The Evolution of Tropical Cyclone Memory in the North Atlantic Basin

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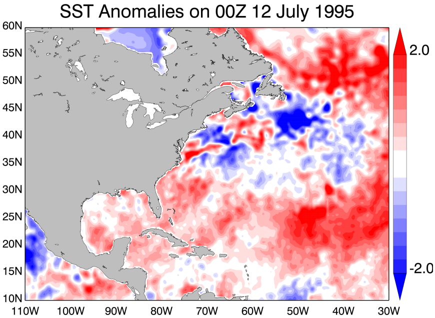
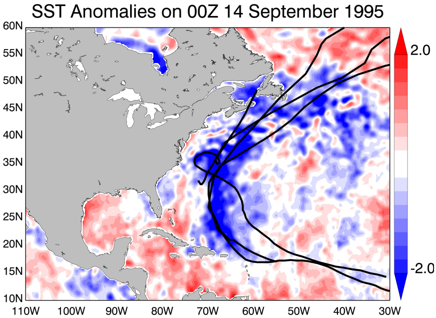
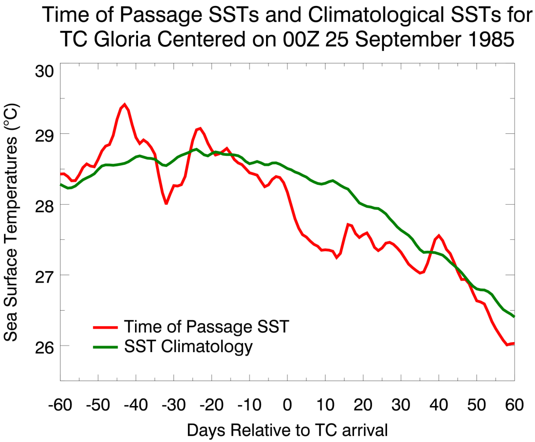
Motivation





- What is the spatial and temporal response of the atmosphere to TC passage?

Quantification of Environmental Response



- Hart et al. (2007) measured the response of the SSTs and the atmosphere to the passage of a TC
- MPI, SST, and 1000–200 hPa thickness anomalies were calculated relative to an **evolving climatology**
- **Anomalies averaged over 5° by 5° box** centered on TC for each best-track (Jarvinen et al., 1984) and ATCF (Chu et al., 2002) datapoint
- Anomalies composited according to intensity for 60 days prior to 60 days after TC

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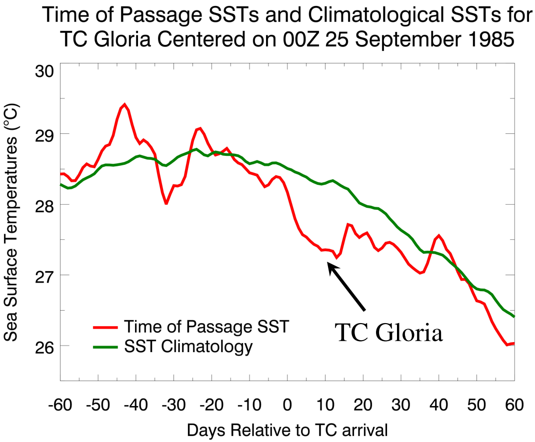

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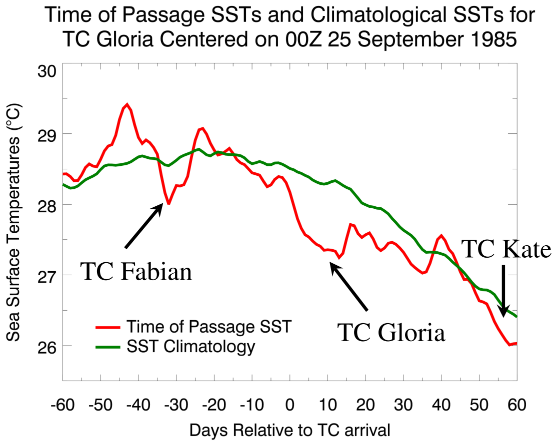

