The Impacts of Ocean-Atmosphere Coupling

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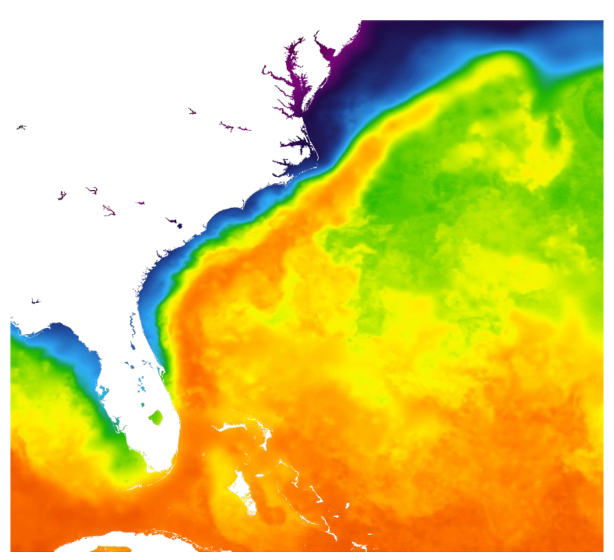
Motivations and Outline

- Positive correlations between sea surface temperature (SST) and near surface wind speeds/stress at ocean mesoscales are interpreted as the ocean driving the atmosphere[5]
- SST fronts are capable of modifying surface turbulent heat and momentum fluxes[3,5]
- Small scale changes in the boundary layer lead to large scale changes in winds and circulation ultimately affecting the ocean[3]



- Using WRF and Oceananigans[2,4], we analyze an uncoupled ocean simulation, an uncoupled atmosphere simulation, and a fully coupled system that idealizes the gulf stream (left)
- The ocean and atmosphere share a lateral grid, and the atmosphere has 12 time steps between every ocean time step

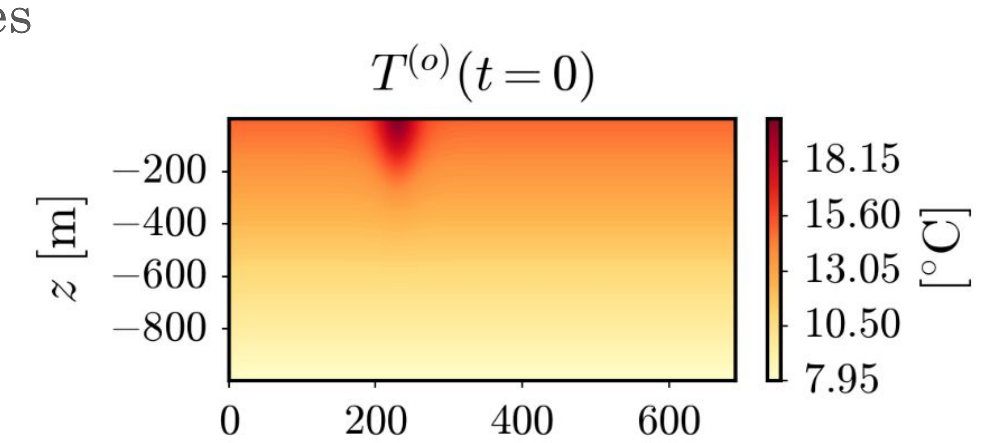
Image Source: NASA Worldview Snapshots (https://wvs.earthdata.nasa.gov/)

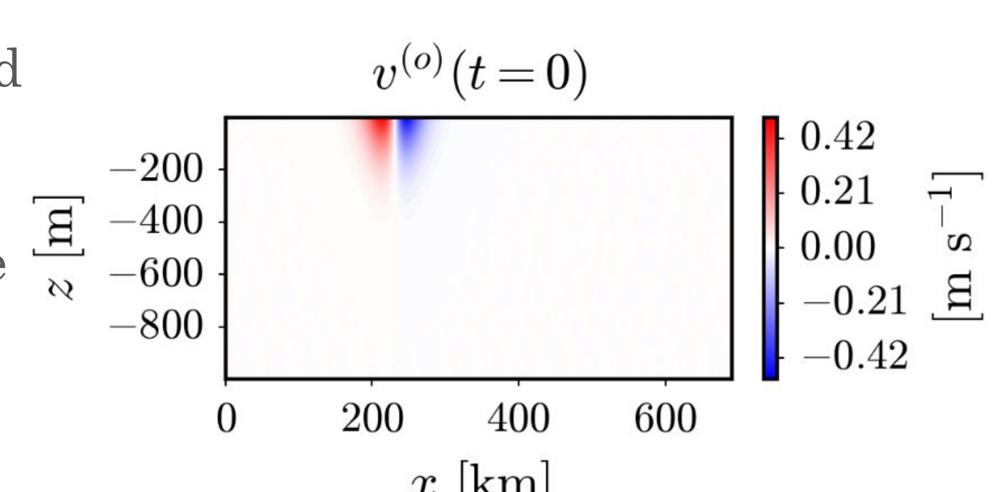
Initial Conditions

We construct a 3D atmosphere and ocean to emulate an idealized region of the gulf stream with variation only occurring in the zonal direction and depth. Small perturbations are added to ensure the development of 3D turbulence.

