NORTH DAKOTA

INVESTIGATION OF THE EXISTENCE OF VERTICALLY ORIENTED ICE CRYSTALS IN WINTER STORMS





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Motivation

- A dual-polarized radar product, ZDR, measures the differential equivalent-reflectivity of a sample volume.
- Through ZDR and other studies and observations, it has been shown that ice crystals typically orient roughly parallel to the horizontal plane (Thomas et al. 1990; Hogan 2012).



Dual-polarization radar depiction from Weather.gov



Vertically Oriented Ice Crystals

• Laboratory studies have revealed ice crystal alignment with electric field (EF) lines when in the presence of EF charging (Magono and Sekiya 1965; Weinheimer and Few 1987; Foster 2002; Foster 2008 and Hashino et al. 2014).



- Vertically oriented ice crystals are most often associated with thunderstorm anvil regions.
- Example of Radar Base Reflectivity and Differential Reflectivity published in the Journal of Operational Meteorology (Kumjian 2013).

Non-Thunderstorm, Cold Season Application

- Less is known about vertical ice crystal orientation occurrence in winter storms.
- A largely overlooked ice crystal property is the spatial arrangement of ice crystal axes and faces, which can exhibit specific orientations due to aerodynamic, electric, and gravitational forces (Weinheimer and Few 1987).
- Purpose: relate remotely sensed observations to in situ measurements.
- Ice crystal orientation directly relates to:
 - Particle scattering properties
 - Cloud reflectance
 - Particle fall speed (Jiang et al. 2019)
 - Precipitation growth (Jiang et al. 2019)
 - Ice and total water content measurements
 - Climate model implications

NASA IMPACTS Field Campaign

Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms







Data Collection:

- Jan Feb 2020
- Jan Feb 2022
- Jan Feb 2023



- Targeted Nor'easters affecting the Atlantic Coast and Northeastern United States.
- Objectives related to a better understanding of precipitation processes in winter storms.

NASA P-3 Research Aircraft

- The NASA P-3 is an all-weather aircraft modified extensively for airborne scientific research.
- Powered by four turbopropellers.
- Wing-mounted instruments were outboard.









*Two-Dimensional Stereo (2D-S) Optical Array Probe (OAP)

February 7th, 2020 Science Flight

NOAA/NESDIS 06 Feb 2020 Satellite Image from GOES-East in ABI Geocolor





- Dubbed "Winter Storm Kade" by The Weather Channel.
- Mature synoptic low pressure system.
- Well-supported by combined jet region of over 200 knots.
- Simultaneously created winter conditions and a line of thunderstorms.
- Forecast significant, hazardous weather in New York and surrounding regions.
- Concurrently sampled by the NASA P-3 and NASA ER-2.
- Produced ten cases of interest.

Two-Dimensional Stereo Optical Array Probe (2D-S)

- Two perpendicular laser beams.
- Illuminates 10 to \sim 2000 µm diameter particles.
- Records shadow image and associated parameters.







Example 2D-S Data



2DS Ch.	ID	Time	Dia.	Area Ratio	Asp. Ratio	Ang.	AI	Х	Buffer Time	Y	IPT
		(sec)	(µm)			(deg)		(µm)	(sec)	(µm)	(sec)
Н	Α	61786.926	1097	0.22	0.24	-28.0	1	1000	61786.926	610	0.000671
Н	В	61786.926	731	0.36	0.49	-33.7	1	670	61786.926	460	0.003619
V	С	61786.770	1214	0.19	0.25	29.3	0	1090	61786.770	640	0.001291
V	D	61786.020	927	0.29	0.33	6.9	0	920	61786.020	390	0.003834

Science Questions

- Can ice crystal vertical orientations be observed through in situ measurements?
- Can any relationship be drawn between ice crystal vertical orientations and cold season cloud top electric field charging?
- Is there any relationship between ice crystal vertical orientations and periods of high particle concentration?





Case Selection Methodology

- The 2D-S Image Data appears to show similar angles in the low aspect ratio ice crystals.
- Isolate the low aspect ratio ice crystals of interest observed in the 2D-S Image Data.
- Statistically analyze orientation angles of low aspect ratio ice crystals.



Case Selection Methodology





Time Series of 2D-S Orientation Angles





Subset Criteria

- All-in particles
- Diameters greater than 100 µm
- Aspect ratios up to 0.6
- Area ratios greater than 0.1

Minor Axis of Particle Image Aspect Ratio = $\frac{Major}{Major Axis of Particle Image}$

Area Ratio = $\frac{Area \ of \ the \ Particle \ Image}{4}$ Area of the Bounding Circle

February 7th, 2020 Cases

- ID Particle Habit(s) Observed
- 1 Plates
- 2 Columns
- 3 Plates, Plate Aggregates, Plates Fragments
- 4 Needles, Columns, Prisms
- 5 Column Aggregates
- 6 Columns, Needle Aggregates
- 7 Plates, Sectored Plates, Plate Aggregates
- 8 Plates, Prisms
- 9 Plates Aggregates, Columns, Prisms, Plates
- 10 Rimed Plate Aggregates.Rimed Columns, PlateAggregates, Columns, Prisms



PHIPS Image. Photo credit: Christian Nairy



Orientation Angle Histograms

- (V) consistently peaks near +21°
- (V) peaks tend to be more prominent with columnar ice crystal cases
- (H) more randomly distributed
- (H) favors a modest peak near 0° (±30°) generally with plate crystal cases



Orientation Angle [deg]

- Case 4 was further subset with an aspect ratio of
 - (a) 0.1 to 0.4
 - (b) 0.2 to 0.3

Aircraft Maneuvers within Cases

- Objective: validate probe-measured ice crystal orientation
- **Hypothesis:** if truly sensing atmospheric vertically oriented ice crystals, **the histogram peak should shift** during an aircraft banking turn
- A select few cases were examined:
 - Case ID Maneuver
 - a Straight & Level
 - b Banking Right
 - c Banking Left
 - 2 a Descending
 - b Banking Right & Descending
 - c Straight & Level
 - 4 a Straight & Level
 - b Banking Right

Case 1: 14:57:00 - 15:19:59 UTC







Aircraft Maneuver Comparisons from Cases 1 and 4



Orientation Angle [deg]

Orientation Angle [deg]



Aircraft Maneuver Comparisons from Case 2

- Descending sub-case resulted in a wider distribution of negative orientation angles in the horizontal channel and multiple peaks in the vertical channel
- Roll angle near zero
- Pitch angle near zero
- Nearly constant true air speed

Conclusions

- Can ice crystal vertical orientations be observed through in situ measurements?
 Yes... but no
- Can any relationship be drawn between ice crystal vertical orientations and cold season cloud top electric field charging?
 - Nothing conclusive without additional measurements
- Is there any relationship between ice crystal vertical orientations and periods of high particle concentration?
 - Nothing conclusive due to misleading periods of high concentration
- Key findings: the data collection method is problematic

Future Work

- Change of aircraft
- Speed runs, aircraft stalls
- Direct EF measurement
- Laboratory experiments isolating possible causes of vertical orientation
- High Volume Precipitation Spectrometer (HVPS-3) dataset
- Other cases/science flights
- Reconstruction data processing method to include not all-in particles

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