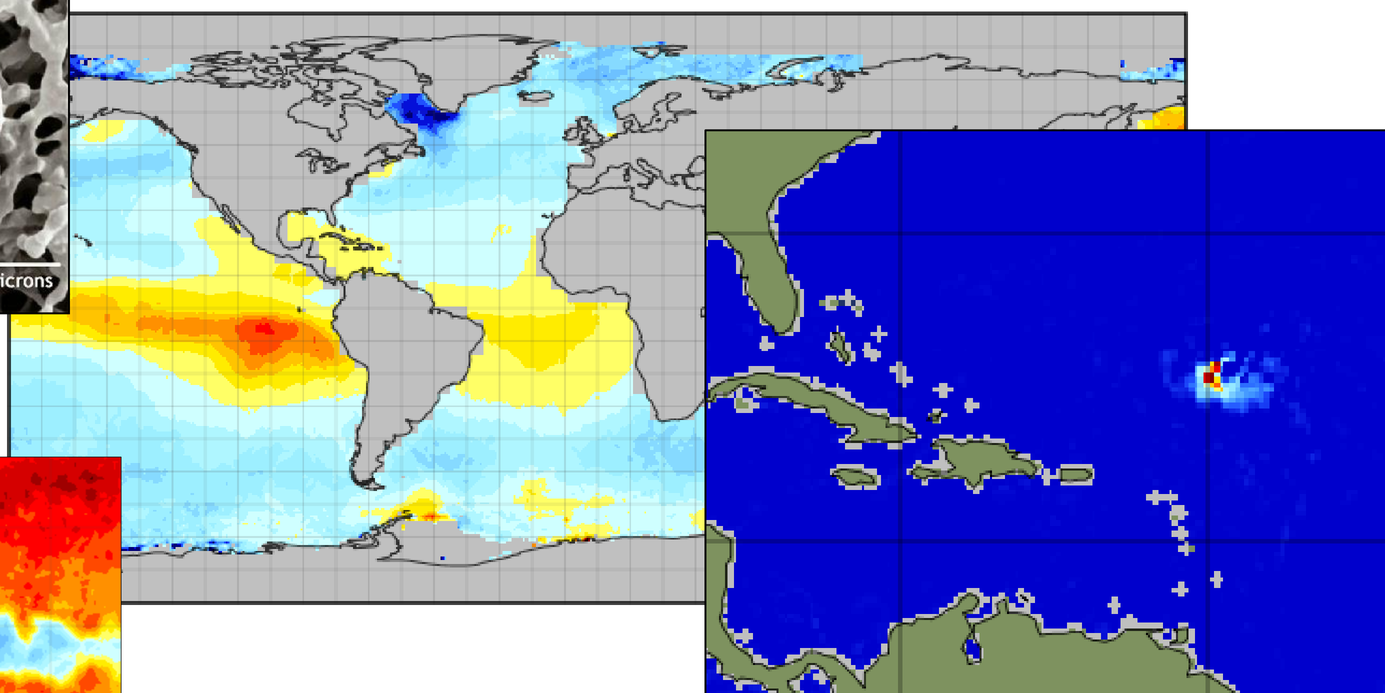
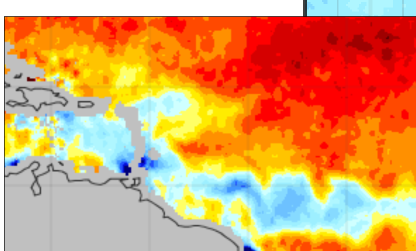
Marine carbon from space

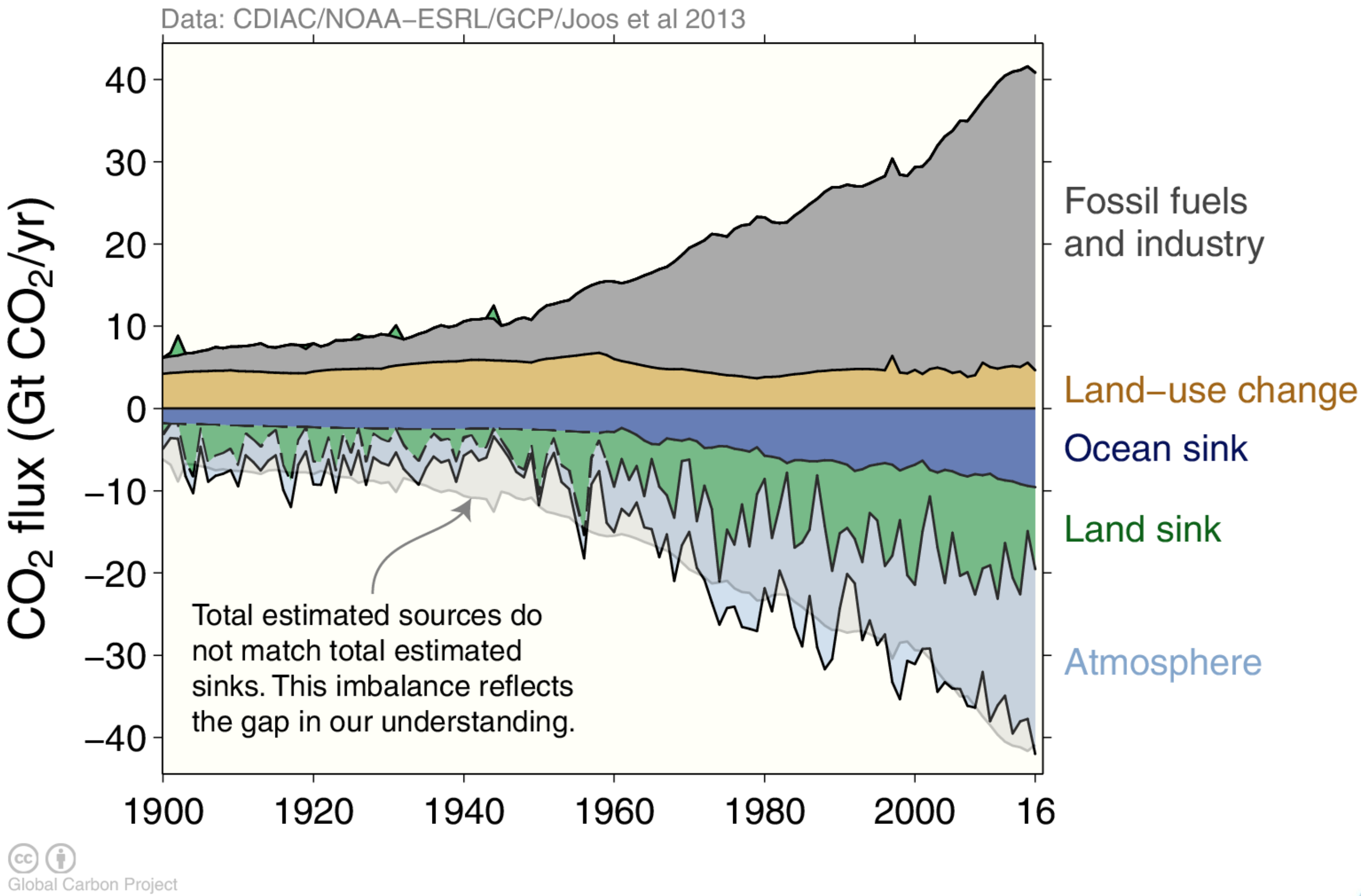
Jamie Shutler, University of Exeter, UK

j.d.shutler@exeter.ac.uk



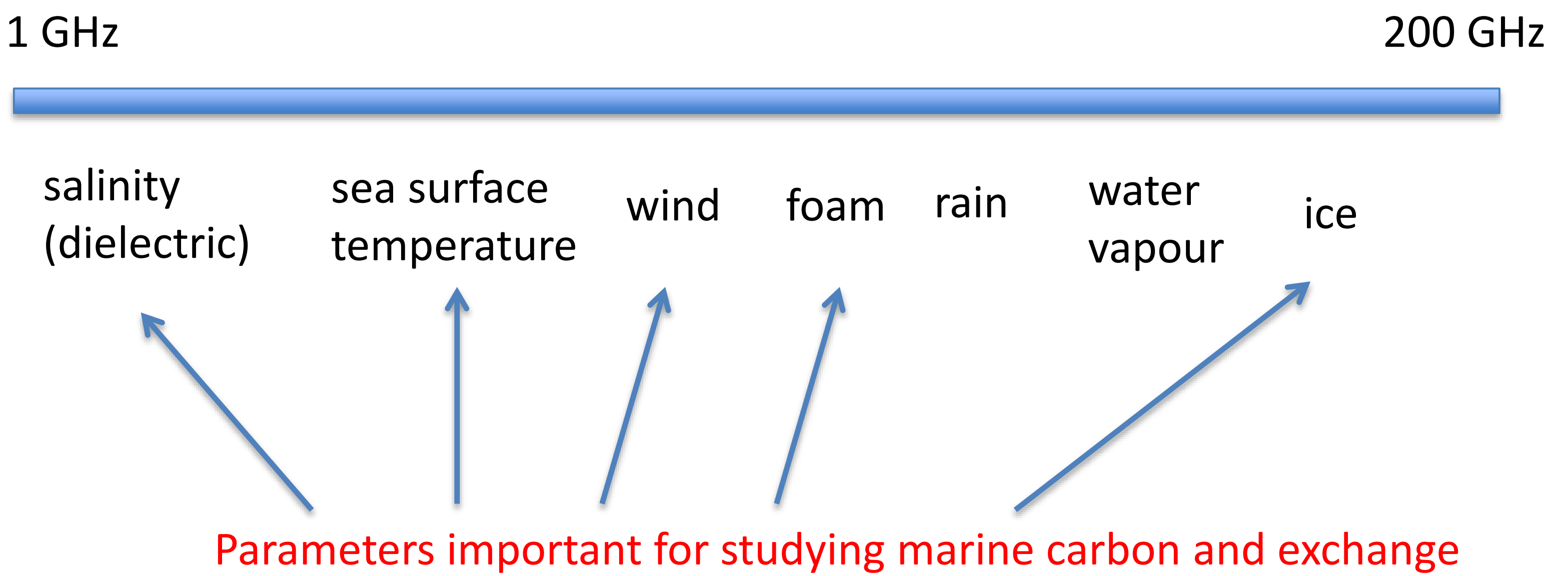


The importance of monitoring the oceans



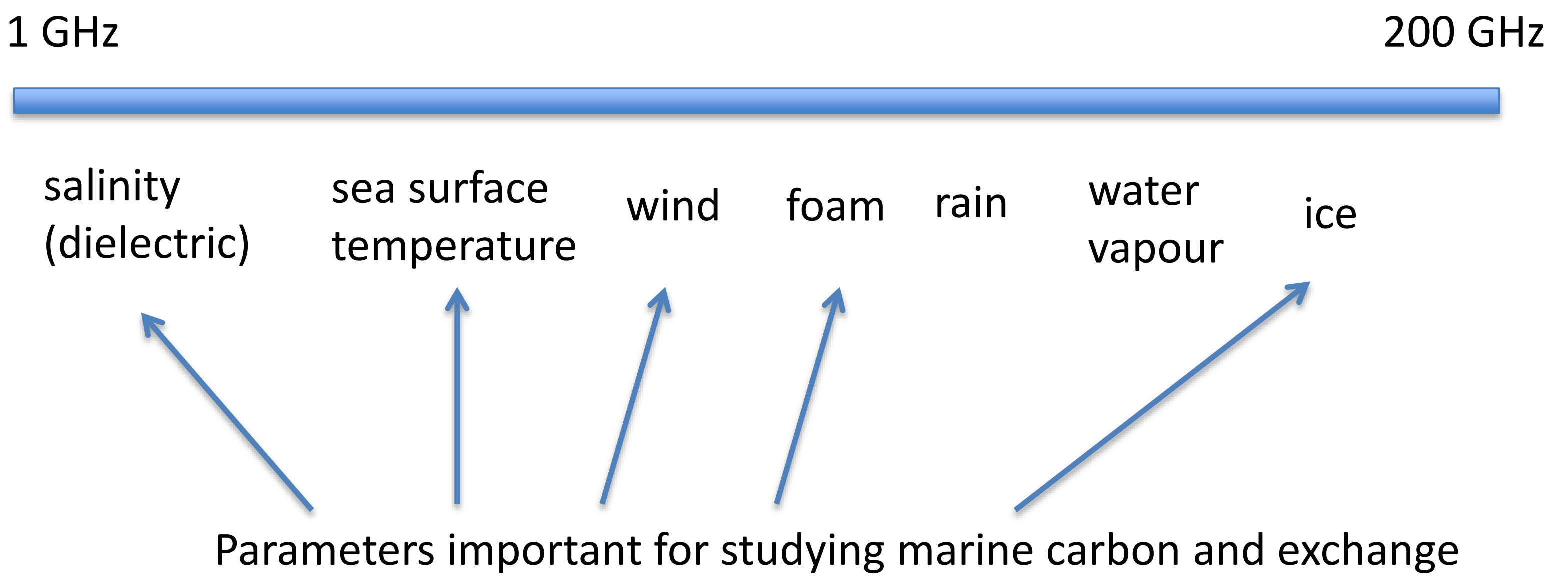
GLOBAL CARBON PROJECT

Passive microwave – key for monitoring marine carbon



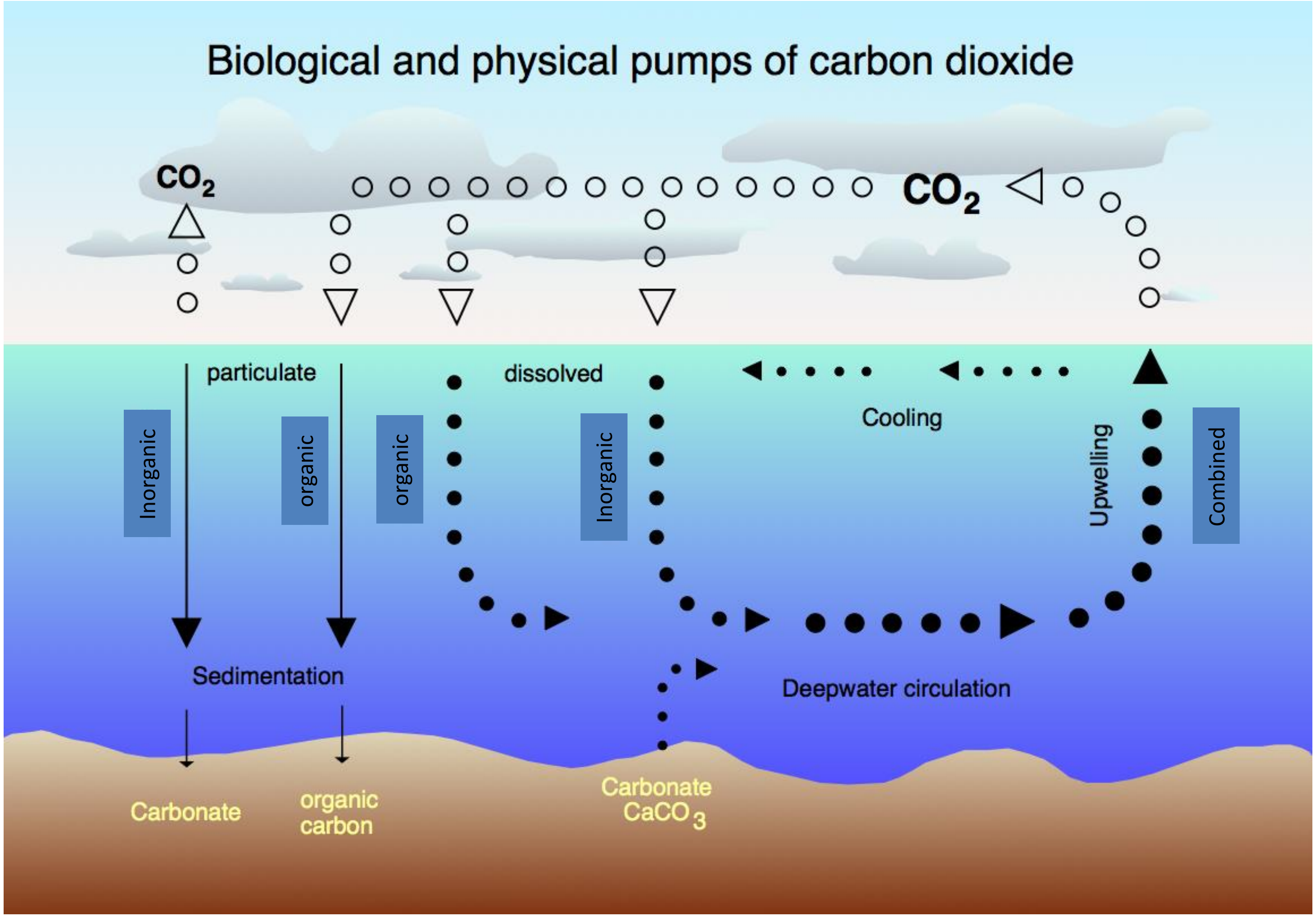
Highlight further potential of passive microwave measurements.

