Ocean response to Tropical Cyclone Vayu

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Motivation

Enthalpy fluxes from the ocean are the primary source of energy for a tropical cyclone (TC). When sea surface temperature (SST) under the storm cools due to the shear-induced vertical mixing, the fluxes are reduced, limiting further intensification of the cyclone. Hence, SST cooling is negatively coupled to the TC intensity and it is essential for a cyclone forecast model to capture this feedback effect for accurate intensity predictions. Sub-surface oceanic conditions present prior to the storm can control the amplitude of this feedback. Here, we look at the ocean response to TC Vayu and try to understand the role of ocean in intensification and weakening of the storm.

Data and Methodology

Simulation of TC Vayu is performed using the Weather Research and Forecast system for hurricane (HWRF[1]). It is a primitive-equation, non-hydrostatic, coupled atmosphere-ocean model with atmospheric component as the Non-hydrostatic Mesoscale Model (NMM) dynamic core of the WRF model and employs Hybrid Coordinate Ocean Model (HYCOM) as the ocean component.

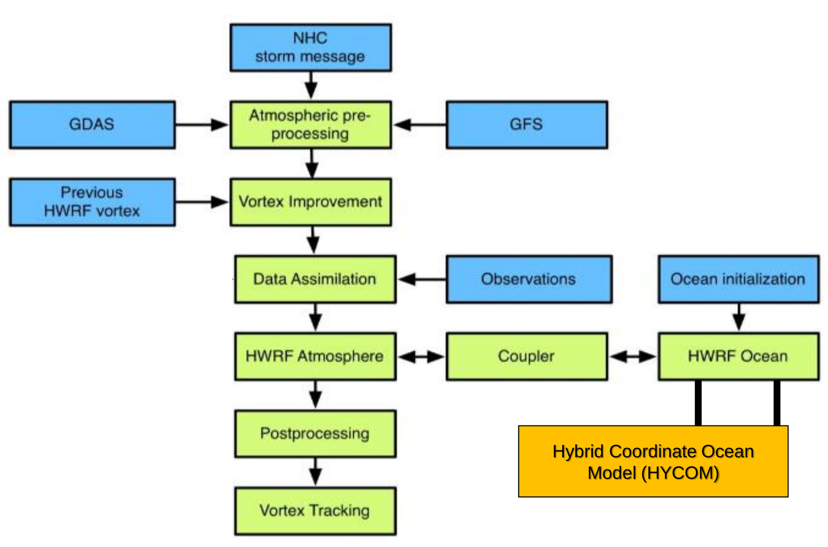

Fig 1: Schematic of different components of HWRF modeling system. *Source*[1]

The model is configured with a stationary parent domain spanning 80° x 80° on a rotated latitude /longitude E-staggered grid with a resolution of 0.135° (18 km) and two telescopic nested domains that follows the storm (6 km and 2 km resolution). The 1/12th degree ocean model used for coupling derives its initial and boundary conditions from the Indian Ocean HYCOM setup at INCOIS.

