Mesoscale and Submesoscale Structures in the Arabian Sea

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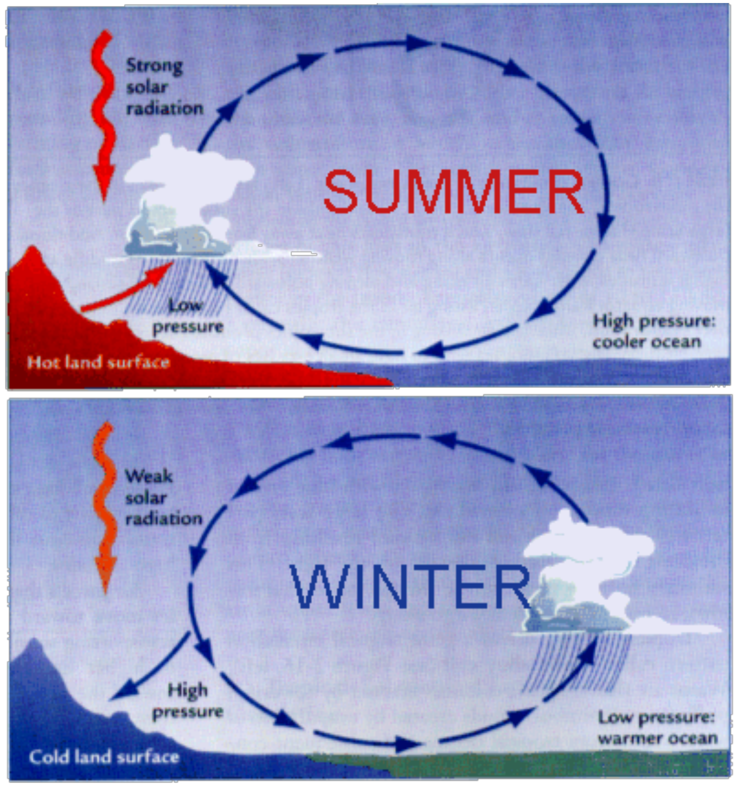
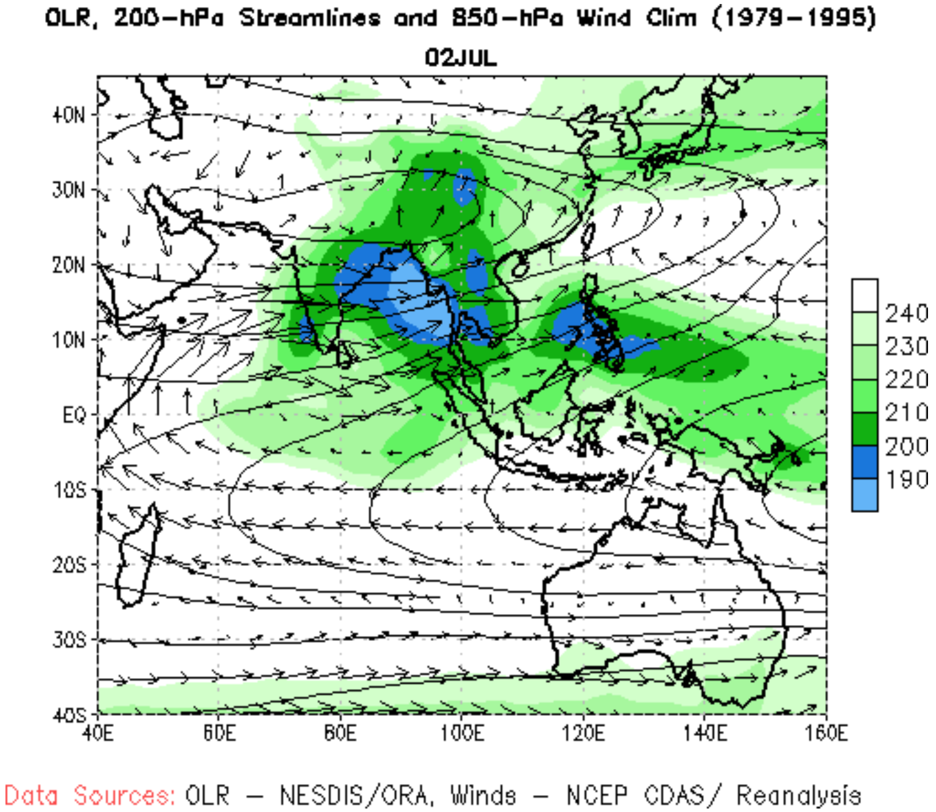
Indian Monsoon

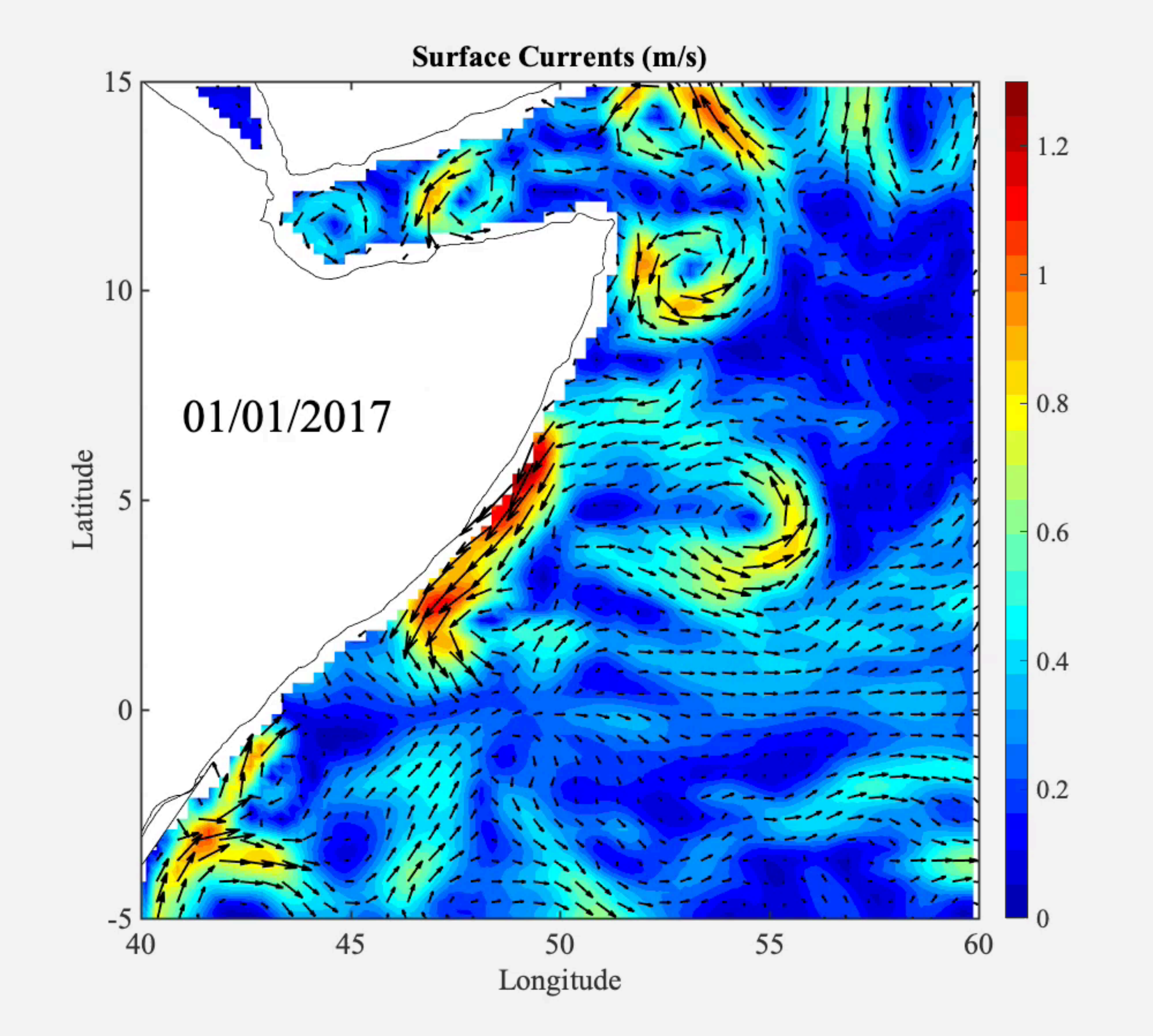
- Seasonally reversing phenomenon separated into the summer or Southwest Monsoon (June-Sept) and winter or Northeast Monsoon (Nov-Feb)
- Leads to heavy seasonal rainfall over southern Asia
- Extremely important, but highly variable and difficult to predict