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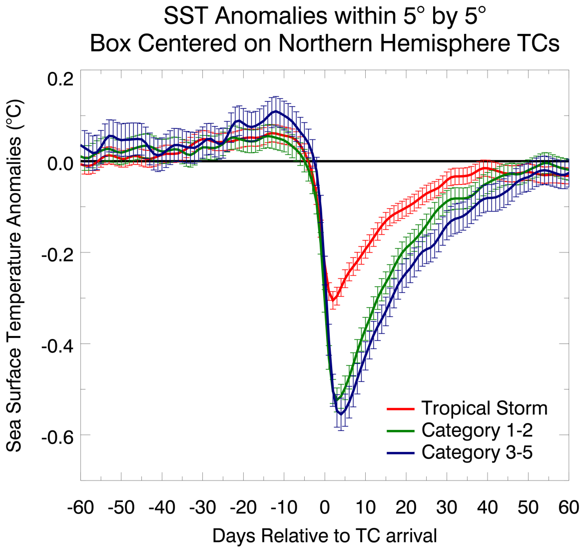
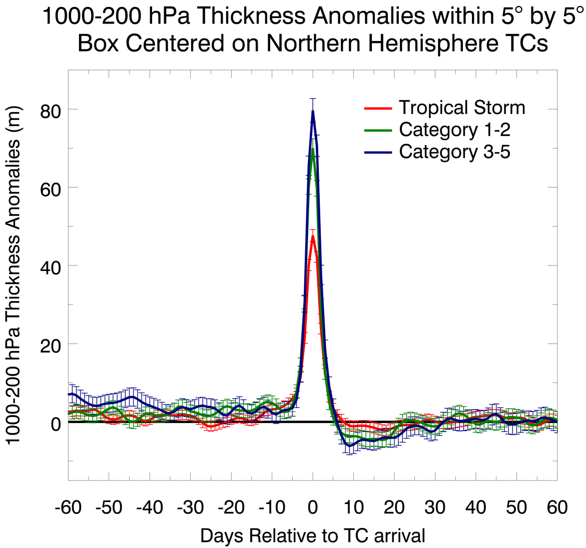
Quantifying TC Induced Cooling of SSTs



Modified from Hart et al. (2007)

- SSTs are warmer relative to climatology prior to TC passage
- Restoration of cold SST anomalies to climatology can take **months to occur**

Quantifying Warming/Drying of the Troposphere by TCs



Modified from Hart et al. (2007)

- Atmosphere is slightly warmer than climatology prior to TC passage
- TC passage causes atmosphere to warm and dry initially and eventually becoming colder than climatology
- Restoration of atmosphere occurs on **much shorter time scales**

Relevant Questions

- How does the **4–D structure** of the environment compare before and after TC passage with respect to an evolving climatology?
- Does the environment retain "memory" of TC passage both spatially and temporally beyond what was indicated by Hart et al. (2007)?
- What is the source of the pre–conditioning?
- What are the relative roles of the large scale processes and the TC?
- **In the interest of time, we will be considering these questions with regards to Category 3–5 TCs in the North Atlantic Basin**

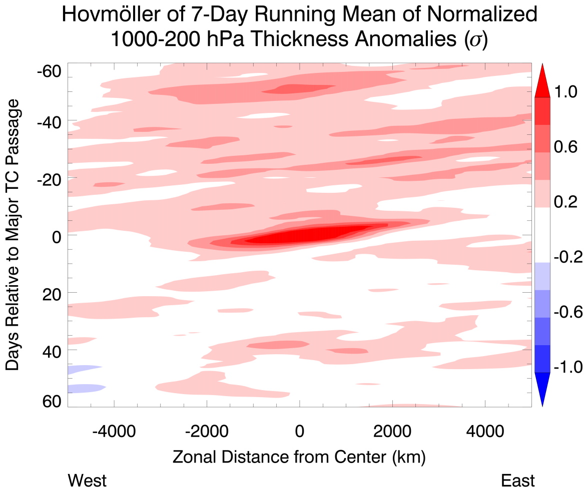
Methodology

- Variables (u, v, ϕ, r, T) used to construct **4–D composites** were obtained from NASA's MERRA reanalysis (Bosilovich et al., 2006)
- Anomalies were computed relative to a daily climatology (1982–2001) and normalized by the standard deviation to provide statistical relevancy:

$$N = \frac{X - \mu}{\sigma} \tag{1}$$

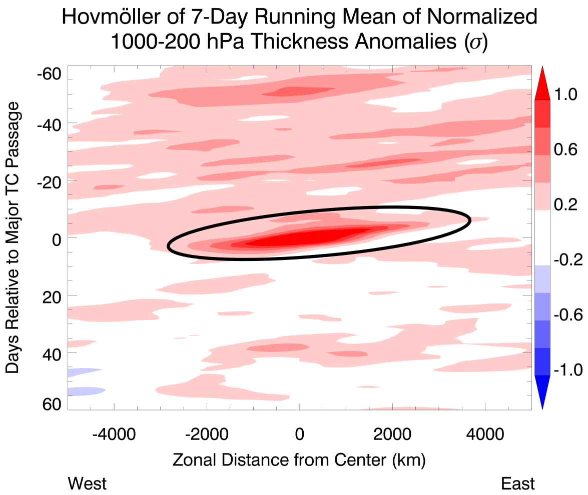
- A 7-day running mean is applied to all fields to reduce noise
- All TCs equatorward of 36°N in the North Atlantic from 1982–2001 appearing in the best-track (Jarvinen et al., 1984) were included in the composites