Track and Intensity

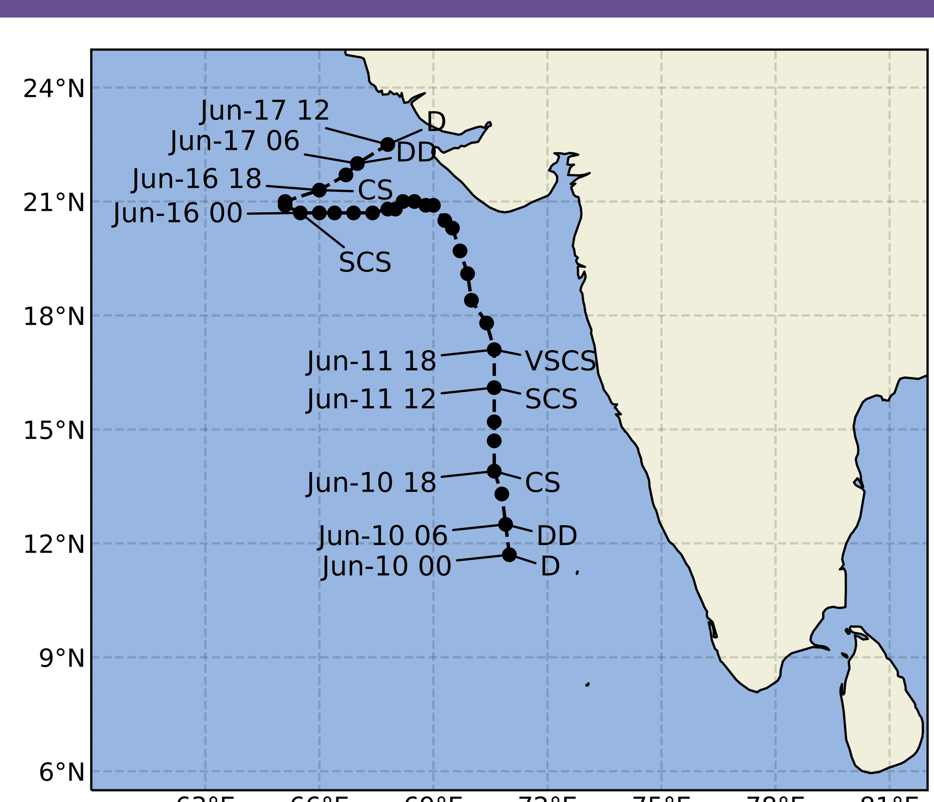

Fig 2: Observed track of tropical cyclone Vayu

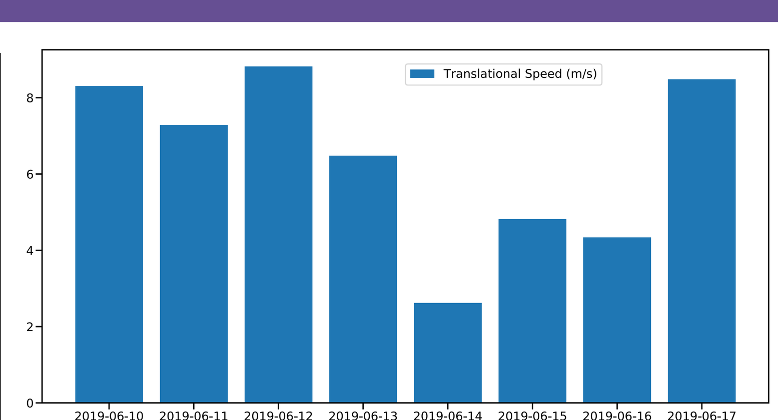

Fig3: 12-hr average translational speed of TC Vayu

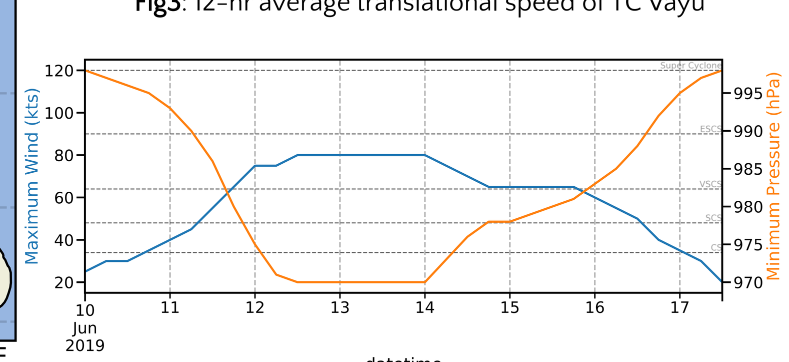

Fig4: Observed intensity of tropical cyclone Vayu

- Intensity of TC Vayu increased continuously as it moved northward towards the Gujarat coast
- The 12-hr average translational speed of cyclone during its northward movement before turning westward was around 7.5 m/s.
- As the cyclone turned westward, the 12-hr average translational speed reduced to 3.9 m/s and after recurving to north eastward direction, it increased to 5.5 m/s
- TC Vayu weakened after 2019-06-14 00hr and became a depression 60 hours afterwards.

