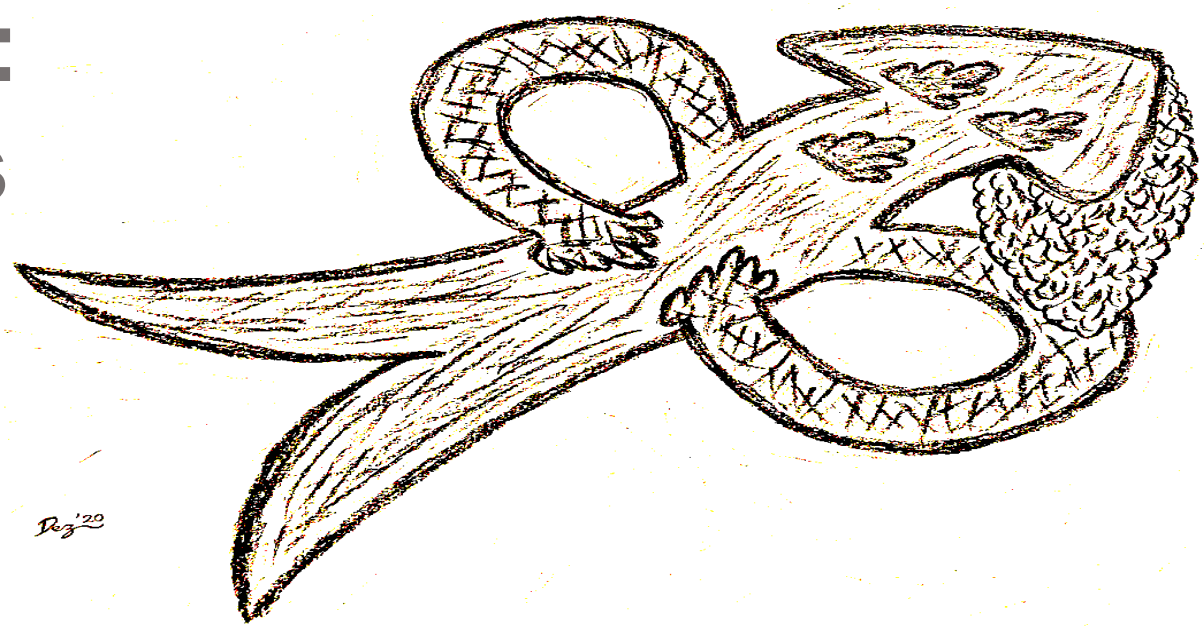
Climate change & extreme events in the Middle East: mechanisms and impacts



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NASA GSFC & UMBC

Nov 8, 2023 – University of Arizona (virtual)

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- Global Modeling and Assimilation Office (GMAO) Core funding, provided under NASA's Modeling, Analysis and Prediction (MAP) program.
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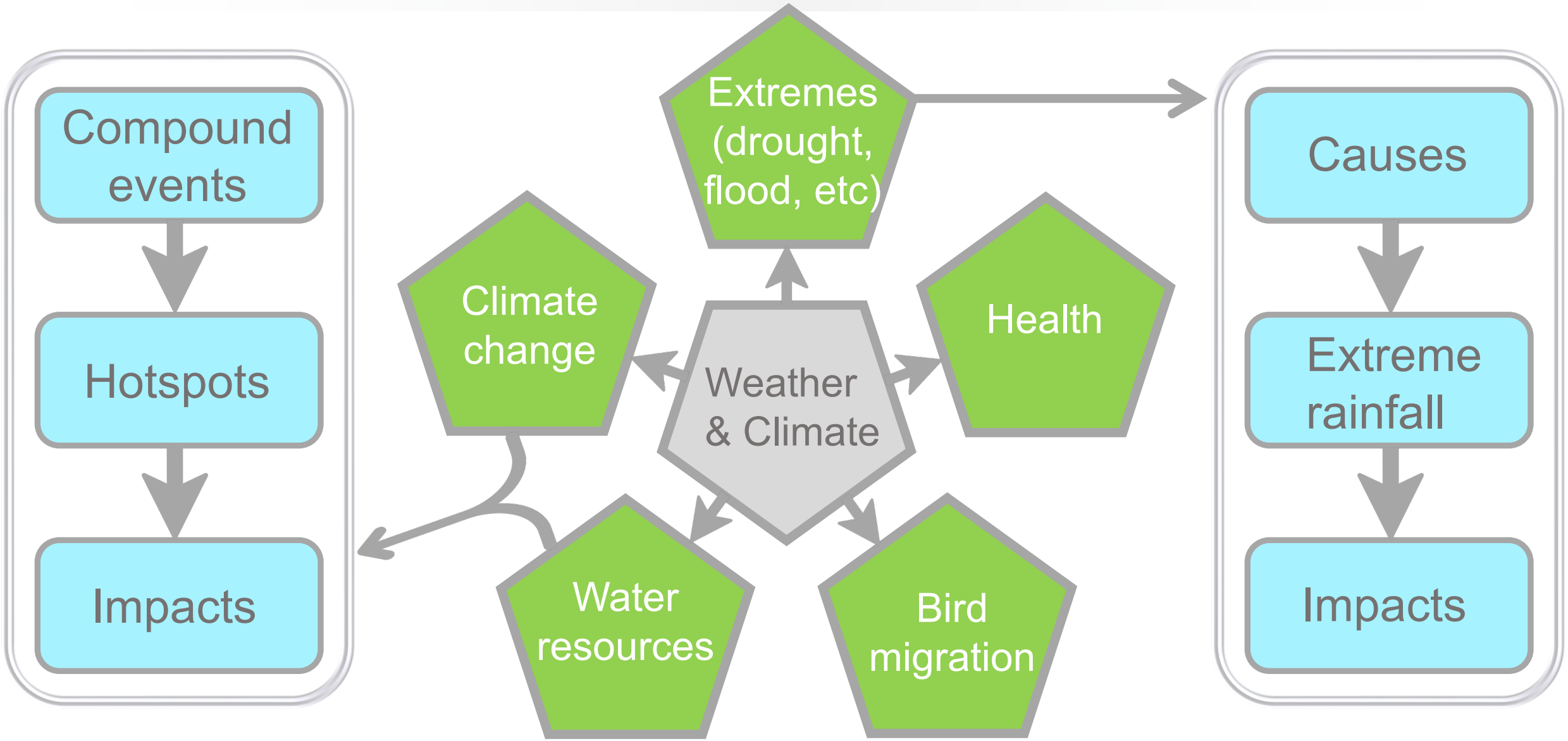
Acknowledgments:

- Members of the GMAO NCA group: Michael Bosilovich, Allison Collow, Randal Koster, Young-Kwon Lim, Sarith Mahanama, Siegfried Schubert, Natalie Thomas.

My Research Interests: Past, Current, and Future Directions



PART 1 Atmospheric Rivers caused record floods & dust. Are they predictable?

PART 2 2021: record heat and drought caused socio-environmental crises.

PART 3 Climate change increases future transboundary water conflicts.

PART 1 **Atmospheric Rivers caused record floods & dust. Are they predictable?**

PART 2 **2021: record heat and drought caused socio-environmental crises.**

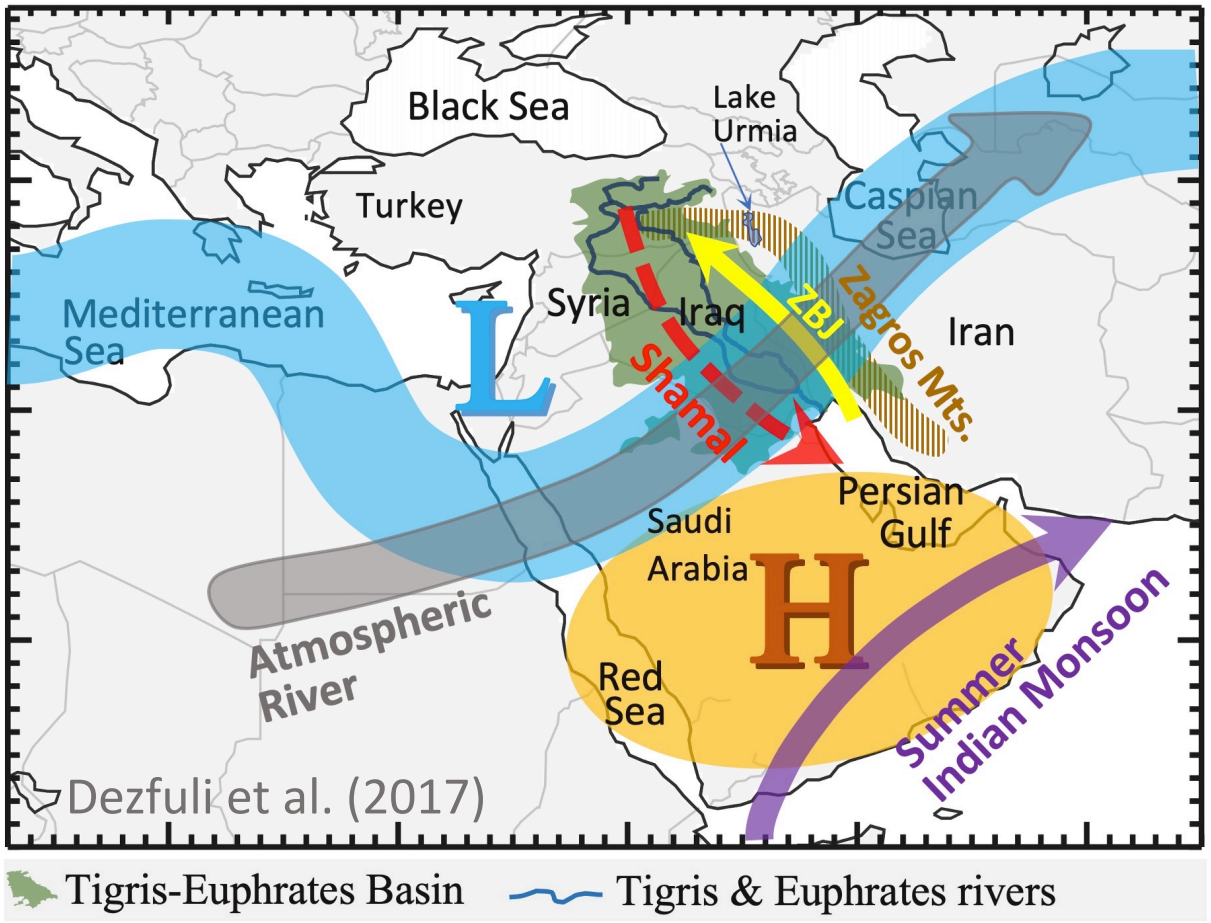
PART 3 **Climate change increases future transboundary water conflicts.**

Climate-related Issues in the Middle East

- **Region prone to natural disasters:**
  - Devastating floods, prolonged droughts, drying lakes, …
  - Syrian unrests partly attributed to prolonged droughts (Kelley et al. 2015).
  - More cardiovascular, respiratory, ... diseases caused by dust storms (Soleimani et al. 2020).
- **Transboundary water resources conflicts:**
  - GAP project rises tension between Turkey, Iraq and Syria (Jongerden 2010).
- **Uncertain future projections:**
  - Rainfall increase in south & decrease in north (Evans, 2009).
  - More prolonged droughts by the end of the century (Tabari and Willems, 2018).

It is crucial to know: why/where/when/how much it rains in the region!

Drivers of Regional Weather & Climate

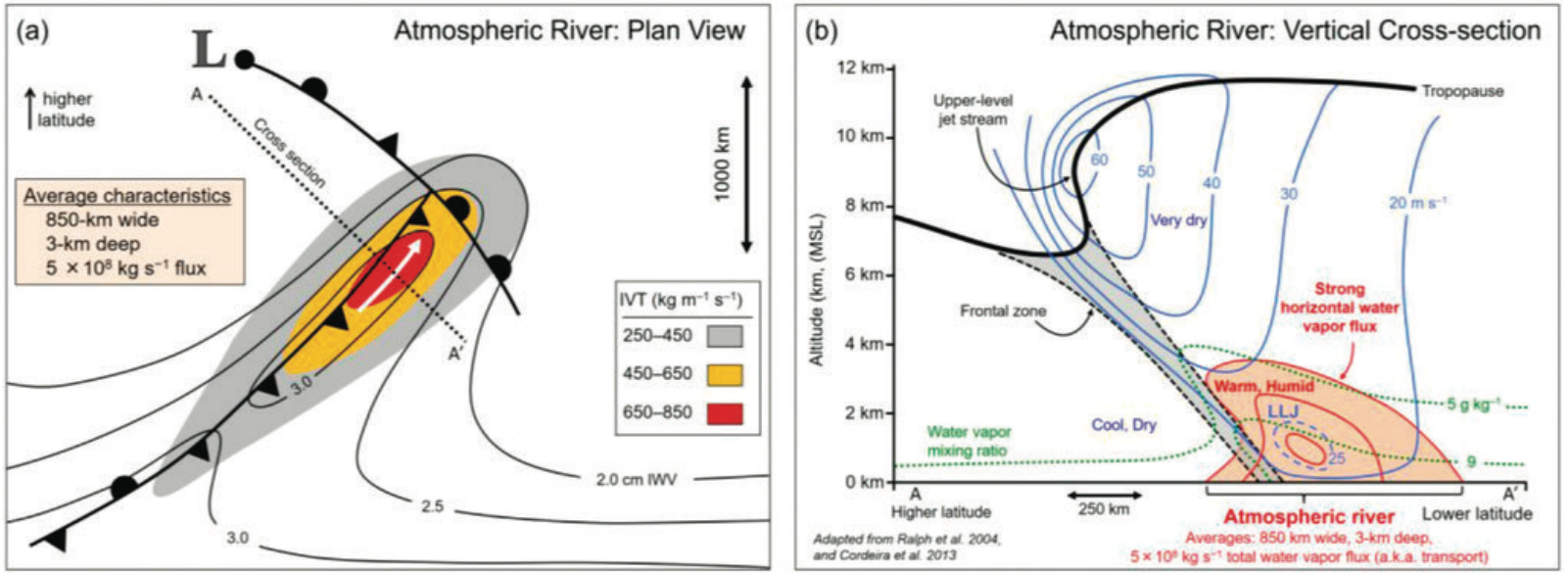


- **North:** mid-latitude cyclones in winter & spring
- **South:** summer Indian monsoon
- **Regional features:**
  - Zagros Mts.
  - Zagros Barrier Jet
  - Shamal winds (summer & winter)
  - Dust aerosols
  - Regional moisture sources
- **Atmospheric Rivers**

Weather & climate of the region is the result of interaction between several features, acting across spatio-temporal scales.

Atmospheric River – Definition from Glossary of Meteorology, AMS

- "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." Ralph et al. (2019)
- Identified by vertically integrated water vapor transport (IVT) > 250 kg m^{-1} s^{-1}.
- Or vertically integrated water vapor (IWV) – less common.



Atmospheric Rivers in the Middle East

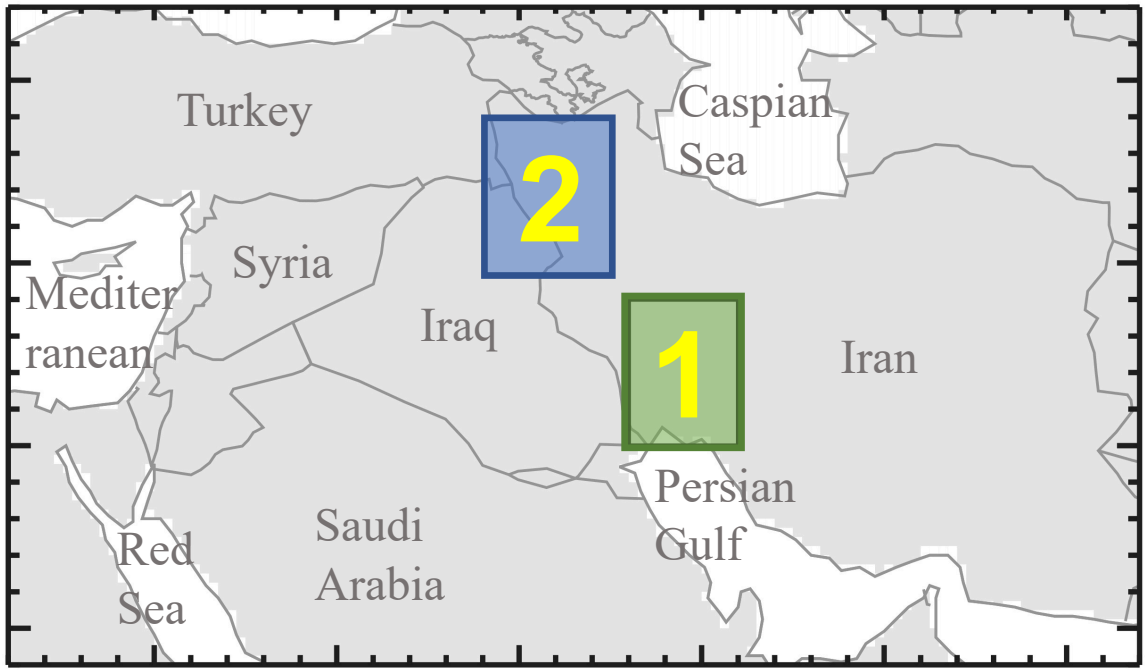
- Most AR research has focused on coastal regions of the western U.S. and Europe.
- Relatively little is known about mechanisms & impacts of ARs in the Middle East:
  - Some statistical properties (Akbary et al. 2019; Esfandiari & Lashkari 2021; Bozkurt et al. 2021):
  - ~13-30 ARs occur in the MENA annually.
  - Moisture is supplied from the Atlantic Ocean, Red and Arabian Seas.
  - ARs account for 20–50% of total heavy precipitation in Iran.
  - ARs most common in April.
  - AR frequency is projected to increase in northern part (Massoud et al. 2020).
- Much more to learn: mechanisms, moisture flux of ARs, particularly those associated with heavy floods, dust transport and interaction with ARs, their predictability, …

CASE 1

Record floods of March 2019

CASE 2

April 2017 floods in northwestern Iran



Data

- **Atmospheric & soil variables:**
  - MERRA-2 Reanalysis (Modern-Era Retrospective Analysis for Research and Applications, version 2)
- **Precipitation:**
  - Daily and monthly GPCP (Global Precipitation Climatology Project)
  - Daily and monthly IMERG (Integrated Multi-satellitE Retrievals for GPM)
- **Sea Surface Temperature (SST)**
  - OISST (NOAA Optimum Interpolation SST V2)
- **Weather forecast model:**
  - GEOS (Goddard Earth Observing System) version 5.16

CASE 1

Record floods of March 2019

Scale of the floods and consequences

- Unprecedented floods across the Middle East; Iran hit hardest.
- Affected 26 out of 31 provinces in Iran.
- Early estimates: $2.5 billion worth of damage to infrastructures, homes, agriculture, ...

(Reuters, 2019)

(Photo courtesy of Internet Archive)

Scale of the floods and consequences

- Damaged one-third of the country's roads.
- Destroyed 700 bridges.
- Death toll of at least 76.
- Forced mass emergency evacuations.