4–D Structure of Large Scale Anomaly



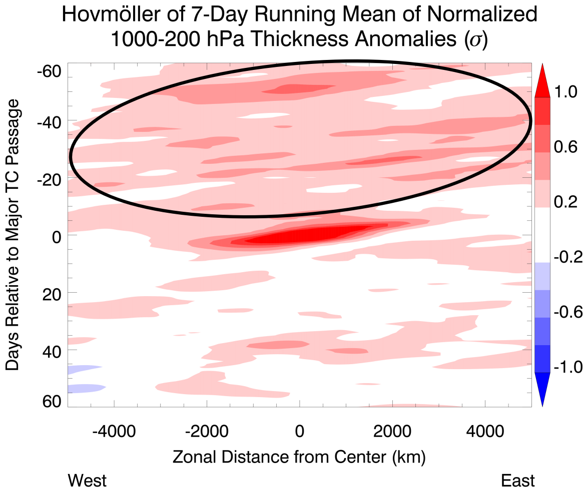
- Hovmöller average of data within 500 km of the TC center in meridional direction

4–D Structure of Large Scale Anomaly



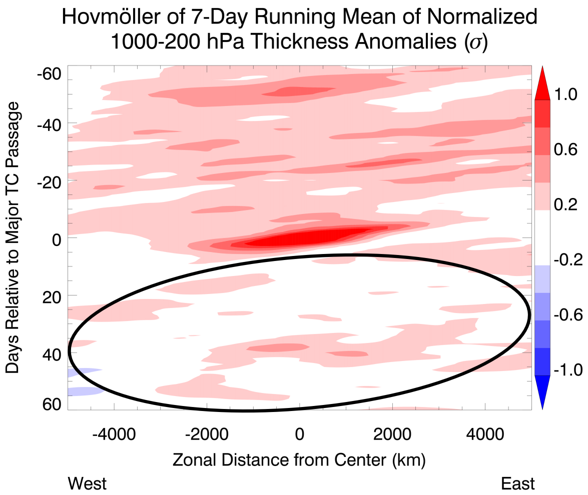
- Hovmöller average of data within 500 km of the TC center in meridional direction
- Largest thickness anomalies associated with passage of TC

4–D Structure of Large Scale Anomaly



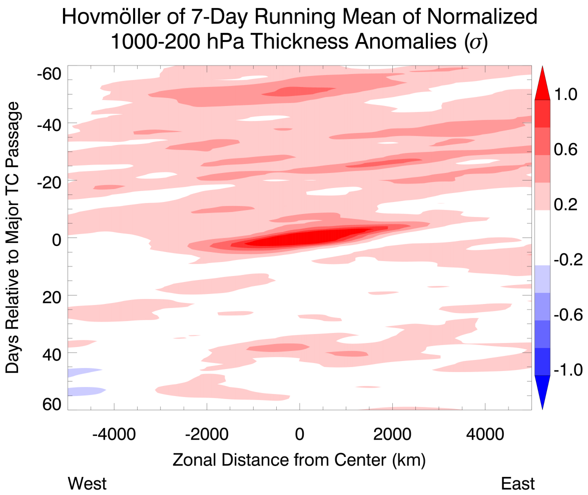
- Hovmöller average of data within 500 km of the TC center in meridional direction
- Largest thickness anomalies associated with passage of TC
- Positive thickness anomalies prior to TC passage due to large scale warming and/or moistening

4–D Structure of Large Scale Anomaly



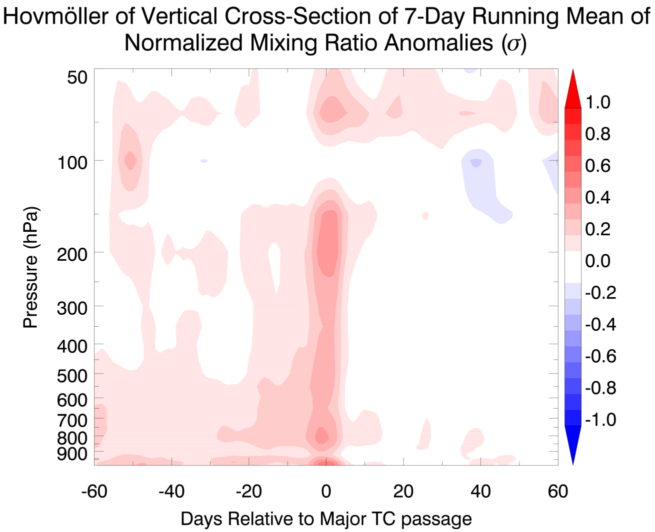
- Return to climatological thickness through **drying** via high precipitation efficiency of TCs (Emanuel, 2008) and **cooling** due to reduction of sensible heat fluxes from ocean