Left: Seasonal monsoonal circulation (from globe.gov)
Right: NESDIS OLR and NCEP 200-hPa Streamlines and 850-hPa wind Climatologies (1979-1995)

Somali Current Reversal & Eddies



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AVISO geostrophic surface currents

Eddy Tracking

- Objectives of this research:
  - Track eddies in the Arabian Sea
  - Quantify their characteristics

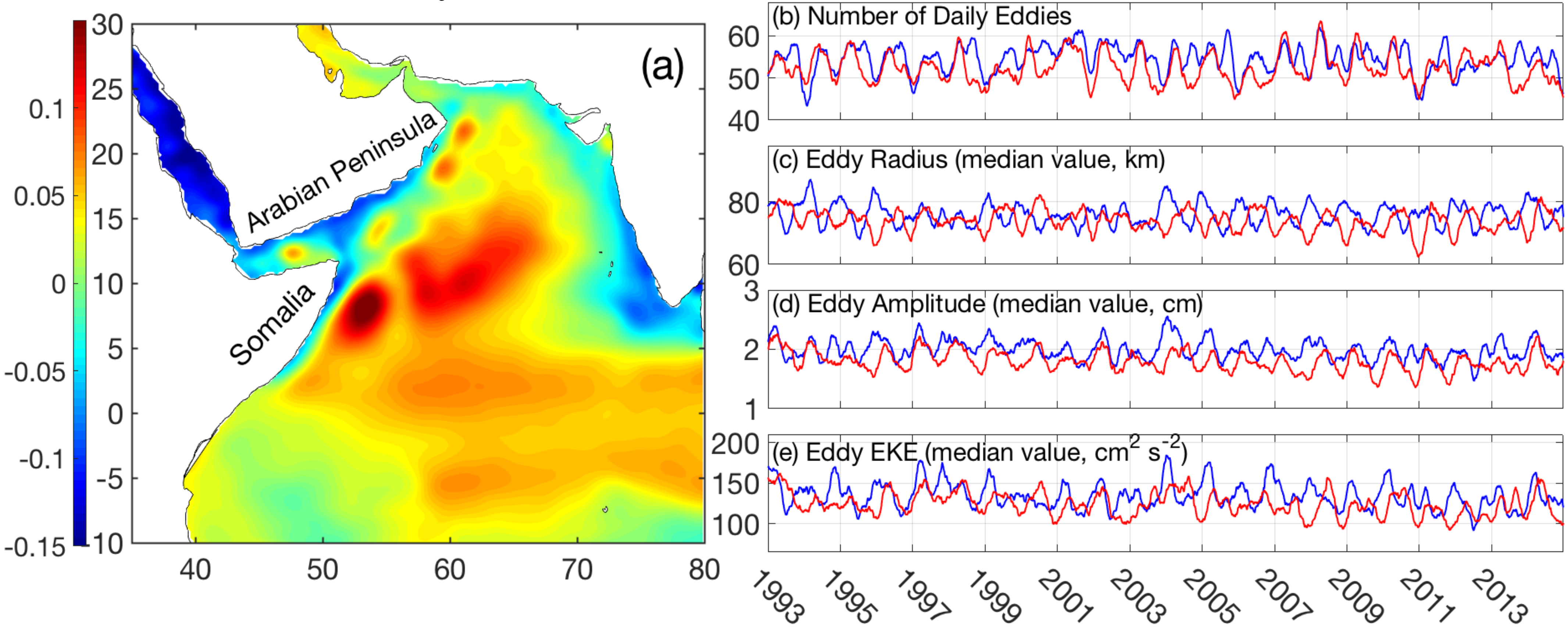
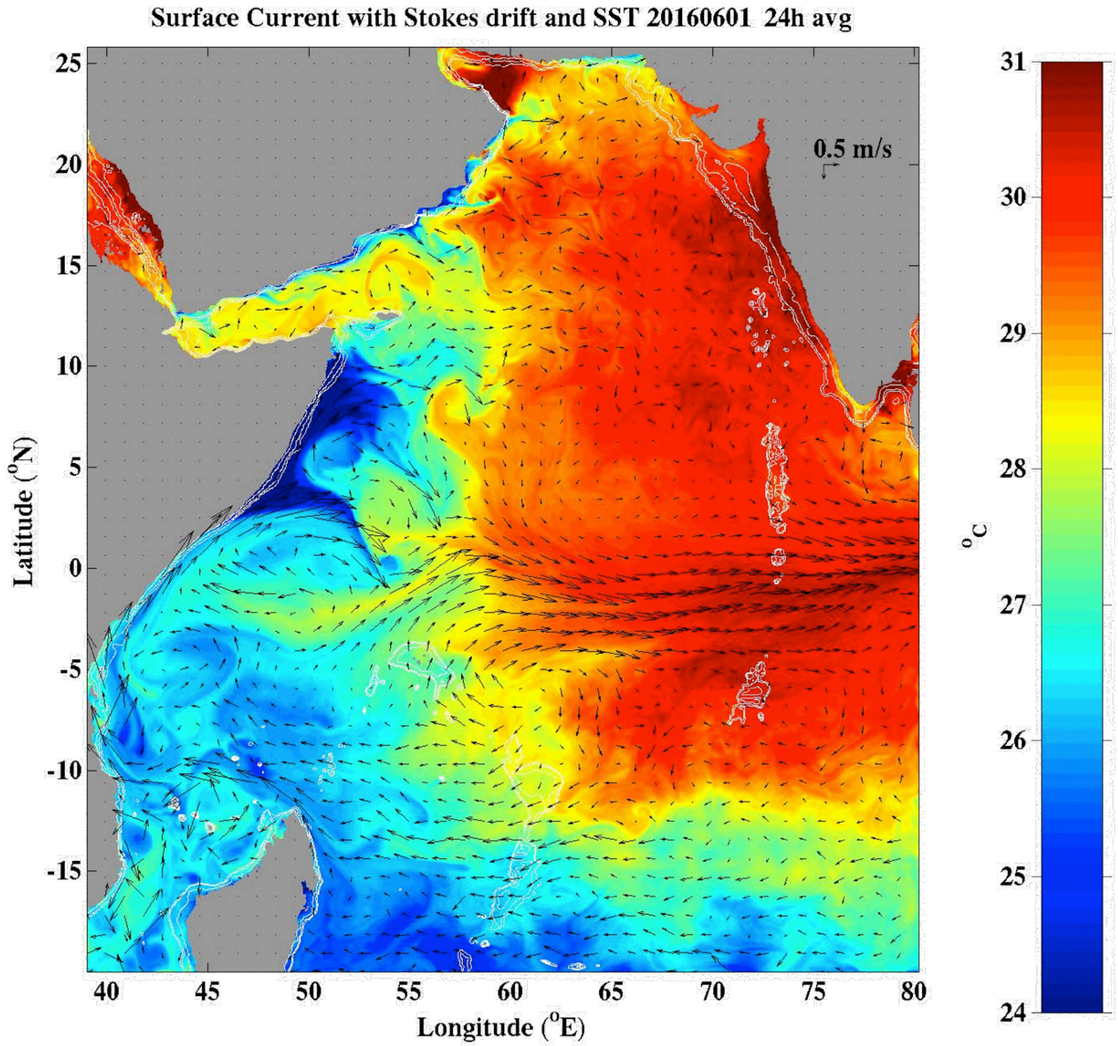


Figure: Mean SLA during summer & eddy characteristics in the NIO.
Red lines = anticyclonic eddies, blue lines = cyclonic eddies