(Reuters, 2019)

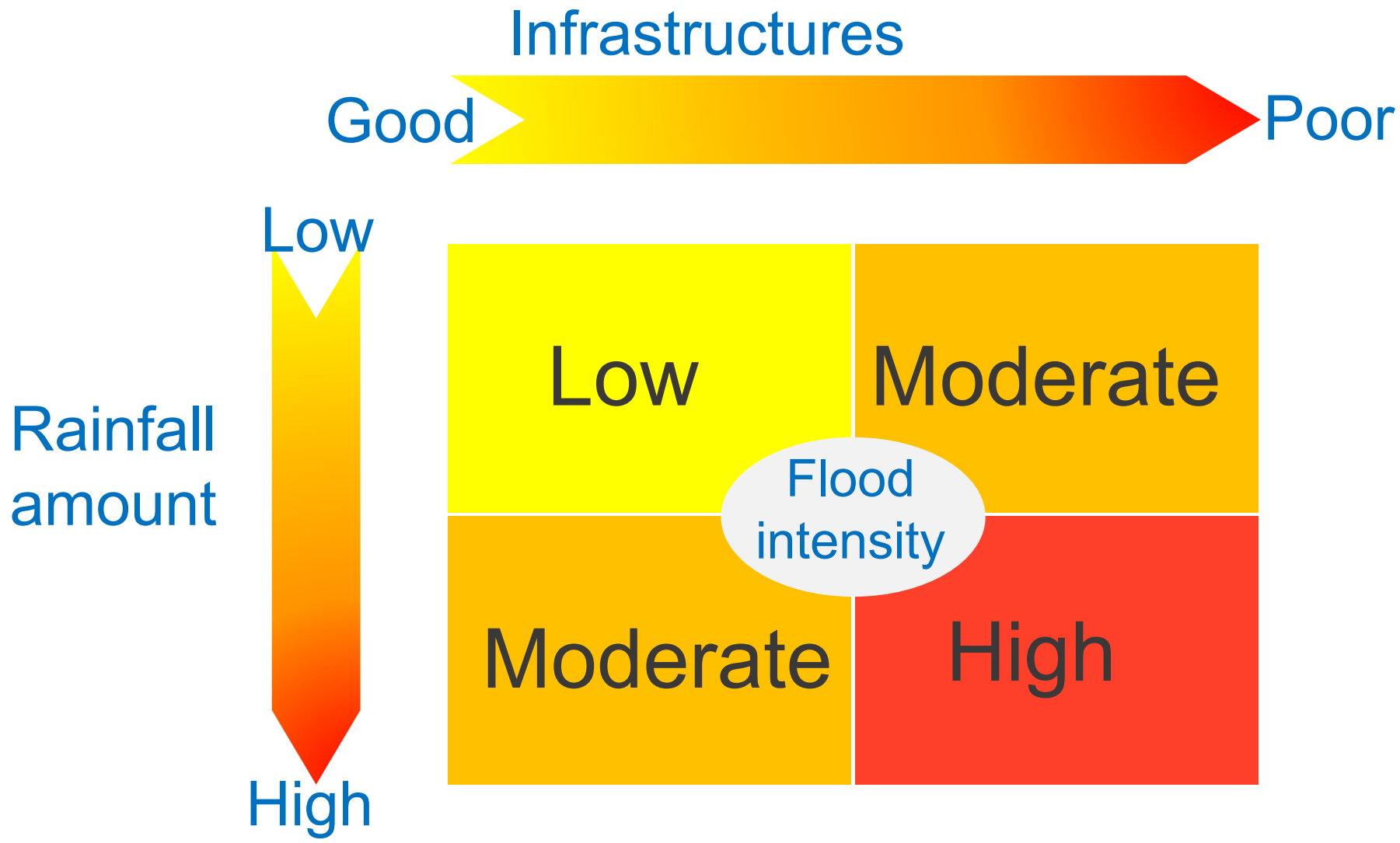
(Photo courtesy of Internet Archive)

Scale of the floods and consequences

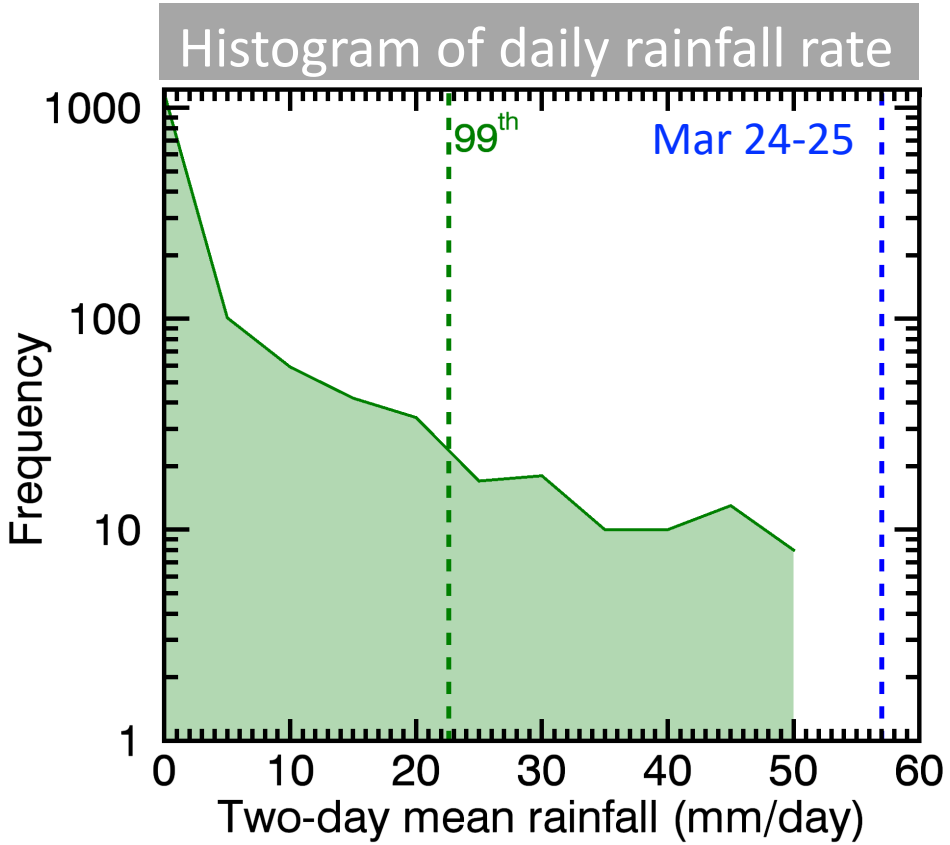
- Chance of flooding remained high several weeks after the event since major dams were brought to their maximum level and could not hold more water influx resulting from the snow melting in spring.
- People were wrestling with the aftermath of the crisis for months!

(Photo courtesy of Internet Archive)

What Causes an Extreme Flood? Multiple Factors, but Simply …



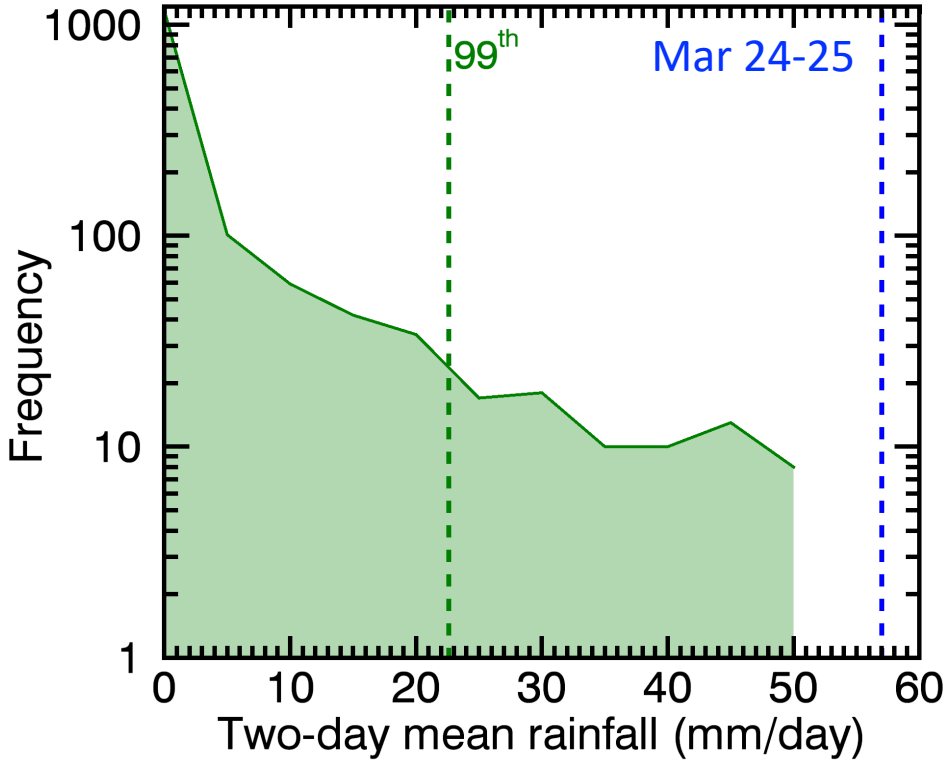
Comparing rainfall conditions in 2019 with the past



- March 24-25, 2019: the record two-day rainfall event

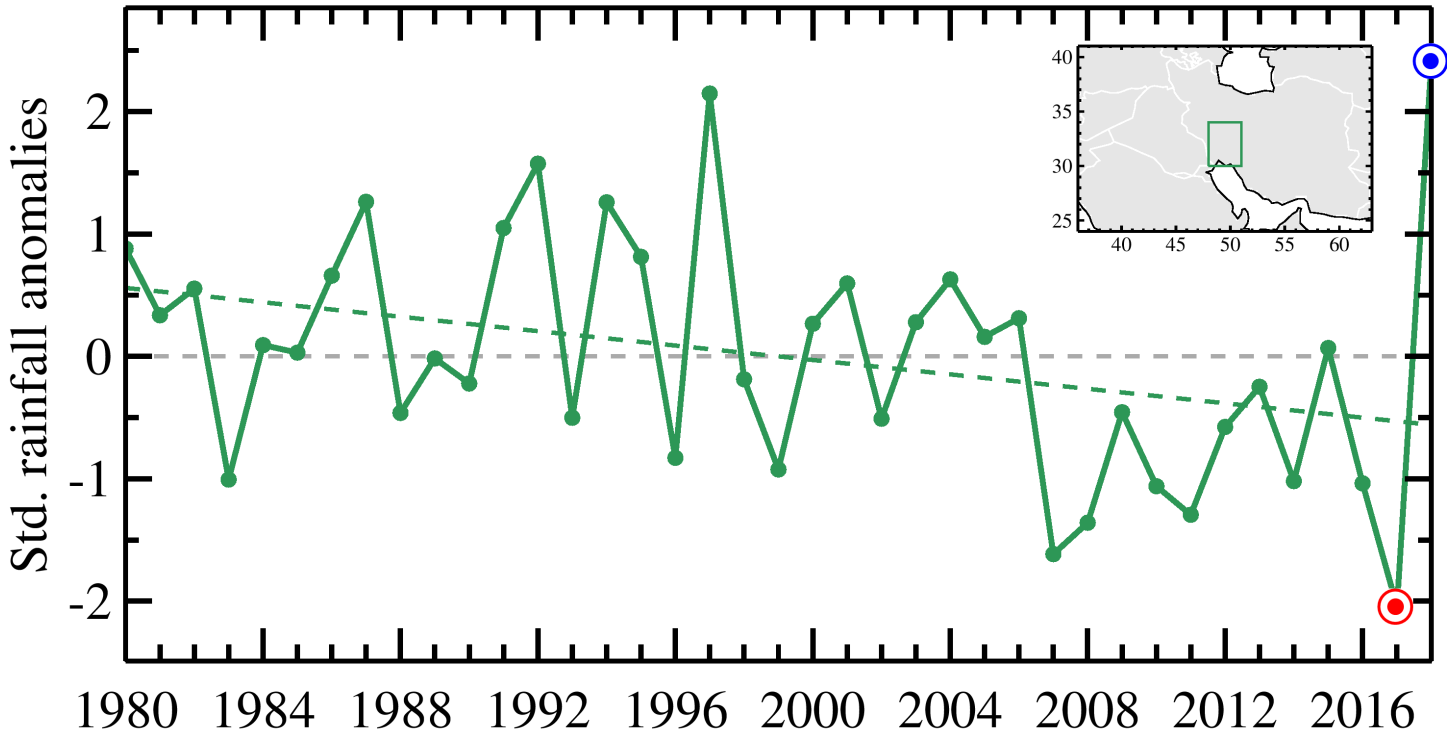
Comparing rainfall conditions in 2019 with the past

Histogram of daily rainfall rate



- March 24-25, 2019: the record two-day rainfall event

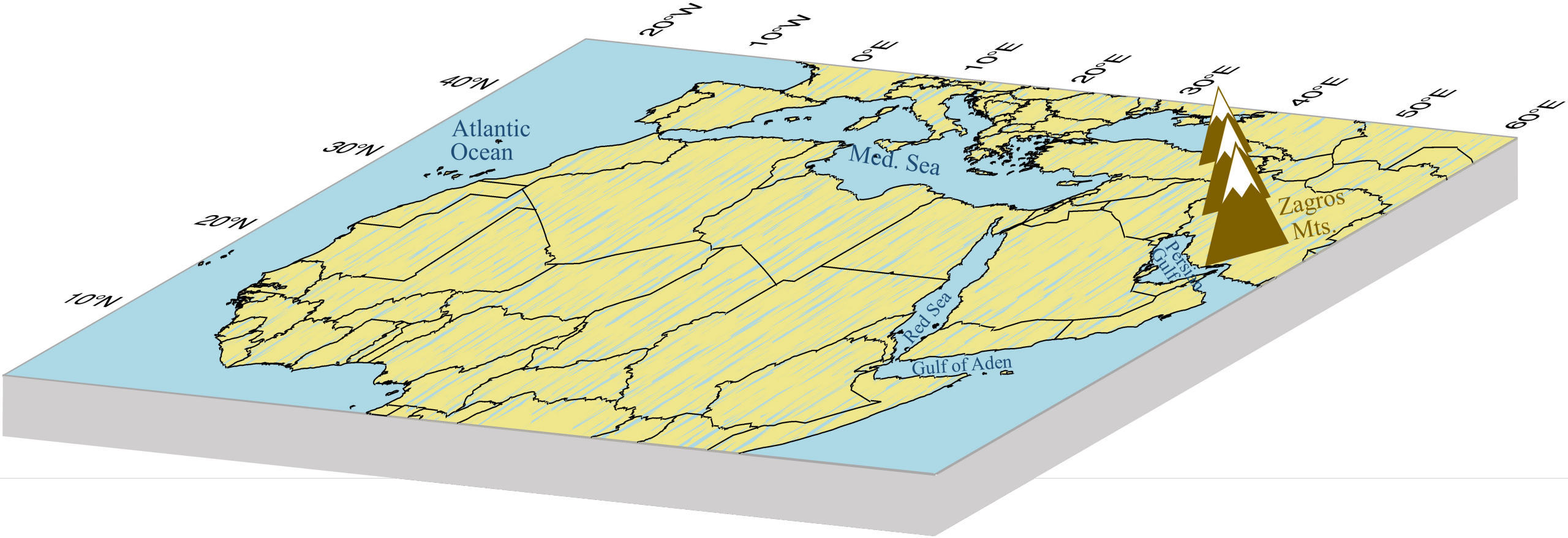
Year-to-year variability of seasonal (Oct-Mar) rainfall



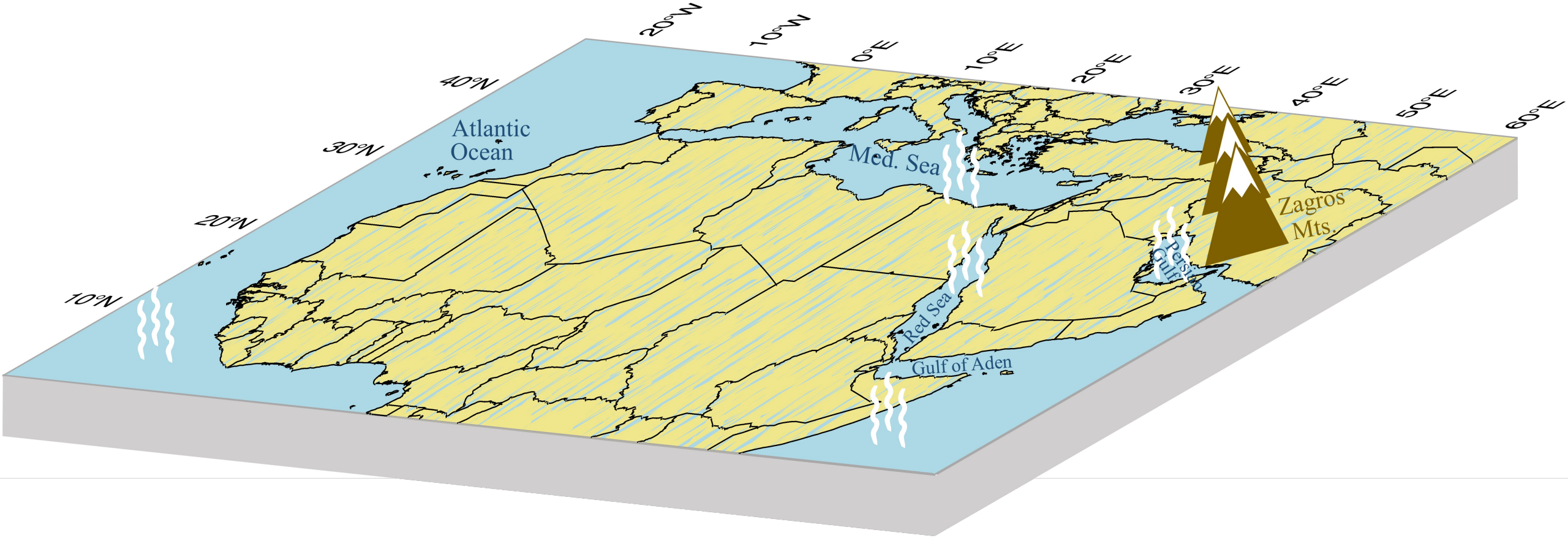
- 2017-18 to 2018-19: the most rapid dry-to-wet transition
- Increased chance of landslides

Story of record rainfall during March 24-25, 2019

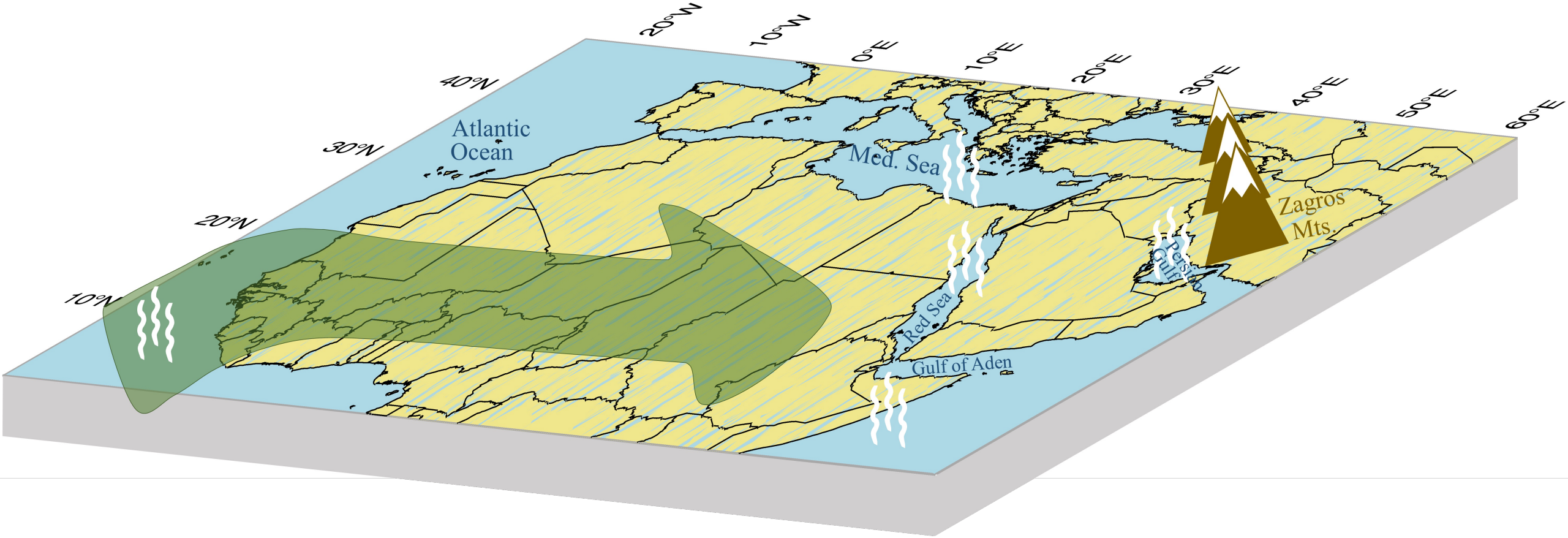
Geographical features affecting climate of Iran