4–D Structure of Large Scale Anomaly



- Return to climatological thickness through **drying** via high precipitation efficiency of TCs (Emanuel, 2008) and **cooling** due to reduction of sensible heat fluxes from ocean
- Aside from date of TC occurrence, TCs occur only 5-10% in the days prior and after Major TC passage suggesting that larger scales are responsible for positive thickness anomalies

Local and Large Scale Forcing of Moisture Anomalies



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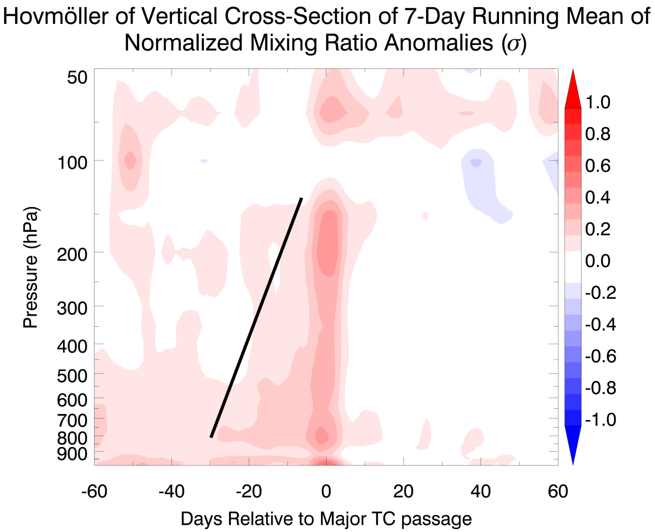

- Anomalies in moisture field deepen in the vertical prior to TC passage

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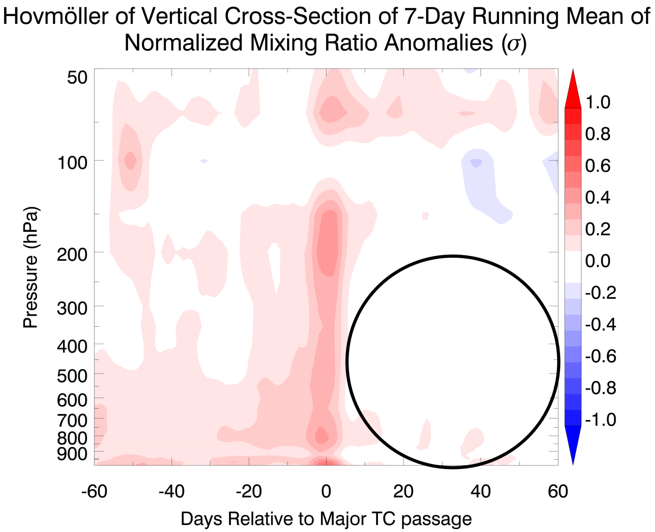

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- Anomalies are removed afterwards

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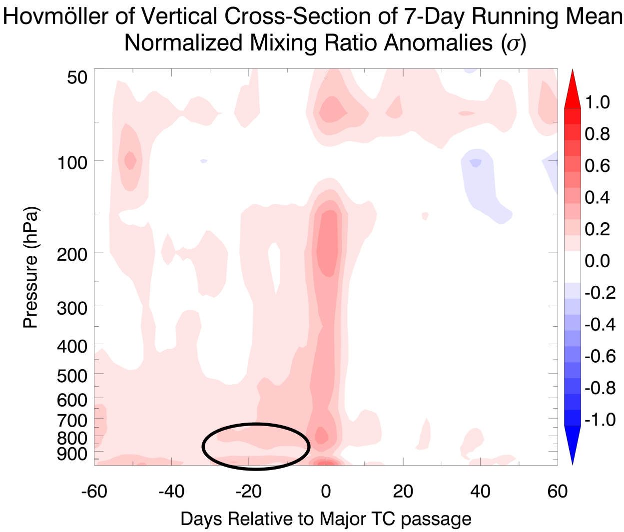
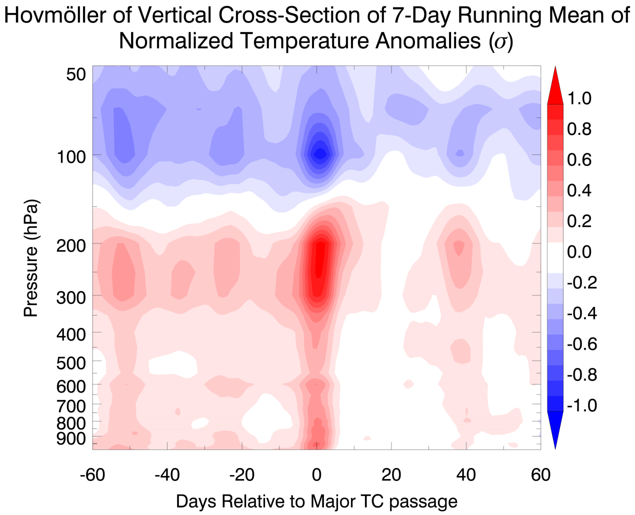


