Ocean Color Remote Sensing from EPIC DSCOVR (L1 Orbit)

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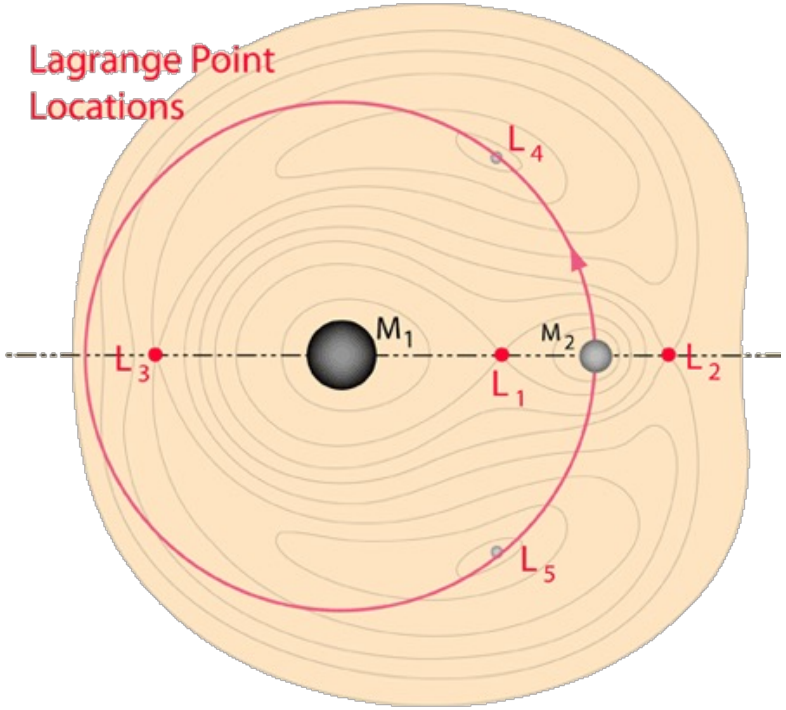
LAGRANGE POINTS



•At Lagrange points, gravitational pull of large masses M1 (Sun) and M2 (Earth) equals the centripetal force for a small object (satellite) to move with them, i.e., the relative positions of the 3 objects are fixed.

•L_1 is at about 1.5 million km from Earth. From L1, the entire face of the Earth lit by the Sun can be regularly observed.

Image of the Earth from L_1 by the Earth Polychromatic Imaging camera (EPIC) onboard the DSCOVR observatory on 6 July 2015.

ADVANTAGES of L_1 ORBIT FOR OCEAN COLOR REMOTE SENSING

-Entire Sunlit oceans can be observed simultaneously at high temporal resolution from a single platform, allowing detailed coverage of evolving systems and diurnal (e.g., tidal) phenomena.

-Spatial coverage is not an issue at low/middle latitudes, unlike with LEO polar orbiters; Sun glint can be mitigated; polar regions partially seen from GEO satellites can be viewed.

-Atmospheric correction may be facilitated by viewing at the same scattering angle but different zenith angles.

-Radiometric calibration, pixel-to-pixel uniformity, and long-term instrument stability can be maintained by lunar observations whenever the Earth has a full moon (once a month), i.e., no need for an onboard calibration system (saving a lot of cost and complexity).

-Quiet thermal environment (no day-night thermal changes) and particle radiation environment; Small fuel consumption to maintain position.