All waters warmer than normal in March 2019 → more evaporation

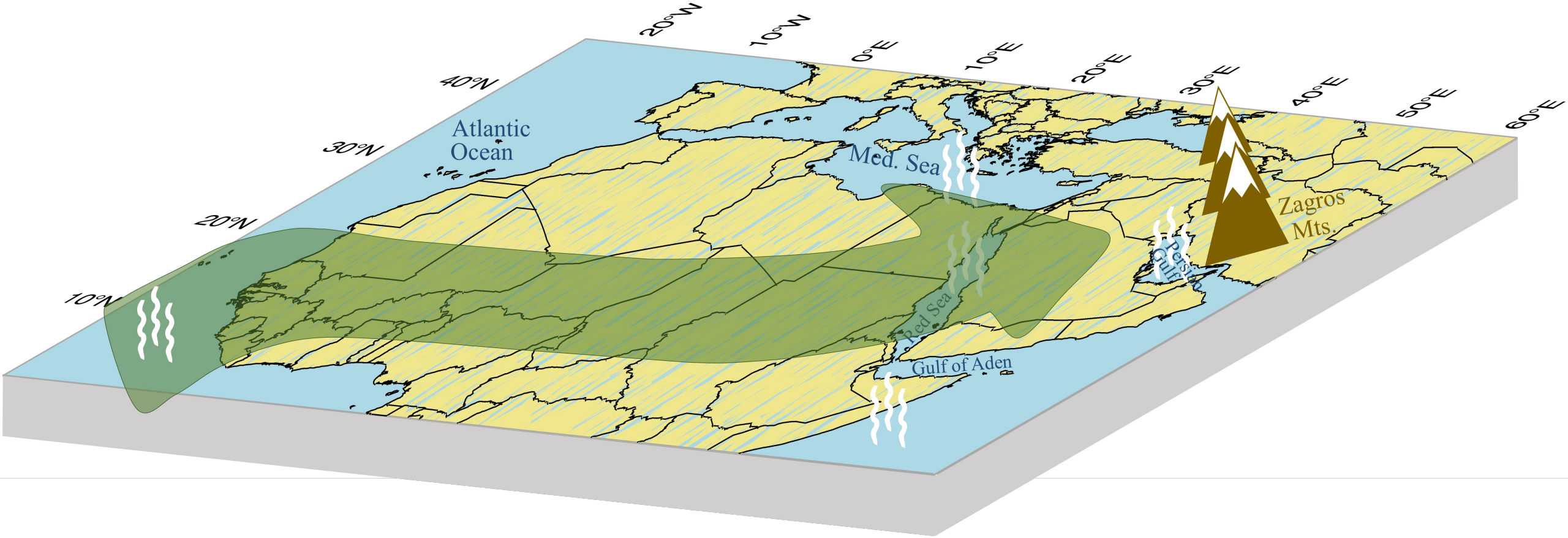


Subtropical jet (March 24-25): moisture transport from Atlantic

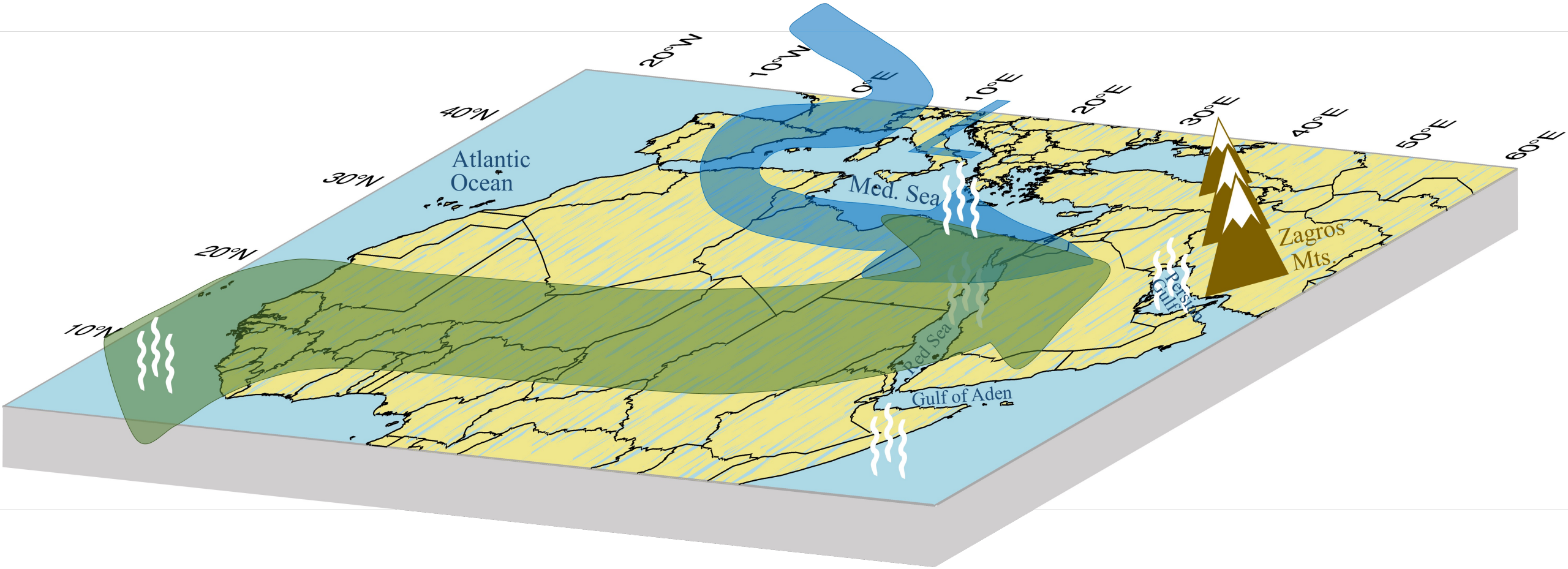


An Atmospheric River (AR) forms

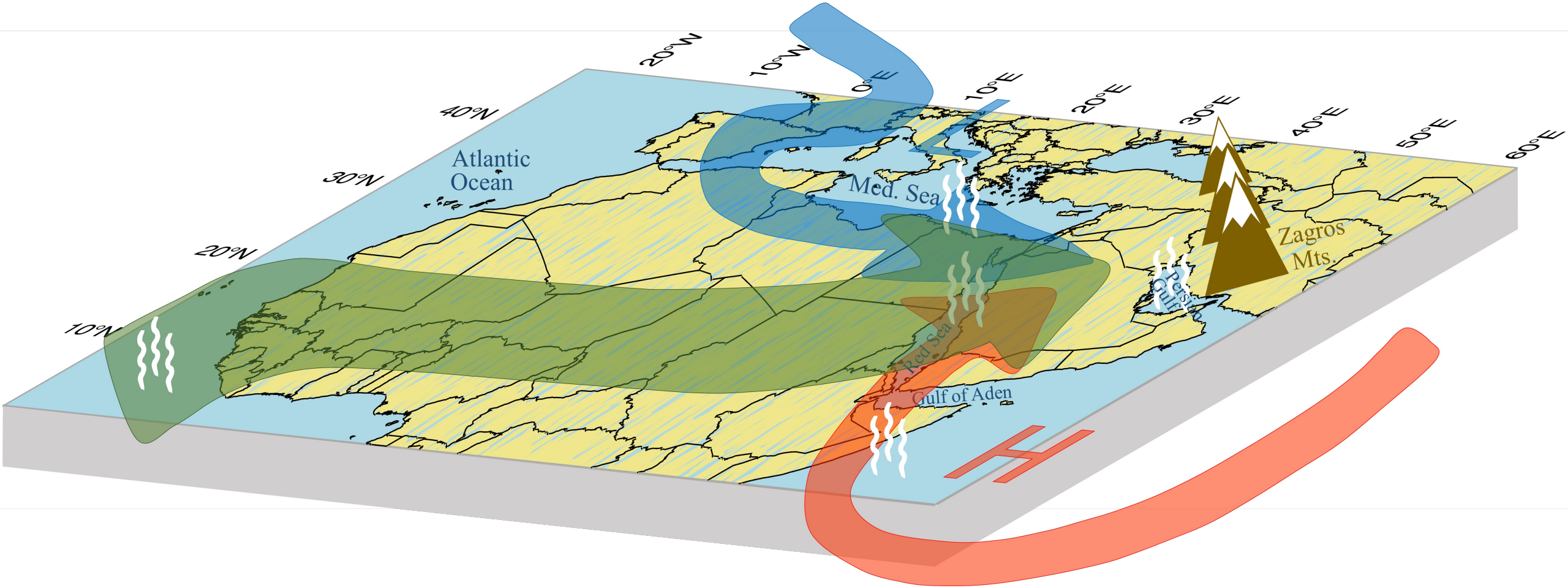
AR: long, narrow, and transient corridor of strong horizontal water vapor transport from tropical or extratropical moisture sources (*AMS Glossary*).



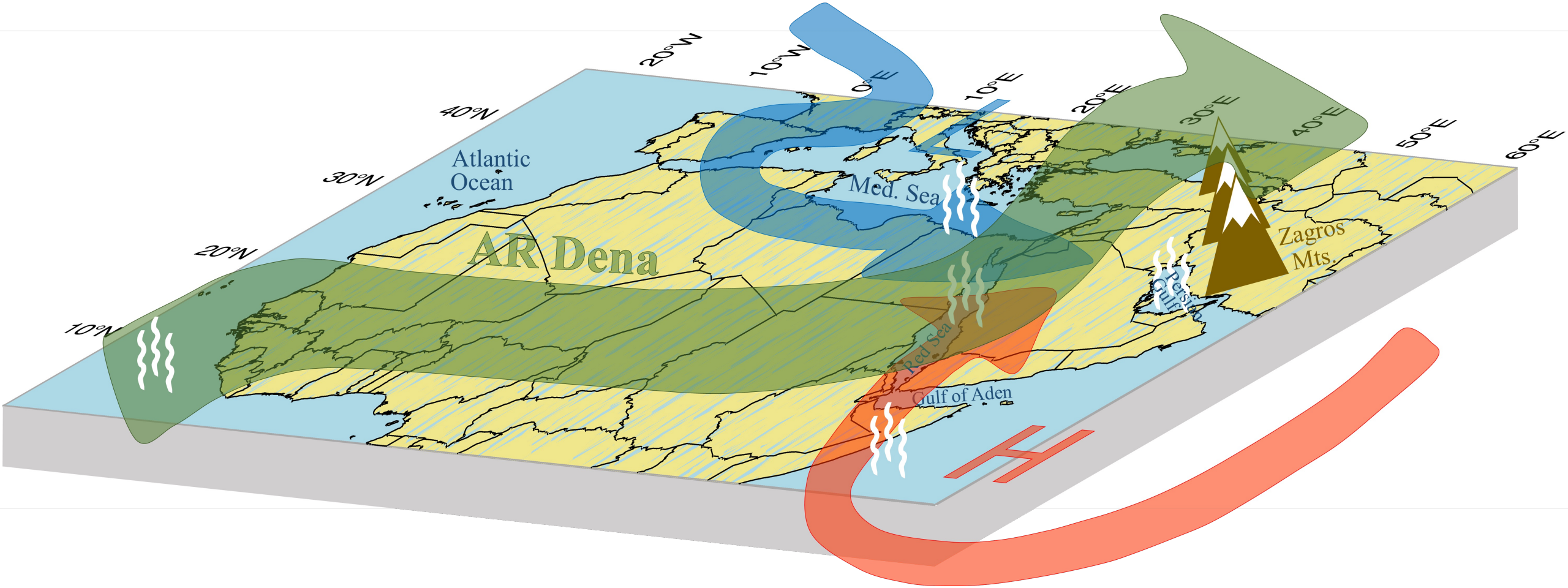
Low-pressure system: additional moisture from Mediterranean



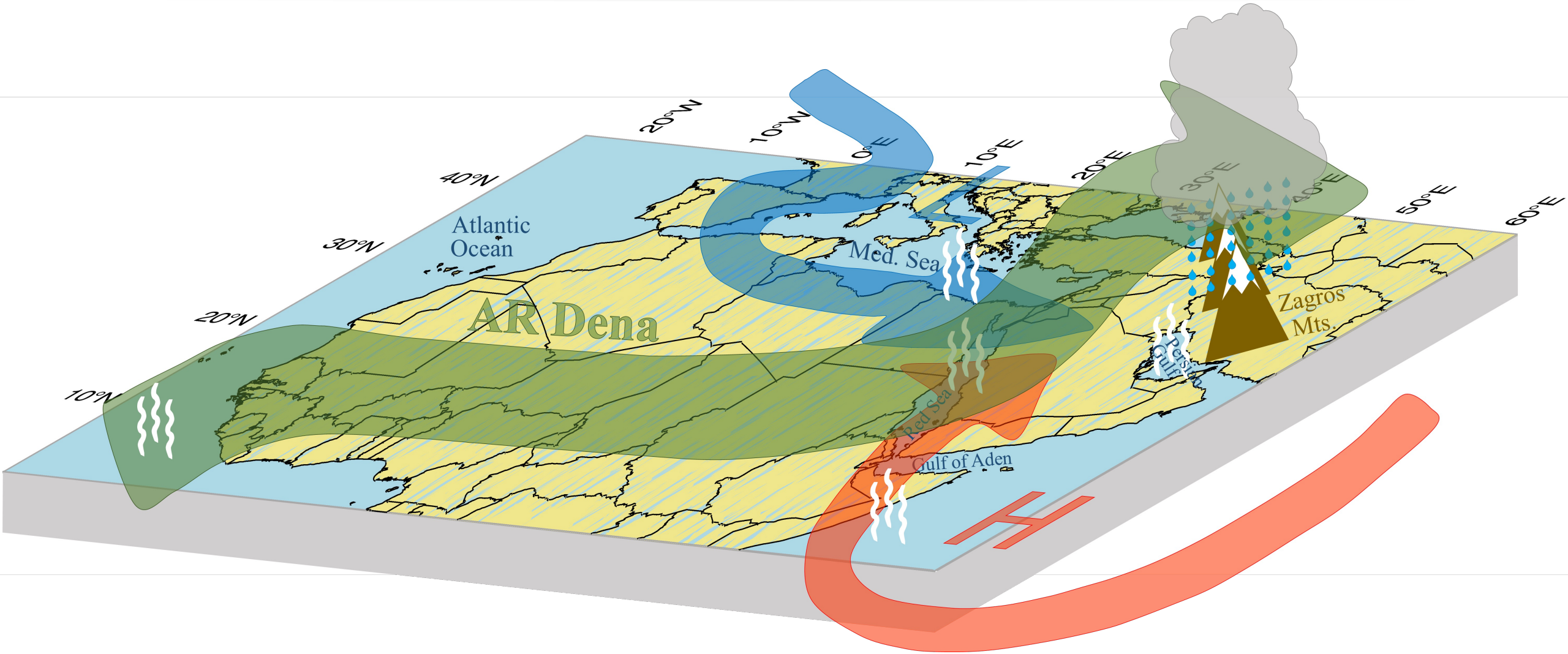
High-pressure system: more moisture from Red Sea, etc.



AR propagates further, hits Zagros, and rises

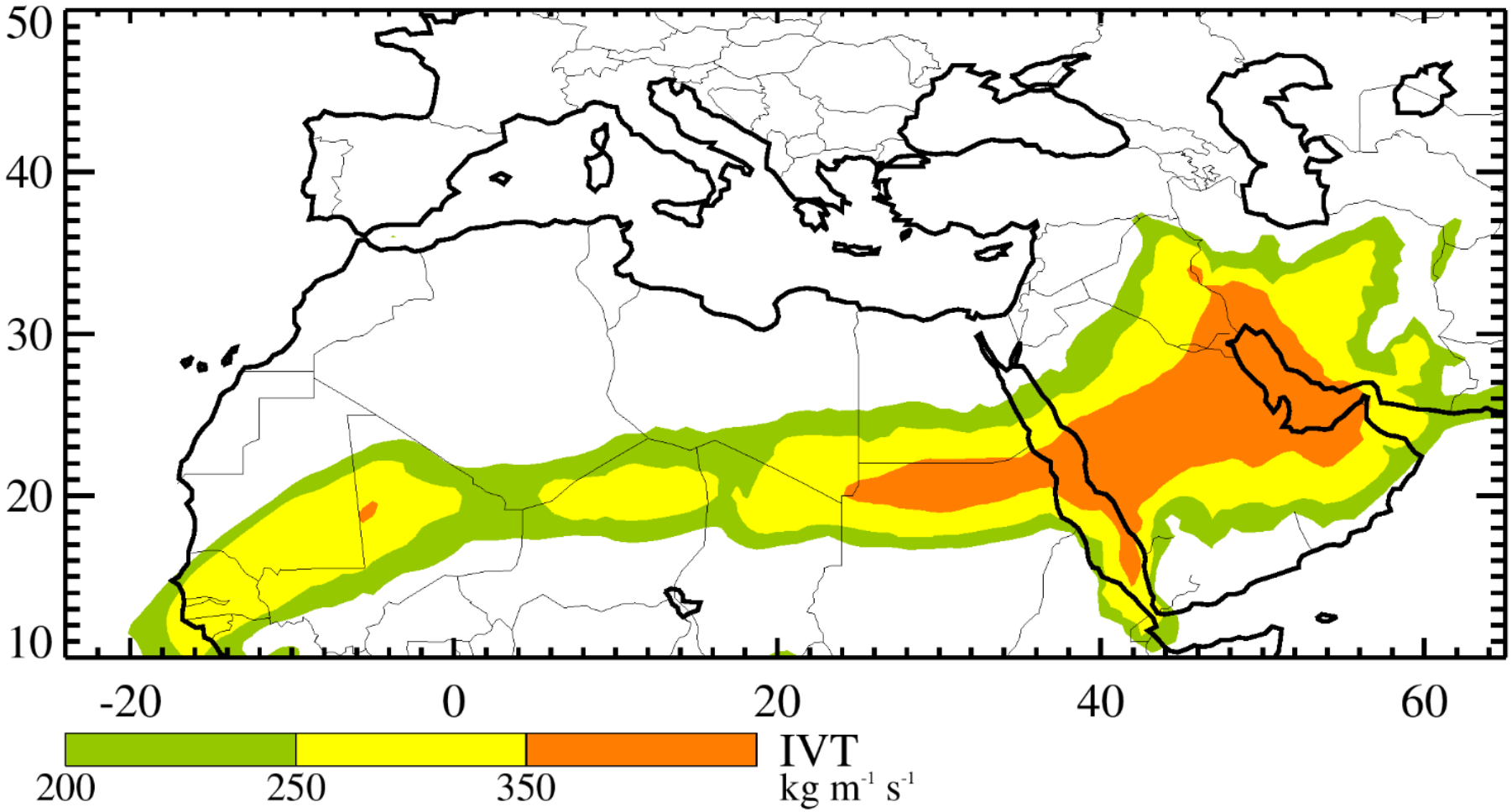


Moist air cools, and heavy rainfall forms



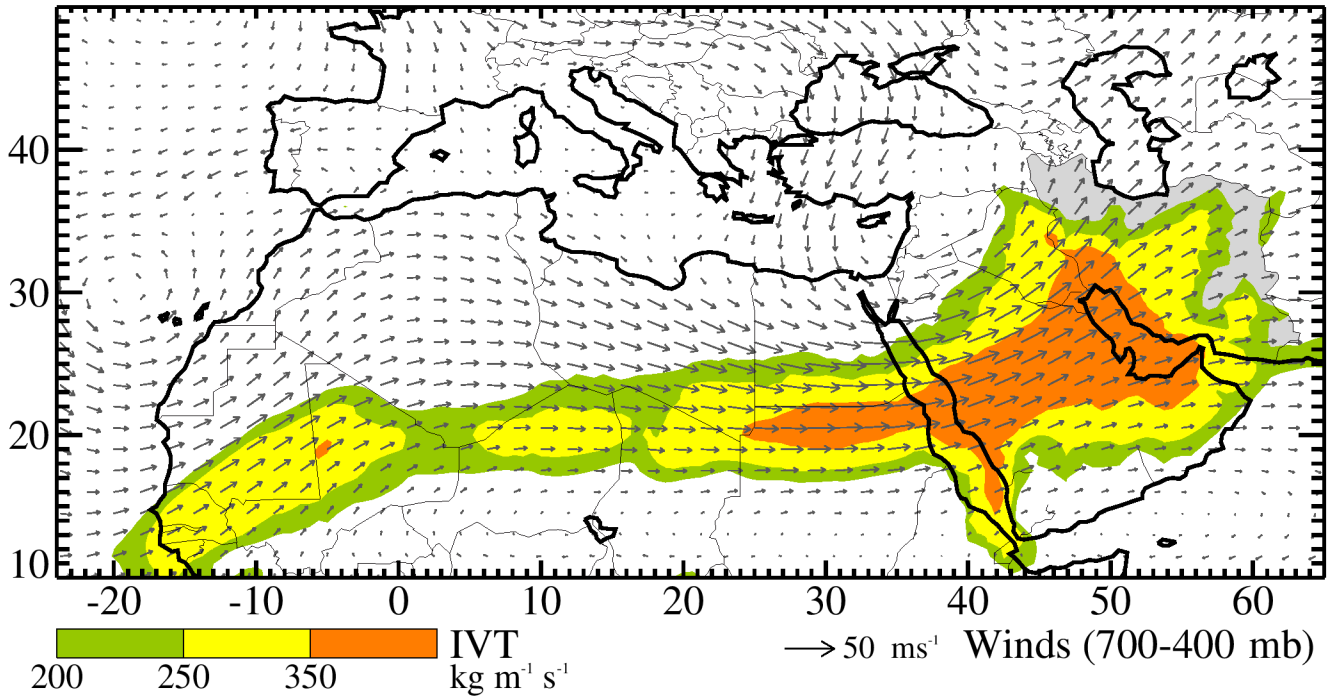
Identify AR Dena

Using NASA's MERRA-2 data averaged over 24-25 March: Integrated water vapor transport (IVT) > 200 kg m^{-1} s^{-1}



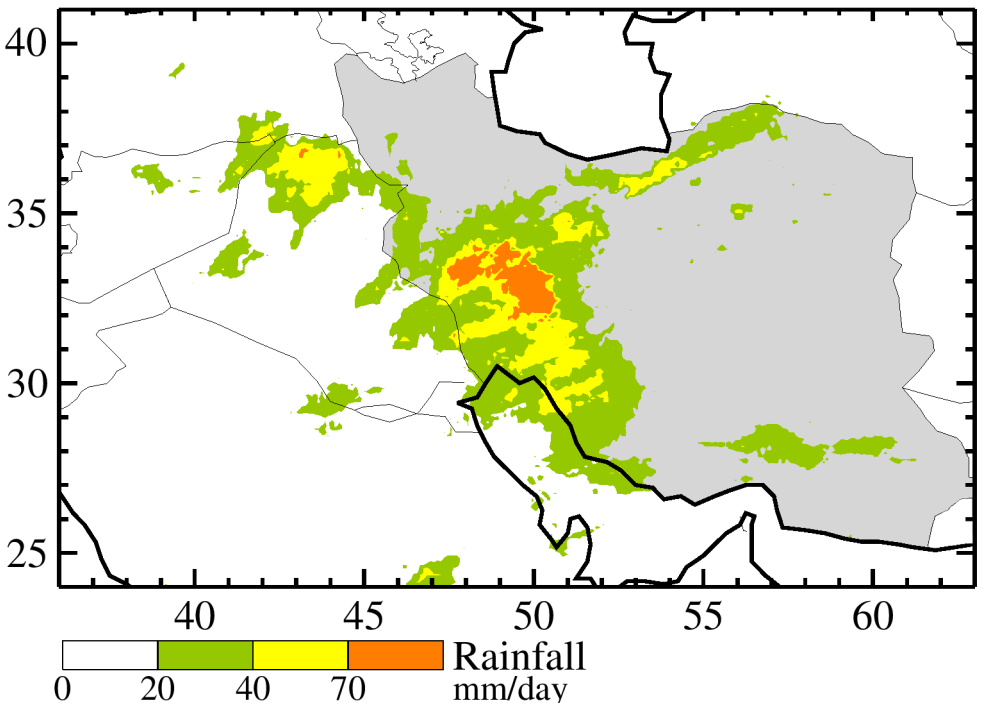
AR Dena, horizontal winds and rainfall patterns during March 24-25

Total moisture flux (IVT) and winds (~3000-5500 m)



- Subtropical jet and the Low are apparent.

