Regional Online Training Course on the Relationship Between Ocean Environment Variability and Marine Resource Abundance and Oceanographic Sampling

Oceanographic Phenomena Related to Marine Productivities and Physical Oceanographic Sampling

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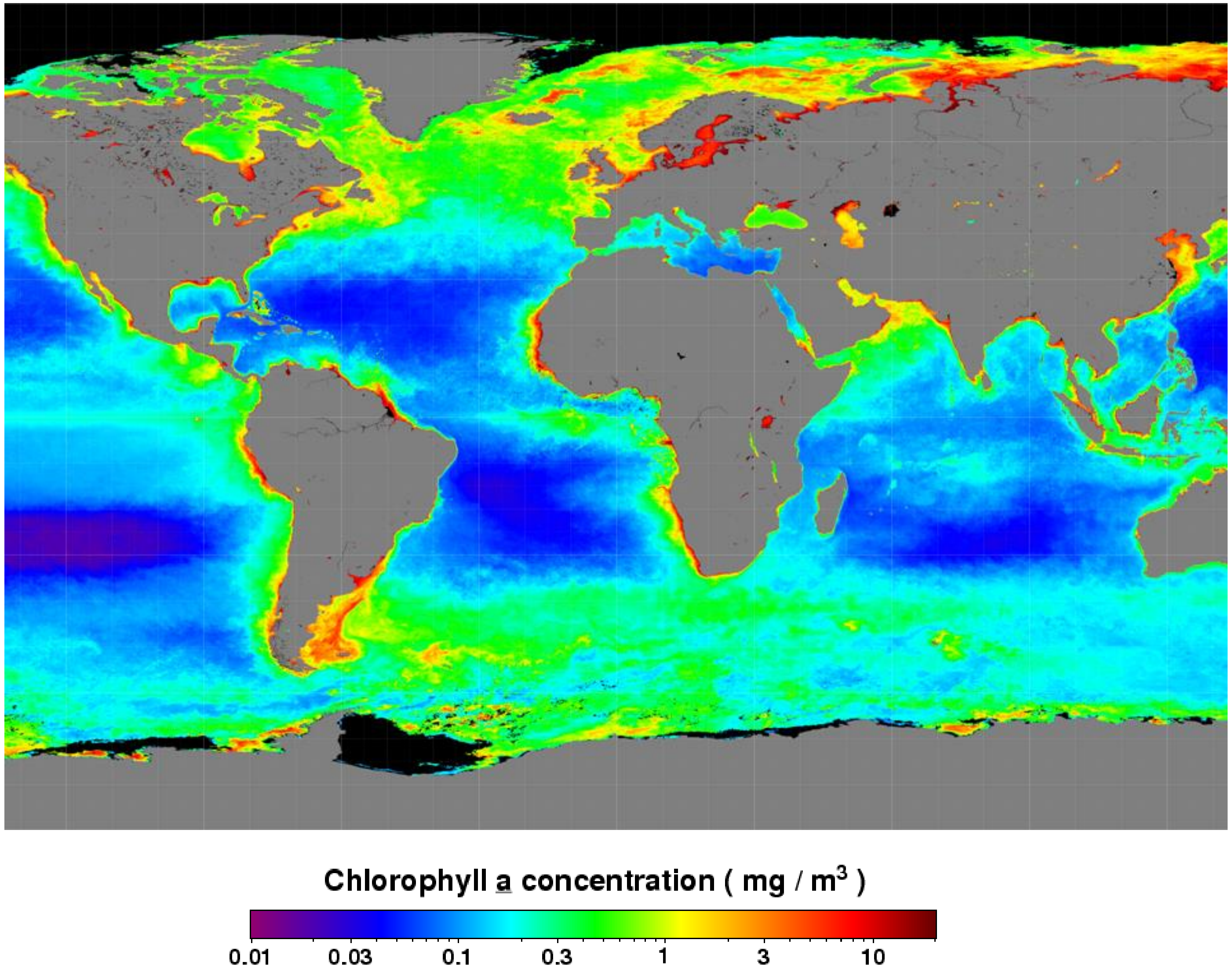
Overview

- Global Productivities
- Important upwelling regions
- Oceanographic conditions and primary productivities
- Eutrophication and the degradation of marine ecosystems

Global Productivities

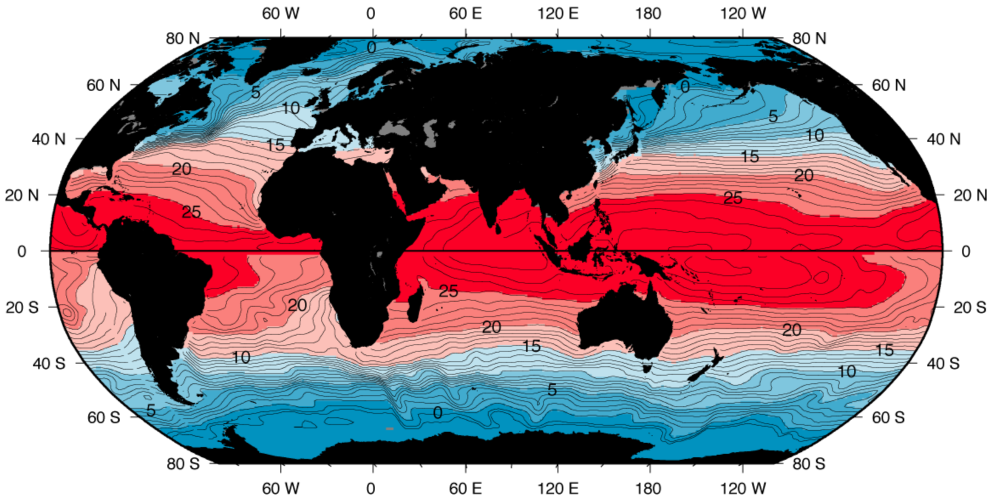
MODIS Surface Chlorophyll-a



- Primary productivity or chlorophyll is high in upwelling regions, marginal seas, polar regions, and coastal seas.
- The productivity is low in the open ocean because the water is so deep. Therefore nutrient supply to the sea surface where phytoplankton dwells is limited.

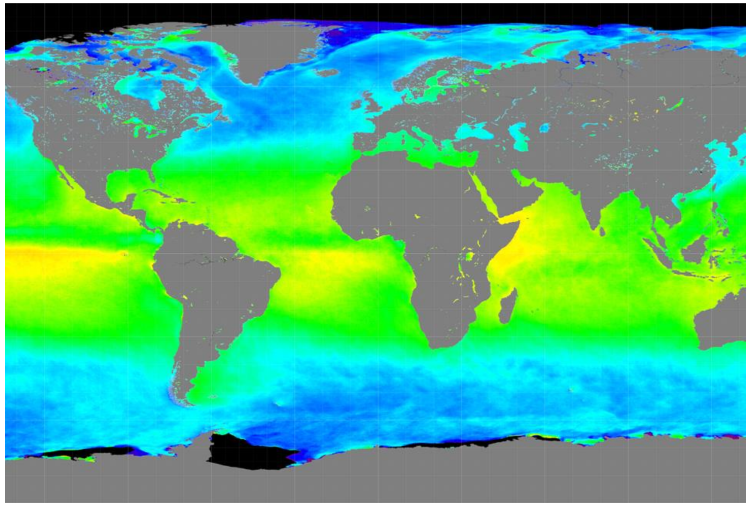
Factors controlling primary productivities in the global ocean

SST (◦C)

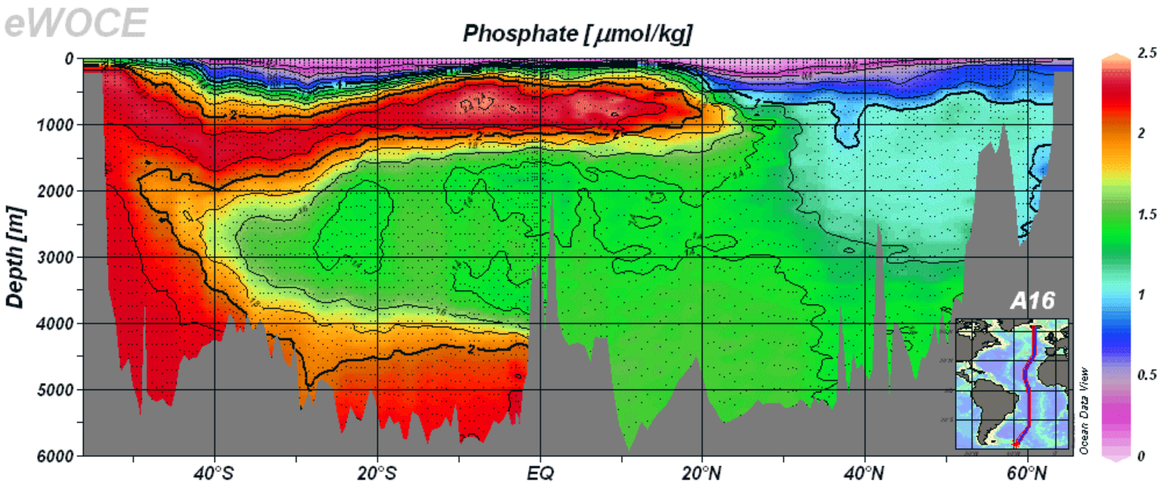


- Temperature, light and nutrients are mainly determined the productivity in each area of the sea.
- Light and temperature is the limiting factors for primary productivity in temperate and polar regions. High productivity usually occurs in spring, called spring bloom.
- Nutrients are limited to the sea surface in the tropical zone. Nutrient supply is abundant in upwelling regions, therefor the productivity is very high there.

MODIS PAR

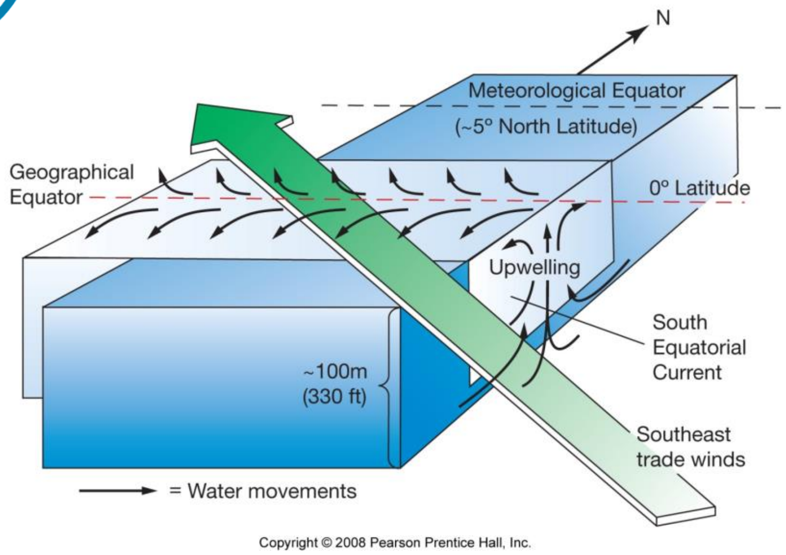


Nutrients



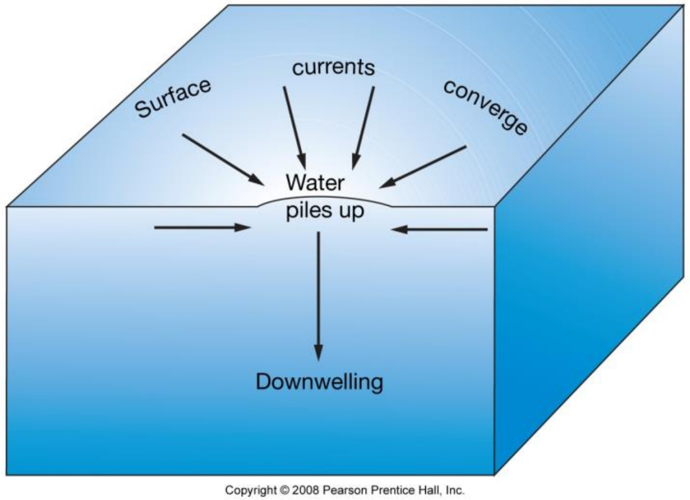
Upwelling Mechanism

Upwelling: Diverging surface seawater



- Upwelling occurs where surface water divergence develops.
- When surface seawater moves away, deeper seawater (cooler, nutrient-rich) replaces surface water. This process is called upwelling.
- High biological productivity
- This figure shows the development of equatorial upwelling.

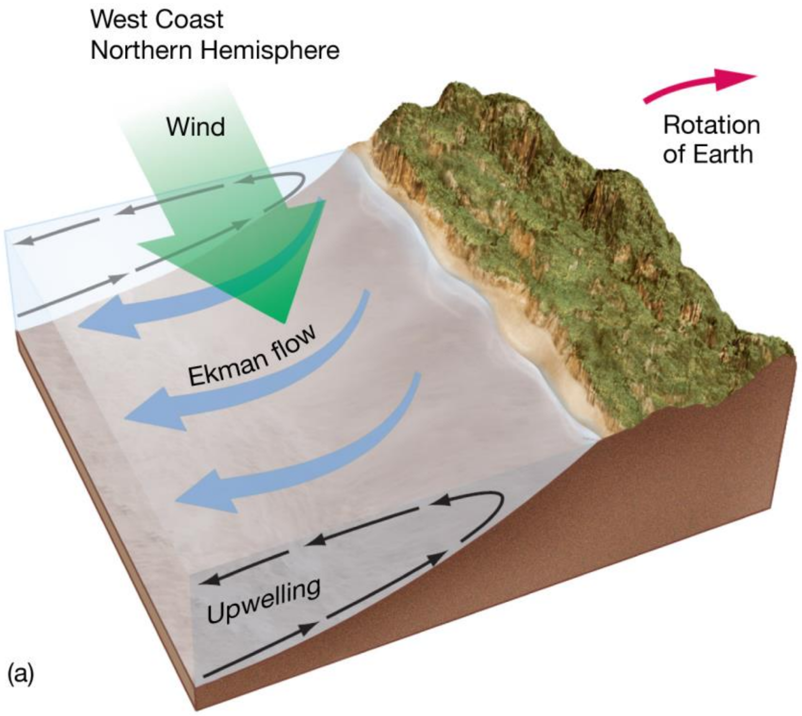
Down welling: Converging surface seawater



- Convergence is when surface seawater moves towards an area.
- Surface seawater then piles up and moves downward generated downwelling.
- Low biological productivity

Coastal upwelling and downwelling

- Ekman transport moves surface seawater offshore (upwelling) and onshore (downwelling).
- Figures show the situation in the northern hemisphere.



(a)

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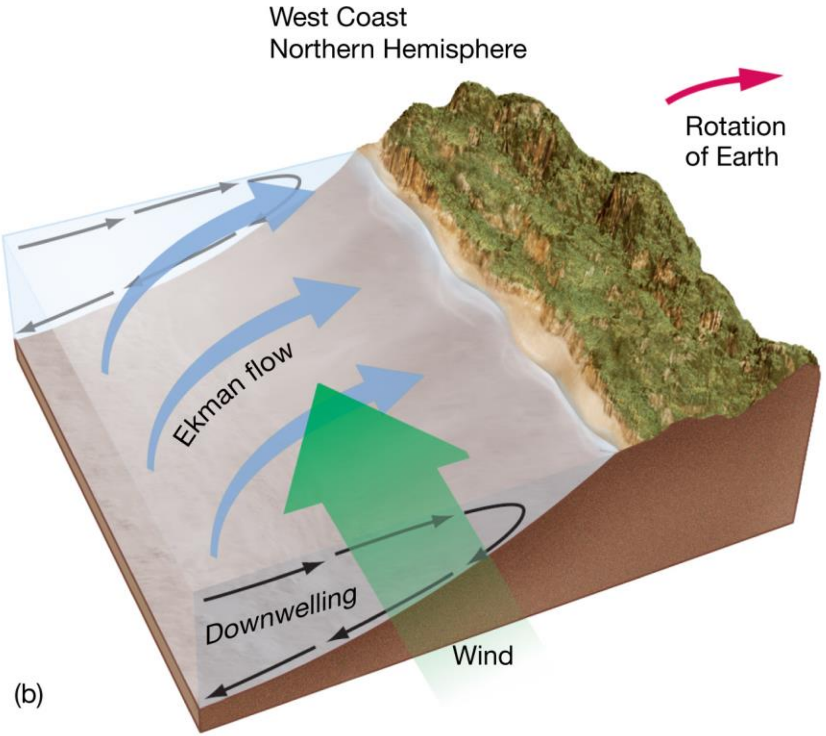

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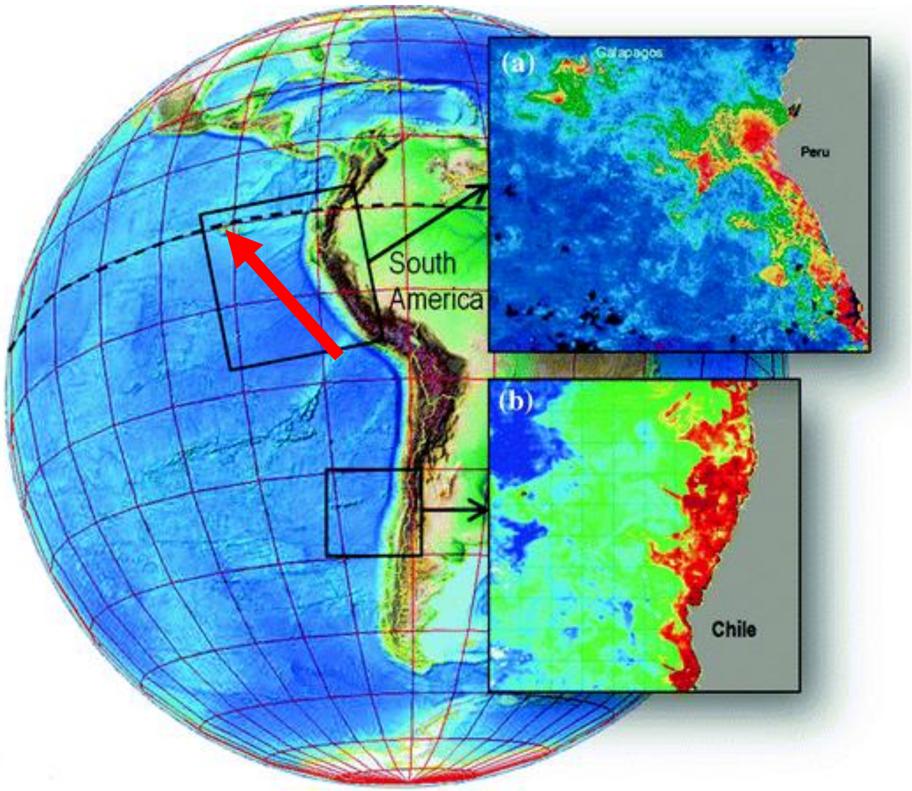
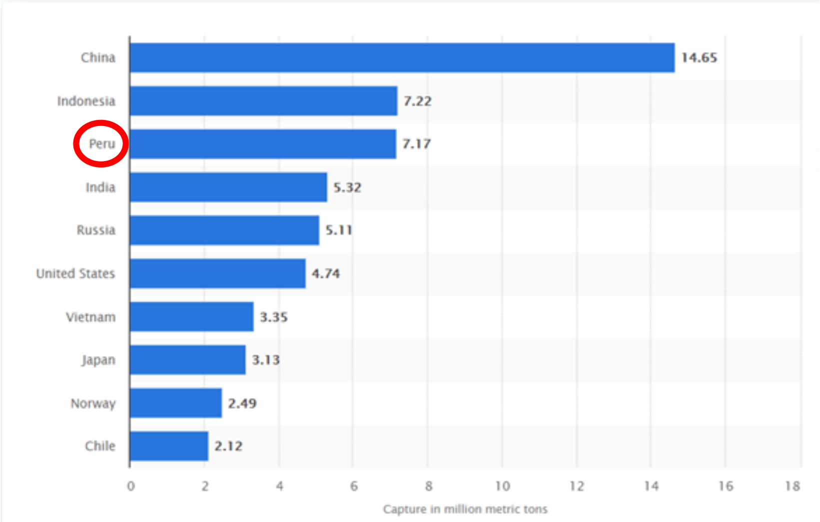
Upwelling: Peru coast



https://link.springer.com/chapter/10.1007/978-3-319-42524-5_5

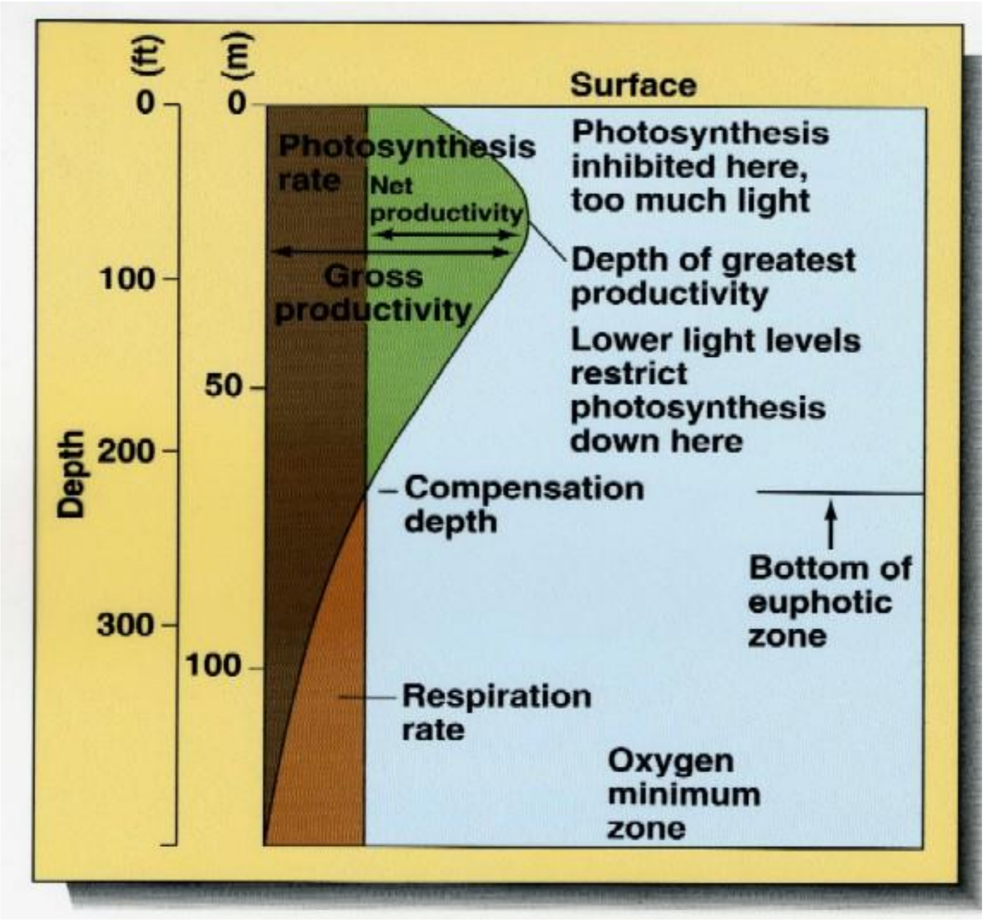
Top 10 fishing nations worldwide in 2018 (in million metric tons)*



https://www.statista.com/statistics/240225/leading-fishing-nations-worldwide-2008/

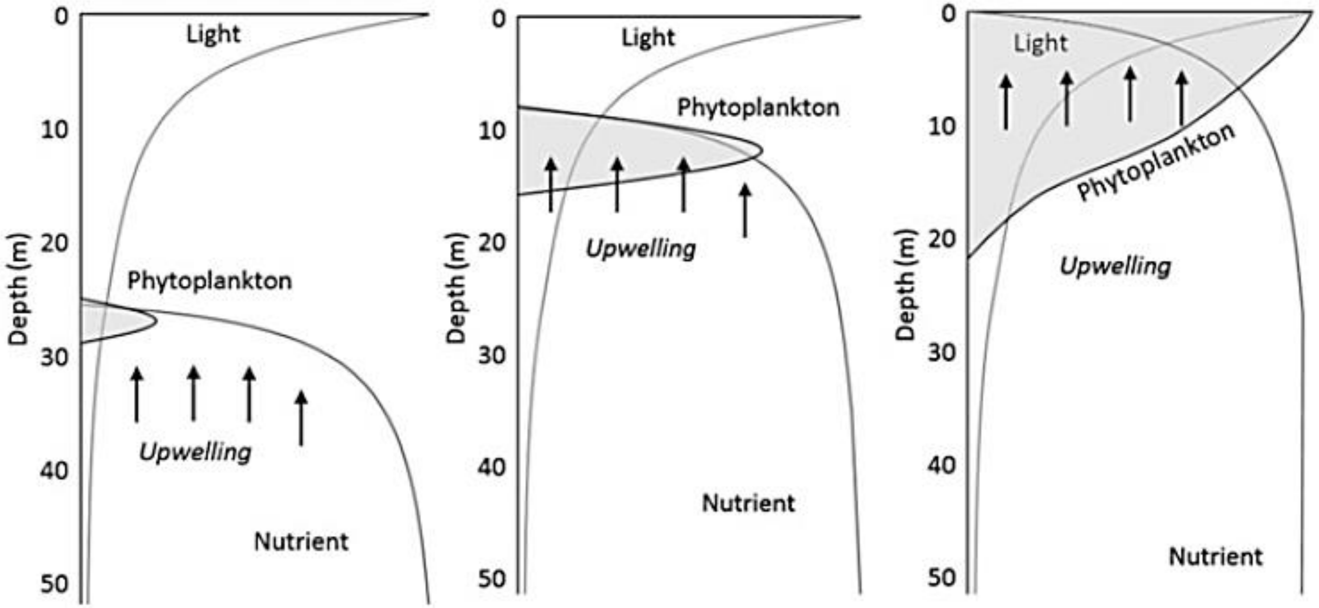
- Upwelling along Peru coast is induced by the southeast trade wind.
- This phenomenon made this area very productive for fisheries.
- Peru is one of the world's top 10 nations for fisheries production.

