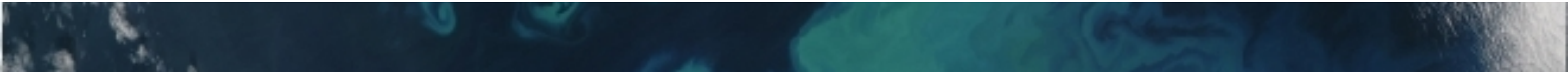
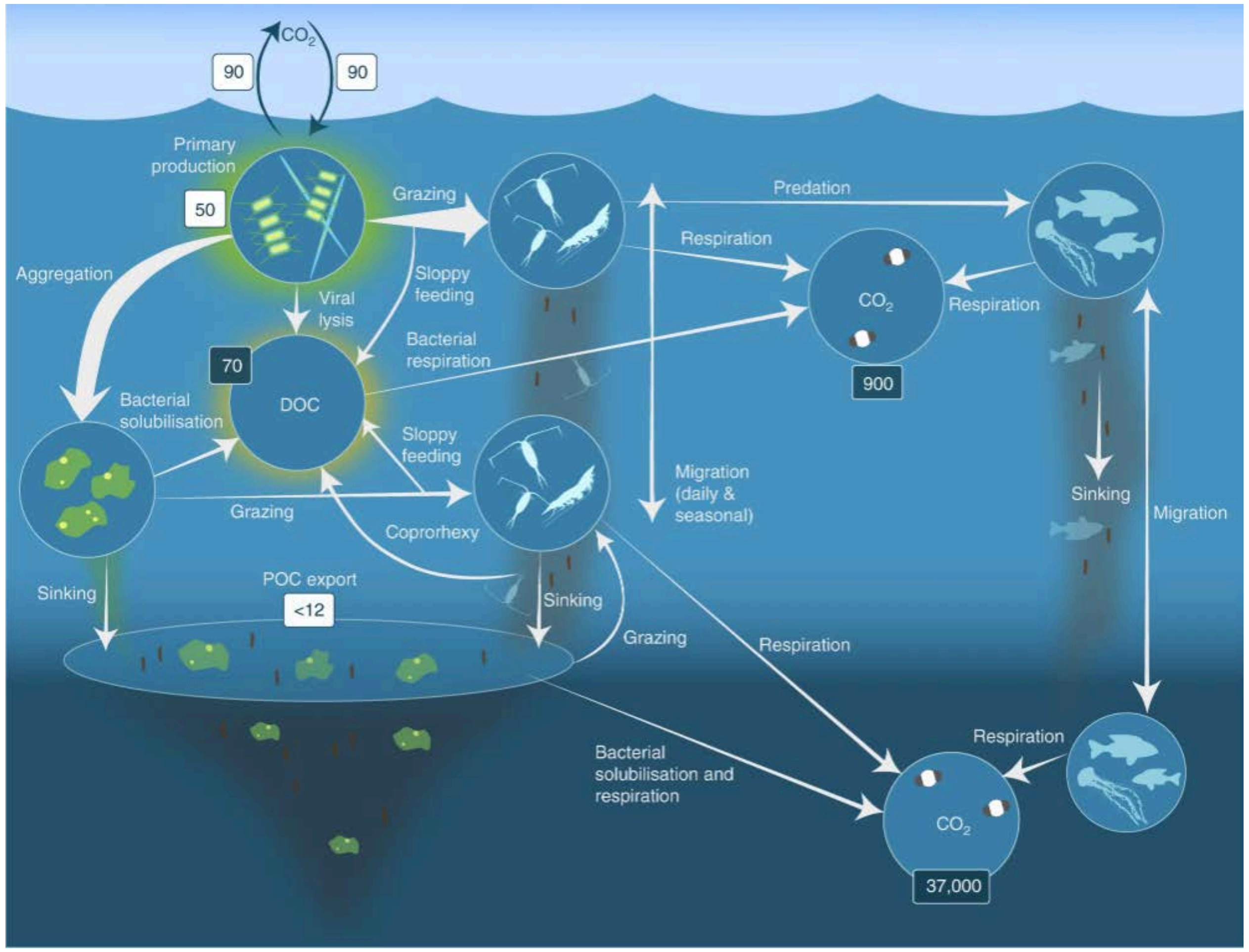
IMPACT OF SUBMESOSCALE DYNAMICS ON OCEAN BIOGEOCHEMISTRY IN A CHANGING CLIMATE

Channing J. Prend, US CLIVAR Summit 2023



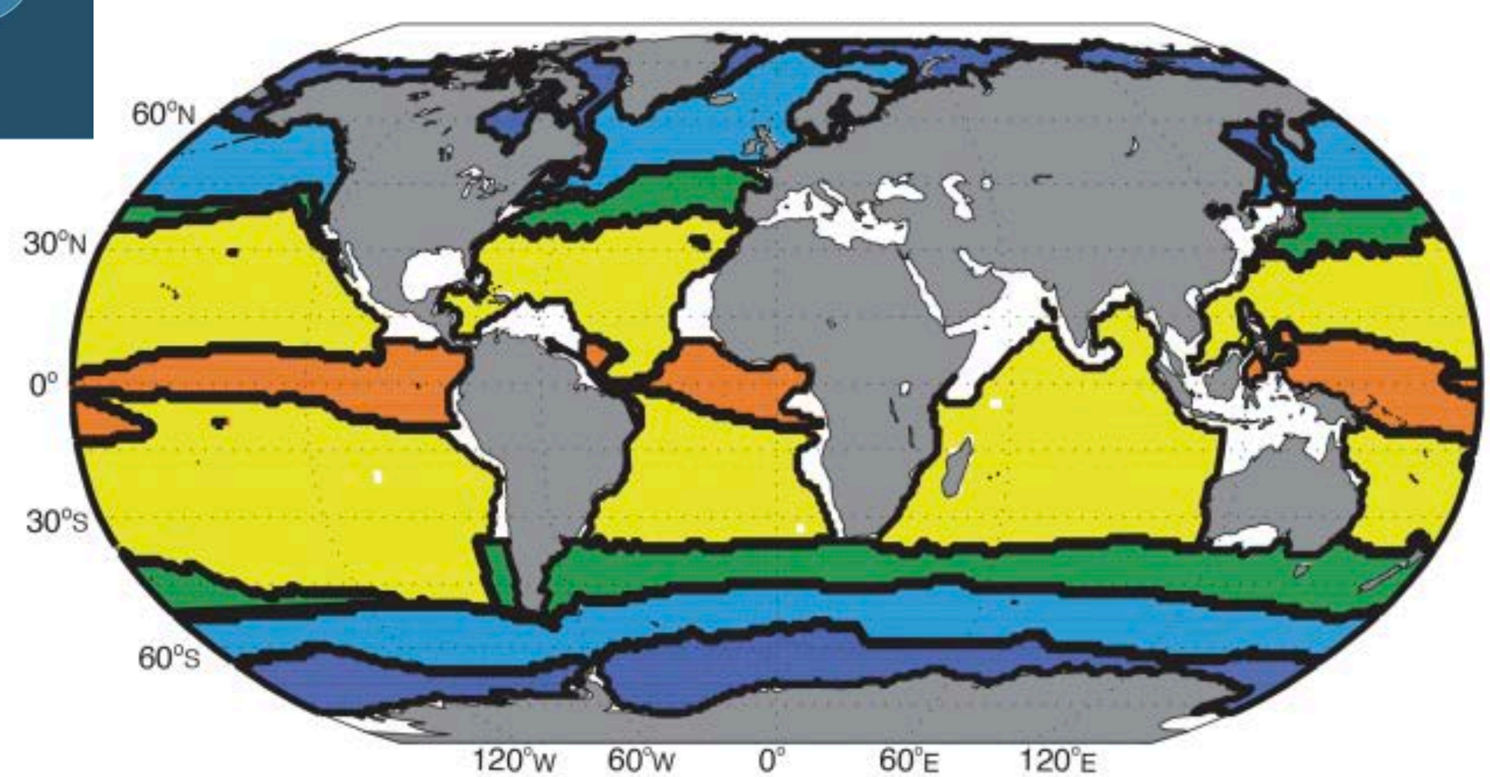
WHAT ARE BIOGEOCHEMICAL CYCLES?



(Cavan et al., 2019)

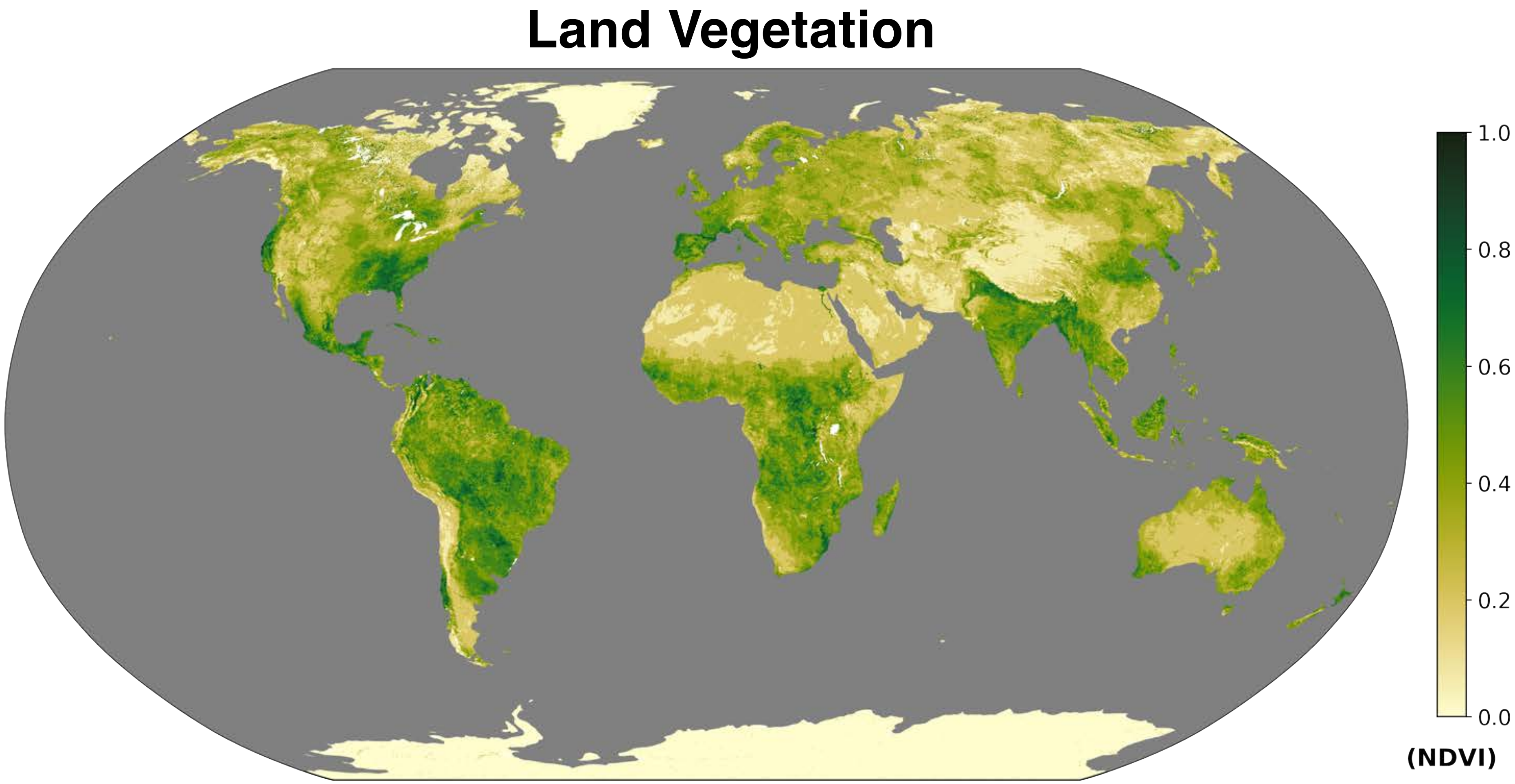
Marine biogeochemical cycle refers to the transport and transformation of chemical elements (e.g. carbon, nitrogen, phosphorous, oxygen) between different reservoirs in the ocean.

