Impact of Power Extraction on the Florida Current/Gulf Stream System: New Results

Alexandra Bozec[1], Eric Chassignet[1], Howard P. Hanson[2]

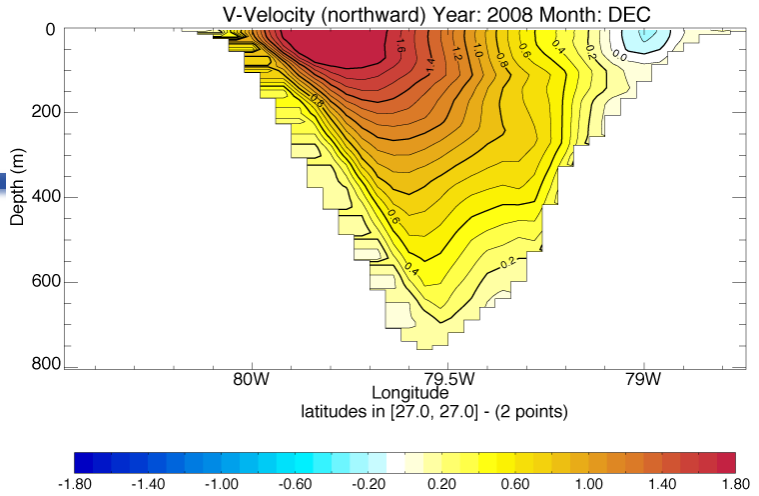
1 Center for Ocean-Atmospheric Prediction Studies, Tallahassee, FL
2 Center for Ocean Energy Technology, Florida Atlantic University, Dania Beach, FL, USA

Objectives of the Project

- ✓ to assess the power availability in the Florida Current in the Fort Lauderdale region.

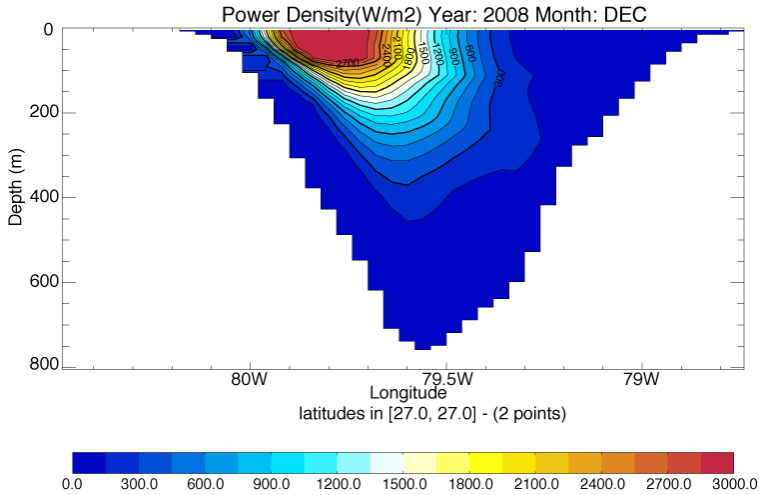
- ✓ to assess the impact of turbines on the Florida Current/Gulf Stream system

Total Power Availability (GW)



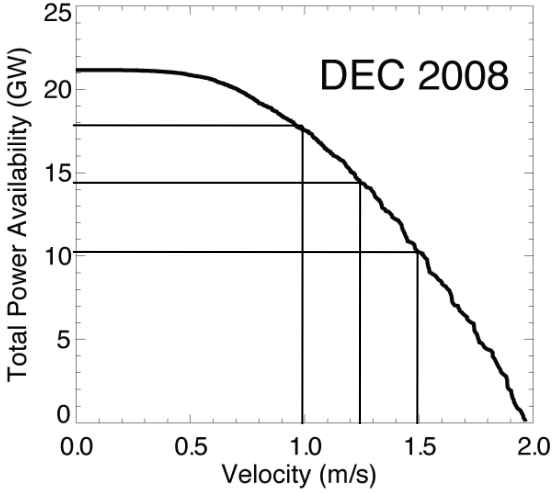
Power Density (W/m^2):

$$P = \frac{1}{2}\rho V^3$$



Total Power Availability (GW):

$$P_A = \frac{1}{2}\rho \int_A V^3 dA$$



18.8GW available

6.0GW available

or

Rotor minimum Operating Speed

Best efficiency : Only ~ 60% of the energy can be captured

$1GW = 10^9 W \approx 1$ Nuclear Power Plant

Tools

✓ to assess the power availability in the Florida Current

⇒ Global 1/12º resolution (~8 km) assimilated simulations of the HYbrid Coordinates Ocean Model (HYCOM)

(Hanson et al., 2011, EOS Trans. AGU, 92(4), 29-30.)

✓ to assess the impact of turbines on the Florida Current/Gulf Stream system (circulation, transport, power and energy)

⇒ Atlantic Ocean 1/12º resolution HYCOM simulations (no assimilation)

Atlantic Ocean Configuration

Atlantic configuration of HYCOM (ATLg0.08):

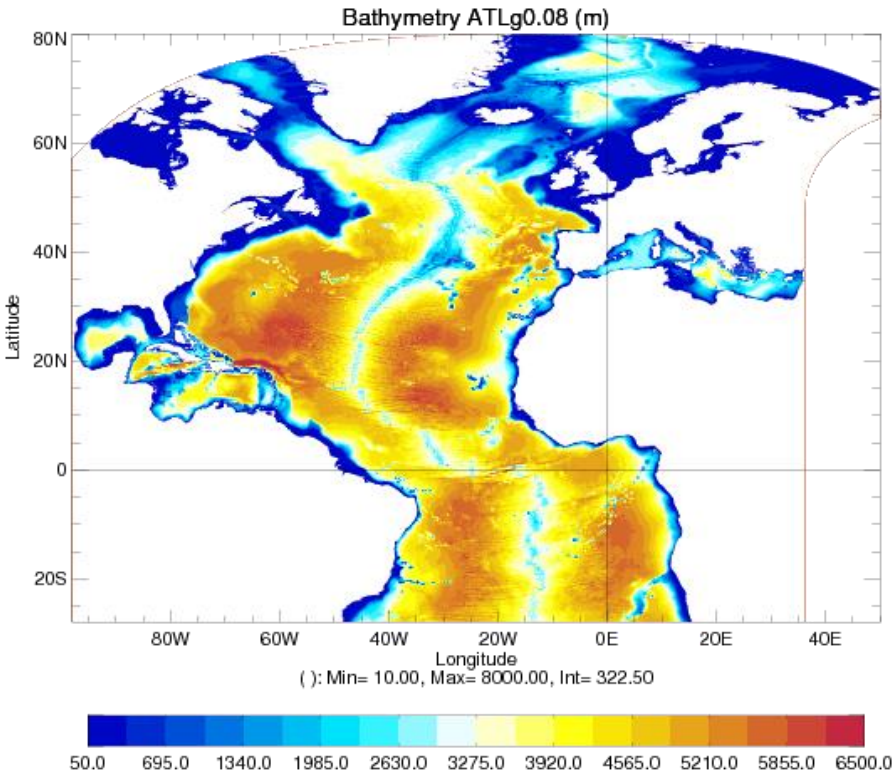
⇒ 1/12º horizontal resolution (~7-8km)