Somali Upwelling



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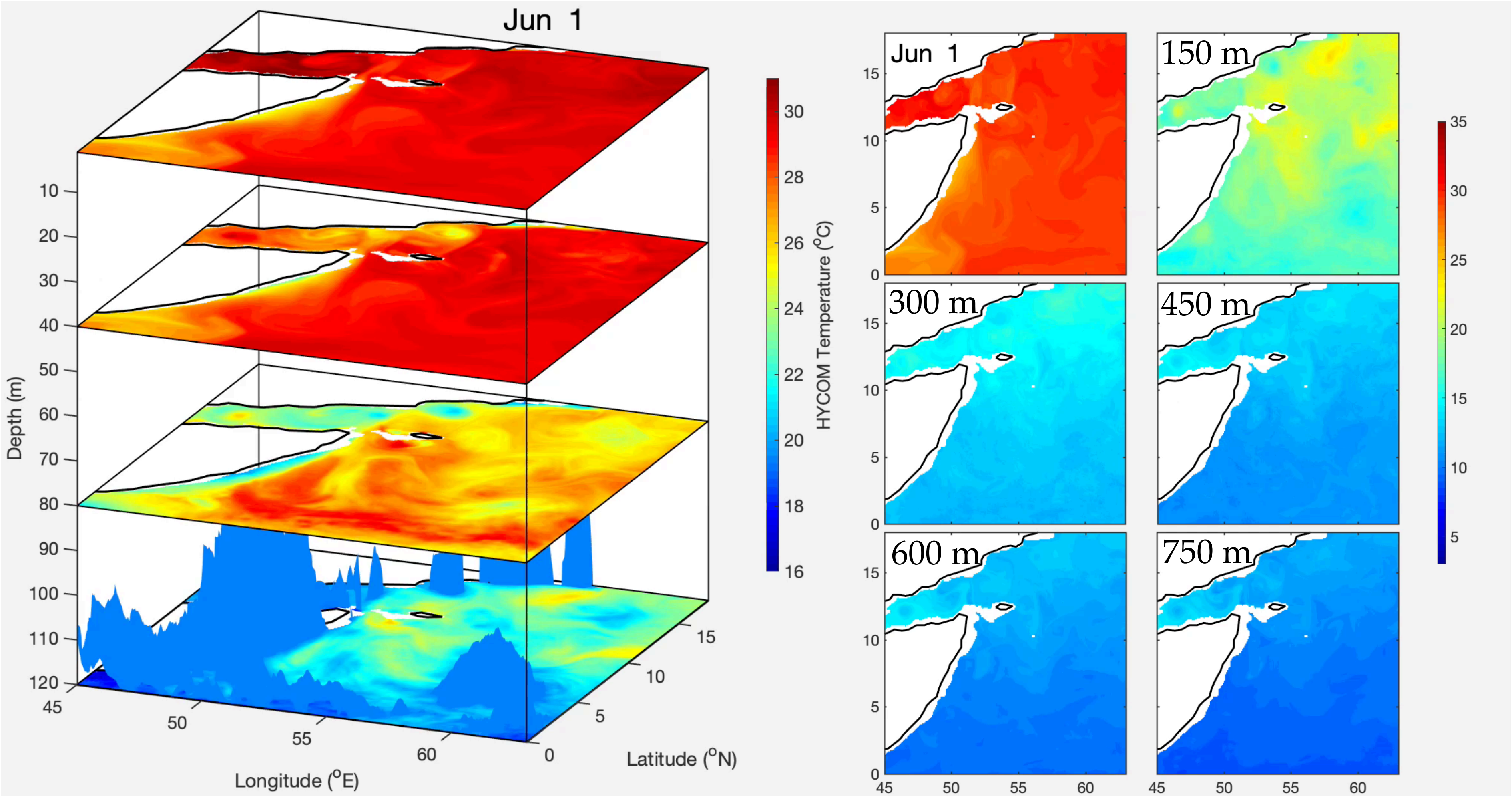
Courtesy of Tommy Jensen (NRL)

Somali Upwelling



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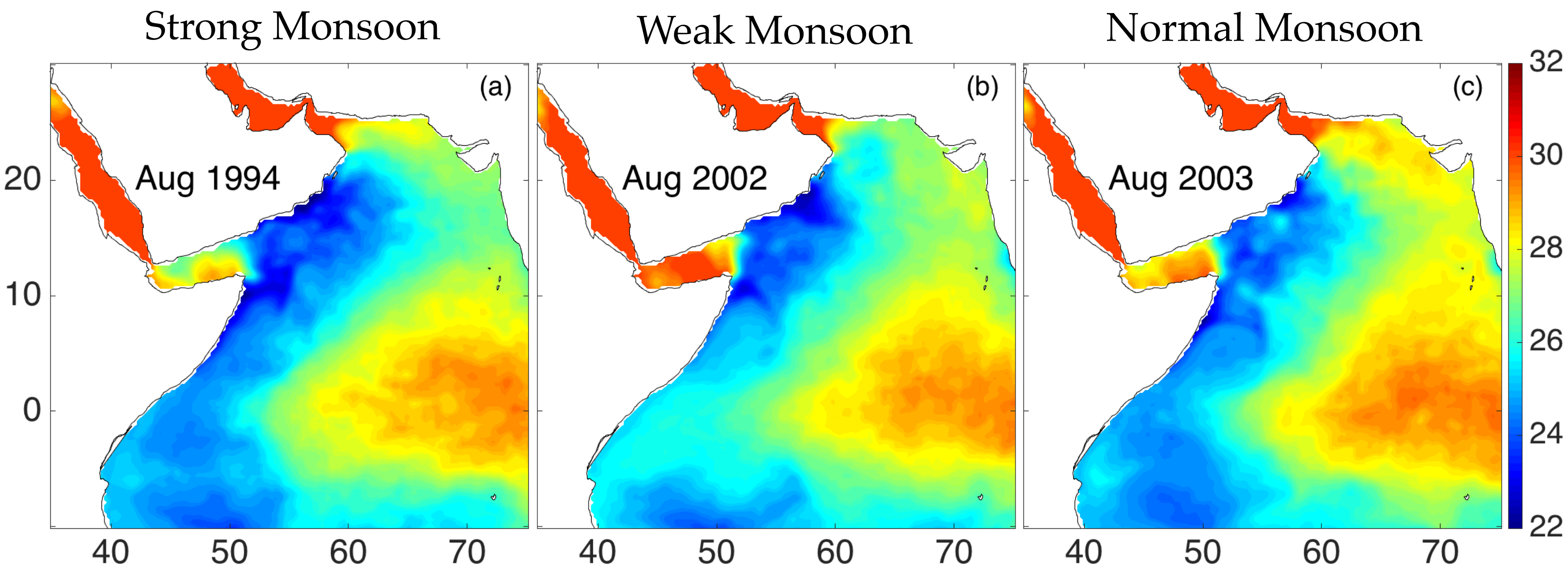
HYCOM Temperature for 1994.

