A sea drag relation for hurricane wind speeds

Air-sea interaction and sea-state forecasting in extreme weather events

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Outline

Introduction

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- Aim

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Background

Air-sea interaction: understanding of e.g.

- interaction between wind and waves
- impact of sea spray droplets on the momentum and energy budget near the sea surface

Important for e.g. weather, wave and storm surge forecasting, particularly in severe weather conditions

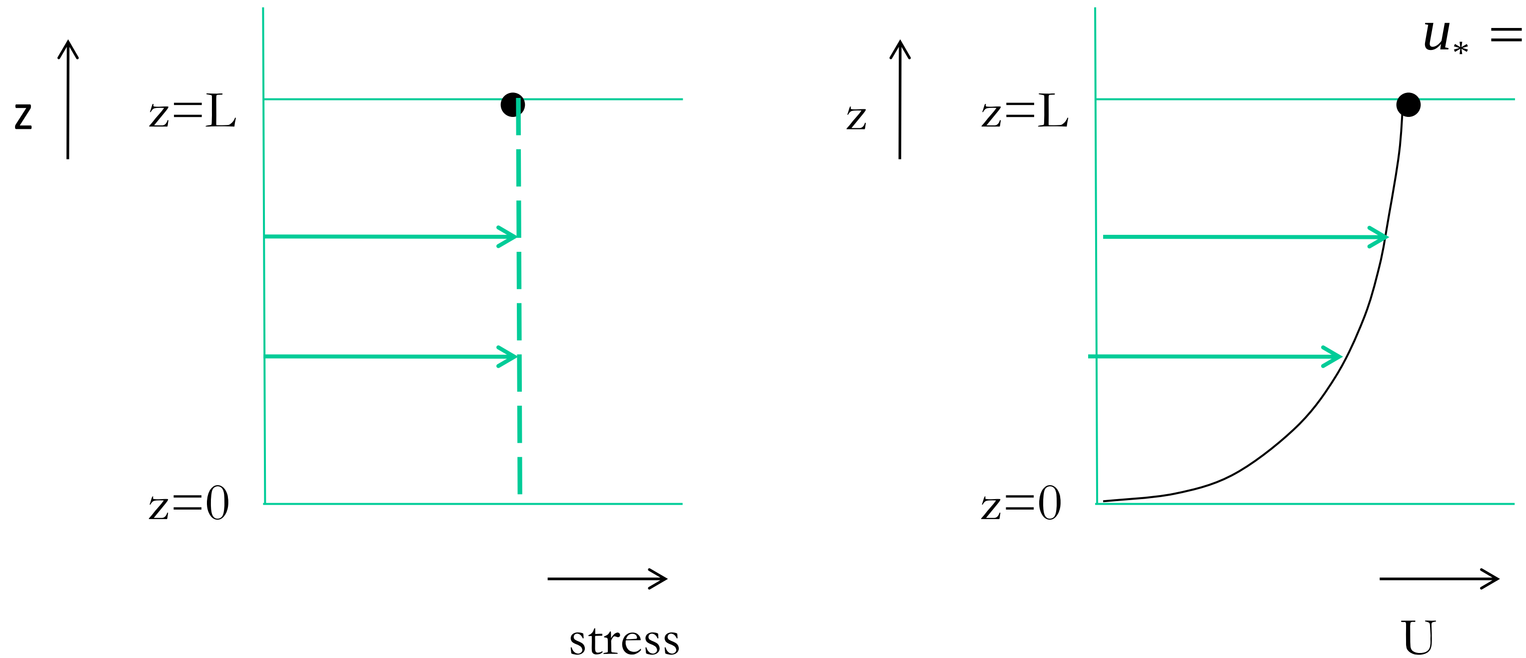
Here, focus on hurricanes

Background

- 10-meter wind field commonly based on constant flux layer assumption

$$U(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$

$$u_* = \sqrt{\tau / \rho_a}$$



Background

- Momentum flux computation in NWP models and oceanographic applications is based on a relation for the drag coefficient

Wind stress: $\tau \equiv \rho_a {u_*}^2 = \rho_a C_D U_L^2$

Drag coefficient: $C_D = (u_* / U(z))^2 \sim \ln^{-2}(z / z_0)$

- Tuning parameter for U_{10} and C_D is the roughness length z_0

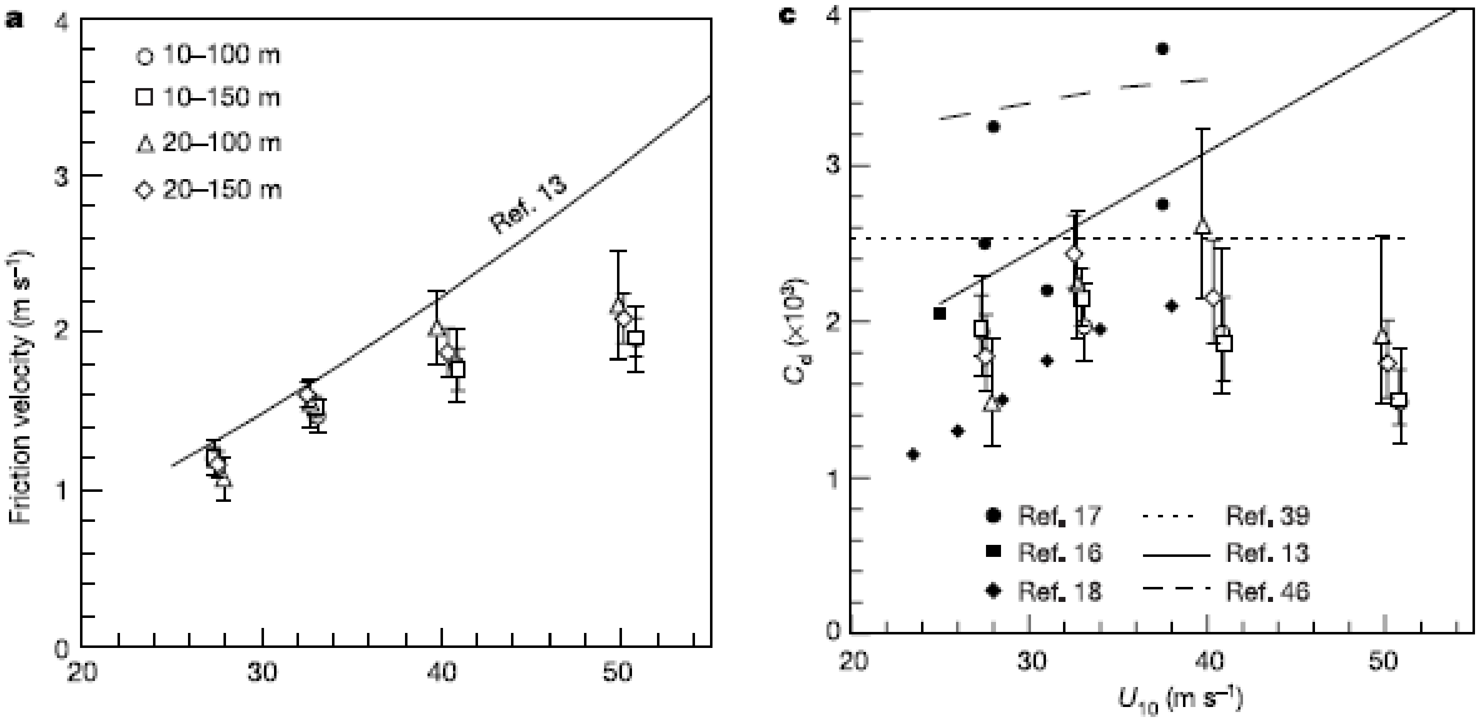
Background

- Usually z_0 is based on the Charnock relation: $$z_0 = z_* \frac{{u_*}^2}{g}$$
- z_*: Charnock parameter, 0.010-0.034
- Formulation works well, predicts the observed linear increase of C_{D10} with increasing U_{10}