⇒ 32 hybrid layers

⇒ Climatological initial conditions (T,S) from GDEM3

⇒ Climatological atmospheric forcing from ERA40

⇒ Start from a 10 year spin-up



(Courtesy of X. Xu)

Experimental Set-up

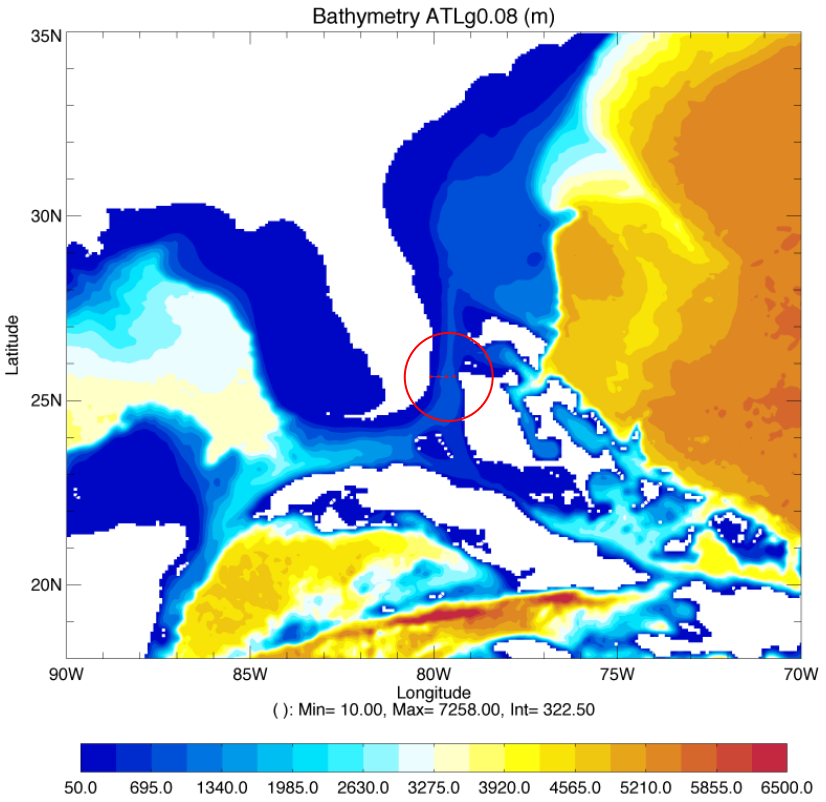
Turbine parameterized as a drag :

$$-\frac{1}{2} C_T \sqrt{(U^2 + V^2)} \cdot \vec{U}$$

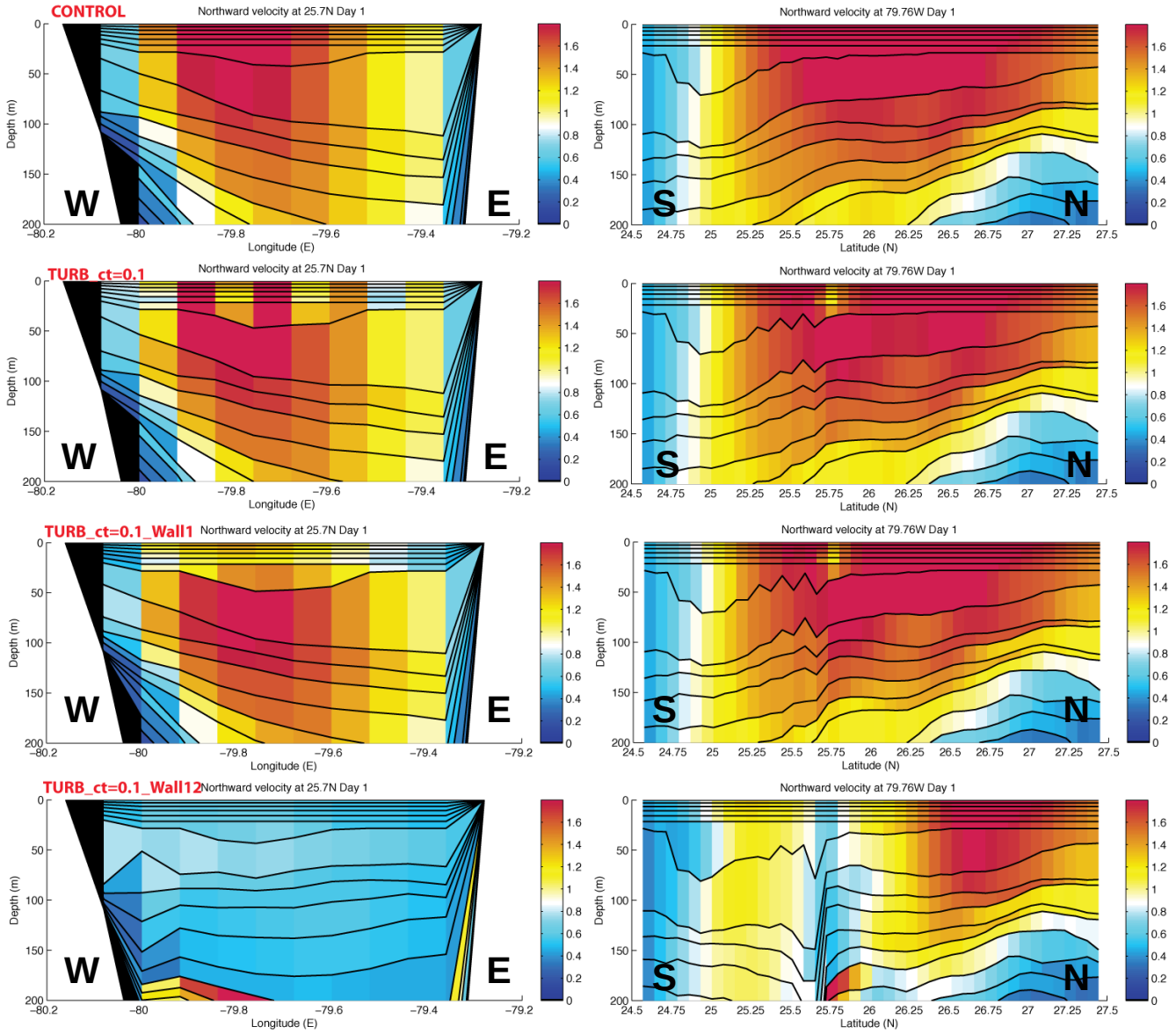
with C_T=0.1

⇒ 4 Simulations of 3 years :

- control simulation (CONTROL)
- 4 turbines at 25.7ºN (TURB_C_T=0.1)
- 12 turbines across the 25.7ºN section (TURB_C_T=0.1_WALL1)
- wall of turbines across the 25.7ºN section over 12 layers (TURB_C_T=0.1_WALL12)