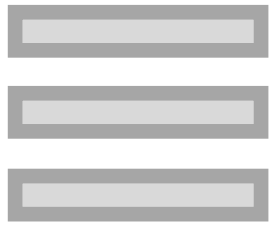
IMERG satellite-based rainfall



- Rainfall maximum over Zagros Mts.

How much water?

Water transport by **AR Dena**



? x

Combined flow of **Tigris** + **Euphrates** + **Karun** + **Karkheh**

How much water?

Water transport by **AR Dena**

≡ 150 x

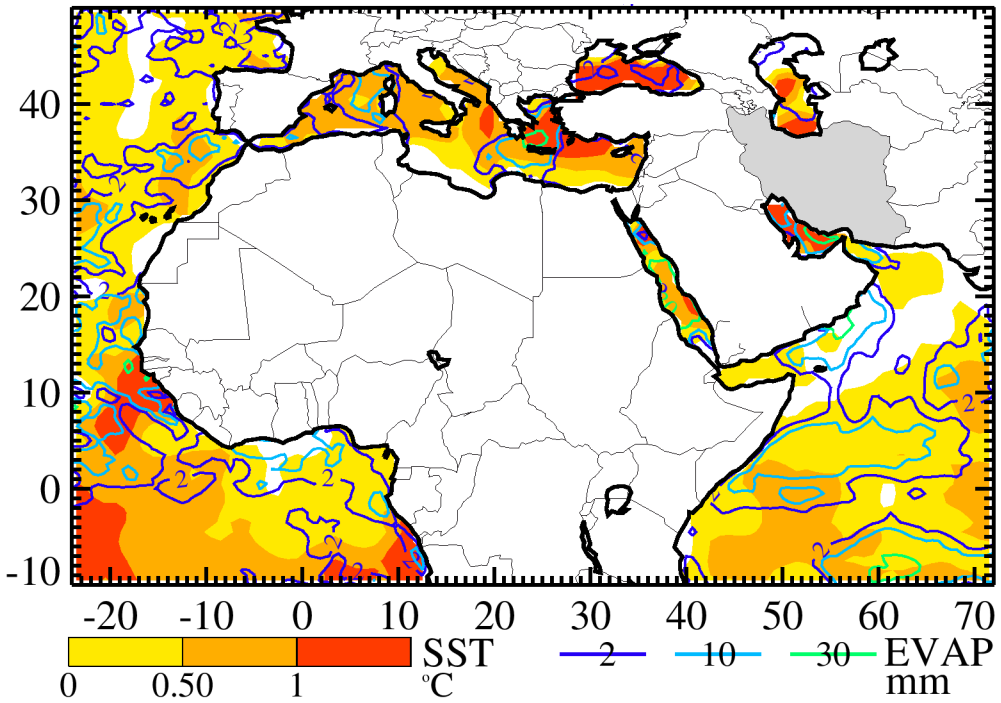
Combined flow of **Tigris** + **Euphrates** + **Karun** + **Karkheh**

≡ 6 Billion

(in two days)

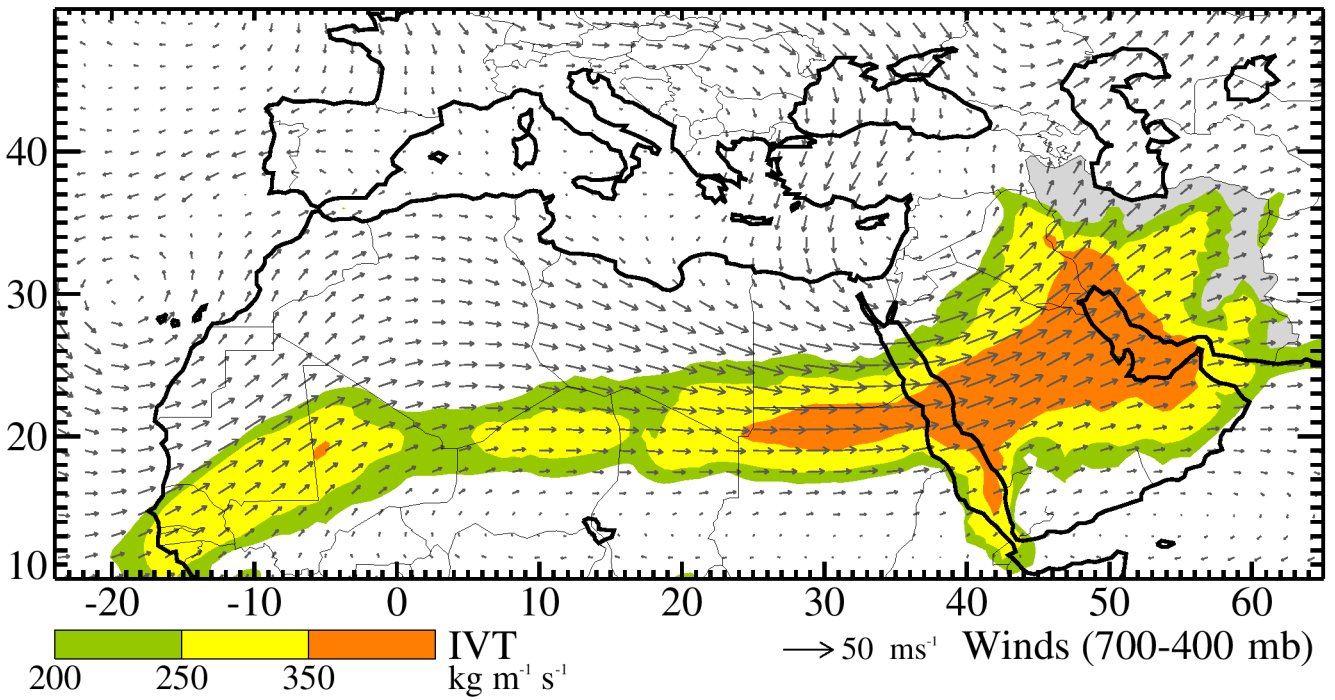
AR Dena, SST and evaporation patterns

SST & evaporation anomaly, Mar 2019



- All water basins warmer than normal with more evaporation

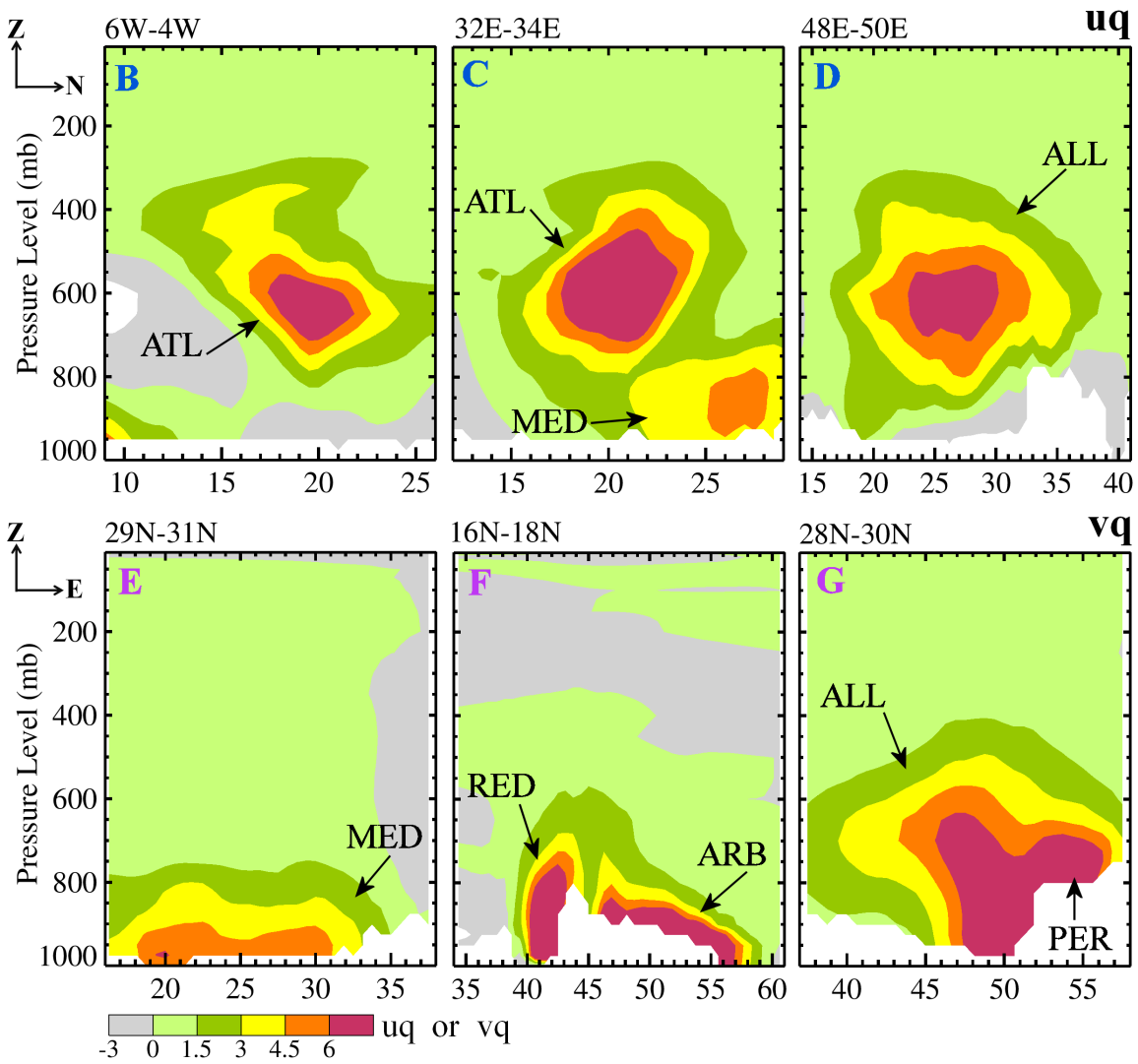
Total moisture flux (IVT) and winds (~3000-5500 m)

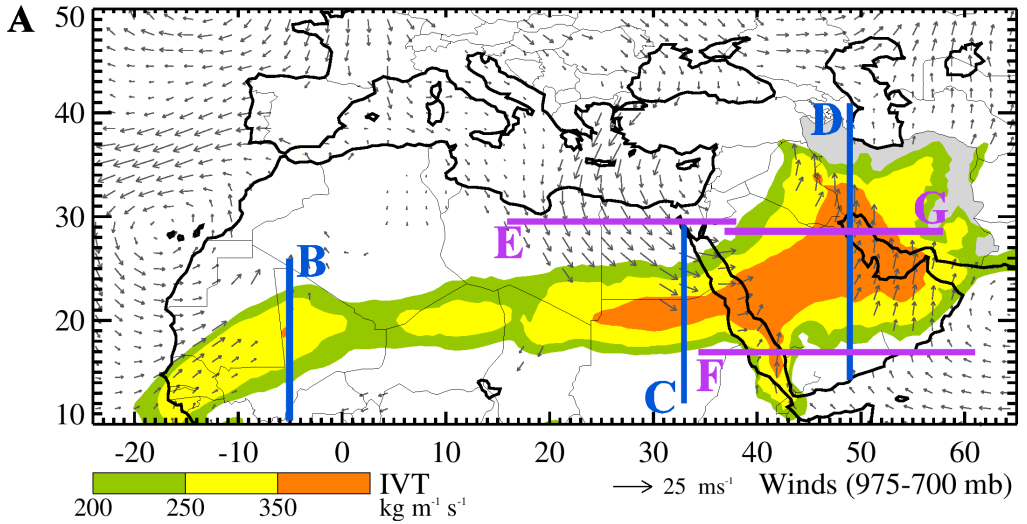


- Subtropical jet and cut-off low are apparent.

Moisture contribution of various water basins to AR Dena

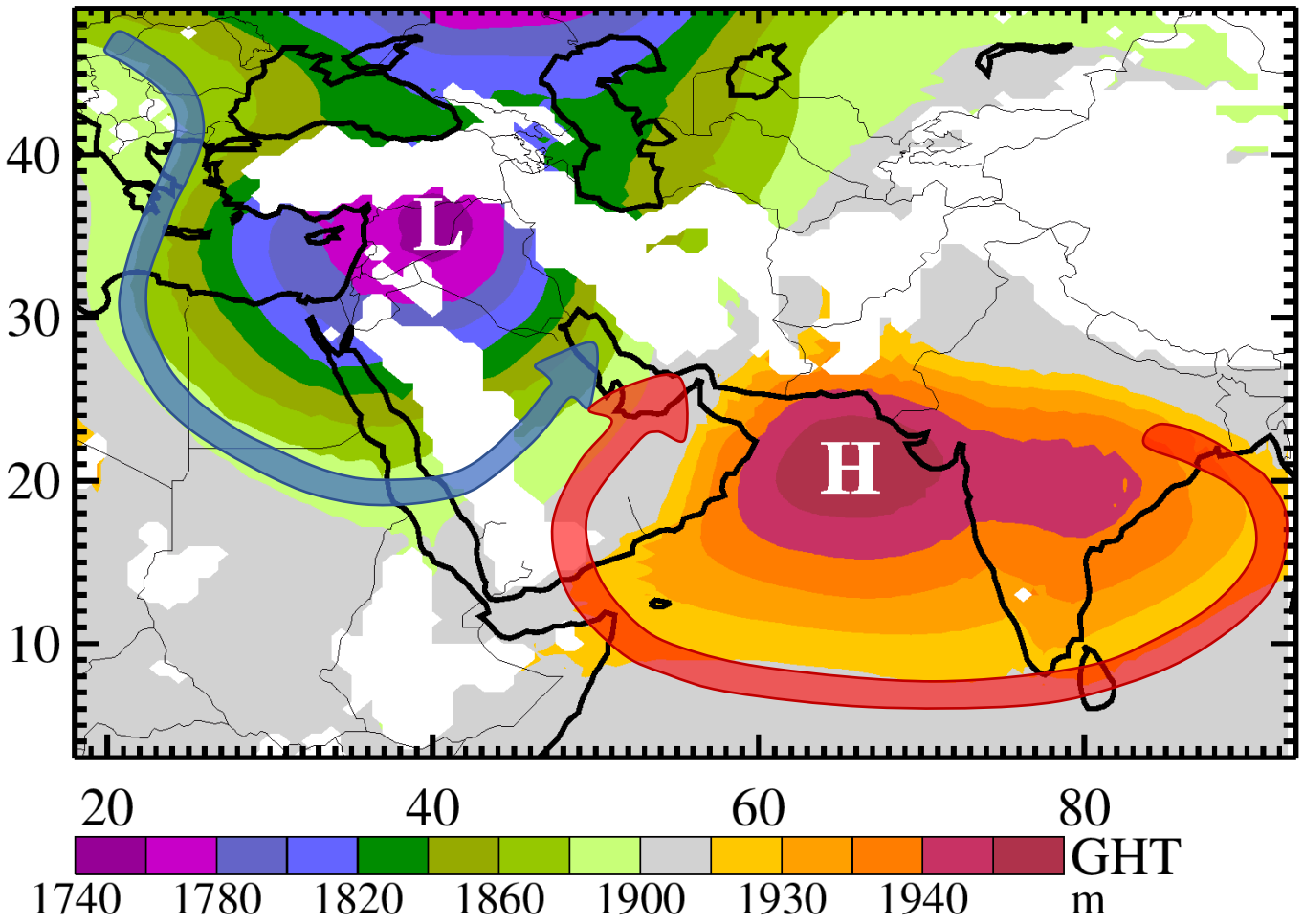
Vertical cross-section of moisture transport





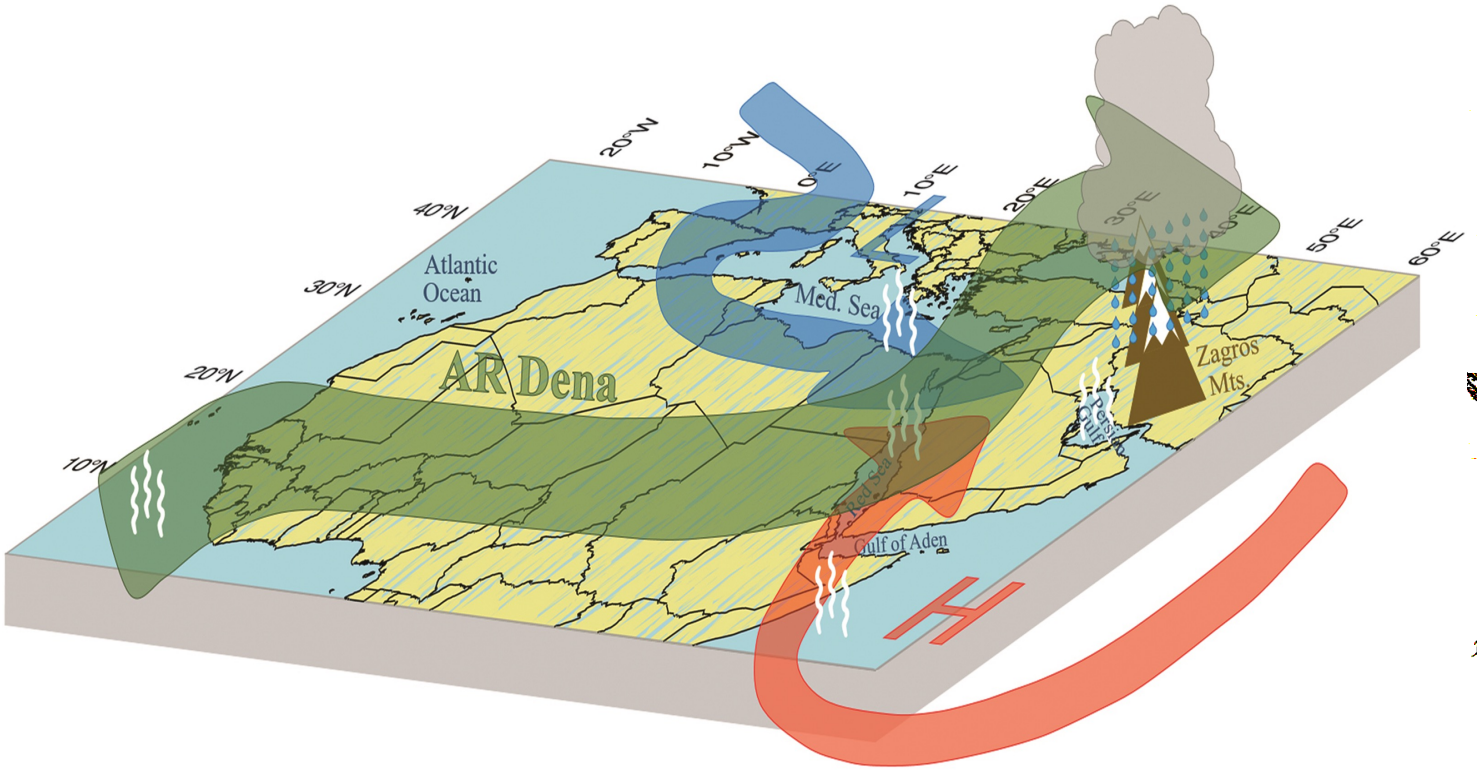
- Moisture supply starts from the Atlantic Ocean.
- Additional contribution from the Mediterranean, Arabian, Red Seas, Gulf of Aden, Persian Gulf—confined at lower levels.

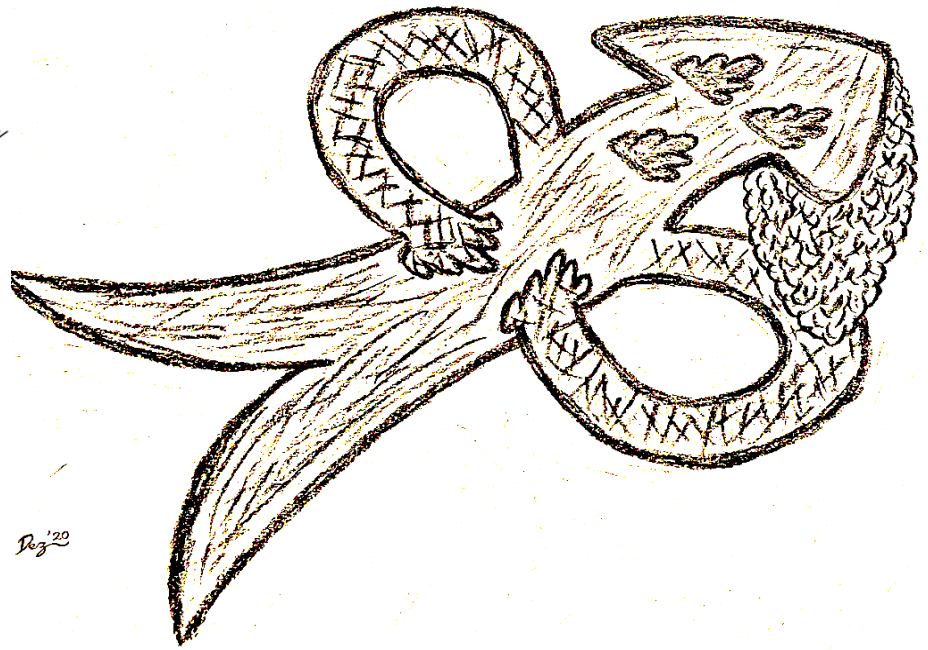
Geopotential heights (GHT) in the lower troposphere (925-700 mb)



- Configuration of low and high pressure systems facilitated moisture transport from regional water basins.
- AR Dena can be characterized in the context of tropical-extratropical interactions as it owes its existence to the combined effects of a subtropical jet and a mid-latitude system.