References

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SST Evolution

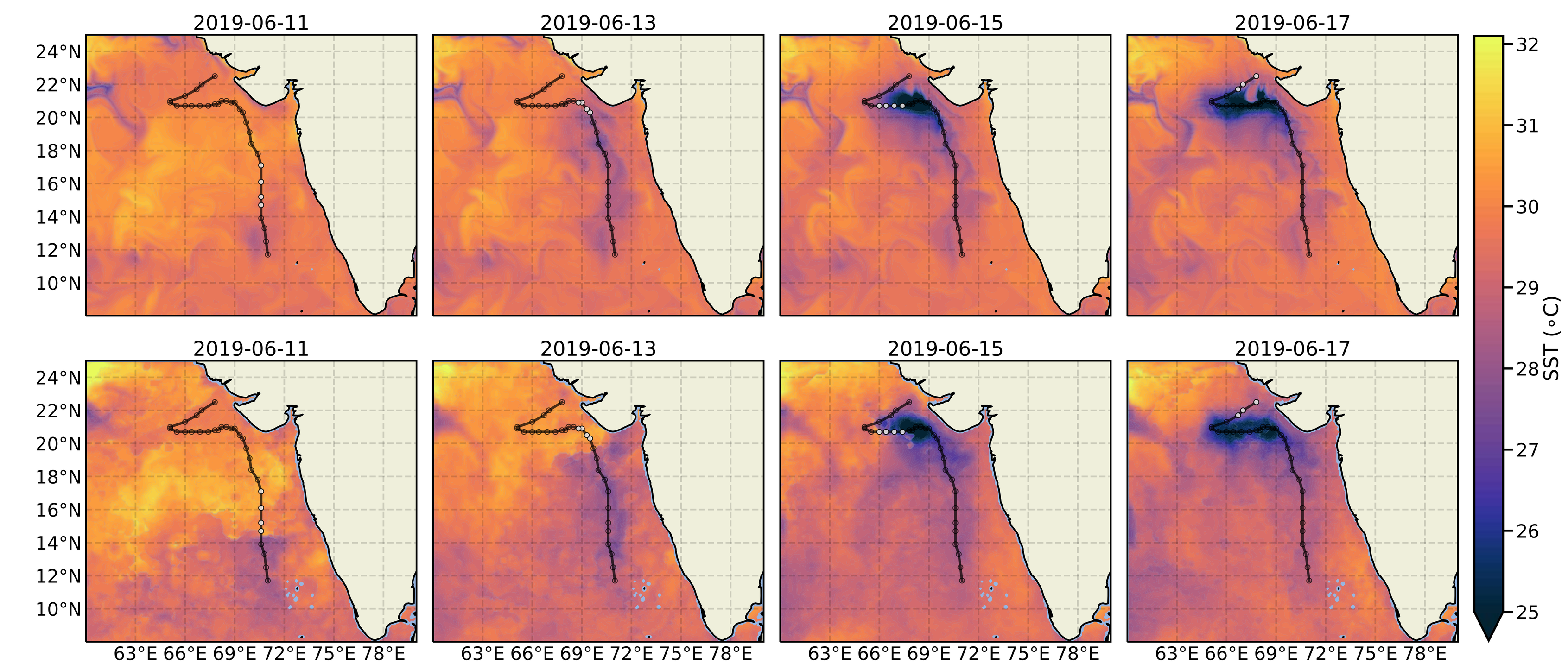

Fig 5: Time evolution of SST during TC Vayu. (top panel) SST from ocean model (bottom panel) SST from satellite measurement. Black line indicates the observed track of TC Vayu and the white markers show the cyclone position at a given time.

- Model simulation has well captured the observed evolution of SST.
- Though the cyclone reached its peak intensity on 2019-06-12, pronounced cooling of SST seen only after it crossed the 20 ° N latitude.
- SST Cooling in the westward branch was asymmetric with a rightward bias, which later became symmetric across the track.

Response of Mixed Layer Depth (MLD)