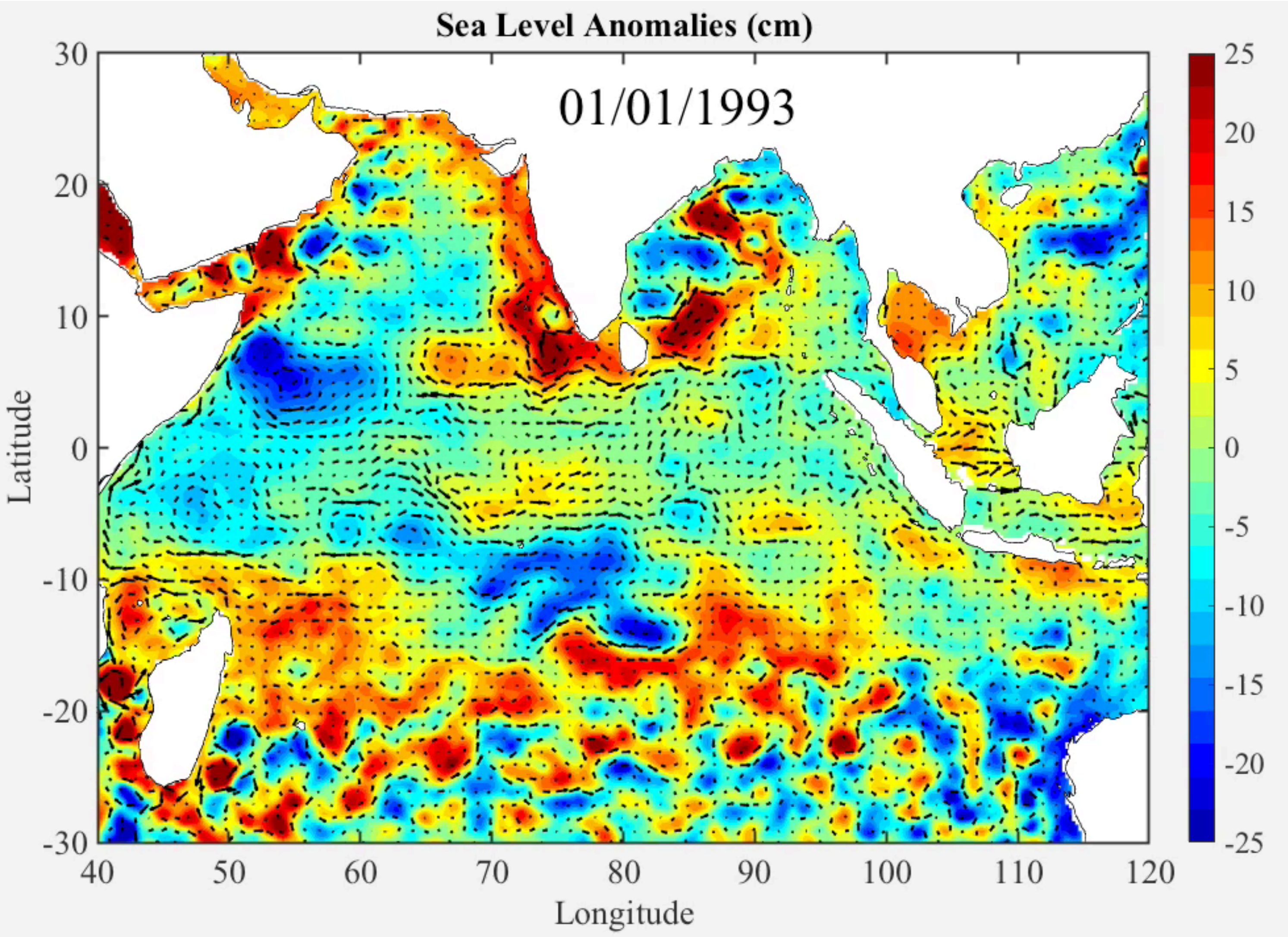
Ekman Pumping

- Increased coastal upwelling in stronger summer monsoon seasons
  - Upwelling is suppressed in weak summer monsoon
  - Can be seen in “cold wedges” redirected by major eddies



Monthly AVHRR SST

Rossby Waves

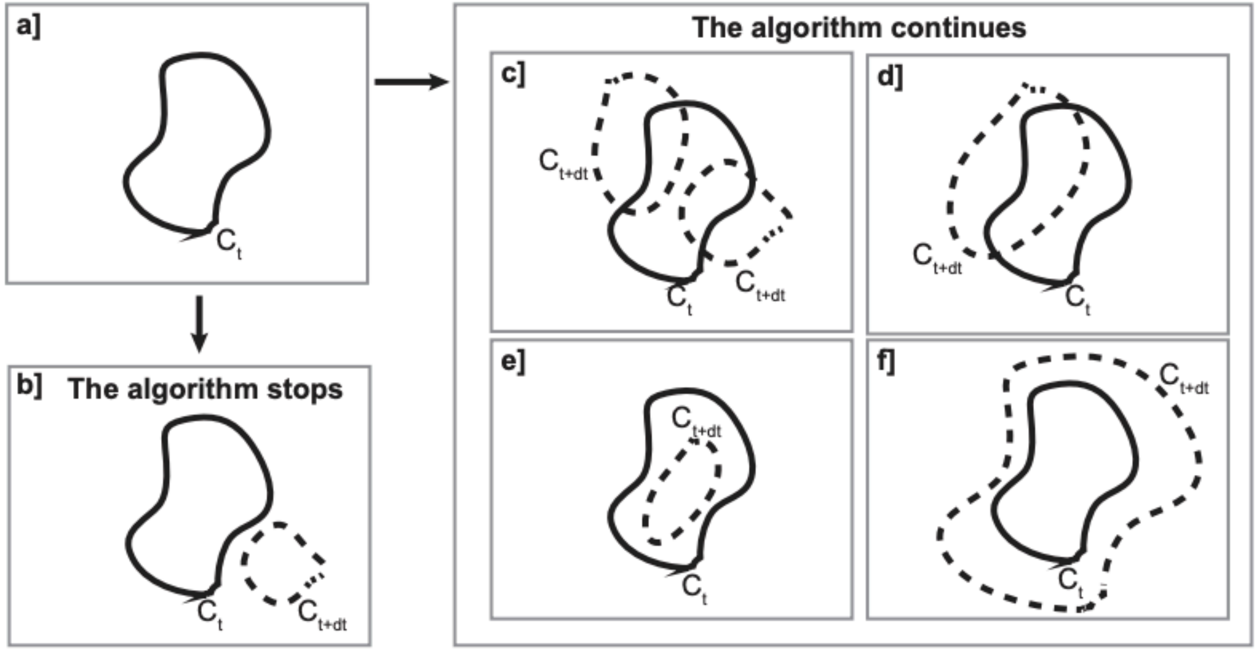


Daily AVISO Sea Level Anomalies

Eddy Tracking Methodology

- First step: Identification
  - Local extremes were found on each daily sea level anomaly map
  - Eddy edge was the outermost closed sea level anomaly contour
- Second step: Tracking
  - Minimized a cost function

$$CF=\sqrt{\left(\frac{\Delta R-\overline{\Delta R}}{\sigma_{\Delta R}}\right)^2+\left(\frac{\Delta A-\overline{\Delta A}}{\sigma_{\Delta A}}\right)^2+\left(\frac{\Delta EKE-\overline{\Delta EKE}}{\sigma_{\Delta EKE}}\right)^2}$$



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(Pegliasco et al., 2015)

Eddy Characteristics

- Highest number of eddies along the coast of the Arabian Peninsula
- Eddies in Somali Current region are the most robust
- Region of cyclonic eddies with high radii is located to the east of their anticyclonic counterpart
  - Due to circulation of CEs about Great Whirl
  - These CEs have high amplitudes, EKEs

