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Estimating Zonal Ekman Transport along Coastal Senegal during passage of Hurricane Fred, 30 – 31 August 2015

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Outline

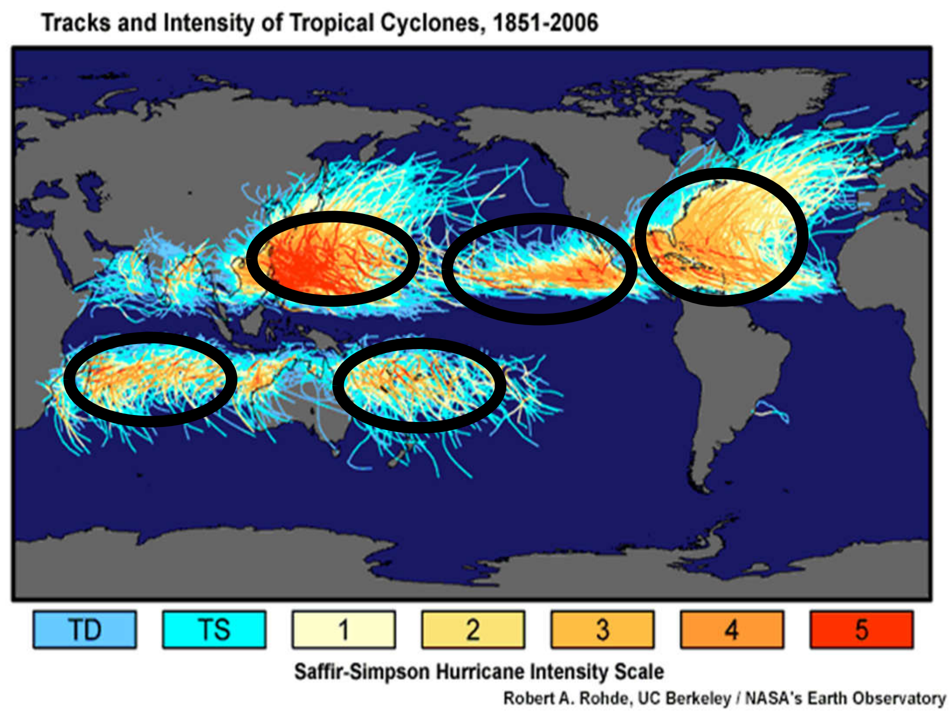
1. Background
2. Methodology

- Model setup
- Ekman transport computation

1. Results
2. Conclusion
3. Perspectives

Global Distribution of Tropical Cyclones

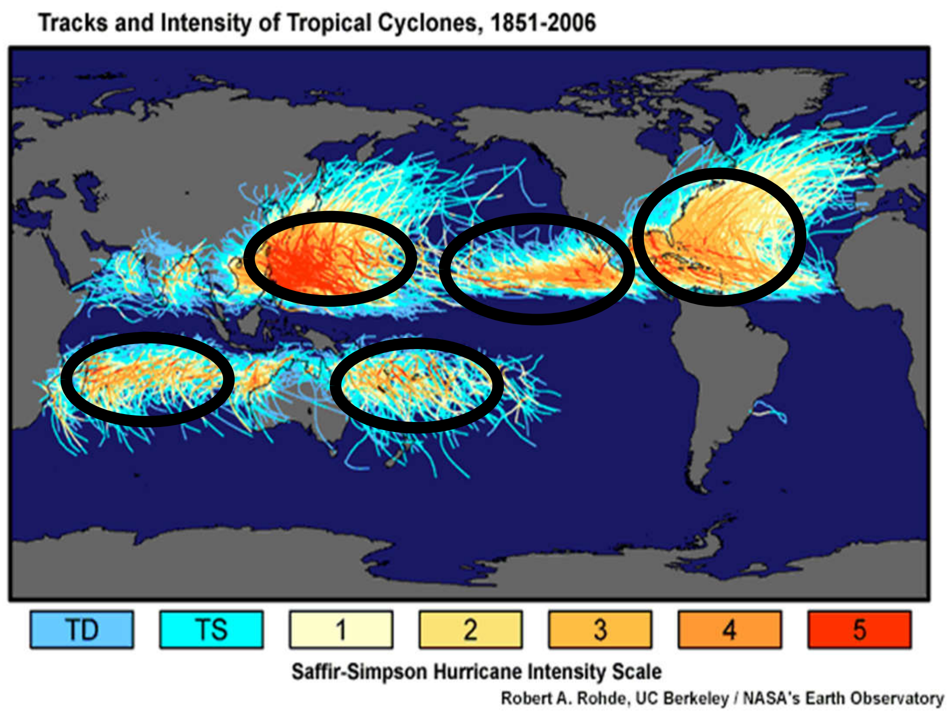
The terms **"hurricane"** and **"typhoon"** are regionally specific names for a strong **"tropical cyclone"**. A tropical cyclone is the generic term for a non-frontal synoptic scale low-pressure system over tropical or sub-tropical waters associated with organized convection (i.e. thunderstorm activity) and cyclonic surface wind circulation *(Holland 1993)*.



