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Temperature and PAR as predictors of chlorophyll in the subtropical gyres

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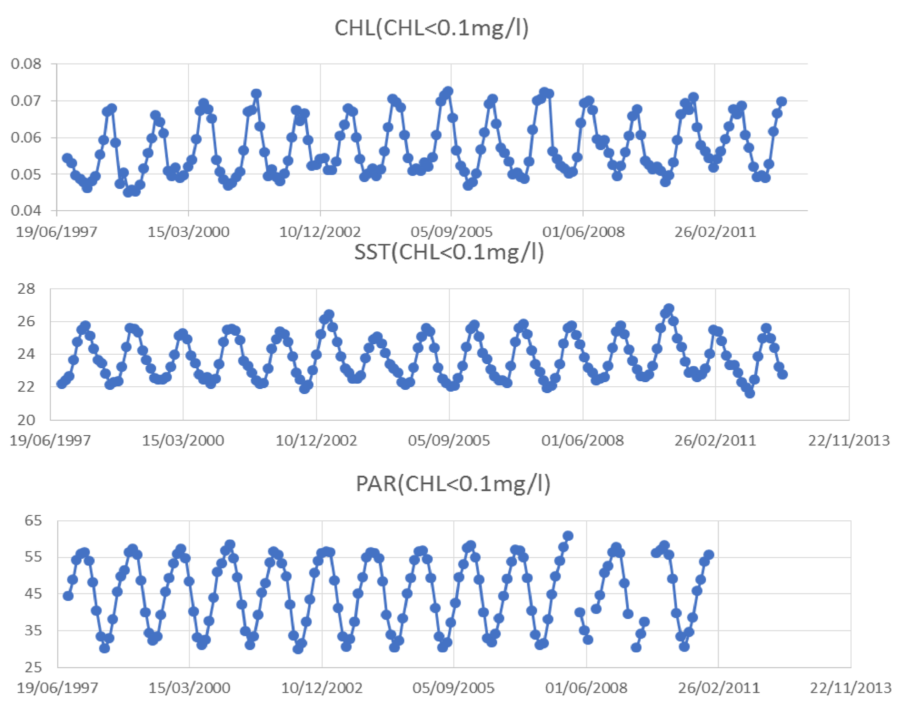
Abstract

This research presents early-stage integration of Atlantic Meridional Transect (AMT) data for the North Atlantic Gyre (NAG) and South Atlantic Gyre (SAG), with remote sensing observations (CHL, PAR, SST) and a 1D coupled physical-ecosystem modelling (ERSEM-GOTM, Aiken et al. 2016, doi: 10.1016/j.pocean.2016.08.004). Preliminary results show consistent functional forms of the relationships between the key biogeochemical (BGC) variables, for all 3 data types, taking account of temporal lags. These relationships provide insights into the processes that drive the gyre properties. The results offer prospects for the prediction of sub-surface biological structure from satellite remotely-sensed observations, which would aid forecasting of the responses of stratified ecosystems to diverse climate change scenarios.

Satellite remote sensing

CCI data gyre monthly mean.

Look at the data!

