

# **Application of a Coupled EnKF and 4DVar Data Assimilation Method in the Study of Tropical Cyclone Genesis**

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**The 6th EnKF Workshop  
May 21st 2014**

# Introduction

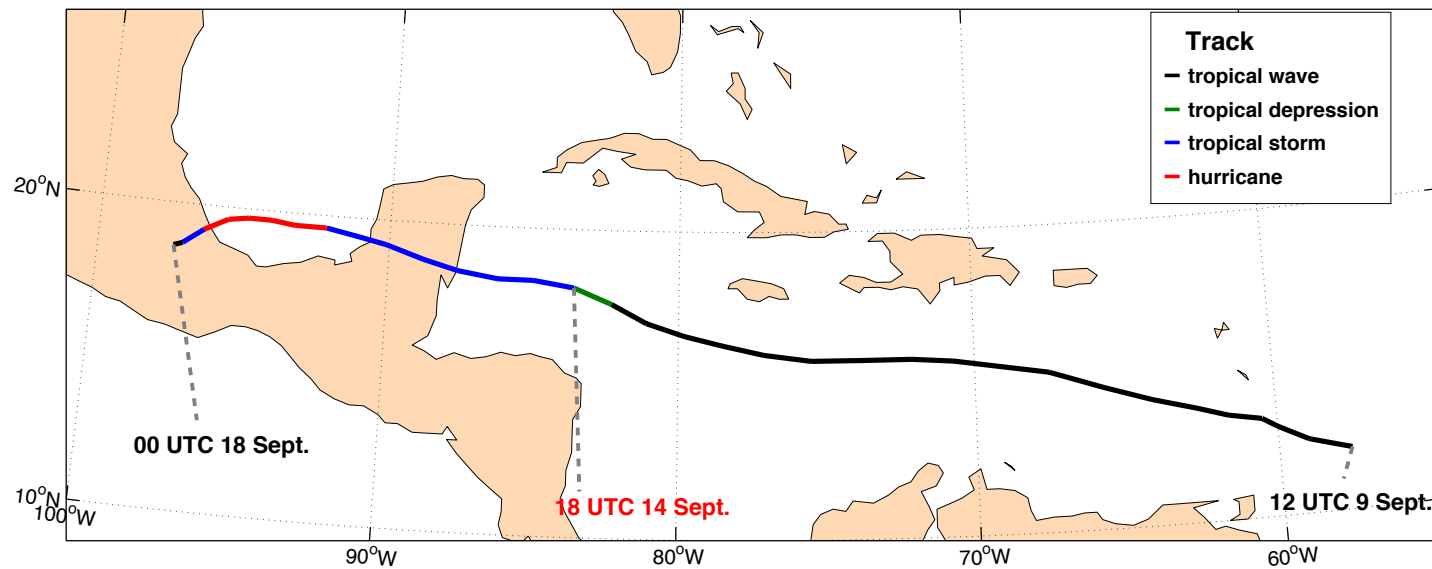
This study makes use of a coupled EnKF-4DVar data assimilation method (known as **E4DVar**) to assimilate conventional and field campaign observations taken during NASA Genesis and Rapid Intensification Processes (GRIP) and NSF Pre-depression Investigation of Cloud Systems in the Tropics (PREDICT) conducted in summer of 2010.

The objective of both GRIP and PREDICT was to collect observations of tropical cyclones in order to test certain hypothesis for genesis and rapid intensification.

For this study we will examine and compare the genesis of hurricane Karl and tropical storm Mathew of the 2010 hurricane season.

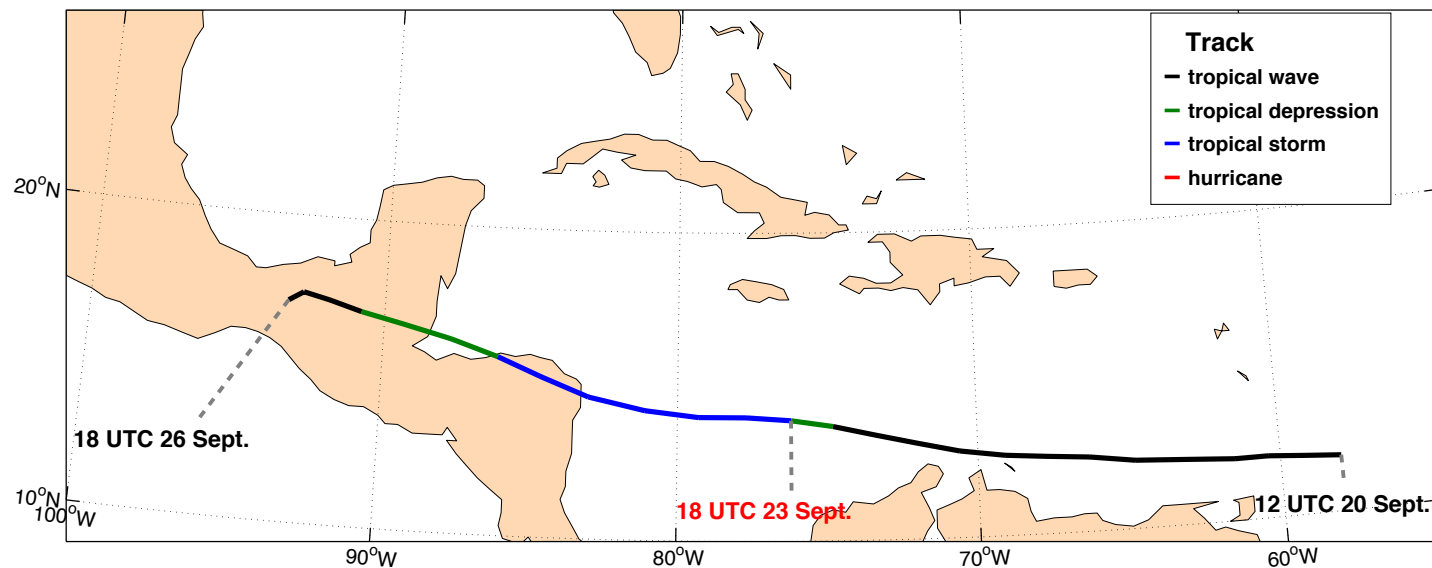
# Case Studies

## Hurricane Karl (2010)



- Karl was a category 3 hurricane with a minimum central pressure of 956 hPa and maximum sustained winds of 110 knots. Formed at 18.1 N, 83.6 W on September 14th at 18Z.

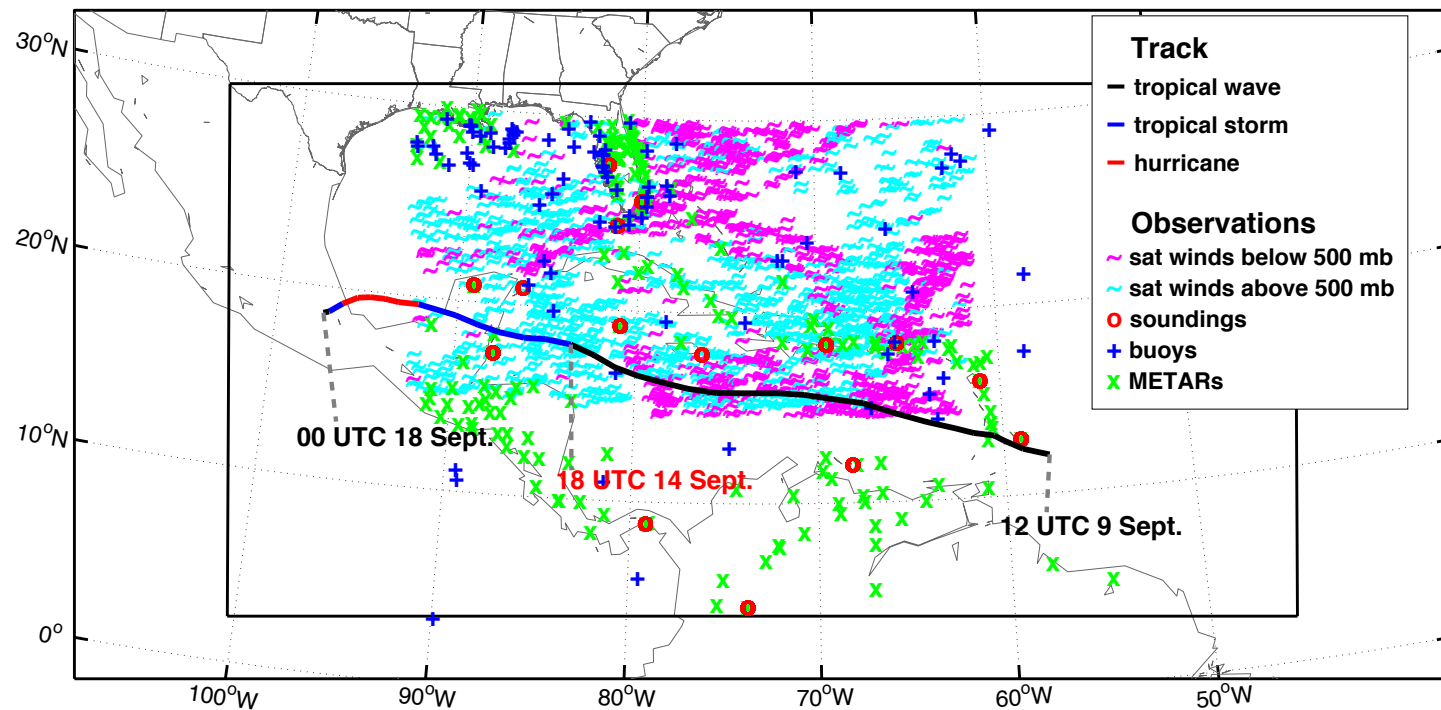
## Tropical Storm Mathew (2010)



- Mathew had a minimum central pressure of 998 hPa and maximum sustained winds of 50 knots. Formed at 13.9 N, 76.2 W on September 23rd at 18Z.

