How the Kuroshio enriches the southern coast of Japan and its downstream regions

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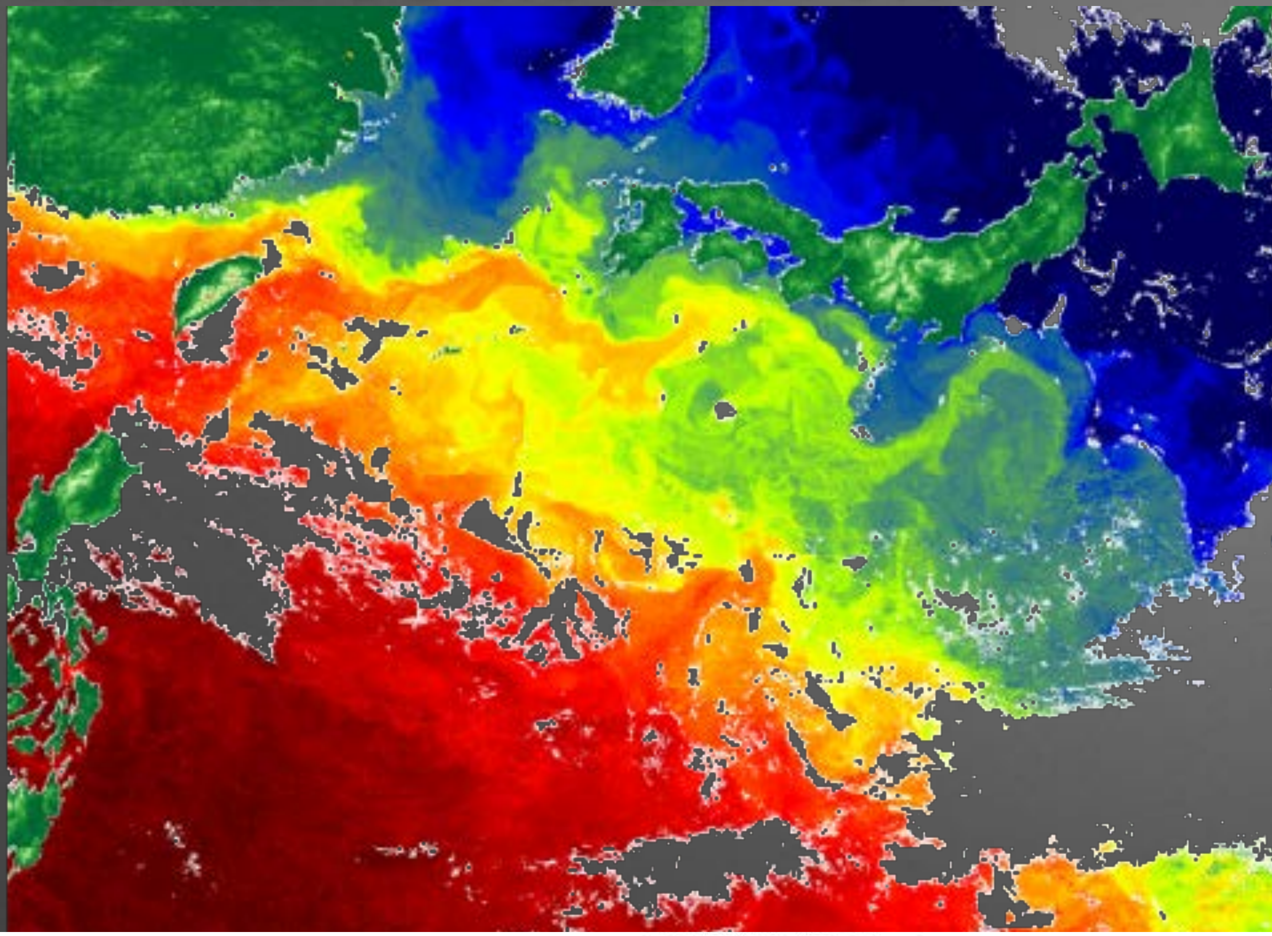
S K E D