Why tropical cyclones can not form every where?

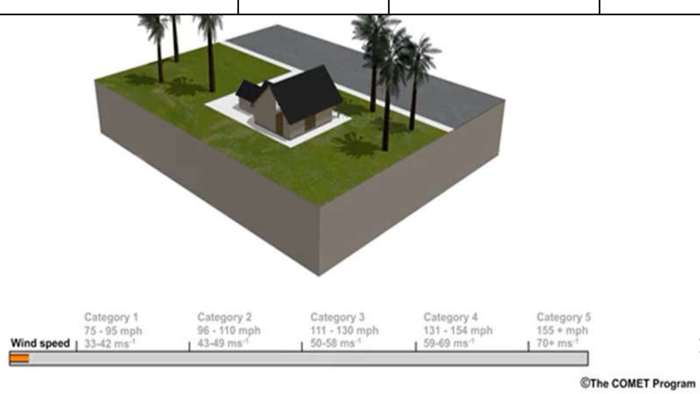
Necessary conditions for TC formation

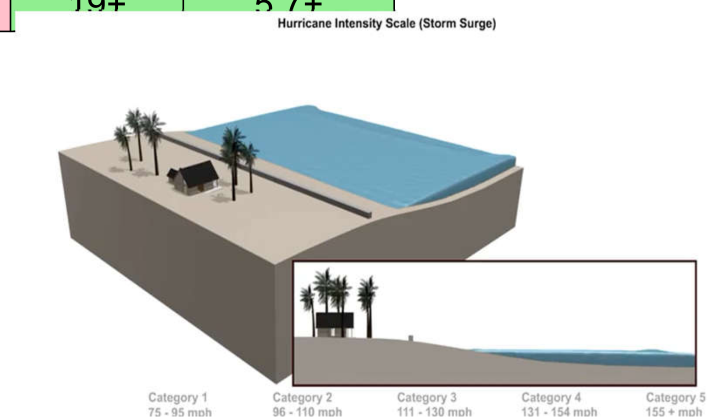
(i)	Sufficient ocean thermal energy [SST > 26°C in a depth of 60 m],
(ii)	Enhanced mid-troposphere (700 hPa) relative humidity,
(iii)	Conditional instability,
(iv)	Enhanced lower troposphere relative vorticity,
(v)	Weak vertical shear of the horizontal winds at the genesis site
(vi)	Suffisant Coriolis force (at least 5° latitude away from the equator.)



Saffir-Simpson Scale: Cat 3-5 are referred to as Major Hurricanes

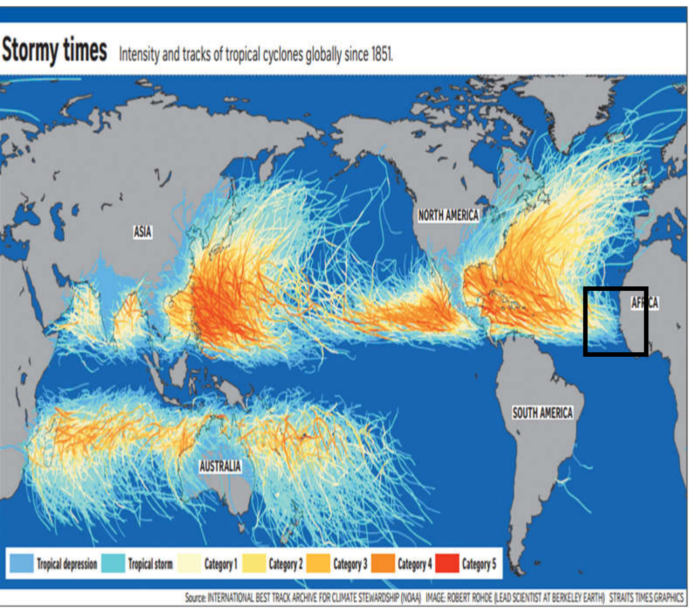
Saffir-Simpson Category	Maximum sustained wind speed			Minimum central pressure	Storm surge		Expected Level of Damage
	mph	m/s	kts	mb	ft	m	
1	74-95	33-42	64-82	> 980	3-5	1.0-1.7	Minimal
2	96-110	43-49	83-95	979-965	6-8	1.8-2.6	Moderale
3	111-130	50-58	96-113	964-945	9-12	2.7-3.8	Extensive
4	131-155	59-69	114-135	944-920	13-18	3.9-5.6	Extreme
5	156+	70+	136+	< 920	19+	5.7+	Catastrophic

