A-Train Based Analysis of Frontal Cloud and Precipitation Structures: A Case Study

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INTRODUCTION

Extratropical cyclones (ETC) play an important role in regulating Earth's energy balance, as they produce a majority of precipitation received in temperate and polar regions. A preponderant amount of moisture within an ETC is transported through the warm conveyor belt (WCB), an airstream of ascending moisture rising from the boundary layer to the upper troposphere. Given the large impact that ETCs and their WCBs have on general atmospheric circulation, it is important to conduct research to better understand the relationships between cyclone dynamics and cloud structure and properties.

The goals of this project are to understand 1) how changes in cyclone circulation and environment are related to changes in physical cloud properties and distribution/intensity of precipitation and 2) the interactions between frontal clouds and synoptic scale flow.

Our analysis was based on a case study from a long-lived ETC that remained nearly stationary northward off the Eastern Seaboard of the United States in late November 2006 (Figure 1). Due to its longevity over the same region, multiple observations were taken by various instruments in NASA's A-Train. When combined with operational numerical analysis, A-Train observations provide insight into the relationship between mesoscale cloud and precipitation features and cyclone-scale dynamics and its thermodynamic environment.

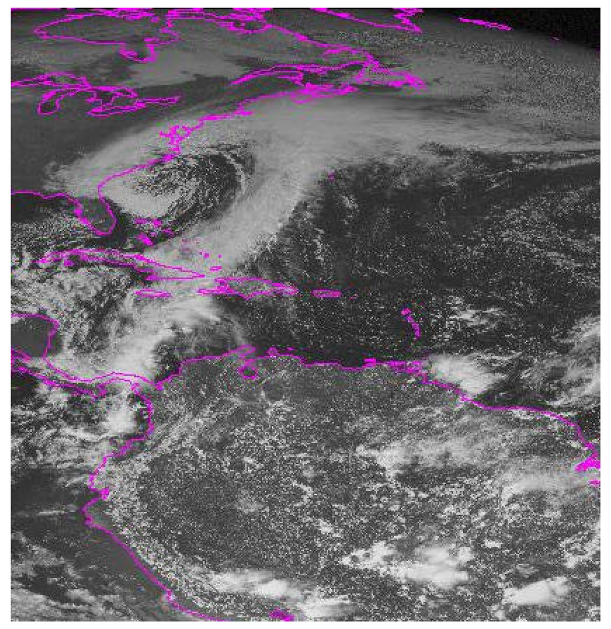

Figure 1: GOES-12 Visible Imagery 11/22/2006 at 16:15 UTC. Source: SSEC University of Wisconsin

DATA & METHODS

Two platforms of analysis used for this study:

- **GFS Analysis Data**
  - 6-hourly, 1.0° resolution model analysis
  - Analyze properties throughout the system at the synoptic scale
- **NASA's A-Train Satellite Constellation**
  - AMSR-E (6 microwave frequencies ranging 6.925-89.0 GHz)
  - MODIS (36 visible and IR bands ranging 0.4-14.5 µm)
  - CloudSat (94 GHz Cloud Profiling Radar (CPR))
    - ECMWF-AUX model data

