Contribution of zooplankton fecal pellets to deep ocean particle flux in the Sargasso Sea using quantitative image analysis

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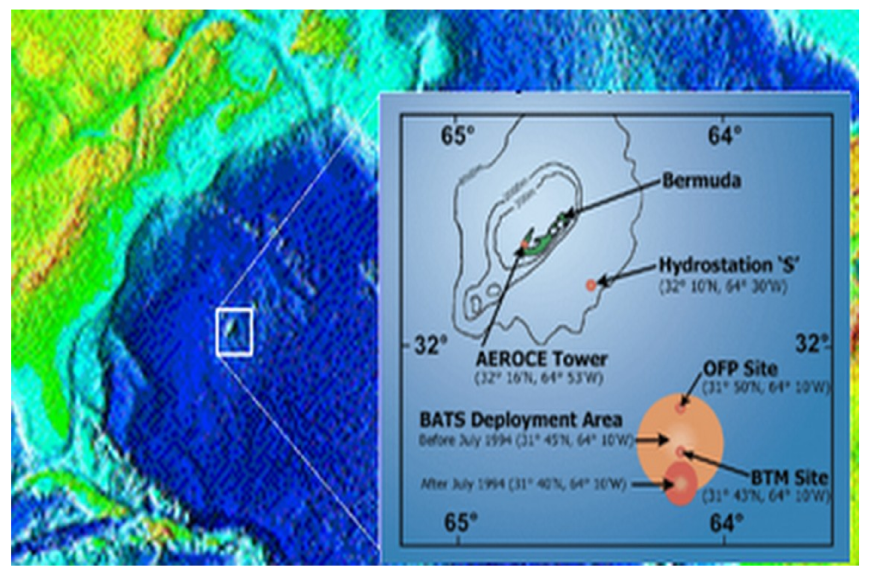
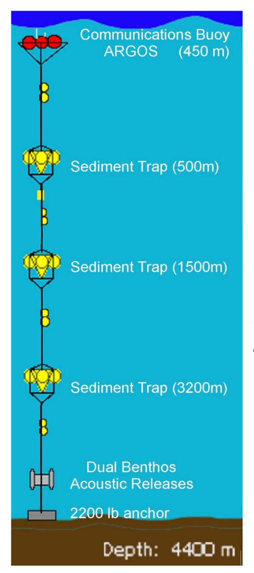
ABSTRACT

Zooplankton fecal pellets are an important part of the particle flux because they export carbon and other nutrients to depth. However, little is known about their temporal variability over longer time scales. We set out to develop a record of fecal pellet flux in the deep ocean for an entire year (2007) to understand the role of fecal pellets in mesopelagic particle flux.

The Oceanic Flux Program (OFP), located 75km southeast of Bermuda in the Sargasso Sea, has continually collected deep ocean particle flux since 1978 and is the longest running deep ocean sediment-trap time series in the world. Recent application of digital microphotography to the time series has brought about a wealth of new visual information to study particle flux dynamics. We quantitatively analyzed the digital microphotographs of the 125-500 µm size fraction to better characterize the zooplankton fecal pellet contribution to mesopelagic particle flux. We then compared our data with satellite and *in-situ* data to examine the effects of mesoscale upper ocean variability on the zooplankton fecal pellet fluxes in the deep ocean.

