Particle Dynamics on the River-dominated Continental Shelf: The Coupling between Physics and Biogeochemistry

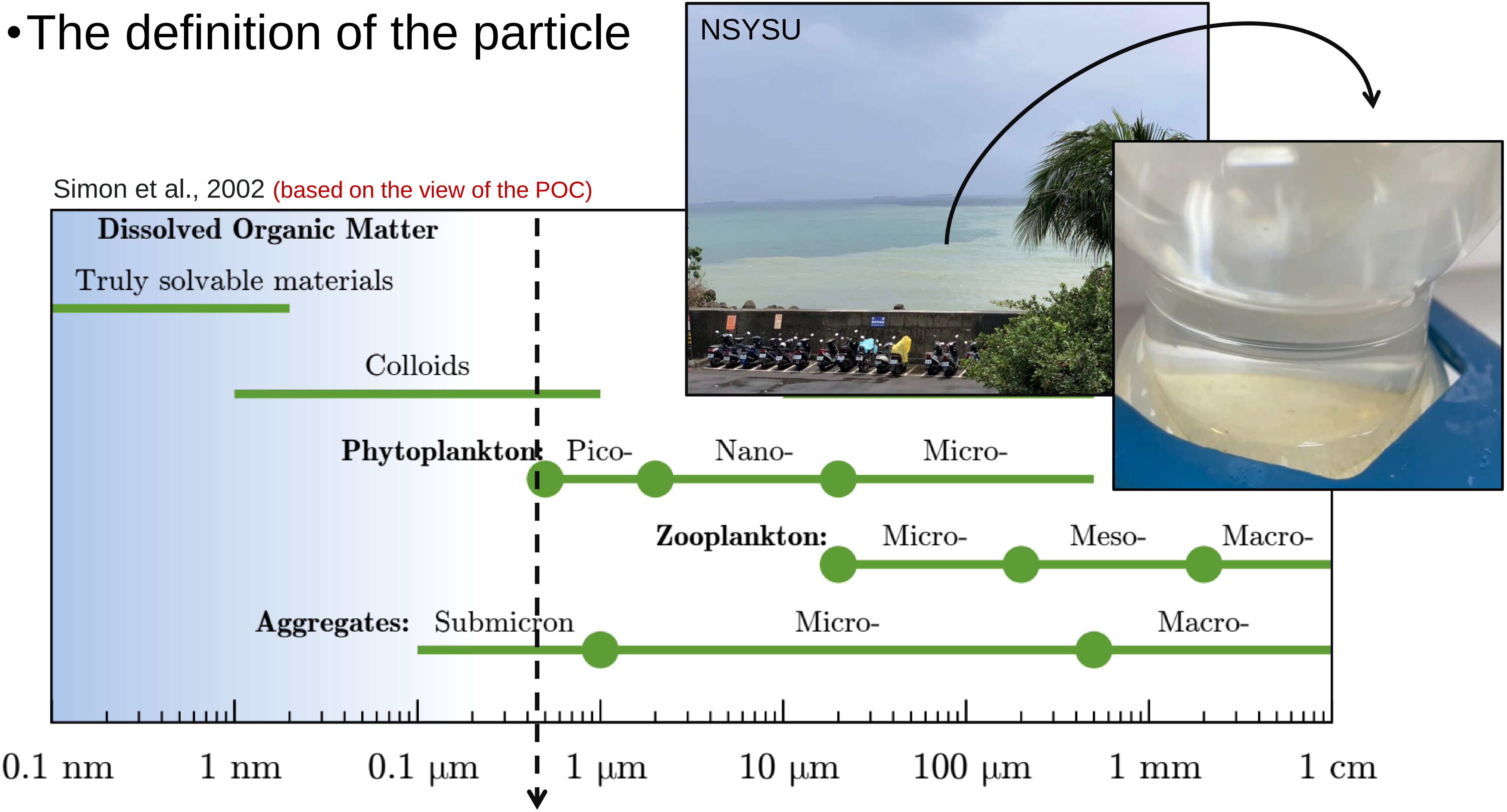
ES&AG, NCU. 22nd Dec., 2023

Speaker: Jay Lee

RCEC, Academia Sinica

• The definition of the particle

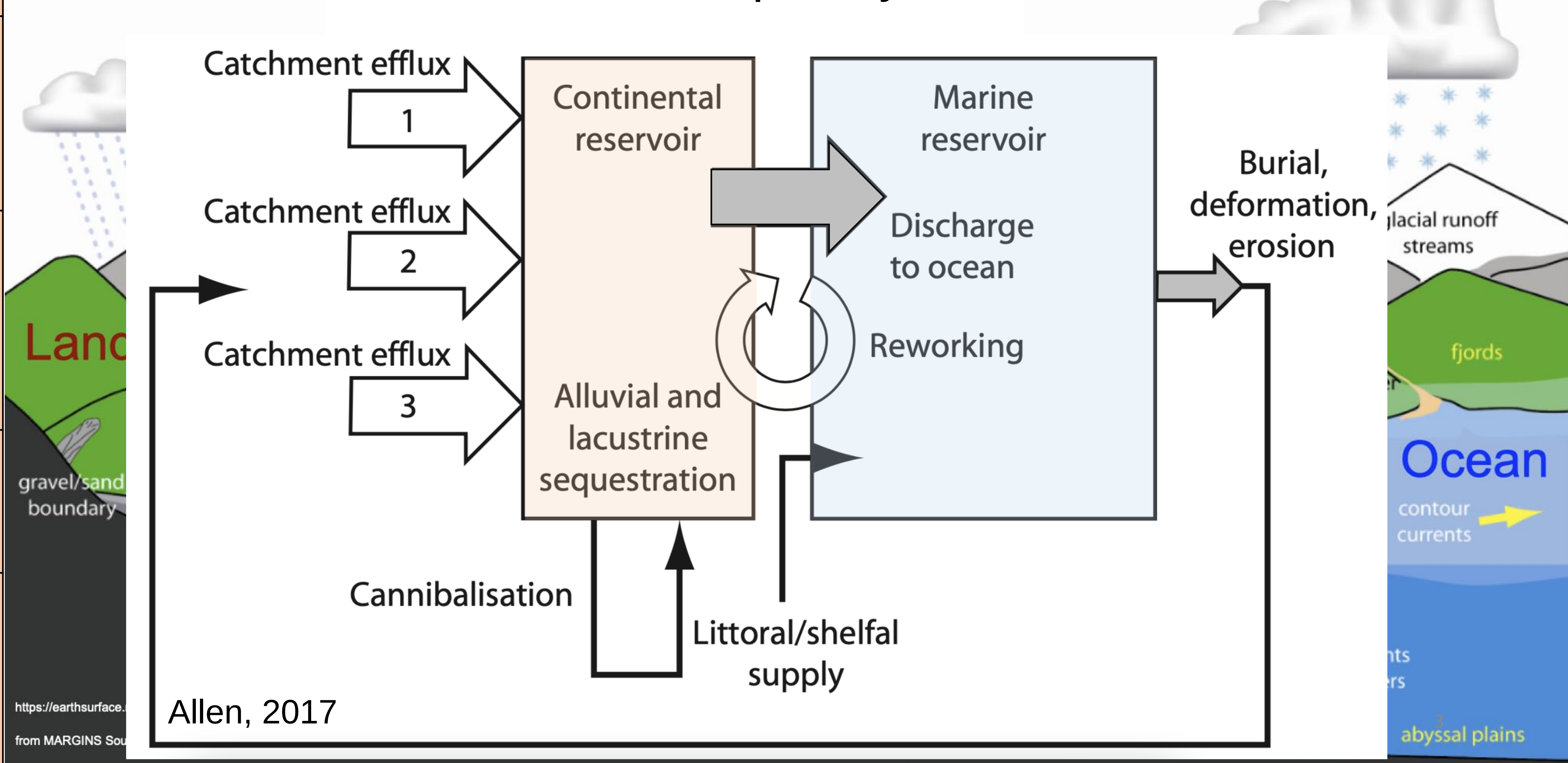
Simon et al., 2002 (based on the view of the POC)



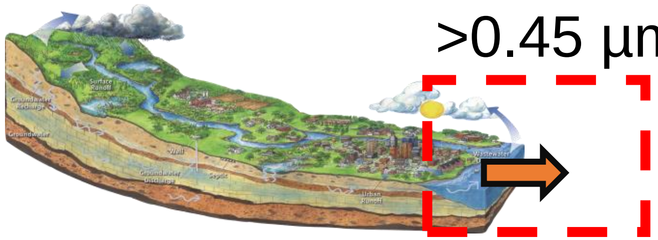
>0.45 µm (Operation Definition)

- The routing system from its **S**ource to **S**ink (S2S).
- The Land-Sea continuum transport system

e.g., the particle could be a TRACER!!!!

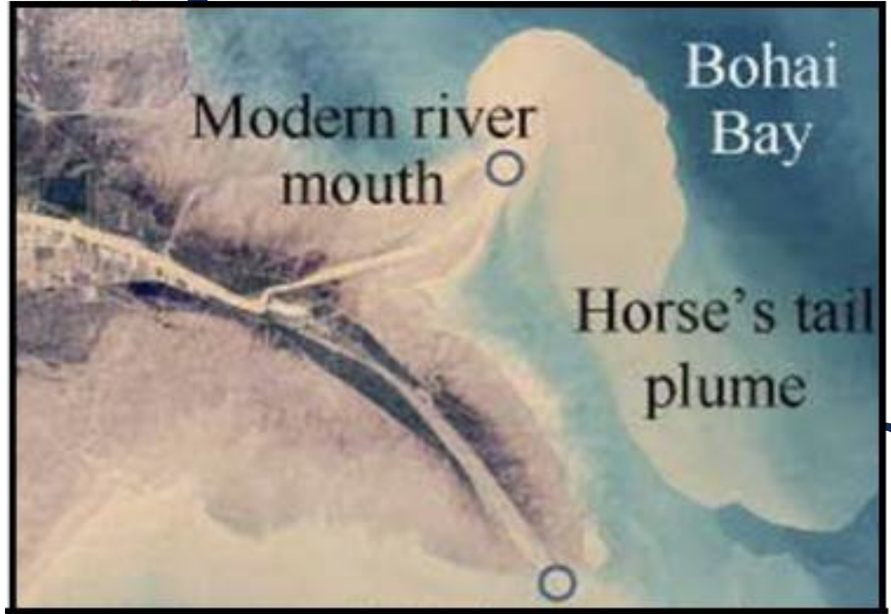


Allen, 2017



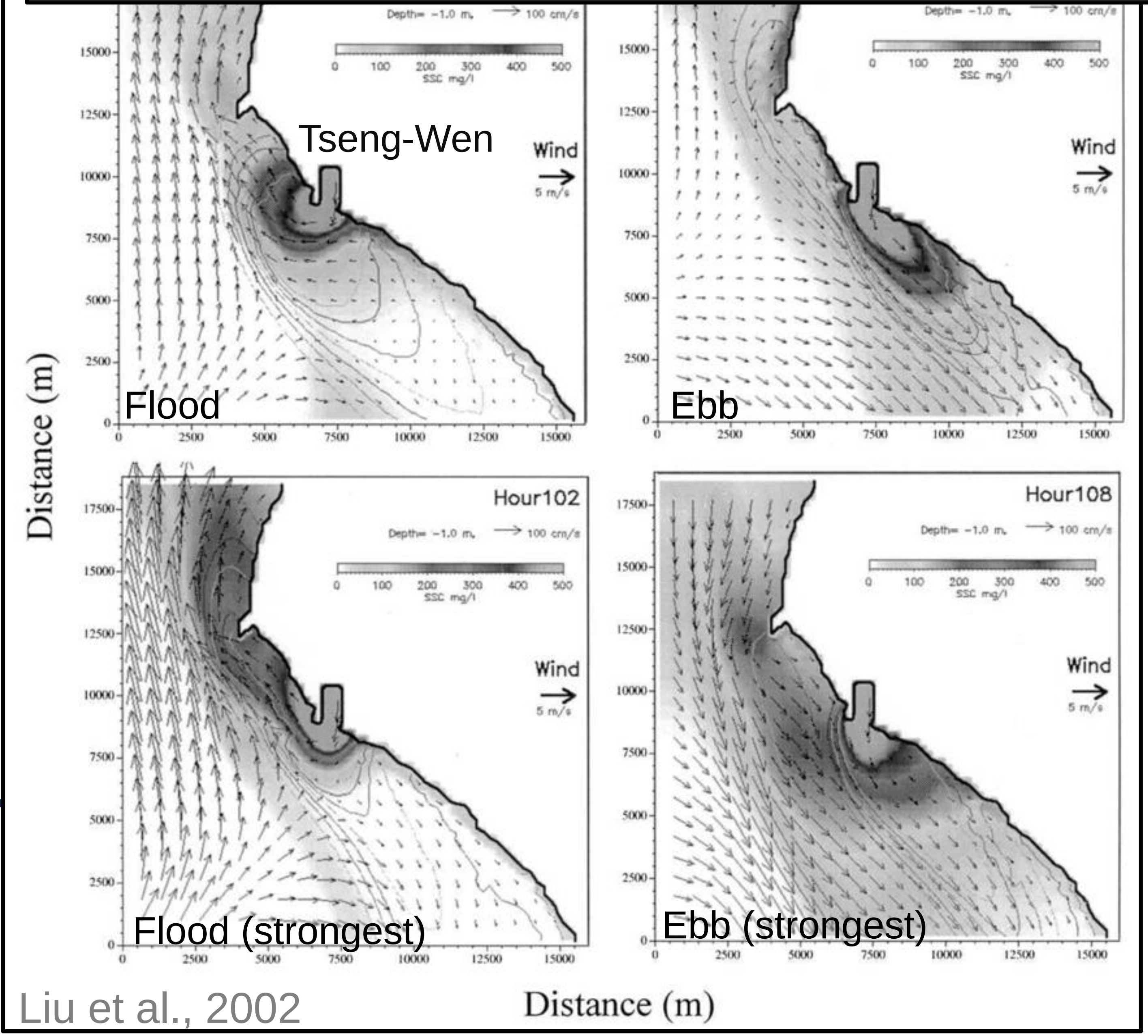
I. Supply via plumes

Shanmugam, 2019

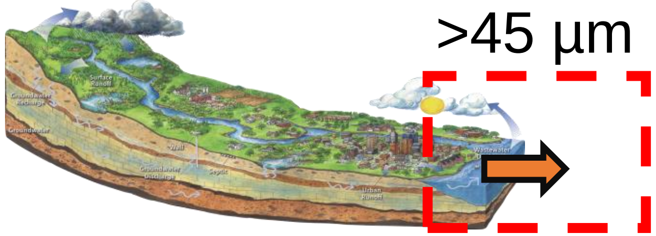


Yellow River Plume

Coriolis force, wind, tide, coastal current, etc.



Liu et al., 2002



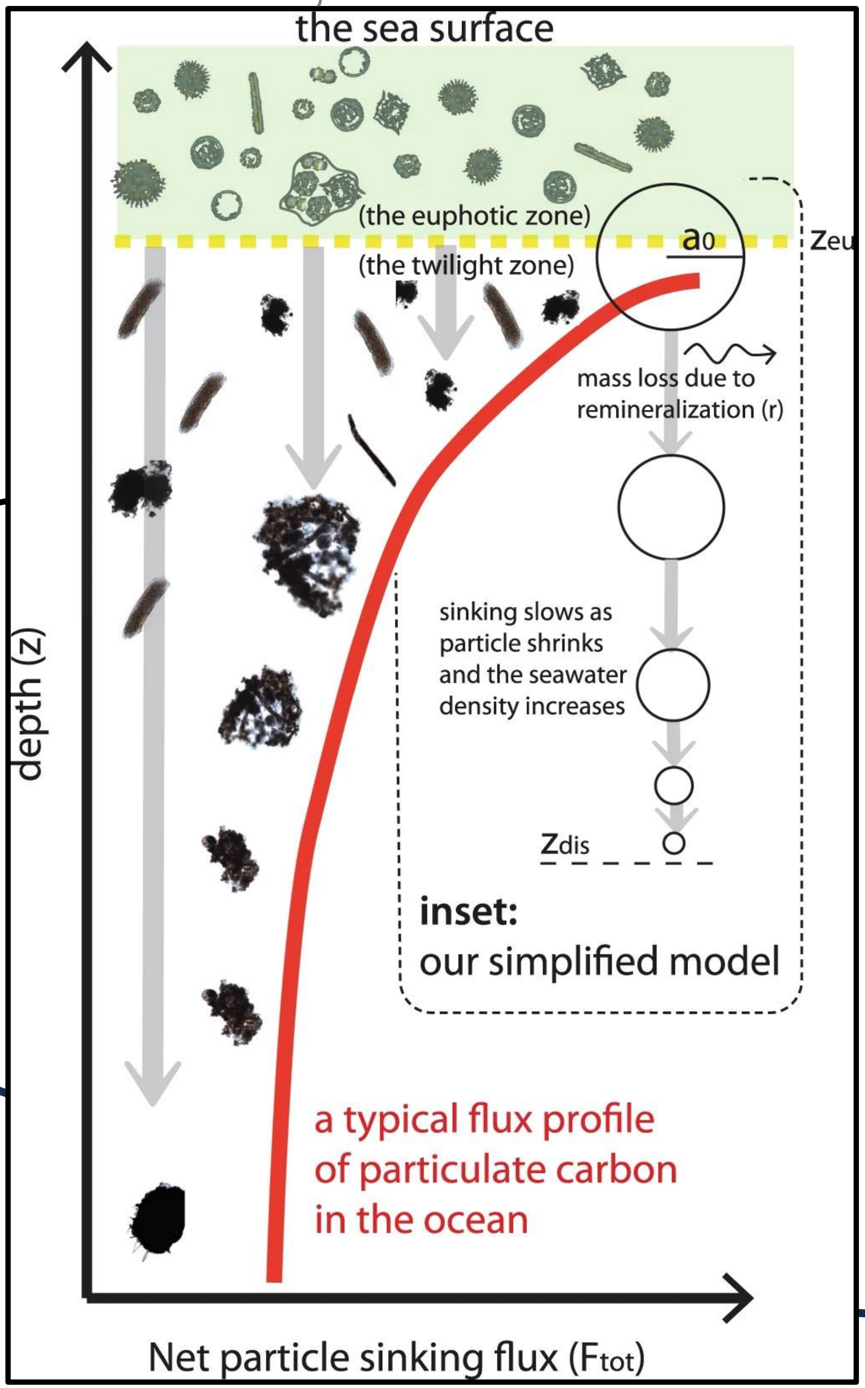
>45 μm

I. Supply via plumes

Land

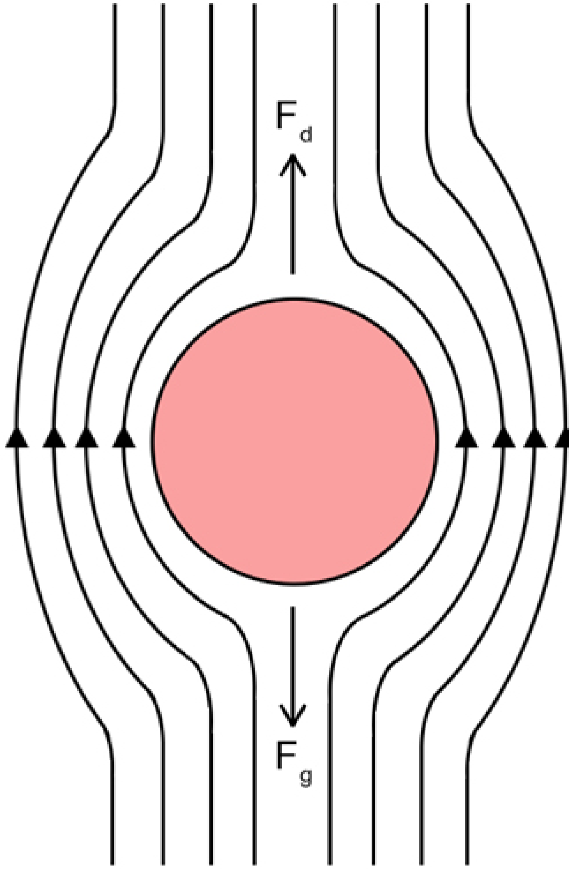
II. Initial Deposition

Omand et al., 2020

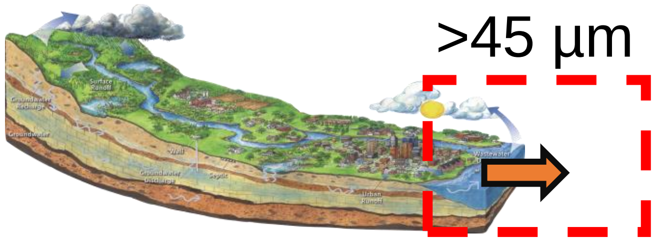


Stokes Law

$$v_t = \frac{2}{9}\frac{(\rho_s - \rho_f)gr^2}{\eta}$$



Wright and Nittrouer, 1995



>45 µm

I. Supply via plumes

II. Initial Deposi

Land

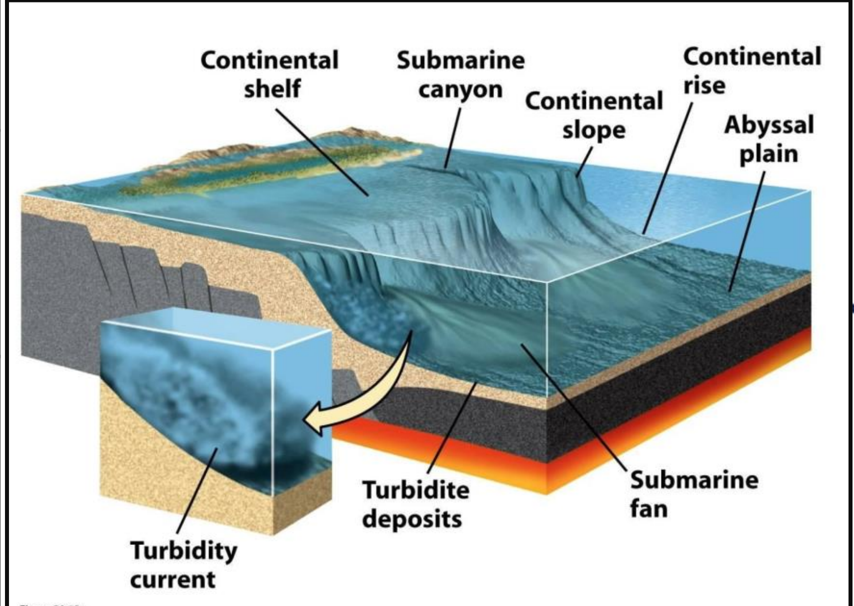
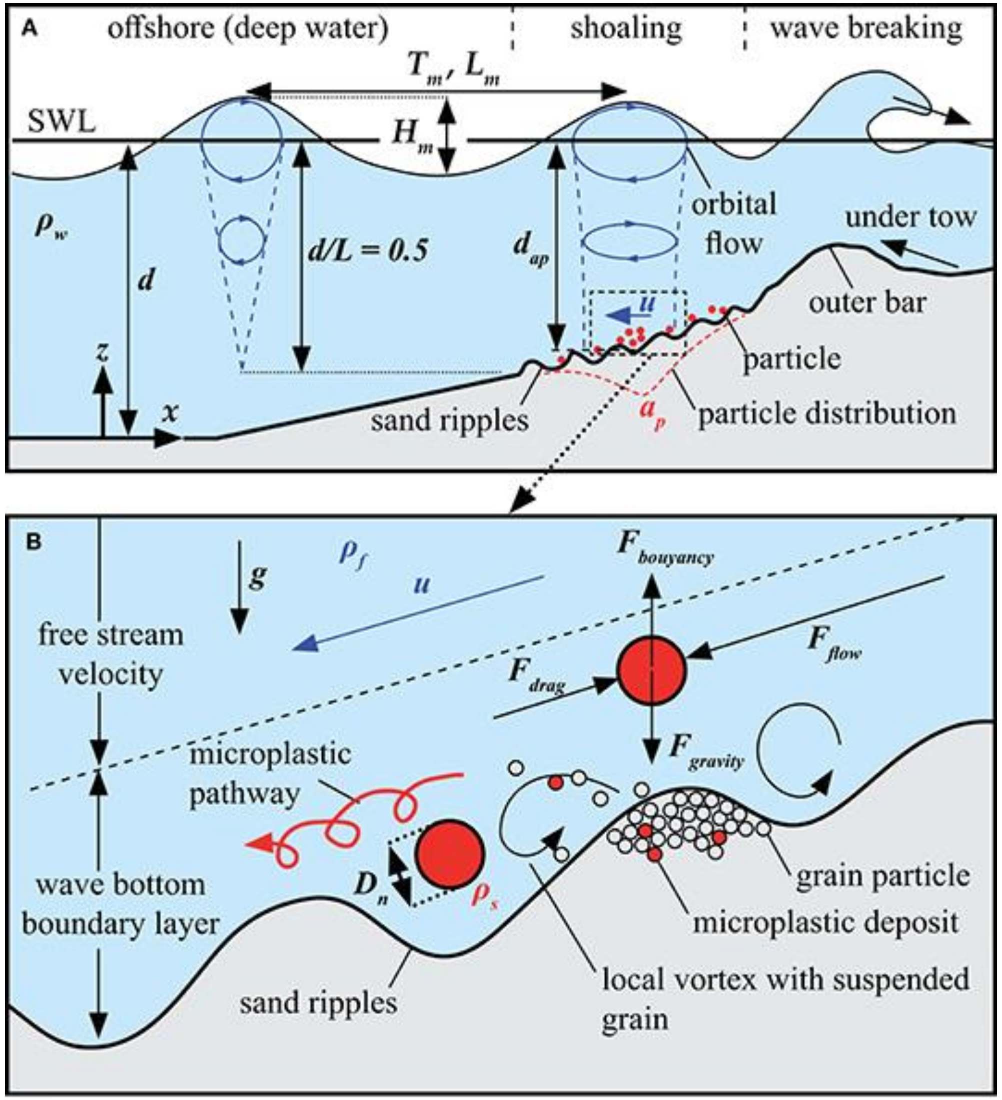


Figure 20.19a
Understanding Earth, Sixth Edition
© 2010 W. H. Freeman and Company

III-I. Resuspension



Kerpen et al., 2020

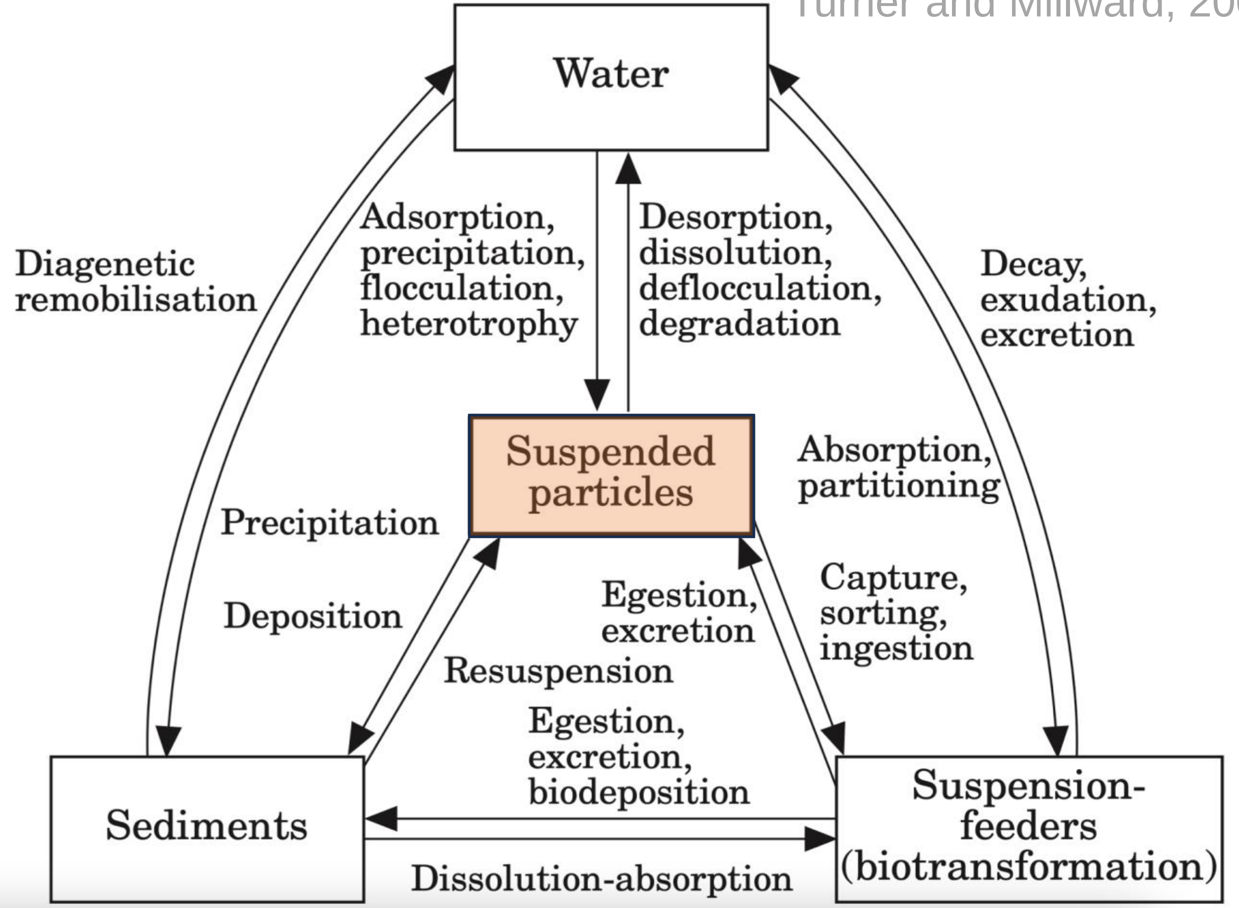
III-II. Slope failure processes

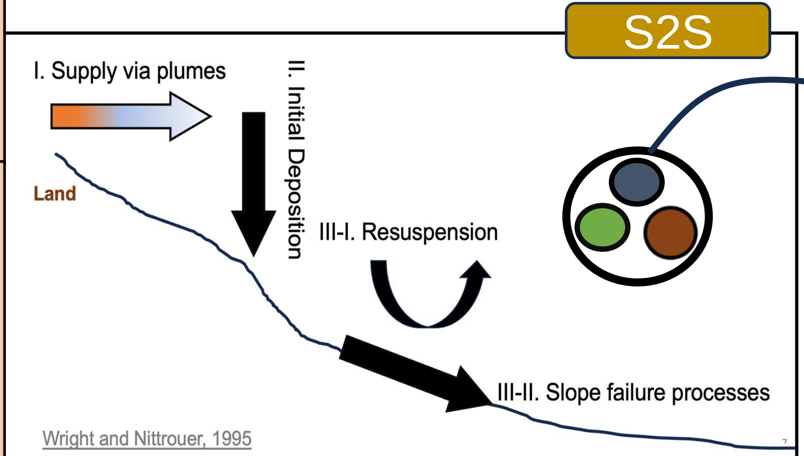
- Different types of particles
- Complicated couplings

Challenging in the S2S

- How & What?

