Solar Transmission and Radiant Heating in the Central Equatorial Indian Ocean

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Abstract Air-sea heat and momentum fluxes in the equatorial Indian Ocean are believed to play essential roles in MJO control. Ocean radiant heating is a dominant term in tropical air-sea heat budgets. In addition to supplying thermal energy to the ocean, solar radiation, through its vertical divergence, plays a primary role in the diurnal (mixed layer) stratification process influencing both daytime EKE dissipation and setting up nighttime upper ocean convection. In situ upper ocean solar heat flux data are presented. These direct measurements of in-water solar flux divergence, or solar attenuation, allow variations in solar forcing of upper ocean mixed layer stratification to be accurately quantified. Solar attenuation depends primarily on upper ocean chlorophyll biomass concentration in open ocean waters. Chlorophyll biomass depends largely on the availability of light and nutrients. In situ ocean chlorophyll and nutrient data that inform on bio-physical feedbacks are also presented. The data show relatively low chlorophyll concentration values near 0.15 mg m^{-3} with a single episodic increase to 0.4 mg m^{-3} that influenced on the depth distribution of ocean radiant heating.

PROJECT GOALS

• Measure upper ocean solar flux profiles during the DYNAMO field experiment.

• Parameterize solar transmission (flux divergence) in the Equatorial Indian Ocean.

• Understand reasons for variations in solar transmission (i.e. how/why upper chlorophyll concentration varies).

RATIONALE

Solar radiation plays a primary role in the diurnal (ocean mixed layer) stratification process influencing both daytime EKE dissipation and setting up nighttime convection. Direct measurement of the in-water solar flux divergence, or radiant heating rates, allows variations in solar forcing of stratification, that can be significant, to be accurately quantified.

EXPERIMENTAL DESIGN

Profiles of in water solar flux data and collection of water samples for analysis of chlorophyll biomass.

Solar radiation is a unique component of air – sea heat exchange

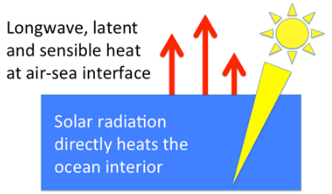

Figure 1. Cartoon showing air - sea heat flux components. Solar radiation is unique as it penetrates beyond the air sea interface and (through its vertical divergence) directly heats water at depth.

Upper ocean chlorophyll concentration is primary regulator of in water solar transmission

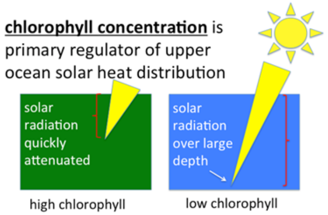

Figure 2. Cartoon showing the role of upper ocean chlorophyll concentration in regulation of solar transmission.

Upper ocean chlorophyll concentration can thus influence ocean dynamics and air-sea heat exchange

Measurements

- in water spectral irradiance (solar flux) profiles
- water samples for *hplc* chlorophyll analysis
- water samples for nutrient analysis
- net surface irradiance
- chlorophyll fluorescence

In water solar transmission (*Tr(z,t)*)

$$Tr(t,z) = En(z,t)) / Ed(0^+,t) \quad \text{(net solar flux at depth / surface solar flux)}$$

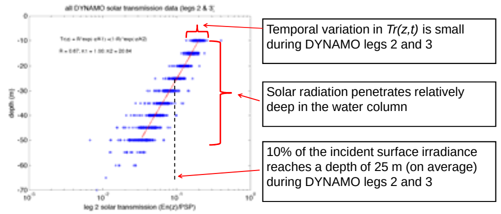

Figure 3. All *Tr(z,t)* data collected during legs 2 and 3 of DYNAMO. A mean profile is computed from the available data and mean *Tr* parameters are given.