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RESULTS

Synoptic Overview

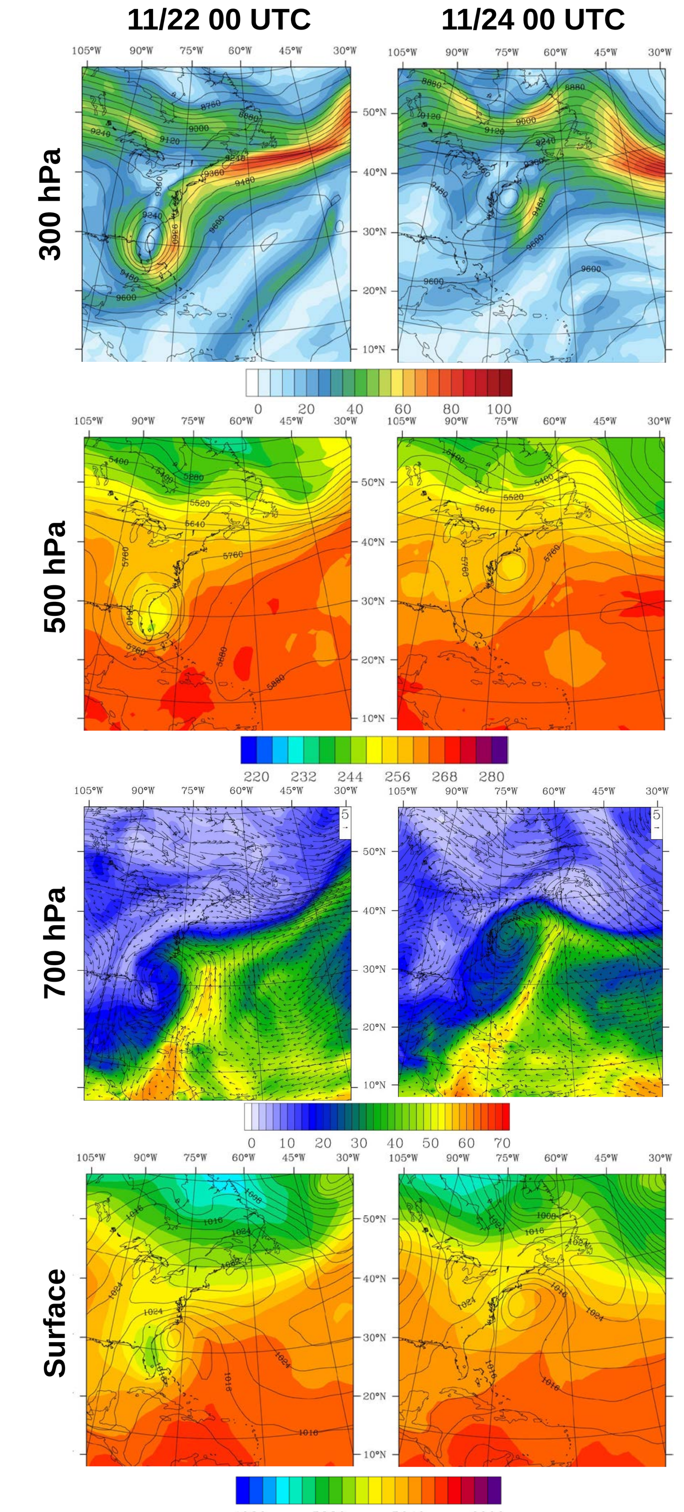

Figure 2: Synoptic scale analysis of the ETC on 22nd and 24th of November, with levels at 300 hPa (winds (m/s) and geopotential height (m)), 500 hPa (Temperature (K) and geopotential height (m)), 700 hPa (winds (m/s) and precipitable water (kg/m^2)), and at the surface (pressure (hPa) and 1000-500hPa geopotential height difference (m))