EPIC/DSCOVR

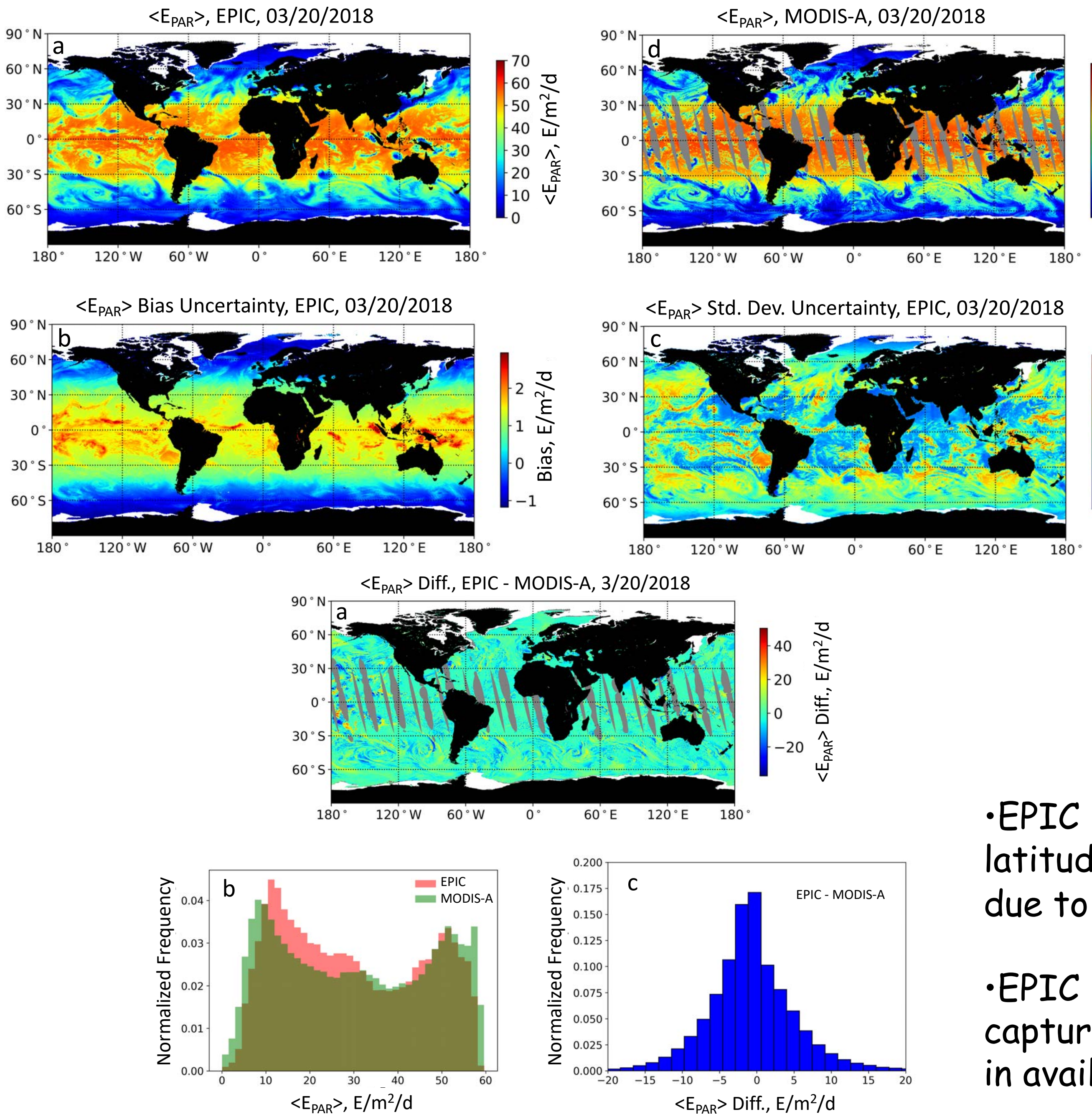
-The EPIC camera onboard the DSCOVR observatory in L_1 orbit (https://epic.gsfc.nasa.gov/about/epic) provides imagery of the Earth's surface lit by the Sun at a cadence of 13 to 22 images/day and optical resolution of about 18 km in 10 spectral bands from 317 to 780 nm, i.e., centered on 317.5, 325.0, 340.0, 388.0, 443.0, 551.0, 680.0, 687.7, 764.0, and 779.5 nm with FWHMs of 0.8 to 3 nm.

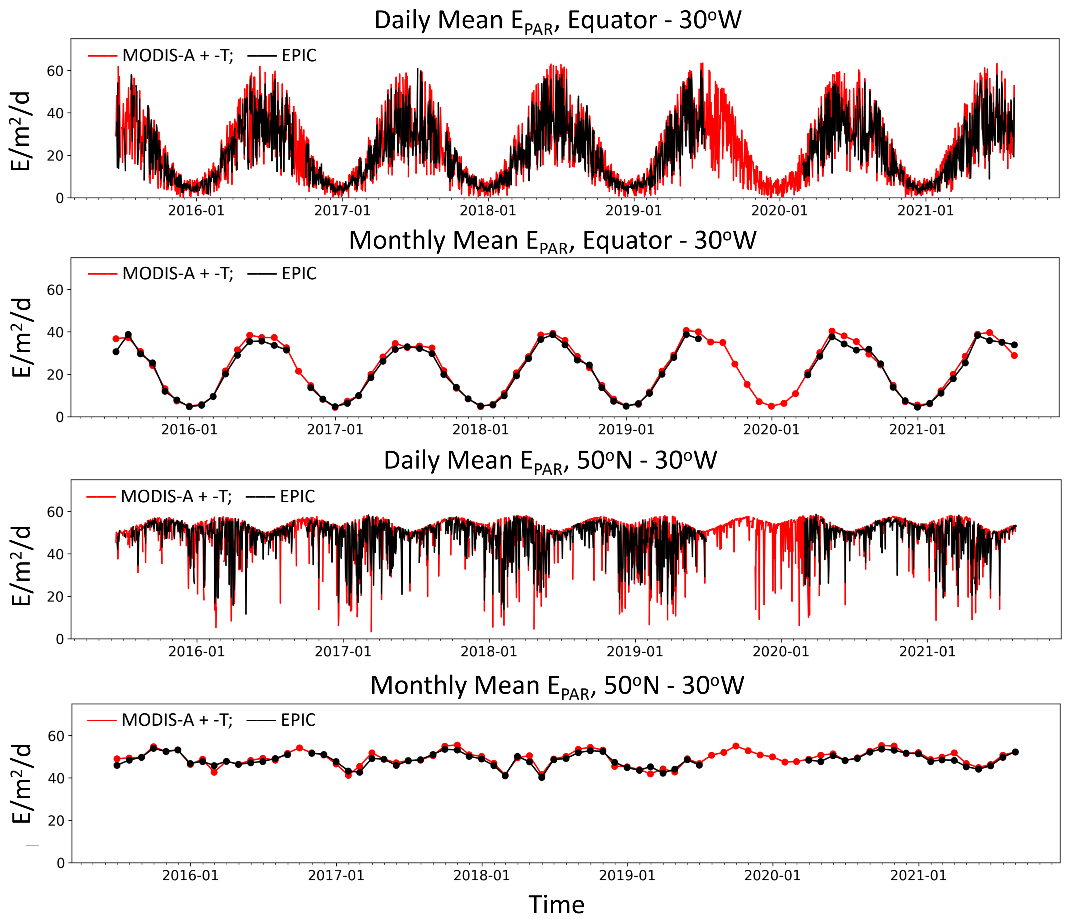
-The data can be used to estimate surface solar irradiance and water reflectance, basic variables from which a variety of optical and biogeochemical products can be derived. The band at 687.7 nm (FWHM of 0.84 nm) may be used to estimate FLH by quantifying the filling of the O_2-B band by the inelastic chlorophyll fluorescence signal but limited by the relatively low S/N ratio.

