Refining the Climate Role of Tropical Cyclones: Key Constituents of the Summer Hadley Cell?

Benjamin A. Schenkel[1] (bschenkel@albany.edu), Daniel Keyser[1], Lance F. Bosart[1], and Robert E. Hart[2]
1: University at Albany, State University of New York, 2: The Florida State University

Introduction

- Upper-tropospheric outflow of tropical cyclones (TCs) can extend thousands of kilometers from TC redistributing potential energy and heat (Fig. 1)

- Composites of western North Pacific TCs (WPAC) suggest TC outflow can extend from Northern Hemisphere (NH) tropics into Southern Hemisphere (SH) tropics (Frank 1982)

- Transport of potential energy and heat from NH tropics to SH tropics by upper-tropospheric TC outflow may significantly enhance energy transports by zonal mean meridional circulation during boreal summer and fall

- **Objective:** Determine whether upper-tropospheric TC outflow transports significant quantities of total energy from NH tropics into SH tropics
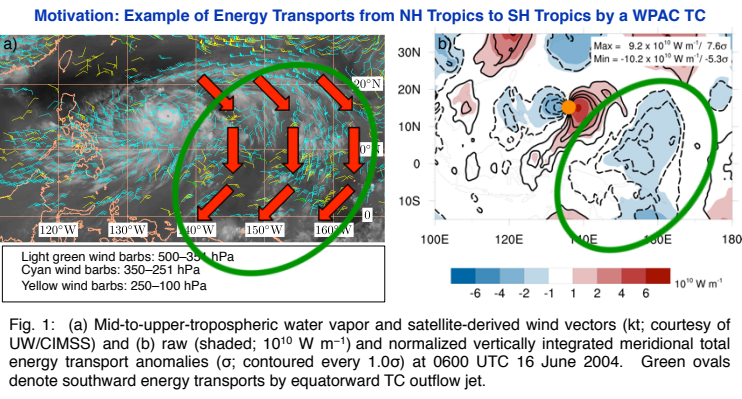
Data and Methods

- **Overview:** Storm-relative composites of meridional total energy transports calculated from reanalyses to quantify transports from NH tropics to SH tropics by WPAC TCs
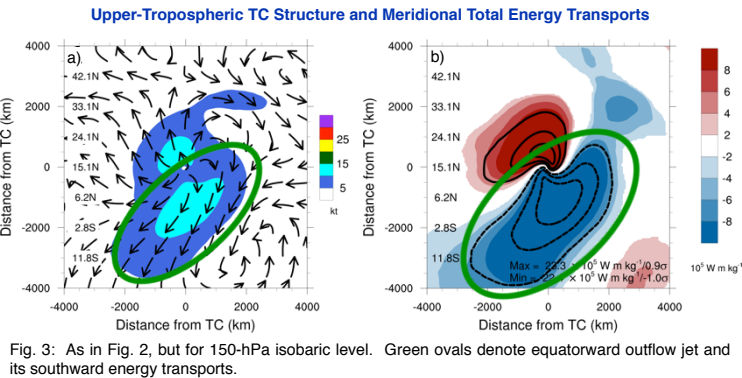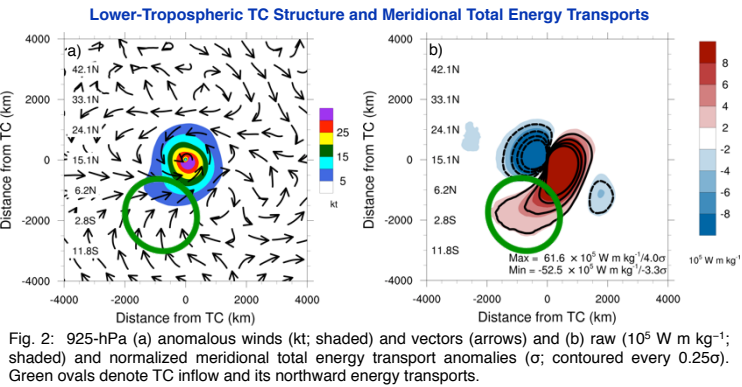
- WPAC TCs (max 10-m wind speed $\geq$ 34 kt) at or equatorward of 20°N from 1979–2010 (N = 694) in JTWC Best-Track (Chu et al. 2002) are examined