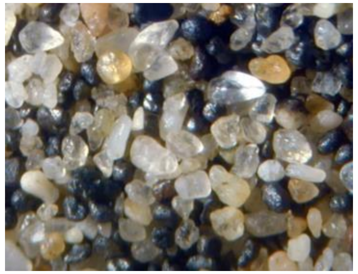
Turner and Millward, 2002





Biogenic

Lithogenous



Anthropogenic

Started in 1999…

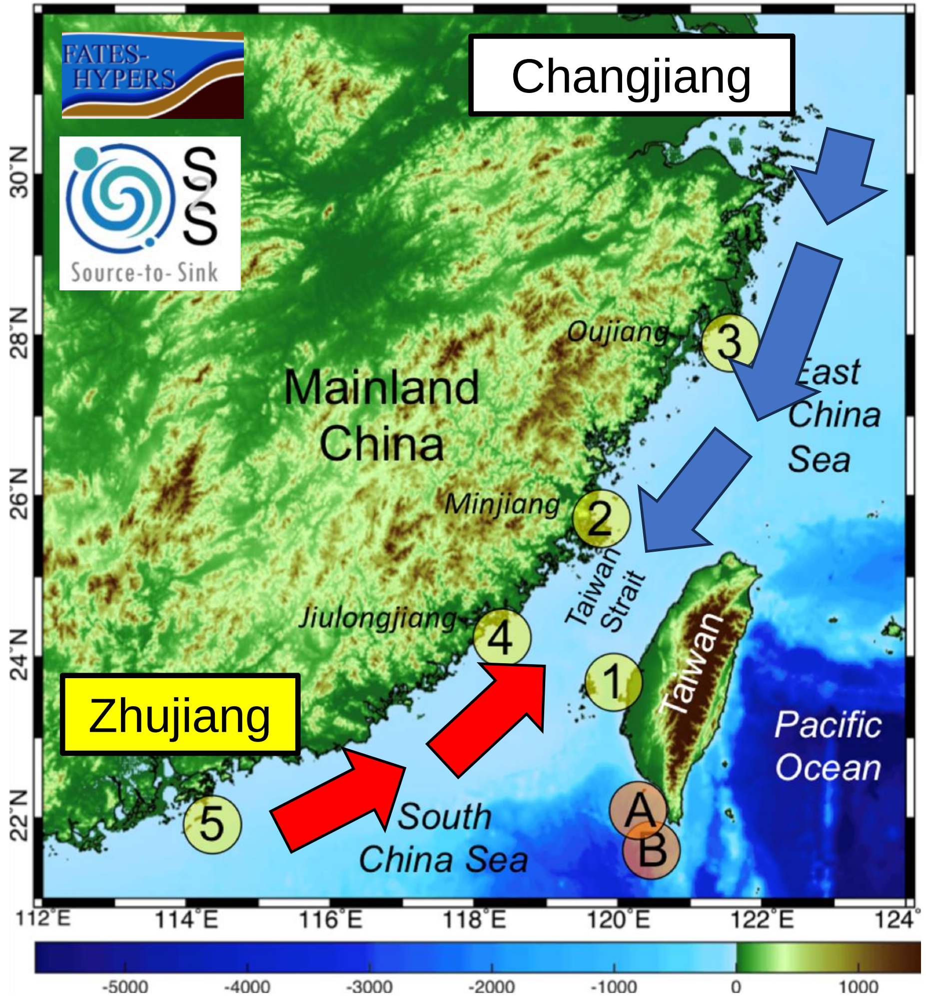
James T. Liu

FATES-HYPERS Sites

- A Gaoping Canyon
- B Fangliao Canyon

TS-S2S Sites

1. Zhuoshui R.
2. Minjiang R.
3. Zhe-Min Mud Belt
4. Jiulongjiang R.
5. Zhujiang R. (Pearl River)



Marine Geology
Volume 380, 1 October 2016, Pages 219-230

River plume induced variability of suspended particle characteristics

Jay Lee [a], James T. Liu [a], Chin-Chan Hung [a], Saulwood Lin [b], Xiaoqin Du [a]

Marine Geology
Volume 271, Issues 1–2, 15 May 2010, Pages 119-130

Quantifying tidal signatures of the benthic nepheloid layer in Gaoping Submarine Canyon in Southern Taiwan

James T. Liu [a], Yu Huai Wang [b], I-Huan Lee [c], Ray T. Hsu [d]

Article | Open access | Published: 09 March 2018

A comprehensive sediment dynamics study of a major mud belt system on the inner shelf along an energetic coast

James T. Liu, Ray T. Hsu, Rick J. Yang, Ya Ping Wang, Hui Wu, Xiaoqin Du, Anchun Li, Steven C. Chien, Jay Lee, Shouye Yang, Jianrong Zhu, Chih-Chieh Su, Yi Chang & Chih-An Huh

Scientific Reports 8, Article number: 4229 (2018) | Cite this article

Marine Geology
...lume 442, December 2021, 106657

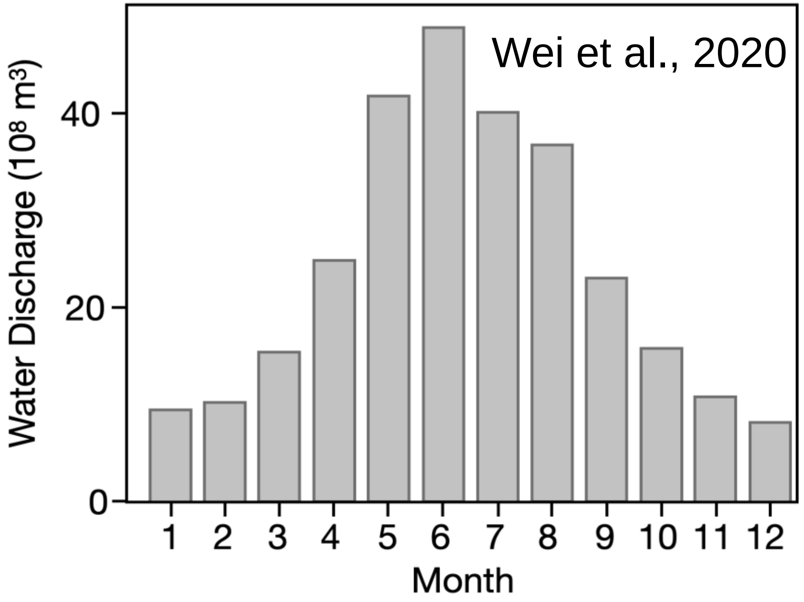
Research Paper

Coupling between physical processes and biogeochemistry of suspended particles over the inner shelf mud in the East China Sea

James T. Liu [a], Jay Lee [a], Rick J. Yang [a], Xiaoqin Du [b], Anchun Li [c], Yu-Shih Lin [a], Chih-Chieh Su [d], Shuqin Tao [e]

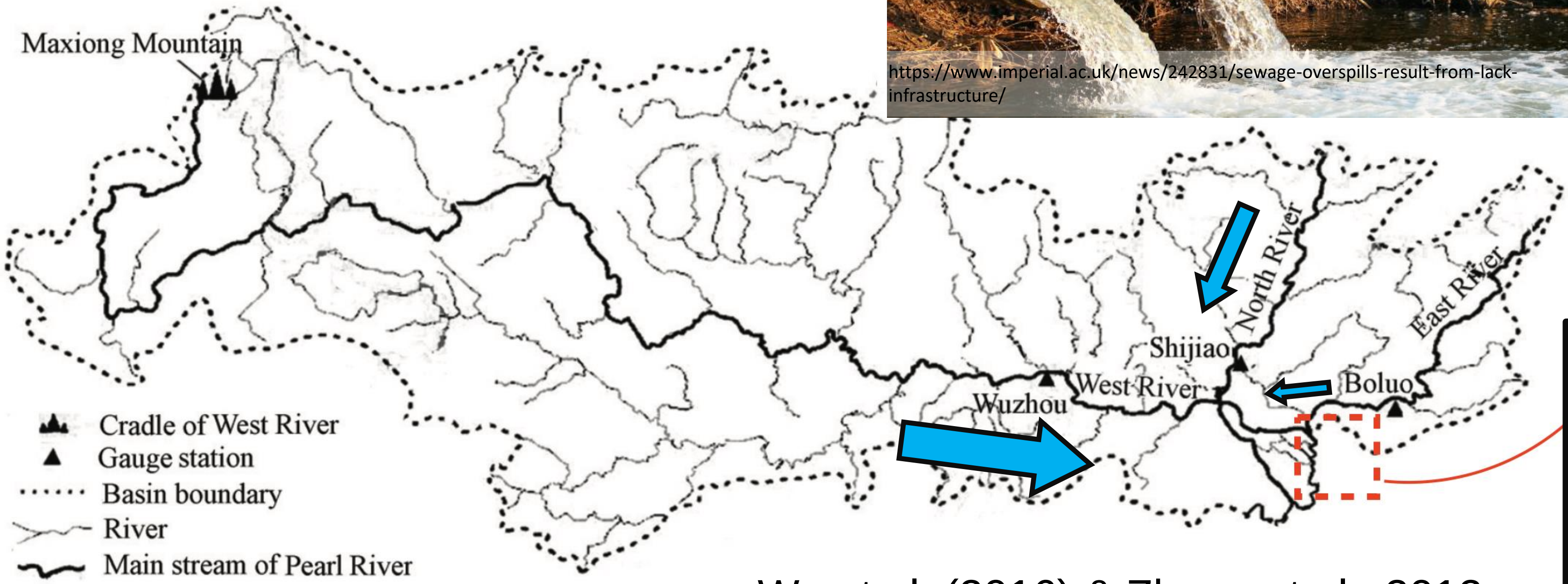
⋮

• Zhujiang River (Pearl River)



- Len: 2,214 km
- RD: 10^4 m^3/s
- SL: 88 Mt/y
- W (75 %)
  N (15.7 %)
  E (8.8 %)

Len: length
RD: River Discharge
SL: Sediment Load



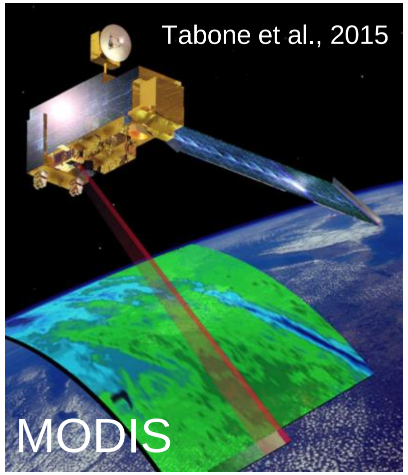
Wu et al. (2016) & Zhang et al., 2012

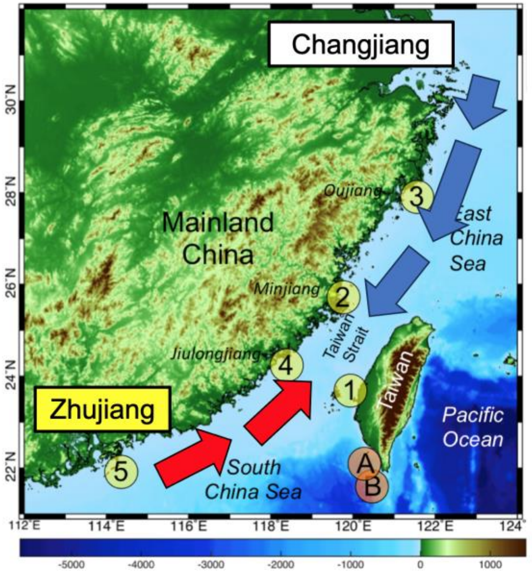
- C_3 plants
- High N/P ratio
- From May to July

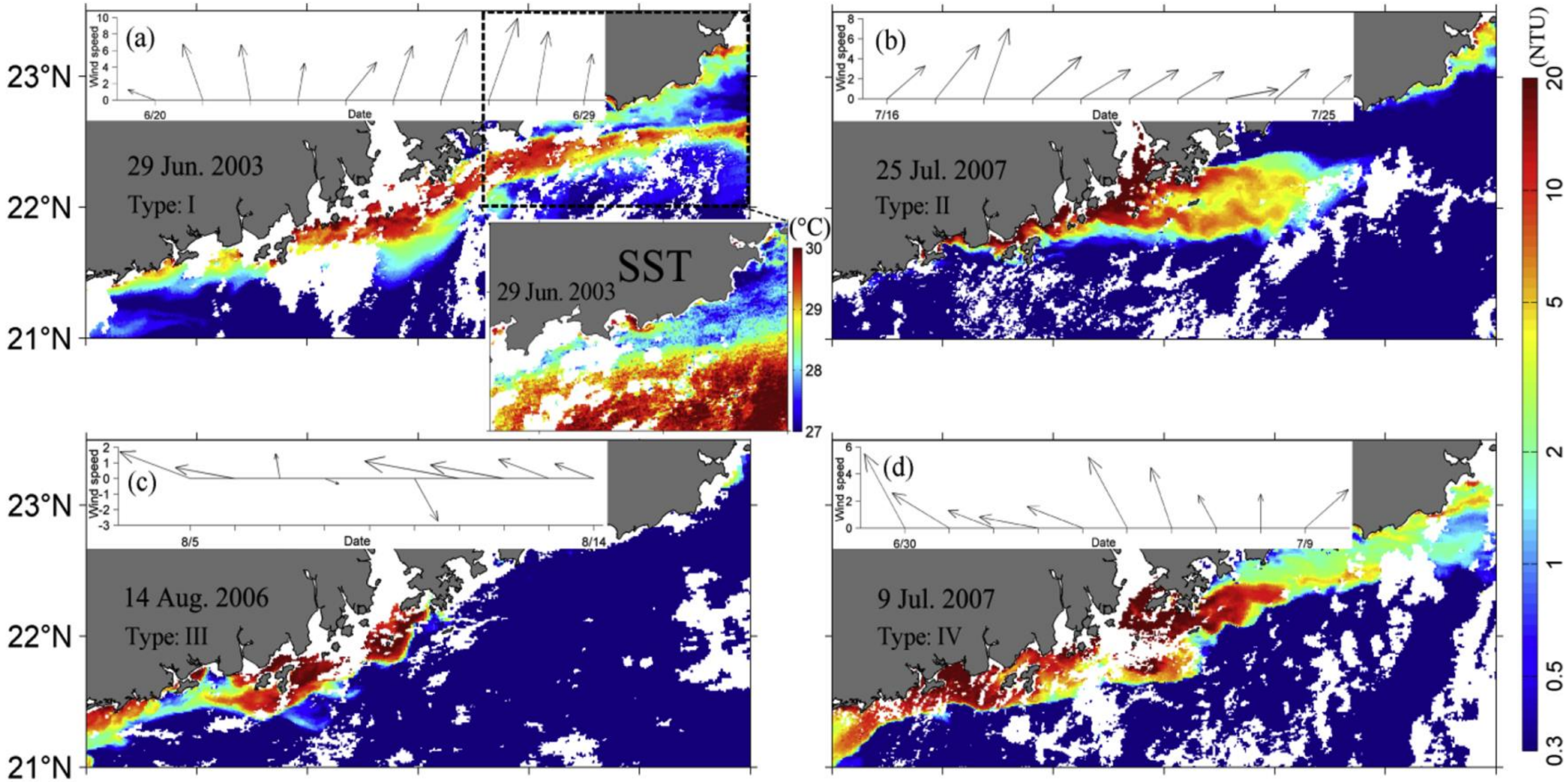
Estuarine, Coastal and Shelf Science
Volume 194, 15 July 2017, Pages 252-262

Dispersal of the Pearl River plume over continental shelf in summer

Zhaoyun Chen [a b], Wenping Gong [a b], Huayang Cai [a b], Yunzhen Chen [a b], Heng Zhang [a b c]







Type

I: East Coastal Jet

II: East Offshore Spreading

III: West Alongshore Spreading

IV: Symmetrical Alongshore Spreading

V: Offshore Bulge Spreading

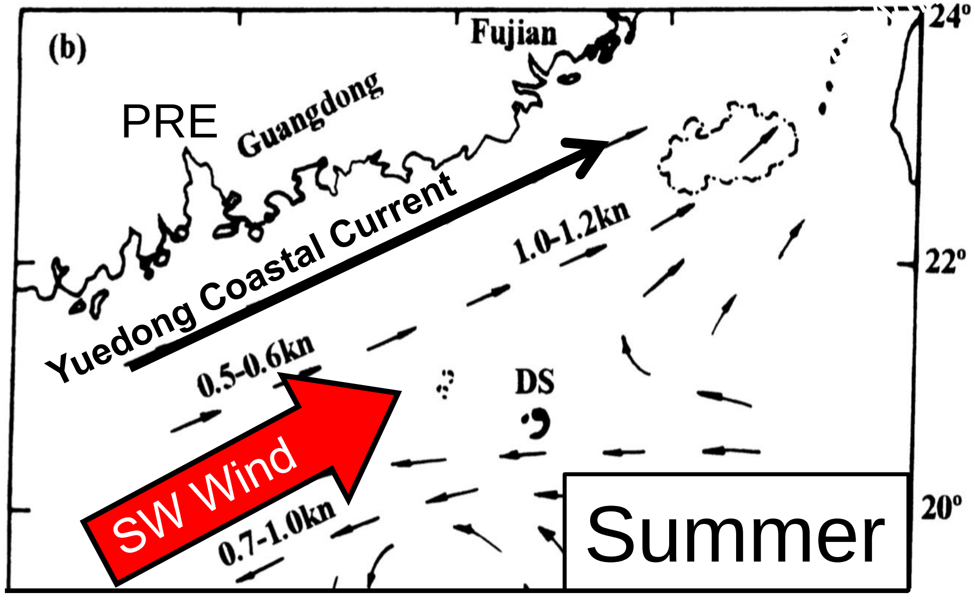
VI: East Isolated Patch

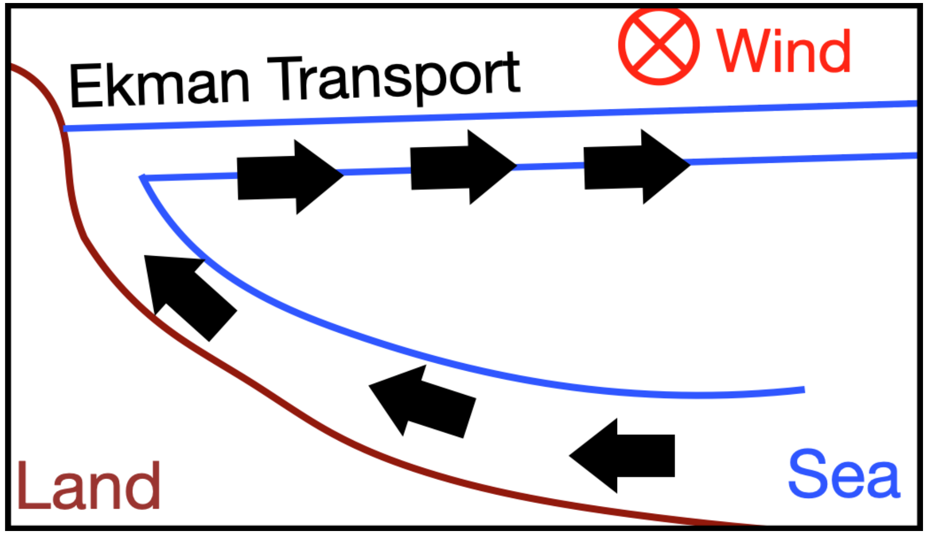
VII: East Offshore Branch

VIII: Offshore Filaments

- Wind-driven currents and upwellings

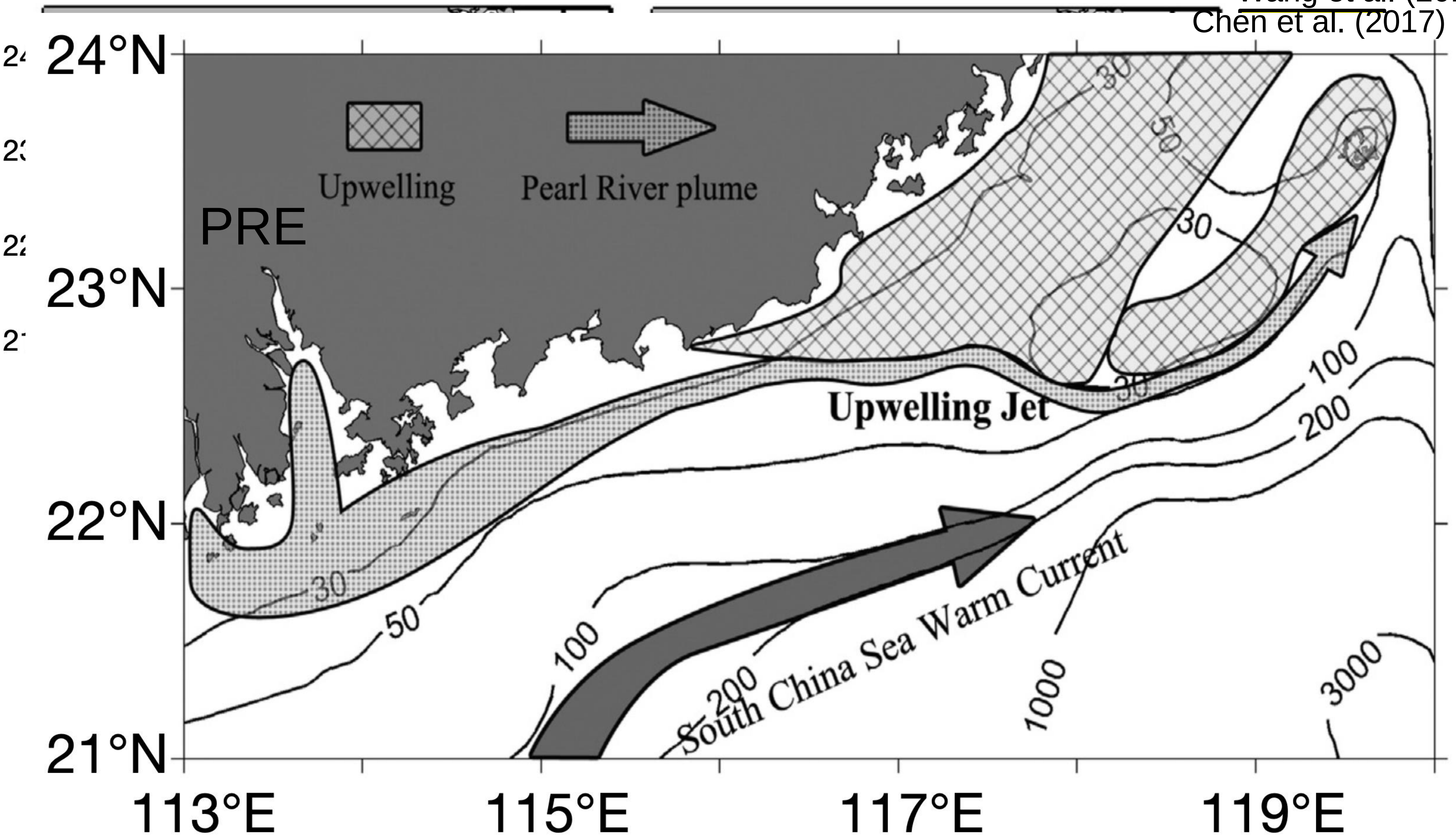
Hu et al. (2000)





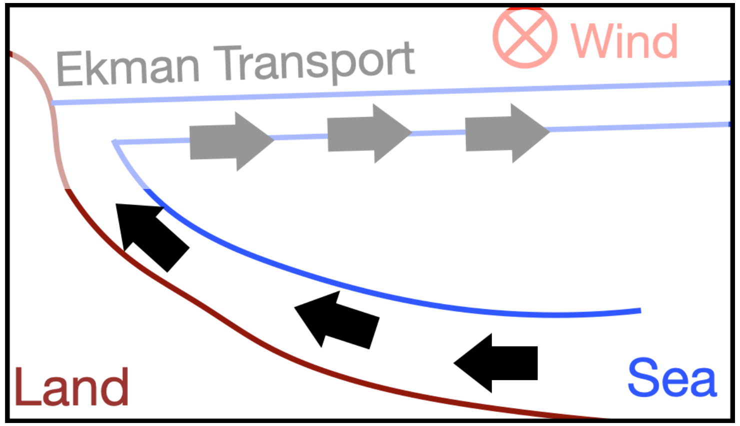
- Association between upwellings and currents

Wang et al. (2014)
Chen et al. (2017)

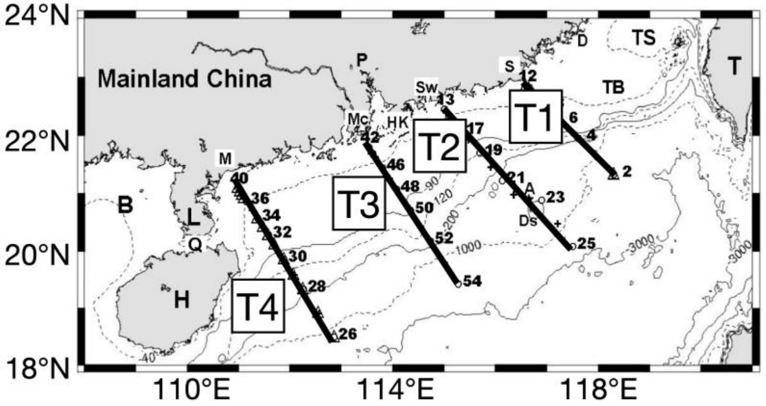


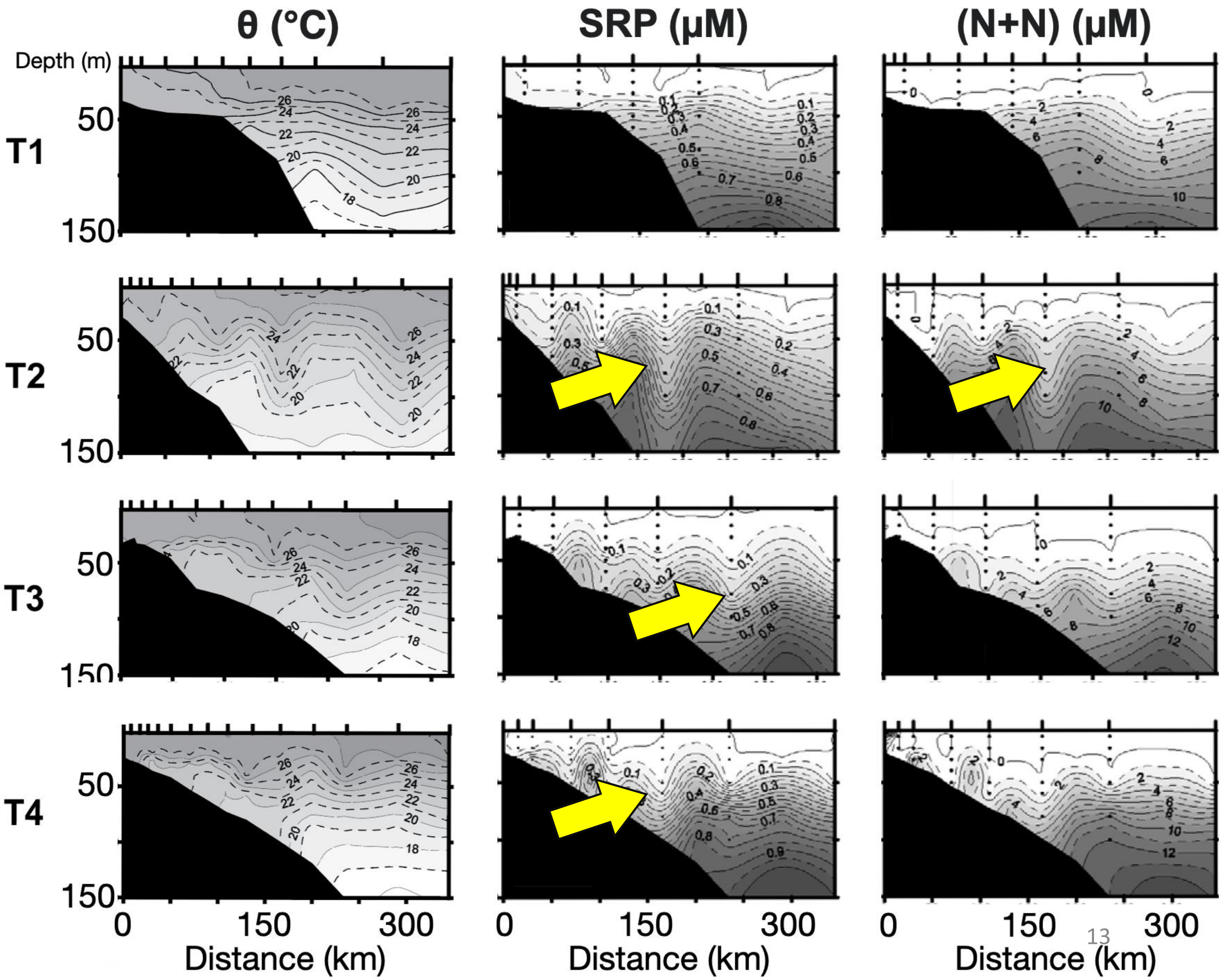
ind
/ wind

- Wind-driven upwelling (Lower water column)