-Global products for ocean biology and biogeochemistry have been obtained. They include surface fluxes (above and below surface, planar and scalar) in the ultraviolet and visible, average cosine for total light, photosynthetically available radiation (PAR), water reflectance, chlorophyll-a concentration.

Scalar Irradiance: $E_o = \int_{4\pi} L(\theta,\phi)d\omega$ Average Cosine: $\mu = E_d - E_u)/E_o$

Daily mean planar PAR just above surface



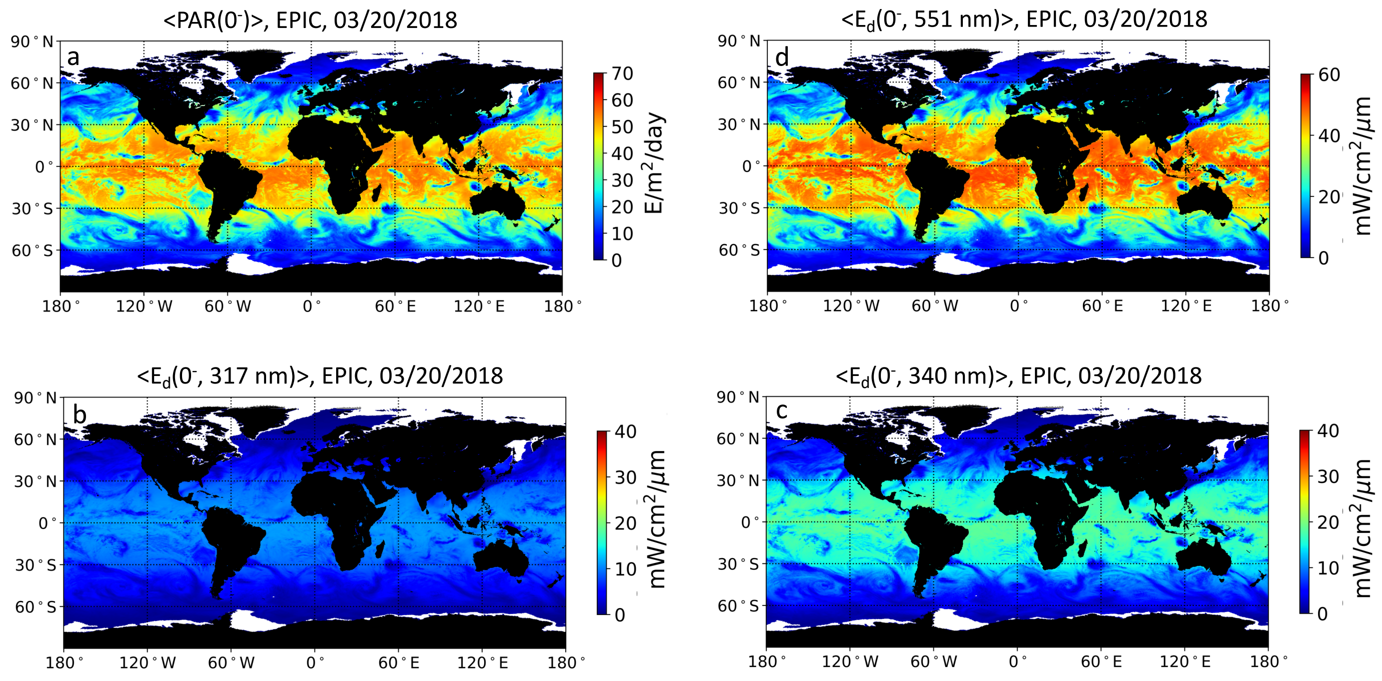


- EPIC PAR imagery less noisy with no gaps at low/middle latitudes and values slightly lower than MODIS values, which is due to using multiple observations during the day.

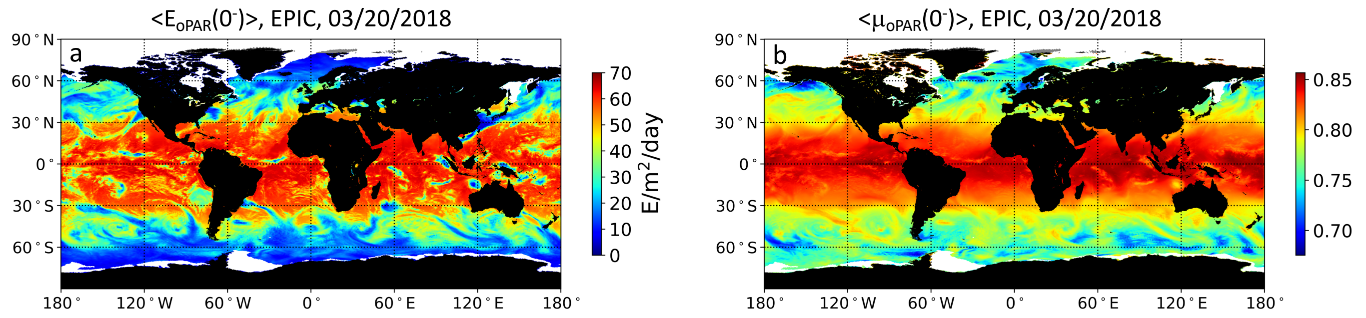
- EPIC PAR 2015-2021 time series demonstrate ability to capture variability for investigating ocean response to changes in available light over a wide range of temporal scales.

