Synoptic Wind-Dependent Sampling Asymmetry Biases Satellite Sea Surface Chlorophyll-a in the Mid-to-High-Latitude North Pacific and North Atlantic



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Key Points:

- Wintertime satellite-derived chlorophyll-a is lower under high wind conditions in mid-to-high-latitude North Pacific and North Atlantic
- Valid retrievals of chlorophyll-a are fewer under high wind speed conditions, generating wind-speed-dependent sampling asymmetry
- The sampling asymmetry biases wintertime gyre-mean chlorophyll-a upward by 1.4%, with local values over 10%

Background

Satellite ocean-color observations provide basin-scale sea surface chlorophyll-a (SChl), but clouds and other observing limits create retrieval gaps. Collectively, low and high wind speed conditions may diverge in both SChl retrieval gaps and SChl values. This joint effect may introduce bias into mean SChl estimates in the mid-to-high-latitude North Pacific and North Atlantic.

Why wind matters

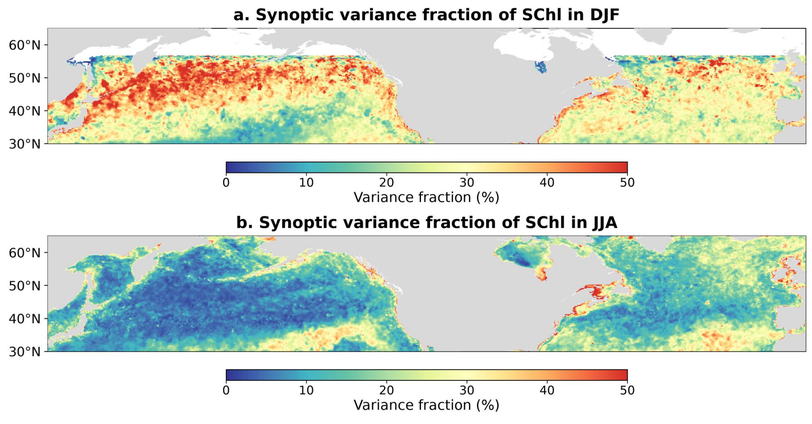
In mid-to-high latitudes, wind, cloudiness, and satellite observing conditions vary together. Low- and high-wind periods can therefore differ in both SChl retrieval success and actual SChl, especially in winter when stronger mixing can deepen the mixed layer and reduce light. This combination can bias mean SChl estimates.

Hourly SChl generation

• MODIS Aqua Level-2 ocean-color data were processed in SeaDAS 9.1.0.
• Valid pixels were mapped to a 0.25° grid to produce hourly SChl fields.
• Each hourly SChl field was matched with the corresponding ERA5 synoptic wind anomaly.

