Daily and annual cycles of precipitation and convection over the continental United States

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1. A radar echo climatology for the United States presented by a Canadian at a European radar conference???

In the early 1990s was deployed the U.S. WSR-88D radar network, the first national Doppler radar network in the world. More importantly, a framework and process for monitoring and maintaining radar data quality was implemented and adhered to since. From 1996 onwards, the reflectivity data has been composited into a national mosaic by a variety of actors, including private companies, research institutes, and the National Weather Service itself. A unique dataset now exists to study radar echoes collected by the same radars over a period of more than 15 years over an area of the size of Europe.

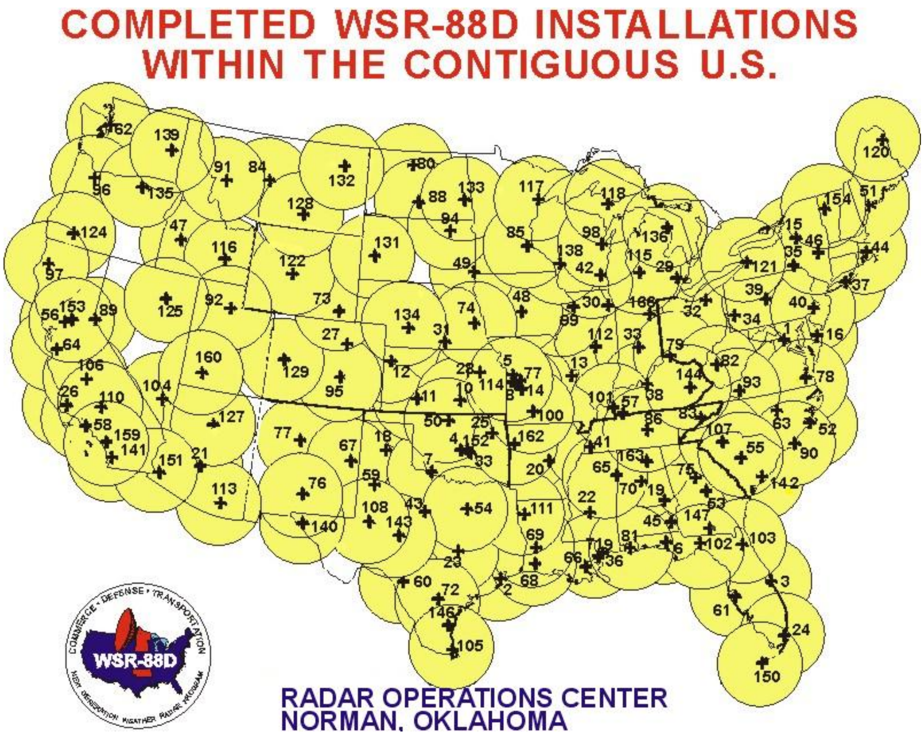

Fig. 1: WSR-88D Radar sites in the contiguous US. Circles have a 230 km radius. Figure courtesy of NOAA ROC.

Radar data offer information on precipitation climatology that is simply not available or archived elsewhere: how often does it rain at any particular location? At what time? And with what intensity distribution? What are the geographical and temporal patterns of precipitation occurrence, formation, and decay? What is the climatology of severe weather? Answers to these questions invariably trigger more questions about the processes causing these patterns as well as suggest some answers. These tend to be of a different nature than those arising from individual case studies because the specificity of atmospheric conditions leading to one storm instead of another are being washed out. What are left are the persistent features that often or always influence precipitation occurrence which, in the end, are the most important to get right both in the context of process studies and of numerical modeling. And suddenly, the fact that the climatology used for that type of work is for the United States and not for your own country loses much of its importance.

But before we can reach that point, one has to build and look at such climatology, and this has been rarely done (my respects go to Carbone et al. (2002,2008) for having started this line of inquiry). The field is hence open, and it makes the exercise even more interesting to undertake. A radar echo climatology for the conterminous U.S. was therefore built, and its initial analysis is presented here.

Of course radar data processing and interpretation is fraught with complications. Are all radars properly calibrated? Have the data been properly cleaned of ground echoes, of insects, of birds? Is radar coverage sufficient everywhere? Are there range or topography dependent biases? These questions both complicate the interpretation of a radar echo climatology and also can be partially answered by it.