Daily mean planar and scalar fluxes just below surface

Planar PAR and spectral fluxes at 317, 340, and 551 nm



Scalar PAR and average cosine



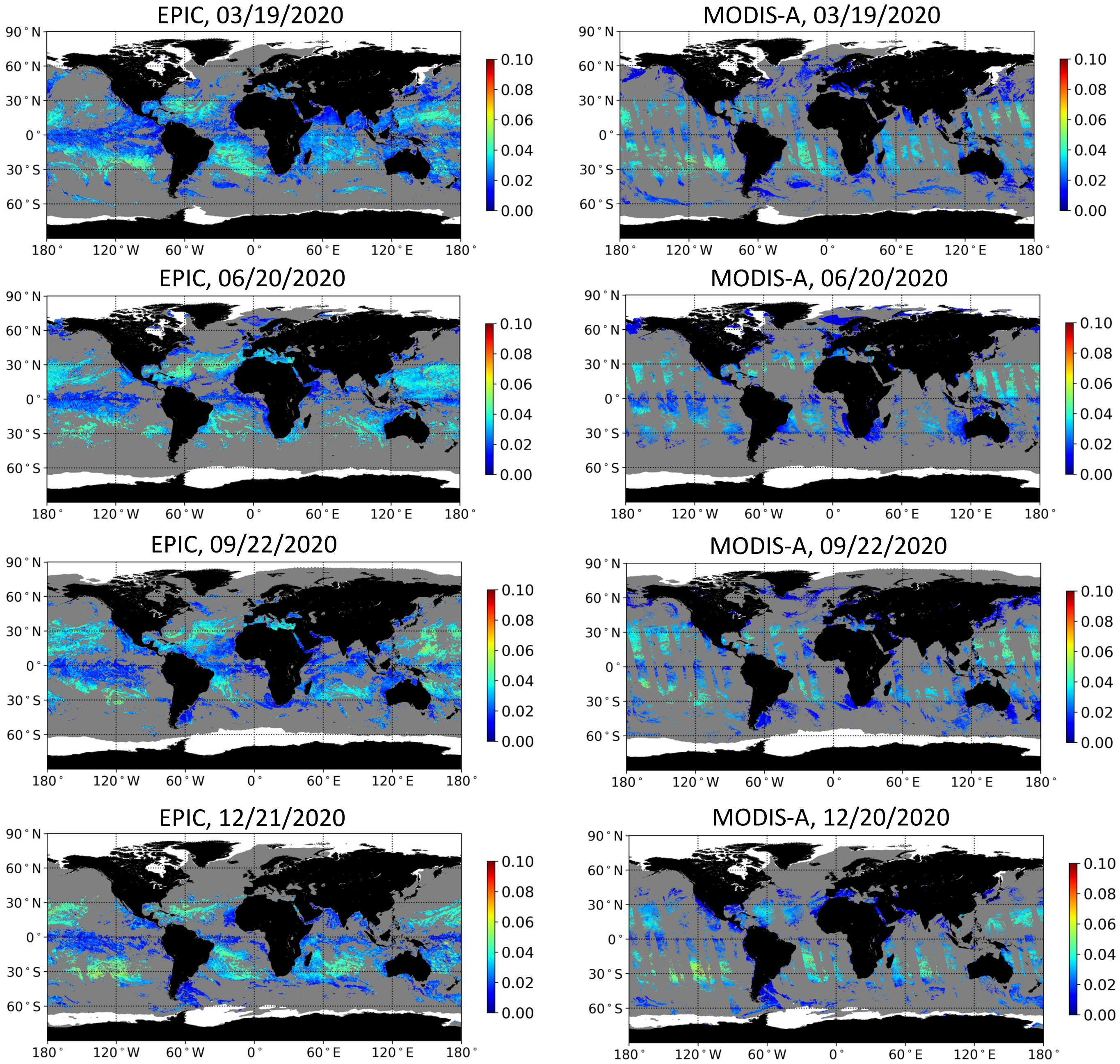
- Planar PAR values below the surface are lower than those above surface by 3 to about 10% depending on latitude and cloudiness. The UV fluxes resemble the flux at 551 nm but have much smaller magnitude and are more modulated by ozone distribution.

- Scalar PAR and average cosine are obtained from cloud factor (effect of cloudiness on PAR) and clear sky PAR just above surface.

- Scalar PAR below surface follows planar PAR above and below surface, but the values are somewhat higher, as expected.

- Average cosine for total PAR light has relatively high values of 0.8 to 0.85 at low and tropical latitudes (illumination more vertical), i.e., the average nadir angle of the upwelling and downwelling photons is small (32-37 deg.), but values are as low as 0.70 at high latitudes, especially in clear sky regions (illumination more slanted and less diffuse).