Wong et al. (2015)

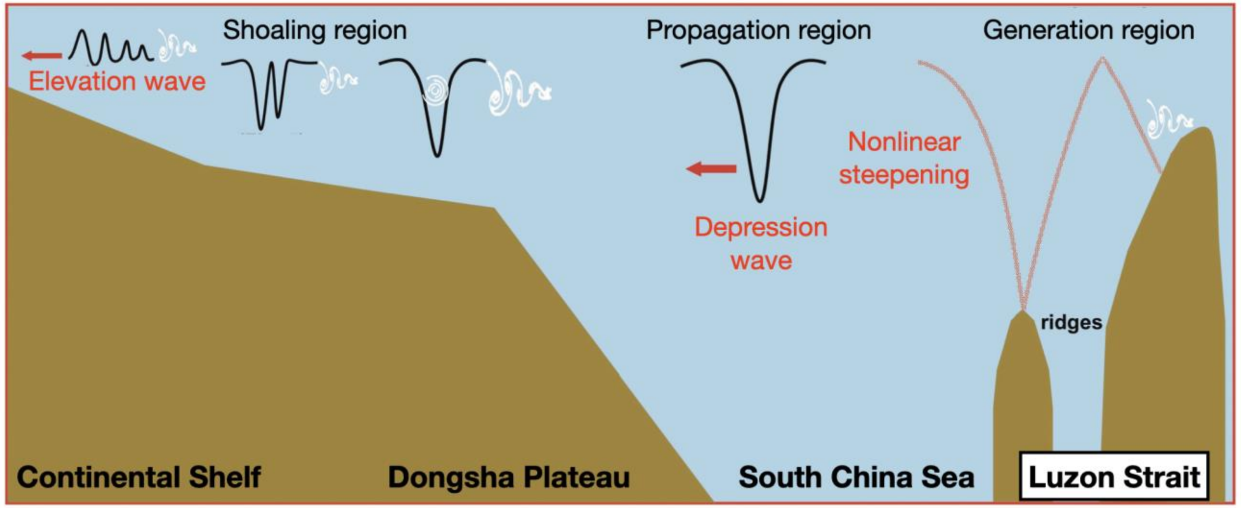


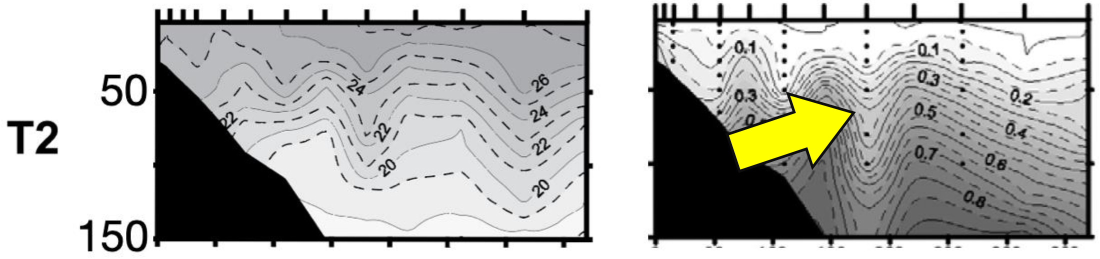


- Cold water mass
- High nutrients

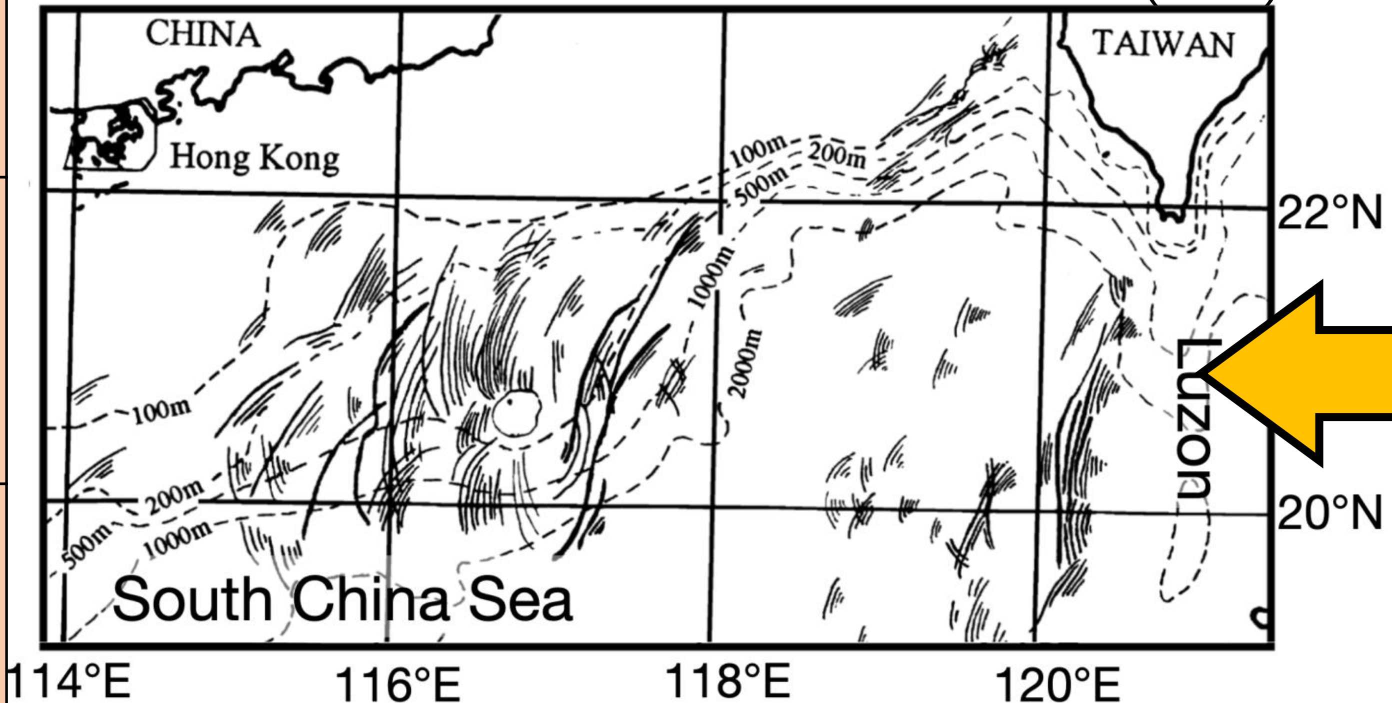
- Nonlinear internal waves (NIWs)

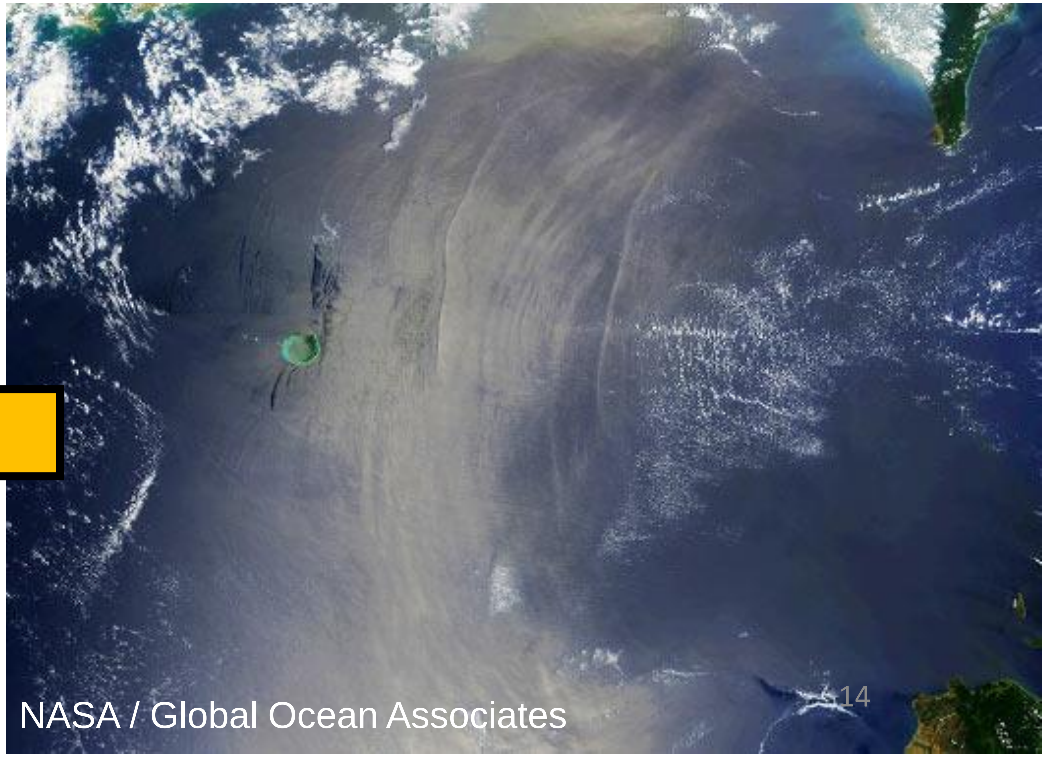
Wong et al. (2015)



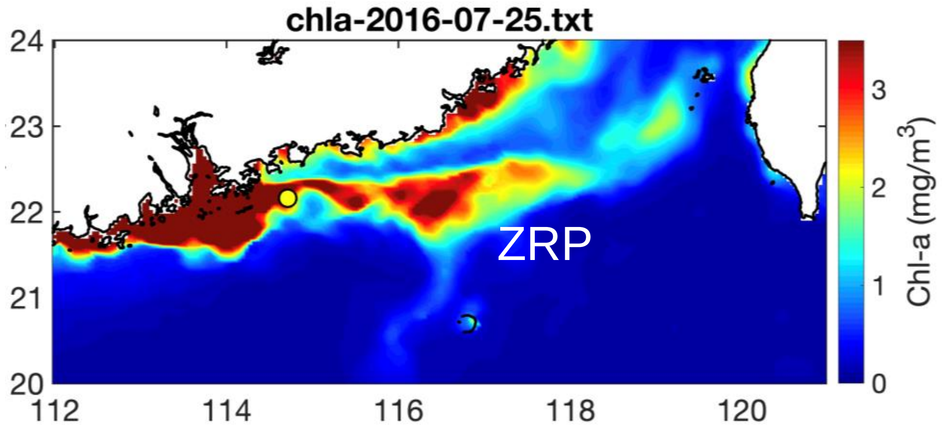


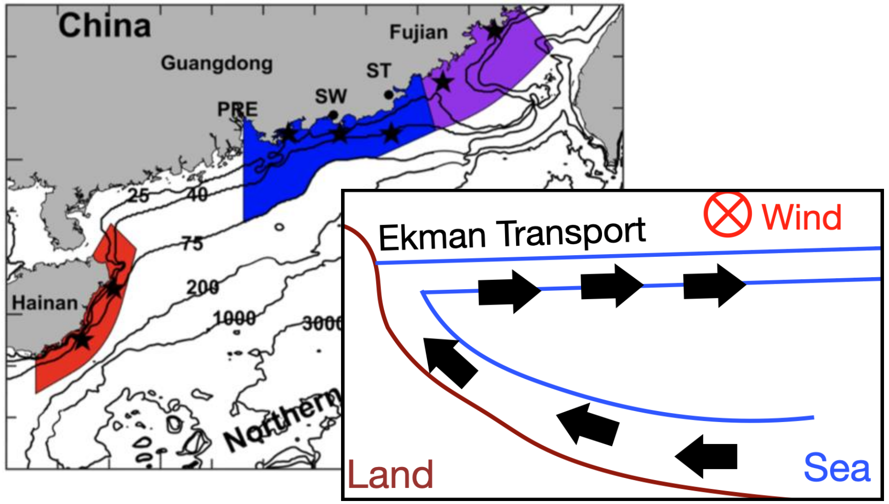
Hsu et al. (2000)

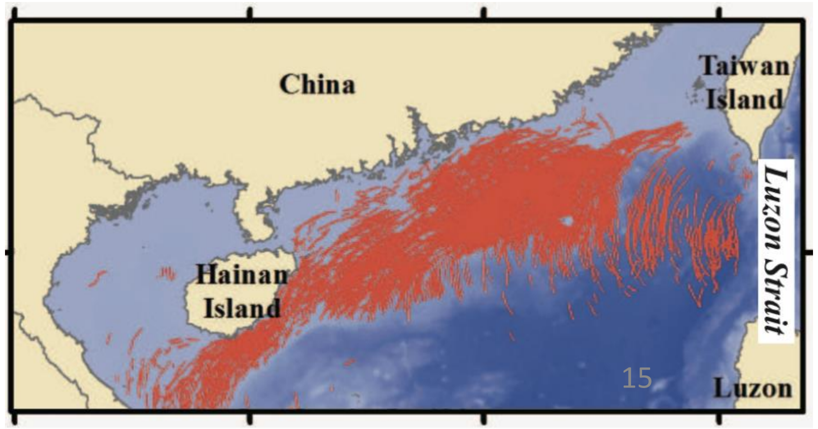




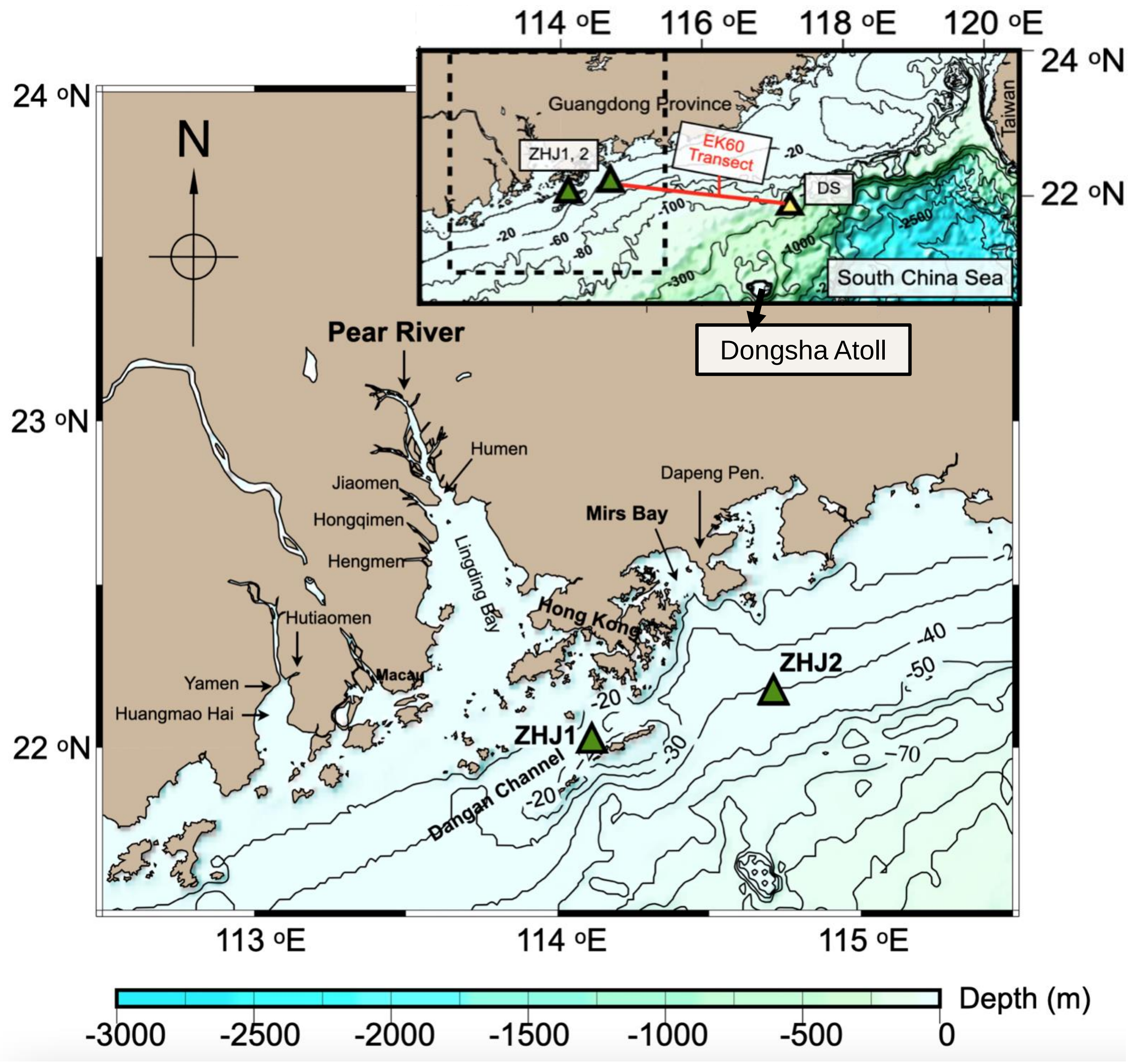
- Scientific Question & Hypotheses
  - ➢ What are the associated physical processes to transport those particles?
    - Wind-driven current?
    - Upwelling?
    - NIWs?
  - ➢ What are the SPs on the inner shelf?
    - Terrestrial or Marine sourced?
    - Physiochemical characteristics (e.g., size)?

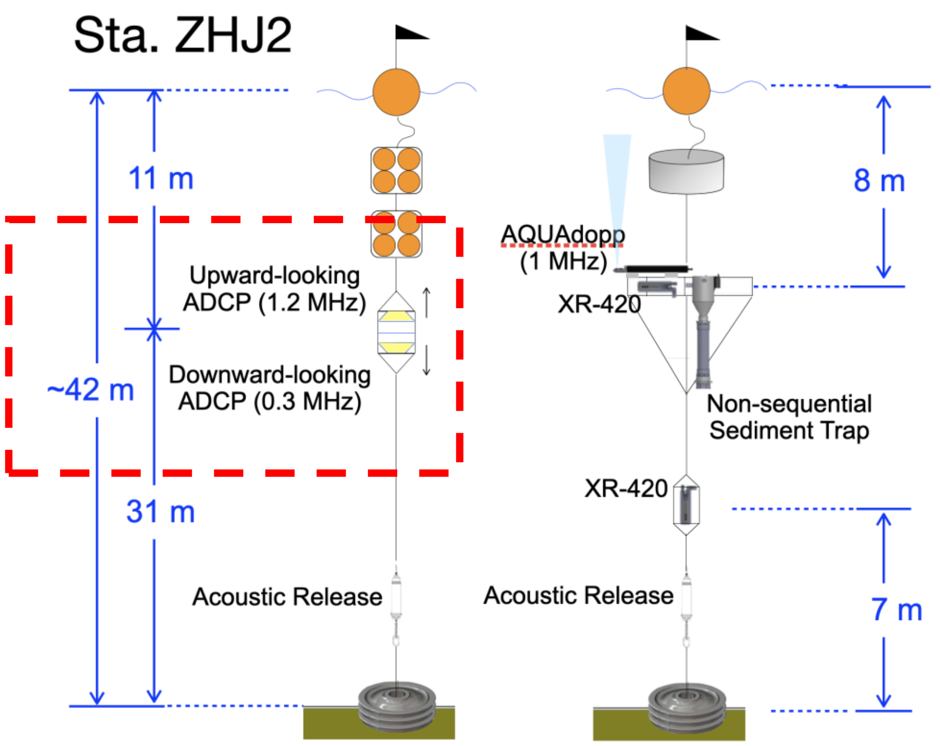






- Hydrodynamic Measurements



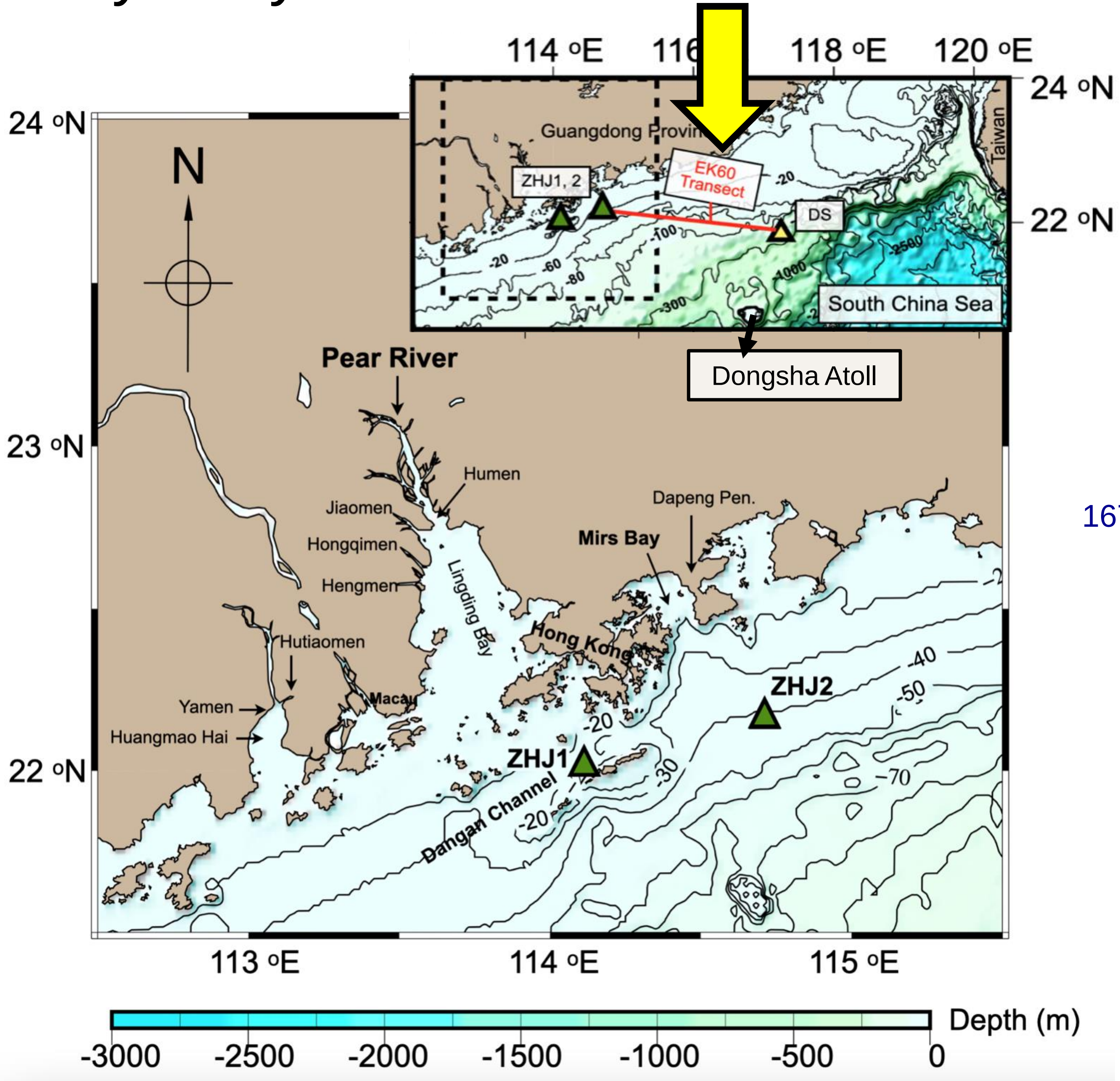


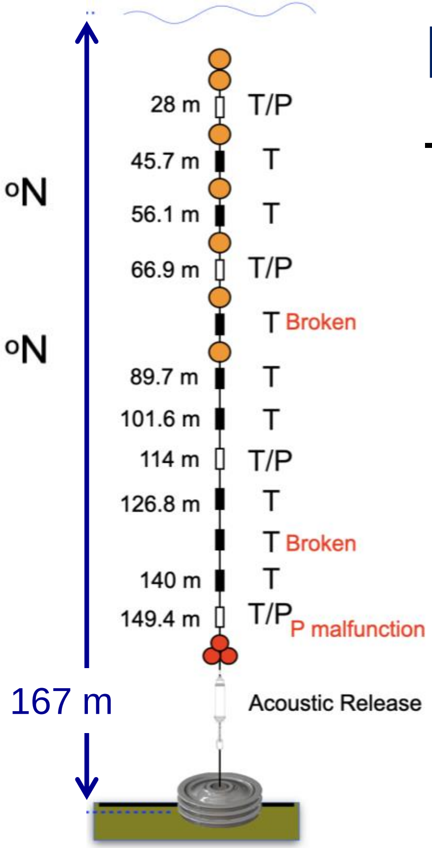
Flow Structure

- Shipboard-ADCP (10 min; ZHJ1)
  - 75 kHz
  - BD: 16.5 m
  - BS: 8 m
- Mooring-ADCPs (10 min; ZHJ2)
  - 300 & 1200 kHz
  - BD: 0.8 & 3.3 m
  - BS: 0.25 & 1 m

