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Lightning Initiation Forecasting: An Operational Dual-Polarimetric Radar Technique

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Purpose:

• To improve algorithms for the short-term prediction of lightning initiation through development and testing of operational techniques that rely on parameters observed and diagnosed using C-band dual-polarimetric radar.

Motivation:

• Many researchers have developed and tested different methods and tools of first flash forecasting, however few have done so using dual-polarimetric radar variables and products on an operational basis.

• To determine the advantages of first flash forecasting with dual-polarimetric radar

Objectives:

• **Basic Science**: To develop and evaluate C-band dual polarimetric radar-based algorithms for the short-term prediction of lightning initiation.

• **Applications**: For warning and short-term prediction of lightning potential in support of operational decision making and situational awareness.

Methodology and Tools:

Instruments:

NAL LMA- Northern Alabama Lightning Mapping Array

- Network of 10 time of arrival VHF total lightning sensors (Goodman et al. 2005)

ARMOR- Advanced Radar for Meteorological and Operational Research

- Dual-polarimetric radar, C-band (5.33 cm) (Petersen et al. 2007)

SOLOII

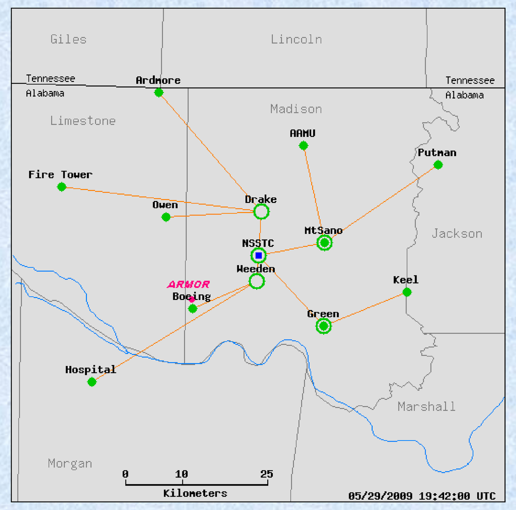
- NCAR radar sweep file viewer

ANGEL- Analysis of NEXRAD, GPS, EDOT, and LMA

- UF (universal format) radar, LMA and NLDN lightning viewer

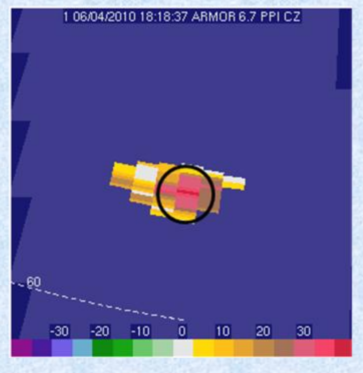
PID- Particle Identification

- Modified NCAR fuzzy-logic based particle identification (PID) algorithm for C-band polarimetric radar (Vivekanandan et al. 1999, Deierling et al. 2008)



Northern Alabama LMA Sensors and ARMOR

- Green: NA LMA network of 10 sensors
- Pink: ARMOR



Solo II image of Area of Interest

Cell 1 of Case 20100604

Area of Interest defined by:

Z_h of 30 dBZ at elevation angle closest to -10°C

Sample Size:

50 cells from eight case dates

31 thunderstorms and 19 non-thunderstorms

Methodology:

Quality Control

- Correct Z_h and Z_{dr} data for precipitation attenuation and differential attenuation (Bringi et al. 2001) and absolute and relative calibration biases, respectively (Ryzhkov et al. 2005, Bringi and Chandrasekar 2001)
- Determine optimum distance from radar for quality coverage of cells as defined by the scan strategy
- Scan strategy = PPI sector volume scans with optimized vertical coverage typically in ≈ 3 minutes but < 5 minutes