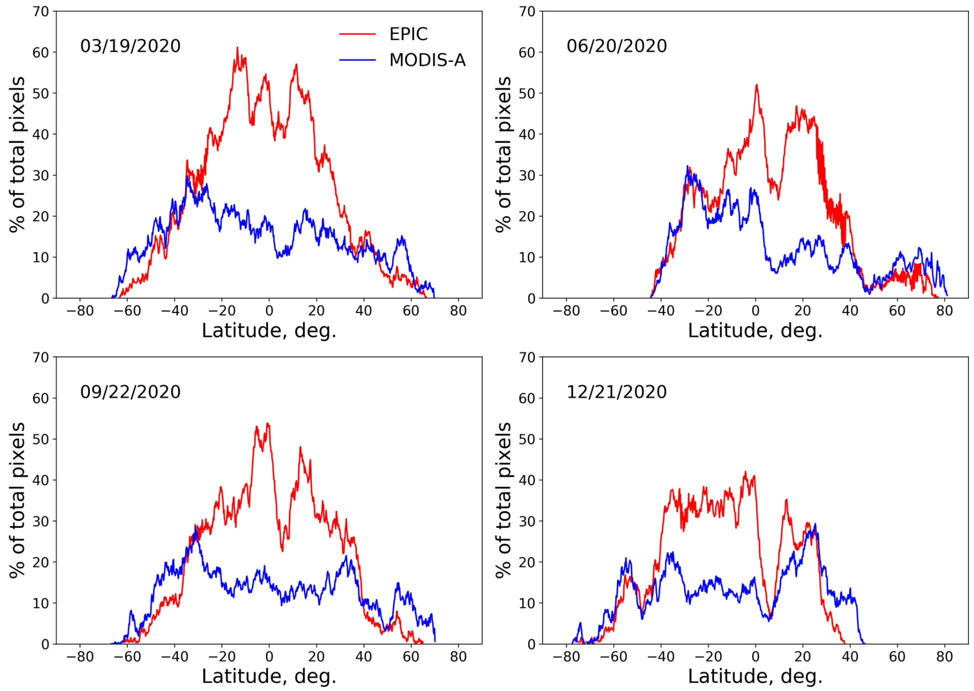
Daily mean water reflectance just above surface, 443 nm (spectral matching algorithm)



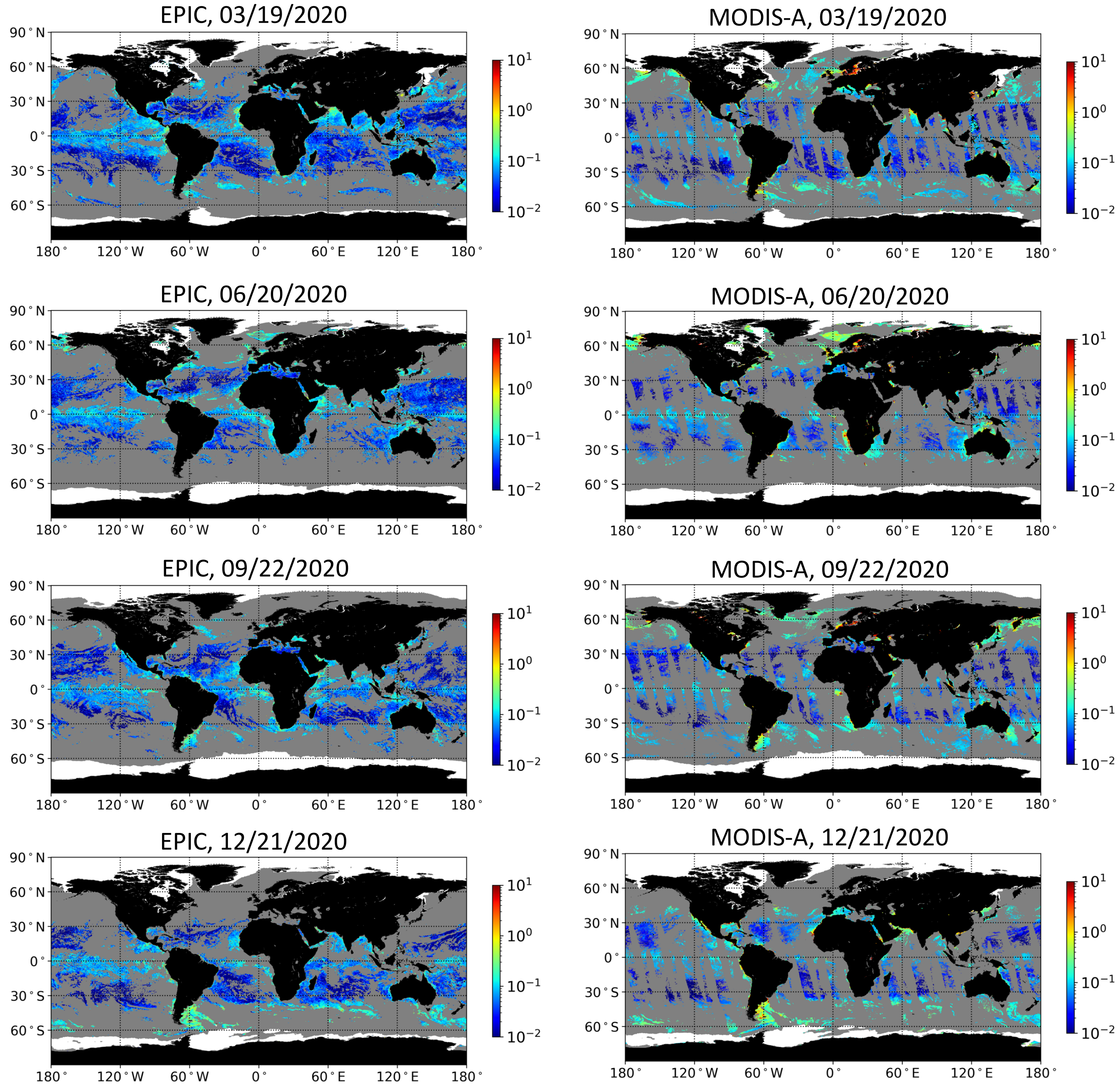
•Retrieval is performed using spectral matching algorithm (Steinmetz et al., 2011).