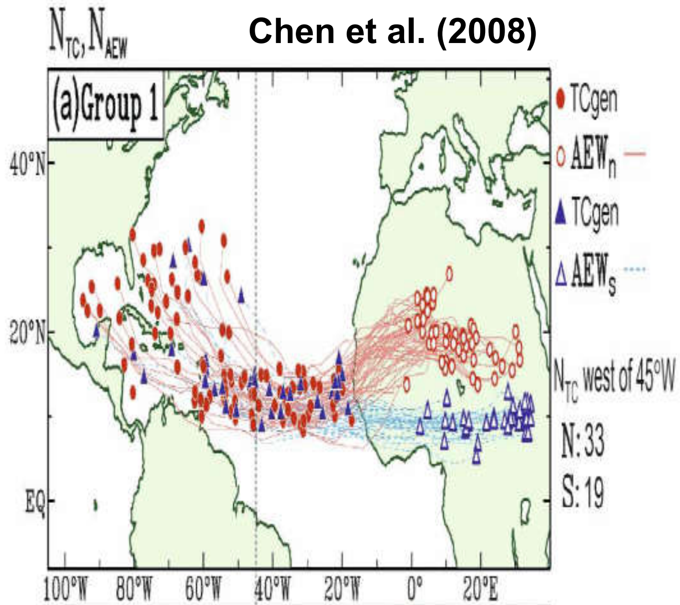


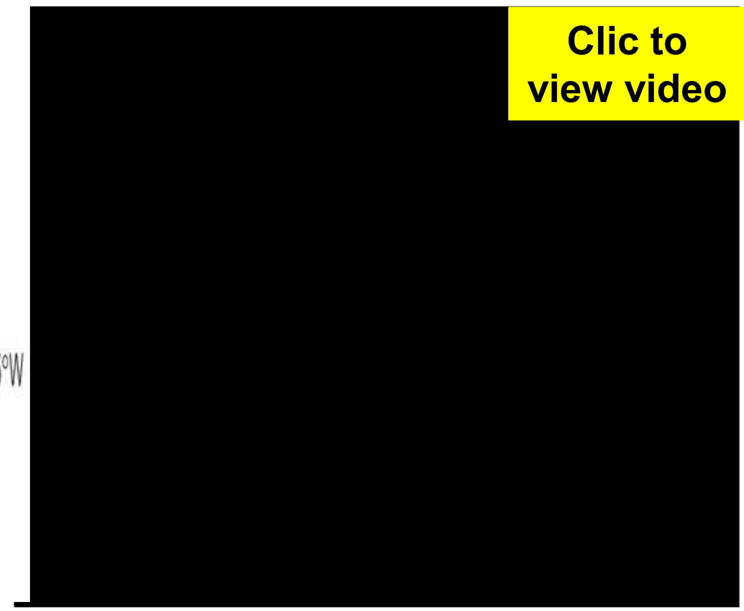


- More than 90% of US hurricanes are from African Easterly Waves (Dieng et al 2017; Thorncrof et al 2001) developing the continent

- Hurricanes rarely occur in the extreme Eastern Atlantic Ocean. The only ones that impacted Cape Verde occurred in 1892 and 2015, respectively.