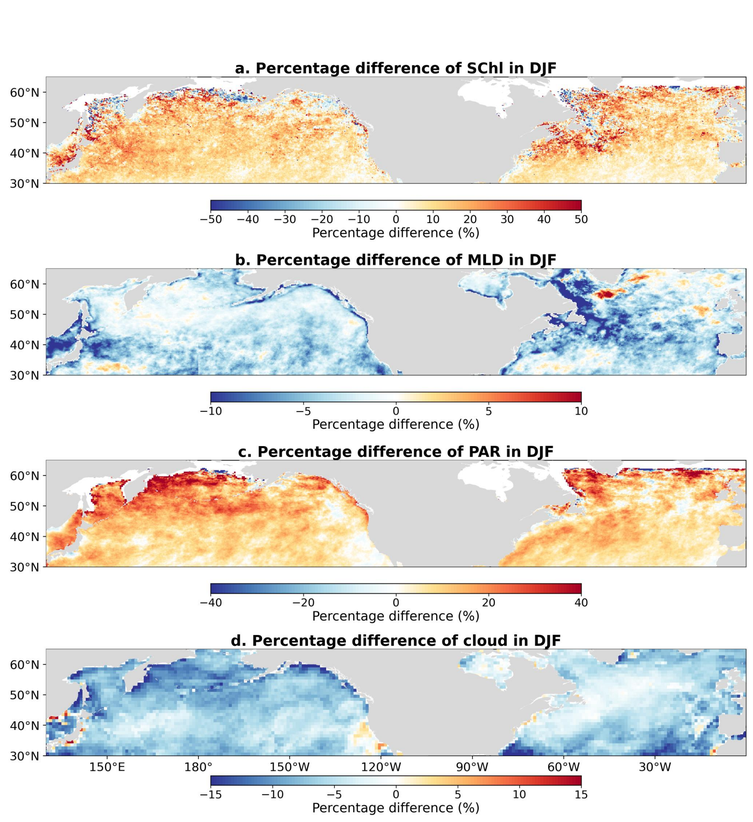
Resampling under low and high wind

• Hourly SChl were separated into low-wind and high-wind conditions.
• Unbalanced samples retained the observed retrieval distribution.
• Balanced samples were resampled to match the satellite overpass ratio between low and high wind speed conditions.
• The difference between unbalanced and balanced SChl estimates quantifies wind-dependent sampling bias.



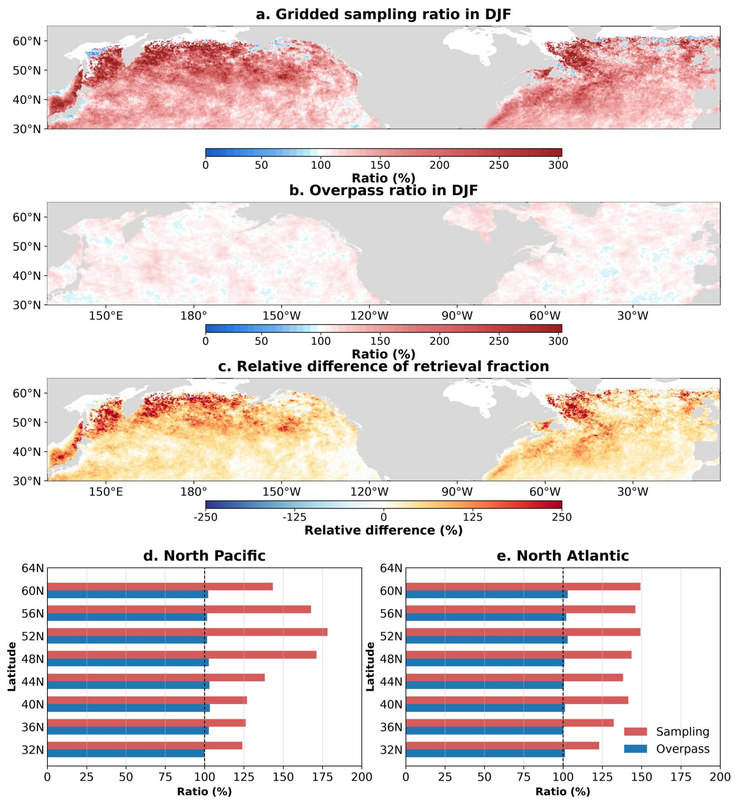
Synoptic variability is strongest in winter

Synoptic-scale (2–10 day) variability explains 30.0% of SChl variance in DJF, compared with 15.2% in JJA. Local DJF maxima reach 55.1%. Winter therefore shows the strongest weather-scale SChl variability.



Low-wind conditions are associated with higher SChl and PAR, but lower MLD and cloud amount.

In DJF, low-wind conditions are associated with:
Sea surface chlorophyll-a (SChl) ..... +7.1%
Photosynthetically available radiation (PAR) ..... +9.0%
Mixed-layer depth (MLD) ..... −2.9%
Cloud amount ..... −6.2%
Positive values indicate larger values under low-wind conditions.