Photosynthesis and light with depth



- Photosynthesis is possible near the sea surface where light is available. Primary productivity is then high in the upper layer and low in the lower layer while respiration rate is almost similar throughout the water column.
- "Gross primary production" (GPP) refers to the total rate of organic carbon production by autotrophs, while "respiration" refers to the energy-yielding oxidation of organic carbon back to carbon dioxide.
- "Net primary production" (NPP) is GPP minus the autotrophs' own rate of respiration; it is thus the rate at which the full metabolism of phytoplankton produces biomass.
- Photosynthesis is inhibited close to the sea surface because of too much light energy.
- Compensation depth is where the primary productivity is equal to the decomposition, which is the lower limit of euphotic depth.

Schematic of the response in phytoplankton production to upwelling of nutrient-rich sub-surface water



- The left figure shows in the summer situation for temperate waters in which thermal stratification triggers sub-surface phytoplankton production in a narrow zone near the base of the surface mixed layer.
- As the upwelling continues, this zone is moved upward in the water column to a level of greater light intensity, which increases production in the middle figure.
- The maximum possible production occurs for full upwelling (right figure)

Zonation of different trophic levels in an upwelling region

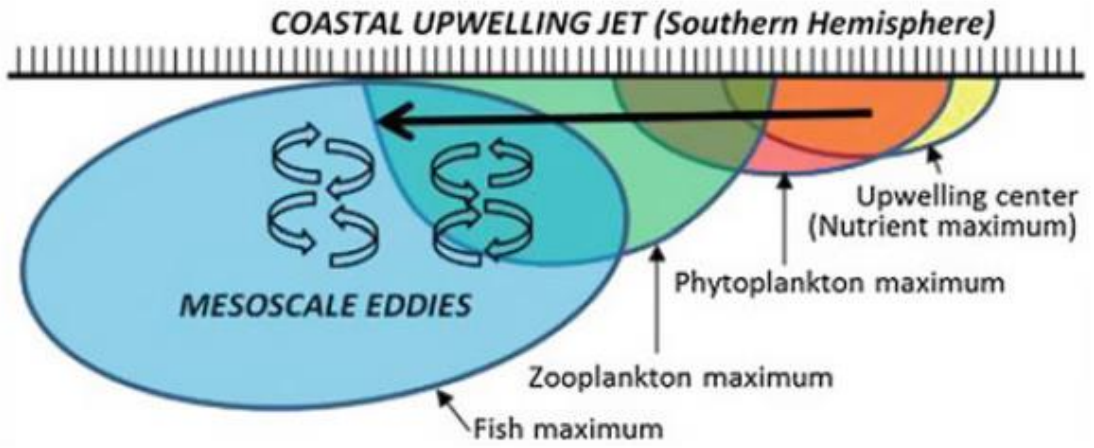
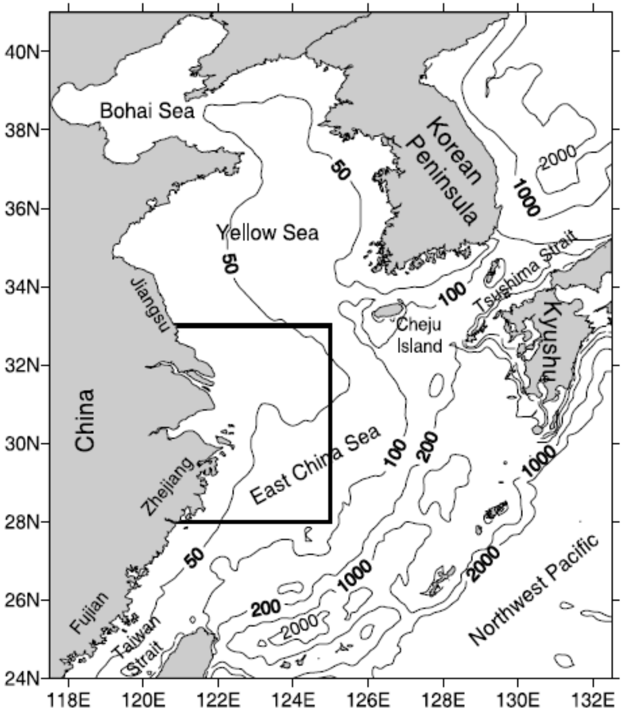


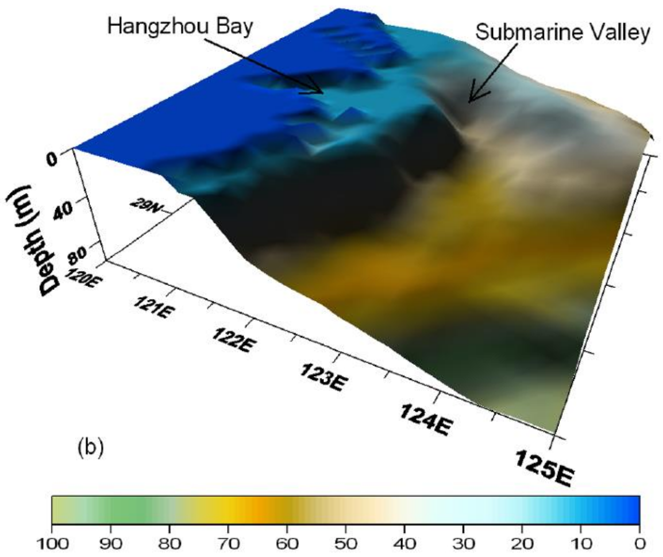
Fig. 2.18 Zonation of different trophic levels of the marine food web in upwelling regions (*top view*). Shown is the case for the southern hemisphere. The coastline is located along the top of the graph

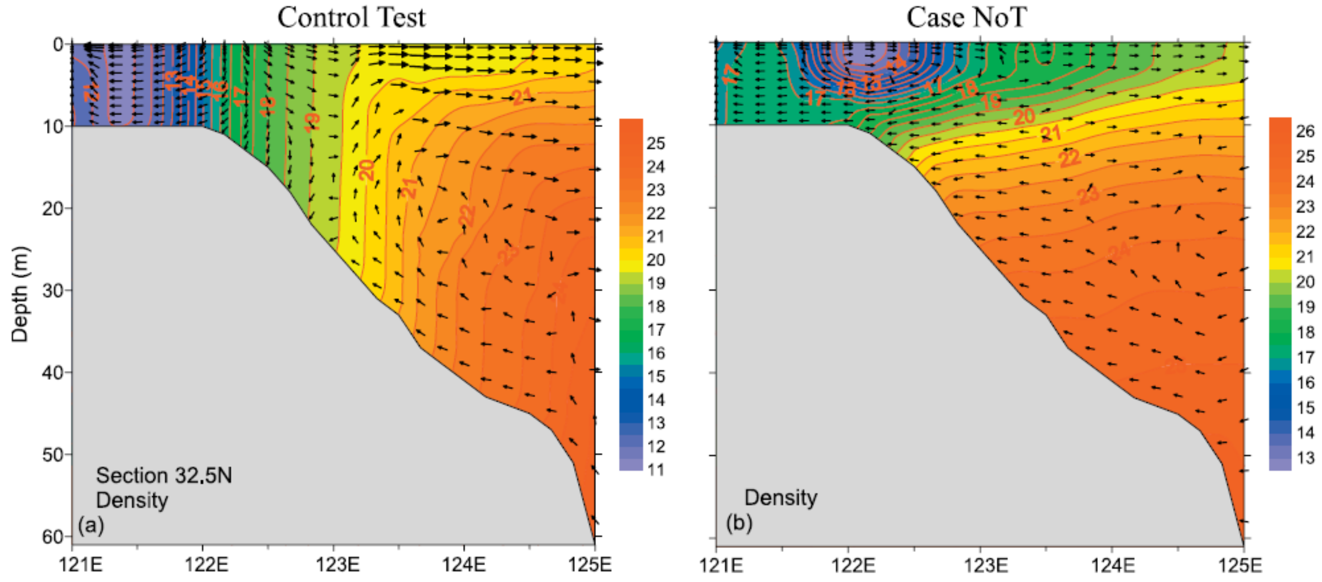
- Lower trophic levels are located near the upwelling center.
- Maximum fishery resources can be found farther from the upwelling center due to food chain succession.

Upwelling induced by tidal current



- Upwelling can be induced by strong tidal current flow toward the steep continental slope.
- The results from numerical model simulation show that not wind but tidal current induces coastal upwelling off the Yangtze River estuary in summer.





Lu et al.(2006) Upwelling off Yangtze River estuary in summer

Man-made upwelling

- Man-made upwelling was made using concrete construction in Japan to enhance primary productivity in water column.
- This application needs oceanographic knowledge including sea bottom bathymetry and tidal current speed and direction for selecting a suitable place to install the construction.

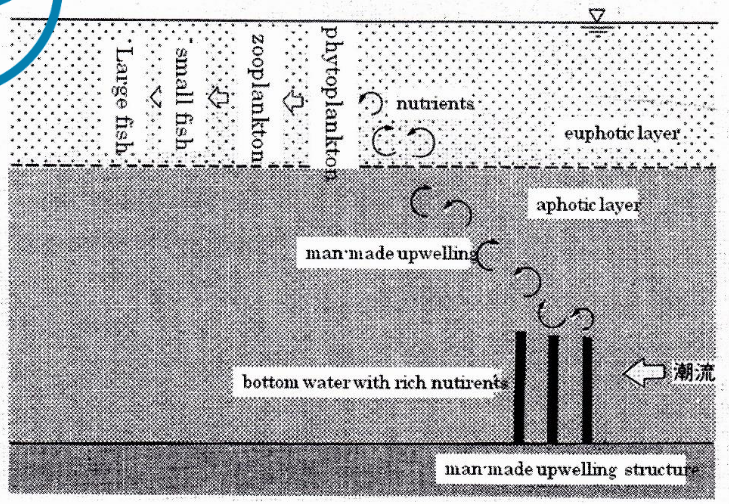


Fig. 4.10. Idea of increasing primary production in the euphotic layer of the coastal sea by a man-made upwelling structure (Yanagi, 1994, 2000).

Yanagi (1994)

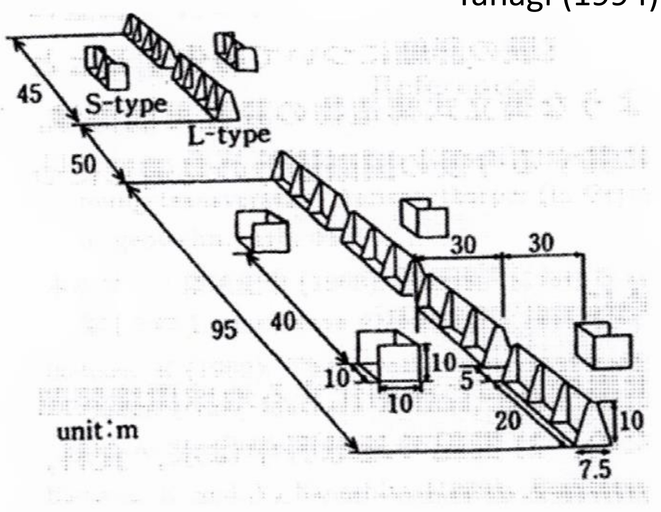
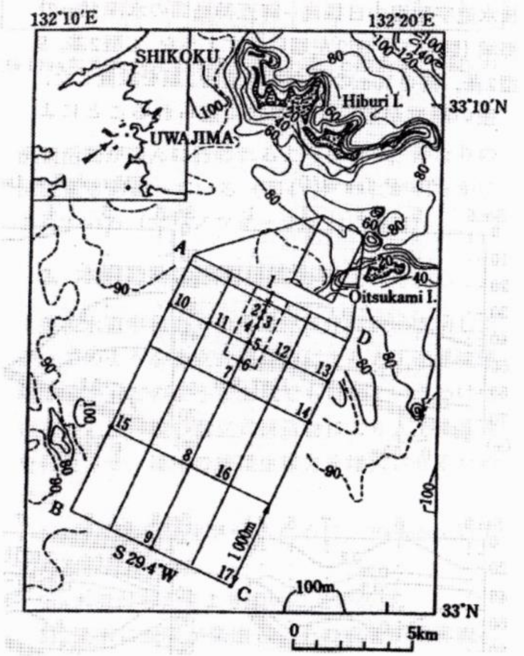


Fig. 4.11. Three sets of man-made upwelling structures in the Bungo Channel.



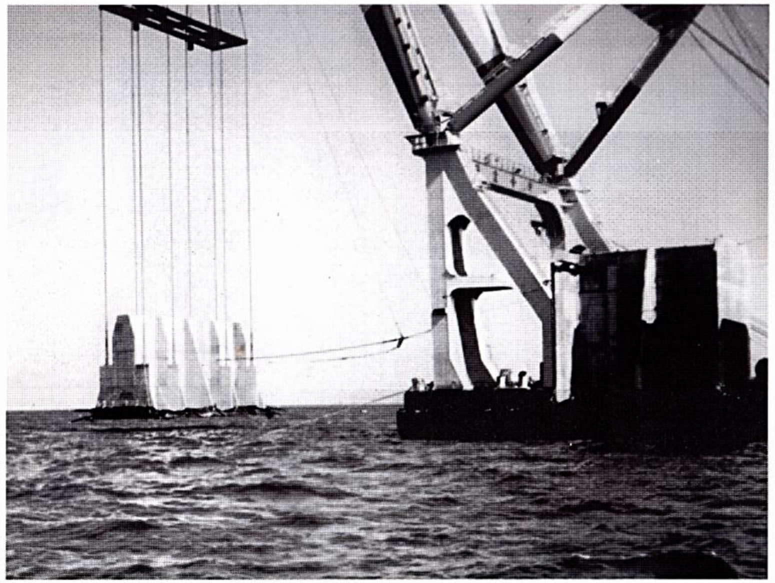
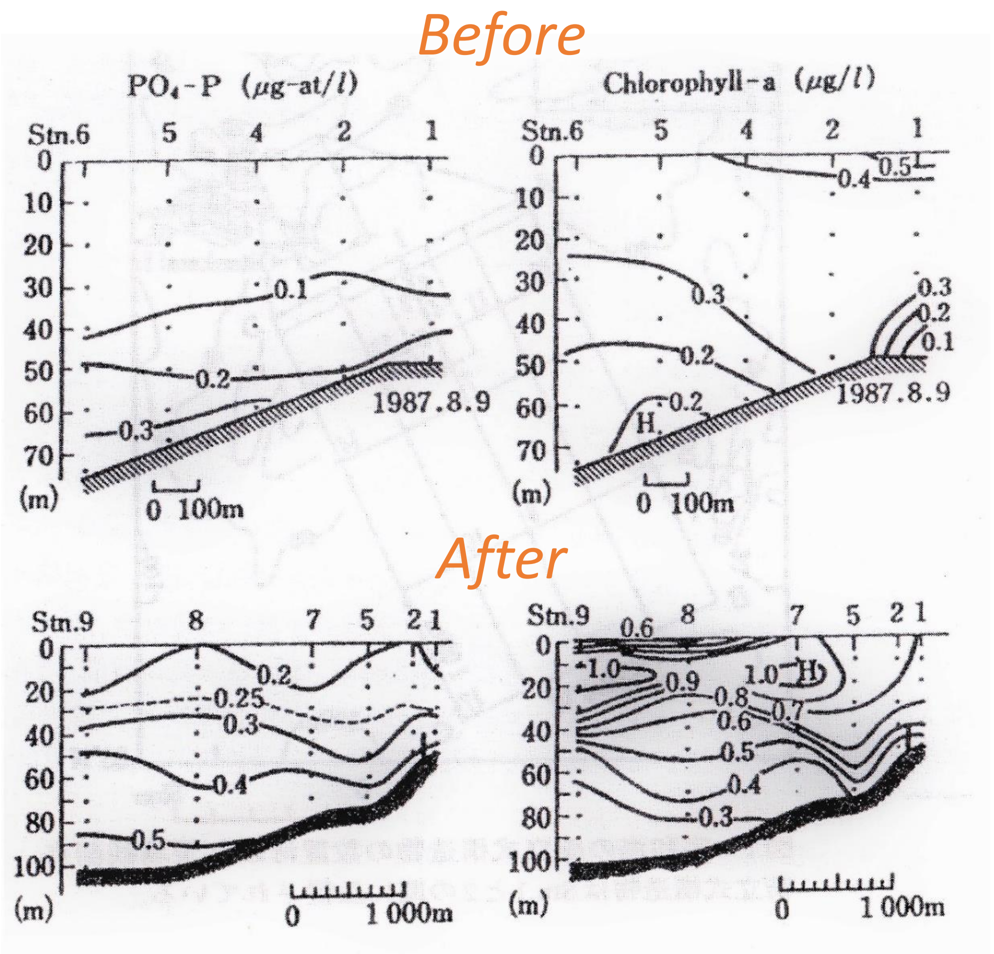


Fig. 4.13. A type-L man-made upwelling structure hung from a giant crane before being placed in the Bungo Channel.

Man-made upwelling



Yanagi (1994)

- DIP and Chl-a distributions at the flood tidal current before and after the installation of the man-made structure for upwelling which was located between Station 1 and 2 in the lower figure.
- Upwelling induced by the structure can increase DIP and Chl-a in the water column.
- Fishery resource enhancement is expected.

Cyclonic eddies in the Andaman Sea

Upwelling induced by cyclonic eddies in the Andaman Sea

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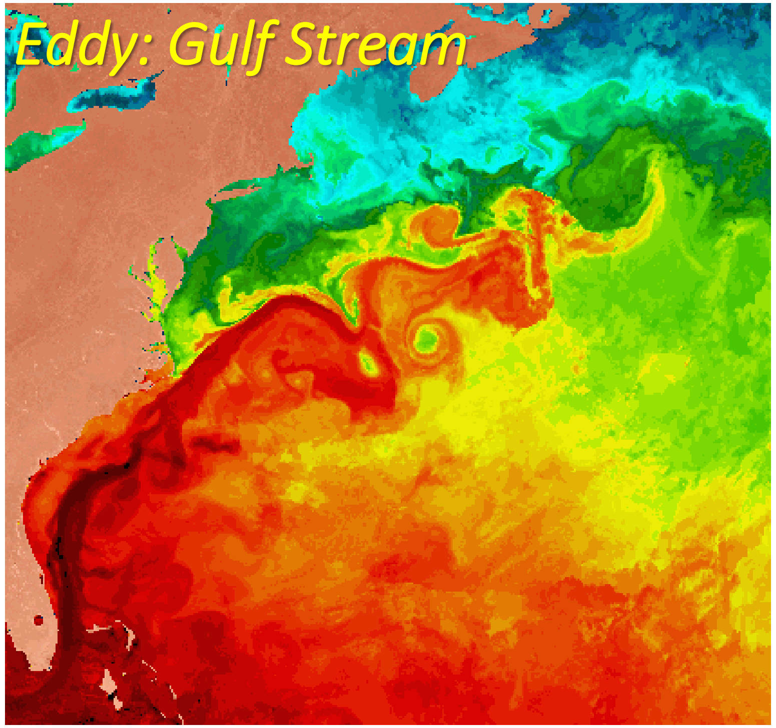
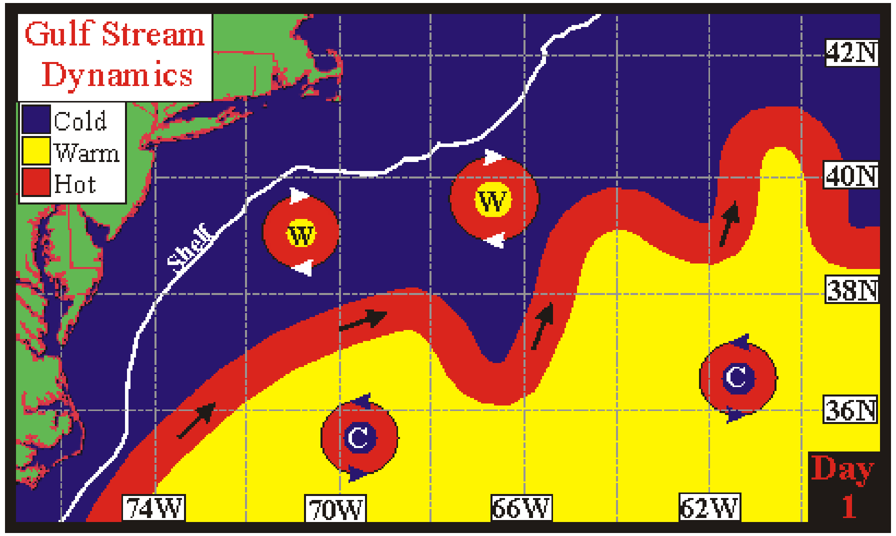
Penchan Laongmanee, SEAFDEC TD

Eddies and vertical transports



- Eddy is a small circular water movement generated by strong current or water turbulence.
- Gulf stream is a strong current that can generate eddies clearly seen from SST satellite images.
- There are two types of eddies specified by the directions of circulation, cyclonic and anti-cyclonic eddy.
- In the northern hemisphere, cyclonic eddy induces upwelling while anti-cyclonic eddy generates down welling.