Large *Tr(z,t)* and little temporal variability in central Equatorial Indian ocean is due to consistency of "chlorophyll desert"

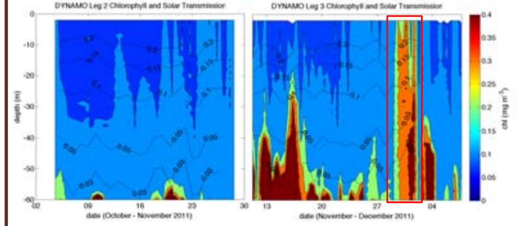

Figure 4. Chlorophyll concentration from in situ fluorometer and corresponding *Tr(z,t)* contours for DYNAMO legs 2 and 3 (80° E, 0° N). Chlorophyll values in the top 40 m are generally small (< 0.1 mg m^{-3}). A doubling of chlorophyll occurs from 29 Nov – 1 Dec, only 3 days. *Tr(z,t)* response is relatively small. Need to understand why.

Comparison with TOGA-COARE data in western Pacific

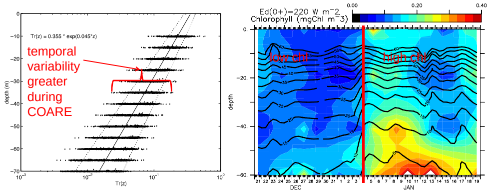

Figure 5. Mean *Tr* from TOGA-COARE is almost identical. However, COARE data showed significantly more temporal variability and a chl bloom that lasted 10 days.

Remotely sensed chlorophyll concentration data from ocean color (Aqua) supports "chlorophyll desert"

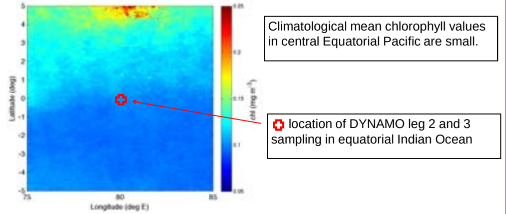

Figure 6. Mean upper ocean chlorophyll concentration from 11 years (2002 – 2013) of Aqua ocean color (4 km) data. Climatological values are similar to values collected during DYNAMO. Chlorophyll concentrations begins to increase near 5° N.

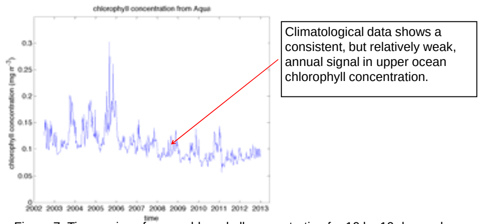

Figure 7. Time series of mean chlorophyll concentration for 10 by 10 degree box shown in Figure 6. 11 years (2002 – 2013) of chlorophyll data are from Aqua satellite ocean color data.

Chlorophyll values at "deep chl max" can be large (> 0.5 mg m^{-2}) but negligible influence on *Tr(z,t)* as deep *En(z,t)* is small

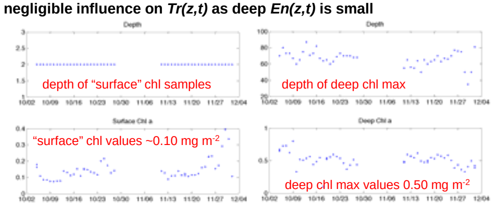

Figure 8. Time series chlorophyll concentration determined with *hplc*. Deep chlorophyll maximum values are large, but have little influence on solar attenuation variations as solar flux values are very small at large depths.

CONCLUSIONS

•mean *Tr* during DYNAMO similar to that for TOGA-COARE
•small variations in *Tr(z,t)* during DYNAMO
•Equatorial Indian ocean is a chlorophyll desert
•upper ocean chl values near 0.1 mg m^{-3} with little temporal variability
•climatological remotely sensed data support DYNAMO obs
•*Tr(z,t)* does not appear to influence synoptic variability in ocean dynamics and air-sea heat fluxes as in the western Pacific

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