- Storm-relative composites of vertically integrated meridional energy transports calculated from 6-h 0.5° NCEP Climate Forecast System Reanalysis (Saha et al. 2010)

- Vertically integrated meridional total energy transports defined as (Trenberth et al. 1997):
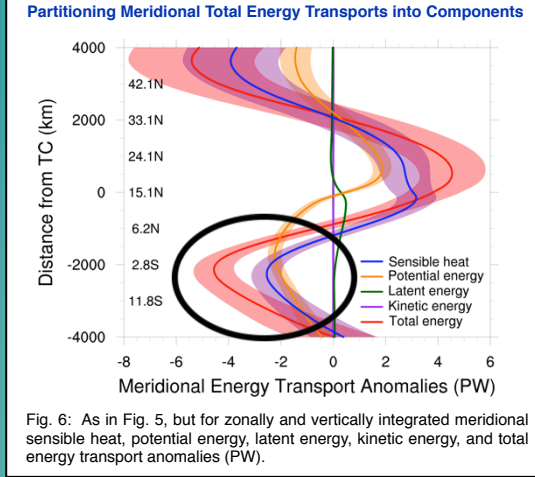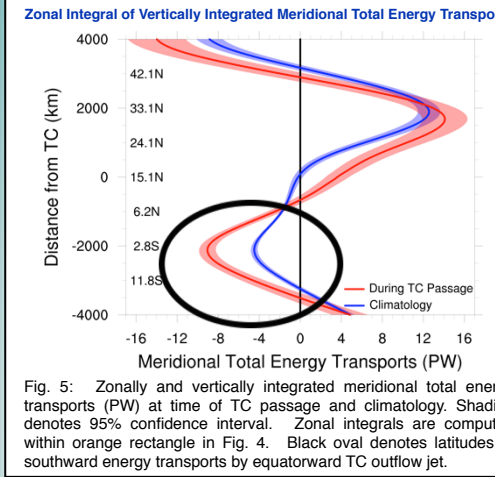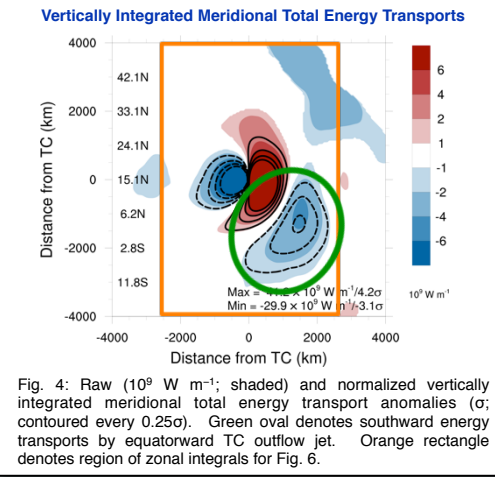
$$\frac{1}{g}\int_{p_t}^{p_s} v\frac{1}{2}(u^2+v^2)dp + \frac{1}{g}\int_{p_t}^{p_s} v(L_v q)dp$$
$$+ \frac{1}{g}\int_{p_t}^{p_s} v(c_p T)dp + \frac{1}{g}\int_{p_t}^{p_s} v(gz)dp$$

Horizontal Structure of Meridional Total Energy Transports by TCs in Lower and Upper Troposphere
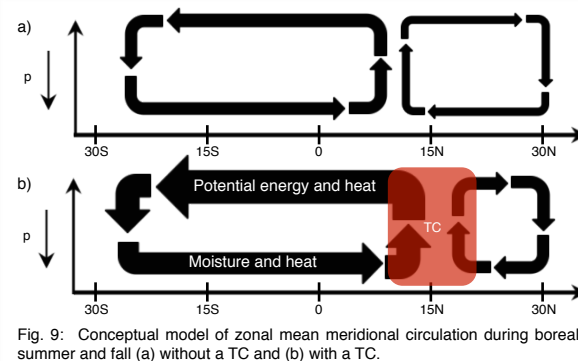
Motivation: Example of Energy Transports from NH Tropics to SH Tropics by a WPAC TC

Fig. 1: (a) Mid-to-upper-tropospheric water vapor and satellite-derived wind vectors (kt; courtesy of UW/CIMSS) and (b) raw (shaded; 10^{10} W m^{-1}) and normalized vertically integrated meridional total energy transport anomalies (σ; contoured every 1.0σ) at 0600 UTC 16 June 2004. Green ovals denote southward energy transports by equatorward TC outflow jet.