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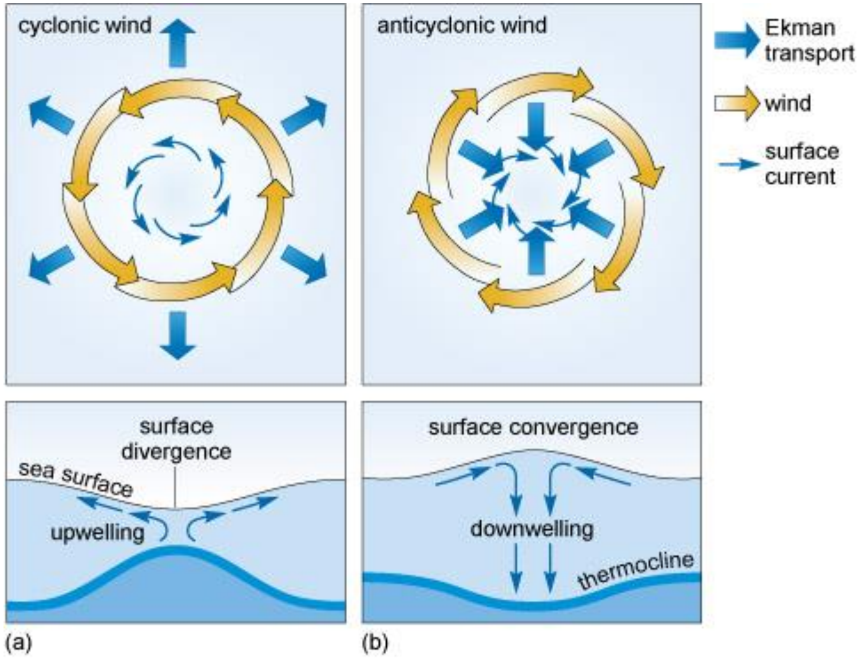
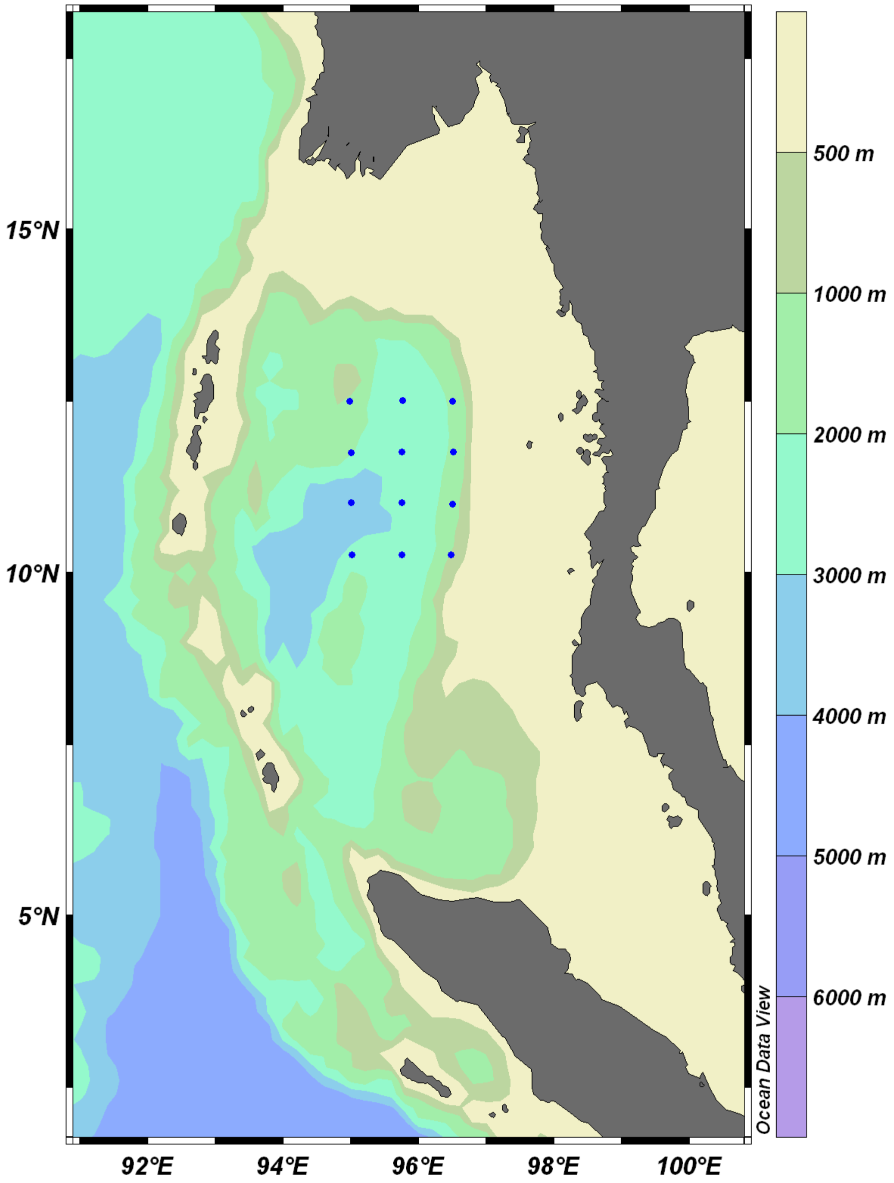


The Bay of Bengal Initiative for Multi-Sectional Technical and Economic cooperation

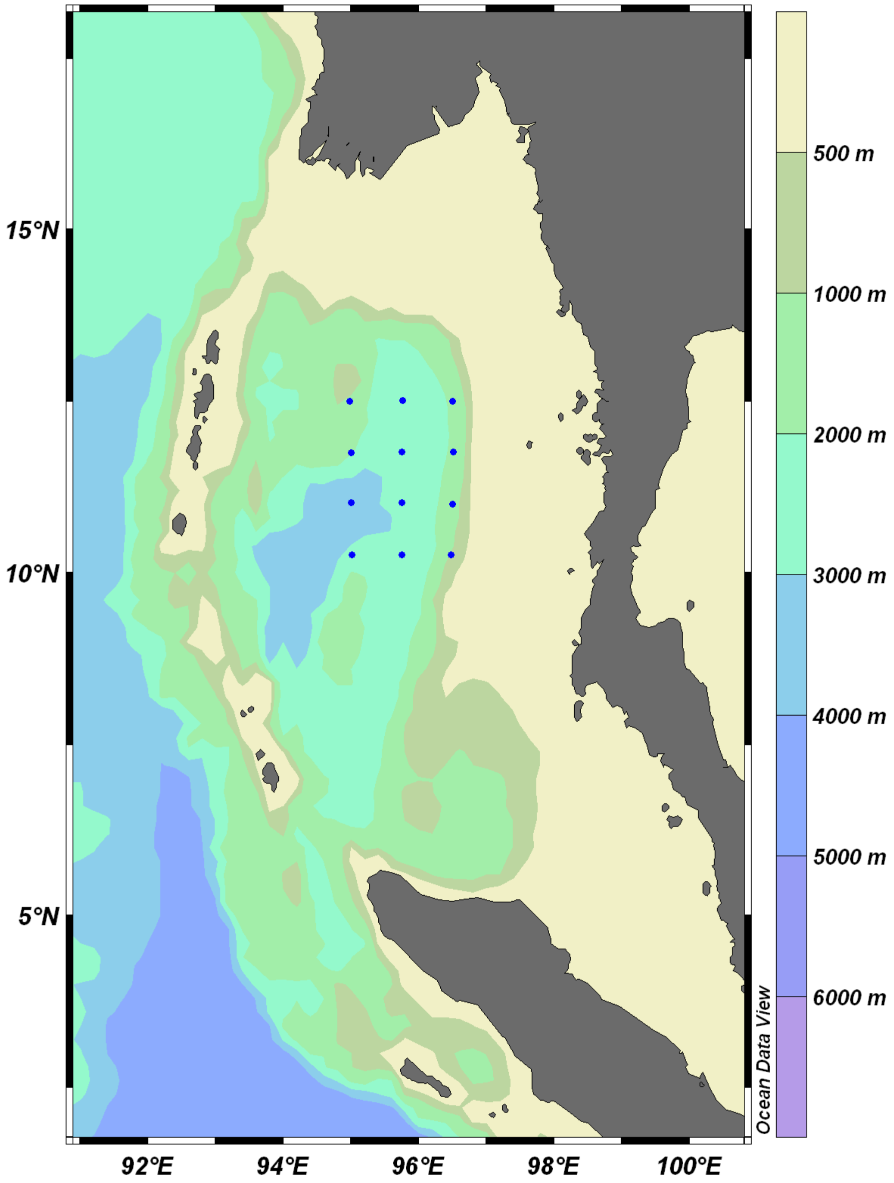
ECOSYSTEM-BASED FISHERY MANAGEMENT IN THE BAY OF BENGAL

(Thailand is the leader of the project.)



The Andaman Sea

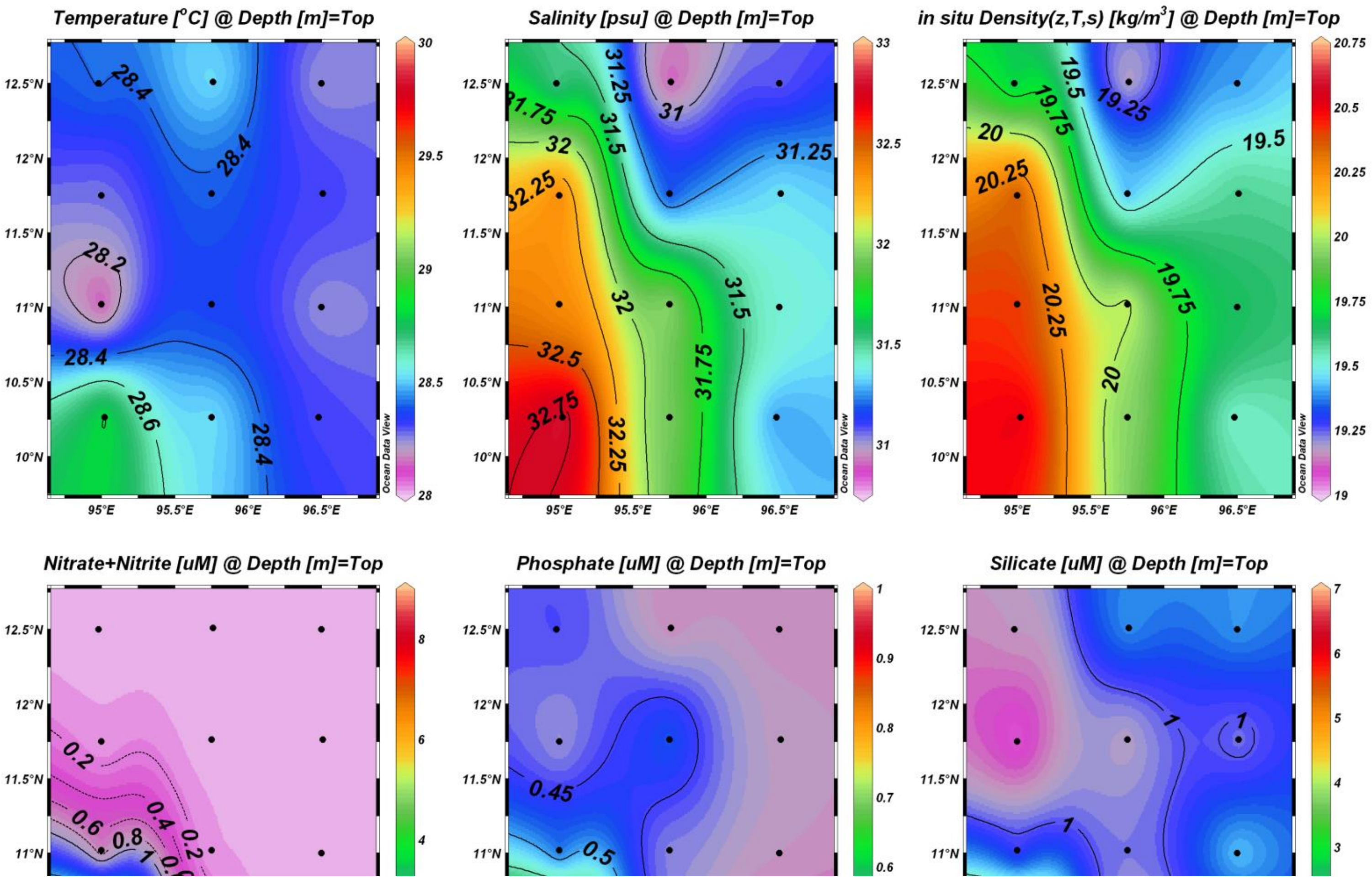
- Basin-like adjacent sea, bounded by Andaman and Nicobar Island chain, connected to the Bay of Bengal in the west, average depth of 1,100 m covering the area of 600,000 km^2.
- Has been interested in seismic activities especially after the tsunami event on December 26, 2004.
- Short residence time of near bottom water, compared to other basins, due to released heat from sea bottom from volcanic activities.
- Internal wave is generated in this area.



The Oceanographic Survey in the Andaman Sea

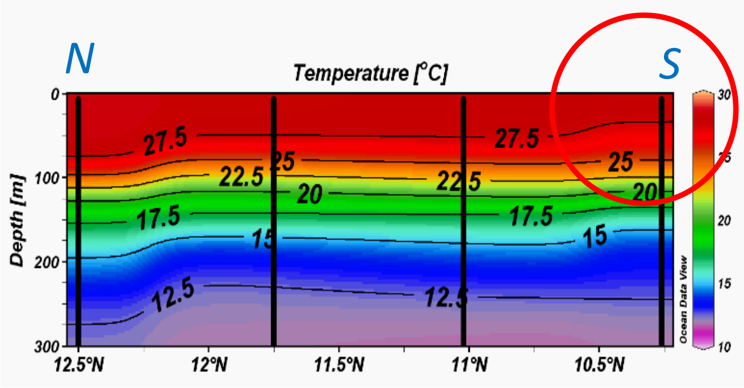
- BIMSTEC survey from 6 – 15 November 2007 was conducted to collect oceanographic data.
- Spatial variations of oceanographic data were investigate to investigate their relationship to some oceanographic phenomena.
- Parameters collected and used for analysis:
  - Temperature
  - Salinity
  - Nutrients - Nitrite + Nitrate, Silicate, Phosphate
  - Chlorophyll-a

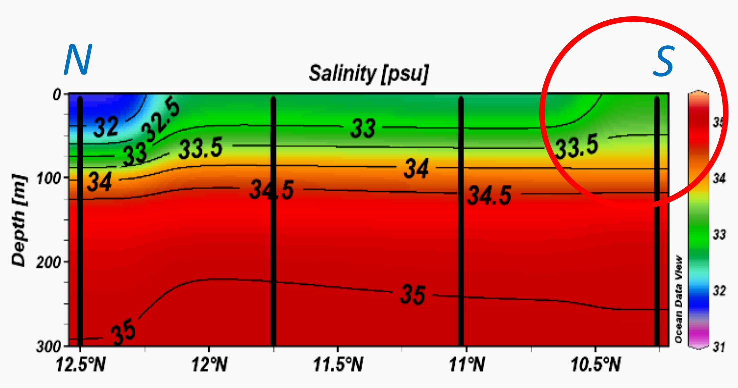
Results: Physical Parameters and nutrients

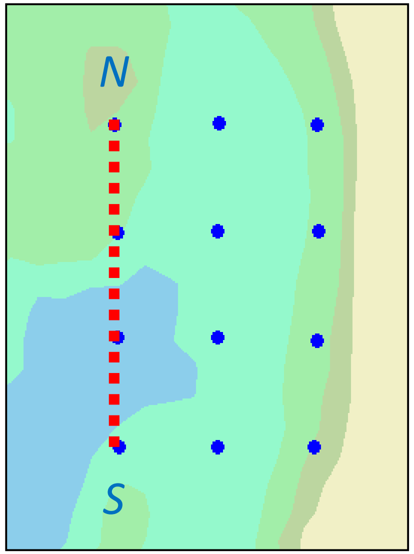


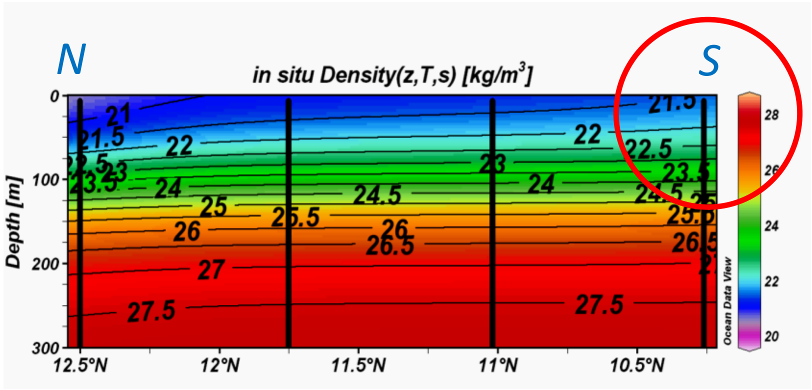
- Horizontal distributions of the measured parameters.
- High salinity and density are clearly observed in the southwest corner of the survey area.
- Does Low salinity and density in the northeast area occur because of the influence of fresh water from land ?
- What is the controlling mechanism?
- Nutrients do not show a clear trend.

Results: Physical Parameter cross section





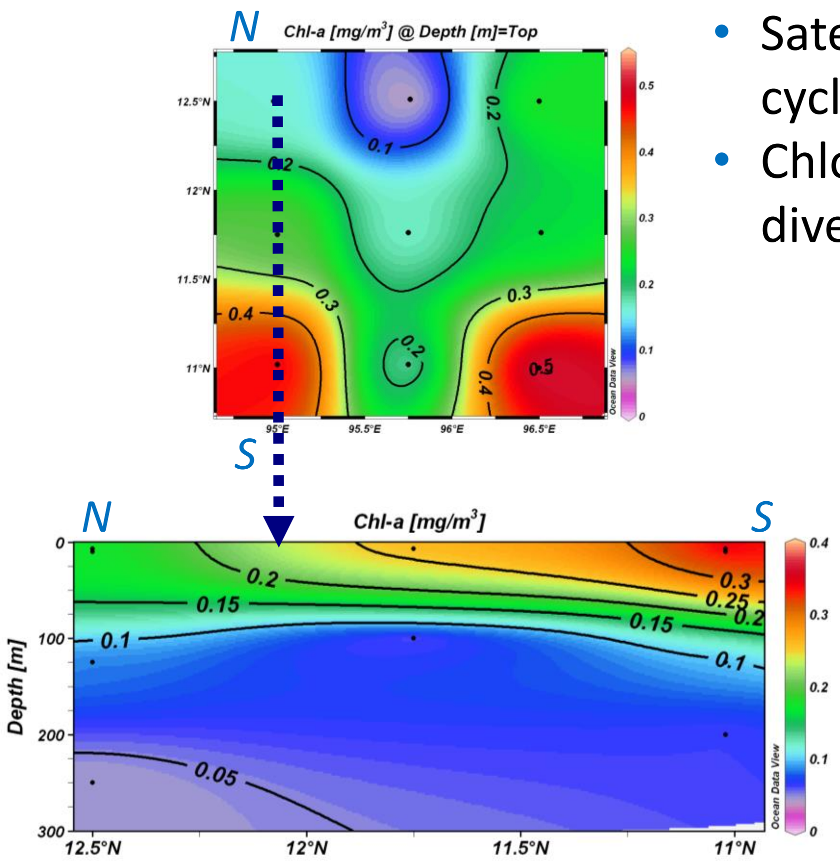


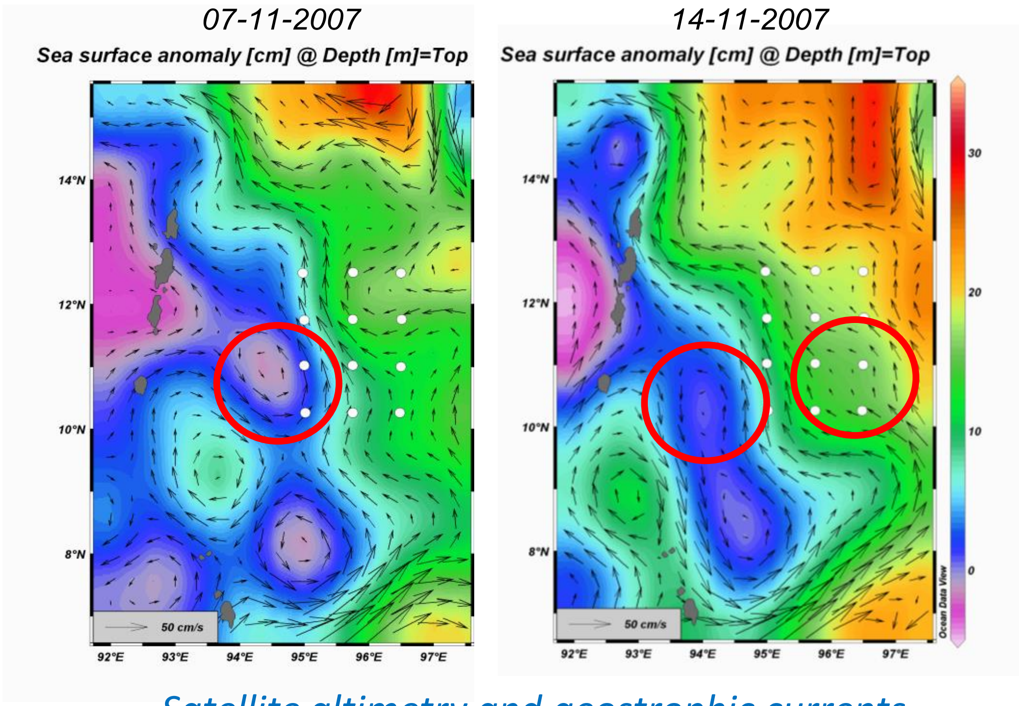


- Upwelling is observed at the southwest station from cross section distribution.
- The upwelling is clearly seen in the salinity distribution.
- It is not clear in the case of temperature a because upwelling is not strong and surface temperature mixed layer is quite deep.

Results: Chl-a and eddies

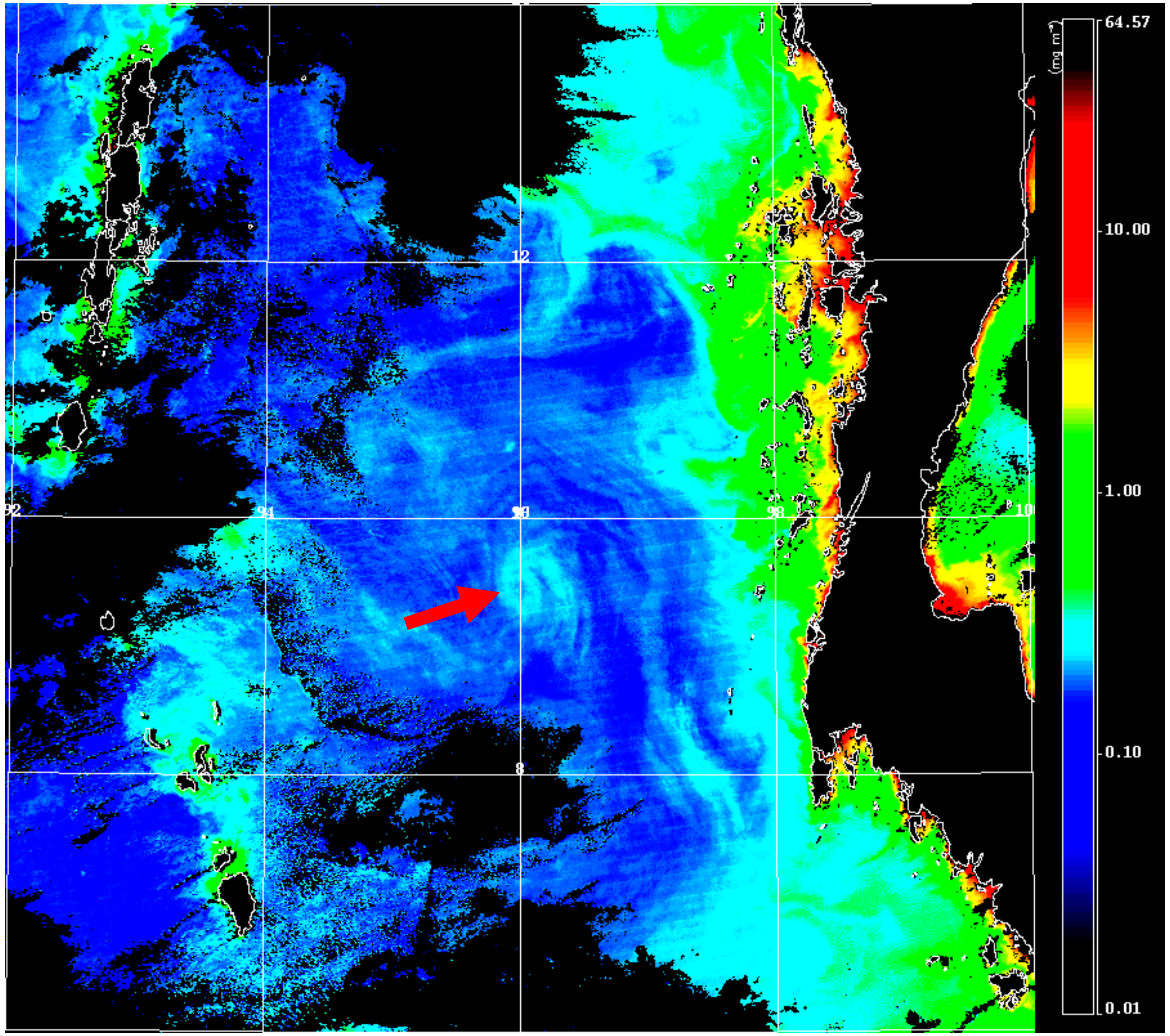
- Chlorophyll is high where upwelling occurs in the southwest station.
- High chlorophyll is supposedly supported by nutrients from upwelled water.
- Satellite altimetry and geostrophic currents – 7 days averaged – reveal cyclonic eddies develop in the same area of upwelling.
- Chlorophyll is high in the southeast corner station because of surface water divergence that can also induce upwelling of water mass.





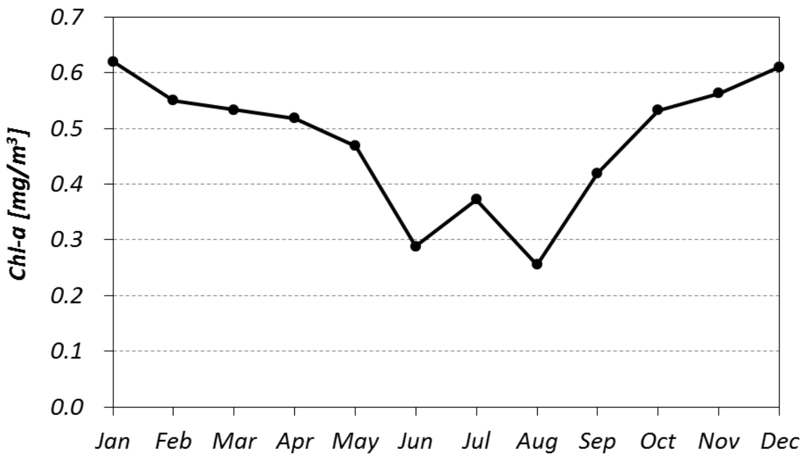
Satellite altimetry and geostrophic currents

MODIS Chl-a image on November 29, 2007



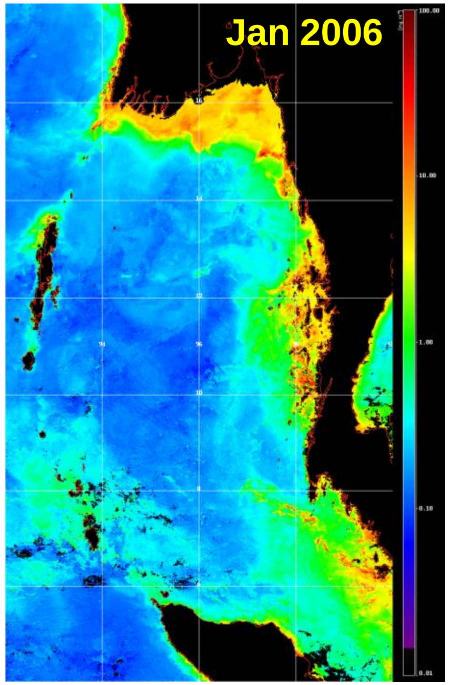
- Cyclonic eddies, found in altimetry images, were compared with surface Chl-a derived from MODIS data.
- Unfortunately, MODIS data during the period of field observation were not available due to cloudiness.
- A whirlpool of relatively high Chl-a is observed in a MODIS imagery captured on November 29, 2007.
- Chl-a in the whirlpool was as high as 0.2 – 0.3 mg/m^3 while that in surrounding water was lower than 0.1 mg/m^3.
- This phenomenon may be used to confirm the existence of upwelling induced by cyclonic eddies in this area.