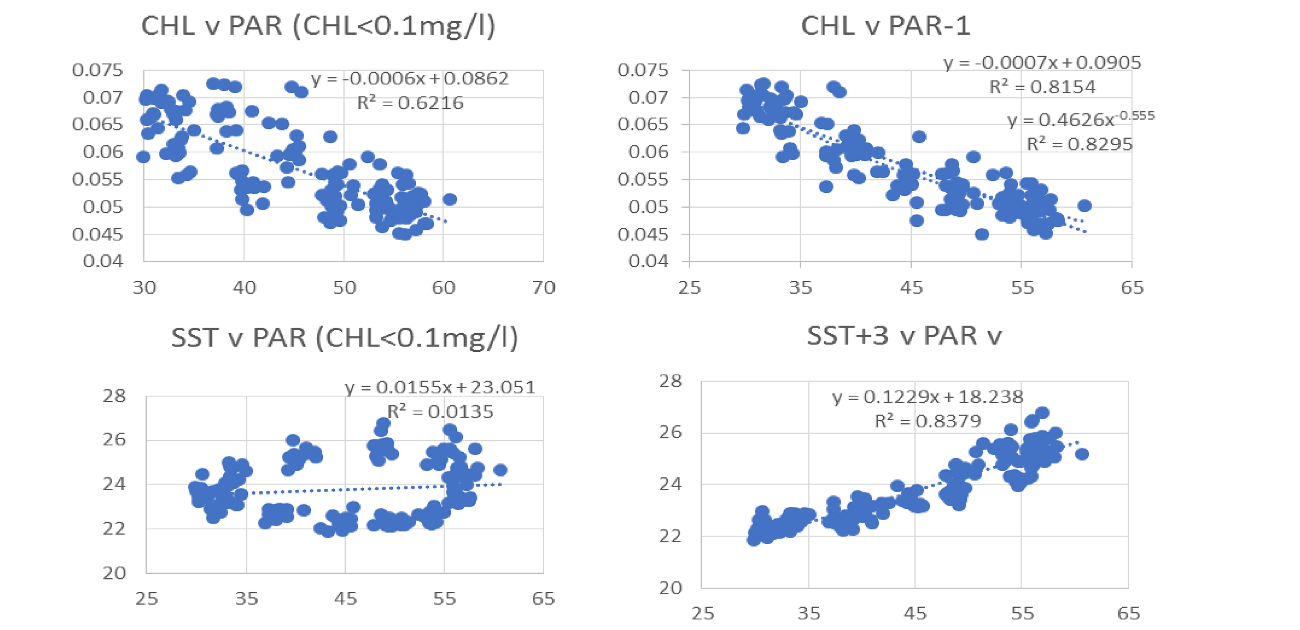


SST & PAR quasi-sinusoidal; CHL shows accumulation of data at mid-winter (high) and mid-summer (low) with transition of 1 or 2 months.

The CHL v PAR functional form is negative, 2 main data clusters for mid-winter (high) and mid-summer (low) and 2 intermediate clusters. Suggest bio-optical 'switching' from high-PAR, low-CHL to low-PAR, high-CHL & brief transition periods ~2 months.

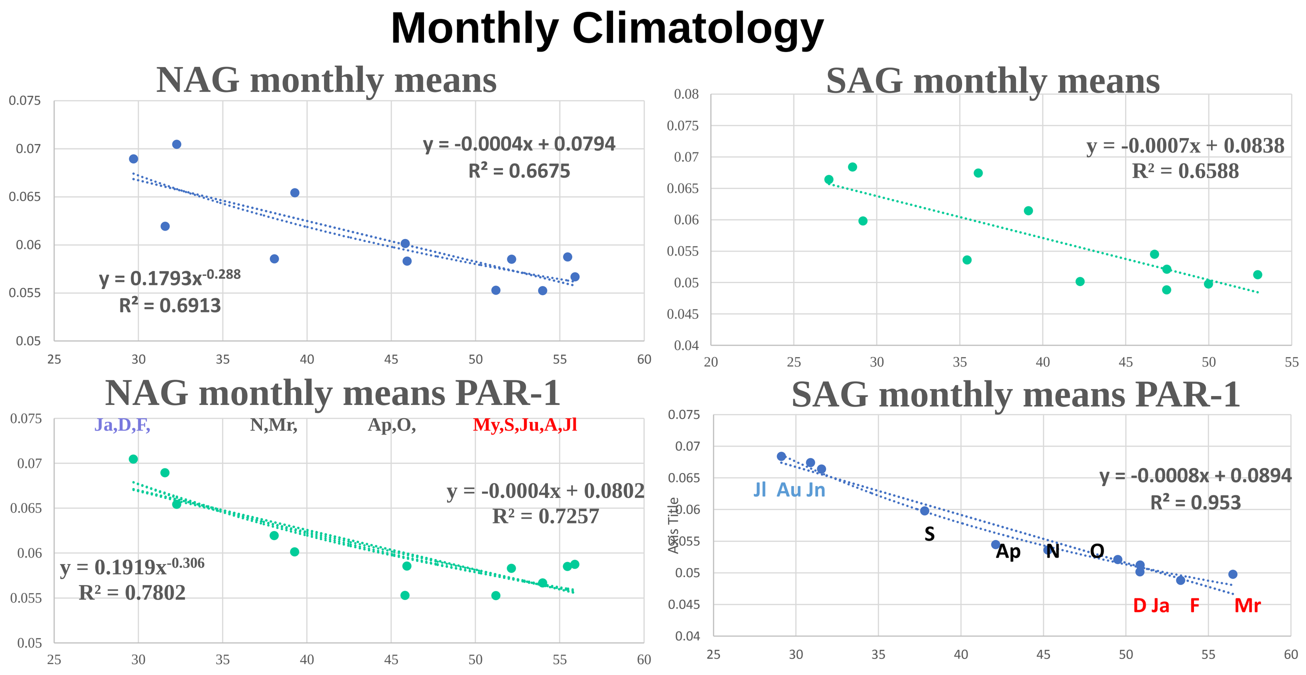
Relationships CHL v PAR & SST v PAR (SAG)