Ocean

- A jet which only varies in the zonal direction and depth is constructed in hydrostatic and geostrophic balance
- Parameters are checked to avoid unwanted inertial and gravitational instability
- Only the temperature and meridional velocity are needed





Atmosphere

- The atmosphere is initialized with a stable prescribed lapse rate with uniform in space winds blowing in the positive zonal direction at 3 m/s

Boundary Conditions

Uncoupled Ocean Surface

- A constant in time, uniform in space, quadratic wind stress based on the 3 m/s wind speed in the atmosphere[1]

$$Q_u^{(o)} = -\frac{\rho_0^{(a)}}{\rho_0^{(o)}} C_D U_{10}^{(a)} |U_{10}^{(a)}|,$$

$$Q_v^{(o)} = -\frac{\rho_0^{(a)}}{\rho_0^{(o)}} C_D V_{10}^{(a)} |V_{10}^{(a)}|,$$

- A temperature flux is chosen such that the background stratification of the ocean is continuous at the boundary

Uncoupled Atmosphere Surface

- The initial SST is read in as constant in time, and the WRF surface parameterization uses this information to calculate the associated near surface fluxes

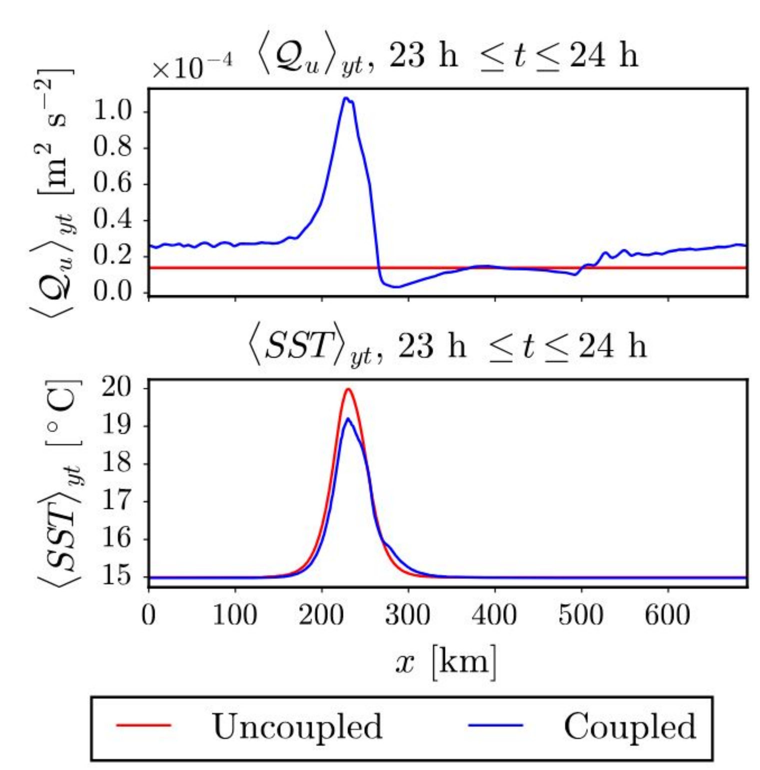
Coupled Interface

- At every ocean time step the WRF surface parameterization uses the current SST to calculate the associated surface heat and momentum fluxes, these are then used to calculate the ocean boundary conditions dynamically
- A comparison of these uncoupled and coupled fluxes near the end of the simulation can be seen below

$$Q_u^{(o)} = -\frac{\rho_0^{(a)}}{\rho_0^{(o)}} \left(u_*^{(a)}\right)^2 \frac{u_{10}^{(a)}}{\sqrt{\left(u_{10}^{(a)}\right)^2 + \left(v_{10}^{(a)}\right)^2}},$$

$$Q_v^{(o)} = -\frac{\rho_0^{(a)}}{\rho_0^{(o)}} \left(u_*^{(a)}\right)^2 \frac{v_{10}^{(a)}}{\sqrt{\left(u_{10}^{(a)}\right)^2 + \left(v_{10}^{(a)}\right)^2}},$$

