JP5.3 OCCURRENCE AND PERSISTENCE OF HAILSTREAKS IN THE VEGETATED LAND SURFACE

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1. INTRODUCTION

Hail is a major cause of crop loss and property damage in the United States. In recent years, annual costs of crop loss and property damage due to hail in the United States has been estimated at $1.3 billion and $1 billion, respectively (Changnon 1997). Hail can accumulate into columns that sweep the ground in a long narrow path producing a hailstreak (Changnon 1970). Devegetation of the land surface by hailstreaks can have significant biogeophysical consequences. Changes in the surface energy balance and local wind fields can give rise to sea-breeze type circulations that may trigger convection and severe weather (Anthes 1984; Mahfouf et al. 1987; Avissar and Liu 1996). Our interest here is to characterize hailstreaks that are observable in coarse spatial resolution imagery, including the relationship between hail occurrences and the appearance and persistence of hailstreaks in AVHRR image time series.

2. METHODS

We used three data sources: (1) the biweekly composites of the AVHRR maximum Normalized Difference Vegetation Index (NDVI) from 1990-1999 available from the USGS, which indicates the green vegetation density on the land surface, across the conterminous US (Eidenshink 1990); (2) National Weather Service reports of hail occurrences across the conterminous US from 1990-1995 (NOAA SPC 1997); and (3) SeverePlot v2.0, a historical severe weather report database software program which contained hail reports for 1996-1999 (Hart & Janish 1999). These data sources were imported and integrated into a geographic information system (ArcGIS) for data display, analysis, and interpretation. Hail occurrences could then be selected according to their attribute set, e.g., date, time, and hail size.

Compositing AVHRR images acquired over several days can generate relatively cloud-free images that are spatially continuous (Holben 1986),

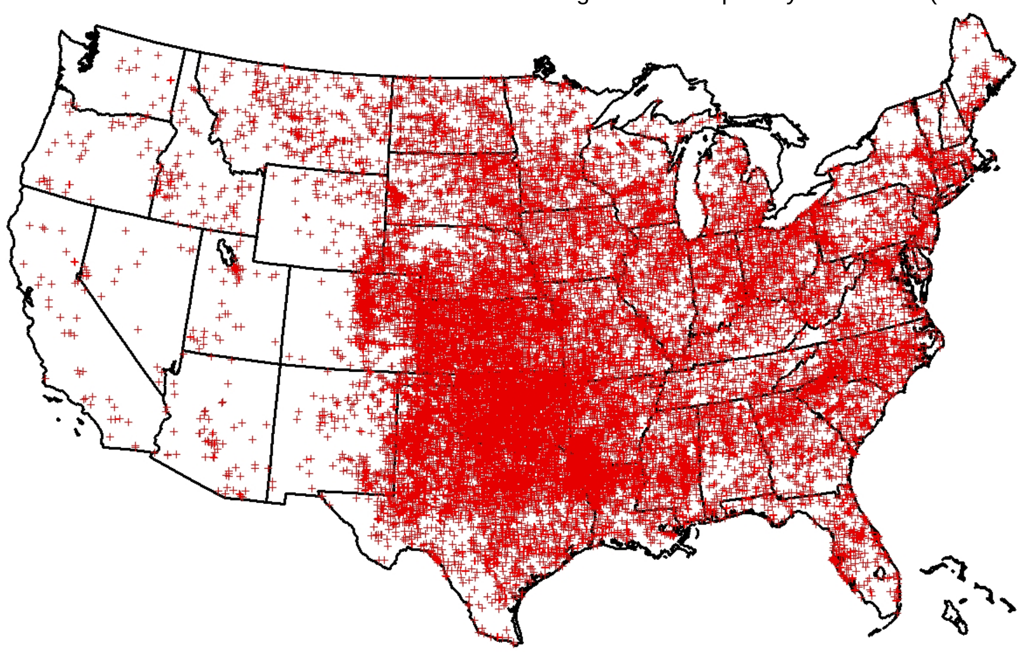

Fig. 1. Geographic distribution of hail reports from 1990-1995 (33,272 observations).

although compositing artifacts are possible (Moody and Strahler 1994). The AVHRR composites are generated from images acquired over a period of 14 days. Only the highest NDVI value during the period for each pixel location is selected for

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inclusion in the composite image. The composited data have a nominal spatial resolution of 1 km^2.

In NDVI images, lighter shades of gray indicate a higher density of active, green vegetation and darker shades of gray indicate little or no green vegetation at the surface. Hailstreaks can be identified by abrupt decreases in NDVI imagery between sequential acquisitions. To identify abrupt, anomalous decreases in NDVI and quantify the persistence of the anomalies, a series of simple difference images were generated within each growing season:

$$\Delta NDVI = NDVI_{(t+1)} - NDVI_{(t)} \quad [1]$$

In these difference images, the darker (lighter) tones indicate a decrease (increase) in NDVI between compositing periods.