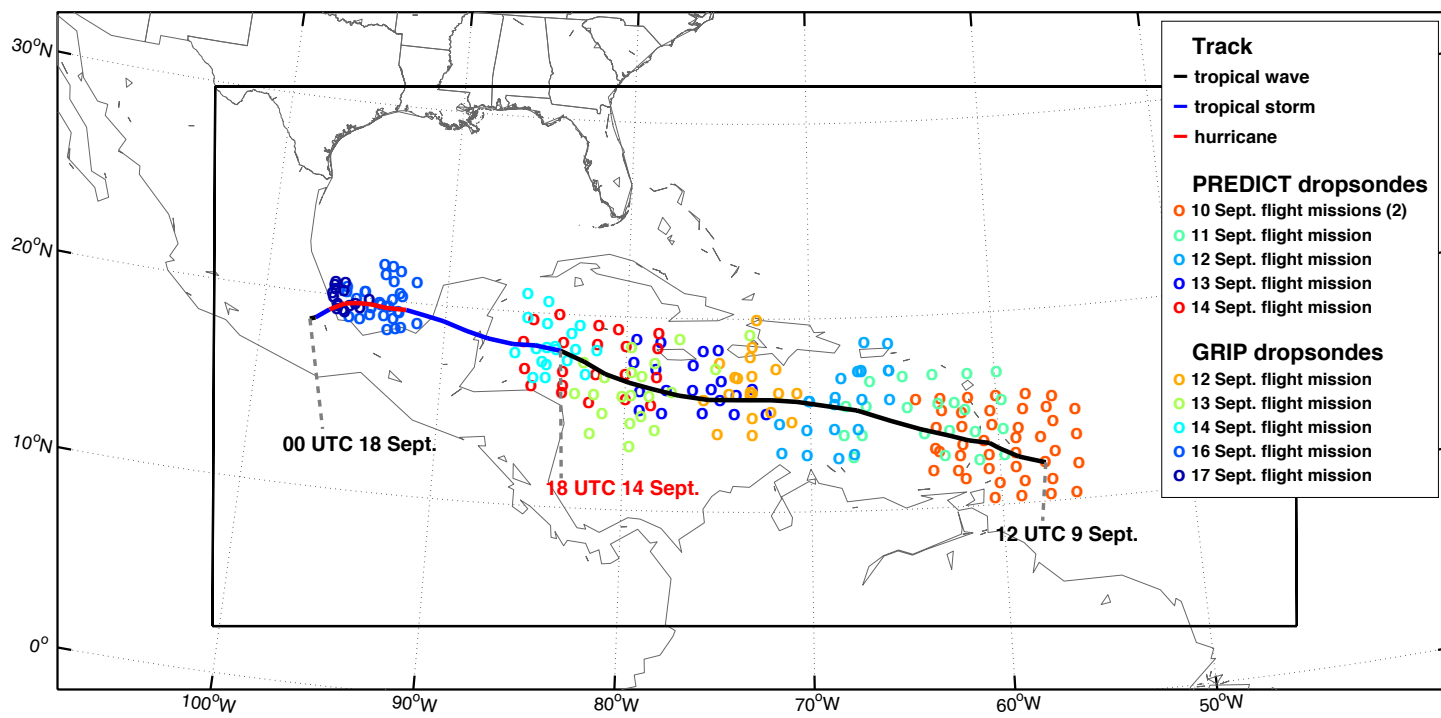
# Observations

## Conventional Observations

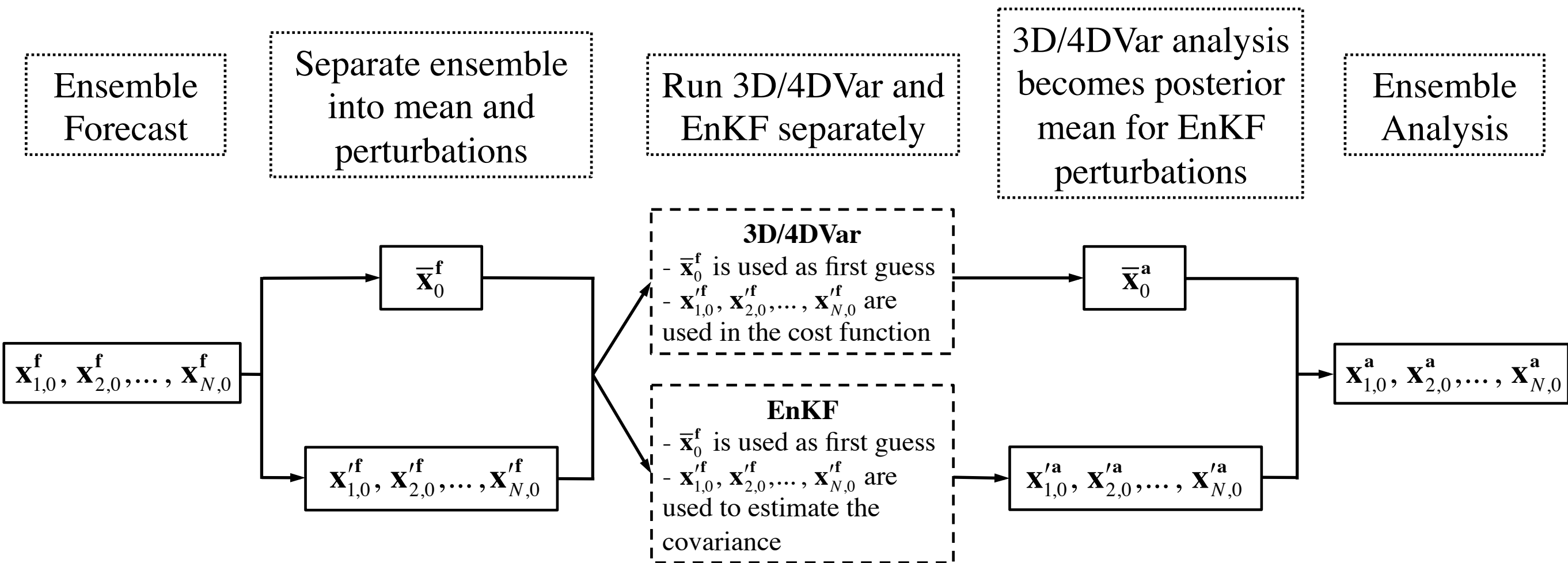


- Conventional observations were obtained from the Meteorological Assimilation Data Ingest System (MADIS).
- The assimilated data include conventional observations from MADIS and dropsonde measurements collected during PREDICT and GRIP field campaigns.