$$Q_T^{(o)} = \frac{Q_h^{(a)}}{\rho_0^{(o)} c_p^{(o)}},$$



Acknowledgements

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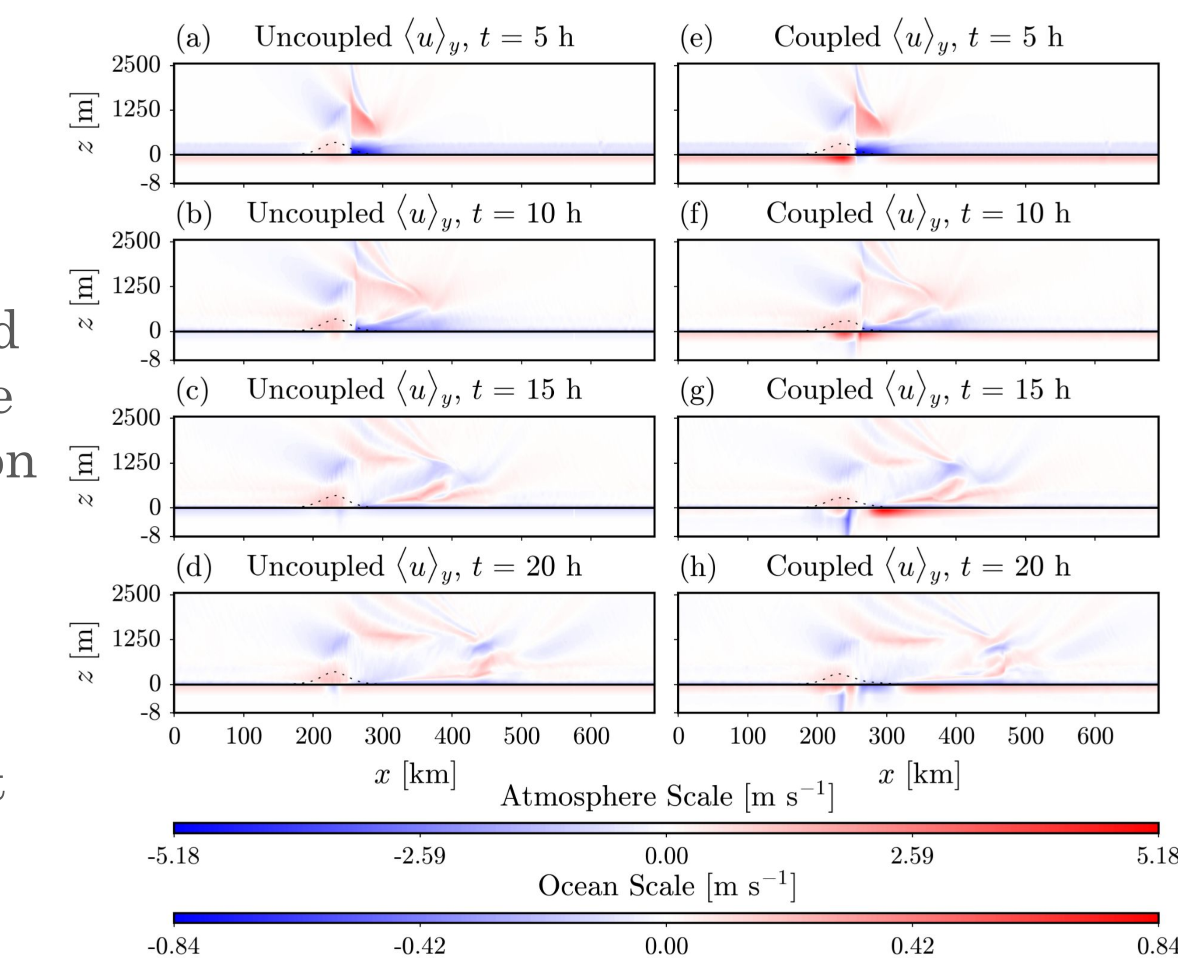
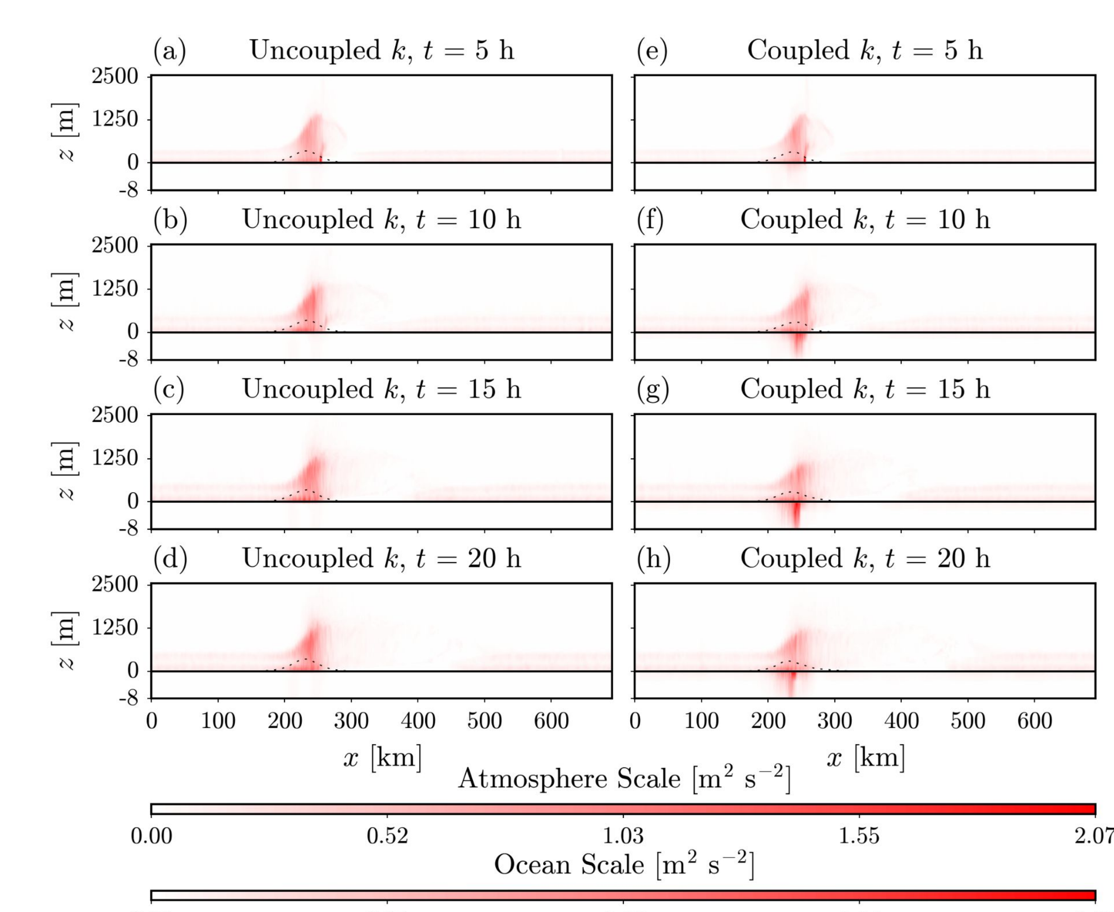
Zonal Velocity Evolution