- Anomalies in moisture field deepen in the vertical prior to TC passage
- Anomalies are removed afterwards
- Reversal of anomalous moisture gradient at 900 hPa suggests separation between anomalies forced by SSTs and larger scales

Oscillatory Behavior of Temperature Anomalies



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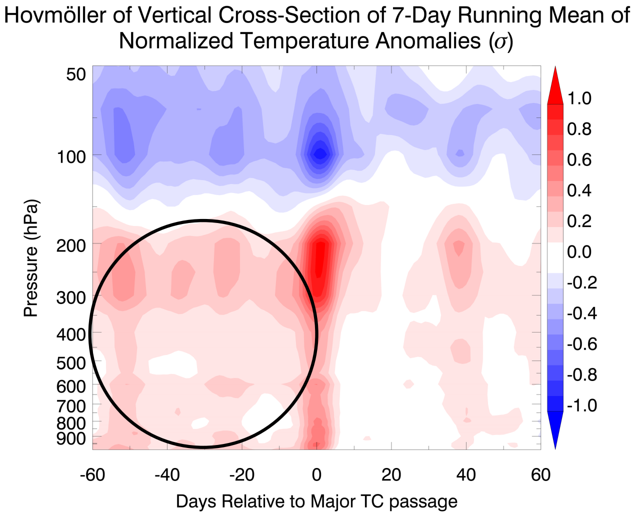
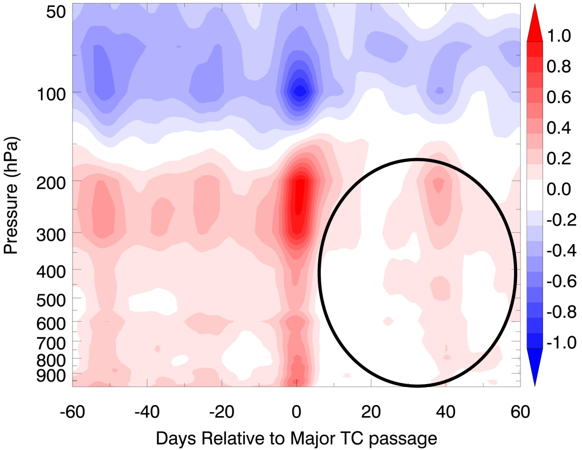


- Troposphere deep warm anomalies occur prior to TC passage

Oscillatory Behavior of Temperature Anomalies

Hovmöller of Vertical Cross-Section of 7-Day Running Mean of Normalized Temperature Anomalies (σ)



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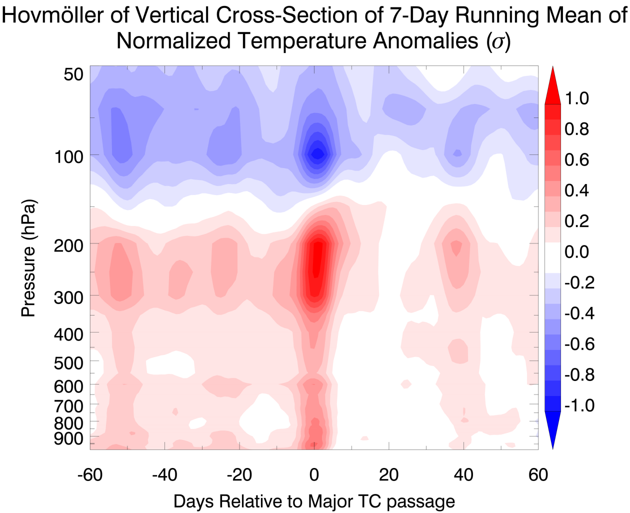
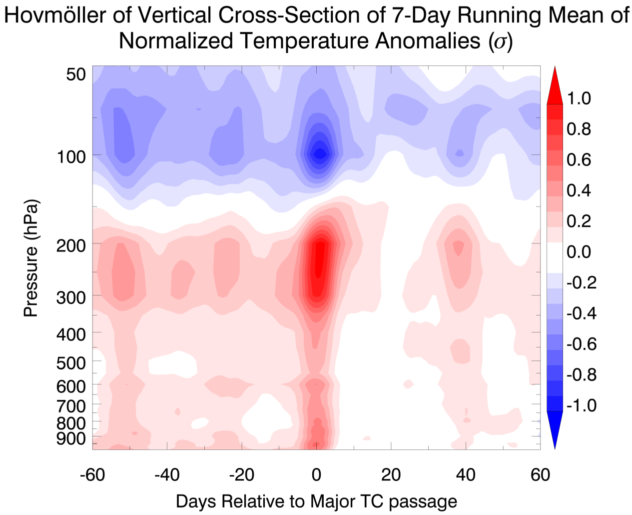


