The downstream impact of extratropical transition from an eddy kinetic energy perspective

DFG-FOR 896

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PANDOWAE

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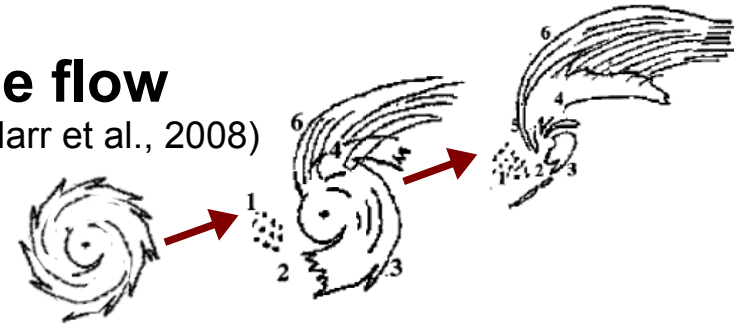

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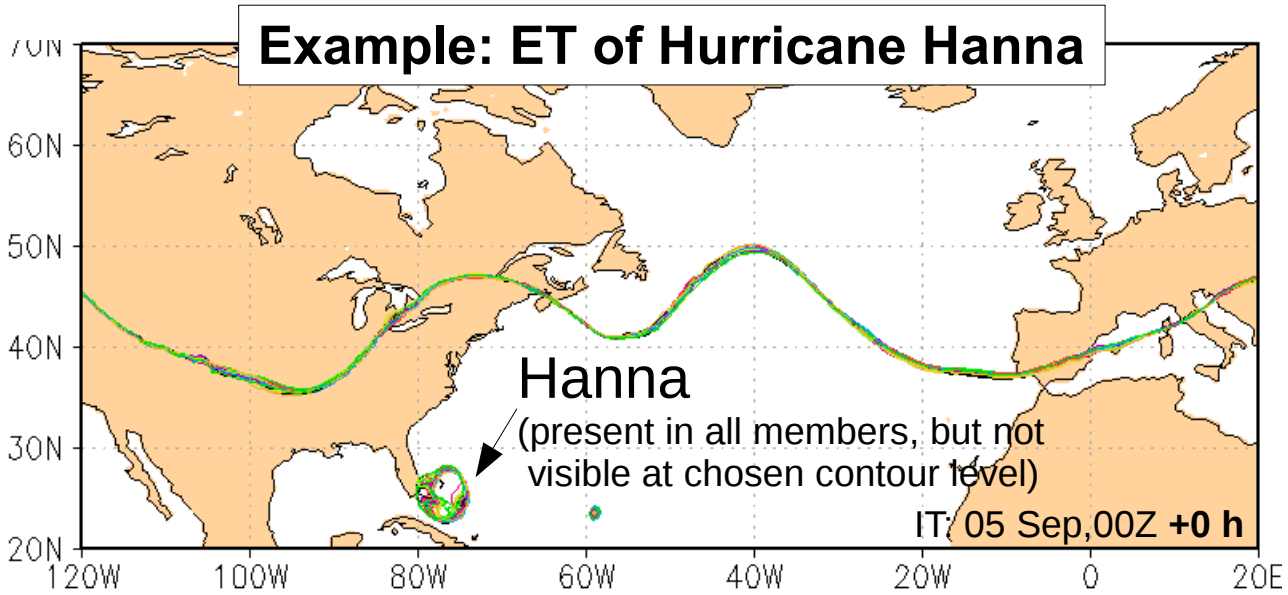

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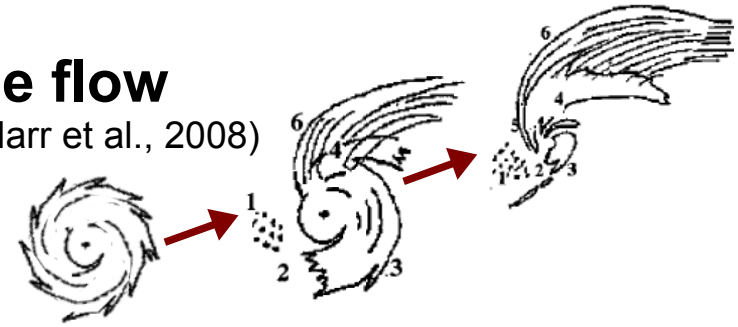

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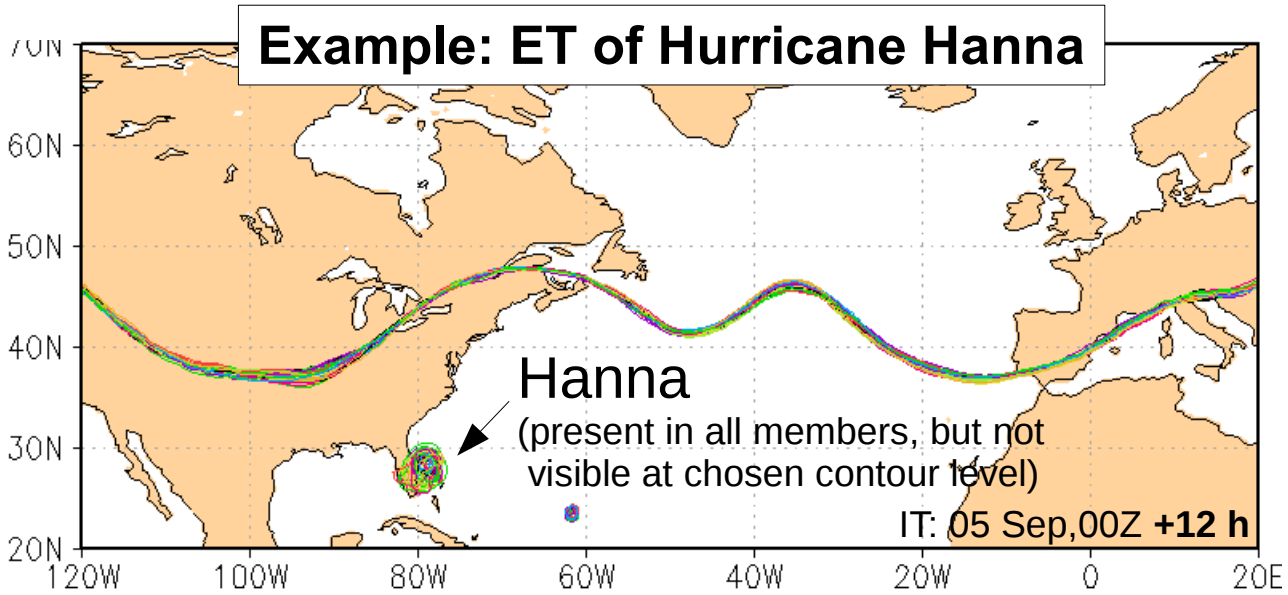

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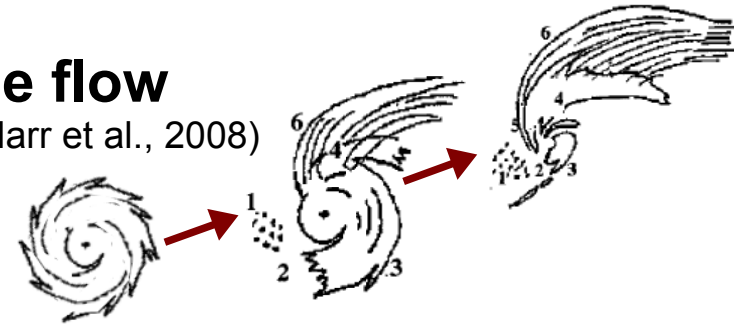

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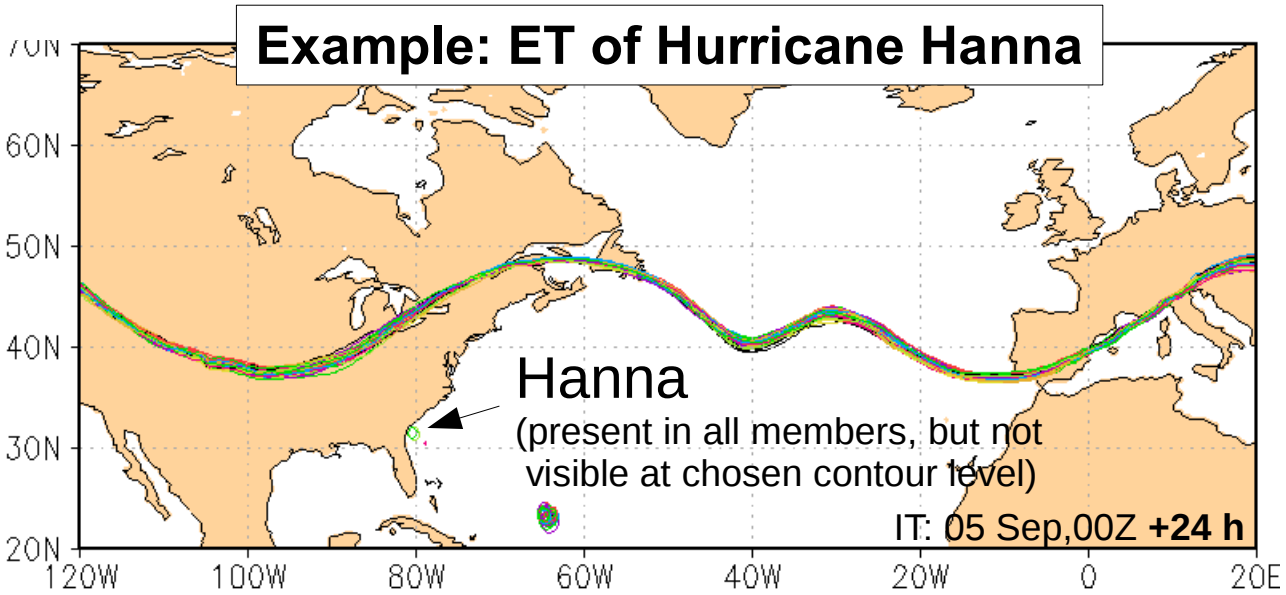

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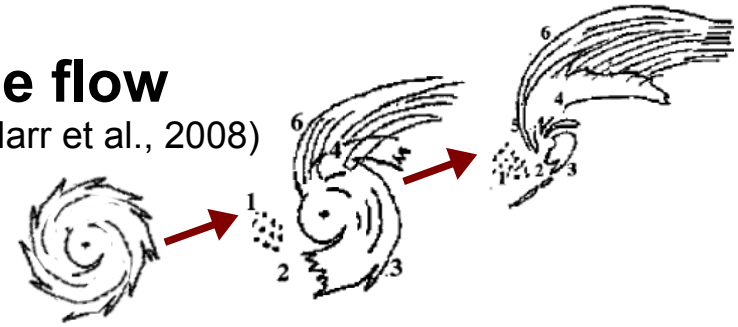