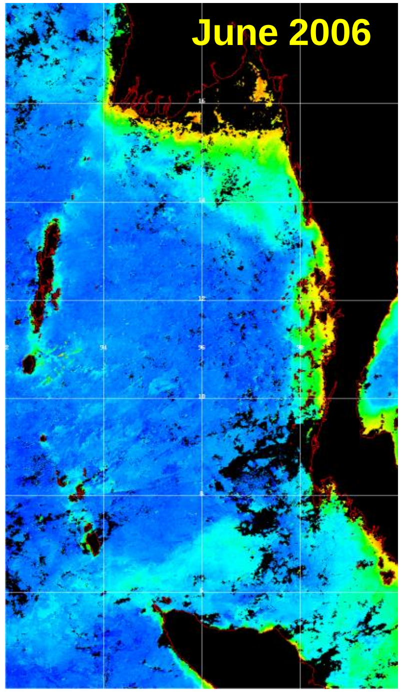
Seasonal variations in sea surface chlorophyll-a in the Andaman Sea

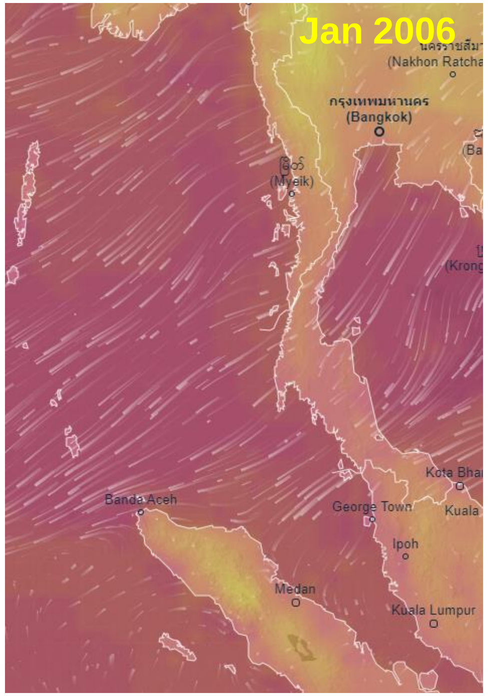


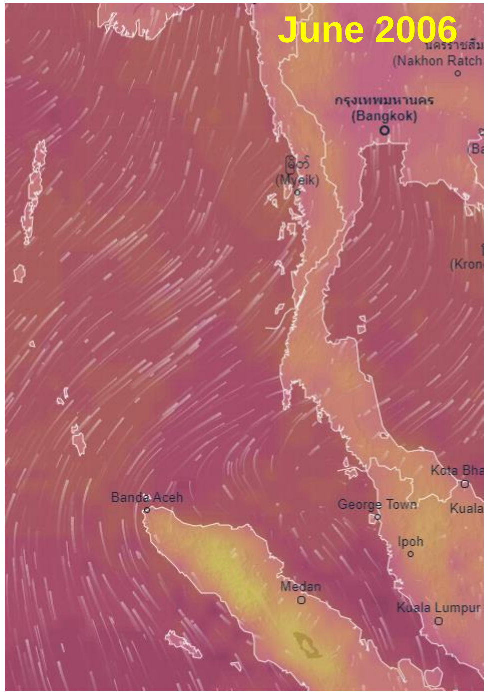
Seasonal change in sea surface chlorophyll-a in the Andaman Sea from monthly mean data during 2003-2009.

- Surface chlorophyll in the Andaman Sea is high during the northeast monsoon and low during the southwest monsoon.
- This variation is related to the development of upwelling and down welling during the northeast and the southwest monsoon.



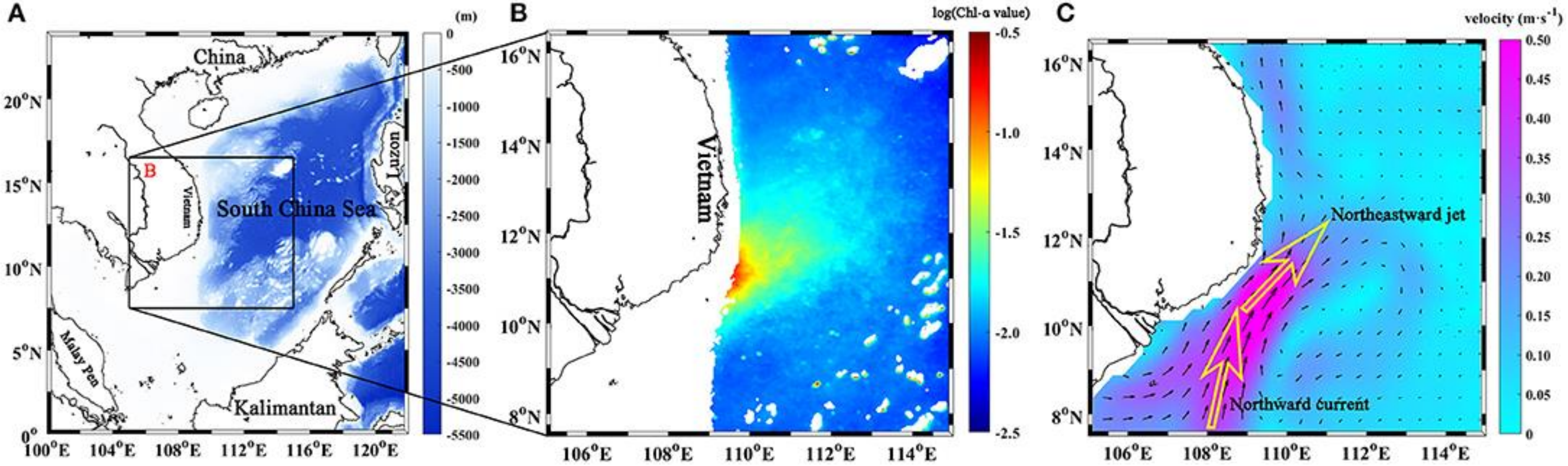






Upwelling in the South China Sea

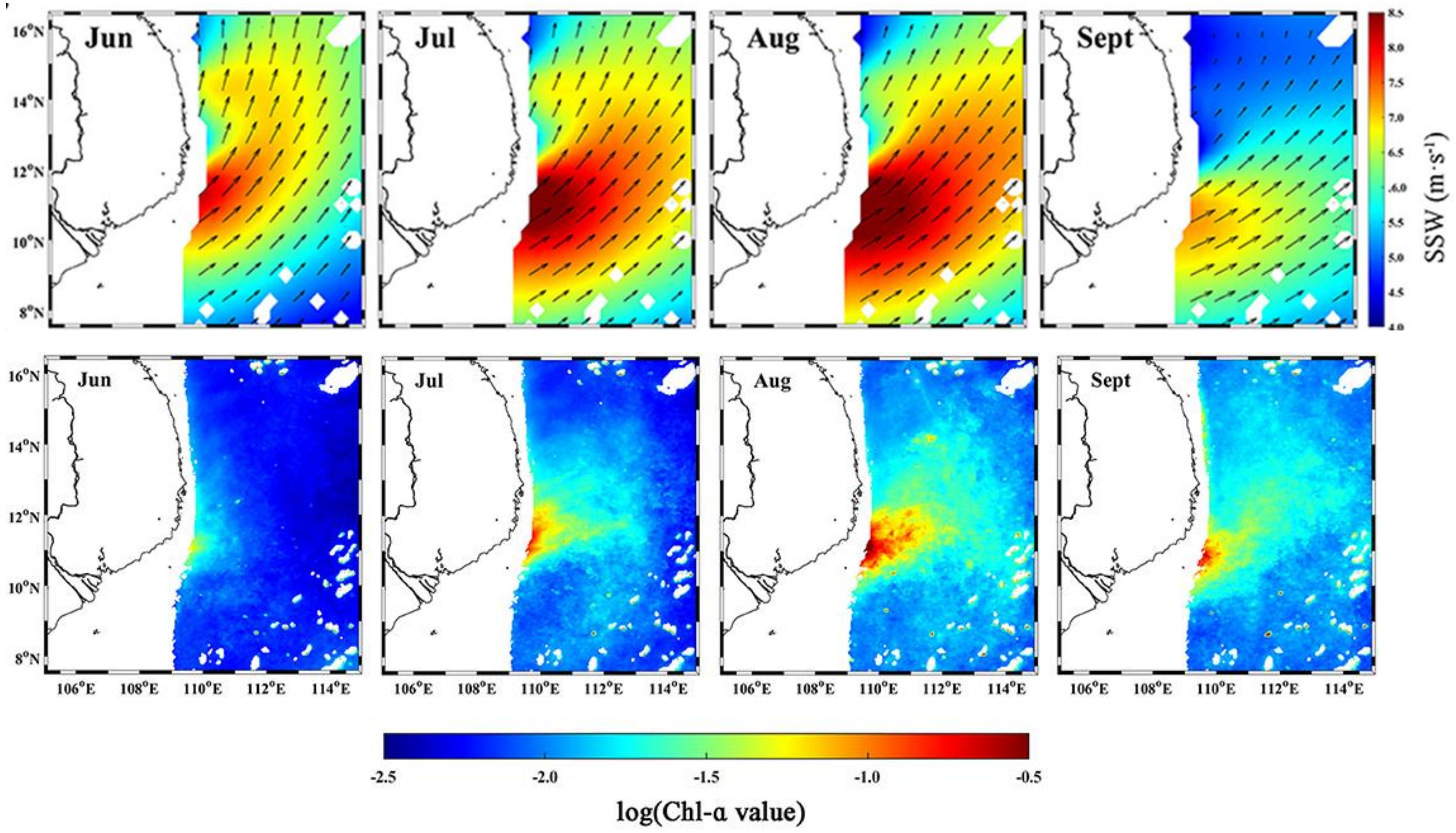
Summer Phytoplankton Blooms Induced by Upwelling in the Western South China Sea



- The summer (June–September) climatological Chl-a concentration (1998–2020) in the study region.
- The region where the depth is shallower than 200 m is ignored to remove the influence of coastal water.
- The geostrophic flow velocity northwest of SCS. The arrow indicates the direction and size of the geostrophic flow.

Chen et al. (2021)
https://www.frontiersin.org/articles/10.3389/fmars.2021.740130/full

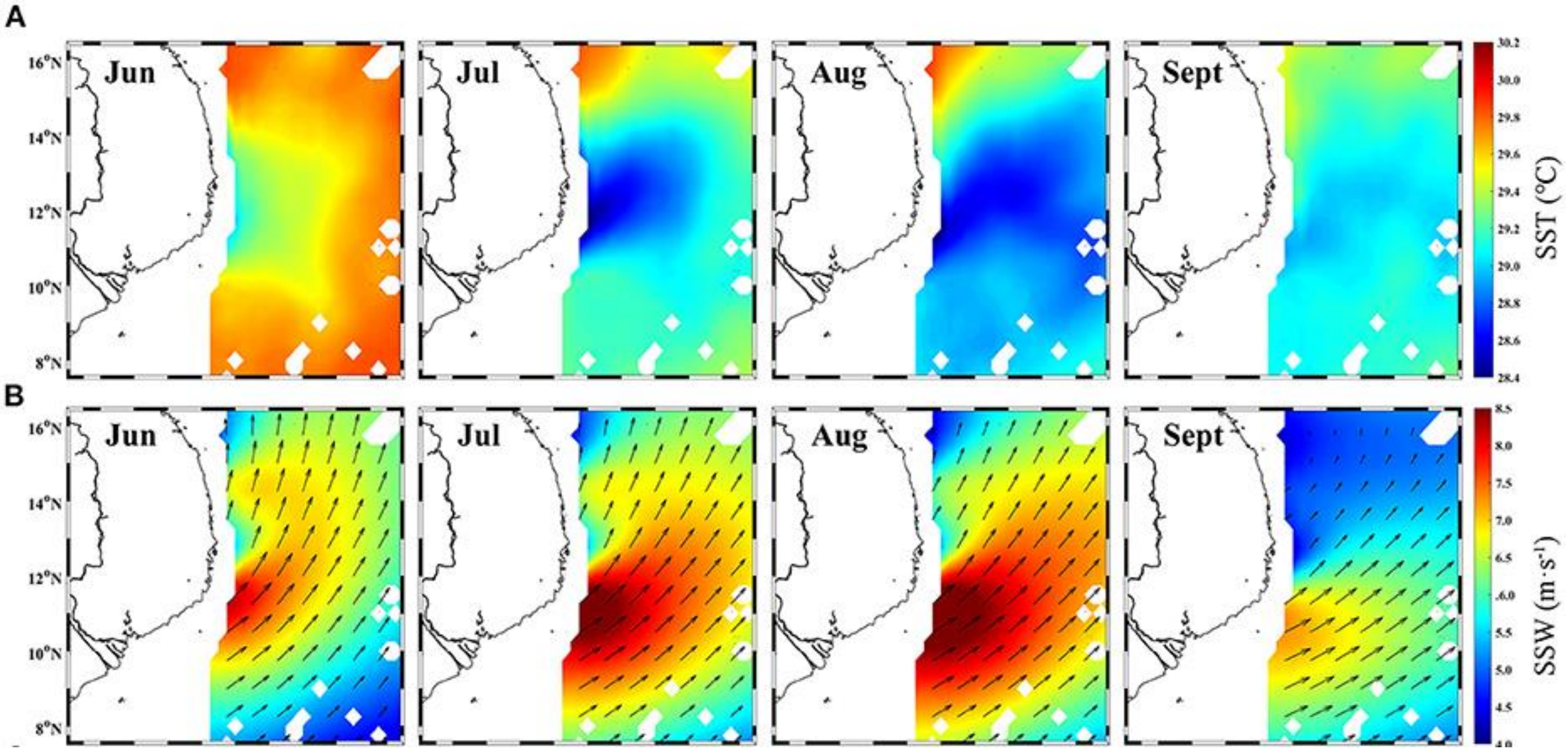
Summer Phytoplankton Blooms Induced by Upwelling in the Western South China Sea



- Monthly climatology of satellite Chl-a in the period 1998–2020 shows the development of high Chl-a during the southwest monsoon.
- The blooming starts to emerge in June, develops to a high peak in August, and declines in September.
- The Mekong discharge may contribute to this blooming.

Chen et al. (2021)
https://www.frontiersin.org/articles/10.3389/fmars.2021.740130/full

Summer Phytoplankton Blooms Induced by Upwelling in the Western South China Sea

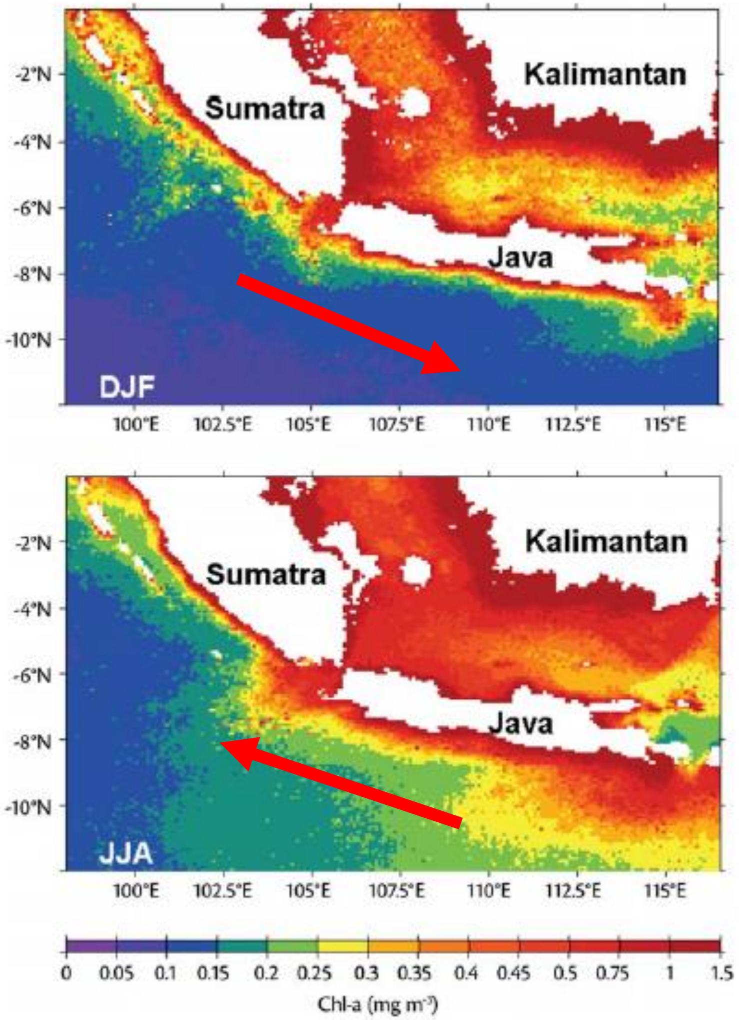


- The evidence of upwelling is confirmed from low sea surface temperature (satellite data) nearby the blooming region.

Chen et al. (2021)
https://www.frontiersin.org/articles/10.3389/fmars.2021.740130/full

Upwelling in the south of Java Island and the influence of IOD

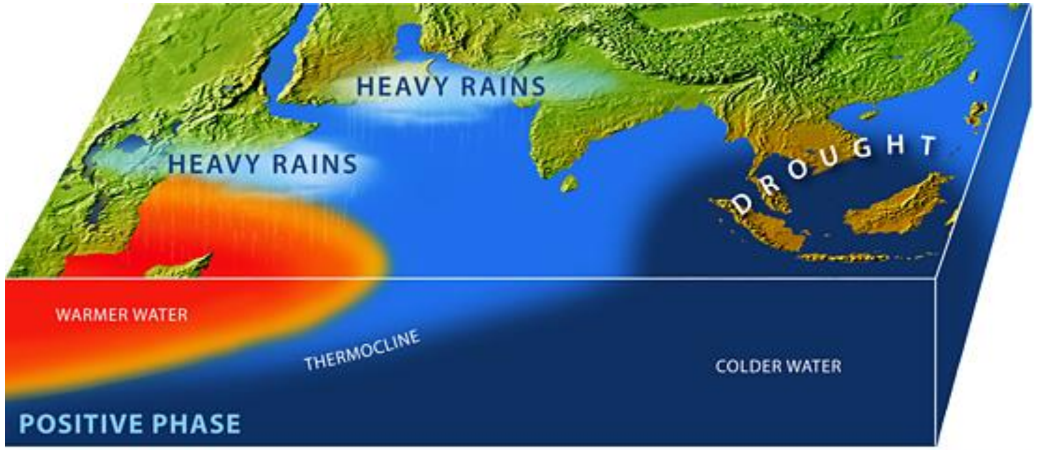
Upwelling in the south of Java Island

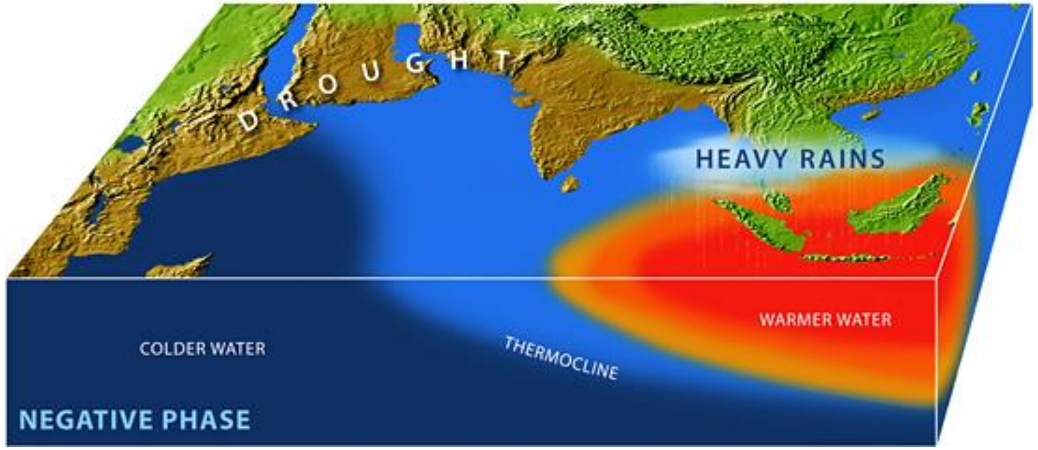


(Susanto and Marra, 2005; Susanto et al., 2006)

- Upwelling along the southern coast of Java Island is developed during the southeast monsoon (lower panel).
- Down welling occurs during the northwest monsoon (upper panel).
- Productivity is high during the southeast monsoon, and low during the northwest monsoon.
- Remember that Java Island is located in the southern hemisphere, therefore Exman transport moves to the left hand side of wind direction (red arrows).

Indian Ocean Dipole (IOD)





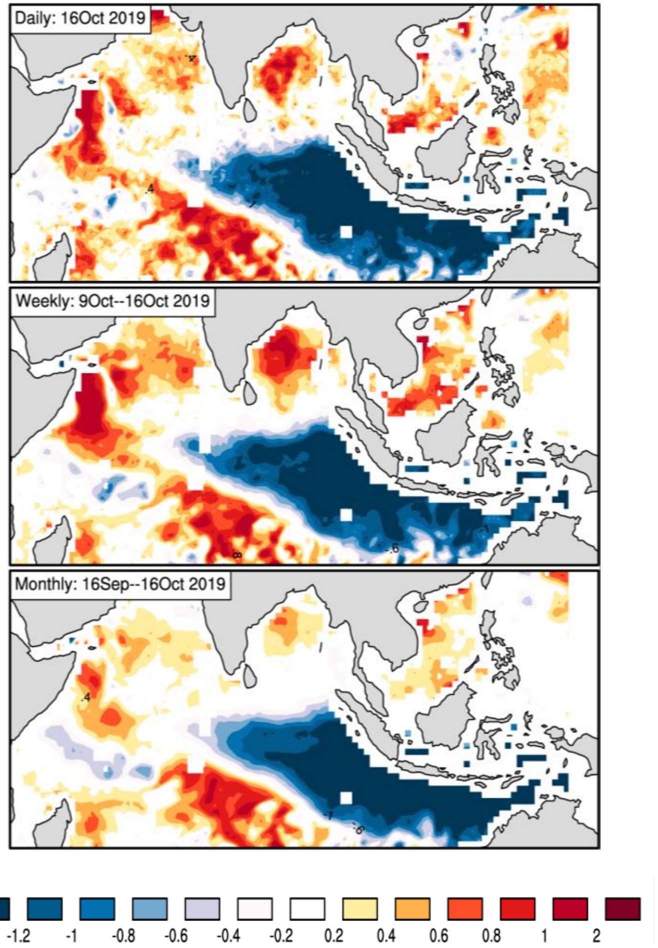
Positive IOD

- The wind blows to the west of the Indian Ocean.
- High and low sea surface temperature/precipitation are in the west and the east of the Indian Ocean.
- Upwelling is strong in SEA waters.

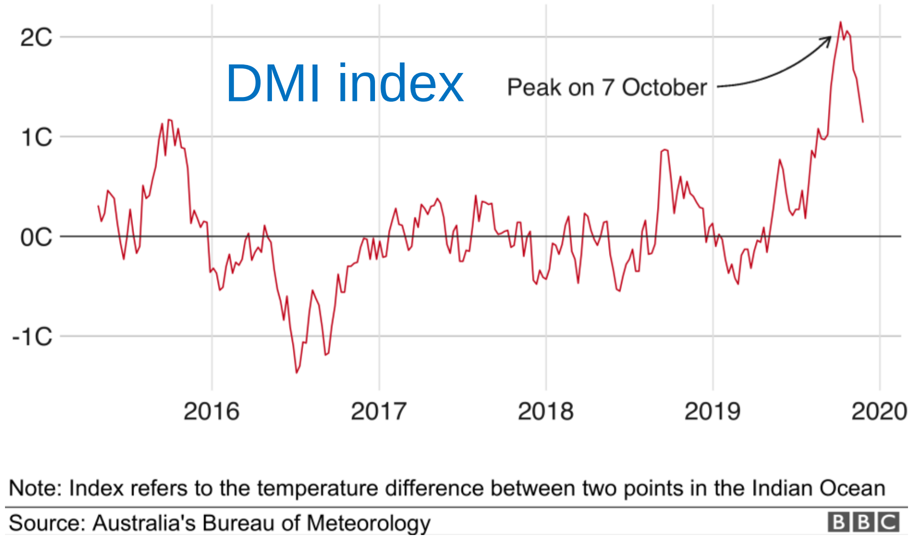
Negative IOD

- The wind blows to the east of the Indian Ocean.
- High and low sea surface temperature/precipitation are switched in the east and the west of the Indian Ocean.
- Upwelling in SEA waters disappears.