2. To build a climatology

For reasons of simplicity, and because we did not have access to the raw radar data for the whole U.S. over such a long period, we have chosen to build the radar echo climatology from existing mosaics. But while the radars collecting the data have not changed much since the mid-1990s, the process of cleaning radar data and compositing it into a national mosaic certainly has. And because the interest in radar echo climatology has been small until now, there has been no reanalysis effort undertaken. We must hence contend with radar mosaic maps whose recipe has changed over the years (Table 1). To complicate matters, the early maps we have access to were made by a private company that treats its mosaic making process as a trade secret and will not share it with us.

Period	Source	Resolution	Processing
1995-2001	Weather Services International (WSI)	5 dB(Z); 2 km * (~2 km); 15 min	Unknown
2002-2007	Weather Services International (WSI)	1 dB(Z); 2 km * (~2 km); 15 min	Unknown
2004-2011	NSSL / Weather Decision Technologies	5 dB(Z); .9 km * (~1 km); 5 min	Lakshmanan et al. (2006, 2007)
2011-2012	NSSL / Weather Decision Technologies	.33 dB(Z); 1 km * (~1 km); 5 min	Lakshmanan et al. (2006, 2007)

Table 1: Composite radar maps used in this study.

Peculiarities of the radar data processing may introduce biases, and we have to watch for them. Nevertheless, despite a few data gaps, more than 15 years of radar data composites at 15 min resolution can be accessed and processed. However, I am a bit behind where I thought I was going to be when I submitted my abstract. Results shown here will hence be essentially for the period between 1995-2007, though the oral presentation covered the whole 1995-2012 period.

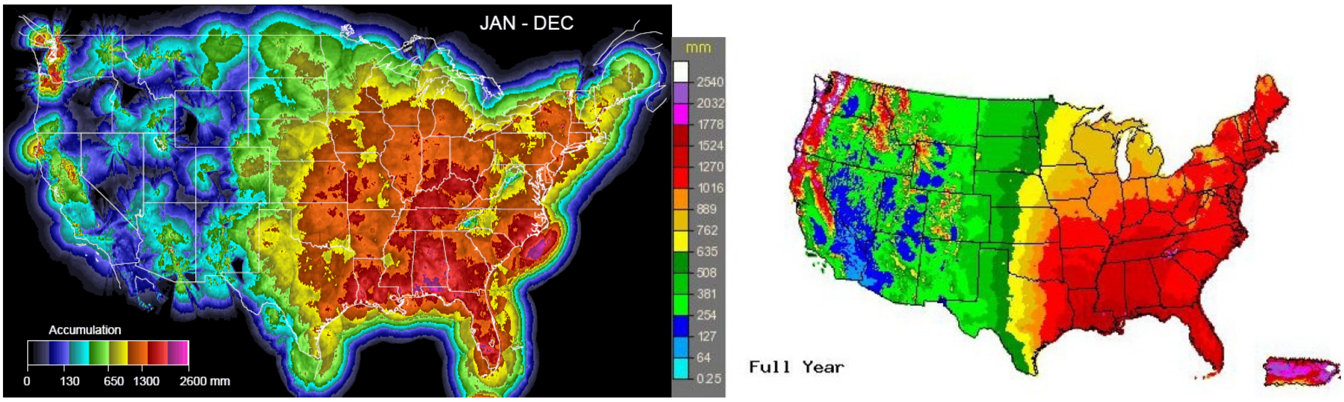

Fig. 2: Average radar-derived rainfall accumulation (left) compared to a raingauge-based climatology (right).

A first acid test was made by comparing radar accumulation over 11 years computed using $Z=300R^{1.5}$ with a 30-yr climatology from gauges (Fig. 2). In radar-sparse areas, which also correspond to mountainous regions and along the west coast, radar-estimated values are considerably lower than climatology. Otherwise, except for the fact that radar accumulation had some globular appearance with weak local maxima observed around each radar, the two maps compared reasonably well. If instead of accumulations we focus on the probability of exceeding a certain reflectivity threshold (Fig. 3), we find that the “footprint” of individual radar coverage is more visible for weaker thresholds, less so for stronger thresholds.