- However, for hurricane wind speeds the situation is different…

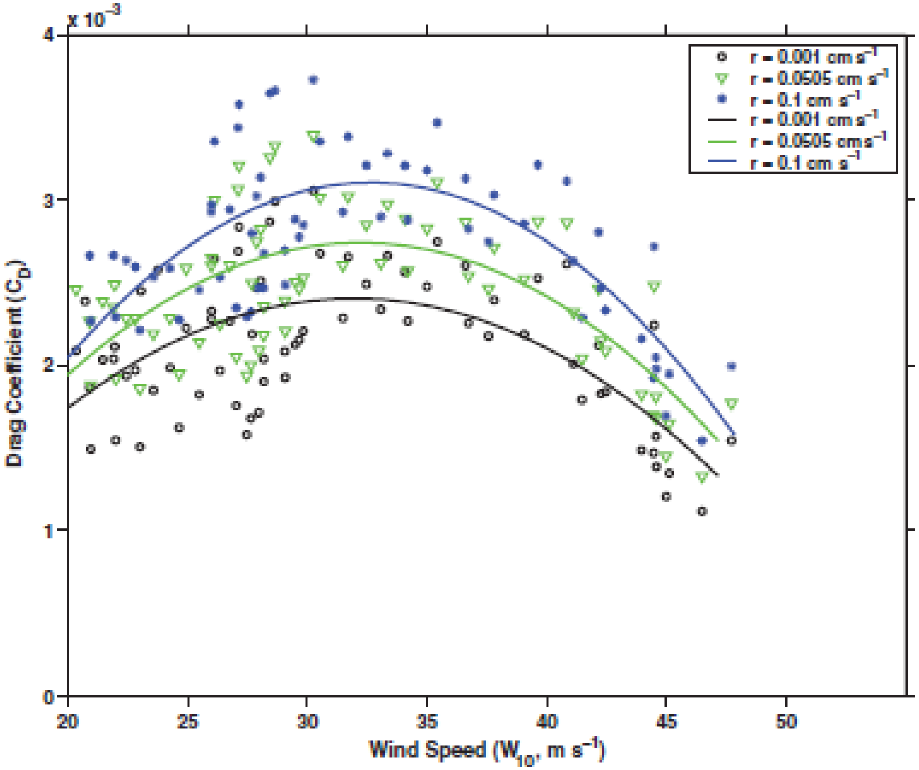
Background

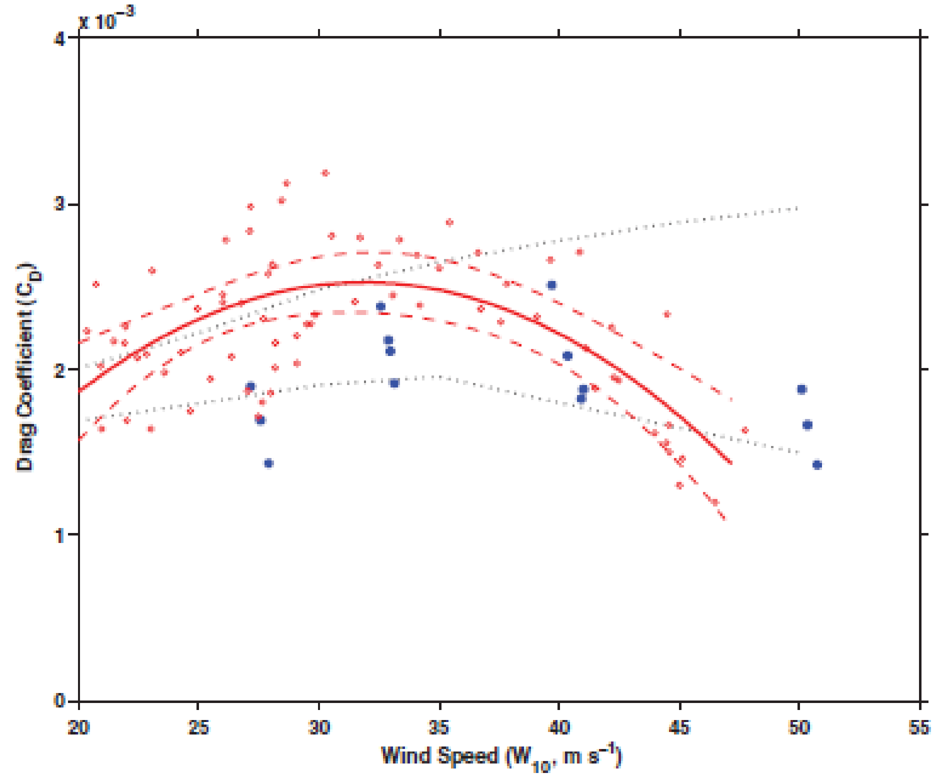
Powell et al. (2003) show – by analysis of observational data – that u_* starts to saturate for very high wind speeds and that the magnitude of C_D decreases



Background

- Another paper (for the disbeliever): Jarosz et al. (2007)





Background

- Why does the drag coefficient decrease for high wind speed?

- Formation of a foam layer that forms a ‘slip’ surface, which reduces the sea drag
- Injection of sea spray droplets into the atmospheric flow, by which a stable suspension layer is formed

Background

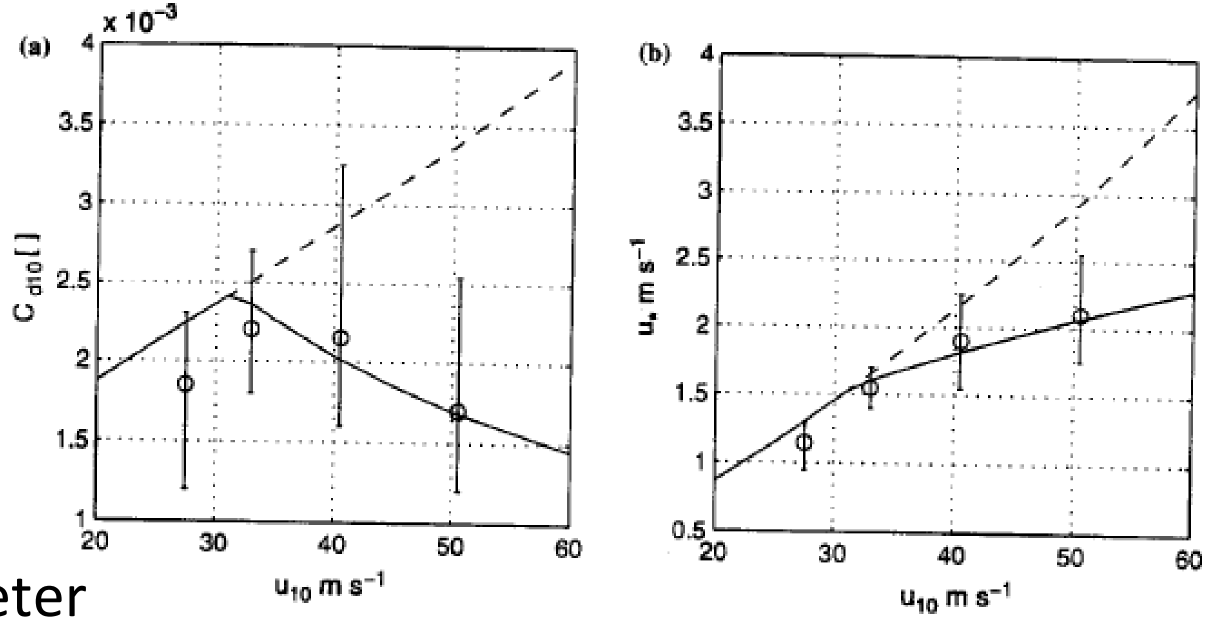
- Makin (2005): directly above the air-sea interface a suspension layer is formed where sea spray droplets are injected in and absorbed by the atmospheric flow
- Solve the turbulent kinetic energy (TKE) equation for a flow with suspended particles
- Makin (2005) suggests a sea drag relation that predicts the decrease in C_D

Aim

- We implement a drag parameterization – based on Makin (2005) – in HIRLAM, one of our (operational) NWP models
- Modeling several hurricanes, we examine the impact of the parameterization on the <u>prediction of the hurricane track</u>, <u>10-meter wind speed</u> and <u>sea level pressure</u>

- The parameterization by Makin (2005):