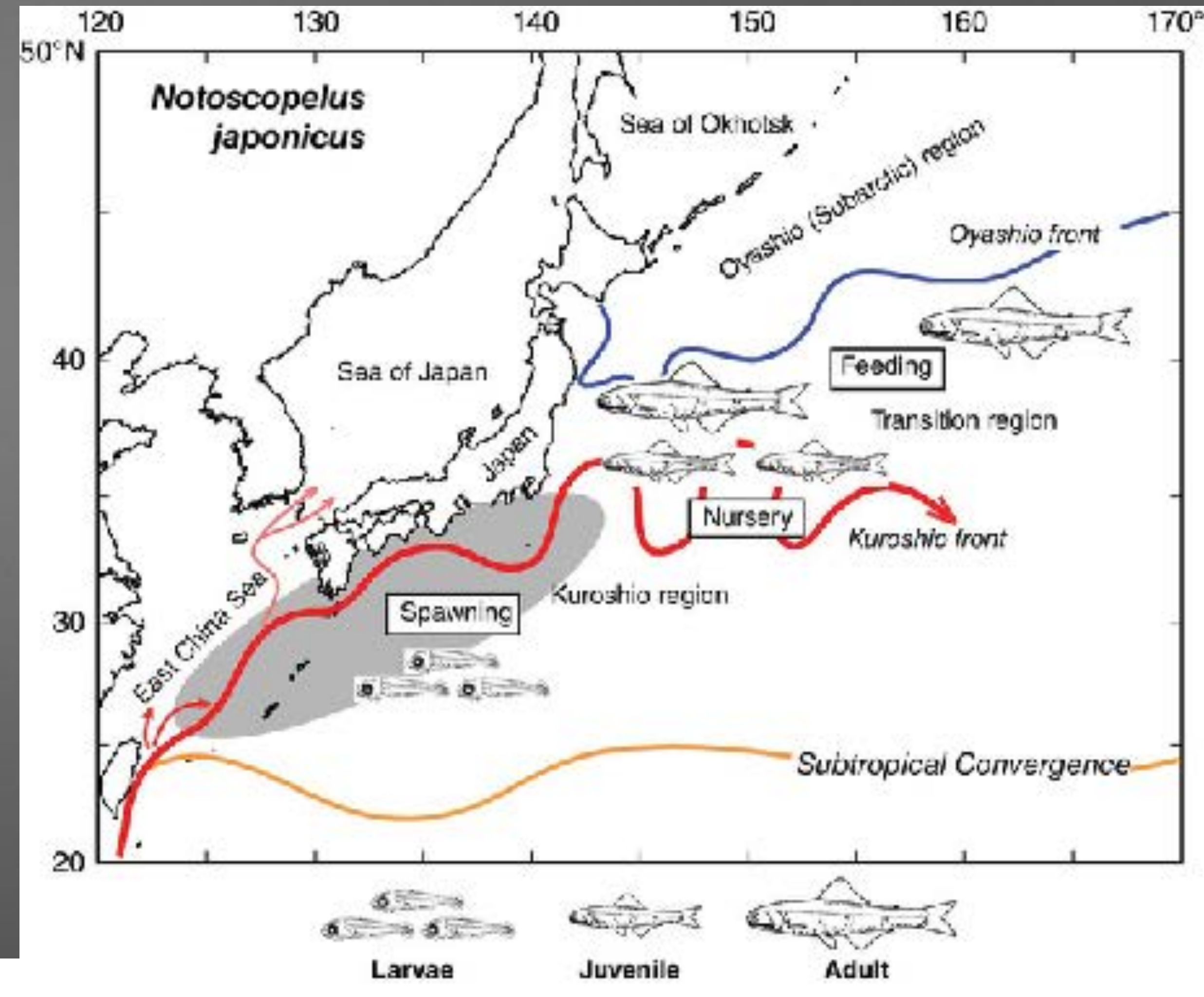
科研費 KAKENHI

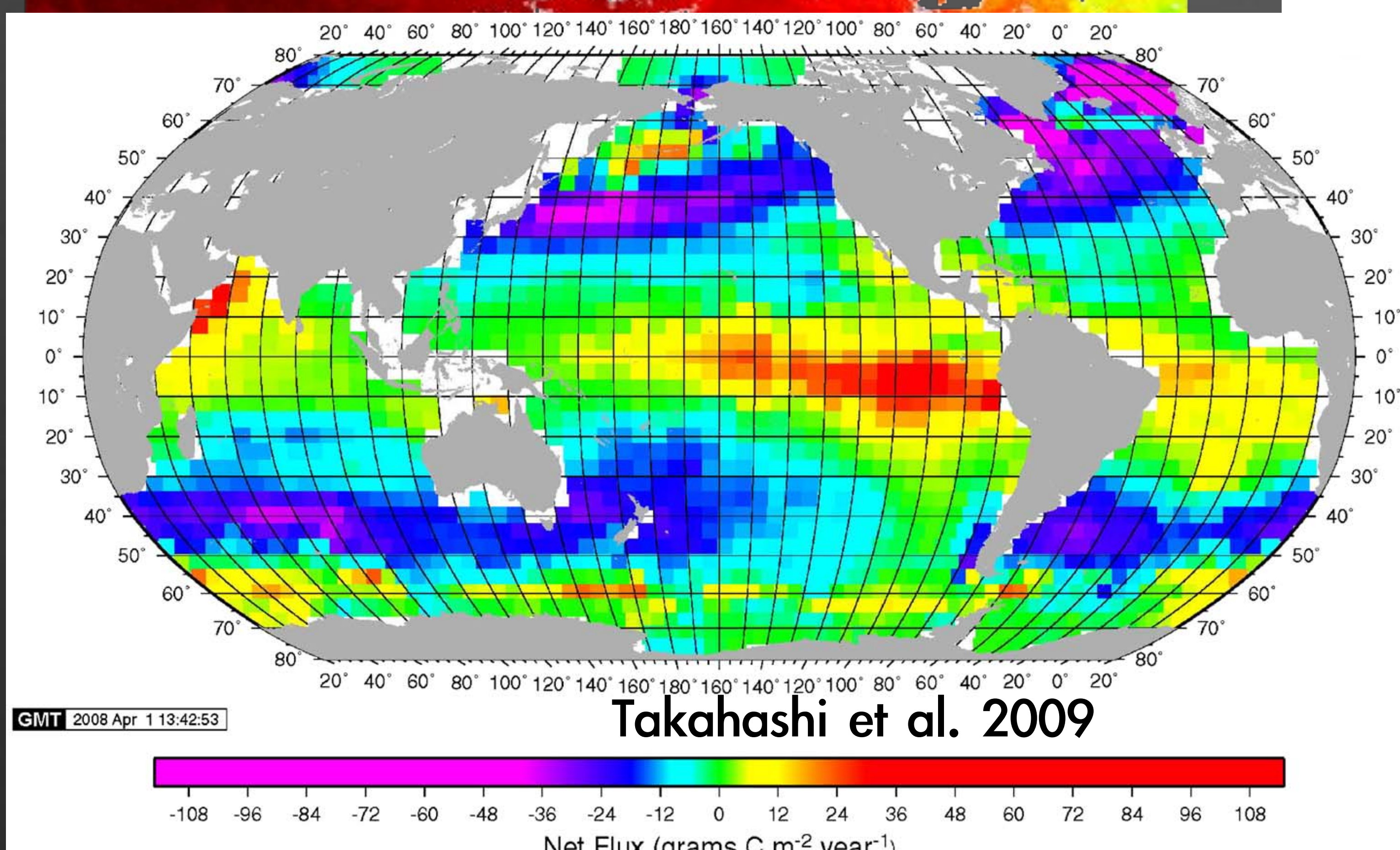
ocean mixing process mix

The Kuroshio Current



Sassa 2019





Takahashi et al. 2009

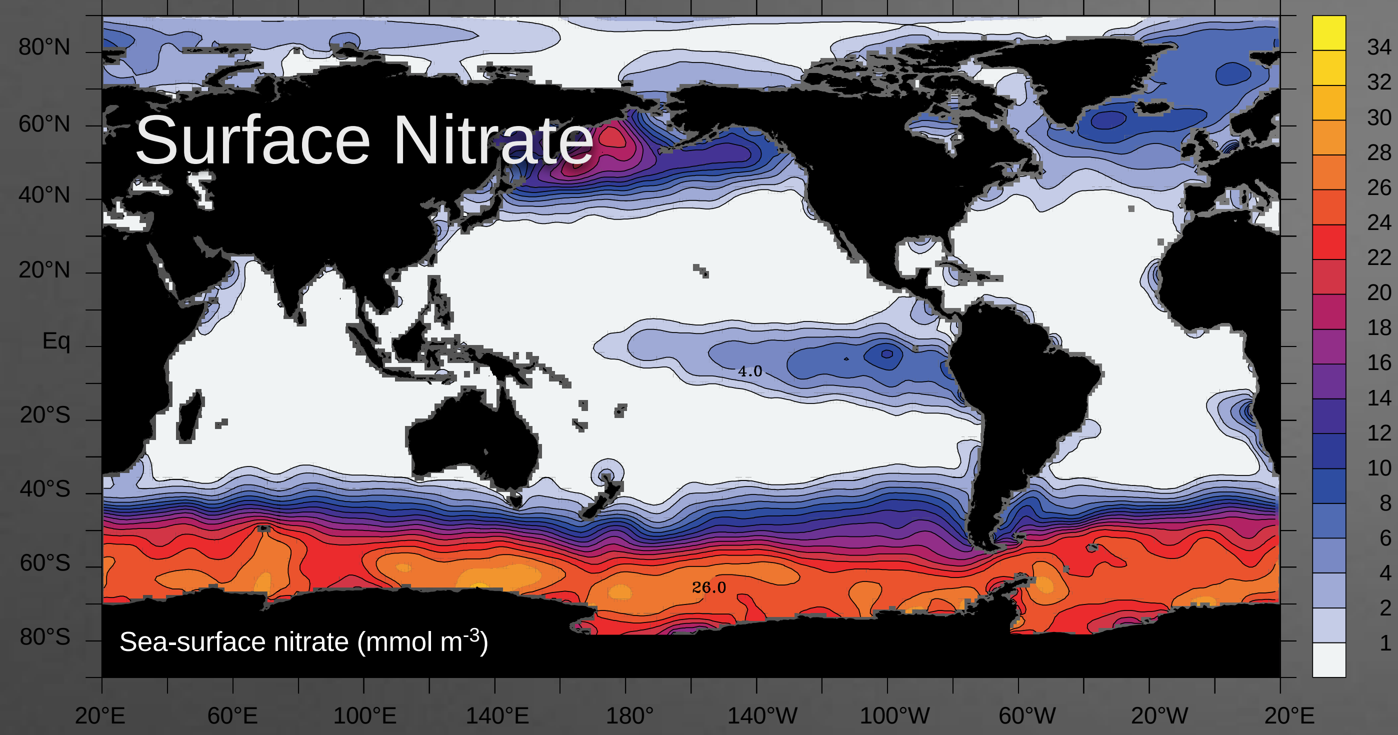
Fig. 13. Climatological mean annual sea–air CO_2 flux ($g\text{-}C\ m^{-2}\ yr^{-1}$) for the reference year 2000 (non-El Niño conditions). The map is based on 3.0 million surface water

Many fish species including Lanternfish use the Kuroshio region for their spawning and nursery sites.

The Kuroshio Extension region is one of the major net CO_2 sink in the ocean

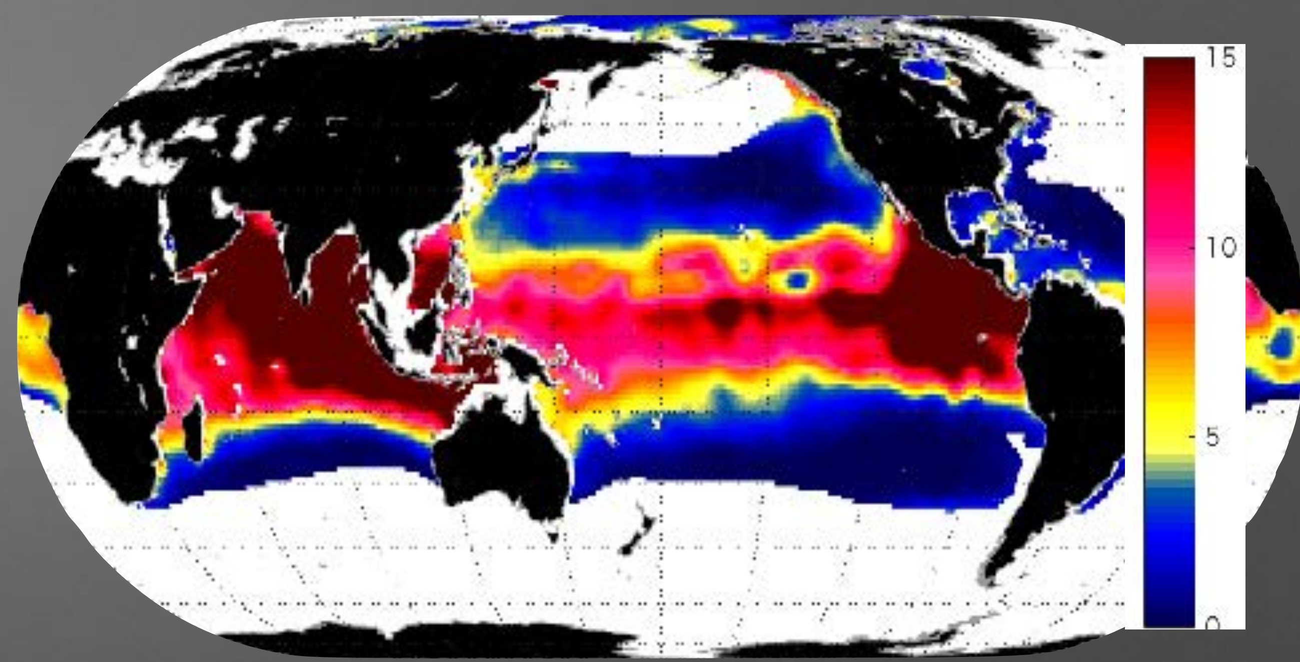
The Kuroshio Current

Sarmient and Gruber 2006



WOA Nitrate on σ_θ=25

Nagai et al. 2019

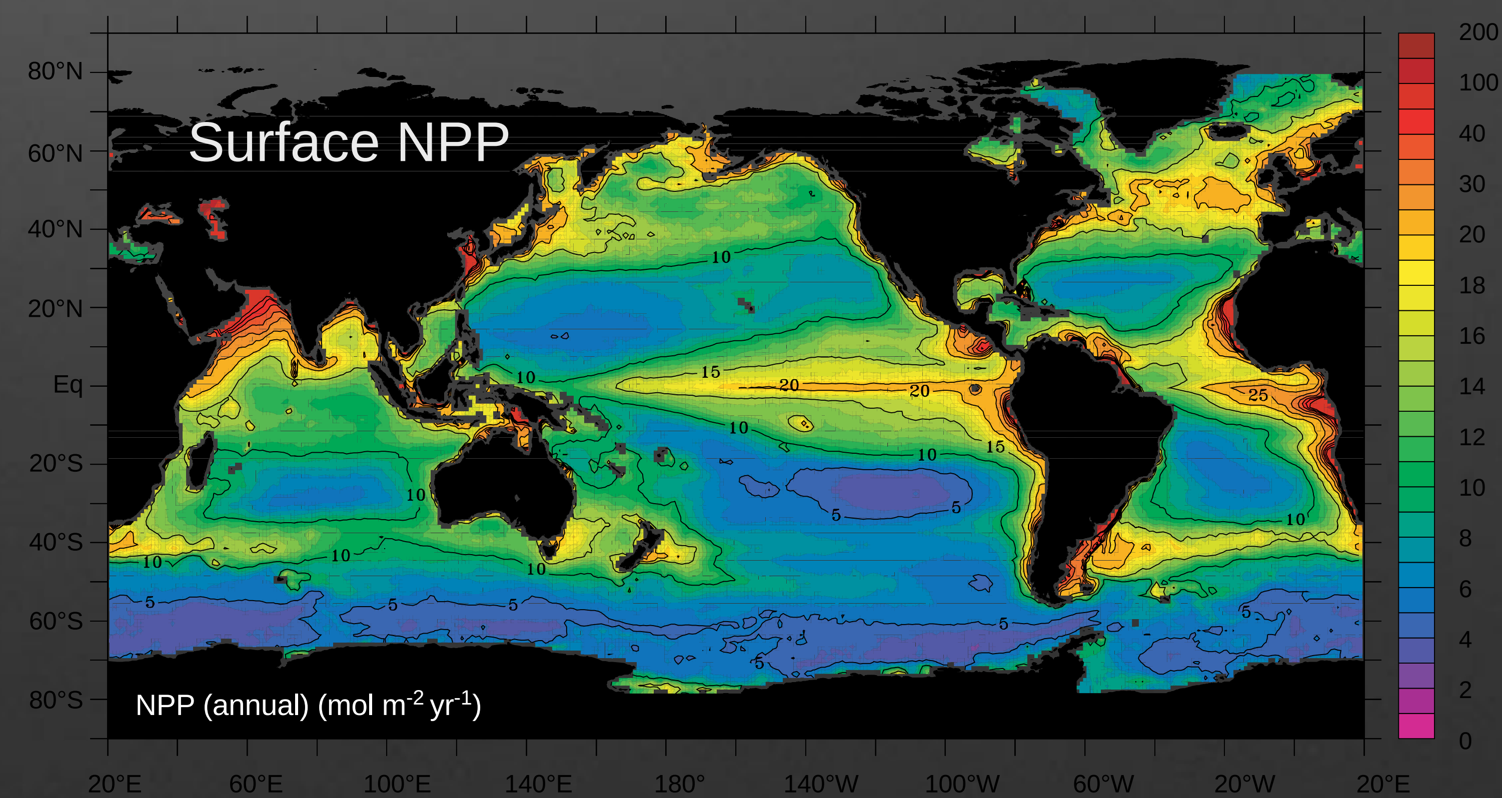


However, surface layers of the Kuroshio is nutrient poor.