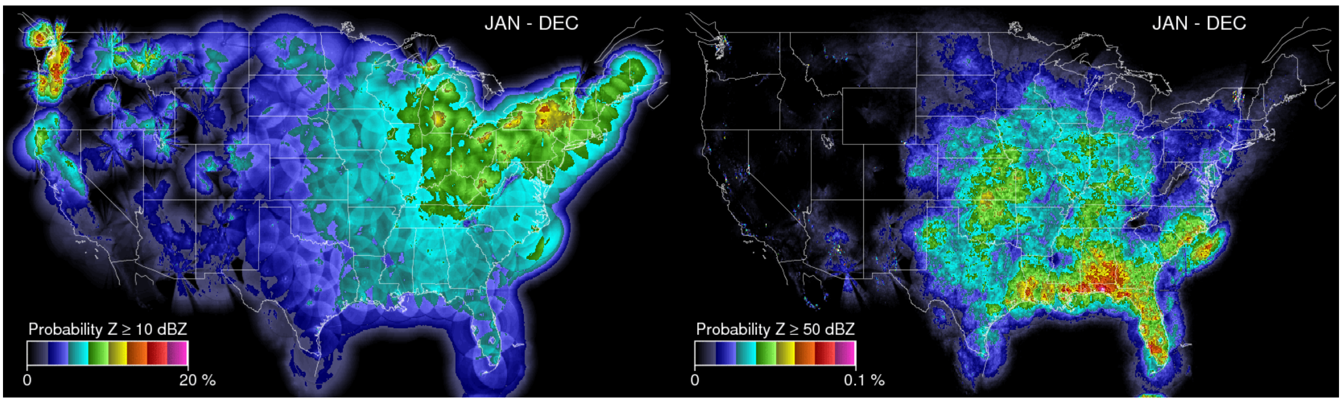

Fig. 3: Probability of observing echoes of at least 10 dBZ (left) and at least 50 dBZ (right). Artifact-wise, we can see more artificial transitions at low reflectivity than at high reflectivity. Meteorology-wise, precipitation is more frequent in the mid-latitudes (West Coast & north east). Heavy rain occurrence is highest on the Gulf Coast and southern Atlantic Coast where sea breezes often play a major role in convection initiation, and lowest on the West Coast bathed by cold ocean water.

3. Precipitation occurrence vs. threshold

A first set of illustrations of the kind of information retrievable by radar is a set of maps of the likelihood of observing precipitation with different reflectivities. Precipitation ($Z \geq 10$ dBZ, Fig. 3) is most frequent in mid-latitude regions to the north, especially near the oceans or the Great Lakes area. Precipitation is observed 11% of the time in Buffalo (43° N) on the Great Lakes and 15% of the time just east of Seattle (47° N) on the foothills of Mount Rainier, but 2% in Los Angeles (33° N) and 4% in Miami (26° N). As we increase the threshold, the area of higher occurrence shifts southward. At a 50 dBZ threshold, which correspond to strong convection, maximum occurrence is shifting south. Heavy convection is essentially never observed on Mount Rainier or in Los Angeles in the west, detected 0.01 % of the time (1 hour per year) in Buffalo, but 0.05 % of the time in Miami. If we further increase the threshold to 60 dBZ (Fig. 4 left), a reflectivity associated with hail, the peak of occurrence shifts towards the west of the Central Great Plains, peaking near Amarillo TX and Colorado Springs (15 minutes per year). Interestingly, the map compares well with that of severe hail occurrence made by the Storm Prediction Center (Fig. 4 right), except that it shifts the hail capital away from Norman OK where the SPC is located and where careful weather observers tend to be concentrated.