Passive microwave – key for monitoring marine carbon



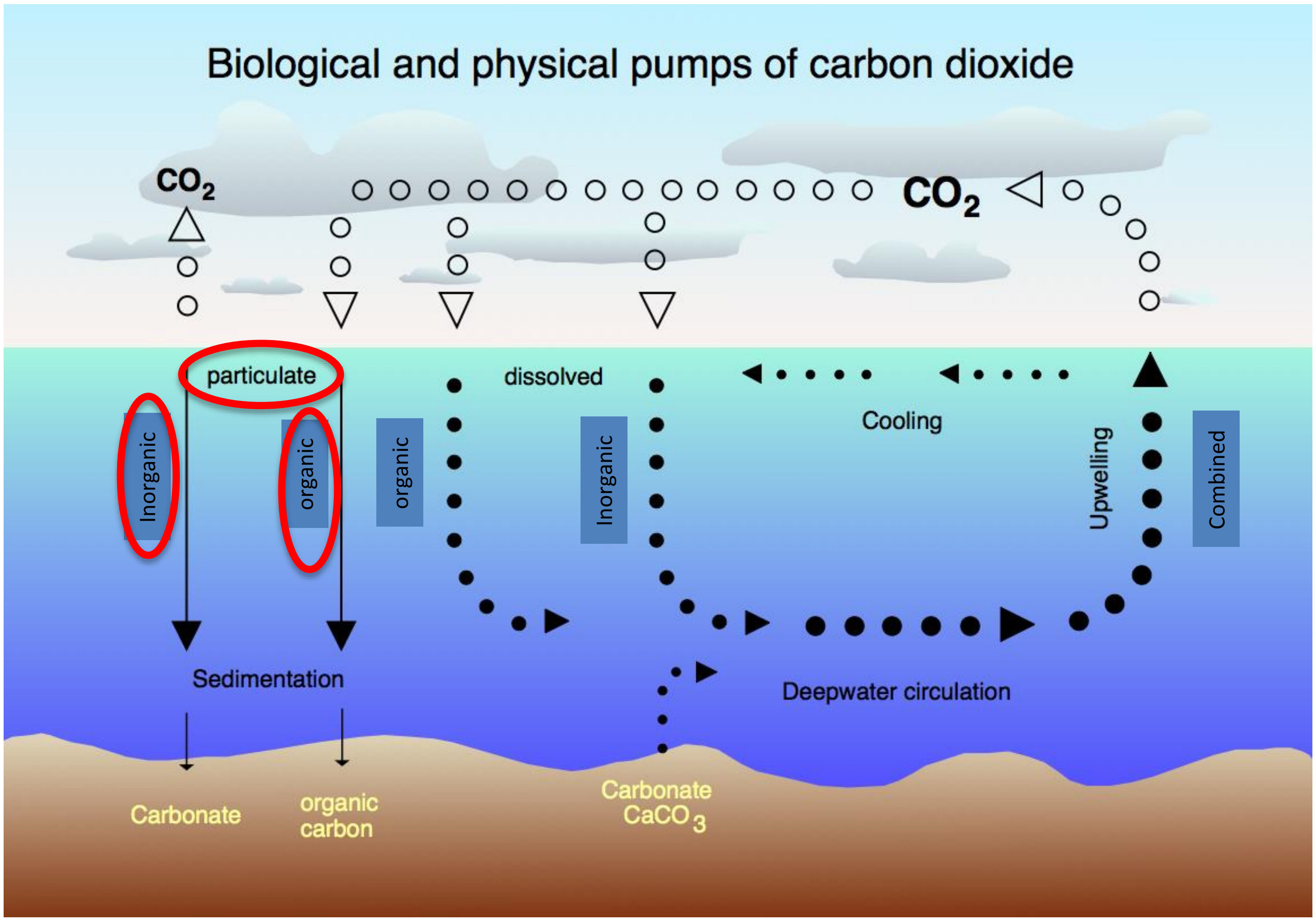
Highlight further potential of passive microwave measurements.

Marine carbon cycle



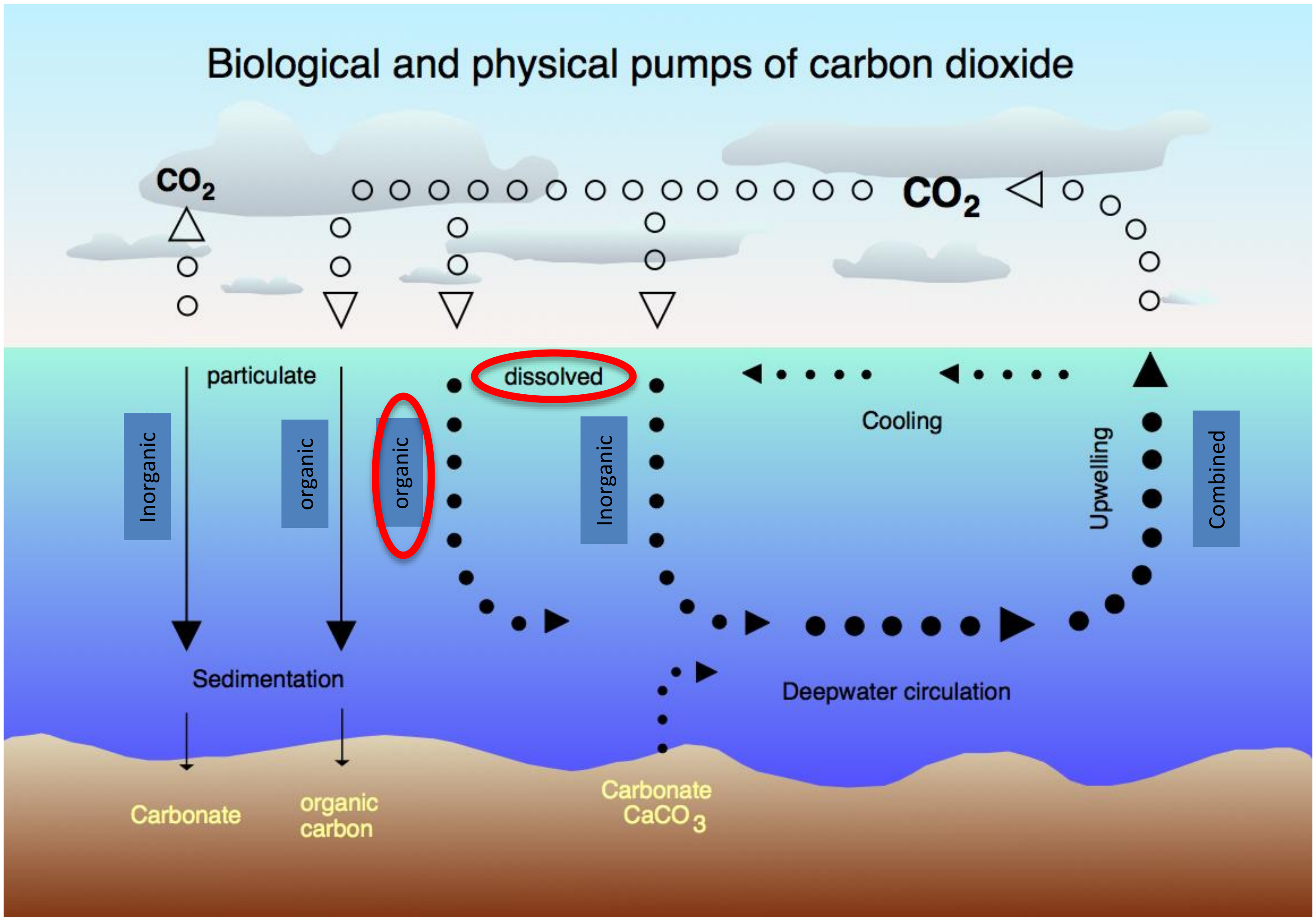
Marine carbon cycle

Visible spectrum ocean colour observations



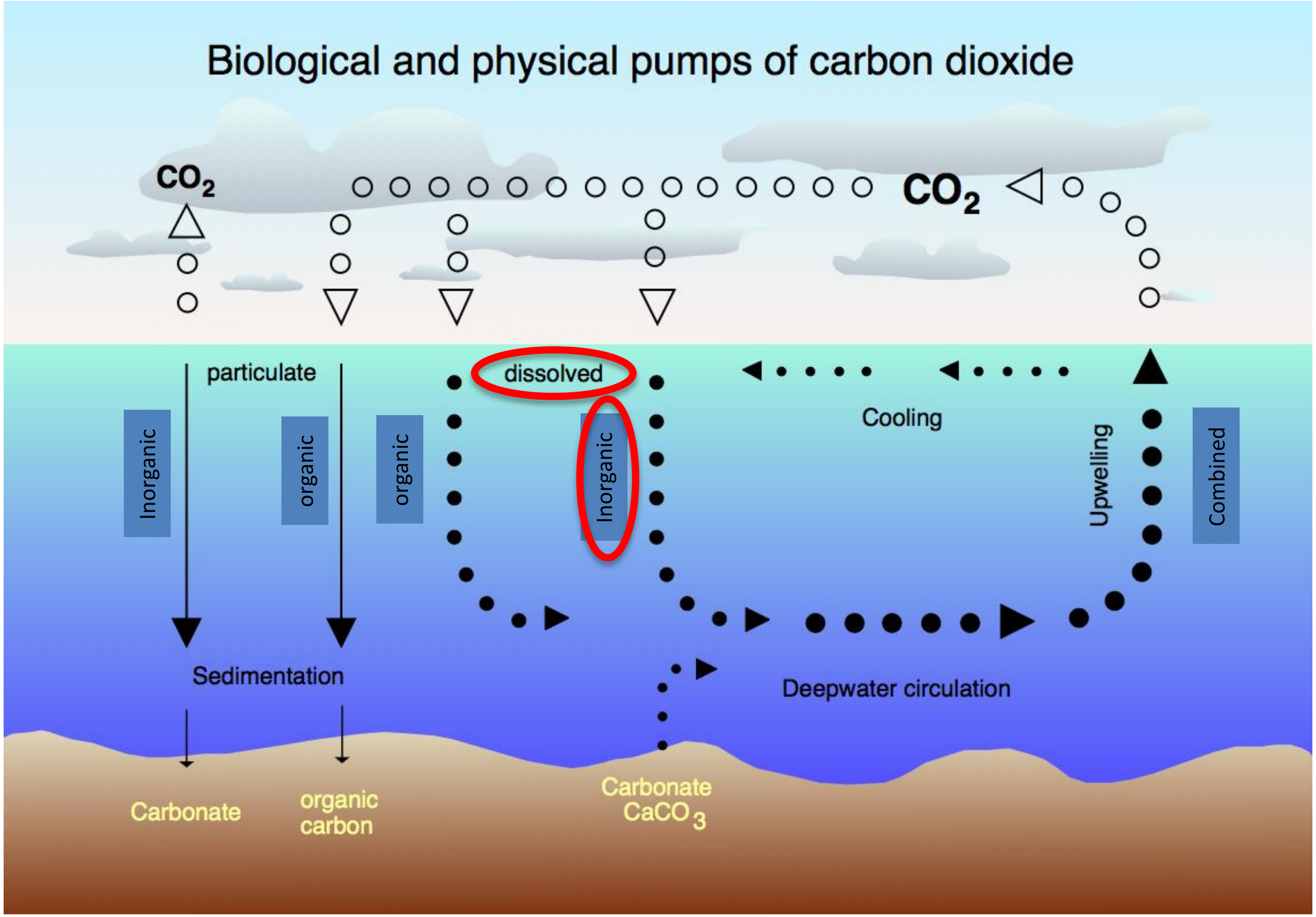
Marine carbon cycle

Visible spectrum ocean colour observations (but could use passive microwave!)



Marine carbon cycle

Thermal infrared/passive microwave (SST), passive microwave (SSS), passive and active microwave (wind, ice)



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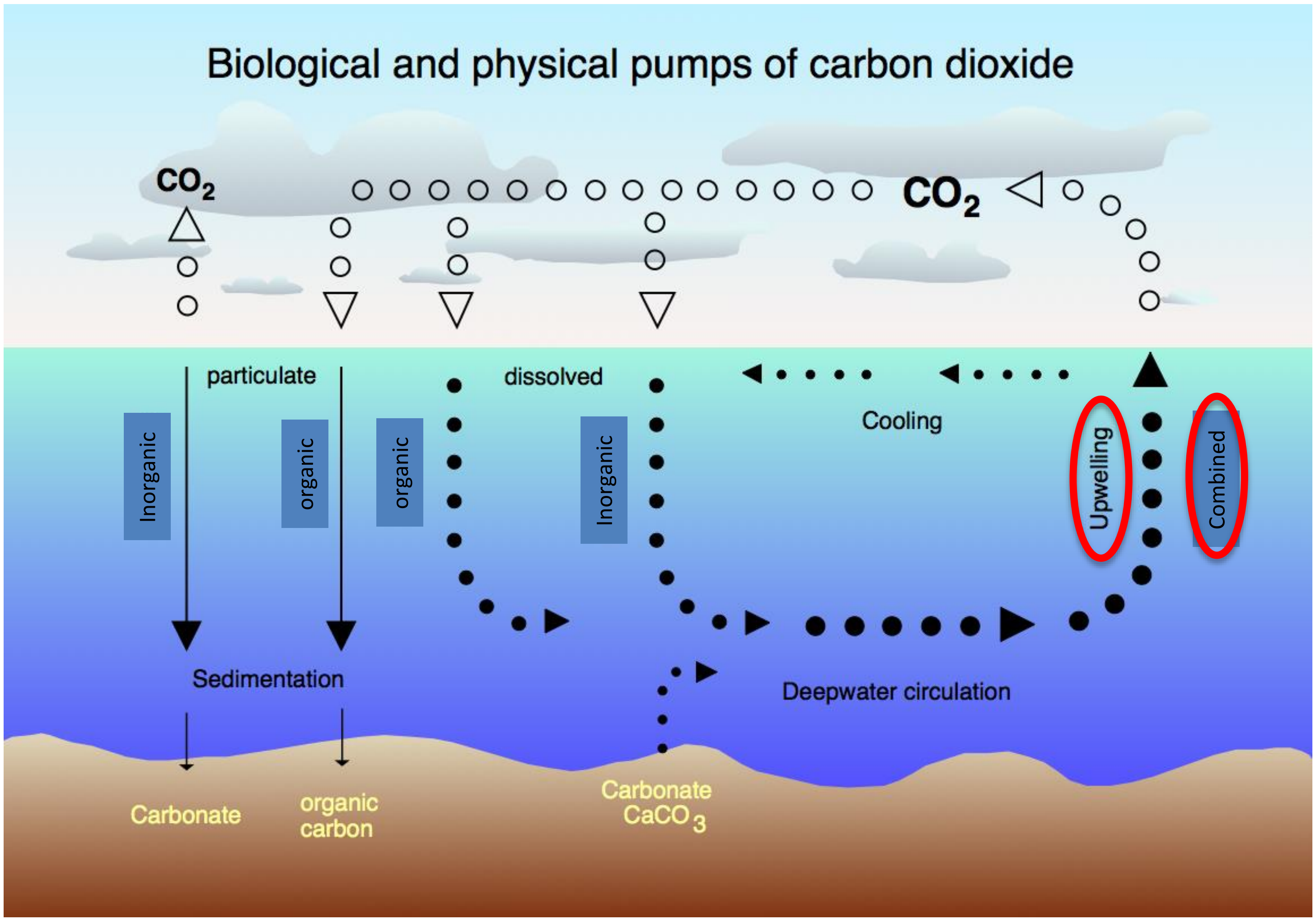

