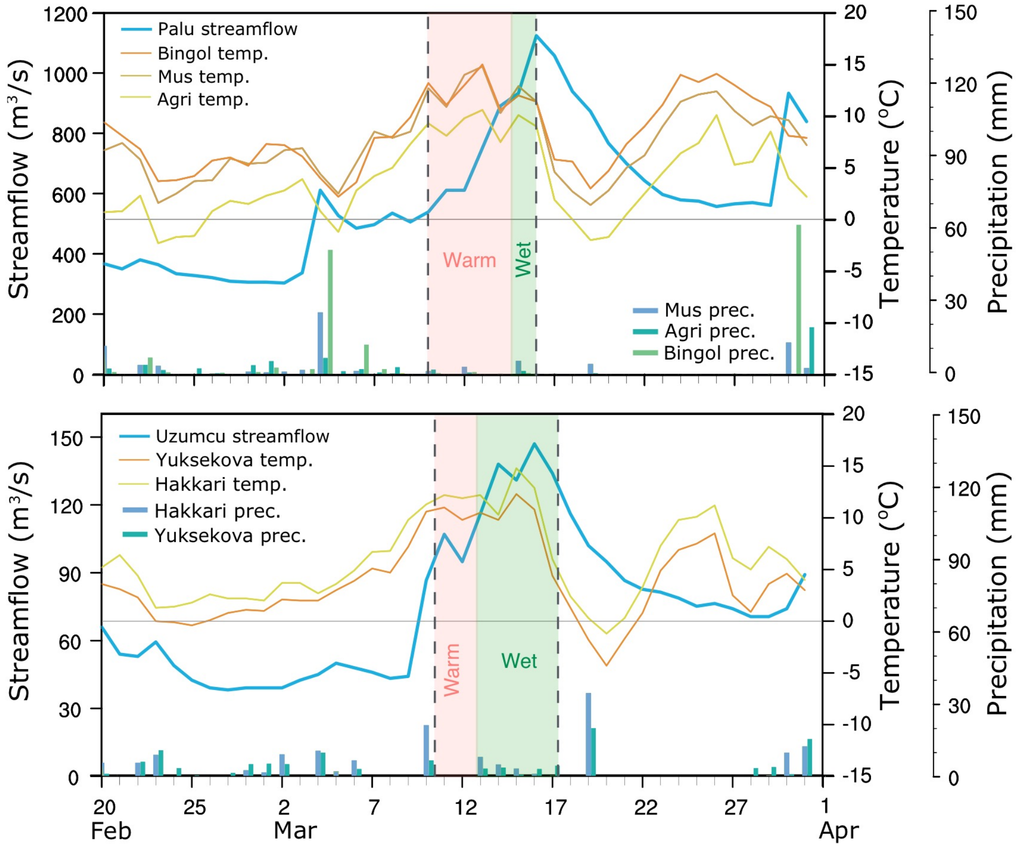
Bozkurt, D., Ezber, Y., Sen, O.L., 2019. Role of the East Asian Trough on the eastern Mediterranean temperature variability in early spring and the extreme case of 2004 warm spell. Climate Dynamics, 53(3-4), 2309–2326, https://doi.org/10.1007/s00382-019-04847-5.

