Correcting in situ chlorophyll fluorescence time series observations for non-photochemical quenching and tidal variability reveals non-conservative phytoplankton variability in coastal waters

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Problem: Non-photochemical quenching of F_{chl} in coastal waters

- **Chlorophyll fluorescence** (F_{chl}) is one of the most common approaches to estimating phytoplankton biomass in situ
- Documented sources of natural variability and instrumental uncertainty exist in the relationship between in vivo fluorescence and chlorophyll concentration
  - The largest source of variability is **non-photochemical quenching**[1] (NPQ; Figure 1).

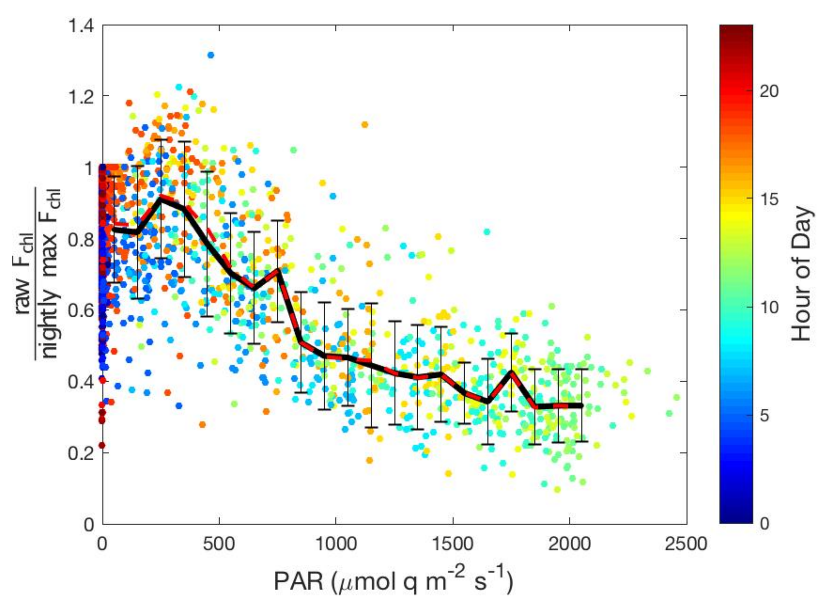


Figure 1. Hourly F_{chl} observations, scaled to the nightly maximal F_{chl}, as a function of incident PAR.

- Strategies to account for NPQ in the open ocean assume either spatial homogeneity or long temporal variability
- These assumptions are unsupported in coastal waters due to **short temporal and small spatial scales of variability** induced by:
  - Mixing of freshwater runoff, ocean surface waters and deep waters by:
    - Wind
    - Bathymetry
  - Tidal advection[2] (notice nighttime variability in F_{chl} between tidal maxima; Figure 2)
- A model is required that can correct F_{chl} for NPQ in the presence of tidal advection.