The point locations of the National Weather Service reports of hail from 1990-1999 (n=71,367) were grouped by date to match the dates associated with the NDVI biweekly composites (Fig. 1). The hail reports consisted of the date, time, latitude and longitude, state code, FIPS county code, hail size, fatalities, injuries and property damage (NOAA SPC 1997). The database is restricted to reports of hail at least ¾ inch (1.91 cm) in size. There is a clear bias in reporting hail size (Fig. 2).

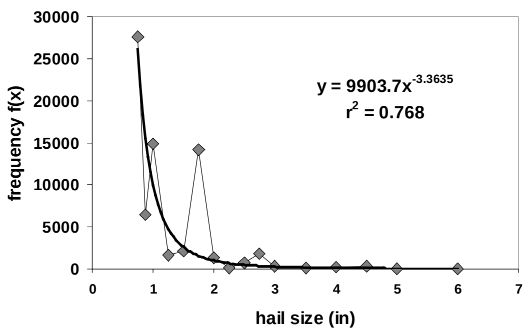

Fig. 2. Size distribution of reports of hail >¾ inch from 1990-1999.

The hail report locations were geographically overlaid onto the NDVI difference images and hailstreaks were identified as dark areas coincident with or proximate to reports of hail (Fig. 3a). Only identified hailstreaks with associated reports were included in the geographic database. The shape of the hailstreak was manually digitized in ENVI; the area of the hailstreak was measured by the number of pixels within the digitized boundary (Fig. 3b). Hailstreaks have a characteristic long and narrow shape, which aids identification. However, the boundaries of the hailstreaks was sometimes difficult to identify in the difference images. Possible sources of confusion include the coarse spatial resolution of the imagery, sub-pixel cloud cover, image misregistration, compositing artifacts, and undisturbed adjacent areas displaying lower ΔNDVI. The shape and area of the hailstreaks were determined to the best of the analyst's ability. The length of the hailstreaks was found by determining the major axis of the streak and measuring only the devegetated (dark ΔNDVI) areas. Restricting measurement to devegetated areas was necessary since some hailstreaks were discontinuous in shape, similar to beads on a necklace. The digitized hailstreaks were then imported into the GIS as shapefiles.

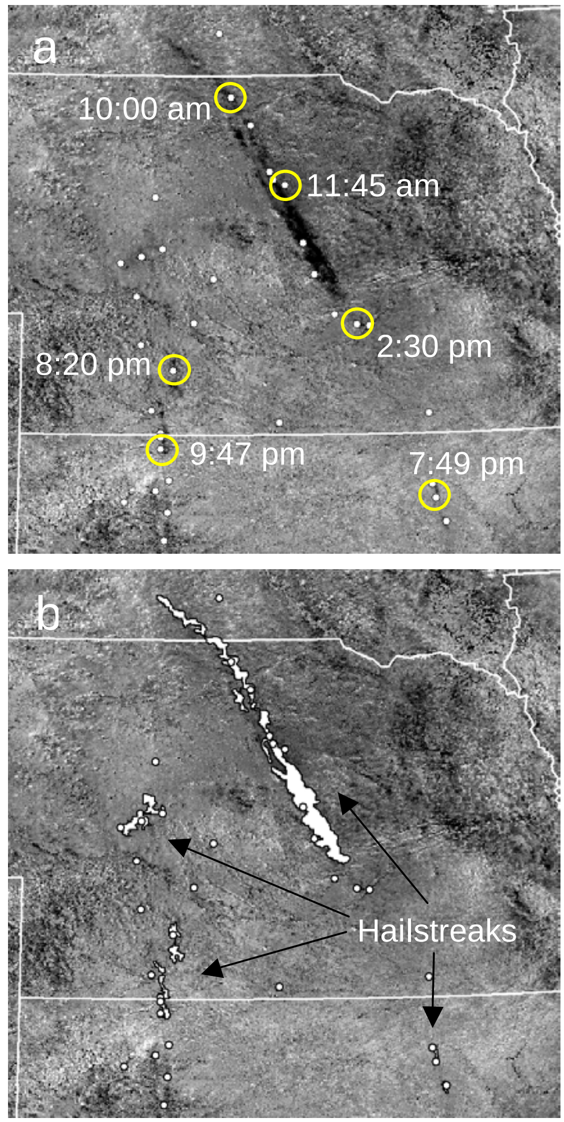

Fig. 3. Difference image with hail reports (white circles) for 04 August 1992 overlaid: (a) times of hail report; (b) digitized hailstreaks (white areas).

The primary layers in the GIS consisted of (1) the hail report locations, (2) the ΔNDVI images, and (3) the digitized shapes of the hailstreaks. Other ancillary data layers—urban areas, hydrology, land cover and shaded relief (National Atlas 2000)—were imported into the GIS to help further distinguish the hailstreaks from confounding influences. For example, the shape and extent of a hailstreak could be misinterpreted due to urban areas or water bodies within the region of a hailstreak.