Ellipsoids indicate lag: 1 mth CHL v PAR; 3 mth SST v PAR



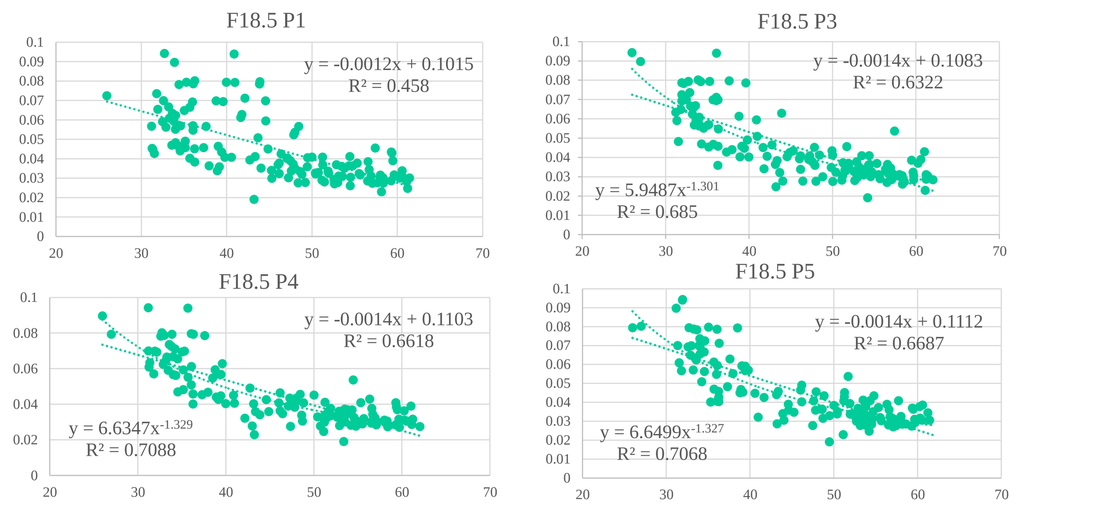
Relationships CHL v PAR (NAG & SAG)

Monthly Climatology



CCI weekly data in SAG at 18.5S, 25W

CHL v PAR with lags P1, P3, P4, P5 for 1 week, 3 week, 4 week, 5 week prior to CHL. R^2 suggest P4, P5 best, possible non-linear relationship



Summary regression analyses, monthly data whole time series and means by month for whole time series. PAR-1 is PAR for the previous month to CHL data.