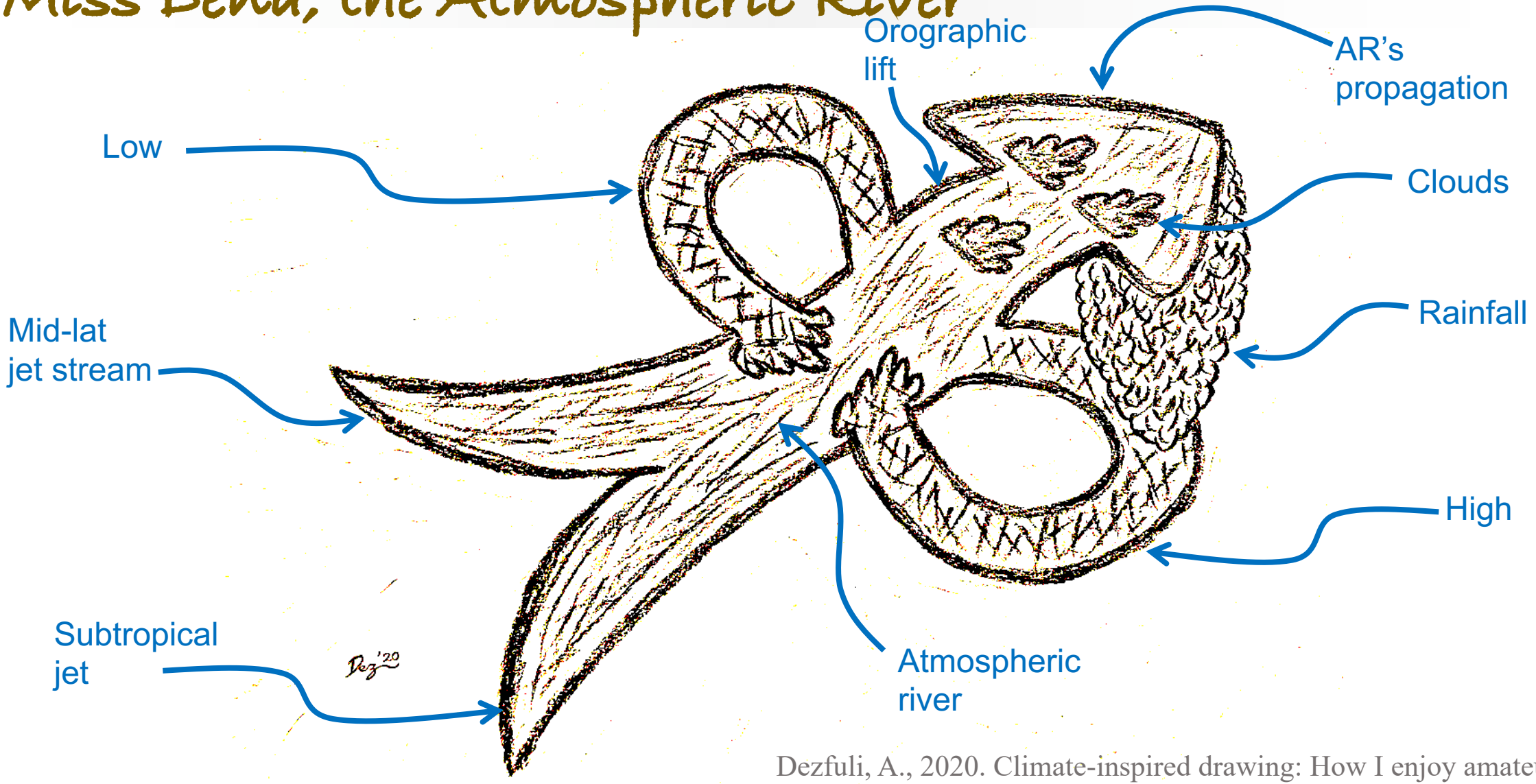
Miss Dena, the Atmospheric River





Dezfuli, A., 2020. Climate-inspired drawing: How I enjoy amateur art. *Bulletin of the American Meteorological Society*, 101, 759-760.

Miss Dena, the Atmospheric River



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CASE 2

April 2017 floods in northwestern Iran

(Photo courtesy of Internet Archive)

Contribution:

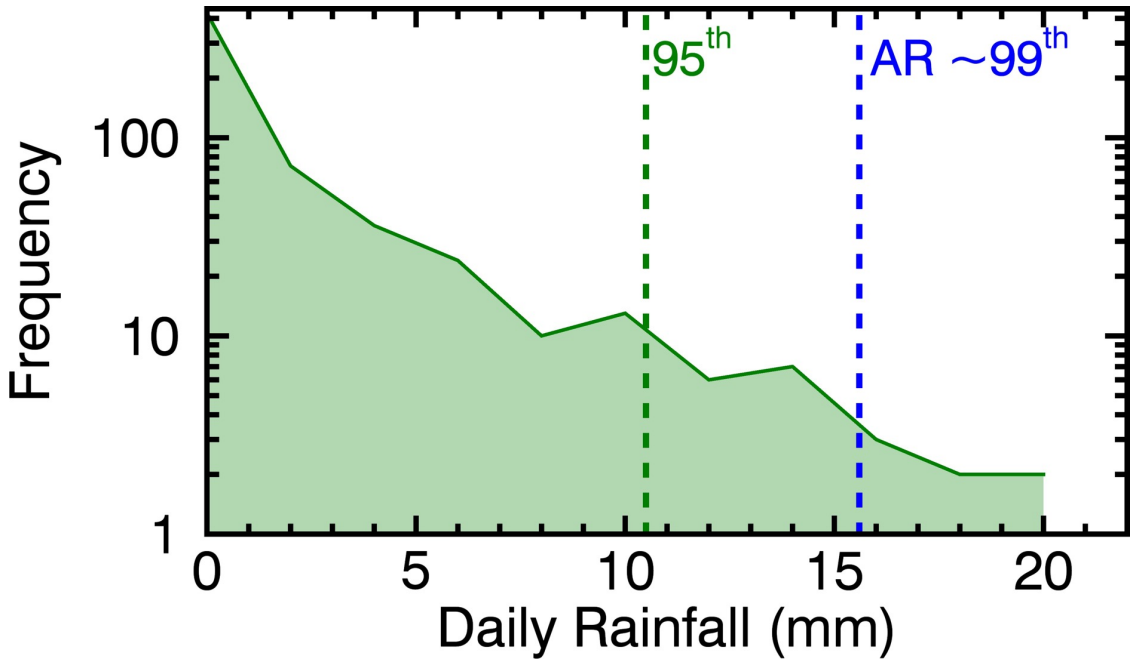
Michael Bosilovich & Donifan Barahona

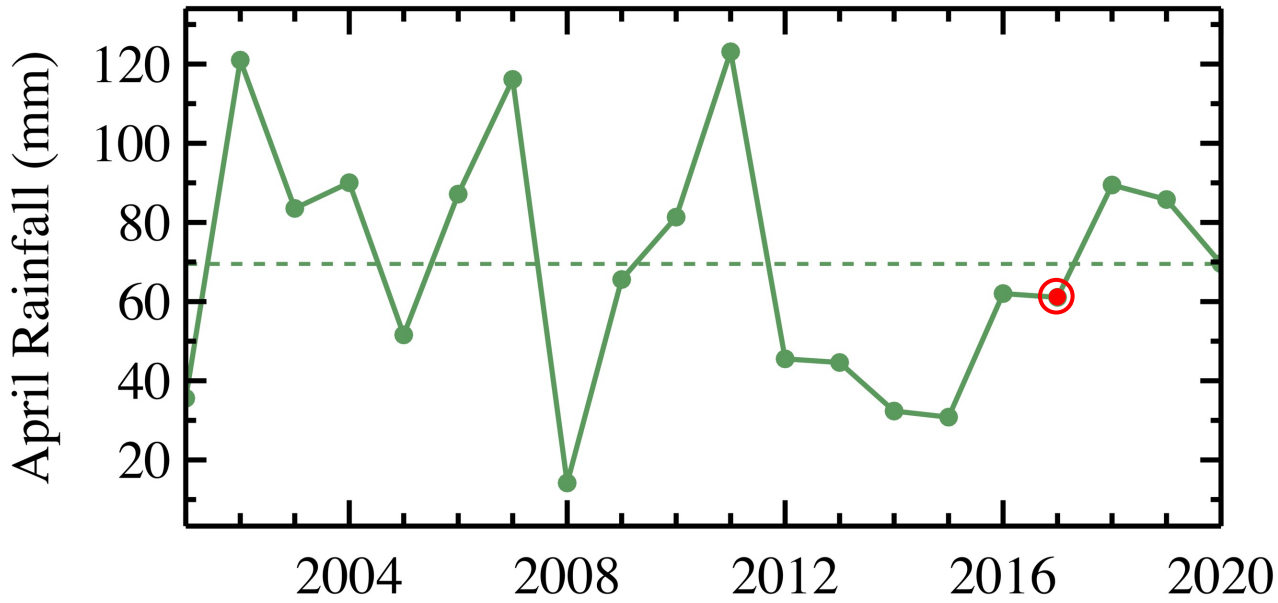
NASA/GSFC

Flash Floods in Northwestern Iran – Lake Urmia Basin

- Torrential rainfall caused flooding and landslide.
- Occurred over the drying Lake Urmia.
- Maximum daily rainfall total reported was 48 mm in some stations.
- Claimed 48 lives, mainly in villages due to lack of early warning systems.

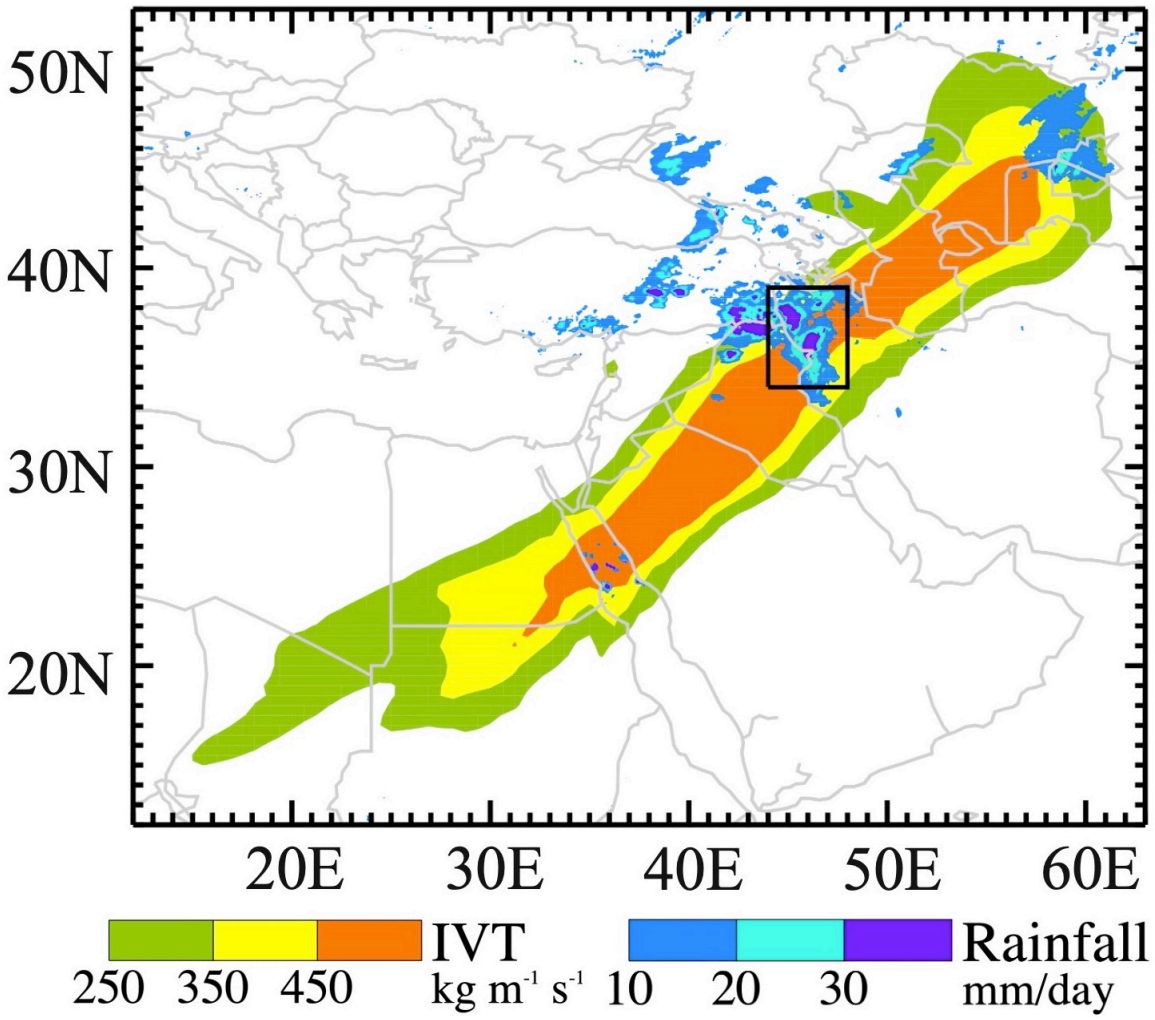
Daily and Monthly Rainfall in April 2017





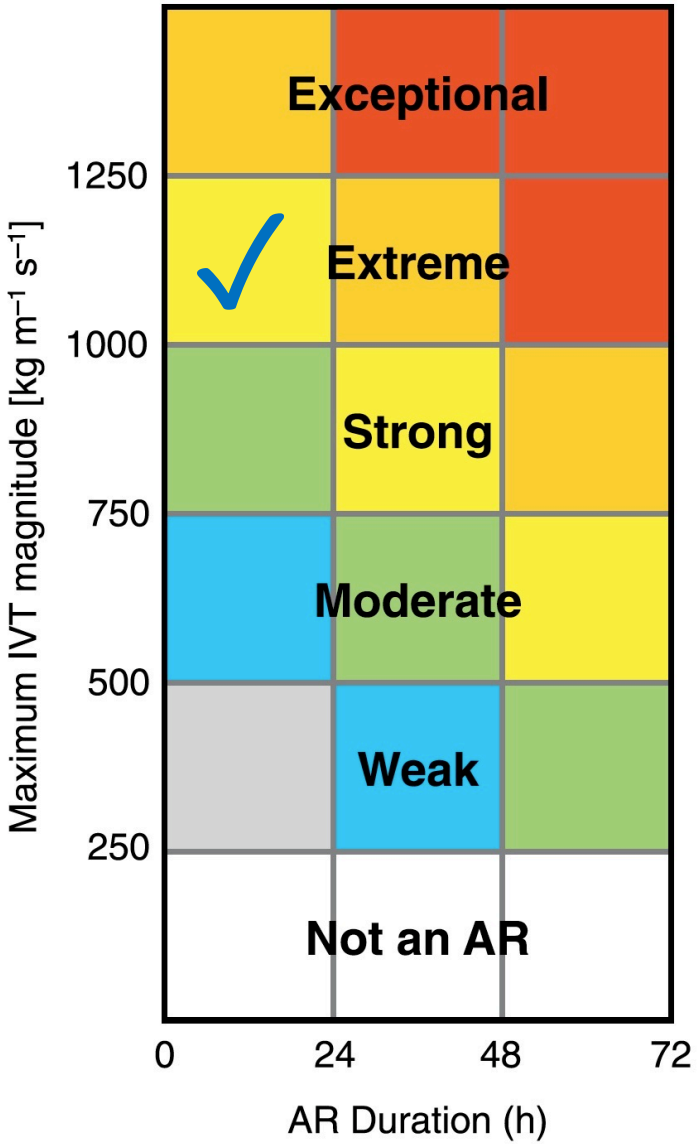
- Histogram of daily IMERG data: rainfall resulted from this AR was equivalent to the 99th percentile of April.
- April 2017 was relatively dry: extreme rainfall events can happen in seasons with both above and below normal conditions.

Atmospheric River & Rainfall



- Extent of the AR identified by IVT $\geq$ 250 kg m^{-1} s^{-1} during April 14, 2017.
- Maximum precipitation occurred over the Lake Urmia Basin, consistent with orographic forcing.
- Despite adverse effects, heavy rains positively contributed to restoration of the drying Lake Urmia.

AR Categories based on Intensity and Duration (Ralph et al. 2019)



- Cat 5 – Primarily hazardous
- Cat 4 – Mostly hazardous, also beneficial
- Cat 3 – Balance of beneficial and hazardous
- Cat 2 – Mostly beneficial, also hazardous
- Cat 1 – Primarily beneficial

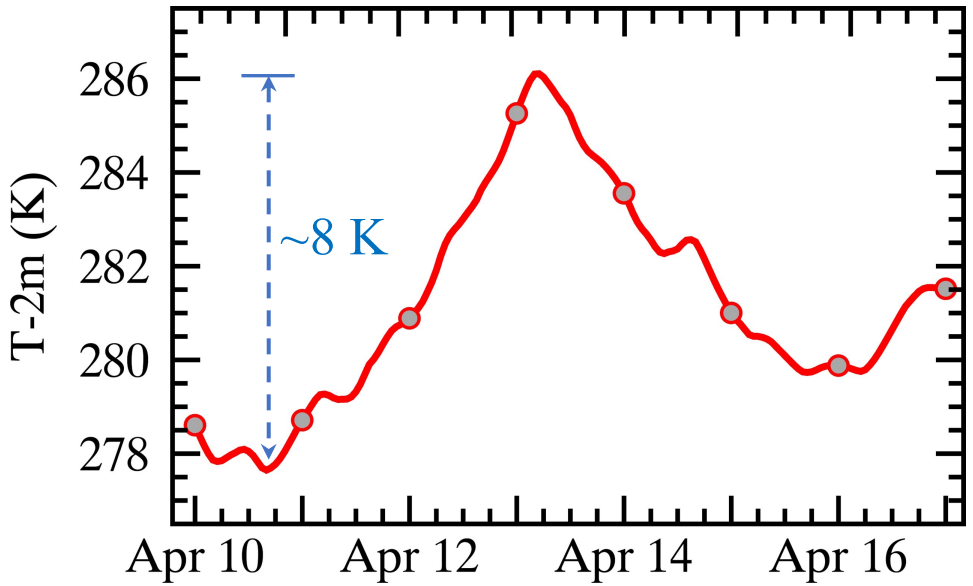
The scale is based on

- **Maximum** instantaneous IVT at a given location
- **Duration** of AR conditions (IVT ≥ 250 kg m^{-1} s^{-1}) at that location