Light green wind barbs: 500–351 hPa
Cyan wind barbs: 350–251 hPa
Yellow wind barbs: 250–100 hPa

Lower-Tropospheric TC Structure and Meridional Total Energy Transports

Fig. 2: 925-hPa (a) anomalous winds (kt; shaded) and vectors (arrows) and (b) raw (10^5 W m kg^{-1}; shaded) and normalized meridional total energy transport anomalies (σ; contoured every 0.25σ). Green ovals denote TC inflow and its northward energy transports.

Upper-Tropospheric TC Structure and Meridional Total Energy Transports

Fig. 3: As in Fig. 2, but for 150-hPa isobaric level. Green ovals denote equatorward outflow jet and its southward energy transports.

Horizontal Structure of Vertically Integrated Meridional Energy Transports by TCs

Vertically Integrated Meridional Total Energy Transports

Fig. 4: Raw (10^9 W m^{-1}; shaded) and normalized vertically integrated meridional total energy transport anomalies (σ; contoured every 0.25σ). Green oval denotes southward energy transports by equatorward TC outflow jet. Orange rectangle denotes region of zonal integrals for Fig. 6.

Zonal Integral of Vertically Integrated Meridional Total Energy Transports

Fig. 5: Zonally and vertically integrated meridional total energy transports (PW) at time of TC passage and climatology. Shading denotes 95% confidence interval. Zonal integrals are computed within orange rectangle in Fig. 4. Black oval denotes latitudes of southward energy transports by equatorward TC outflow jet.

Partitioning Meridional Total Energy Transports into Components

Fig. 6: As in Fig. 5, but for zonally and vertically integrated meridional sensible heat, potential energy, latent energy, kinetic energy, and total energy transport anomalies (PW).

Meridional Total Energy Transports by TCs in a Global Context

Vertically Integrated Meridional Total Energy Transports in Global Domain

Fig. 7: As in in Fig. 4, but for alternative set of composites centered upon TC only in zonal direction. Orange rectangle denotes region of zonal integrals for Fig. 9.

Zonal Integral of Meridional Total Energy Transports in Global Domain

Fig. 8: Vertically integrated meridional total energy transport anomalies (PW) integrated in region surrounding TC (within orange rectangle in Fig. 7), environment outside TC (outside orange rectangle in Fig. 7), and all longitudes (all longitudes in Fig. 7). Black oval denotes latitudes of southward energy transports by equatorward TC outflow jet.

Summary: A Conceptual Model

Fig. 9: Conceptual model of zonal mean meridional circulation during boreal summer and fall (a) without a TC and (b) with a TC.

Discussion

- Northward energy transports in lower troposphere at equator due to inflow of TC (Fig. 2)

- Southward energy transports in upper troposphere at equator due to equatorward TC outflow jet (Fig. 3)

- Southward energy transports by equatorward TC outflow jet is only source of significant vertically integrated transports at equator (Fig. 4)

- Equatorward TC outflow jet significantly enhances southward energy transports from NH tropics into SH tropics by zonal mean meridional circulation (Fig. 5) with transports primarily consisting of potential energy and heat (Fig. 6)

- Global composite domain reveals southward transports by equatorward TC outflow jet is only source of significant vertically integrated transports at equator (Fig. 7)

- Southward transport by equatorward TC outflow jet yields −0.5 PW transport anomalies at equator for zonal integrals calculated across entire globe (Fig. 8)

- Southward transport anomalies of −0.5 PW by TC (Fig. 8) are ~25% to ~50% of climatological southward transports at equator during August and September

- **Summary:** TCs enhance zonal mean meridional transports at equator through significant southward upper-tropospheric transports of heat and potential energy by equatorward TC outflow jet (Fig. 9)