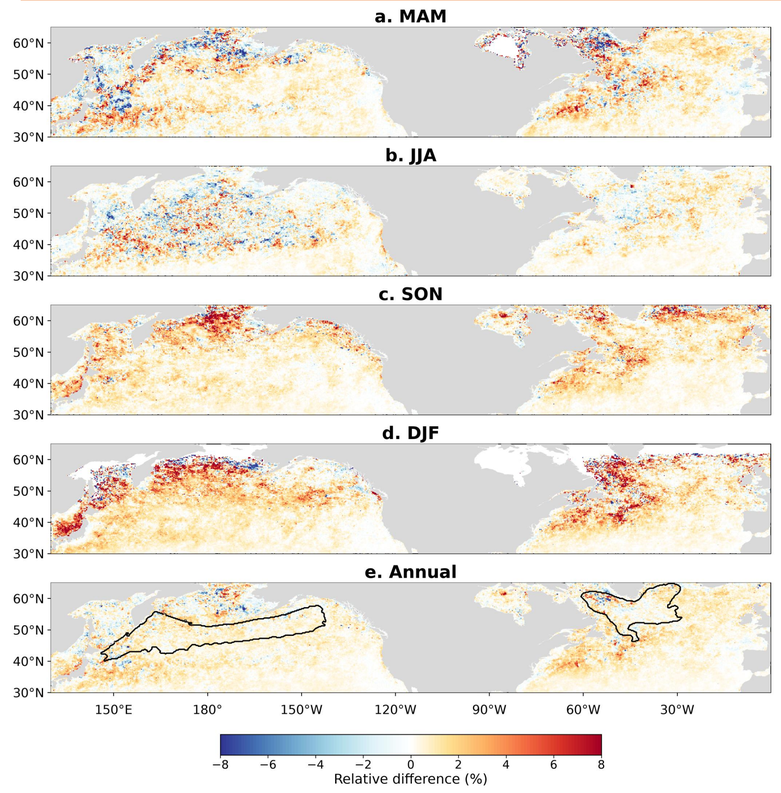


Low-wind conditions are oversampled

Gridded sampling ratios reached 133.4% in the North Pacific and 101.9% in the North Atlantic during DJF. Retrieval success was 29.4% higher under low wind than under high wind, so low-wind states are overrepresented in the satellite record.

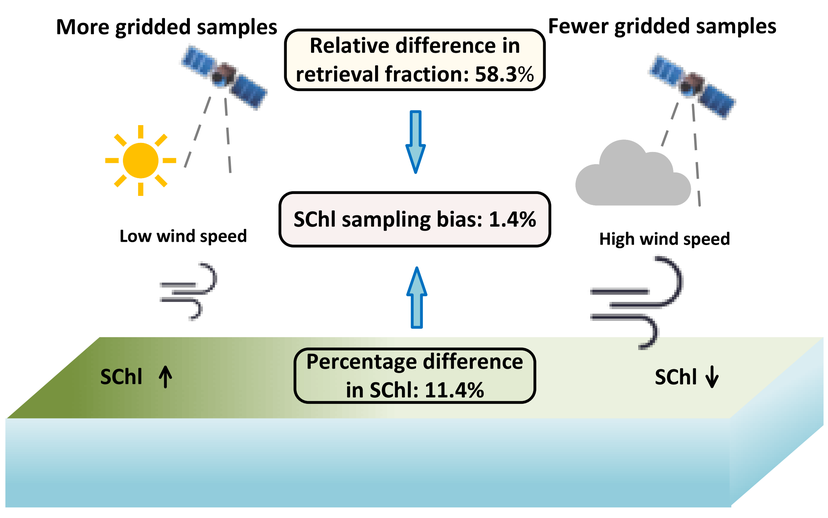
Questions/comments?

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Wind-dependent sampling bias is strongest in winter, with local SChl biases exceeding 10%.

The positive bias is largest in DJF, followed by SON and MAM, and weakest in JJA. Across the combined North Pacific and North Atlantic subpolar gyres, the gyre-mean bias is **1.4% in DJF** and decreases to **0.3% in the annual mean**.
This bias arises because low-wind conditions combine **higher observed SChl** with **more successful gridded retrievals**, causing low-wind states to be overrepresented in the satellite record.



Conclusions and Discussion

1. Wind-dependent sampling asymmetry causes a positive satellite SChl bias, strongest in winter, with a gyre-mean bias of about 1.4% and local values exceeding 10%; this bias also propagates into satellite-based productivity estimates.
2. Our resampling approach isolates this bias using an observation-constrained reference, avoiding the model or assimilation errors associated with reconstructing unobserved full-field SChl.
3. The balanced reference remains a reduced-bias resampled estimate rather than an observed truth, and the reported bias may underestimate the total bias because extremely high-wind, low-SChl conditions are poorly retrieved.