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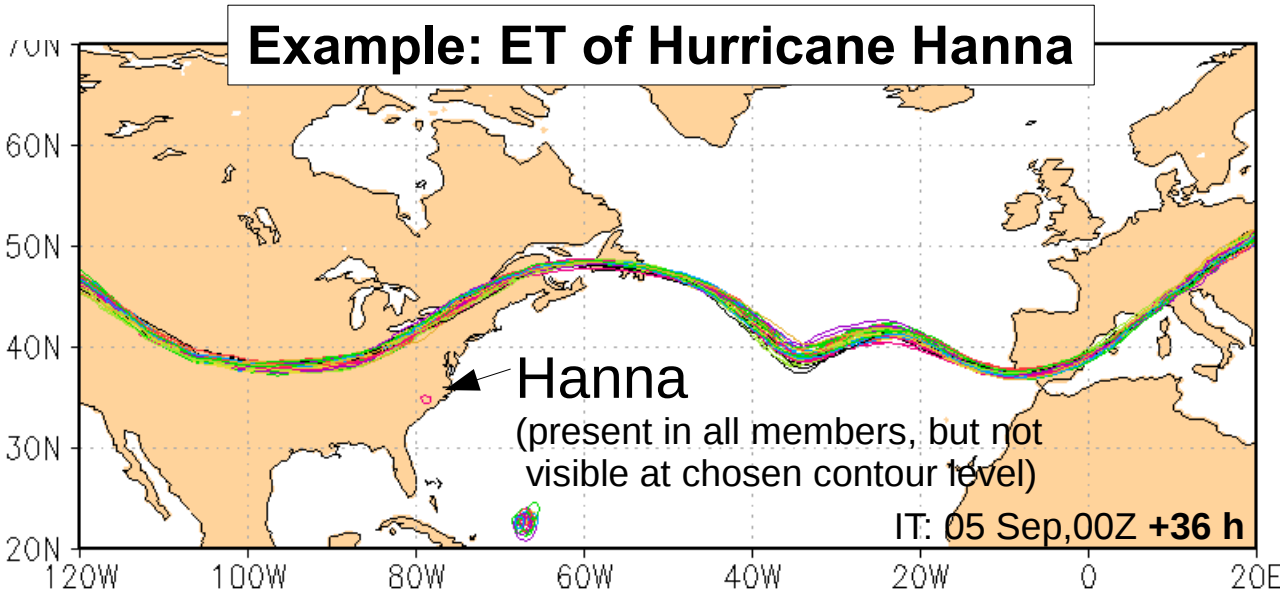

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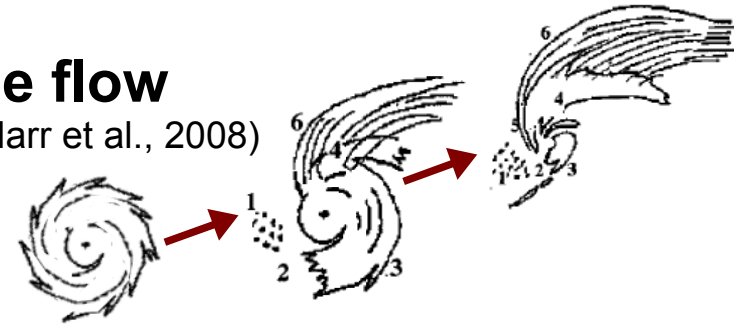

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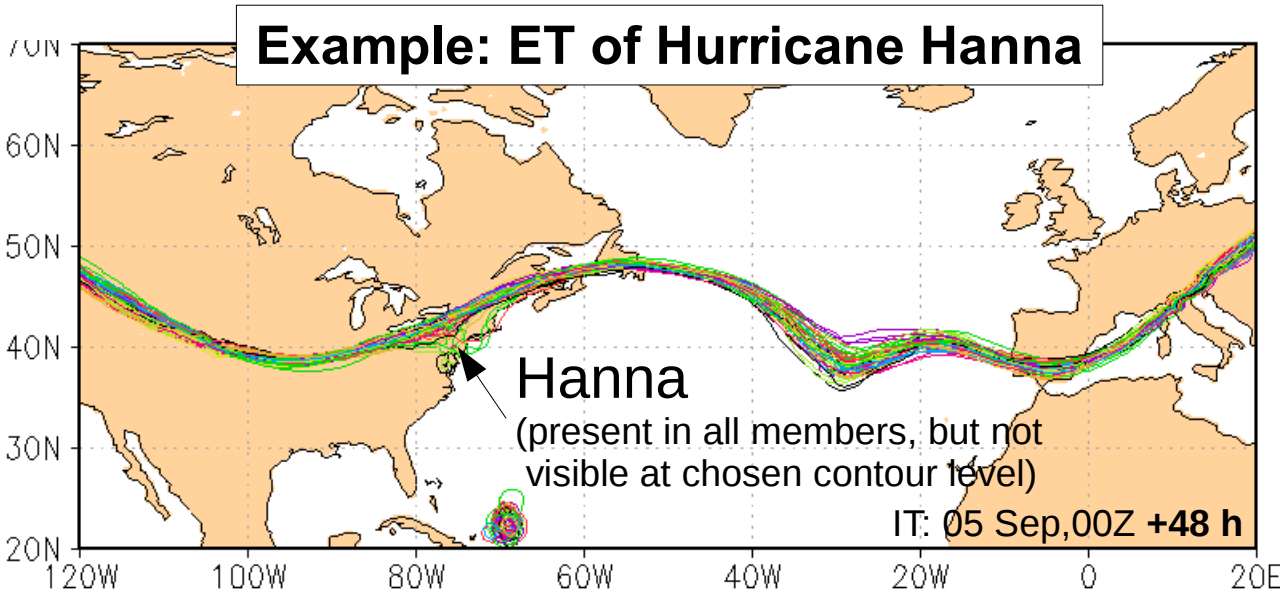

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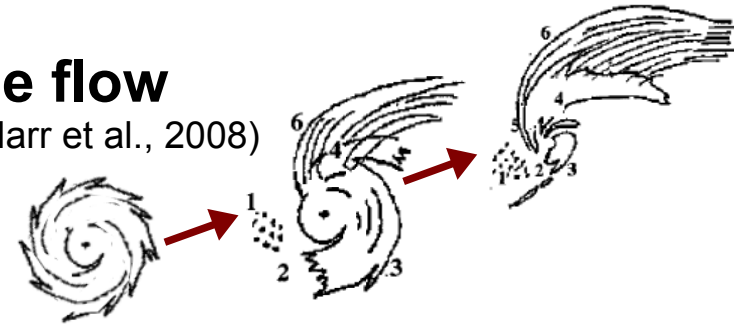

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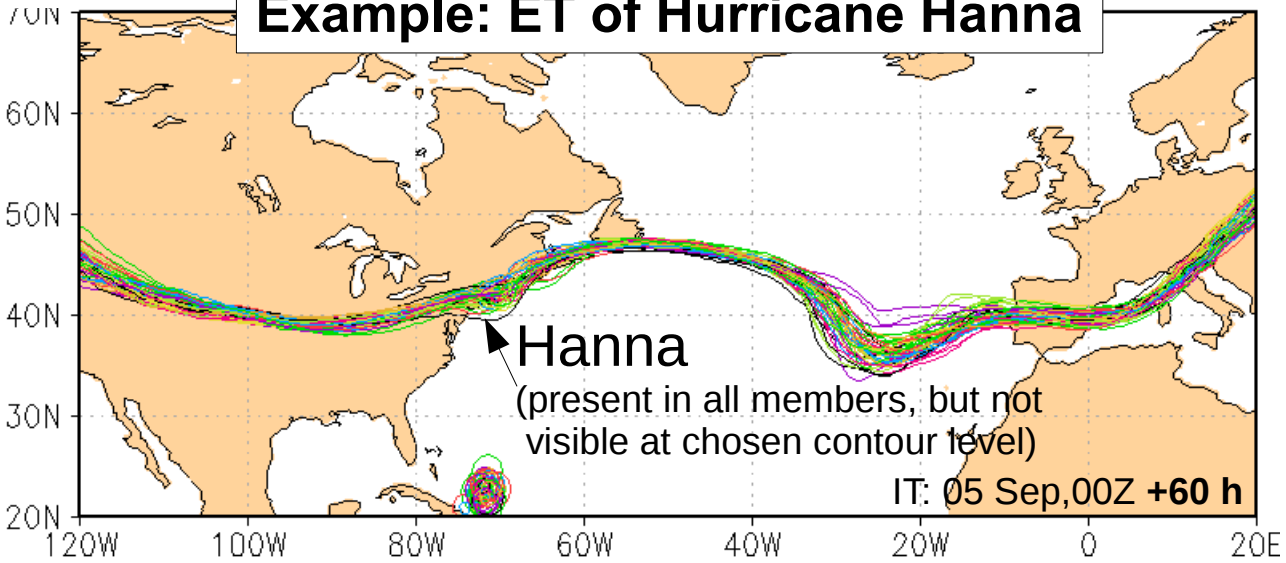
Example: ET of Hurricane Hanna



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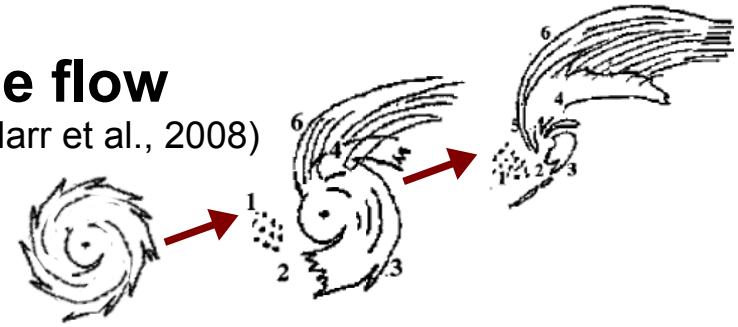

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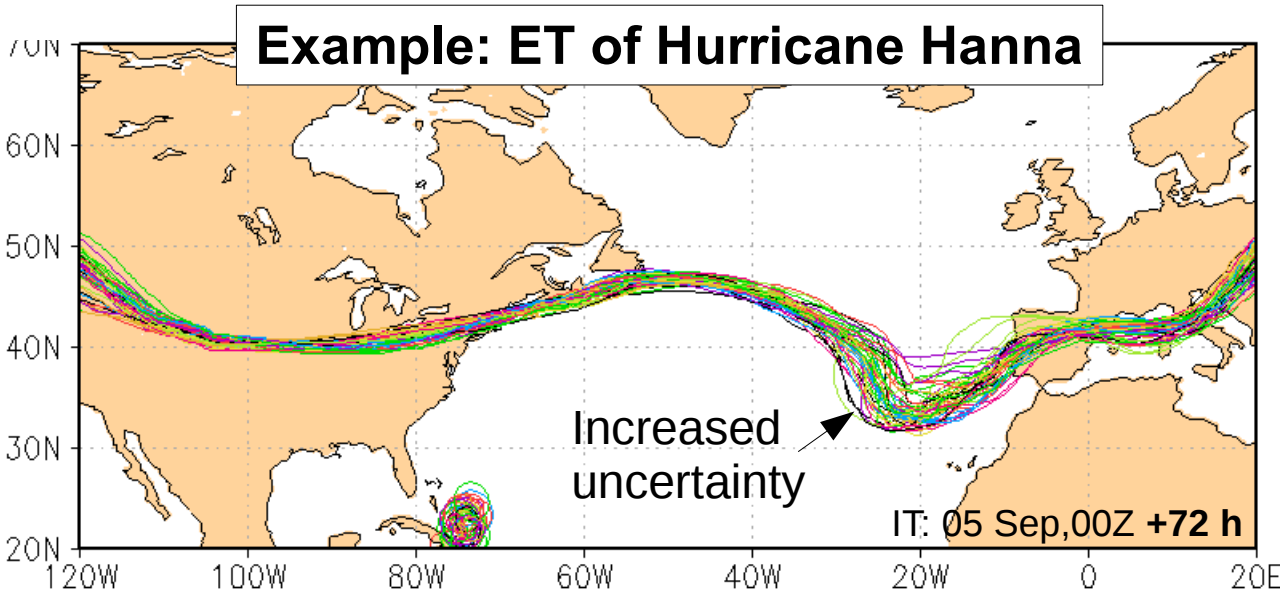

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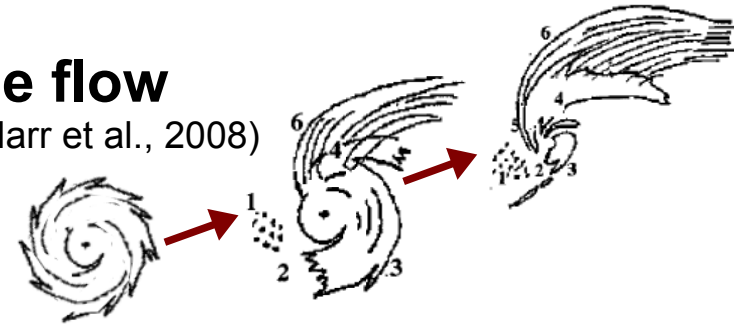