Strong positive IOD in 2019

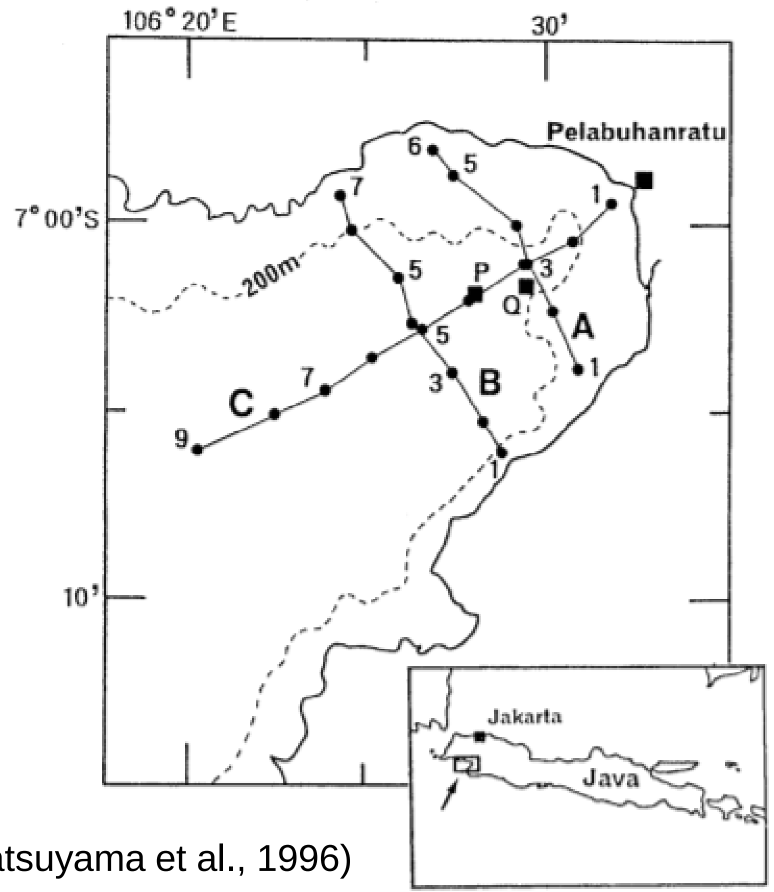


https://u-aizu.academia.edu/SajiHameed

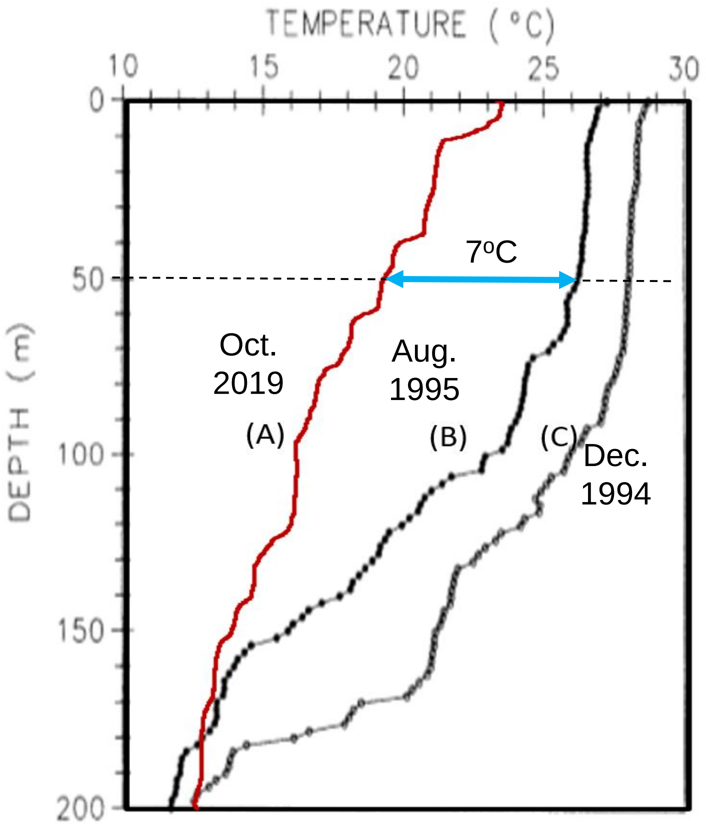


- DMI is an index indicates the occurrence of IOD
- It is calculated from the difference in SST between West and East Indian Ocean.
- What are the responses of ecosystem and fishery resources in Indonesia during such strong positive IOD?

Comparison of the vertical profiles of temperature between during positive IOD in 2019 and other periods at the Pelabuhan Ratu Bay



(Matsuyama et al., 1996)

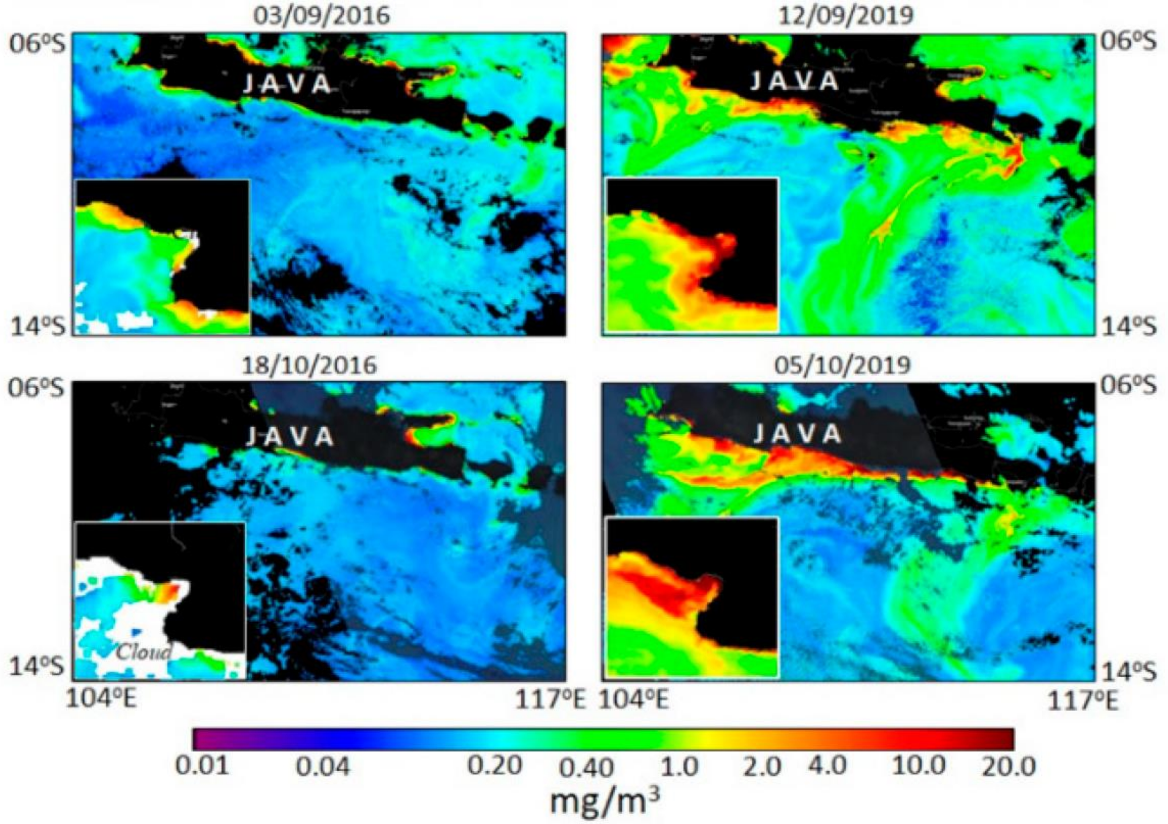


Lumban-Gaol et al. (2021)

- A. Oct. 2019, Strong upwelling due to positive IOD
- B. Aug. 1995, Regular upwelling during the southeast monsoon
- C. Dec. 1994, downwelling during the Northwest monsoon
- Temperature drops significantly during positive IOD indicating the upwelling of subsurface cold water to the sea surface.
- The temperature at 50 m deep during positive IOD is lower than that normal upwelling for about 7 °C.

Comparison of sea surface Chl-a between during positive IOD in 2019 and negative IOD in 2016 at the Pelabuhan Ratu Bay

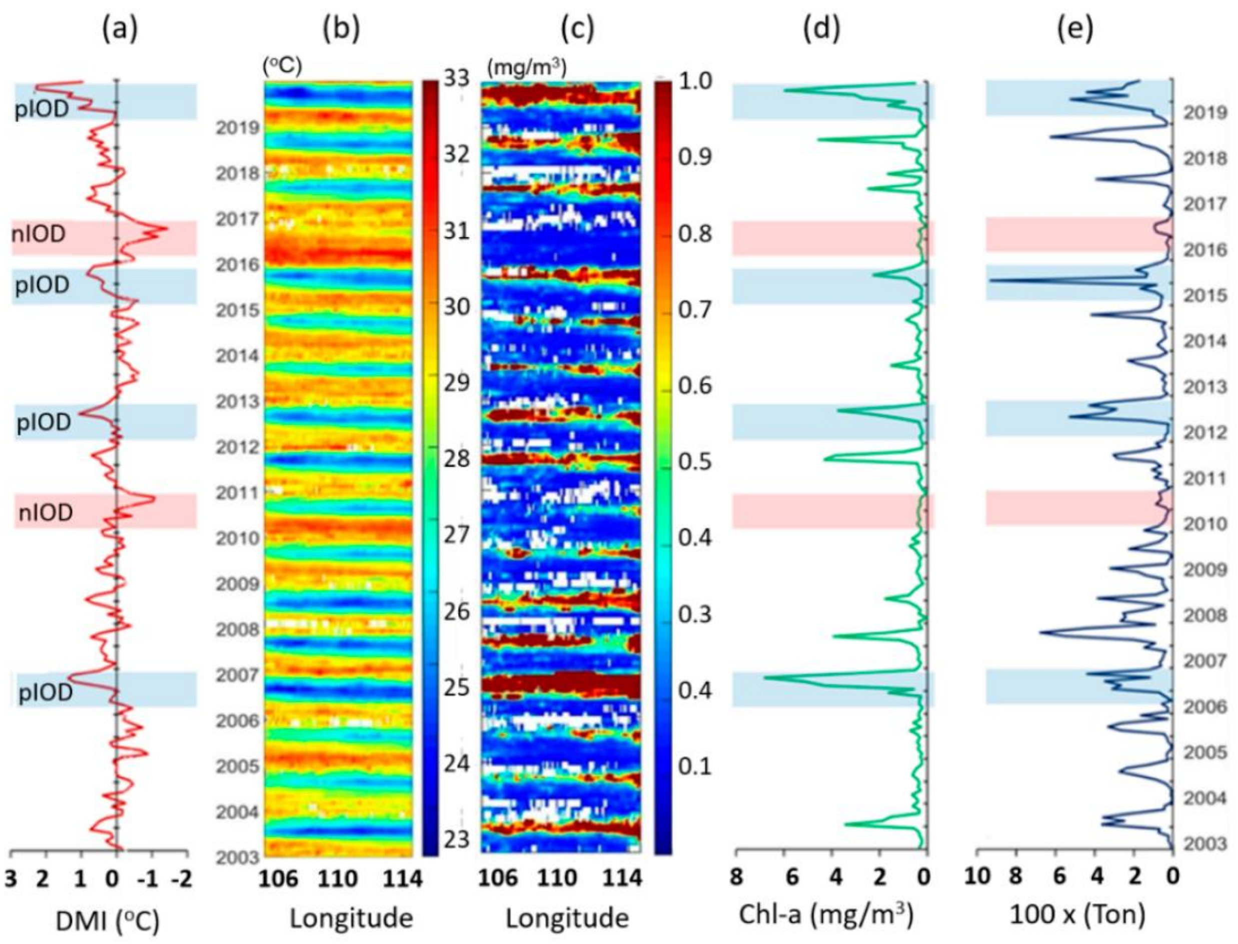
Negative IOD | Positive IOD



Lumban-Gaol et al. (2021)

- Distributions of chlorophyll-a concentration (September–October) in the Eastern Indian Ocean off Java and the Palabuhan Ratu Bay during the 2016 Indian Ocean Dipole negative phase (left); and the 2019 Indian Ocean Dipole positive phase (right).
- The chlorophyll images of each month (July–October) are shown using the daily image of the cloud-free days available during the respective months.

Comparison of Chl-a Concentration between pIOD in 2015 and nIOD in 2016



Lumban-Gaol et al. (2021)

- (a) Monthly time series of the dipole mode index during 2003–2019 showing the positive Indian Ocean Dipole phases (pIOD) and negative Indian Ocean Dipole phases (nIOD) along with the Hovmöller diagram of satellite-derived data of (b) sea surface temperature and (c) Chl-a.
- Monthly time series of (d) observed chlorophyll-a in the Eastern Indian Ocean off Java; and (e) landing of small pelagic fish catch in the Palabuhan Ratu fishing port during the same period.
- pIOD clearly corresponds to low SST, high SSChl-a, and high fish catches.
- nIOD clearly corresponds to high SST, low SSChl-a, and low fish catches.

Fish catch observation in Palabuhan Ratu Fishing Port on Oct 5, 2019

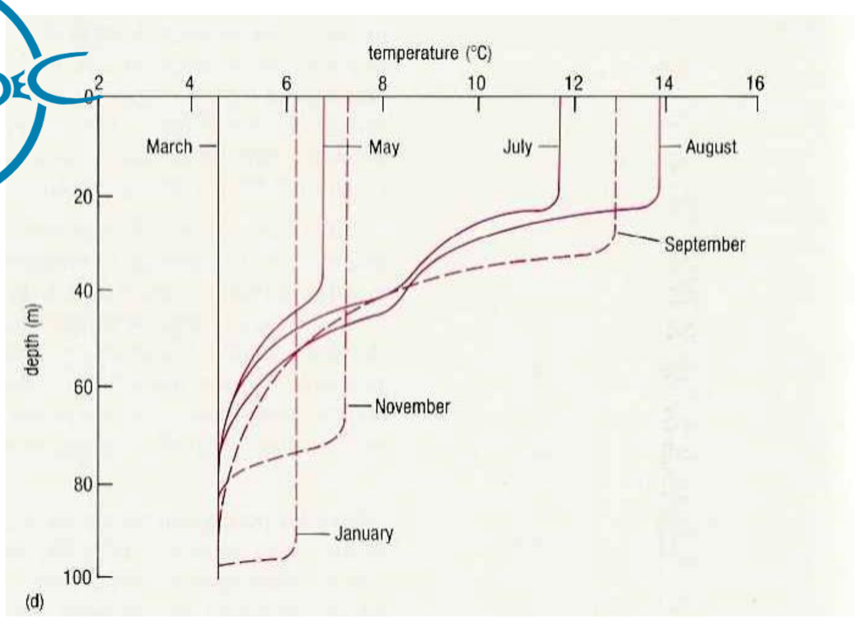
- Fish Catch increased more than 3 times
- The Price dropped 4 times
- Normal price of small shrimp (1 basket/20 kg) is 200,000 Rp. but on Oct 5, 2019 the price dropped to 50,000 Rp.

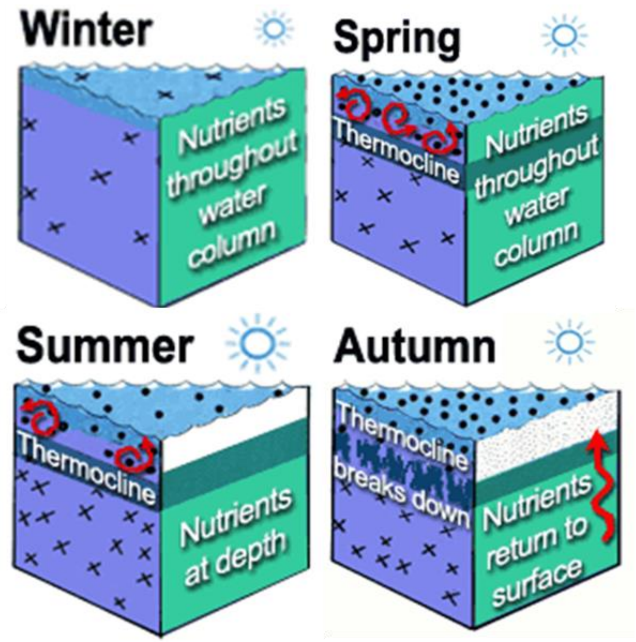
Photos and data by Dr. Jonson Lumban-Gaol

A lot of Juvenile

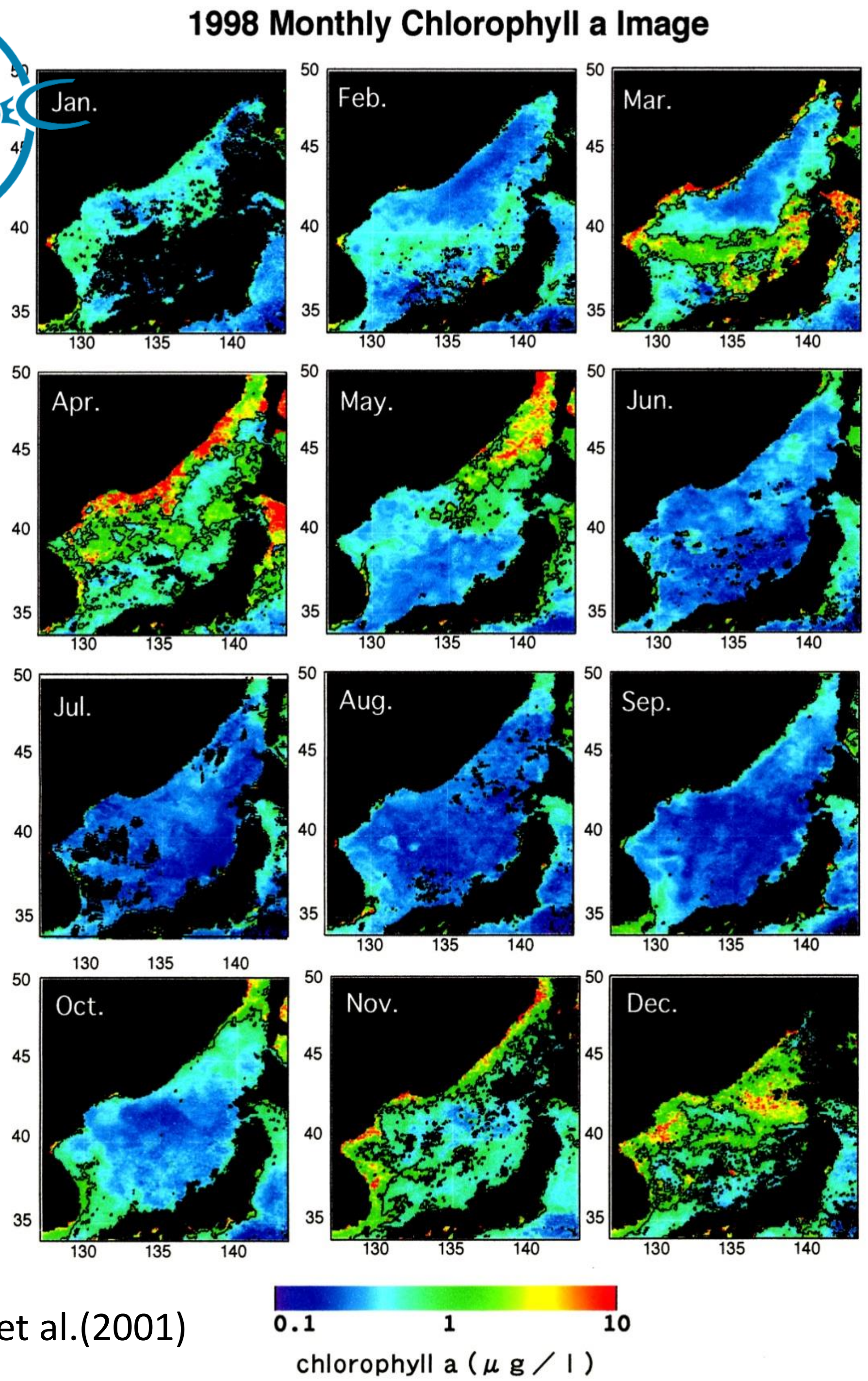
Oceanographic conditions and primary productivities

Seasonal Thermocline and algal bloom





- Seasonal thermocline fully develops in summer and decays in winter.
- Spring and autumn, when the thermocline starts to develop and decay, are the important periods for primary productivity in the water column.
- Nutrients are high in winter due to strong vertical mixing, but the light is limited. Low primary productivity is as a result.
- Low productivity occurs in summer because strong stratification limits nutrients to be vertically mixed into the well-lit region.
- Strong algal bloom develops in spring because nutrients are high, water is warm and light is high enough for photosynthesis.
- The bloom in autumn is moderate because nutrients in the mixing layer is lower than in spring.



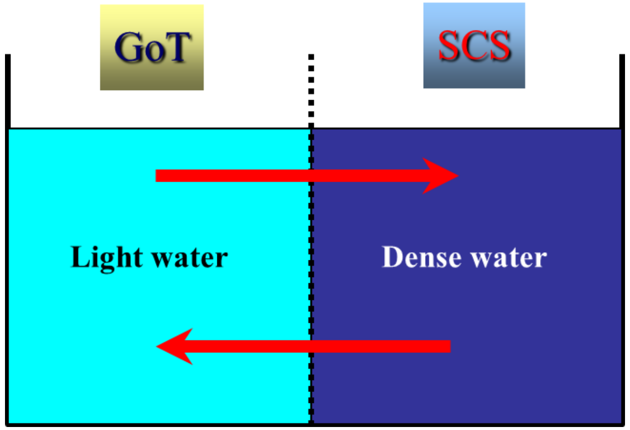
Spring Bloom in Japan Sea

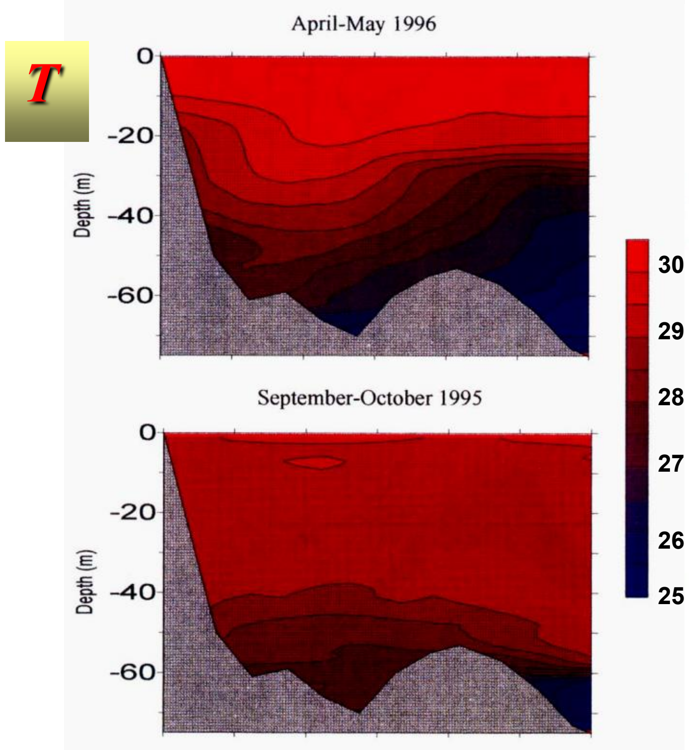
- Monthly surface Chl-a images based on SeaWiFs sensor reveals the development of spring bloom during March and May, and autumn bloom during November and December.
- The period of autumn bloom is quite late. This may be due to slow temperature decrease and slow decay of water stratification.
- The modification of these phenomena under climate change is very interesting.

