Analyzing Elevated Convective Cells Within The Banded Regions of Snowstorms

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1. Objectives

Elevated convective cells (CCs), including generating cells (GCs), that exist in association with banded structures in winter storms are studied to better understand processes leading to precipitation bands to ultimately improve their predictability.

This study sought to:

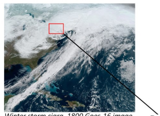
- Find general relationships between small-scale vertical velocity and in-situ microphysics
- Identify CCs through remote sensing, and evaluate against in-situ measurements of vertical velocity
- Use a novel algorithm to detect and characterize CCs within banded structures through the sole use of in-situ velocity data

2. IMPACTS Datasets

Impacts sampled storms Jan. 18, 2020 to Feb. 27, 2020. Two other years as well, but only 2020 used here.

P-3	2-DS	Optical array particle images give N(D) 50 µm < D < 1 mm, IWC, MMD, MND
P-3	HVPS-3	Optical array particle images give N(D) 200 µm < D < 10 mm, IWC, MMD, MND
P-3	FCDP	Forward Scattering gives N(D) 2 µm < D < 50 µm, LWC, MND, MMD
P-3	TAMMS	Pressure ports measure in-situ vertical velocity
P-3	RICE	Ice sensor measures presense of supercooled liquid water.
ER-2	CRS	94GHz nadir-pointing radar gives radar reflectivity, radial particle velocity, linear depolarization ratio.

3. P-3 & ER-2

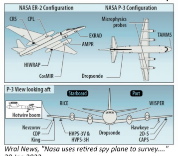


Winter storm ciara. 1800 Goes-16 image for 7 Feb 2020

Deep (980hPa) cyclone sampled by IMPACTS

High altitude ER-2 flew high above troposphere, P-3 penetrated storms below

ER-2 equipped with remote sensing, P-3 with in-situ instruments



Wral News, "Nasa uses retired spy plane to survey...." 20 Jan 2022

4. Flight Tracks

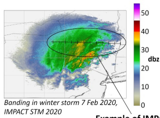
Flight tracks typically perpendicular to banded precipitation

ER-2 flew faster than P-3; flight tracks arranged so they were horizontally collocated at middle of flight track

Horizontal distance determined by the Haversine formula where:
ϕ_1 = latitude of P-3, ϕ_2 = Latitude of ER2
$\Delta\lambda$ = Difference between longitude of aircraft
r = radius of Earth for specific latitude

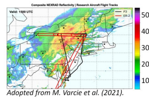
$$\Delta\sigma = \arctan\frac{\sqrt{(\cos\phi_2\sin(\Delta\lambda))^2 + (\cos\phi_1\sin\phi_2 - \sin\phi_1\cos\phi_2\cos(\Delta\lambda))^2}}{\sin\phi_1\sin\phi_2 + \cos\phi_1\cos\phi_2\cos(\Delta\lambda)} \;;\; d = r\,\Delta\sigma$$

Example of ER-2 overshooting P-3 after brief period of collocation



Banding in winter storm 7 Feb 2020, IMPACT STM 2020

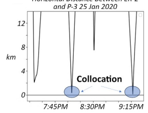
Example of IMPACTS flight track



Adopted from M. Varcie et al. (2021).

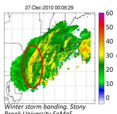
Racetrack patterns to differentiate legs

Horizontal Distance Between ER-2 and P-3 25 Jan 2020



5. Substructures

*Substructure figure examples not taken from IMPACTS



Winter storm banding. Stony Brook University SoMaS

Location of banded structures determine intensity and variability of precipitation

CCs characterized by tall towers of convection with local maximum in reflectivity within cloud below echo-top

GCs characterized by smaller turrets of reflectivity and convection near echo-top

Elevated Convective Cells (CCs)

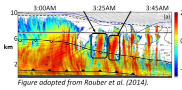


Figure adopted from Rauber et al. (2014).

Subtype of Convective Cells, Generating Cells (GCs)

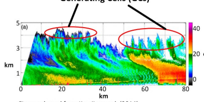


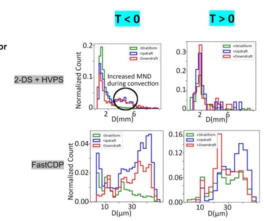
Figure adopted from Kumjian et al. (2014).

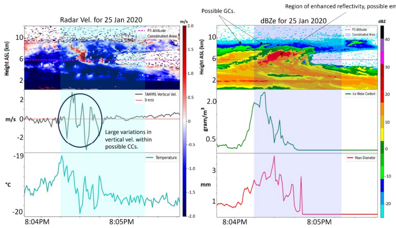
6. Comparing Microphysics to TAMMS

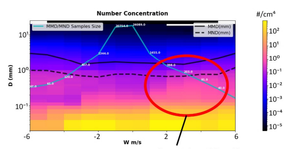
Distribution of mean diameter for updrafts/downdrafts/stratiform

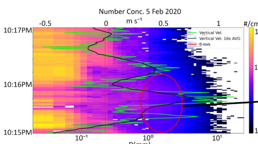
Updraft/Downdraft defined as ±1.5m s^{-1}

N(D) compared directly against velocity data









Time series analysis of TAMMS velocity, temperature, MND, IWC, and remote sensing measurements

Coodinated aircraft time period shaded, P-3 altitude noted

Higher conc. of large (~1 mm) particles during convective periods consistent with Plummer et al. (2014)