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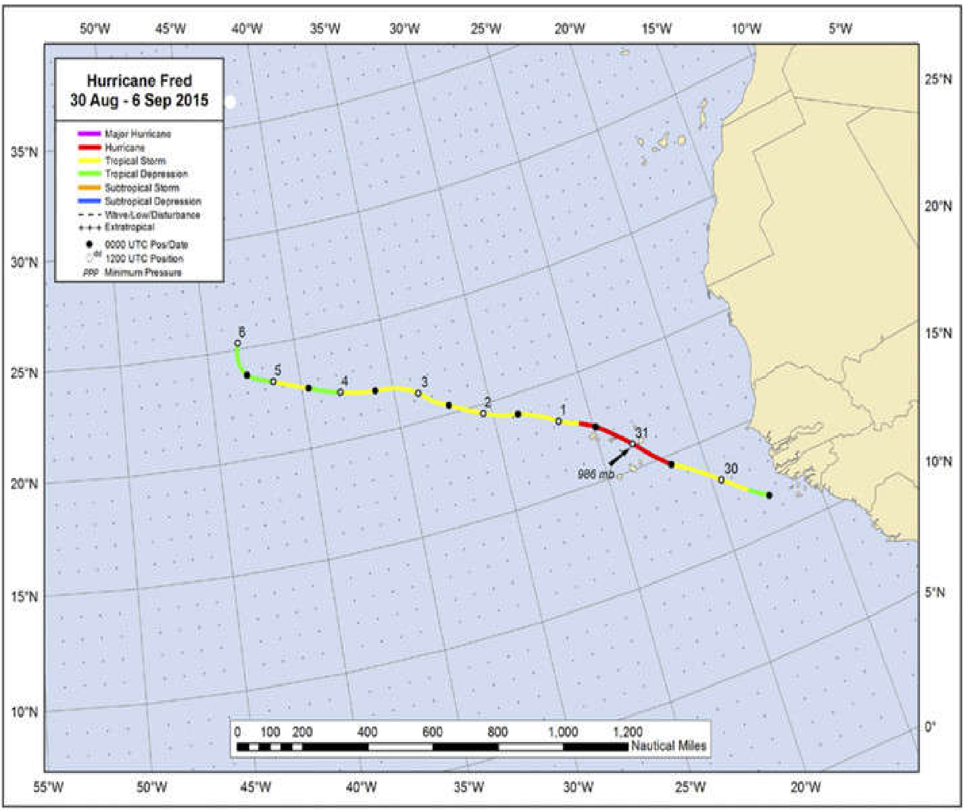
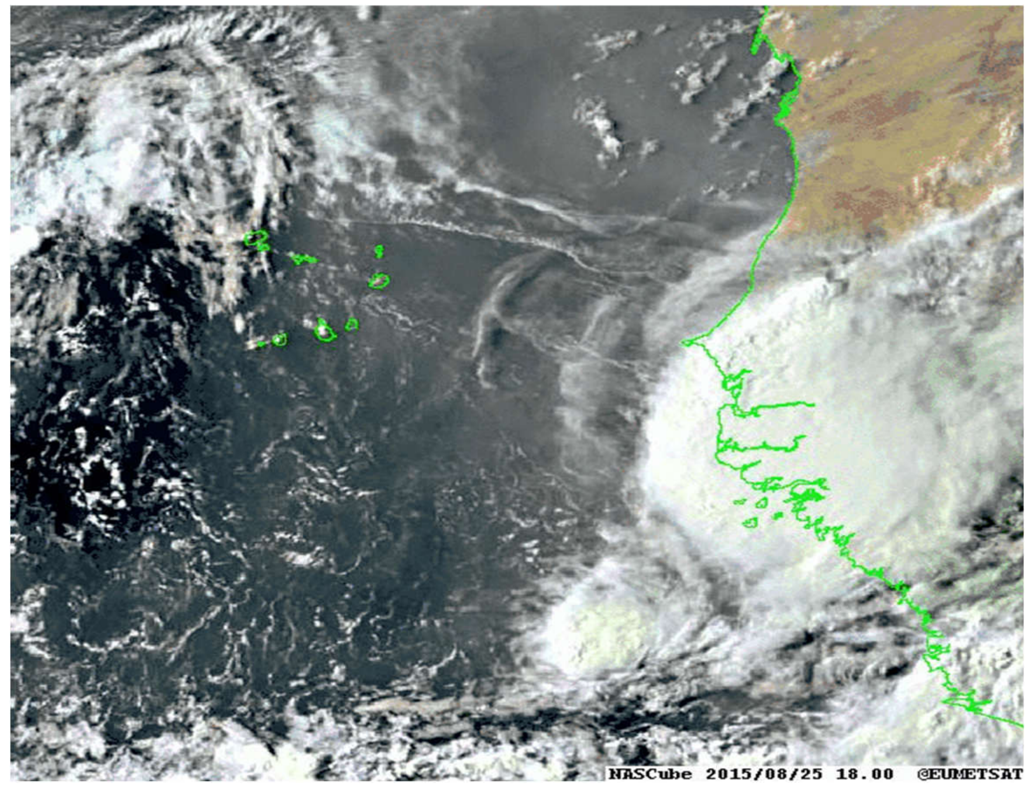
However, prior to reaching Cape Verde, this storm caused seven fatalities associated On 30 August, 2015 reports by administrative authorities of Fatick region,.. (Figure S1)



Track of the hurricane Fred (2015)



MSG images, showing the evolution of the MCS that spawn Hurricane Fred, on 31 August 2015 off the coast of Senegal

(a)

(b)

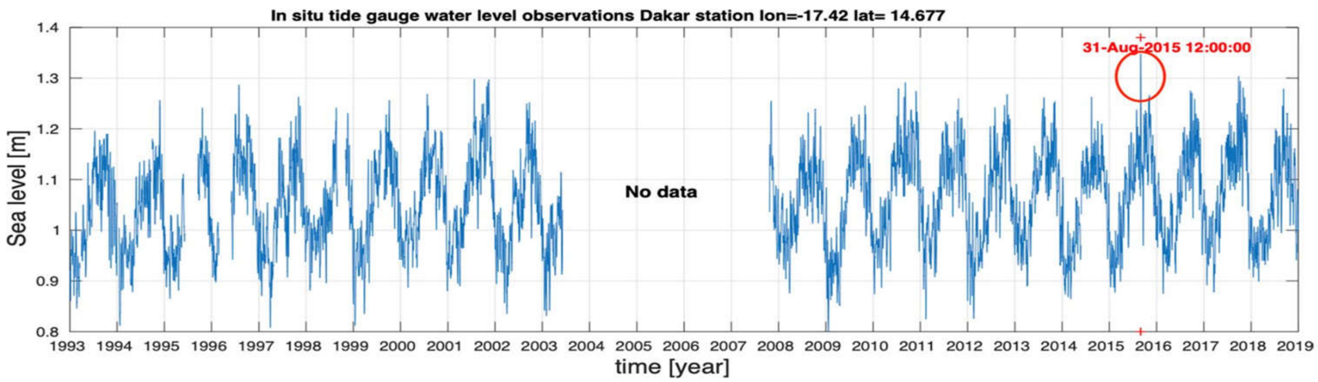
(c)