## Field Campaign Observations

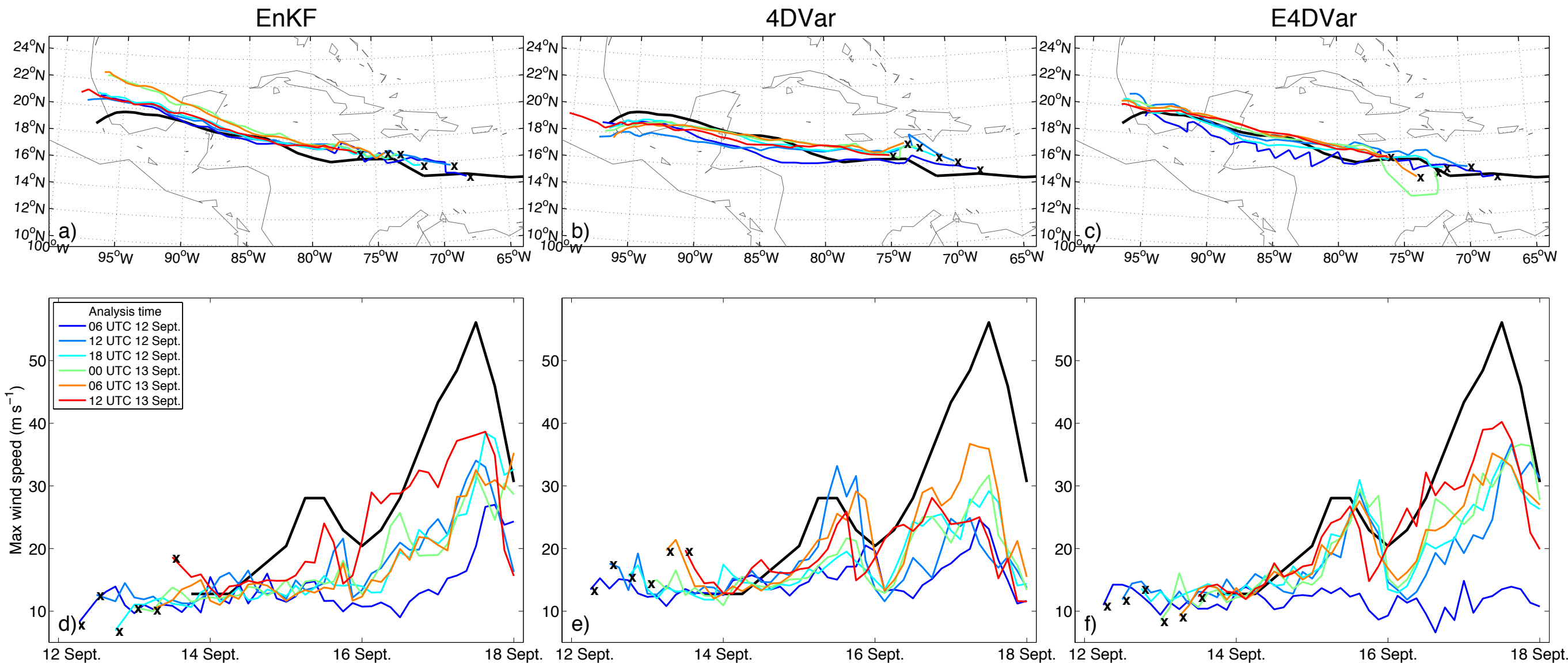


# Coupled EnKF-4DVar Data Assimilation Schematic



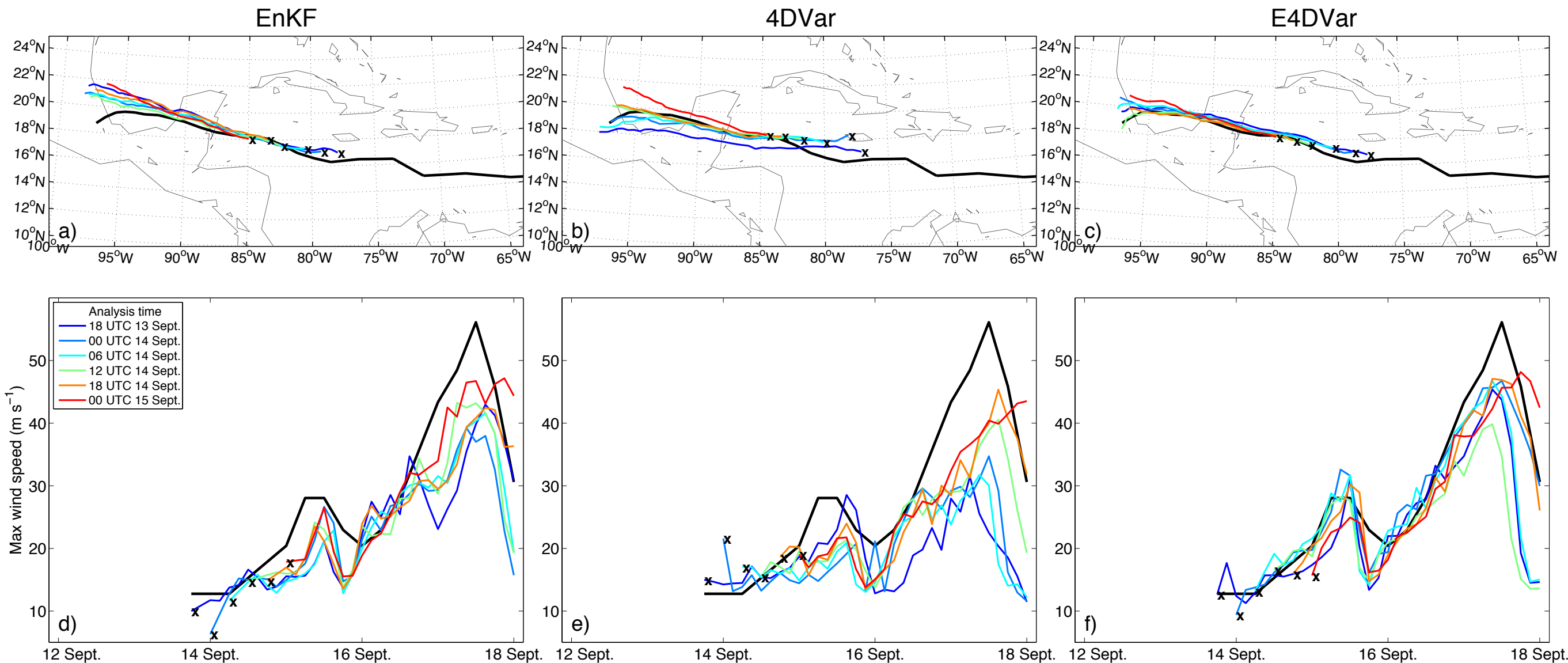
# **EnKF, 4DVar and E4DVar Comparison**

# Deterministic Track and Intensity Forecasts



- Karl's forecasts initialized 30–60 h before genesis and run to 00 UTC Sept. 18th.

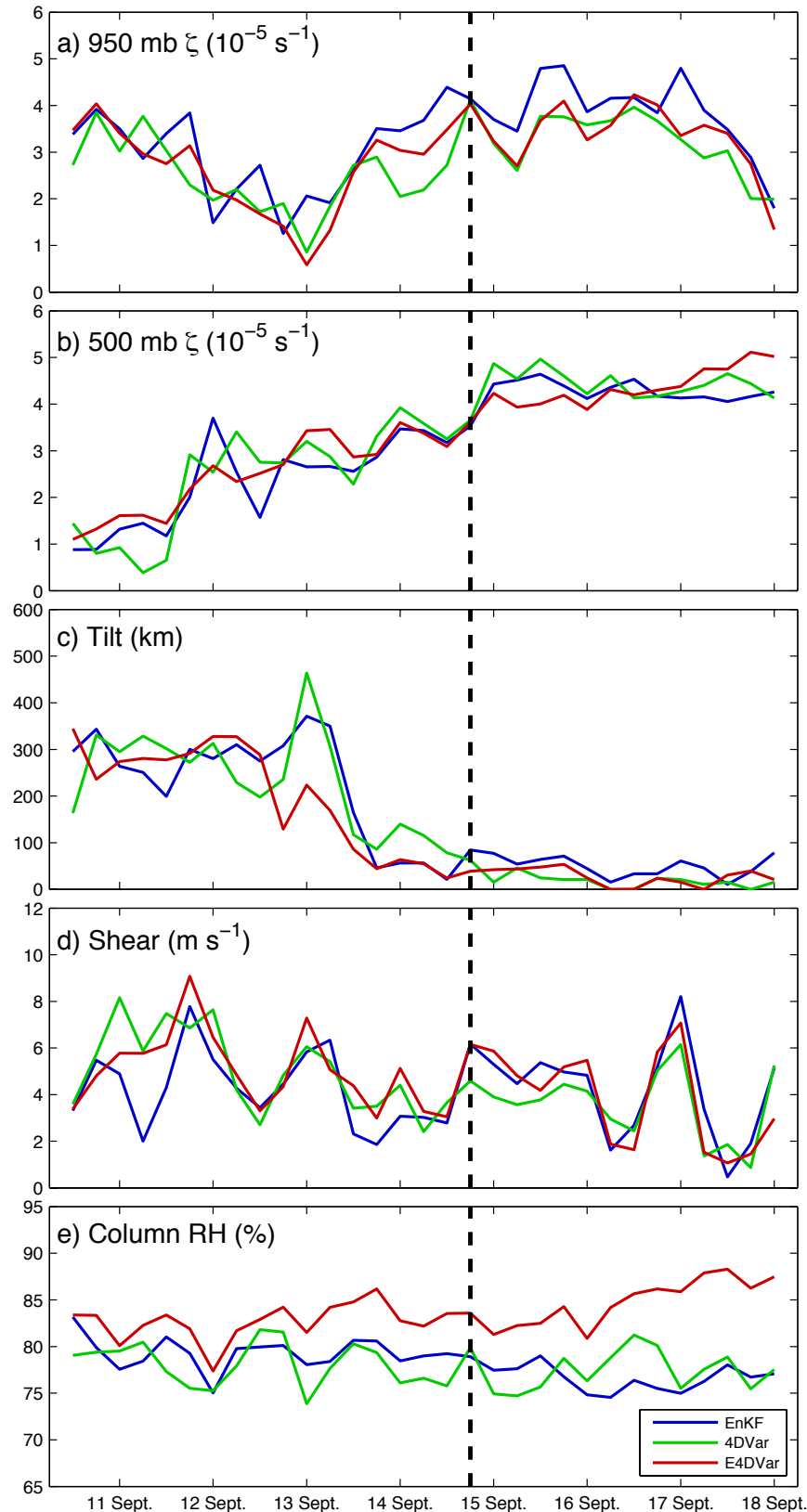
# Deterministic Track and Intensity Forecasts



- Karl's forecasts initialized within 48 h before genesis and run to 00 UTC Sept. 18th.



# EnKF, 4DVar and E4DVar Analyses



- Analyses are compared between 12 UTC Sept. 10th and 00 UTC Sept. 18th.
- Vorticity and 950-500 mb column relative humidity are averaged within 3 degrees of the storm center.
- 950-500 mb vertical shear and vortex tilt are estimated using winds within 3 degrees of the storm center.
- E4DVar analyses have smaller 950-500 mb vortex displacements and much higher column relative humidity.