*BD: Blank Distance
*BS: Bins Size

- Hydrodynamic Measurements

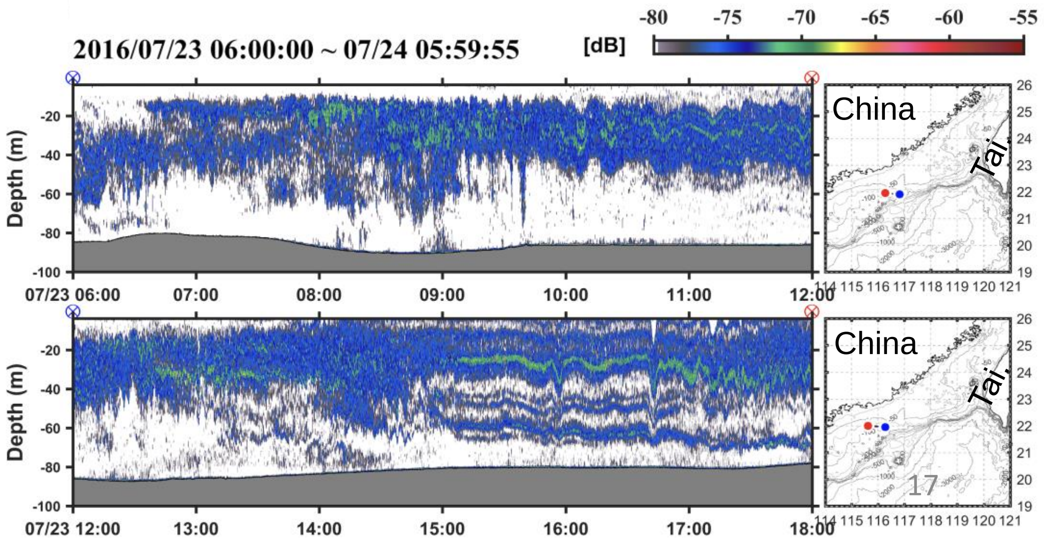




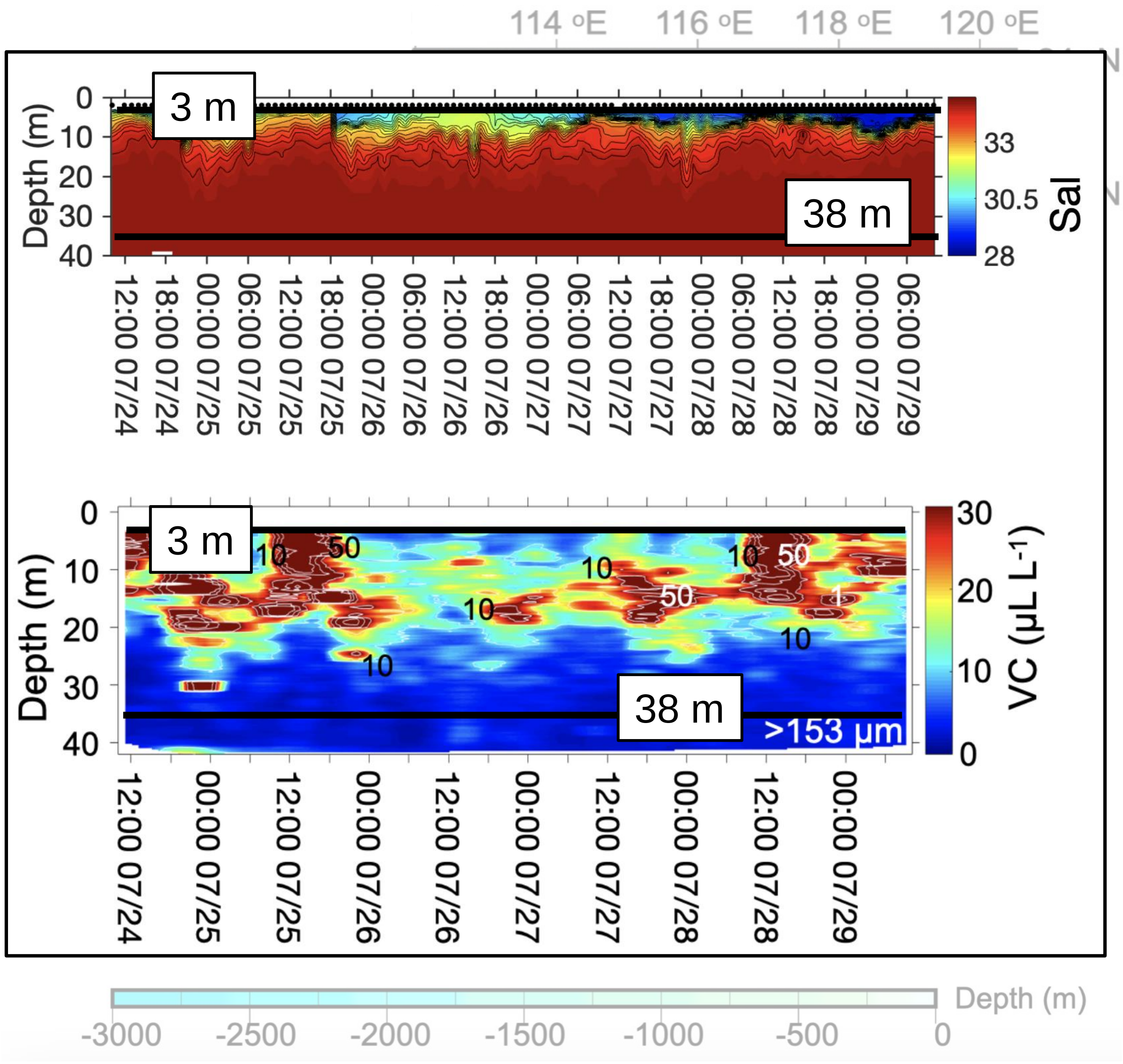
NIWs Observation

- Minilog (6 mins; DS)
  - 8 8-bit loggers (T)
  - 4 DST milli-TDs (T&D)
  - 06/03 - 07/23 in 2016
- EK60 transect (1 sec)
  - From DS to ZHJ2
  - Shipboard EK60
  - 38 kHz
  - BS: 0.4 m

*BS: Bins Size



- Hydrographic Measurements

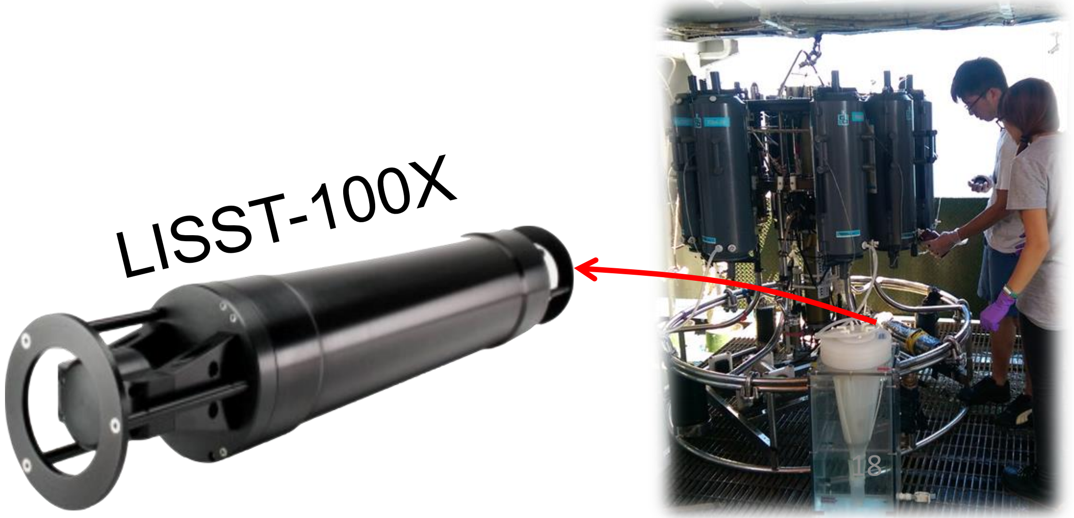


CTD Profiling (hourly)

- Sal, Temp., Turb., Fluor.
- SF: 0.04 sec *SF: Sampling Frequency
- Lowering rate: <0.5 m/s
- Averaged to 0.2 m/record

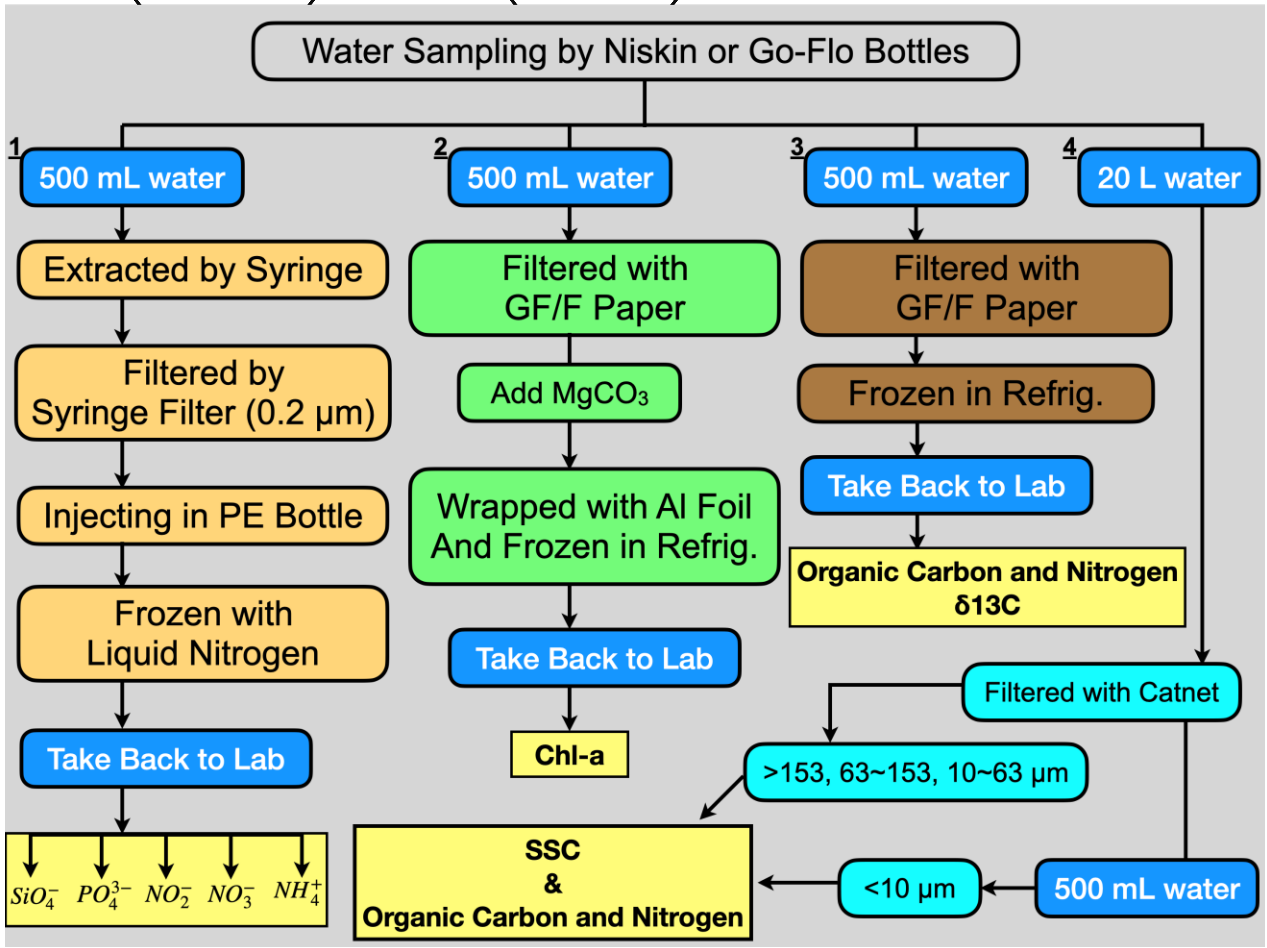
LISST Profiling

- Volume concentration
- 32 size groups from 2.5-500 μm
- Classified into 63, 63-153, >153 μm



• Water & Particle Sampling

*3 m (Surface) & 38 m (Bottom)



Nutrients

Prof. C.-T. A. Chen's lab

POM

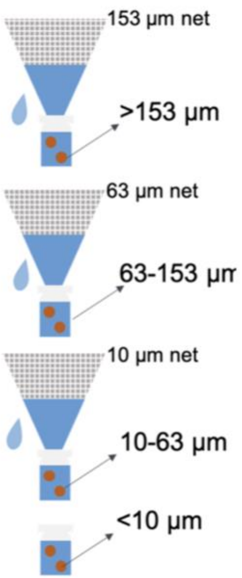
Prof. Y.-S. Lin's lab

Water Mass Properties

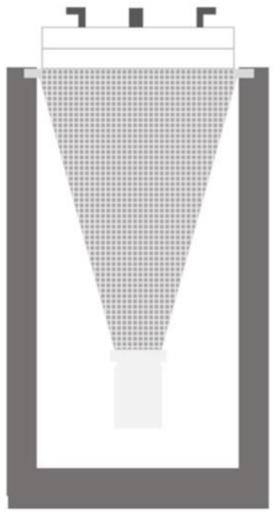
- SiO_4, PO_3, NO_2, NO_3
- SF: 3 hours *SF: Sampling Frequency

Particle Characteristics

- Chl-a, SSC, POC, PN, $\delta^{13}C$
- SF: 3 hours *SF: Sampling Frequency
- SSC (63, 63-153, >153 µm)



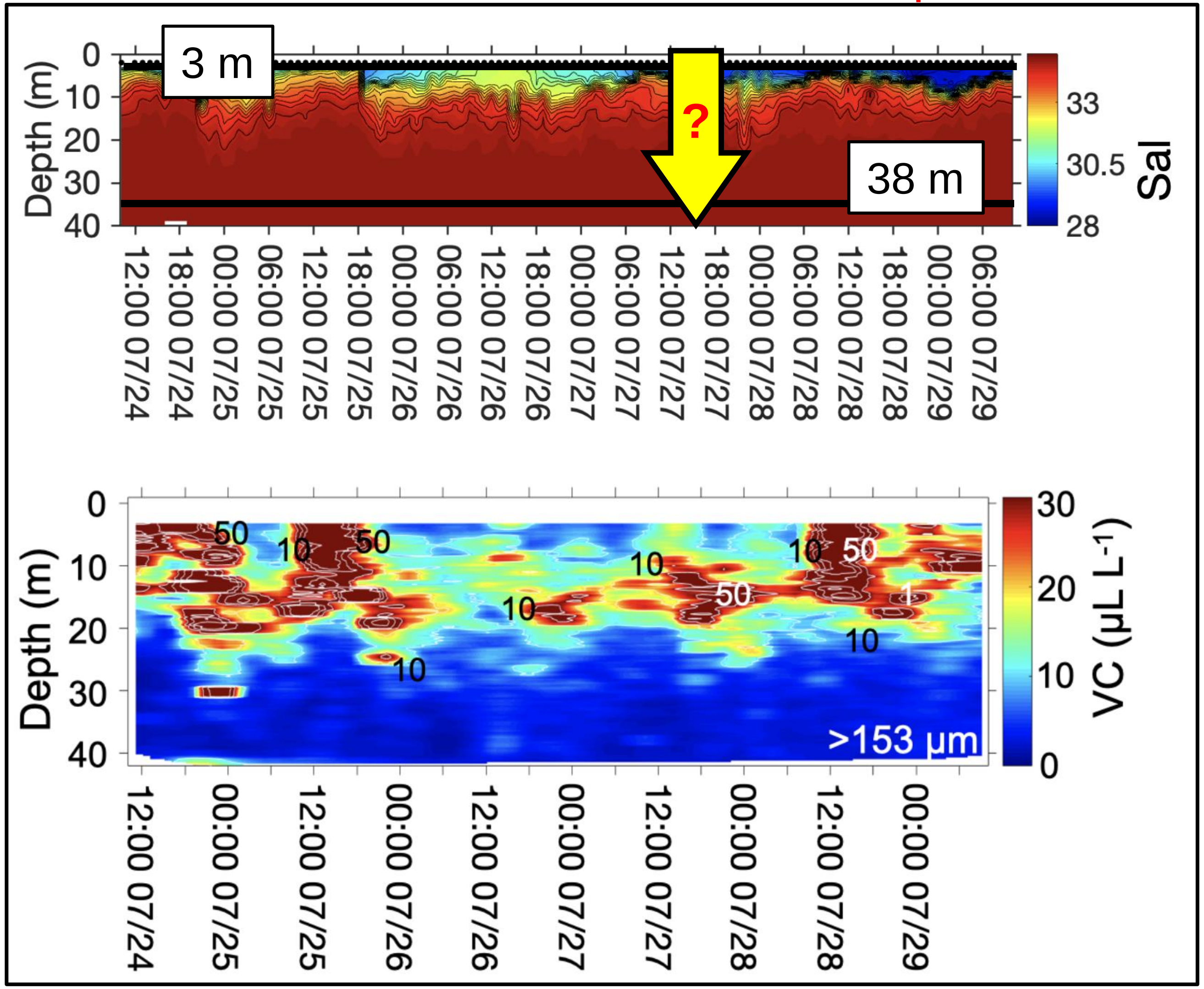
Catnet



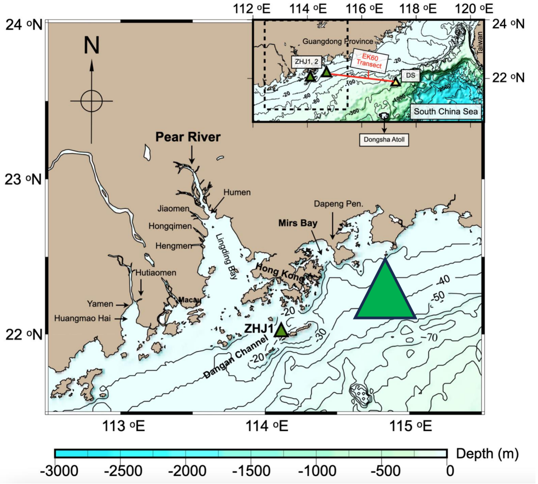
20 L Niskin

- Settling Particles (Linking surface and bottom)

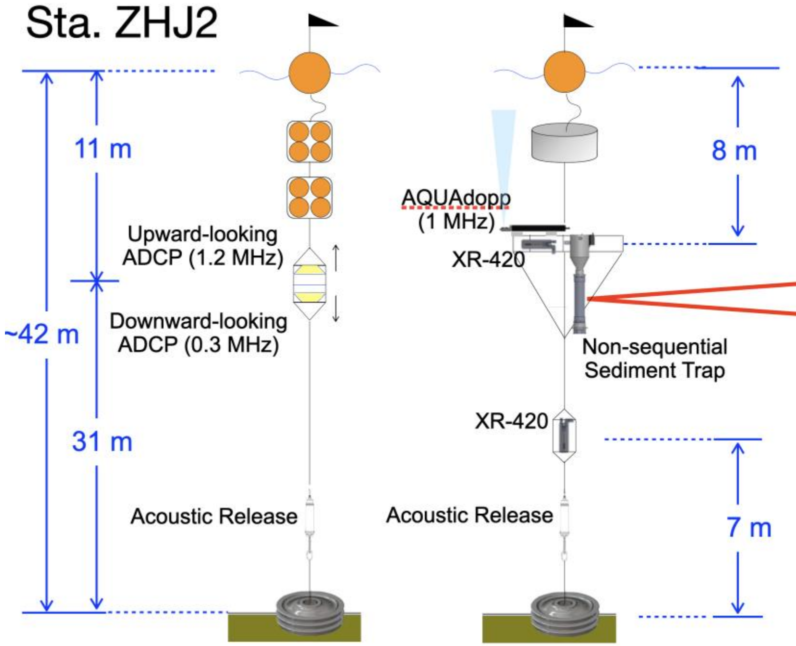
Assumed the vertical transport is 0!!!



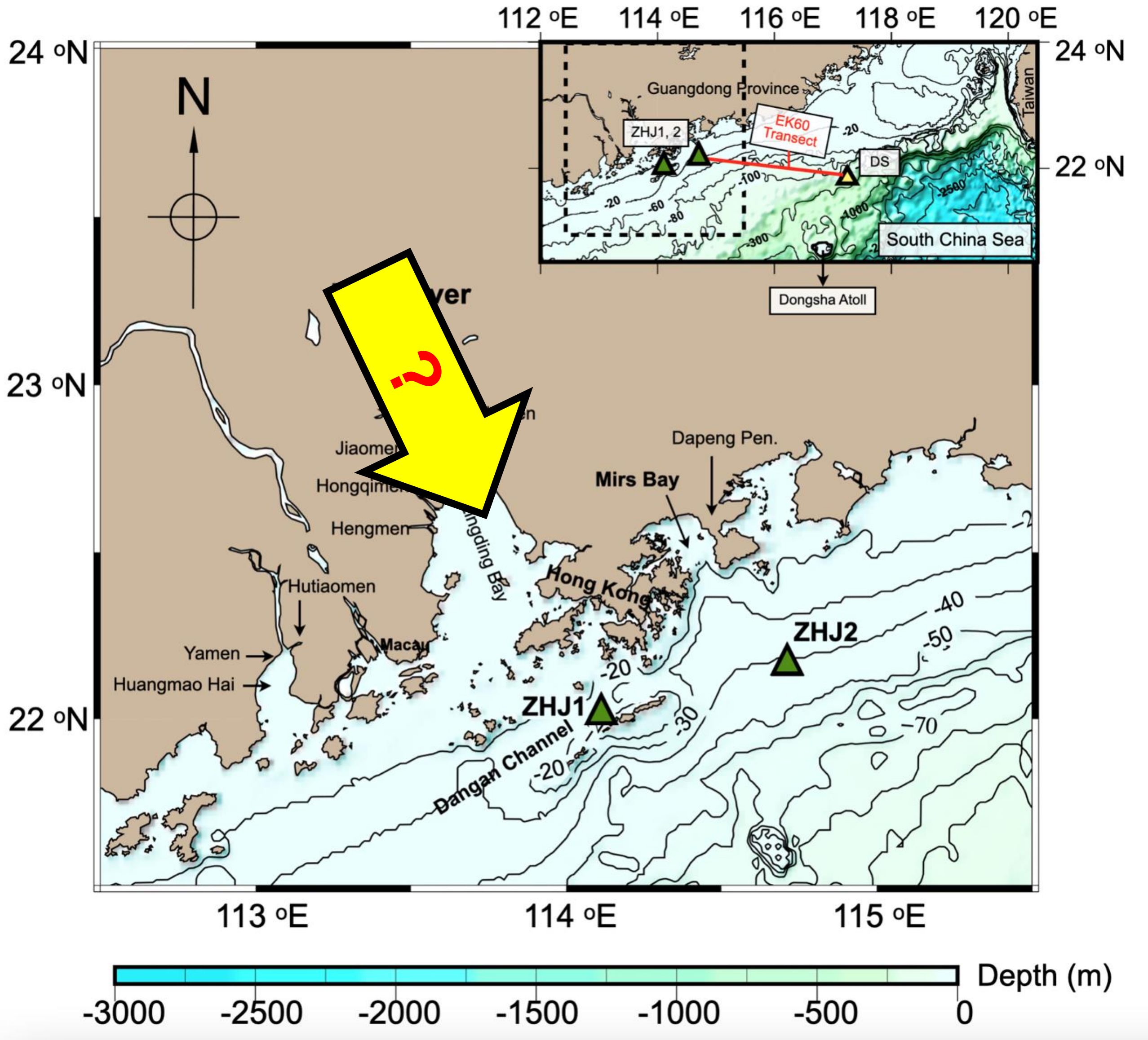
- USGS-type sediment Trap

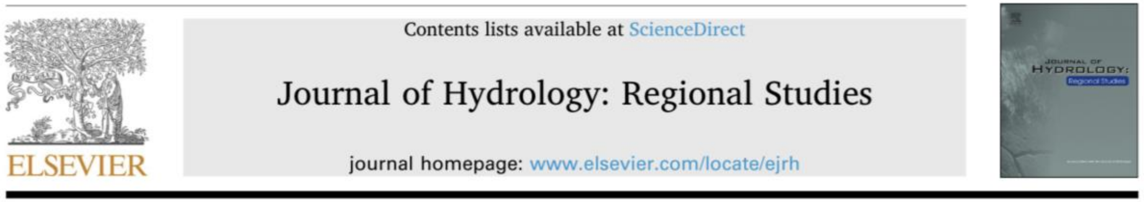


Empty!!!



- River Discharge (How much?)



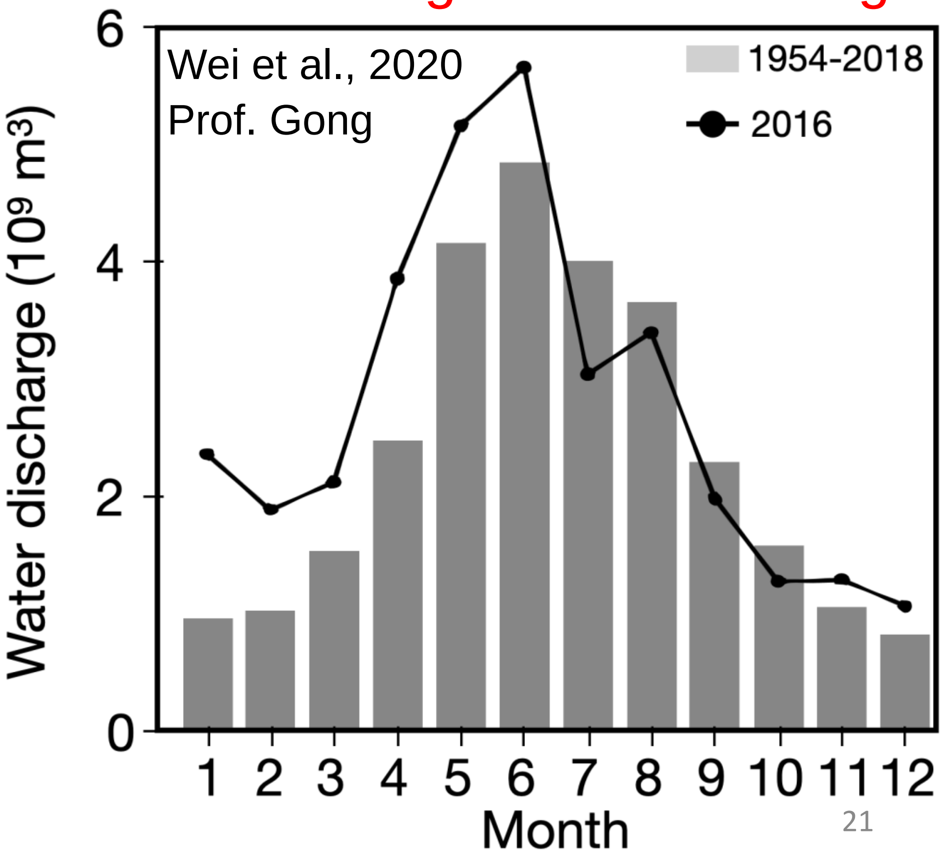


Contents lists available at ScienceDirect
ELSEVIER
Journal of Hydrology: Regional Studies
journal homepage: www.elsevier.com/locate/ejrh

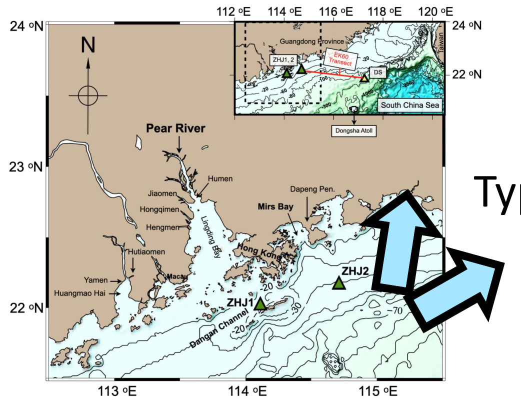
Influence factors and mechanisms of 2015–2016 extreme flood in Pearl River Basin based on the WSDI from GRACE

Lin Zhang [a], Yunzhong Shen [a,*], Qiujie Chen [a], Fengwei Wang [b]

High River Discharge!