•Level 1b EPIC reflectance at 388, 443, 551, 680, and 780 nm is used. Water reflectance is retrieved on source grid for each EPIC observation during the day, normalized, then remapped to 18.4 km grid, and averaged.

•Spatial coverage is increased at low/middle latitudes using EPIC (compared with MODIS) data.

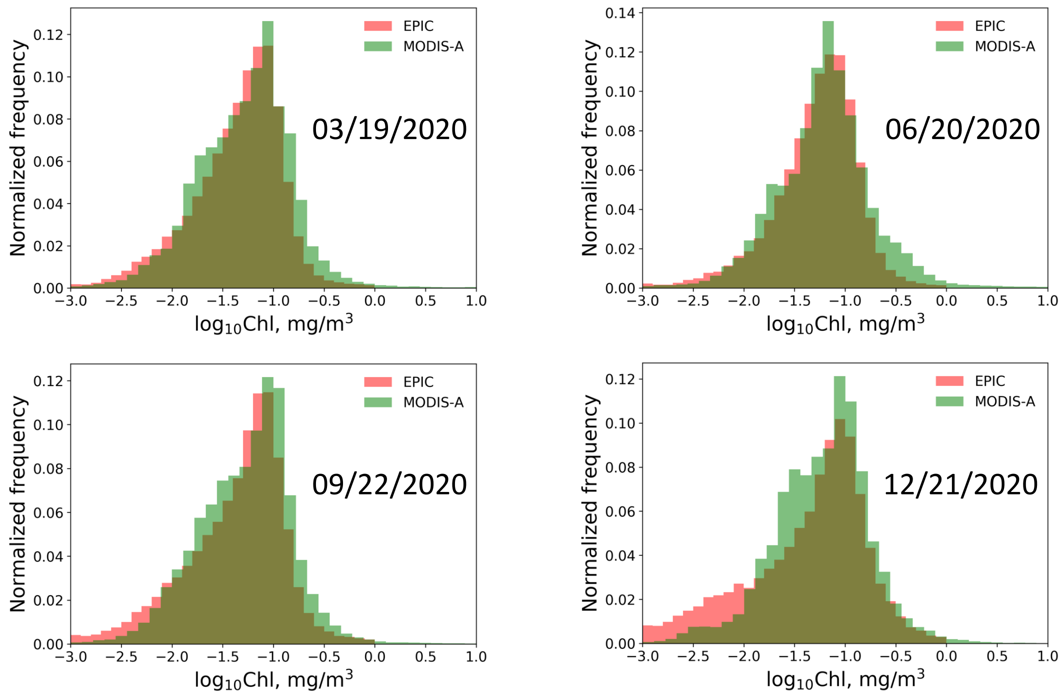


Surface chlorophyll concentration, mg/m^3 (OC3 algorithm)



•OC3-type bio-optical algorithm adapted to EPIC bands centered on 443, 488, and 551 nm and developed on NOMAD data is used.

•Good agreement between EPIC and MODIS-A chlorophyll concentrations. Histogram of values is similar for both sensors, but significant number of MODIS-A intermediate values shifted to lower EPIC values on December 21, 2020.



MULTI-DIRECTIONAL ALGORITHM FOR WATER REFLECTANCE

-TOA reflectance, R_{TOA}', outside Sun glint region, after correction for gaseous absorption and molecular scattering, can be expressed as:

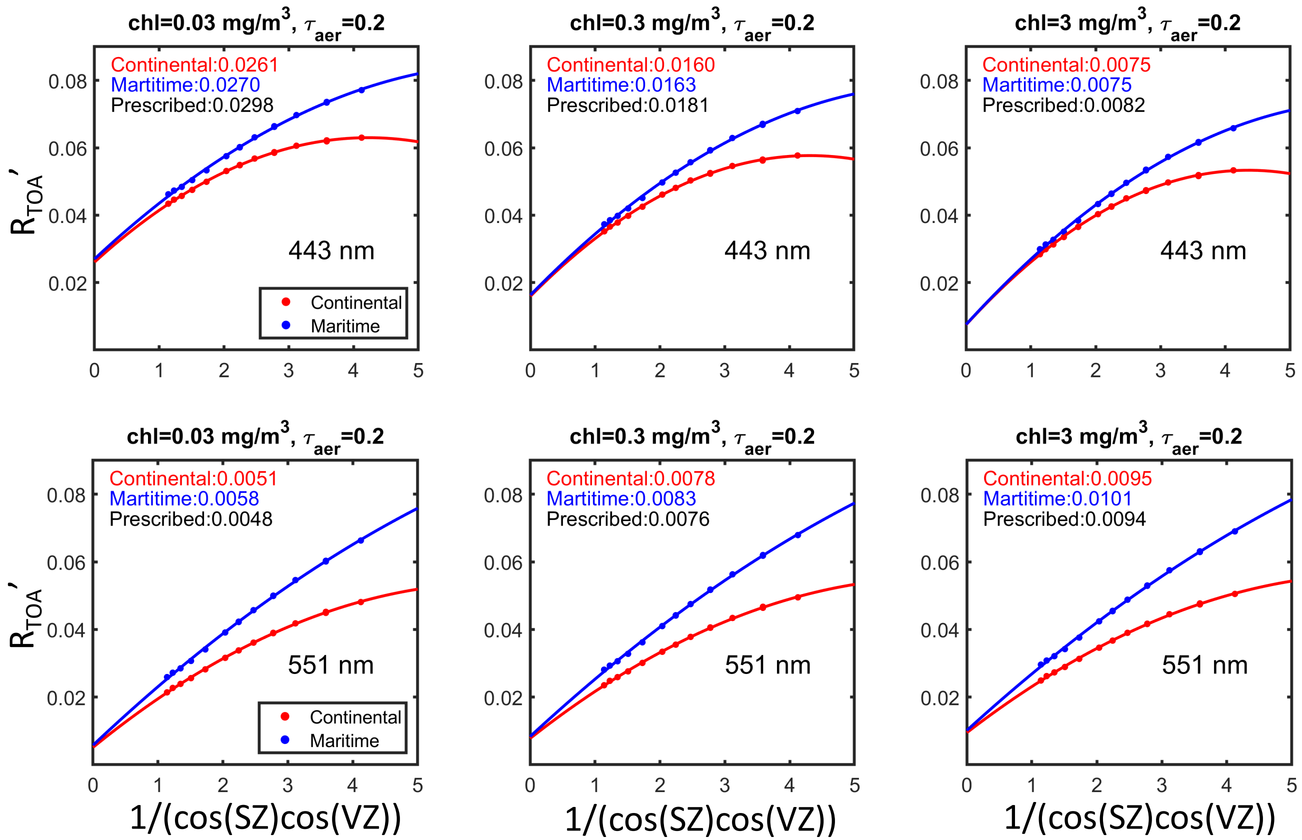
$$R_{TOA}' = R_{aer} + R_w\, T_{atm} \approx C\, P(\Theta)/(\cos(SZ)\cos(VZ)) + R_w\, T_{atm}(SZ, VZ)$$