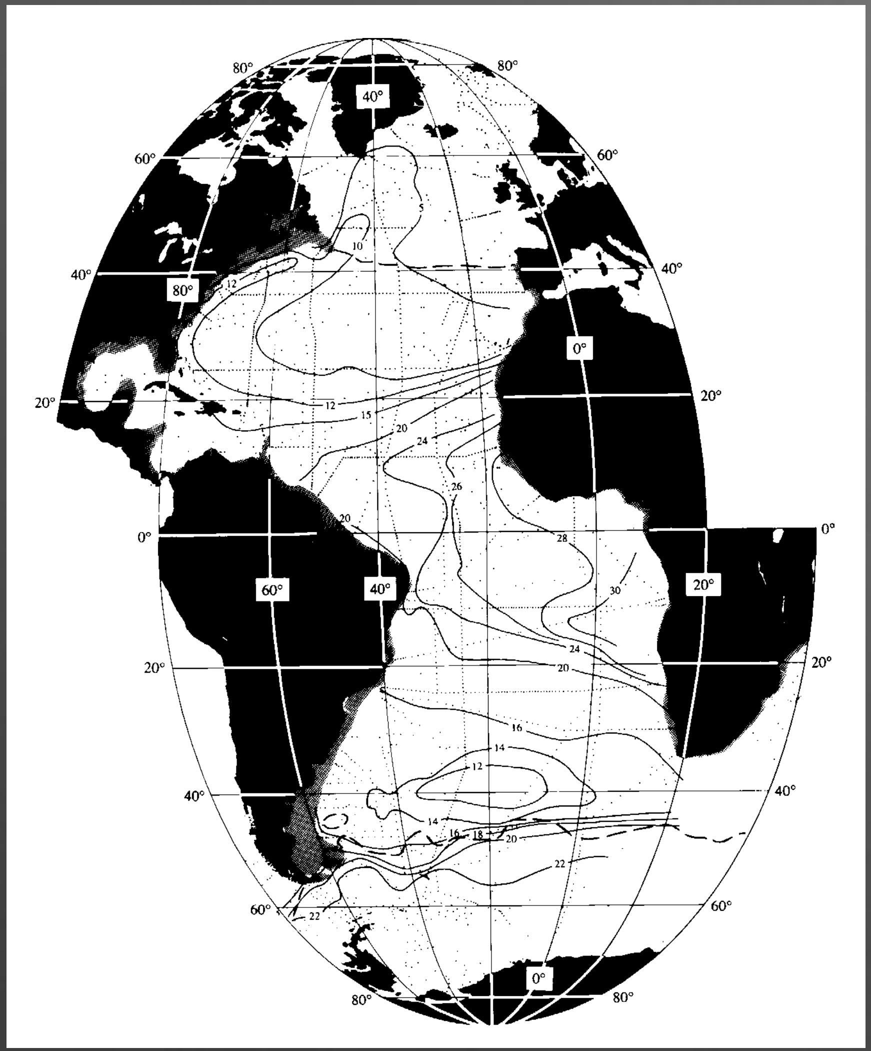
On the other hand, subsurface layers of the Kuroshio carries a large amount of nutrients (Guo et al. 2012), with elevated concentrations on the density surface (Nagai et al. 2019).

Though it is caused by other reasons as well, bands of high production in the Kuroshio Extension could be due to this nutrient transport by the Kuroshio.

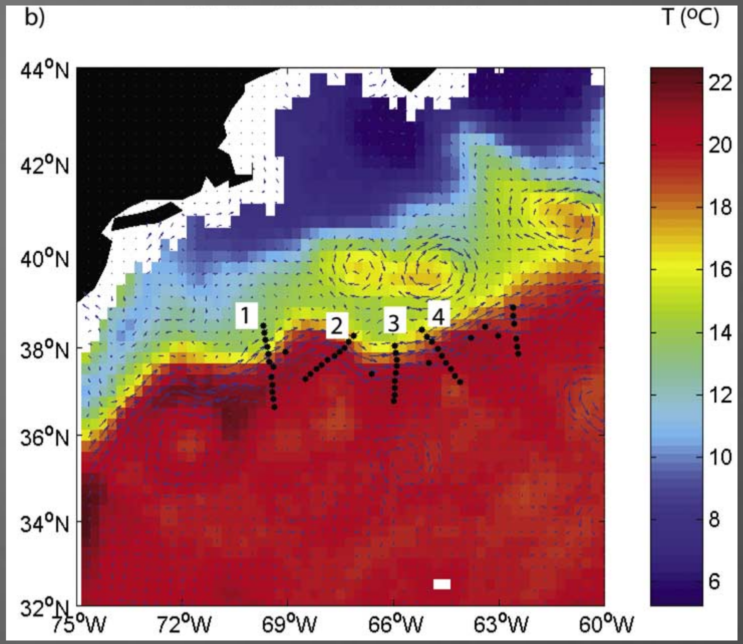
Sarmient and Gruber 2006

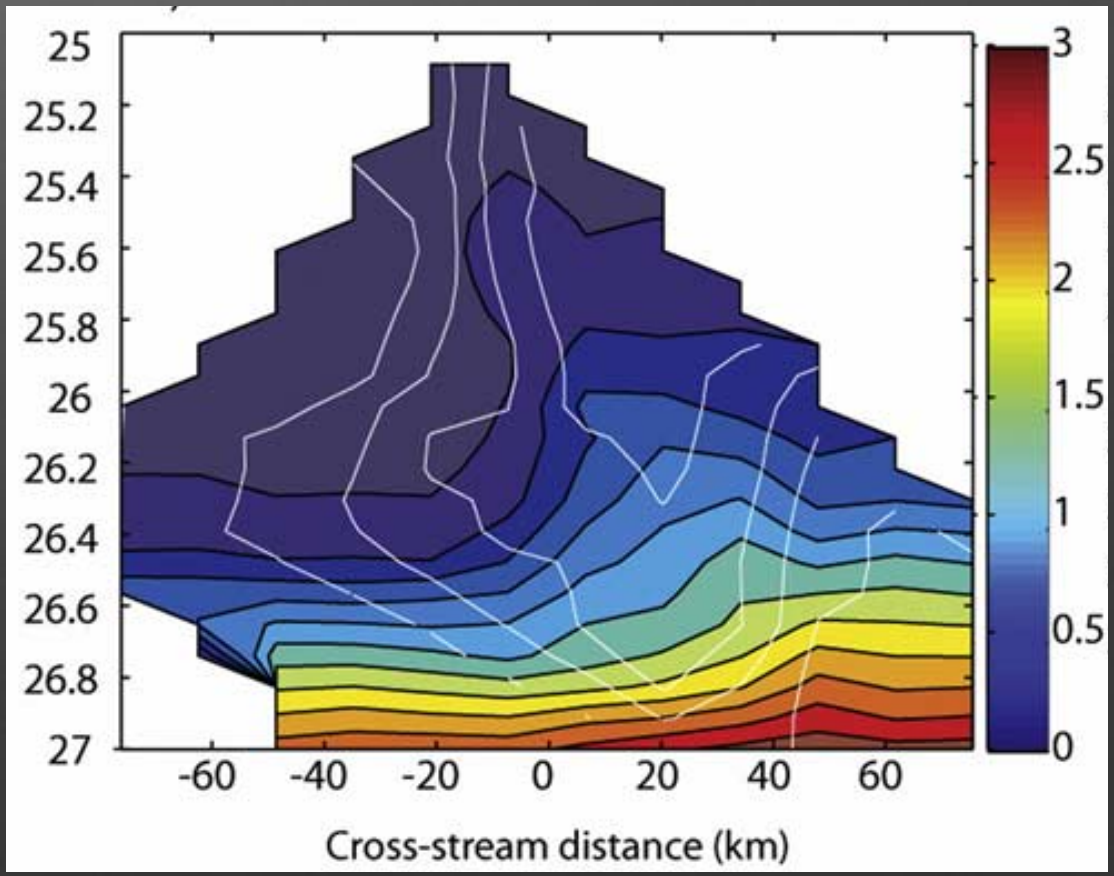


Gulf Stream: Nutrient Stream



Pelegri et al. (1996) found that the Gulf Stream transport a large amount of nutrients, and nutrient concentration is higher along the stream on the density surface.