(d)

Images of the damage caused by the passage of Hurricane Fred in the night of 30 August 2015 off the coast of Senegal:

Damages caused by hurricane Fred on august, 30

- Seven fatalities associated with a fishing vessel.
- More than 100 houses were destroyed along the Senegalese coast, displacing many people



Temporal series of the tide gauge data of Dakar station (longitude = −17.42°W, latitude = 14.67°N) from 1993 to 2019

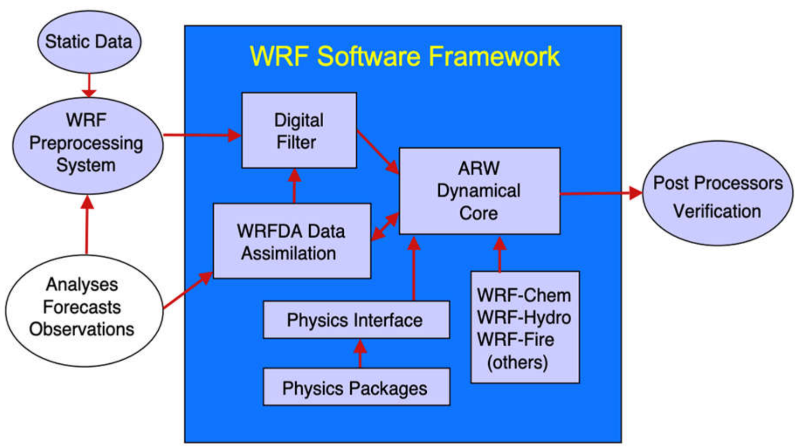
the maximum height measured from 1993-2019 period is 1.35 m corresponding to the passage the Hurricane Fred

OBJECTIVES

- Use the Weather Research and Forecasting Model (WRF) model to characterize the disturbance associated with TC Fred through the period of 29 and 30 August during its evolution
- Use WRF output from these simulations to estimate Ekman transport of water towards the coast of Senegal that could have been associated with coastal damage on 30 August 2015.

The Weather Research and Forecasting (WRF) model is a numerical weather prediction (NWP) and atmospheric simulation system designed for both research and operational applications.

Its development is led by NCAR, NOAA with partnerships with other federal agencies, and collaborations with universities and research laboratories in the US and overseas



The Advanced Research WRF ARW dynamic core solves explicitly the conservation of fluid dynamics equations and implements the main physical processes relevant to climate (Skamarock et al. (2008))

- Exchange and radiative transfer at short and long wavelengths ;
- Movement and turbulence in the planetary boundary layer;
- Convection schemes and cloud microphysics;
- Interaction of water, soil, vegetation and the urban pole with the lower atmosphere
- etc.