The persistence of a hailstreak was found taking the NDVI composite image prior to the hailstreak appearance as the baseline image and generating difference images with subsequent images until the hailstreak was no longer visible.

$$\Delta_k NDVI = NDVI_{(baseline+k)} - NDVI_{(baseline)} \quad [2]$$

Each NDVI composite nominally spans 14 days. The number of days a hailstreak persisted was calculated as the sum of (1) the product of the *k* number of composite images containing the hailstreak times 14 days plus (2) the difference in days between the date of the associated hail report and the date of end of the compositing period for the baseline image.

3. RESULTS

From 1990-1999, 112 events of significant hailstreaks were observed. The hailstreaks ranged in length from 9 to 367 km (median=66 km) and in area from 21 to 8443 km^2 (median=408 km^2). The total area of the hailstreaks measured 79,227 km^2 for the decade of the 1990s. The majority of hailstreaks were identified in the Midwest and Great Plains regions and during the months of June and July (Fig. 4).

Hailstreak persistence (Fig. 5) ranged from 9 to 94 days (median=34 days). Persistence was a complex function of seasonal timing of the event, vegetation type and phenology, and event severity.

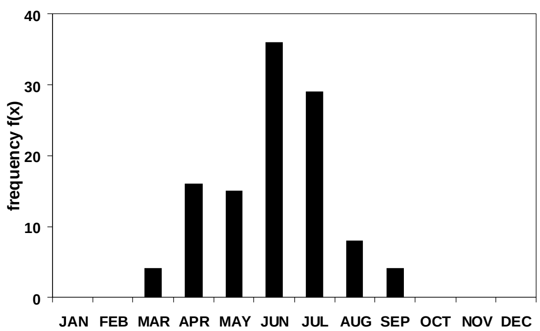

Fig. 4. Identified hailstreaks by month.

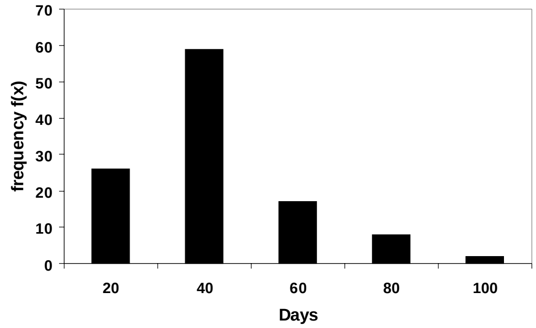

Fig. 5. Persistence of identified hailstreaks.

4. CONCLUSIONS

Hailstreaks can be identified using AVHRR NDVI difference images in combination with NWS hail reports. Hailstreaks were most prevalent in the Great Plains. Many of the hailstreaks identified covered more than 1000 km^2 with the largest covering 8443 km^2. These numbers are significant underestimates of the actual frequency and area of hailstreak devegetation, due to the bias against low NDVI in the compositing process and the coarse spatial resolution of the image data. However, we now have a foundation to construct a detailed climatology of hailstreaks in the conterminous US for inclusion into NWP models. The next significant step will be to evaluate efficacy of MODIS data in the detection and quantification of hailstreaks.

5. PROJECT WEBSITE

http://www.calmit.unl.edu/BDEI/hail

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Anthes, R.A., 1984: Enhancement of convection by mesoscale variations in vegetation coverage in semiarid regions. *Journal of Climate and Applied Meteorology*, **23**, 541-554.

Avissar, R., and Y. Liu, 1996: Three-dimensional numerical study of shallow convective clouds and precipitation induced by land surface forcing. *Journal of Geophysical Research*, **101**, 27,499-27,518.

Changnon, S. A., 1970: Hailstreaks. *Journal of Atmospheric Science*, **27**, 109-125.

Changnon, S. 1997: Trends in hail in the United States. *Workshop on Social and Economic Impacts of Weather*. http://sciencepolicy.colorado.edu/socasp/weather1/changnon.html.

Eidenshink, J.C. 1992: The 1990 conterminous U.S. AVHRR data set. *Photogrammetric Engineering and Remote Sensing* **58**, 809-813.

Hart, J. and P. Janish. 1999: SeverePlot v2.0 Historical severe weather report database. National Weather Service Storm Prediction Center, Norman, Oklahoma. http://www.spc.noaa.gov/software/svrplot/.

Holben, B.N. 1986: Characteristics of maximum-value composite images from temporal AVHRR data. *International Journal of Remote Sensing* **7**(11), 1417-1434.

Mahfouf, J.-F., E. Richard, and P. Mascart, 1987: The influence of soil and vegetation on the development of mesoscale circulations. *Journal of Climate and Applied Meteorology* **26**,1483-1495.

Moody, A., and A.H. Strahler, 1994: Characteristics of composited AVHRR data and problems in their classification. *International Journal of Remote Sensing*, **15**(17), 3473-3491.

National Atlas.gov. Shaded relief map of the United States. http://www.nationalatlas.gov/atlasftp.html.

NOAA Storm Prediction Center. 1997: Historical U.S. hail data 1955 to 1995. http://www.spc.noaa.gov/archive/hail/.