Identify

- Identify cells of interest based on cell evolution, first flash, and data coverage
  - Cell must be spatially distinct from any other convective system
  - Cell must be covered by the radar from initial echo formation to first flash
- Determine area of interest, or "Larsen area", based on a Z_h reflectivity threshold at a temperature level of importance: ≥30 dBZ at -10˚C
  - Based on the NIC (non-inductive charging) method (charge separation by chance collision of large ice particles with smaller crystalline particles in the presence of supercooled liquid)
  - ≥ 30 dBZ implies larger precipitation size/concentration required for electrification
  - -10˚C is approximately the location of the main negative charge center created by charge separation based on the tripole model
- Area of interest is defined by subjective visual assessment with SOLOII and ANGEL
- Identification of first flash of lightning

Analyze

- Extract radar values from UF radar data to a text file based on defined Larsen areas of interest
- Test algorithms on extracted values

Test Algorithms

Focus	Thresholds	Thermal levels	
Z_h and temperature	35, 40, 45 dBZ	-10, -15, -20 ˚C	First occurrence of Highest value
2nd level Z_h and temperature (1st level Z_h > 30 dBZ at -10ºC)	15, 20, 25 dBZ	8 km	First occurrence of Highest value
Z_{DR} and Z_h with temperature (Z_h >40 dBZ)	>1dB	-10, -15, -20 ˚C	First instance of Highest value
PID and temperature	PID = 8,9 (graupel) PID = 7,9,14 (supercool drops)	-10, -15, -20 ˚C	First instance of PID value

Tests:

Radar Reflectivity

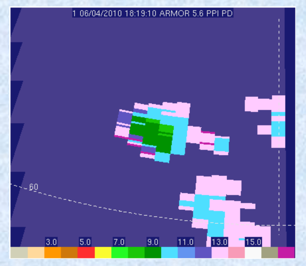
- Sensitivity tests of Z_h to establish a basis of comparison for dual-polarimetric variables and previous research
- Z_h thresholds (35-45 dBZ) are indicative of mm-sized precipitation at significant charging levels (-10 to -20˚C)
- The maximum value is interpolated linearly between two elevation scans for greater accuracy

Secondary Reflectivity Level

- Paired with the lower threshold of Z_h ≥30 dBZ at -10˚C
- Used to evaluate vertical development, a factor of NIC charge separation

PID First instance

- The first occurrence of a single value (PID or dBZ) at a defined temperature threshold
- This can be a value interpolated linearly between two elevation scans for greater accuracy (as employed for Z_h)
- PID values are grouped into bulk hydrometeor categories related to NIC

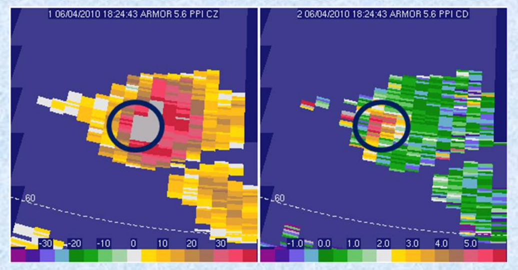


First instance of Graupel PID
Cell 1 of Case 20100604

Z_{DR} Column

- Indication of lofted supercooled drops, a key ingredient leading to formation of graupel and hail related to NIC
- Z_h >40 dBZ is indicative of mm-sized particles, and Z_{DR} > 1 dB is indicative of oblate spheroids

Z_{DR} Column of Cell 1 of Case 20100604



NCAR PID Chart

Category	Color	NCAR PID
1		Cloud
2		Drizzle
3		Light Rain
4		Moderate Rain
5		Heavy Rain
6		Hail
7		Rain and Hail
8		Graupel and Small Hail
9		Graupel and Rain
10		Dry Snow
11		Wet Snow
12		Ice Crystals
13		Irregular Ice Crystals
14		Supercooled Liquid
15		Flying Insects
16		Second Trip
17		Ground Clutter

Z_{dr} and Z_h

Z_{DR} (Differential Reflectivity)

- A ratio of $Z_{DR} = 10*LOG_{10}(z_h/z_v)$
- Has been used to identify rain/ice when coupled with Z_h (Bringi et al. 1984)