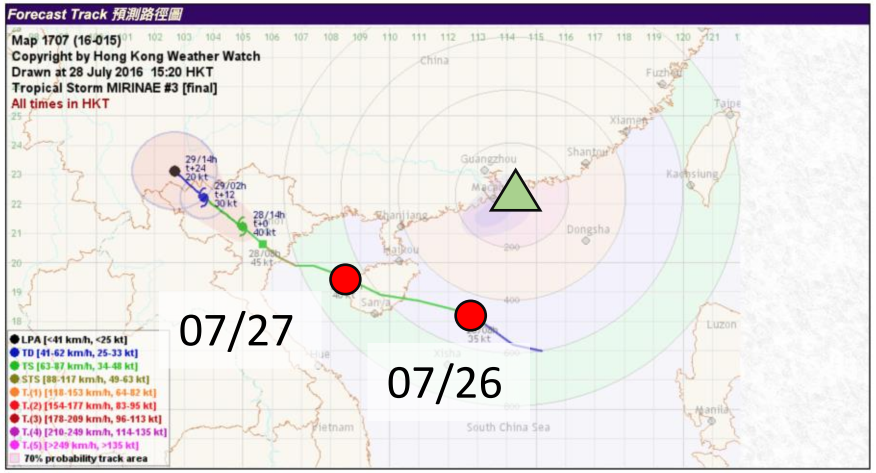


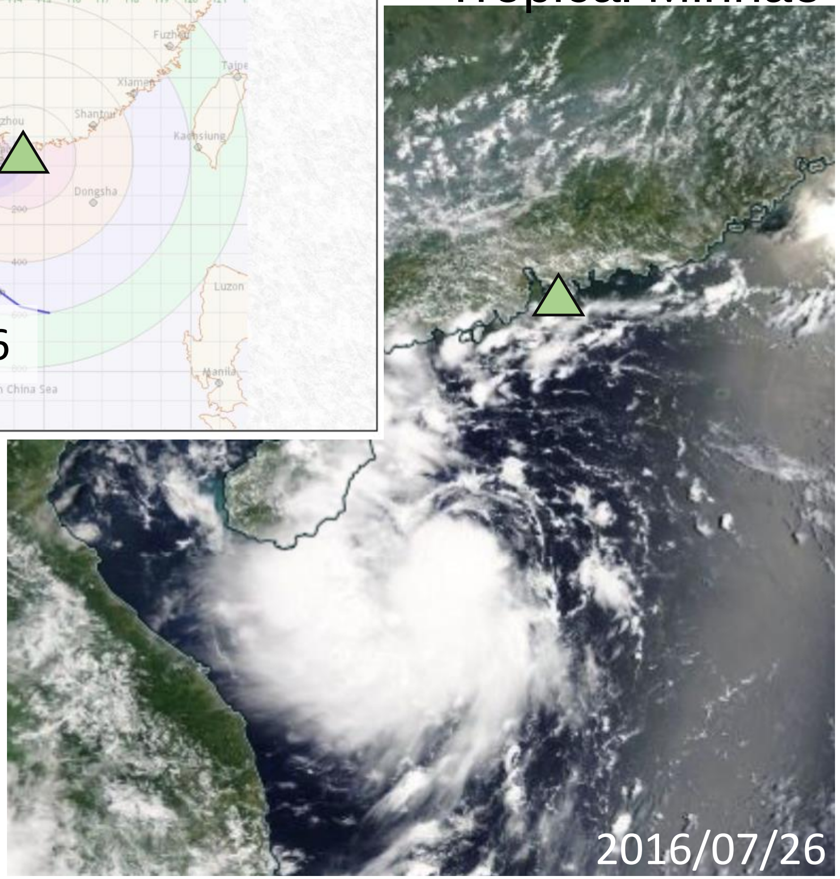
• Wind Fields

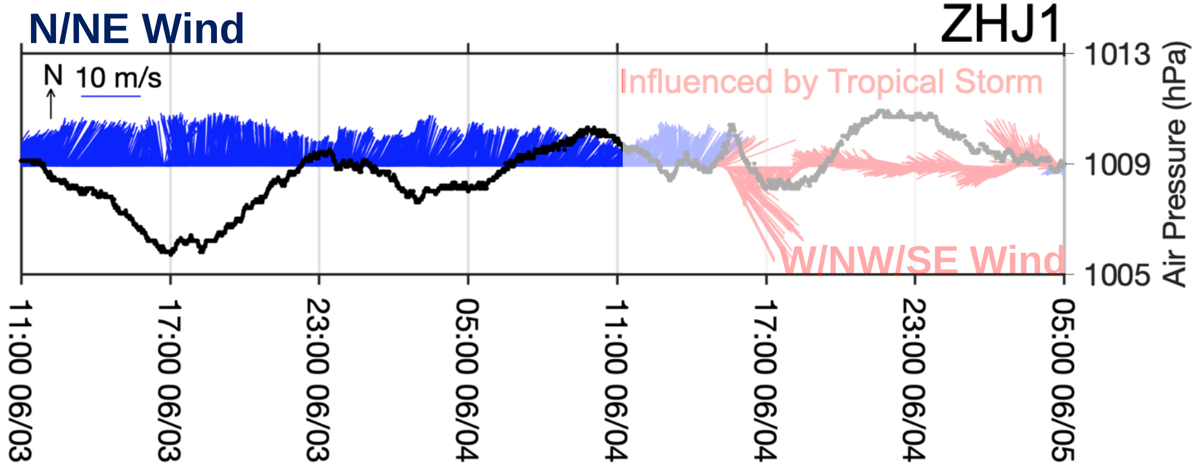


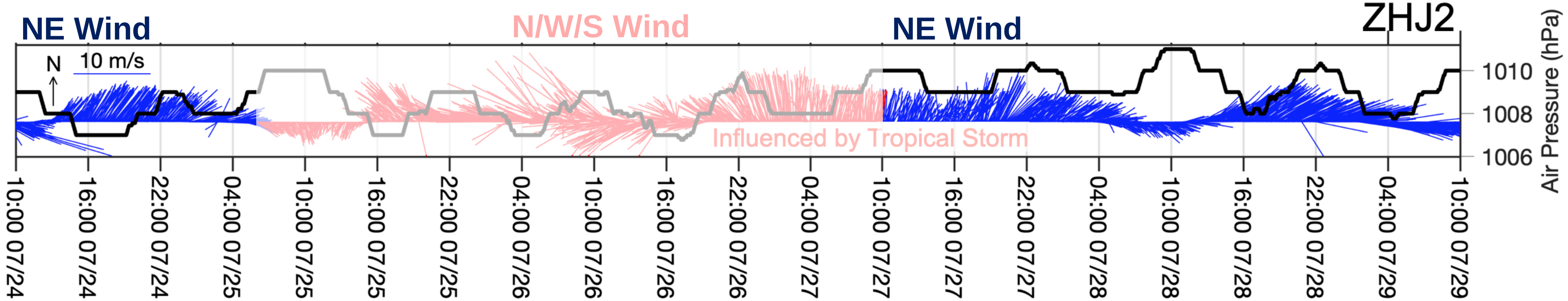
Typical summer wind field

Tropical Mirinae





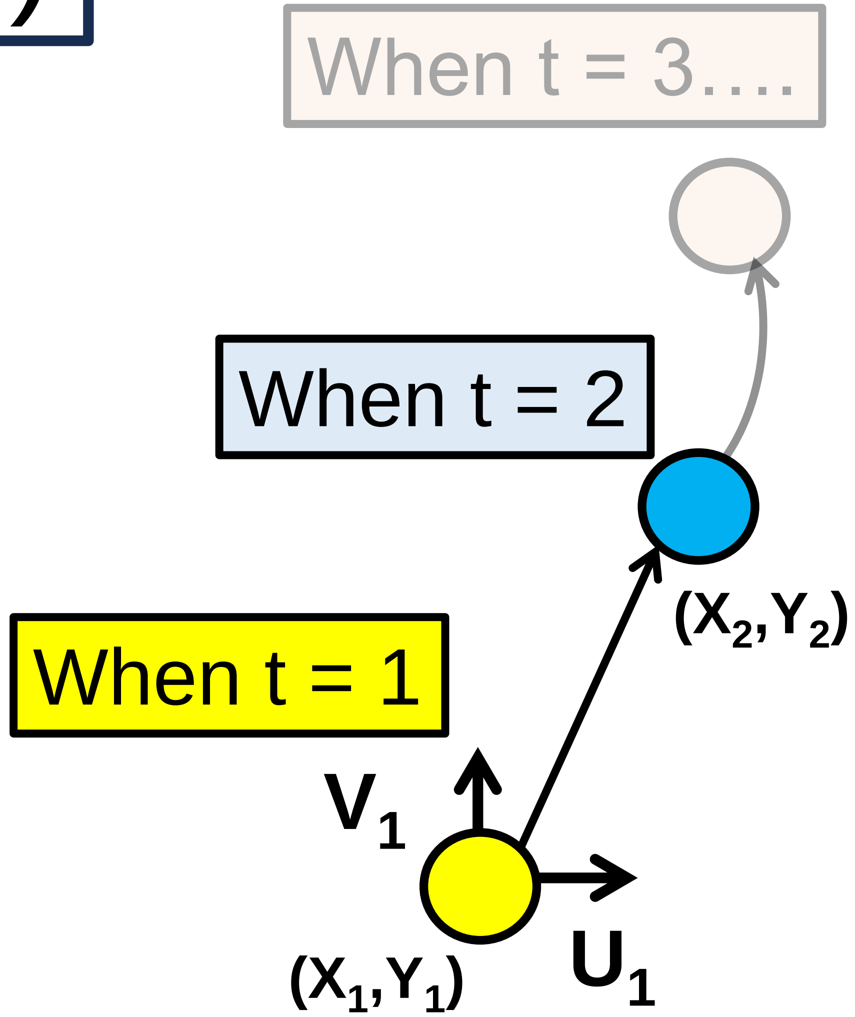




Progressive Vectors (PVs)

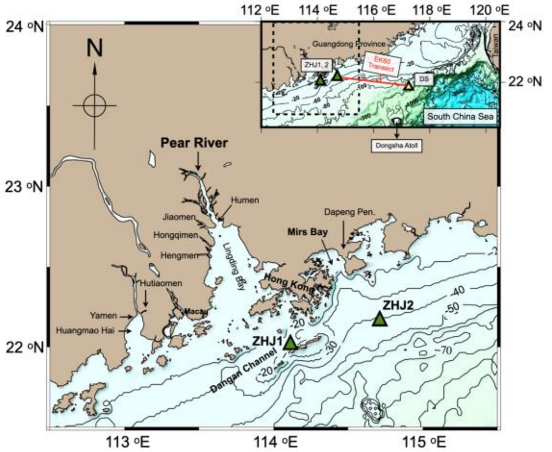
$$\overrightarrow{PV_{X,z}} = \sum_{t=1}^{m} (\overrightarrow{X_{z\,t}} + \overrightarrow{U_{z,t}} \times \Delta t)$$

$$\overrightarrow{PV_{Y,z}} = \sum_{t=1}^{m} (\overrightarrow{Y_{z,t}} + \overrightarrow{V_{z,t}} \times \Delta t)$$



X, Y: Position; U, V: Velocity; Δt Sampling Interval

- Flow Fields (Quantify)



Harmonic Analysis

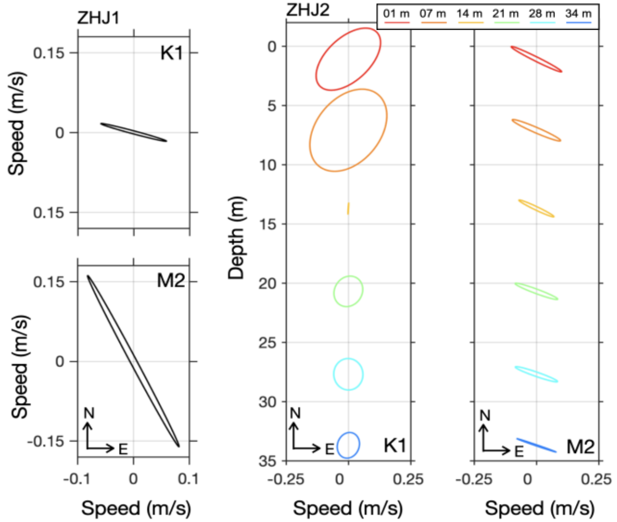
$$V_{tidal}(t)=V_p(t)=\sum_{k=1}^{m}\alpha_k(\cos\omega_k t-\theta_k)$$

Form Number

$$F=\frac{K_1+O_1}{M_2+S_2}$$

Energy Ratio

$$ER=\frac{\sum_{t=1}^{n}(V_p(t)-\overline{V_p})^2}{\sum_{t=1}^{n}(V(t)-\overline{V})^2}\times 100\%$$

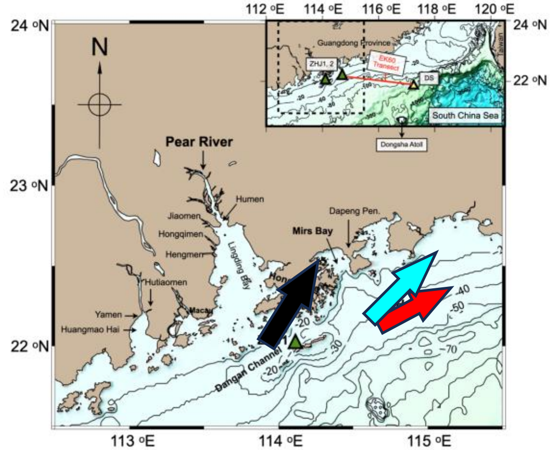


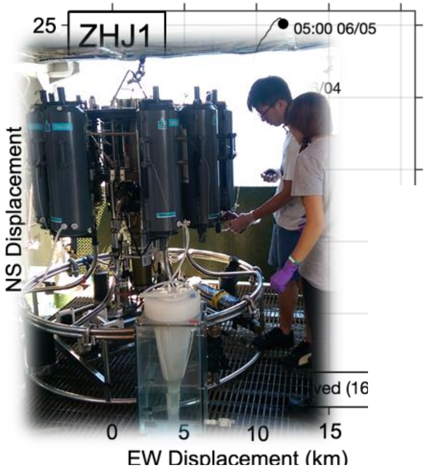
Station	Dep. (m)	K_1 (m/s)		M_2 (m/s)		F	ER (%)
		Major	Minor	Major	Minor		
June (ZHJ1)	16.6	0.06	0.00	0.18	0.01	0.19	38.9
July (ZHJ2)	1	0.16	0.09	0.11	0.01	1.7	17.3
	7	0.19	0.13	0.11	0.01	2.1	20.4
	14	0.02	0	0.07	0.01	0.3	12.0
	21	0.07	0.06	0.09	0.01	1.0	36.7
	28	0.07	0.06	0.09	0.01	1.0	49.3
	34	0.05	0.04	0.08	0	0.8	44.3

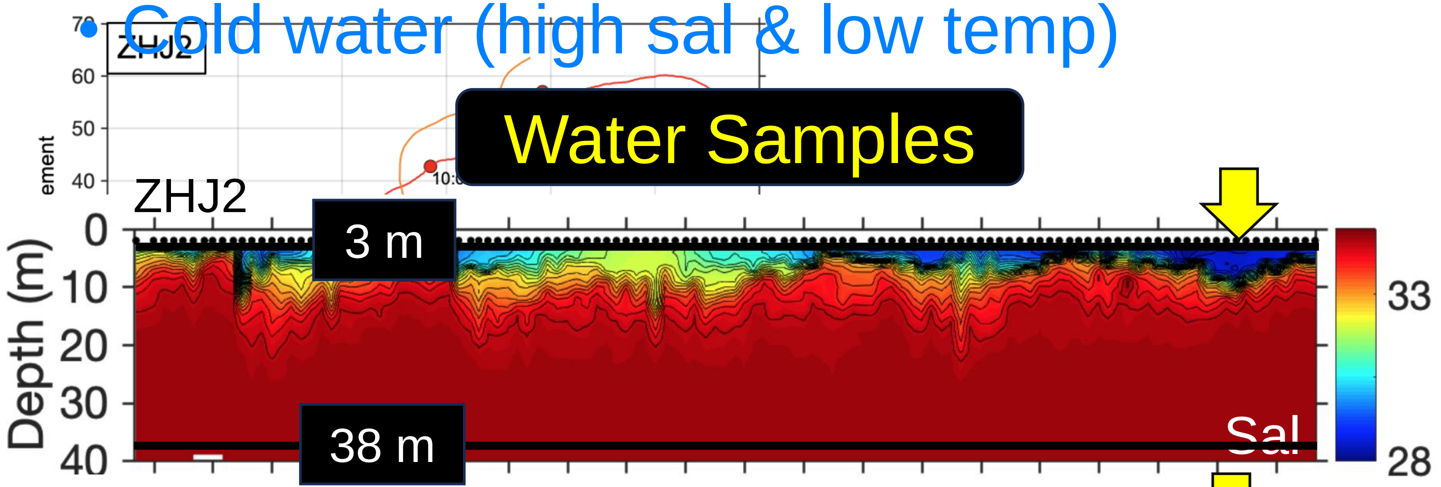
- **Energy Ratio**
  - Nontidal flow dominated at ZHJ1 & ZHJ2
  - The tidal flow became stronger in the lower layers at ZHJ2
- **Form Numer**
  - Mixed tide (K_1 & M_2)
- **Tidal ellipses**
  - NW-SE at ZHJ1 (M2 dominated)
  - NE-SW (K_1) and NW-SE (M_2) at ZHJ2

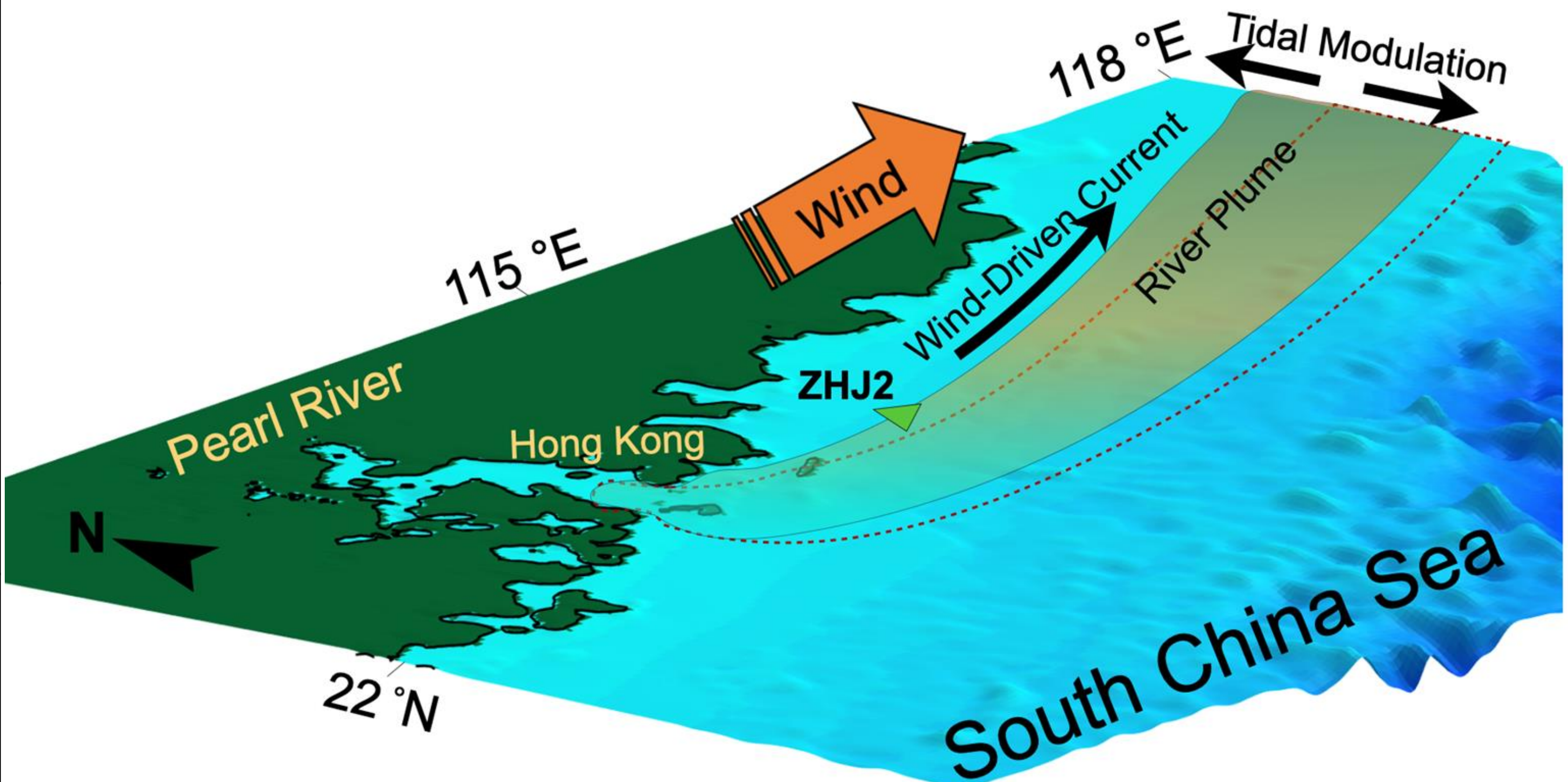
- Hydrographic Profiles

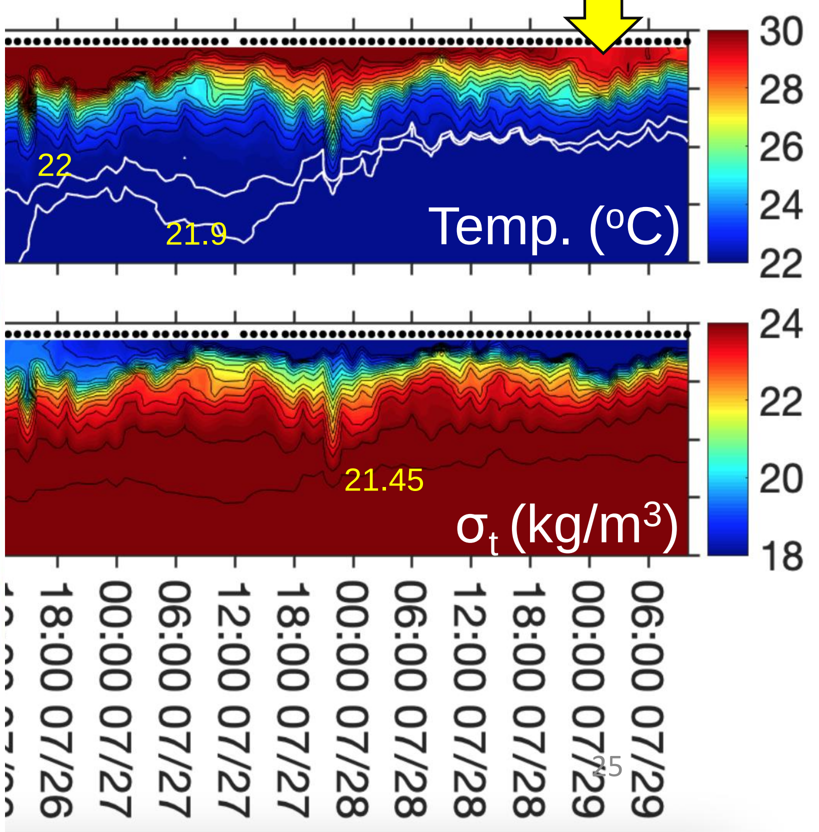
- Diluted water (low sal & high temp.)
- Cold water (high sal & low temp)



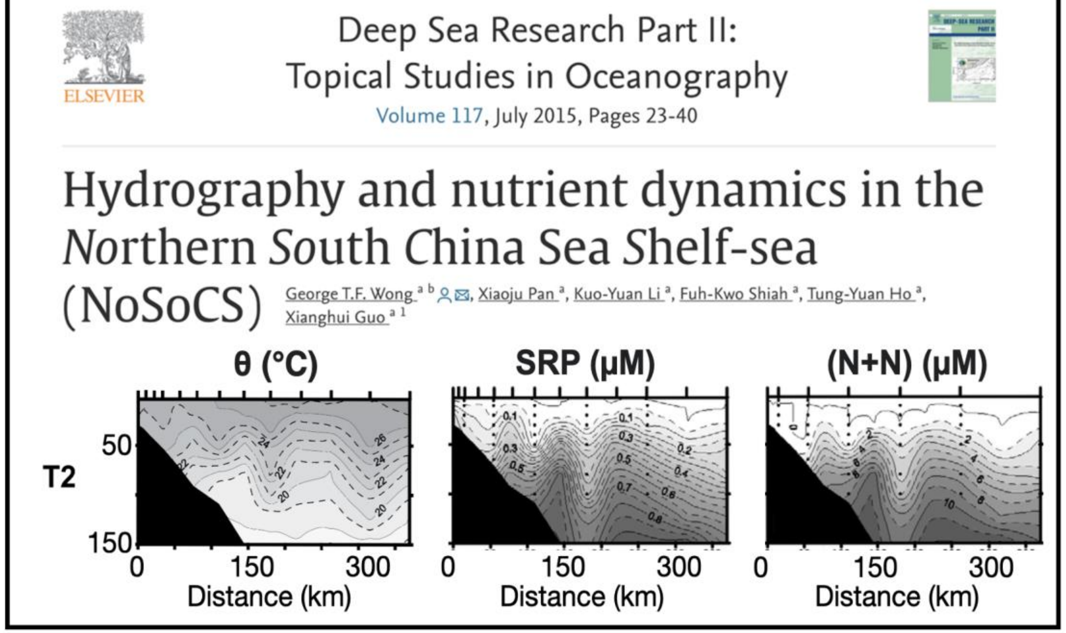








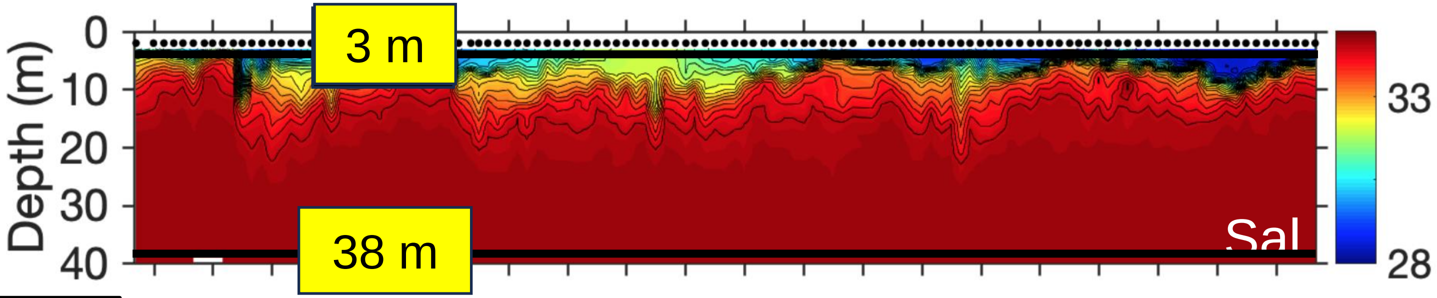
- Diluted water (low sal & high temp.)
- Cold water (high sal & low temp)

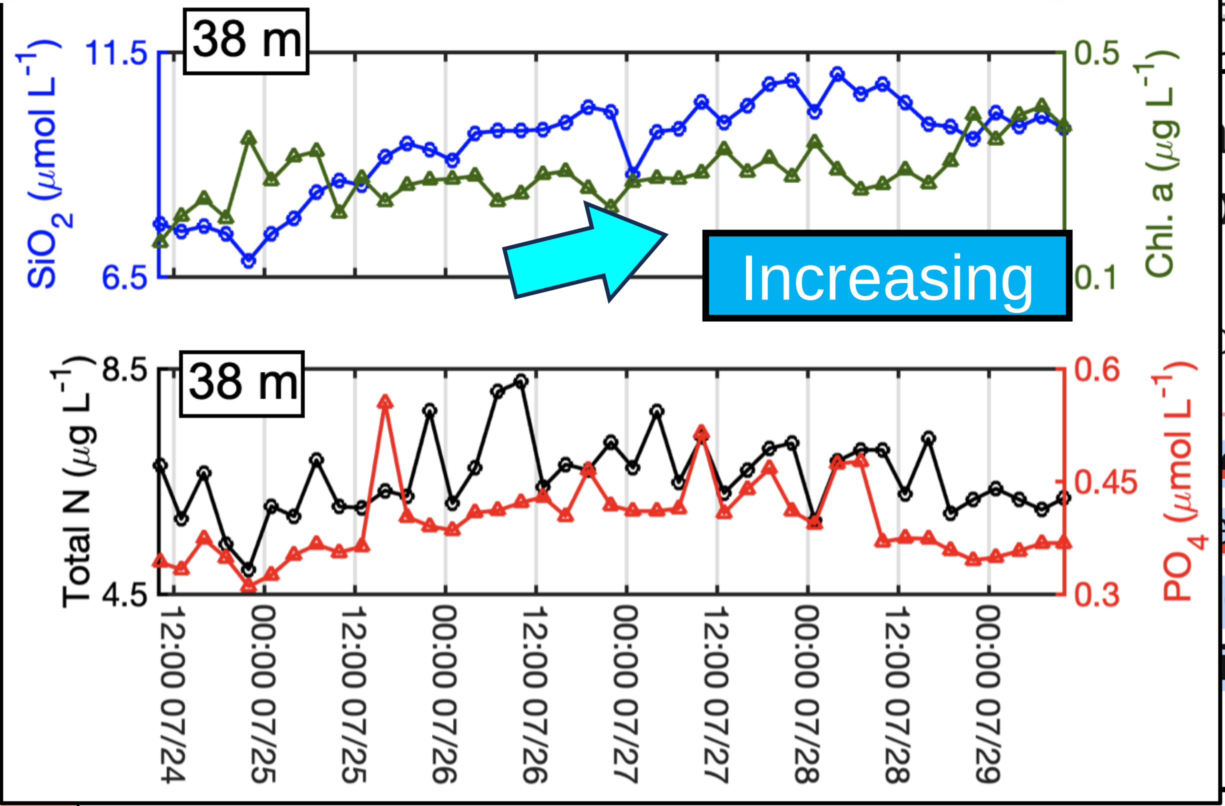

Deep Sea Research Part II: Topical Studies in Oceanography
Volume 117, July 2015, Pages 23-40

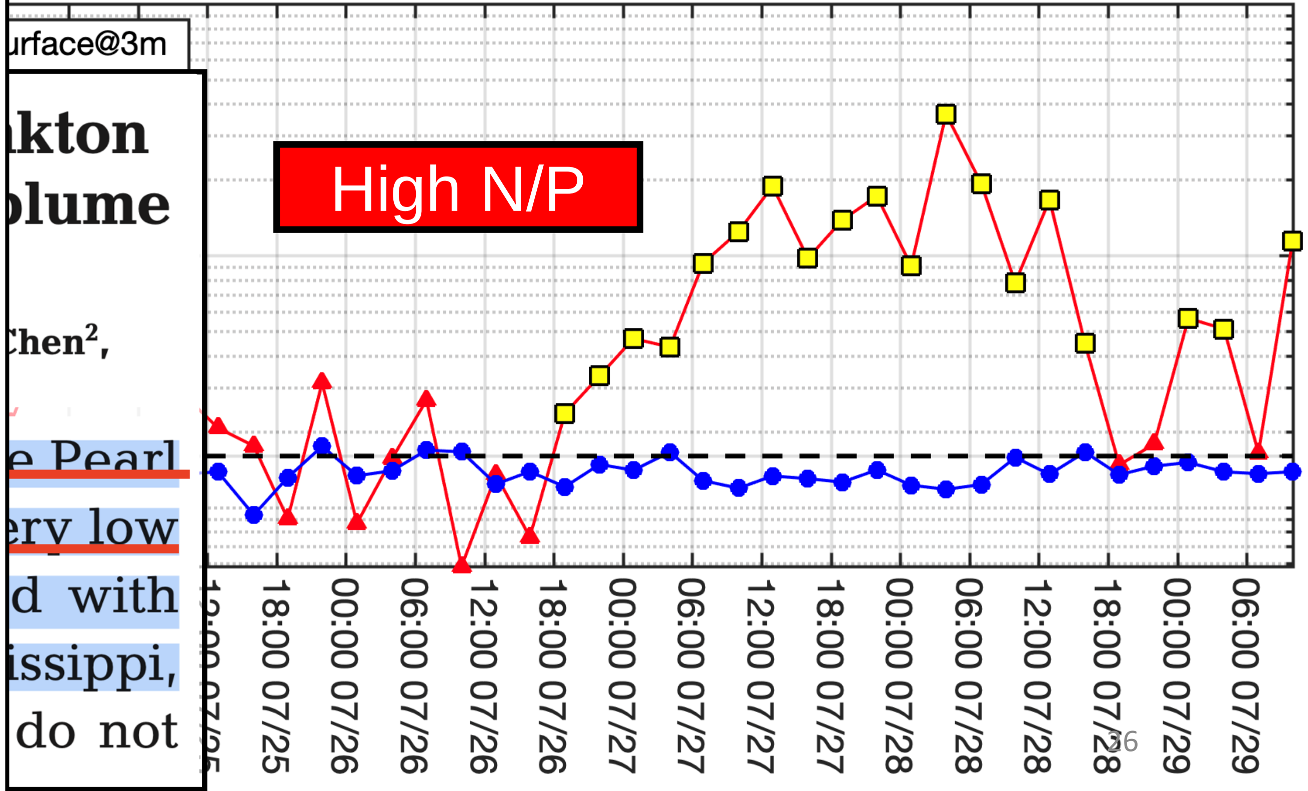
Hydrography and nutrient dynamics in the *Northern South China Sea Shelf-sea* (NoSoCS)