-For EPIC, scattering angle Θ is constant, i.e., by regressing R_{TOA}' versus $1/(\cos(SZ)\cos(VZ))$ for various SZ and VZ one may infer R_w as the intercept at $1/(\cos(SZ)\cos(VZ)) = 0$

-Method assumes that the clear atmosphere, in particular aerosols and water properties, does not change significantly during the day.

-Relation between $1/(\cos(SZ)\cos(VZ))$ and R_{TOA}' may not be linear, which complicates the regression, but may be somewhat linearized.

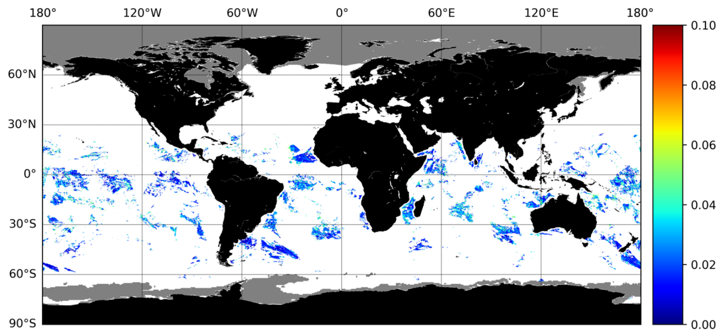
-In practice, atmosphere may not be clear during all day, limiting the number of clear observations, therefore method applicability.



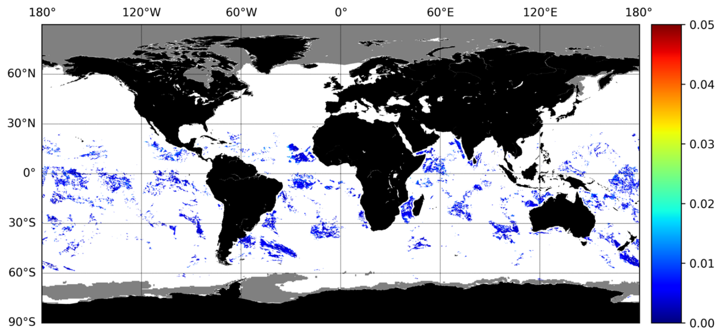
•Relation is more non-linear for continental aerosols, especially in blue (443 nm). Water reflectance estimate in reasonable agreement with prescribed values.

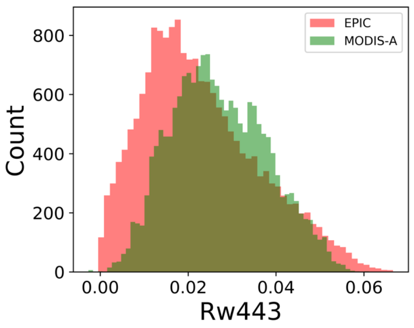
Application of multi-directional algorithm