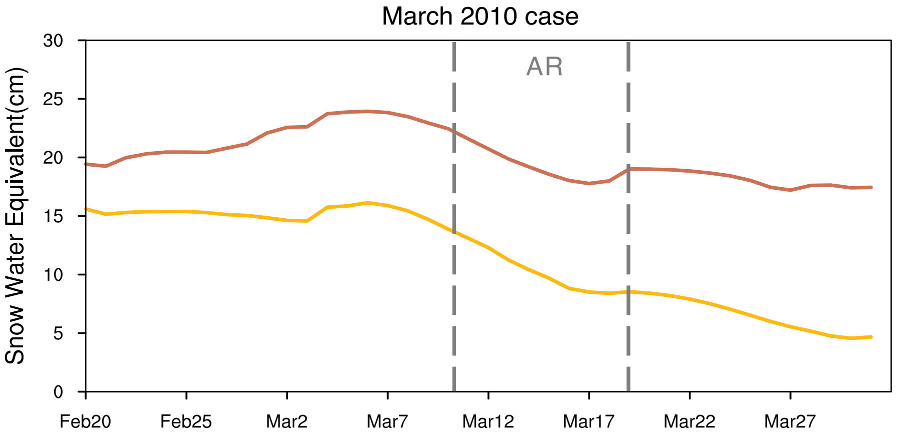
March 2010 case





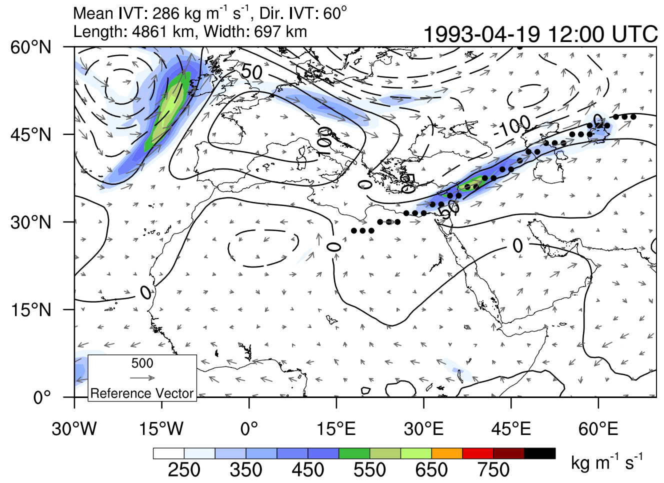
The AR originated from over northeast Africa, and similar to the previous cases, ridge and trough formations over the NE-Caspian Basin and eastern Europe-Balkan Peninsula, respectively, favored the narrow moisture transport corridor towards the eastern Anatolia.



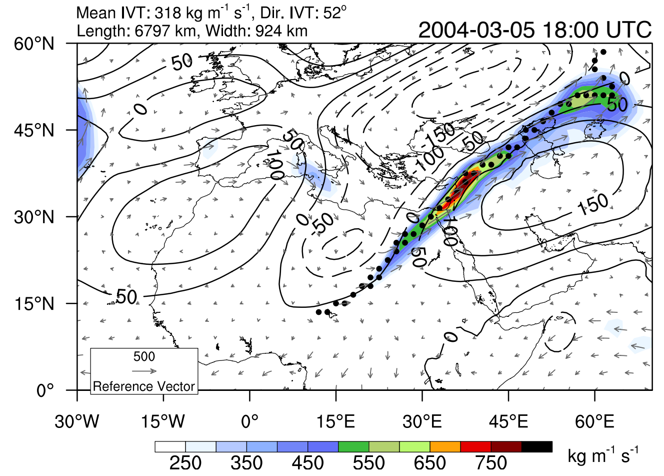


Notable decreases in SWE were captured in both basins during the warm period, while the higher-elevation Uzumcu Basin showed a slight increase in SWE during the wet period.