- Not much qualitative difference between uncoupled and coupled atmosphere
- No evolution of ocean in uncoupled case
- Dramatic adjustment in coupled ocean



TKE Evolution



- Coupling causes a slightly weaker atmospheric TKE
- No evolution of ocean in uncoupled case
- Large TKE generation above strongest coupled winds

References

1. A B Kara, A J Wallcraft, E J Metzger, H E Hurlburt, and C W Fairall. Wind stress drag coefficient over the global ocean. Journal of Climate, 20(23):5856–5864, 2007
2. A Ramadhan, G L Wagner, C Hill, J Campin, V Churavy, T Besard, A Souza, A Edelman, R Ferrari, and J Marshall. Oceananigans.jl: Fast and friendly geophysical fluid dynamics on gpus. Journal of Open Source Software, 5(53):2018, 2020. doi: 10.21105/joss.02018. URL https://doi.org/10.21105/joss.02018
3. H Seo, L W O'Neill, M A Bourassa, A Czaja, K Drushka, J B Edson, B Fox-Kemper, I Frenger, S T Gille, B P Kirtman, et al. Ocean mesoscale and frontal-scale ocean– atmosphere interactions and influence on large-scale climate: A review. Journal of Climate, 36(7):1981–2013, 2023
4. W C Skamarock, J B Klemp, J Dudhia, D O Gill, D M Barker, MG Duda, X Huang, W Wang, J G Powers, et al. A description of the advanced research WRF version 3. NCAR technical note, 475(125):10–5065, 2008.
5. RJ D Small, S P deSzoeke, SP Xie, L O'neill, H Seo, Q Song, P Cornillon, M Spall, and S Minobe. Air–sea interaction over ocean fronts and eddies. Dynamics of Atmospheres and Oceans, 45(3-4):274–319, 2008.