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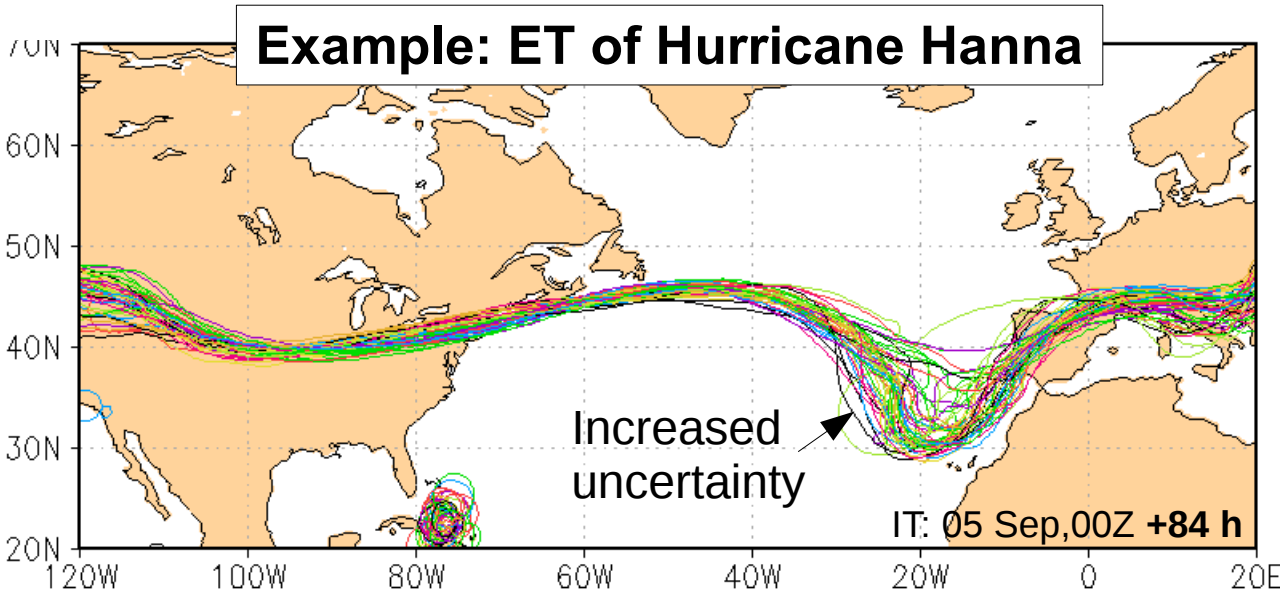

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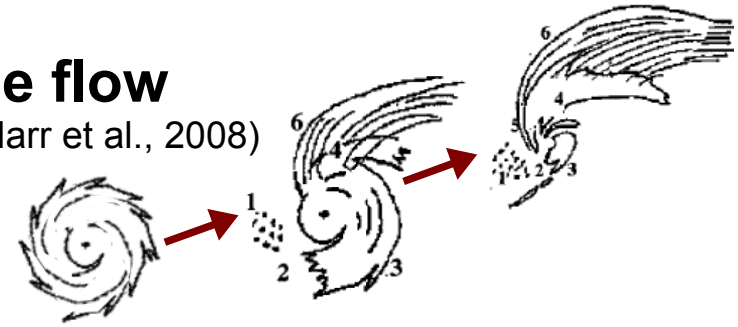

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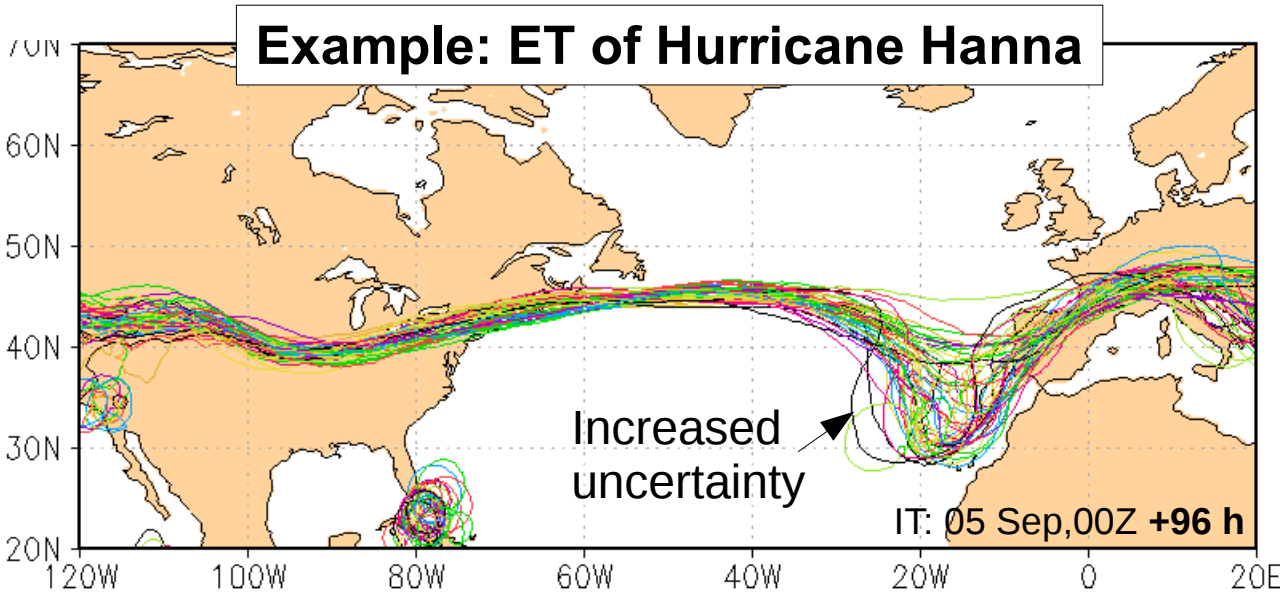

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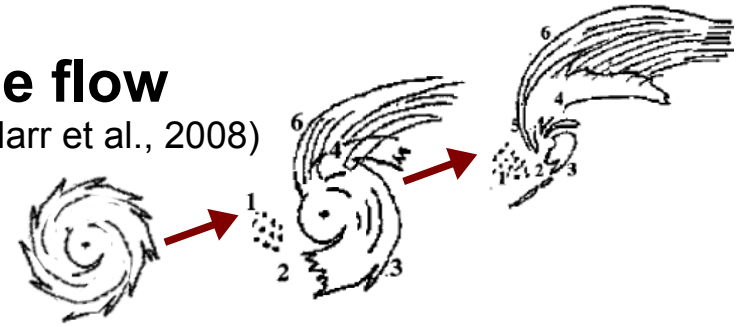

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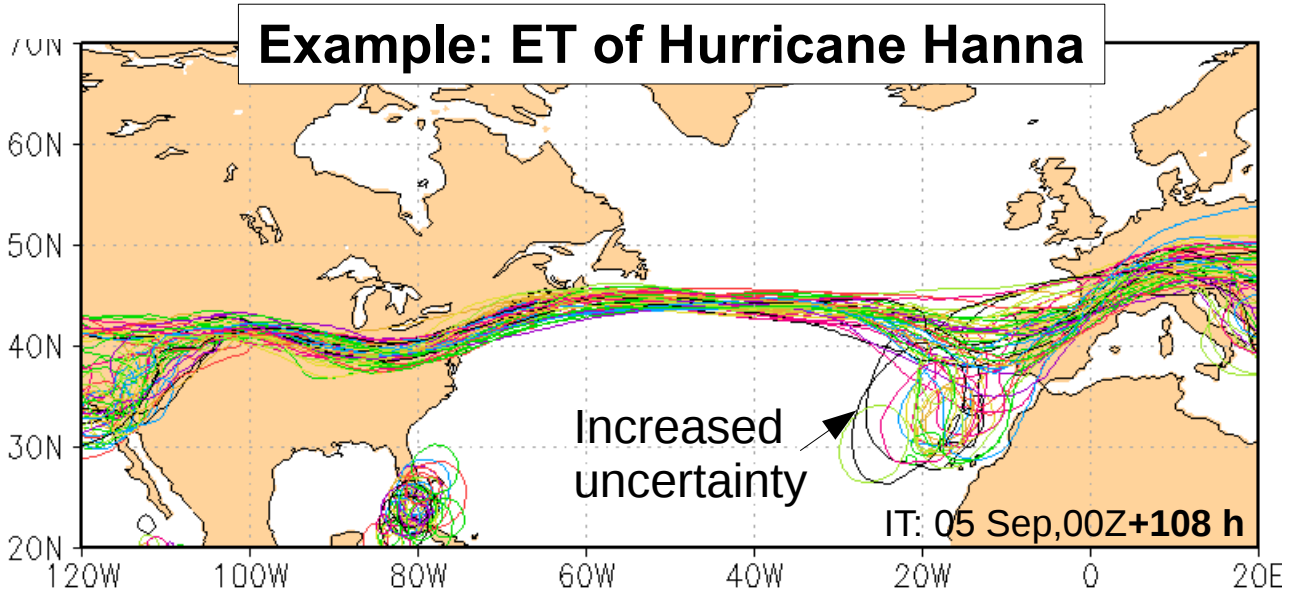

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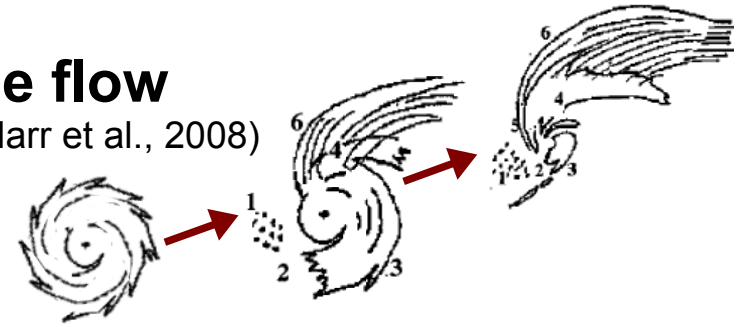

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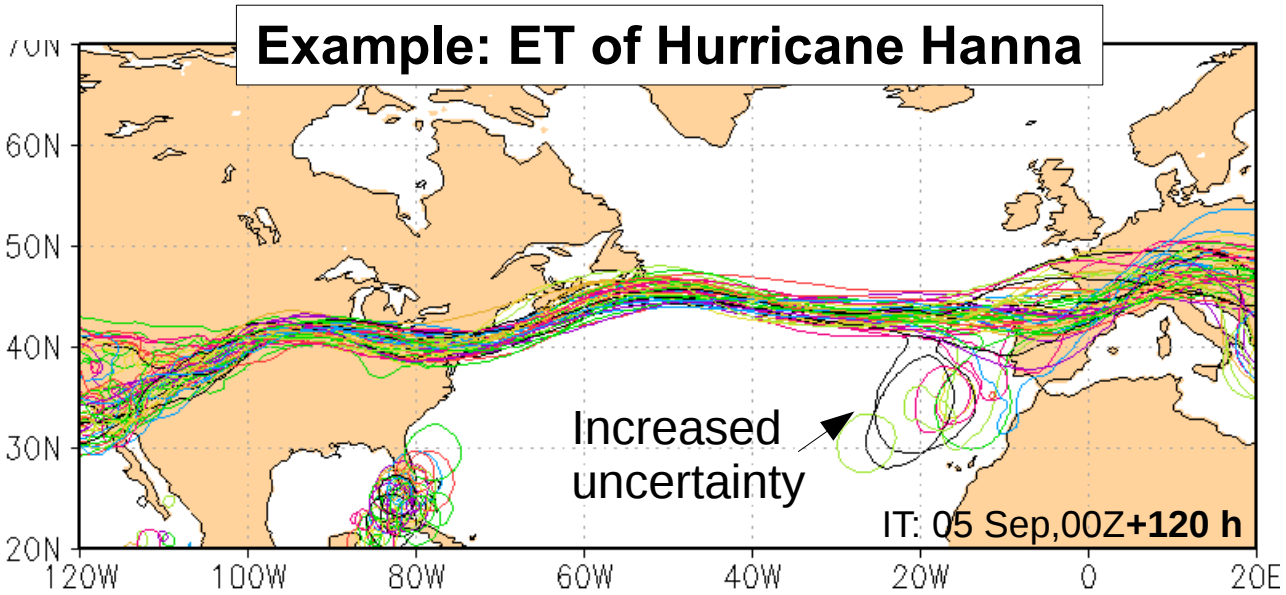