Ocean Biomes

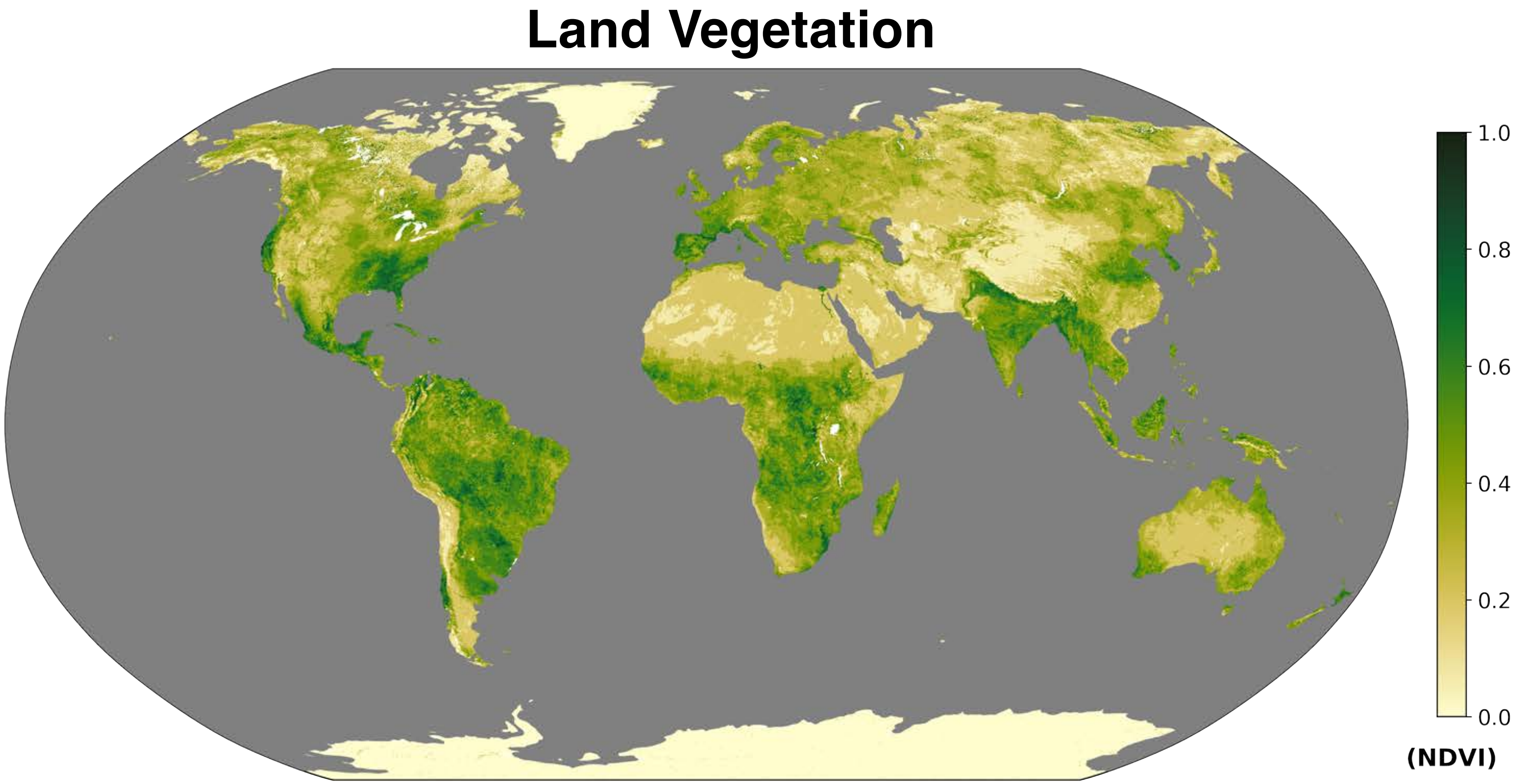


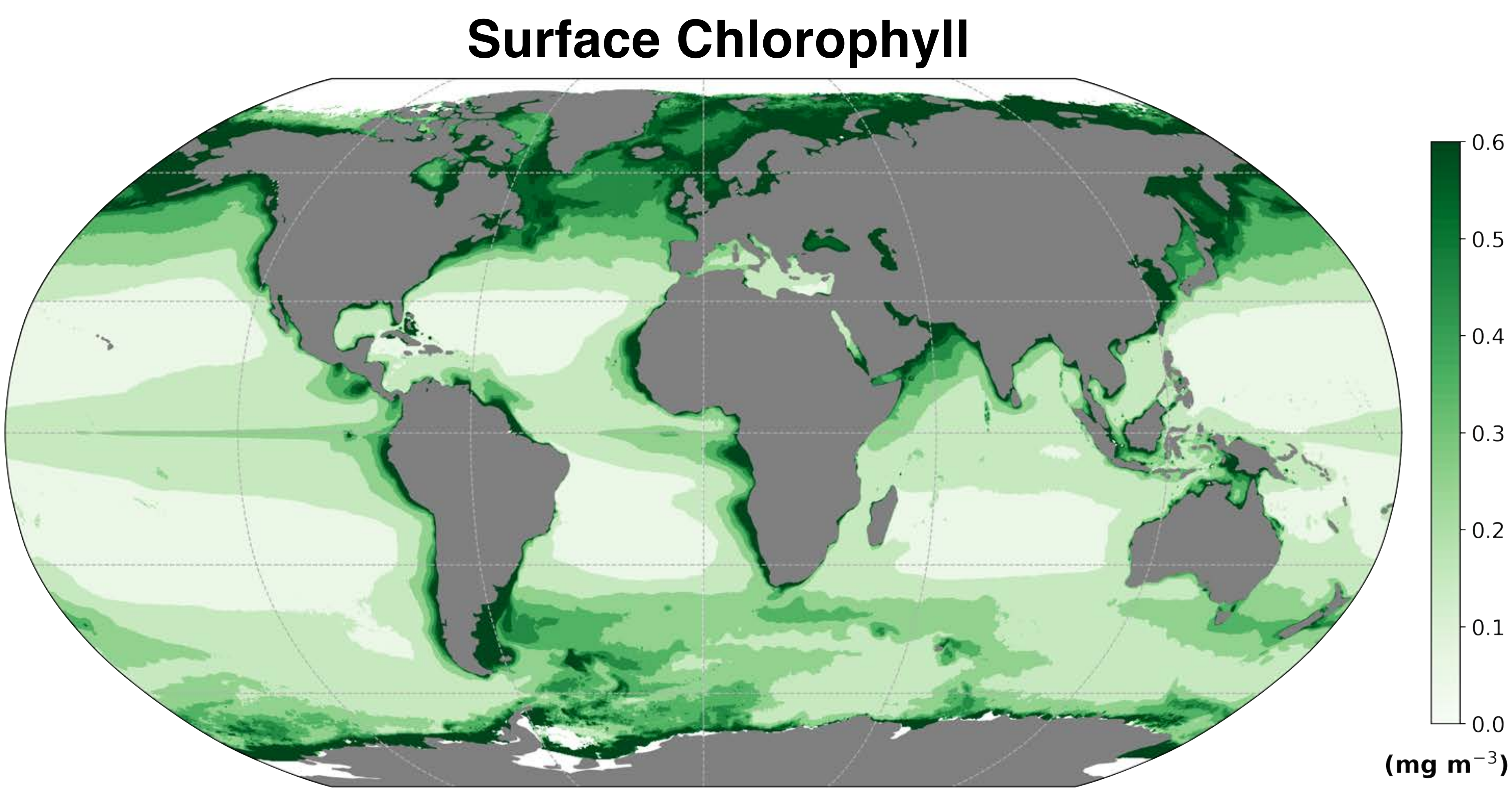
(Fay & McKinley, 2014)

Phytoplankton are central to these cycles, which help regulate the entire global climate system.



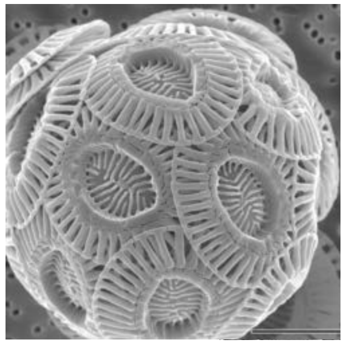
The distribution of terrestrial biomes is linked to environmental factors such as temperature, rainfall, soil type, etc.

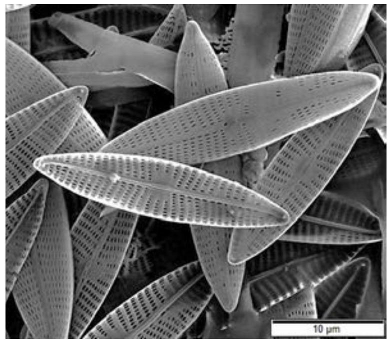




Marine ecosystems exist in a fluid environment.

Biogeography is linked to environmental controls (light and nutrient availability), which are related to the ocean circulation.

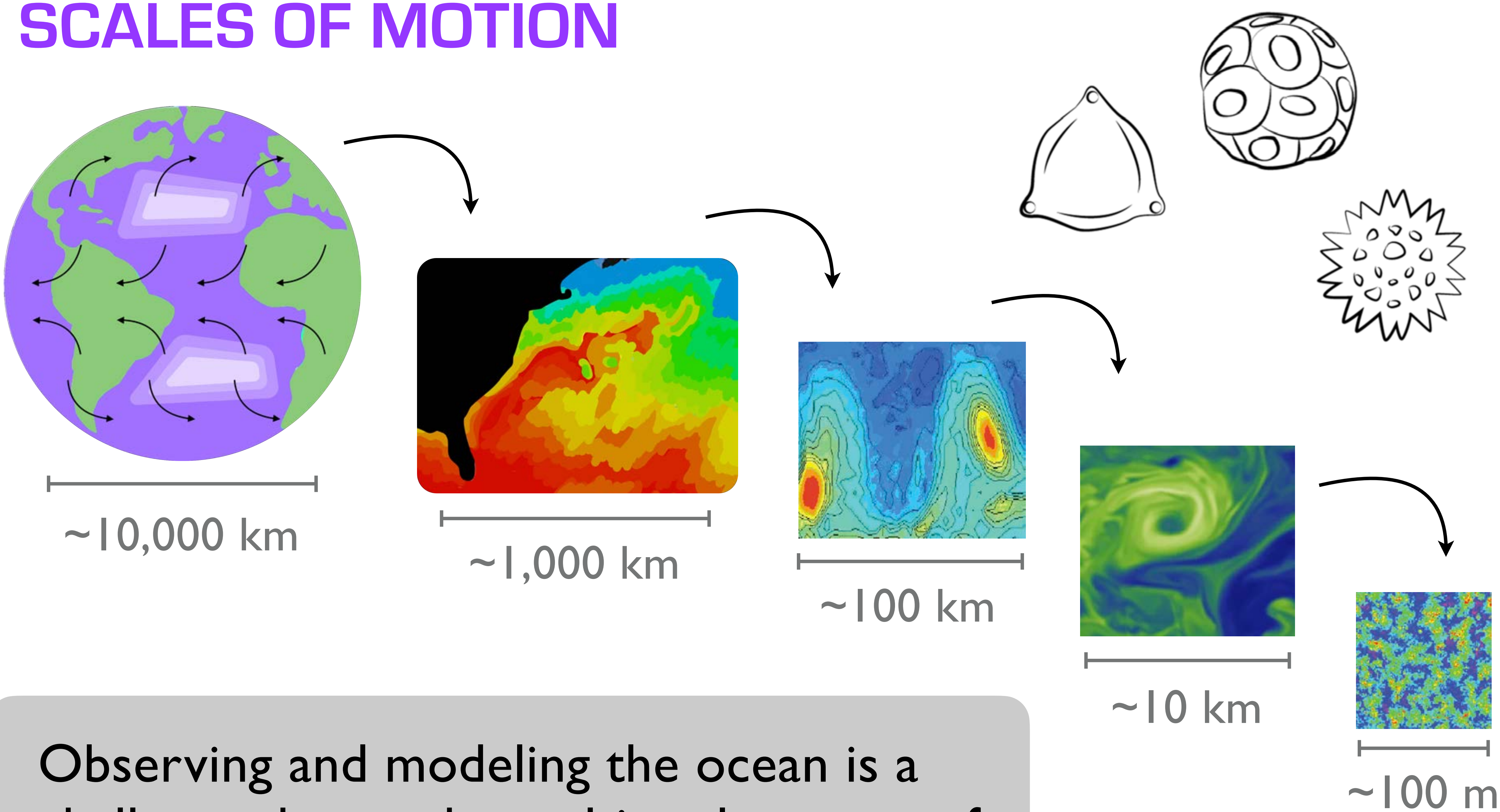

UNCW


USGS

Ocean color exhibits variability at small scales

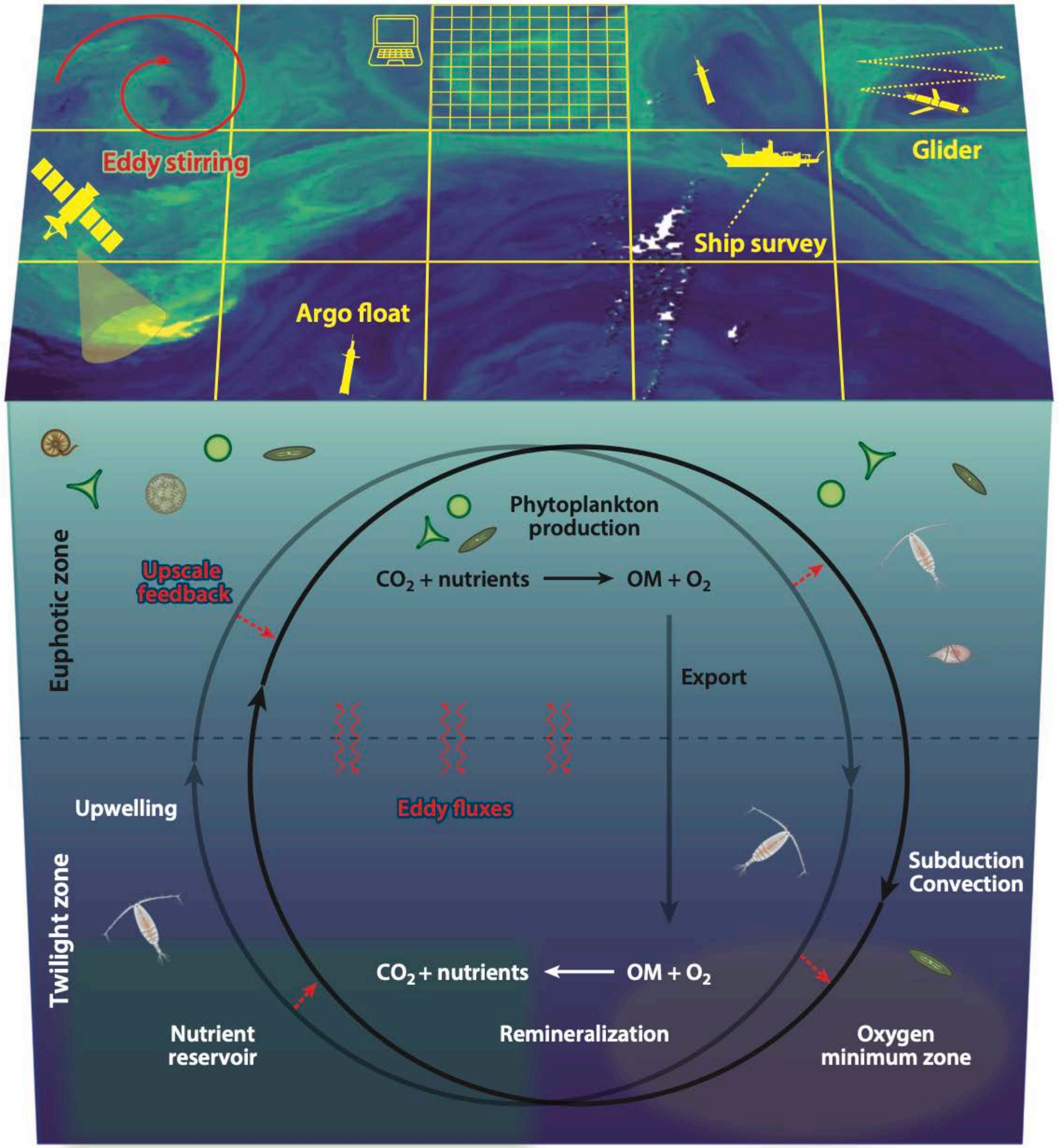
OCEAN IS A MULTI-SCALE SYSTEM!

SCALES OF MOTION



Observing and modeling the ocean is a challenge due to the multi-scale nature of ocean dynamics and biogeochemistry.

EDDY FLUXES OF NUTRIENTS & CARBON

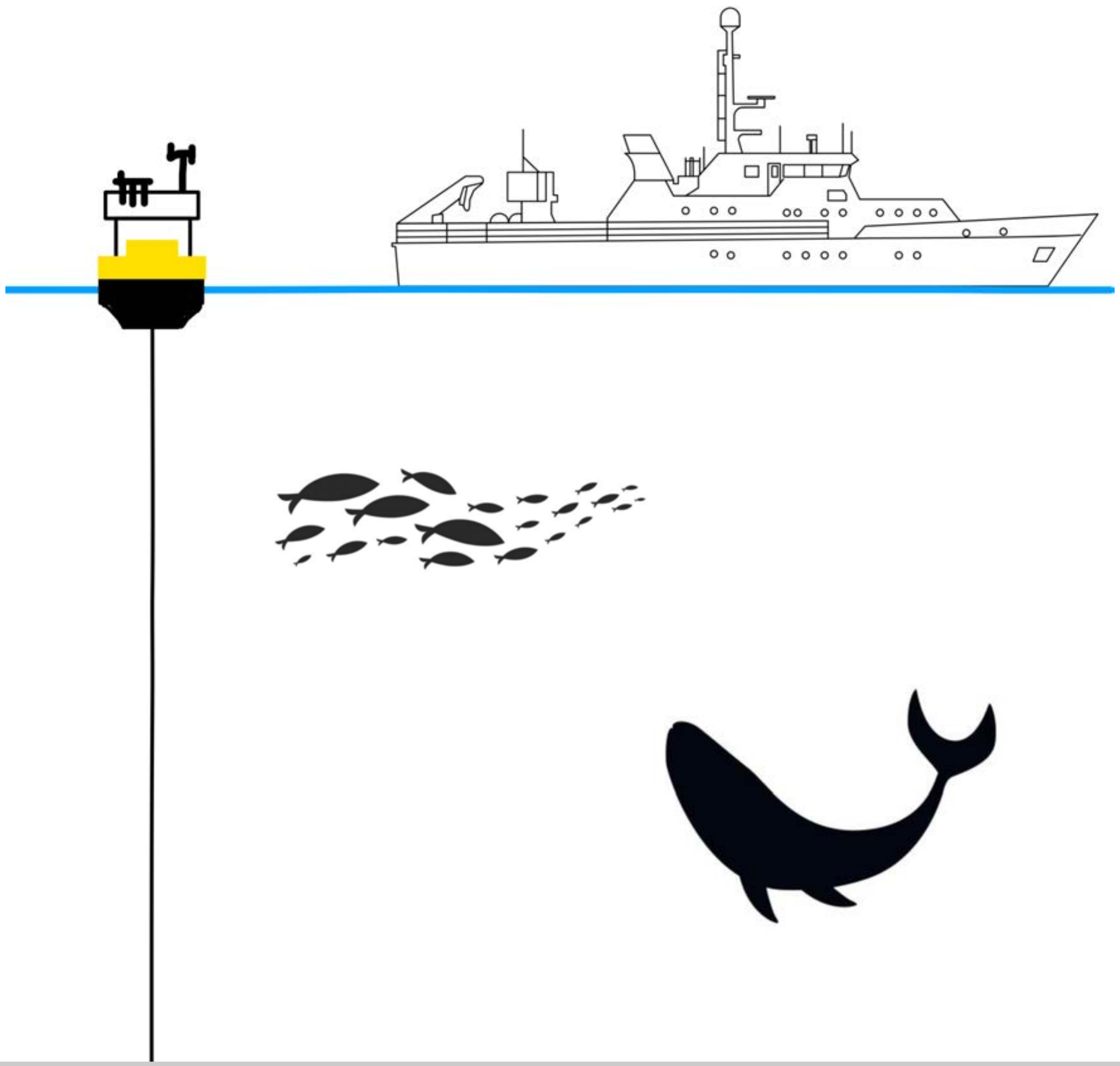


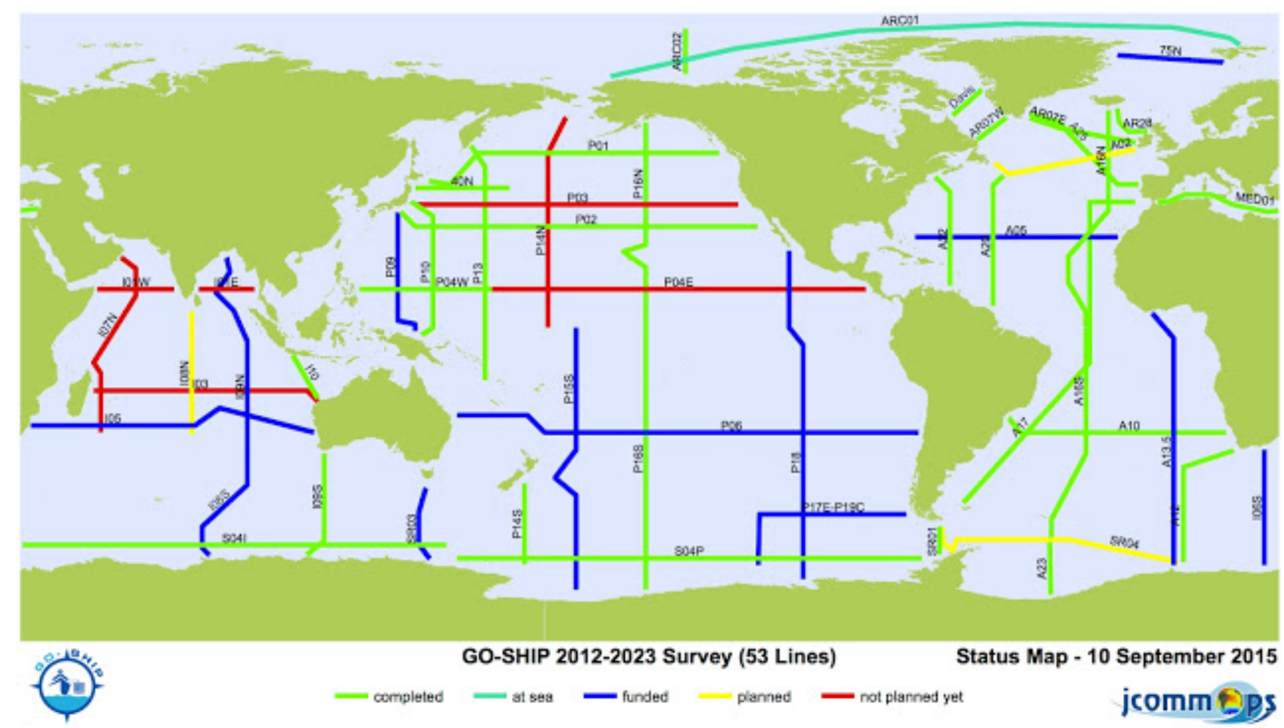
(Lévy et al., 2023)

Fine-scale processes O(1-100 km, days-months) modify nutrient and carbon inventories. But **generalizing their impact is non-trivial**. e.g. eddies can alter both nutrient and light availability, and the sign of the response will depend on what is limiting at a particular time/location.