Impact of the turbines at 25.7ºN



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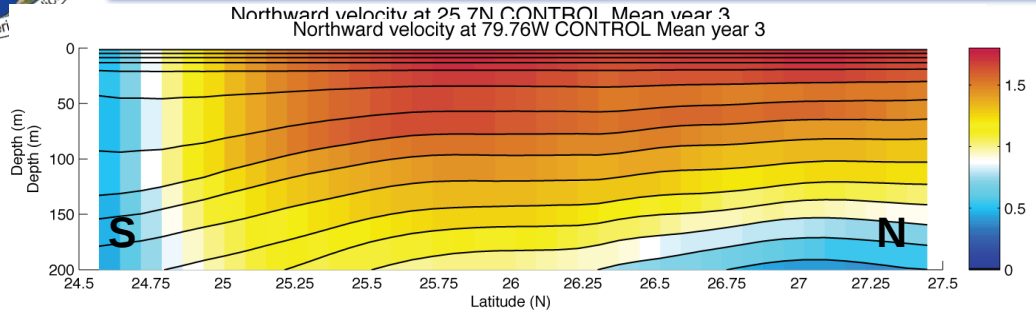
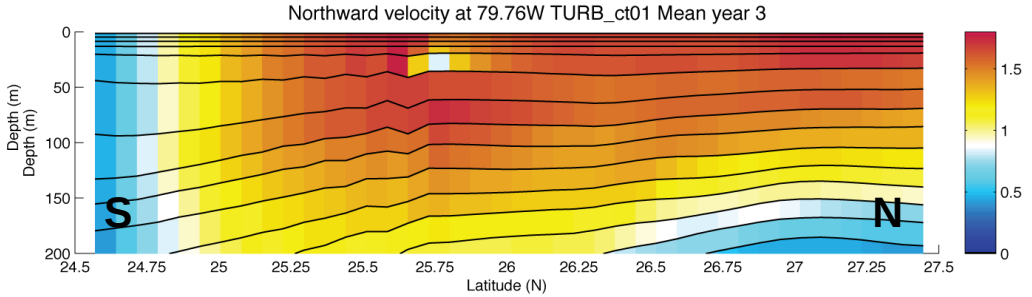
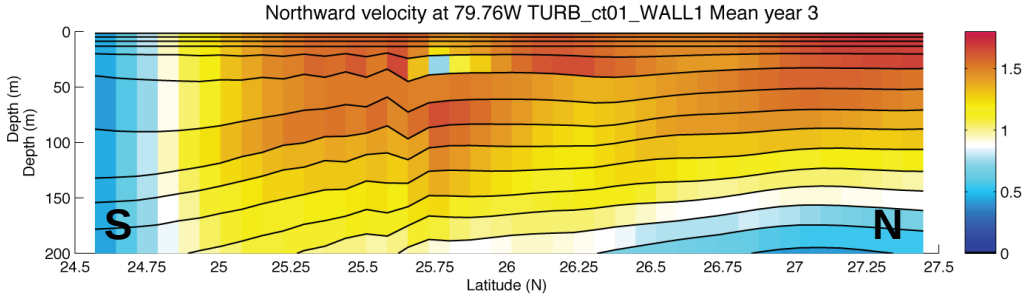
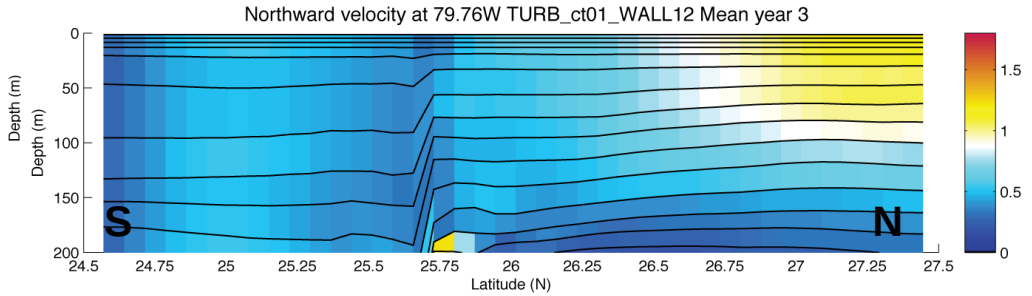


