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CHARACTERIZATION OF MESOSCALE CONVECTIVE SYSTEMS BY MEANS OF COMPOSITE RADAR REFLECTIVITY DATA

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Bart Geerts

1. Introduction

A mesoscale convective system (MCS) is broadly defined (as in Houze 1993), i.e. a cloud and precipitation system of mesoscale dimensions (often too large for most aircraft to circumnavigate) with deep-convective activity concentrated in at least part of the MCS, or present during part of its evolution. A large areal fraction of MCSs is stratiform in nature, yet estimates from MCSs over the Great Plains (Biggerstaff and Houze 1991), the Southeast (Knupp et al 1997), and tropical waters (Houze an Cheng 1977; Mapes and Houze 1993) indicate that at least half of the precipitation is of convective origin. The presence of localized convection is important, because within convective towers cloud particles and hydrometeors are carried upward towards the cloud top. Ice crystals then move over more stratiform regions, either laterally, or through in situ settling over decaying and spreading convection. These ice crystals then grow to precipitation-size particles in mid- to upper tropospheric mesoscale updrafts. The convective portion of a MCS is often a more or less continuous line of thunderstorms, and may be either short-lived or long-lived.

Geerts (1997) presents a preliminary climatology of MCSs in the southeastern USA, using just one year of composite digital radar reflectivity data (the same data as used for this project, see Section 2). In this study MCSs are identified and characterized by means of visual inspection of animated images. A total of 398 MCSs were identified. In the warm season MCSs were found to be about twice as frequent as in the cold season. The average lifetime and maximum length of MCSs are 9 hours, and 350 km, respectively, but some MCSs are much larger and more persistent. In the summer months small and short-lived MCSs are relatively more common, whereas in winter larger and longer-lived systems occur more frequently. MCSs occur more commonly in the afternoon, in phase with thunderstorm activity, but the amplitude of the diurnal cycle is small compared to that of observed thunderstorms. It is estimated that in the Southeast more than half of all precipitation and severe weather results from MCSs.

2. The data

We are using the composite digital radar reflectivity data available at a resolution of 2x2 km and 15 minutes, archived at the NASA Marshall Space Flight Center (MSFC). There are 16 possible values of radar reflectivity, ranging from 2.5 dB (level 0) to 75.5 dB (level 15), in 5 dB increments. For instance, level 4 data have a radar reflectivity ranging between 20 and 25 dBZ. The recorded reflectivity is the maximum value within a 2x2 km box at any vertical level, recorded by any radar in the network. Most but not all of these radars are WSR-88D NEXRAD.

Since some NEXRAD radars came online after 1994, because radar down-times have been reduced lately, and because the algorithms to remove ground clutter and other anomalies have improved in recent years, it is likely that the more recent data are of superior quality. The best coverage is east of the Rockies, because topographic blockage is minimal and the density of radars in the network is slightly higher. Therefore, the data is excellently suited to study precipitation characteristics in the Mississippi drainage basin (Goodman and Raghavan 1997).

For the dataset examined by Geerts (1997), ie the southeastern quadrant from 5/'94 to 4/'95, about 3% (or a cumulative period of 11 days) of the data were missing from the archive. Usually the gaps were found to be fairly long (up to 2 days), sometimes they are very short (one single 15 min interval). Occasionally a considerable number of radars is not included in the composite image. In this case large gaps can be seen, as well as concentric rainfall boundaries around those radars that are in operation.

The actual grid size is 2 km or less. The zonal (east-west) dimension of the grid drops from 2 km at the southern border (20N) to 1.28 km at the northern border (53N). Rows and columns in the data set are aligned with meridians and latitude circles, so there is some distortion. In some regions (furthest away from radars, in the northern states), the grid spacing actually smaller than the radar beamwidth/gate_spacing, so some interpolation occurs in the cartesian transformation.

3. The algorithm that identifies mesoscale precipitating systems

Currently we are processing the 2x2 km composite radar reflectivity data archived at NASA MSFC, to extract the spatial characteristics of all precipitating systems (PS). A PS is defined more broadly as a continuous area of precipitation (at least 20 dB, ie level 4) of mesoscale dimensions (at least 500 km^2). For every gridpoint within a PS, the reflectivity value is retained, as well as a stratiform/convective qualifier, based on the algorithm by Steiner et al (1995), and used by Steiner and Houze (1997). We used the 'medium' size domain of influence of a local convective dB maximum, as defined in Steiner et al (1995).