Evaluating the net effect of fine-scale processes on the large-scale biogeochemical balance requires resolving both small and large scales.

HISTORICAL OBSERVATIONAL METHODS

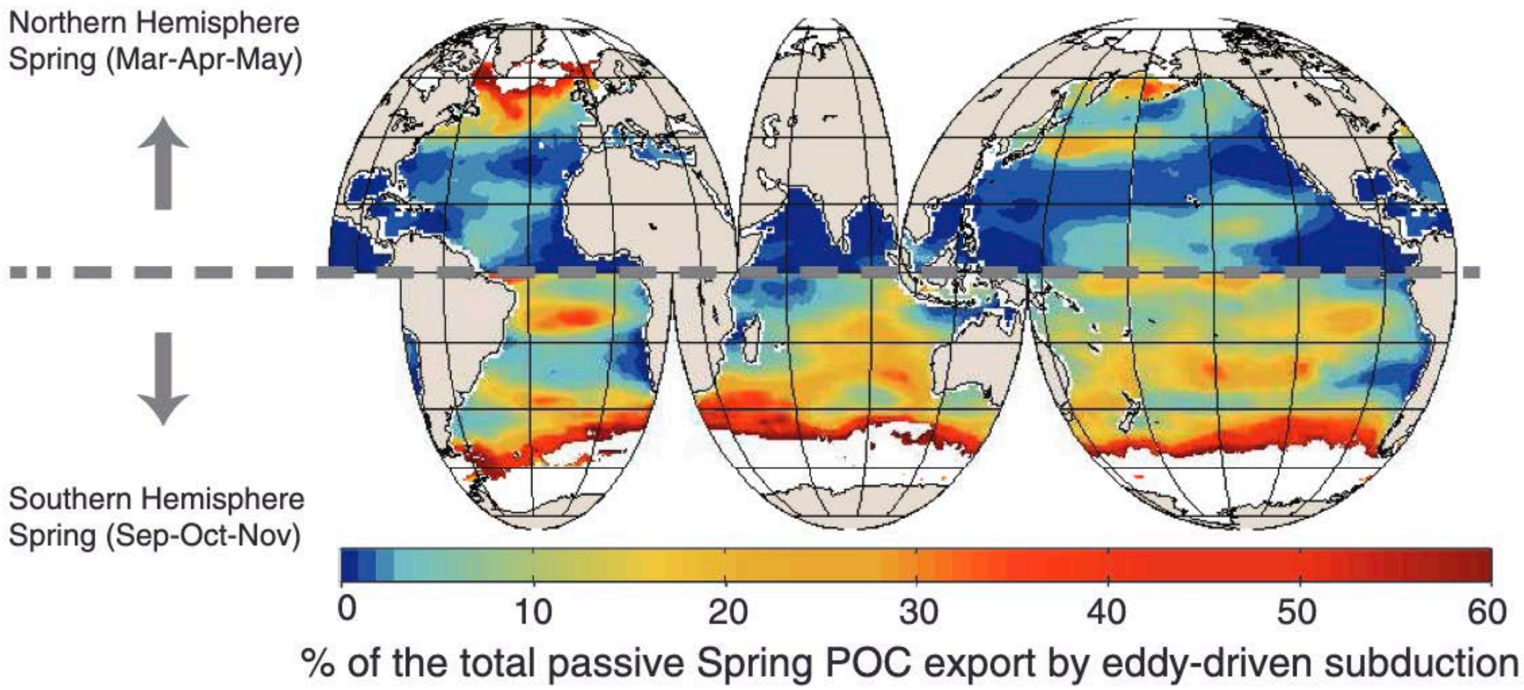




OceanOps

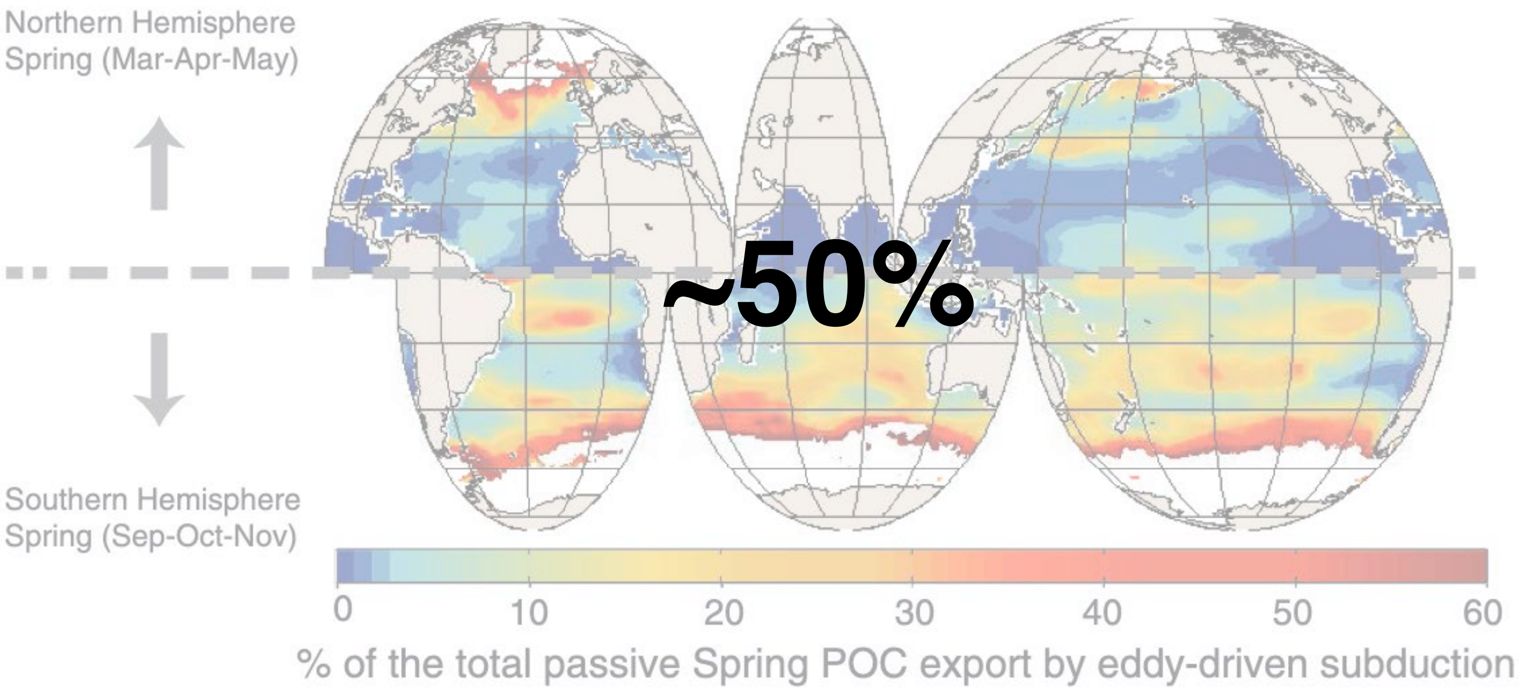
Traditional in situ observational methods are limited in space and/or time. Biogeochemical tracers vary over many different scales, which makes them challenging to observe and model.

EDDY-SUBDUCTION PUMP

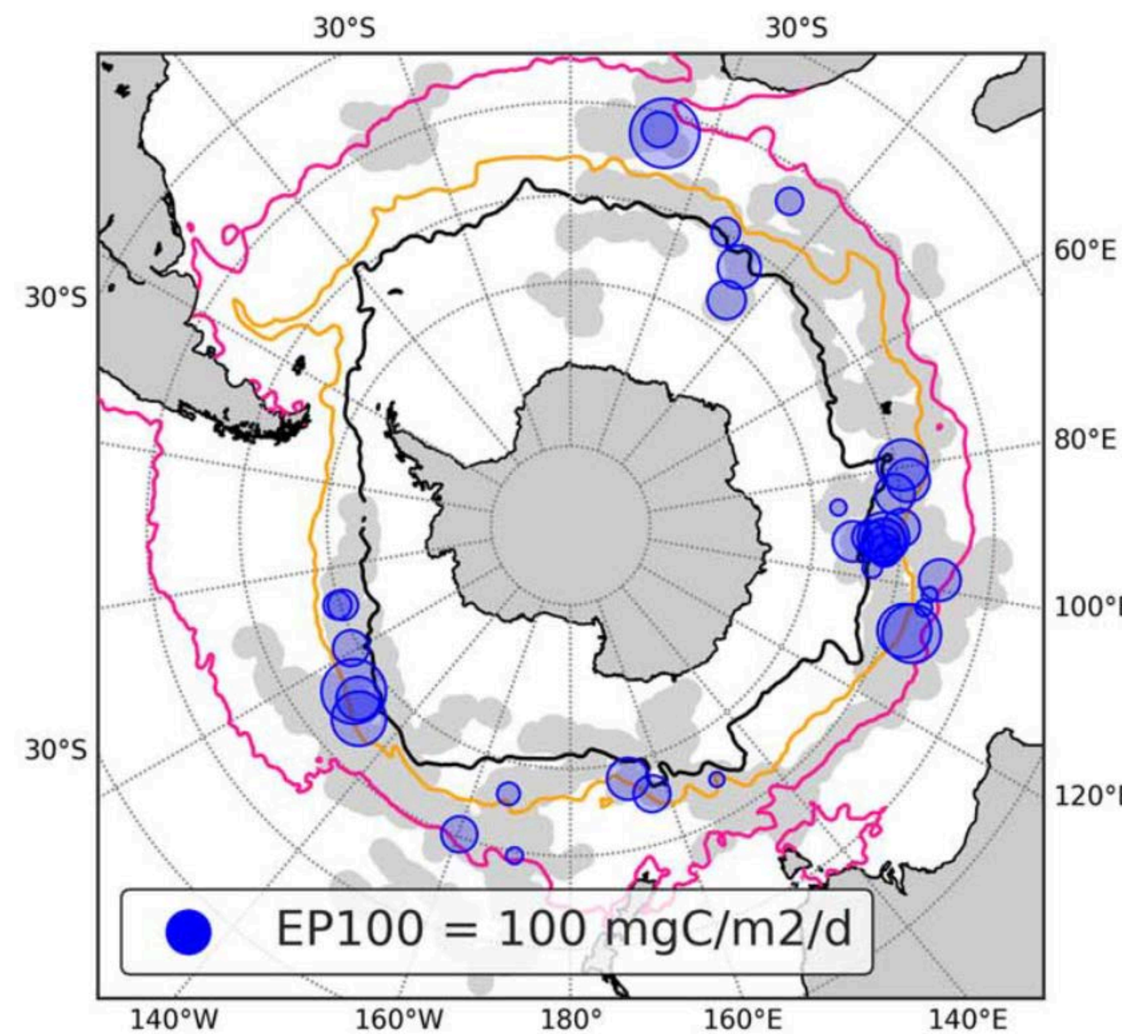


(Omand et al., 2015)

EDDY-SUBDUCTION PUMP

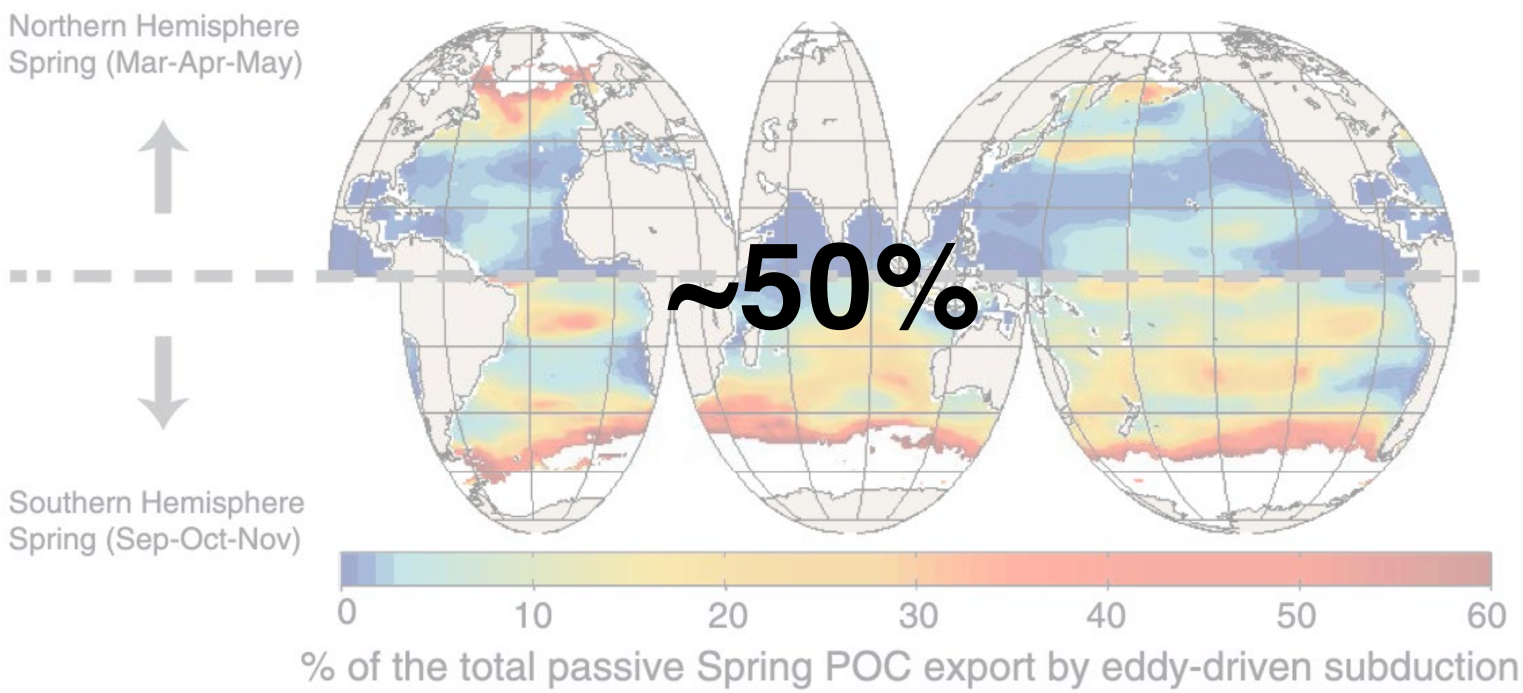


(Omand et al., 2015)