This is also confirmed by more recent field data in CLIMODE (Palter & Lozier 2008)

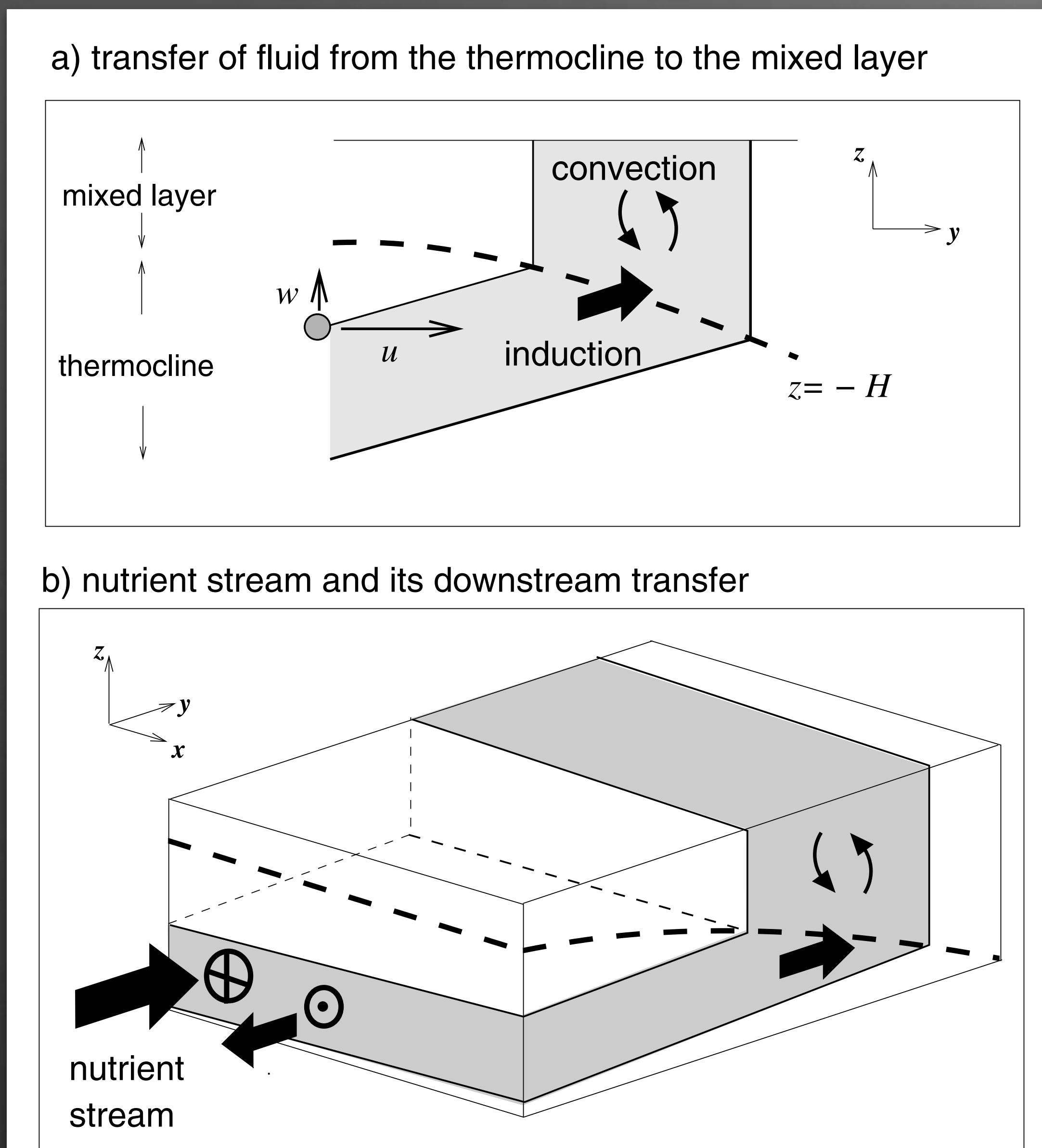
Induction

The subsurface nutrients are transported by adiabatic flows along isopycnal.

They encounters deeper mixed layer while they travel northward in the winter season.

The nutrients can be obducted through inclined mixed layer base by along isopycnal flows