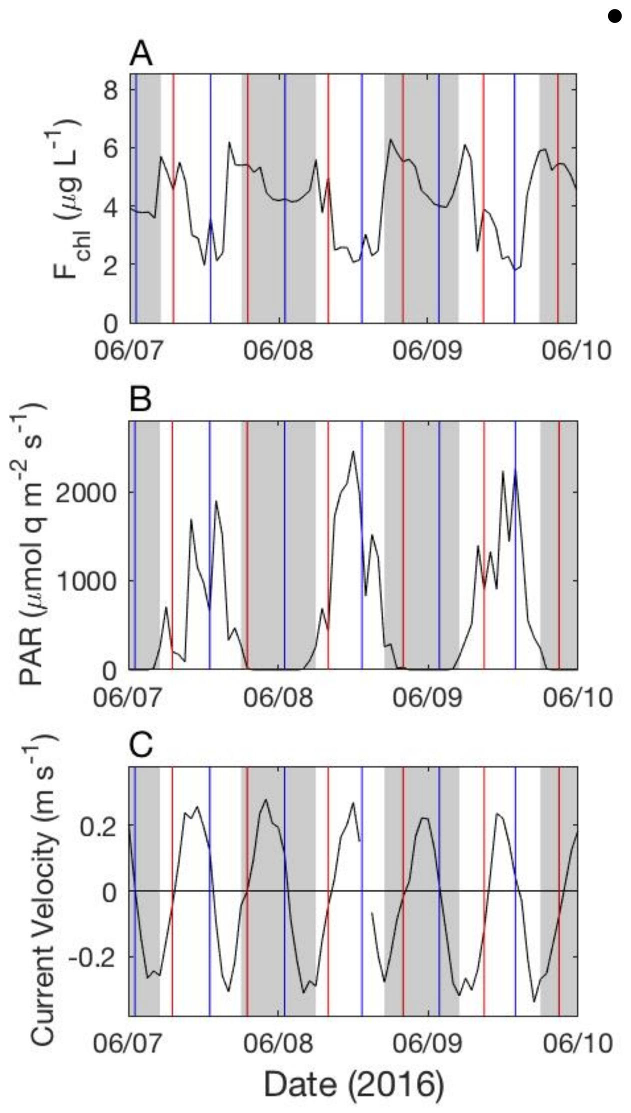
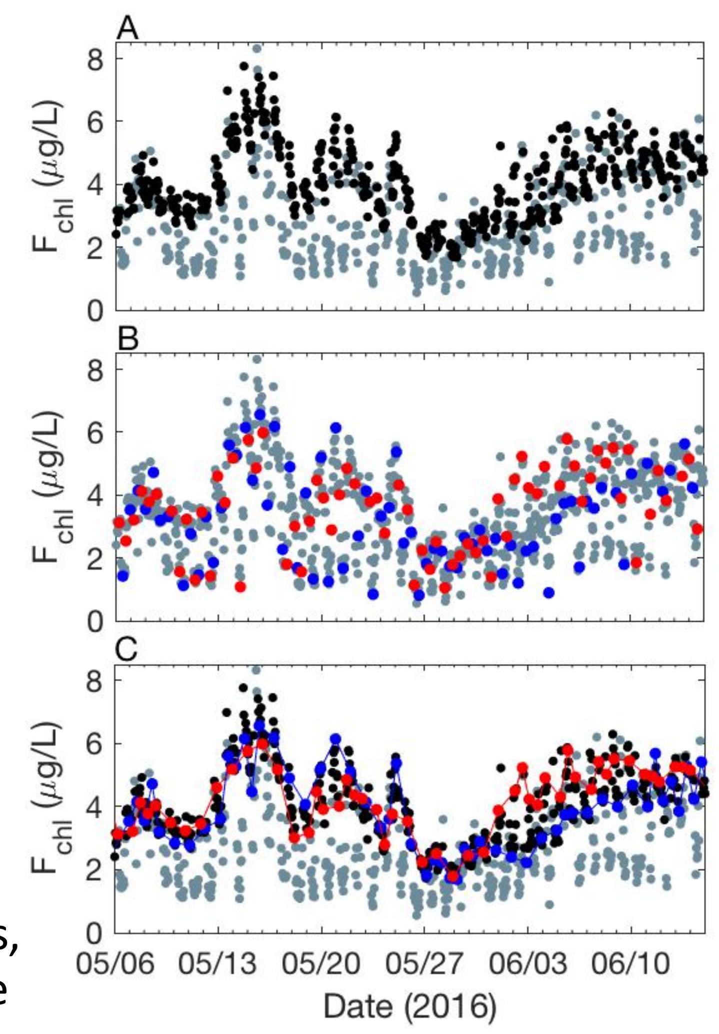