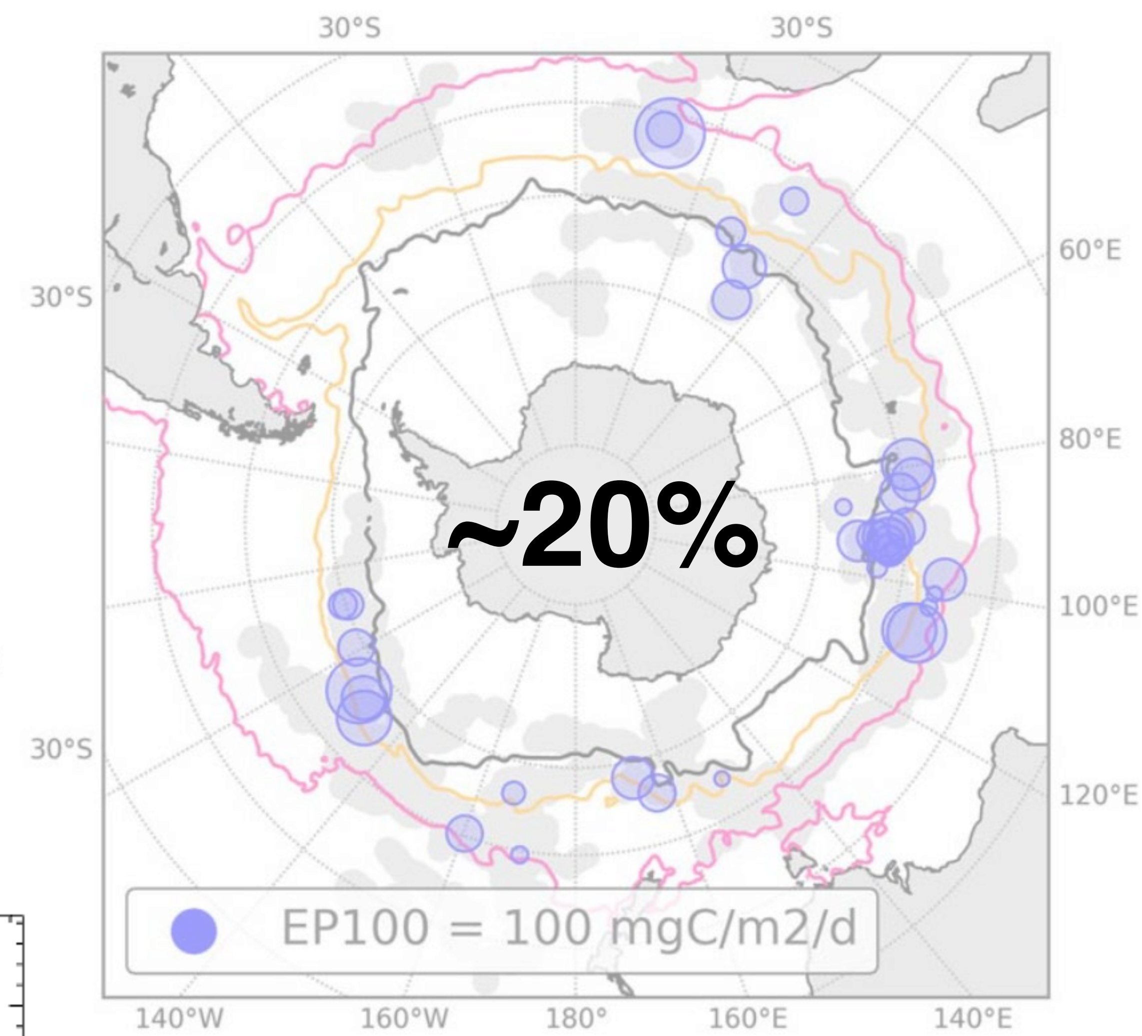


(Llort et al., 2018)

EDDY-SUBDUCTION PUMP

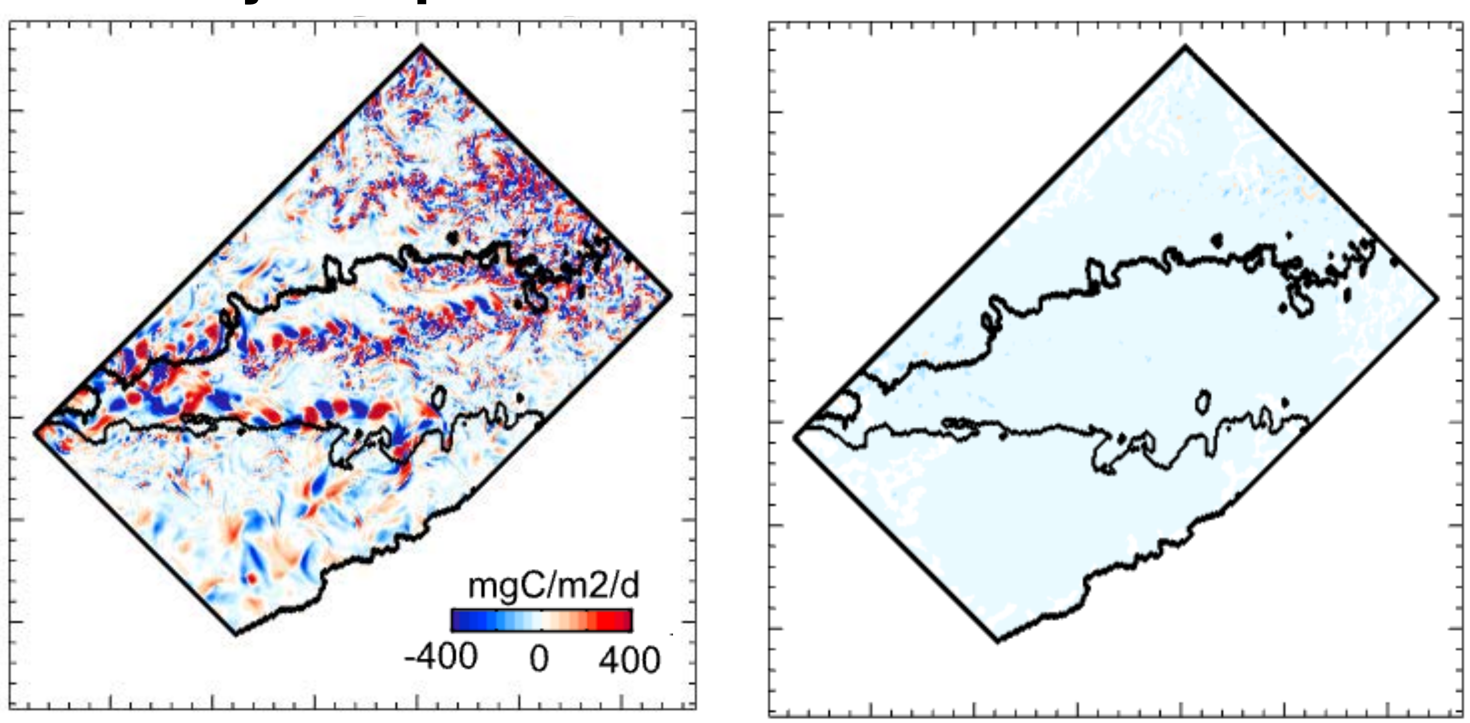


(Omand et al., 2015)



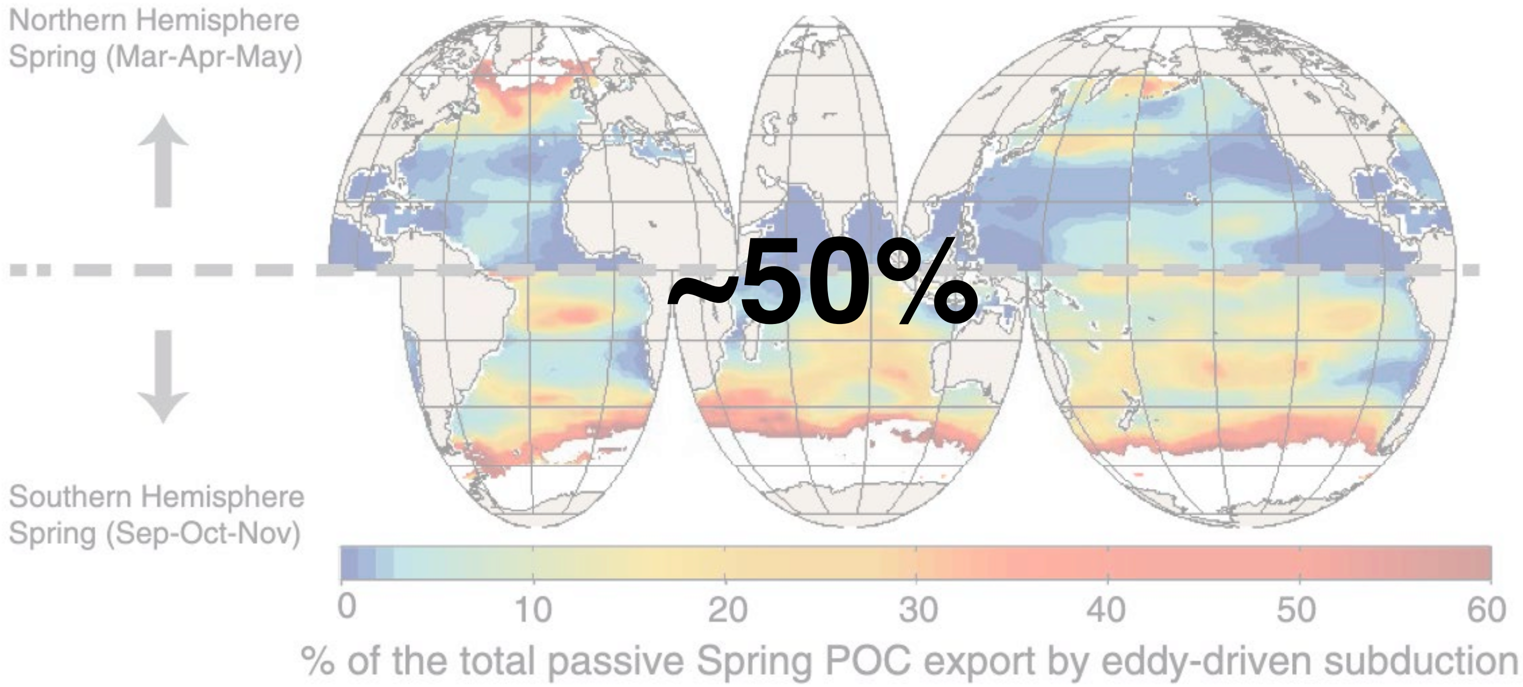
(Llort et al., 2018)

Daily Snapshot **Annual Mean**

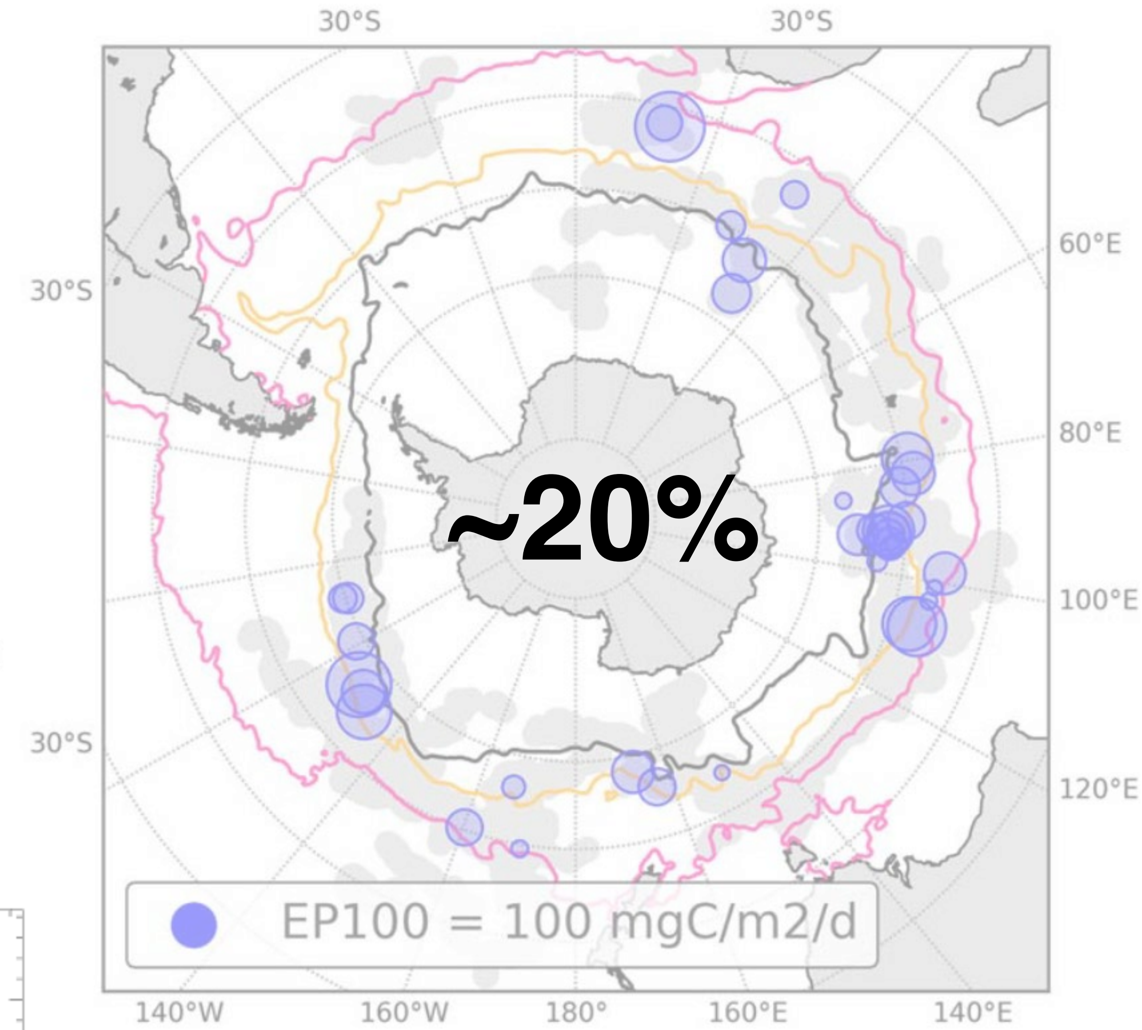


(Resplandy et al., 2019)

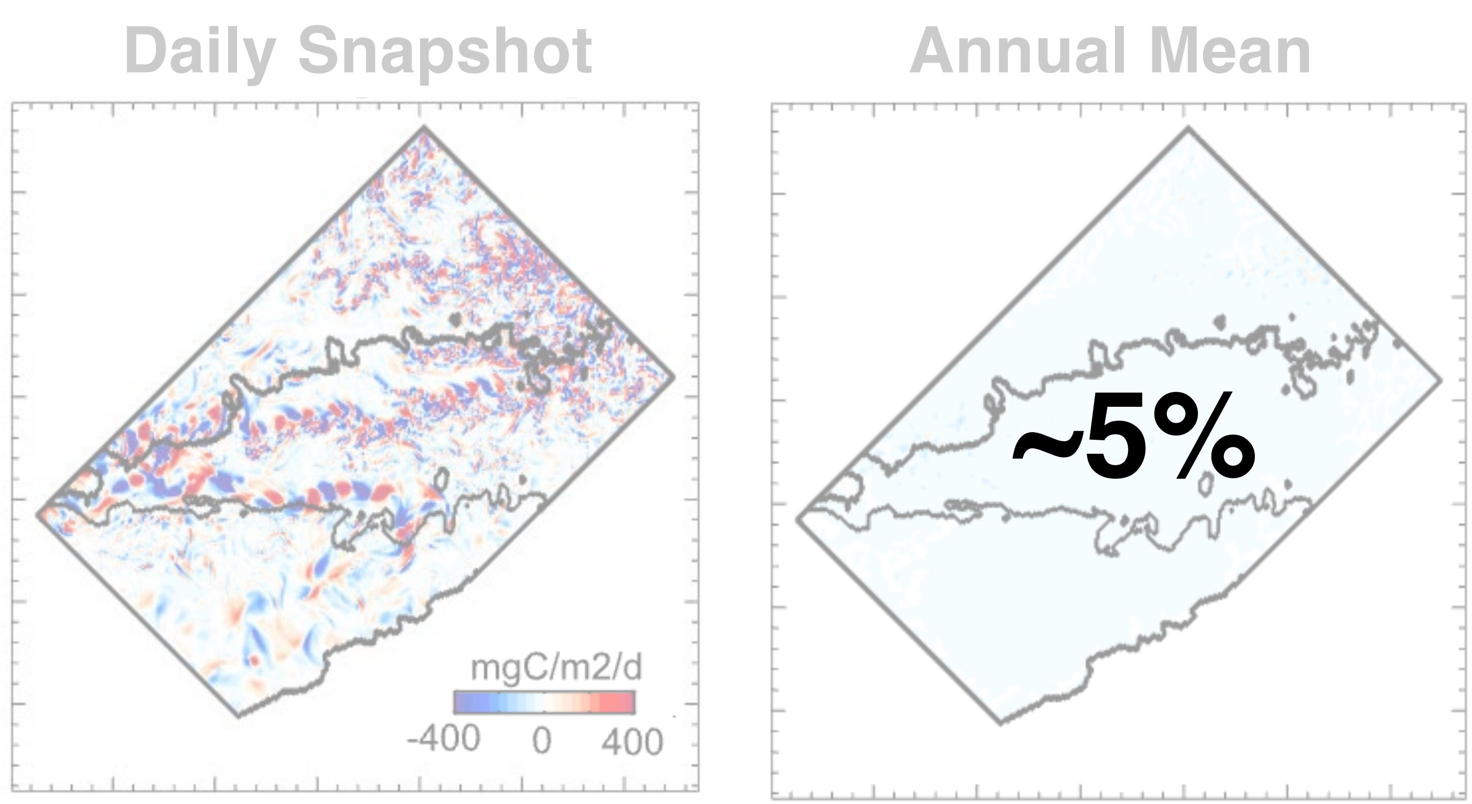
EDDY-SUBDUCTION PUMP



(Omand et al., 2015)