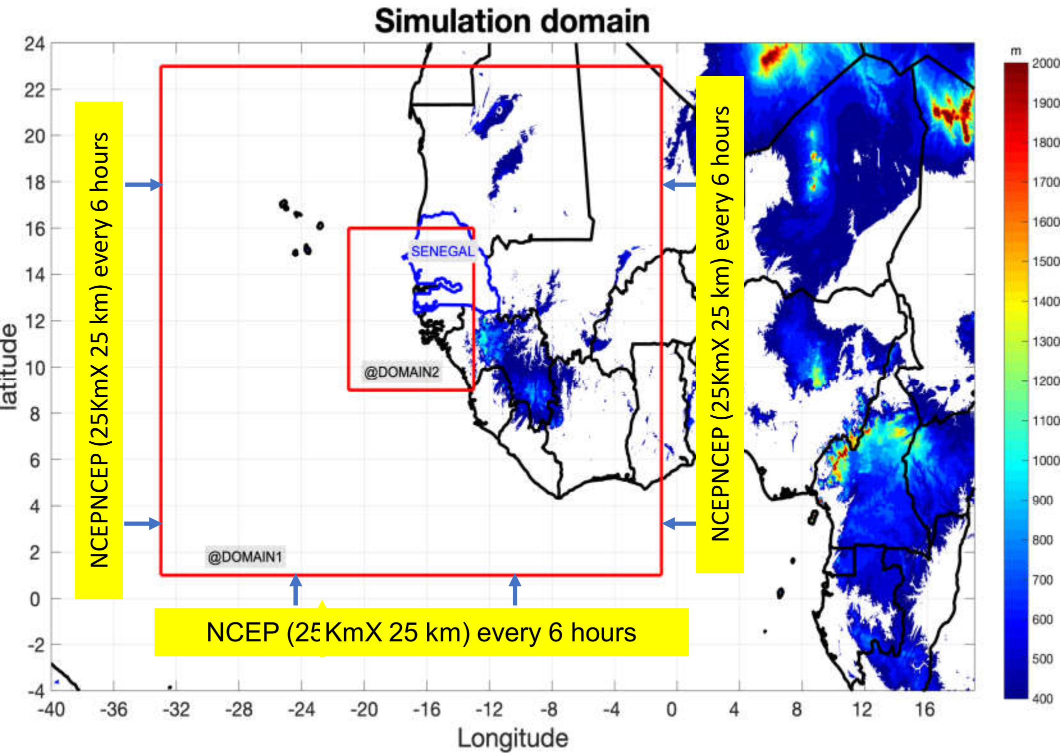


Table 1: MODEL SETUP

Simulation Name	Start time (UTC)	End Time (UTC)	Grid spacing
D1A	2808 0000	3108 0000	12 km
D2A	2808 0600	3108 0000	4 km
D1B	2808 1200	3108 0000	12 km
D2B	2808 1800	3108 0000	4 km
D1C	2908 0000	3108 0000	12 km
D2C	2908 0600	3108 0000	4 km

- WRF model version 3.71 (Skamarock et al. 2008) with two way nested domains
- National Centers for Environmental Prediction (NCEP) are used as lateral boundary conditions
- Simulations at different times initiation beginning on 28 August 0000 UTC and initialized every 12 hours (Table1)
- Only the simulations in the in the inner domains are used for evaluation.

- **Ekman transport computation**

$$\tau_x = \rho_a \cdot C_d \cdot \sqrt{u^2 + v^2} \cdot u$$

$$\tau_y = \rho_a \cdot C_d \cdot \sqrt{u^2 + v^2} \cdot v$$

$$Q_y = \frac{-\tau_x}{\rho \cdot f} (m^3 \cdot S^{-1} \cdot m^{-1})$$

$$Q_x = \frac{\tau_y}{\rho \cdot f} (m^3 \cdot S^{-1} \cdot m^{-1})$$

Q_x = zonal Ekman transport.

$Q_{y=}$ Ekman transport meridional

ρ_a is a constant atmospheric density ($\rho_a = 1.2 kg \cdot m^{-3}$)

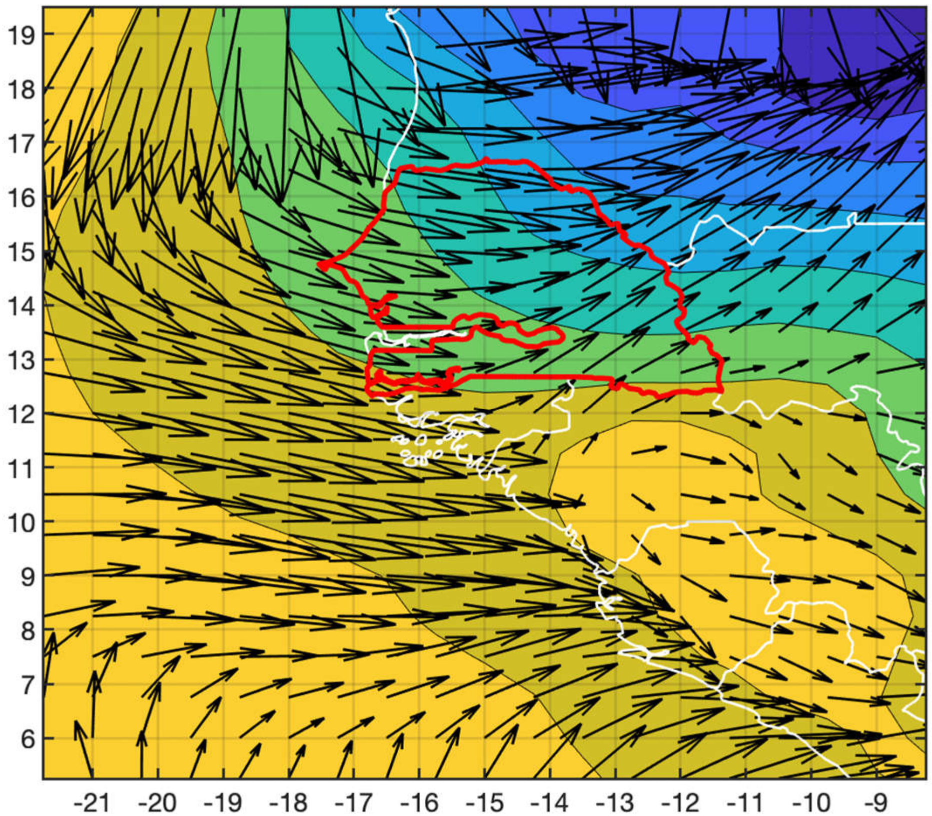
Cd = 1.3 × 10^{-3}; emperical drag coefficient

