A brief primer on lightning, predicting it and detecting it

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Overview of talk:

• Background info on cloud/storm electrification

• 4DWX short-term lightning potential product

• Longer term lightning potential product (in development)

• Lightning detection systems
Cloud Electrification

Two ingredients are generally required for the electrification of clouds: 1) convection, specifically strong updrafts; and 2) ice particles, specifically a mixture of ice crystals and actively riming particles, such as graupel \textit{(i.e., the ice phase precipitation process)}.

The progression of riming is illustrated in the photos, with graupel (soft hail) shown in the lower right. Under most conditions, graupel charges negatively and smaller crystals charge positively, which then separate by sedimentation and updrafts into the typical dipole charge structure of a storm.
Cloud Electrification

Section 2
Thunderstorm Charge Distribution

1. Electrification continues with the maintenance of strong updraft and riming

2. Distinct charge regions develop as charge is generated and advected

3. A layered charge structure is the result
Cloud Electrification and Lightning

Negative CGs much more common than positive CGs.
What does this mean for lightning prediction?

• Recall that for electrification to occur, strong updrafts and ice phase precipitation processes needed.

• For very short lead time applications, can utilize radar reflectivity information above the freezing level to infer if appreciable ice mass is present.

• For longer lead time applications, really need to focus more on if the forecast environmental conditions are favorable for supporting strong moist convection.
Comprehensive Lightning Forecast System

NLIDN C-G/LMA Total Ltg
Short-term Ltg Potential
ANC Forecast
Out to 15 min
Out to 30/60 min
0 min
Forecast Lead Time

Sounding Based Statistical Forecast (Utilizing range and/or RT-FDDA virtual soundings)

Convective Climatologies
Short-Term Lightning Potential

- Currently implemented at EPG and WSMR
- Utilizes local WSR-88D radar data to monitor reflectivity above the freezing level
- Outputs elliptical markers highlighting storms determined to be capable of producing CG lightning in the very near term
- Lead times typically in the 5 to 15 minute range
Short-Term Ltg Potential Example
Short-Term Ltg Potential Example
Lightning Alert Circles

- Map files with 5, 10, and 20 mi radii around key test sites

- Colored alert circles for sites activate based on short-term lightning potential forecast and observed LMA total lightning data
Lightning Alert Circles

• Something similar could be setup at other ranges

• Utilize:
  – Extrapolated reflectivity rather than lighting potential for forecast
  – Gridded C-G lightning rather than LMA data for truth
Long-Term Lightning Potential

• Goal: Produce a prognosis product of the potential for lightning occurrence using a statistical method for sounding analysis
  
  – Use: Additional guidance for issuing lighting predictions
  
  – Apply at all ranges
Shafer and Fuelberg, *WAF*, 2006

- Developed statistical method to predict the amount of lightning at various locations in Florida from soundings

- 16 years of data:
  - 12Z sounding to compute various indicators
  - NLDN CG as truth

- Noon-midnight

- Binary logistic regression technique selected
  - Gives the probability that an event will occur
  - Select a threshold to separate “events” from “non-events”
    - Useful for decision tree
Steps in Shafer and Fuelberg Method

- Use binary logistic regression to calculate equation for probability of ≥1 CG flash
  - Discriminates “no lightning” days from “lightning” days

- Next, given conditional probability of ≥1 CG flash, calculate equations for amount of lightning expected
  - From climatology, assign range of flashes to quartiles (Q1, Q2, Q3, Q4) for each region
    - For Miami-Dade: Q1 1-11; Q2 12-52; Q3 53-166; Q4 >166
    - Eqns to discriminate Q1 from all others; Q4 from all others; and (Q3, Q4) from (Q1, Q2)

- Apply decision tree
Shafer and Fuelberg Decision Tree

Q1: 1-11 Flashes
Q2: 12-52
Q3: 53-166
Q4: >166

Results:
1. Outperformed persistence
2. Highest skill for flashes > 1
3. Hit rate ~40% within correct quartile
4. Hit rate ~80% off by 1 quartile

Eq. 3 (Q3, Q4)
Prob (≥ 53 flashes)

Eq. 2
Prob (< 12 flashes)

(Q1)
≥ 0.358
Q1
< 0.358
Q2

≥ 0.498
Q3
< 0.372
Q4
≥ 0.372

Eq. 4 (Q4)
Prob (> 166 flashes)

Fig. 7. Probability decision tree used to determine the predicted lightning quartile for the Miami–Dade domain.
Proposed Plan

- **Research and Development Phase**
  - At WSMR w/ observed EPZ sounding at 12Z
    - Valid for southern region of WSMR, nearest EPZ
    - Proof of Concept
      - If good results found, continue
  - At WSMR w/ RT-FDDA virtual soundings
    - Forecasts will have spatial and temporal variation
    - If good results found, continue

- **Operational Implementation Phase**
  - Replicate and tune for the other ranges
  - RT-FDDA virtual soundings
R&D Phase w/ Observed Sounding

- 1998-2006, July and August at WSMR
- 12Z sounding from EPZ
  - Compute various parameters and indices
- From ANC, use # storms >35 dBZ above the freezing level
  - Proxy for lighting occurrence (storm=lightning)
    - Lightning archival is incomplete
  - Time period: 17Z to 02Z (11-20 Local time)
  - Southern region of WSMR, nearest to EPZ
  - Forms the “truth” data set
R&D Phase w/ Observed Sounding

- **Binary Logistical Regression technique**
  - Follow Shafer and Fuelberg methodology, modified for WSMR
    - Discriminate between 0 and ≥1 storms/lightning
    - Given storms/lightning occurs, develop equations to quantify amount of storms/lightning expected and apply decision tree

- **Random Forest technique**
  - Decision tree that may be able to quantify amount of storms/lightning expected
  - May be easier to implement

- **Compare techniques**
  - Evaluate performances with summer 2007 data
Timeline

- **FY08**: Complete proof-of-concept evaluation at WSMR using EPZ 12Z sounding data.
  - Assuming promising results: Develop methods utilizing RT-FDDA virtual soundings.

- **FY08**: Evaluate initial forecasts

- **FY09-FY12**: Extend to other ranges and develop decision support systems based on the forecasts.
Lightning Detection

- E-field (DC) changes (field mill network)
- LF and VLF radiation (NLDN)
- VHF radiation (LMA, LDAR)

Figure 1. Overall time waveforms for the multiple-stroke negative cloud-to-ground flash
The location is based on the intersection or hyperbolas produced by arrival-time-differences between pairs of sensors. Additional sensors or information can eliminate false stroke locations.

Oftentimes combined with direction finding information to give more accurate detection locations.

2-D information only on CG flashes.
Lightning Mapping Array (LMA) Type Systems

Also a TOA system, but in 3-D. Detects hundreds to thousands of sources per flash.

Note: Lightning signals travel about 300 meters per microsecond.

Provides 3-D information on all lightning flashes, not just CG flashes.
LMA Example
Remarkable lightning flash from Alabama LMA network
LMA Analysis

• Climatological analysis of WSMR LMA data underway
  – Wiebke Deierling, Post Doc

• Useful to characterize storms and their evolution
  – AutoNowcaster

• Currently working to improve the quality of the LMA data
  – Removal of aircraft tracks and geometrical errors
LMA Preliminary Results: Data Quality Improvements

- Removal of aircraft tracks and badly located sources
Questions or Comments?