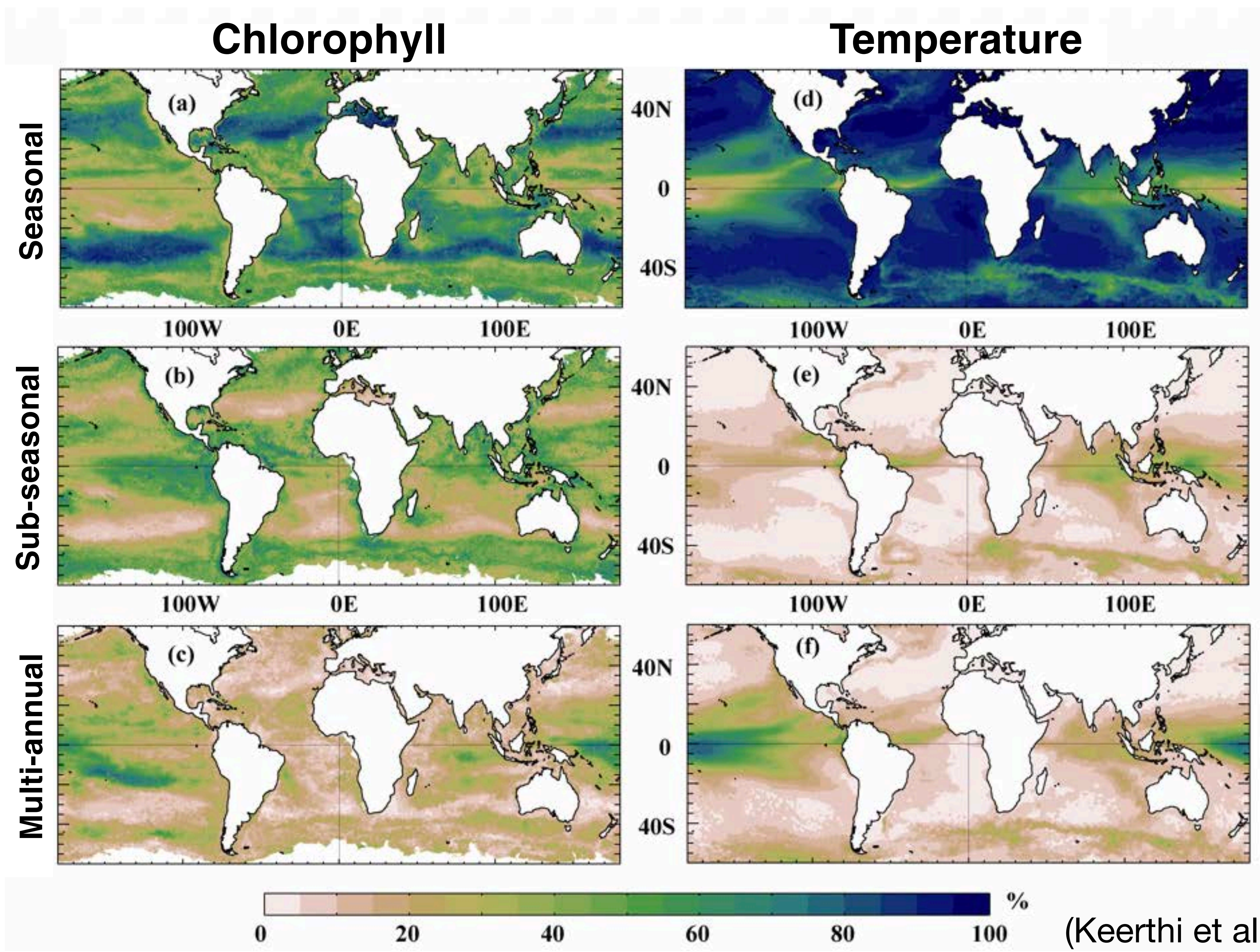


(Llort et al., 2018)



(Resplandy et al., 2019)

CONTRIBUTION TO NATURAL VARIABILITY



Spatial scales:

>600 km

~50-100 km

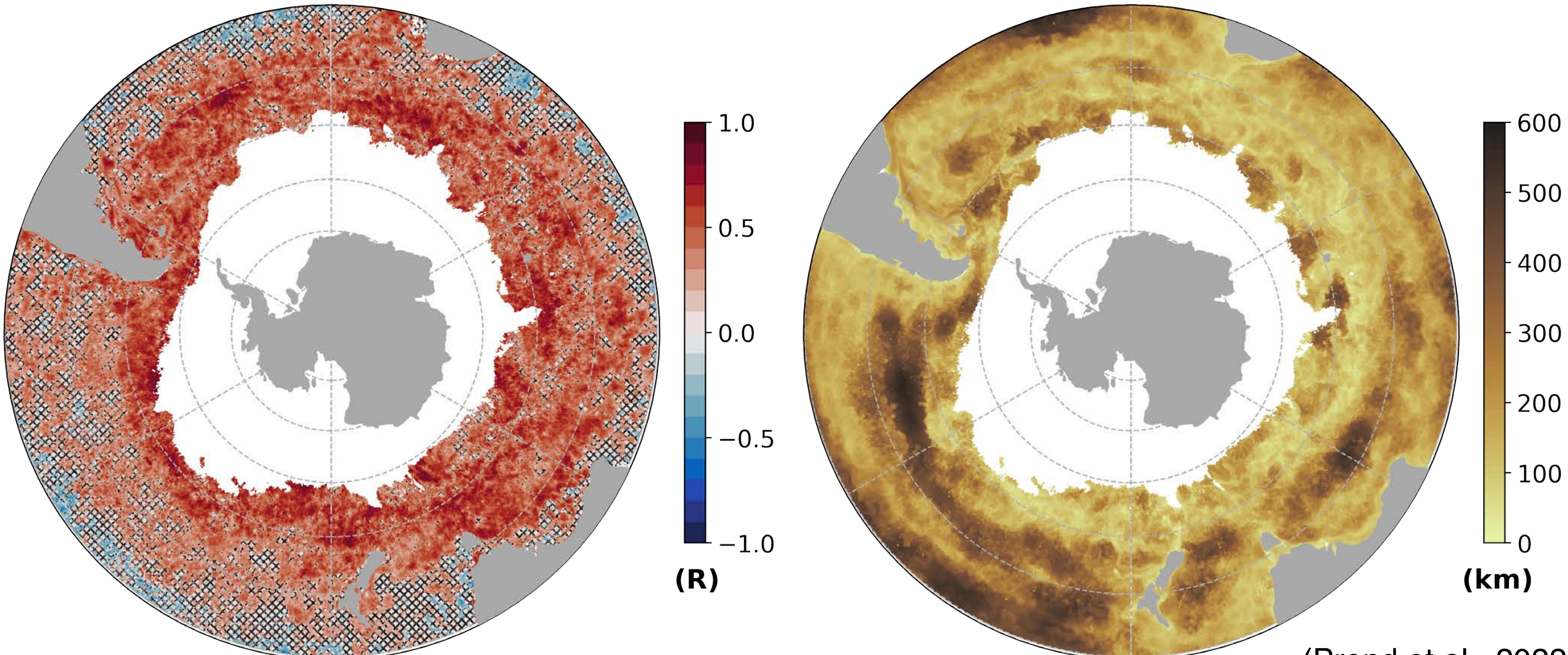
~200-400 km

(Keerthi et al., 2022)

Chlorophyll has a significantly larger percentage of total variance explained by high frequency processes compared to sea surface temperature.

FINE-SCALES DRIVE INTERANNUAL VARIABILITY

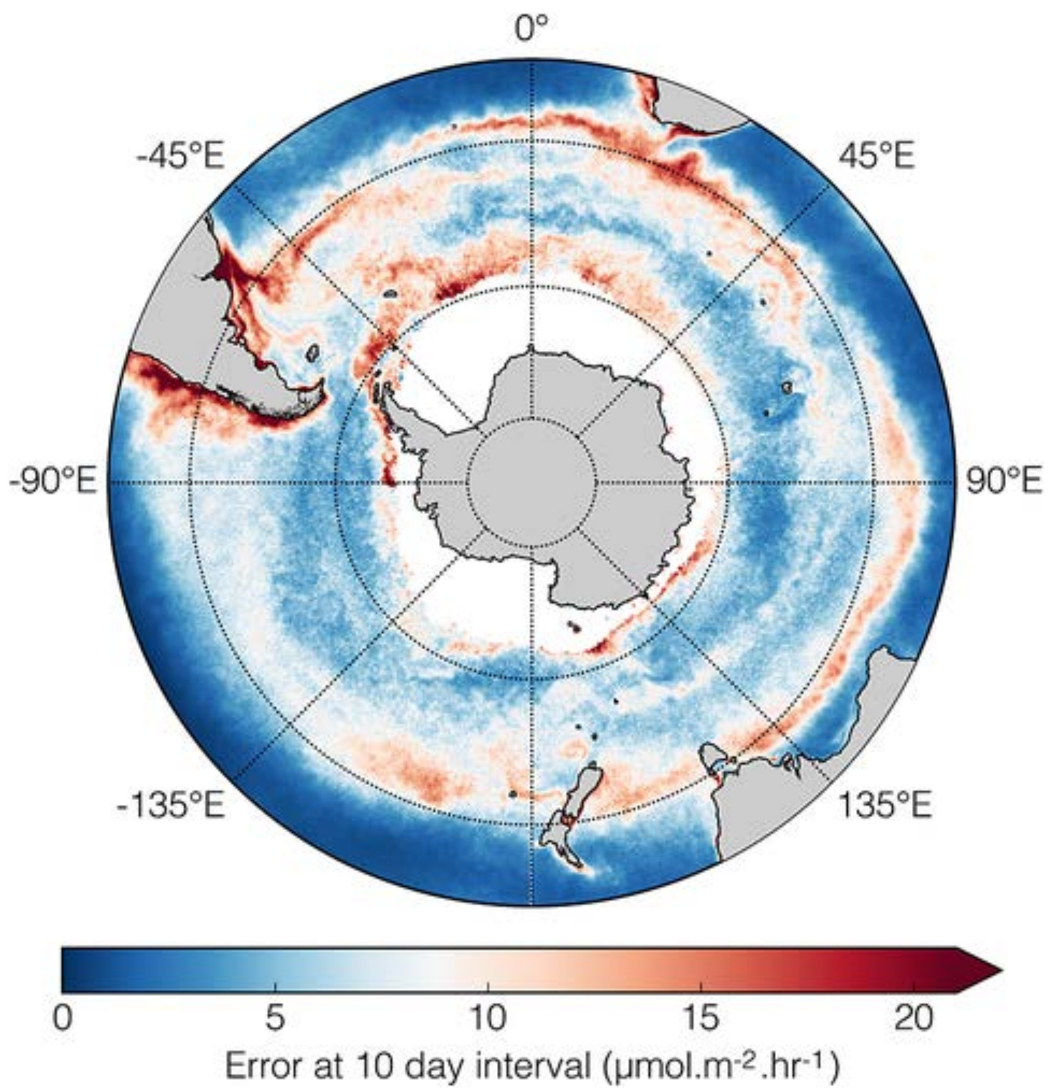
Fine-scale variability projects onto fluctuation in the annual mean



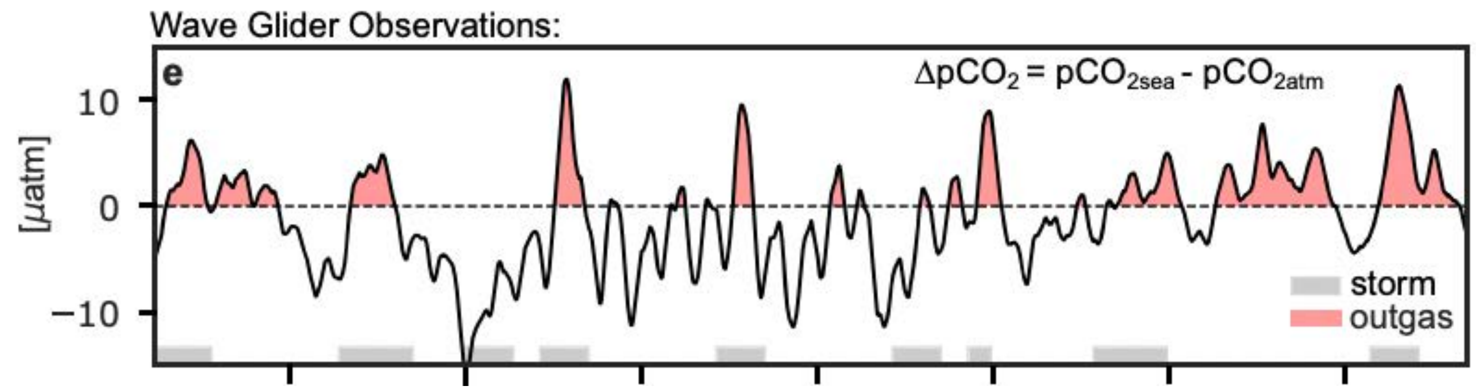
(Prend et al., 2022)

Consequently, the spatial scales associated with consistent variations in the annual mean are small (~200 km in the Antarctic Circumpolar Current).

HIGH-FREQUENCY AIR-SEA CARBON FLUXES



(Monteiro et al., 2015)



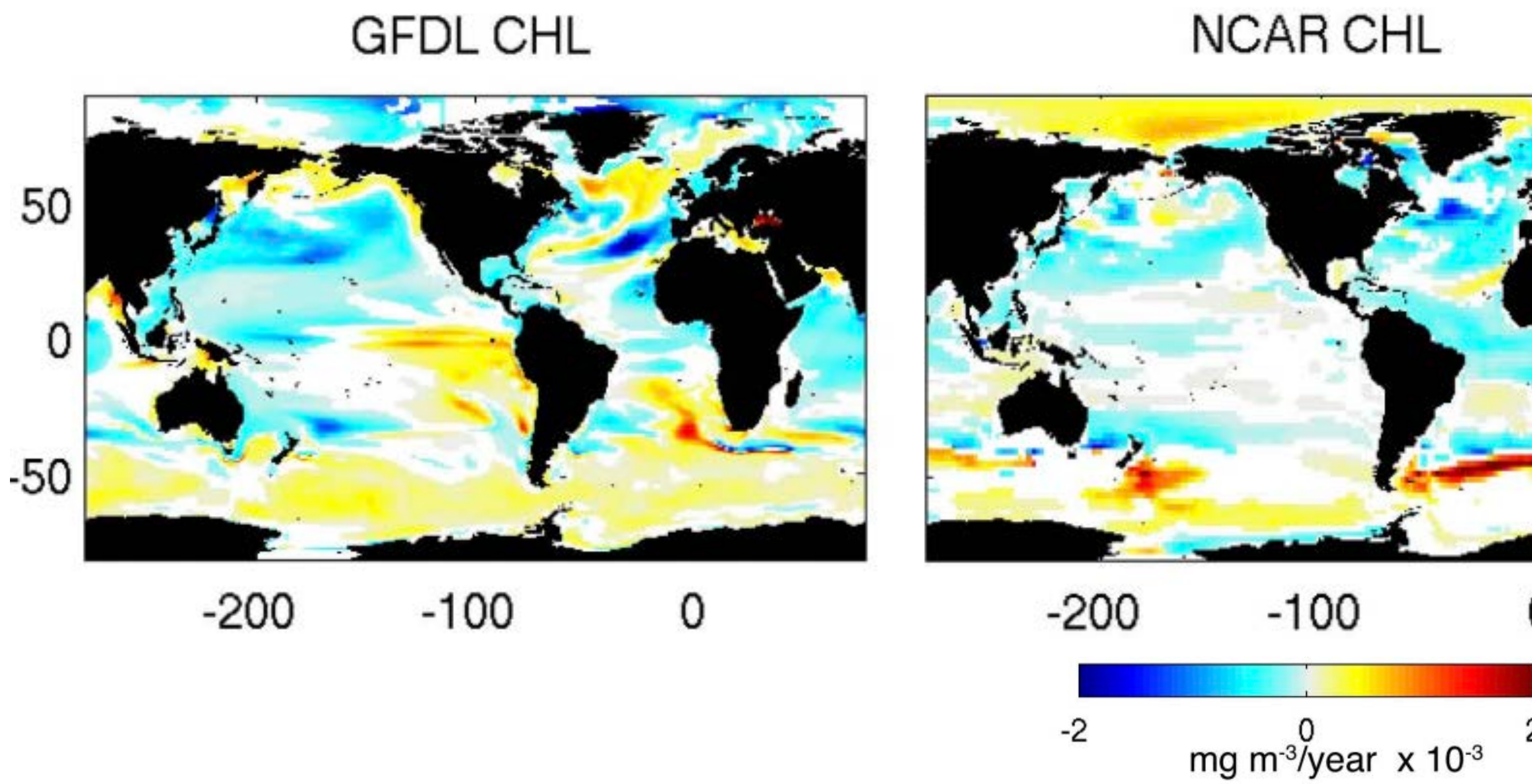
(Nicholson et al., 2022)

Storm-driven entrainment can modulate air-sea carbon fluxes. High-frequency variability potentially imprints on the annual mean value.