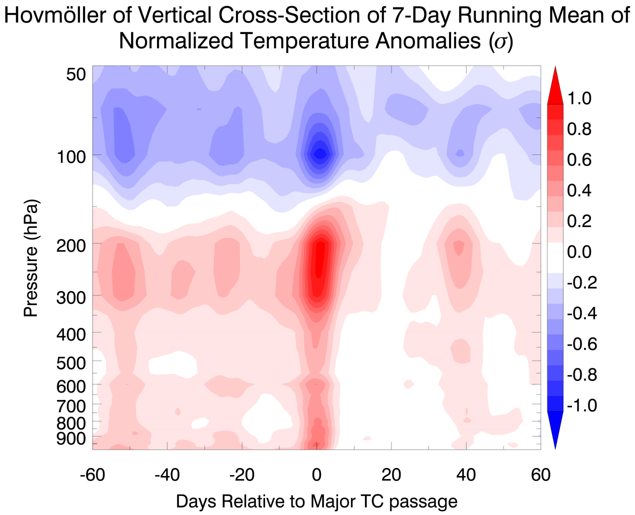
- Troposphere deep warm anomalies occur prior to TC passage
- Positive anomalies are reduced after TC passage
- Warm anomalies in the troposphere and cold anomalies in the stratosphere may be attributable to preference for major TCs to occur over anomalously warm SSTs

Oscillatory Behavior of Temperature Anomalies



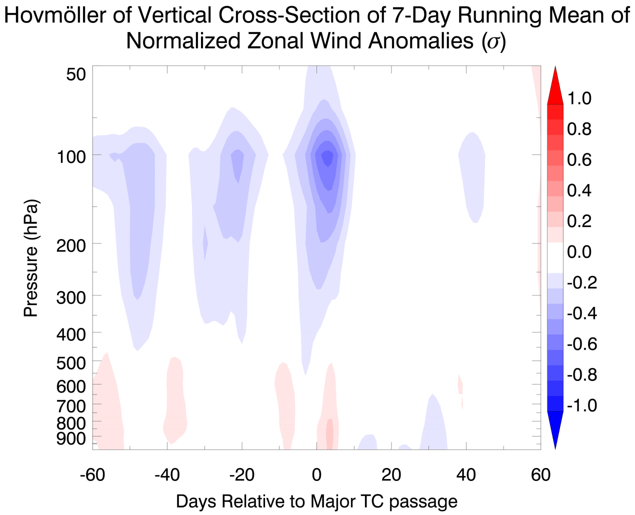
- Combined the thickness, moisture, and temperature anomalies suggest that the drying virtually dominates the warming after TC departure

Oscillatory Behavior of Temperature Anomalies



- Combined the thickness, moisture, and temperature anomalies suggest that the drying virtually dominates the warming after TC departure
- Oscillation present in upper troposphere and lower stratosphere not directly associated with TCs

Relationship Between Large Scales and Major TC Passage?



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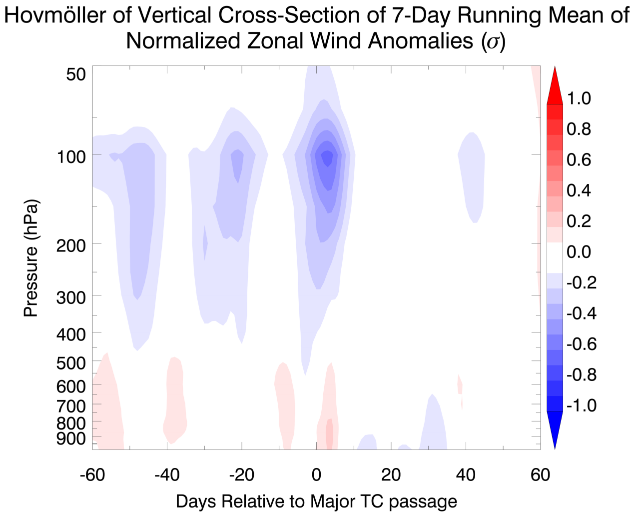