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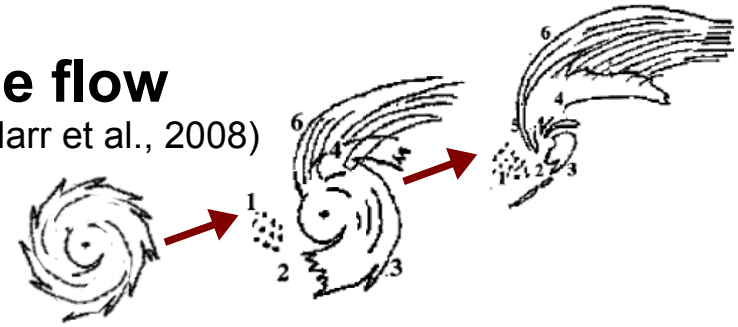

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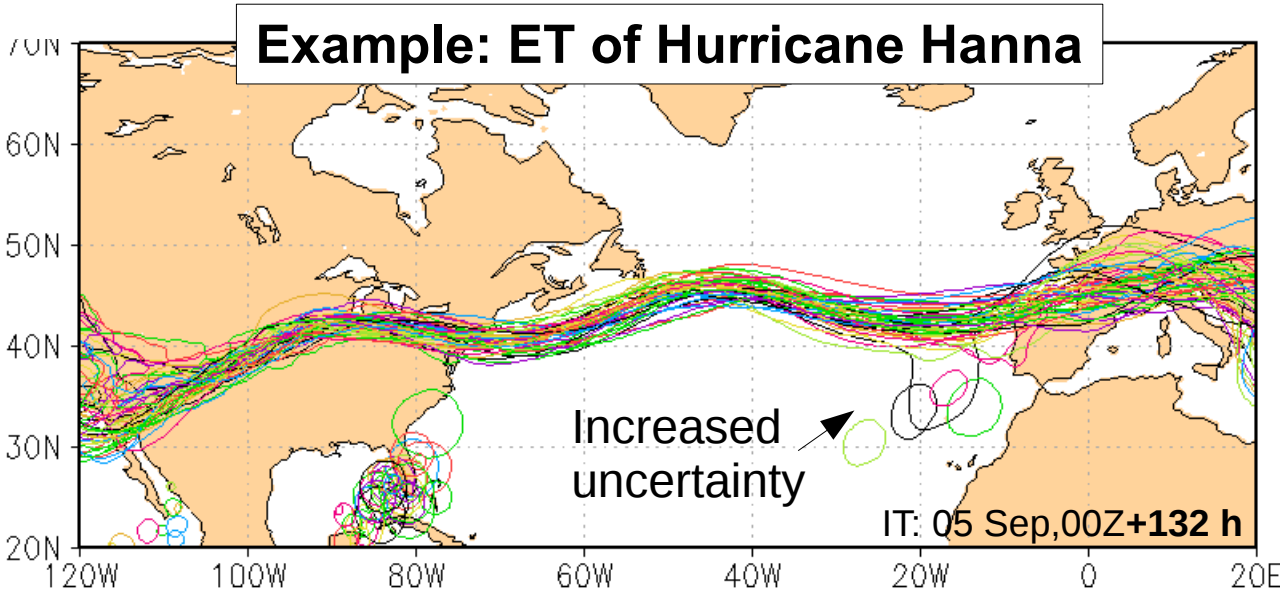

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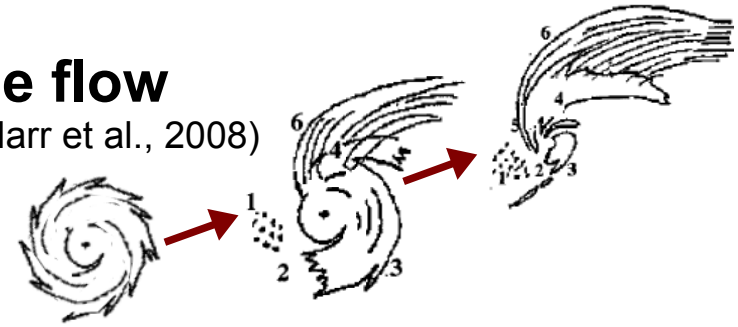

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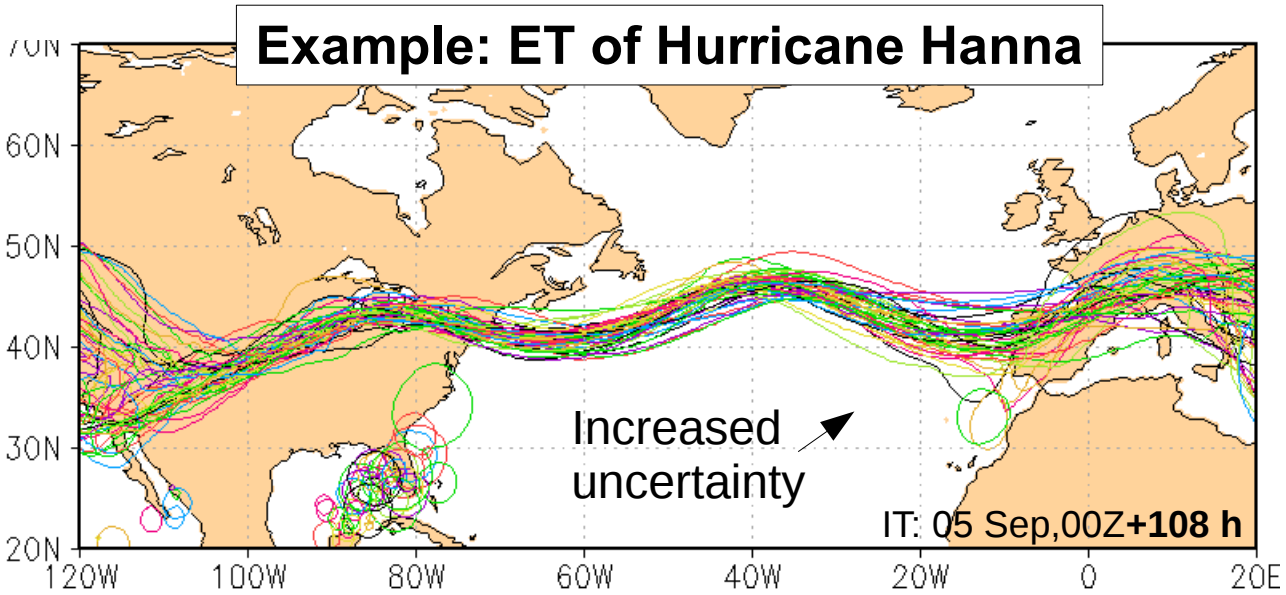

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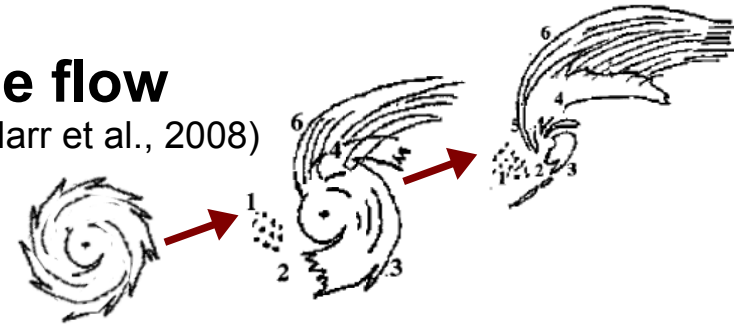

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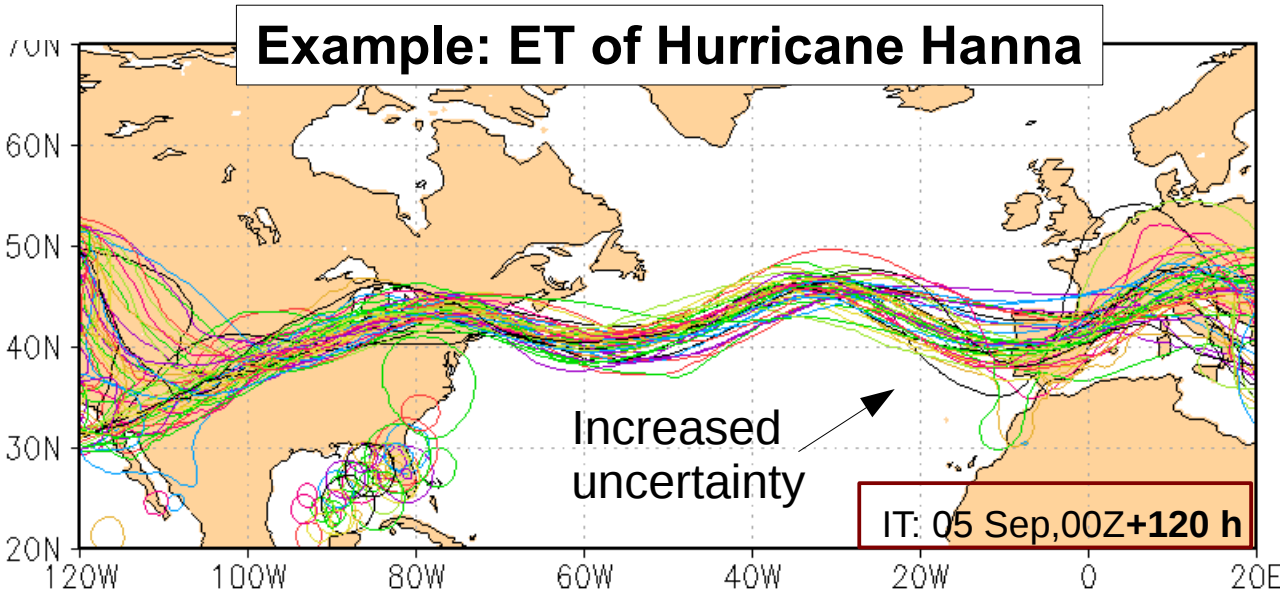

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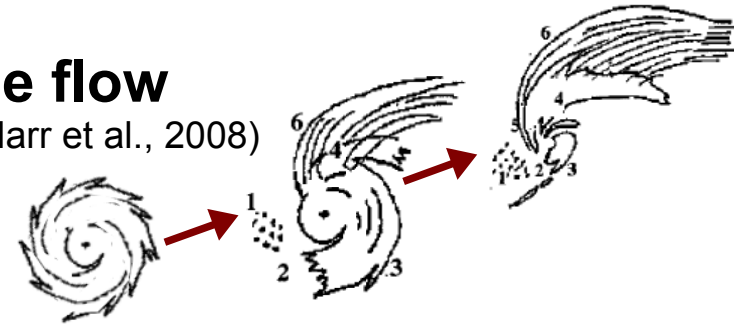

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Improve forecasts for ET events

Better understanding of processes involved in interaction

- Detailed description of distinct processes
- Impact of interaction on dynamics and predictability
- Respective contributions of midlatitudes and TC