Yanagi et al.(2001)

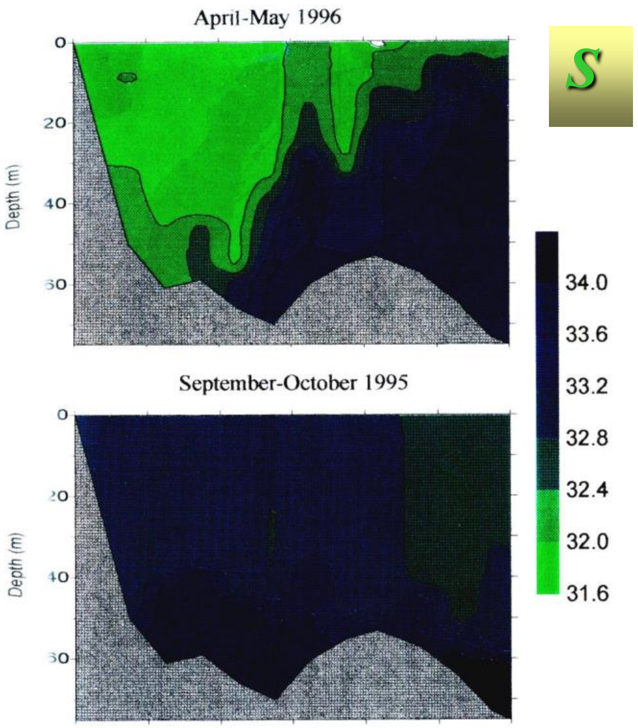
Subsurface chlorophyll maxima and water column conditions in the Gulf of Thailand

Vertical distributions of T and S





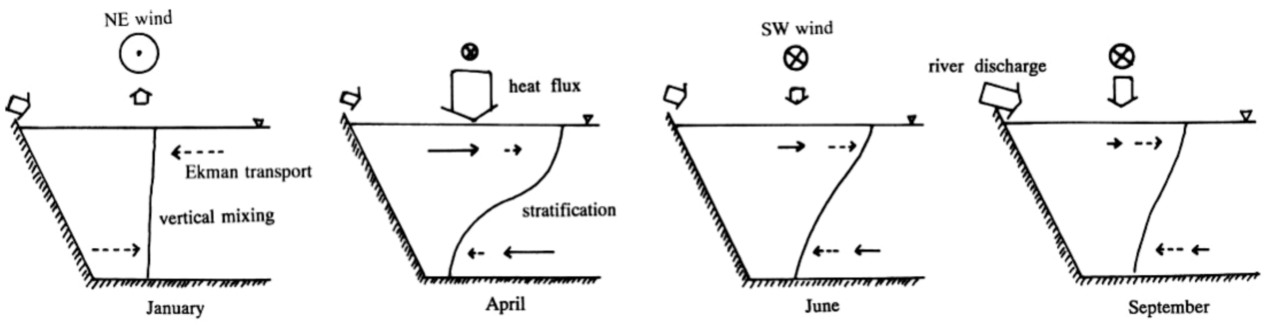
(a) Vertical section of temperature along the central axis of the Gulf of Thailand (Data from Snidvongs *et al.* 1995)



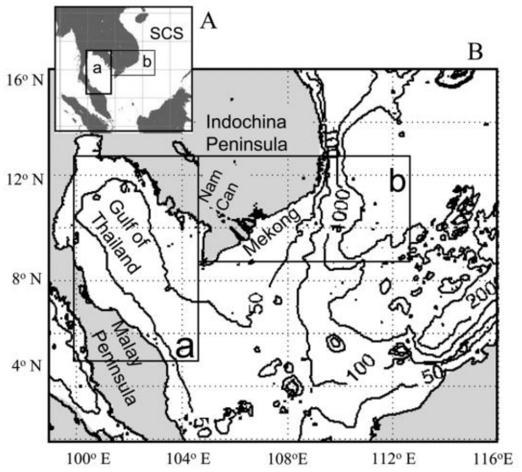
SEAFDEC Collaborative Research : 1995 - 1996

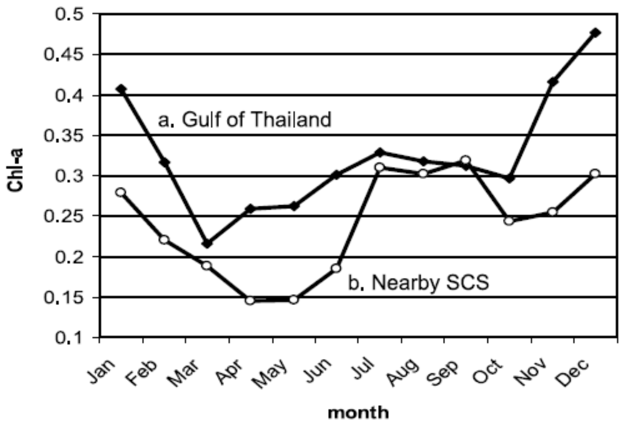
- Water density in the Gulf of Thailand is always lower than that in the South China Sea. The interaction between them looks like an estuarine system.
- Strong stratification occurs in April – May because of surface heating in summer.
- More vertical mixing is observed in September – October due to lower surface heat flux and stronger wind magnitude than those in April – May.
- Density driven is strong in summer, controlled by surface heating.

Water column and surface productivity



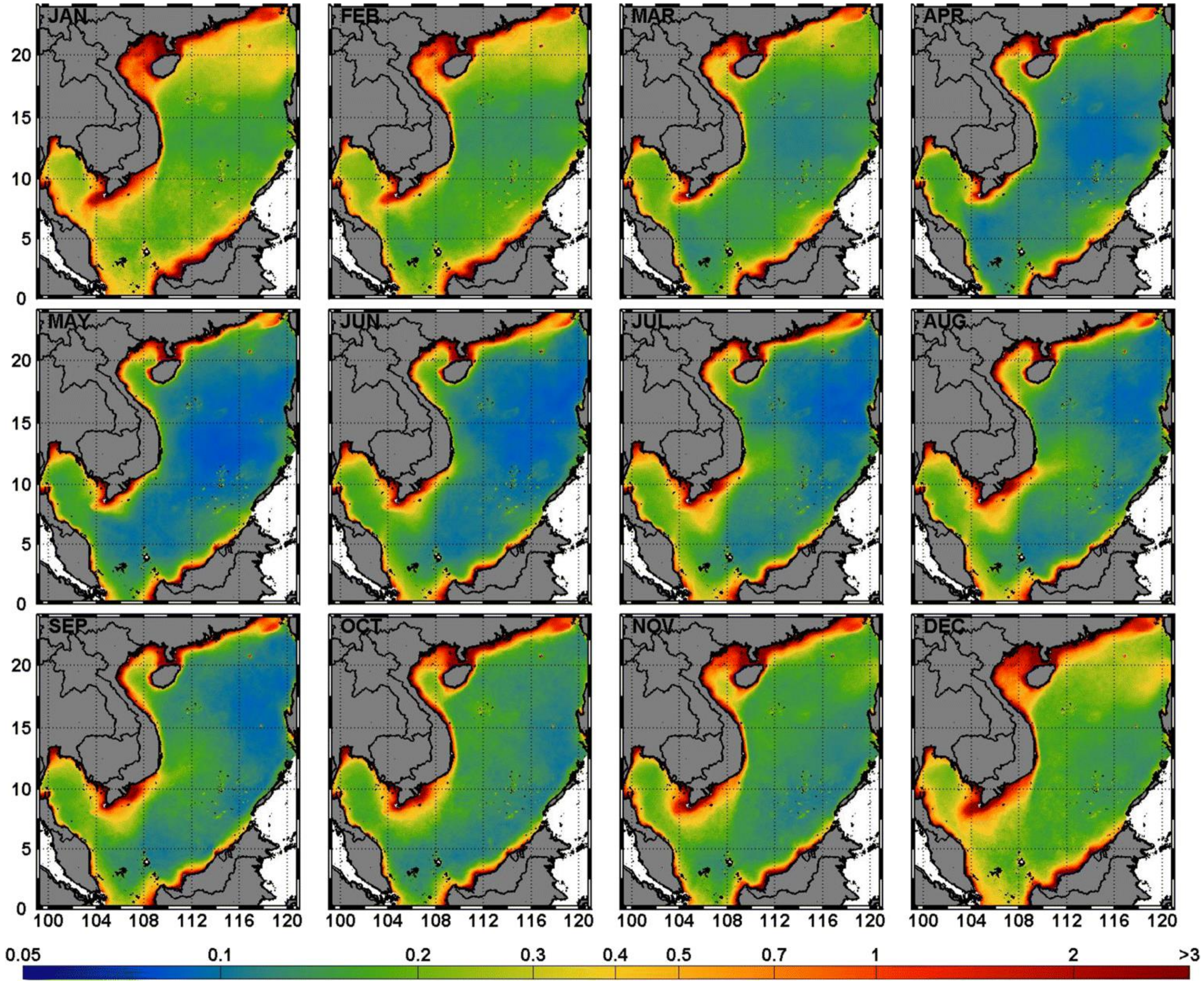
Yanagi et al. (2001)





Tang et al. (2006)

- Yanagi et al.(2001) analyzed the factors to control water column conditions in the Gulf of Thailand based on data from the NAGA expedition. Well-mixing water column and strong stratification were found in winter and summer, respectively.
- Tang et al. (2006) tried to connect seasonal variations in water column conditions and sea surface Chl-a based on satellite imageries. High surface Chl-a in winter occurs because of water column well-mixing, and low Chl-a in summer is due to water column stratification.
- This report addresses the importance of water column condition as one of the significant factors to control primary productivity.



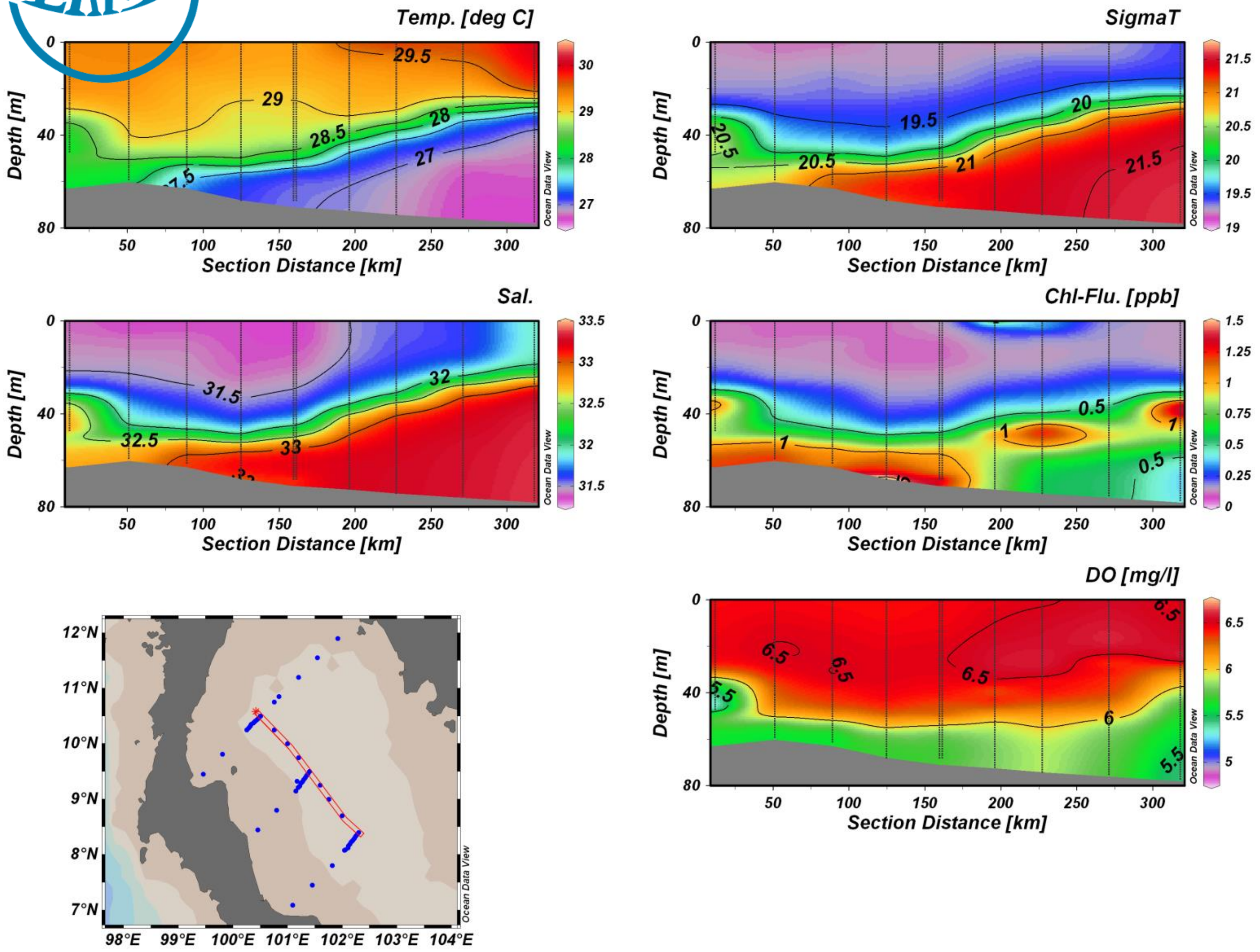
Monthly MODIS-A Surface Chl-a

- These satellite images also reveal seasonal variations in sea surface Chl-a in the South China Sea.
- Surface Chl-a is also high in winter and low in summer due to well-mixing and stratified water column.
- High Chl-a along the southern Vietnam coast in July and August has resulted from coastal upwelling induced by the southwest monsoon.

Huynh et al. (2006)
https://link.springer.com/article/10.1007/s10236-019-01308-9

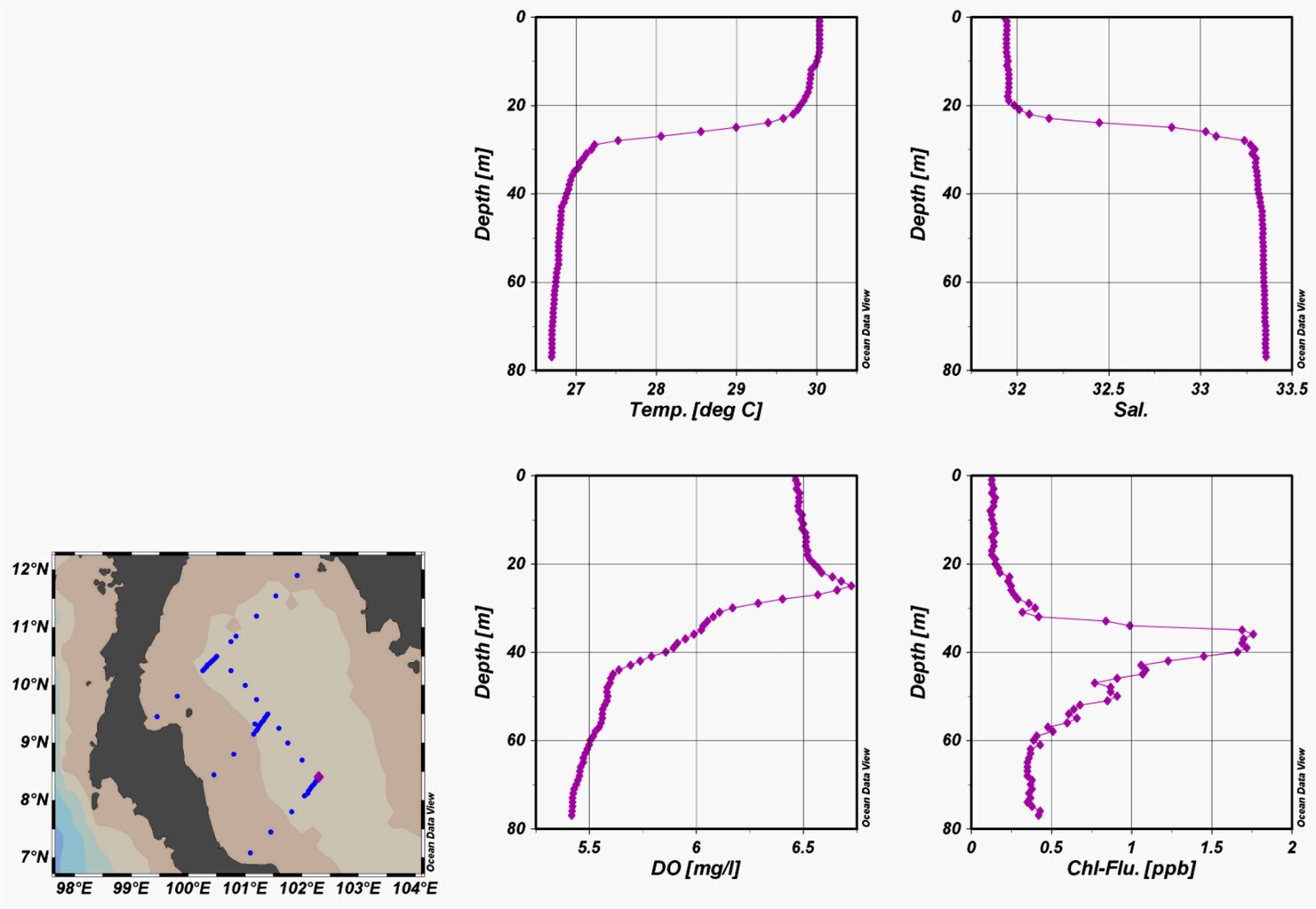
Gulf of Thailand Cruise

August 2011



- The cross-sectional distributions of water parameters reveal the intrusion of sub-surface water from the South China Sea to the Gulf of Thailand.
- Chl-a is found high along the boundary between those two water masses.
- This is called subsurface chlorophyll maxima.
- Due to water column stratification, DO is low in the bottom water mass. Sometimes hypoxia can develop here.

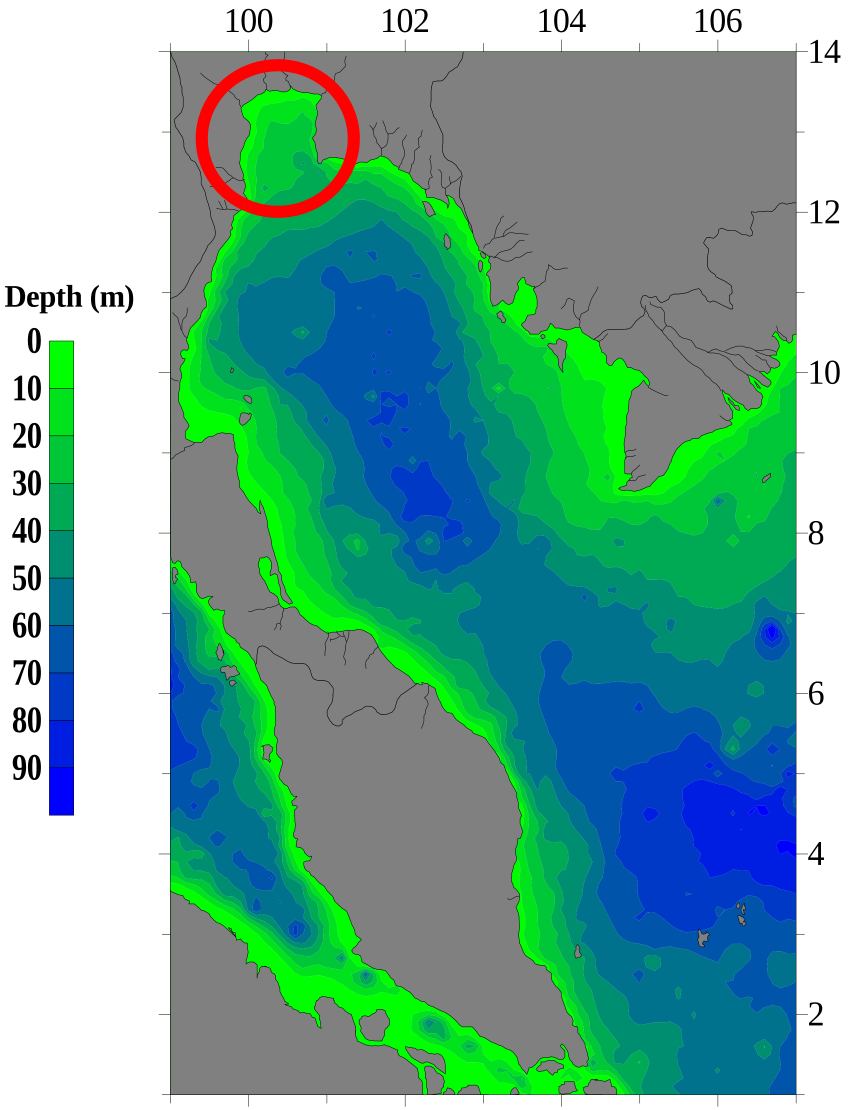
Subsurface Chlorophyll Maxima



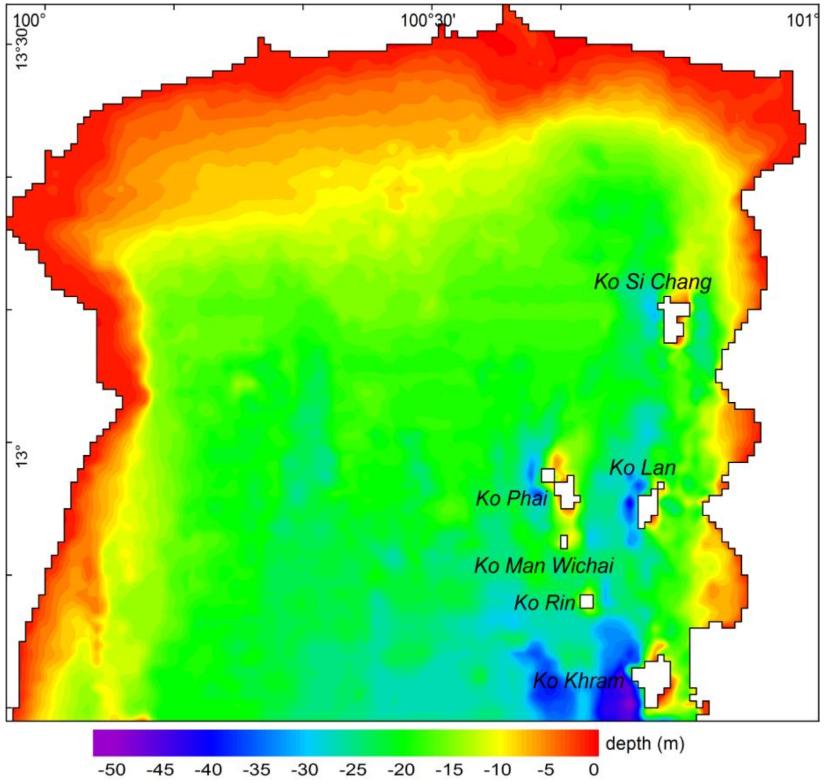
- Subsurface chlorophyll maxima (SCM) develop at the base of the thermocline or the halocline, where the boundary between two water masses locates.
- DO a little increases and drops abruptly at the top of thermocline.
- Subsurface DO increase may come from photosynthesis by phytoplankton dwelling at SCM, and near-bottom DO decrease may be from decomposition in the bottom water mass.

Eutrophication and the degradation of marine ecosystems

The upper Gulf of Thailand

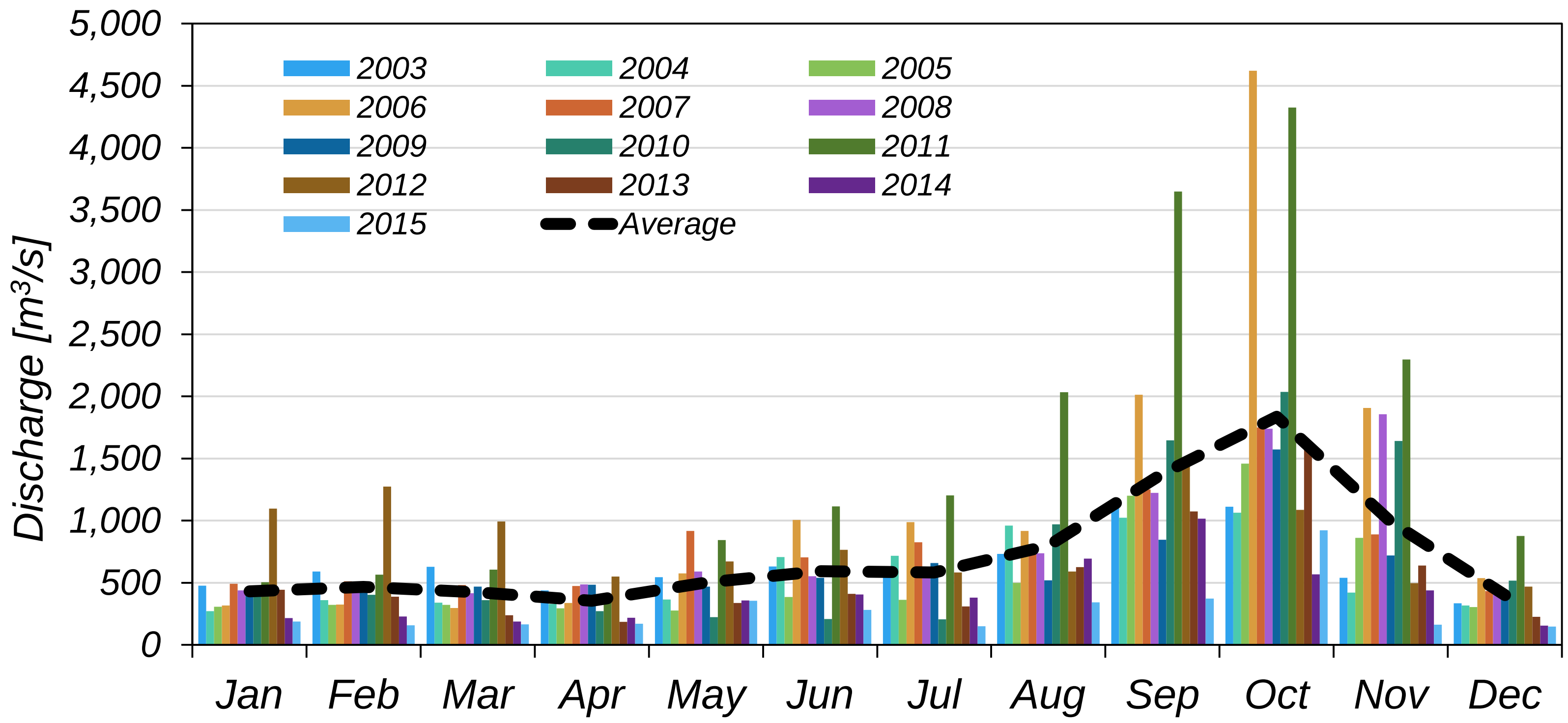


- A shallow coastal sea (or estuary) with average depth of 15 – 20 m
- Most rivers in Thailand including the Chao Praya River in emptying freshwater in here



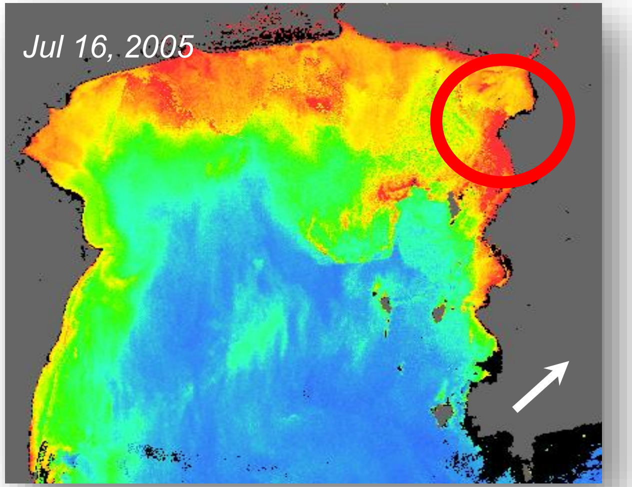
Prepared by P. Jintasaeranee

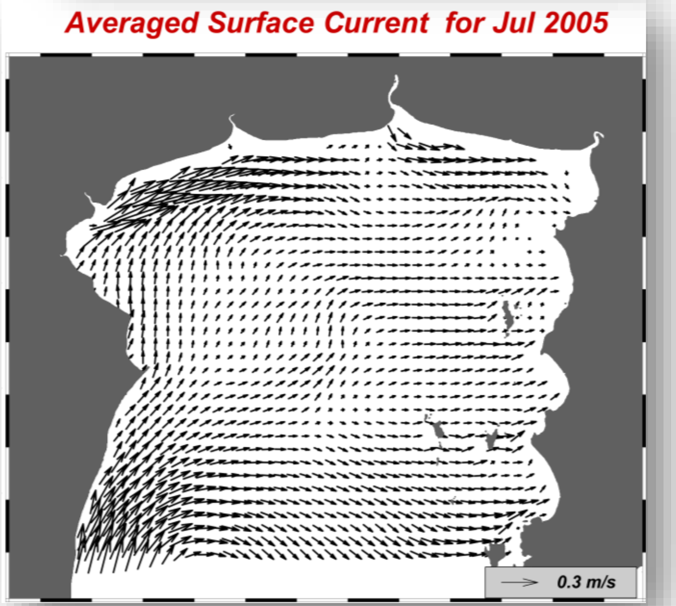
Monthly discharges of the Chao Praya River



- The discharges of the Chao Praya River vary with seasons.
- The lowest average discharge of about 400 m^3/s is in April, and the highest average of about 1,400 m^3/s discharge is in October.
- The height peaks can reach over 4,000 m^3/s in high flooding years.
- The influences of freshwater discharge in the Gulf of Thailand vary with seasons and years.