George T.F. Wong[a b], Xiaoju Pan[a], Kuo-Yuan Li[a], Fuh-Kwo Shiah[a], Tung-Yuan Ho[a], Xianghui Guo[a 1]

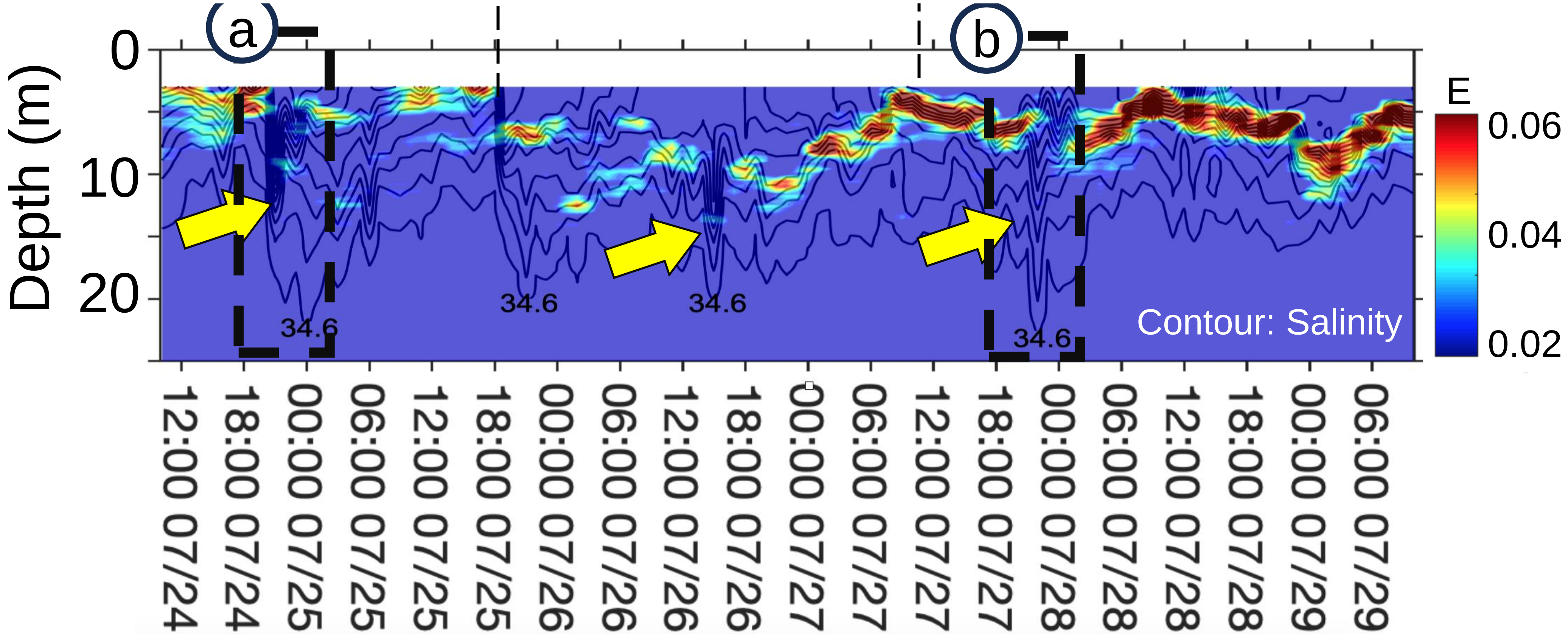
Water Samples

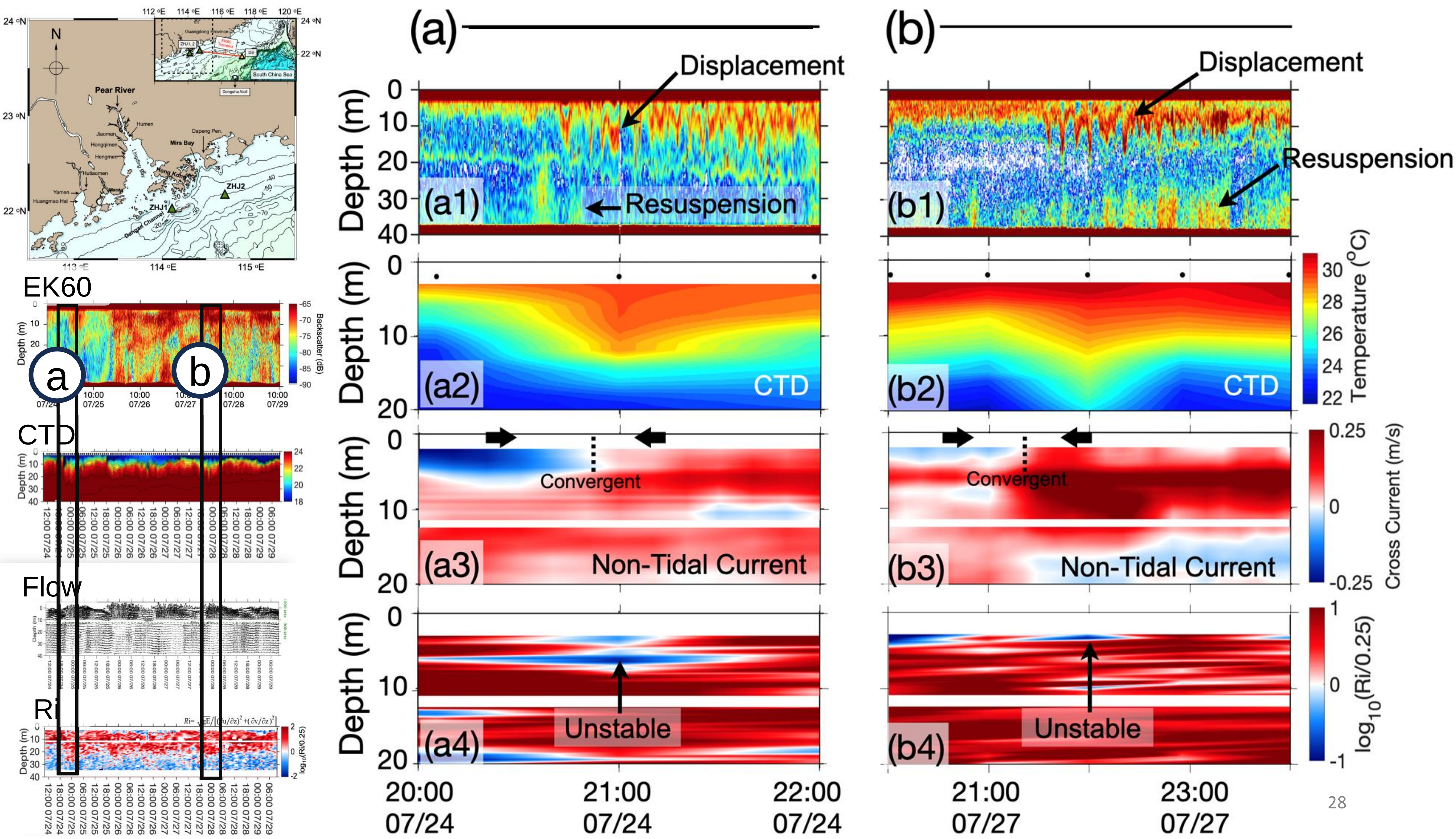


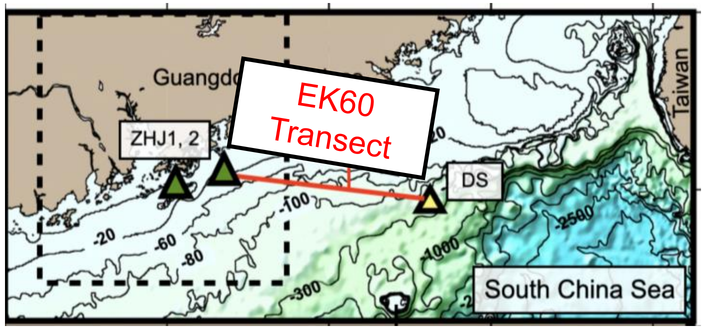


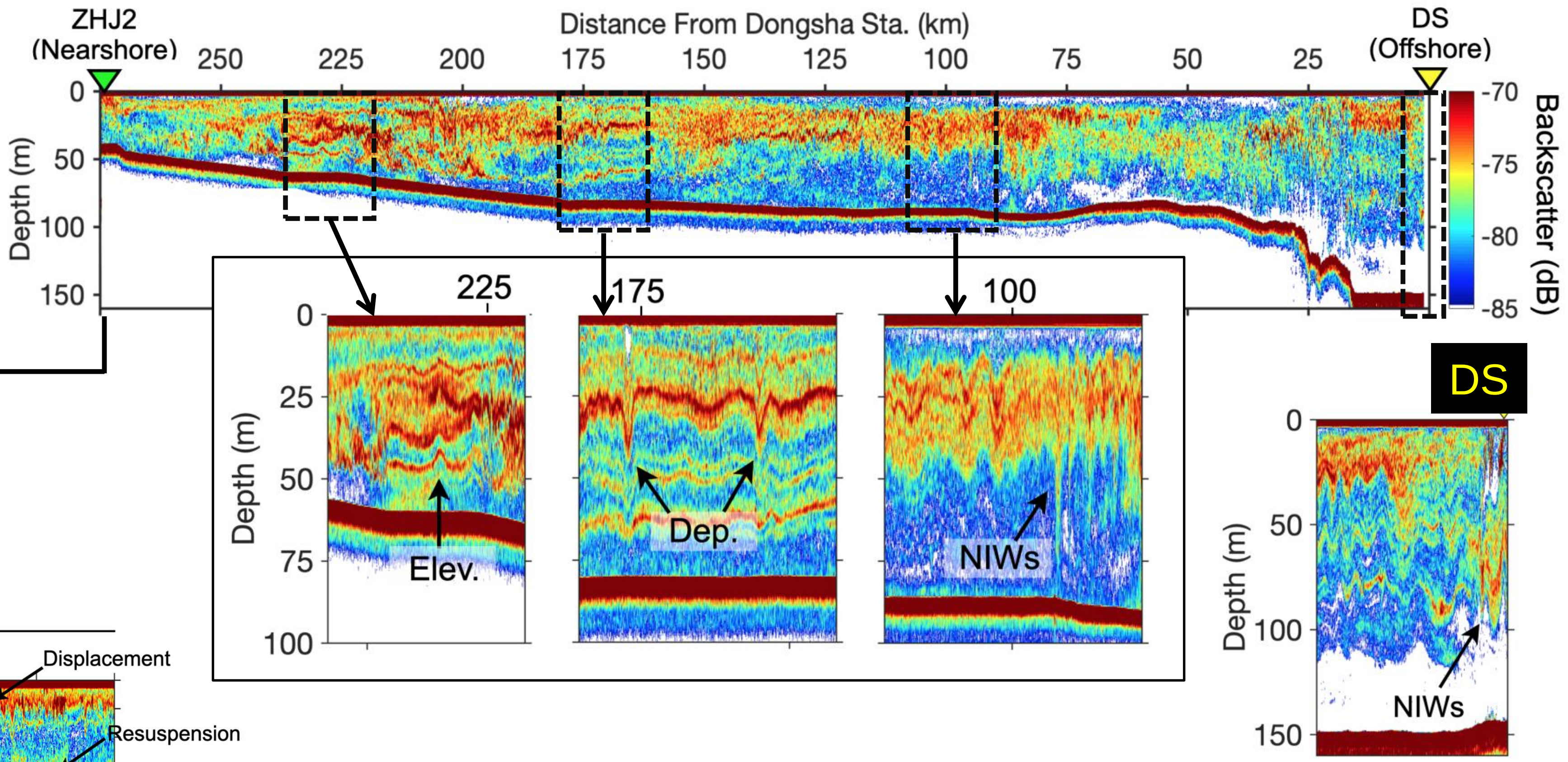


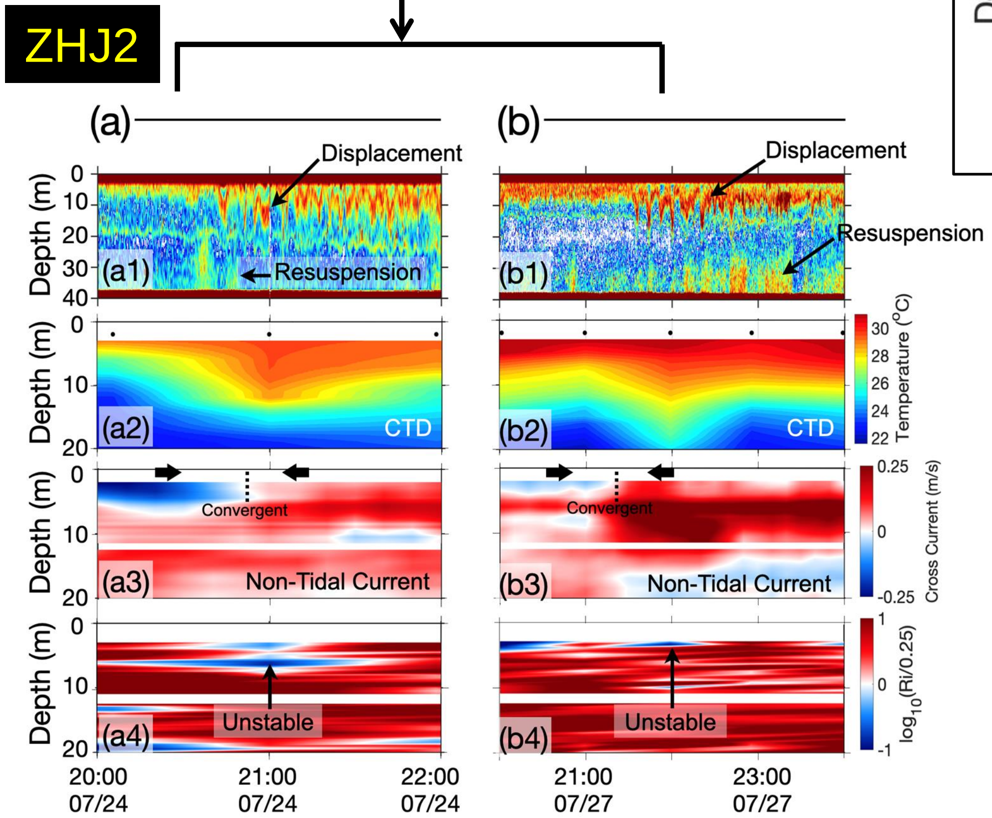
- Stratification & Mixing

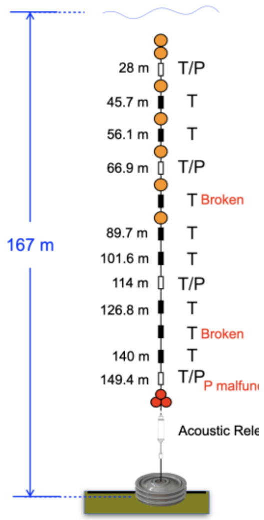


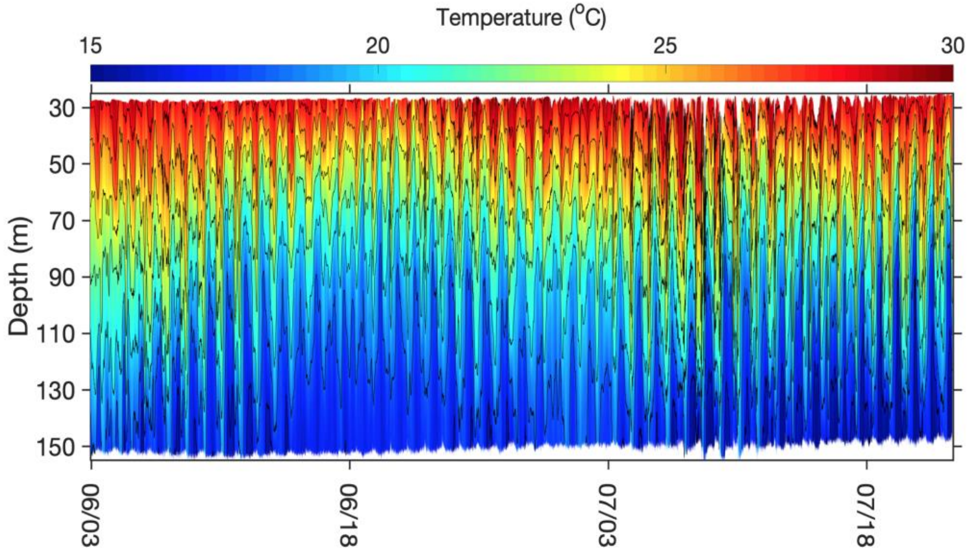

N
Pear River
Humen
Jiaomen
Hongqimen
Hengmen
Hutiaomen
Yamen
Huangmao Hai
Lingding Bay
Mirs Bay
Dapeng Pen.
Hong Kong
ZHJ1
ZHJ2
Dangan Channel
24 °N
23 °N
22 °N
113 °E
114 °E
115 °E
112 °E
116 °E
118 °E
120 °E
Guangdong Province
South China Sea
Dongsha Atoll
EK60
CTD
Flow
Ri
a
b
Backscatter (dB)
Depth (m)
(a)
(b)
Displacement
Resuspension
(a1)
(b1)
(a2)
(b2)
CTD
Temperature (°C)
(a3)
(b3)
Convergent
Non-Tidal Current
Cross Current (m/s)
(a4)
(b4)
Unstable
log10(Ri/0.25)
20:00 07/24
21:00 07/24
22:00 07/24
21:00 07/27
23:00 07/27


Guangdo
EK60 Transect
ZHJ1, 2
DS
Taiwan
South China Sea

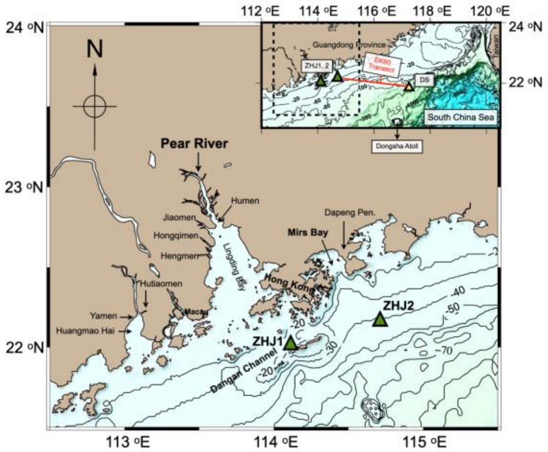

ZHJ2 (Nearshore)
Distance From Dongsha Sta. (km)
DS (Offshore)
Depth (m)
Backscatter (dB)
Elev.
Dep.
NIWs
DS

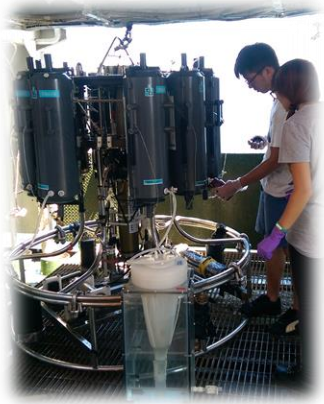

ZHJ2
(a)
(b)
Displacement
Resuspension
(a1)
(b1)
CTD
(a2)
(b2)
Temperature (°C)
Convergent
Non-Tidal Current
(a3)
(b3)
Cross Current (m/s)
Unstable
(a4)
(b4)
$\log_{10}(Ri/0.25)$
Depth (m)
20:00 07/24
21:00 07/24
22:00 07/24
21:00 07/27
23:00 07/27

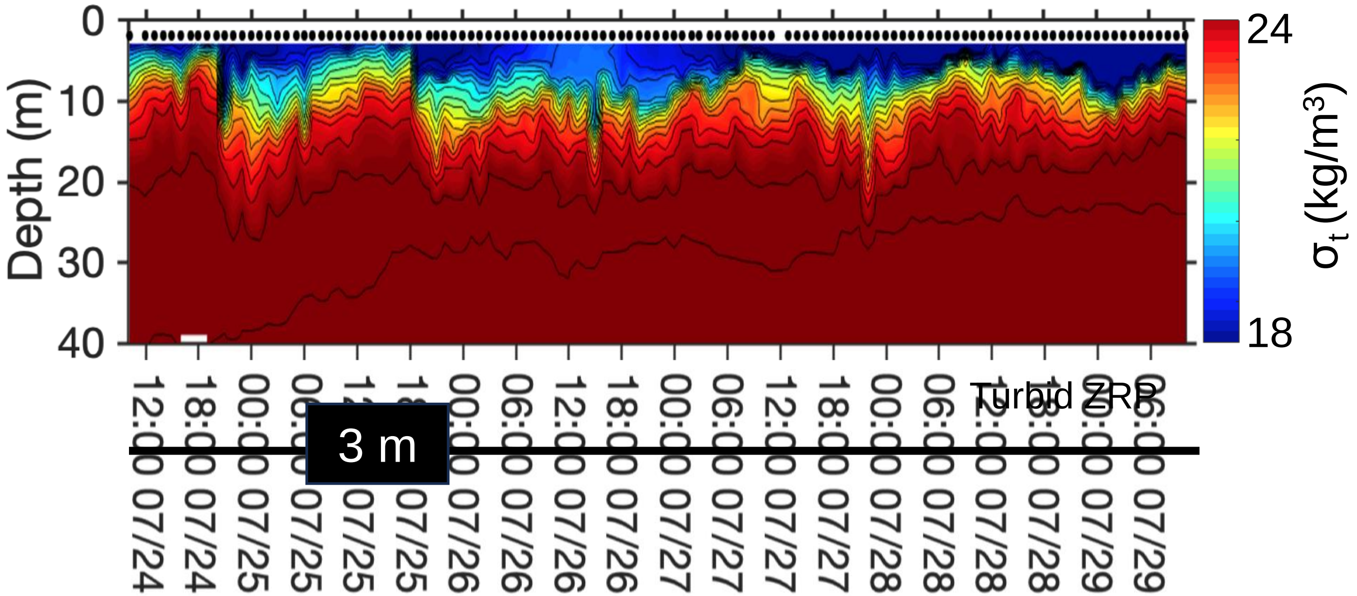

167 m
28 m T/P
45.7 m T
56.1 m T
66.9 m T/P
T Broken
89.7 m T
101.6 m T
114 m T/P
126.8 m T
T Broken
140 m T
149.4 m T/P
P malfun
Acoustic Rele


Temperature (°C)
Depth (m)
06/03
06/18
07/03
07/18

• SPs Characteristics







38 m

BNL

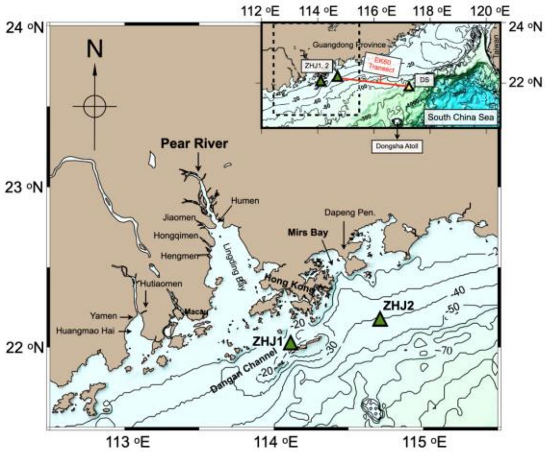
• Upper Water Column

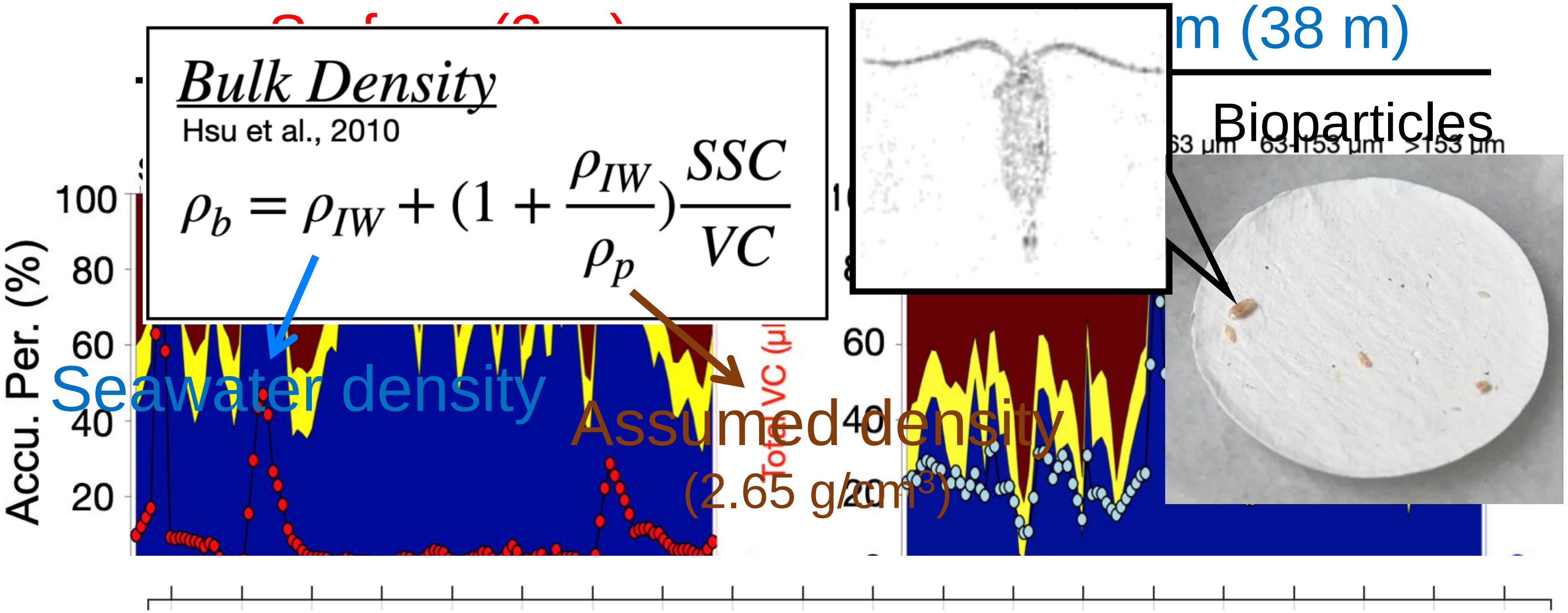
- ➢ Diluted water regime (ZRP)
- ➢ Low salinity (tidal modulation)
- ➢ Low light transmission (< 50 %)
- ➢ High fluorescence (> 2 μg L^{-1})

• Lower Water Column

- ➢ Cold offshore regime
- ➢ Bottom nepheloid layer (< 70 %)
- ➢ Low fluorescence

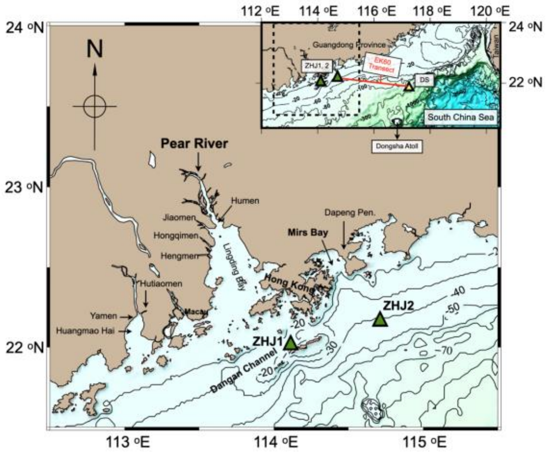
- SPs Characteristics





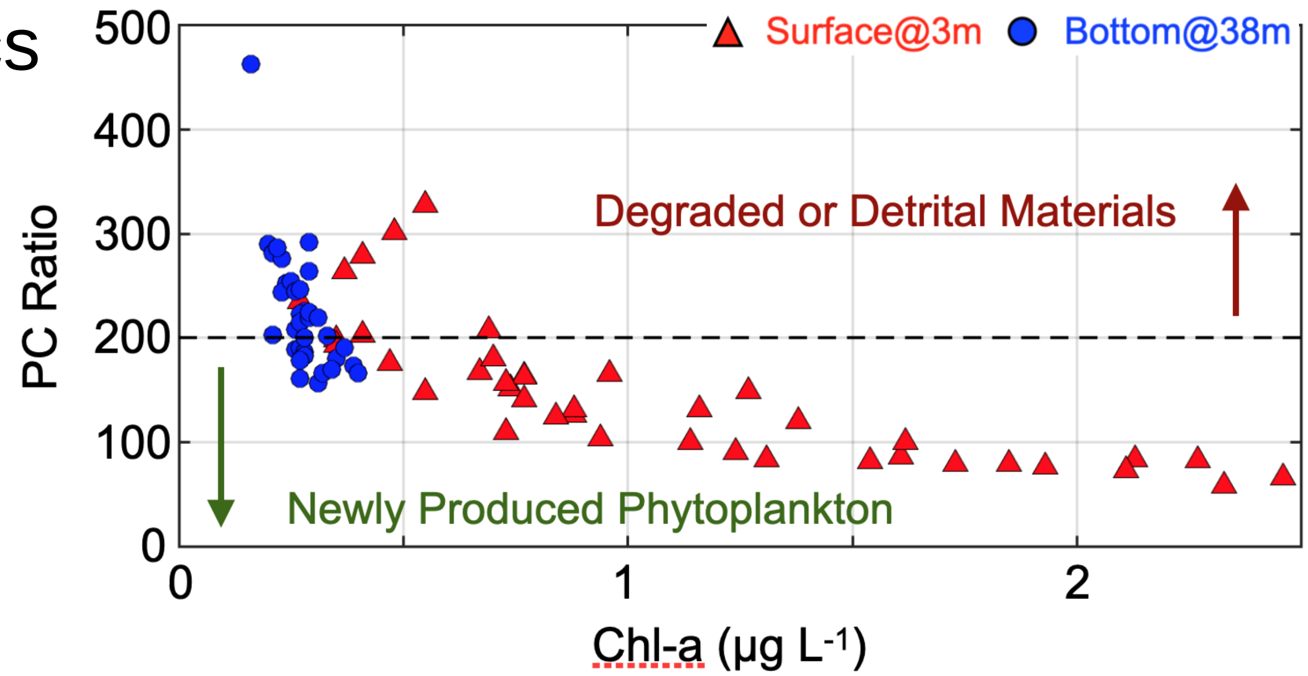
- **Surface**
  - Diurnal var. in VC
  - VC dominated by >153 µm
  - SSC dominated in <63 µm
  - Lighter SPs
- **Bottom**
  - High-frequency var. in VC
  - VC dominated by <153 µm
  - SSC dominated by <63 µm
  - Heavier SPs