We define the reflectivity-weighted centerpoint of any PS, as well as the basic PS spatial pattern. The centerpoint is used to allow easier tracking of PSs (see Section 5), and also to plot geographical distributions of PSs. The reflectivity weighting is justified is follows: the area of highest reflectivity is the area of strongest vertical and also horizontal storm-scale motions, and dynamically it is area of highest energy conversions, so it is the 'center of activity'. Also, from the perspective of storm tracking, we believe that the weighted centerpoint is more stable than the un-weighted centerpoint, considering the occasional appearance of false low-dB echoes, and the rapid expansion and decay of stratiform regions.

The spatial pattern is described simply as the ellipsoid that most closely approximates the PS. The orientation of the long axis is found, and its length is defined as four standard deviations (2 SDs from the centerpoint). The length of the short axis, then, is +/- 2 SDs in the direction normal to the long axis. SDs are calculated as the distance of any PS gridpoint from the centerpoint, again weighted by reflectivity (in dB units). The ratio of the respective lengths of the axes is a measure of how linear the PS is.

A PS is considered to be a *potential MCS* if it satisfies the following criteria: the long axis has to be at least 100 km long; and the peak reflectivity needs to be at least 40 dB (level 8). We say potential MCS because a complete definition of a MCS also includes a time dependency (see Section 5). Rather than thresholding the data arbitrarily, we are examining the entire spectrum of PSs, not just the potential MCSs, as discussed in the next section.

4. Survey of the mesoscale organization of precipitating systems

For the month of June '95, we identified and characterized all PSs. Note that time continuity is not checked, and the number of PSs reflects both the number of precipitation systems, and the number of times that they are sampled (at a 15 min interval) during their lifetime. We do not attempt to define a lifetime here, because we are not tracking a PSs. Rather, the total number of PSs, divided by the number of samples (2544, that is 88.3% of all possible samples for the month of June), gives an average number of precipitation systems that occurred at any time somewhere in the continental USA during June '95. The information we collected is as follows:

- the size distribution (in area units, km^2) of all PSs, for various threshold Z levels; the default is level 4 (20 dB); alternative cut-offs are levels 3 (15dB) and 5 (25 dB);
- a histogram of the convective fraction within all PSs, as well as the fraction of convective rainfall;
- the average dBZ (calculated in units of mm^6/m^3, ie linear Z) as well as the relectivity distribution;
- using the default threshold of level 4, display the following, for small, medium, and large size PSs:
    - diurnal variation

- geographical distribution
- spatial patterns (length, linearity, and orientation)

We define a small PS as 500 km^2 < A < 4,000 km^2, a medium-size PS is 4,000 km^2 < A < 32,000 km^2, and a large PS has an area exceeding 32,000 km^2. Some of the large-size PSs will qualify as mesoscale convective complexes (MCC), which are defined by means of satellite IR imagery. For an MCS to qualify as a MCC, its anvil (T<220K) needs to be at least 50,000km^2 (Maddox 1980).

The number of PSs drops off exponentially both with increasing PS size and increasing convective fraction. The scale factor in the exponential approximation was found to be 2,000 km^2 and 5%, respectively (ie the probability of encountering a PS of 2,000 km^2 is 2.7 times less than that of a PS of 500 km^2, and the odds of finding a PS with 4-6% convection is 2.7 times less than that of a PS in which 0-2% of the pixels are convective). This argument provides an inductive, rather than ad-hoc definition of a MCS. Mesoscale convective systems are defined as those PSs that are of mesoscale dimensions (at least 2,000 km^2) and contain some convective activity (at least 5% of the pixels are convective).

We found that for June 1995, 22% of the PSs qualified as MCSs, yet these MCSs produced an estimated 84% of the overall rainfall. A clear diurnal oscillation occurs. For the entire contiguous USA, the number of PSs, and their convective fraction, peak at about 3pm local time, and they reach their minimum around 7 am. The amplitude of the diurnal cycle is 30-50% of the mean, both in terms of frequency and convective fraction. MCSs peak at a slightly later time, 4-5pm local time, and they are more common in the first half of the night. On a pixel-by-pixel basis, we find that the higher the radar reflectivity, the more intense the diurnal modulation. A slight phase shift is observed from the most intense echoes, which are most common around 4pm, to stratiform precipitation, which is most common at 6pm.

Some characteristic spatial patterns of PSs emerged. For instance we found that by far the most common orientation is SW-NE (some 60% of the PCs have a northeast limb between 30° and 70° from north), and that 80% of the PCs had an aspect ratio (length-to-width) between 3 and 8. MCSs tend to be more elongated than PSs in general. The mean length of MCSs and PSs is about 230 km and 120 km, respectively.

