



An Examination of Summertime Cyclones in the Context of the Classical Warm Conveyor Belt Definition Established During the Cool Season

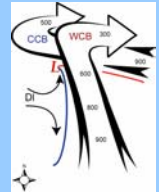


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1. Introduction

Warm Conveyor Belt

- A narrow stream of air that transports large amounts of heat, moisture, and westerly momentum (*Glossary of Meteorology*)
- Air which originated far south of the low in the warm sector, ascended toward the north, achieved saturation near or north of the warm front, where it rose rapidly, and joined the upper-level westerly flow northeast of the low center (*Carlson, 1980*)



Air stream configuration as depicted in the classic cyclone model (adapted from Carlson, 1980). Airstreams are the warm conveyor belt (WCB), cold conveyor belt (CCB), and dry intrusion (DI). The surface low pressure center is indicated with L, while the numbers depict pressure altitudes (hPa) of the various airstreams.

Study Objectives:

- WCBs and deep convection have been shown to be the primary mechanisms for transporting pollution during the cool season
- Transport during the other half of the year, the warm season, has received much less attention
- Characteristics of lifting and transport mechanisms observed during INTEX-A are documented and compared to the classical cases

2. Data

MM5 Domain:

- Positioned over United States and western Atlantic
- 60 km horizontal separation
- 40 vertical sigma levels

MM5 Parameterization:

- Kain-Fritsch cumulus parameterization scheme
- MRF PBL
- Simple Ice (Dudhia) microphysical scheme

Initialization Data:

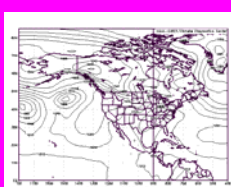
- Initial and lateral boundary conditions obtained from 3-D global reanalyses prepared by NCEP and available from NCAR
- 6-hour intervals
- 1° horizontal resolution
- FDDA employed to nudge the model toward synoptic analyses

Model Output:

- Hourly wind data from MM5 used to calculate forward air trajectories out 2 days
- In addition to MM5 output parameters, convective upward mass flux from Kain-Fritsch archived

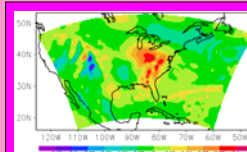
3. Classical WCB Case (85 Dec 1977)

Synoptic Pattern:

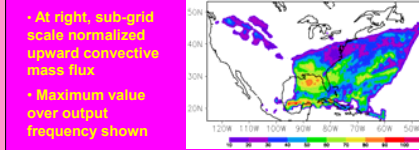


- Cyclone used by Carlson (1980) to define WCB
- 85 Dec 1977
- Minimum central pressure 992 hPa at 12 UTC

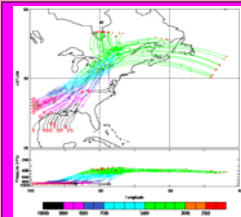
Forward Trajectories and Mass Flux:



- At left, 700 hPa grid scale vertical motion utilized in forward trajectory calculations



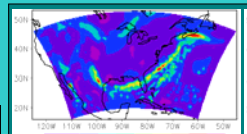
- At right, sub-grid scale normalized upward convective mass flux
- Maximum value over output frequency shown



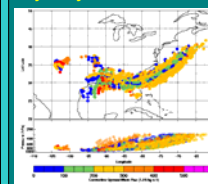
- 2 day forward trajectories starting at 900 hPa, indicating location of Carlson's WCB (1980)
- Largest ascent near cyclone center

4. INTEX-A WCB Case (19 Jul 2004)

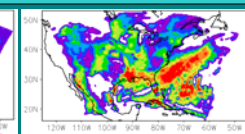
Forward Trajectories and Mass Flux:



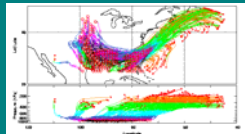
- 700 hPa grid scale vertical motion utilized in forward trajectory calculations



- Sub-grid scale convective upward mass flux (not included in trajectory vertical motion) interpolated to 4-D trajectory locations



- Sub-grid scale normalized upward convective mass flux
- Maximum value over output frequency shown
- Note larger magnitude than Carlson's case



- 2 day forward trajectories starting at 900 hPa, indicating location of possible WCB
- Largest ascent away from cyclone

Radar and Satellite:

17 July 1556 UTC



18 July 1500 UTC

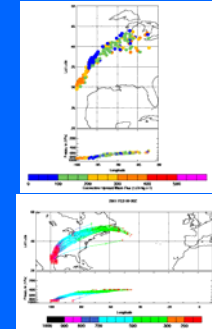


19 July 1845 UTC

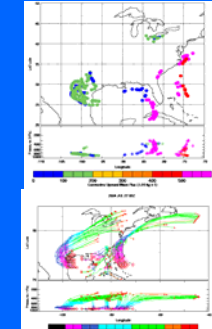


5. Additional WCB Cases:

COOL SEASON



WARM SEASON



- Sub-grid scale convective UMF (top), not included in trajectory vertical motion, interpolated to 4-D trajectory locations. Both cool and warm season 2-day forward trajectories (bottom) are influenced by UMF. Warm season UMF stronger than cool season.

6. Discussion

- Divergence, vorticity, and temperature advection terms (not shown) all support upward vertical transport in Carlson's case
- These patterns are much weaker in warm season than Carlson's
- Sub-grid scale convective UMF occurs throughout the entire year, although UMF is weaker in cool season (Carlson) than warm season
- Sub-grid scale convective UMF found at INTEX-A trajectory locations, but not at Carlson's trajectory locations
- 2 day forward trajectories indicate air lofted from the boundary layer to the free troposphere in all cases

7. Results

- Summertime transport resembles the WCB; however, lofting often takes place very quickly (away from the cyclone) due to convection
- Convection dominates lofting in the summertime
- Classical WCB ascent is gradual and does not rise rapidly until reaching the warm front (near the cyclone)
- Including the strength of the UMF with the summertime trajectories would produce even stronger vertical ascent