Approach

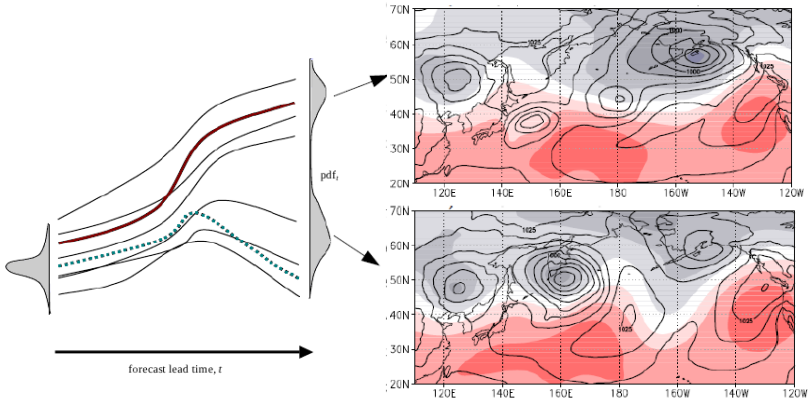
Basic Idea

Medium-range **ensemble forecast** for ET event:

➔ Several scenarios for ET of one particular storm

➔ Identify processes that cause differences in realisations

➔ Confirm and quantify using whole EPS



Procedure

EOF- and Fuzzy-Clustering Analysis
(Harr et al., 2008, Anwender et al., 2008)
➔ Identify dominant forecast scenarios

Eddy Kinetic Energy (EKE) Analysis
(Harr & Dea, 2009, Keller et al. 2014)
➔ Amplification of downstream flow

Sensitivity of wave train amplification to EKE of transitioning TC and upstream midlatitudes
(Torn & Hakim, 2009, Keller et al., 2015)
➔ Confirm findings by using entire EPS

Example: Hurricane Hanna

Characteristics

- Increased forecast uncertainty
- Approached weakly amplified trough
- Strong diabatic modification of midlatitude flow
- Formation of cut-off in Mediterranean
- Heavy precipitation events in EU
  Max: 228mm/24h in Torino, Italy

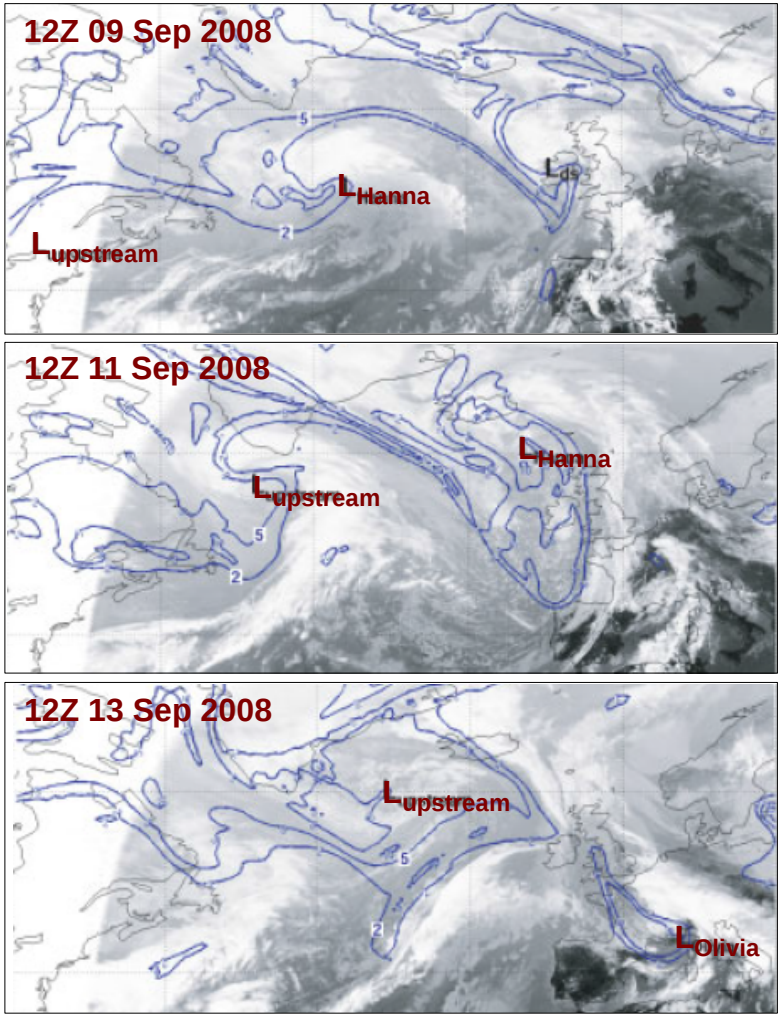
  ➔ **Grams et al., 2011, QJRMS**

Data Set

- Experimental ECMWF EPS
  (Lang et al., 2012)
- Forecast initialized: *05 Sep 2008, 00 UTC*
- Clustering: *09 Sep 2008, 00 UTC*
  (detection of scenarios based
  on 500 hPa geopotential)

  ➔ **2 forecast scenarios**

Meteosat IR Image and 320K PV



Figures adapted from Grams et al. (2011)

Approach

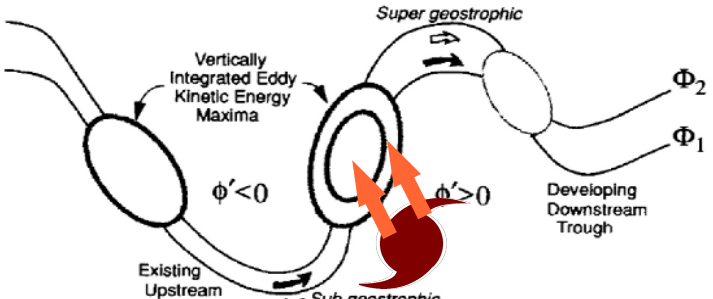
Amplification of downstream midlatitude flow?

Downstream Baroclinic Development
(e.g. Orlanski & Sheldon, 1995)

Eddy kinetic energy (EKE/K_e):
Deviation from monthly mean

Waves and Cyclones:
Maxima of EKE

Downstream propagation:
Steered by EKE fluxes



(Orlanski & Sheldon, 1995)

➔ EKE from transitioning storm may help sustain upstream maxima (Harr & Dea, 2009)

Vertically integrated EKE budget:

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

EKETendency — Baroclinic conversion — Convergence of ageostrophic geopotential flux — Convergence of advective flux

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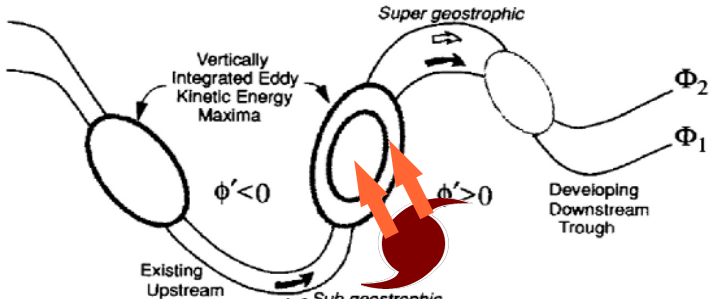

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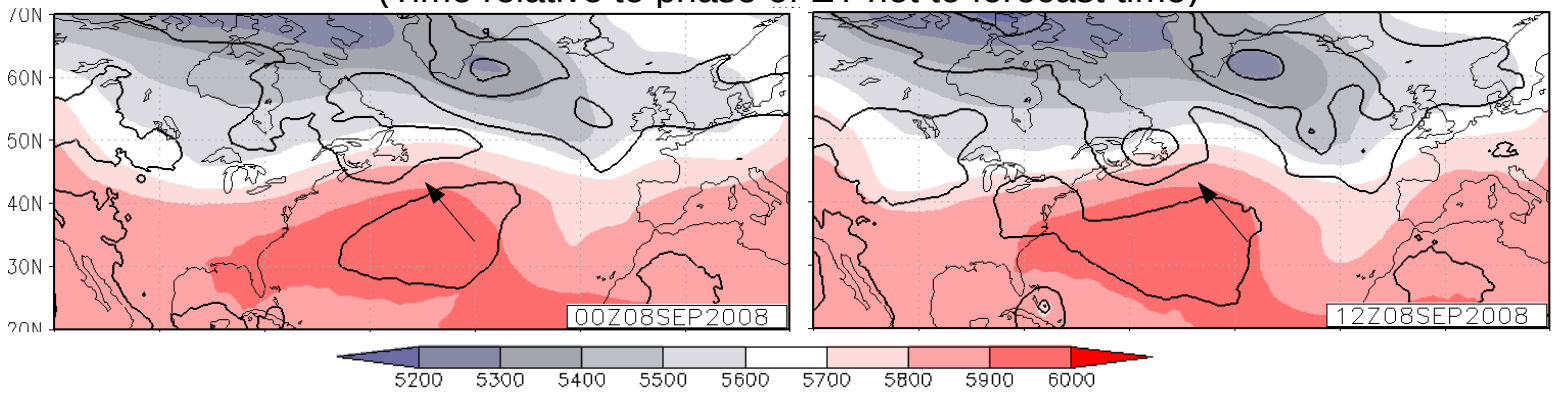
Hanna: Two possible developments

Scenario I 00 UTC 8 Sep 08

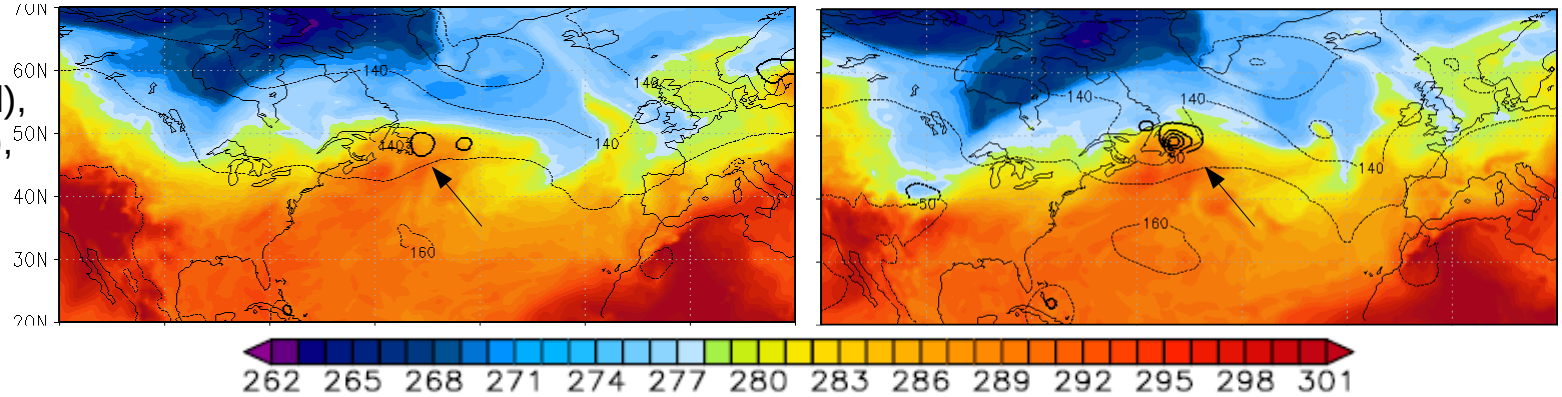
Scenario II 12 UTC 8 Sep 08

(Time relative to phase of ET not to forecast time)