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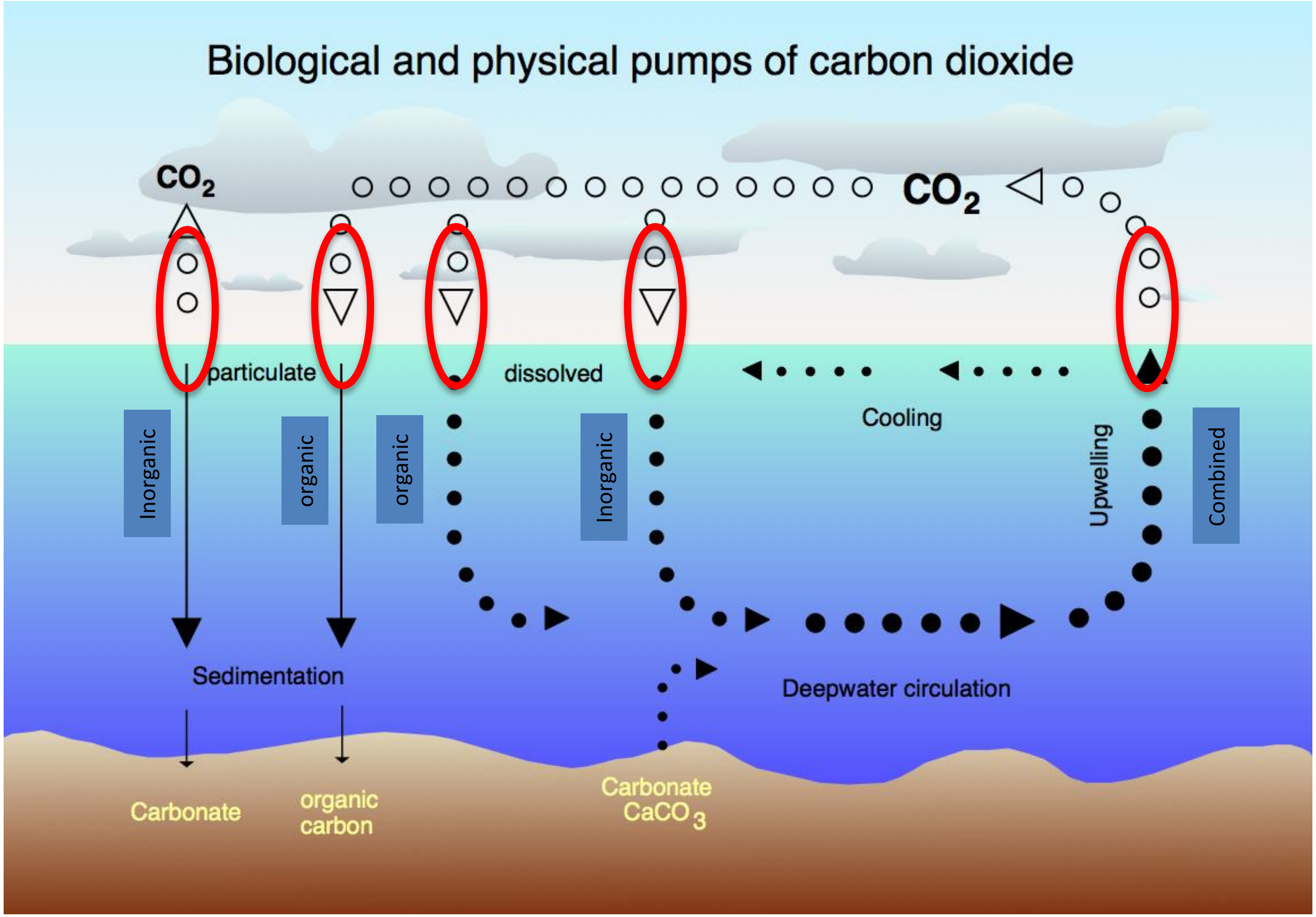
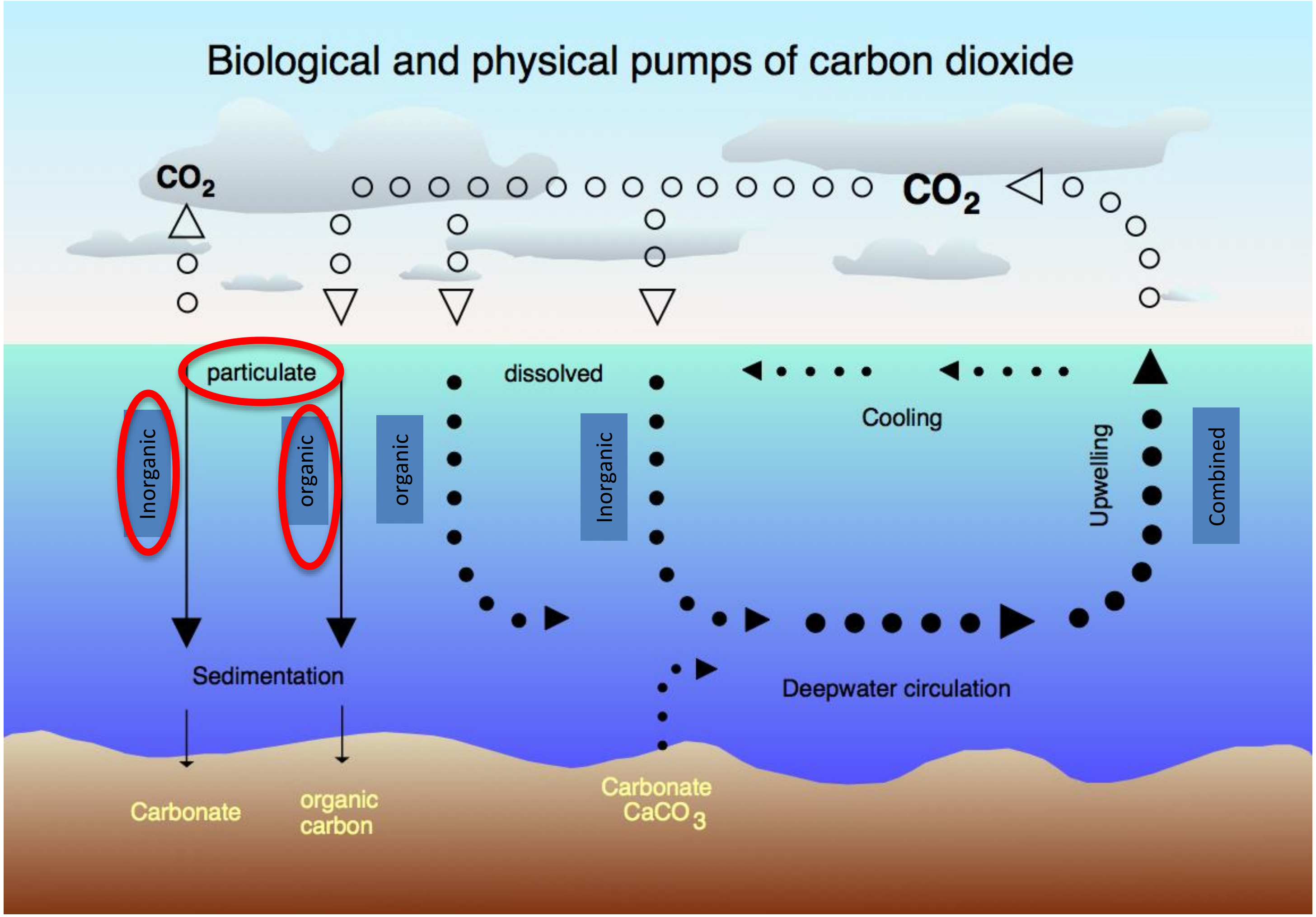


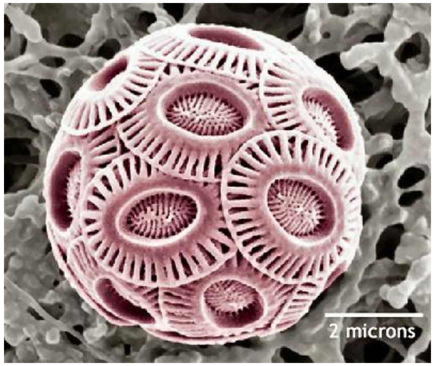
Marine carbon cycle

Visible spectrum ocean colour observations

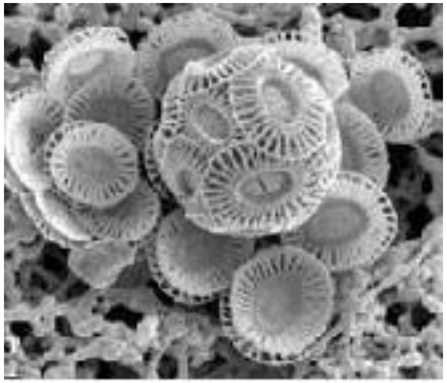


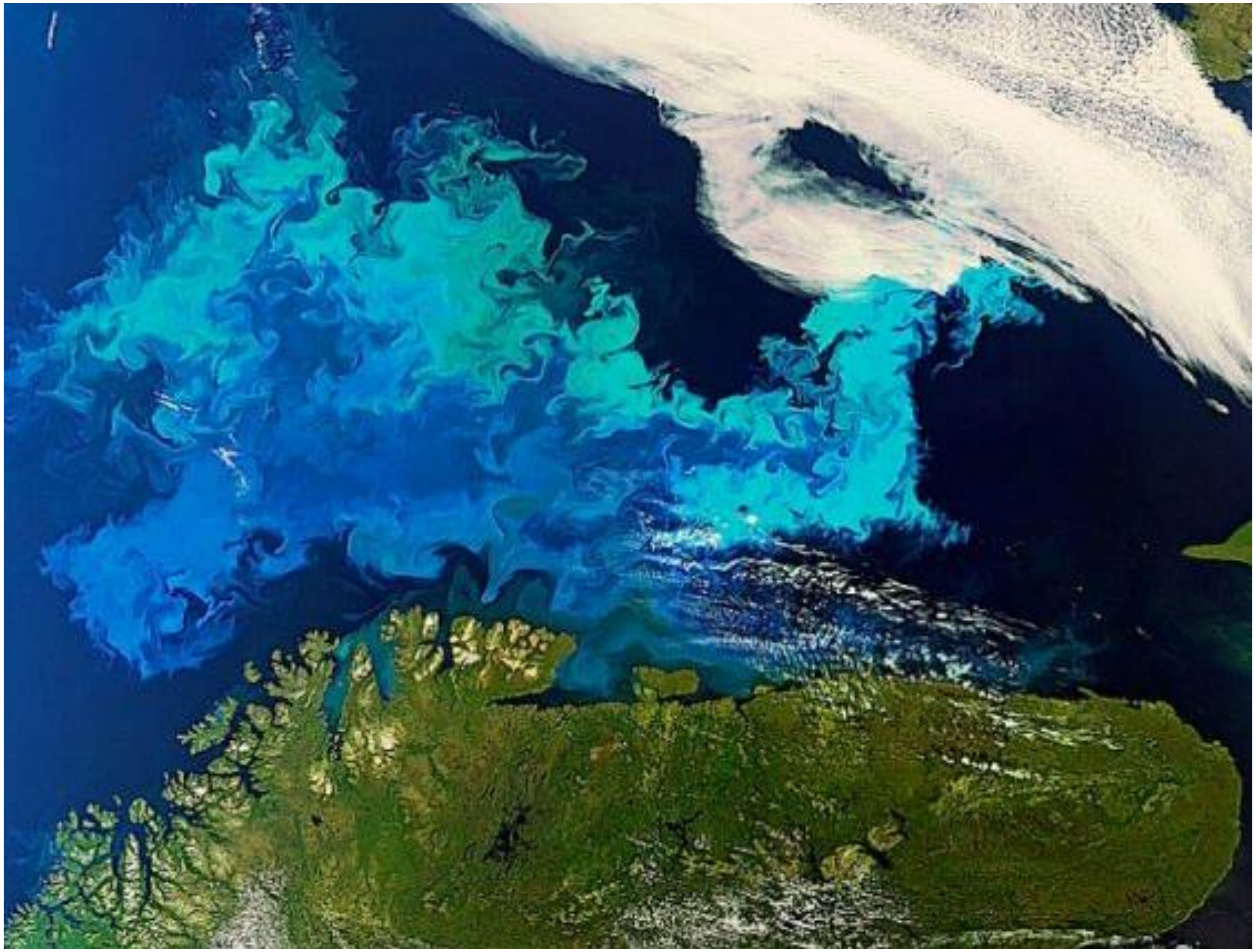
Particulate Inorganic Carbon (PIC) coccolithophores

Visible spectrum ocean colour observations



Emiliania huxleyi





Particulate Inorganic Carbon (PIC) coccolithophores

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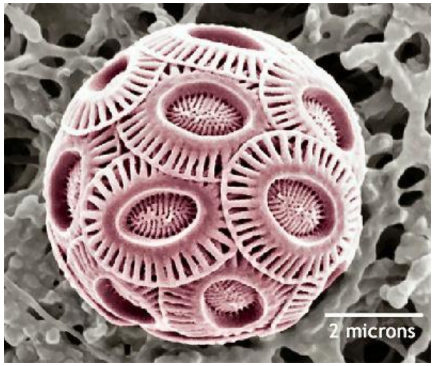

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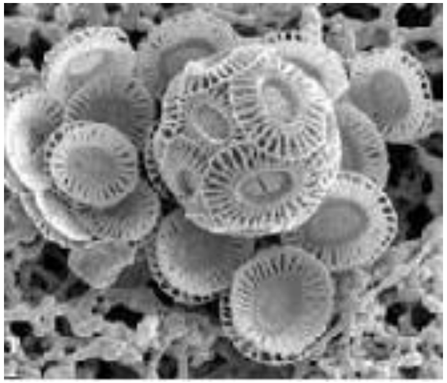
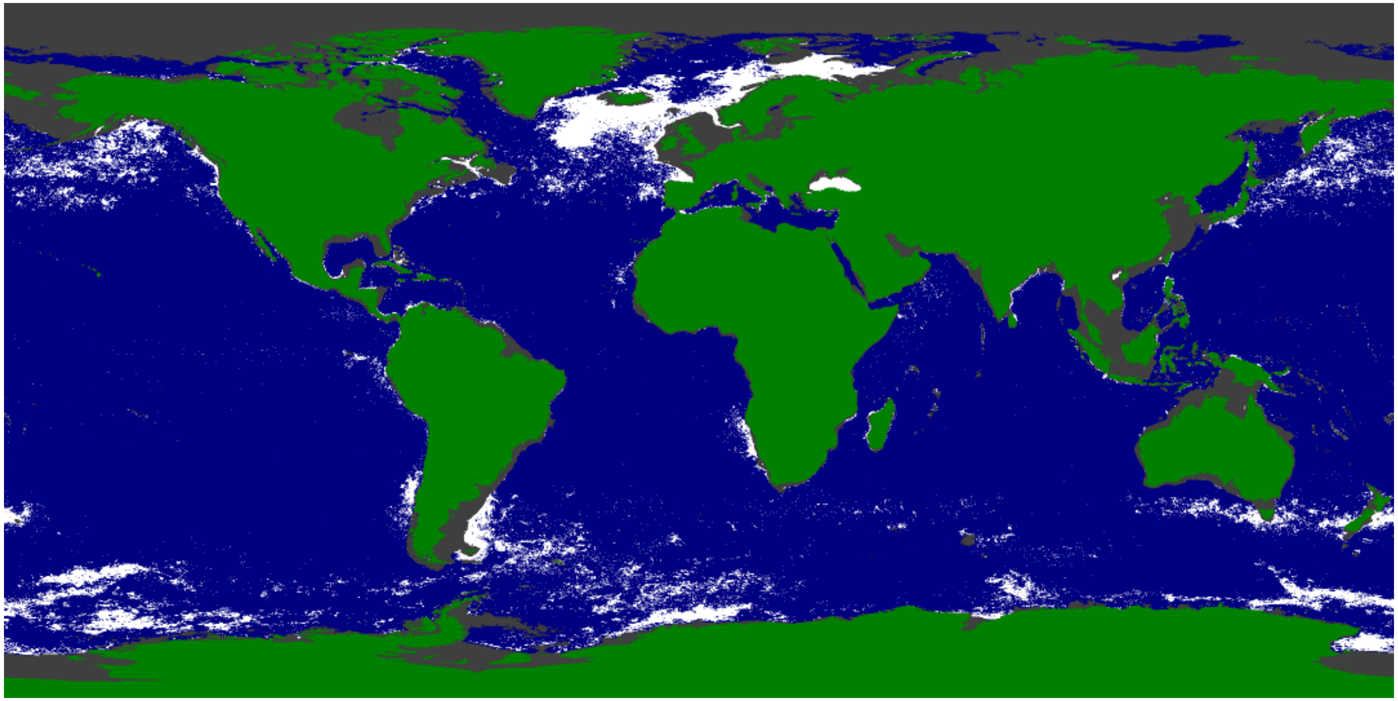
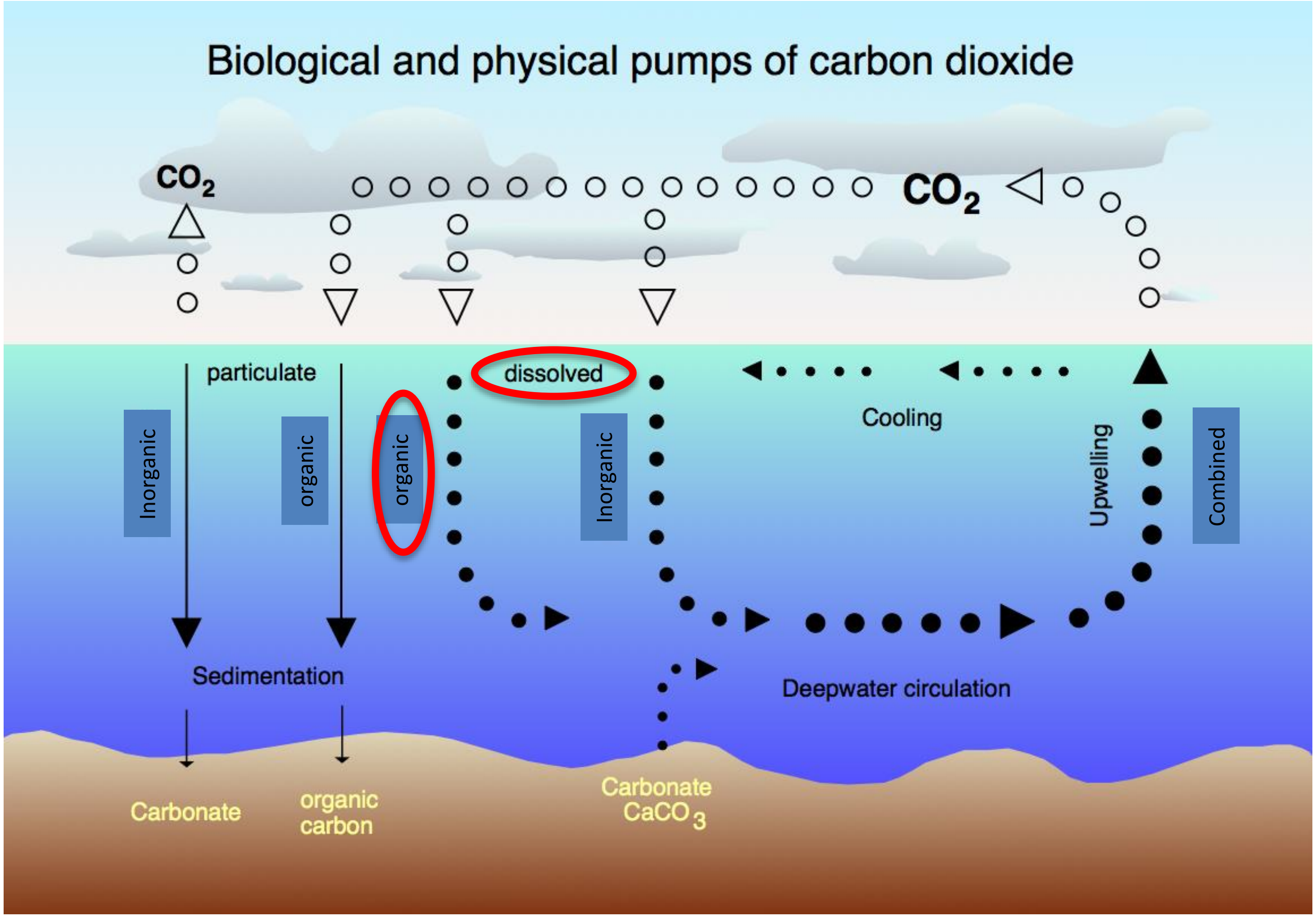




