Sensitivity of the downstream impact to the eddy kinetic energy budget of transitioning tropical cyclones

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**Motivation**

**ET Event may impact predictability in downstream regions**

**ECMWF EPS Forecast during Typhoon Choi-Wan (2009)**

Improve predictability during ET events:

→ Better understand processes involved in interaction

- Detailed description of distinct processes
- Impact of interaction on dynamics and predictability
- Respective contributions of midlatitudes and TC
Amplification of downstream midlatitude flow?

➔ Downstream Baroclinic Development paradigm (Orlanski & Sheldon, 1995)

Eddy kinetic energy ($K_e$): Waves and Cyclones: Downstream propagation:

Deviations from monthly mean  Maxima of $K_e$  Steered by $K_e$ fluxes

Harr & Dea (2009):

Transitioning TC may act as additional source of $K_e$, enforcing an amplification of the midlatitude wave pattern
Examine several forecast scenarios for same ET event

Previous study was based on analysis data:

➔ Only hypothesize about other possible developments

Here: Apply analysis method to ECMWF EPS

Investigate different development scenarios for the same transitioning TC

Identify processes that cause the distinct developments
**Cases to study**

**Hurricane Hanna**
August 28 – September 08, 2008
- ET along coast of North America
- Slight reintensification
- Modification of midlatitude flow
  ➔ Formation of cut-off low in Mediterranean
  Reduced predictability over Europe

(Details are provided in Grams et al, 2011)

**Typhoon Choi-Wan**
September 12 – September 20, 2009
- Reached Super-Typhoon intensity
- Interaction with extratropical wave
- Strong reintensification
- Amplified midlatitude Rossby wave train
  ➔ High impact weather in North America

(See Poster 1181, Keller & Grams)
Approach

➔ Identify dominant forecast scenarios

➔ Investigate $K_e$ budget for forecast scenarios

➔ Confirm findings by using entire EPS
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  EOF- and Cluster Analysis (Talk SCI-PS 244.03)

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➔ Confirm findings by using entire EPS
Resulting Scenarios

**Hurricane Hanna:**
Two scenarios
Differences in
- Short-wave trough
- Hanna's intensity

**Typhoon Choi-Wan:**
Four scenarios
Differences in
- Phasing with trough
- Position and interaction with frontal wave

= Resembles Analysis
Approach

➔ Identify dominant forecast scenarios
   EOF- and Cluster Analysis (Talk SCI-PS 244.03)

➔ Investigate $K_e$ budget for forecast scenarios

➔ Confirm findings by using entire EPS
Examine Tendencies for Eddy Kinetic Energy ($K_e$)

Vertically integrated $K_e$ budget highlights downstream propagation

- $K_e$ maxima at trough and ridge flanks
- Budget terms indicate accumulation or dispersion of $K_e$

→ Transitioning storm can provide additional $K_e$ to sustain upstream maxima

Vertically integrated $K_e$ budget is affected by:

$$\frac{\partial K_e}{\partial t} = -\nabla_p \cdot (v'_a \phi') - \omega' \alpha' - \nabla_p \cdot (vK_e) + \text{residue}$$

- $K_e$ Tendency
- Convergence of ageostrophic geopotential flux
- Baroclinic conversion
- Convergence of advective flux
Results Typhoon Choi-Wan

Meridional wind
300 hPa (m/s)

- Storm > 30°N
- Storm < 30°N
- Extratropical

Baroclinic Conversion
(cont., every 50 W/m²)

Eddy kinetic energy
(shaded, J/m²)

Divergence of Ageostrophic Geopotential flux
(cont., every 50 W/m²)
Typhoon Choi-Wan:

Phasing between Choi-Wan (CW), midlatitude trough and frontal wave determines outcome:

- CW ahead of trough, close to frontal wave:
  Strong generation and downstream dispersion of $K_e$

- CW further away from frontal wave:
  Some dispersion into frontal wave, weak support toward downstream midlatitude wave train

- CW in ridge:
  Generation of $K_e$ not before trough approaches storm.
  Support of second downstream wave train

Sensitivity of midlatitude flow to interaction with a TC seems to be restricted to a short period of time (~ 2 days)

Plots inspired by: Lisa-Ann Quandt
Scenario I, ave. 40-60°N

Eddy Kinetic Energy (shaded, J/m²)
Baroclinic Conversion (cont., every 50 W/m²)

Scenario II, ave. 40-60°N

Eddy Kinetic Energy (shaded, J/m²)
Divergence of Ageo.
Geopotential Flux (cont., every 50 W/m²)

Results Hurricane Hanna
Hurricane Hanna:

Duration of baroclinic conversion and downstream dispersion:

- Stronger at the beginning of ET:
  Generation and dispersion ceases to exist before remnants of storm approach weak short-wave trough

- Stronger at later phases of the ET:
  Generation and dispersion continues until remnants interact with shortwave trough → reintensification

Keller, Jones and Harr, 2014, Mon. Wea. Rev. 142, August Issue, pp.2751–2771
Approach

➔ Identify dominant forecast scenarios
  EOF- and Cluster Analysis (Talk SCI-PS 244.03)

➔ Investigate $K_e$ budget for forecast scenarios

➔ Confirm findings by using entire EPS
Ensemble Sensitivity Analysis of ECMWF EPS $K_e$ budget

Ensemble Sensitivity Analysis

\[ \frac{\partial J}{\partial x} = \frac{\text{cov}(J, x)}{\text{var}(x)} \]

Regression between forecast metric $J$ and state variable $x$ (Torn & Hakim, 2008)

**Basic Idea:** Small variances in $x$ are related to changes in $J$ under the assumption of linear error growth

- Confirm findings from scenarios
- Elucidate relative role of transitioning TC and upstream midlatitudes in amplification of downstream wave train

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- Ryan Torn for valuable discussions about the results!
How to define amplification of downstream wave train?

- Identify downstream $K_e$ maximum as object
  - Forecast metric $J$: Upper 5% of $K_e$ values (- Angle of $K_e$ maximum) at specific forecast time
  - State variable $x$: Ke budget terms in upstream regions 12-48 h before time of metric
Sensitivity Results

Typhoon Choi-Wan
12 hr before metric time

Hurricane Hanna
12 hr before metric time

- Baroclinic conv.

How to read:
Ke changes as indicated when budget term is enhanced by one standard deviation
### Summary Sensitivity Study

**Choi-Wan:**
- Northeastward shift of cyclone
  - → Enhanced Ke in downstream wave when Choi-Wan is at more NE-ward position
- Position and strength of baroclinic zone / frontal wave
- Just weak signals from upstream regions

**Hanna**
- Baroclinic conversion within Hanna during ET
- Important contribution from upstream regions

### Open questions:
- Impact of stochastic perturbations on sensitivity results?
- Role of frontal wave in Choi-Wan case?
- Impact on midlatitude predictability?
An eddy kinetic energy perspective on the downstream impact of tropical cyclones undergoing extratropical transition

**Approach**

- Analysis of $K_e$ budget for ECMWF EPS forecasts
  - $K_e$ budget for several forecast scenarios
  - Confirm findings with entire ensemble and identify role of TC and midlatitudes using ensemble sensitivity analysis

**Results**

- Phasing between storm and midlatitude flow features is crucial
- Duration of $K_e$ release and its impact on midlatitude flow important
- Minor role of upstream midlatitudes in the case of Choi-Wan, stronger impact in case of Hurricane Hanna