Many locations in the Southern Ocean require sampling at higher frequencies than the 10-day float cycle time in order to accurately capture changes in the annual mean air-sea carbon flux.

DETECTING AND PREDICTING TRENDS

Linear trend in modeled chlorophyll over the 21st century under anthropogenic forcing:



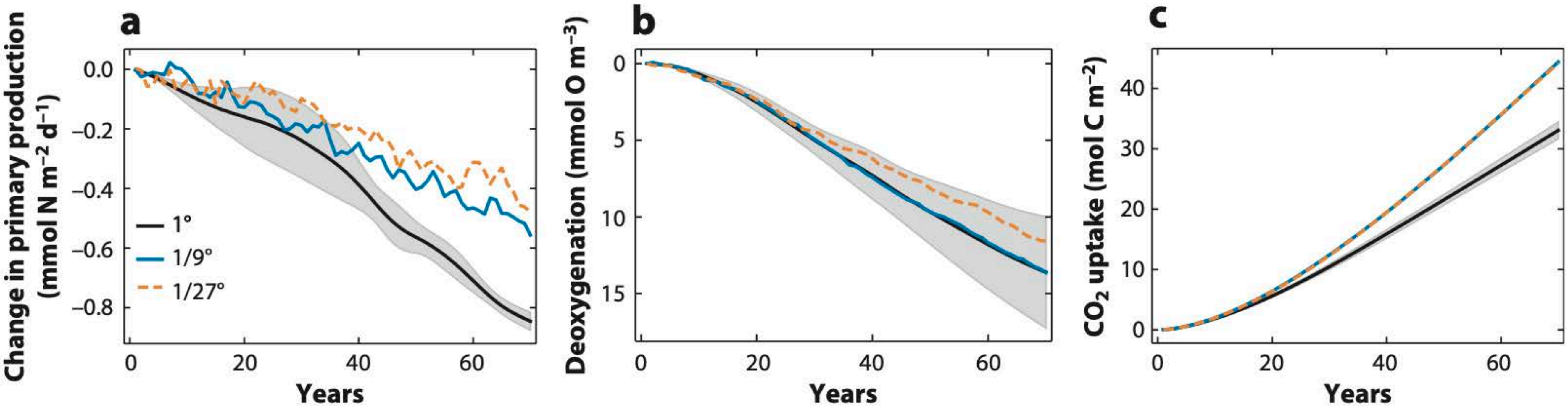
(Henson et al., 2010)

Characterizing natural variability (and understanding the mechanisms that drive it) is necessary to detect long-term trends associated with climate change and predict future changes in marine primary production.

There is significant uncertainty in the magnitude and even the sign of the response to climate change.

FINE-SCALES REGULATE CLIMATE RESPONSE

Predicted trends in primary production, deoxygenation, and carbon uptake are sensitive to model resolution



The mechanisms driving this sensitivity remain to be fully investigated. It is also unclear how this resolution-dependence changes for different biogeochemical models and configurations.

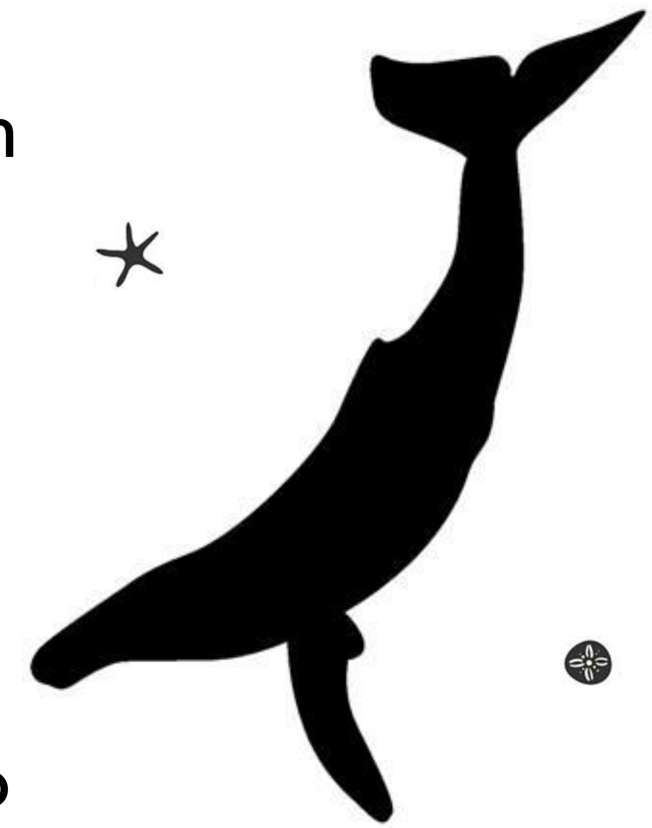
Still, it is likely that **unresolved eddy fluxes are poorly parameterized in coarse resolution models**. Flux-gradient parameterizations breakdown when physical and biological timescales are of the same order (~submesoscale).

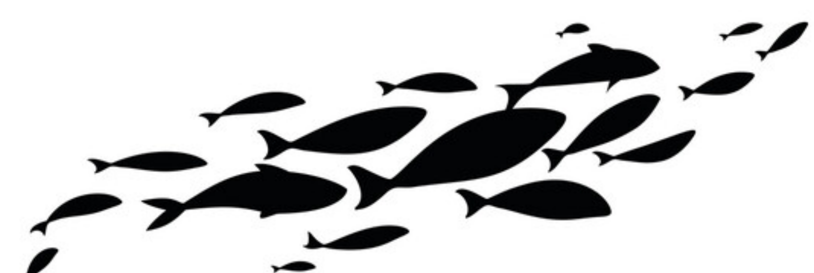
Pressing Questions

- **How can we best extrapolate observations that are local in space/time to quantitatively assess the role of fine-scales in large-scale biogeochemical cycling?**
- **How best to combine observations from different platforms to make these estimates more robust?**
- **What are the mechanisms by which fine-scale processes contribute to low-frequency natural variability of biogeochemical tracers?**
- **How do fine-scale processes modulate the response of biogeochemical cycles to anthropogenic forcing?**

FINAL PERSPECTIVE

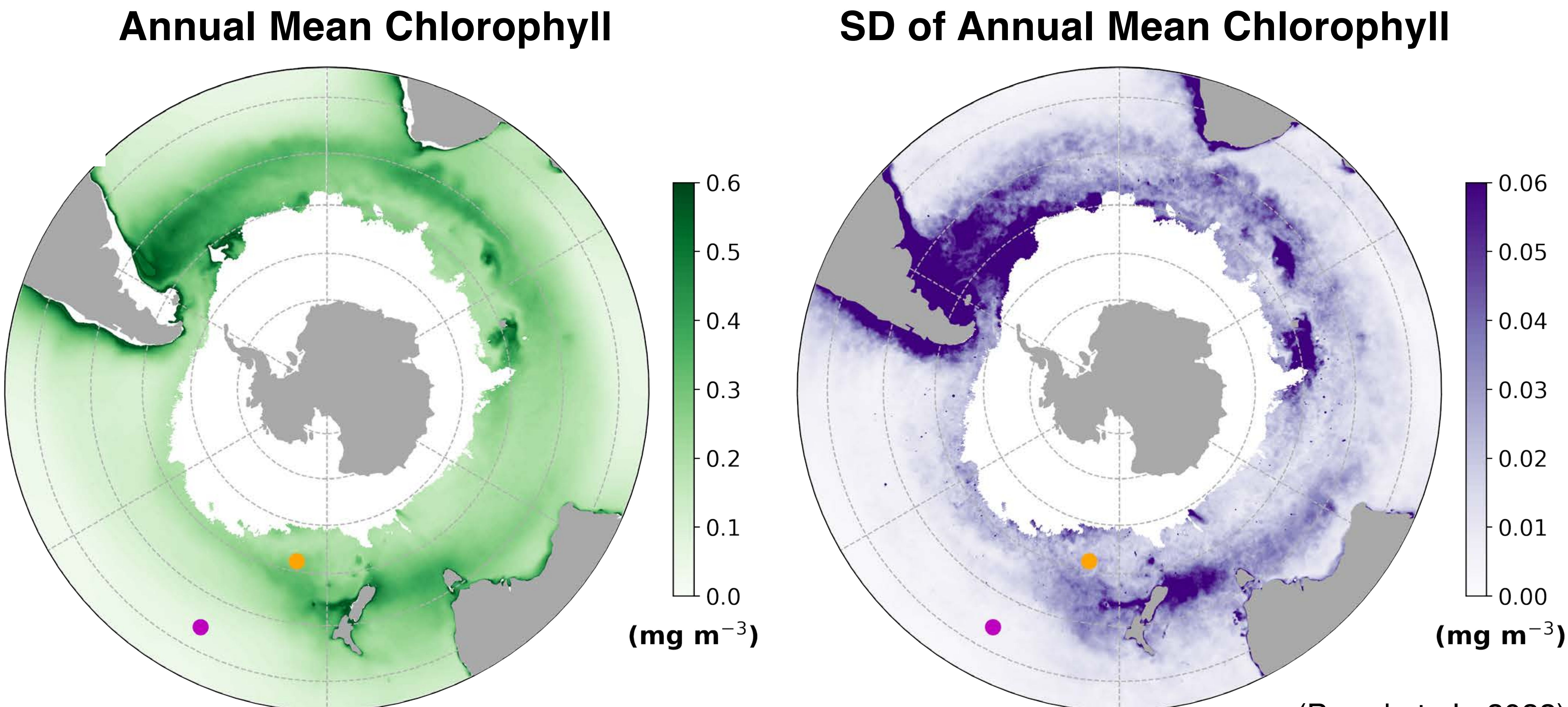
- Observing and modeling marine primary production is made difficult by the large fraction of variance at small and fast scales.
- Quantifying the overall impact of fine scales on global biogeochemical cycling requires resolving both small and large scales.
- Understanding the mechanisms of biophysical coupling across a range of scales is necessary to predict future changes in primary production.
- An integrated approach that combines autonomous measurements, satellite data, and a hierarchy of models can help shed light on these complex problems.





email: cprend@uw.edu

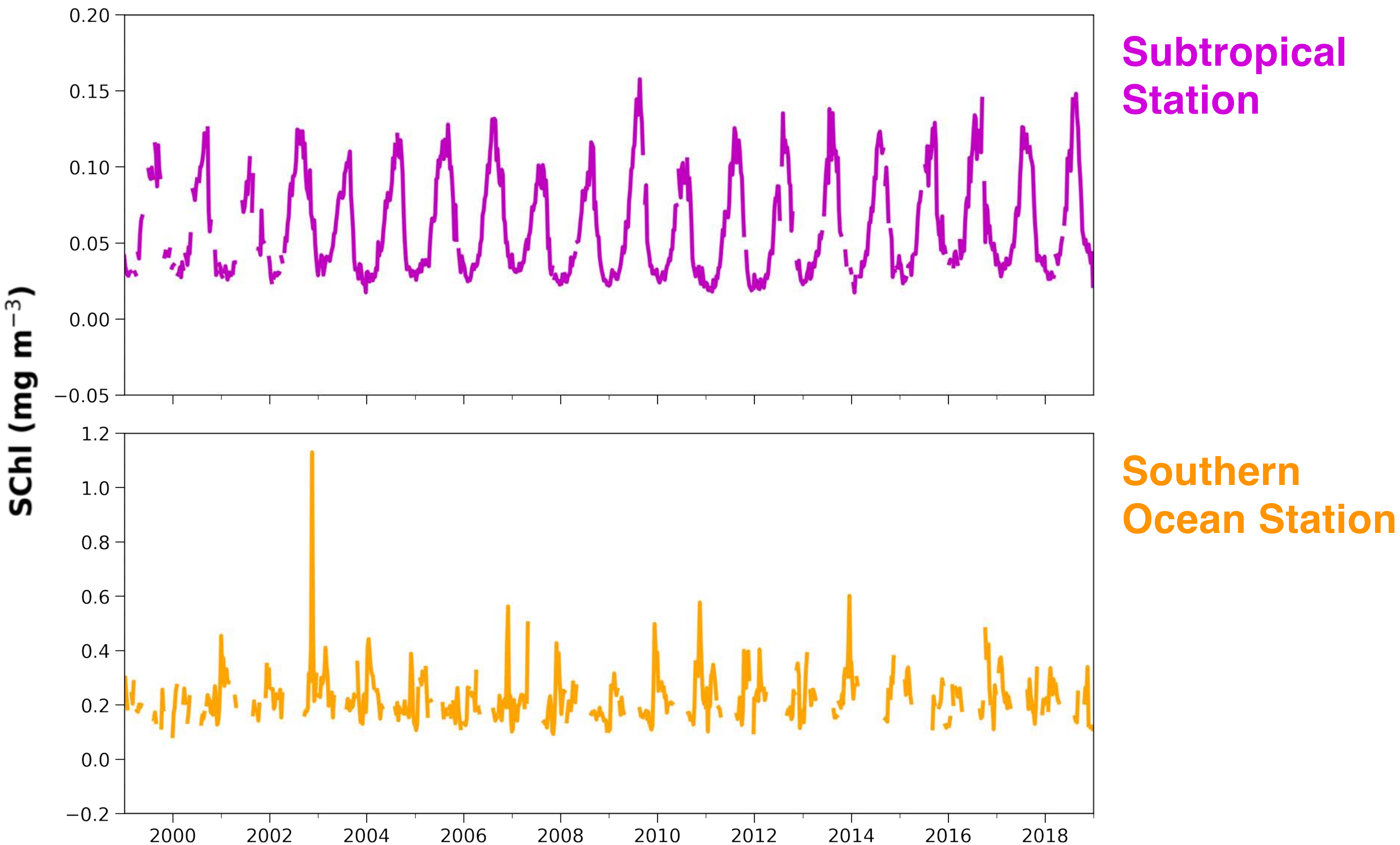
SATELLITE CHLOROPHYLL OBSERVATIONS



(Prend et al., 2022)