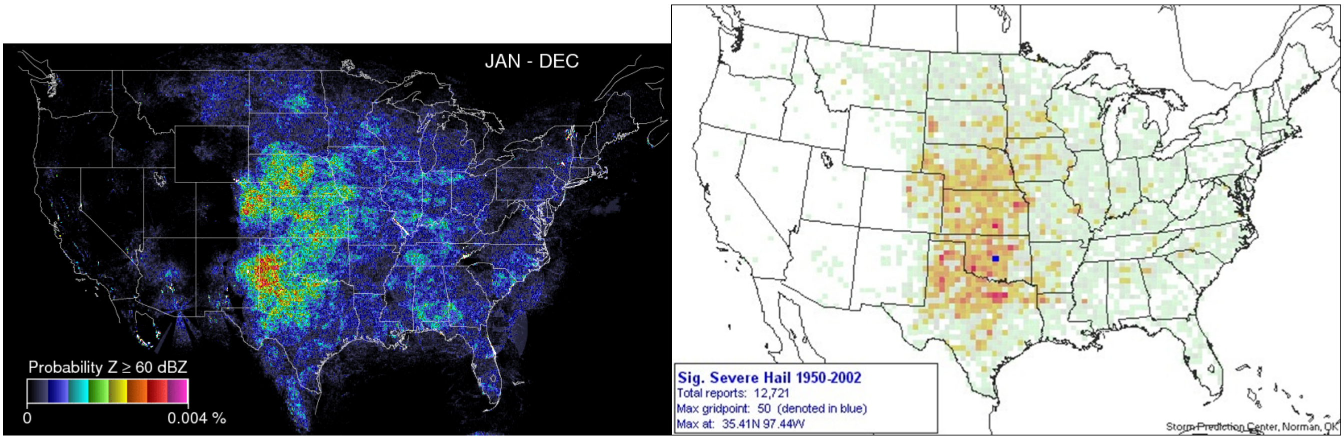

Fig. 4: Probability of observing echoes of at least 60 dBZ (left) compared with the climatology of severe hail (right).

4. Annual cycle

The annual cycle of precipitation can be documented (Fig. 5). Much of what we observe is already well known: in winter, peak occurrence of precipitation is seen in coastal areas or near the Great Lakes; in summer, precipitation occurrence is generally lower, but peaks in hilly areas (Adirondacks) and near the southern coast thanks to the effect of sea breezes. Precipitation occurrence maps in Fig. 5 are clearly affected by sampling issues: in winter in the North-East, precipitation occurrence peaks around each radar as many events are weak and shallow; in summer, the contours of many radar coverages can be identified. Nevertheless,

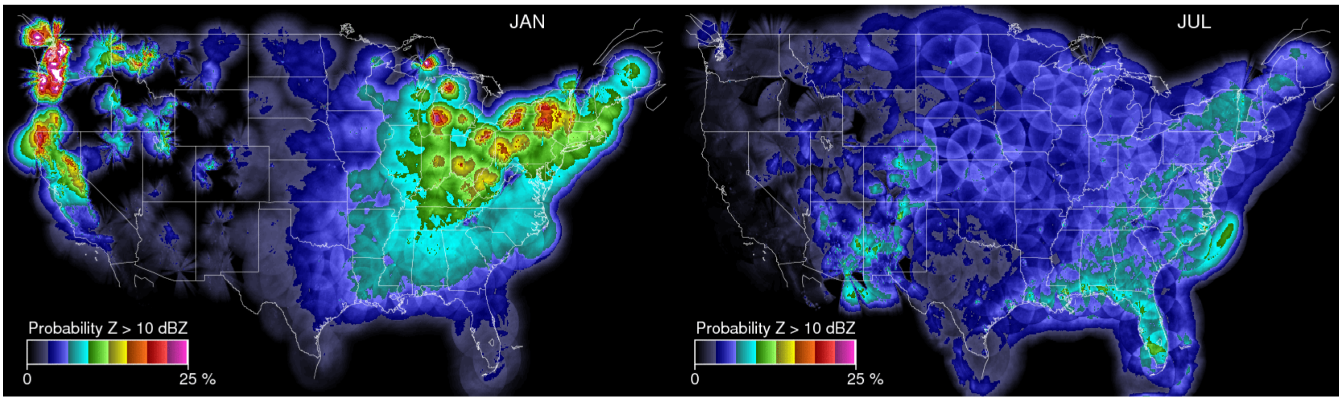

Fig. 5: Probability of observing echoes of at least 10 dBZ in January (left) and July (right).

Similarly, we can observe the annual cycle of convection occurrence (Fig. 6). It obviously peaks in the warm season, but in different months at different locations. While convection driven by local heating (e.g., in the south east) peaks in July, convection triggered thanks to upper air support (e.g., Central Plains) peaks earlier in the season, while that driven by monsoons (e.g., in the south west) will peak later.

