The Physics of Banded Structures in Extra-Tropical Systems: A Combined Remote Sensing and Modeling Perspective from NASA IMPACTS 2020

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Abstract

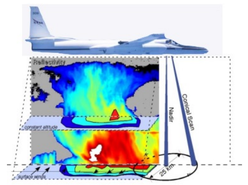
Banded structures in extreme weather systems are generally turbulent perturbations to a balanced, background flow that can organize and concentrate variables such as moisture, momentum, and energy. The concentration of these variables can lead to intense bands of multi-phase precipitation that are difficult to measure, model and predict with significant consequences for society in the energy and travel industries. The current understanding of the physical processes controlling the formation and evolution of these precipitation bands and their representation/predictability in numerical models is limited.

In this study, airborne and spaceborne remote sensing measurements along with large-eddy numerical simulations will be used to advance the understanding of the physics of banded structures in extra-tropical cyclones. The measurement aspect focuses on EXRAD scanning airborne radar data collected during the Feb. 1, 2020 IMPACTS case along with supporting satellite data from GOES-16. The modeling aspect provides a testing ground for airborne simulation studies and a mechanistic understanding of the banded structures using a dynamical budget methodology.

Data Sources: Remote Sensing and Modeling

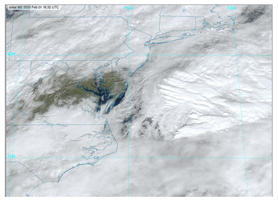
NASA EXRAD Scanning Radar

- ✓ X-band, ~ 32º nominal tilt
- ✓ Max swath width: ~ 23 km
- ✓ 3D winds/reflectivity spacing: 500 m/250 m in horizontal/vertical
- ✓ Fully resolved scales: 4 – 5 Δx or 2 – 2.5 km
- ✓ Lowest good level: ~ 1 km height
- ✓ See Guimond et al. (2014) and Guimond et al. (2018a) for details

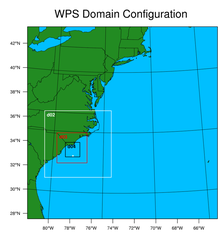


GOES-16 Mesoscale Scans

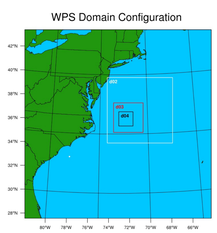
- ✓ VIS channel 2 (for now)
- ✓ Scaled reflectance data
- ✓ 1 min refresh rate
- ✓ 500 m pixels



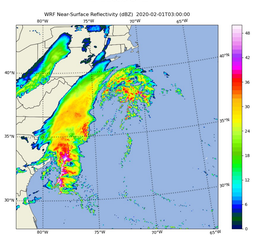
WRF Large Eddy Simulations



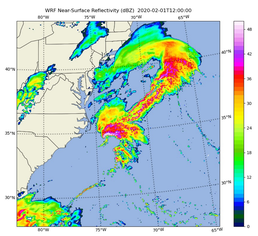
Domain 1 = 2 km, (874,883,121)
Domain 2 = 0.667 km, (919,919,121)
Domain 3 = 0.222 km, (1246, 1246, 121)
Domain 4 = 0.074 km, (1801,1801,121)

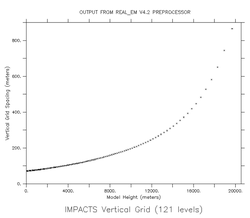


Phase 1



Phase 2



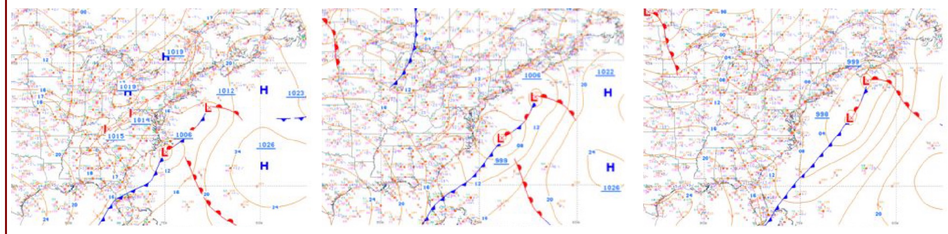


IMPACTS Vertical Grid (121 levels)