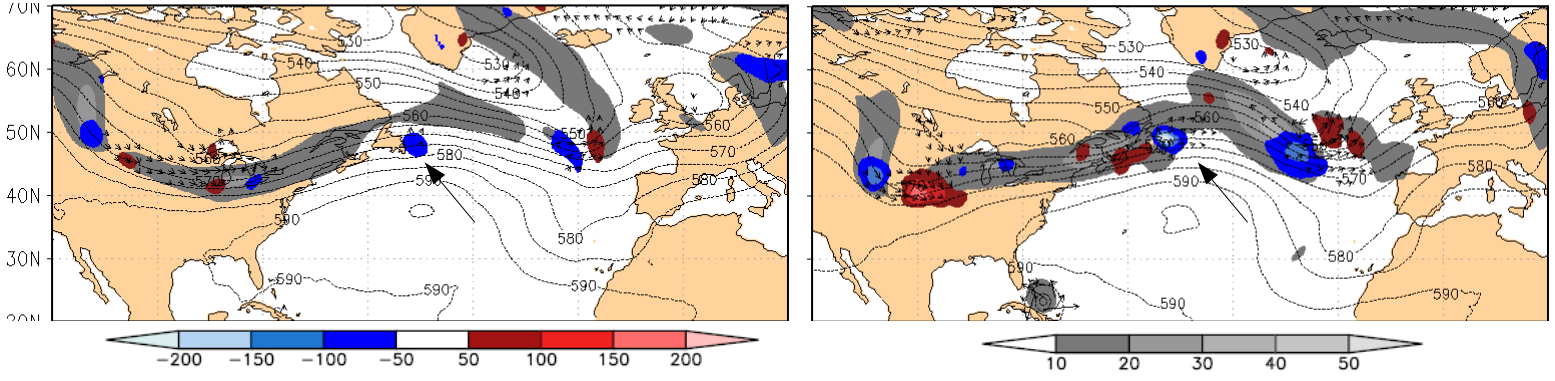
500 hPa geopotential height & mslp



850hPa Temp(shaded), geopotential (contour), & baroclinic conversion (cont., W/m²) of EKE



EKE (grey, 10^5 J/m²), ageo. geopot. flux (→) & its div-/convergence (colors, W/m²)



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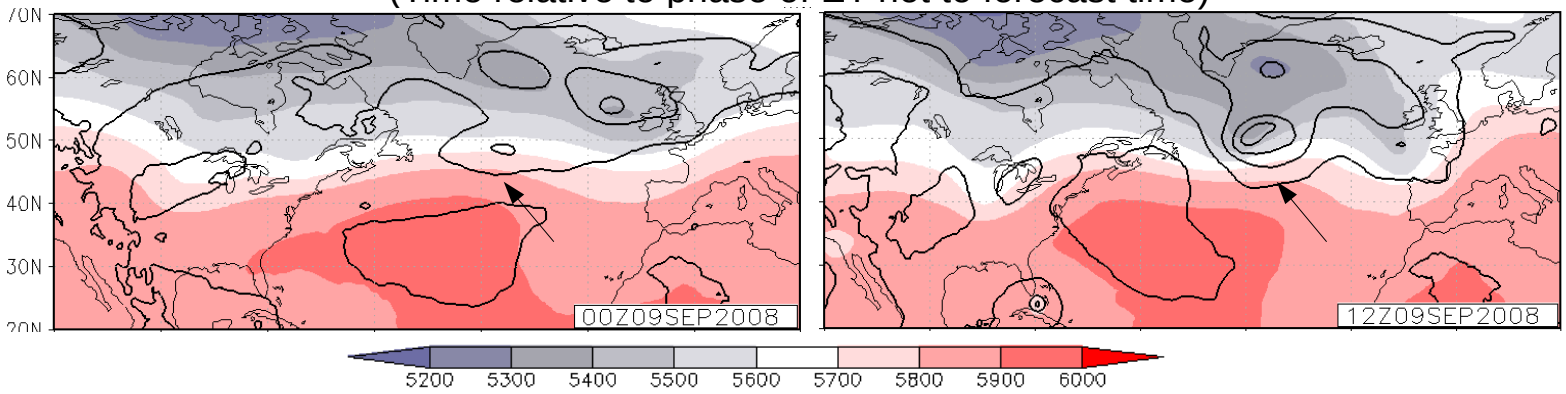

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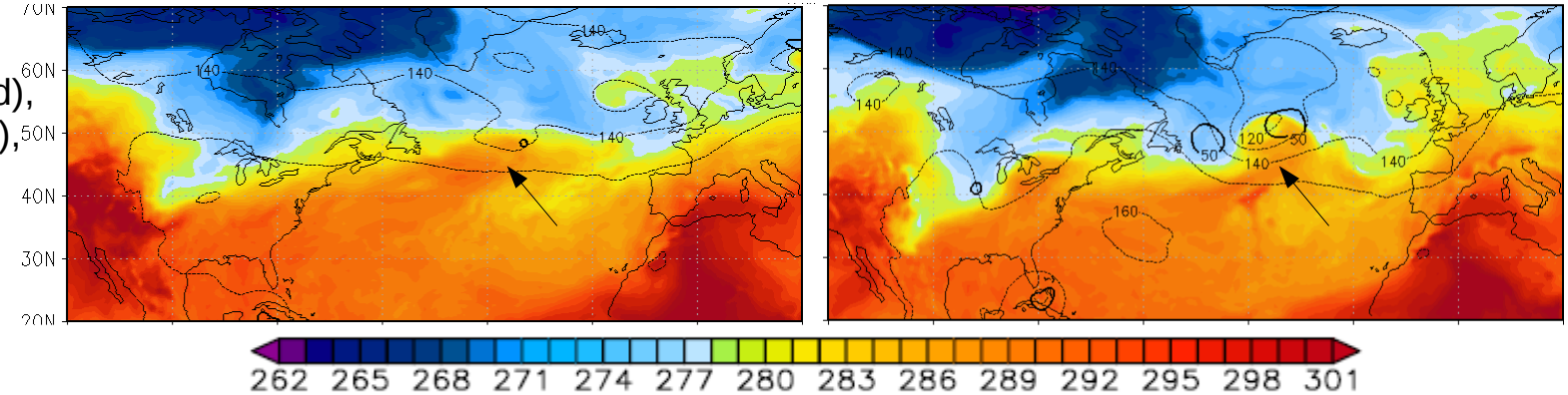

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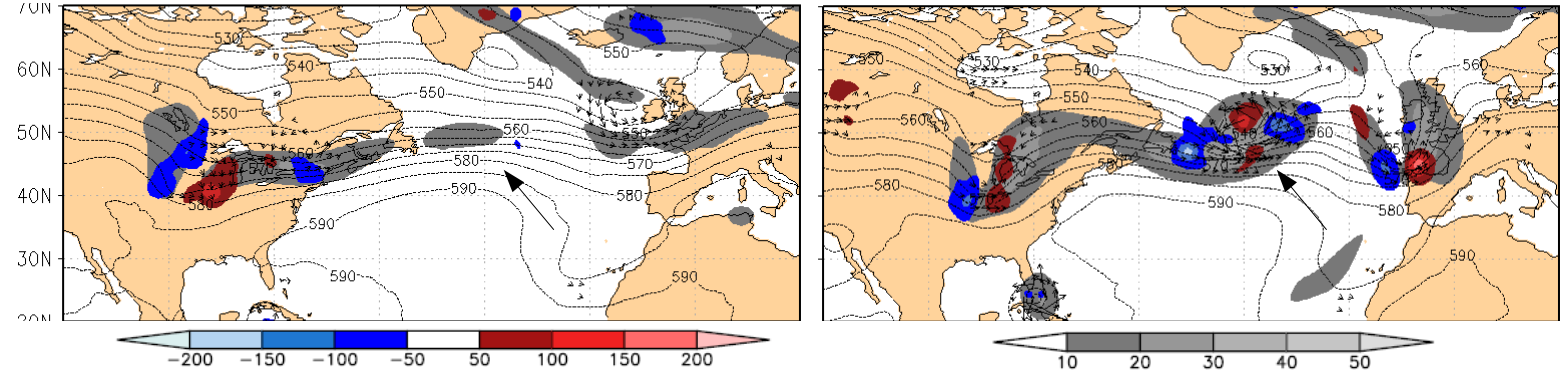
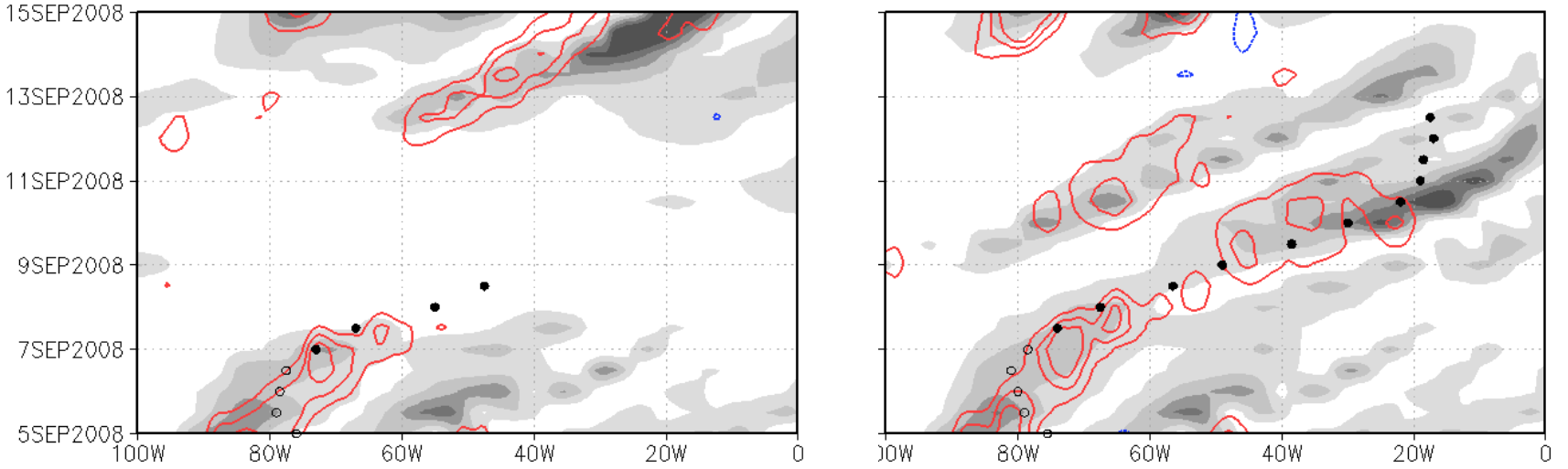


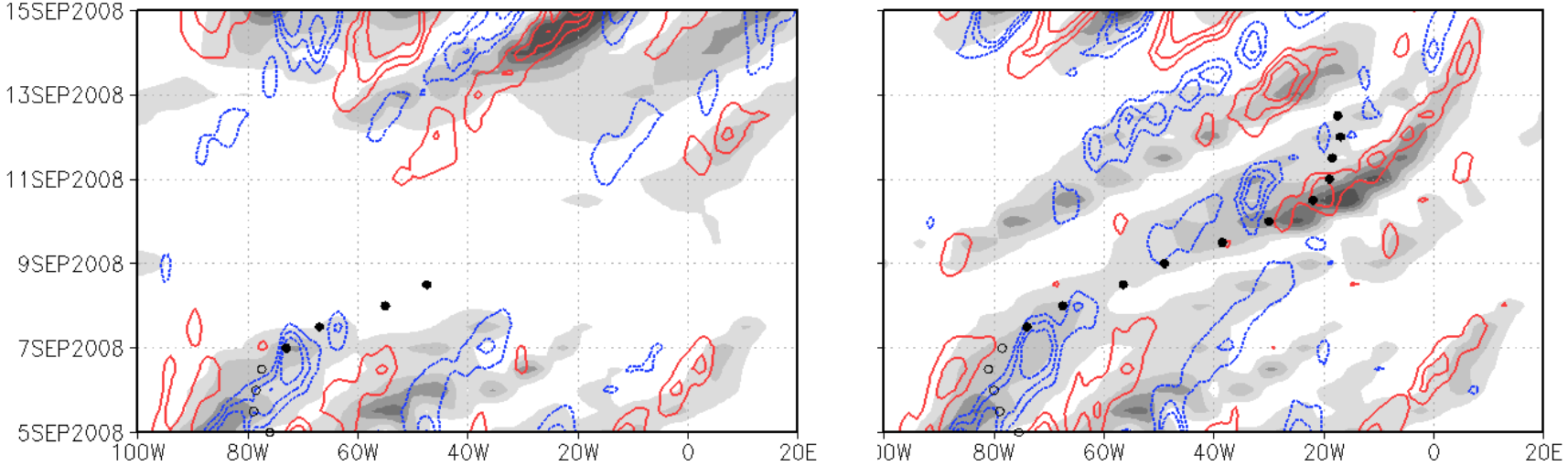
Hanna: Two possible developments

Scenario I, ave. 40-60°N

Scenario II, ave. 40-60°N



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



Divergence of Ageostrophic Geopotential Flux (cont., every 50 W/m²)