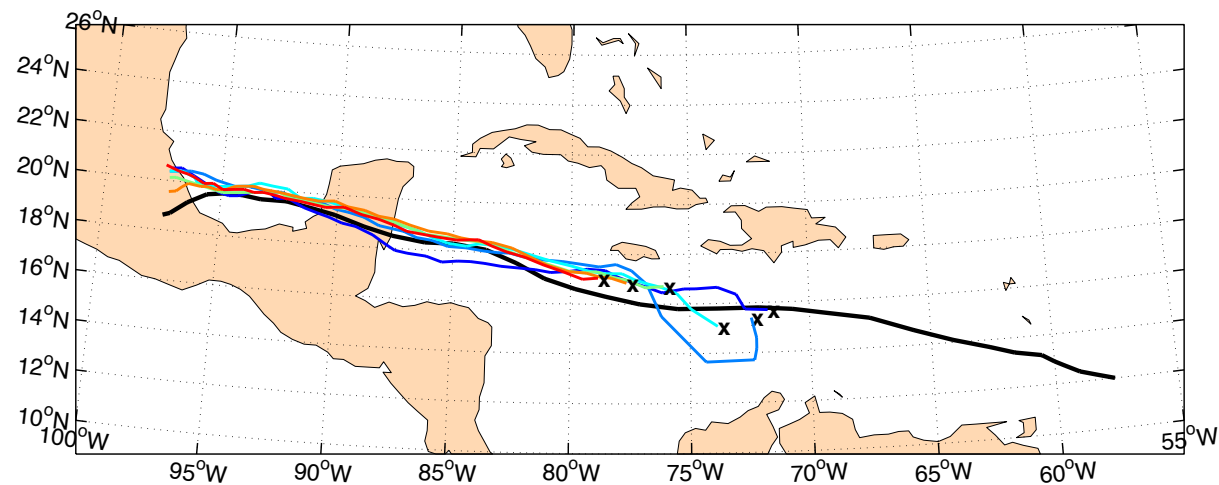
**E4DVar**

# Experimental Design

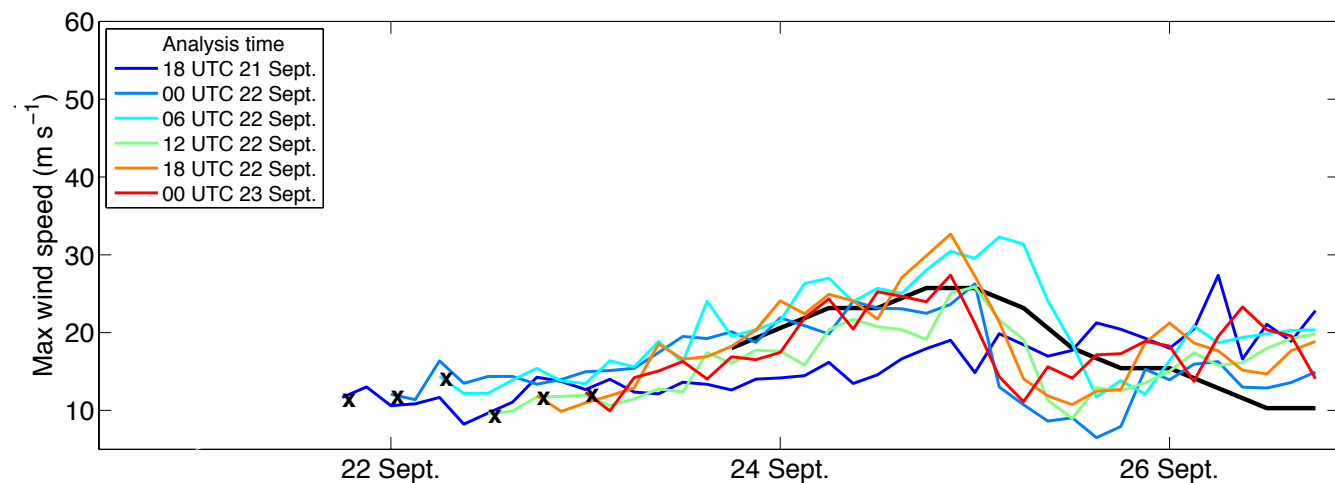
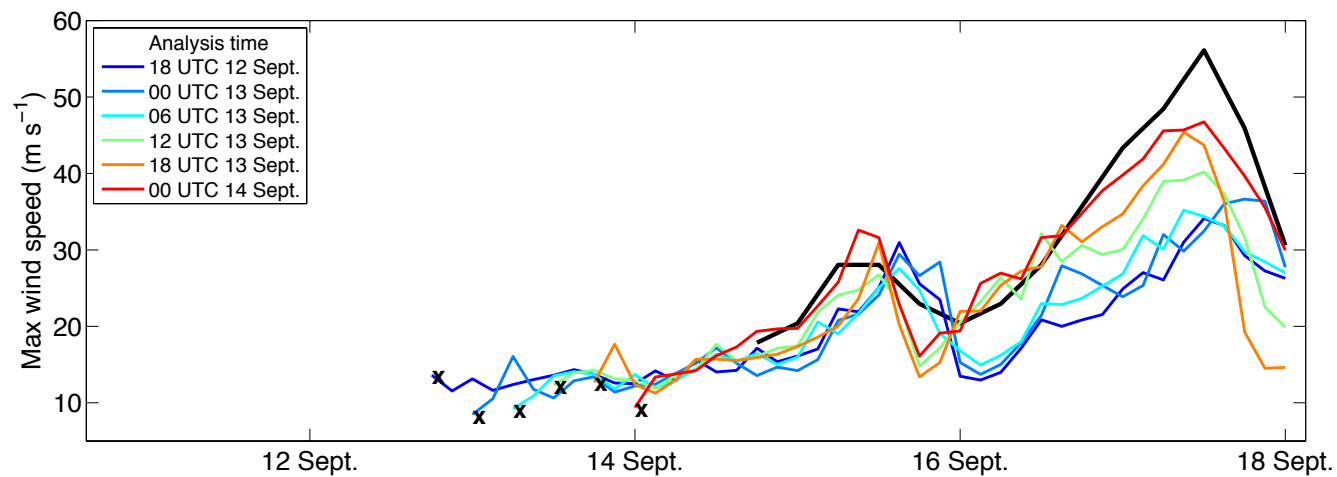
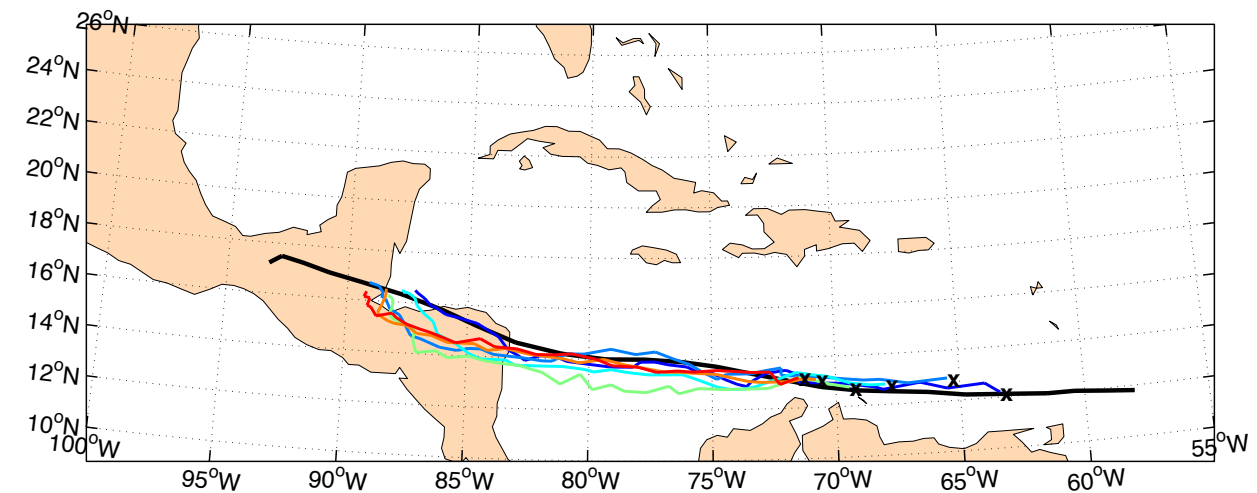
- 60 ensemble members
- Localization of 900 km in the horizontal & 15 levels in the vertical
- Relaxation coefficient of 0.8
- Two way coupling between EnKF and 4DVar
  - ▶ 4DVar uses ensemble mean first guess and ensemble perturbations
  - ▶ EnKF update the ensemble members
  - ▶ Hybrid 4DVar analysis replaces the EnKF analysis
- 80% of the increment comes from the ensemble perturbations during the hybrid minimization.
- Assimilation performed on 13.5-km grid spacing with 35 vertical levels and a 4.5-km two-way nested forecast.
- Experiments were initialized from GFS/GDAS analysis and cycled every 6 hours.

# Deterministic Track and Intensity Forecasts

## Karl



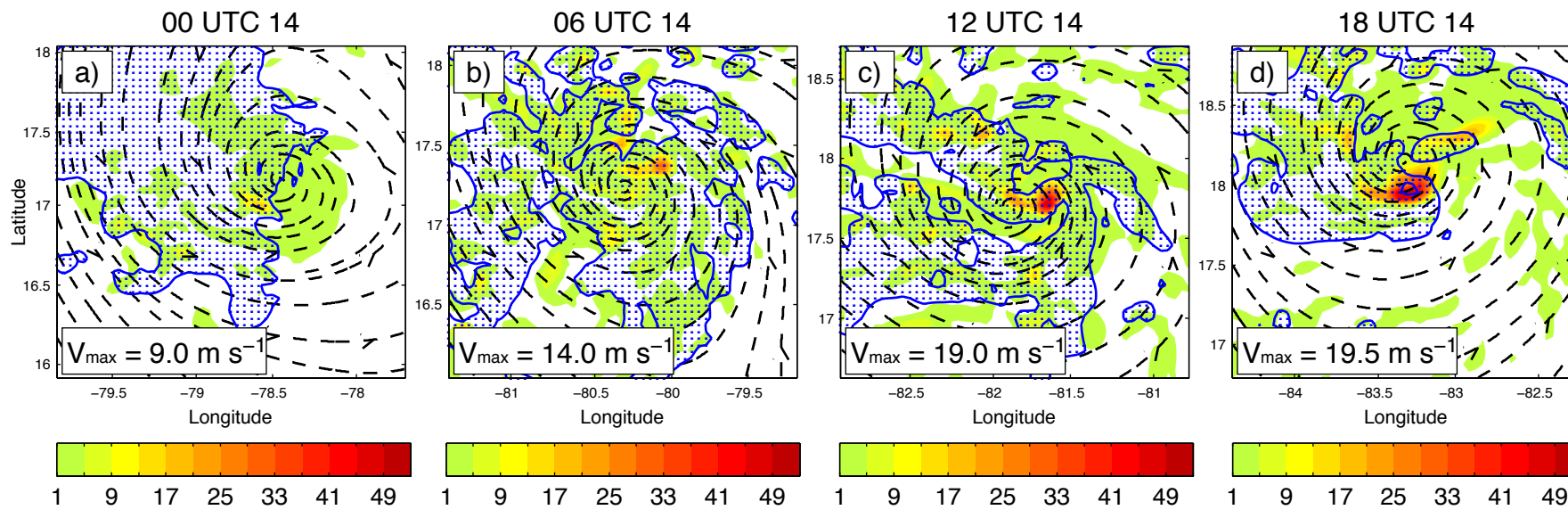
## Mathew



- Forecasts initialized within 48-18 h before genesis.

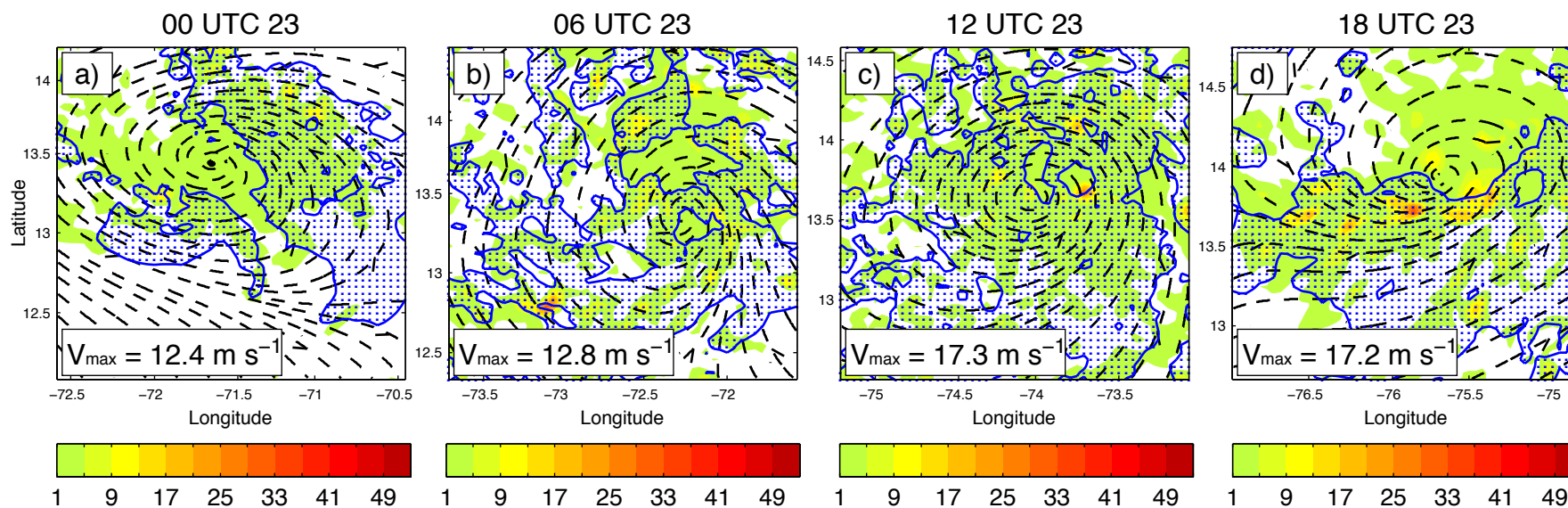
# Deterministic Forecasts

## Karl



- Forecasts initialized 18 h prior to genesis.
- Dashed: 950 mb storm-relative streamlines.