Sensor: SeaWiFS, 1997-2009 accumulated coverage

Marine carbon cycle

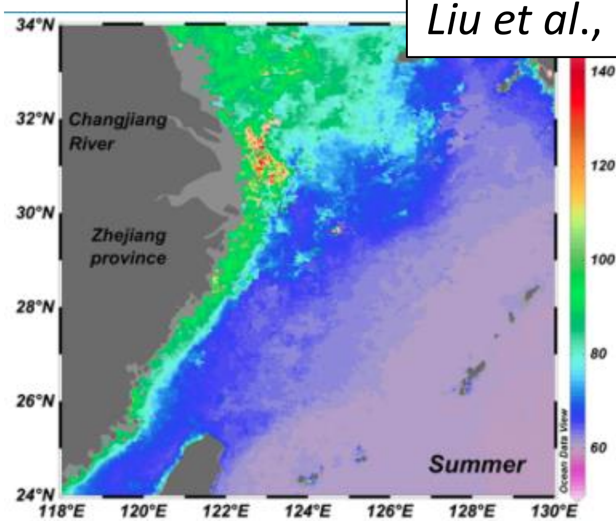
Visible spectrum ocean colour observations



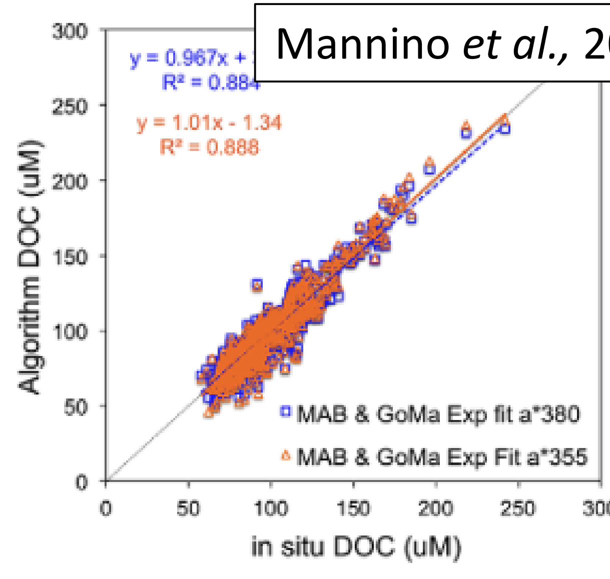
Dissolved organic carbon (DOC)

DOC has many components, one is Colored Dissolved Organic Matter (CDOM)
DOC correlates with a_{CDOM} in coastal, estuarine and shelf seas.
Regional approaches, exploit DOC-a_{CDOM}-salinity linkages.
Published methods ocean colour satellite sensors.

Liu et al., 2014



Mannino *et al.*, 2016

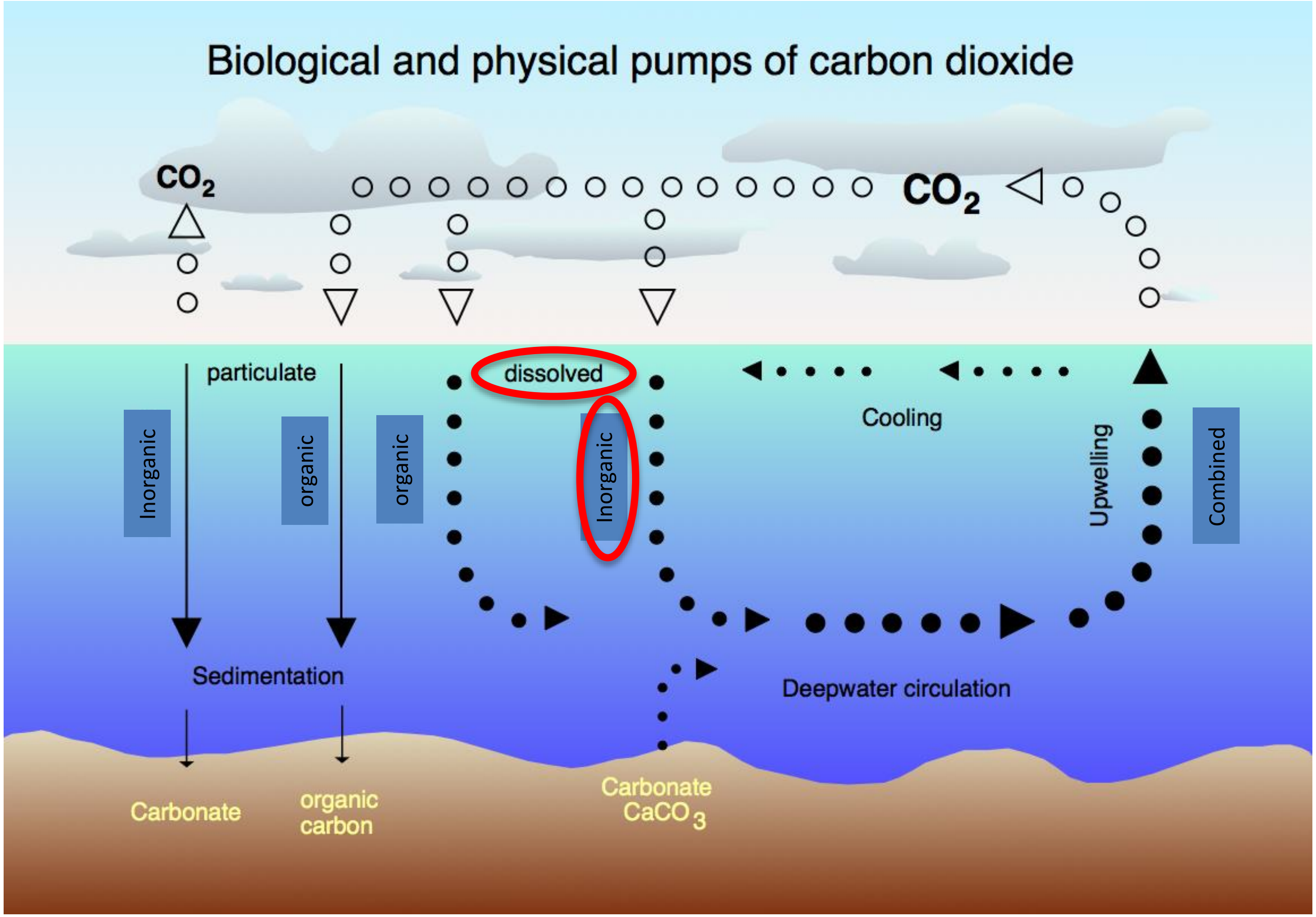


Stocks:
Del Castillo and Miller, 2008; *Mannino et al.*, 2008; *Griffin et al.*, 2011; *López et al.*, 2012; *Liu et al.*, 2014; Mannino *et al.*, 2016.

Fluxes:
Del Castillo and Miller, 2008; *López et al.*, 2012; Mannino *et al.*, 2016

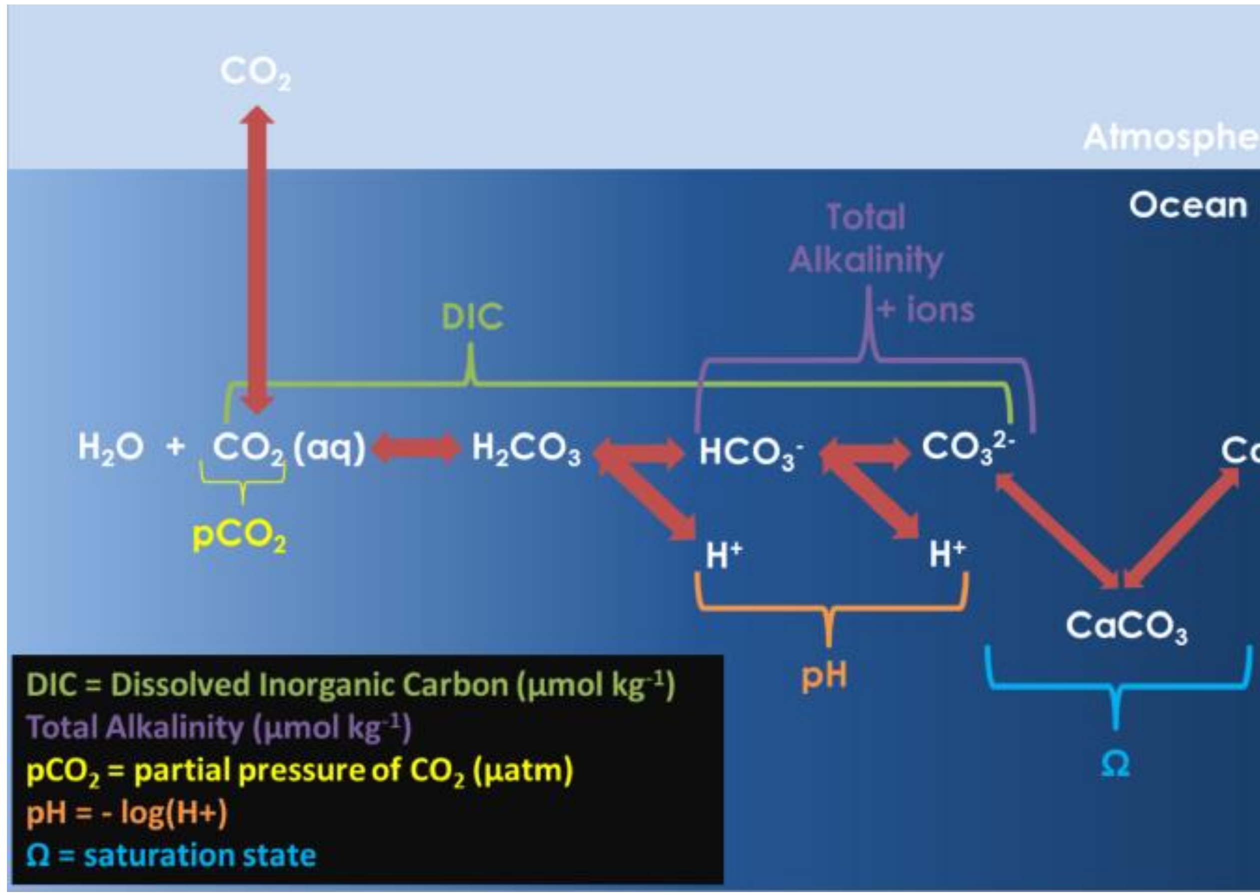
Marine carbon cycle

Thermal infrared/passive microwave (SST), passive microwave (SSS), passive and active microwave (wind, ice)



Ocean acidification (inorganic carbon)

Increasing pCO_2 decreases the pH of the water (CO_2 reacts with water for form carbonic acid which releases H^+ ions and reduces the pH). So, known as 'the other CO_2 problem'.



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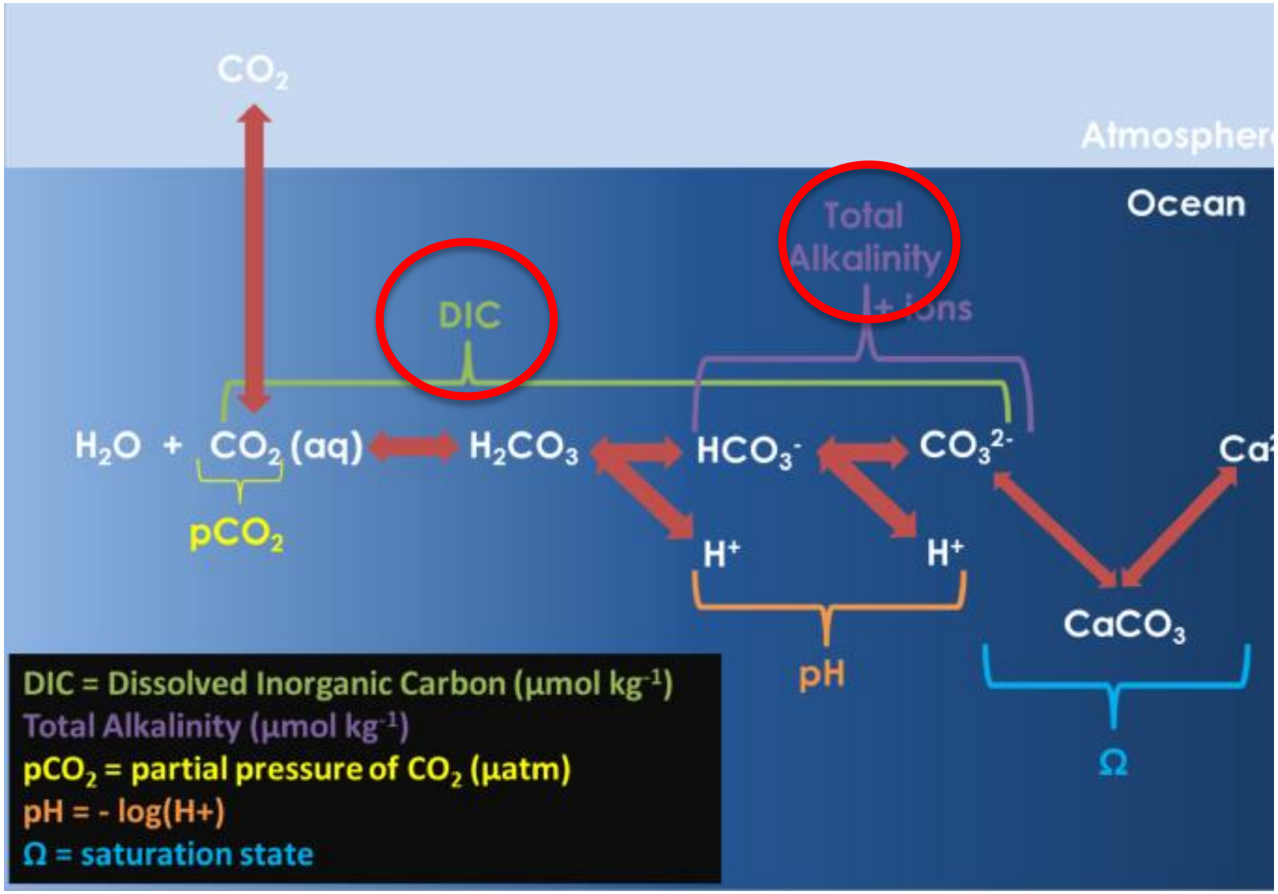
Determining two parameters along with knowledge of salinity and temperature enables you to resolve whole system.



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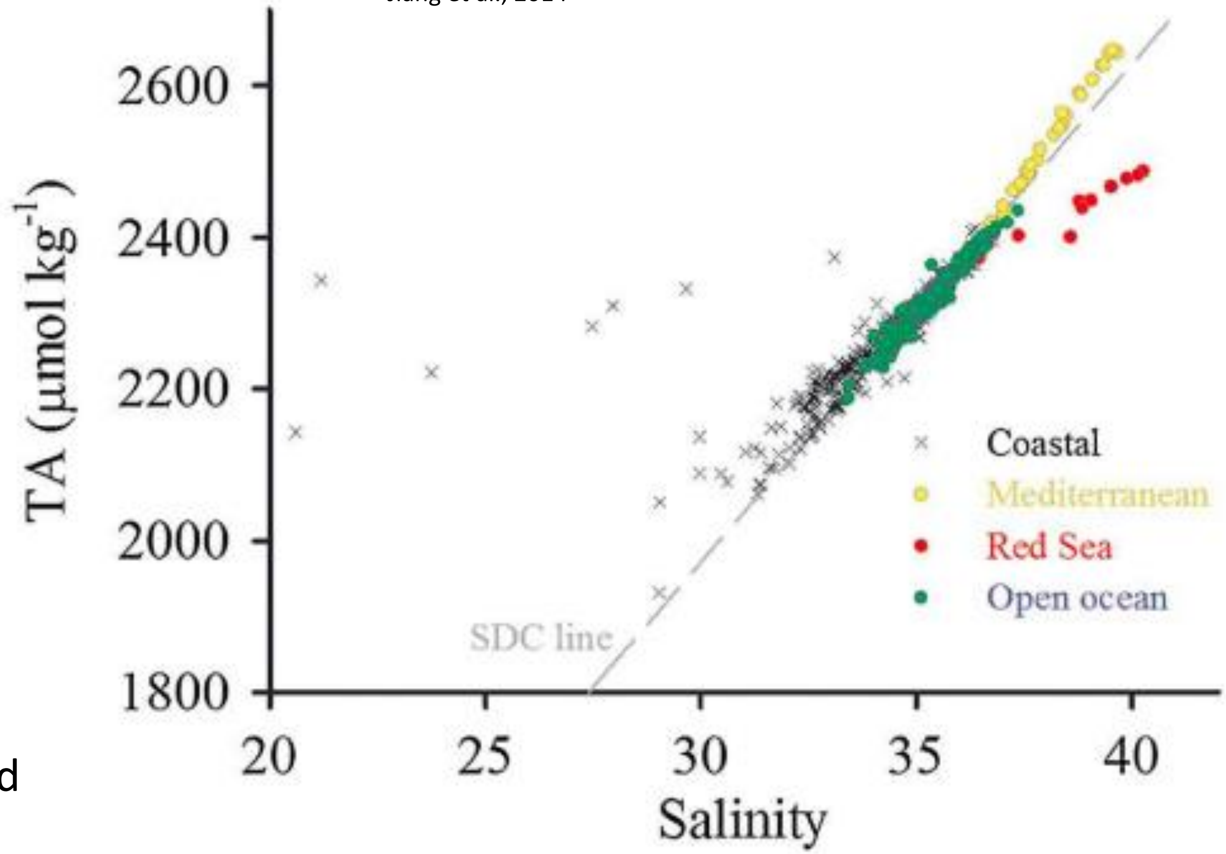
Jiang et al., 2014