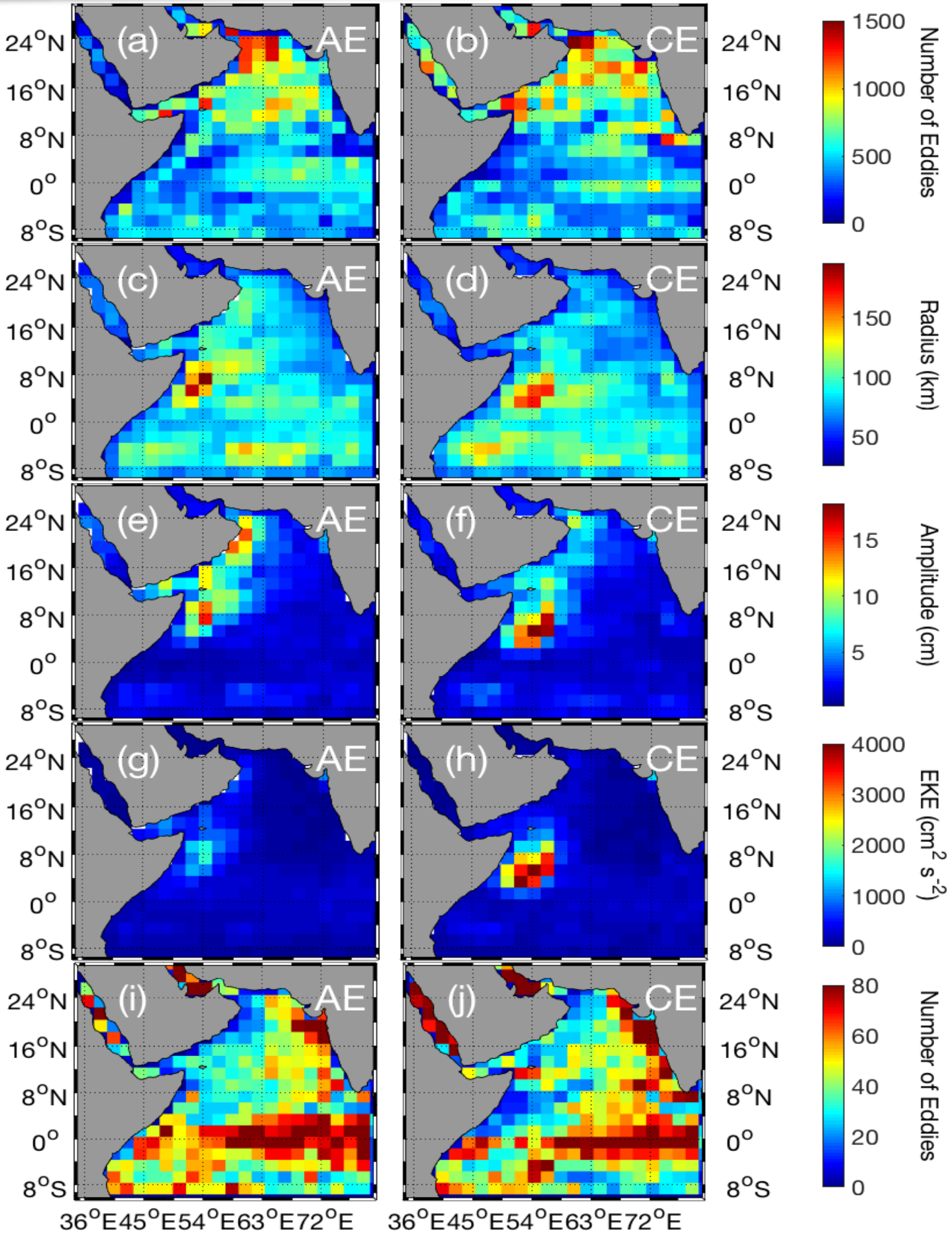


Figure: Mean spatial distribution of eddy characteristics during summer monsoon season (June-September) for AEs (left panel) and CEs (right panel). (a-b) Number of eddies; (c-d) radius (in km); (e-f) amplitude (in cm); (g-h) EKE (in cm^2 s^{-2}); (i-j) Number of eddy generation.

Eddy Trajectories

- Significant eddy generation in Somali Current and Arabian Peninsula regions
- Westward propagation of CEs concurrent with upwelling Rossby wave development
- Clockwise trajectory of CEs about larger AE Somali Current eddies

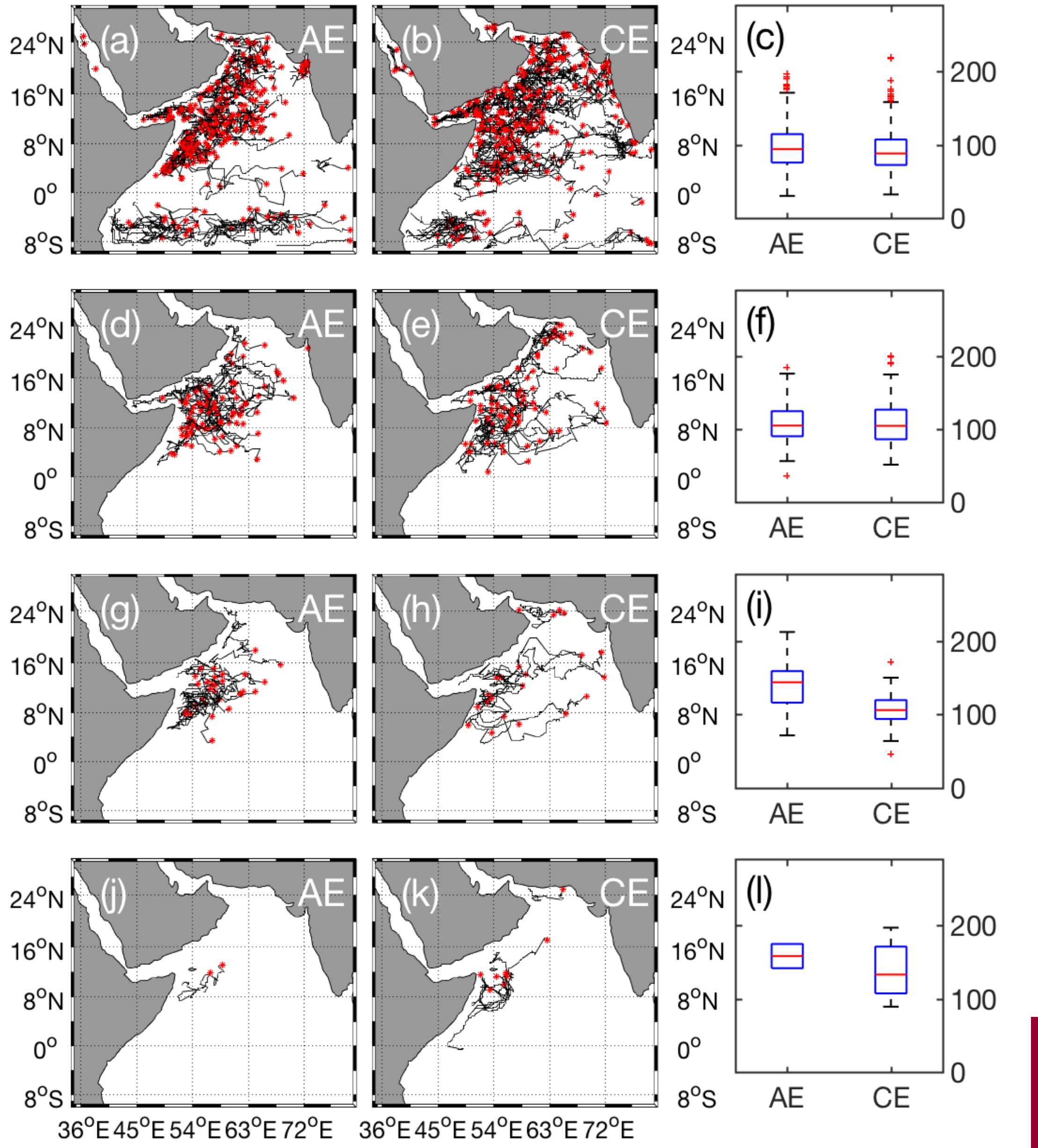
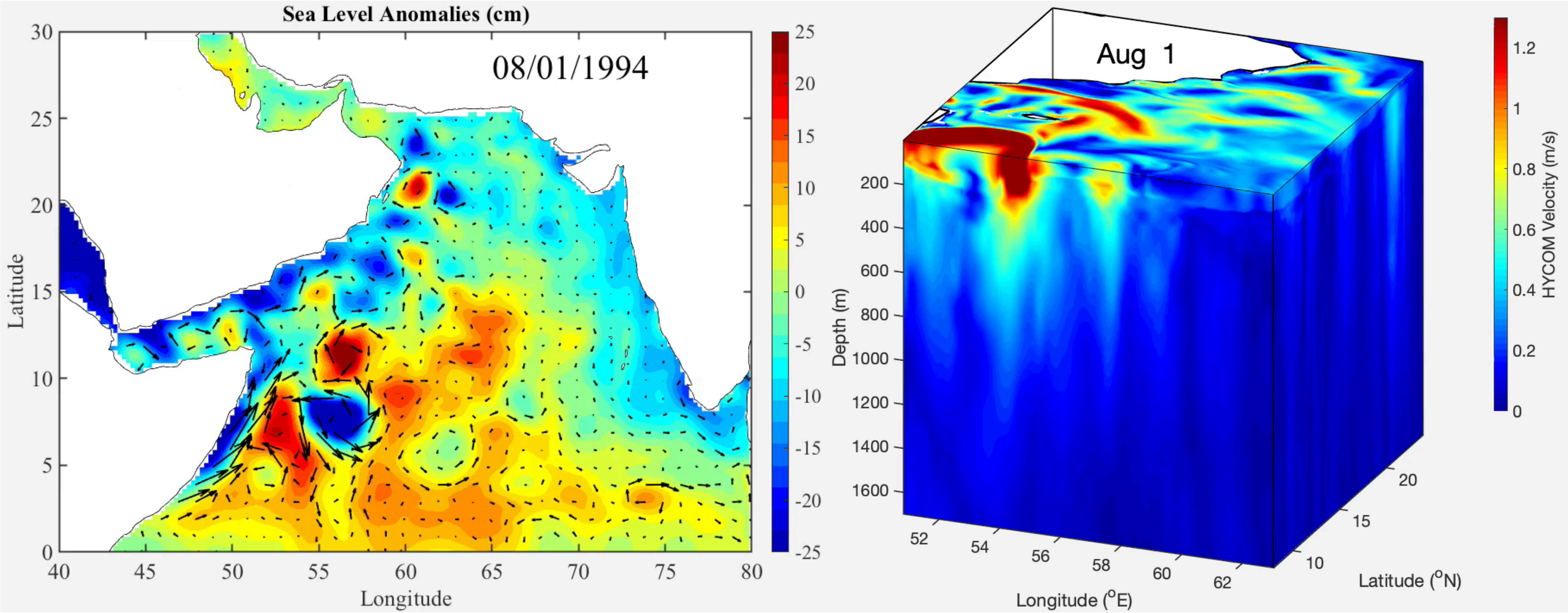