Green Noctiluca blooms in the east of the upper Gulf of Thailand during the southwest monsoon

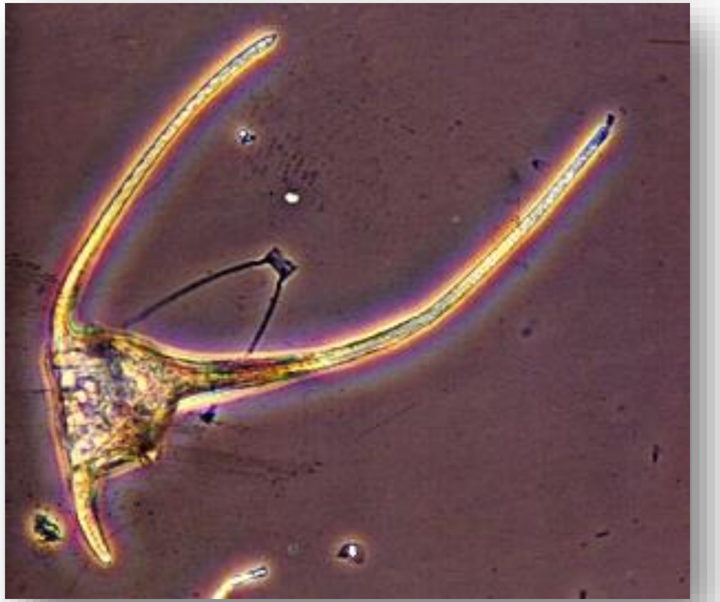




- Strong phytoplankton blooms usually occur along the north coast year-round, and in the northeast area during the southwest monsoon.
- The blooms deteriorate water quality and result in the mortality of cultured shellfishes and marine life.

Dominant blooming phytoplankton

Ceratium spp.



Chaetoceros spp.

Noctiluca spp.

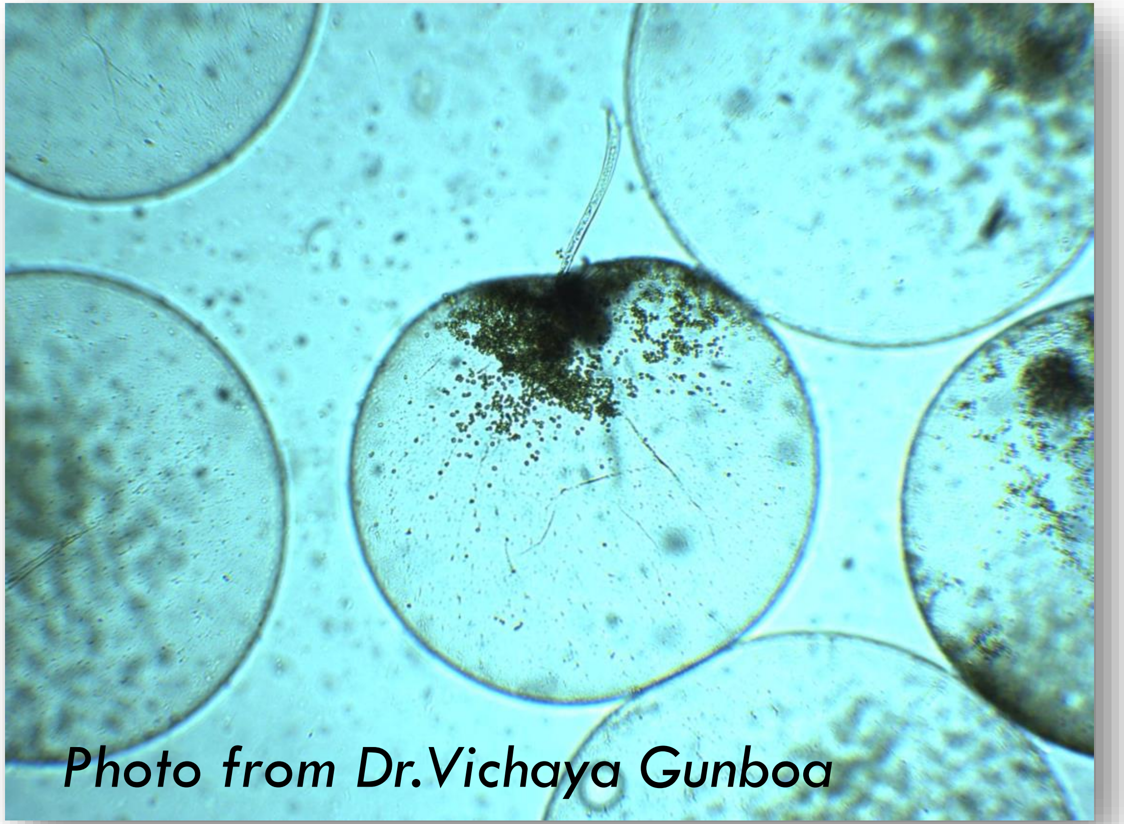


Photo from Dr.Vichaya Gunboa

Bangpakong Estuary Surveys

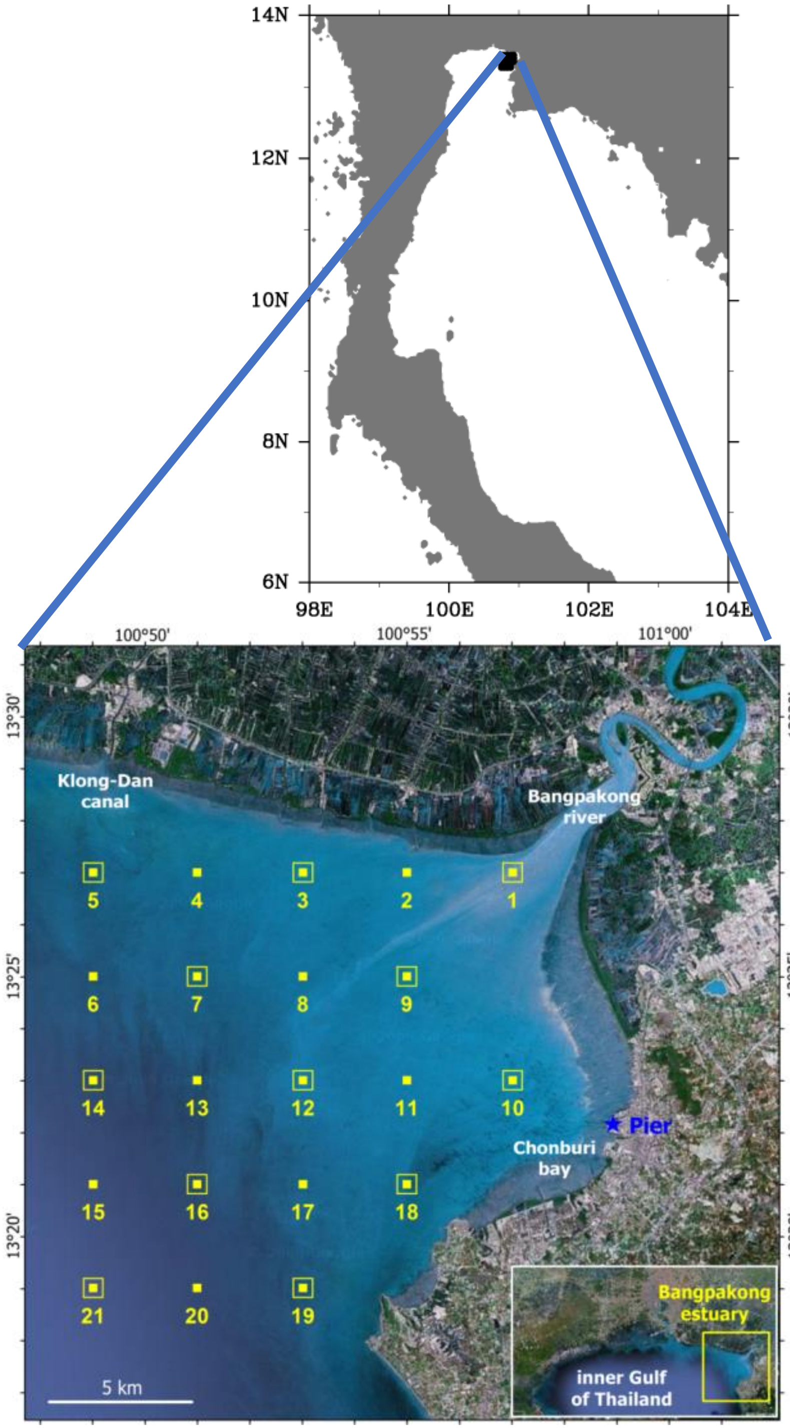
2011

- September 4-5
- October 4-5
- October 24-25

2012

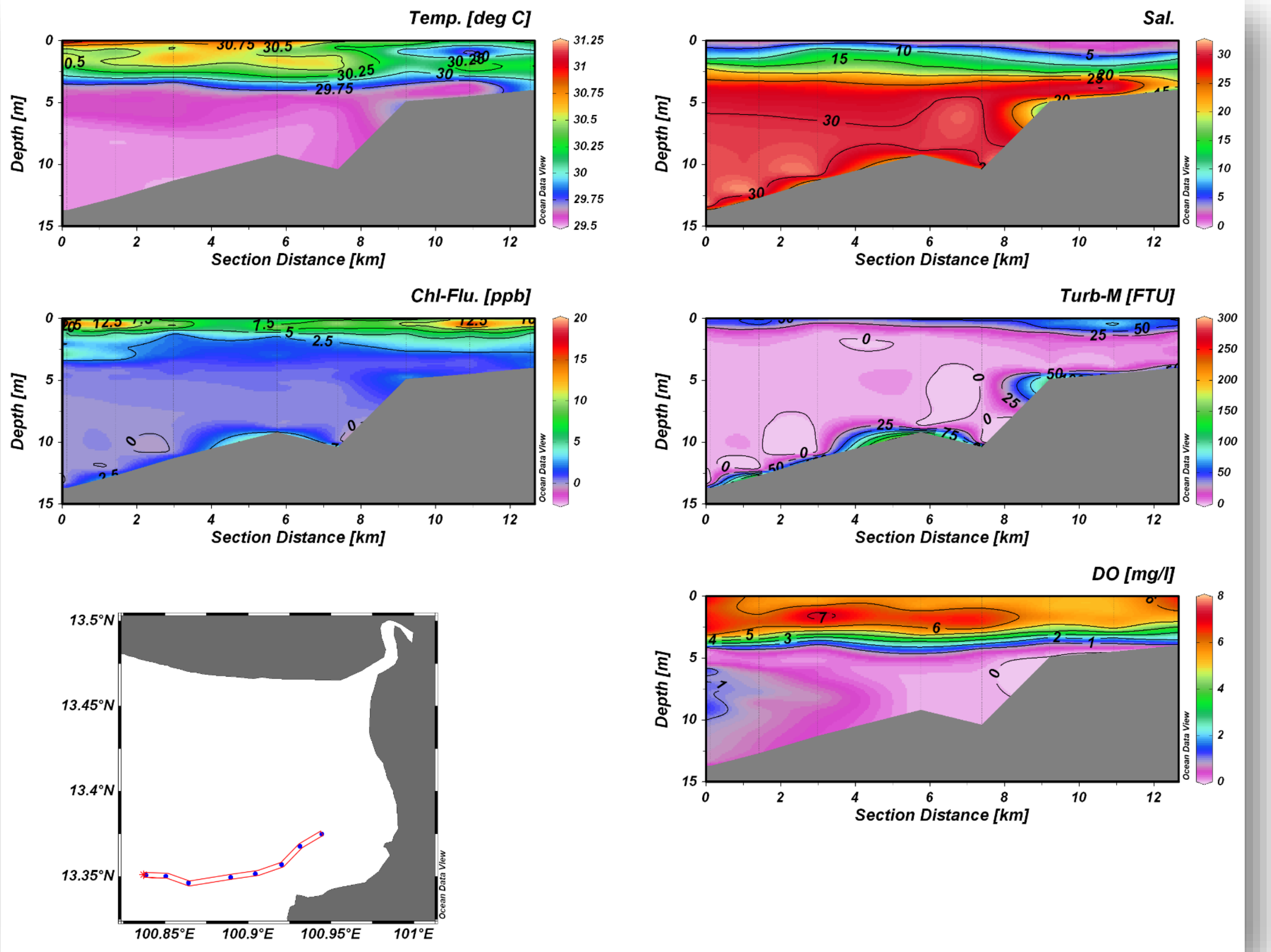
- August 30-31
- September 21-22
- October 21-22

- Temperature
- Salinity
- Dissolved Oxygen
- Turbidity
- Chlorophyll a
- Nutrients
- Phytoplankton



Dr. A. Morimoto

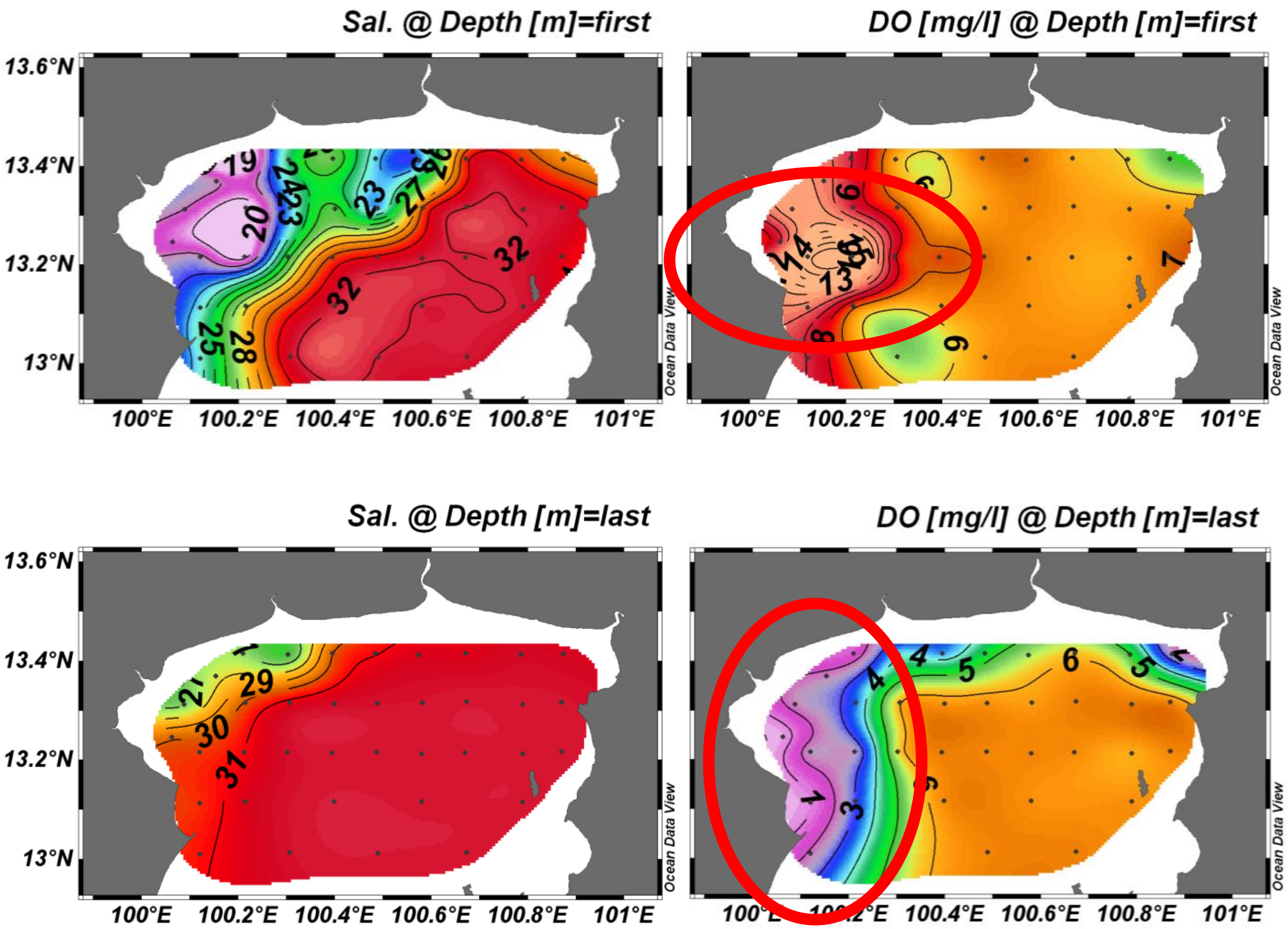
Offshore Bangpakong survey on 9 Sep 2012



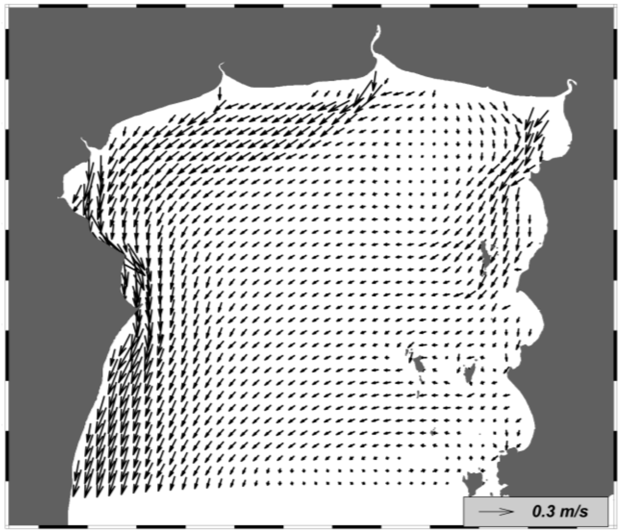
- This is a short survey of when cultured shellfish mortality was found.
- Strong stratification develops due to high river discharge in the wet season. Salinity at the sea surface is almost zero while that at the sea bottom is about 30 PSU.
- Anoxia in bottom water develops due to strong stratification and decomposition, an oxygen consumption process.
- This should be the cause of shellfish mortality at that time.

Hypoxia in the west of UGoT

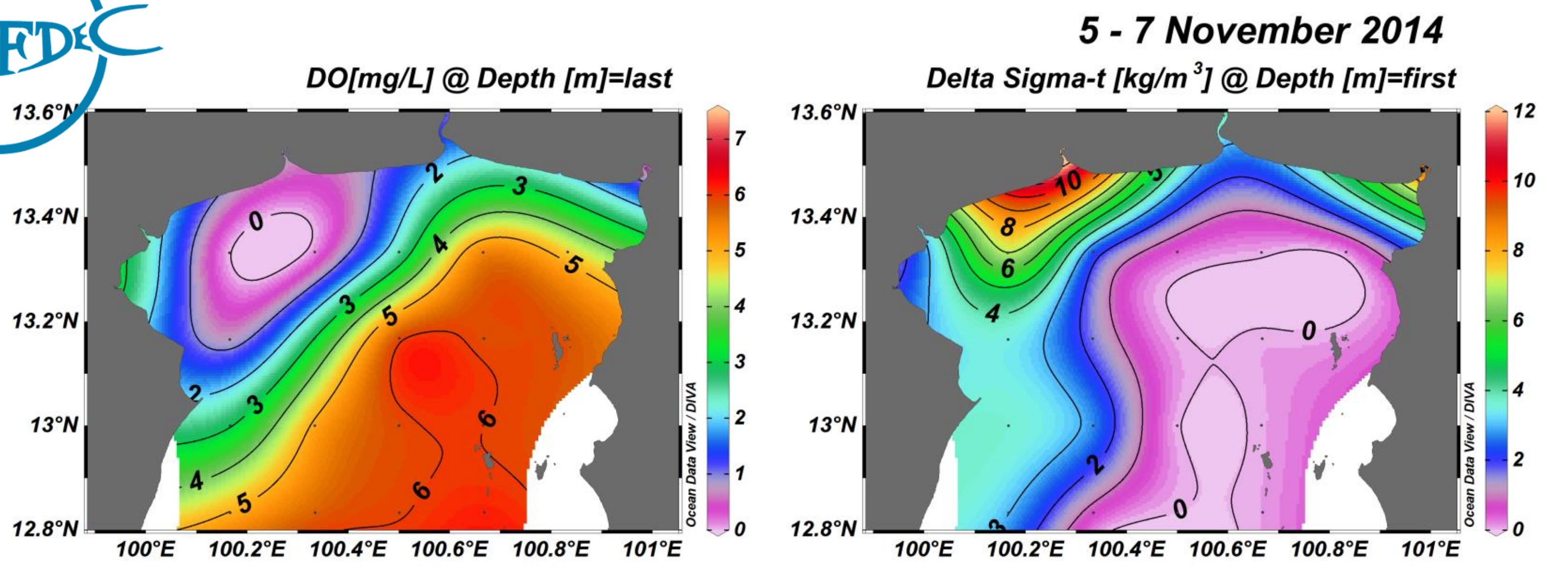
DMC Survey on 5 - 8 Dec 2011



Averaged Surface Current for Dec 2003



- Strong near bottom hypoxia also occurred in the west of UGoT in a wide area.
- It is situated in the west because the circulation in the northeast monsoon was directed westward with freshwater from the river mouths.
- DO near the sea surface was very high (over saturation) due to strong phytoplankton bloom in the same area.



