2. HEAVIEST PRECIPITATION EVENTS, 1998-2007: A NEAR-GLOBAL SURVEY

BRIAN MAPES
Rosenstiel School of Marine and Atmospheric Sciences
University of Miami, Florida, USA
Email: mapes@miami.edu

The greatest 1-day and 3-day precipitation accumulations in a 10-year period have been identified, at every grid cell in the 0.25-degree 3-hourly TRMM 3B42 data set covering 50°S-50°N. Basic seasonality and statistics of these record precipitation amounts are shown here. The mean size of contiguous regions where the record was set on the same day is just a few pixels, and record 3-day rainfalls are only about 50% larger than record 1-day totals. Both these finding highlight the importance of convective and mesoscale processes in extreme precipitation events. Still, satellite imagery of cases also shows that high-amplitude synoptic patterns are important. Tropical cyclones set the precipitation record in many locations, but tropical-extratropical interactions, including poorly understood long-range interactions ahead of transitioning tropical systems, seem to be another powerful combination. An interactive web atlas http://www.rsmas.miami.edu/users/bmapes/HeavyRains_clickmaps allows anyone to find these record events by clicking on detailed maps and getting back web links to satellite imagery and other case-study resources.

1. Introduction

Monsoons bring life-giving but also sometimes damaging rains. Within the broad topic of ‘monsoon severe weather’, heavy rains seemed the most tractable hazard to study, since satellite-derived estimates are available globally. Comparative studies of such events at various locations may reveal interesting synoptic commonalities and differences, as well as giving a sense of the random or unpredictable aspects. With ever-increasing data availability and computing capabilities, both vast surveys and detailed case studies can be readily assembled, dissolving some historical divisions between climate and weather research. Decade-length datasets can now be viewed not merely via bland averages, but also as an index to the world’s rich archives of data on high-impact events and their predictability. The purpose here is not to reach facile conclusions, but rather to introduce some methods and products that might be of use for forecaster training as well as research.

2. Dataset Used

Our 1998-2007 heavy precipitation event catalog was constructed from the Tropical Rainfall Measuring Mission (TRMM) 3B42 precipitation rate product (Huffman et al. 2007), version 6. This 3-hourly 0.25 degree data set uses microwave satellite observations wherever
available, regionally-calibrated infrared cloud-top data to fill gaps, and rain gauge analyses to adjust final calibration. These data are far from perfect quantitatively, and are but one of several data products available. Although quantitative values are debatable, when 3B42 indicates very heavy precipitation accumulations the meteorological situation is surely significant and worth studying.

At each point in the dataset (50°S-50°N latitude belt), accumulated precipitation was computed using a moving average in time. A 9-point centered window produced 1-day (strictly, 27-hour) accumulations, while a 25-point smoother produced 3-day (actually 75-hour) accumulations. The largest value of the smoothed time series within the 10-year record was identified as the heaviest precipitation event. Its amount (in mm) and its central date and time were captured in latitude x longitude arrays. Actually, we isolated the heaviest several precipitation events in each of the 12 calendar months, but this paper discusses only the single heaviest event in the entire 10-year record at each location. Because the events are so small scale, any region contains many different record-setting events, so simply examining the heaviest events near a place of interest reveals a sufficiently diverse set of weather situations that could have produced extreme events in that place. Examining the 2nd-heaviest, 3rd-heaviest etc. only adds excess to an abundance of information.

The 10-year monthly climatology was also computed from the same dataset, so that “heavy” precipitation events can be viewed in that spatially varying context. A digital elevation model was obtained on the same 0.25-degree grid, so we can isolate events over land or (potentially) subdivide by ground altitude or slope. For present purposes the elevation data were simply used as a contoured overlay in some figures here.

High-resolution (1200 x 1200 pixel full disk) 3-hourly geostationary satellite imagery covering this entire 10-year period (and more) is freely available at http://www.ncdc.noaa.gov/gibbs, and scripts were developed to download multiple images and call the free software convert to crop them to an area of interest and create animation loops. The scripts are available on request or on my web site. I hope to develop the site to produce automatic links to synoptic charts, and even (for year 2007 and beyond) to THe Observing System Research and Predictability Experiment (THORPEX) Interactive Grand Global Ensemble (TIGGE)’s forecast database, which could be used to evaluate forecast model performance for these extreme events (extending studies like Schumacher et al. 2010 globally).

3. Climatological and Record Rainfalls

The calendar months of greatest climatological and 3-day record precipitation are shown in Figs. 1a, b. The color legend is shifted so that green is summer and red-white-black-purple shows winter in both hemispheres.

The climatological wettest month tends to be in the summer for subtropical lands, and up to 50°N in eastern Asia (green colors in Fig. 1a). Winter is the wet season for some higher latitude lands (white-black-purple areas: the Middle East, horn of Africa, California, the southwestern tips of Africa and Australia). A purple-white linear boundary on the west coast of North America is an artifact of the data set: The TRMM satellite only samples up to
latitude 38, so the data poleward of there has very different sampling and measurement characteristics, and will be excluded from some statistics below. Spring maxima (May or November) are seen in several off-equatorial land regions (China, inland North America, southeast Australia, eastern South America). Autumn maxima (yellow-orange) are found on high-latitude west-coast regions, including Europe, southern Africa, western Australia, and parts of southeastern South America, presumably aided by the warm sea temperatures persisting in autumn even as the cold-season polar vortex begins to intensify. Autumn maxima are also seen in some tropical areas, like in Central America and the adjacent seas and in southern Asia, associated with tropical disturbances and perhaps the retreating monsoon in this season of warmest ocean waters.