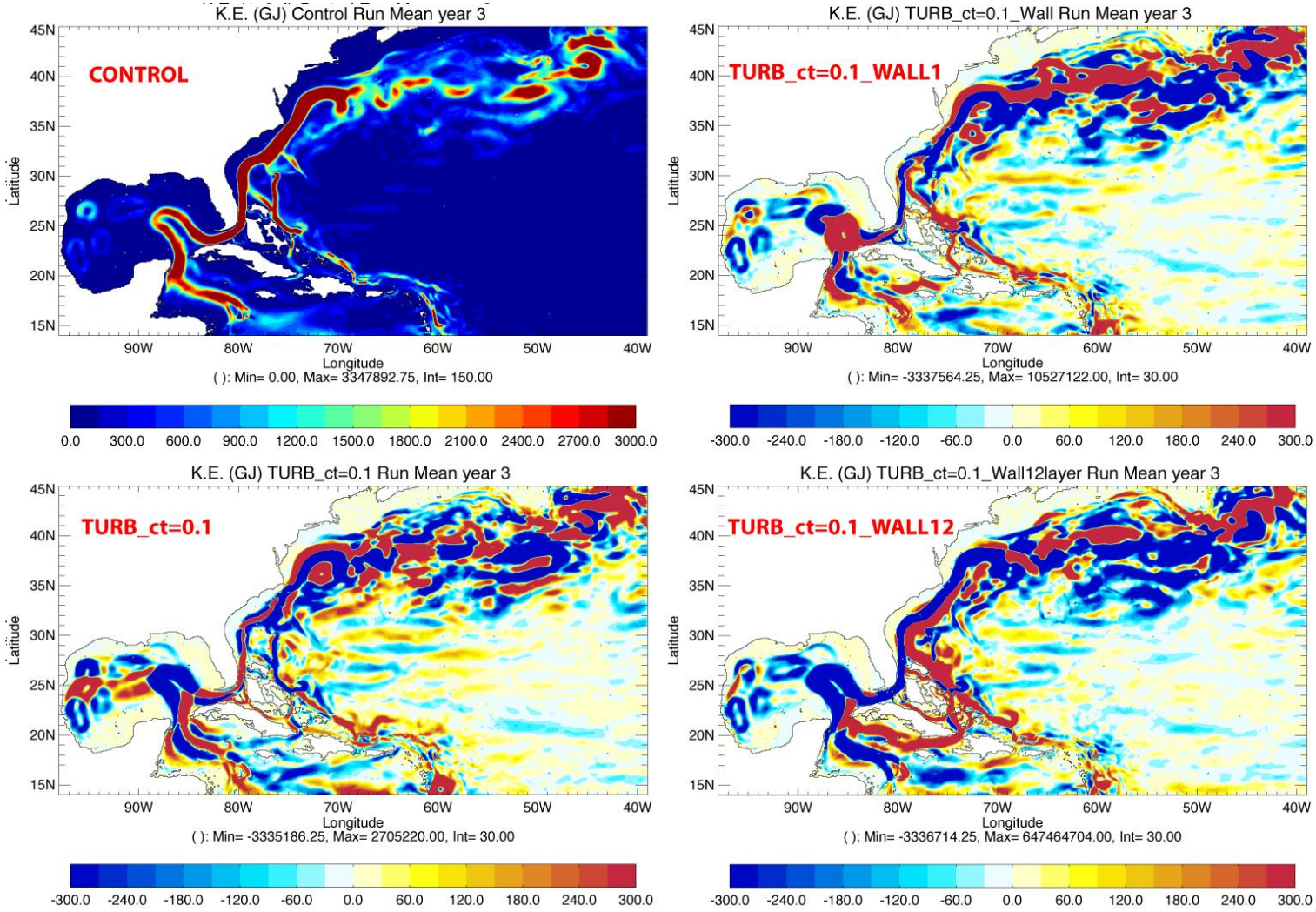




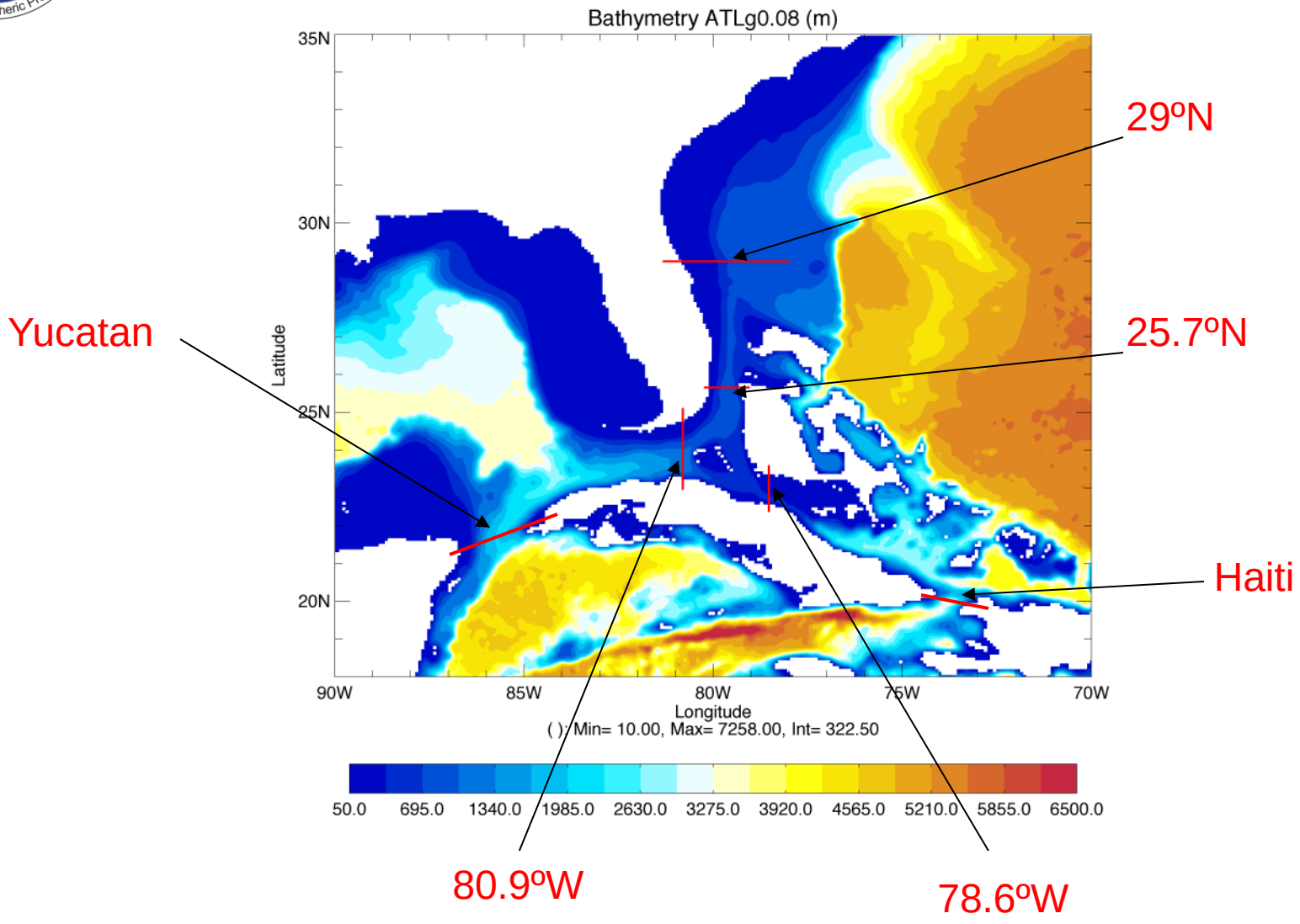


Mean Northward Velocity year 3

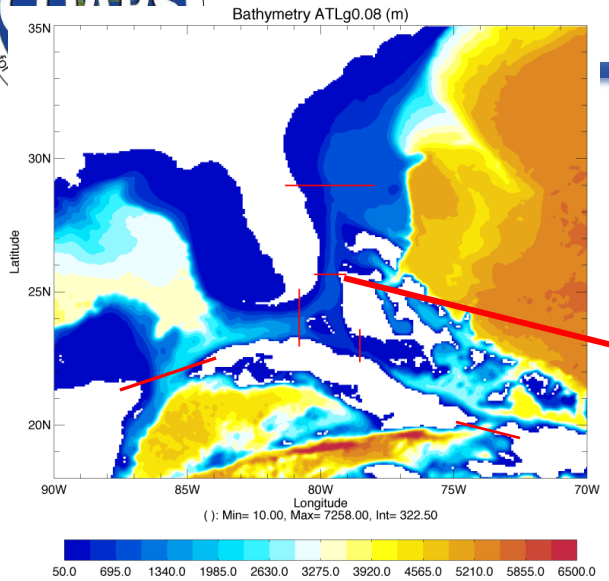
Impact on the Circulation

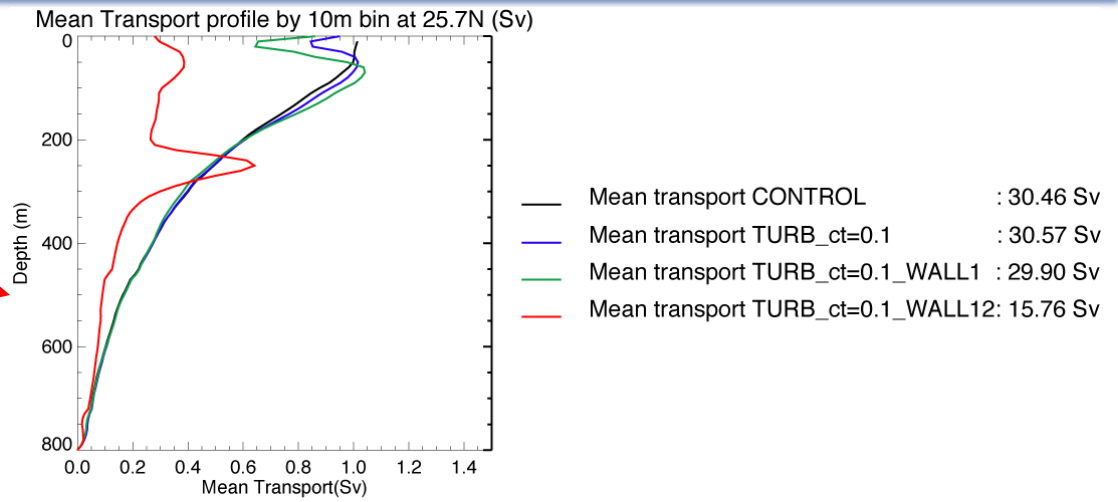


Impact on Transports

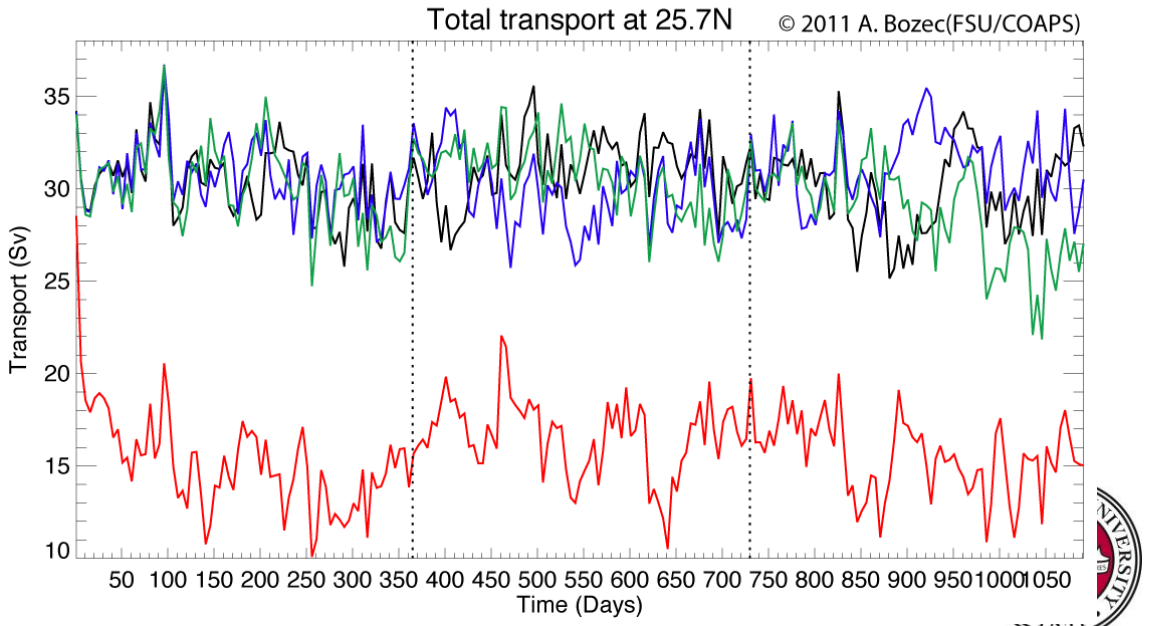


Transport at 25.7ºN