$$z_0 = c_l^{1-1/\omega} c_{z_0}^{1/\omega} u_*^2 / g$$



with

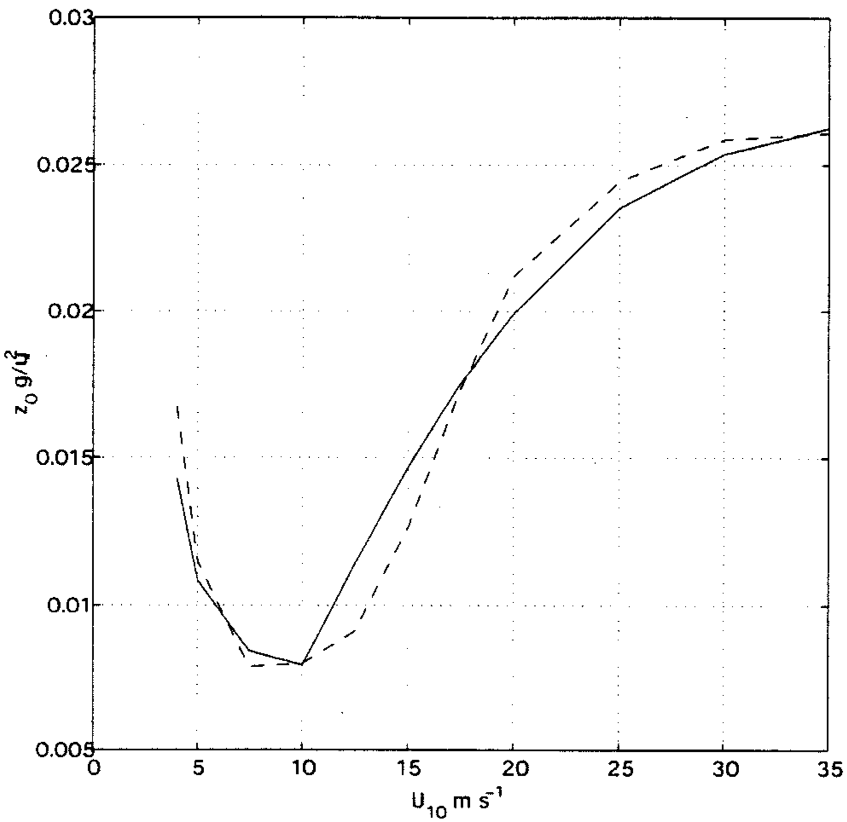
c_{z0}: Charnock parameter

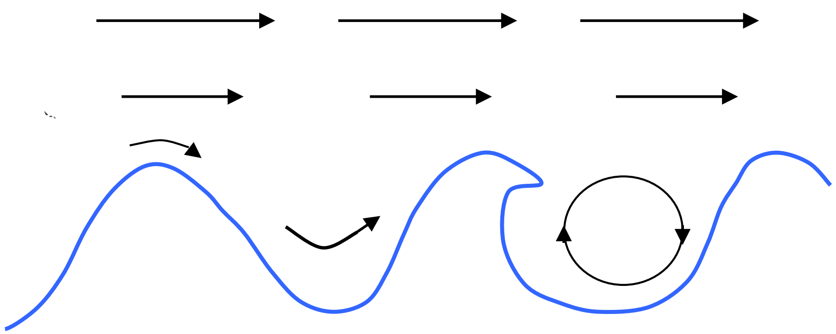
$\omega = \min[1, a_{crit} / \kappa u_*]$

a_{crit}: critical terminal fall velocity

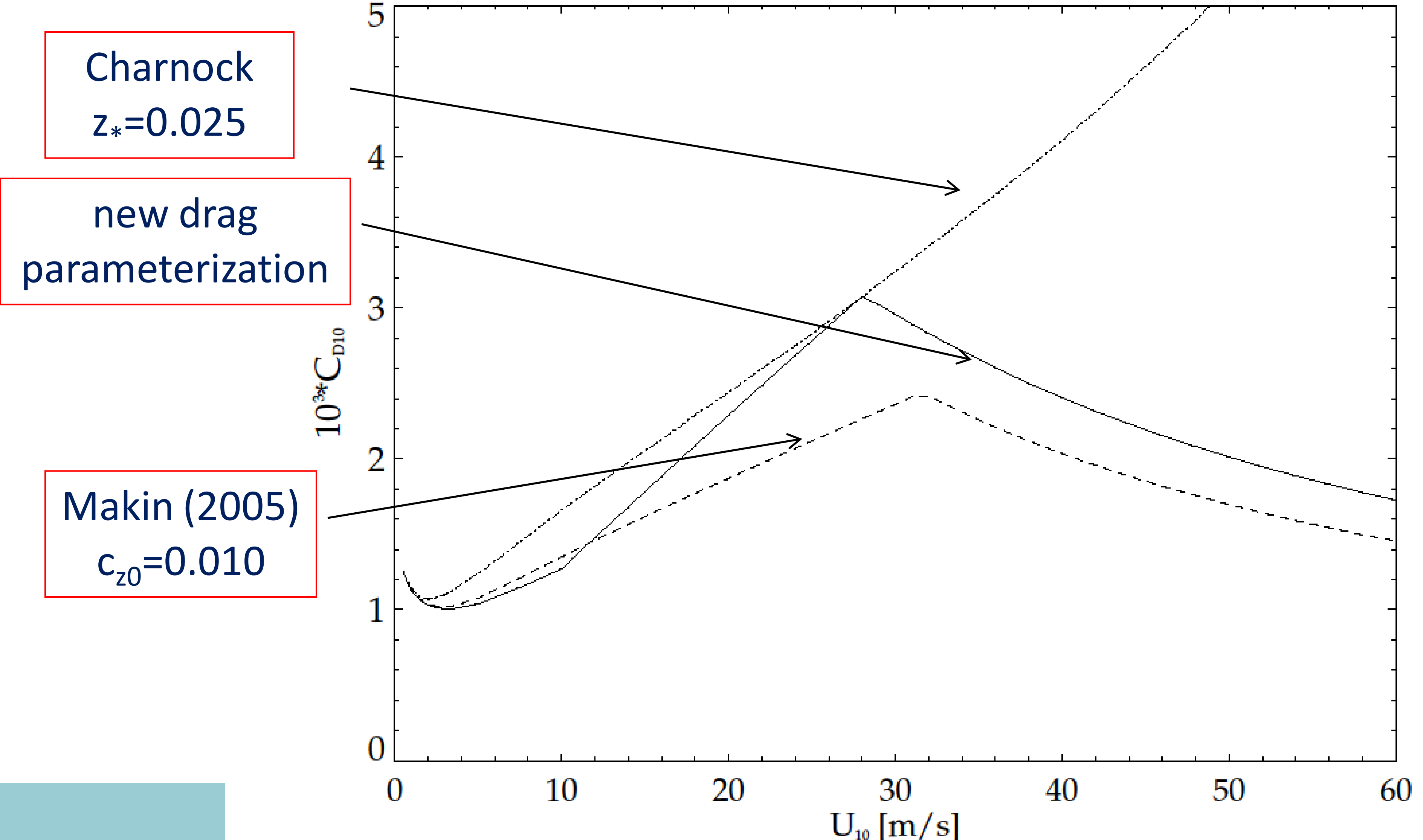
c_l: constant

- Makin (2005): c_{z0}=0.010
- Present study: $c_{z0}=f(U_{10})$ from Makin (2003)





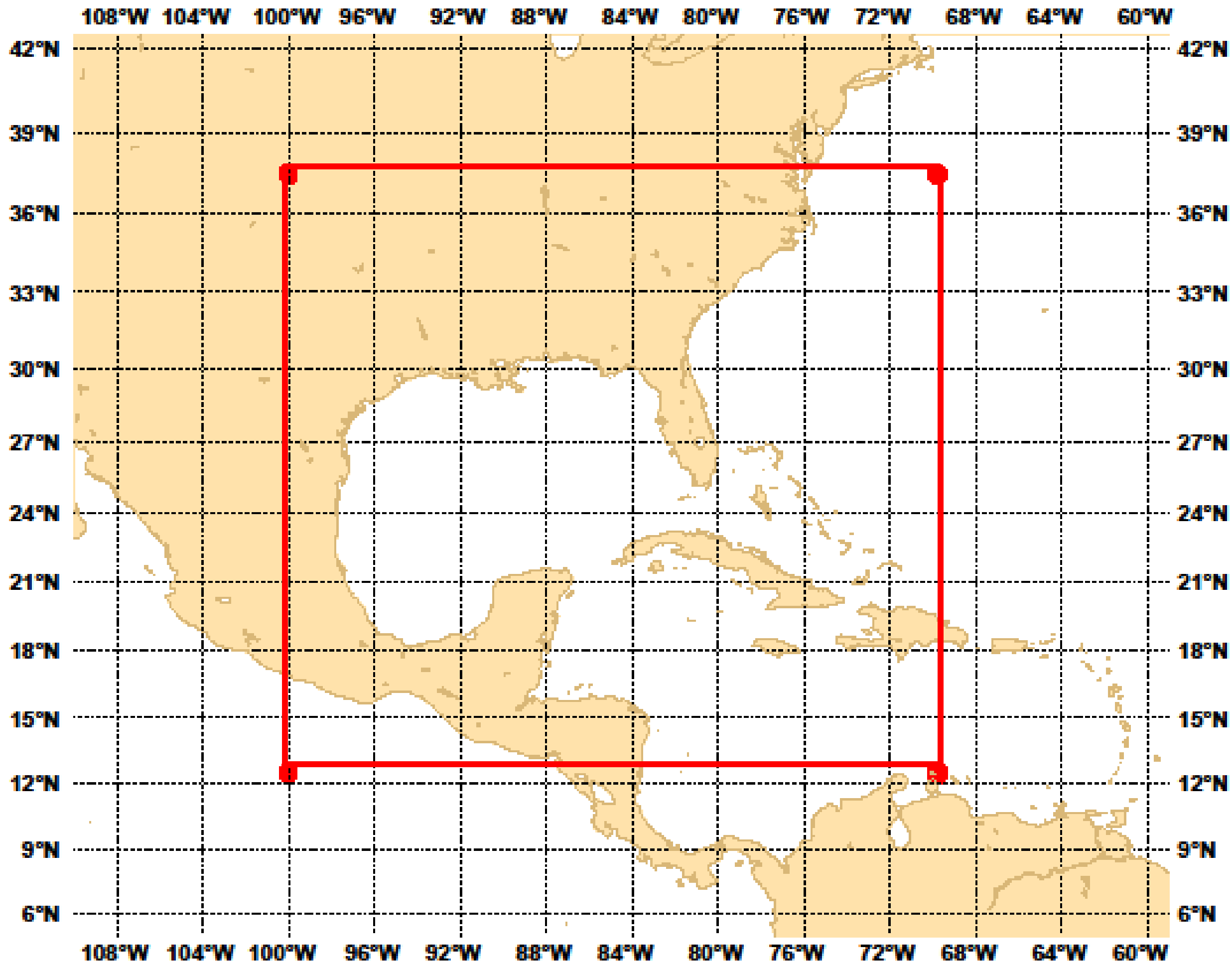
Methodology drag coefficient



Methodology simulations

HIRLAM in the Gulf of Mexico

Resolution: 5km



Methodology simulations

- Simulate two hurricanes: Katrina (2005) and Ivan (2004)
- Forecasts with duration of +48h, +72h, +96h
- Forecasts with 6-hours analysis cycle, analysis based on previous forecast and assimilation of observations