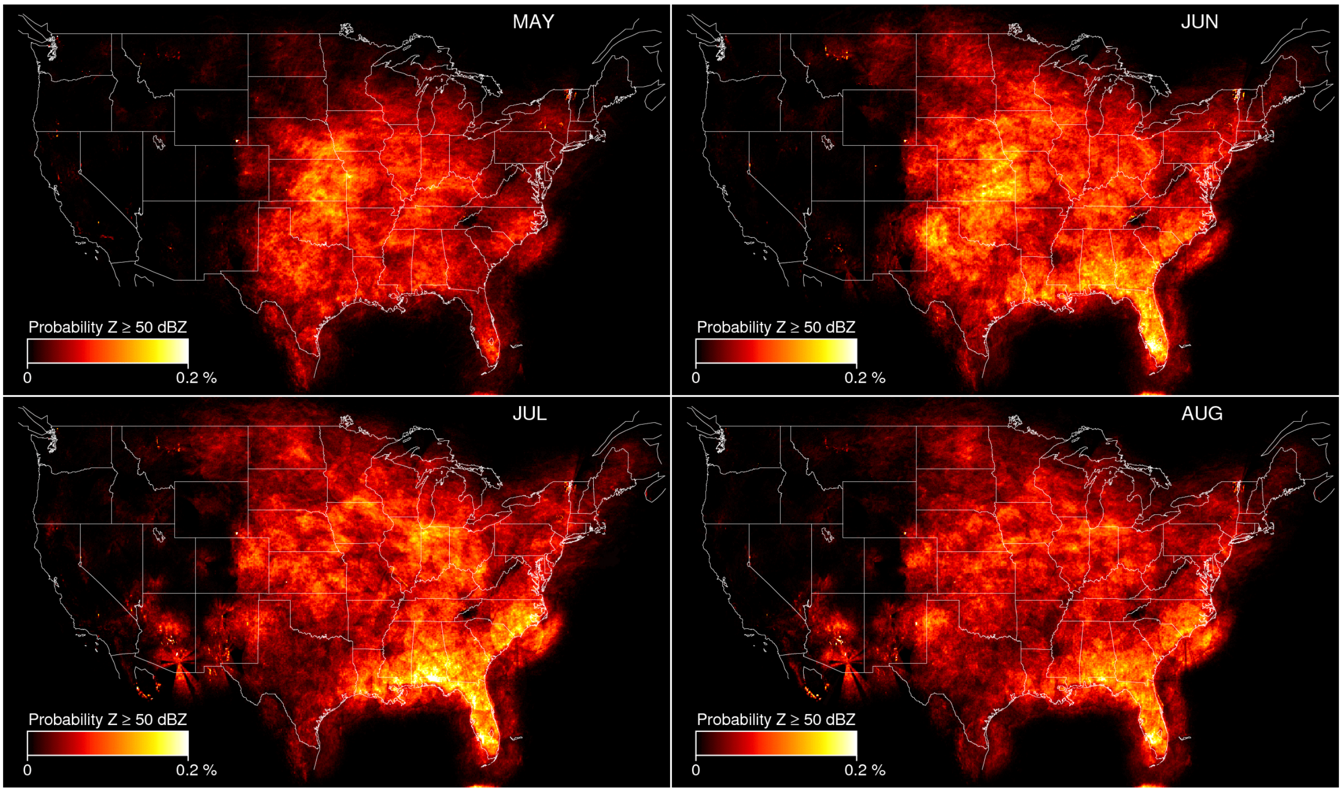

Fig. 6: Probability of observing echoes of at least 50 dBZ in May (upper left), June (upper right), July (lower left), and August (lower right). Severe convection peaks in late spring in the Central Plains when the air is humid enough near the surface and upper-level support is still important, later elsewhere where these factors are less important.

