Assimilating IMPACTS Data For 7 Feb 2020 Storm To Improve WRF Winter Cyclone Prediction

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Introduction

Winter cyclones frequently cause significant injuries, damages, and economic loss, especially in the Eastern US. Timely and accurate forecasts are critical to minimize those harms, especially for heavy precipitation from embedded mesoscale snowbands. Recent advances in ensemble techniques have been useful (e.g. better error estimation), but there remains much room to improve.

We use data assimilation **(DA)** with novel, high spatial- and temporal-resolution observations from the NASA IMPACTS (2020-2023) field campaign to improve PSU WRF-EnKF forecasts of a 7 Feb 2020 case study, and examine in detail how the model results change, focusing on radar reflectivity **(refl)**. The changes to placement and accuracy of precipitation features can tell us a great deal about how similar observations can be best used in the future.

What is IMPACTS?

The **I**nvestigation of **M**icrophysics and **P**recipitation for **A**tlantic **C**oast-threatening **S**nowstorms is a 2020-2023 NASA field campaign to study East Coast winter storms via multiple aircraft, plus ground and sonde observations. Special focus is placed on inner workings and prediction of snowbands, and applying results to modeling techniques.

Objectives

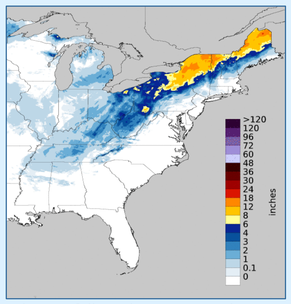
1. Assess IMPACTS DA effects on PSU WRF-EnKF forecast error via pointwise comparison: location of features, duration of effects
2. Create algorithm to identify major precip features via radar reflectivity, assess DA effects on accuracy of feature placement and motion
3. Use results to recommend methods and locations for future obs/campaigns: most useful data for assimilation + what similar available data could have the best impact on specific features for operational forecasting of snowstorms

Case Study

- 7 February 2020
- Deep trough over central US supported extratropical cyclone, deepening rapidly as it rolled up the NE Coast
- Significant damage, over 12” of snow in parts of NY

Why choose this case?

New, high spatial- and temporal-resolution data available from IMPACTS field campaign aircraft flying over and through the storm provides a chance to evaluate utility of new data and new techniques with DA.



24h snowfall totals 12z 7 – 8 Feb 2020
(NOAA National Snowfall Analysis)

Data

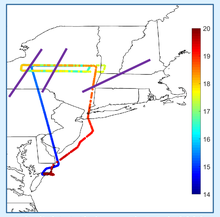
Observations

- ER-2 satellite-sim aircraft X-band radar [EXRAD] (3D Wind Retrievals)
- P-3 aircraft (in-situ temperature)
- Conventional observations from NOAA MADIS

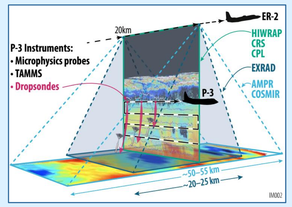
Verification

- WSR-88D **(NEXRAD)** N0Q 0.5°-elevation angle base refl mosaics **(OBS)** (courtesy Iowa Environmental Mesonet)

Flight legs pass through storm, across rain/snow line (approx. line locations at 6Z, 12Z, 18Z in purple)



P-3 Flight Path (Hour Z), 7 Feb 2020



IMPACTS ER-2 and P-3 Aircraft range and instrumentation diagram: EXRAD has a ground radius of ~10 km to either side of flight path.

Model

Five PSU WRF-EnKF experiments on Stampede2

- Initial conditions from GEFS ensemble at 18Z 6 Feb, 0Z 7 Feb; spin-up 0Z-3Z
- Conventional obs assimilated on the hour 3Z-14Z, then splits into multiple experiments:
  - Conventional + IMPACTS, 14-18Z **(AIR)**; conventional only, 14-18Z **(CONV)**
  - Free runs from 14Z **(NODA)**, AIR 18Z **(AIR-F)**, CONV 18Z **(CONV-F)**, all to 0Z 8 Feb
- 2 nested domains: 9/3 km resolution, 399x399x50 grid, 40 members
- Relaxation to prior perturbation with coefficient 0.8 to prevent filter divergence
- Physics: Thompson microphysics, RRTM longwave, Dudhia shortwave, MYJ PBL, Noah LSM, Eta surface layer

Analysis Methodology

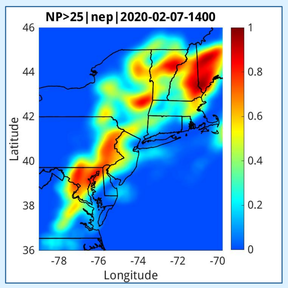
Analysis is split into 2 major parts: pointwise comparison and snowband tracking. Both are focused on radar reflectivity, and have distinct methods of error estimation.