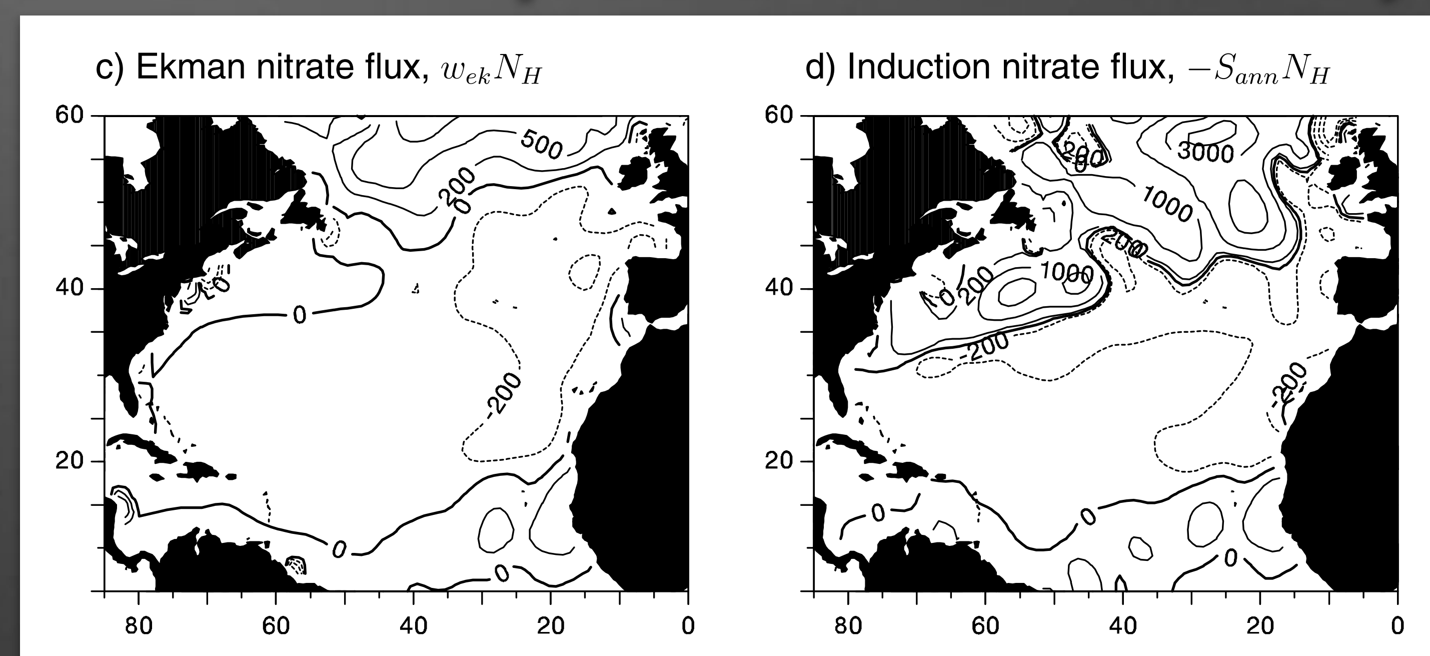
Williams et al. 2006



The nutrient ultimate supply in the subpolar regions is achieved by induction

Ekman m mol m^{-2}yr^{-1}

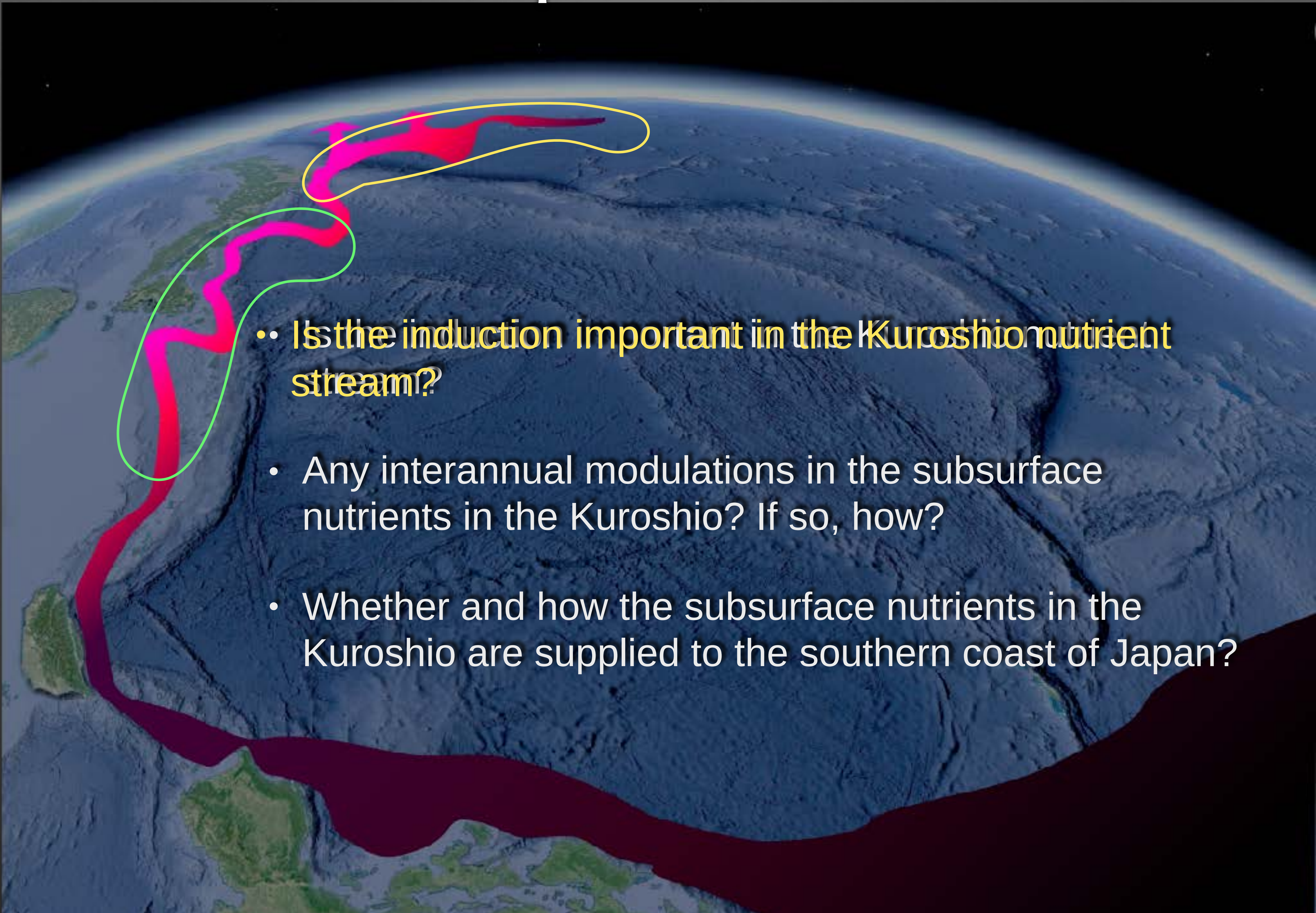
Induction m mol m^{-2}yr^{-1}



Williams et al. 2006

Ekman upwelling < Induction

Scientific questions

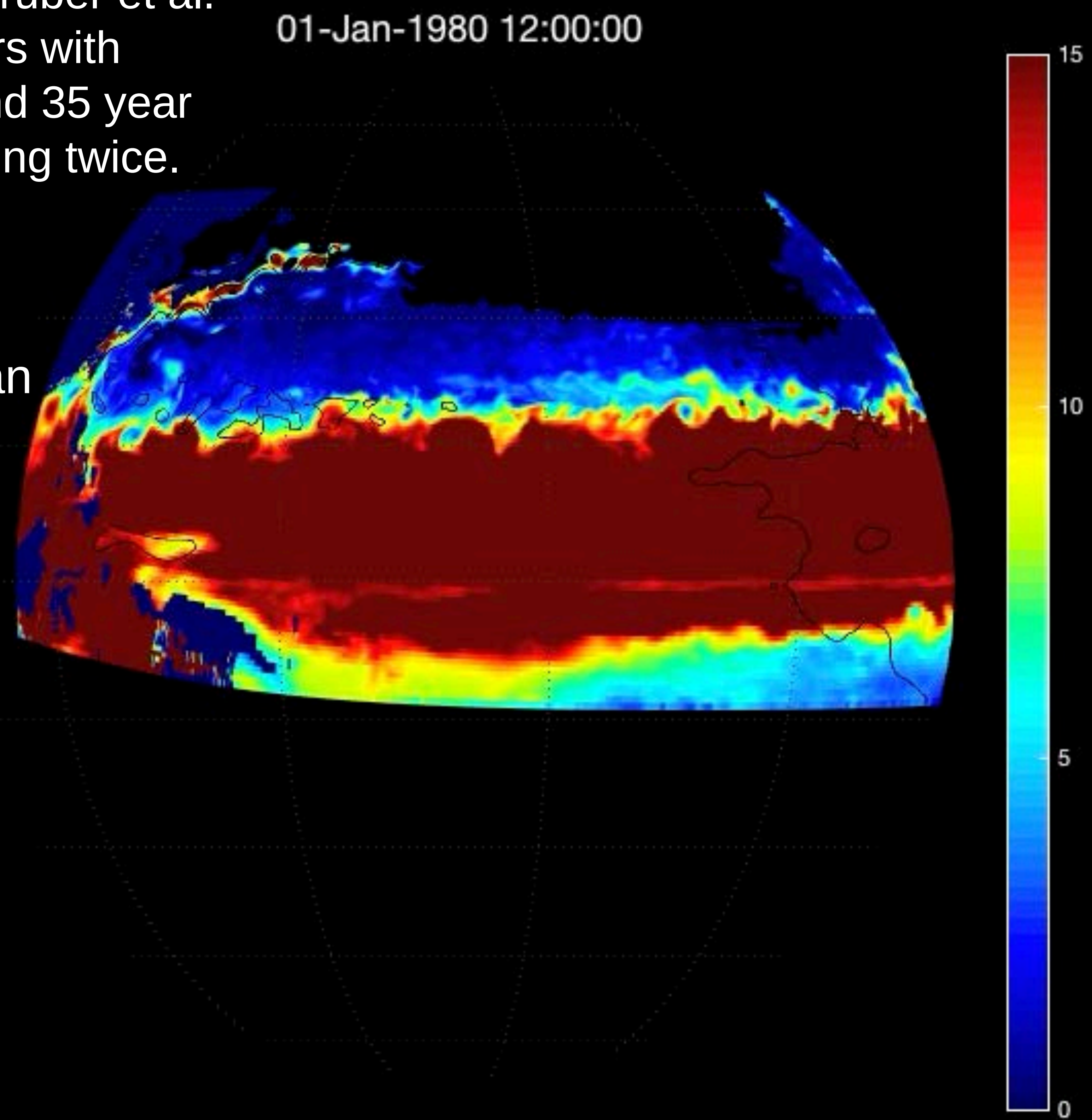


- Is the induction important in the Kuroshio nutrient stream?
- Any interannual modulations in the subsurface nutrients in the Kuroshio? If so, how?
- Whether and how the subsurface nutrients in the Kuroshio are supplied to the southern coast of Japan?

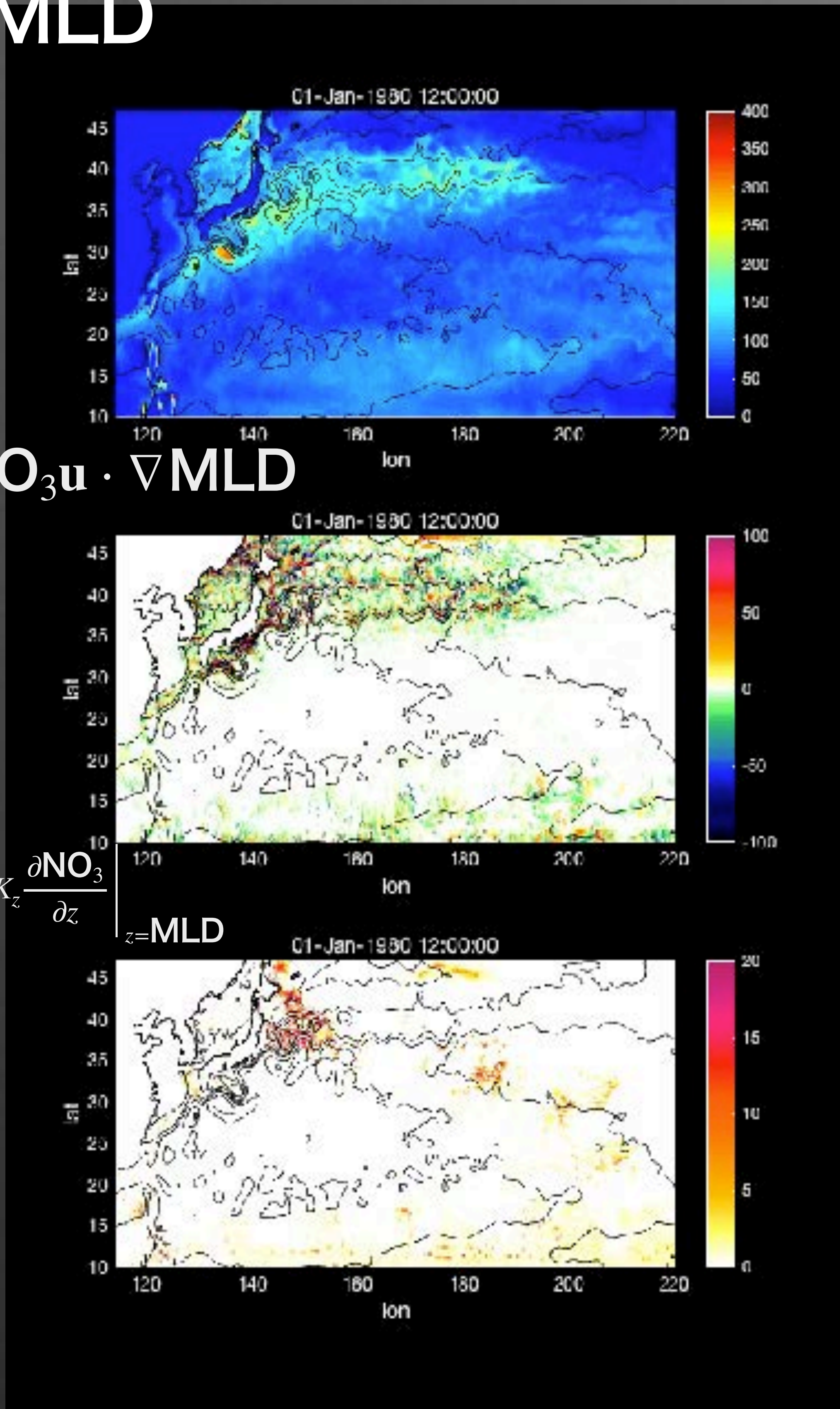
ROMS N_2PZD_2 and PN-Line and 137°E nitrate data

ROMS N_2PZD_2 Model [Gruber et al. 2006] forced 10 years with climatological forcing and 35 year NCEP(1980-2015) forcing twice.

Eddy permitting-resolving simulation can reproduce elevated nitrate along the Kuroshio with right magnitude.



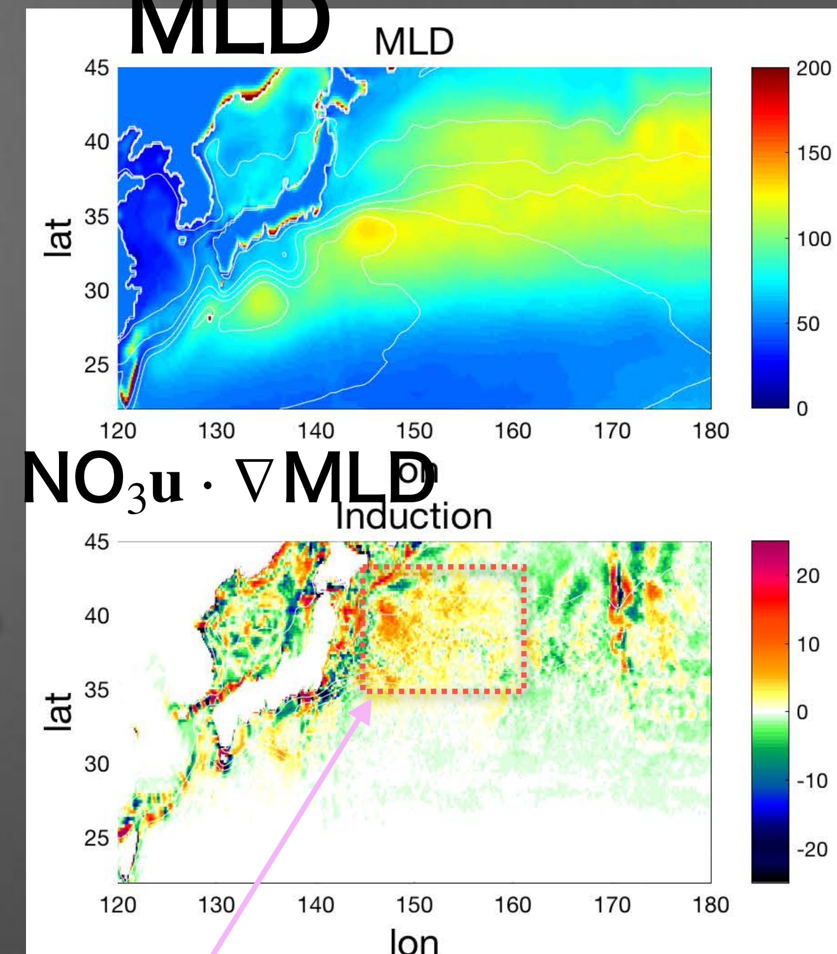
Nitrate flux through mixed layer base in 35 years

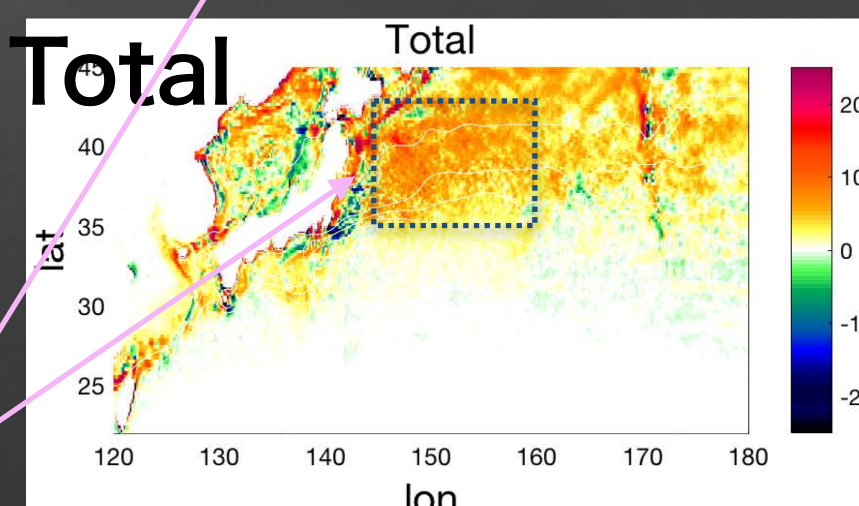


Model mixed layer depth show good agreement with the climatological mean.