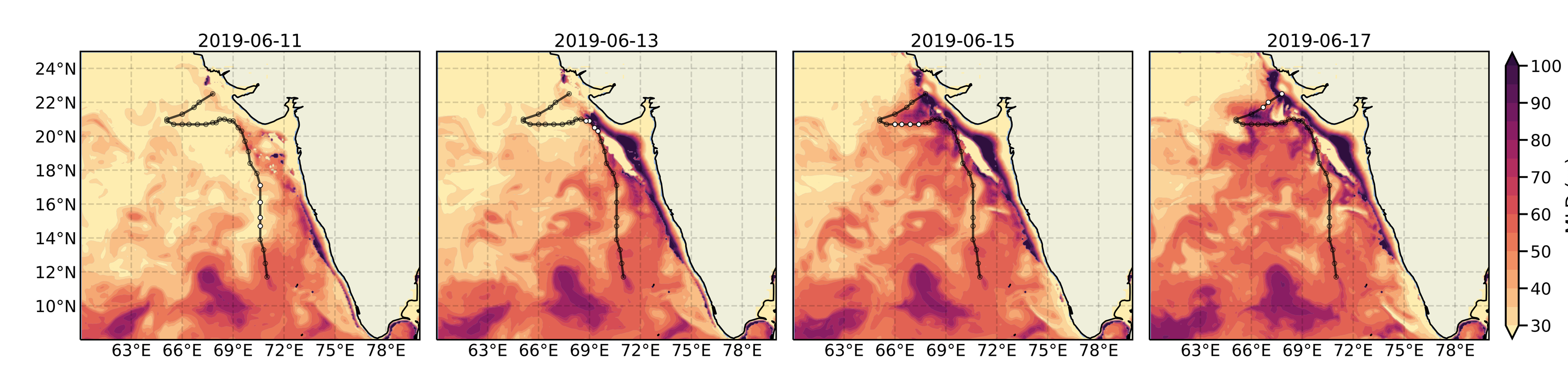

Fig 6: Evolution of mixed layer depth during TC Vayu.

- Initial mixed layer to the north of 20° N was thin (<30 m) prior to TC arrival.
- Enhanced vertical mixing of coastal waters extending to depth >80 m can be seen.
- Rightward bias[2] in vertical mixing is evident when cyclone track turned westward.

Tropical Cyclone Heat Potential (TCHP)

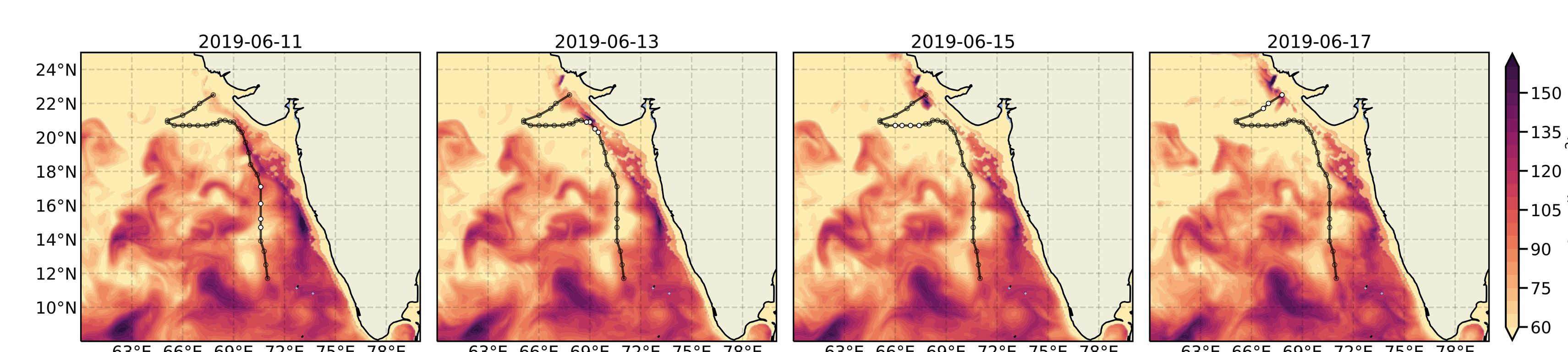

Fig 7: TCHP during TC Vayu

- Even though coastal waters show deepened MLD, it's TCHP values remains high (>90 kJ/cm^2) and constant with time.
- It suggests that the entire column of coastal waters was above 26° C
- After 2019-06-13, cyclone entered a region of low THCP values (<60 kJ/cm^2), which are known[3] to be a non favorable condition for TC development.

Conclusions

- Maximum SST cooling of about 3.5° C occurred to the north of 20° N as the cyclone turned right and moved away from Gujarat coast.
- During the northward movement of TC along the west coast of India, SST cooling was suppressed due to the lack of vertical thermal gradient, thus offering a favorable condition for TC intensification.
- As the cyclone crossed 20° N and turned westward, shallow background MLD and enhanced mixing on the right side of the track caused entrainment of colder water from the base of the mixed layer to the surface, thereby cooling SST.
- The presence of colder SST and reduced translational speed contributed to the weakening of TC Vayu.

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