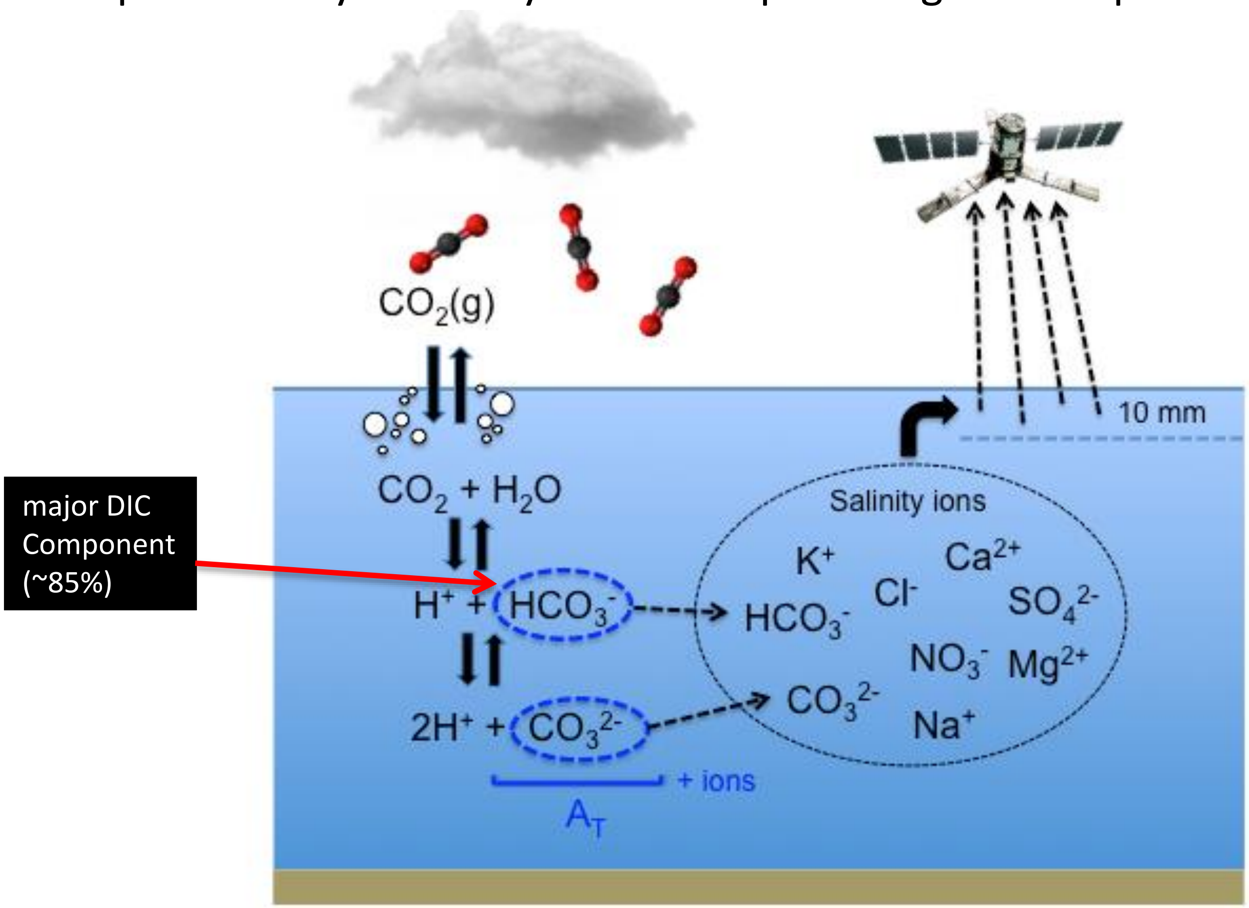


Alkalinity is highly correlated (conserved) with salinity (and temperature).

DIC highly correlated with temperature (and salinity)

Ocean acidification (inorganic carbon)

L-band Salinity and thermal infrared temperature from space allows space-based observations of total alkalinity (A_T) and DIC.
Exploit salinity-alkalinity relationships via regional empirical algorithms



Capability from space identified by:

Land et al., 2015
Salisbury et al., 2015

Review and forward look

Environmental Science & Technology

Feature

pubs.acs.org/est

Salinity from Space Unlocks Satellite-Based Assessment of Ocean Acidification

Peter E. Land,*[,†] Jamie D. Shutler,[‡] Helen S. Findlay,[†] Fanny Girard-Ardhuin,[§] Roberto Sabia,[∥] Nicolas Reul,[§] Jean-Francois Piolle,[§] Bertrand Chapron,[§] Yves Quilfen,[§] Joseph Salisbury,[⊥] Douglas Vandemark,[⊥] Richard Bellerby,[#] and Punyasloke Bhadury[∇]

[†]Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, U.K.

[‡]University of Exeter, Penryn Campus, Cornwall TR10 9FE, U.K.

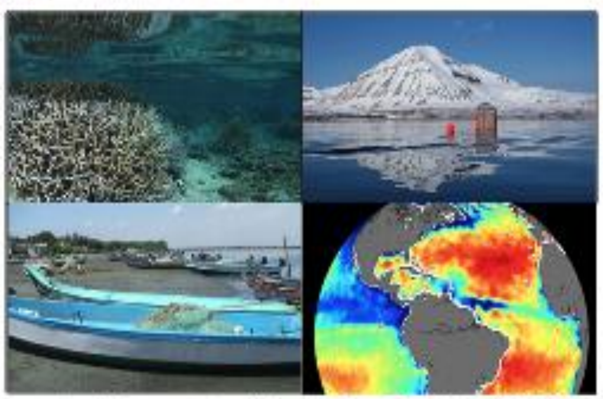
[§]Institut Francais Recherche Pour ĹExploitation de la Mer, Pointe du Diable, 29280 Plouzané France

[∥]Telespazio-Vega U.K. for European Space Agency (ESA), ESTEC, Noordwijk, The Netherlands

[⊥]Ocean Processes Analysis Laboratory, University of New Hampshire, Durham, New Hampshire 3824, United States

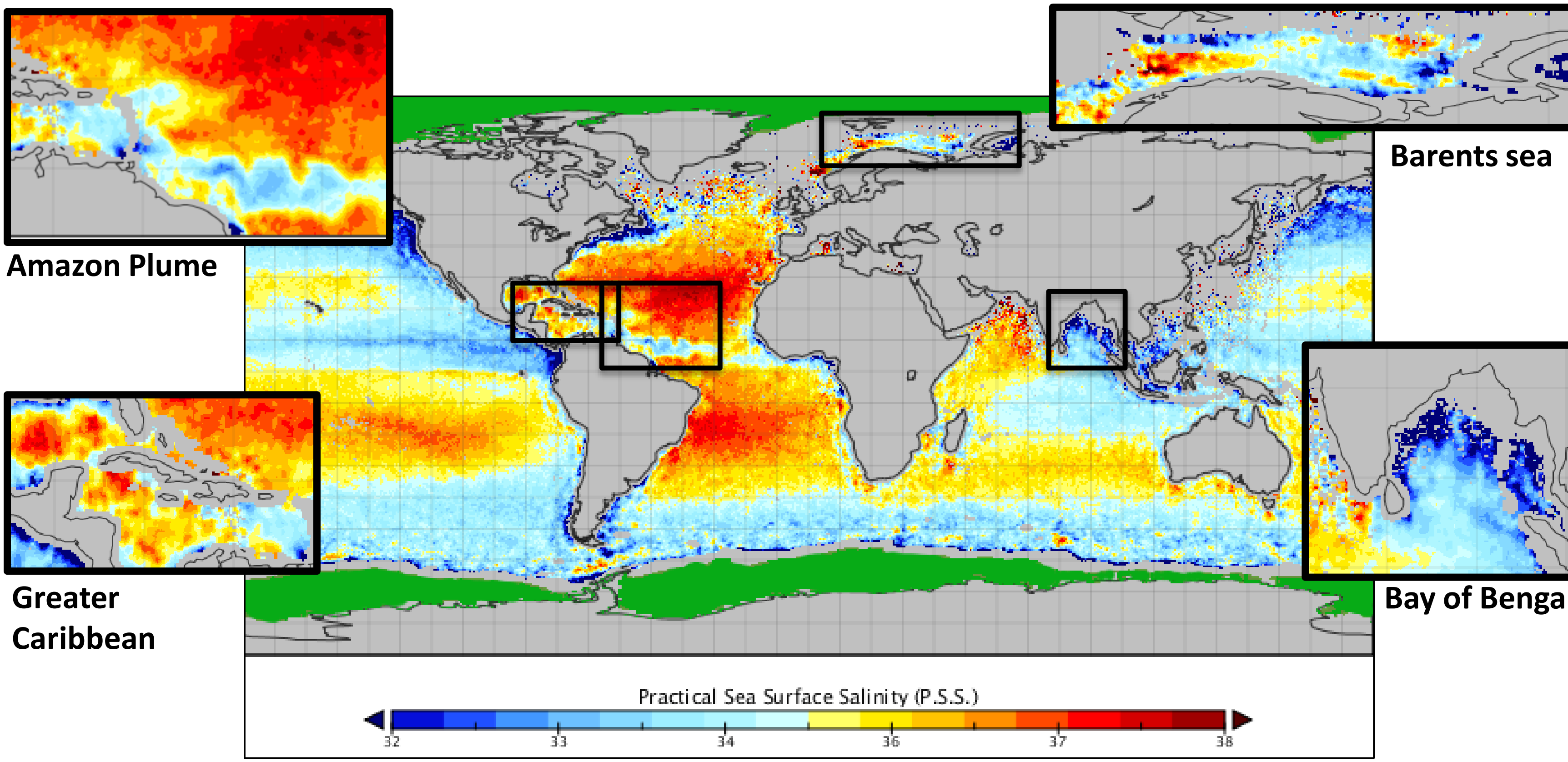
[#]Norwegian Institute for Water Research, Thormøhlensgate 53 D, N-5006 Bergen, Norway

[∇]Department of Biological Sciences, Indian Institute of Science Education and Research-Kolkata, Mohanpur 741 246, West Bengal India



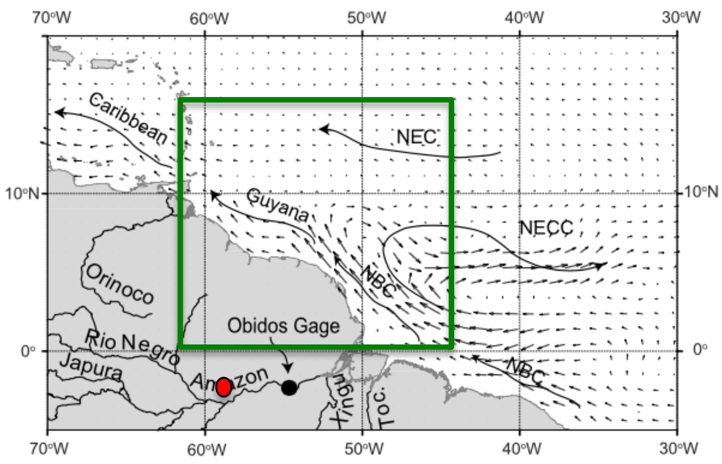
Highlights that L-band salinity from space enables us to monitor and study marine carbonate parameters.

ESA Pathfinders Ocean Acidification project

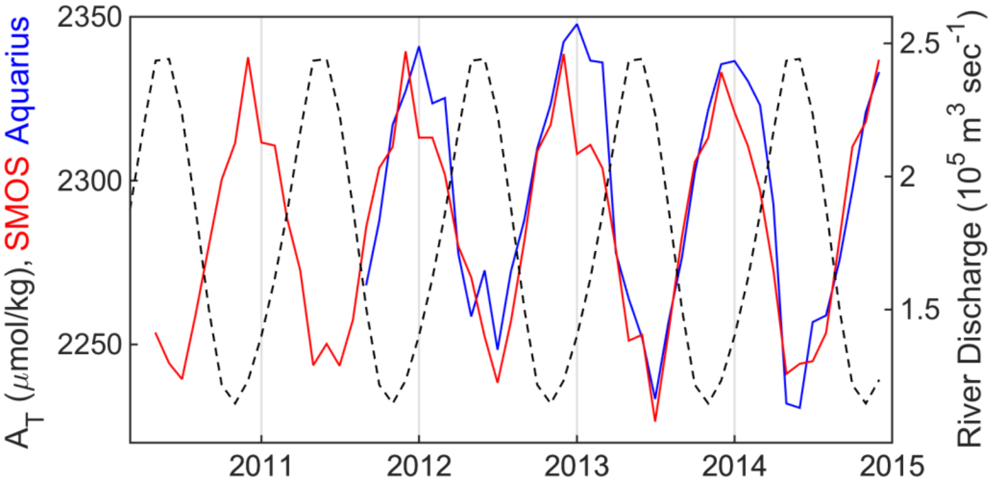


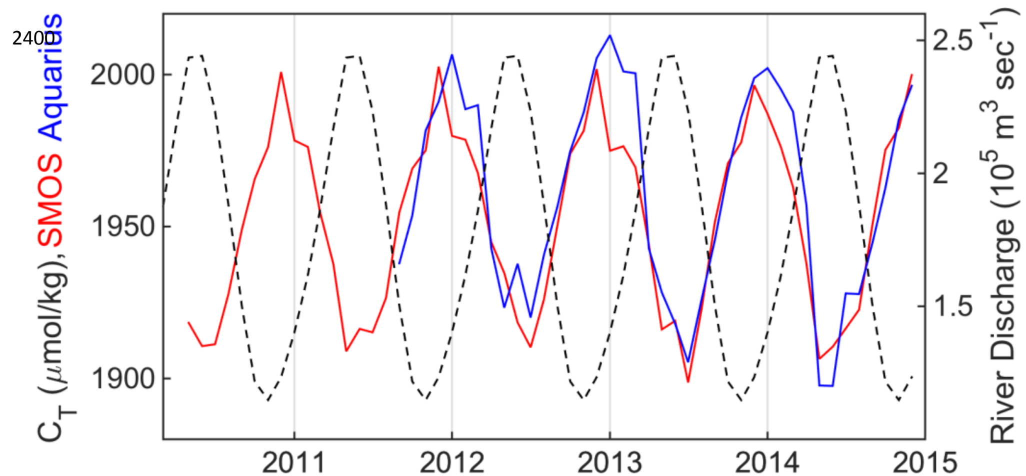
SMOS salinity for October 2010 (blue-red)
Sea ice (green)

L-band & SST -Total alkalinity time series



Underlying map from Salisbury et al., 2011





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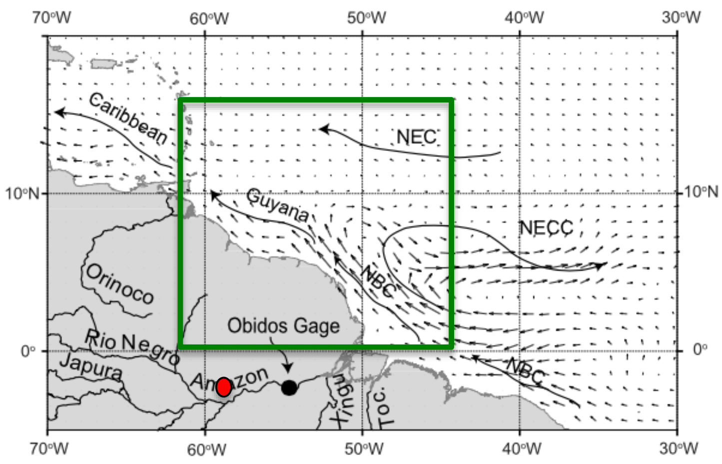