Pointwise Comparison

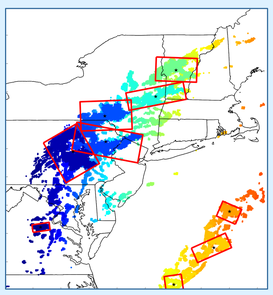
Ensemble members/means regridded, 3D reflectivity sampled and interpolated to match NEXRAD base refl obs

- Quantitative: point-to-point RMSE & bias, snowfall plumes
- Qualitative: Neighborhood Probability **(NP)**

$$NP_i = \frac{1}{n_r}\sum_{m=1}^{n_r} BP_m$$



AIR Ensemble Mean NP: dBZ > 25, 30 km radius



Band clusters: 14z (AIR)

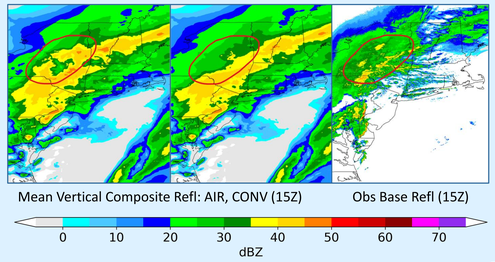
Snowband Tracking

Reflectivity objects are identified by thresholding to above μ + 1.25*σ, then grouped into “bands” using a modified Single Linkage Hierarchical Clustering **(SLINK)** algorithm. Bands are checked against snowband criteria (e.g. size and aspect ratio), then matched to objects from obs/other experiments via Demons Image Registration **(ImReg)**, with Euclidean distance as error.

Results

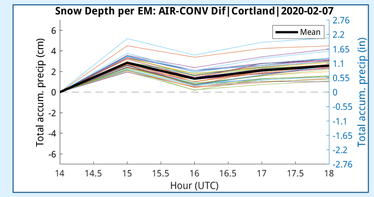
Highlighted results from current state of analysis:

1) AIR captures the shape of NW precipitation shield better than CONV, compared to OBS



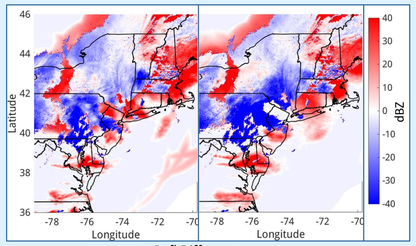
Mean Vertical Composite Refl: AIR, CONV (15Z) | Obs Base Refl (15Z)

2) W NY Ens Mean Snow Depth 1-3 cm closer to OBS across 14-18Z in AIR (vs CONV), inconclusive in E NY



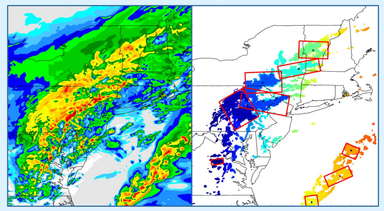
Physical Snow Depth per Ensemble Member:
CONV 27.7 cm, AIR 28.8 cm, NY Mesonet Obs 28.7 cm @ 18Z

3) Free runs keep same basic structure, shift some convection SW (closer to obs); AIR-F shows marginal improvements to RMSE



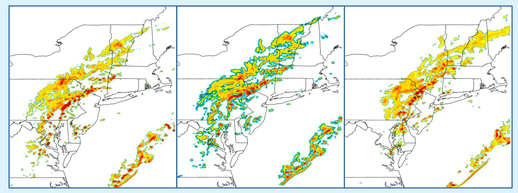
Refl Difference
AIR-F Mean – Obs (19Z) | NODA Mean – Obs (19Z)
RMSE 17.613 | RMSE 17.678

4) SLINK can identify band objects that forecasters would, but algorithm doesn’t account for directional gradients (based only on a binary of >= threshold)



M1 (AIR) 14Z VC Refl | SLINK Clusters (colored by cluster)

5) Demons ImReg can successfully morph one timestep to overlay the next; focuses on central convection at expense of trailing cells



14Z, thresholded → Demons Transform | 15Z, thresholded

Both techniques help us move towards quantitative, object-based verification of the modeled storm’s precipitation features

Conclusions

- AIR shows some improvements over CONV in placement of precipitation features, especially in areas immediately downwind of the assimilation locations.
- Single Linkage Clustering is able to identify reflectivity objects, but requires more fine-tuning to properly identify & separate objects into reasonable “snowbands”
- Snowfall totals slightly improved in all ensemble members by assimilating IMPACTS data
- Goals for future work: fully quantify accuracy of precipitation feature placement and motion; apply additional error metrics to pointwise comparison
- Next steps: refine band ID & Demons matching; Equitable Threat Scores, ensemble clustering per feature