- SPs Characteristics



- **Surface**
  - POM was higher
  - Follows Redfield
  - POM was fresh
  - Marine-sourced

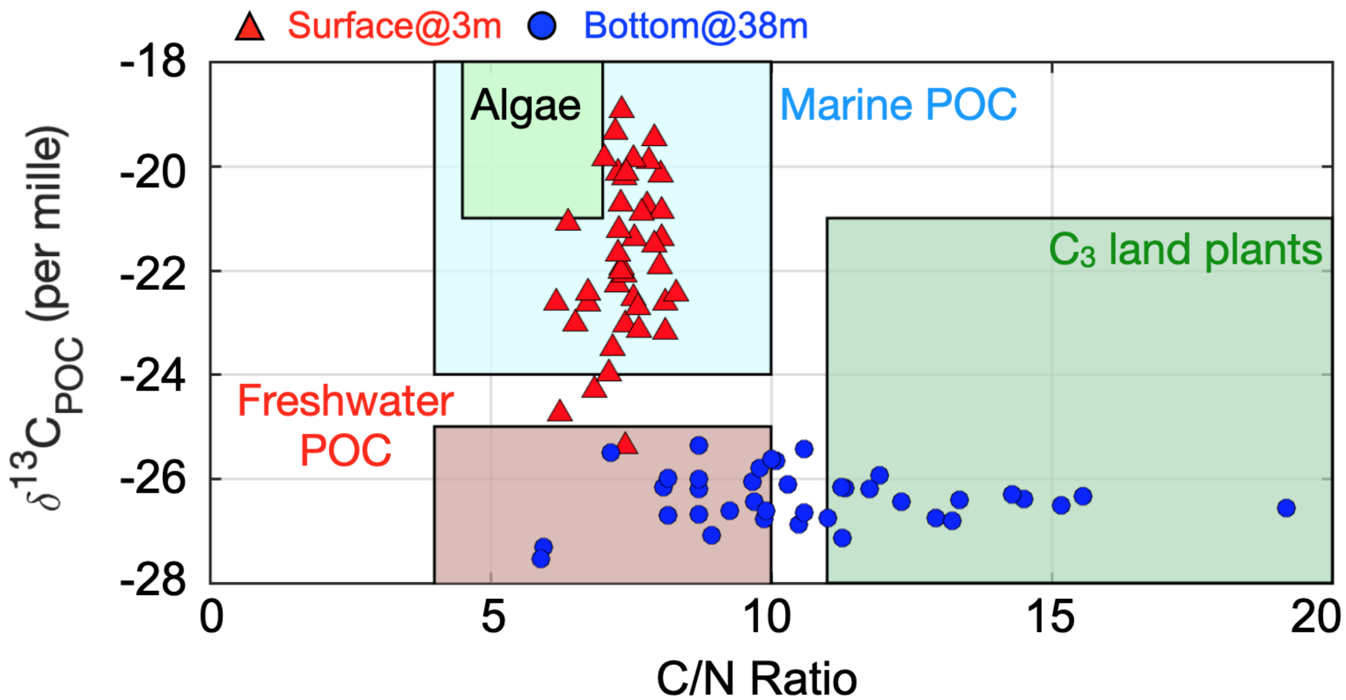
- **Bottom**
  - POM was lower
  - Not follows Redfield
  - POM was degraded
  - Terrestrial-sourced **(?)**



PC Ratio

$$\frac{POC}{Chl\text{-}a}$$

Guo et al., (2015)

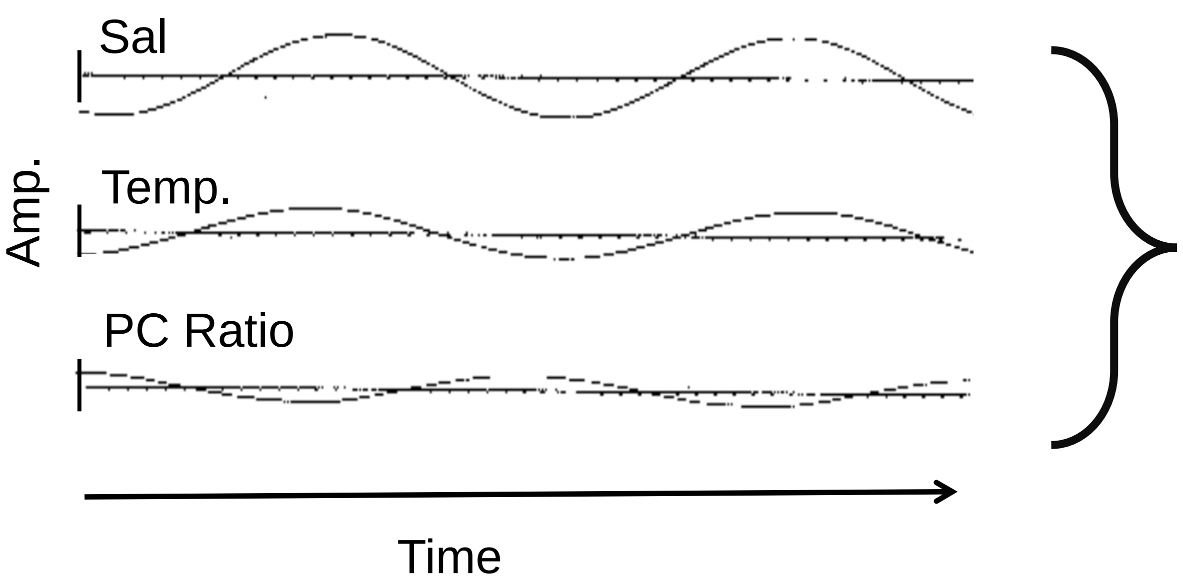


C/N Ratio

$$\frac{POC}{PN}$$

EOF

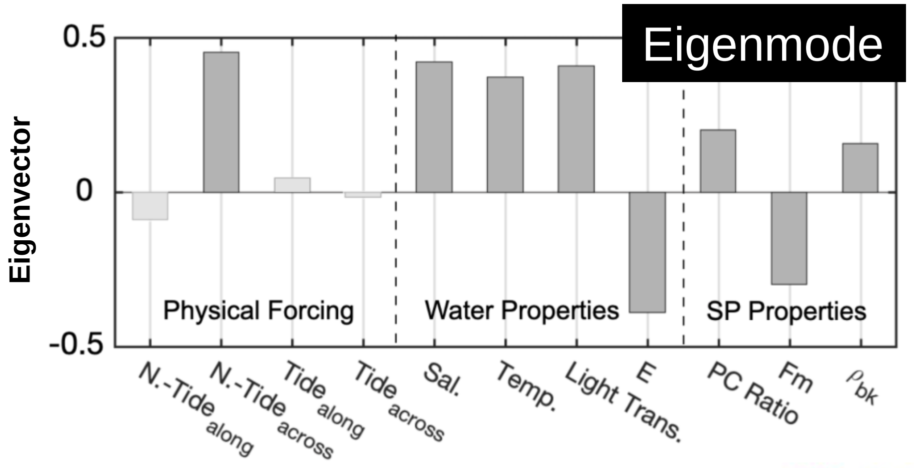
Independent Variables

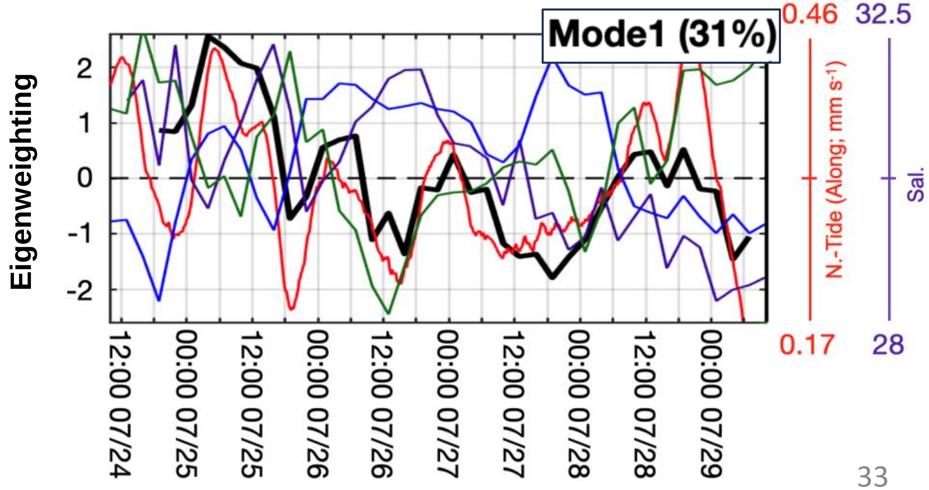


NOAA (https://tidesandcurrents.noaa.gov/harmonic.html)

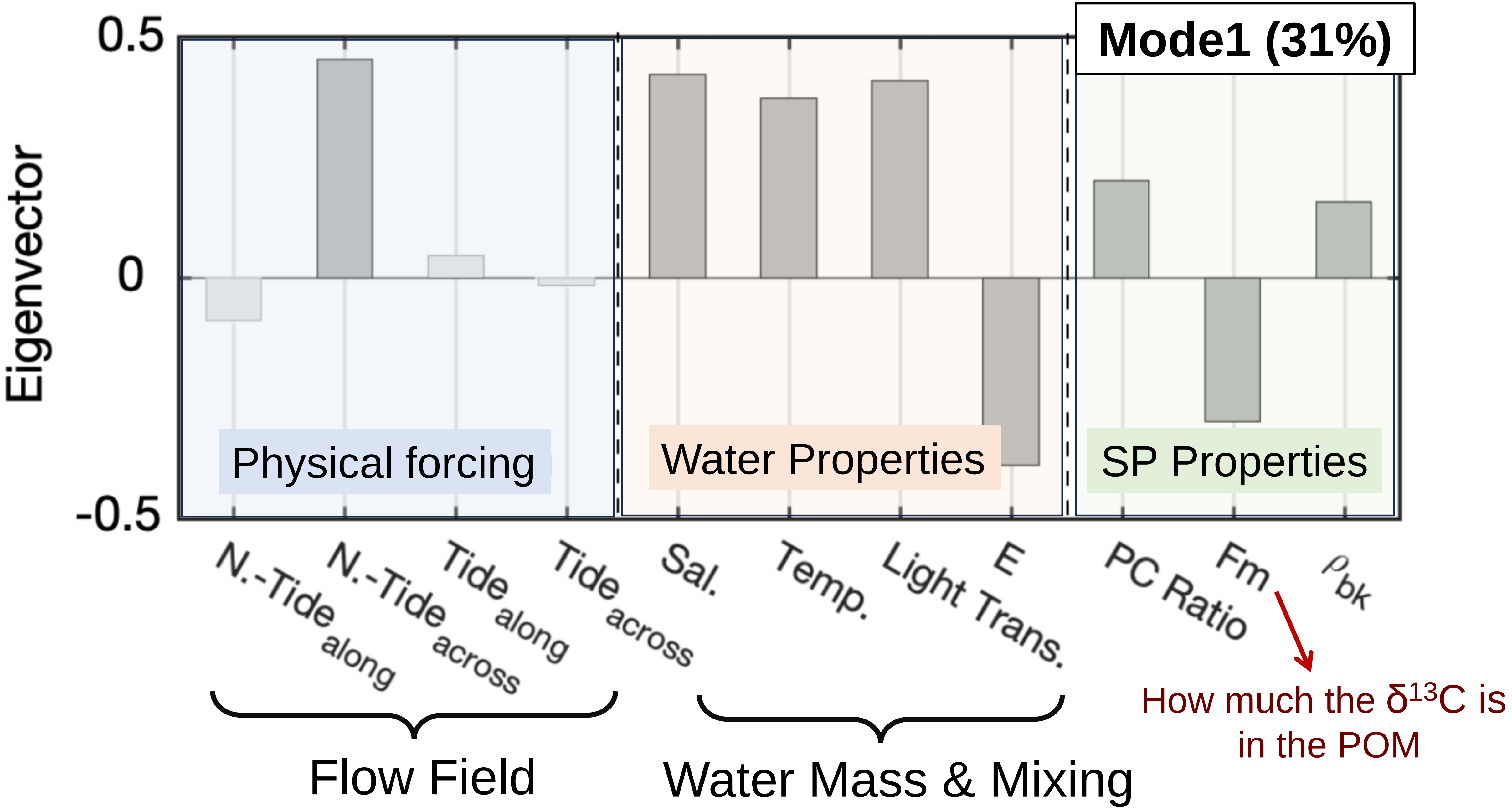
Covariability

Mode1, Mode2…

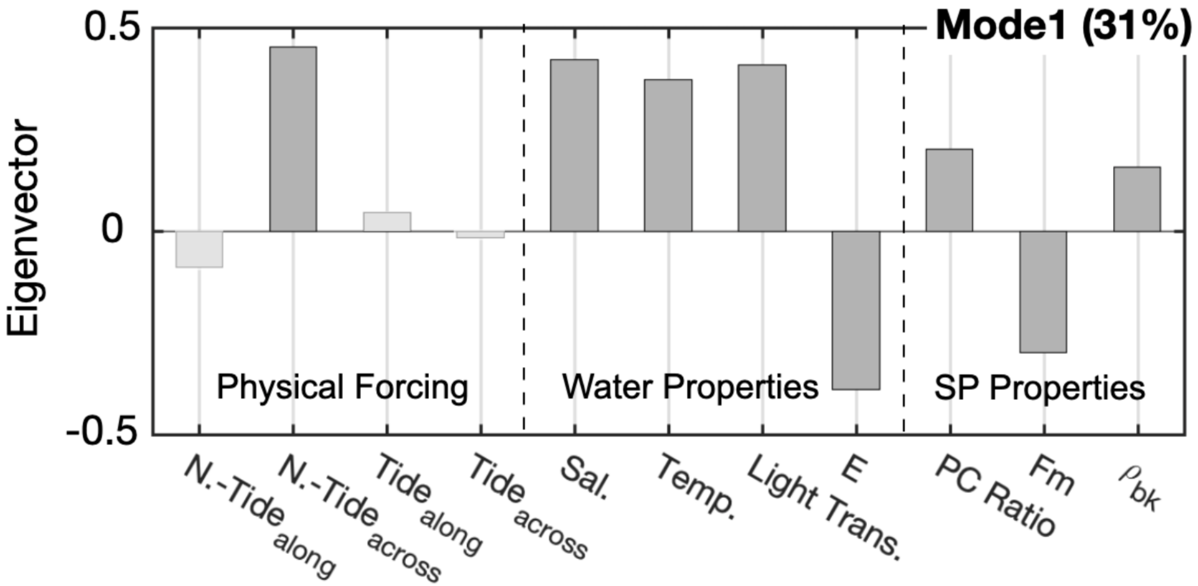


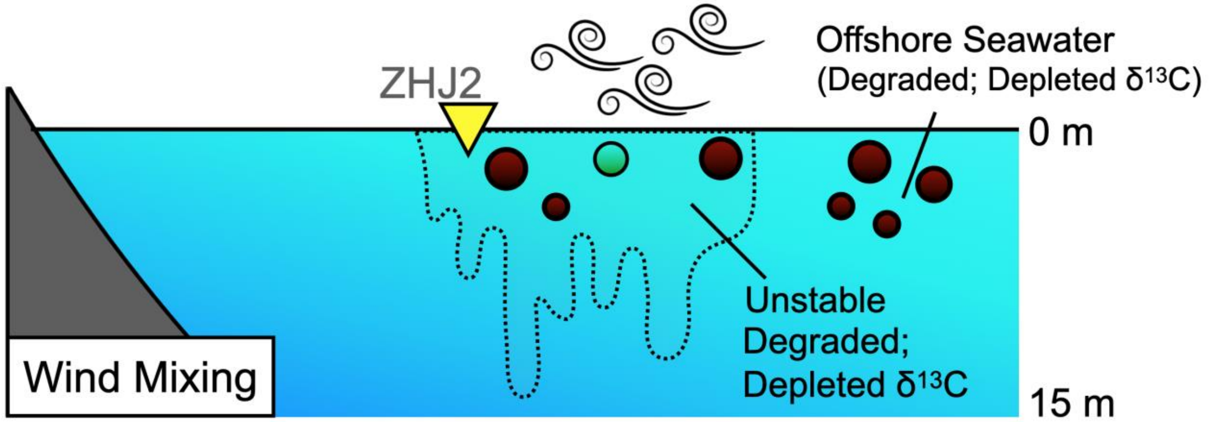


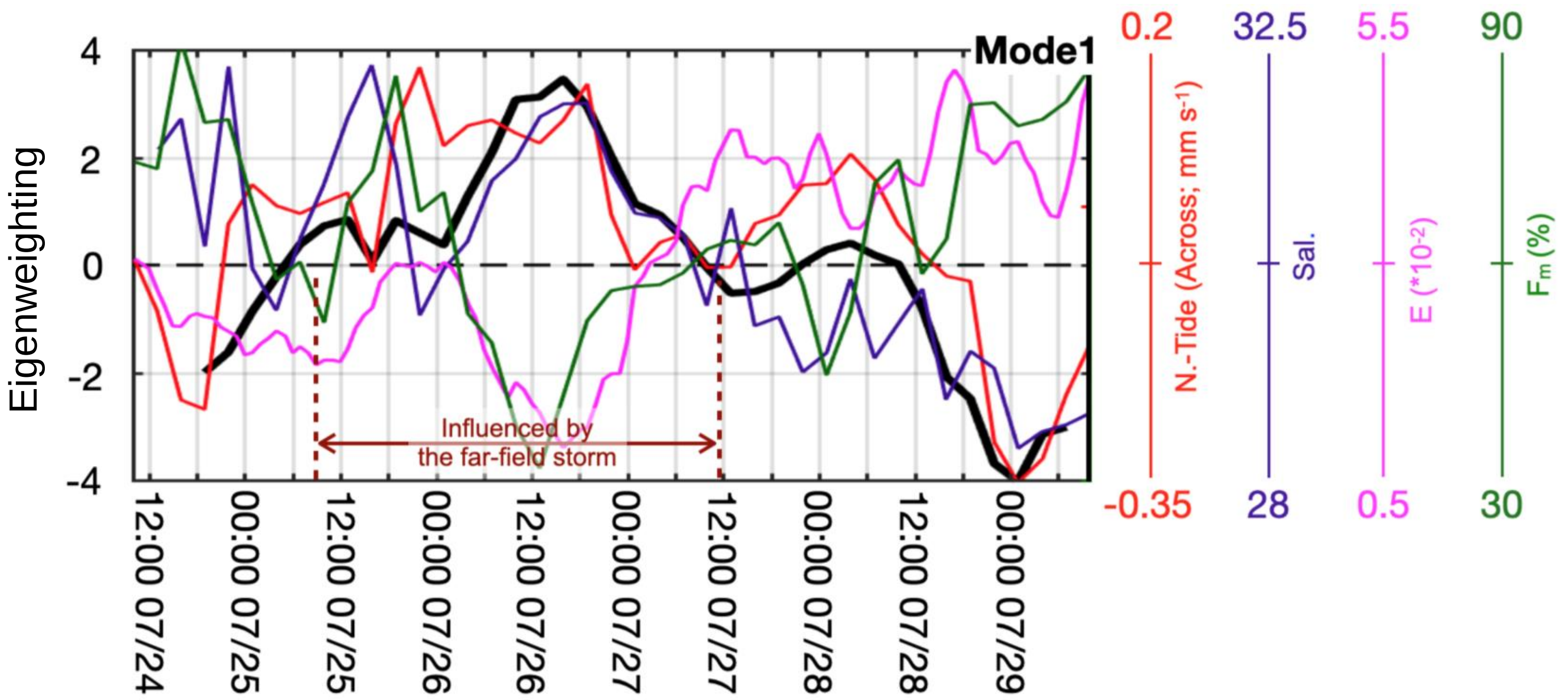
- Empirical Orthogonal Function

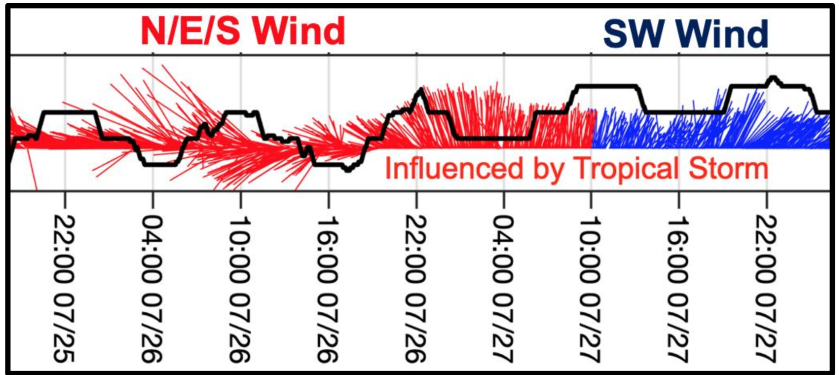


- EOF (Surface; 3 m)

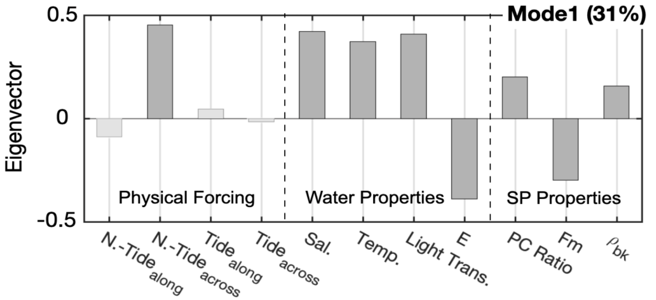


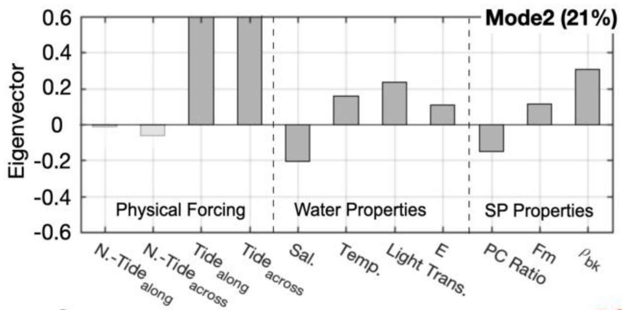


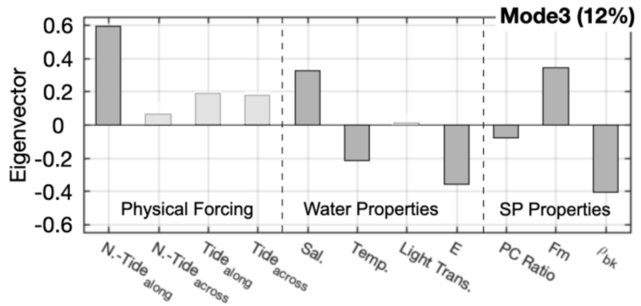


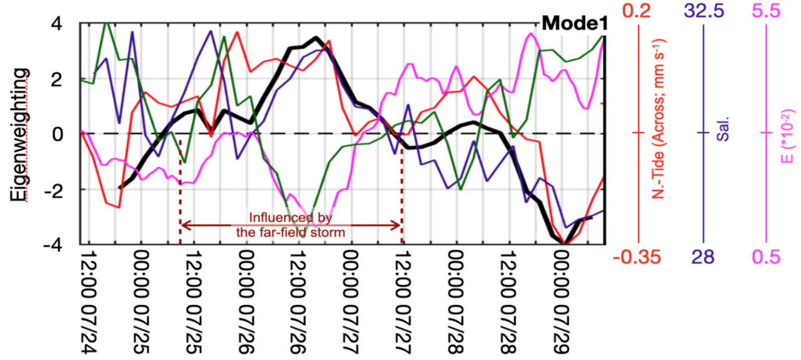


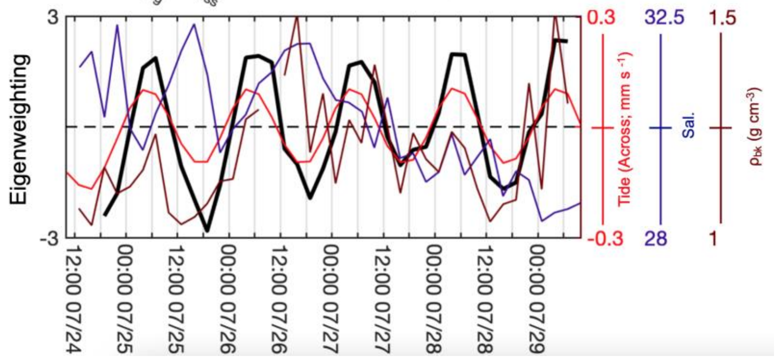
- EOF (Surface; 3 m)