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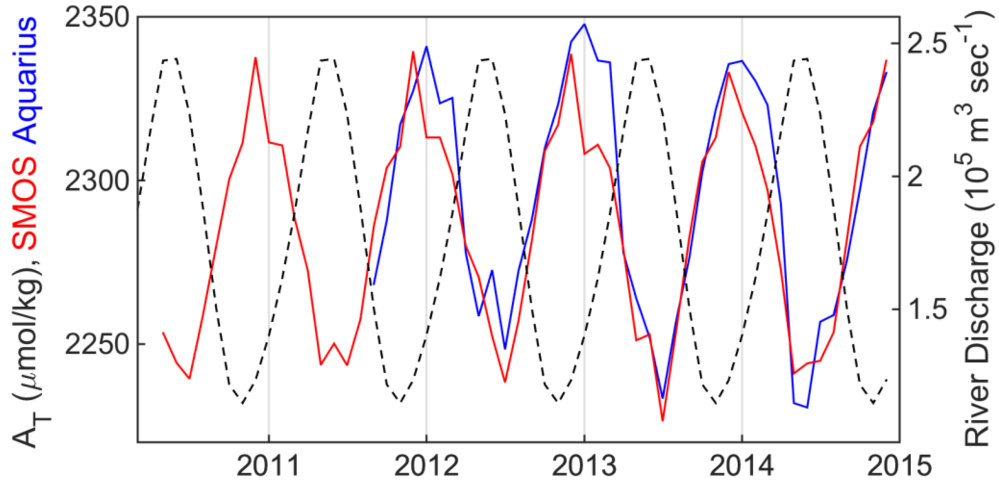
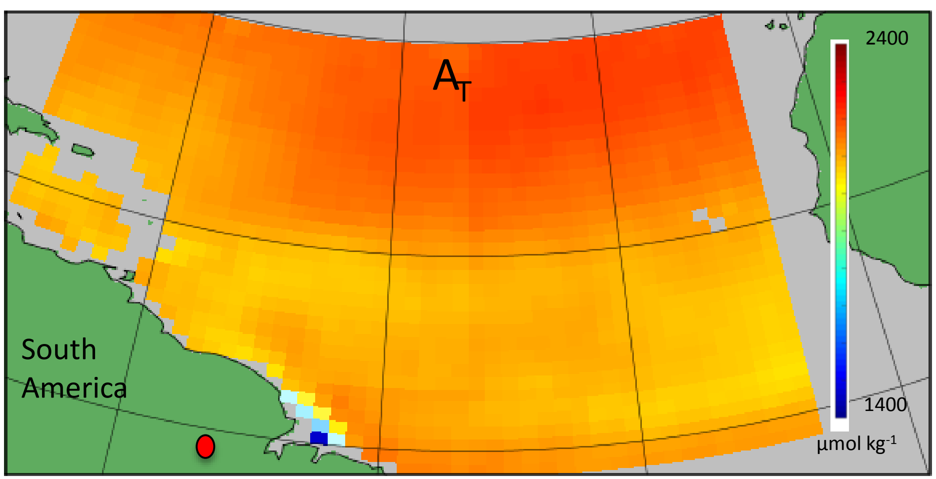
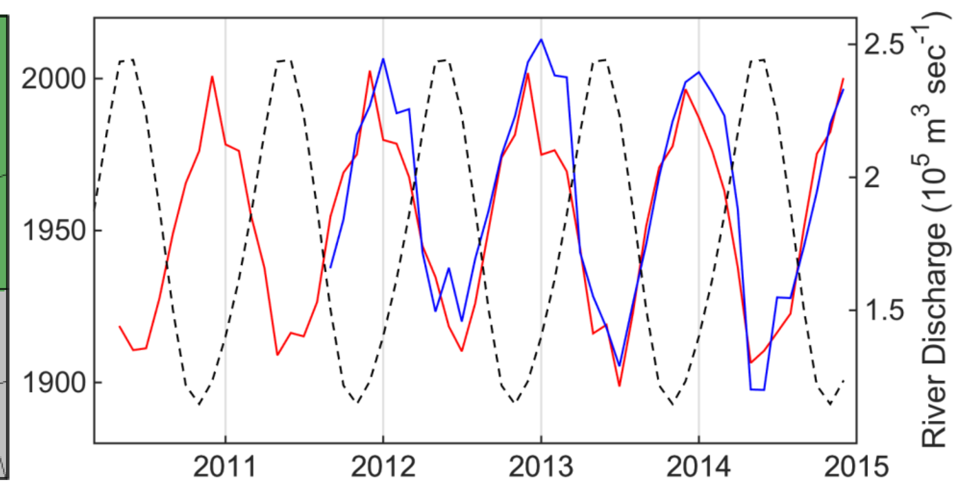
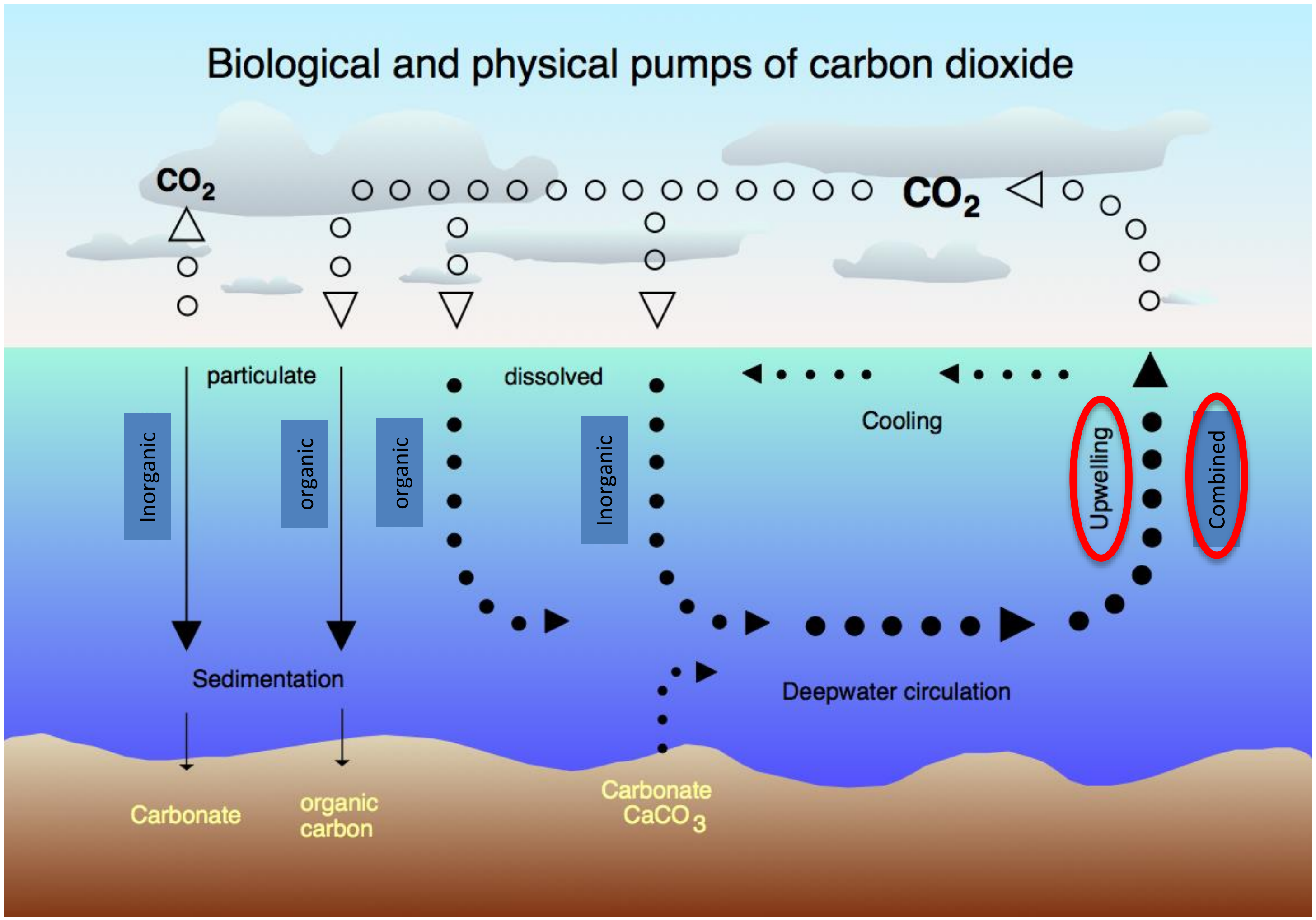




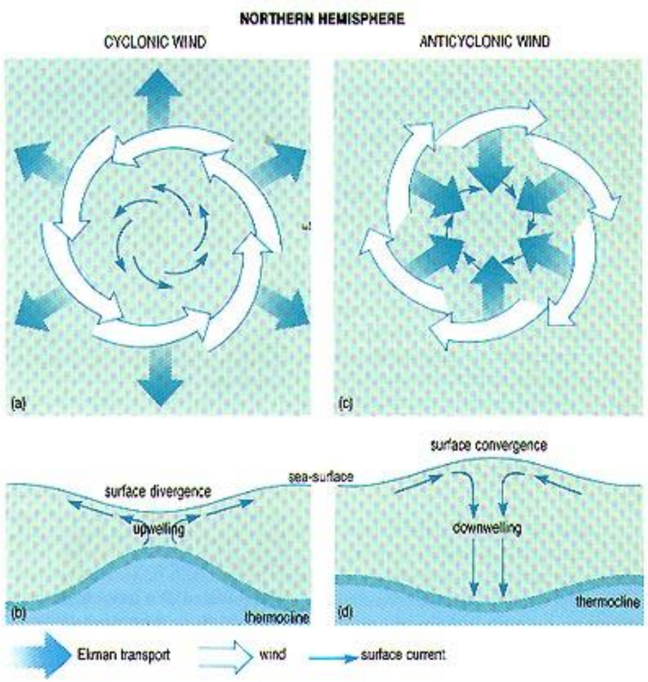


Marine carbon cycle

Thermal infrared/passive microwave (SST), passive microwave (SSS), passive and active microwave (wind, ice)



Identifying regions of upwelling - episodic low pH events



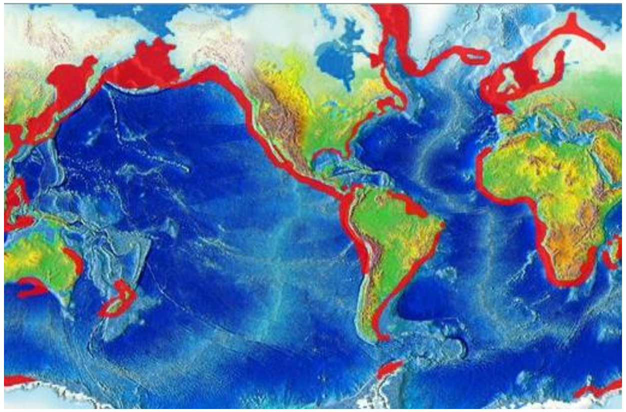
Upwelling: mostly a wind driven effect

Offshore: Ekman pumping
driven by the divergence or convergence of the surface e.g. the wind stress curl in hurricanes.

Coastal: Ekman transport and pumping
Across most continental shelves, especially eastern boundaries of ocean basins (forced by wind systems).

Low temperature upwelling waters bring nutrients, but also low pH water to the surface. Low pH can upset food webs, growth, reproduction and energy balances of marine animals.

Identifying regions of upwelling - episodic low pH events



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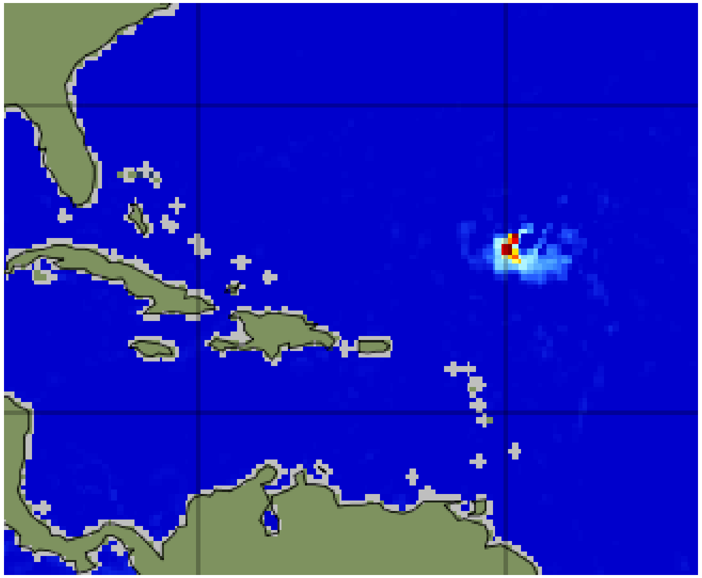
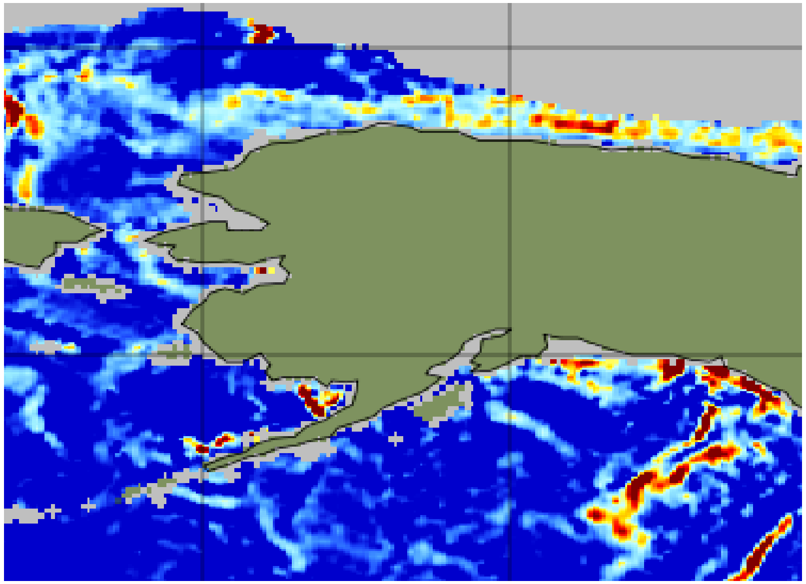


Hurricane Igor, 2010

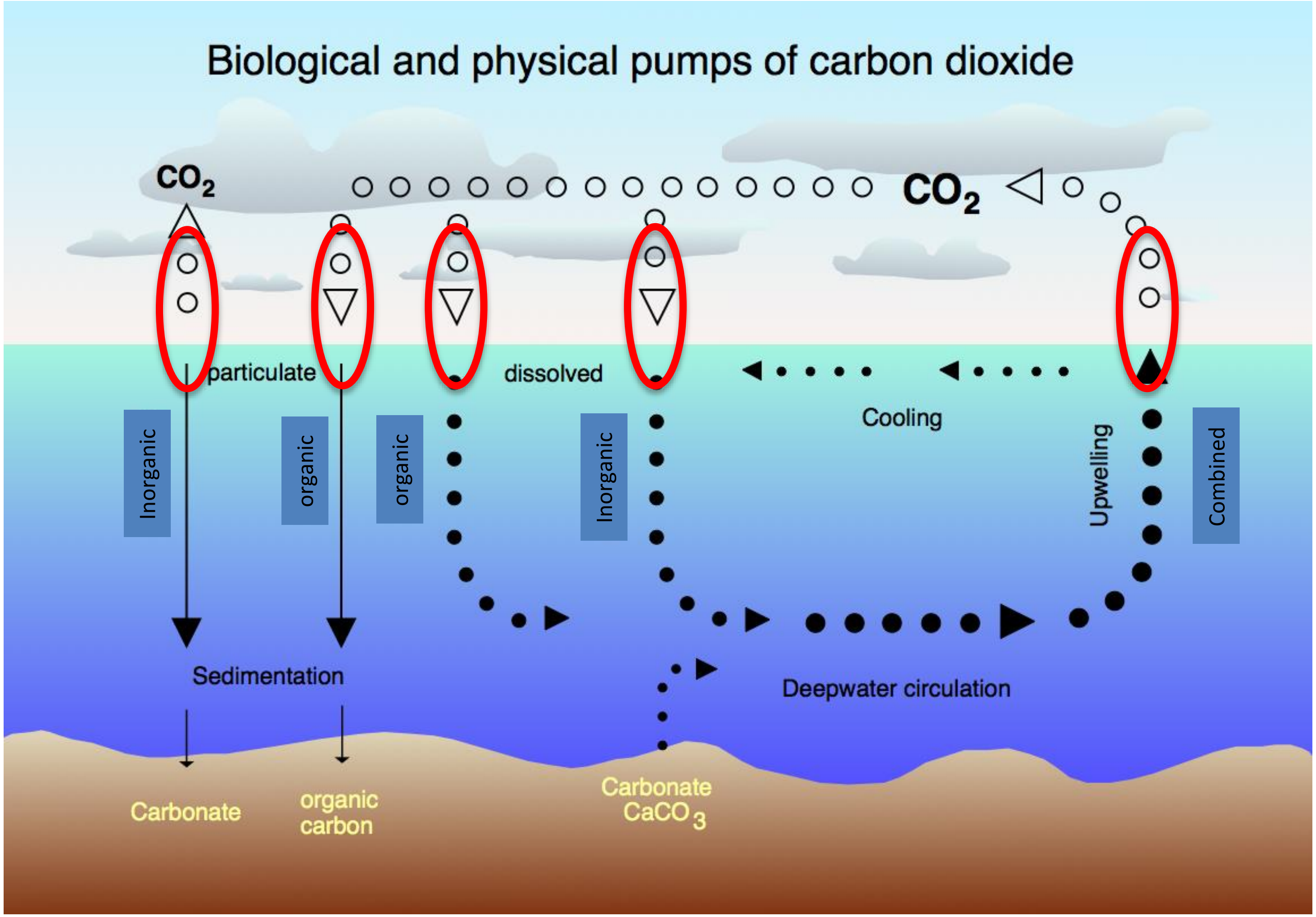


Chuckchi and Beaufort seas

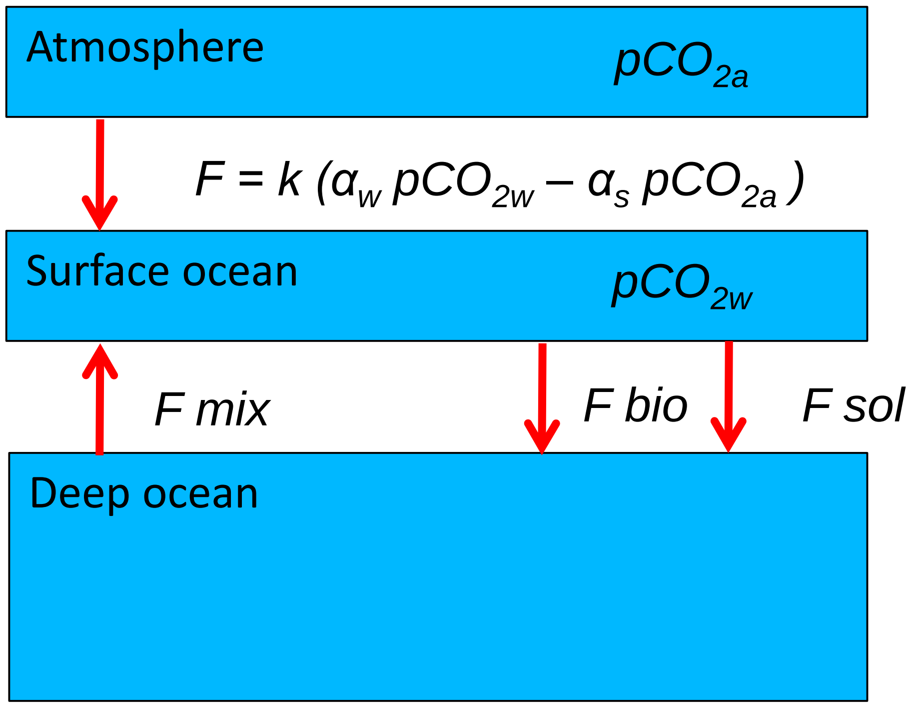
Example are from scatterometer data (active microwave, 25-50 km).