5. Diurnal cycle

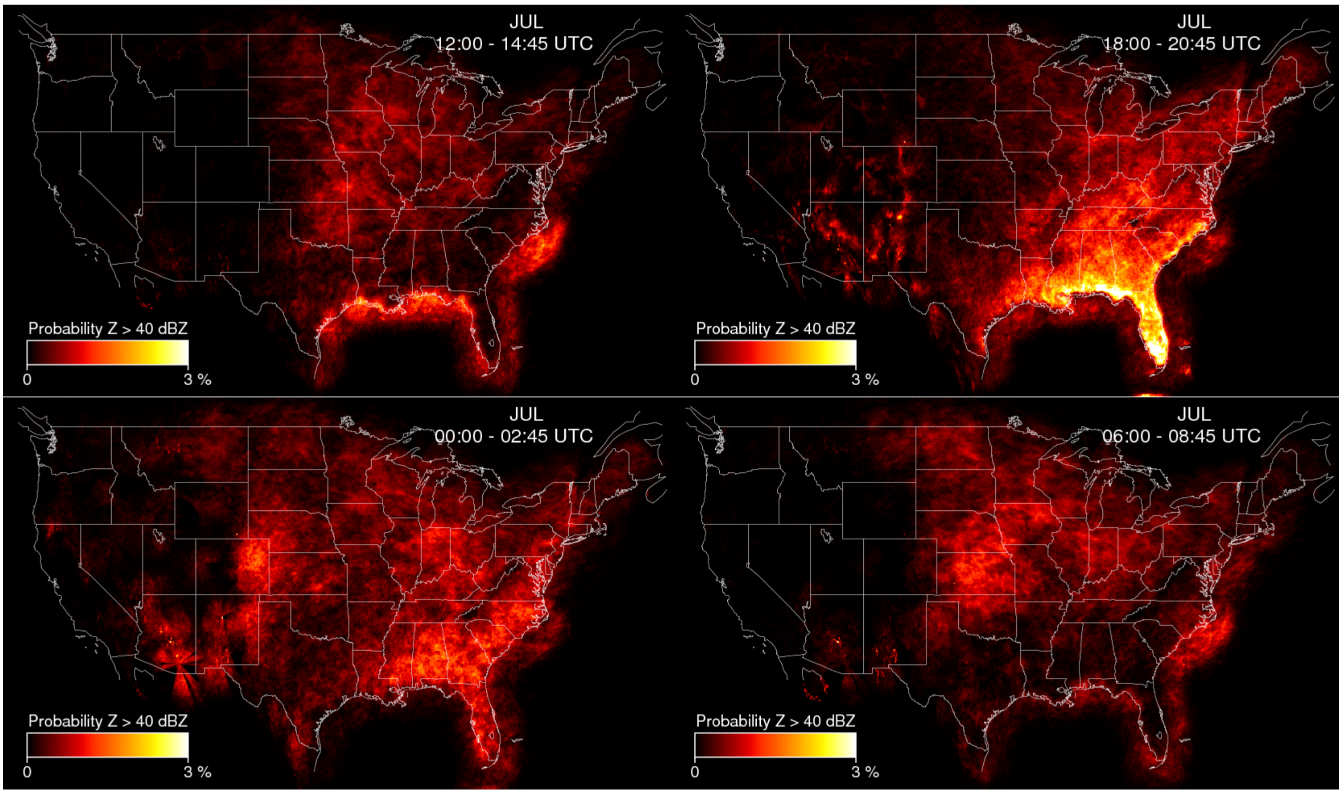

Fig. 7: Probability of observing echoes of at least 40 dBZ (the typical threshold for convection) in July in the morning (12-15 UTC, upper left), afternoon (18-21 UTC, upper right), evening (0-3 UTC, lower left), and night (6-9 UTC, lower right).

It is the diurnal cycle maps that provide the most unusual information because the time information of rainfall occurrence is rarely logged, and even less so analyzed. The largest diurnal cycle signal is obviously in summer (Fig. 7) when solar heating can trigger convection. They also make great maps to illustrate basic meteorology concepts. For example, in the SE, the signal of the sea and land breeze can be clearly observed. As first documented by Carbone et al. (2002), the formation of convection of the foothills of the Rockies in the afternoon that then moves eastward towards the Great Plains is also well seen. A very weak signal is also seen in winter, and we are still trying to determine whether it is statistically significant or not.

6. Now what?

This is the beginning of a process. We are rapidly getting to a stage where such analyses a) can be made in many locations, and b) can be used for new and unexpected meteorological studies, from long-term model validations to new kinds of weather studies or climatological analyses. What we then need are eyes, and enough curiosity to find the nuggets that hide in such datasets.

References

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