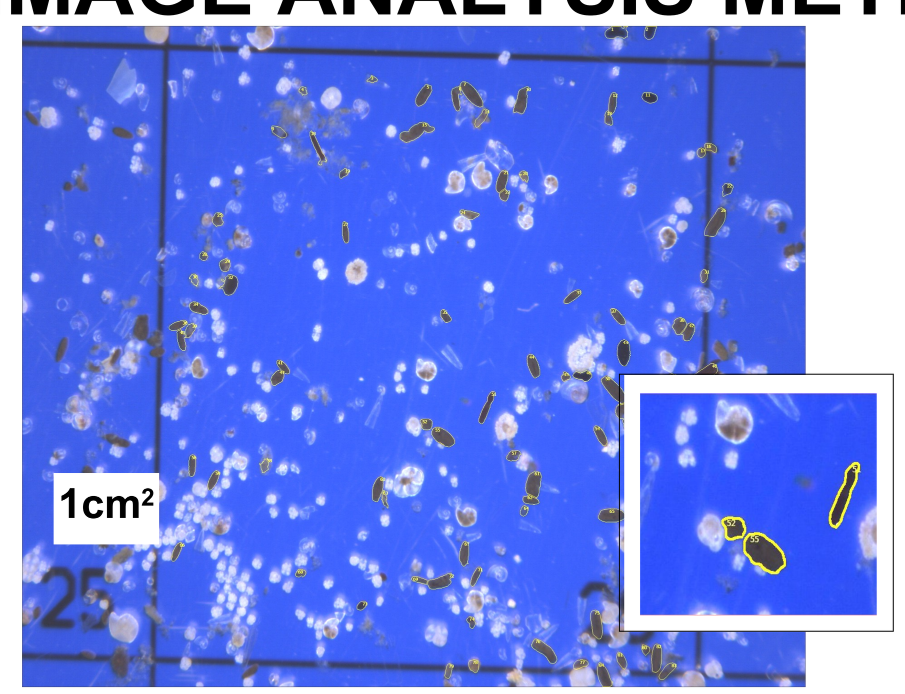




OFP mooring diagram with sediment traps located at 500m, 1500m and 3200m depth.

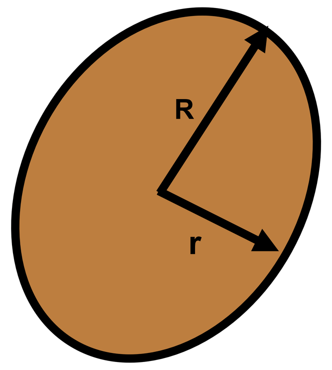
Bermuda Time Series Site (above left): Co-location of the OFP, BATS, and BTM allows for complementary studies of surface ocean-deep ocean connections.

IMAGE ANALYSIS METHODS



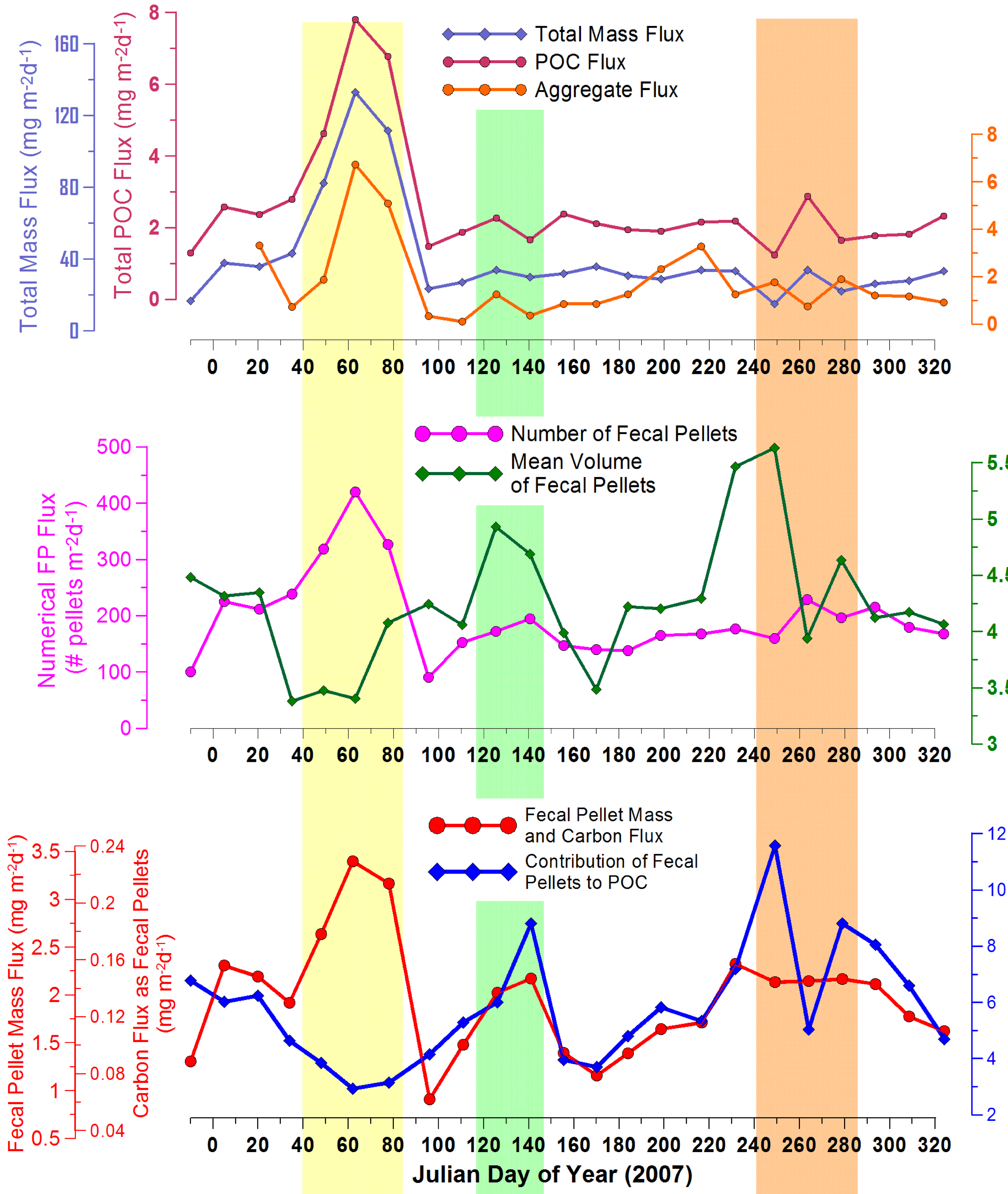
Left: Example of an image processed for fecal pellet analysis
We empirically optimized an automatic measurement feature of Zeiss Axiovision (v.4.8.0) utilizing RGB color and size criteria to separate fecal pellets from the rest of the sample image (matrix). Yellow outlines show automatic delineation of fecal pellets from the matrix. Each sample consists of 69 1cm² grids.

