An Improved NPQ Correction through a light threshold

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The Issue

✧ Both X12 and S08 have problems of over-correction, in the deep-mixing waters (e.g. Southern Ocean)

✧ Possible Reasons: False/Improper "Mixing" Layer Depth definition

✧ Improvement:
  ᶦ Using a smaller density difference as the criteria (like 0.005 or 0.01 kg m\(^{-3}\))
  ᶦ Or Considering of the light intensity, as no NPQ happens without light.
Light-dependent NPQ

Stratified waters
(DFM > MLD)

Mixed waters
(DFM ≤ MLD)
The Method

- Using a light threshold (iPAR=40) to determine the NPQ layer (originally using MLD) which is needed to find the maximum FChla (DFM) and maximum ratio of FChla/bbp (DRM) within the mixed layer for NPQ correction.

- DFM and DRM is computed from surface to min($z_{iPAR40}$, MLD), then for X12 and S08, respectively.

- If radiometry is not available:
  - Using Gregg-Car der model to estimate the clear-sky spectral Ed(0+)
  - Estimating Kd
  - Estimating iPAR profile
How to estimate $K_d$(PAR)

- 1. Using MM01 Kw (pure water) to replace $K_d$ to get an upper limit of $z_{i\text{PAR}40}$, it is sure that iPAR cannot reach 40 $\mu$W m$^{-2}$ s$^{-1}$ deeper than this depth.

- 2. Using the un-NPQ-corrected FChla and the default F factor ($F_R=0.5$) to estimate $K_d$ with MM01, than to estimate $z_{i\text{PAR}40}$.
How to estimate $K_d$(PAR)

- **Estimated iPAR**
  - 1) Gregg-Carder clear-day $E_d(\lambda,0^+) \text{ spectra from 400 to 700nm, 1nm resolution}$
  - 2) $E_d(\lambda,0^-) = E_d(\lambda,0^+)*0.98$
  - 3) $K_d = K_w + \chi (FChla*0.5)^e$ (For Compromise Model 1, all FChla=0) with coefficients from MM01
  - 4) $E_d(\lambda,z_i) = E_d(\lambda,z_{i-1})\exp(-K_d(\lambda,z_i)(z_i-z_{i-1}))$ (i starts from sea-surface)
  - 5) $i\text{PAR}(z) = \frac{1}{hc} \int_{400}^{700} \lambda E_d(\lambda,z) d\lambda$
Tests

✧ Four Models:
  ✧ Original Method (without considering of light threshold)
  ✧ Improved Method (using \( \min(\text{MLD}, z_{\text{iPAR40}}) \)) X12+ & S08+
  ✧ Modelled Method (Using Gregg-Carder and Kd derived from FChla*0.5 to roughly estimate \( z_{\text{iPAR40}} \)) X12m & S08m

✧ 25 Criteria for MLD determination:
  ✧ Density difference from the one at 10 meters reaches: 0.005, 0.010, ..., 0.125
Original Method (using MLD0.03)
Statistics (Light Threshold Model)

Adding the Light threshold could improve the correction a lot.

(a) RMSE (Original)
(b) SMAPE (Original)
(c) RMSE (Light Threshold)
(d) SMAPE (Light Threshold)

X-axis: different MLDs
Y-axis: RMSE (absolute error) and SMAPE (relative error)
Statistics (Modelled Method)

- Its results are very close to the light threshold model.

X-axis: different MLDs

Y-axis:
- RMSE (absolute error) and SMAPE (relative error)
Conclusions

- The CTD-based method (like density difference) cannot effectively detect the mixing layer and remnant mixed layer, at least in the Southern Ocean.

- This results in a very limited improvement through using smaller density differences as the criteria (like 0.005 or 0.01 kg m$^{-3}$)

- The synchronous radiometry could improve this issue effectively, and the MLD criterion is better to choose larger value, like 0.02 or 0.03 kg m$^{-3}$.

- If without iPAR measurement, a compromise method is suggested using Gregg-Carder clear-day iPAR and empirical Kd from un-NPQ-corrected FChla*0.5 (default F factor)
SOCCCOM Test

Simulating a SOCCCOM profile (lower resolution of FChla) Measured by SOCLIM floats

Resolution Lowered
**SOCCOM Test**

- Results: Even better than the original one, as less noises.

![Images of graphs showing RMSE and SMAPE comparisons between SOCCOM and the modeled iPAR with FChla*0.5](image)

- (g) RMSE (Modeled iPAR with FChla*0.5)
- (h) SMAPE (Modeled iPAR with FChla*0.5)
- (i) RMSE (SOCCOM Test)
- (j) SMAPE (SOCCOM Test)
**SOCCCOM Test**

- Conclusions:
  - 1. It is suggested for SOCCCOM floats, to use the modelled iPAR profile and $z_{iPAR40}$.
  - 2. The MLD criterion is better to choose 0.02 or 0.03 kg m$^{-3}$. 
North Atlantic Test

- 6 floats
- 280 pairs of day-night profiles

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A large density difference for MLD determination (>0.04) is not proper for stratified waters. The suggested MLD criterion is from 0.01 to 0.04 kg m\(^{-3}\), within this range, light threshold has much less improvement of NPQ correction than well-mixed waters.
Compromise Model 2 is very efficient to correct NPQ as long as using a MLD criterion from 0.01 to 0.04 kg m$^{-3}$
NPQ vs iPAR

[Graphs showing data for Uncorrected, Original X12, and X12+ in Stratified and Mixed conditions.]

[FChl/bbp] @ D/FChl/bbp @ N vs iPAR for different conditions.]
NPQ vs iPAR
Final Conclusions

1) Light threshold will be useful for both 2 kinds of waters, but much more important for well-mixed waters.

2) A compromise model is suggested to estimate $z_{\text{PAR40}}$, if without radiometry, to improve the NPQ correction, combining clear-sky iPAR model (Gregg-Carder-90), empirical relationship between $K_d$ and [Chla](MM01), and un-NPQ-corrected $F_{\text{Chla}}*0.5$ (as [Chla]).

3) The suggested MLD criterion is 0.02 or 0.03 kg m$^{-3}$ of density difference from 10 m value.

4) Lower resolution is OK for the NPQ correction.