Figure 1. Calendar month of (a) maximum climatological precipitation (2 panels: with and without land mask); and (b) 3-day record precipitation at each location (land only, see web site for ocean data).
Figure 2. Precipitation amounts. (a) Climatological annual rainfall divided by 12 (mm). (b) Maximum 3-day rainfall accumulation occurring in 1998-2007 (mm). (c) Ratio b/a.
The month of record 3-day precipitation accumulation at each point is shown in Fig 1b. Often it coincides with the climatological wet season (Fig. 1a), but naturally this extremum is a noisier statistic, so that some off-peak-month events can win the prize. In tropical cyclone affected regions (southeastern North America and Asia), rainfall records are frequently set in autumn, despite summer-peaked mean rainfall seasonality.

The characteristic spatial size of heavy rain events is quite small, even for 3-day accumulations, as seen in the small patch sizes in Fig. 1c, and also in Fig. 2b, which shows the record rainfall amounts at each location. These fine scales suggest that mesoscale and convective scale enhancements to synoptic weather systems are important aspects of very heavy rain events everywhere.

For comparison, the same gray scale is used for the annual climatology (expressed in mm/month) in Fig. 2a. In wet locations, record 3-day rains are seen to be roughly comparable to ‘a month of rain’ (or 1/12 the annual mean). In climatologically drier locations, dividing the record precipitation by the average (Fig. 2c) shows values up to 12, indicating that a year’s mean rainfall can happen in a single 3-day event in the most arid regions.

The spatial scales of record-breaking events are indicated by Fig. 3: a map of mean wet-event size on a 10 degree coarse grid. Here a wet event is defined as a contiguous geographical region in which the record was set on almost the same date (different definitions for “almost” give very similar results). In equatorial Africa and South America, record setting wet events on average cover less than 2 of these 0.25-degree pixels. Oceanic precipitation records, especially in dry regions, are simultaneously set over much larger patches by rare synoptic events comprised of many pixels, which brings the average up above 4 in Fig. 3. The information content of Fig. 3 can be appreciated directly from Fig. 1b over land, and web atlas figures over ocean. The lesson is that record-setting precipitation events are of quite small scale. Of course, very small patches (single pixels even) are very numerous, so the average patch size is dominated by these, making absolute values small in Fig. 3.

The absolute amounts of record precipitation events are depicted in Fig. 4, as histograms for land and ocean areas in the TRMM-sampled latitudes (38°S-38°N). Oceanic records are most frequently (the distribution’s mode) ~130 mm in 27 hours or ~200 mm in 3 days, while land records tend to be lower (~100 and ~150 mm modal values). The fact that 3-day record
totals are only modestly greater than 27 h totals is another indication, now in the time domain, that convective or mesoscale processes (with sub-synoptic time scales), are very important to producing record precipitation events.

![Figure 4. Histogram of record precipitation amounts (mm).](image4)

In light of the small scales indicated above, regional structure and synoptic-mesoscale case studies are the most interesting aspects of this data set. Figure 5 shows 3-day record amounts (like Fig. 2b) for Asia, with topography contoured. Topographic relationships are complex, and in some cases simply coincidental. It is not easy to imagine from this 10-year statistic what a hypothetical infinitely long data record would show. Actually, satellite
estimation of precipitation over this range of geographical conditions is problematic, so we must not take Fig. 5 too literally, but it is still interesting.

Clicking on various features in figures like Fig. 5 (using the Web address in the Abstract above) and examining the satellite imagery for the events reveals a fascinating range of weather processes. For example, the large dark patch along the Yangtze River in east-central China (near 29°N, 116°E) is a precipitation event from September 3, 2005. The Fen Yung 2C water vapor image for this date is Figure 6. Although a detailed case study of Fig. 6 is beyond the present scope, it seems clear that this weather situation involves complex interactions among tropical and midlatitude synoptic influences, as well as mesoscale convective processes. Predecessor Rain Events (PREs), occurring ahead of tropical cyclones in the midlatitudes, are a poorly understood but now familiar phenomenon (Bosart and Carr 1978; Atallah et al. 2007). The nature of the interactions remains unclear, but may involve long-range dynamical processes as well as simply tracer (moisture) transport.

Figure 6. Water vapor image on 3 September 2005 when 10-year record precipitation near 30°N in east-central China occurred.

In summary, heavy rain events have complex causes, often involving powerful synoptic forcings and moisture delivery mechanisms, but also mesoscale and convective enhancements which are necessary to break decade-long records. Studies of many cases are now feasible, including predictability studies which can be done by anyone using forecast archives (Schumacher et al. 2010), not just by prediction centers. As one step toward encouraging such studies, record rainfall events have here been compiled to give a decade-scale perspective on these mesoscale hazards. to the field seems ripe for a renaissance of weather research, with well-contextualized and statistically significant suites of case studies informing an ever richer understanding of weather and climate, all made possible by the rapidly growing abundance of data freely available to all.
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