A-Train Observations

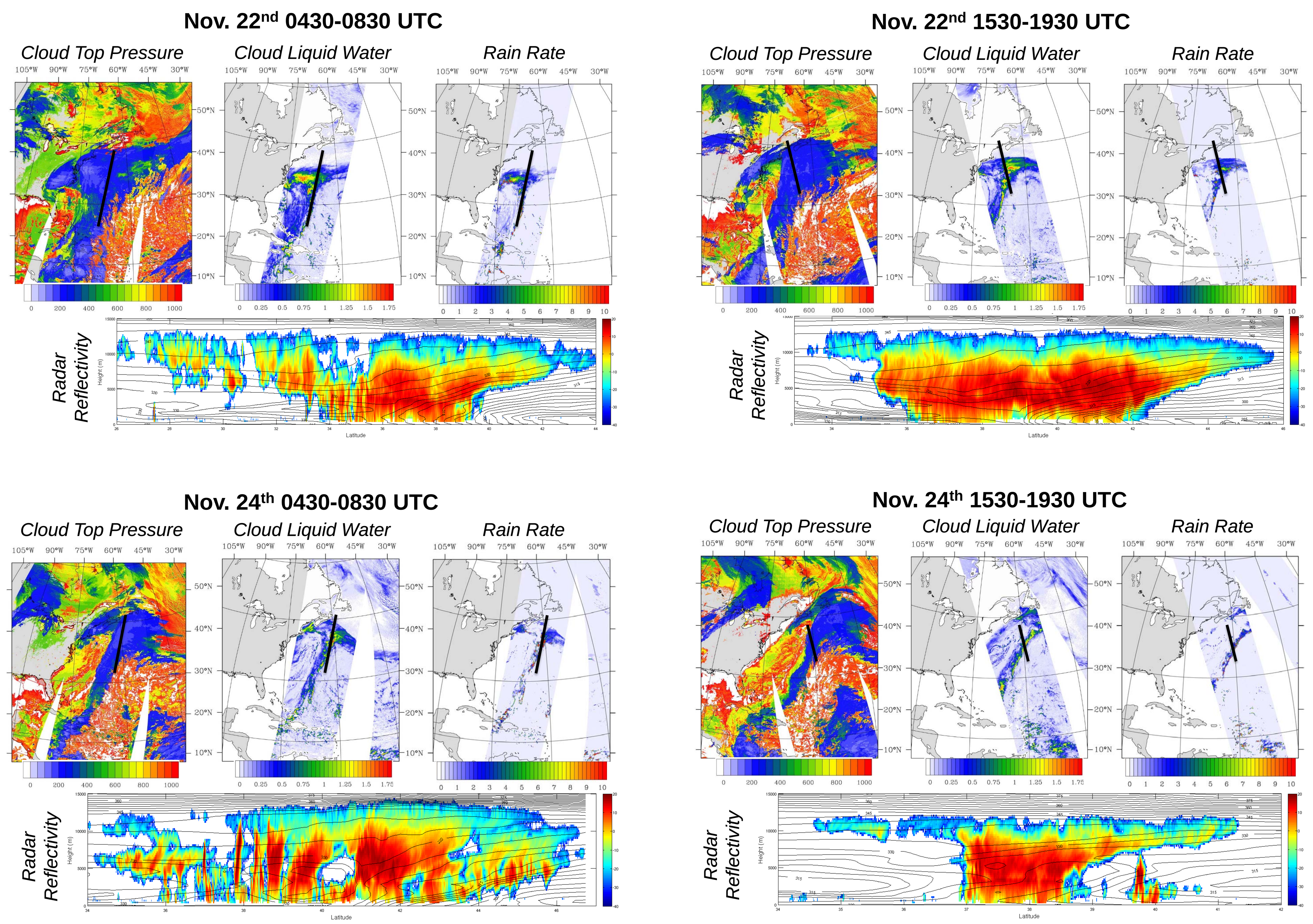

Figure 3: A-Train satellite data from MODIS Cloud Top Pressure [hPa], AMSR-E Cloud Liquid Water [mm], AMSR-E Rain Rate [mm/hr] and CloudSat Radar Reflectivity Factor [dBZ] with Equivalent Potential Temperature from ECMWF [K]. The black lines represent the approximate location of the respective CloudSat path and observation.

DISCUSSION

- Cut-off low formed by Nov. 22nd, exhibited slow northeast movement.
- Precipitable water (PW) and 700 hPa flow (Figure 2), depicts advection of water vapor from tropics into mid latitudes
- Sharp northern boundary seen in the PW implies strong water vapor convergence in the warm frontal region
- Amplification of the downstream ridge with time is evident at all levels
- AMSR-E plots show cloud mass and precipitation focused along the cold front and the northern boundary of the WCB
- As system evolves, precipitation becomes increasingly localized
- CloudSat reflectivity reveals stratiform cloud structures in the warm front through 1800 UTC Nov 22nd
- ECMWF equivalent potential temperature shows atmosphere to be stable in the warm frontal zone at this time
- By 0600 UTC 24 November, convective elements are clearly evident within the warm front, and the thermal stratification has weakened significantly
- After development of convection in the warm front, clouds are deeper and the tropopause is notably higher

CONCLUSIONS

Cloud processes in extratropical cyclones are known to exert an influence on storm dynamics and frontal structure. The WCB, in particular, has been shown to affect the upper troposphere, amplifying the ridge downstream of the parent low pressure system. Our analysis of the details of a single strong WCB case reveals the following:

1. Amplification of the downstream ridge occurs at all levels
2. Precipitation is increasingly concentrated in small regions and with greater intensity as the cyclone evolves
3. There is a notable transition from stratiform to convective clouds structure within the warm front, and an associated weakening of the thermal stratification

Our results indicate a significant transition in the character and distribution of clouds and precipitation with time, and hint at feedbacks between local-scale cloud processes and system-wide dynamics.

Future work will examine how latent heat release affects the cloud structure as the system and its WCB evolves over time. There are also outstanding questions regarding the length of time required to transition from stratiform to convective cloud structure in the WCB, and the associated feedback between changes in stability and frontal dynamics on synoptic scales.