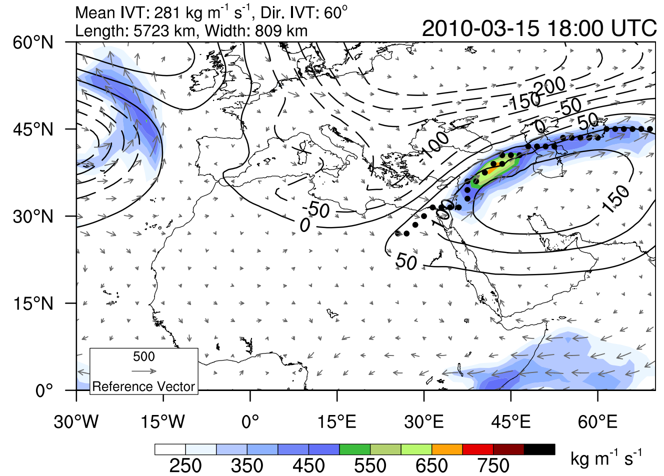
April 1993



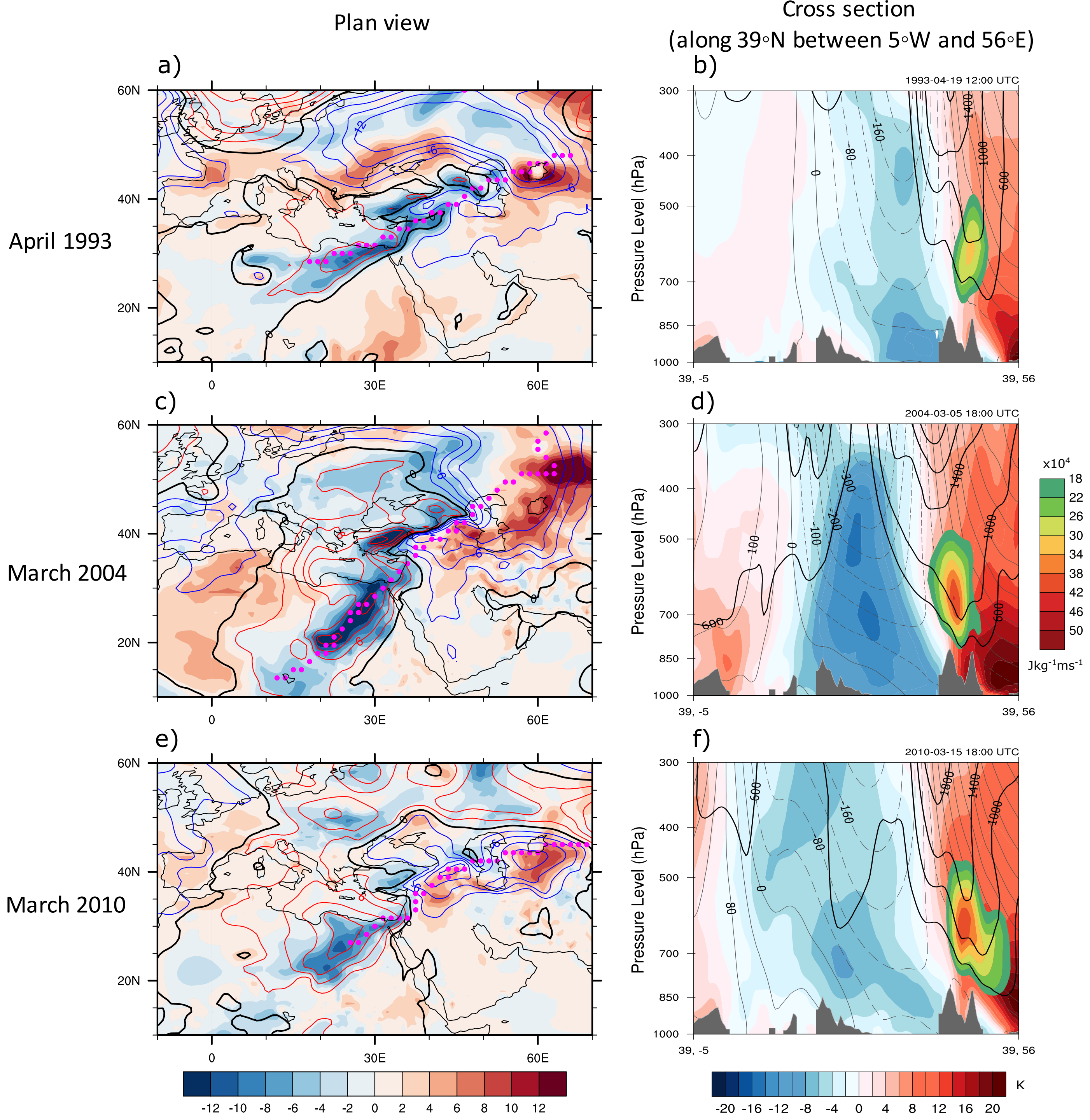
March 2004



March 2010



- Analysis of the three extreme cases suggests that the ARs can influence the hydrometeorology of the Near East's highlands by producing precipitation.
- Snowmelt and form of precipitation depend on several factors including magnitude of associated heat advection and topographic height and aspect. In all three cases, however, the ARs seem to increase the river discharges substantially.
- The response of AR characteristics in the cases of individual extreme events could be different and depends largely on the position and strength of the trough-ride patterns.
- We can also speculate that more northeasterly-oriented ARs (mean angle is between 30◦ to 60◦) can favor more perpendicular flow towards the southwest-facing crescent-shaped mountain ranges of the NE and increase IVT convergence on the uphill side.



- During the events, typically, there was a low pressure center over central or eastern Anatolia with a warm front extending towards Caspian Sea and a cold front extending towards northeast Africa, and the ARs were found to be aligned with the cold front.
- Aloft, the ARs were located along the eastern flanks of the troughs, where zonal temperature anomaly was positive.
- The core of the latent heat transport concentrated around 700 hPa over the highlands of the NE during the events, and contributed to precipitation events.
- Sensible heat was also transported at large quantity, which increased the surface temperatures over the NE highlands significantly.
- The combined effect of both heat transports, therefore, contributed to rises in discharge by melting the snowpack in the highlands.

Key results

- African atmospheric rivers (ARs) can transport tropical humid air towards the Near East in the melt season.

- AR days exhibit enhanced precipitation over the crescent-shape orography of the Euphrates-Tigris Basin in March-April.

- The ARs are typically associated with the eastern Mediterranean trough over the Balkan Peninsula and a blocking anticyclone over the NE-Caspian region.

- The Near East is wetter (up to +2 mm day^{-1}) and warmer (up to +1.5°C) on AR days compared to all-day climatology.

- Depending on the elevation, snowpack can show notable decreases (up to 30% below 1800 m largely in Zagros Mountains) and slight increases (up to 8% over 1800 m largely in Taurus Mountains) on AR days compared to all non-AR days.

- A further analysis with observations and reanalysis indicates that ARs coinciding with large scale sensible heat transport can influence surface hydrometeorology by precipitation, snowmelt and increasing daily discharges.

Open questions

- What is the role of large-scale atmospheric teleconnection patterns in driving the Mediterranean trough and Arabian Peninsula-Caspian blocking anticyclone, and thus, atmospheric rivers?
    - NOA
    - ENSO
    - MJO
    - IOD
- Can the ARs be beneficial for snowpack in winter season? Or are there fingerprints of surface melt events in winter season too?
- Is there a direct and robust relationship between historical floods of the Mesopotamia and ARs?
- Local-scale contributions to snowmelt: Foehn events triggered by ARs on the leeward sides of the Mesopotamian highlands as well as mountain ranges along the Black Sea?