ρ = $1000\ kg \cdot m^{-3}$)

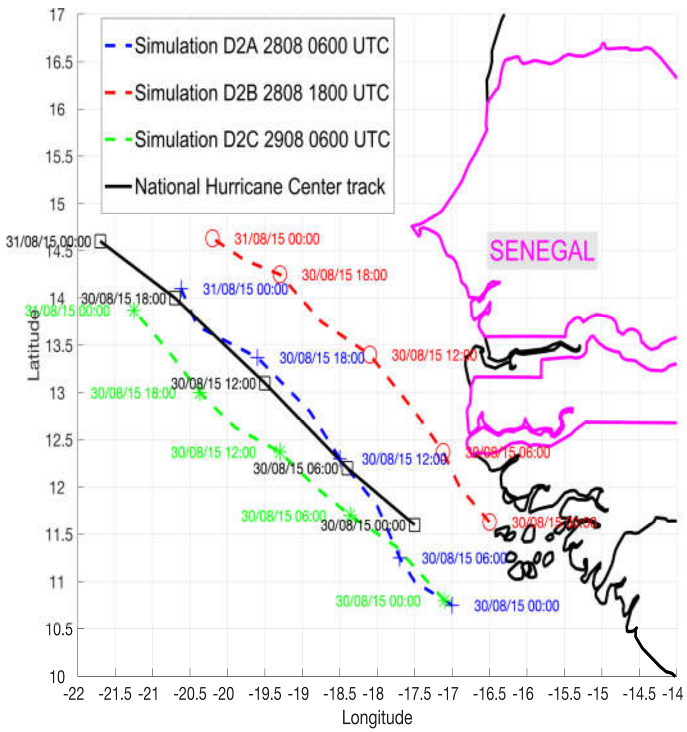
f is the Coriolis parameter

Simulated Wind Surface (arrows)
& mean seal pressure (colour)

28/08/2015 - 00h



The evolution of the hurricane well simulated by the WRF model



- 0000 UTC 31 August, Hurricane Fred is located approximately at 4.2 degrees west of Dakar, according to NHC archives.
- Simulation D2A, shows a track that is closest to the NHC track.
- The track of simulation D2B, is displaced to the east of the NHC official track
- The third simulation, D2C, began at 0600, 29 August, and is displaced to the west of the NHC position.

Model Validation

- Rapid transition to southerly winds is found at the southernmost station of Cap Skirring on 30 August, beginning at 0600 UTC.
- Simulated wind speed captures the transition but overestimates the magnitude.