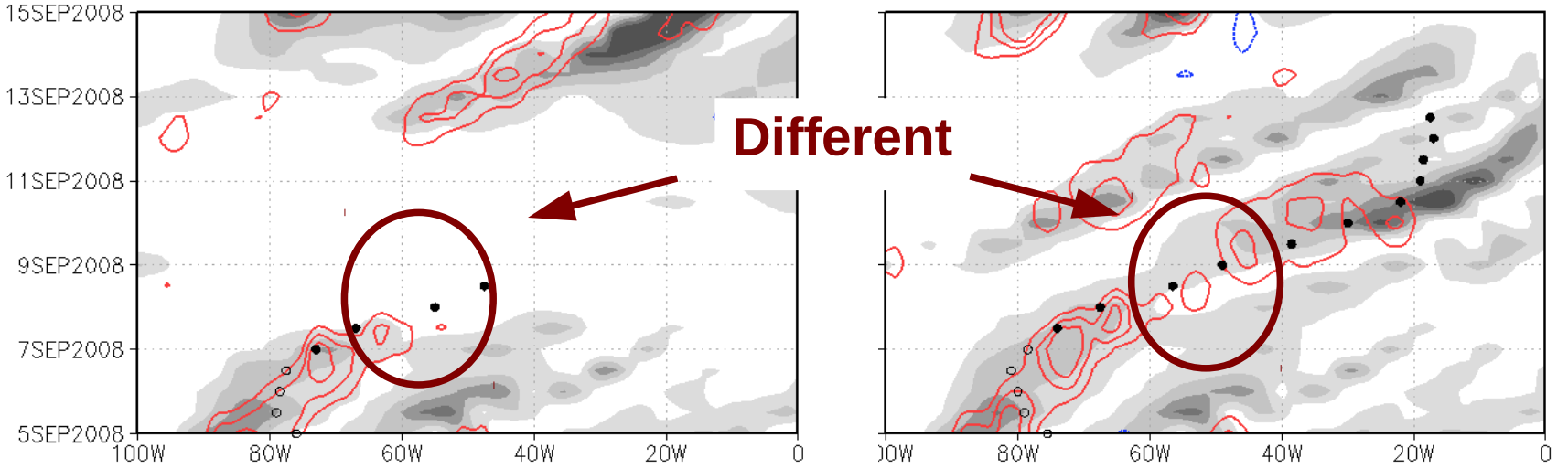
Time

Eddy Kinetic Energy (shaded, J/m²)

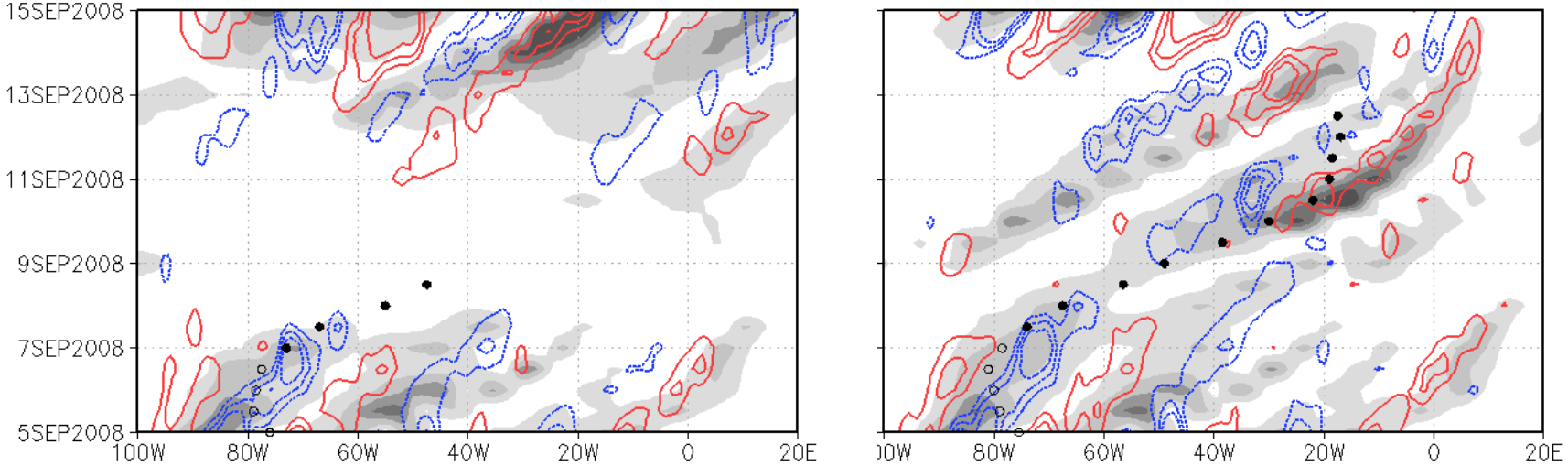
Hanna: Two possible developments

Scenario I, ave. 40-60°N

Scenario II, ave. 40-60°N

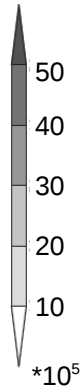


Baroclinic Conversion (cont., every 50 W/m²)



Divergence of Ageostrophic Geopotential Flux (cont., every 50 W/m²)

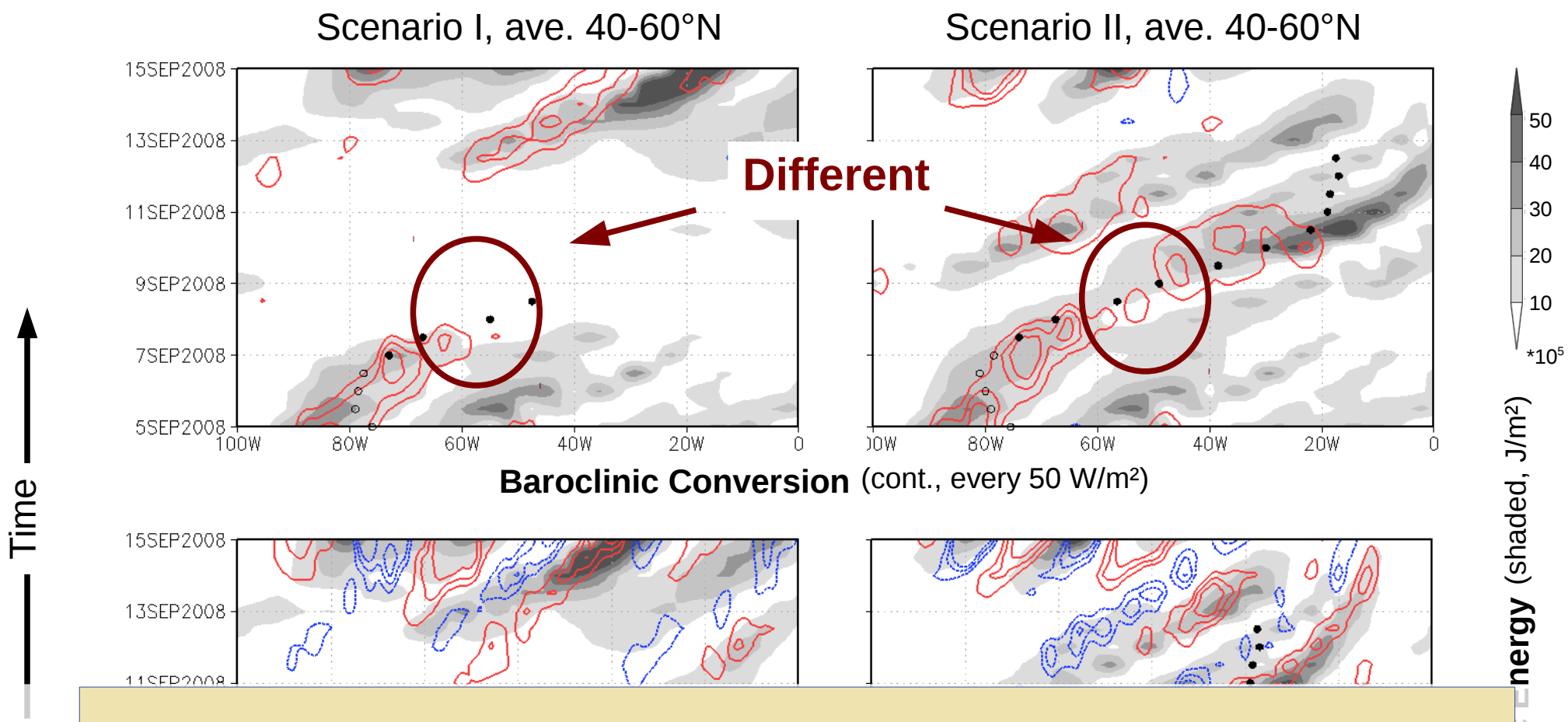
Time



Eddy Kinetic Energy (shaded, J/m²)

Hanna: Two possible developments

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Duration of baroclinic conversion within Hanna during ET is important for reintensification and impact on downstream midlatitude flow in these two scenarios

Sensitivity Studies

Confirm findings from scenarios with entire ensemble

Ensemble Sensitivity Analysis of EKE budget

$$\frac{\partial J}{\partial x} = \frac{\mathrm{cov}(\mathbf{J}, \mathbf{x})}{\mathrm{var}(\mathbf{x})} * \sigma\,(\mathbf{x})$$

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

Basic Idea: Small variances in ***x*** coincide with changes in ***J*** under the assumption of linear error growth

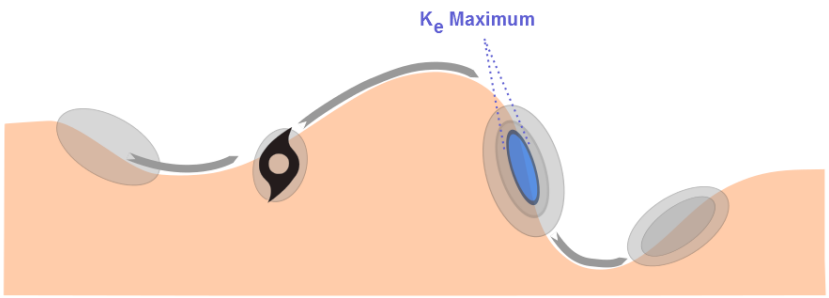
➔ **Sensitivity of amplification of downstream wave train to EKE budget of TC and upstream midlatitudes**

Thanks to: - Greg Hakim for providing the code and assistance
- Ryan Torn for valuable discussions about the results!

Sensitivity Studies

How to define amplification of downstream wave train?