- Do this for the default drag relation (Charnock) and the new drag parameterization

Results

hurricane track

Katrina

■ observed

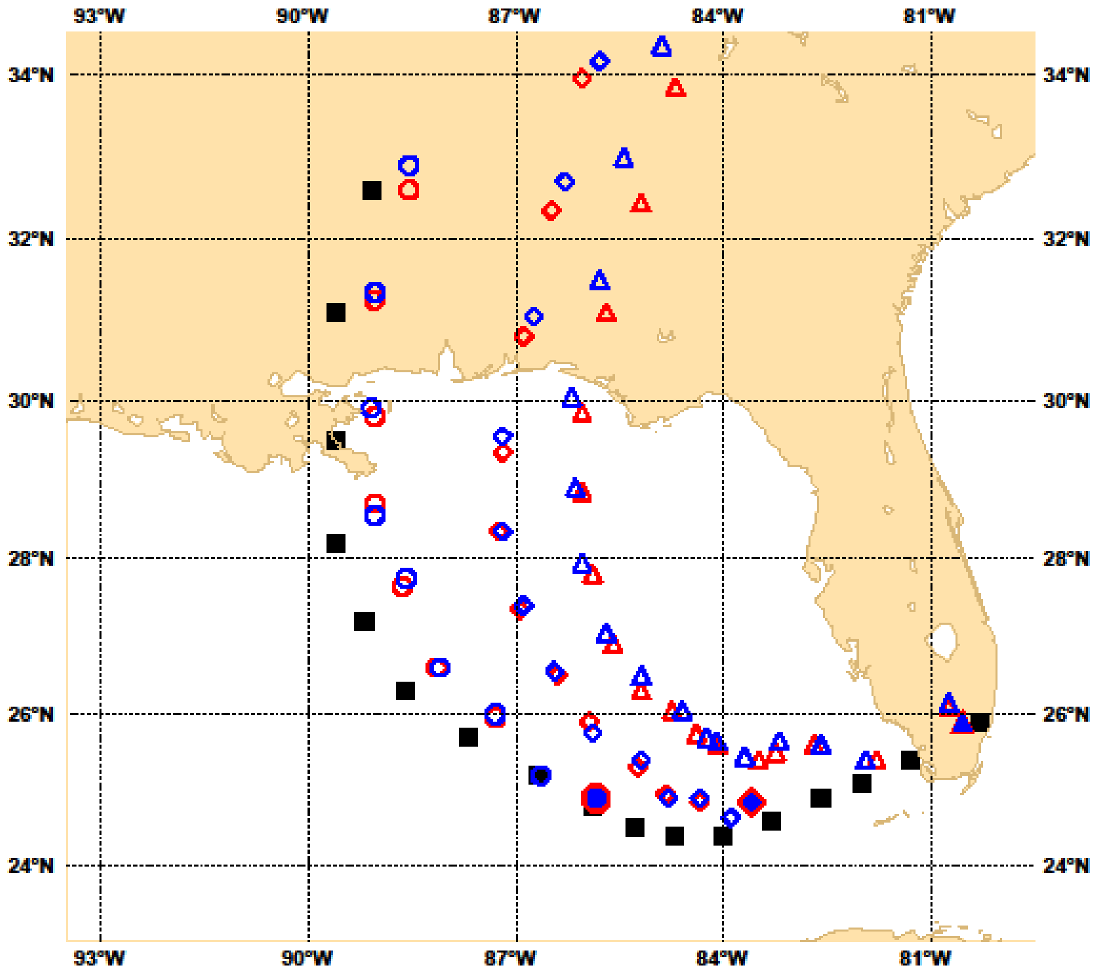
Modeled:

Charnock relation

New parameterization

for

+48h, +72h, +96h



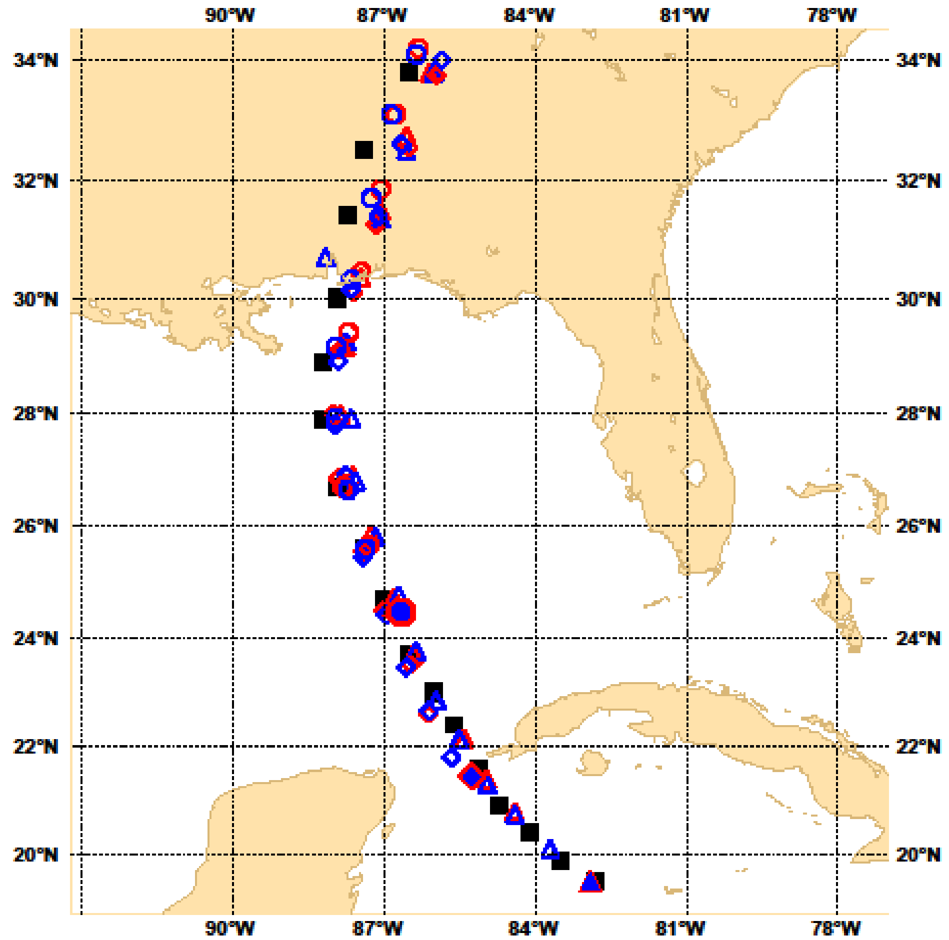
Results hurricane track

Ivan

■ observed

Modeled:
Charnock relation
New parameterization

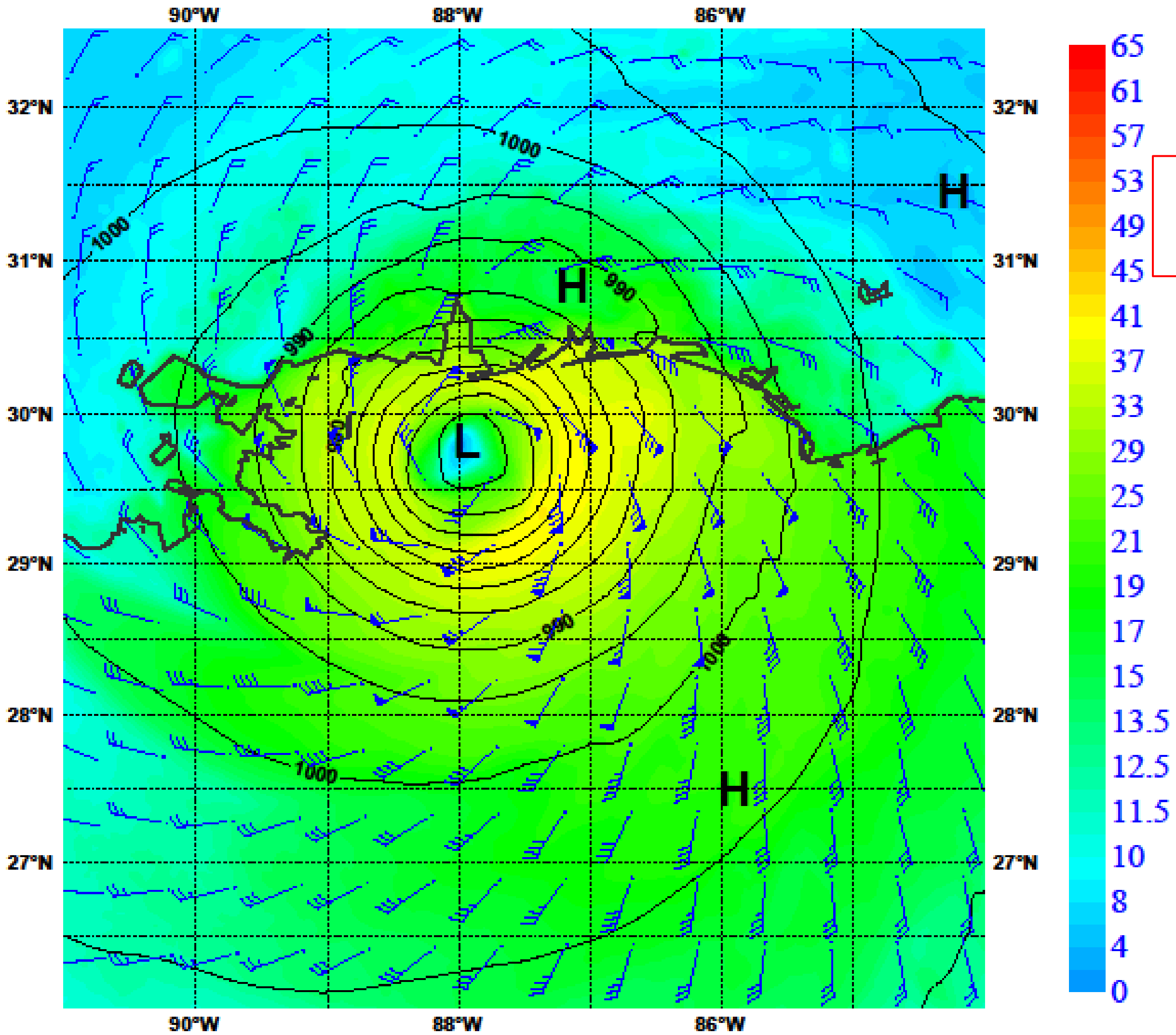
for
+48h, +72h, +96h



With the new drag parameterization in HIRLAM the prediction of the hurricane track does not change, compared to the common Charnock relation