TAMMS velocity compared against particle concentration measurements

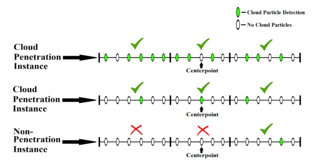
Vertical velocity rolling average of 16 s illustrated to show velocity trend

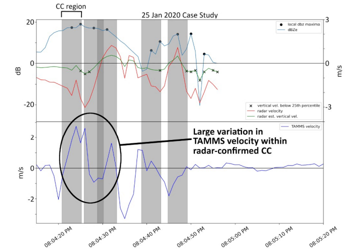
7. TAMMS Algorithm

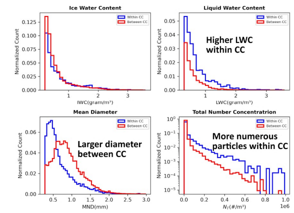
Jan. 25, 2020 case study, one instance of radar-confirmed CCs during aircraft collocation:
Radar data range gate at P-3 altitude
5-second shaded areas use CC cores as centerpoint
TAMMS characteristics noted and used in algorithm for TAMMS-confirmed CCs
Scheme for radar-identified cellular convection adopted from Wang et al. (2020)

All in-situ data seperated by instances of cloud penetration where cloud particles consistently detected

Bulk in-situ characteristics within and between CCs illustrated







8. Findings

- Time series analysis showed higher concentration of particles ≈ 1 mm for convective periods.
- In-situ statistical analysis showed particles 0.5 mm < D < 4 mm and IWC increase in downdraft/updraft
- The following consistencies in radar-confirmed CCs measured by the TAMMS:
  - -Range of TAMMS velocities values greater than 1.2 m s^{-1}
  - -Percentile range of velocities greater than 16.
  - -Largest velocity higher than 30th percentile.
- Observations of microphysics for TAMMS-confirmed CCs:
  - -IWC similar inside/outside CCs, LWC 2.3 times larger within CCs
  - -Total number concentrations were 2.8 times larger within CCs
  - -Mean diameters 0.35 mm larger between CCs
  - -Temperatures 2.4 °C warmer within CCs

9. Discussion & Future Work

- Observations of in-situ data in convection consistent with Plummer et al. (2014), IWC/Diameter within TAMMS-confirmed CCs are not
- Decreased particle diameter within CCs and large LWC/Number concentration suggest numerous small liquid cloud droplets within TAMMS-confirmed CCs, consistent with Rauber et al. (2014)
- Large increases in total concentration and LWC are consistent with banding within CCs
- Future work may:
  - -Look at echo-top altitude for periods without collocated aircraft data to define CCs near cloud top as GCs
  - -Use IMPACTS 2022/2023 data to cross reference accuracy of TAMMS-confirmed CC algorithm
  - -Further categorization of CCs by cloud phase, particle habit, potential temperature level
- *This work funded by the NASA Earth Venture Suborbital-3 (EVS-3) program under Grant 80NSSC19K0399 (OU)*
- *Data obtained from the Global Hydrometeorology Resource Center (GHRC)*

Title: An Analysis of the Microphysical and Thermodynamic Properties of Elevated Convective Cells within Snowbands Associated with Winter Storms.

Poster Submitter: Christian Hall

Abstract: In-situ and remote sensing observations of snowbands were obtained by probes on a cloud penetrating NASA P-3 and a high-altitude NASA ER-2 aircraft, to identify and characterize elevated convective cells (CCs). Observations were made during the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) field campaign in 2020. The radar reflectivity and Doppler velocity measured by a Cloud Radar System (CRS) on the ER-2 were used to identify CCs for time periods when the horizontal separation between the ER-2 and the P-3 was less than 1.4 km, with the characteristics of small-scale air motion subsequently determined by the Turbulent Air Motion Measurement System (TAMMS) on the P-3. Through a case study analysis of collocated regions with radar confirmed CCs, an algorithm that considered the statistical significance of the range in small scale vertical velocity from the TAMMS, as well as the magnitude of the largest velocity, was developed to identify CCs using data exclusively recorded by the TAMMS. Using time periods identified as containing elevated CCs from the TAMMS for the entire 2020 IMPACTS campaign, cloud microphysical properties derived from the Rosemount Icing Detector (RICE), Fast Cloud Droplet Probe (CDP), 2D-S Stereo Probe (2DS), and High-Volume Precipitation Spectrometer (HVPS) installed on the P-3 were used to characterize the cloud microphysical properties inside and between CCs. Cloud penetrations were defined as sequences of 20-second time intervals when the P-3 encountered cloud particles at least once every 6-7 seconds, until there was a gap of at least 6-7 seconds between cloud particles. Of the 94 instances of cloud penetration identified from the P-3 analysis, 29 contained at least one CC. Contrary to previous observations of convective cells such as in generating cells in winter storms, distributions of IWC and mass weighted mean particle dimension were not statistically different for data collected within and between CCs. However, mean number-weighted particle dimensions were 0.35 mm larger between CCs than within. Total number concentrations and LWC averaged 2.8 times larger and 2.3 times larger, respectively, within CCs than between. Temperatures were on average 2.4 °C greater, and dewpoint depressions 0.77 °C smaller within CCs than between. There was a 9% decrease in supercooled liquid water (SLW) presence between CCs compared to within, and SLW was detected within all TAMMS confirmed CCs. The means for defining CC regions in a substantiated way with in-situ measurements depends on the reliability of contrasting data recorded from the ER-2 and P-3 aircraft during collocated time periods, as well as the number of collocated time periods available. It is because of these limitations, and the unconventional means for detecting CCs using the TAMMS, that differences in the observed characteristics of TAMMS-confirmed CCs may be present when compared to previous studies.