What caused the record floods of March 2019 across the Middle East?

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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)

(Photograph courtesy of Internet Archive)
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 are still wrestling with the aftermath of the crisis!

(Photo courtesy of Internet Archive)
What causes an extreme flood?

Infrastructures

- Good
- Poor

Rainfall amount

- Low
- High

Flood intensity

- Low
- Moderate
- High

Low
Moderate
High
Weather phenomena act at different scales

Each weather event is a result of aggregated interactions between several features.

- **Large-scale**
  - El Nino, NAO, PDO, QBO, MJO, IOD, PDO, ...

- **Regional**
  - Monsoons, mountains, lakes, low-level jets, ...

- **Local**
  - Land cover, land-sea contrast, moisture recycling, ...

Local and remote drivers of rainfall in Africa

Regional drivers of rainfall in Middle-East


Dezfuli et al. (2017), JHM.
Rainfall-flood-impacts-management loop

Certain conditions in atmosphere/oceans → Rainfall event → If high rainfall & poor infrastructures → Extreme flooding → Intense impacts → Take lessons! Better prepare for future. → Disaster management
Rainfall-flood-impacts-management loop

- Improve predictions
- Understand climate change impacts

Certain conditions in atmosphere/oceans → Rainfall event

- Extreme flooding
- Intense impacts
- Disaster management
- Take lessons! Better prepare for future.
- If high rainfall & poor infrastructures

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Comparing rainfall conditions in 2019 with the past

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

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

Histogram of daily rainfall rate

Year-to-year variability of seasonal (Oct-Mar) rainfall
Story of record rainfall during 24-25 March, 2019
Geographical features affecting climate of Iran
All waters warmer than normal in March 2019 → more evaporation
Subtropical jet: 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.
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
Geographical similarities between Middle East & West Coast U.S.

- Southeast-northwest oriented mountains (Zagros vs. Sierra Nevada)
- Fertile plain adjacent to Mts. (Fertile Crescent vs. Central Valley)
- Latitudinal extension
- AR-Mts. interactions precipitation formation
- Low-level jets (Zagros Barrier Jet vs. Sierra Barrie Jet)
- Main difference: distance to ocean
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Identify AR Dena

Using NASA’s MERRA2 data average 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

- Subtropical jet and cut-off low are apparent.
- Rainfall maximum over Zagros Mts.
How much water?

Water transport by AR Dena

Combined flow of Tigris + Euphrates + Karun + Karkheh
How much water?

Water transport by AR Dena

Combined flow of Tigris + Euphrates + Karun + Karkheh

150 \times 6 \text{ Billion}

(in two days)
Horizontal and vertical structure of the AR

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

- Subtropical jet and cut-off low are apparent.

Vertical cross-section of moisture flux

- AR core at ~3000-5500 m layer
Subtropical jet and cut-off low are apparent.

All water basins warmer than normal with more evaporation.
Moisture contribution of various water basins to AR Dena

Vertical cross-section of moisture transport
Geopotential heights (GHT) in the lower troposphere (925-700 mb)

- Configuration of low and high pressure systems facilitated moisture transport from regional water basins.
Future work

- Perform a comprehensive analysis of all ARs in the region, using the 40-year MERRA-2 records:
  - Better understand statistics of the ARs (frequency, inter-annual variability, trends, etc)
  - Processes responsible for formation of the ARs
- Skills of subseasonal-to-seasonal (S2S) predictions of frequency of extreme events
- Perform hybrid dynamical-statistical approach using machine learning techniques
- Hydrology modeling and impact analysis
- Future projection of the ARs in the region