NAG: CHL v PAR: $y = -0.0004x + 0.0791$; $R^2 = 0.5404$

CHL v PAR-1: $y = -0.0004x + 0.08$; $R^2 = 0.57$; $y = 4E\text{-}05x^2 - 0.0035x + 0.142$; $R^2 = 0.73$

CHL v PAR: $y = -0.0004x + 0.0794$ $R^2 = 0.6675$

CHL v PAR-1: $y = -0.0004x + 0.0802$ $R^2 = 0.7257$; $y = 0.1919x^{-0.306}$ $R^2 = 0.7802$

Slopes (-0.0004) and intercepts (0.08) are all quite similar

SAG: CHL v PAR: $y = -0.0006x + 0.0862$; $R^2 = 0.6216$

CHL v PAR-1: $y = -0.0007x + 0.0905$; $R^2 = 0.8154$; $y = 0.4626x^{-0.555}$; $R^2 = 0.8295$

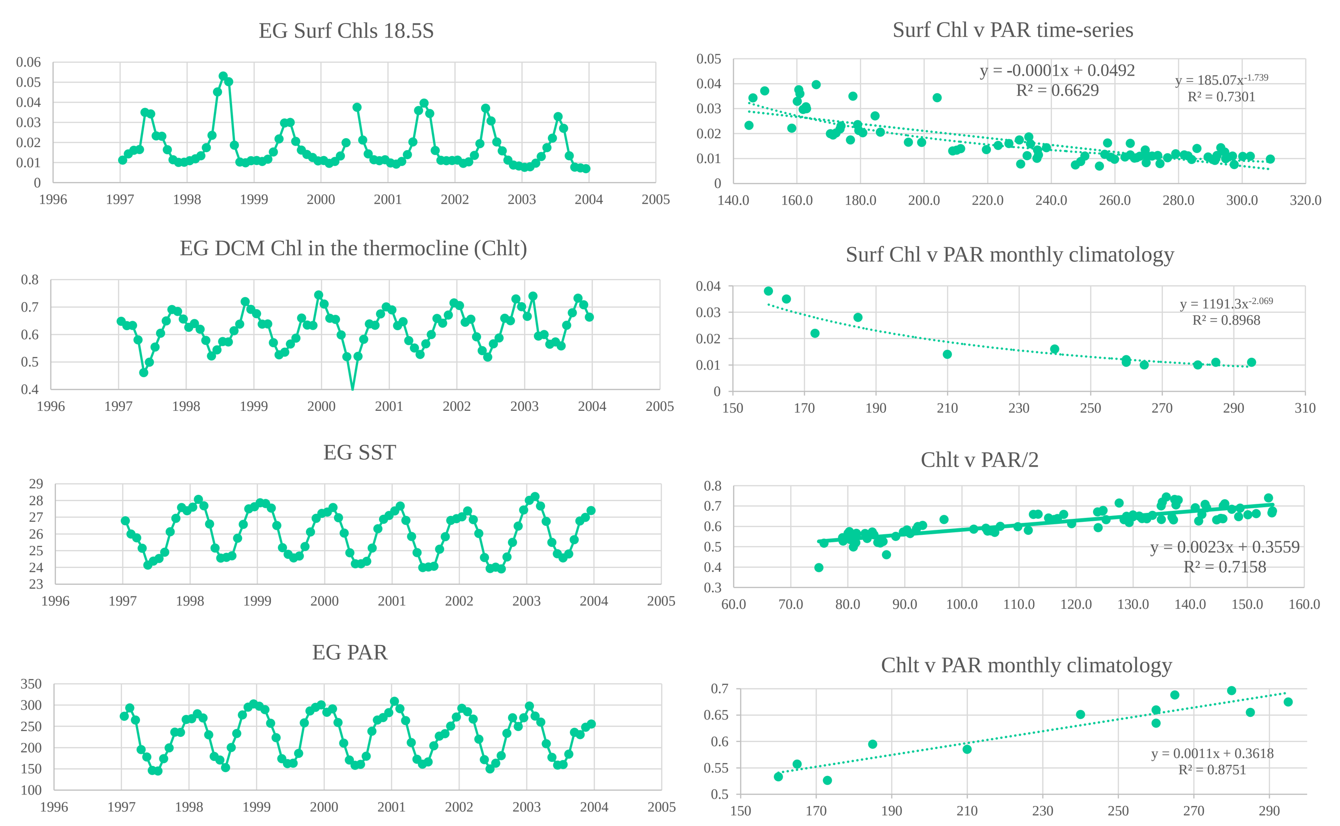
CHL v PAR: $y = -0.0007x + 0.0838$ $R^2 = 0.6588$