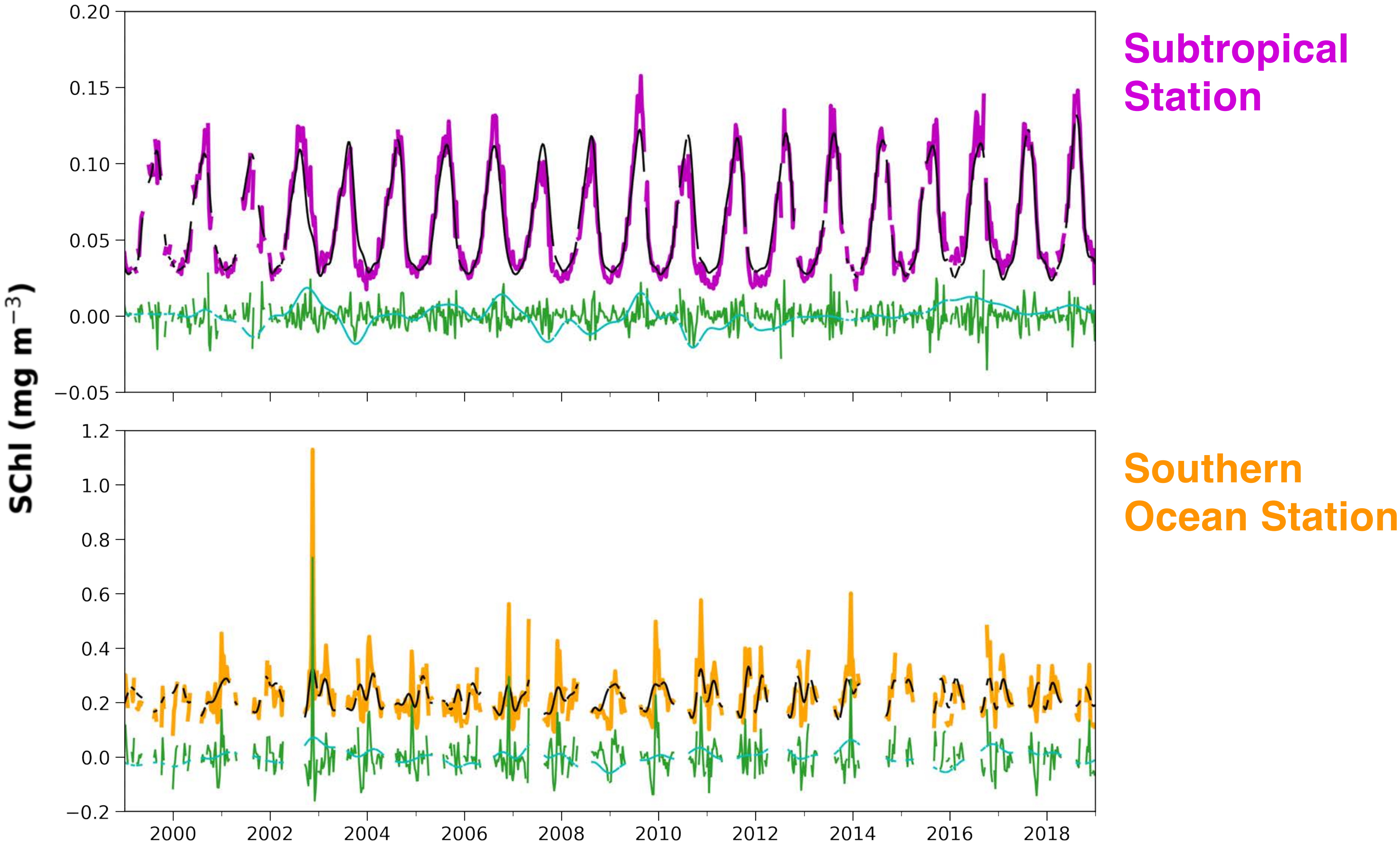
20 years (1999-2018) of satellite-derived chlorophyll from the ESA merged ocean color data product at 8-day temporal resolution (locations with less than 50% data coverage are masked).

Surface chlorophyll varies across a wide range of time scales. How does the dominant time scale vary spatially?



Across much of the Southern Ocean, non-seasonal variability exceeds the amplitude of the seasonal cycle (and occurs at higher and lower frequencies).

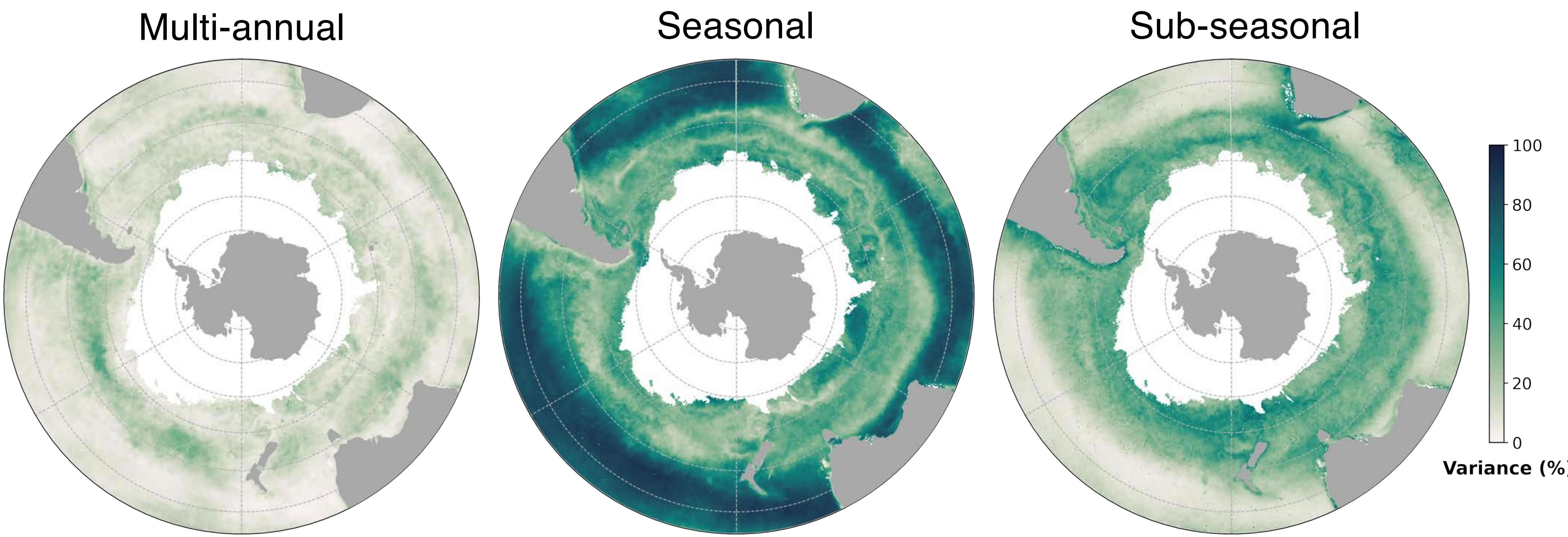
Surface chlorophyll varies across a wide range of time scales. How does the dominant time scale vary spatially?



Decompose the full chlorophyll signal into 3 frequency bands: **sub-seasonal** (0.5-3 months), **seasonal** (3-12 months), & **multi-annual** (>12 months)

PARTITIONING OF VARIANCE

Percentage of total variance explained by each frequency band:

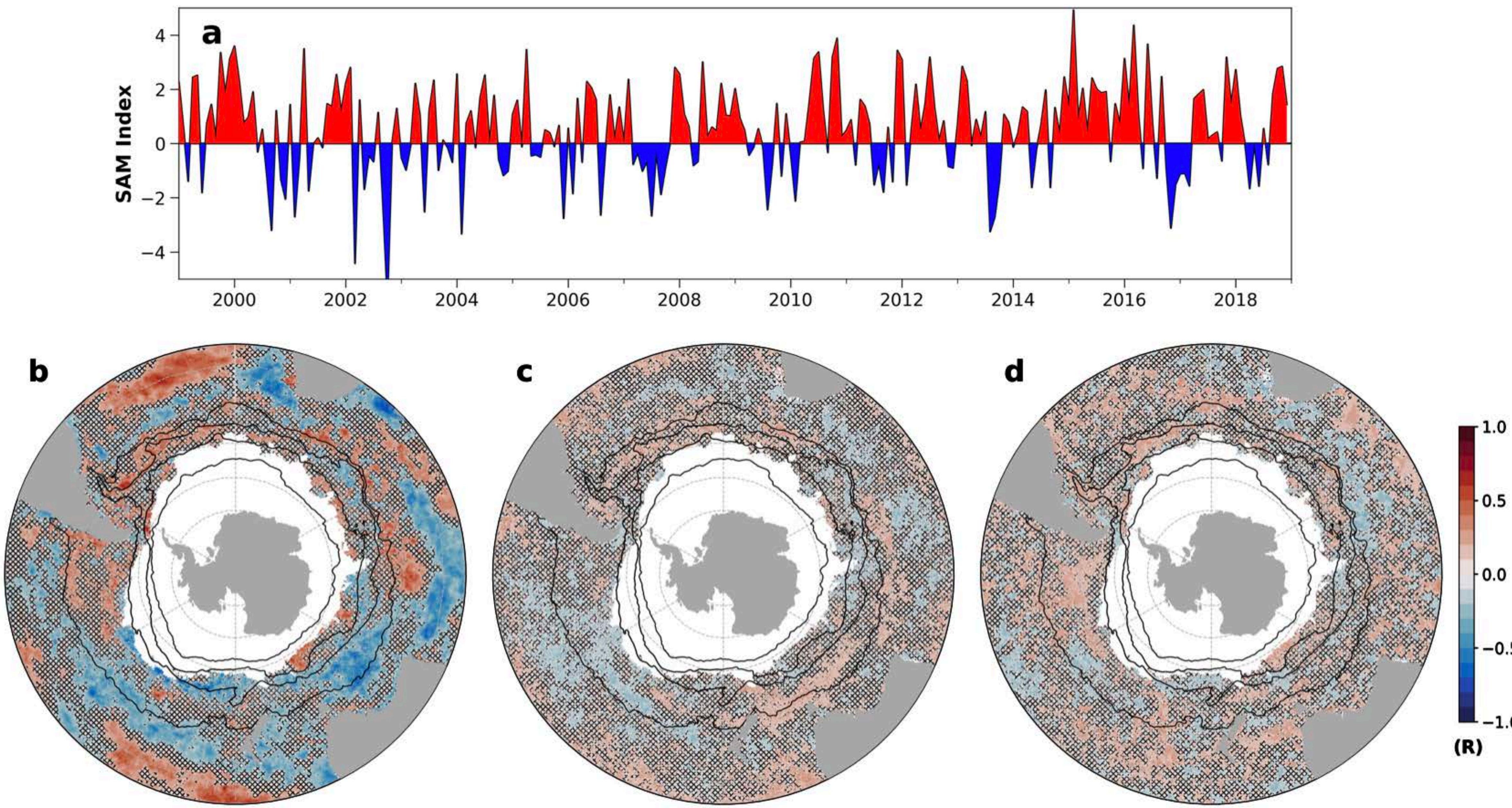


Spatial scales: ~200-400 km | >600 km | ~50-100 km

(Prend et al., 2022)

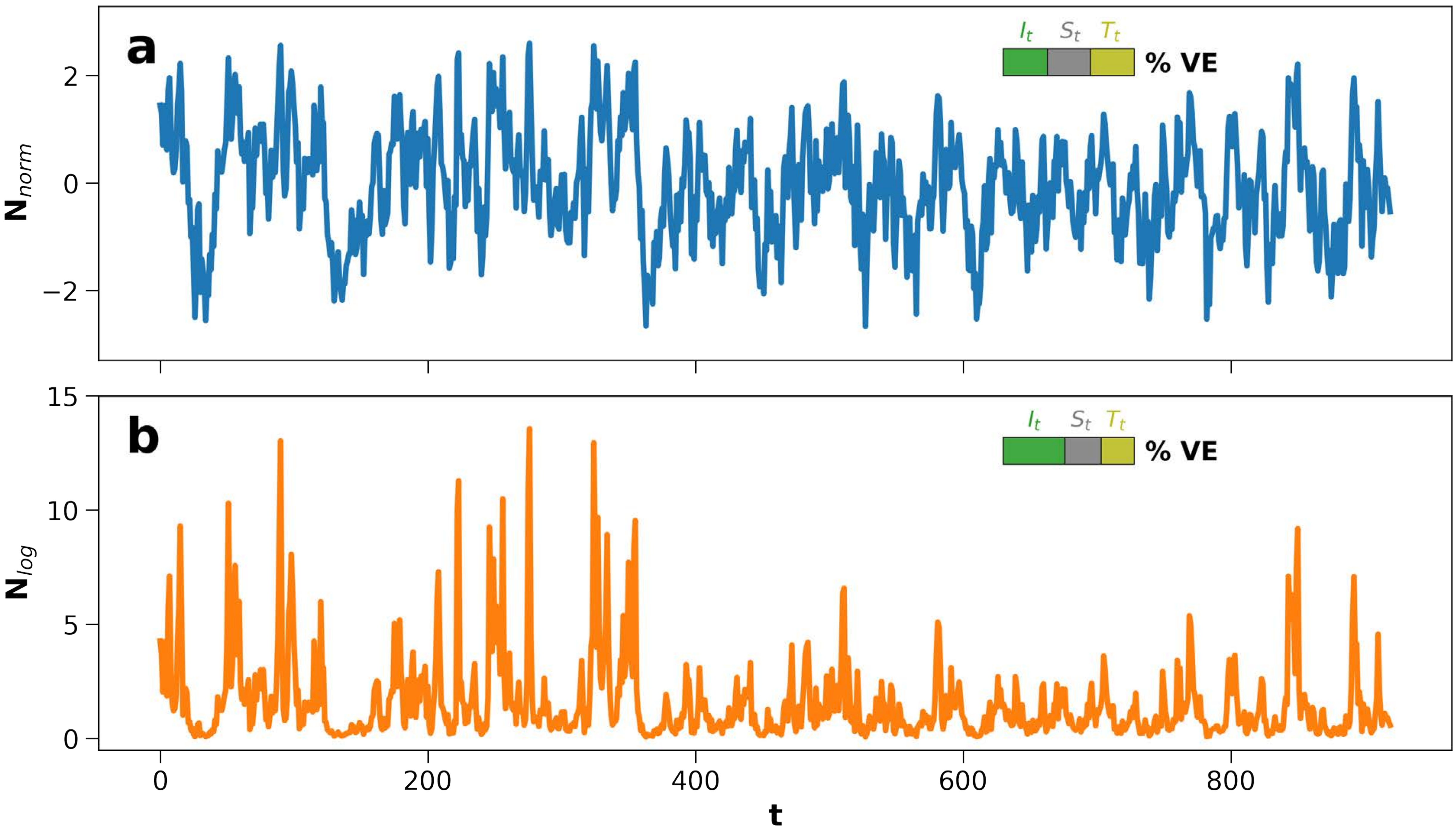
There are significant regional differences in the dominant spatio-temporal scale of chlorophyll variability. **Across much of the Southern Ocean, small-scale sub-seasonal events dominate the total variance.**

CORRELATION WITH THE SAM



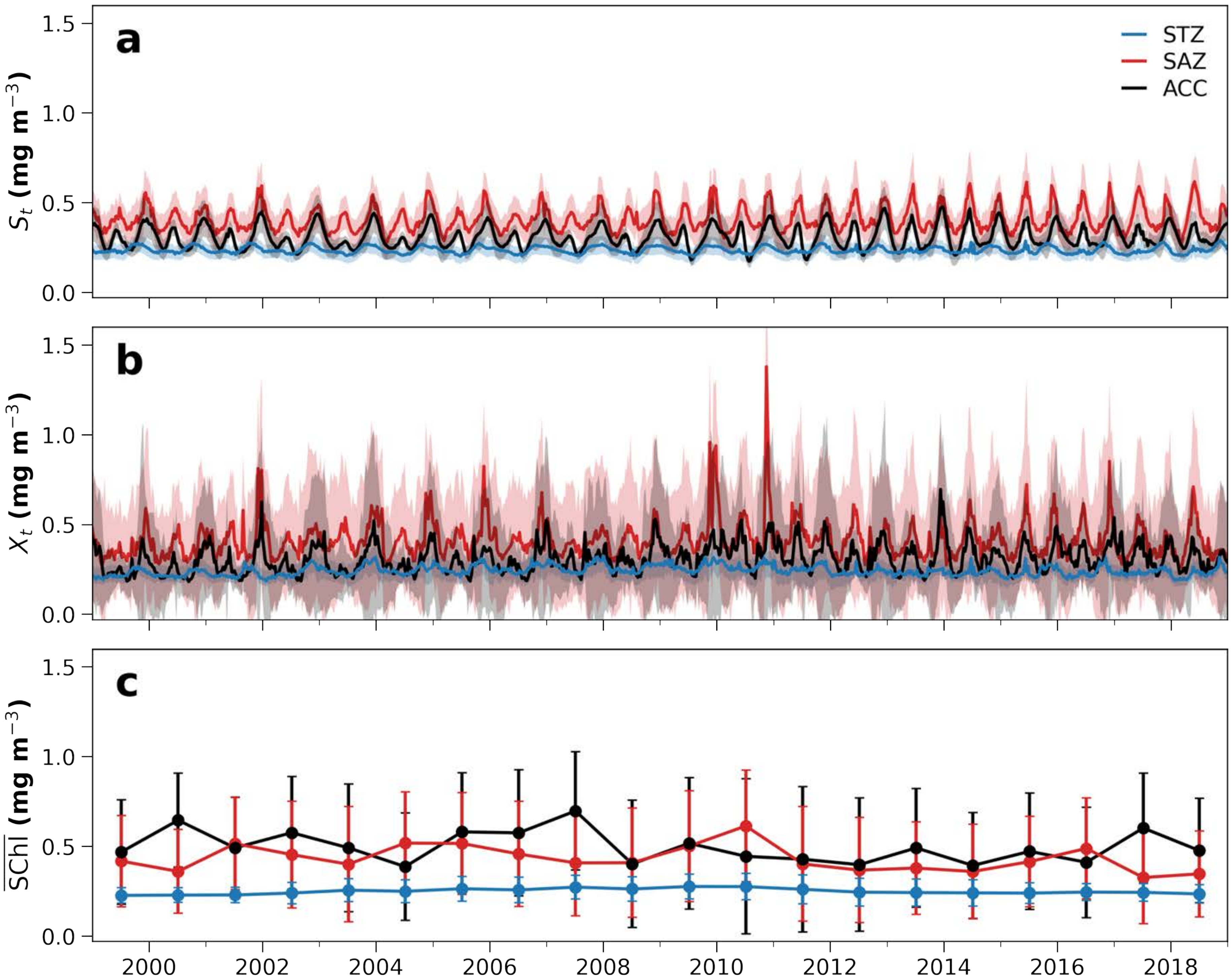
The multi-annual component of SChl variability is the most strongly correlated with the Southern Annular Mode, but only accounts for ~10% of the total SChl variance across most of the Southern Ocean.