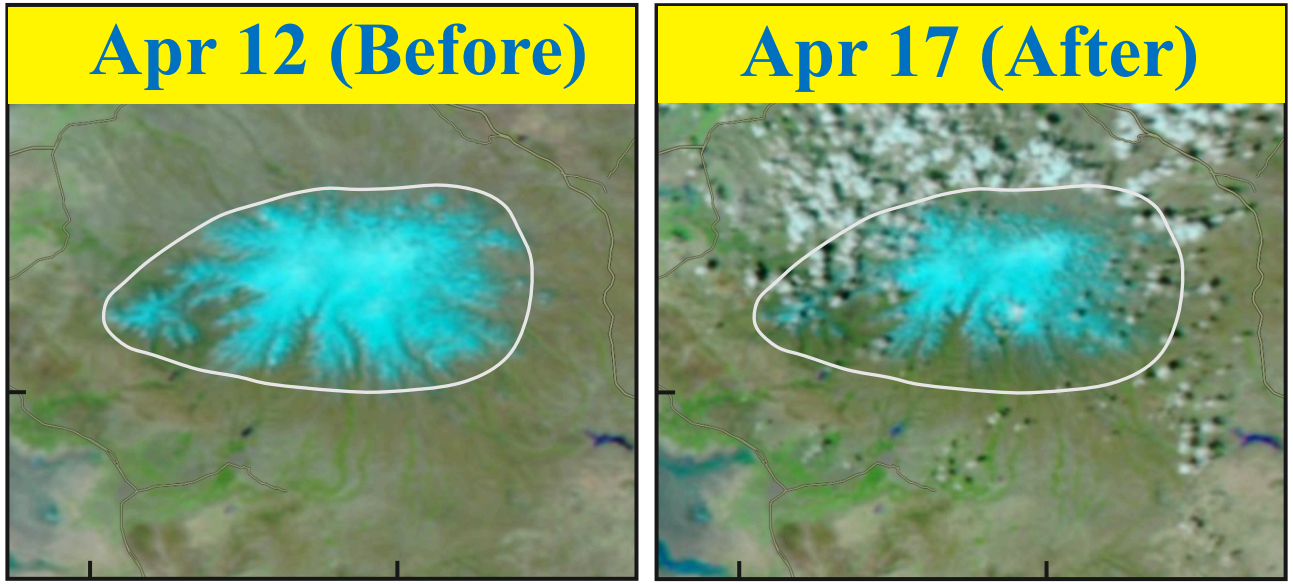
This AR is Cat 3

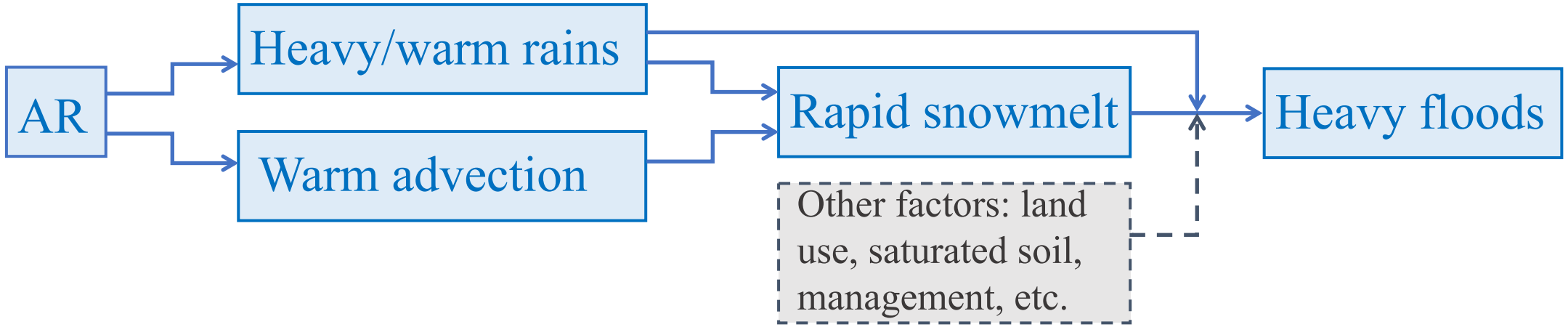
Heavy rains reinforced by rapid snowmelt

Near-surface Temperature

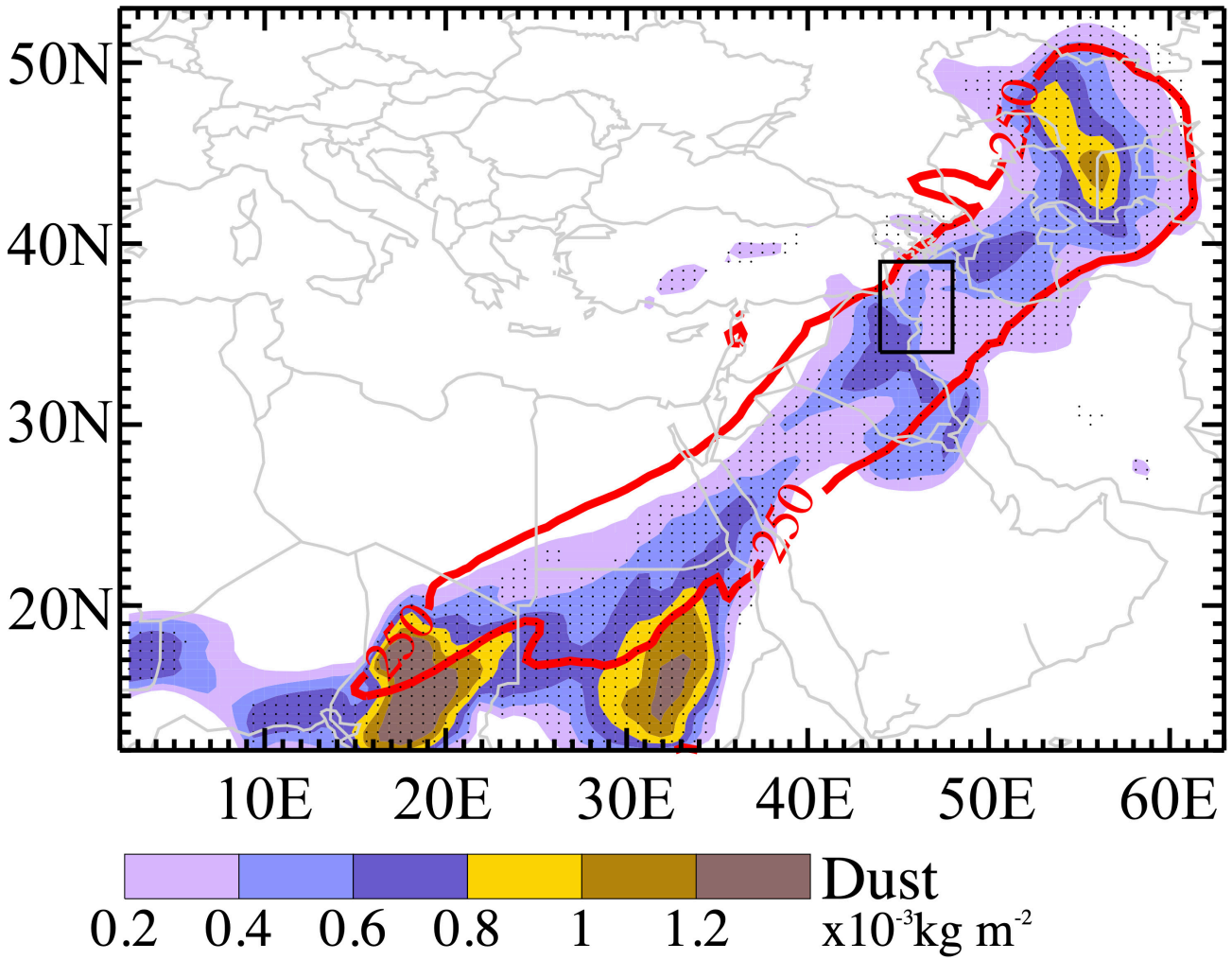


VIIRS Corrected Reflectance from Satellite



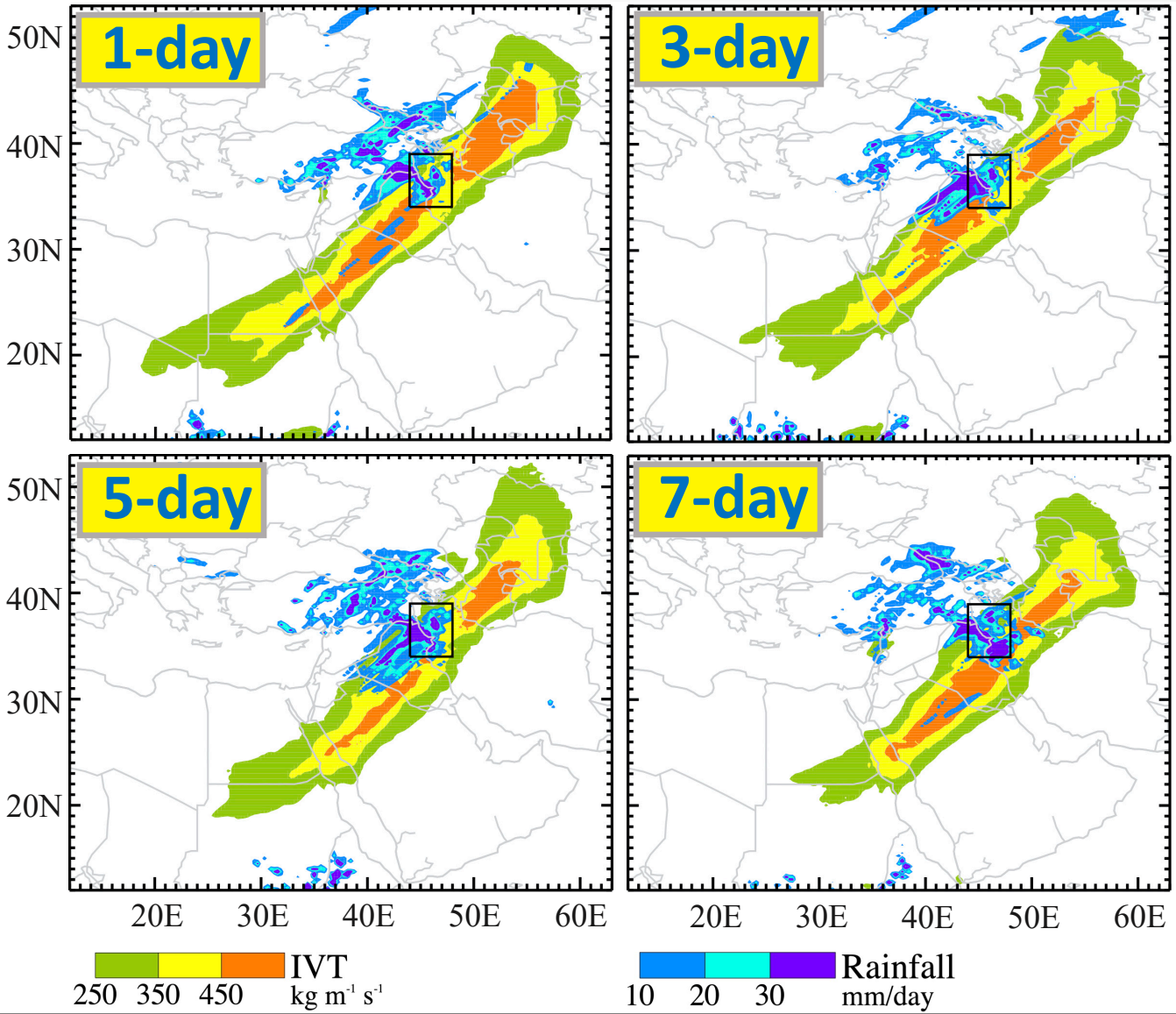


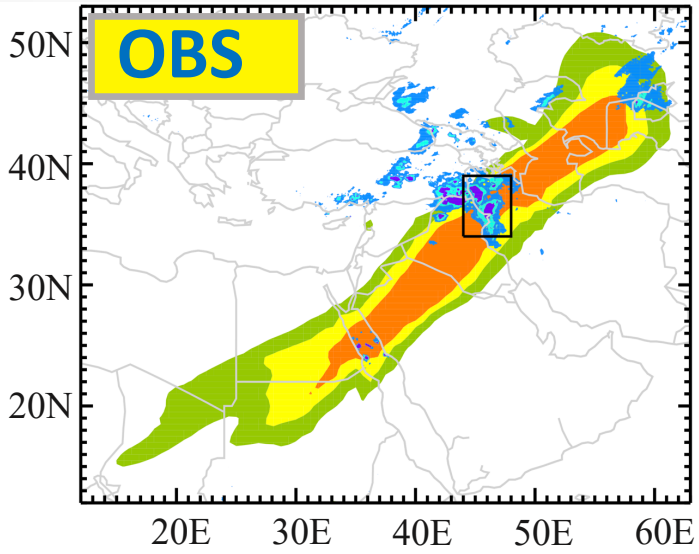
Dust Transport within the AR



- ARs associated with strong horizontal winds.
- Major dust sources are located along the pathway of the ARs.
- Dust column mass density during the event shows a positive anomaly within the AR corridor.
- About 80% of the AR area has a z-score greater than +1.28 (>90th percentile).

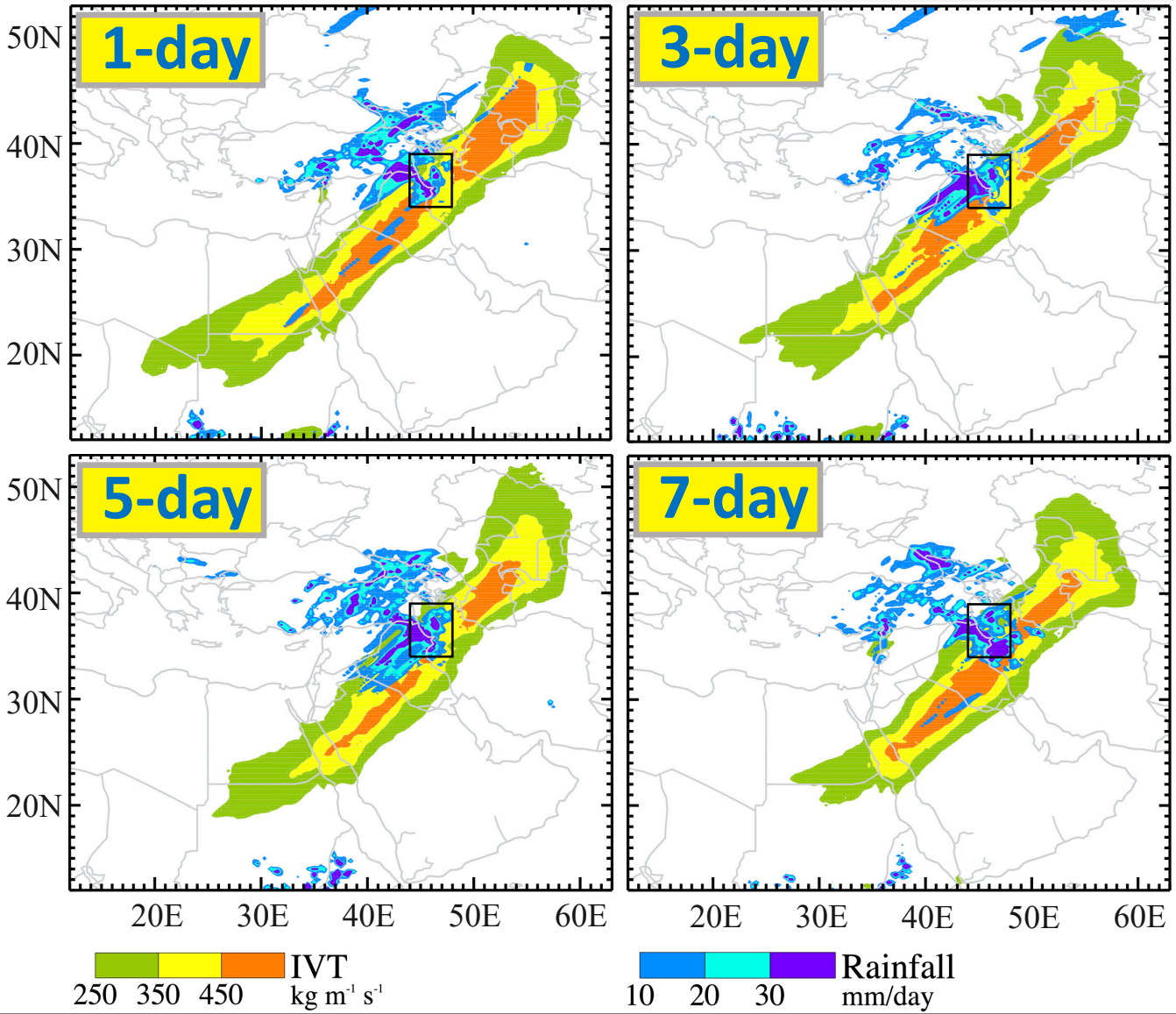
Short-to Medium-range Forecasts Using NASA's GEOS Model

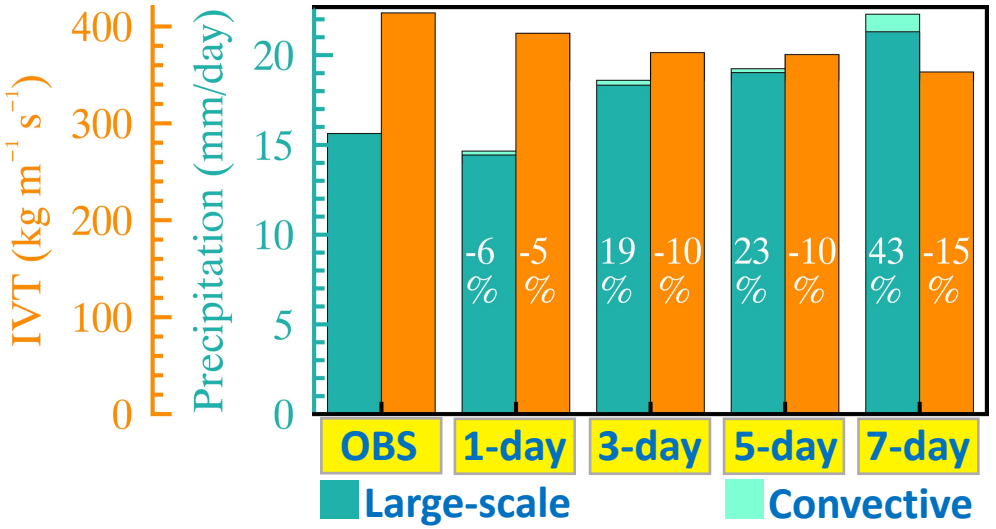




- **Qualitatively:** IVT patterns show that the AR structure is reasonably captured up to 5-day lead, before its horizontal extent starts to shrink, and its axis retracts ~150 km southeastward compared to Reanalysis.

Short-to Medium-range Forecasts Using NASA's GEOS Model



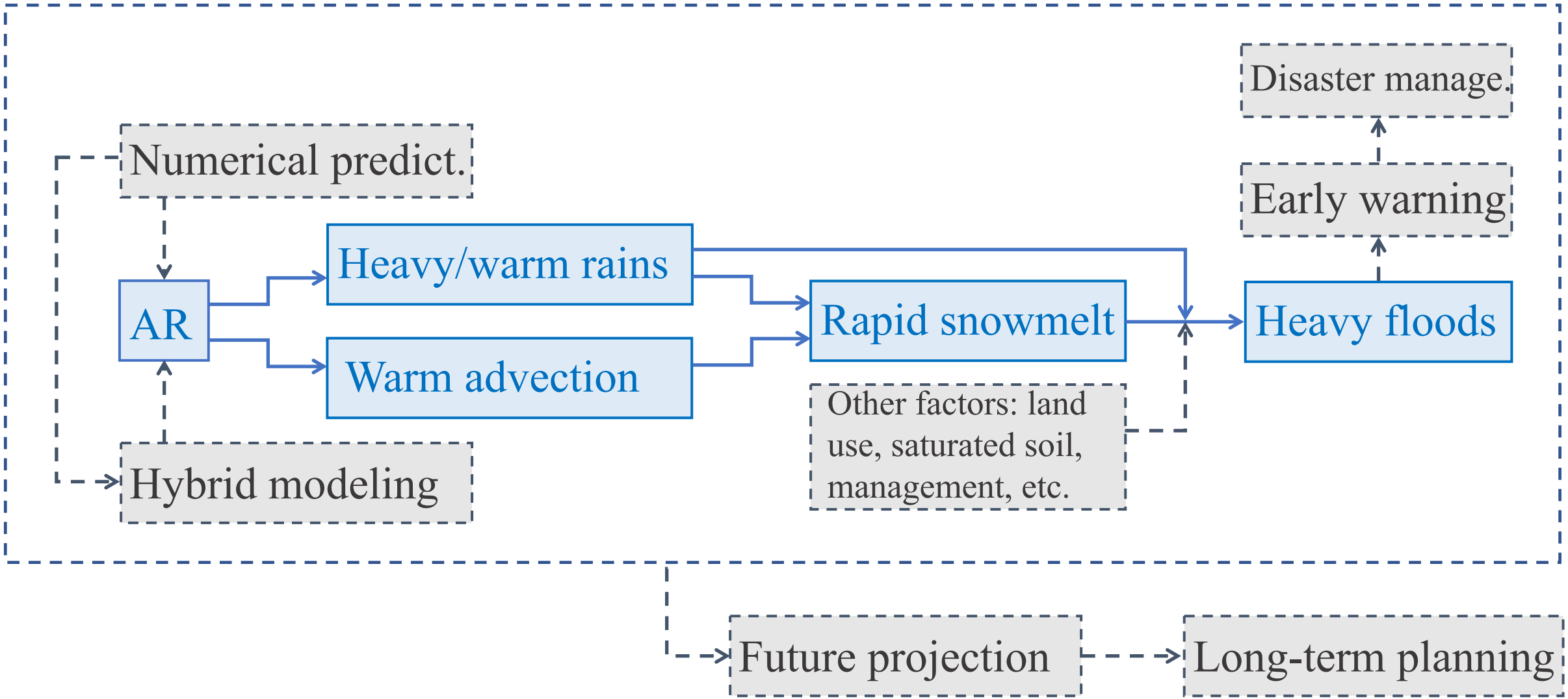


- **Quantitatively:**
  - 1-day: nearly the same as obs.
  - 3 to 5-day: rain is ~20% overestimated.
  - IVT forecast decreases at longer leads but remains close to observations.

Conclusions on Atmospheric Rivers

- Atmospheric rivers can cause heavy rains and floods in regions far from the oceans such as the Middle East.
- ARs can cause floods by heavy rains and snowmelt.
- ARs can be hazardous and beneficial in the region.
- A distinct characteristic of the ARs in the Middle East is their association with dust transport from the major sources along their pathways.
- ARs can be predicted numerically at up to 7-day lead.

Framework to incorporate ARs in short to long-term planning



PART 1

Atmospheric Rivers caused record floods & dust. Are they predictable?