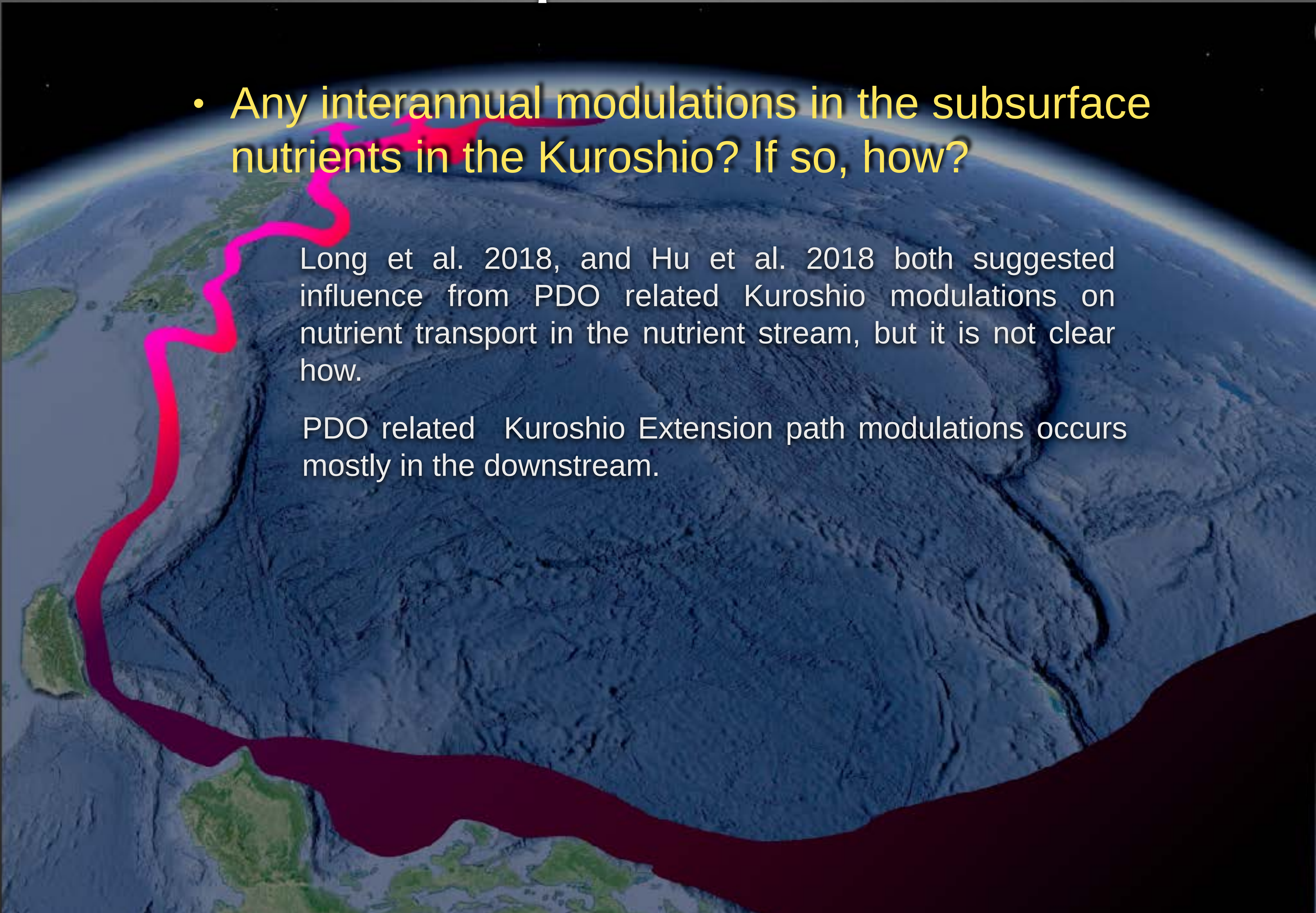
Daily induction is strongest in late winter, affected by mesoscale mixed layer variations

36 year mean suggests more than 30% of total nitrate is provided by induction in this region.





Scientific questions

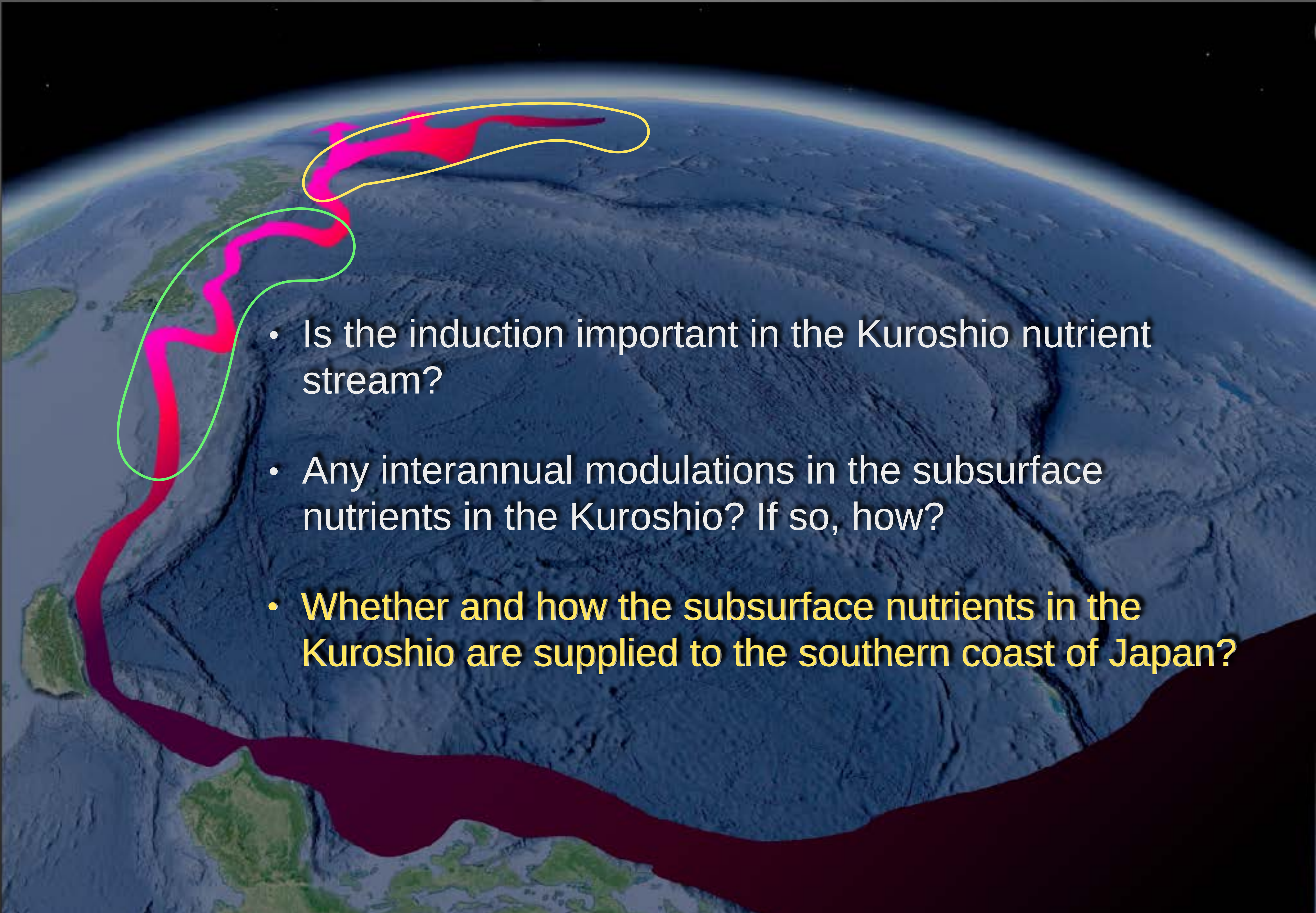


- Any interannual modulations in the subsurface nutrients in the Kuroshio? If so, how?

Long et al. 2018, and Hu et al. 2018 both suggested influence from PDO related Kuroshio modulations on nutrient transport in the nutrient stream, but it is not clear how.

PDO related Kuroshio Extension path modulations occurs mostly in the downstream.