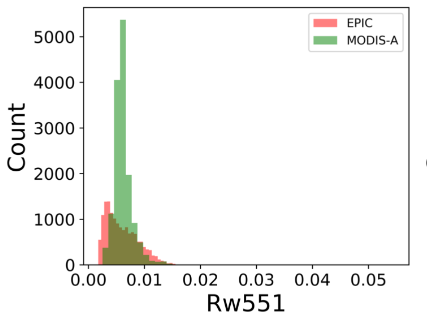
EPIC R_w, 443 nm, 01/01/2018



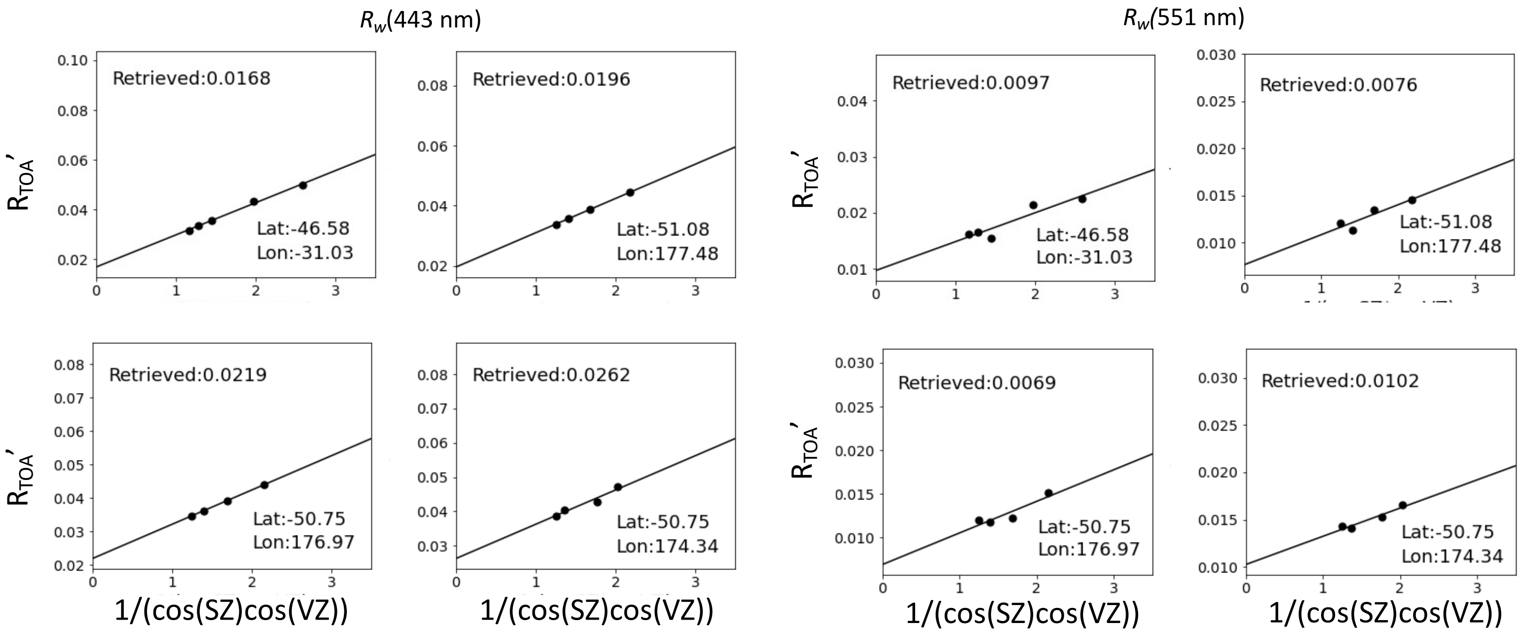
EPIC R_w, 551 nm, 01/01/2018







Examples of EPIC R_w retrievals at 443 and 551 nm, individual pixels.



- Linear relation between R_{TOA}' and *1/(cos(SZ)cos(VZ))* is assumed. Only EPIC observations with *1/(cos(SZ)cos(VZ))* < 3 are used. At least 4 observations are required. Test on goodness of fit.

- Reflectance values are shifted low compared with MODIS values. Spatial coverage is dramatically reduced.

- Results suggest new instrument concept for ocean color remote sensing: Conical scanner with optical axis aligned with the Sun, allowing observations at the same scattering angle but different view zenith angles.

SUMMARY/CONCLUSIONS

-EPIC/DISCOVR has demonstrated the feasibility of ocean color remote sensing from the L_1 orbit.

-Basic quantities for ocean biology/biogeochemistry have been estimated, namely surface solar irradiance (UV, visible, planar, scalar) and diffuse water reflectance, from which a variety of optical and biogeochemical variables can be deduced, e.g., chlorophyll concentration, diffuse attenuation coefficient, and fraction of PAR absorbed by live algae.

-A major advantage of the L_1 orbit compared to LEO and GEO orbits is the possibility, from a single platform, to image the entire sunlit ocean frequently, i.e., to resolve diurnal variability of biological phenomena. This fills a major gap in current satellite ocean color systems.

-Other advantages include increased spatial coverage at low/middle latitudes, no Sun glint problem, better coverage of polar regions than GEOs, especially during summer solstice, and no need for onboard calibration system.

PERSPECTIVE

-The spatial resolution of EPIC (about 18 km at nadir) is coarse for ocean-color remote sensing applications, especially in coastal regions. A spatial resolution of 1 km (or less) is desirable.

-Since the resolving power (angular resolution) of an optical system is $1.22*\lambda/D$ where D is the diameter of the lens' aperture, at the L_1 point (1.5 million kilometers from earth), D of 0.9 m would allow 1 km spatial resolution at 500 nm. This would require a large telescope.

-Several instrument concepts can be envisioned, *e.g.*: 1) Full disk imager (same as EPIC), with aggregated CCD arrays in focal plane; 2) Geographic scanning instrument.

-Issues: Image stabilization to compensate for spacecraft jitter; Correction of straylight; Cost of telescope and of placing large instrument in L_1 orbit.

-Preliminary calculations/considerations and heritage designs indicate that it is feasible to build a hyper-spectral, polarimetric sensor measuring from UV to NIR with 1 km resolution from L_1.

-Space agencies should consider an ocean color mission from the L_1 orbit and commission a pre-phase 0 study.