Model Settings

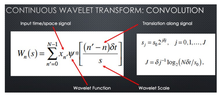
- Microphysics = Thompson scheme (all)
- Radiation = RRTMG for SW/LW (all)
- PBL (vertical diffusion) = YSU (d01/d02 only)
- Horizontal diffusion = Smag-2D (d01/d02), Smag-3D (d03/d04)
- Surface layer fluxes = bulk aerodynamic method (all)
- Gravity wave sponge on upper 3 km
- NCEP GDAS/FNL 0.25º ICs/BCs

Focus on February 1, 2020 Case: Synoptic Scale

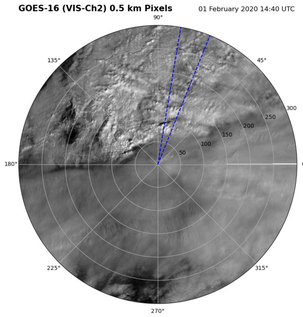


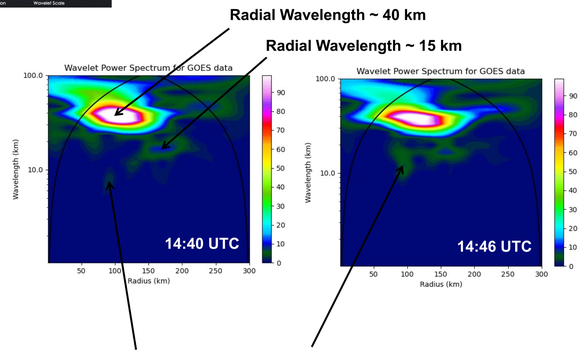
Mean sea level pressure and frontal analysis for, left to right, 1200 UTC 1 Feb, 1800 UTC 1 Feb and 0000 UTC 2 Feb.

Multi-Bands: GOES-16 Wavelet Analysis

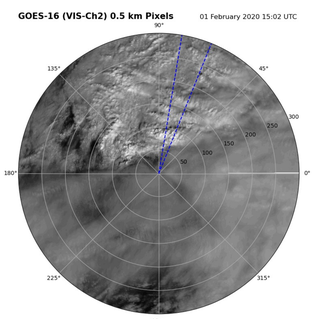


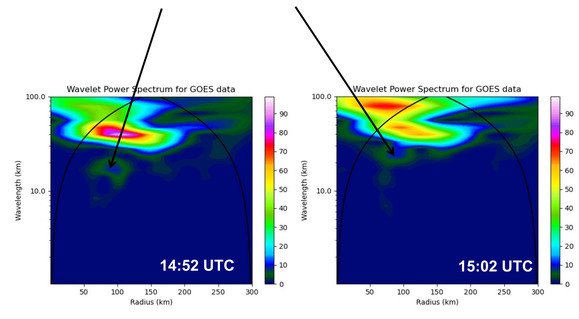
Morlet wavelet used (Fourier scale ~= wavelet scale)



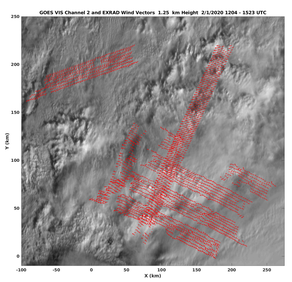


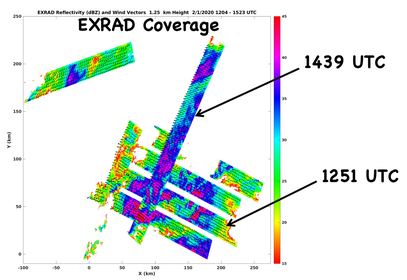
Growth of small-scale bands and potential upscale merging with larger scale band