Right: Ellipse major and minor axes were measured on each fecal pellet and were used to convert area to volume. Fecal pellet volume for all grids was summed and multiplied by estimated density [1.19 g cm⁻³, Dillon 1964 *Limnol. Oceanogr.*] to calculate fecal pellet mass. Volume was converted to carbon using the conversion factor of 0.08 mg C mm⁻³ (Urban-Rich *et al.* 1998, MEPS). As only intact fecal pellets in the 125-500 µm size fraction were counted, our estimates are conservative as fragmented pellets <125µm were not enumerated.



R=ellipse major axis
r=ellipse minor axis

TOTAL MASS, AGGREGATE, AND FECAL PELLET FLUX AT 1500m DEPTH IN 2007



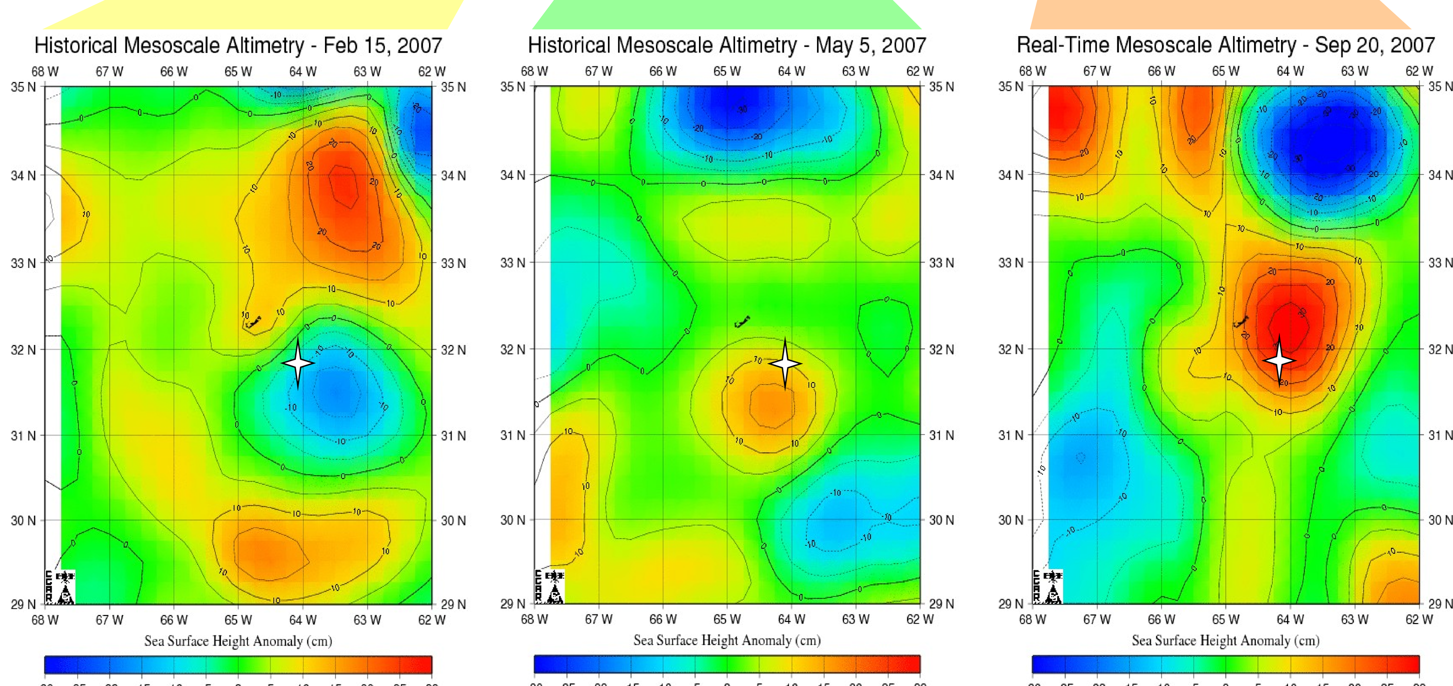
Total mass flux, particulate organic carbon, and macro-aggregate flux records at 1500m depth: The mid-date of each 14-16 day sampling period is plotted. Colored vertical bars indicate approximate time periods when a productive cyclonic eddy (C), a decaying mode water eddy (M) and strong anticyclonic eddy (AC) passed through the Bermuda time series site.