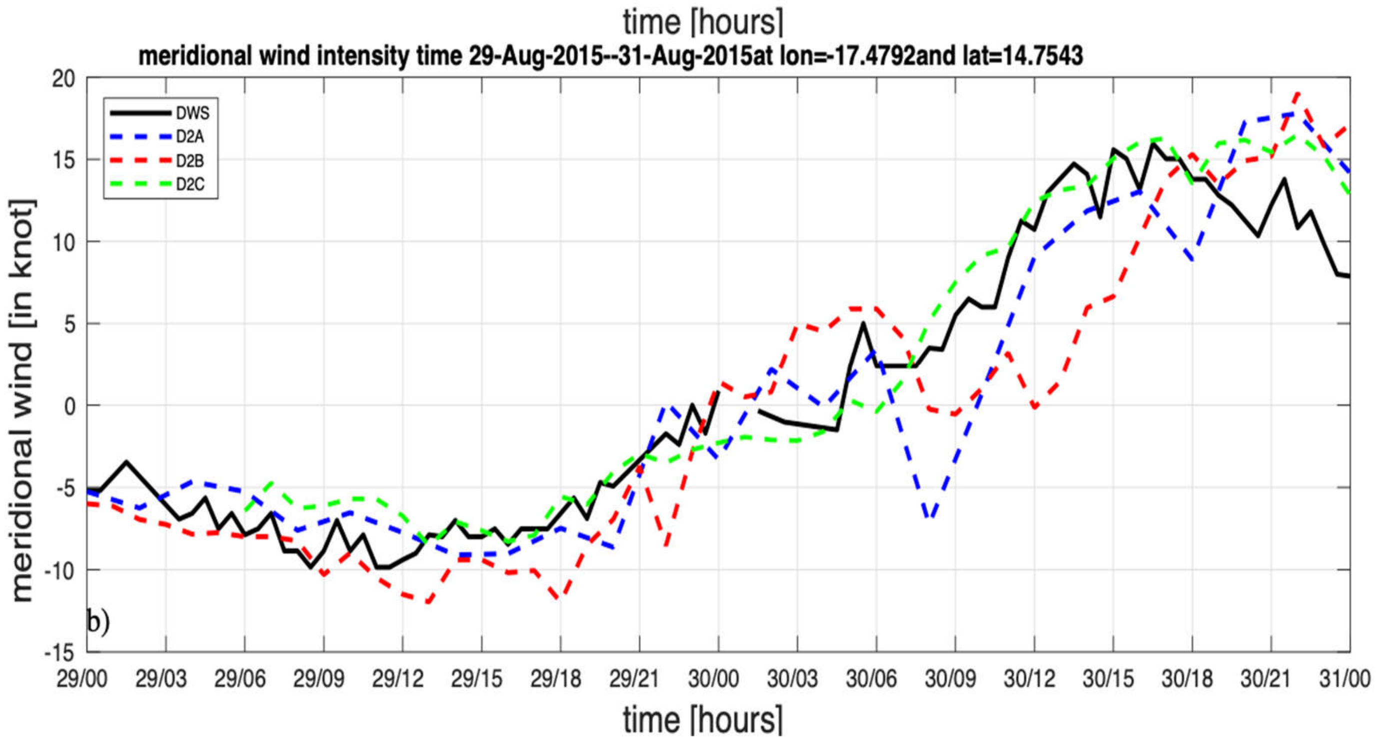
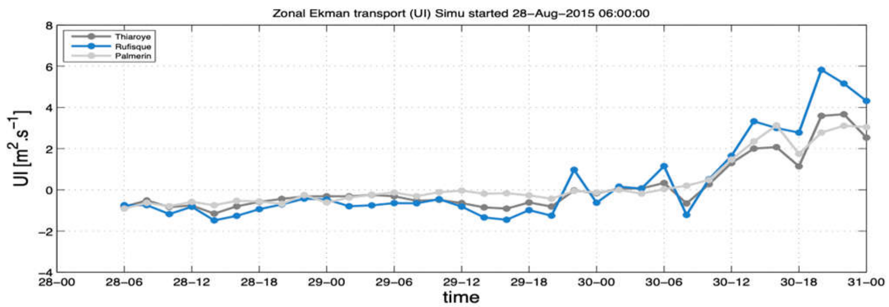
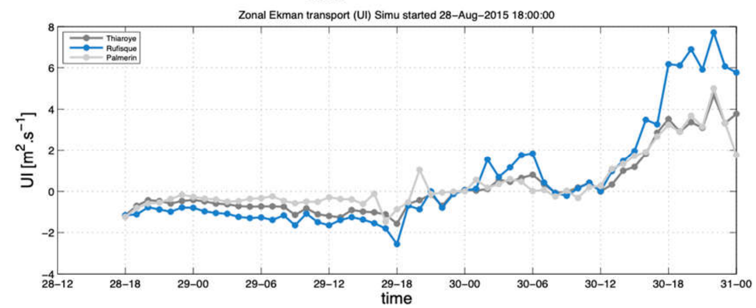


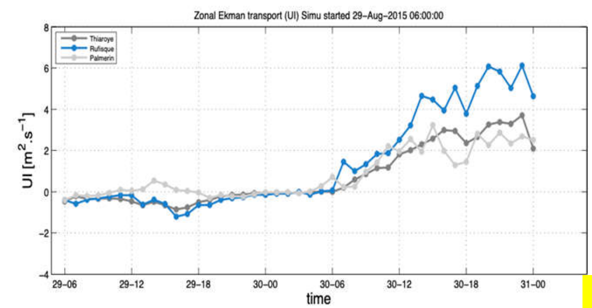
Figure 3 (a): observed Meridional wind at Dakar (red) and Cap Skiring (yellow) from 29 August, at 00:00 UTC to 31 August 29 at 00:00 UTC, (b) simulated WRF meridional winds averaged over the nearest grid point of Dakar observation and during the same as in (a).

Zonal Ekman transportation

- Zonal Ekman transport indicates increasing eastward transport towards the coastline after 1200 UTC, 30 August, based on D2A and D2B.
- The largest transport occurs after 1800 UTC and is found at Rufisque relative to the other coastal locations in these simulations.
- Zonal transport estimated by simulation D3C is smaller relative to D2A and D2B. However, all of the transport is eastward in this simulation, with the largest values found around 0000 30 August and steady westward transport between 0900 and 2000 UTC 30 August.







- Simulations are in agreement with limited coastal observations showing increasing southerly wind speeds during 30 August
- Zonal Ekman transport to the coast of Senegal on 30 August and are likely responsible for some coastal flooding.
- Ekman transport along the coast contributes significantly to the water level variations during swell events.

Thank you for your attention