CHL v PAR-1: $y = -0.0008x + 0.0894$ $R^2 = 0.953$

Slopes (-0.0006 to -0.0008) and intercepts (0.08 to 0.09) show some variance

Ecosystem modelling ERSEM-GOTM (EG)

Look at the data! Relationships



ERSEM-GOTM model simulation SAG (1997 – 2003): Key Messages

All variables show distinct seasonal cycles, resulting auto-correlation, with time-lags of 1 month (e.g. PAR & Chl at the surface (Chls) & Chl in the thermocline (Chlt)) to 3 months (e.g. PAR & SST) and 2 months (e.g. SST & Chls). Summary observations and conclusions:

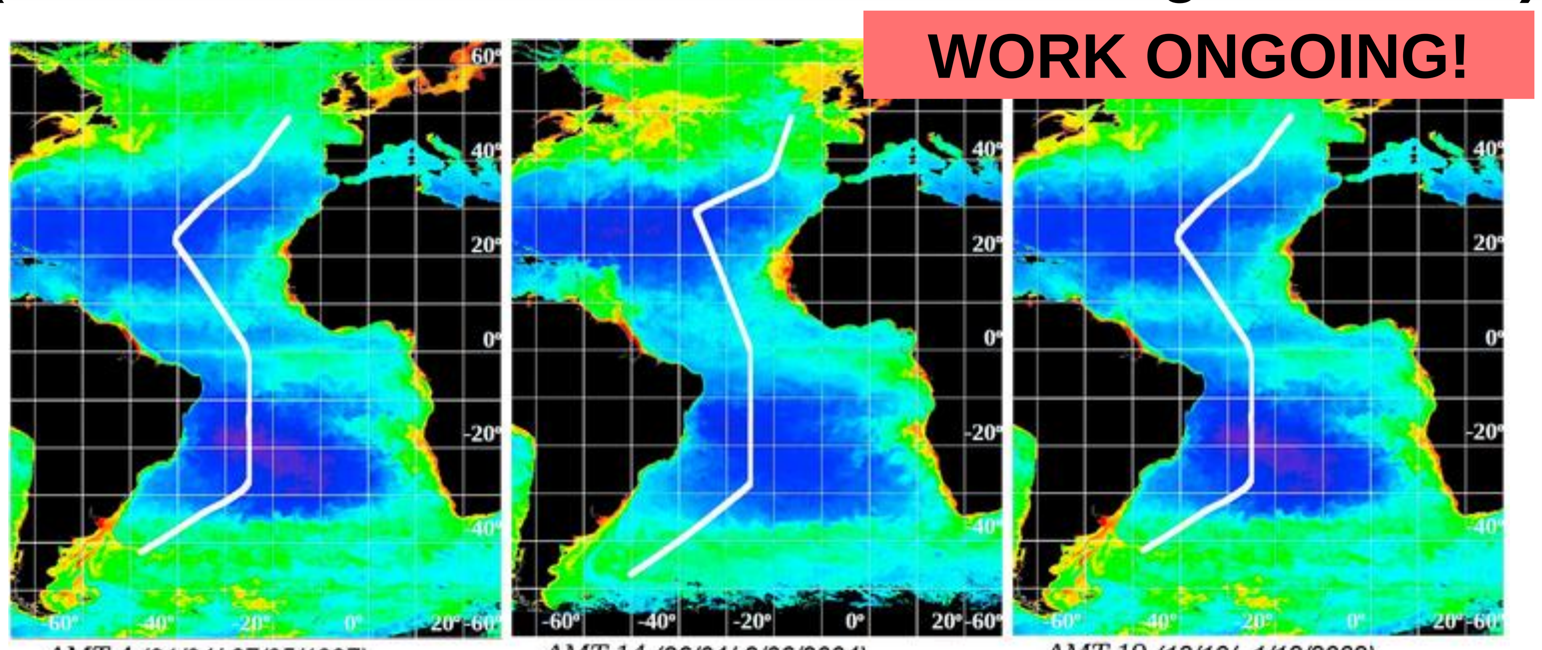
1) Chls has max peak value in mid-winter but has flat, uneven minimum, in mid-summer; Chls has inverse relationship to PAR ; Chls predictable from PAR.
2) Chlt has quasi-sinusoidal annual seasonal cycle, with max in mid-summer, min in mid-winter; Chlt linear relationship to PAR. Chlt predictable from PAR.
3) Chls inversely related to Chlt; Chlt predictable from Chls.
4) Chls/Chlt inversely related to PAR; Chls/Chlt predictable from PAR
5) PAR directly related to SST 3 month lag (time series analyses); PAR & SST predictable from each other.
6) Chls, Chlt, Chls/Chlt, all predictable from SST (taking account of lags).