PART 2

2021: record heat and drought caused socio-environmental crises.

PART 3

Climate change increases future transboundary water conflicts.

Socio-environmental crises across the region in summer 2021

The Washington Post
Democracy Dies in Darkness

Power outages cripple parts of the Middle East amid record heat waves and rising unrest

INDEPENDENT

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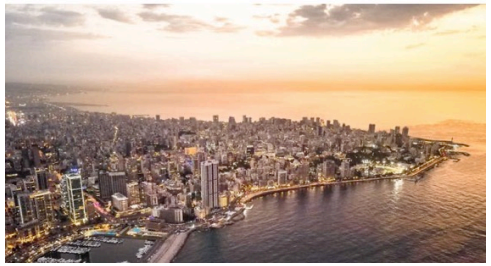
A water crisis is creating nightmare conditions across the Middle East

Concrete global action is required to fix the problems people in the region face – starting with sanitation and hygiene programmes

Bel Trew | Sunday 25 July 2021 14:37 | 161 comments



REUTERS

Turkish wildfires are worst ever, Erdogan says, as power plant breached

By Mert Ozkan and Ezgi Erkoyun 3 minute read

BBC Home News Sport Reel More

NEWS Menu

Iran water: What's causing the shortages?

By Jack Goodman
BBC Reality Check

2 August

Reality Check

The New York Times

'I Am Thirsty!' Water Shortages Compound Iran's Problems

npr DONATE

MIDDLE EAST

Iraq can only cultivate about half of the farmland it usually does due to drought

November 3, 2021 · 4:18 PM ET
Heard on All Things Considered

RUTH SHERLOCK

4-Minute Listen

Drought in Iraq means the country is only able to grow less than half its usual produce and is forcing mass migration from rural communities.

Transcript

AUDIE CORNISH, HOST:

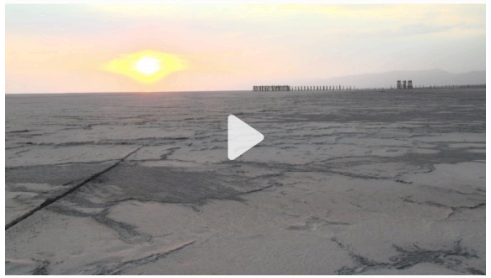
ALJAZEERA LIVE

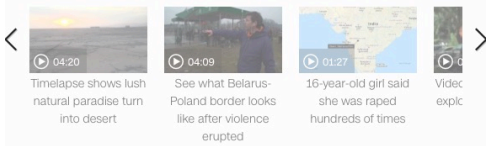
News | Climate Crisis

Water crisis and drought threaten 12 million in Syria, Iraq

The unfolding water crisis will soon become an 'unprecedented catastrophe' across Syria and Iraq, NGOs say.

CNN World LIVE TV





The Middle East is running out of water, and parts of it are becoming uninhabitable

Khaju bridge on the Zayanderud River, Isfahan, Iran: one of many cases!

Once upon a time!

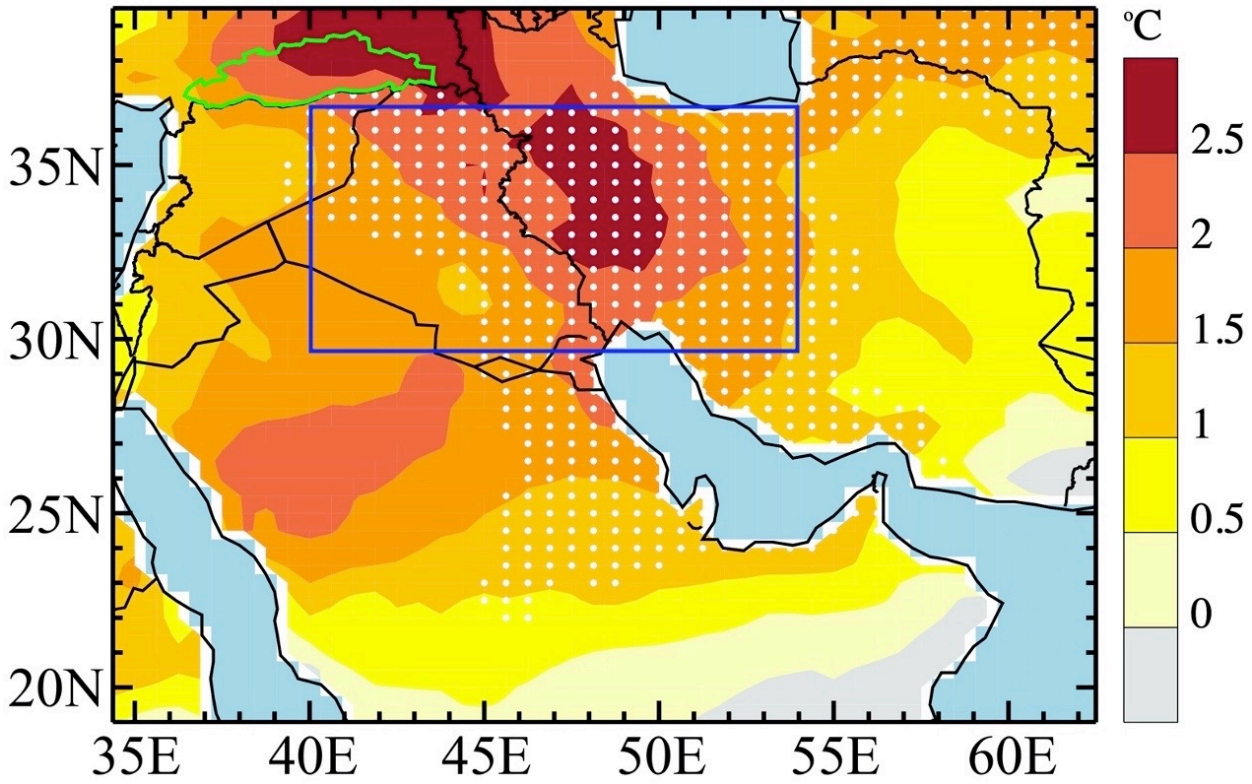
www.iranontrip.ir

November 2021

https://www.bbc.com/persian

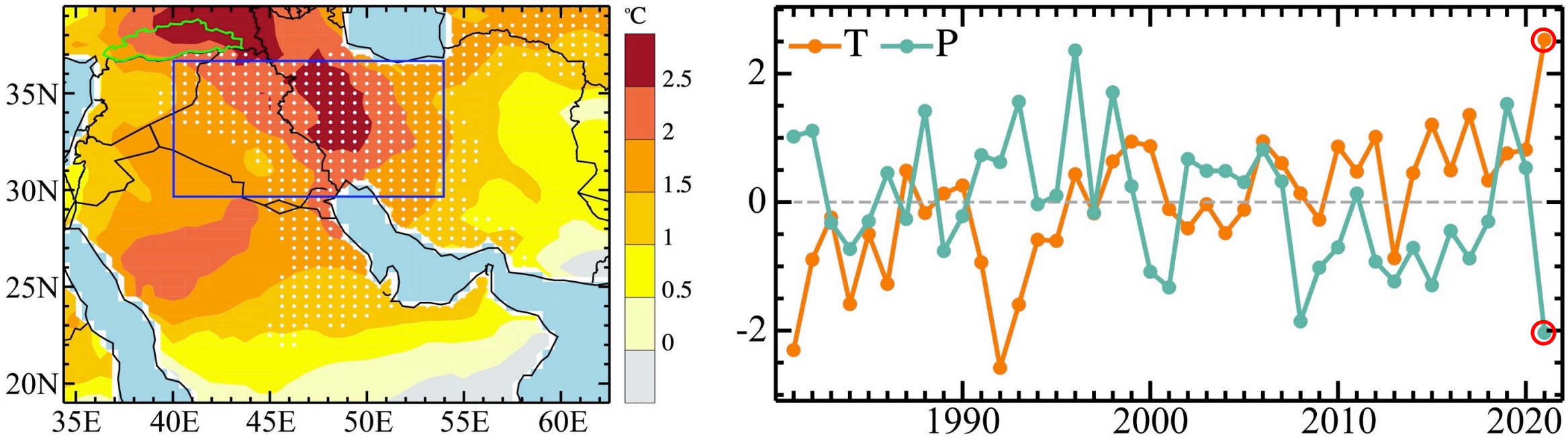
Water replaced with thirsty protesters!

Compound effects of high temperature and low precipitation



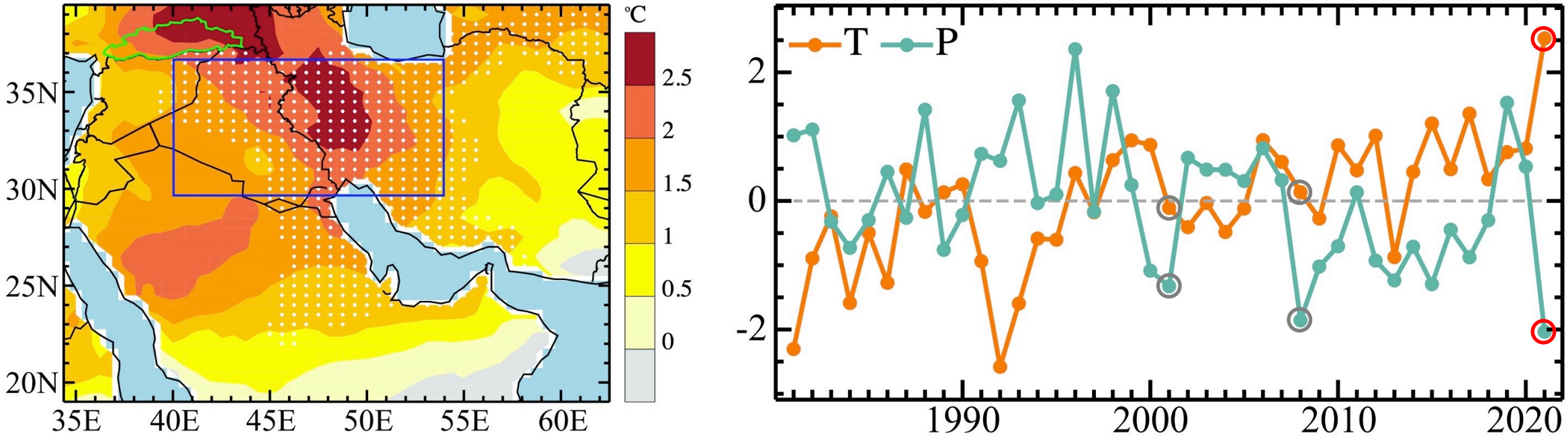
- Shading: Seasonal (May to July) temperature anomaly of 2021.
- White dots: $T\ (May - Jul)\ > 95^{th}$ & $P\ (Jan - Apr) < 5^{th}$ percentile in 2021.

Compound effects of high temperature and low precipitation



- Standardized time-series of regional temperature and precipitation: 2021 was the hottest and driest year in the past four decades.

Compound effects of high temperature and low precipitation



- Standardized time-series of regional temperature and precipitation: 2021 was the hottest and driest year in the past four decades.
- The 2nd and 3rd driest years have nearly normal temperature.

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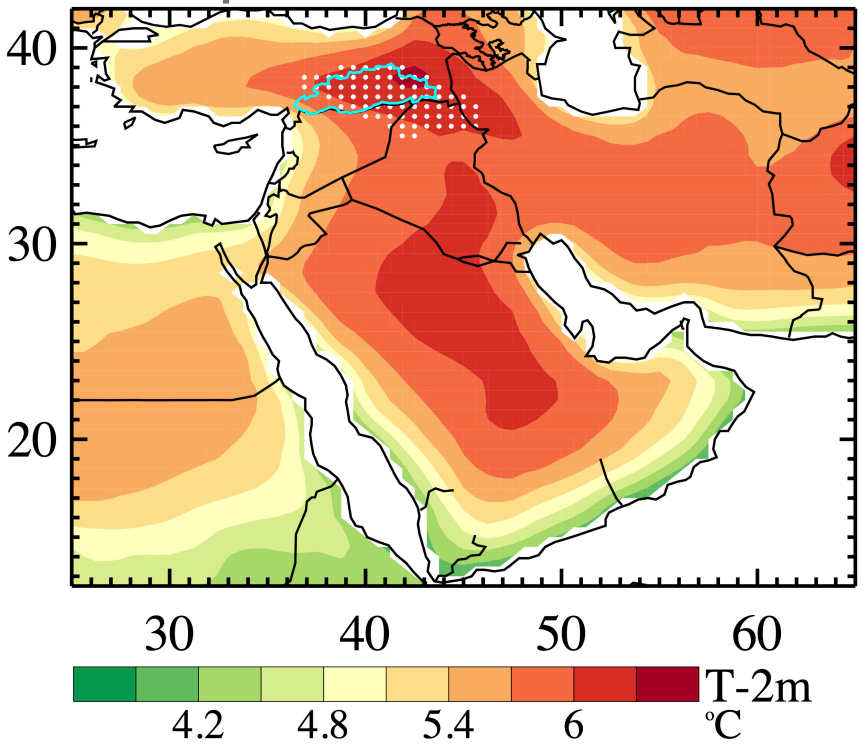
Climate change increases future transboundary water conflicts.

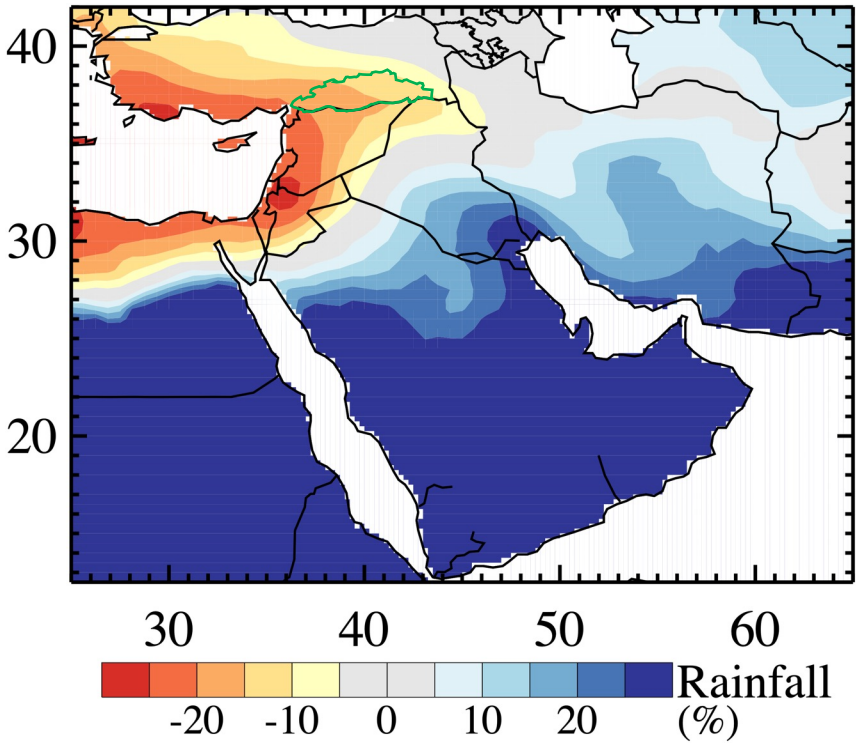
Collaborators: Saman Razavi & Ben Zaitchik

Compound effects of climate change: where are the hotspots?

Temperature Difference

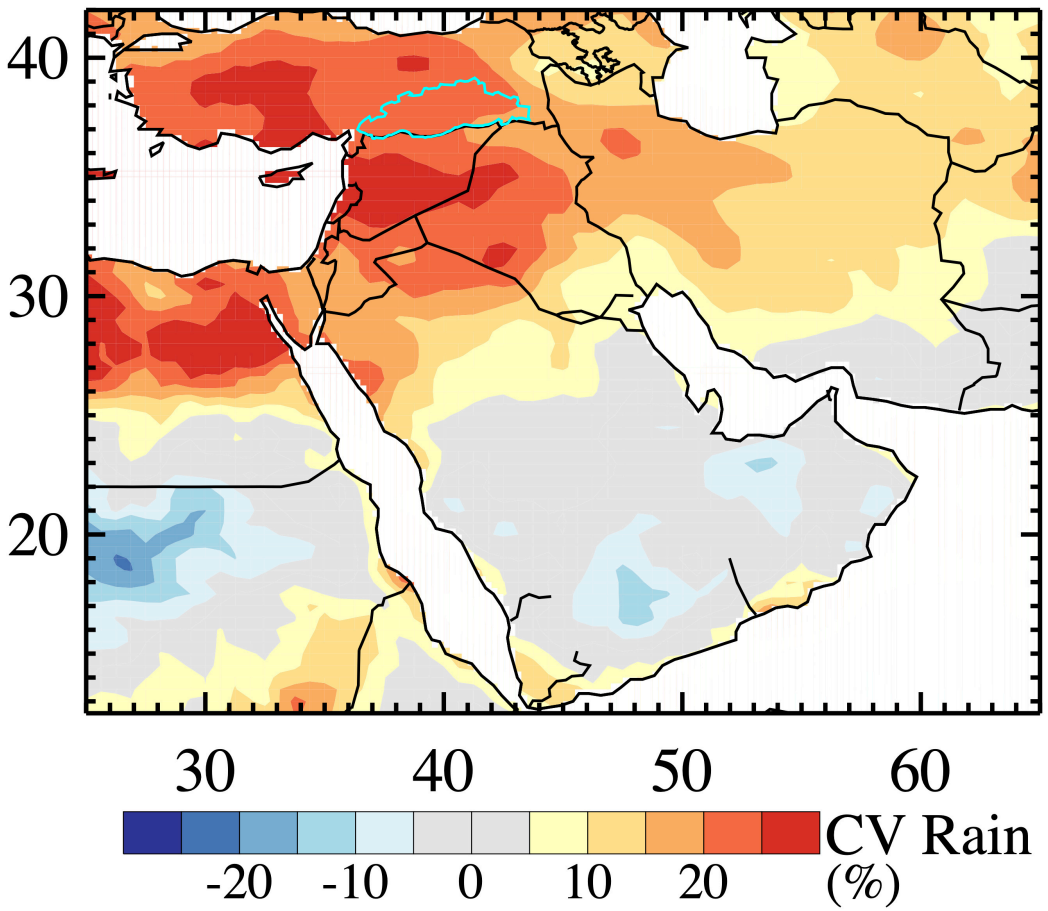


Rainfall Percent Difference



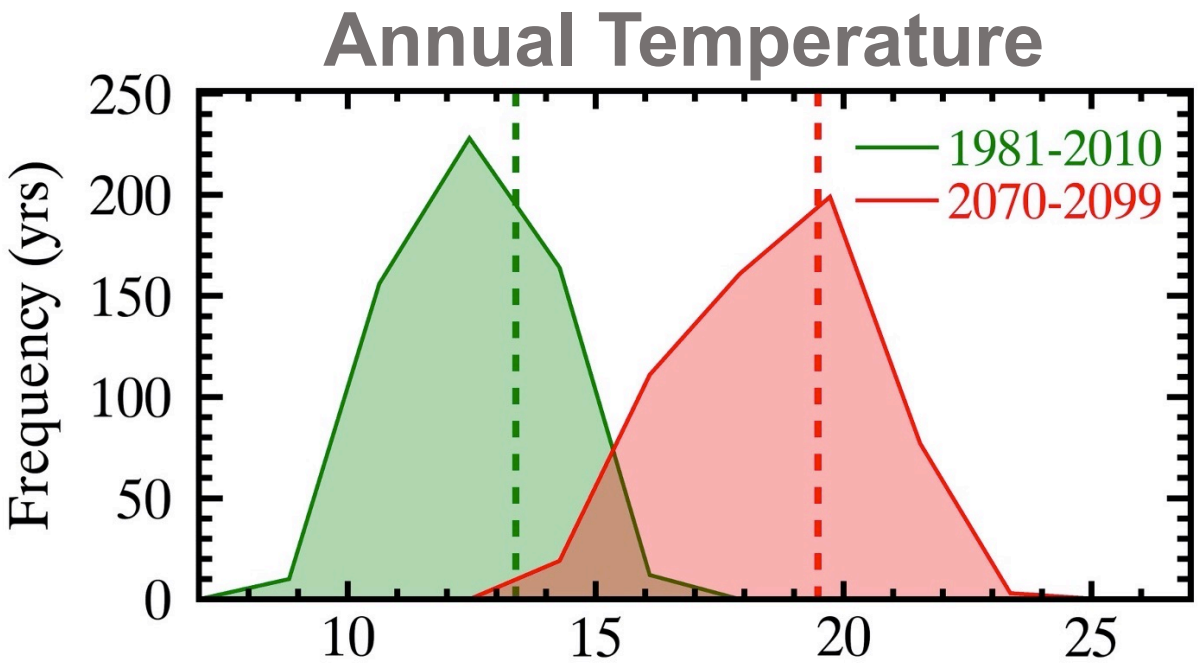
- Difference between multi-model ensemble (MME) mean of 2070-2099 & 1981-2010.
- White dots: compound hot-dry extremes, where an increase in temperature greater than the 85th percentile is projected to occur along with a decrease in percent difference of precipitation to a level lower than the 15th percentile of the entire domain.