Marine carbon cycle

Thermal infrared/passive microwave (SST), passive microwave (SSS), passive and active microwave (wind, ice)



Atmosphere-ocean gas fluxes (ocean carbon sink)



Using: Thermal infrared/passive microwave (SST), passive microwave (SSS), passive and active microwave (wind, ice)

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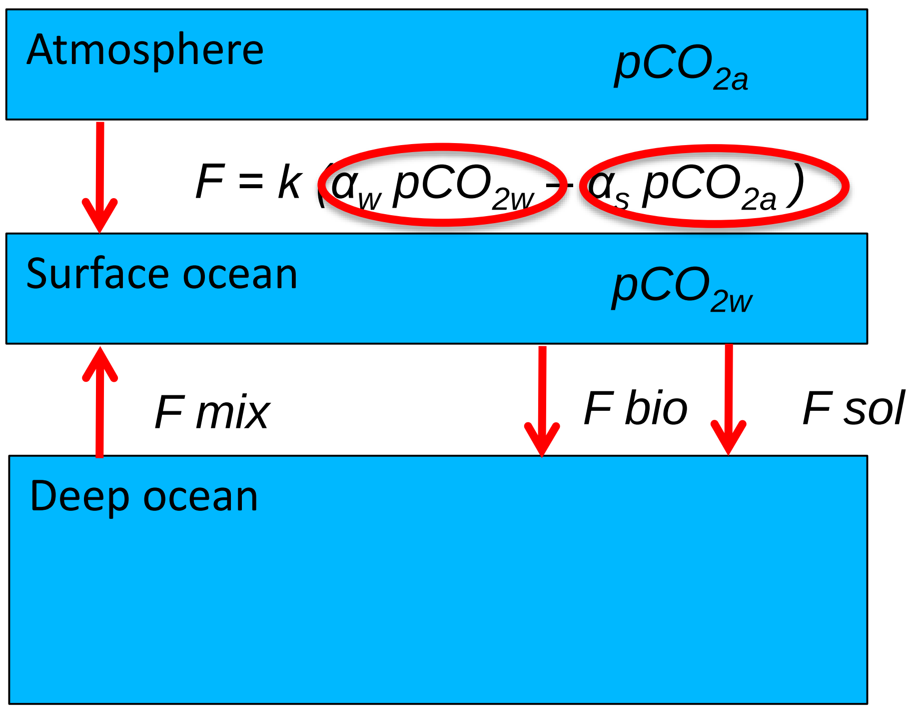

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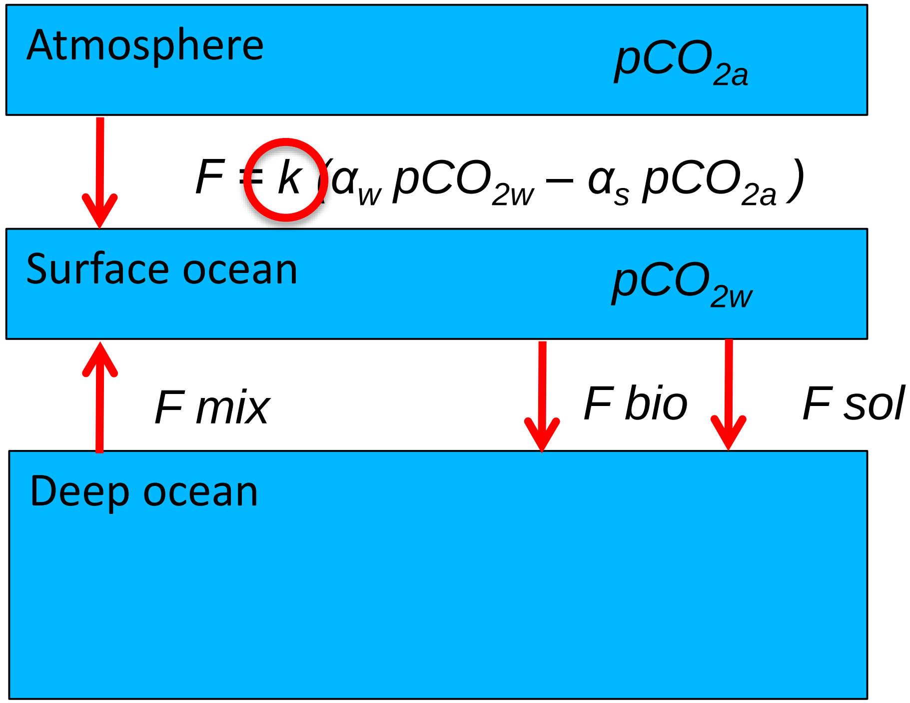

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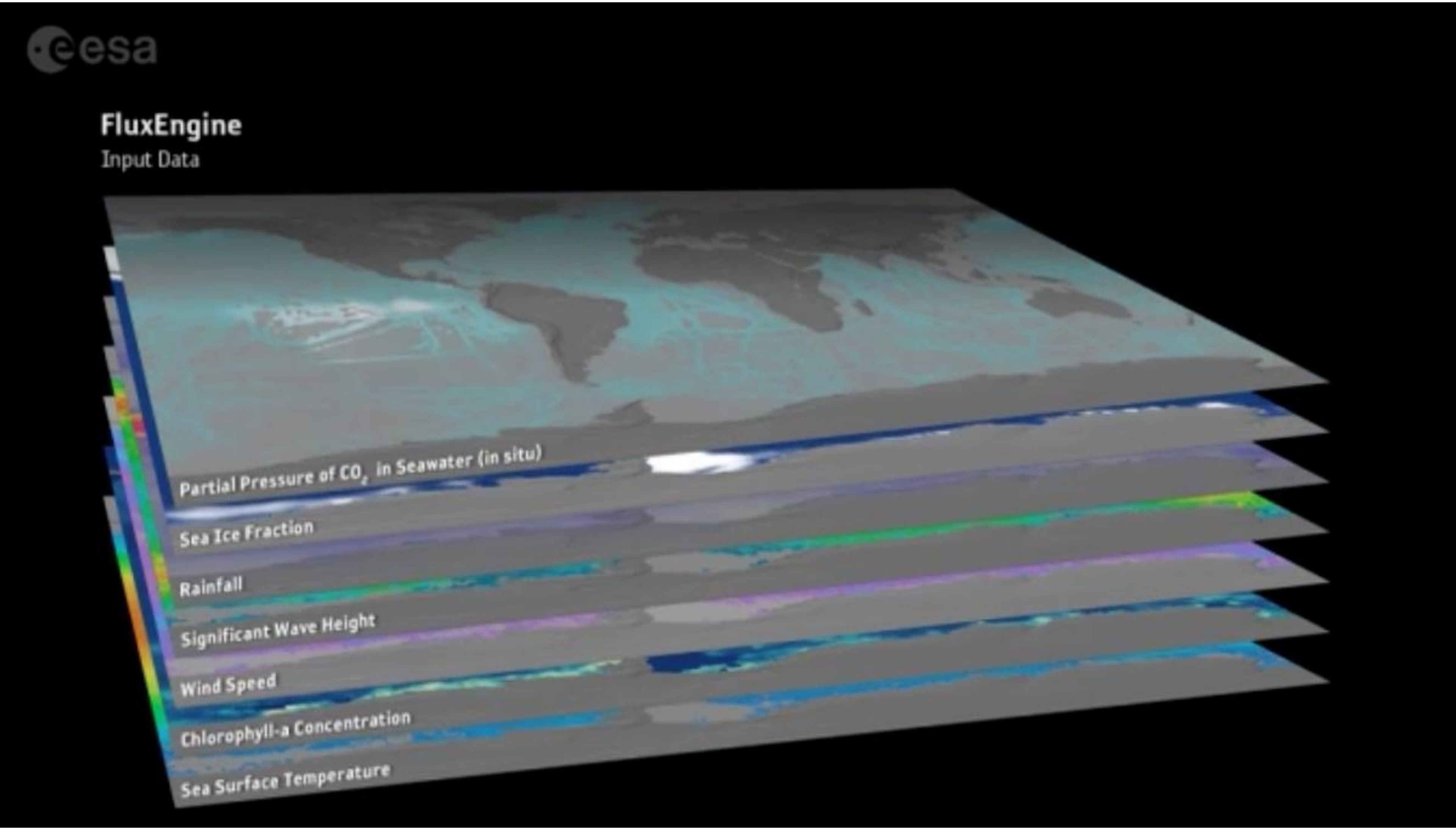
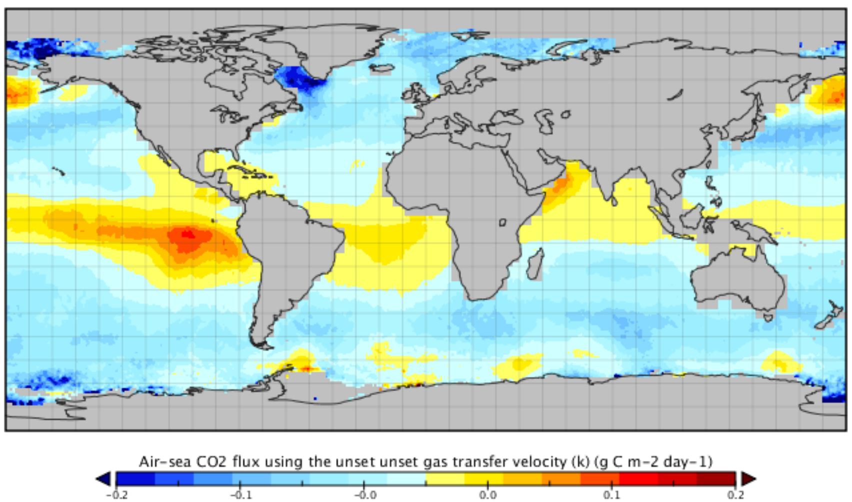


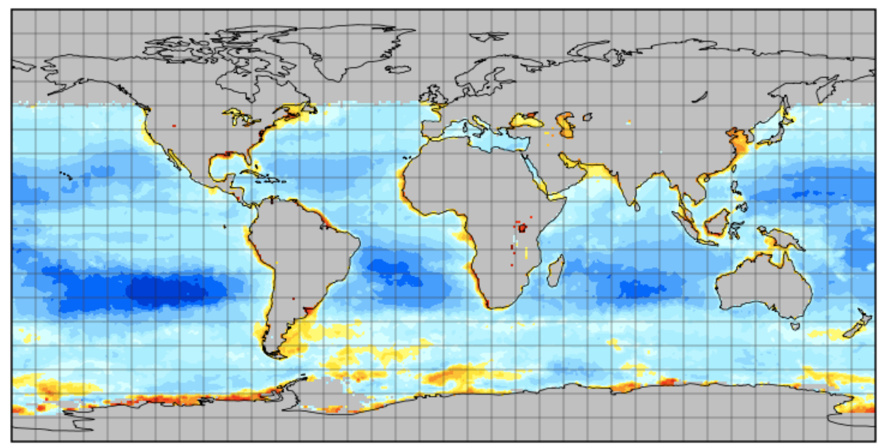
FluxEngine – gas flux toolbox

Toolbox developed for community use:

- Open source license (python and PERL based).
- Standard NetCDF data input and output.
- Net flux tool with traceable land/ocean/basin templates.
- User configurable gas flux calculation.
- Extensively verified using published data.



Example mean daily flux output



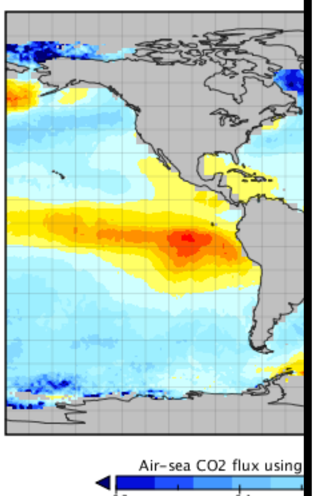
Example process indicator layer output using ESA Climate Change Indices chl-a

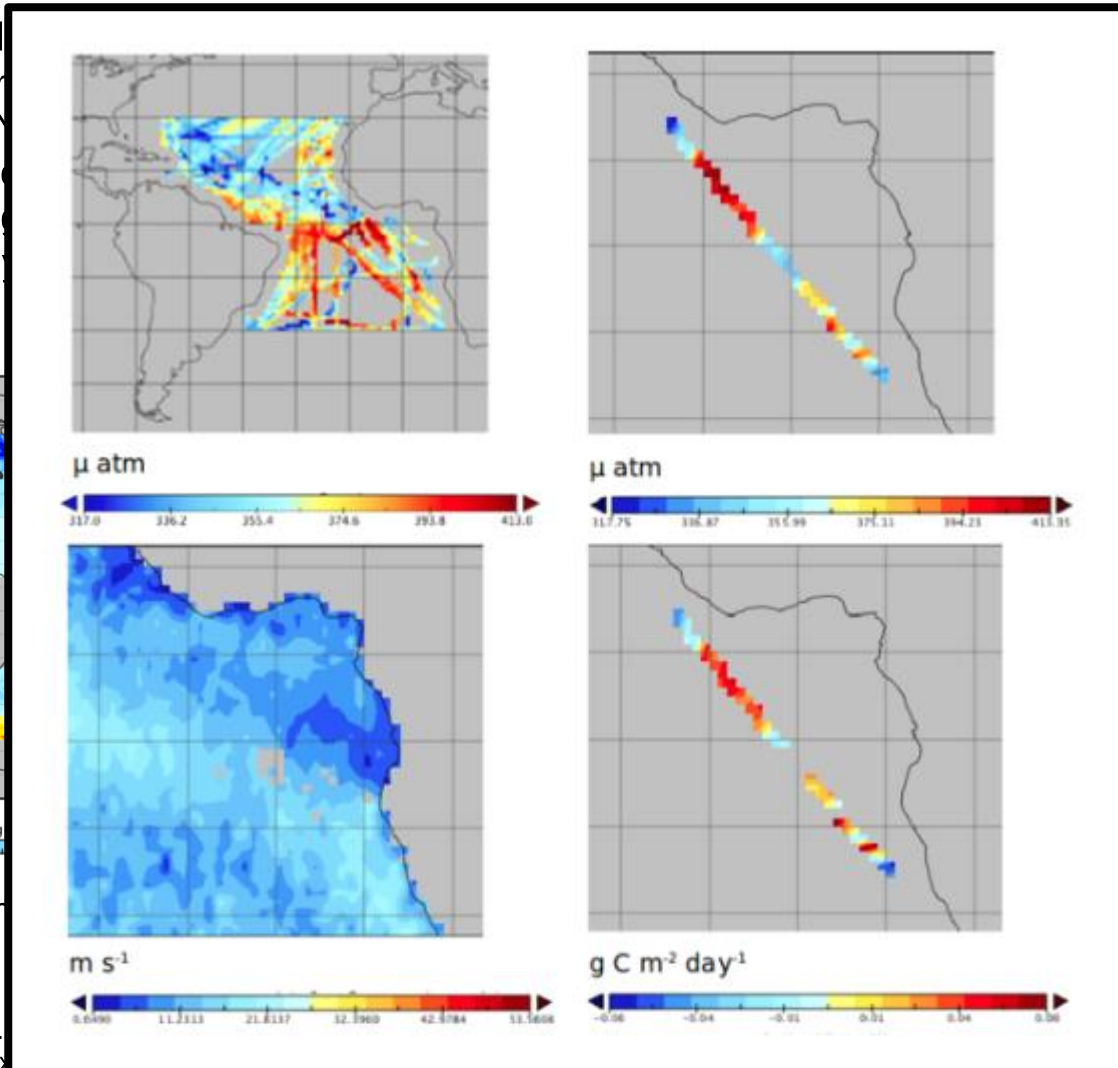
Shutler, J. D., Piolle, J-F., Land, P., Woolf, D. K., Goddijn-Murphy L.,, Paul, F., Girard-Ardhuin, F., Chapron, B., Donlon, C. J., (2016) Flux Engine: A flexible processing system for calculating air-sea carbon dioxide gas fluxes and climatologies, *Journal of Atmospheric and Oceanic Technology.*

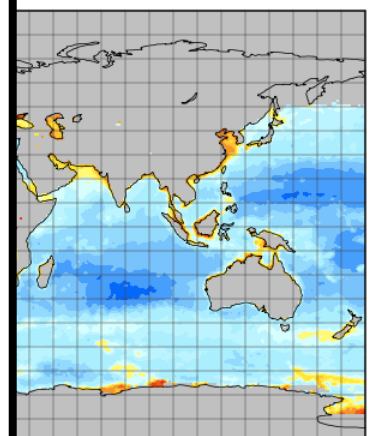
oceanflux evolution
support to science element

FluxEngine – gas flux toolbox

Toolbox devel
- Open sour
- Standard N
- Net flux to
- User confi
- Extensively







Example r

layer output using
Indices chl-a

Shutler, J. D., Piolle, J-F.
Donlon, C. J., (2016) Flux
and climatologies, *Journal of Atmospheric and Oceanic Technology.*