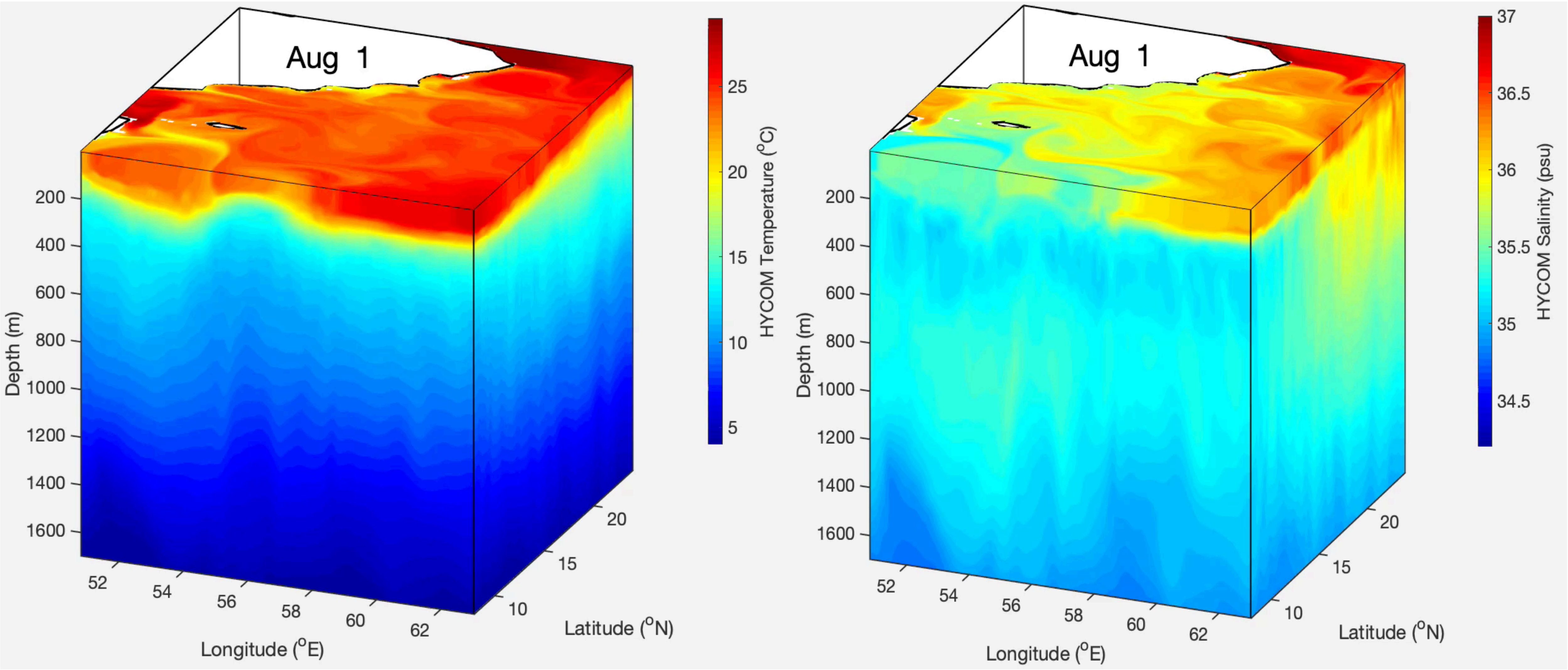
Figure: Trajectories of AEs (left) and CEs (right) generated during summer monsoon season (June to September) from 1993 to 2014 with maximum amplitudes ranging between 10-20 cm (a, b), 20-30 cm (d, e), 30-40 cm (g, h) and >40 cm (j, k).

Great Whirl



AVISO SLA and HYCOM current magnitude for August-September of the strong monsoon of 1994.

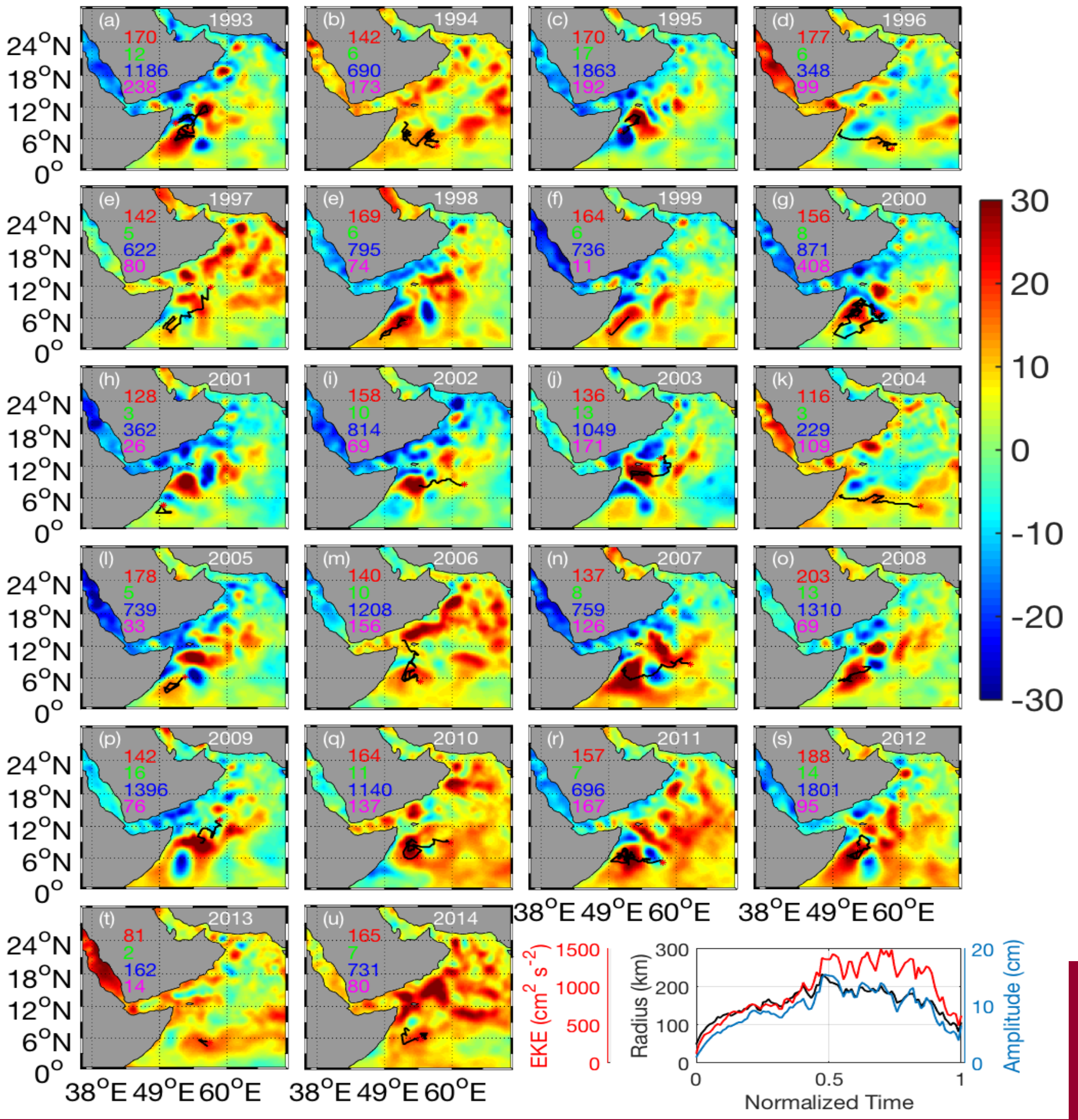
Great Whirl



HYCOM temperature and salinity for August-September of the strong monsoon of 1994.

