Thunderstorm Evolution Analysis and Estimation using Radar and Total Lightning Data

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Motivation

- Thunderstorms accompanied by lightning, heavy rain, strong winds, and hails or tornadoes and have different stages of their life cycles.
- In nowcasting, it is possible to predict the location of a thunderstorm in a 0-2 hour period using echo tracking and extrapolation techniques.
- However, it is hard to predict the change of thunderstorm severity and impact due to thunderstorm evolution when using tracking and extrapolation techniques alone.

Observations: a hail thunderstorm
Nowcastings in 20, 40, 60, and 80 min
Motivation

Some studies focused on using linear or nonlinear methods to nowcast thunderstorm evolution based on the change of some radar echo characteristics, or using some other observations and numerical model outputs.

Some studies showed that lightning activity has a good connection with thunderstorm evolution (Toracinta, 1996; Parker et al., 2001;)

Total lightning data (Goodman et al., 2005; Murphy and Demetriades 2005; Steiger et al., 2007a and 2007b; Williams et al., 1999):
- Intra-Cloud (IC) + Cloud to Ground (CG) lightning
- Information of thunderstorm development (vertical)
Motivation

The aim of this research is

- to investigate thunderstorm’s structure and total lightning activity during its life cycle;
- to find some indicators that depict thunderstorm evolution; and
- to develop a scheme of nowcasting for thunderstorm intensity.
- Motivation
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About 200 thunderstorms over the Yangtze River Delta during 2004 - 2006
- Life cycle longer than 7 radar scans (42 minutes)
- VIL reaches 25 kg/m² at least once

Radar products from the Shanghai WSR-88D
- Echo Top (ET)
- Echo Base (EB)
- Height of Max Reflectivity (HgtMR)
- Vertically Integrated Liquid (VIL)
- Meso-cyclone (M)

Difference of HgtMR and EB (DMRB) (in 0.1 km)
Data

- Total lightning (CG & IC) data from the Shanghai SAFIR 3000 system
  - Total lightning rate (NLTG)
  - Average height of IC (HgtIC)
  - Max height of IC (MxHgtIC)
  - Number of positive CG (NumPosCG)
  - Number of negative CG (NumNegCG)
- Radar and 6-min lightning data within 10 km of the cells are collected and compared during their life cycle.
Fig 1. Time series of a thunderstorm’s structure information and lightning activity in 6-min intervals from 08:36 UTC to 11:18 UTC on June 24, 2006. White histograms stand for counts of total lightning flashes. Gray and purple histograms stand for number of all CG and positive CG lightning flashes. Yellow histograms stand for number of mesocyclones (M). Curves with white (black) circles stand for height of maximum reflectivity - HgtMR (vertically integrated liquid-VIL), curves with black triangles for echo top - ET, curves with blue triangles for echo base 0 EB.
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An entire **life cycle** of a thunderstorm is defined as a duration when it is identified by the WSR-88D Storm Cell Identification and Tracking (SCIT) algorithm.

Three categories by the duration of life-cycle:
- Category I (48 - 72 minutes)
- Category II (78 - 102 minutes)
- Category III (108 - 132 minutes)
Thunderstorm Life Cycle Stages

- A normalized processing scheme: normalizing a general storm life cycle into 10 stages.
  - initiation (1 to 3 stages)
  - mature (4 to 7 stages)
  - decaying (8-10 stages)
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Results

- General Life cycle
- Normalized life cycle
- Life cycle indicator and nowcasting scheme
Thunderstorm structure:
1) Initiation and developing stages: VIL - rapid increase, ET climbs gradually.
2) Mature stage: ET and VIL do not change a lot after reaching their maximum values in the early mature stage.
3) After the mature stage, VIL starts to decline as the storm top, the storm maximum reflectivity and its height are falling.
4) During the decaying and dissipating stages, most of storm structure indicators have rapid drop except that the echo base (EB) is climbing slightly due to the evaporation of low level precipitation.

Thunderstorm Lightning activity:
Lightning activity reaches its peak later than storm top and VIL.
NLTG is increasing in the initiation stage and reaches it peak in the late mature stage.
A lightning burst occurs just after VIL’s maximum.
During the burst of lightning, some severe weather may occur, such as surface wind gusts caused by the downdraft, hail, even tornado.
General Life Cycle

Category II 90 minutes

Category III 120 minutes
Normalized 10-stage storm life cycles:

- VIL, ET, DMRB, and NLTG are similar to the general life cycle.
- DMRB first reaches its highest, about 1 to 3 scans earlier than VIL and ET, and 2-4 scans earlier than NLTG.
- It supports combining these parameters into an indicator for evaluating storm life cycle.
**Life cycle indicator and nowcasting scheme**

DMRB can be a good indicator of storm’s life cycle:
- has a high value when storm just initiates;
- has reached its maximum before VIL and ET;
- stops climbing during the mature stage;
- declines as storm decays;
- reaches its lowest value when the storm dissipates.

A scheme for thunderstorm life cycle nowcasting (a combination of VIL, ET, DMRB, and NLTG):
- when DMRB has not increased for 2-4 scans (12-24 minutes) or it is decreasing gradually, and NLTG has a sudden jump, it can be a signal that the storm has been in its mature stage and is decaying.
Summary

- Thunderstorm evolution can be presented with its structure and lightning activity.
- VIL leads a rapid increase in the initiation stage and peaks 0-15 minutes in the early mature stages ahead lightning activity.
- DMRB has a good correlation with thunderstorm life cycle stage.
- The combination of WSR-88D Doppler radar products and total lightning data can be used as an indicator of thunderstorm evolution.
- These results will improve the nowcasting for thunderstorm evolution and severity.
Summary

- Future work:
  - Height information of IC lightning
  - Surface observations (convergence zones)
  - NWP model outputs
  - Schemes for thunderstorm evolution
References

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Obrigado!
Thank you for your attention!
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