AMT (in situ & surface & shipboard measurements) & RS-AMT (CCI data extracted for co-incident along track AMT)

WORK ONGOING!

There have been 27 AMT cruises between 1995-2017
The AMT covers 4 different physical-ecosystem states (modes):
1. Boreal Fall (BF) southbound Sept/Oct/Nov, post-equinox, PAR on an downward trend, SST declining from summer max.
2. Austral Spring (AS), southbound, Sept/Oct/Nov, PAR on an upward trend, SST rising from Winter min.
3. Austral Fall (AF) northbound, Ap/May/Jun, PAR on an downward trend, SST declining from summer max.
4. Boreal Spring (BS) northbound, Ap/May/Jun, PAR on an upward trend, SST rising from Winter min.

CCI data for AMT along track 1997-2017 (AMT6 to 27); data for CHL, SST & PAR with PAR for 4 previous weeks.
The extra weekly PAR data is used to examine the question of "What PAR?"



AMT 4 (21/04/-27/05/1997) AMT 14 (26/04/-2/06/2004) AMT 19 (13/10/- 1/12/2009)

Summary and forward plan

CCI DATA. We show significant relationships between PAR and surface Chlorophyll (CHL) for monthly mean data (with limits <0.1 mg m^{-3} CHL) with a lag of about 1 month (PAR-1 for previous month) and SST and PAR-3 (3 months previous) conforming to established knowledge (also SST and CHL due to surrogacy). Exploiting Time Series Analyses and using weekly or daily data sets should improve results. These observations apply to time series data sets for the whole of the gyres (both NAG & SAG) and time series at fixed locations within the gyres or for data for monthly mean values for CHL and PAR. The functional form of all the PAR/CHL relationships is negative linear (or near-linear power law) for all regressions with distinct clusters mid-winter and mid-summer.
ERSEM-GOTM (EG) model data. We find a many significant relationships including PAR and CHL consistent with the observations of CCI monthly and weekly time series. It is recognised that EG model has Chls lower than observed. We have merged concurrent CCI and EG model data and could use these analyses to 'tune' the model. Alternatively, we could assimilate AMT Chls & Chlt data or Bio-Argo float data to tune the model data. We need more EG data sets and at least one in the NAG.
AMT cruise data. We have seen from the CCI and EG that PAR (or SI) are the drivers of CHL and SST in the gyres (no surprise) and that there are significant functional processes between these key variables for data at the monthly mean resolution, both for the gyres as a whole or at specific sites within the gyres. It is inconceivable that concurrent CHL and PAR are closely related on a day to day basis; it is likely that the accumulated biomass results from positive and negative production under fluctuating PAR for several previous days (or weeks). Monthly (or weekly) data sets condense these processes and the net biomass that results accounts for the lag between PAR & CHL, ~1 month. The same applies to SI and SST.
We have tested these ideas using CCI along track for AMT cruises from AMT 5 to 27, by retrieving PAR for each of the 4 weeks prior to the cruise dates; results show improved regression analyses in some instances, but nothing systematic or conclusive. Another significant issue is the change of CHL over the previous few weeks and the change of the body of water; the gyres are not static, with low surface currents. With both complexity and very large data sets AI techniques may help to get the answers.