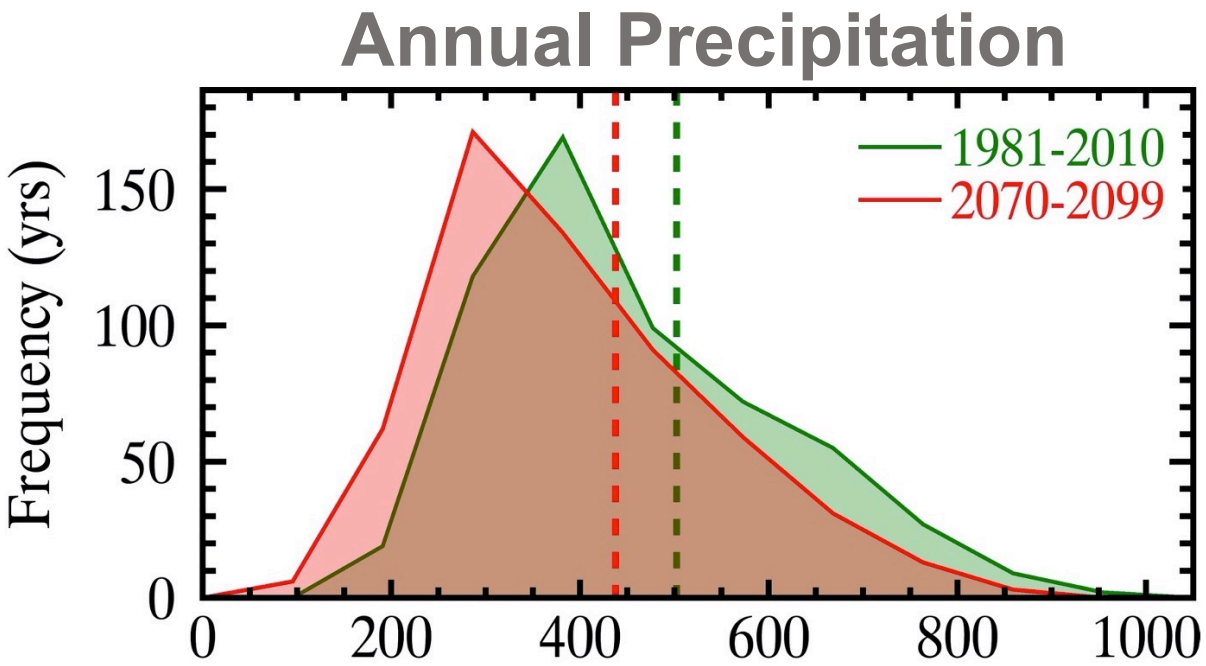
Enhanced interannual variability of precipitation



- Not only warmer and drier conditions, but also enhanced interannual variability of precipitation over GAP.
- Thus, higher uncertainty and risk for future planning.
- Other regions affected:
  - Drying Lake Urmia in northwestern Iran: warmer and more rainfall variability.
  - Syria: reduced rainfall amount & increase in interannual variability.

Climate change in the late 21st century over GAP region

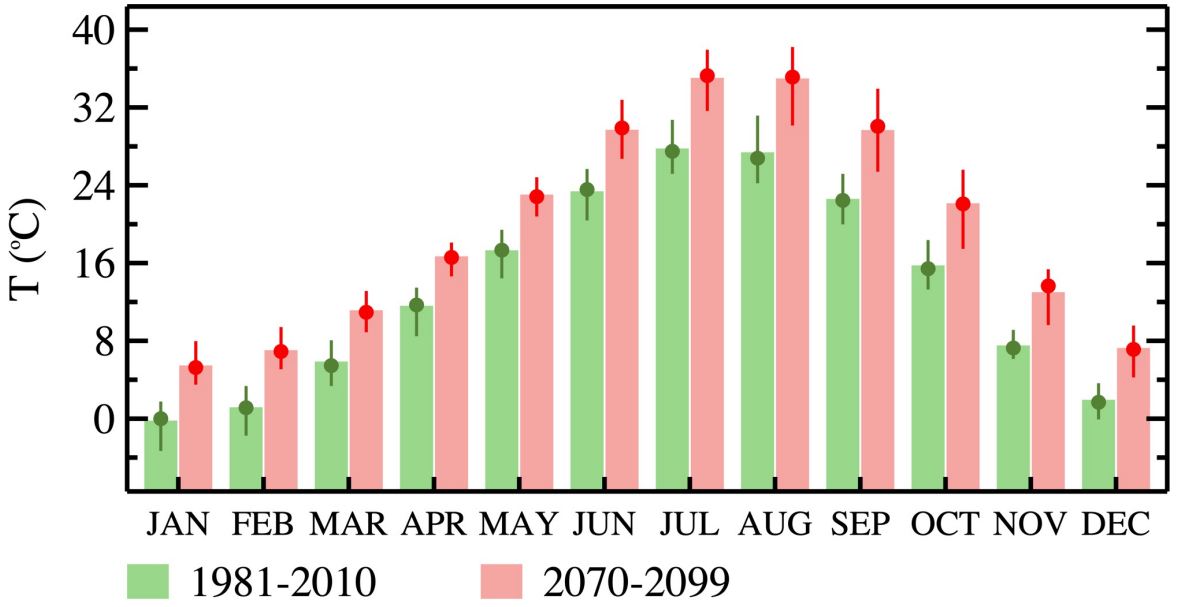




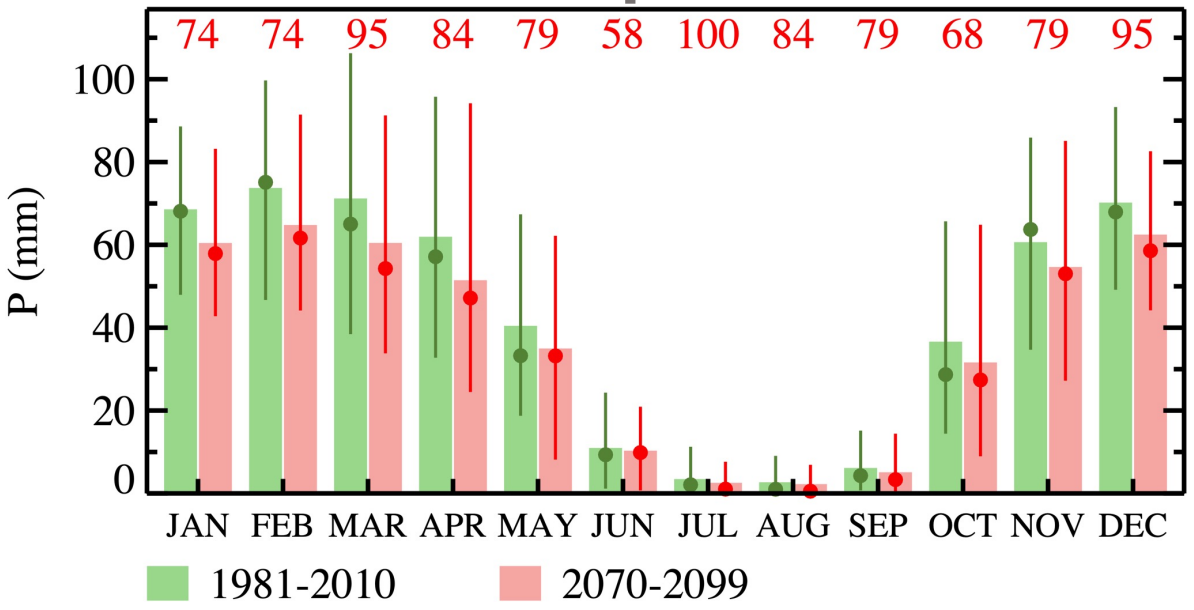
- Histogram of MME mean 1981-2010 vs. 2070-2099.
- 30 years data of 19 individual GCMs are used.
- 6.1°C warming & 13% reduction in precipitation are projected.

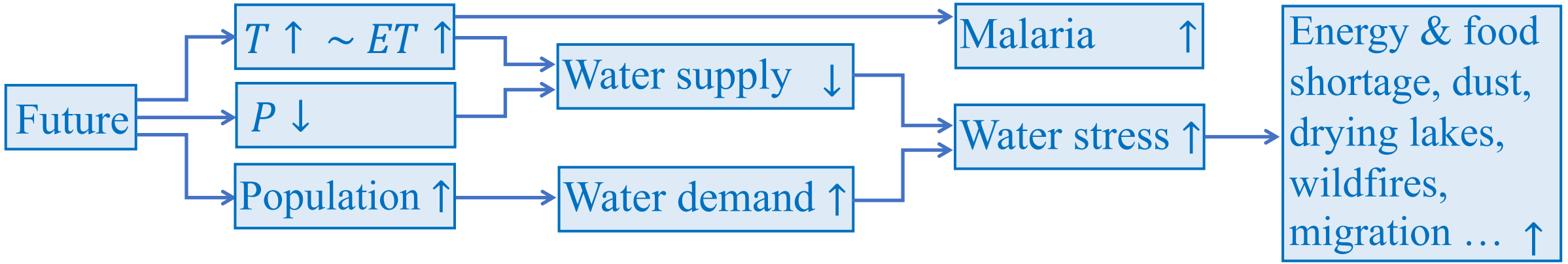
Change in annual cycle in the late 21st century over GAP region

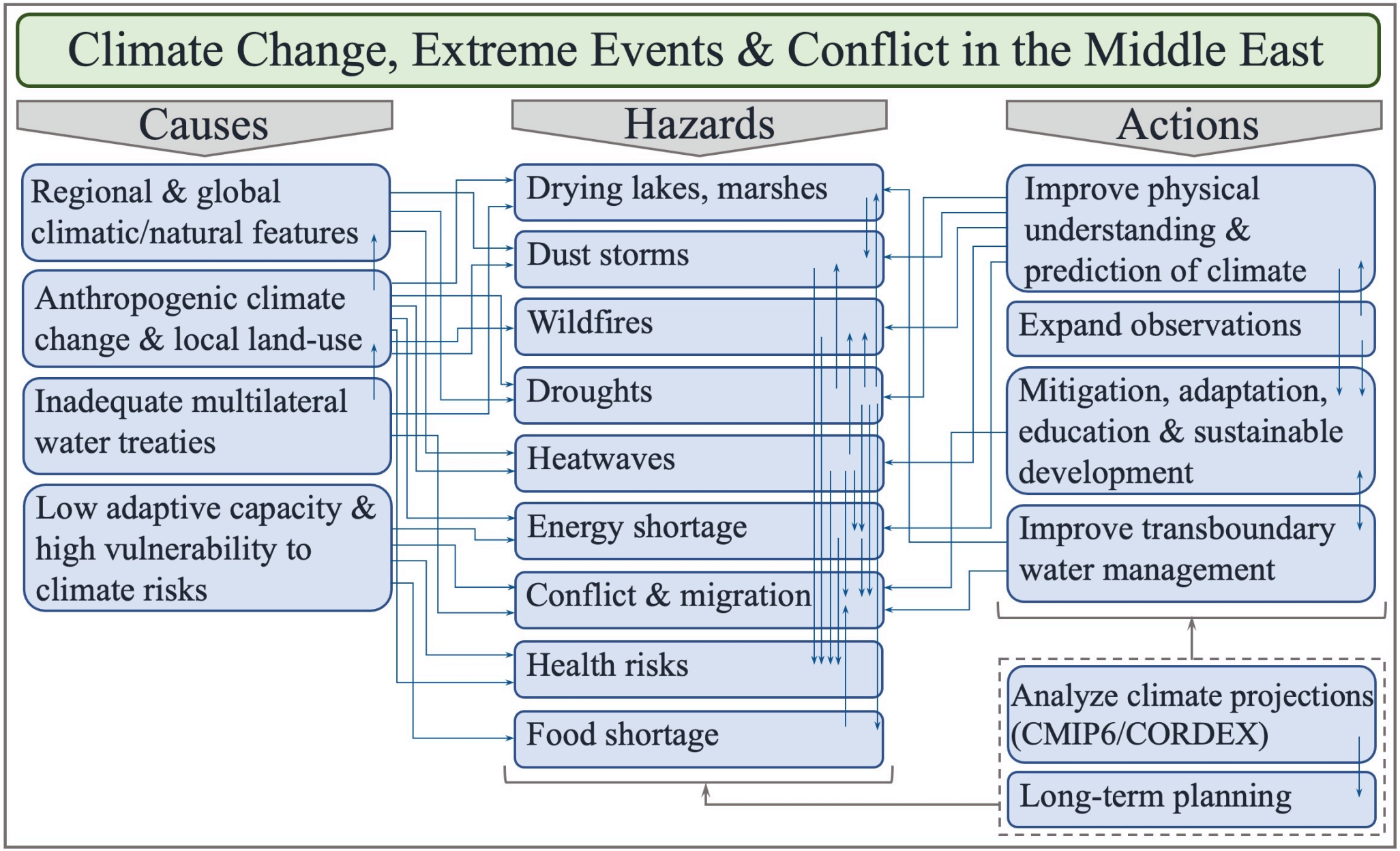
Temperature



Precipitation



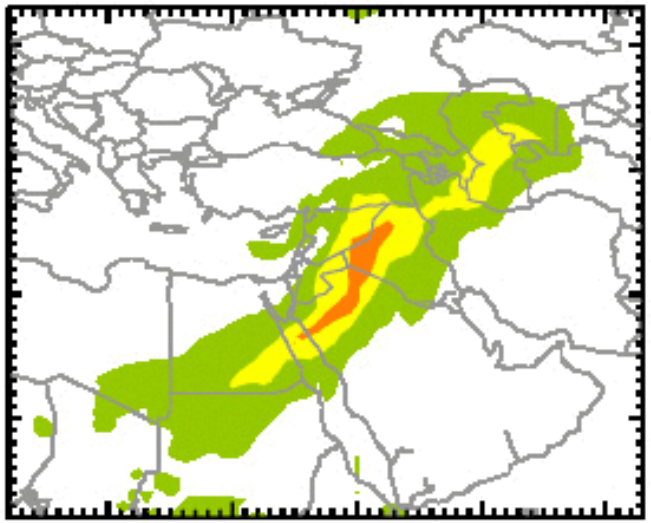



Climate Change, Extreme Events & Conflict in the Middle East
Causes
Hazards
Actions
Regional & global climatic/natural features
Anthropogenic climate change & local land-use
Inadequate multilateral water treaties
Low adaptive capacity & high vulnerability to climate risks
Drying lakes, marshes
Dust storms
Wildfires
Droughts
Heatwaves
Energy shortage
Conflict & migration
Health risks
Food shortage
Improve physical understanding & prediction of climate
Expand observations
Mitigation, adaptation, education & sustainable development
Improve transboundary water management
Analyze climate projections (CMIP6/CORDEX)
Long-term planning

References in the order used in this presentation:

- **Dezfuli, A.**, Zaitchik, B.F., Badr, H.S., Evans, J. and Peters-Lidard, C.D., 2017. The role of low-level, terrain-induced jets in rainfall variability in Tigris–Euphrates headwaters. *Journal of hydrometeorology*, *18*(3), pp.819-835.
- **Dezfuli, A.**, 2020. Rare atmospheric river caused record floods across the Middle East. *Bulletin of the American Meteorological Society*, 101 (4): E394–E400.
- **Dezfuli, A.**, Bosilovich, M.G. and Barahona, D., 2021. A Dusty Atmospheric River Brings Floods to the Middle East. *Geophysical Research Letters*, p.e2021GL095441.
- **Dezfuli, A.**, 2022. Studying the Middle East's sky rivers. *Nature Middle East*. doi:10.1038/nmiddleeast.2022.8.
- **Dezfuli, A.**, 2023. Climate extremes and Middle East protests: Lessons from 2021. *Nature Middle East.* doi:10.1038/nmiddleeast.2023.33.
- **Dezfuli, A.**, Razavi, S., Zaitchik, B.F., 2022. Compound effects of climate change on future transboundary water issues in the Middle East. *Earth's Future.*

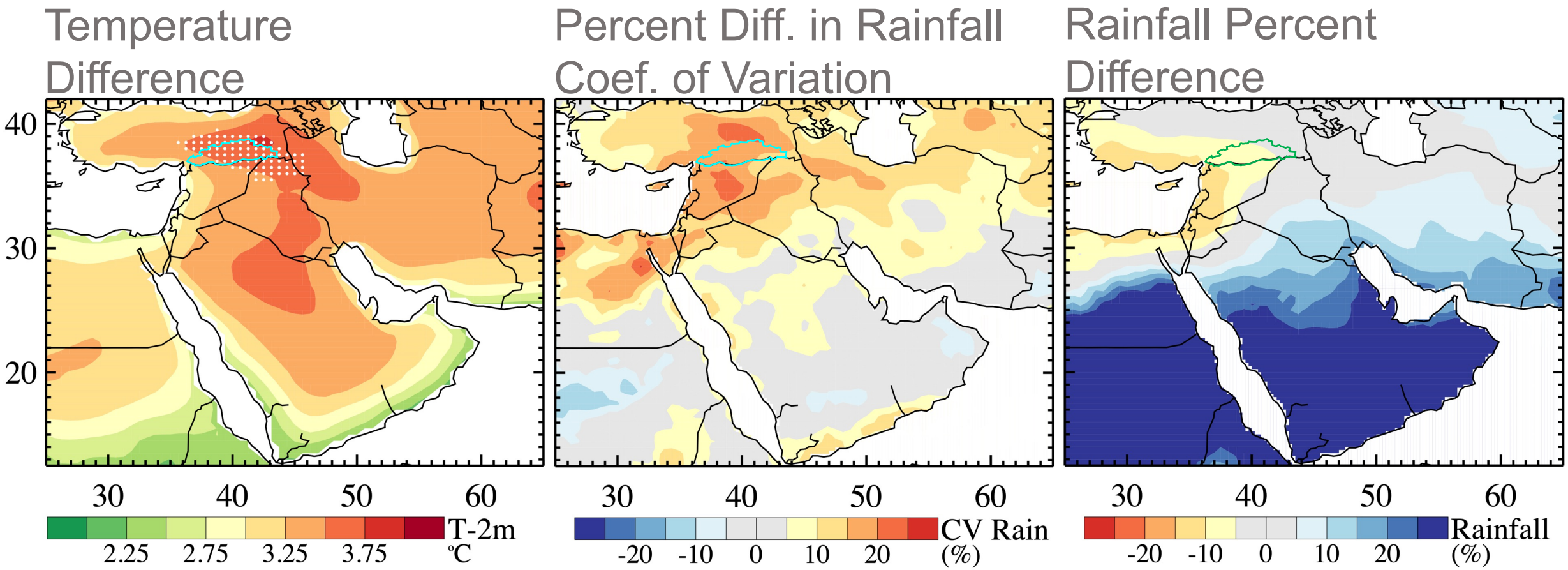
April 2017



Thank you!

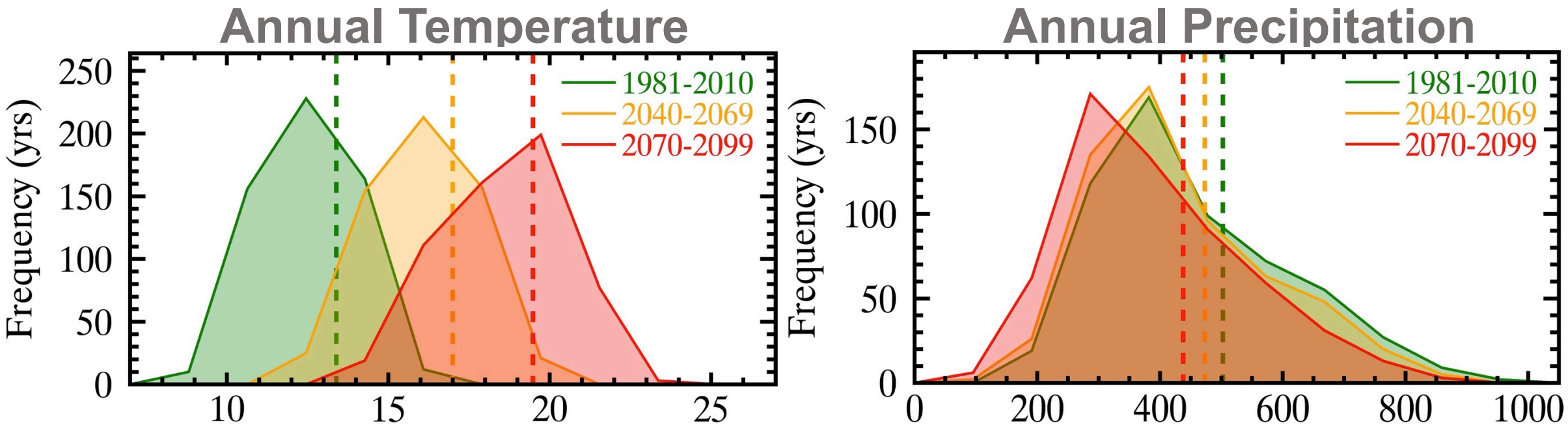
Extra

Difference between the mid 21st century and baseline period



- Patterns are generally similar to those of the late 21st century but weaker.

Climate change in the mid & late 21st century over GAP region



- Histogram of MME mean 1981-2010 vs. 2040-2069 & 2070-2099.
- For 2040-2069: 3.4°C warming & 6% reduction in precipitation are projected.
- For 2070-2099: 6.1°C warming & 13% reduction in precipitation are projected.

Change in annual cycle in the mid & late 21st century over GAP region