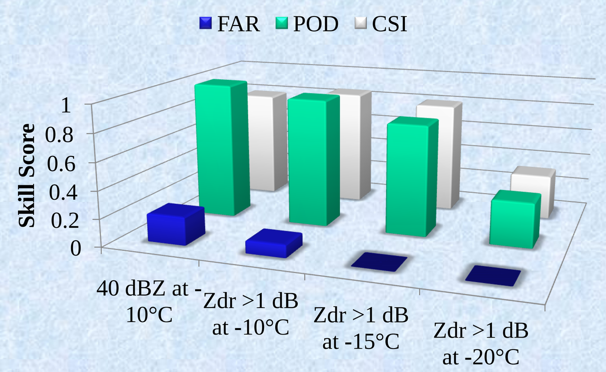
• Rain drops are oblate spheroids, thus returning a high Z_{DR} value (0.5 - 4dB).

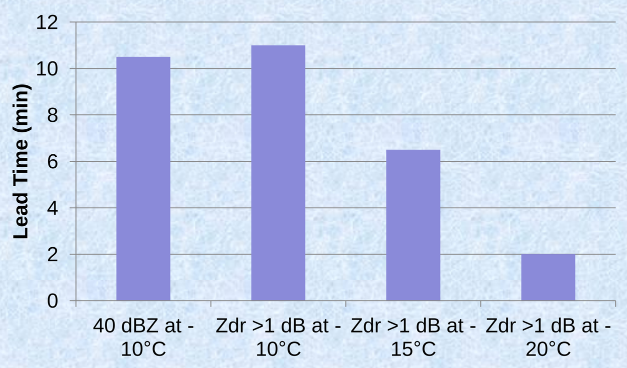
• Nearly spherical, tumbling dry hail/graupel have an averaged Z_{DR} value near zero (-0.5 - 0.5dB)

• Z_{DR} with larger Z_h (size and concentration) to determine approximate hydrometeor type

• In warm cloud base storms, supercooled raindrops later freeze into hail. Z_{DR} columns provide early warning of big ice and lightning.

Z_{DR} Column Results:

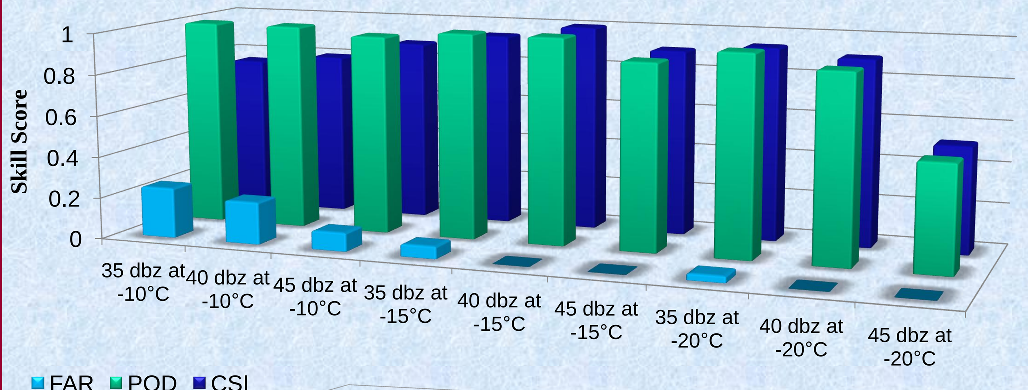


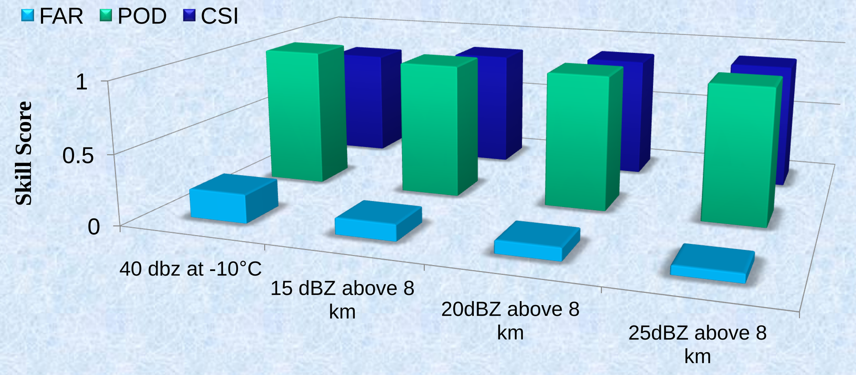


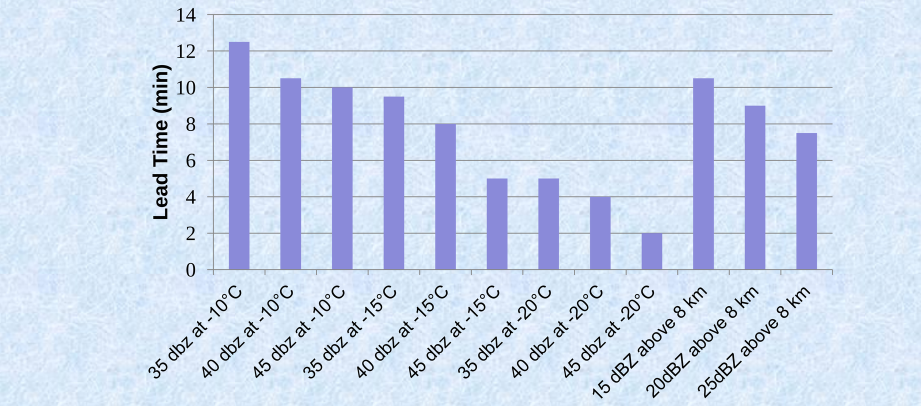
Discussion:

- Comparison of lead time and skill scores of Z_{dr} Column and the benchmark (40 dBZ at -10°C) supports the conclusion that dual-polarimetric variables are useful in first flash forecasting
- The best algorithm is Z_{dr} > 1 dB at -10°C with one minute in increased lead time and reduced FAR
- The reduced FAR results in increased CSI skill score
- The difference of POD and lead time stems from two missed Z_{dr} Column forecasts

Reflectivity Results:



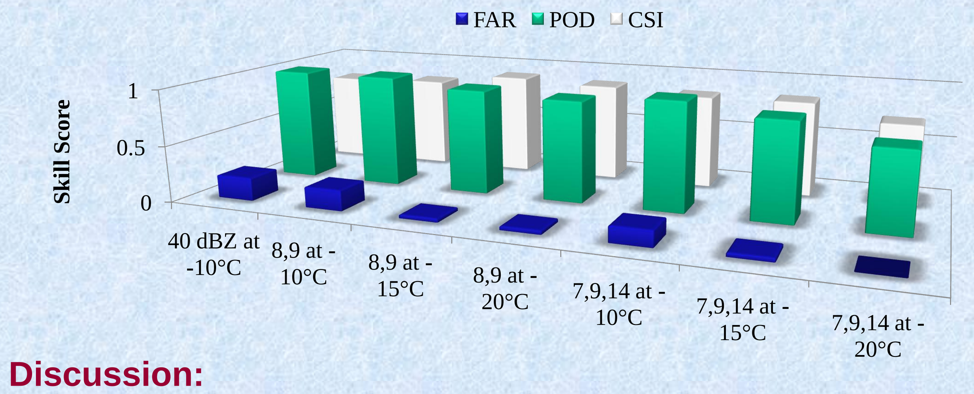


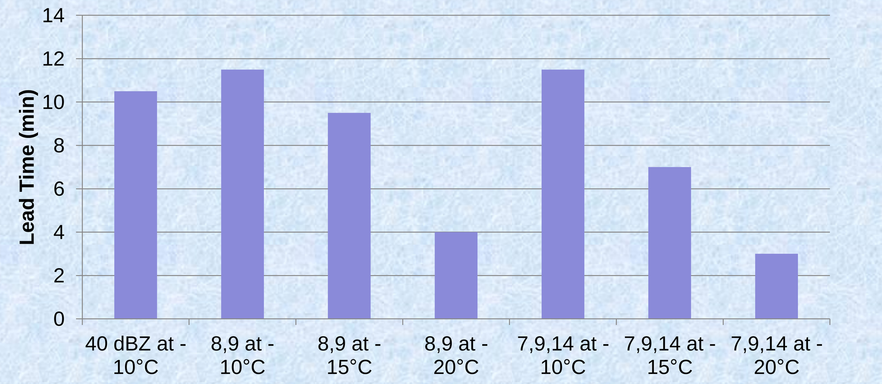


Discussion:

