Anomalous Atmospheric Events Leading to the Summer 2010 Floods in Pakistan

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Introduction

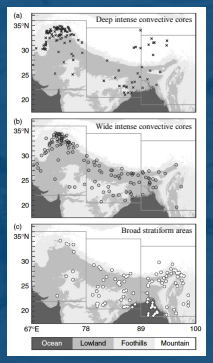
Addressing the United Nations General Assembly about the floods that affected the Indus Valley of Pakistan in July-August 2010, Secretary-General Ban Ki-moon stated, "Almost 20 million people need shelter, food and emergency care. That is more than the entire population hit by the Indian Ocean tsunami, the Kashmir earthquake, Cyclone Nargis, and the earthquake in Haiti—combined." Such a great humanitarian disaster deserves a close look at the conditions under which it occurred. Recent research based on data from the radar onboard the U.S.-Japanese Tropical Rainfall Measuring Mission (TRMM) satellite lead to an understanding of the anomalous character of this event, and suggest how future disasters in this part of the world might be better anticipated through the use of such data to interpret atmospheric forecast models.

Background

Near the Himalayas, mountains can affect rainstorms in two ways:

- Airflow over rising terrain may trigger new intense convective cells
- Orographic upward air motions sustain and broaden stratiform regions that have formed from older convective cloud elements.

The TRMM Precipitation Radar (PR) provides a unique vision of storms in regions inaccessible to land-based surface observations —such as the mountains of Pakistan.

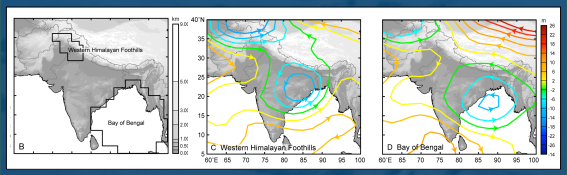


Three characteristic echo types:

- Storms with deep convective cores (40 dBZ > 10 km in height)
- Storms with wide convective cores (40 dBZ echo > 1000 km^2)
- Storms containing broad stratiform areas (stratiform echo > 50,000 km^2)

◀ Regional distribution of storm types (Houze et al. 2007)

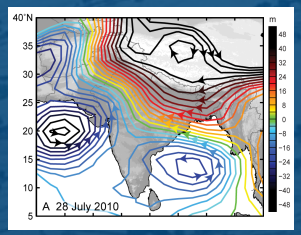
- Storms with deep convective cores common in northern Pakistan
- Storms containing broad stratiform areas extremely rare in northern Pakistan



▲ 500 hPa geopotential height anomalies for typical rainstorms in regions (Romatschke and Houze 2010)

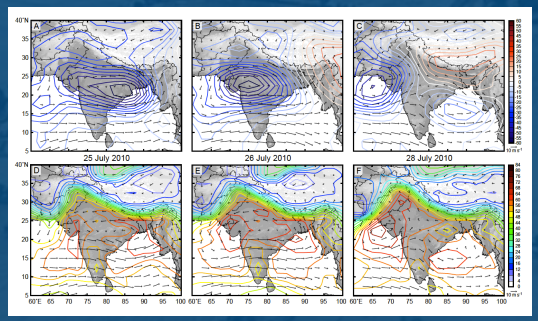
- Western Himalayan Foothills → Dry air from the Afghan Plateau caps moist air from the Arabian Sea
- Bay of Bengal → Low–pressure centered over bay brings a deep layer of moisture over land and NE of the depression

Pakistan Flood July 27-31 2010



◀ 500 hPa geopotential height anomalies on 28 July 2010

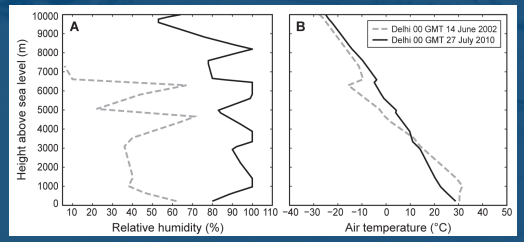
- Unlike previously documented flow anomalies
- Intense southeasterly wind brought moist air from Bay of Bengal across subcontinent and into Pakistan
- Strong high pressure anomalies over Himalayas



▲ Synoptic evolution from 25-28 July 2010

- 700 hPa geopotential height anomalies → Intense Bay of Bengal depression propagates westward and creates SE flow into Pakistan
- Precipitable water → Humid air usually near the Bay of Bengal propagates westward across the subcontinent and into Pakistan

Sounding Profiles

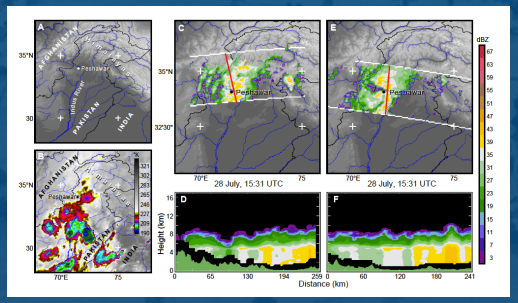


▲ Sounding comparison from Delhi in western India (upstream of Pakistan)

- Dashed line → Environmental conditions responsible for a storm with a deep convective core over Pakistan, dry and steep lapse rate
- Solid line→ Environmental conditions responsible for the 2010 Pakistan flooding, relatively saturated and less steep lapse rate

▼ Infrared satellite image and TRMM Precipitation Radar swaths

- Rain areas are extensive (>200 km) and primarily stratiform rain
- Widespread stratiform rain located over high terrain → produced extensive runoff into the rivers and plains below
- **These types of systems are rarely seen in this mountainous region**



Impacts of Flooding

The flooding in Pakistan caused: 2,000 casualties, displaced 20 million people, 4 billion USD in structural damage, 500 million USD in agricultural crop loss, 70% roads and bridges washed out in affected areas, affected 1/5 of the country, and had a total economic impact of 43 billion USD.

Flooding and damage in Pakistan. *Photos courtesy of the Boston Globe Big Picture Blog.*

Conclusion

The anomalous propagation of a Bay of Bengal depression and its moist environment across the subcontinent to the Arabian Sea together with the development of the high pressure over the Tibetan Plateau, favored the occurrence of this widespread stratiform rain event over the western Himalayan region. This case illustrates that the climatology of the TRMM radar data and associated large-scale flow patterns that have been accumulated over the past 12 years for different regions of south Asia, provide a useful backdrop against which atmospheric forecast models can be interpreted in terms of the form that a rainstorm might take. When the data suggest that storms are likely to have a particularly hazardous structure in relation to the terrain, such an interpretation could be extremely valuable in formulating advance warnings aimed at saving life and property in vulnerable regions such as the Indus Valley of Pakistan.

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