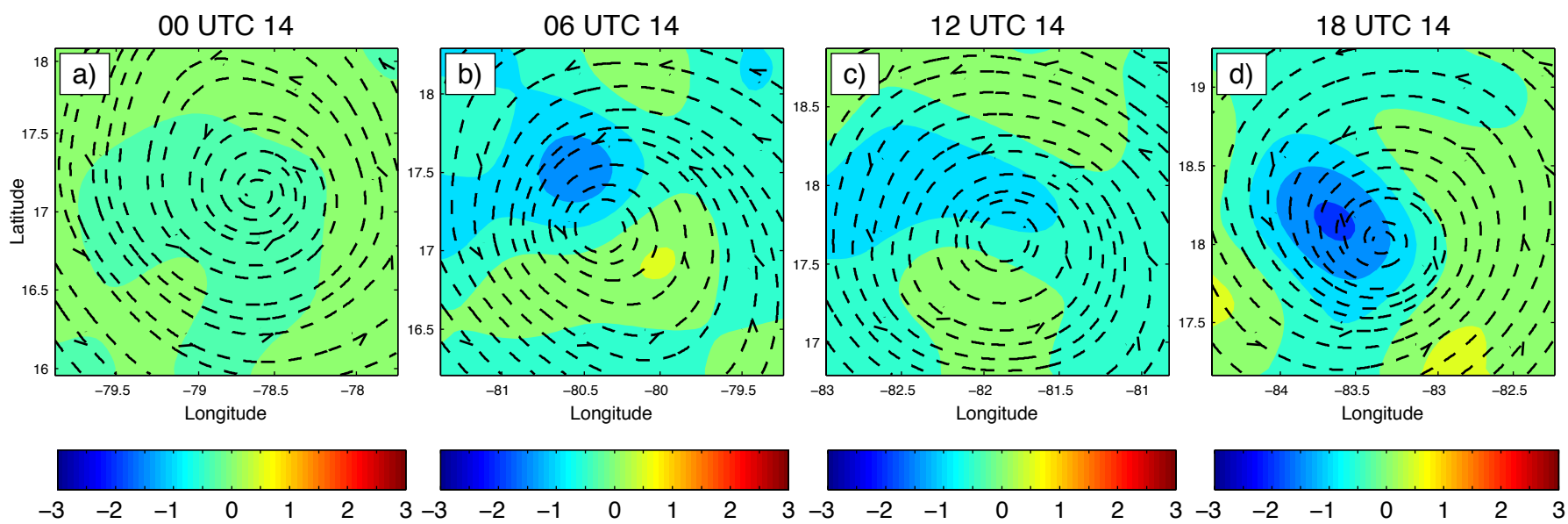
## Mathew



- Shaded: 950 mb relative vorticity ( $4 \times 10^{-4} \text{ s}^{-1}$ ).
- Checkered: 950-500 mb column RH ( $> 90\%$ )

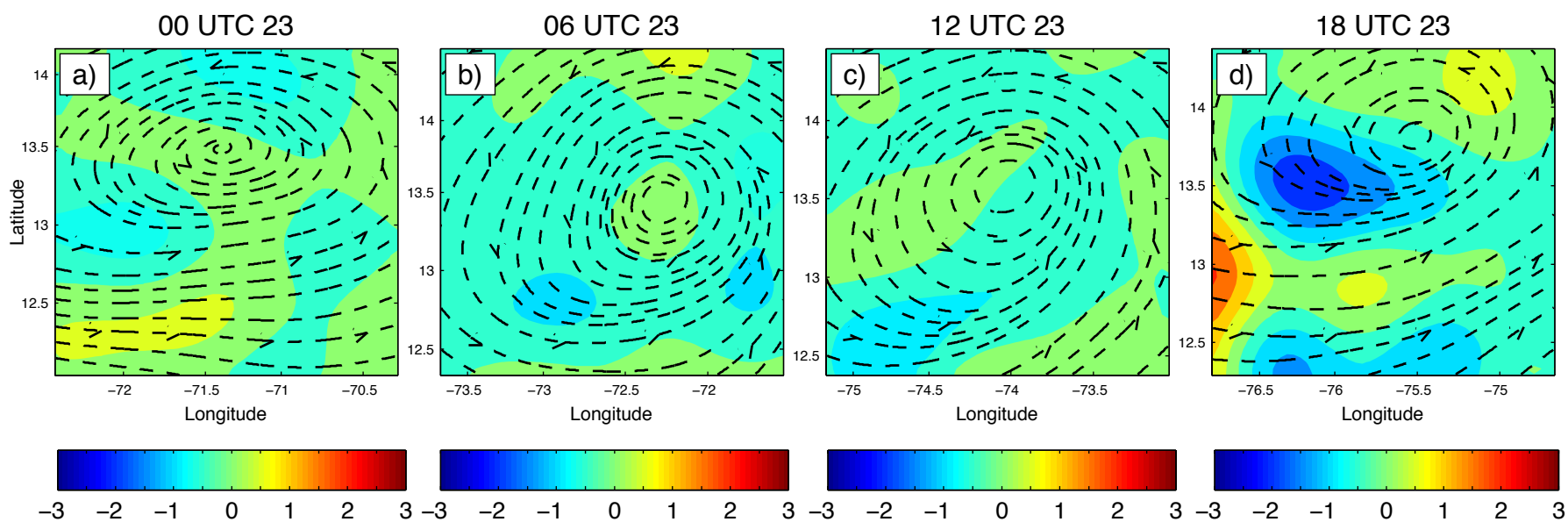
# 850 mb Divergence/Convergence Field

## Karl



- Forecasts initialized 18 h prior to genesis.
- Dashed: 850 mb storm-relative streamlines.

## Mathew

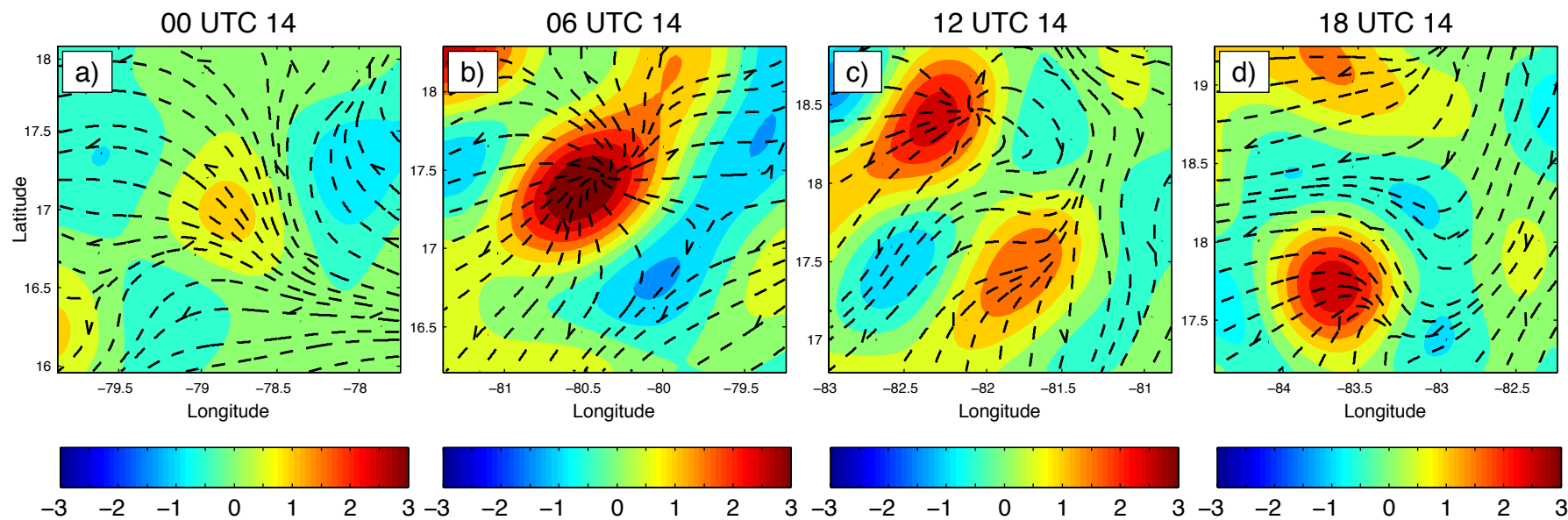


- Shaded: 850 mb divergence ( $10^{-4} \text{s}^{-1}$ ).
- Grid centered over low-level vorticity maximum.