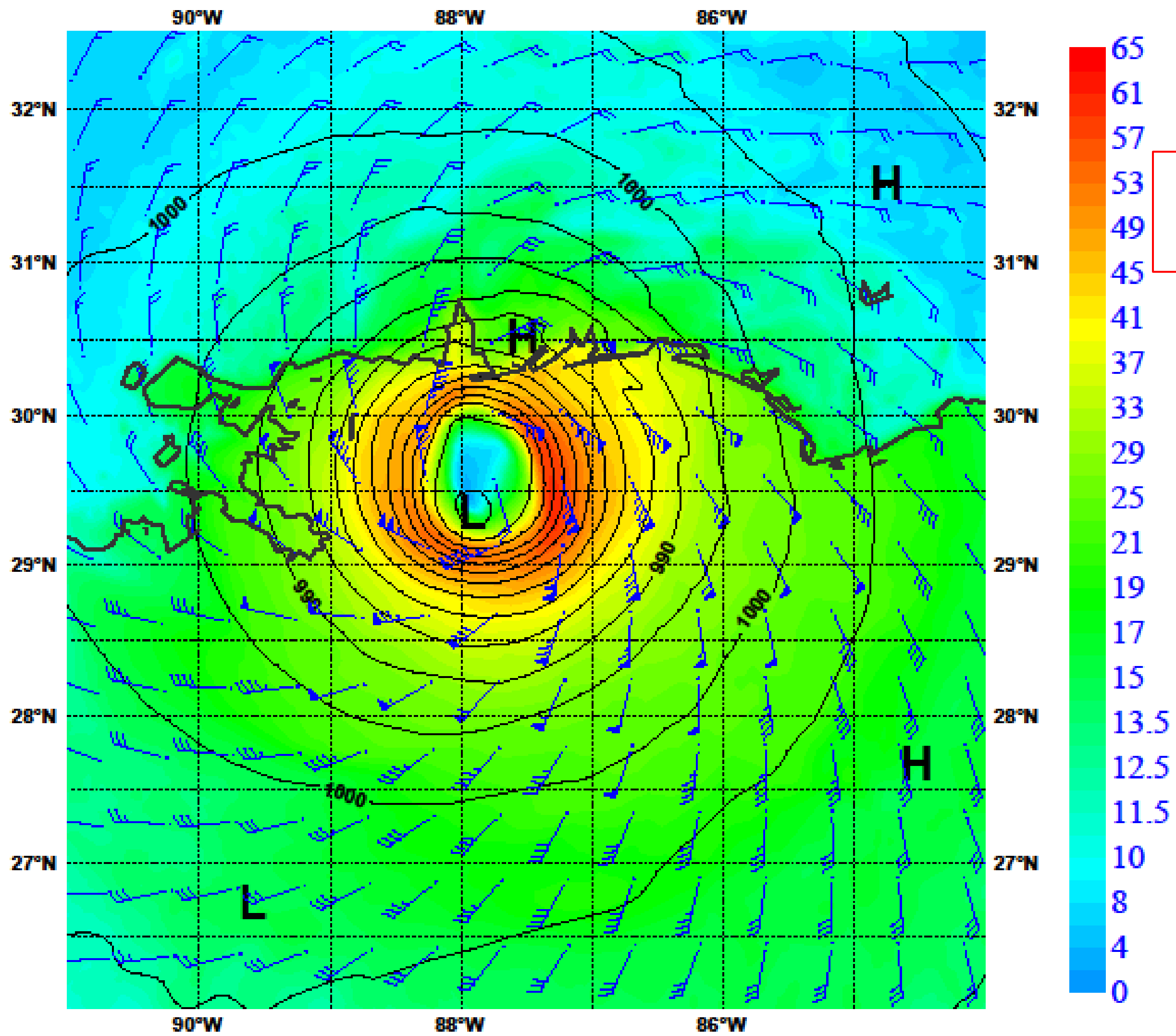
Results

Ivan



Charnock relation

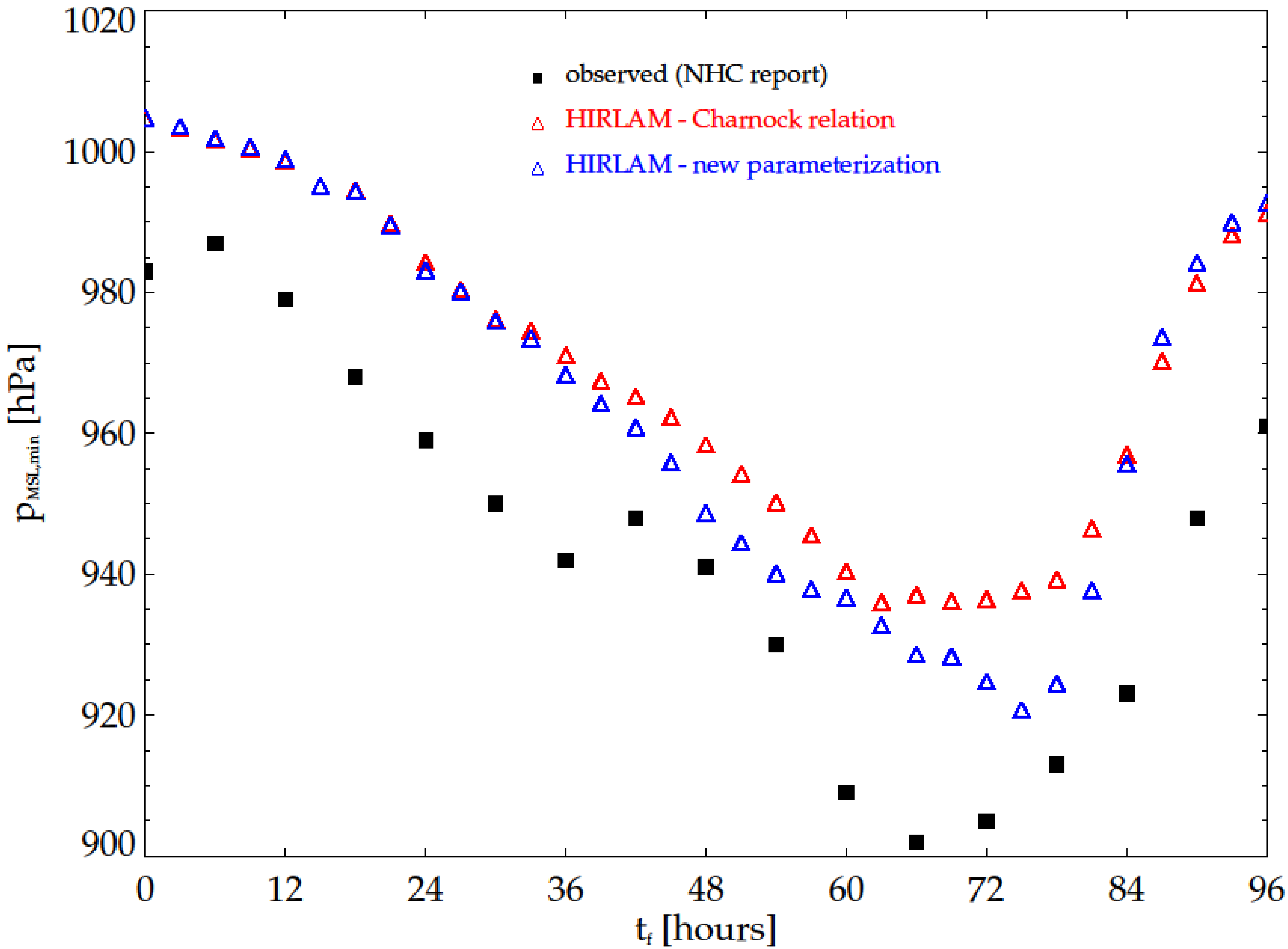
Ivan



new parameterization

Sea level pressure

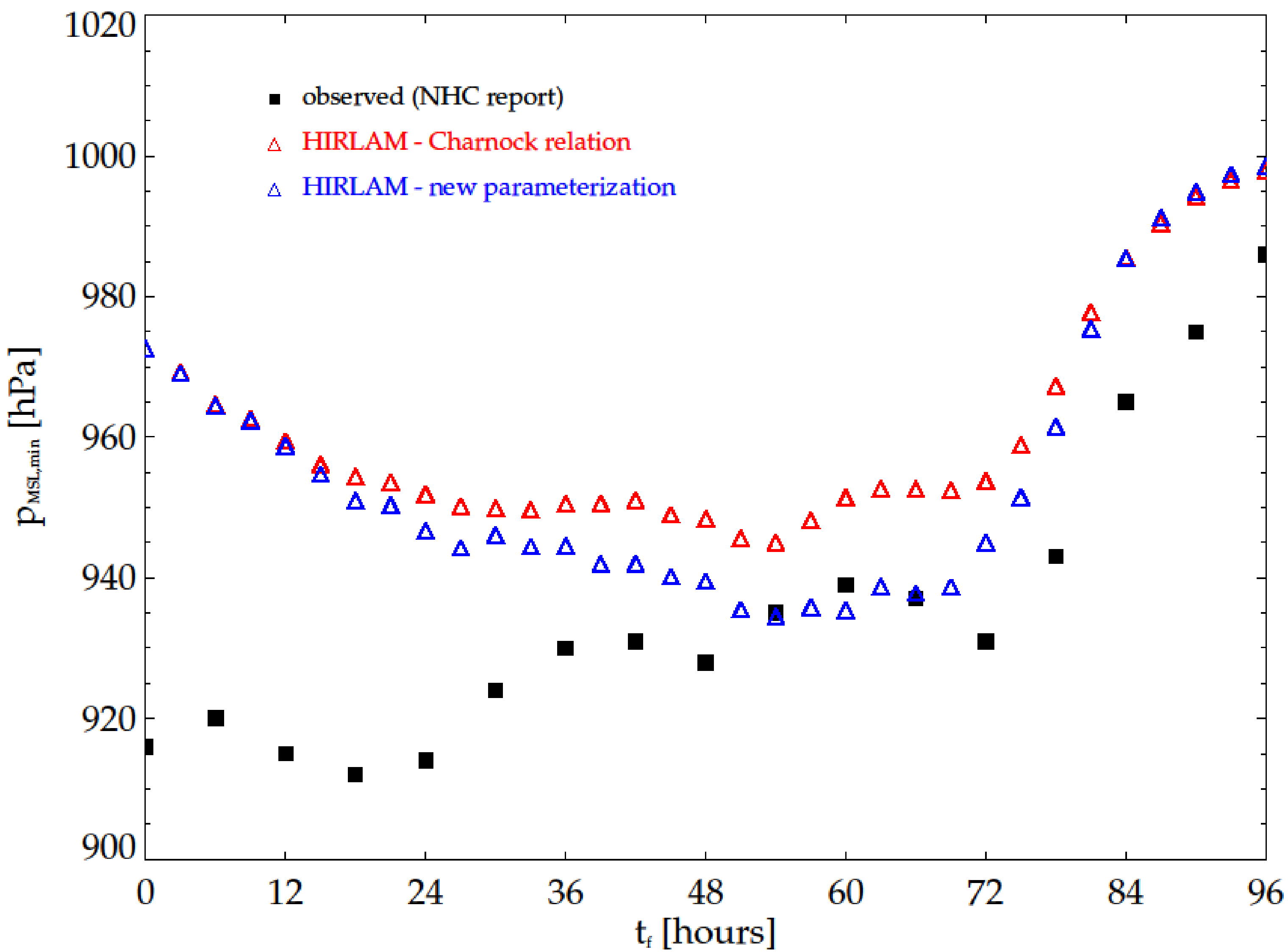
Katrina



Results

Sea level pressure

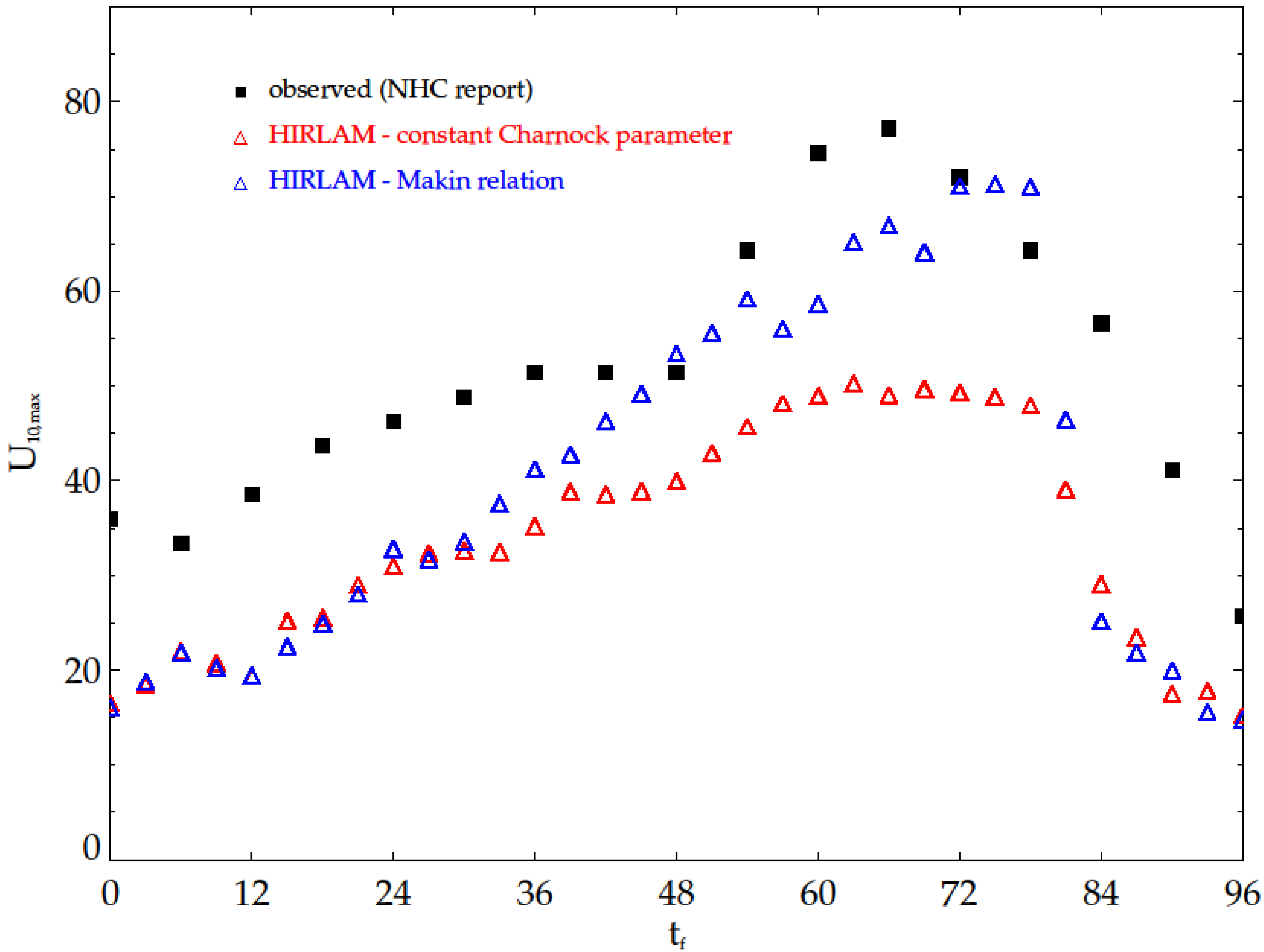
Ivan



Results

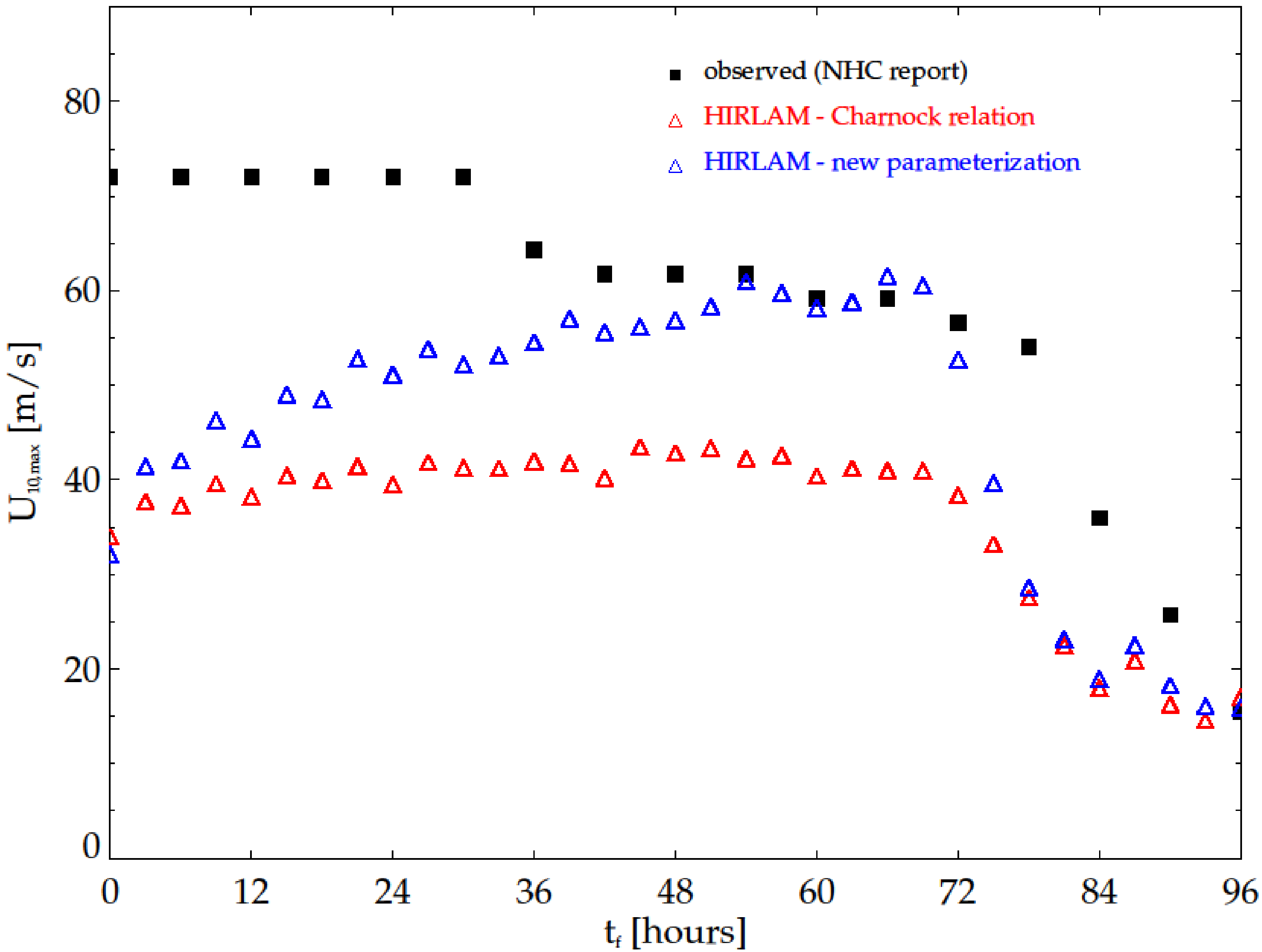
10-meter wind

Katrina



10-meter wind

Ivan

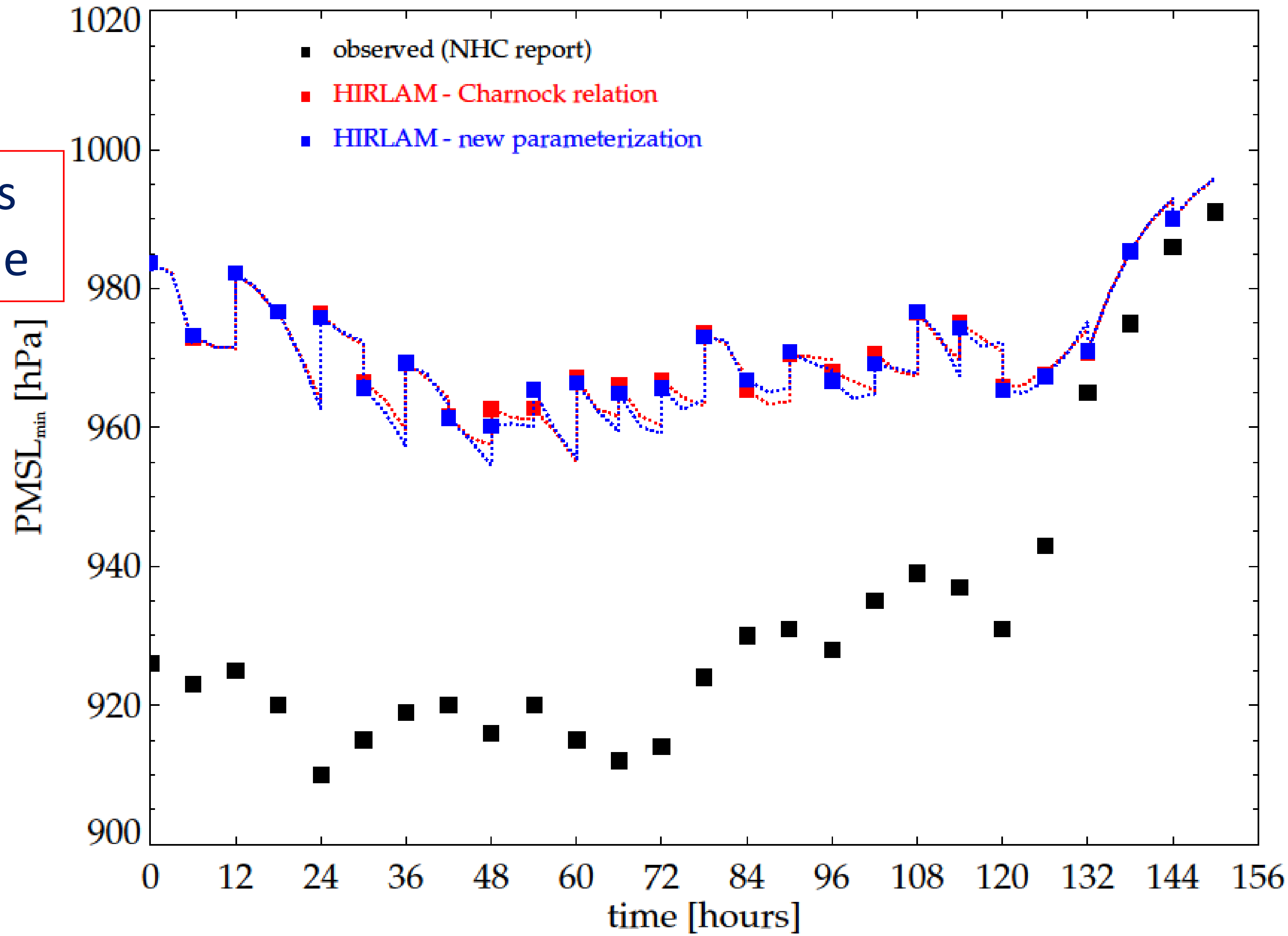


Results

sea level pressure

Ivan

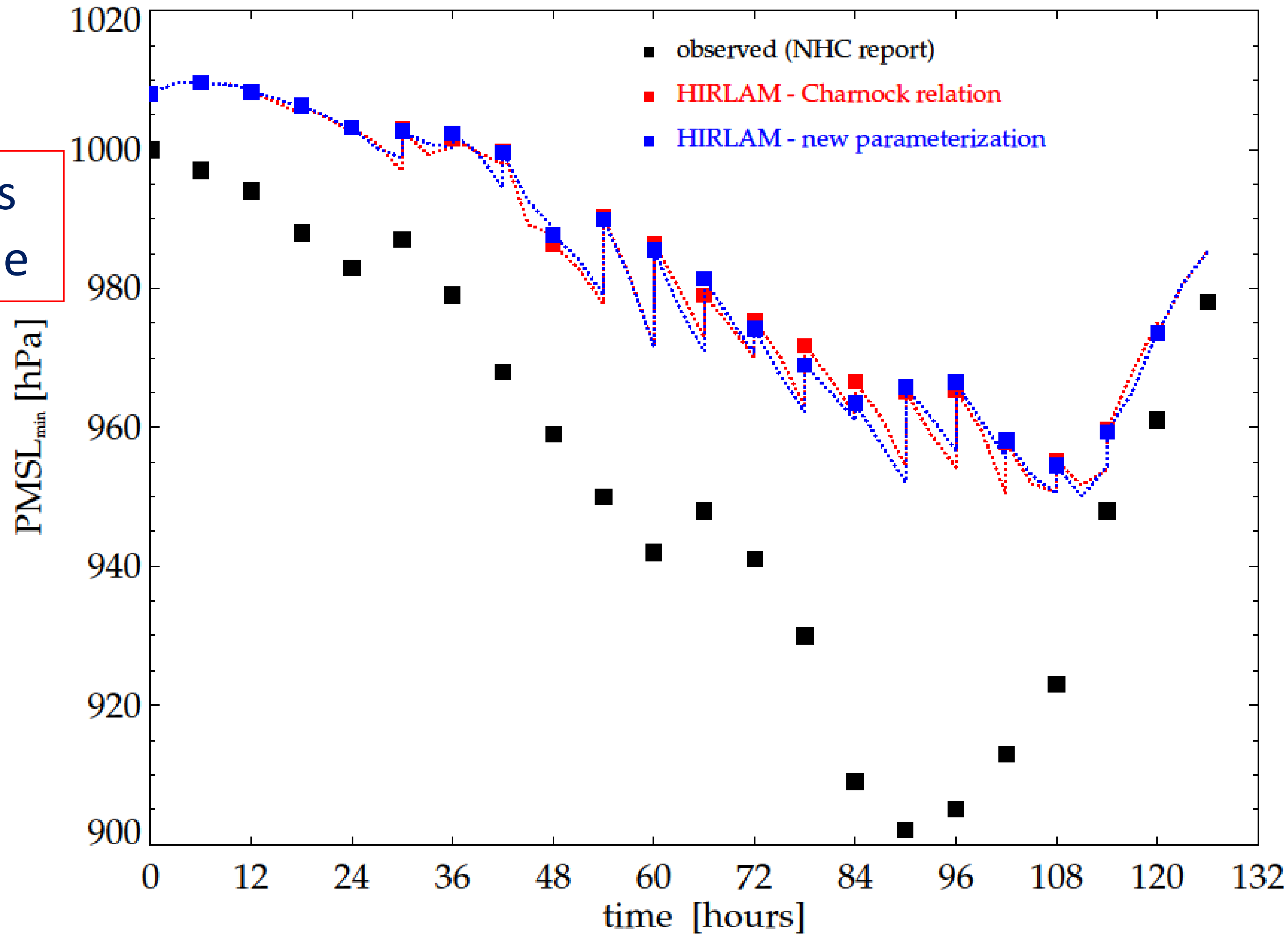
with 6-hours analysis cycle