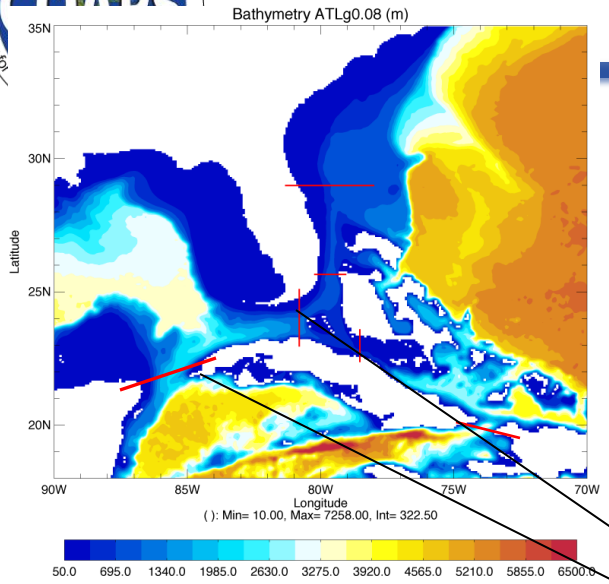


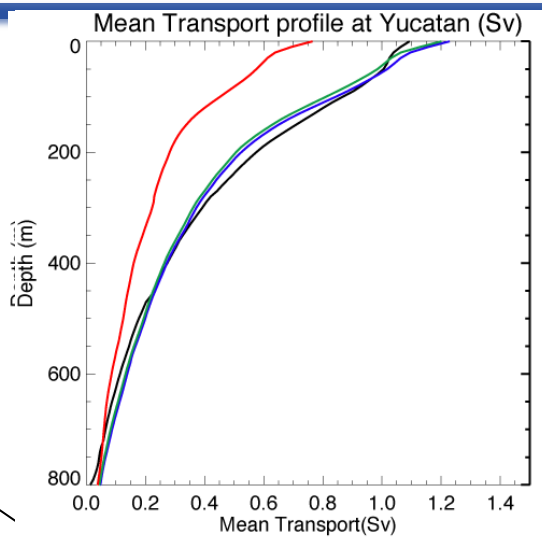


- ✓ The total mean transport is roughly the same between CONTROL and TURB_C_T=0.1/TURB_C_T=0.1_WALL1
  - ✓Compensation between the surface and the deeper transport
- ✓ TURB_C_T=0.1_WALL12 transport is half the CONTROL one