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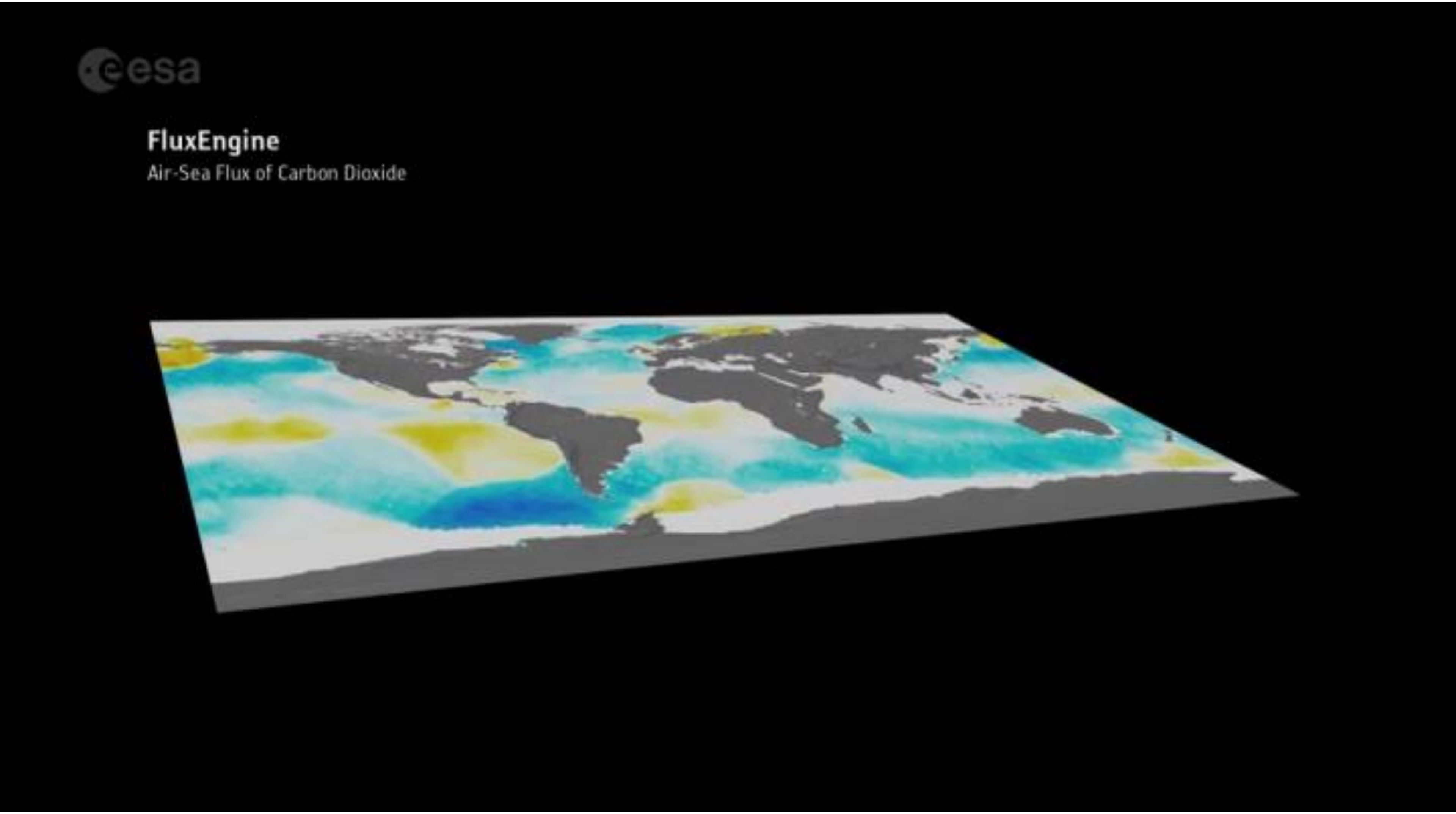
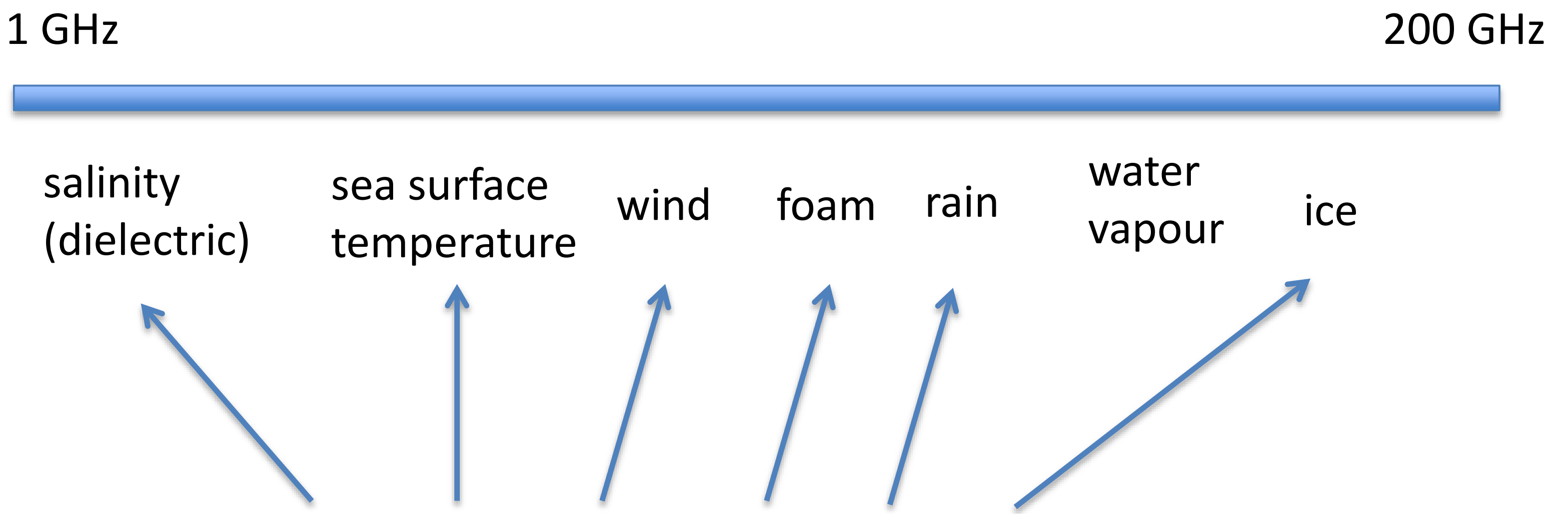
Atmosphere-ocean gas fluxes (ocean carbon sink)



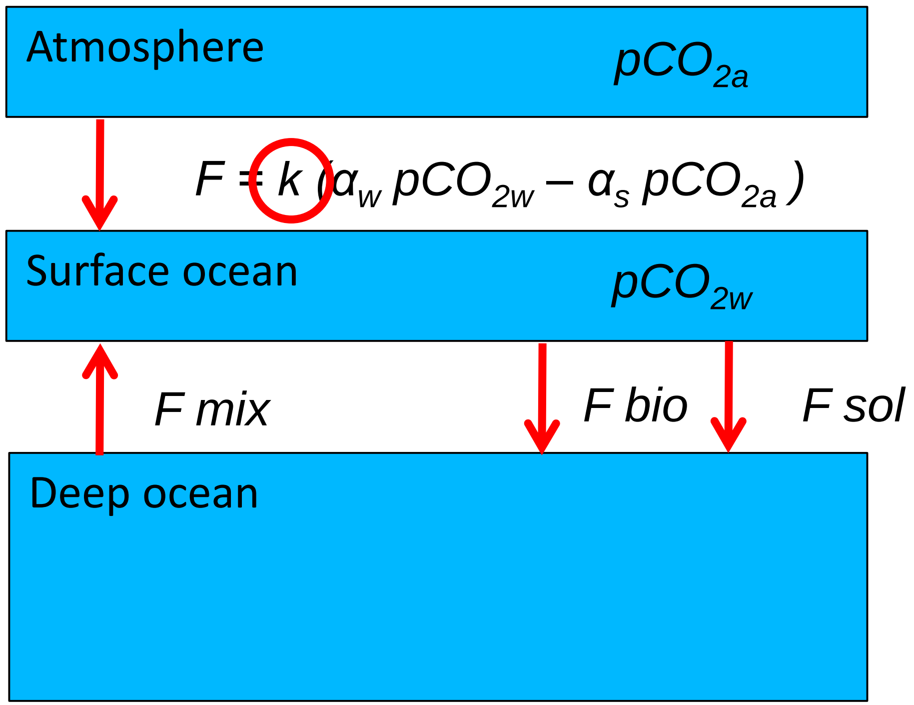
Passive microwave – key for monitoring marine carbon



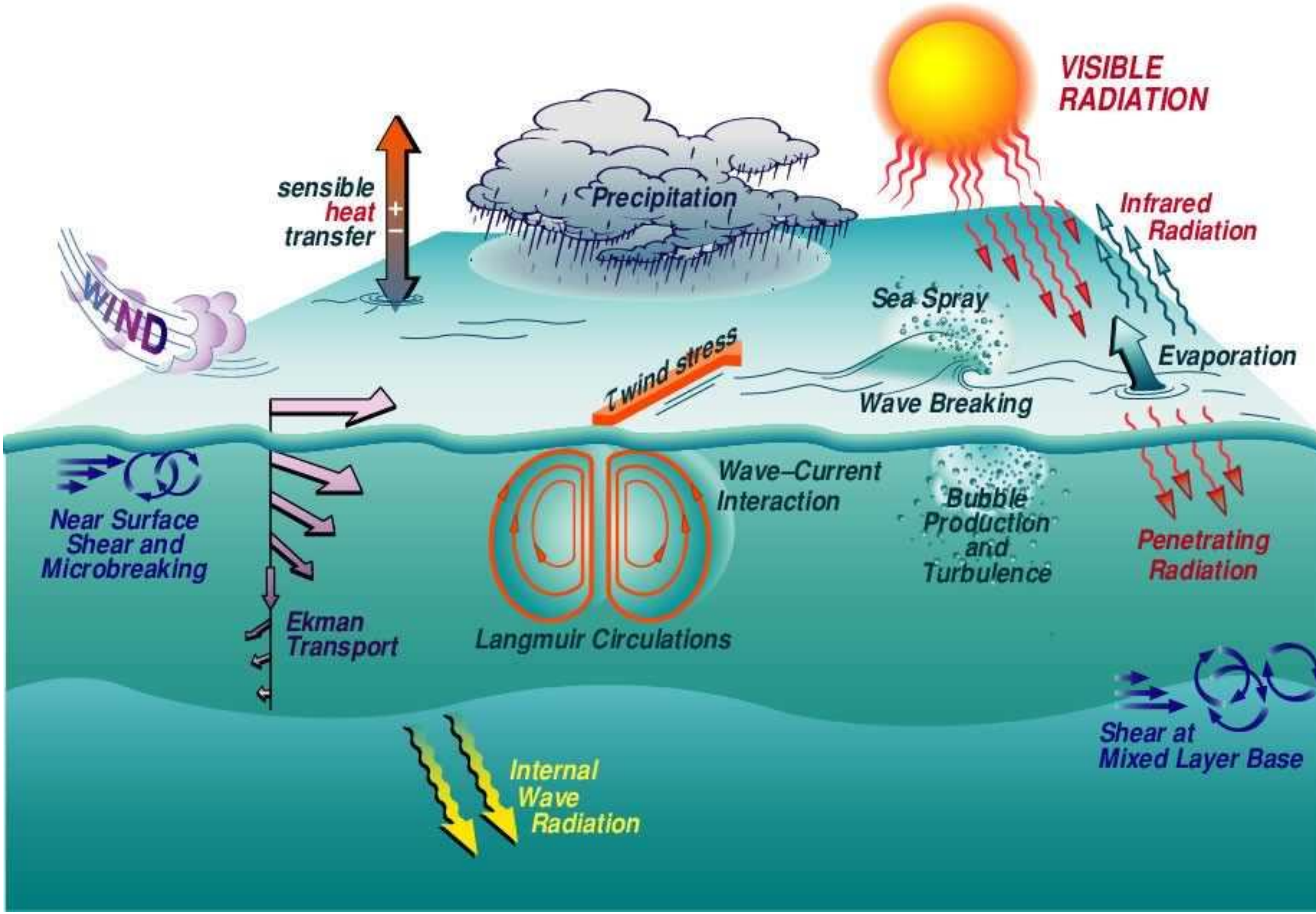
Parameters important for studying marine carbon and exchange

Atmosphere-ocean gas fluxes and exchange (ocean carbon sink)

Some sort of turbulence description called the gas transfer velocity



Gas exchange at the water surface



Gas exchange at the water surface

LIMNOLOGY
and
OCEANOGRAPHY: METHODS

Limnol. Oceanogr.: Methods 12, 2014, 351–362

Relationship between wind speed and gas exchange over the ocean revisited

Rik Wanninkhof
Atlantic Oceanographic and Meteorological Laboratory (AOML) of NOAA, 4301 Rickenbacker Causeway, Miami, FL 33149

Gas exchange at the water surface

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August 2012

Space-based retrievals of air-sea gas transfer velocities using altimeters: Calibration for dimethyl sulfide

Lonneke Goddijn-Murphy ✉, David K. Woolf, Christa Marandino

First published: 24 August 2012 Full publication history

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Gas exchange at the water surface

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A reconciliation of empirical and mechanistic models of the air-sea gas transfer velocity

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Key Points:

- The air-sea gas transfer model presented is consistent with data on a diverse set of gases
- Bubble-mediated air-sea gas transfer cannot be ignored in strong winds
- How the void fraction of bubble plumes could affect air-sea gas transfer velocity is discussed

Gas exchange at the water surface

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Improvements to estimating the air–sea gas transfer velocity by using dual-frequency, altimeter backscatter

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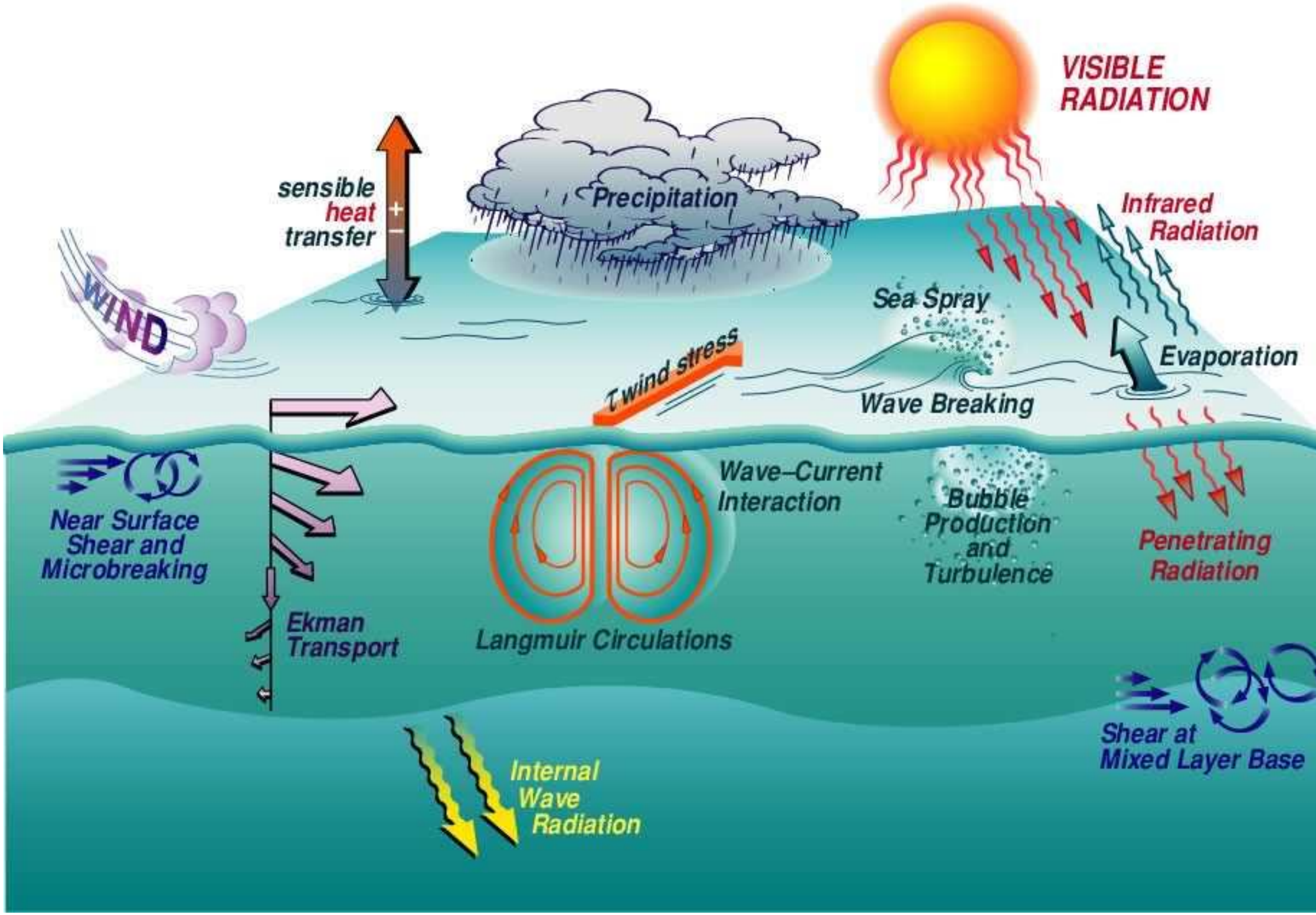
Gas exchange at the water surface



Summary

- Monitoring ocean carbon is key to enable us:
  - i) to track our progress towards reaching the goals of the historic Paris climate agreement,
  - ii) identify and monitor ecosystems at risk of ocean acidification events.

- Passive microwave measurements are key for studying and monitoring marine carbon.
- They are currently being used extensively in synergy with other measurements, both in situ and others from space.

- But the full potential of the use of passive microwave, including L band, for marine carbon research is largely unexplored.

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