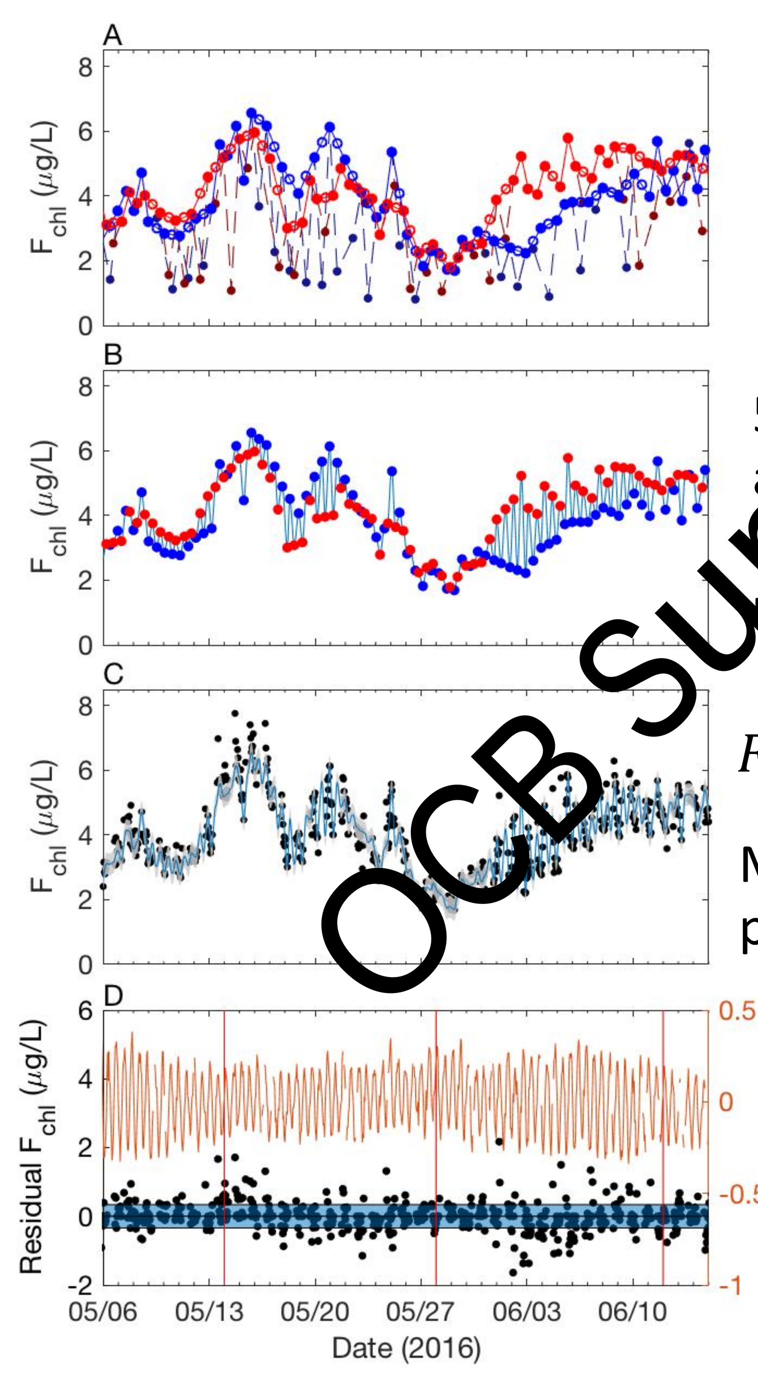
Figure 2. Three-day time series of hourly (A) F_{chl}, (B) PAR and (C) 1.5 m alongshore current velocity observations. Blue lines = high tide, red lines = low tide, dark intervals = nighttime.

Model: Tidal interpolation between F_{chl} high and low tide endmembers



1. Select subset of **unquenched F_{chl} values** (black symbols) based on observed quenching at PAR threshold (300 µmol q m^{-2} s^{-1}, Figure 1).
2. Select subset of high (blue) and low (red) tidal maxima based on current velocity (eqn. 1a and 1b).
   - High tide: $V_a = 0$; and $dV_a/dt < 0$ (1a)
   - Low tide: $V_a = 0$; and $dV_a/dt > 0$ (1b)
3. Intersection of these subsets forms a set of **unquenched high tide F_{chl}** (blue) and a set of **unquenched low tide F_{chl}** (red).

Figure 3. Six week timeseries of F_{chl}, showing identification of unquenched high and low tide subsets.



4. Interpolating over the quenched tidal maxima according to predominant tidal phase (assuming conservation) forms the **high and low tide endmembers**.
5. Interpolating tidally between high and low tide endmembers (using eqn. 2) creates **hourly time series of unquenched, tidally-resolved F_{chl}.**

$$Fchl(t) = -A * \cos\left(\frac{t - t_1}{t_2 - t_1} * \pi\right) + O \quad (2)$$

Model reflects unquenched F_{chl} (black points) well (Figure 3A).

Comparison of model with observed, unquenched values reveals periods of **non-conservative behavior**, possibly related to spring-neap cycle in this instance.

Figure 4. Six week timeseries of F_{chl}, showing implementation of tidal model and comparison with residuals.