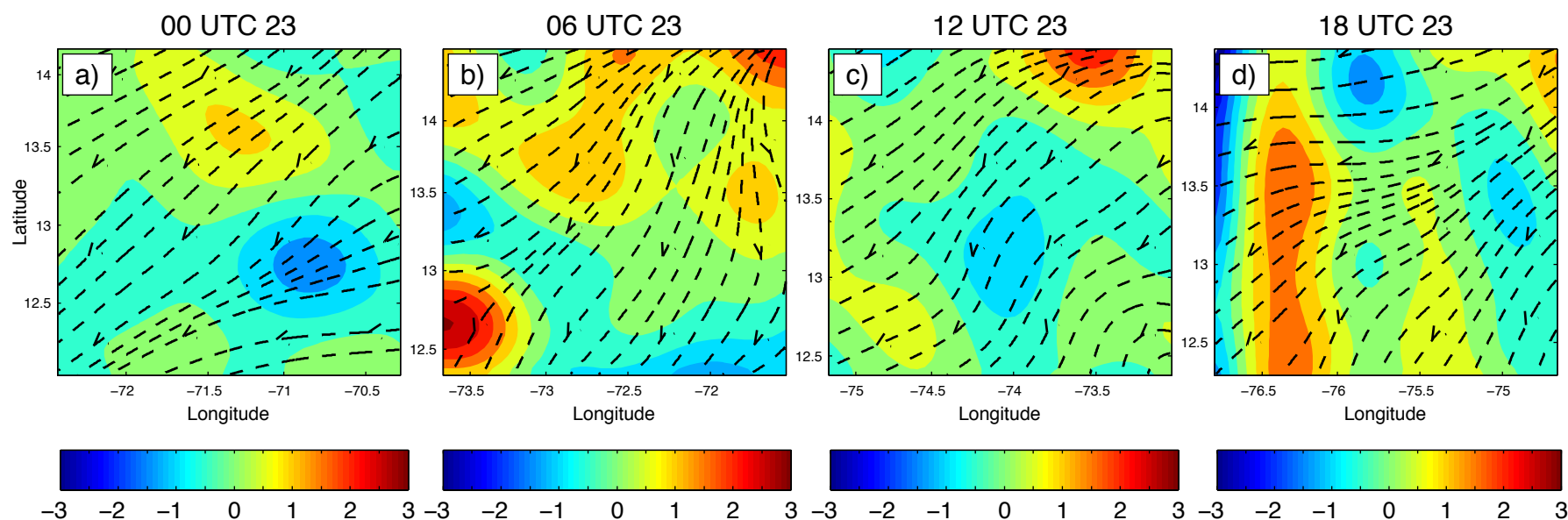
# 200 mb Divergence/Convergence Field

## Karl



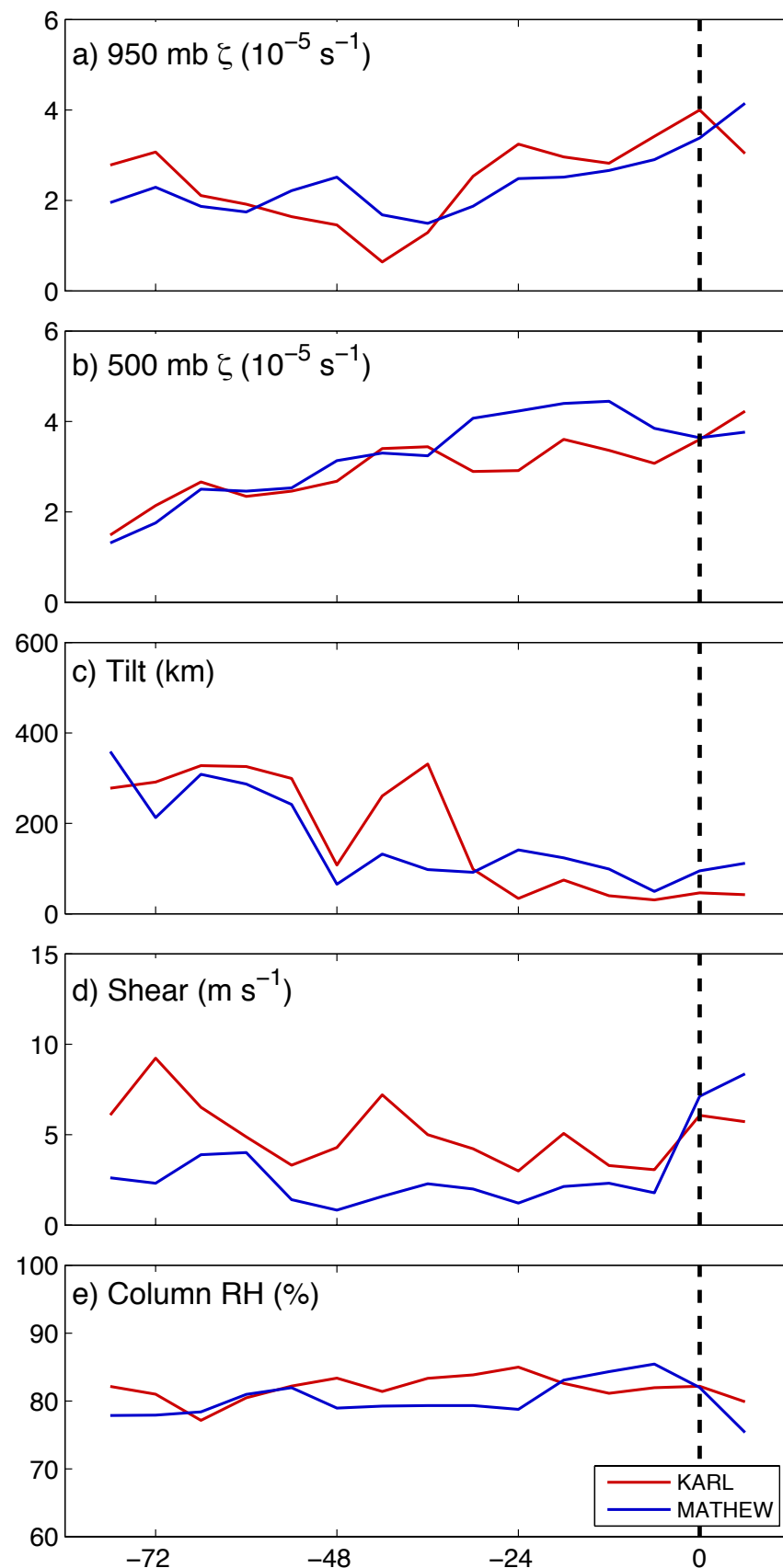
- Forecasts initialized 18 h prior to genesis.
- Dashed: 200 mb storm-relative streamlines.

## Mathew



- Shaded: 200 mb divergence ( $10^{-4}\text{s}^{-1}$ ).
- Grid centered over low-level vorticity maximum.

# E4DVar Analyses

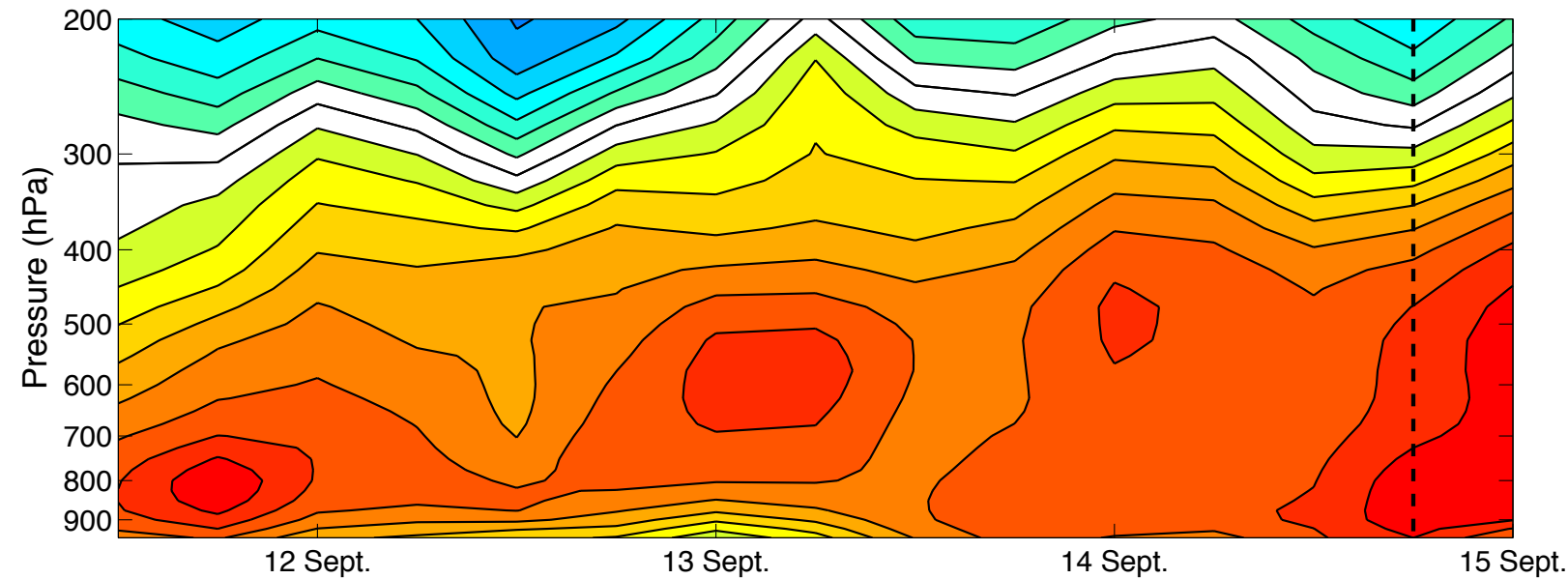


- Karl's analyses from 12 UTC Sept. 11th to 00 UTC Sept. 15th.
- Mathew's analyses from 12 UTC Sept. 20th to 00 UTC Sept. 24th.
- Vorticity, Tilt, Shear and Column RH calculated within 3 degrees of the storm center.
- Both Karl and Mathew showed relatively the same trend prior too and during genesis.



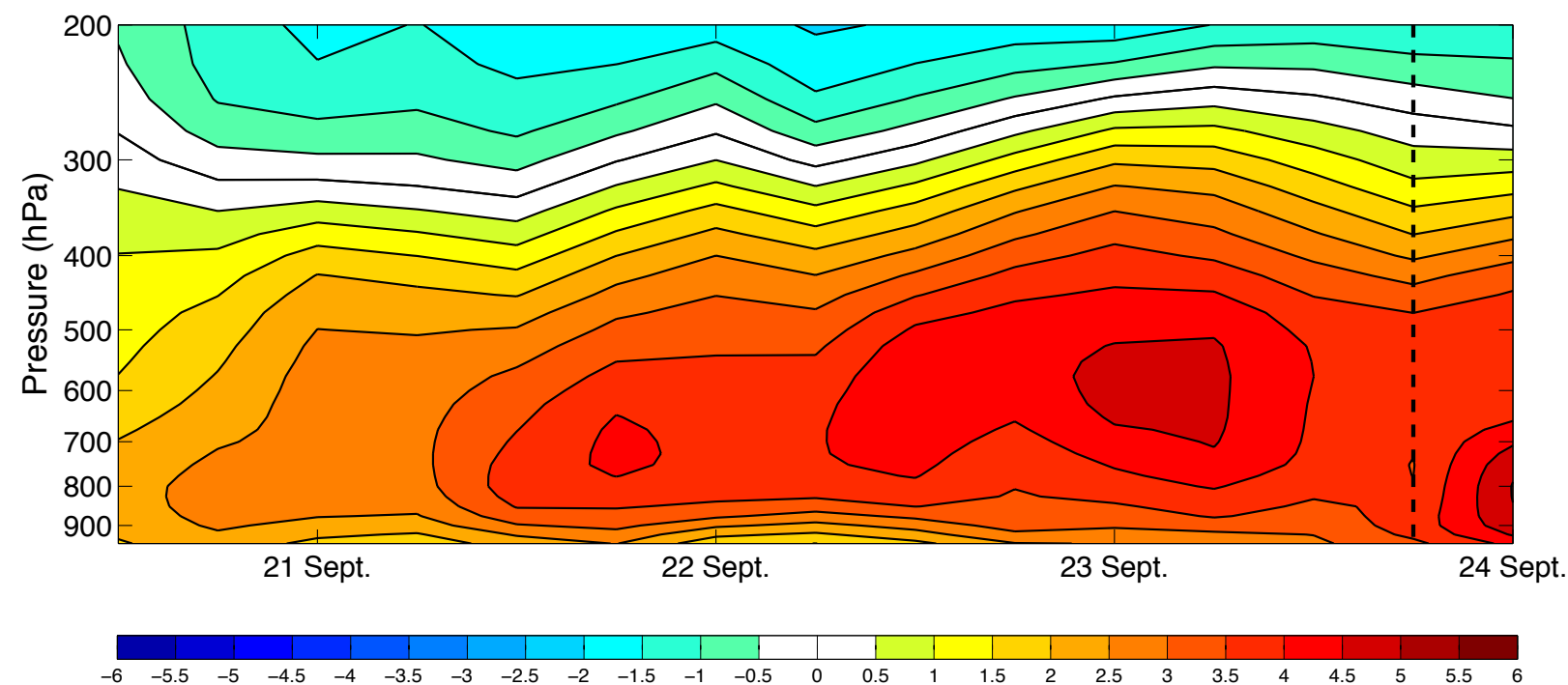
# Vorticity ( $\zeta$ ) Profile

## Karl

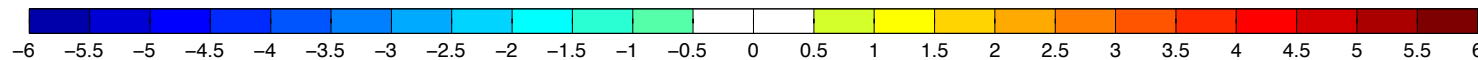


- Karl analysis from 12 UTC Sept. 11th to 00 UTC Sept. 15th.
- Mathew analysis from 12 UTC Sept. 20th to 00 UTC Sept. 24th.