We also contrasted MCS/PC behavior in various geographical regions, in particular, the Great Plains region (with a focus on the Arkansas/Red River Basin), the Southeast, and Florida.

5. Conclusions

The methodology of MCS identification, and subsequent analysis of the US-wide composite radar reflectivity data for June '95, can be summarized as follows.

- A *precipitating system* (PS) is defined as an area (exceeding 500 km^2 in size) of spatially continuous reflectivities exceeding a certain threshold value.
- The higher this threshold reflectivity, the less noise, yet a reflectivity threshold over 20 dB will remove most large systems.
- The frequency of PSs drops off exponentially with increasing PS size.
- Mesoscale convective systems (MCSs) can be defined in various ways, as long as the definition includes a mesoscale dimension and a condition on convective activity. We propose that MCSs are those PSs that are at least 2,000 km^2 in size and have at least 5% convective pixels. This definition excludes 78% of all PSs.
- The fraction of PSs that qualify as MCSs increases with increasing system size. This suggests that the large systems are convectively driven. This result comes as a surprise; we expected that smaller systems would exhibit a larger convective fraction, on average.
- A clear diurnal cycle exists: in the afternoon there are more PSs and MCSs, and they both smaller and more intense.

- Small systems are most active in the early afternoon, while large systems are most active around sunset.
- Geographical differences are present, but they are not outstanding. For instance, PSs in Florida tend to be smaller and those in the Great Plains are larger and are more common towards sunset, but the differences are small.

6. Future work

A first extension of the work done during the summer faculty fellowship will be to repeat the same process for a longer time period, ideally as long as 4 years, ie the entire data set. This would make the results more significant in terms of a typical summer pattern. Also, we could analyse the entire seasonal cycle, and even examine interannual variability.

A complete definition of a MCS also includes a time dependency. Geerts (1997) suggested that a MCS should be recognized (according to the above spatial definitions) for at least 4 consecutive hours. This implies that the movement and evolution of PSs needs to be tracked in time. Visual inspection using time lapse movies easily allows assessment of the continuity of echo patterns, and readily identifies birth or decay, movement or expansion, merger or splitting. On computer this is more difficult, especially the merger and splitting of PSs constitutes a problem and demands complicated tracking software. We have defined the centerpoint to allow easier tracking of PSs.

The tracking of PSs and the description of their evolution (lifetime, convective vs stratiform phase, direction and speed of movement, evolution of size and reflectivity properies …) is a second extension of this work.

Finally, it has been suggested that a similar analysis would be done on lightning data, which are available at the same time/space resolution. Lightning data are primarily an indicator of convective activity. The lightning data can be compared to reflectivity-estimated convective activity, and the two data sets can be combined to obtain a more comprehensive description of MCSs.

5. References

Biggerstaff, M.I. and R.A. Houze, Jr., 1991: Kinematic and precipitation structure of the 10-11 June 1985 squall line. *Mon. Wea Rev.*, **119**, 3035-3065.

Geerts B., 1997: Mesoscale convective systems in the Southeast: A survey. *Wea. and Forecasting*, accepted for publication.

Goodman S.J. and R. Raghavan, 1997: Multi-year characterization of rainfall over the Mississippi River Basin. Proposal in response to NRA-97-MTPE-GCIP.

Houze, R.A.,Jr., 1993: *Cloud Dynamics.* Academic Press, 573 pp.

Houze, R.A.,Jr. And C.P. Cheng, 1977: Radar characteristics of tropical convection observed during GATE: mean properties and trends over the summer season. *Mon. Wea. Rev.*, **105**, 964-980.

Knupp K.R., B. Geerts and S. Goodman, 1997: Structure of a small, vigorous mesoscale convective system. Part I: Formation, echo morphology and lightning behavior. **Mon. Wea Rev.**, in press.

Maddox, R.A. 1980: Mesoscale Convective Complexes. *Bull. Amer. Meteor. Soc.*, **61**, 1372-1387.

Mapes, B.E. and R.A. Houze, Jr., 1993: An integrated view of the 1987 Australian monsoon and its mesoscale convective systems. Part II: Vertical structure. *Quart. J. Royal Meteor. Soc.*, **119**, 733-754.

Steiner, M., R.A. Houze Jr., and S.E. Yuter, 1995: Climatological characterization of three-dimensional storm structure from operational radar and rain gauge data. *J. Appl. Meteor.*, **34**, 1978-2007.

Steiner, M. and R.A. Houze Jr., 1997: Sensitivity of estimated monthly convective rain fraction to the choice of Z-R relation. *J. Appl. Meteor.*, **36**, 452-462.