- 20–30 day oscillation present in zonal winds between 50–400 hPa

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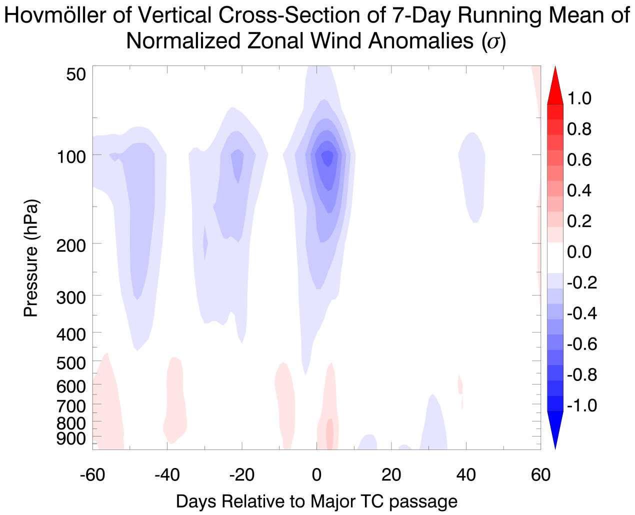

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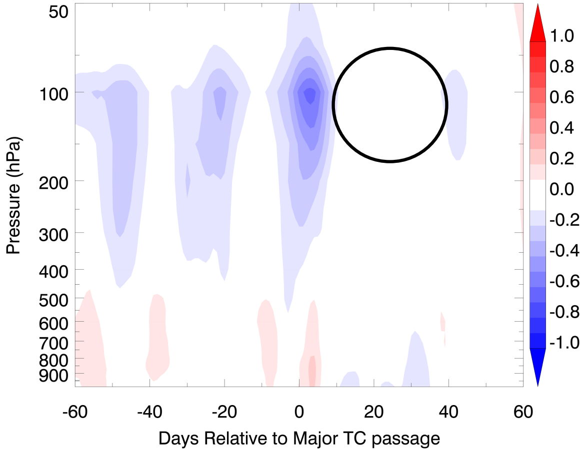
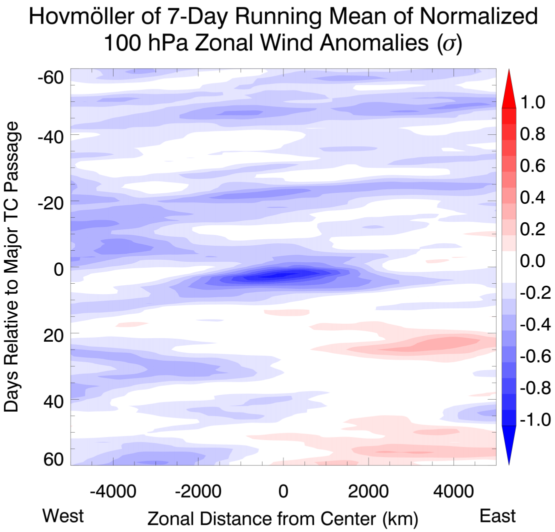


- 20–30 day oscillation present in zonal winds between 50–400 hPa
- Anomalies indicative of the weakening of the subtropical jet
- Absence of zonal wind anomaly at Day 20 may be indicative of feedback between TC and environment

Westward Propagation of Anomalous Zonal Winds



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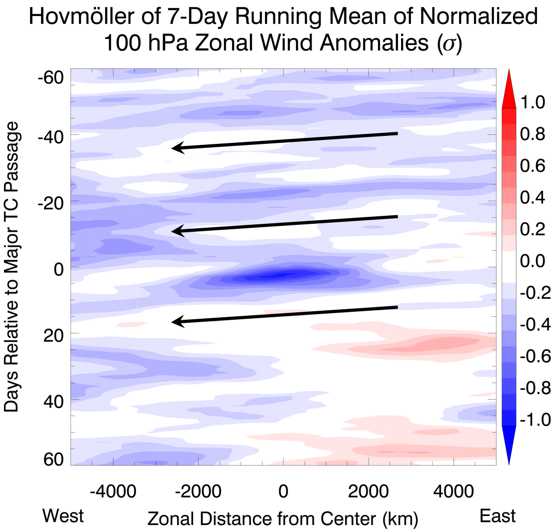

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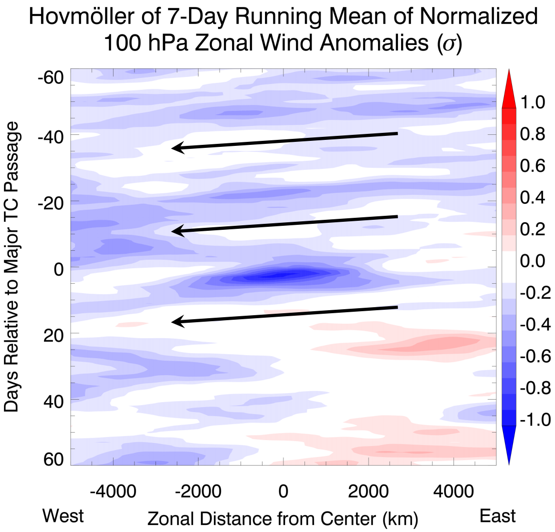