Upstream Transports

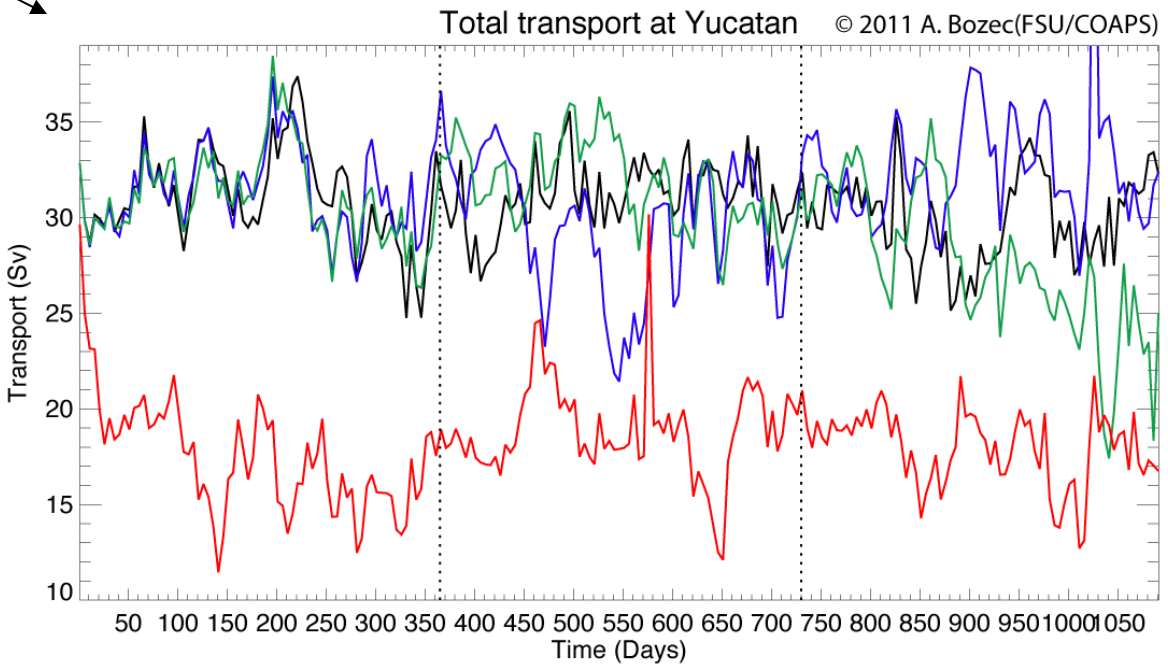




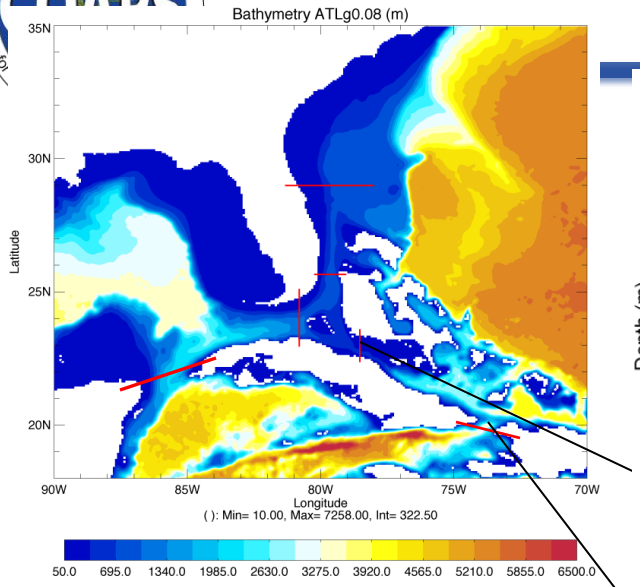
Mean transport CONTROL : 30.73 Sv
Mean transport TURB_ct=0.1 : 31.19 Sv
Mean transport TURB_ct=0.1_WALL1 : 30.10 Sv
Mean transport TURB_ct=0.1_WALL12: 18.11 Sv

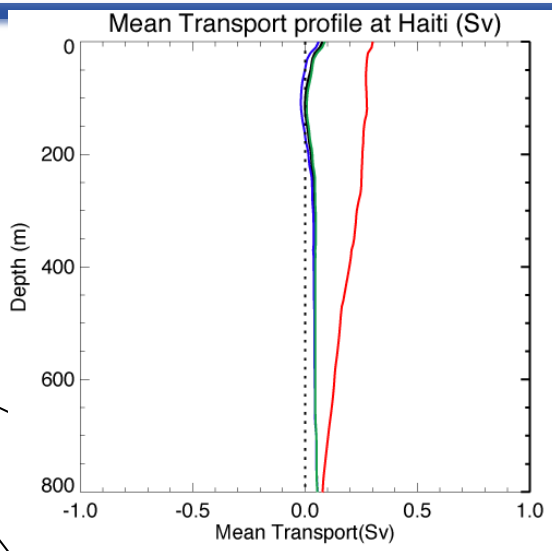
✓ The total mean transport is roughly the same between CONTROL and TURB_C_T=0.1/TURB_C_T=0.1_WALL1

✓ TURB_C_T=0.1_WALL12 transport is **MORE** than a half the CONTROL one



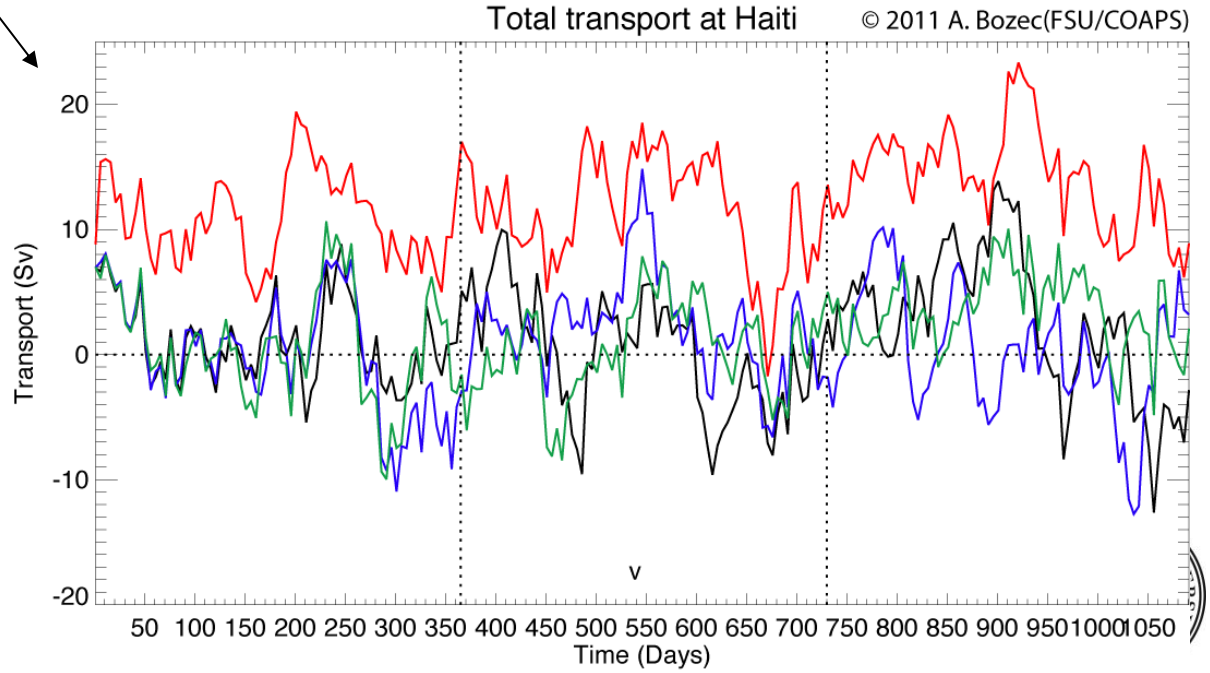
Detoured Transports



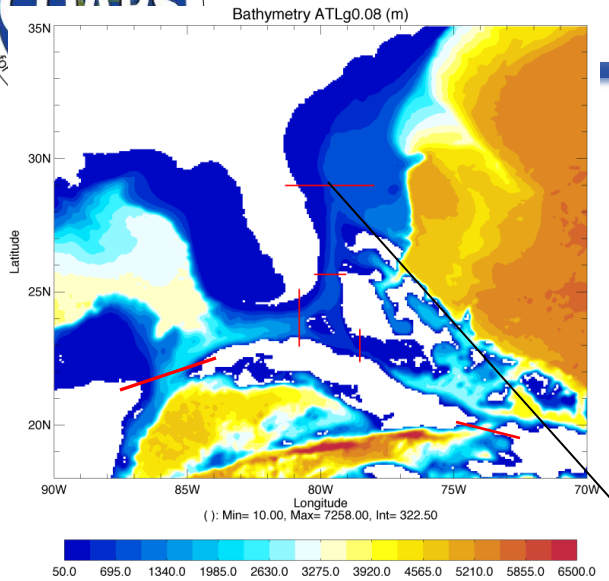


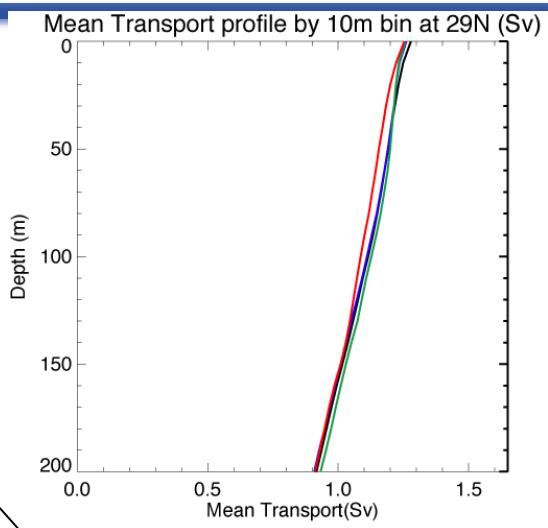
Mean transport CONTROL : 1.23 Sv
Mean transport TURB_ct=0.1 : 0.79 Sv
Mean transport TURB_ct=0.1_WALL1 : 1.54 Sv
Mean transport TURB_ct=0.1_WALL12: 12.17 Sv