## Mathew

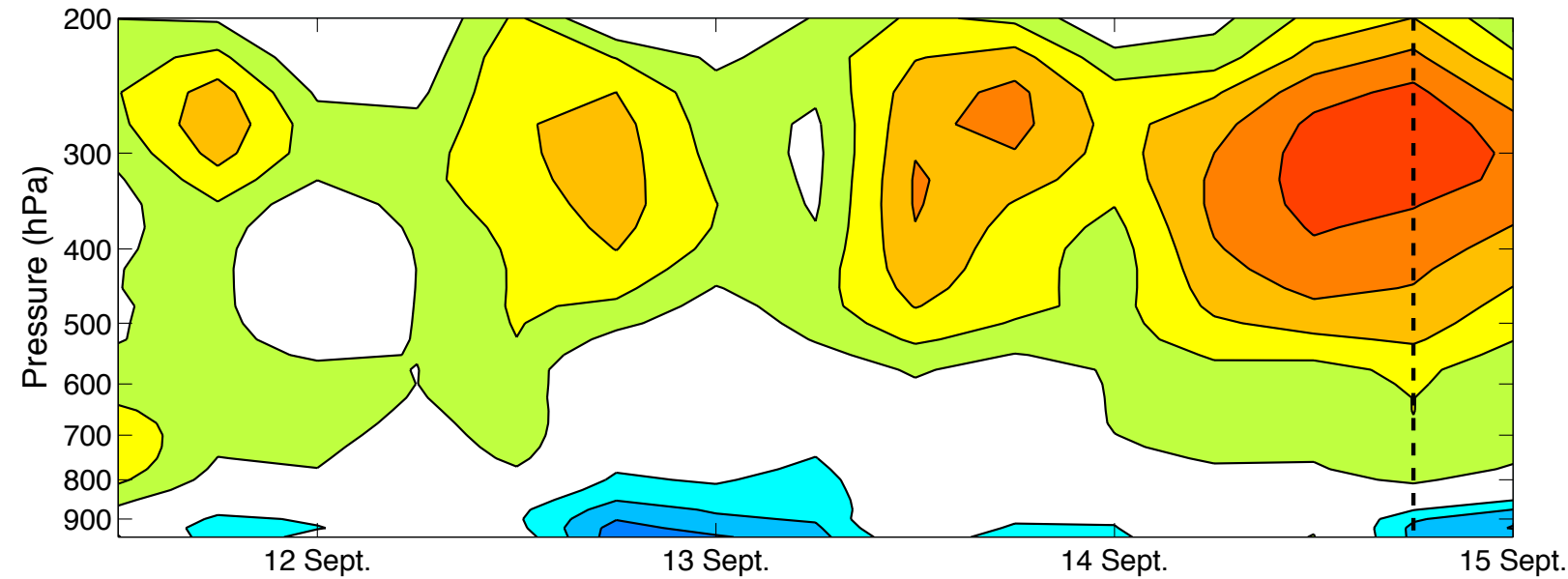


- Mean Vorticity ( $10^{-5}\text{s}^{-1}$ ) calculated within 3 degrees of the storm center.
- Mathew has a stronger mean mid-level vorticity prior to genesis in comparison to Karl.



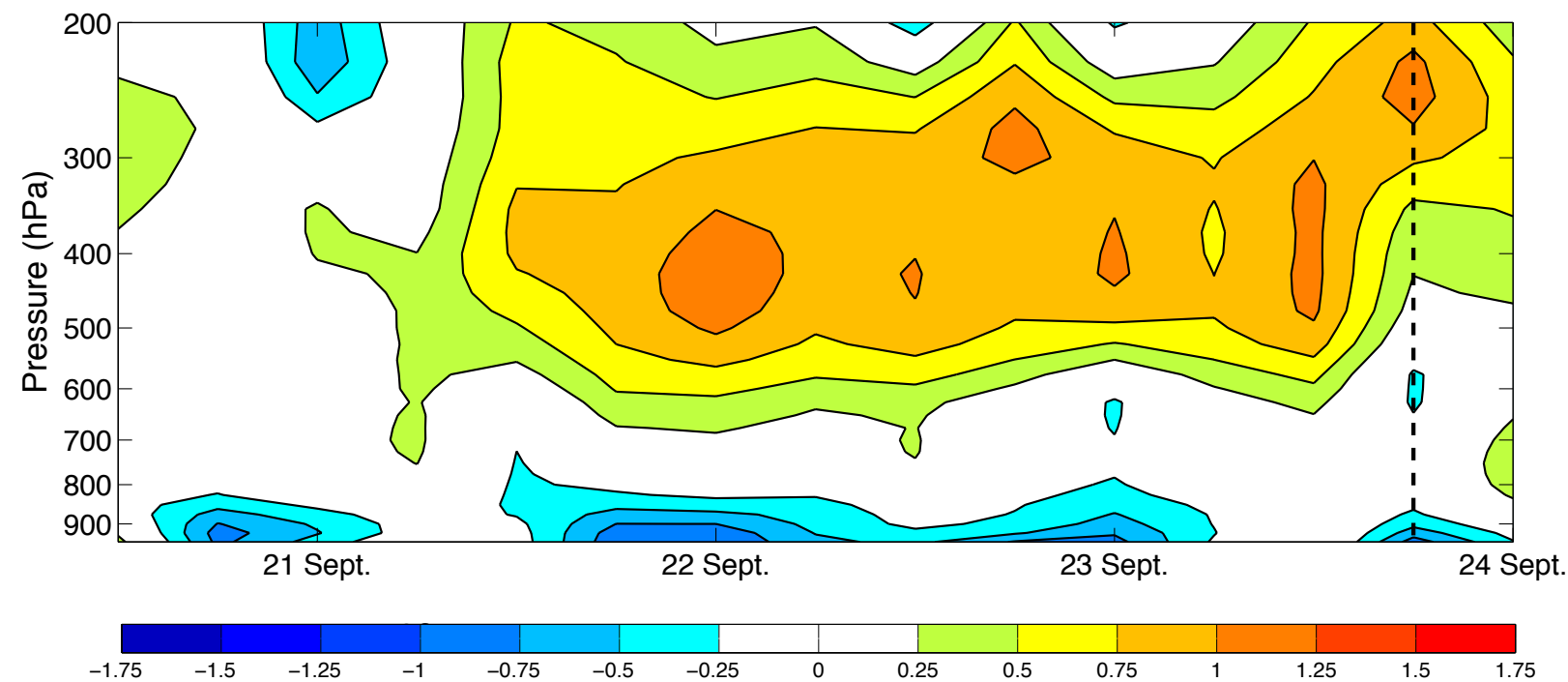
# Perturbation of Potential Temperature ( $\theta'$ ) Profile

## Karl

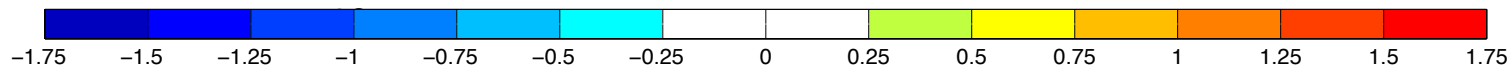


- Karl analysis from 12 UTC Sept. 11th to 00 UTC Sept. 15th.
- Mathew analysis from 12 UTC Sept. 20th to 00 UTC Sept. 24th.

## Mathew

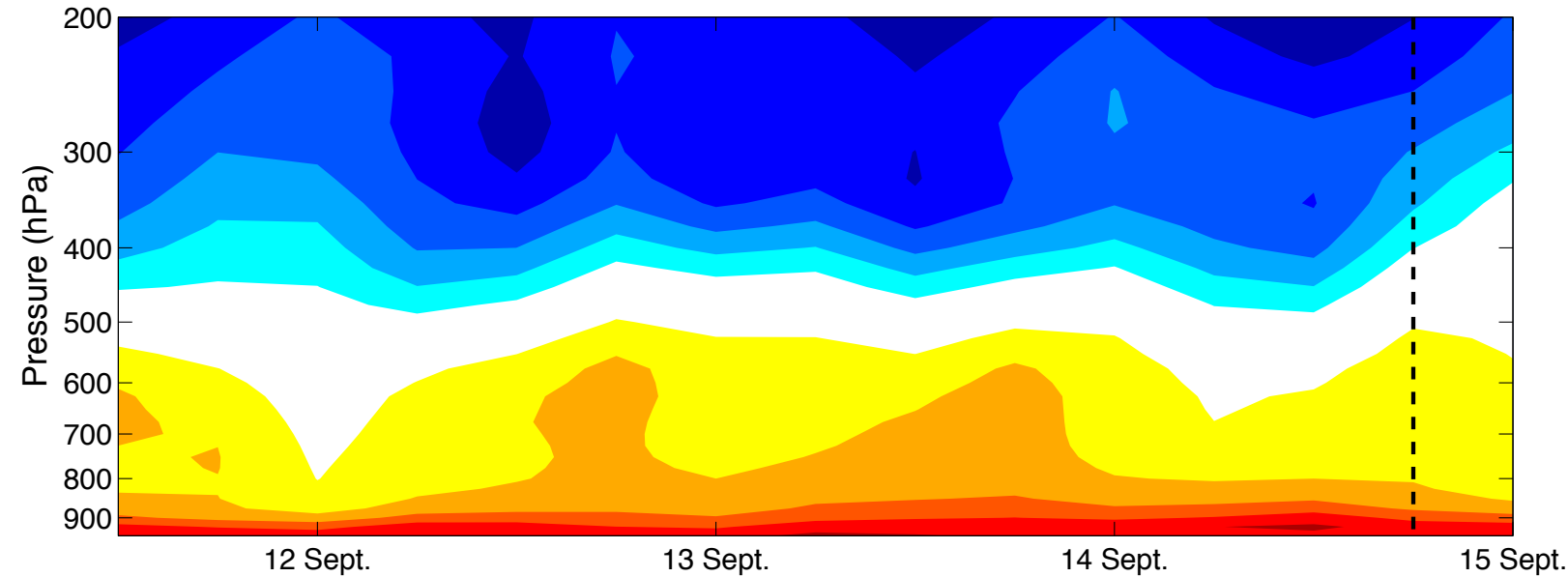


- Warming in the mid to upper levels prior to genesis.
- Cooling at the surface together with warming in the upper levels at time of genesis.