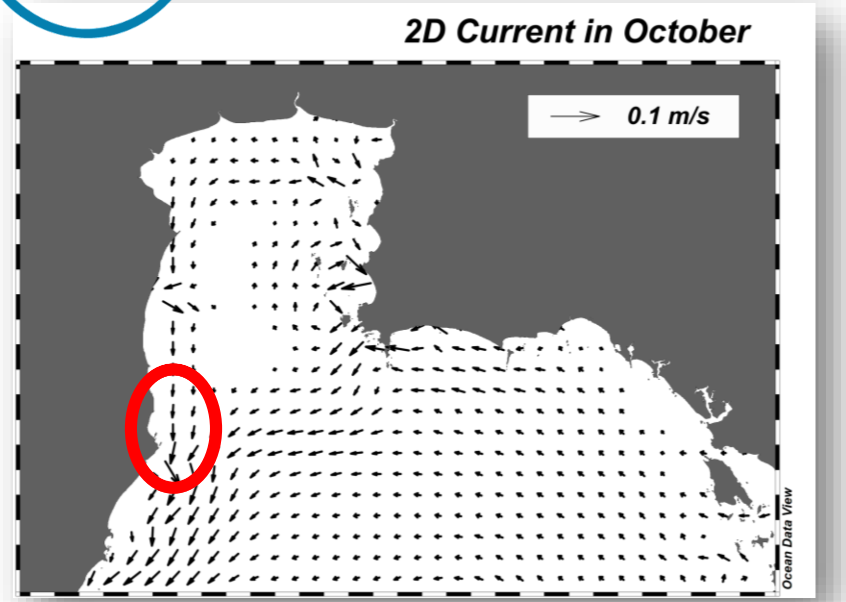
Hypoxia in the west of UGoT

- The hypoxic area is huge.
- Cultured and natural shellfish mortalities were also reported.

https://evergo.in.th/post/640/

https://travel.sanook.com/579951/

Massive fish mortality in the west during the onset of the northeast monsoon

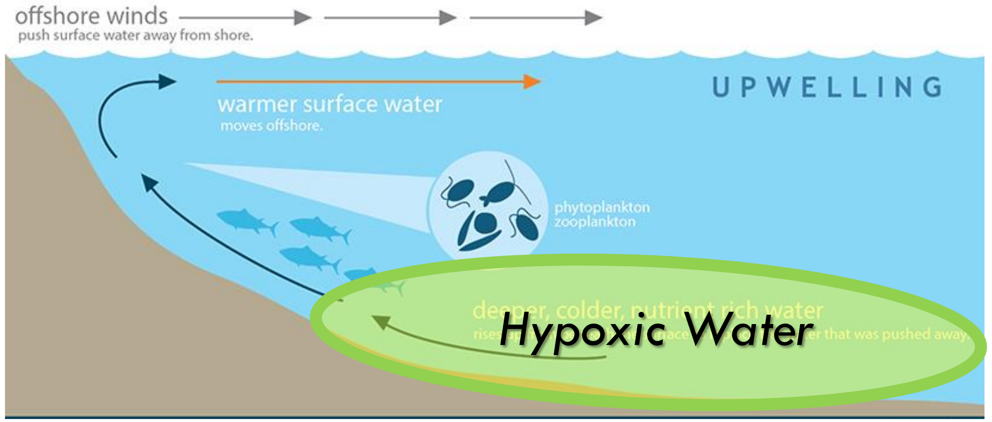


17 Oct 2017

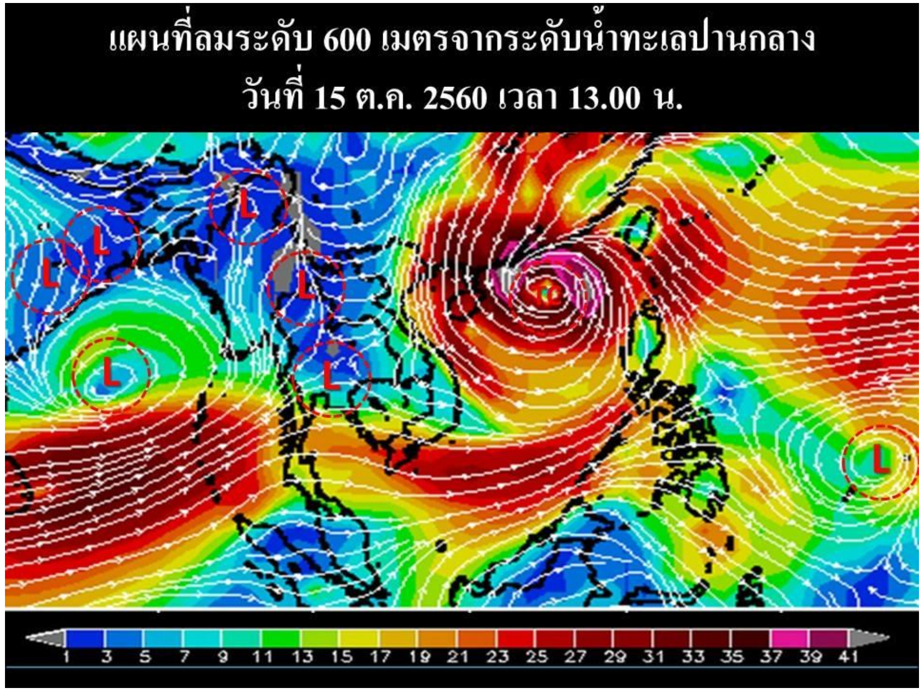
Photo: NEWS and Social media

- No strong phytoplankton bloom
- Offshore sub-surface hypoxia was found.
- Was this related to the hypoxic water mass in the west of UGoT in the west?
- Occurred after topical storm
- Was it related to the upwelling of sub-surface hypoxic water?

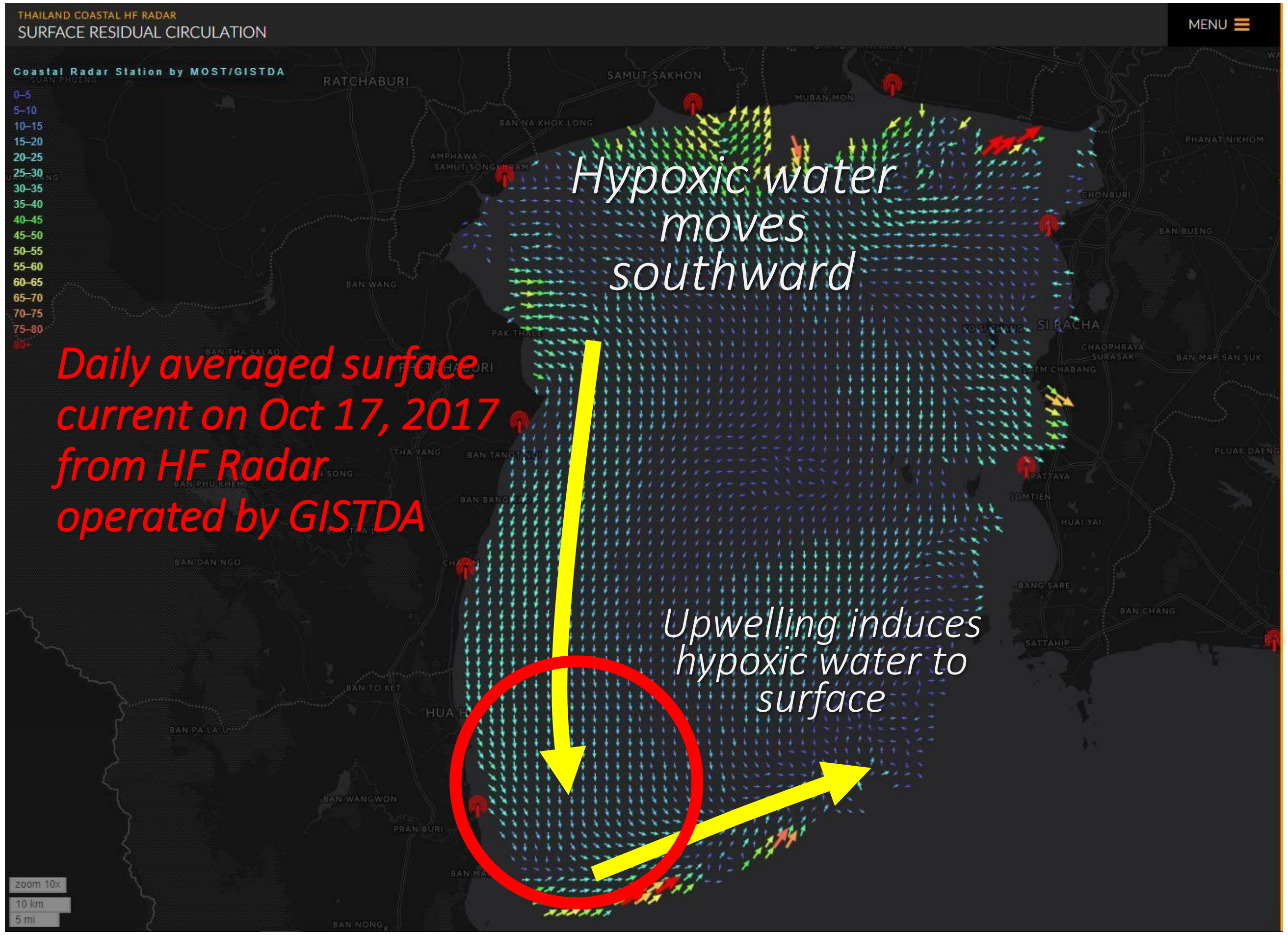
Possible explanation: Nearshore hypoxia induced by coastal upwelling



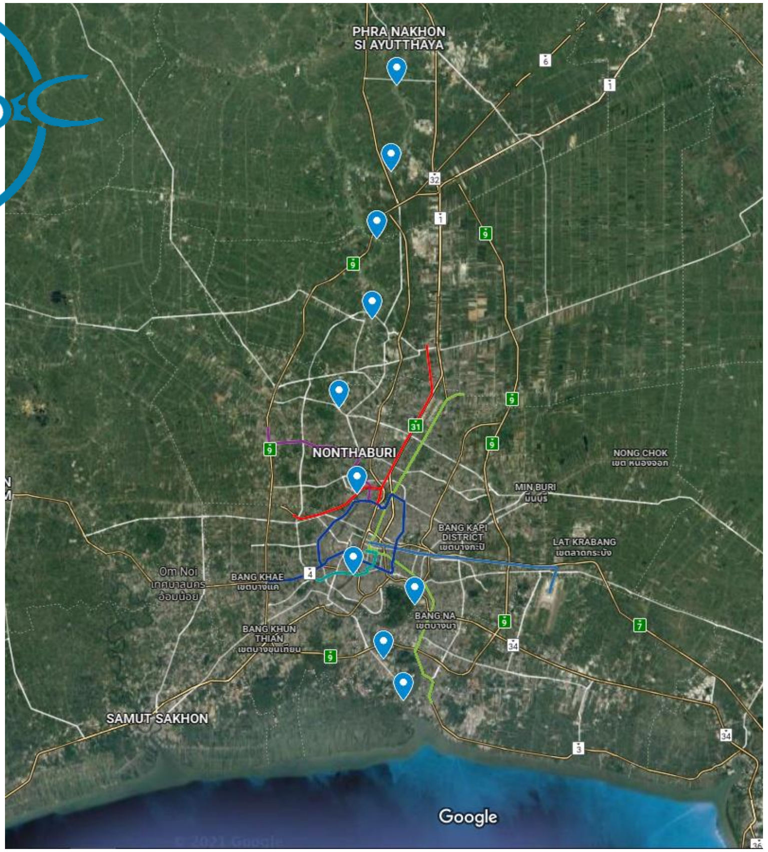
Wind streamline 600 m above MSL on Oct 15, 2017



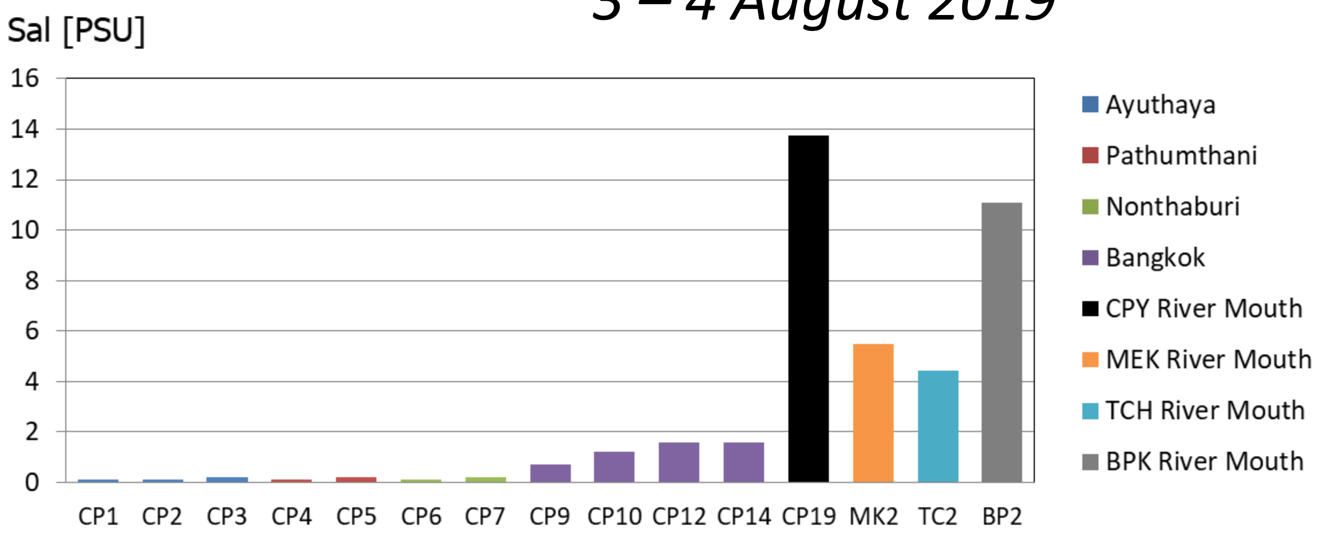
Source: Dr. Wattana Kanboa

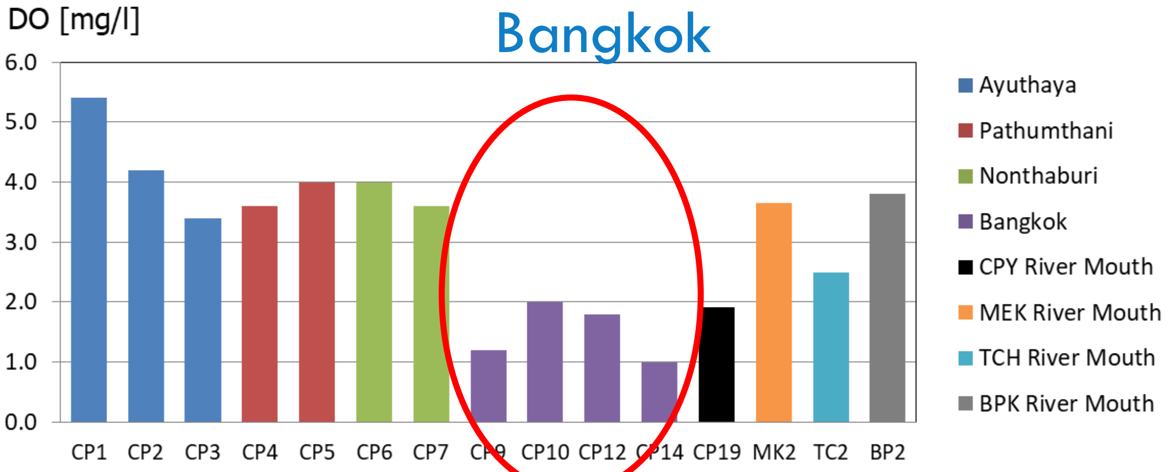


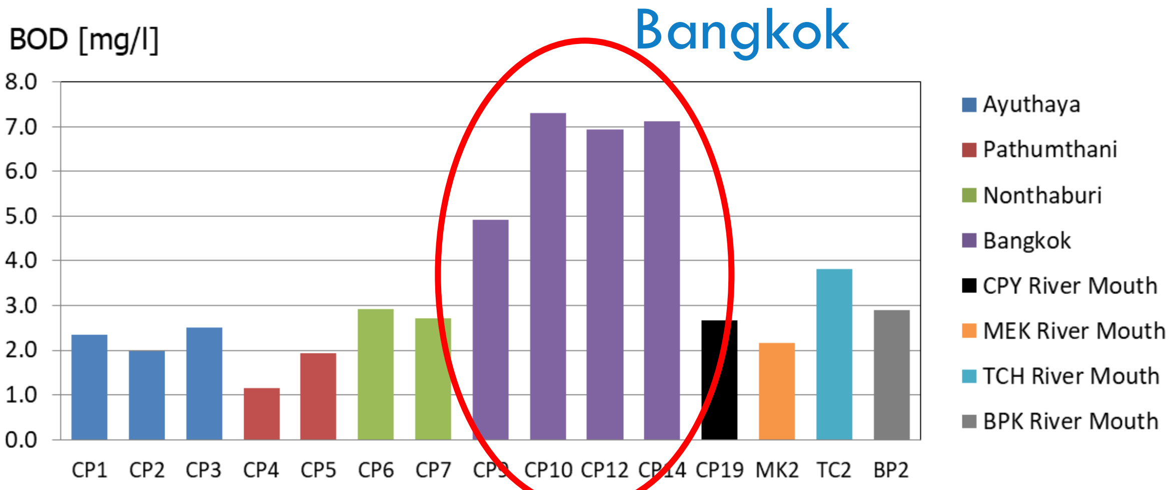
Field surveys in the Chao Praya River



3 – 4 August 2019



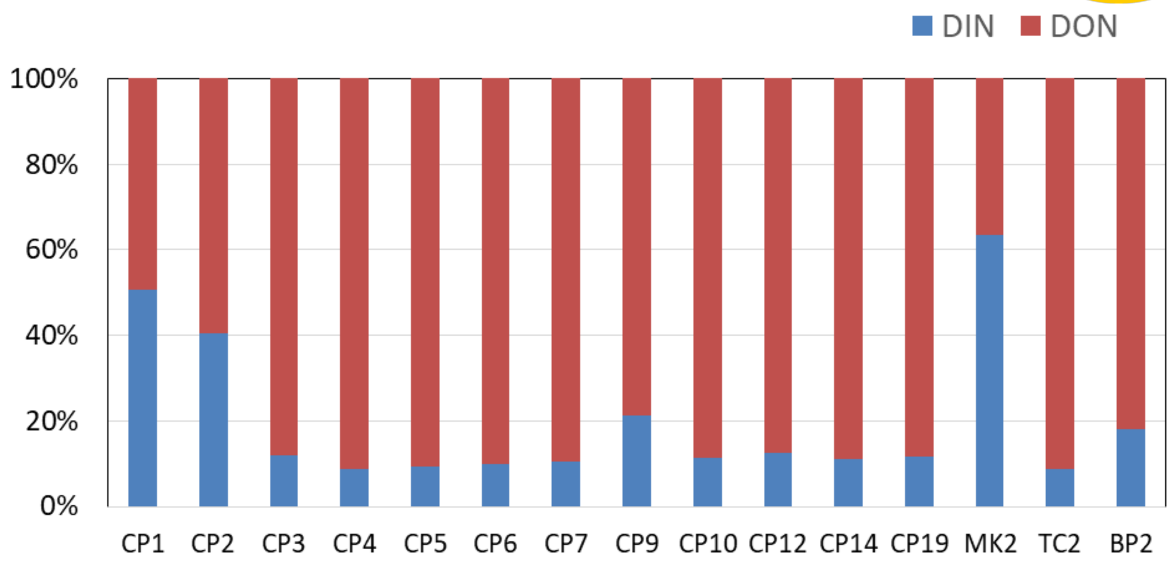


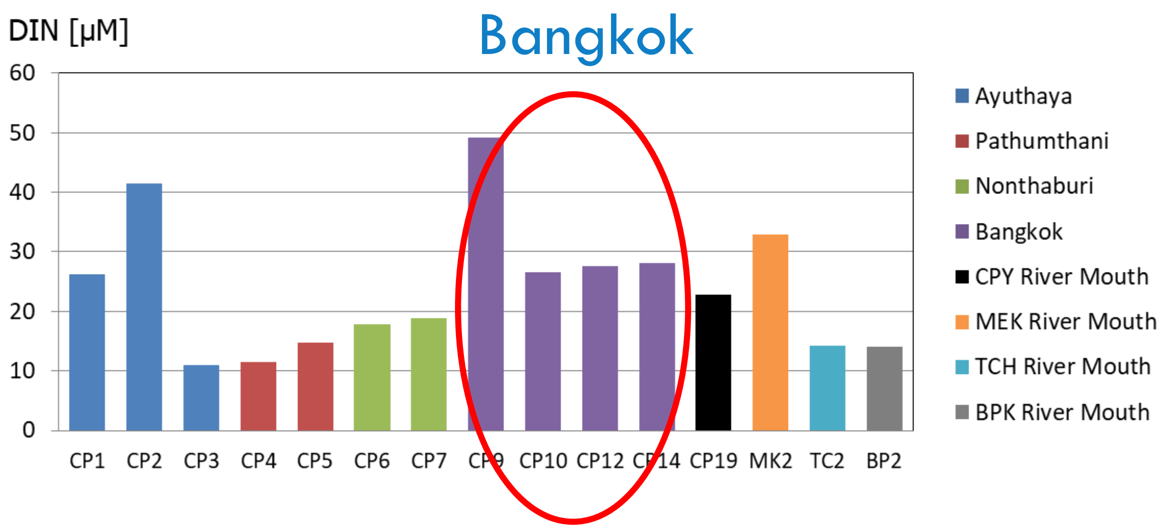


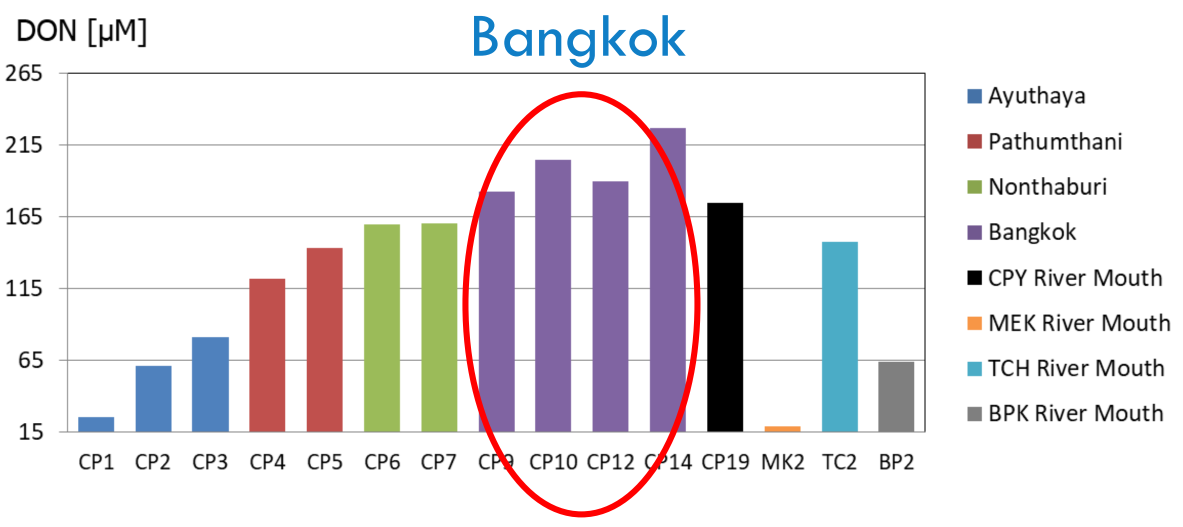
Field surveys in the Chaopraya River

3 – 4 August 2019

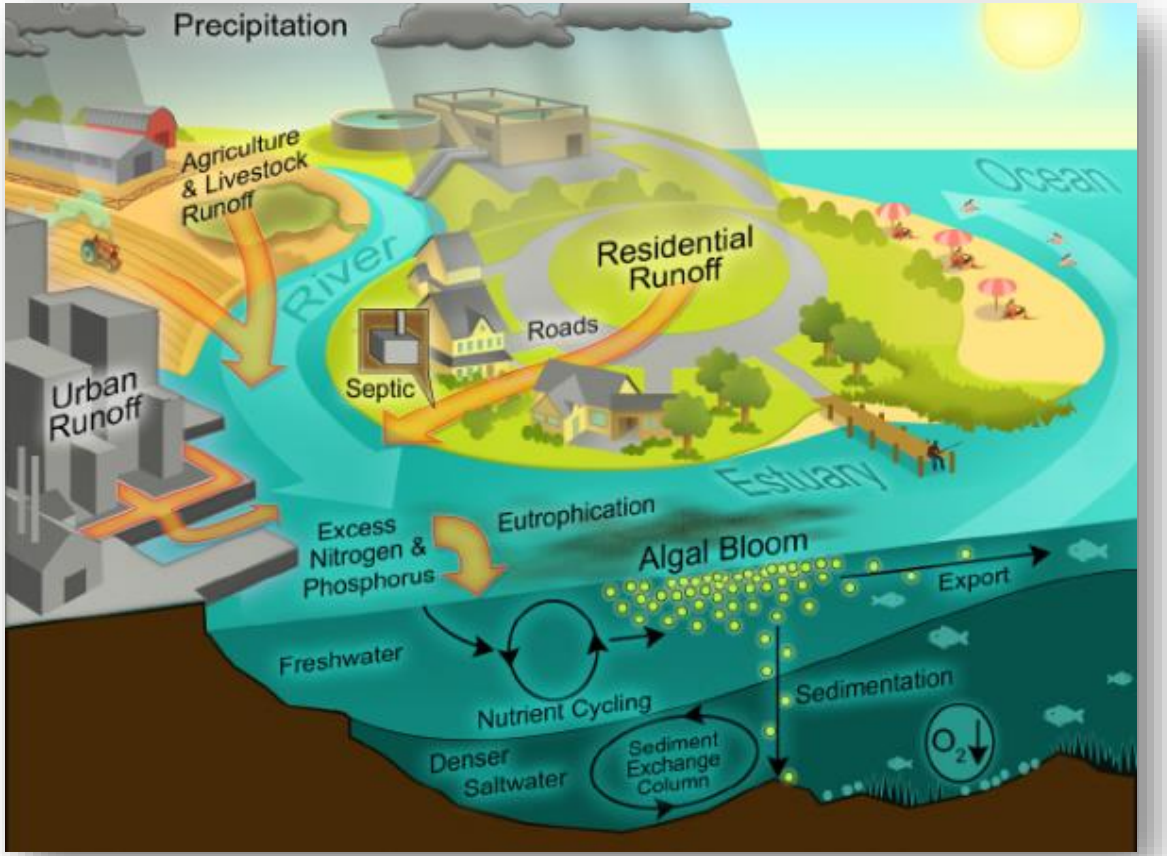
The contribution from DON is large compared with DIN.







Field surveys in the Chao Praya River: Conclusion



http://www.wri.org/our-work/project/eutrophication-and-hypoxia/sources-eutrophication

- Not only red tide but also organic nutrient loads from the rivers play very crucial roles to eutrophication and the development of hypoxia in the upper Gulf of Thailand.
- The measurement of nutrients in organic phases is required.
- To understand clearly in eutrophication mechanism, the estimation of nutrients from surface run-off, groundwater discharge, and precipitation is required.

Thank you