✓ A transport of ~3 Sv detoured at 78W and ~12Sv between Hai and Cuba.

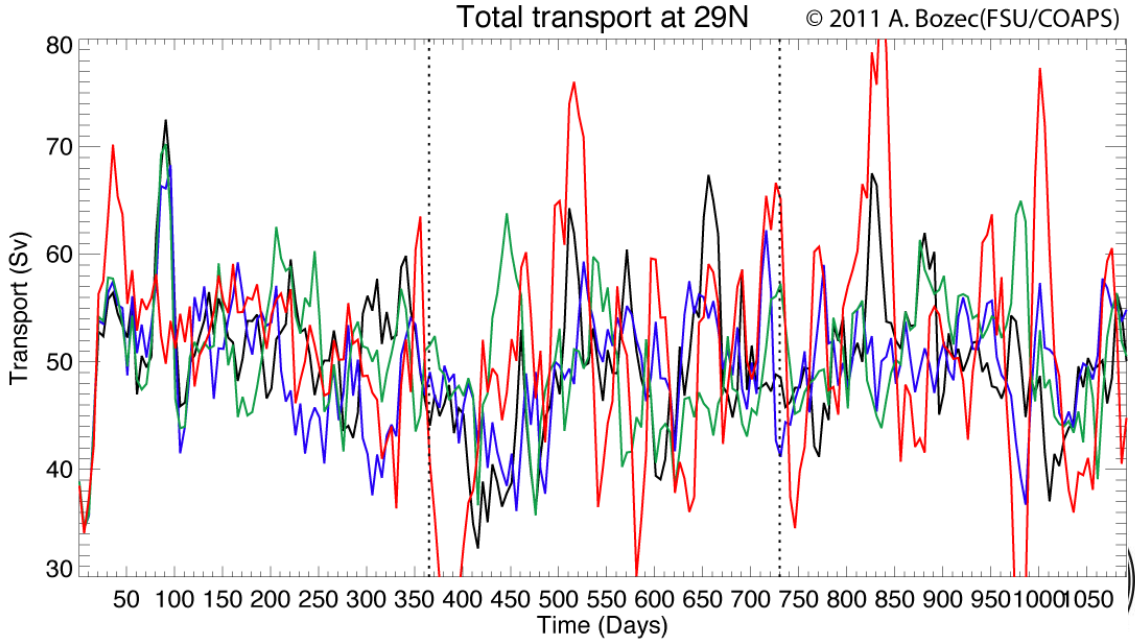


Downstream Transport





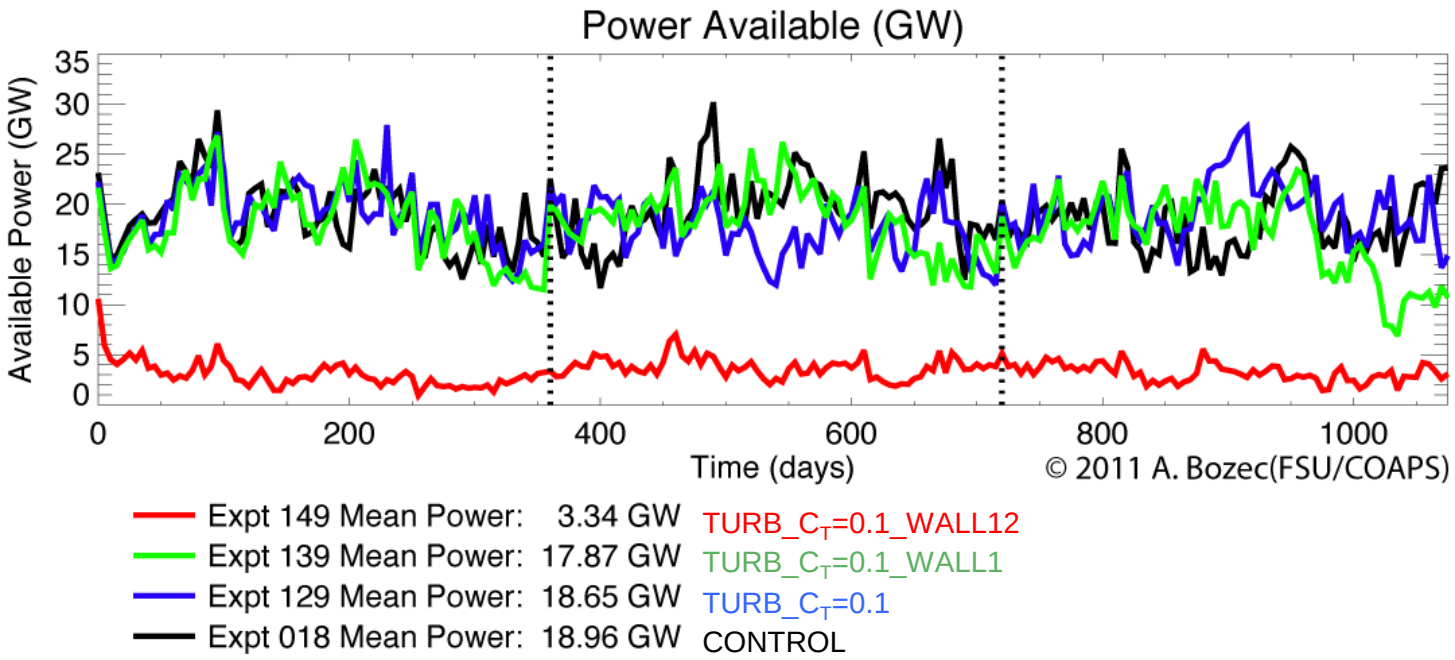
Mean transport CONTROL : 51.07 Sv
Mean transport TURB_ct=0.1 : 50.36 Sv
Mean transport TURB_ct=0.1_WALL1 : 49.99 Sv
Mean transport TURB_ct=0.1_WALL12: 49.62 Sv



✓ The total mean transport is roughly the same between CONTROL and **ALL** turbines simulations