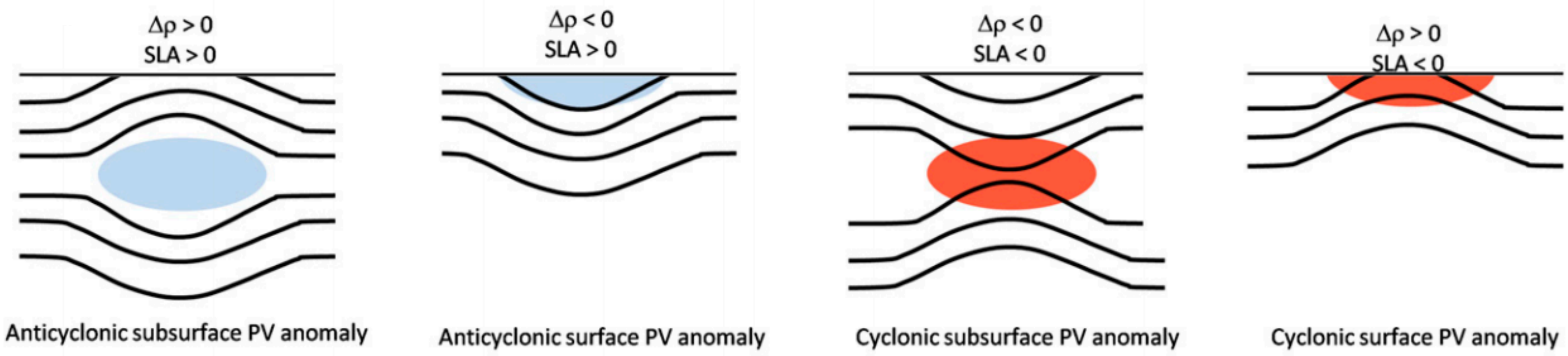
Great Whirl

- Trajectories are in black and red asterisks signify the generation location of each eddy track.
- Bottom right panel shows the ensemble mean radius, EKE, and amplitude for the 18 GW having a lifespan greater than 50 days.



*Trajectories of the AE having the largest maximum radius in the Arabian Sea for each year between 1993 and 2014 **(a-u)** and SLA (color shading, in cm) of the day corresponding to the largest GW radius.*

Surface and Subsurface Eddy Structure

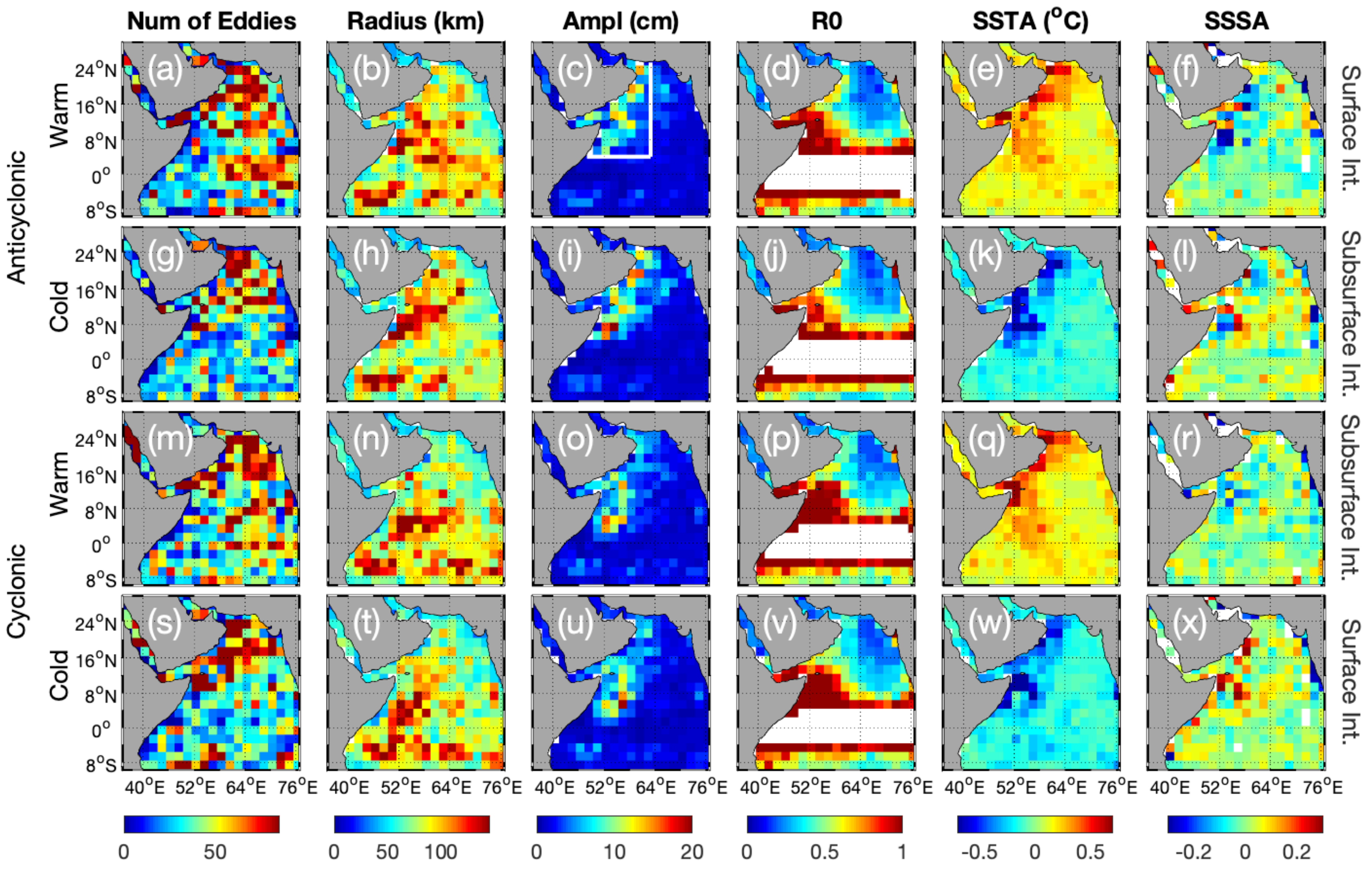


- Surface-intensified anticyclonic eddies have the largest deformation of isopycnals at the surface while those intensified at the subsurface are domed above the center and depressed below it.

- Likewise, subsurface-intensified cyclones have a depressed isopycnal shape above and a domed shape below

Isopycnal displacements and SLA for the four eddy types (Assassi et al., 2016)