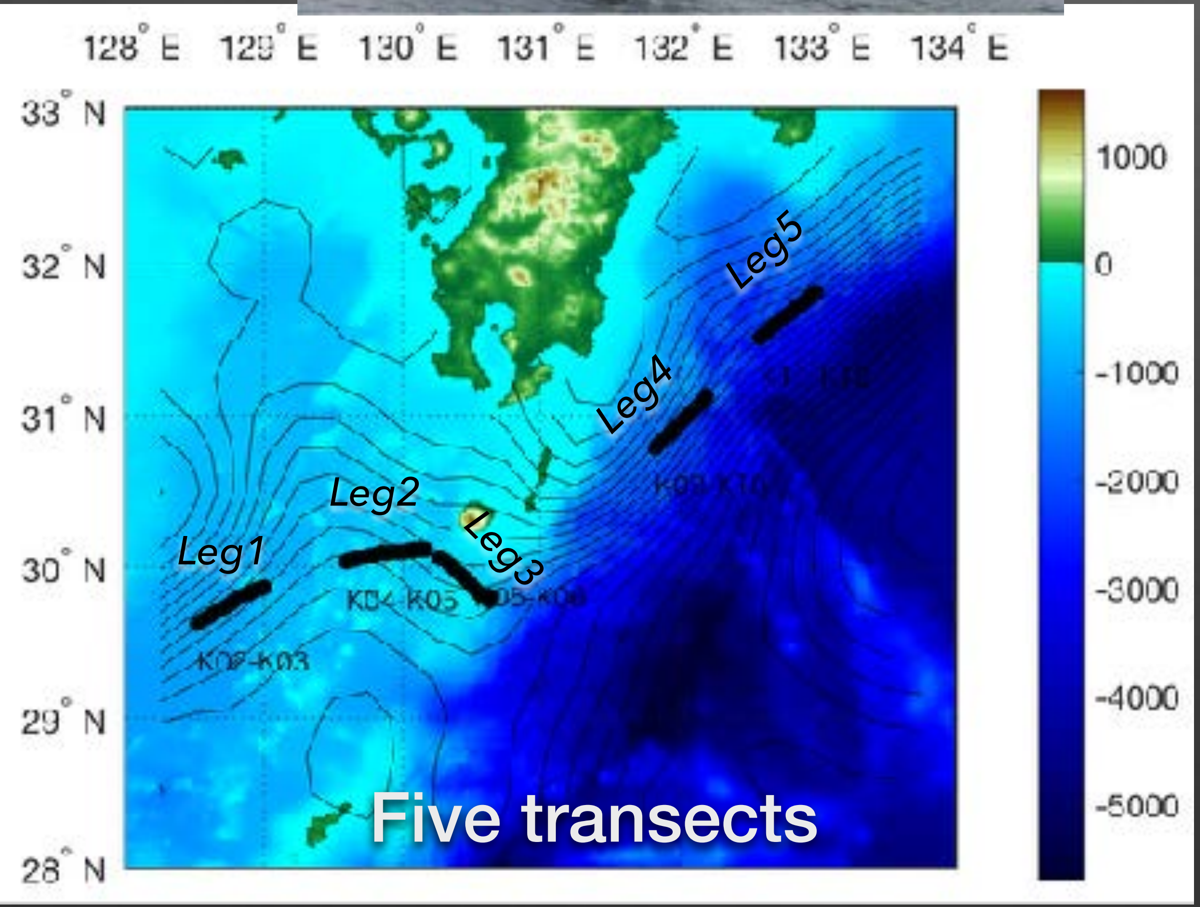
Scientific questions



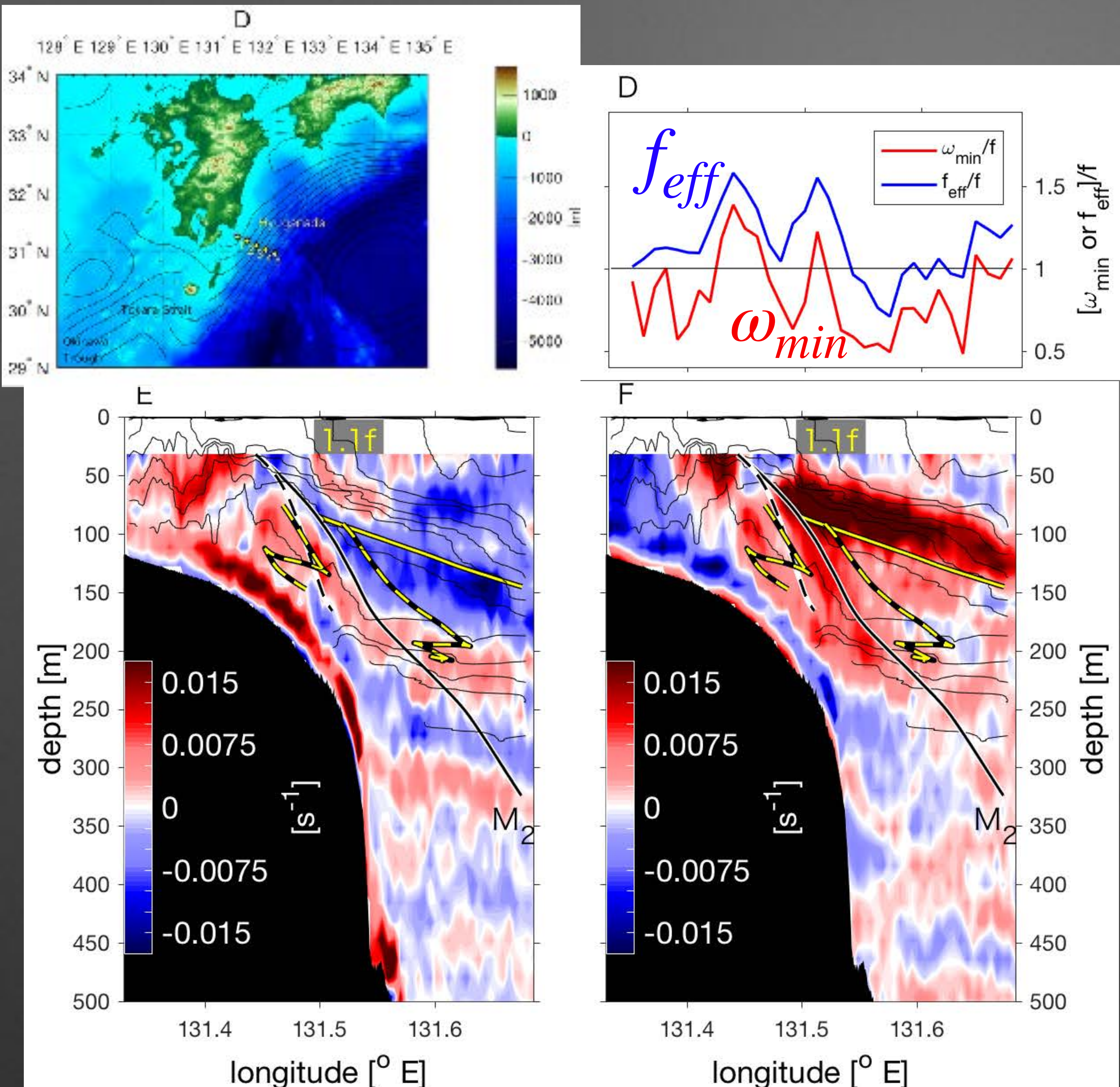
- Is the induction important in the Kuroshio nutrient stream?
- Any interannual modulations in the subsurface nutrients in the Kuroshio? If so, how?
- Whether and how the subsurface nutrients in the Kuroshio are supplied to the southern coast of Japan?

Tow-yo Turbulence observations in November 2017

We tow-yo UVMP along the Kuroshio axis across the Tokara Strait



ADCP Shear November 2018 southeast of Kyushu: Hyuganada sea



Ray tracing

$$c_g^x = \frac{N^2 l}{m^2 \omega} \qquad c_g^z = \frac{N^2 l^2}{m^3 \omega}$$

$$\frac{D\mathbf{k}}{Dt} = -\nabla \omega$$

The 1.1f near-inertial ray-path in quiescent condition agrees well with the angle of the shear away from the front.

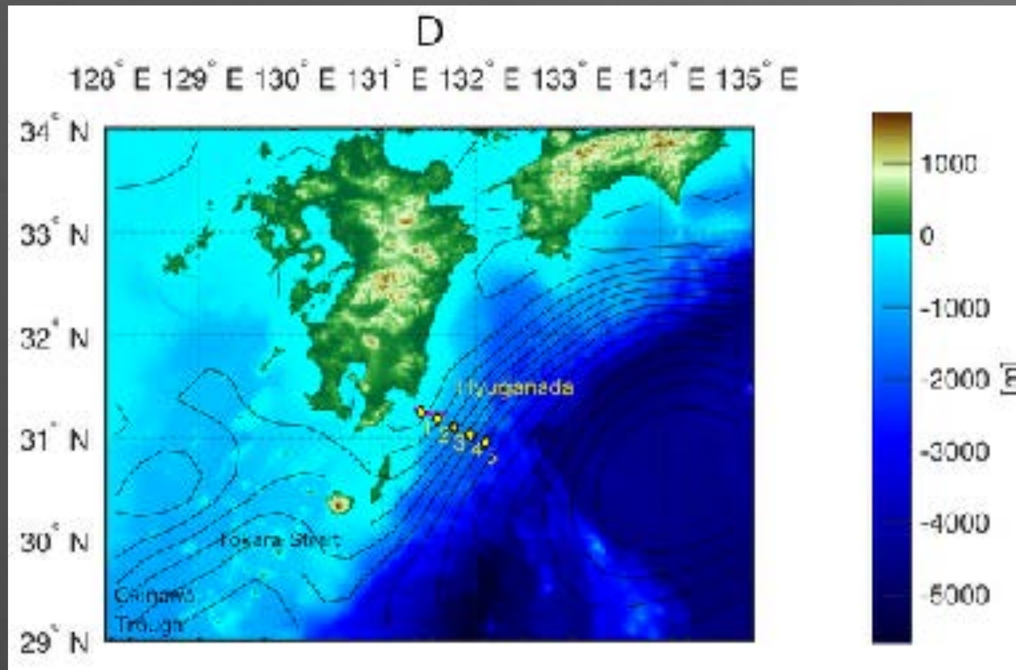
M_2 ray-path agrees better for the steep shear at the Kuroshio axis than the near-inertial ray-path.

With the group velocities considering a 2-D front, the near-inertial ray-path becomes steeper at the front, and agrees better with the observed shear angle.