Impact on Power Availability

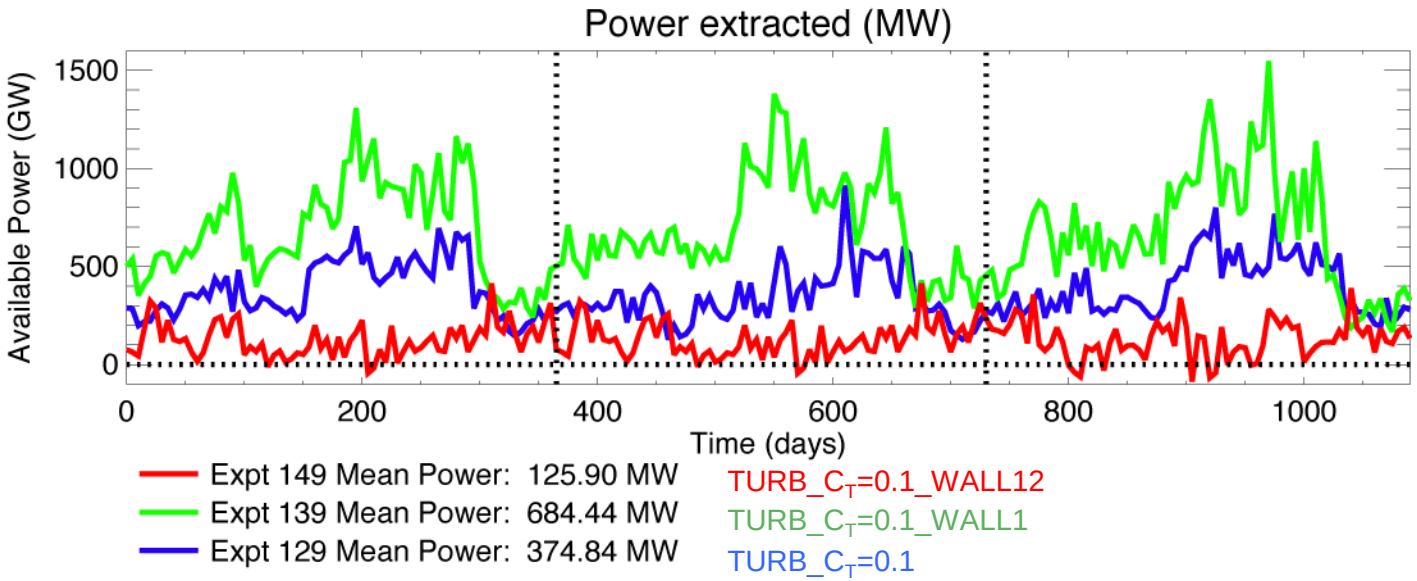
Power Availability: $P_E = \frac{1}{2}\rho \int V^3 dA$



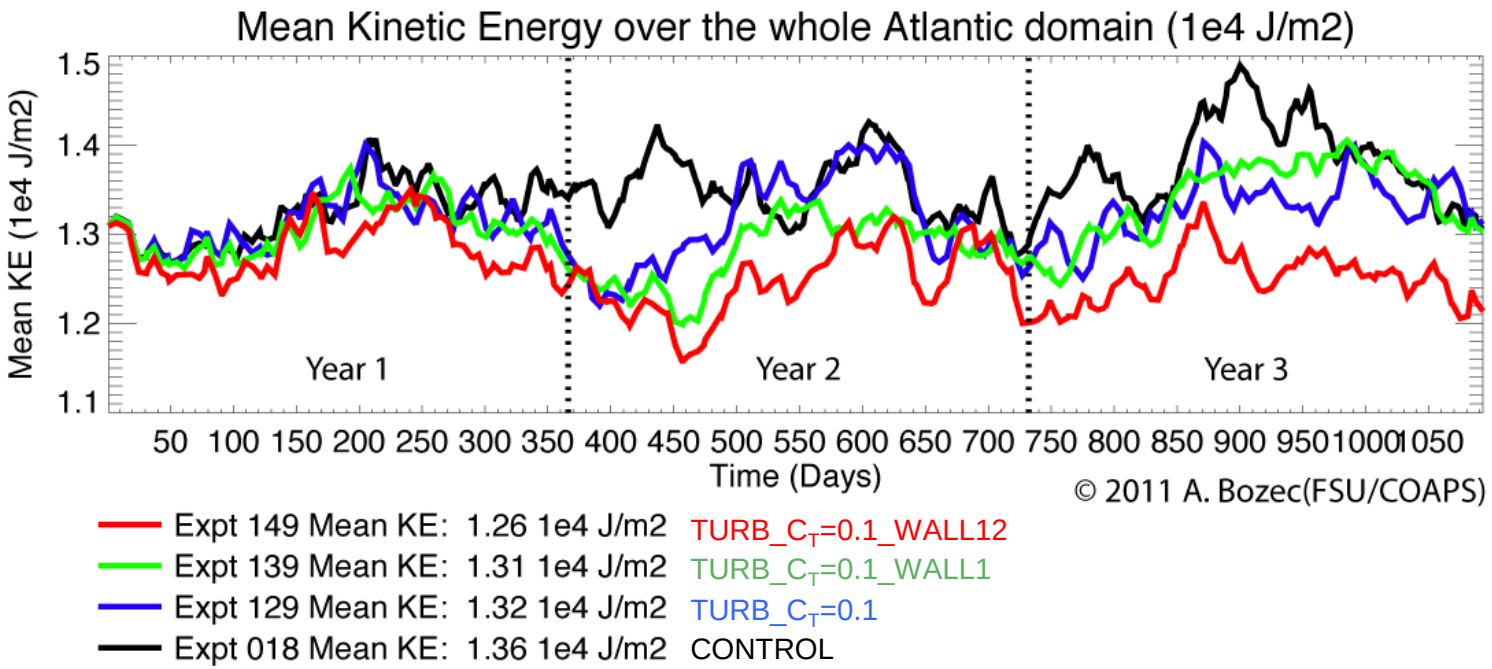
Power Extraction Estimate

Power **Estimate** : Sum of the difference of Kinetic Energy Fluxes between the point before and after the turbines

$$P_E = \frac{1}{2}\rho \int_{\substack{Turbines \\ Grid\ Cells}} V(j-2)^3_{TURB\_C_T}\, dA \; - \frac{1}{2}\rho \int_{\substack{Turbines \\ Grid\ Cells}} V(j+1)^3_{TURB\_C_T}\, dA$$



Mean Kinetic Energy



Summary

3 cases with different distribution of “turbines” in the Florida Current:

- 2 “reasonable” cases with 4 “turbines” and 12 “turbines”
  - ✓ Flow decelerated at the surface but compensated at depth
  - ✓ Circulation and transports remain similar to observations
  - ✓ Kinetic Energy over the basin is slightly decreased
  - ✓ 350-700 MW of power extracted for a power availability of ~20GW as in the observations

- 1 “extreme” case with turbines over the first 180m of the 25.7ºN section
  - ✓ Flow strongly decelerated without compensation at depth
  - ✓ Transports at half the observations at 25.7ºN and upstream
  - ✓ Detour of the flow of about 3Sv at 78W and 12Sv between Cuba and Haiti
  - ✓ No change of the transport at 29ºN
  - ✓ Kinetic Energy over the basin is decreased
  - ✓ 160MW of power extracted for a power availability of ~3.4GW

Future Work:

=> Focus on the Gulf Stream region

=> Focus on the Gulf of Mexico