- Westerly phase direction with approximate phase speed of 4–5 m s^{-1}
- Zonal wind anomalies could be attributable to several types of equatorial waves and interactions among them (Frank and Roundy, 2006)

Questions Raised and Future Work

- What fraction of the pre-storm positive thickness anomalies is removed by the TC? by larger scale phenomena?
- Is there a relationship between TC activity and the strength of the Hadley circulation?
- What is the mechanism responsible for the large scale oscillation and do TCs modulate its occurrence?
- How does the response of the environment scale with TC intensity?
- What are the magnitudes of the processes responsible for the departure and restoration of the environment to climatology?
- Are there substantial interbasin differences in the processes involved?
- Poster Presentation Today (P2.111): “The Fidelity of Tropical Cyclone Representation in Atmospheric Reanalysis Datasets”

References

Bosilovich, M., et al., 2006: NASA's Modern Era Retrospective-Analysis for Research and Applications (MERRA). *Geo. Res. Abstracts*, **8**.

Chu, J., C. Sampson, A. Levine, and E. Fukada, 2002: The Joint Typhoon Warning Center Tropical Cyclone Best-Tracks, 1945–2000. *Naval Research Laboratory, Reference Number NRL/MR/7540-02-16*.

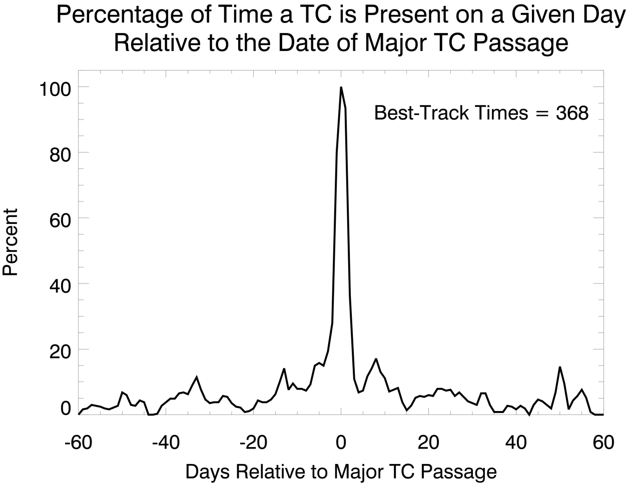
Emanuel, K., 2008: The Hurricane–Climate Connection. *Bull. of the Amer. Meteor. Soc.*, **89**.

Frank, W. and P. Roundy, 2006: The role of tropical waves in tropical cyclogenesis. *Mon. Wea. Rev.*, **134**, 2397–2417.

Hart, R., R. Maue, and M. Watson, 2007: Estimating Local Memory of Tropical Cyclones through MPI Anomaly Evolution. *Mon. Wea. Rev.*, **135**, 3990–4005.

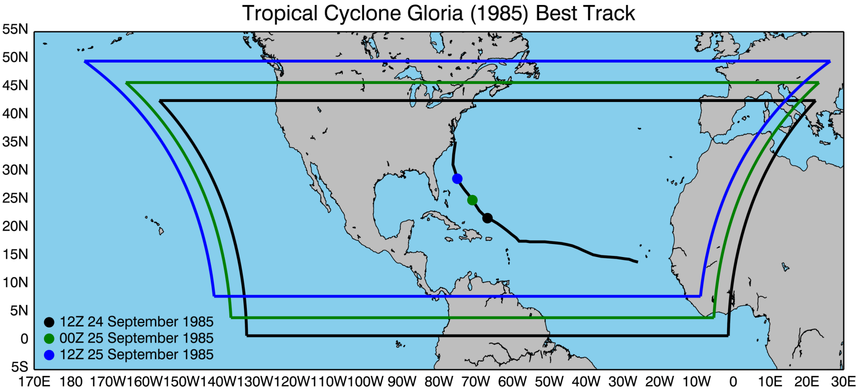
Jarvinen, B., C. Neumann, and M. Davis, 1984: Tropical Cyclone Data Tape for the North Atlantic Basin, 1886–1983: Contents, Limitations and Uses. NOAA Tech. Memorandum NWS NHC 22.

Is Large Scale Anomaly a Proxy for Increased TC Activity?



- TC is present on average in 5-10% of cases for each day
- Anomalous thicknesses do **NOT** appear to be attributable to increased TC activity prior to major TC

Methodology



- Grid with a uniform horizontal resolution (30 km) was constructed for each TC datapoint centered on the storm for 60 days prior to 60 days after TC passage for pressure levels ranging from 1000 hPa to 50 hPa