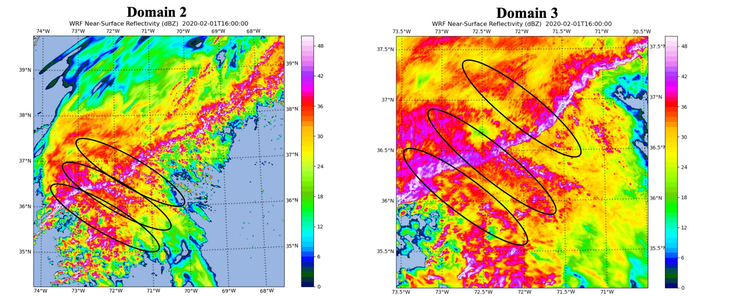


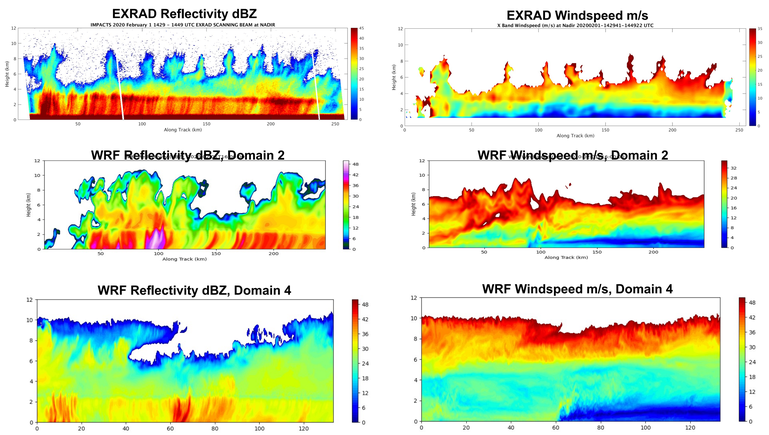
Storm-Relative Vortex Composite Structure (02/01/20 1204 – 1523 UTC)



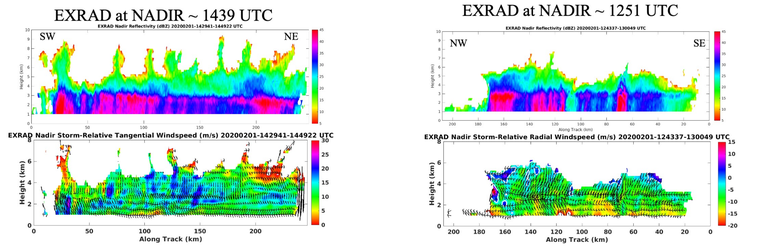


Multi-Bands: WRF and EXRAD Analysis





Banded Structure from Individual Overpasses



- ○ 15 – 20 m/s radial inflow & 1 – 5 m/s ascent at low levels
  - ○ Weak outflow & broad descent at higher levels
- ○ Deep inflow & 20 – 25 m/s localized tang flow
- ○ Low-level ascent (max ~ 4 m/s), upper-level descent (max ~ 5 m/s)

Preliminary Results and Next Steps

- ➢ Preliminary analysis of IMPACTS Feb. 1 '20 data indicates the following results:
  - ○ Dominant/secondary bands have radial wavelengths of ~ 40 km/15 km.
  - ○ Growth and decay of secondary bands on ~ 20 – 30 minute timescales.
  - ○ Observed upscale merger of secondary band with dominant band.
  - ○ WRF simulations display some multi-bands, but not enough of them.
  - ○ Intense, deep inflow in convective bands feeding vortex intensification.
- ➢ Next steps:
  - ○ Use simulation to understand EXRAD sampling context, scale separation, budgets.
  - ○ Is simulation good enough for budget studies of multi-bands?
- ➢ Paper: Guimond, S.R. (2021). The dynamics of precipitation bands in an extra-tropical cyclone: New insights from remote sensing data and large eddy simulations. J. Atmos. Sci., in preparation.

Acknowledgements

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