Results — sea level pressure

Katrina

with 6-hours analysis cycle

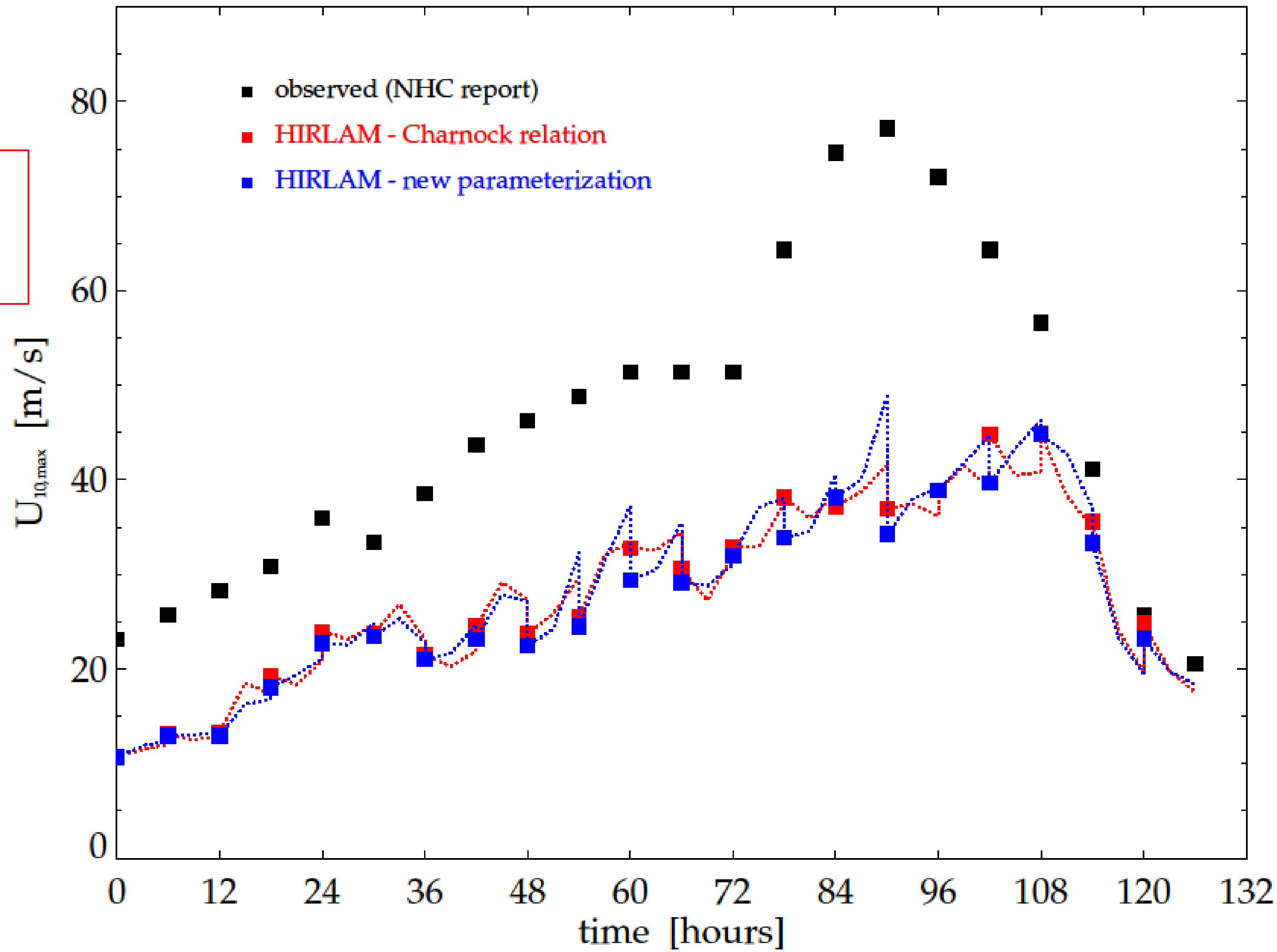


Results

10-meter wind

Katrina

with 6-hours analysis cycle



Conclusion

- With the common Charnock relation simulated hurricanes are too weak
- With the new drag parameterization, that predicts the observed decrease in the drag coefficient, the hurricanes are more intense in the forecasts; the results show quite good agreement with observations of extremes
- With a 6-hours analysis cycle, with assimilation of observations, the forecasts are suppressed by the analysis almost continuously

Possible reasons:

- Six hour interval is too long, the hurricane is at another position
- Observations from outside the hurricane have too much impact on the hurricane

Conclusion

Ongoing work:

- The impact of the analysis cycle and assimilation of observations in HIRLAM
- The impact of the drag parameterization in storm surge modeling; first simulations with Delft3D (in cooperation with Deltares), show positive results

Thank you for

your attention

Questions?

Suggestions?