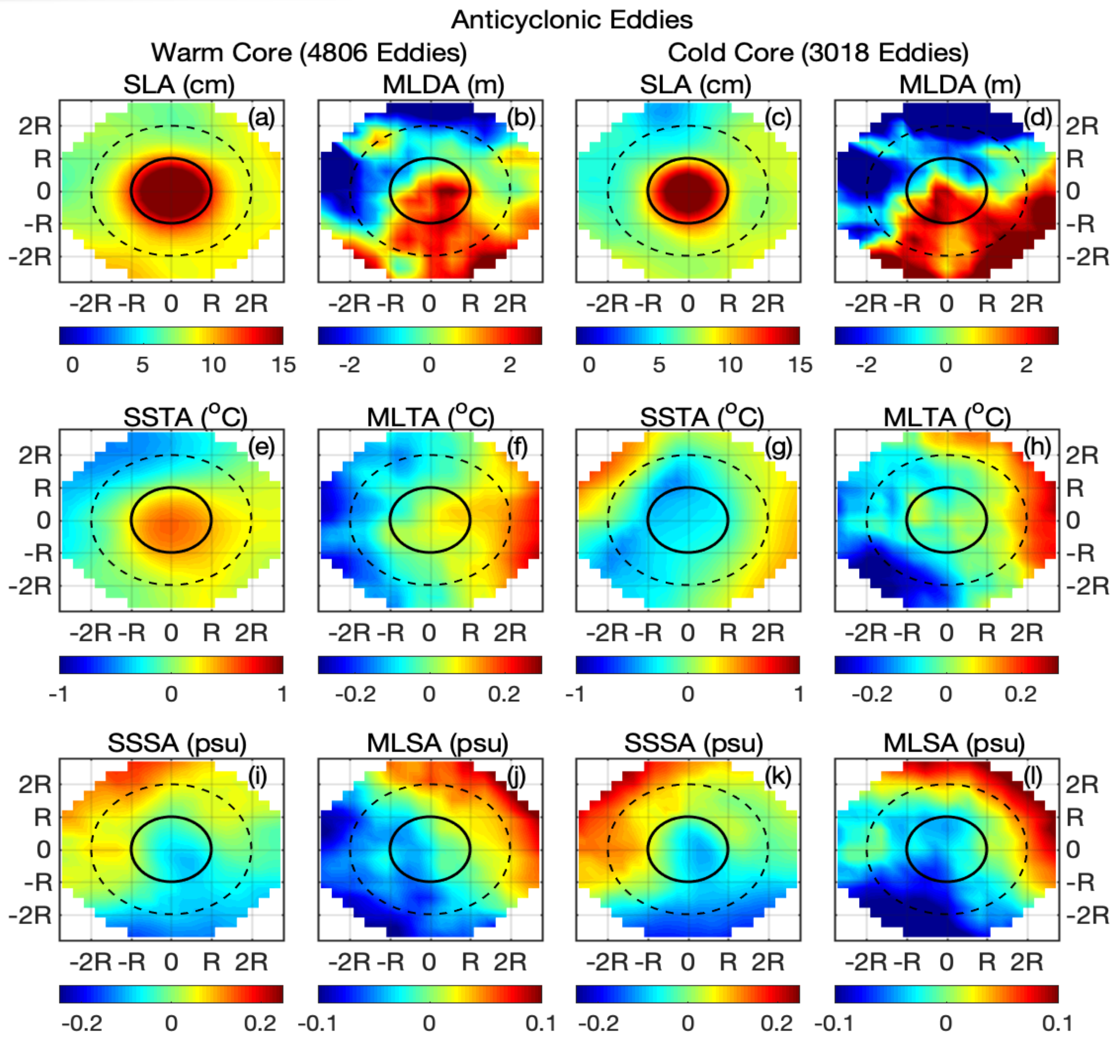
Eddy Characteristics



- When eddies are separated by circulation type and by anomalous temperature (warm or cold core)
    - Similar radii and amplitudes
    - Different distribution of temperature anomalies

Mean spatial distribution of eddy characteristics during summer monsoon season (June-September) from 2015 through 2018.

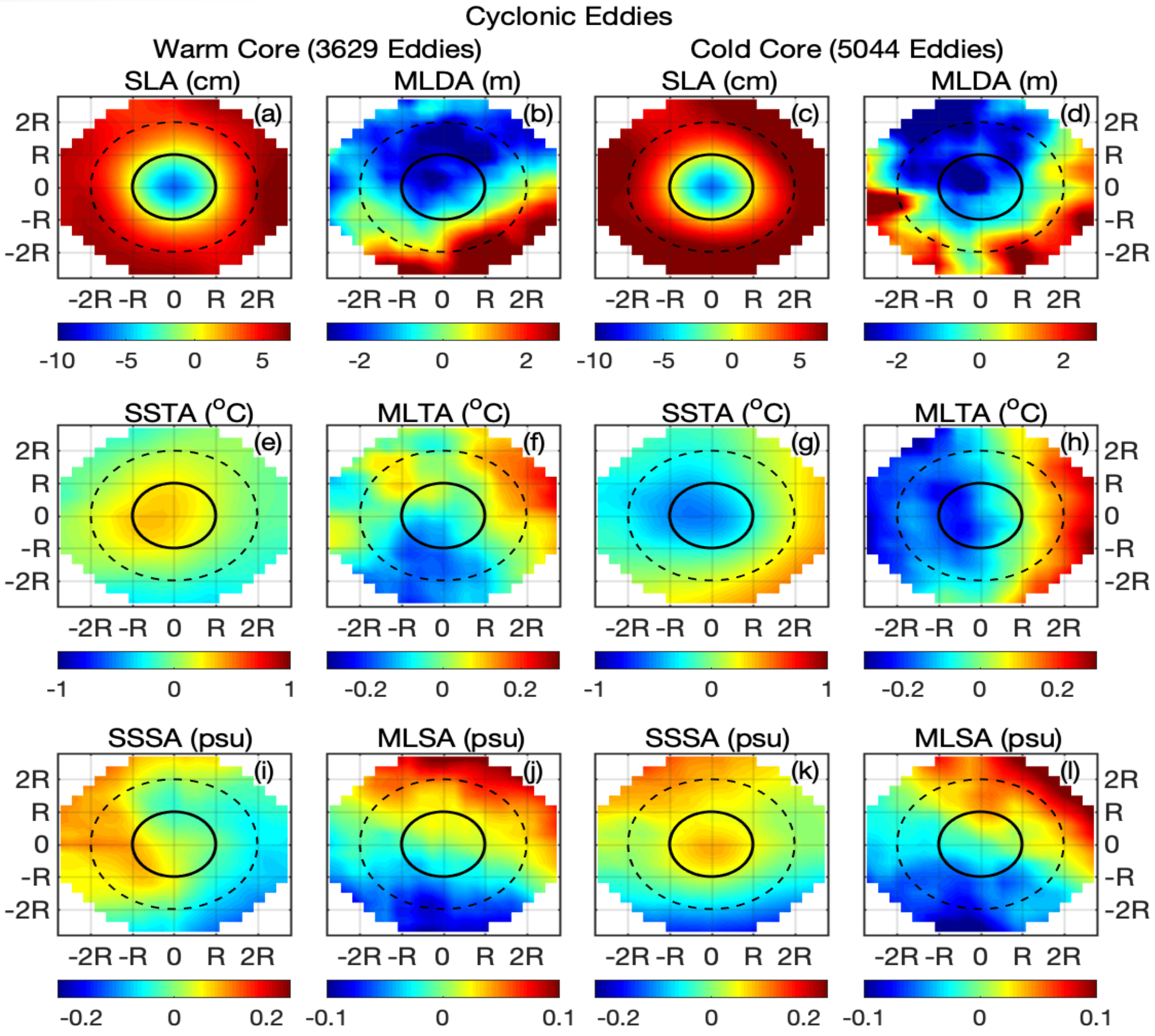
Composite Eddy Characteristics



- Composites (normalized by radius) of anticyclonic eddies in the northwestern Arabian Sea
  - Captured the most robust eddies of the Somali Current and off the coast of the Arabian Peninsula
  - While warm and cold core eddies were opposite in temperature at the surface, this was not the case for salinity

Composites of warm and cold core anticyclonic eddies west of 63°E and north of 4°N. SLA = sea level anomaly, MLDA = mixed layer depth anomaly, SSTA = sea surface temperature anomaly, MLTA = mixed layer temperature anomaly, SSSA = sea surface salinity anomaly, MLSA = mixed layer salinity anomaly.

Composite Eddy Characteristics



- Found composites (normalized by radius) of cyclonic eddies in the northwestern Arabian Sea
  - More cold core cyclonic eddies (5044) than warm core (3629)
  - Smaller temperature anomalies than their anticyclonic counterparts

Composites of warm and cold core cyclonic eddies west of 63°E and north of 4°N. SLA = sea level anomaly, MLDA = mixed layer depth anomaly, SSTA = sea surface temperature anomaly, MLTA = mixed layer temperature anomaly, SSSA = sea surface salinity anomaly, MLSA = mixed layer salinity anomaly.

Summary

- An eddy-tracking algorithm was developed to be used for sea surface height in the Northwestern Indian Ocean to examine eddy characteristics.
  - Applied a cost function to track eddies detected in each daily SLA field with a local extreme value.
  - Sea surface temperature and salinity characteristics were also analyzed

- Summertime eddies are found to be more numerous along the Arabian Peninsula, but larger and more energetic in the Somali Current region.

- This research finds that eddies in the Arabian Sea are primarily surface-intensified rather than subsurface-intensified
  - Dominance of warm, fresh anticyclonic eddies and cool, saline cyclonic eddies.

- This work is able to provide insight into the composite eddy structure to better understand how each circulation type of eddy impacts local stratification.

Publications Discussed Today

- **Trott, C. B.,** B. Subrahmanyam, A. Chaigneau, & T. Delcroix (2018). Eddy Tracking in the Northwestern Indian Ocean During Southwest Monsoon Regimes. *Geophysical Research Letters*, *45*, 6594-6603. doi:10.1029/2018GL078381.

- **Trott, C. B.,** B. Subrahmanyam, A. Chaigneau, & H.L. Roman-Stork (2019). Eddy-induced Temperature and Salinity Variability in the Arabian Sea. *Geophysical Research Letters*. doi:10.1029/2018GL081605.

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