- The best reflectivity algorithm is Z_h > 40 dBZ at -15°C with eight minutes average lead time and perfect POD and FAR
- 35 dBZ at -10°C results in the greatest lead time, however also has the greats FAR and second lowest CSI
- The secondary reflectivity level of 15 dBZ at 8 km increases lead time by about 0.5 minutes average lead time compared to the benchmark, and reduces FAR by half

Particle Identification Results:



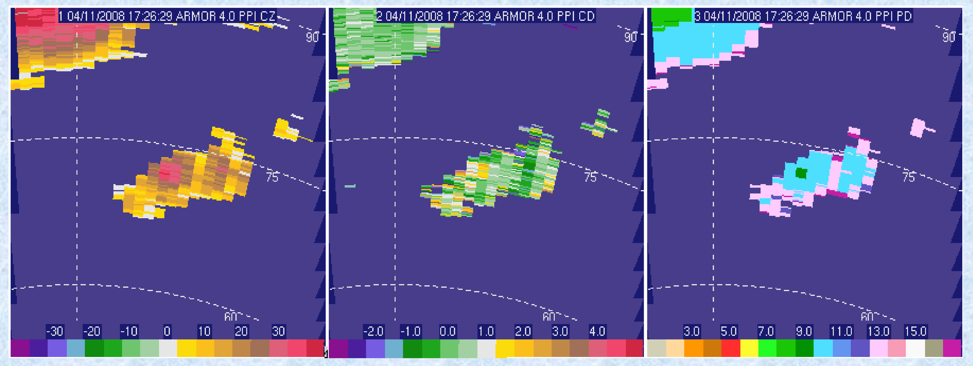


Discussion:

- Comparison of lead time and skill scores of PID and the benchmark (40 dBZ at -10°C) shows a reduction of FAR and increased CSI which supports the conclusion that dual-polarimetric variables are useful in first flash forecasting
- The best algorithm based on skill scores and lead time is the detection of the first instance of graupel PID at -15°C. However weighting lead time over skill, the better forecasting algorithm of this group is the detection of graupel PID at -10°C.
- The lead time of graupel and supercooled drops PID at -10°C results in about a minute increase in average lead time
- Supercooled drops PID algorithm is most frequently triggered by the occurrence of the PID graupel rain mixture. Thus the results are close to those of the graupel PID algorithm, however not quite as well.

Discussion and Conclusions:

- The lead times and skill generally decrease with increasing threshold requirements.
- The limited data set concludes that the utility of dual-polarimetric variables is in the reduction of FAR, however they provide only a marginal increase in skill and lead time.
- A significant increase in lead time would be on the order of five minutes or greater. An increase of only a minute to half a minute is not significant.
- The best method for detection based on high POD and reduced PFA is 40 dBZ at -15°C.
- The best method for detection balanced by lead time is graupel PID at -15°C.
- Depending on the need of the user, dual-polarimetric variables can be more advantageous.
- The utility of the PID algorithm is found in the flexibility of hydrometeor identification compared to the hard set thresholds of such algorithms as the Z_{DR} column for example:



First instance of graupel PID at approximately -10°C of cell 1 case 20080411. Left to right, Z_h, Z_{DR} and PID. There was no associated "hit" forecast for Z_{DR} column due to associated Z_h values.

Potential sources of error

• Potential bias due to small sample size

• Subjective methodology of selecting area of interest.

• PID optimization

Future Work

• Future work includes expanding the data set to different meteorological and convective situations

• Automation of cell selection to reduce possible biases and enabling analysis of larger data set

• Replicating the test in different geographical regions

• Real-time application of dual-polarimetric algorithms to determine cost-benefit

• Tuning of the PID algorithm, to determine the true value of this tool it should be optimized and tuned for accuracy

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