Assessment

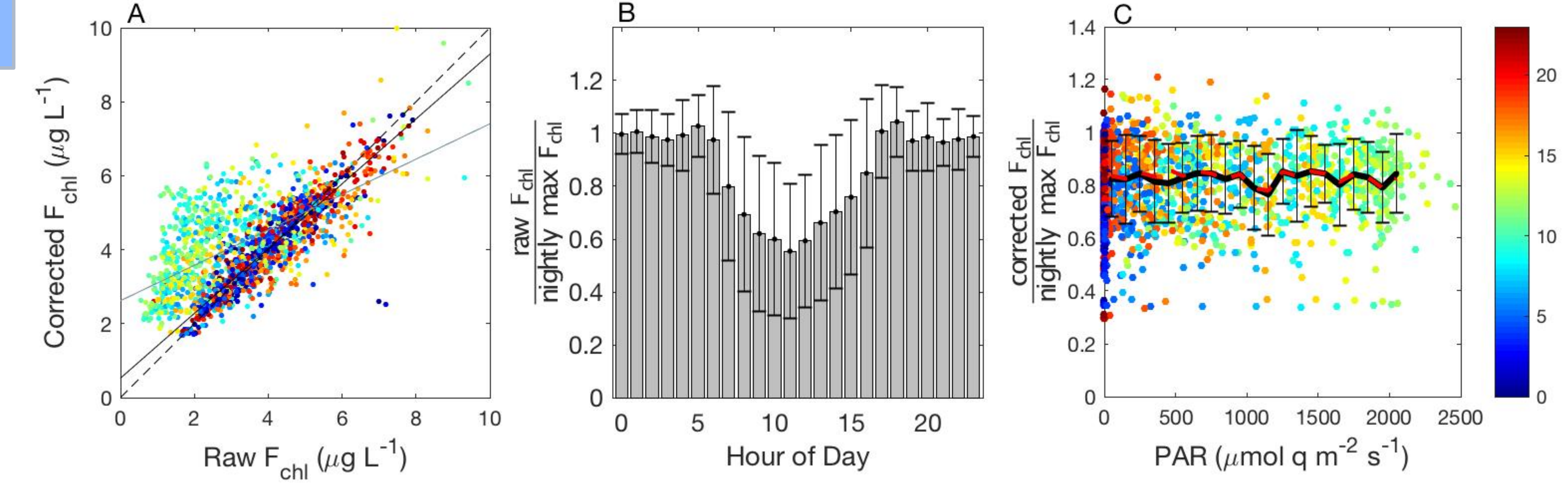


Figure 5. Evaluating the effectiveness of the model in correcting for NPQ.
A. Considerable corrections made to daytime F_{chl} values (light points). Minimal corrections made to nighttime points are due to tidal advection (dark points).
B. NPQ clear throughout the day, with variability at night due to tidal advection.
C. Model enables retrieval of daytime F_{chl} without NPQ, suitable for satellite validation of ocean color data product.