SYNTHETIC DATA



For zero-mean Gaussian red noise, variance is partitioned equally between frequency bands, whereas variance is weighted towards high frequencies for positive-valued log-normal red noise. **SChl is log-normally distributed.**

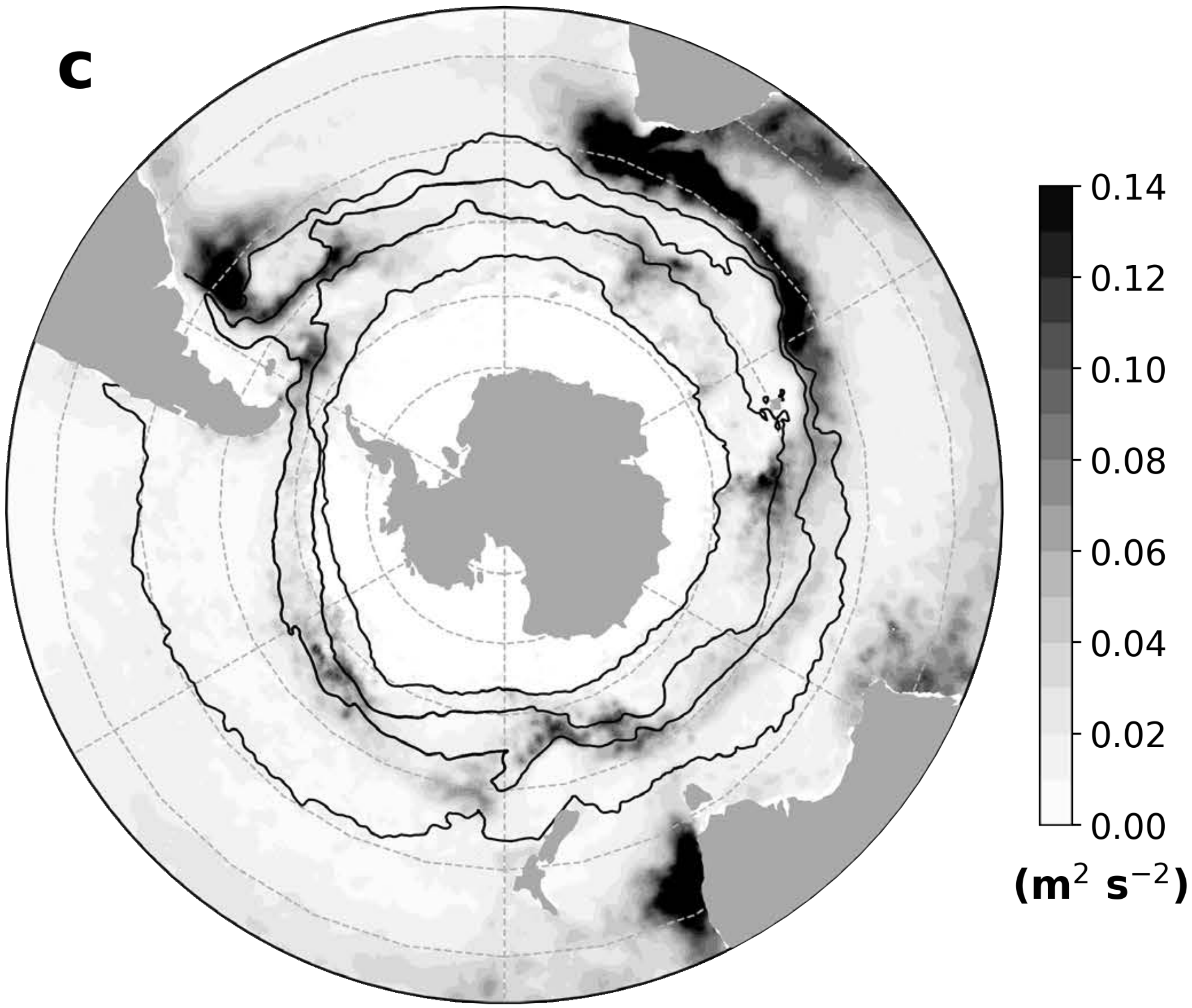
SCALES OF INTERANNUAL VARIABILITY



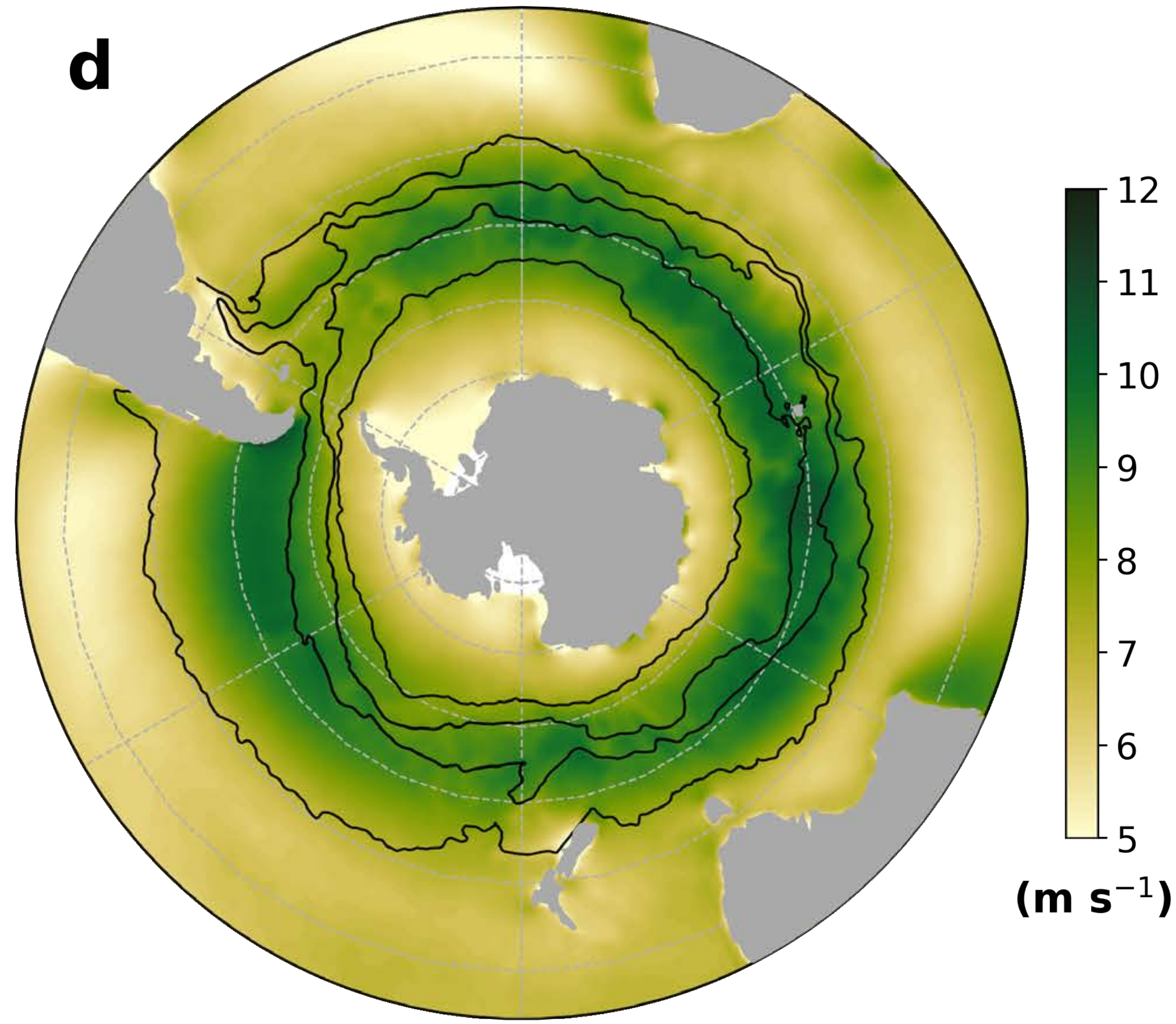
Bloom phenology regimes based on the seasonal cycle may not be relevant to interannual variability.

HIGH FREQUENCY FORCINGS

EKE



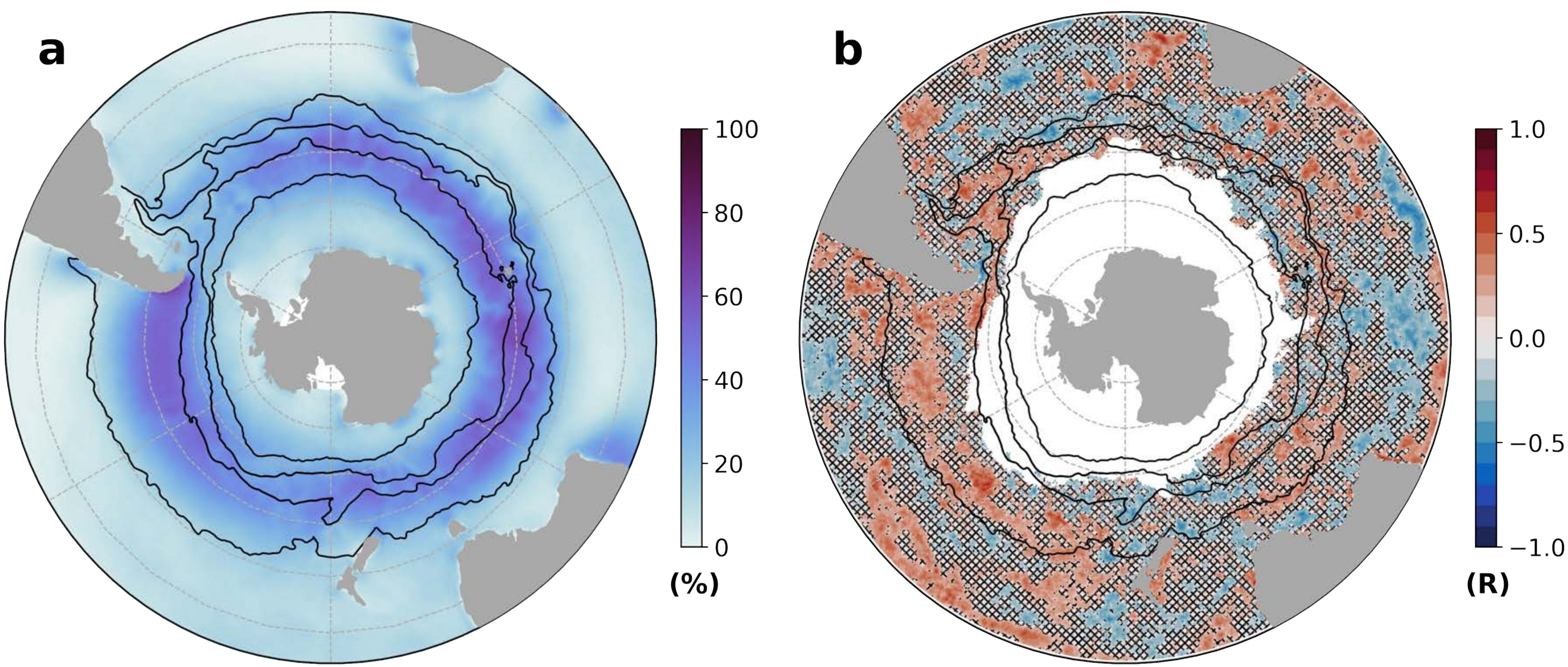
Summer Winds



What forcings drive sub-seasonal SChl variability? Understanding this has important implications for year-to-year SChl variations.

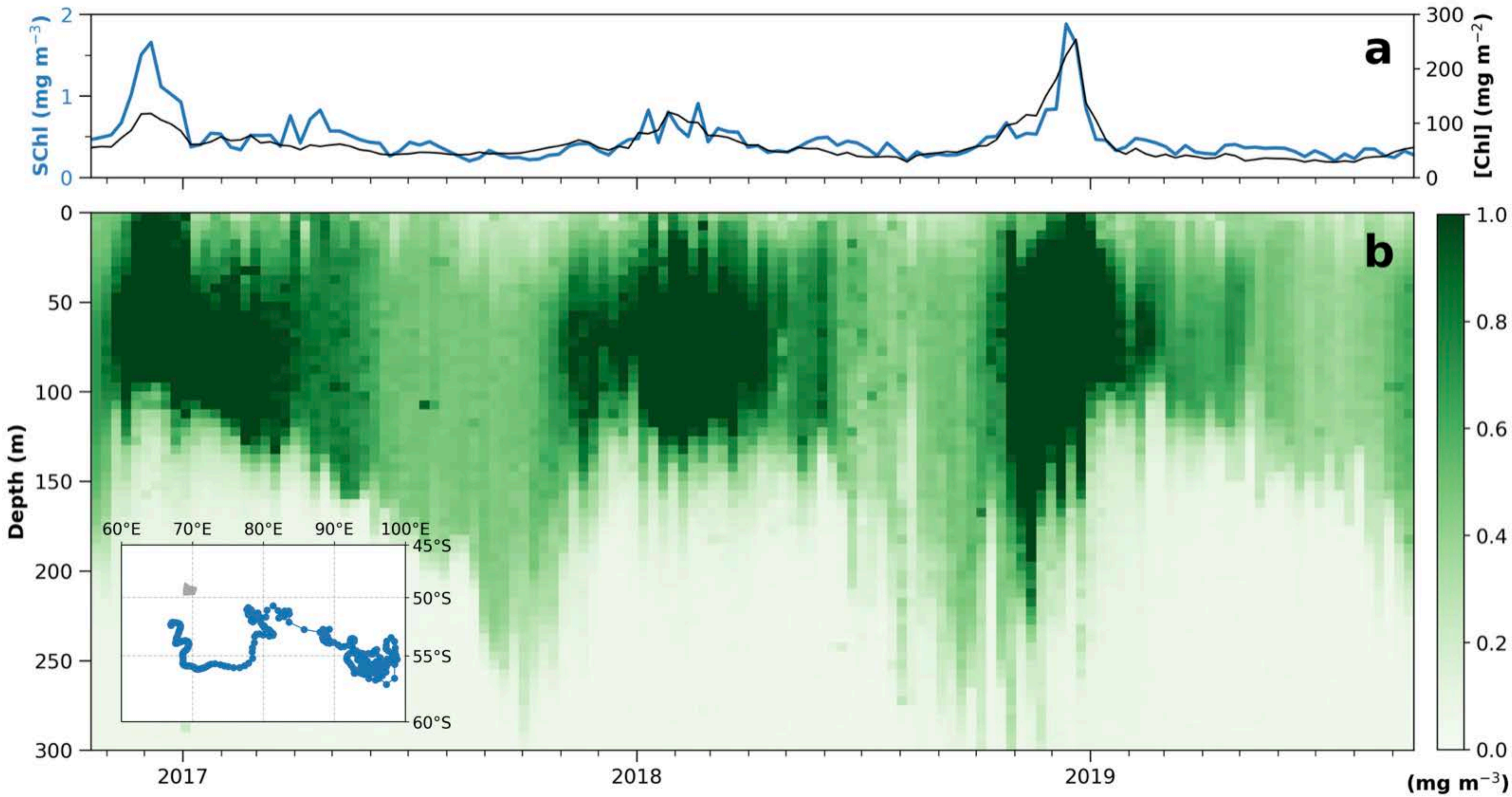
HIGH FREQUENCY FORCINGS

Sub-seasonal SChl variability could reflect high frequency atmospheric forcing from storms, ocean (sub-)mesoscale variability, intrinsic biological variability associated with grazing and/or resource competition.



Untangling these forcings is necessary to develop a mechanistic understanding of year-to-year variations in SChl.

SUBSURFACE CHL



Does high frequency SChl variability reflect changes in the integrated signal?
Use a few floats from the ACC as a case study.

SUBSURFACE CHL