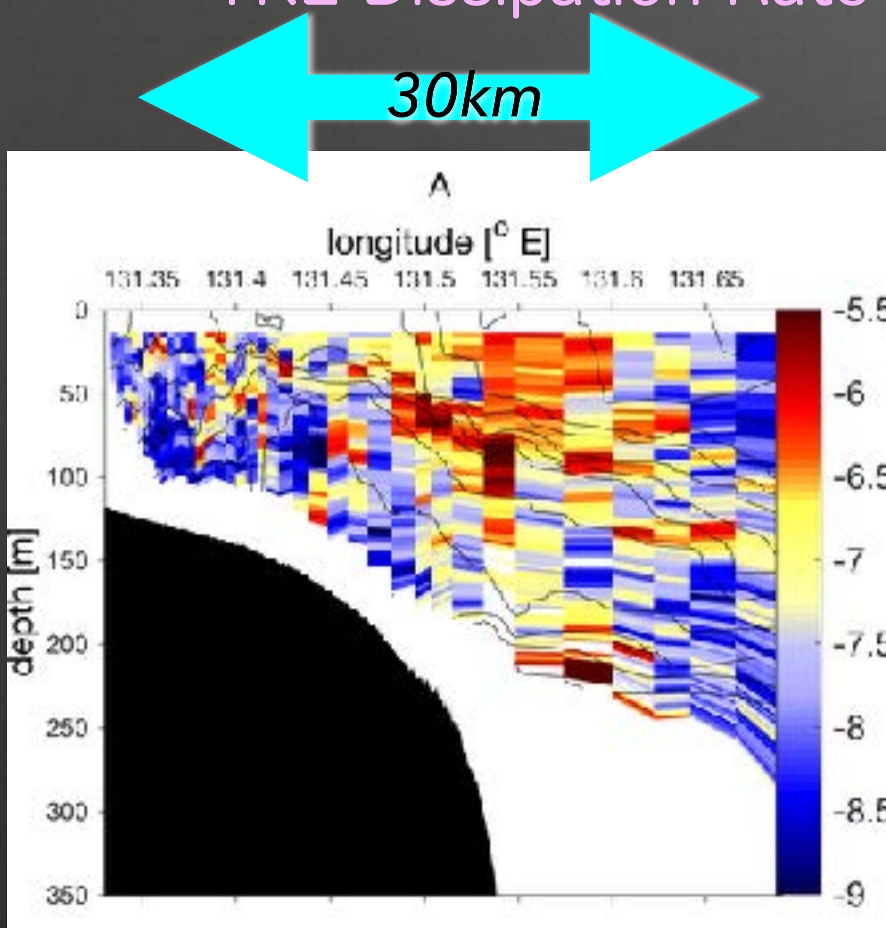
The near-inertial ray-paths reflect back and forth in the regions of lower f_{eff} and ω_{min} .

Nagai et al. 2019

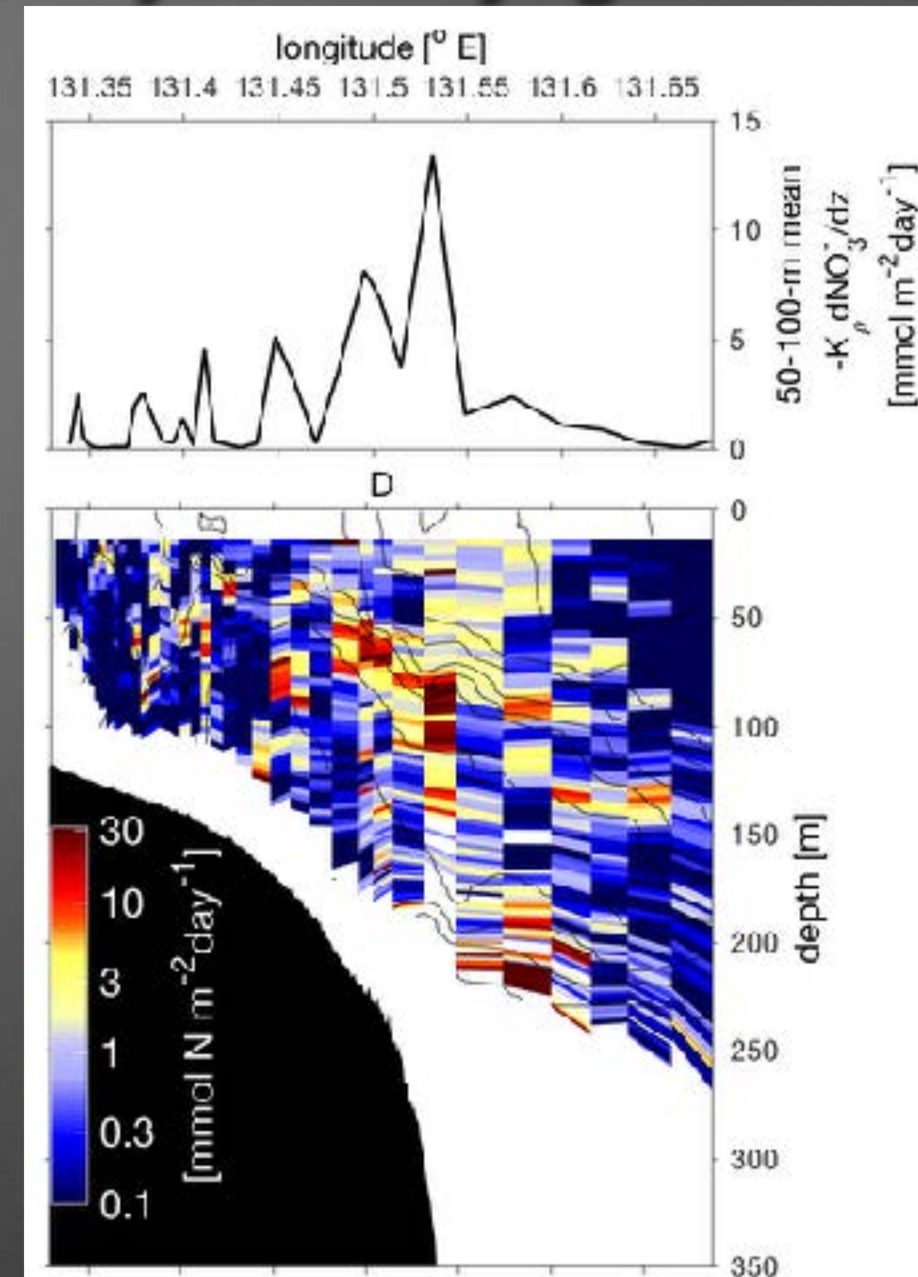
Turbulence and nitrate flux in southeast of Kyushu: Hyuganada sea



TKE Dissipation Rate



Strong turbulence is found over 20-30 km lateral and 200 m vertical scales.

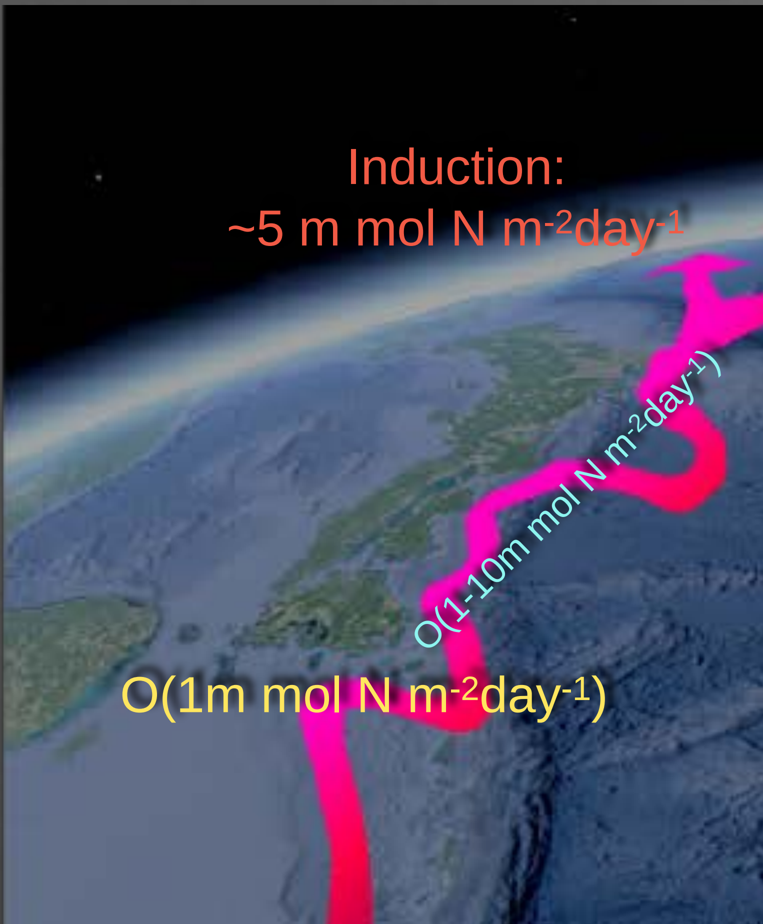


Using water samples and SUNA data, estimated nitrate diffusive flux is 1-10 m mol m^{-2}day^{-1}, which is 10-100 times larger than Kaneko et al. (2012).

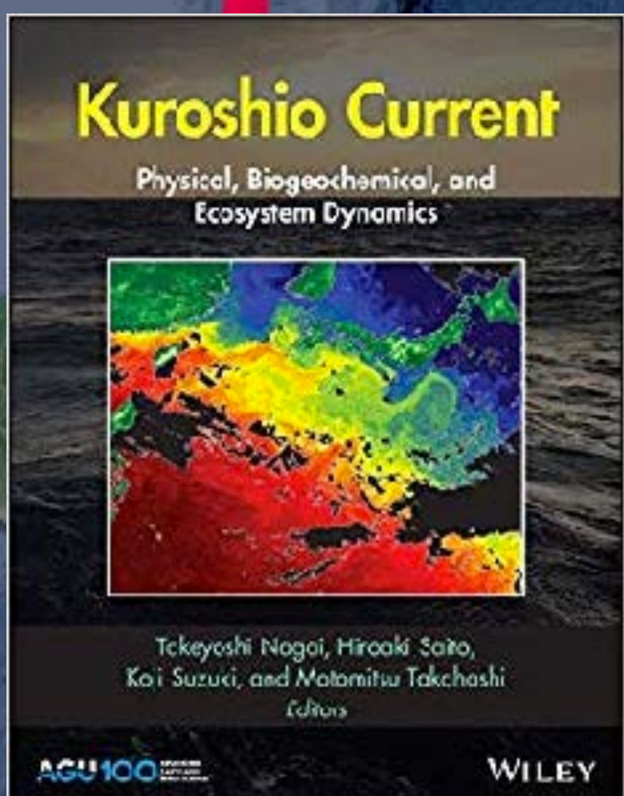
When the Kuroshio approaches to the coast, the large amount of nutrients can be injected between the Kuroshio and the continental slope

Nagai et al. 2019

Conclusions



- Is the induction important in the Kuroshio nutrient stream?
- Yes it is. The induction supplies ~5 m mol $m^{-2}day^{-1}$ of nitrate on average, which is about 30% of the total nitrate supply in the Kuroshio Extension and the Kuroshio-Oyashio confluence region. The maximum induction occurs late winter, and they are strongly affected by the mesoscale mixed layer structures.
- Any inter annual modulations in the subsurface nutrients in the Kuroshio? If so, how?
- Whether and how the subsurface nutrients in the Kuroshio supplied to the southern coast of Japan?
- A large amount of subsurface nutrients in the Kuroshio is injected to the region between continental slope and the Kuroshio when the Kuroshio approaches to the continental slopes at 1-10 m mol $m^{-2}day^{-1}$ caused by the turbulence probably due to trapped near-inertial internal waves.



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