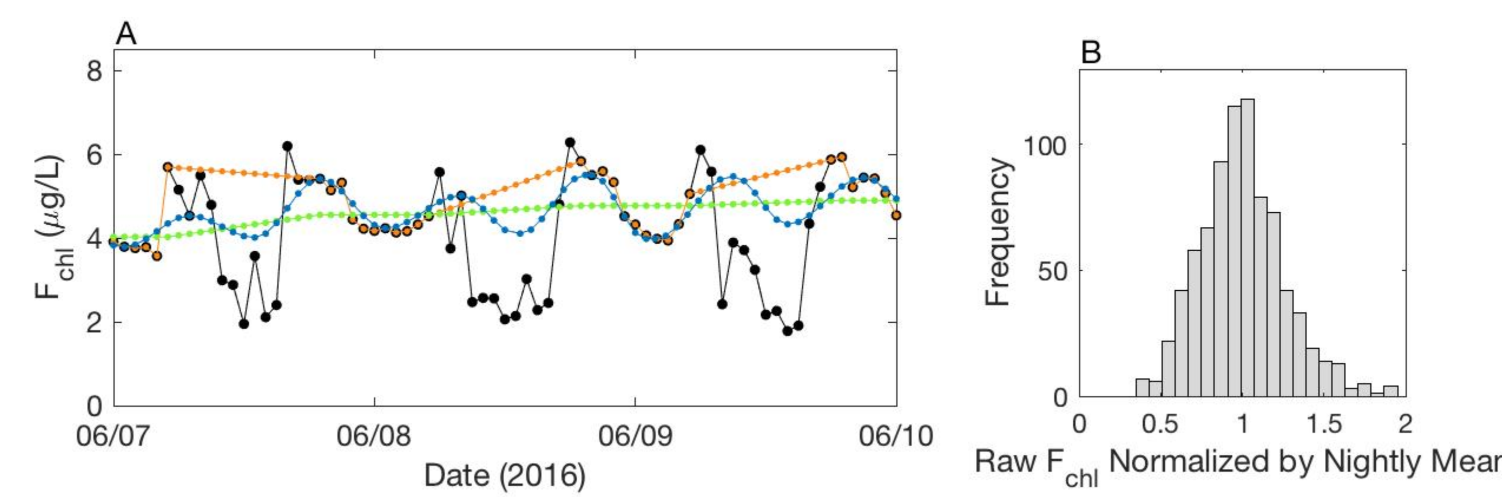


Figure 6. Evaluating the effectiveness of the model in correcting for tidal advection.
A. Model (blue) represents variability in raw unquenched F_{chl} (black) due to tides much better than traditional methods of correction (dawn to dusk interpolation – orange, nighttime average interpolation – green).
B. Raw F_{chl} at night averages ~10% variability due to tidal advection, but reaches 50%, none of which is accounted for by conventional approaches.

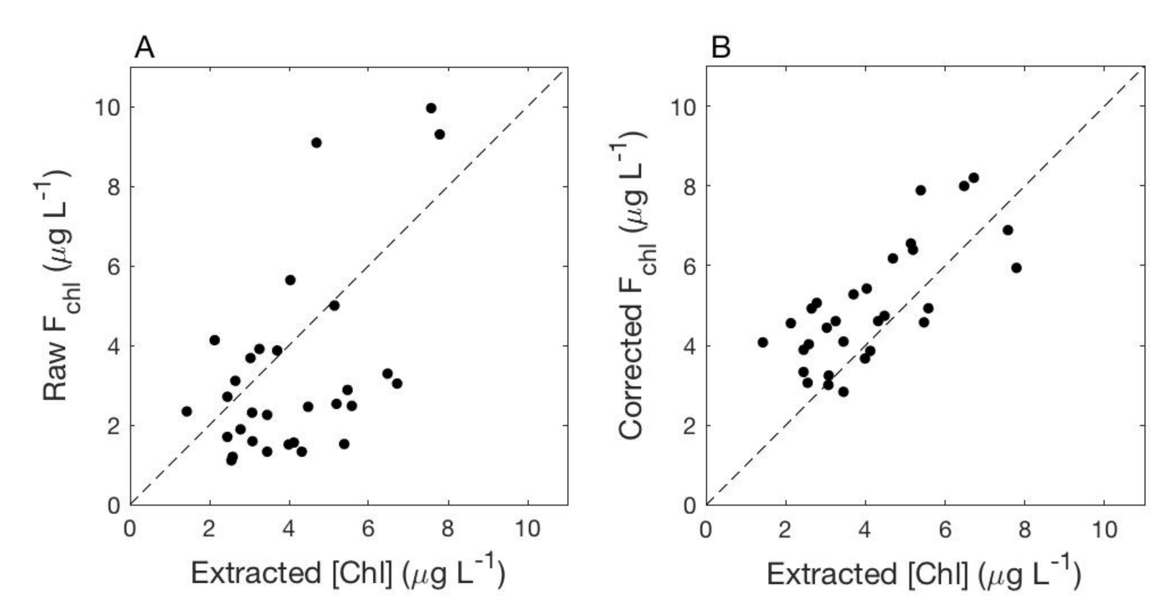


Figure 7. Extracted [Chl] vs. raw and corrected F_{chl}.
In an absolute sense, modeled F_{chl} compares to extracted daytime [Chl] much more accurately than raw F_{chl} does (RMSE is 2.03 in A and 1.03 in B).

Potential

- Measurement and tracking of coastal phytoplankton populations in a Lagrangian sense from Eulerian measurements
- Enables midday matchup with F_{chl} for satellite validation of ocean color data product
- Reveals F_{chl} in the absence of NPQ, to study NPQ
- Reveals F_{chl} in the absence of tide, to study interaction of tidal advection and phytoplankton

Implementation

- Model requires measurements of F_{chl}, PAR and current velocity.
- Can be parameterized:
  - Without PAR (using hours from dawn as a proxy) RMSE=1.13
  - Without current velocity (using a tide chart or a tidal model e.g. U-tide[3] made from sample velocity measurements) RMSE=1.44
  - Without both RMSE=1.25
- Code is available at www.bowdoin.edu/profiles/faculty/croesler/

References

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3. Codiga, D. L. 2011. Unified tidal analysis and prediction using the UTide Matlab functions. Graduate School of Oceanography, University of Rhode Island Narragansett, RI.

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