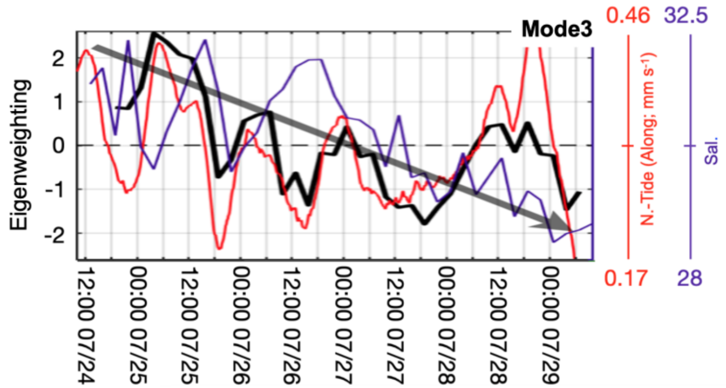


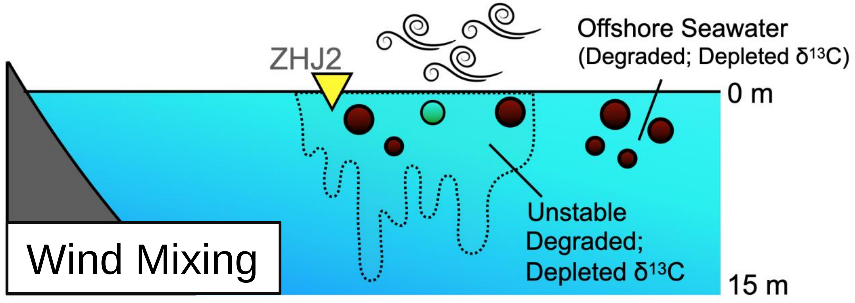


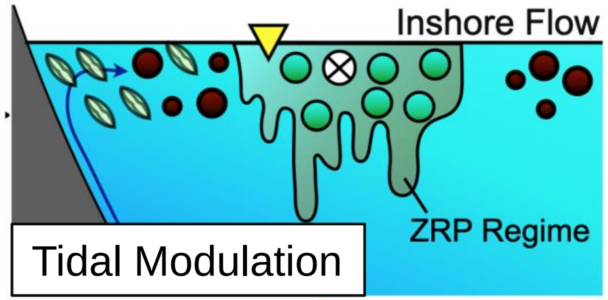


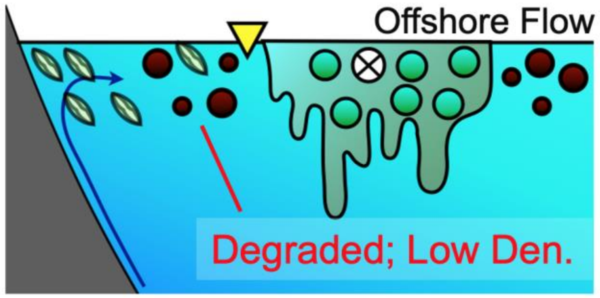


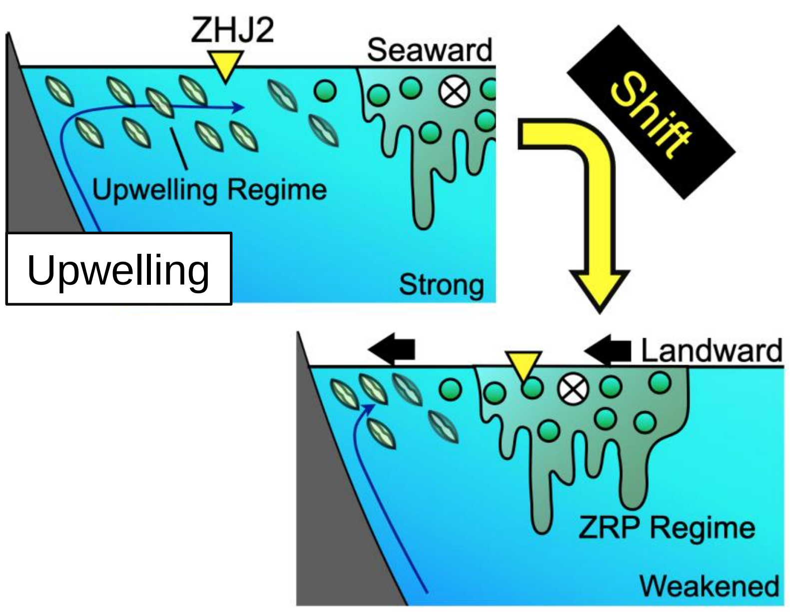




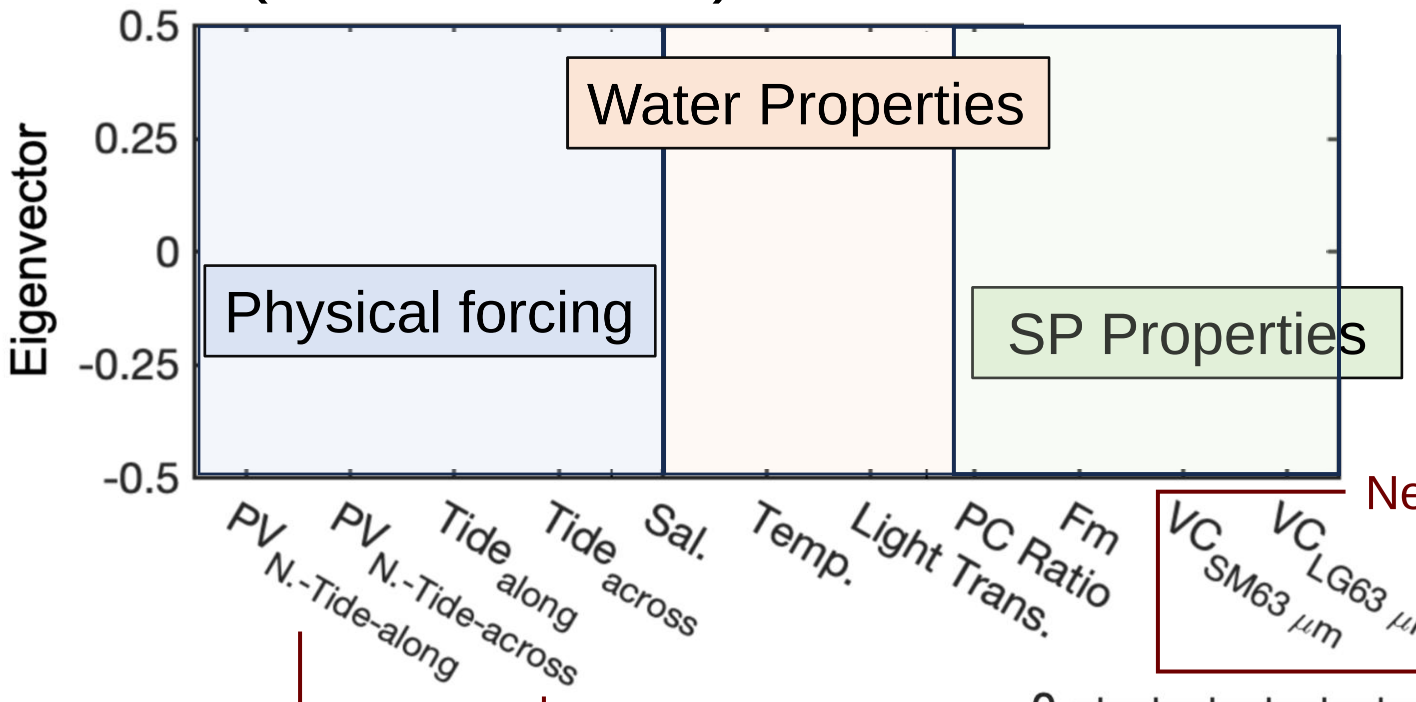








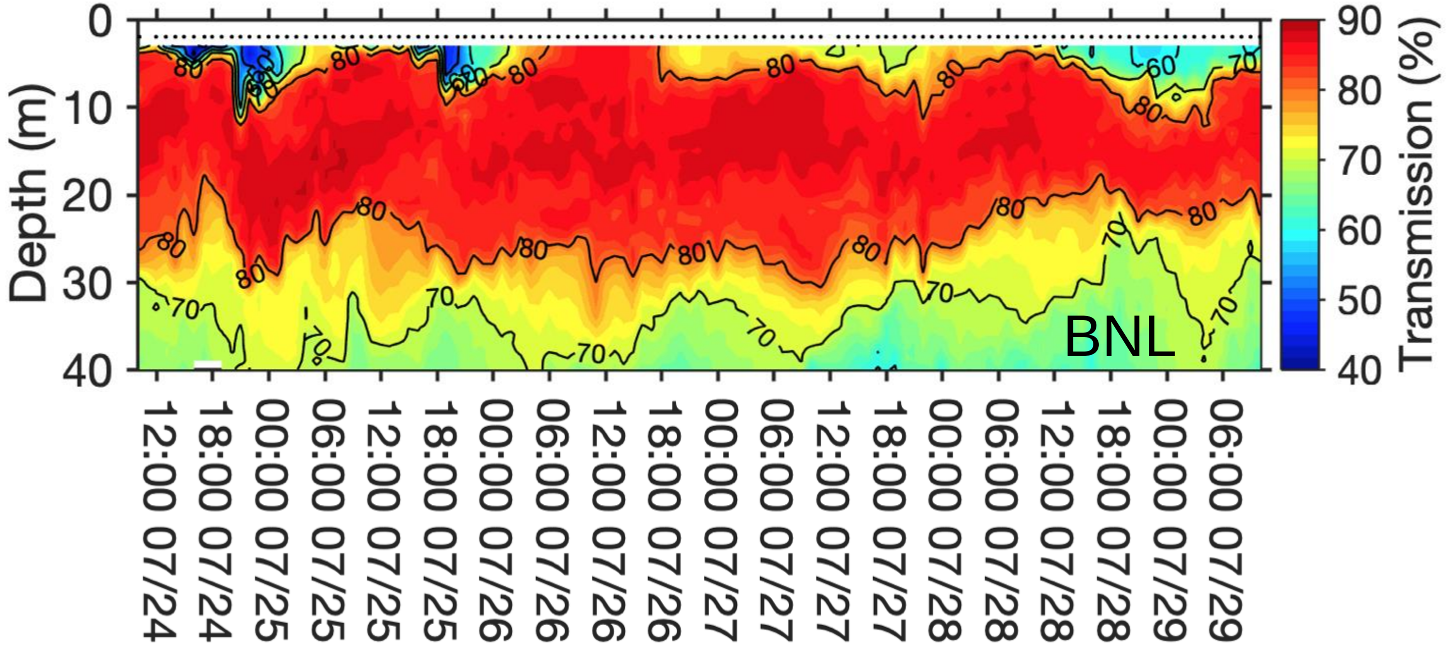
- EOF (Bottom; 38 m)



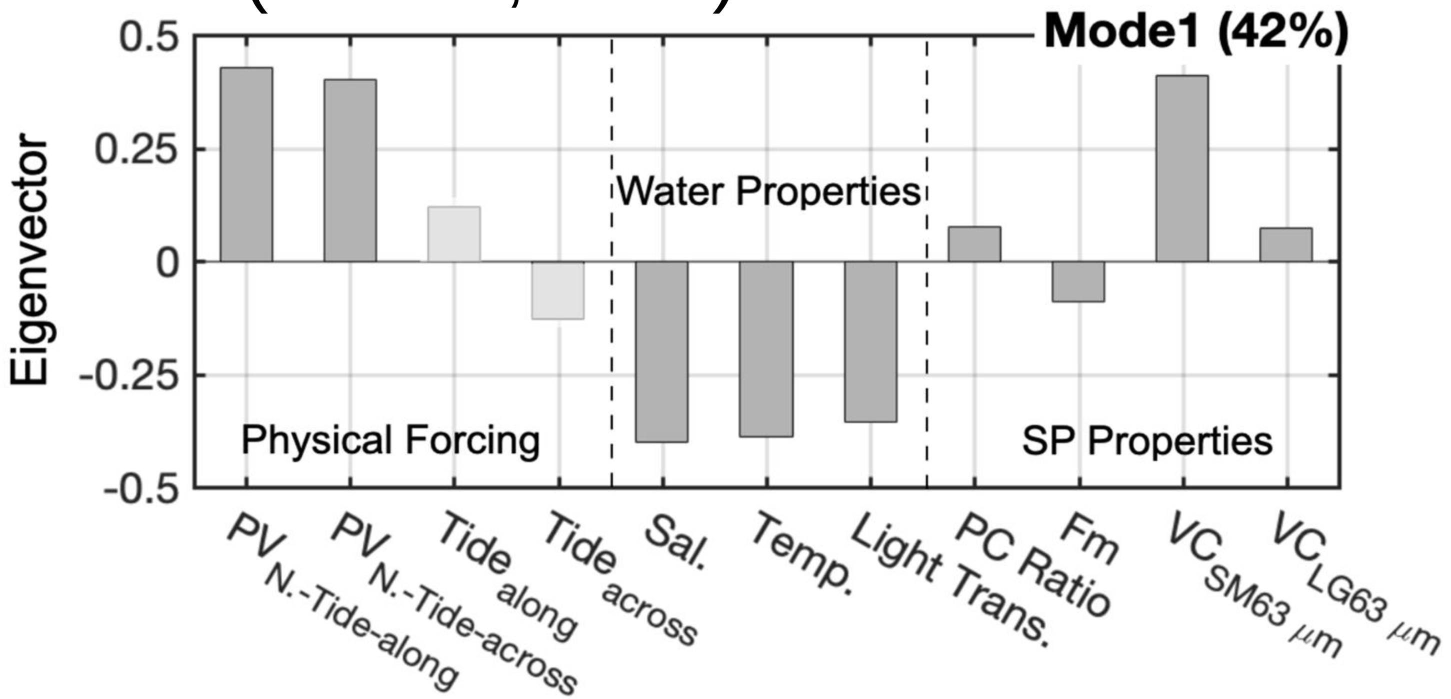
New (Particle Size)

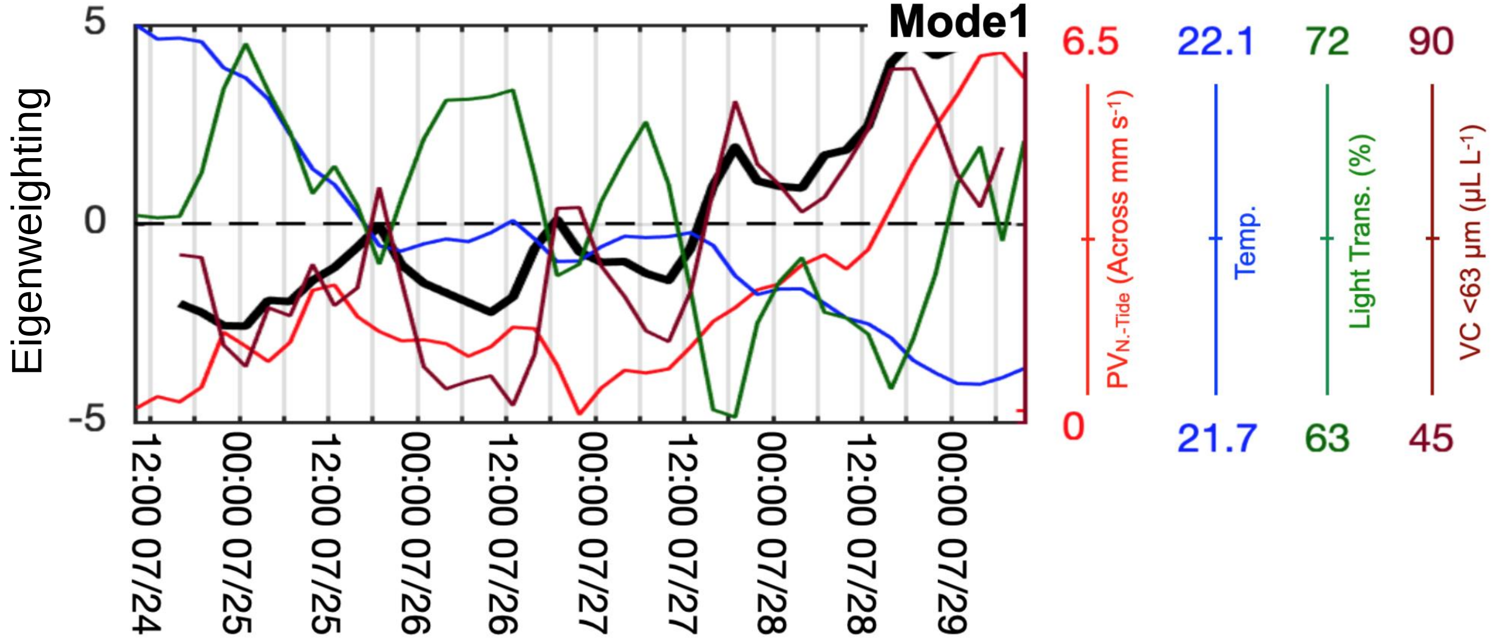
New
(Water Movement)

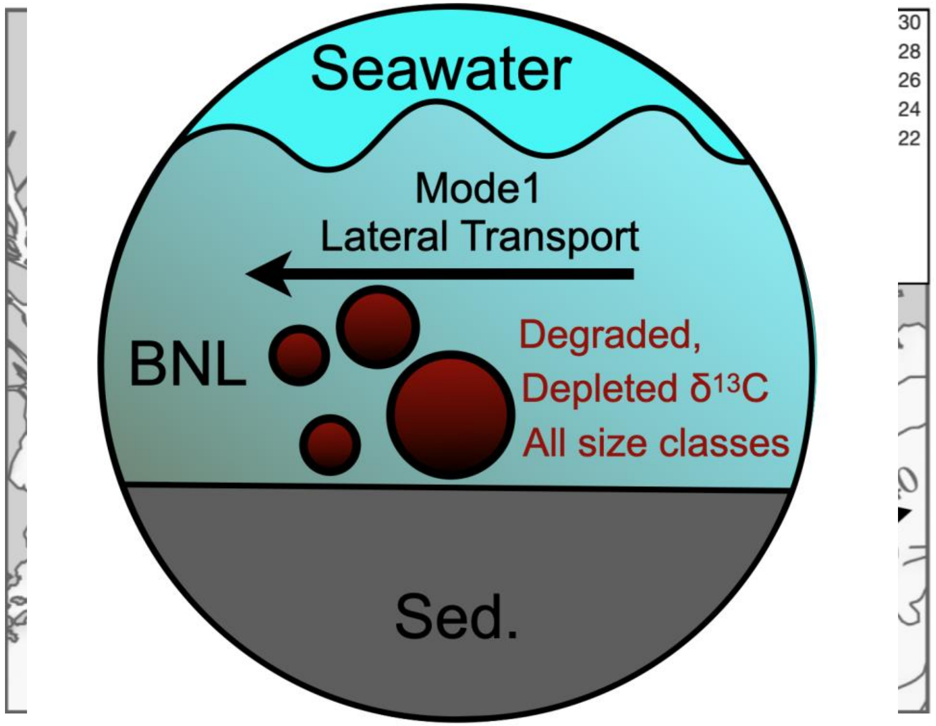
How?



- EOF (Bottom; 38 m)

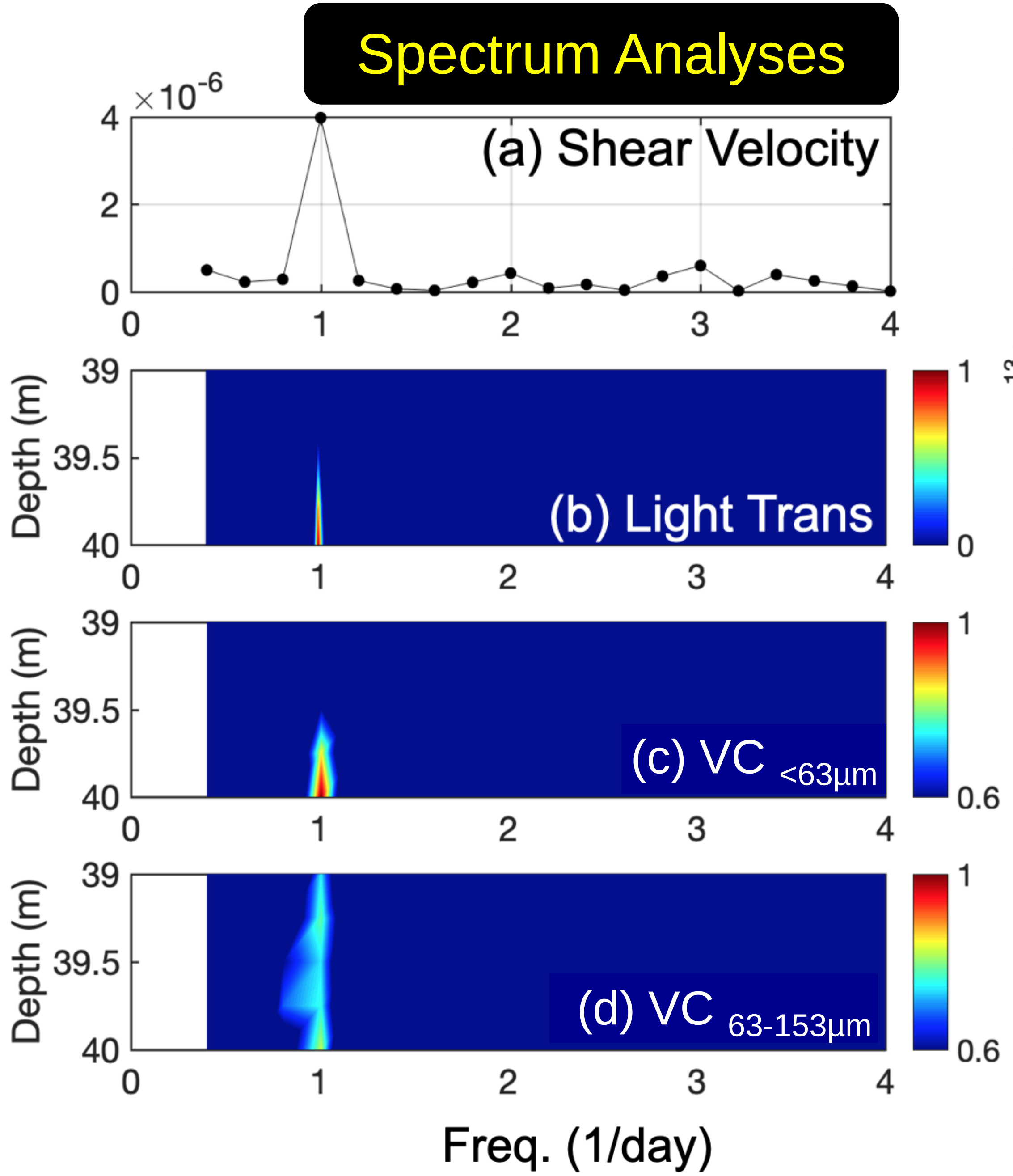


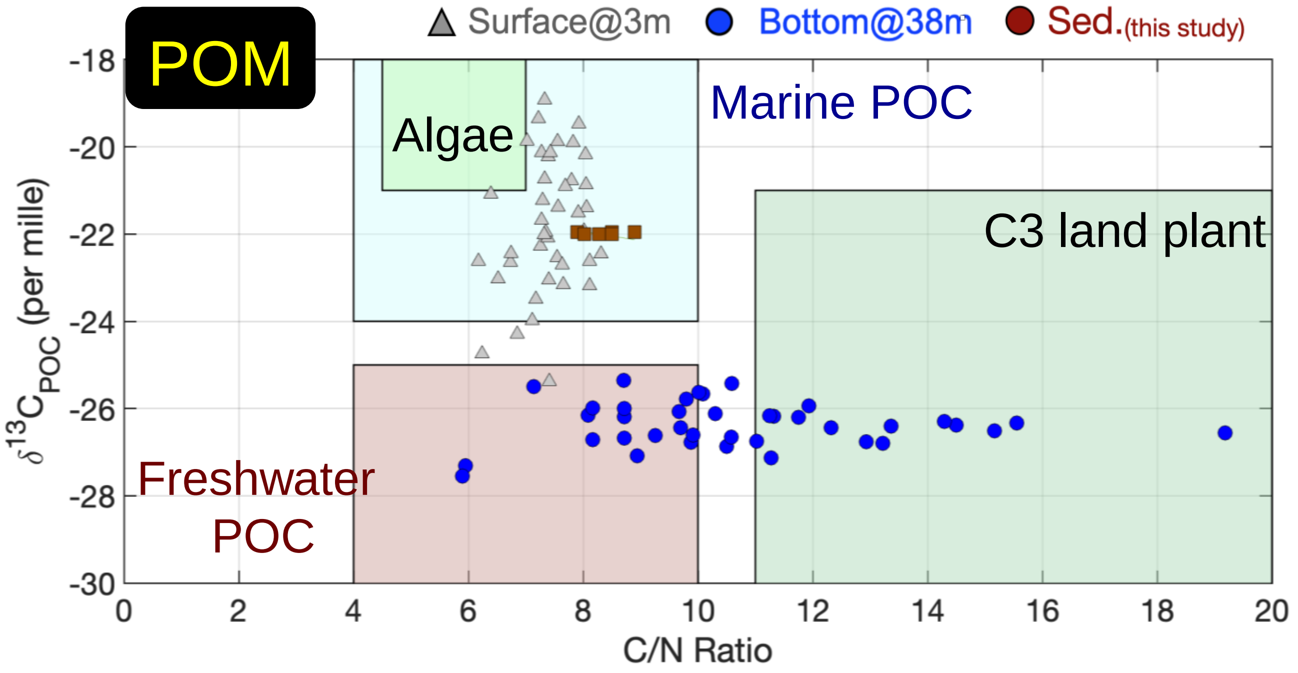


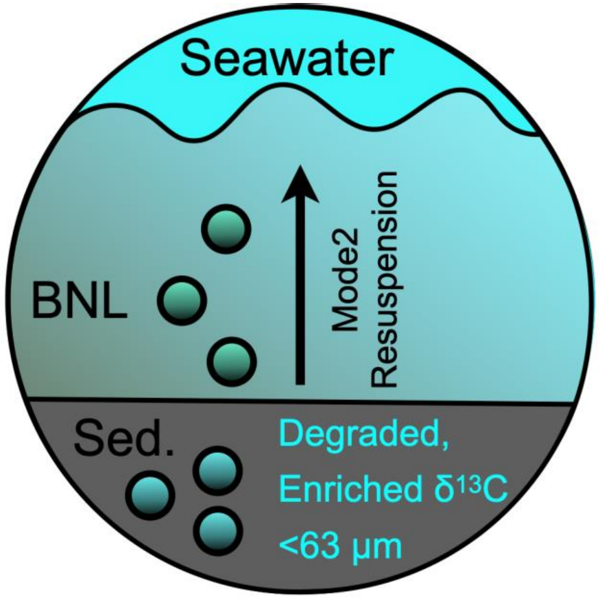


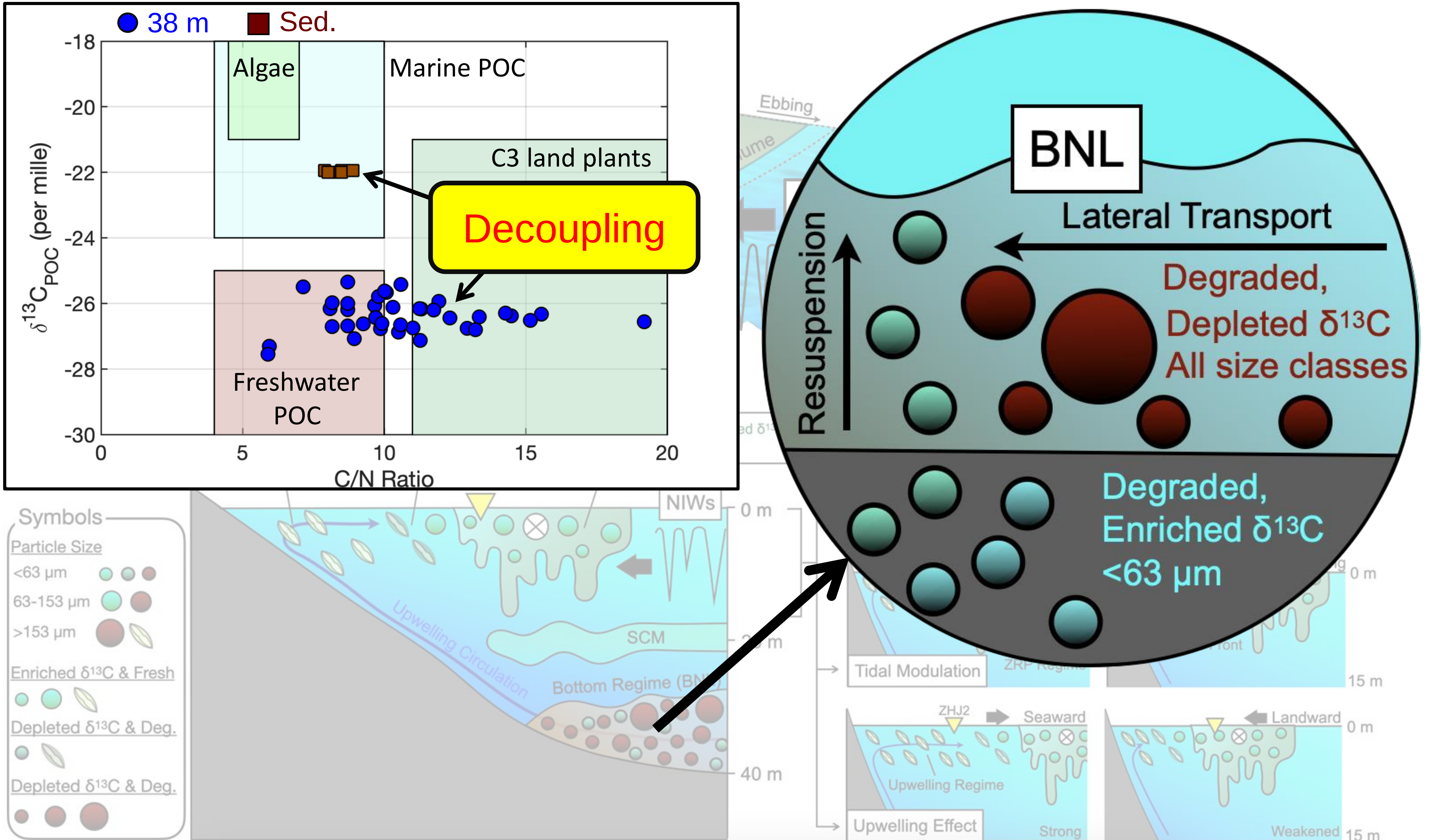
- ➢ Across-shore flow
- ➢ Low temperature
- ➢ Decreasing light trans.
- ➢ Degraded POM
- ➢ Depleted $\delta^{13}C$
- ➢ <63 μm particles mainly

- EOF (Bottom)


Spectrum Analyses
×10^-6
(a) Shear Velocity
(b) Light Trans
(c) VC <63μm
(d) VC 63-153μm
Depth (m)
Freq. (1/day)


POM
Surface@3m
Bottom@38m
Sed.(this study)
Algae
Marine POC
C3 land plant
Freshwater POC
δ13C POC (per mille)
C/N Ratio


Seawater
BNL
Mode2 Resuspension
Sed.
Degraded,
Enriched δ13C
<63 μm


38 m
Sed.
Algae
Marine POC
C3 land plants
Decoupling
Freshwater POC
$\delta^{13}C_{POC}$ (per mille)
C/N Ratio
-18
-20
-22
-24
-26
-28
-30
0
5
10
15
20
BNL
Lateral Transport
Resuspension
Degraded, Depleted δ13C All size classes
Degraded, Enriched δ13C <63 μm
Symbols
Particle Size
<63 μm
63-153 μm
>153 μm
Enriched δ13C & Fresh
Depleted δ13C & Deg.
Depleted δ13C & Deg.
Ebbing
NIWs
0 m
SCM
Upwelling Circulation
Bottom Regime (BNL)
40 m
Tidal Modulation
ZHJ2
Seaward
Landward
Upwelling Regime
Upwelling Effect
Strong
Weakened
15 m