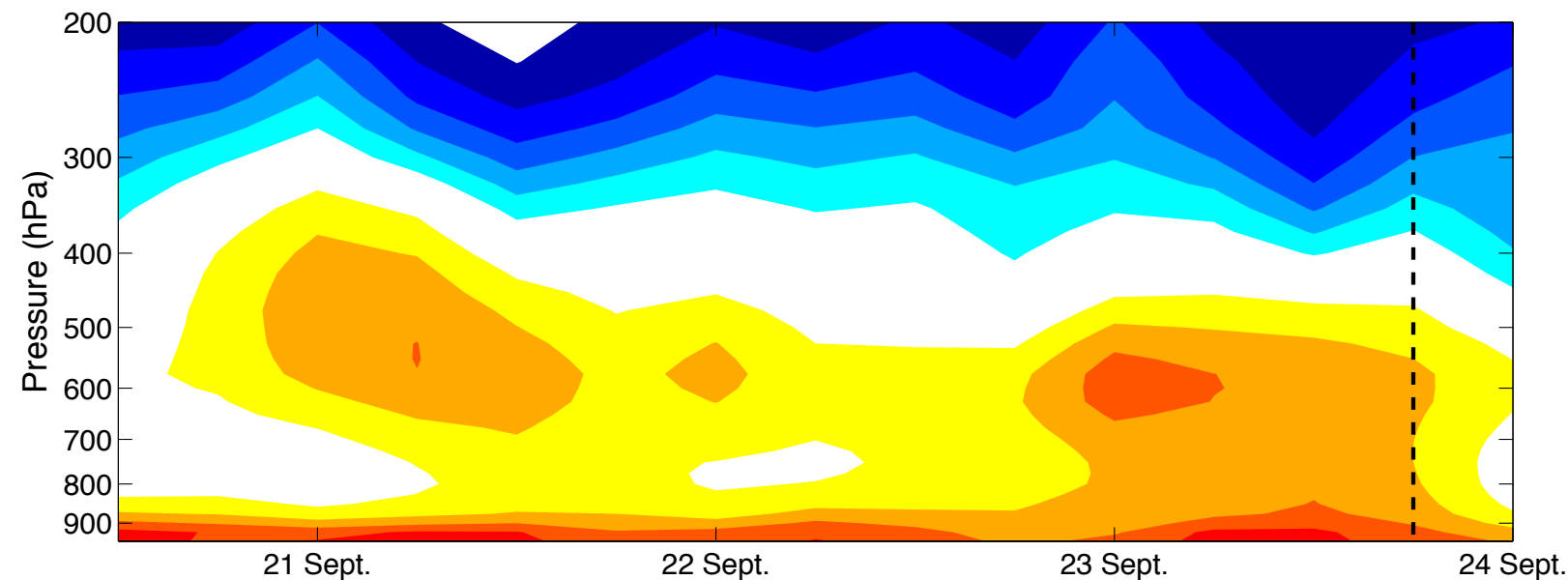
# Relative Humidity Profile (3 Degree Avg)

## Karl

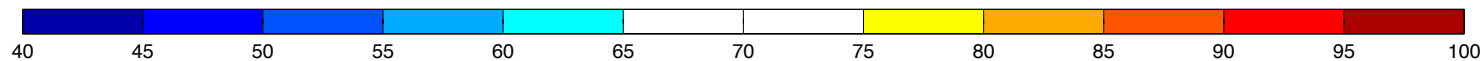


- Karl analysis from 12 UTC Sept. 11th to 00 UTC Sept. 15th.
- Mathew analysis from 12 UTC Sept. 20th to 00 UTC Sept. 24th.

## Mathew

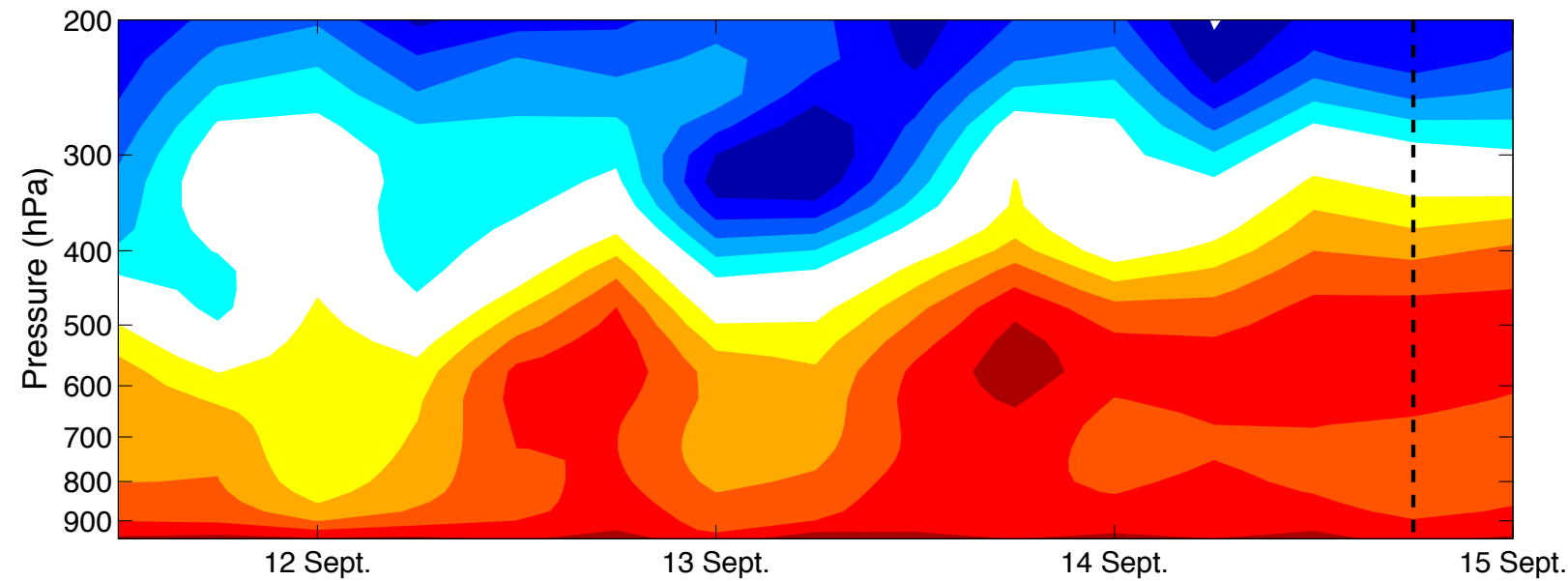


- Mean Relative Humidity (%) calculated within 3 degrees of the storm center.



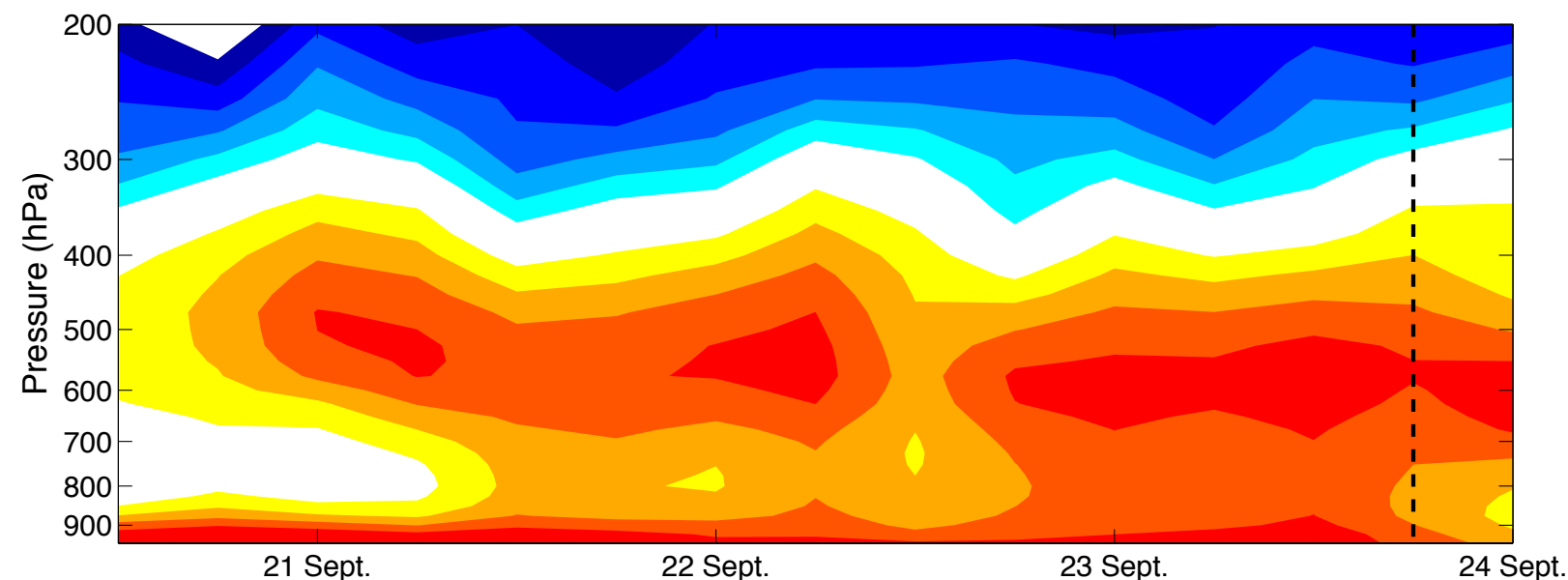
# Relative Humidity Profile (1 Degree Avg)

## Karl

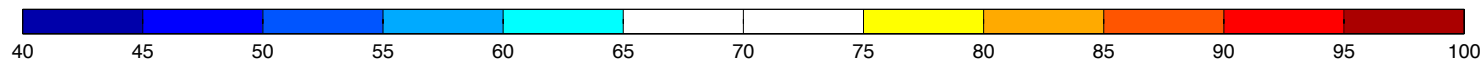


- Karl analysis from 12 UTC Sept. 11th to 00 UTC Sept. 15th.
- Mathew analysis from 12 UTC Sept. 20th to 00 UTC Sept. 24th.

## Mathew



- Mean Relative Humidity (%) calculated within 1 degrees of the storm center.



# Summary and Future Work

- E4DVar has shown significant skill in the genesis of both hurricane Karl and tropical storm Mathew.
  - ▶ E4DVar is able to accurately predict the genesis of Mathew 42 h in advance, which is a significant improvement over the NHC operational forecasts.
- ★ Add GRIP dropsondes and sounding observations to Karl PREDICT case with a 1.5-km two way nested domain.
- ★ Perform an independent quantitative verification using ECMWF analysis for both Karl and Mathew.
- ★ Conduct ensemble sensitivity runs for both Karl and Mathew.
- ★ Analyze the 1.5-km simulations to investigate the dynamics associated with the genesis of Karl and Mathew.

**THANK YOU**