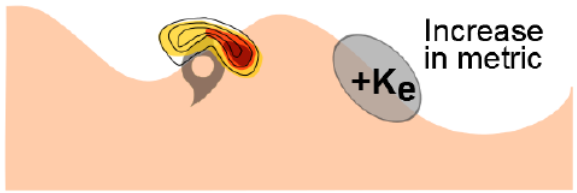
➔ **Downstream EKE maximum = object**



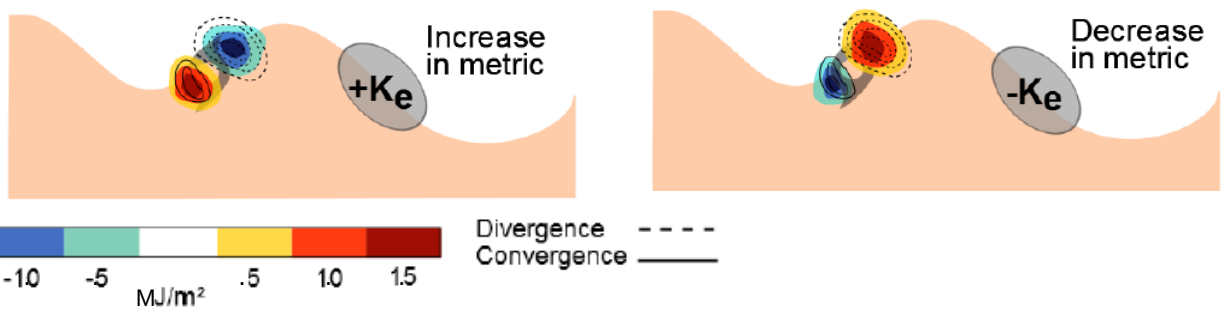
- Forecast metric ***J***:
  - Upper 5% of EKE values
  at specific forecast time
- State variable ***x***:
  - EKE budget in upstream regions
  12-48 h before time of metric

Interpretation:

e.g. baroclinic conversion



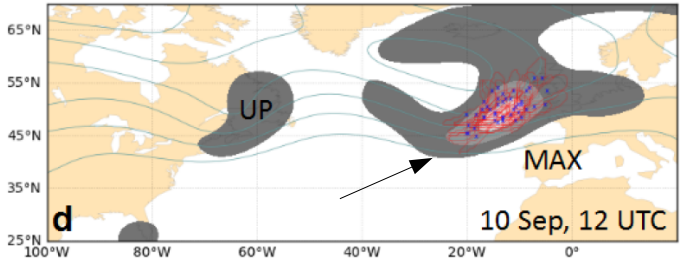
e.g. divergence of ageostrophic geopotential flux



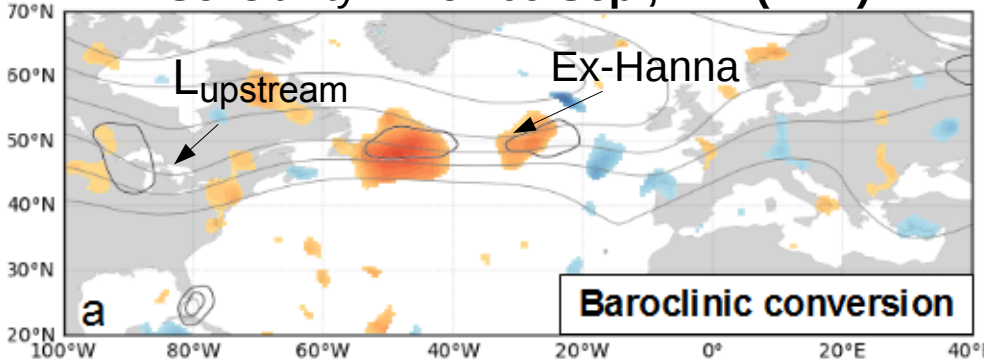
Role of TC and midlatitudes

Sensitivity of wave train amplification to EKE Budget

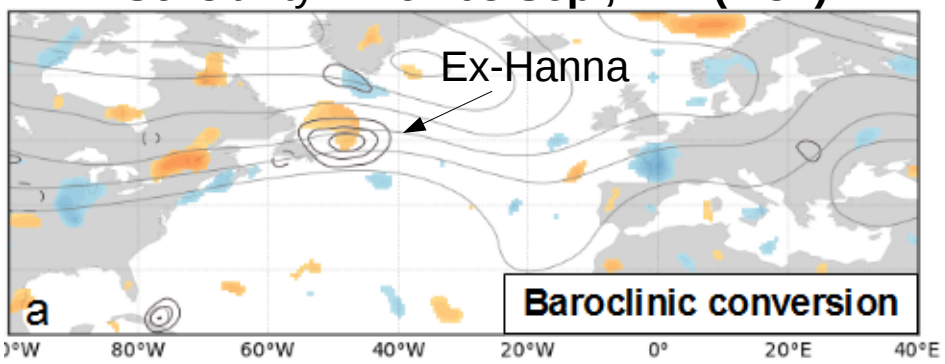
Forecast Metric ***J***:
EKE Maximum near Europe
10 Sep. 12 Z

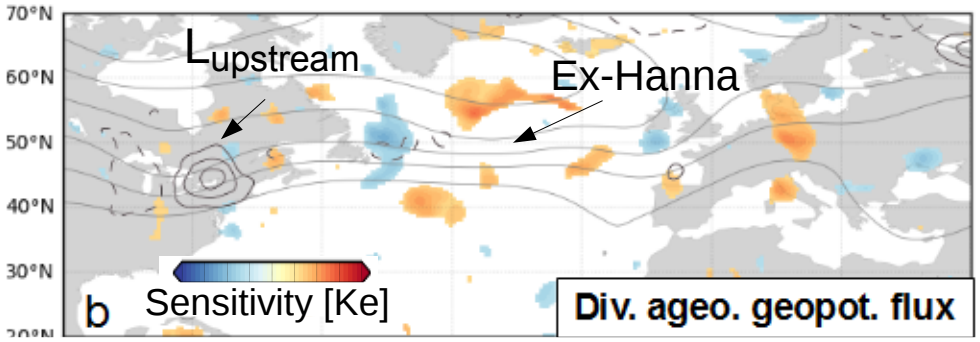


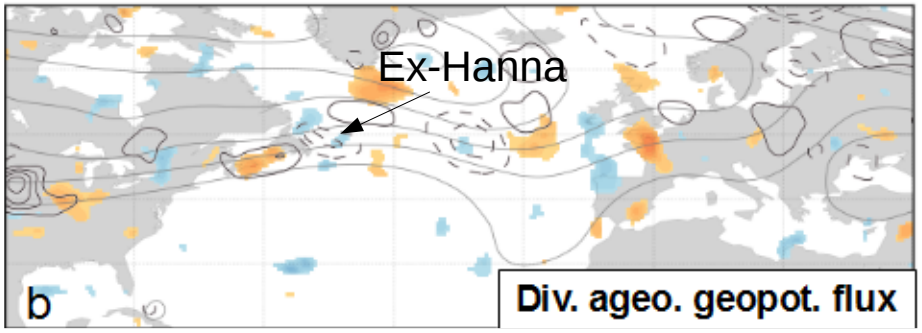
Sensitivity Time: **09 Sep., 12Z (-24h)**

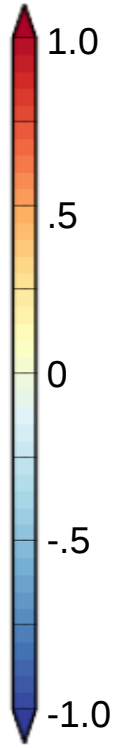


Sensitivity Time: **08 Sep., 12Z (-48h)**









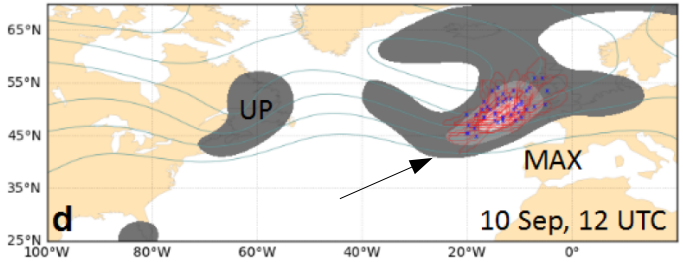
Ensemble-mean of budget term

Ensemble mean of 500hPa gph

Role of TC and midlatitudes

Sensitivity of wave train amplification to EKE Budget

Forecast Metric ***J***:
EKE Maximum near Europe
10 Sep. 12 Z



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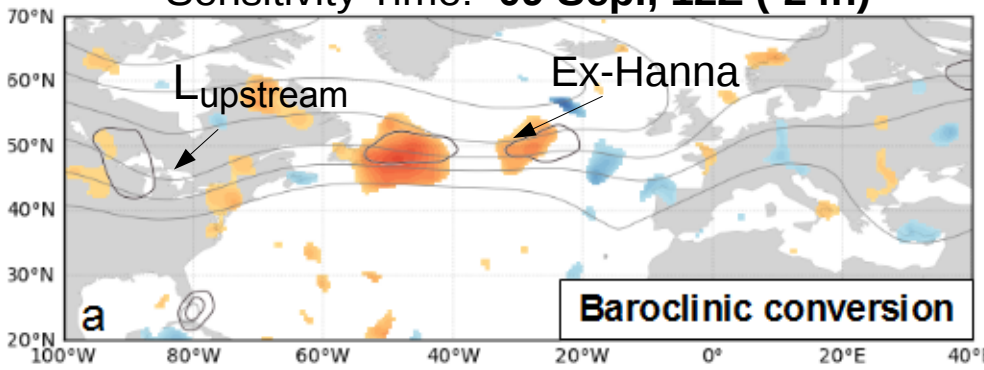

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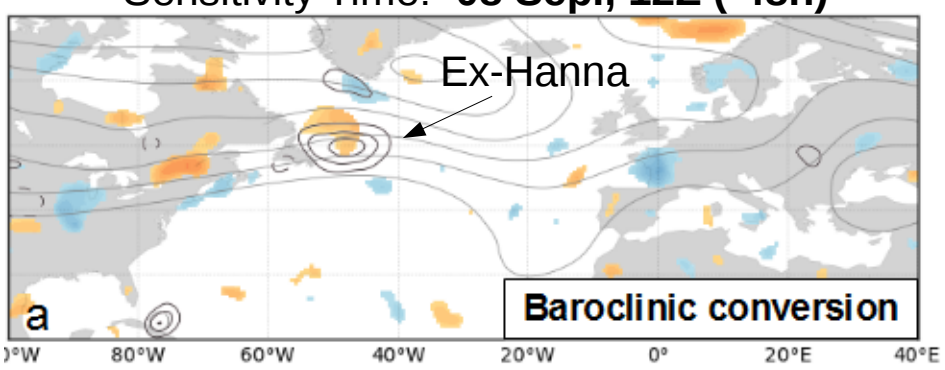

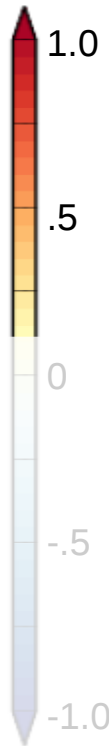

Metric is sensitive to:

- Baroclinic conversion within Hanna during ET
  (up to $7*10^5$ J/m² more EKE in downstream max, if baroclinic conversion is enhanced by 1 stdev)
- Less sensitive to divergence of ageostrophic geopotential flux

Conclusions

→ **Eddy kinetic energy analysis for ET ensemble forecast scenarios**
- Reveal processes for amplification of downstream wave train during ET
- Sensitivity to EKE Budget of TC and upstream midlatitudes

→ **Hurricane Hanna**
- Baroclinic conversion within Hanna during ET crucial for EKE center over Europe
- Weaker impact of divergence of the ageostrophic geopotential flux and upstream midlatitude flow

→ **Ideas for further studies:**
- **Impact of stochastic perturbations on sensitivity results**
- **Other relevant metrics, e.g. intensity of cut-off low**
- **Correlation with verification metrics to address fcst uncertainty**
- **Verify representation of processes in analysis / observations**

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EKE Budget for Scenarios: **Keller, Jones and Harr, 2014, Mon. Wea., Rev.**
Sensitivity studies: **Keller, 2015, in prep. for Mon. Wea. Rev.**