Numerical fecal pellet flux and mean volume records (middle) and fecal pellet mass/carbon flux and contribution to POC (bottom):

Total mass, POC, aggregate, and fecal pellet fluxes increased significantly during passage of the C eddy, with fecal pellet mass flux increasing by 150% from previous values. Mean fecal pellet size decreased in the C eddy, suggesting an increase in immature individuals due to secondary production. Despite the large flux increase, fecal pellet contribution to POC decreased due to increase in large aggregate flux.

During the M eddy passage, fecal pellet flux and fecal pellet contribution to POC also increased. Larger fecal pellets were observed, suggesting a more mature zooplankton community due to earlier production in this eddy. Despite these increases, no significant change was seen in the total mass or POC flux.

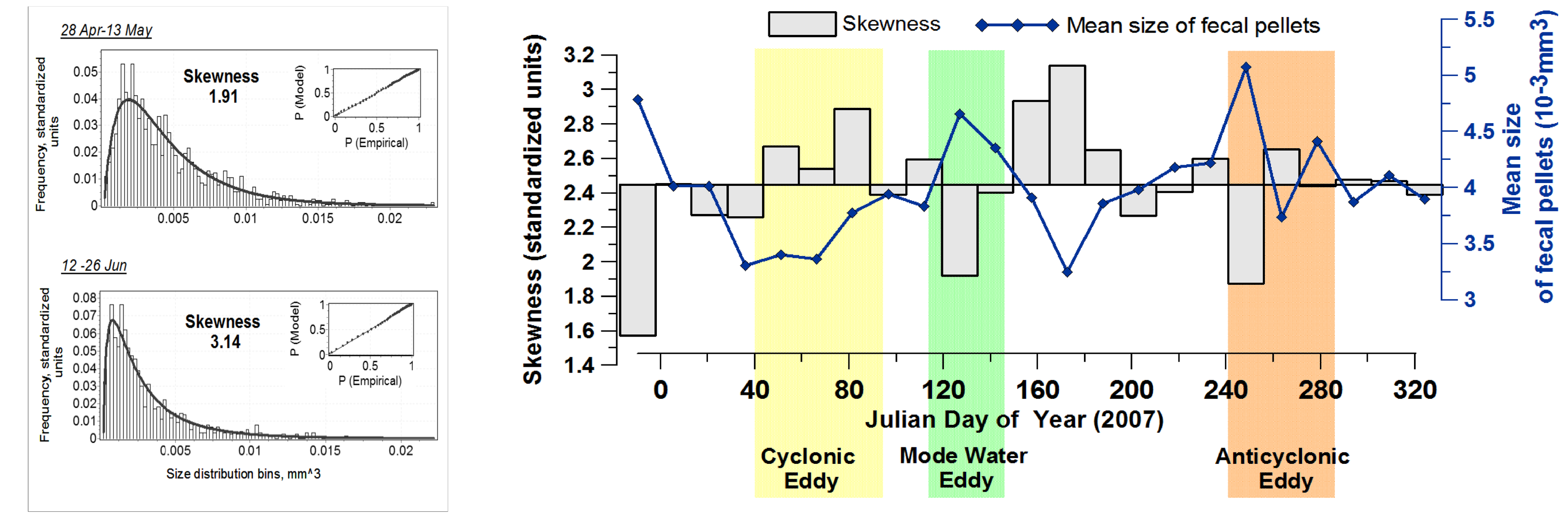
As the edge of the AC eddy passed through, no increase in fecal pellet mass flux was seen, despite indication of increased near surface zooplankton biomass from ADCP backscatter intensity observed on the BTM mooring (Smeti et al., 2011). However, fecal pellet size increased significantly as did fecal pellet percentage of the POC flux.



Cyclonic Eddy **Mode Water Eddy** **Anticyclonic Eddy**

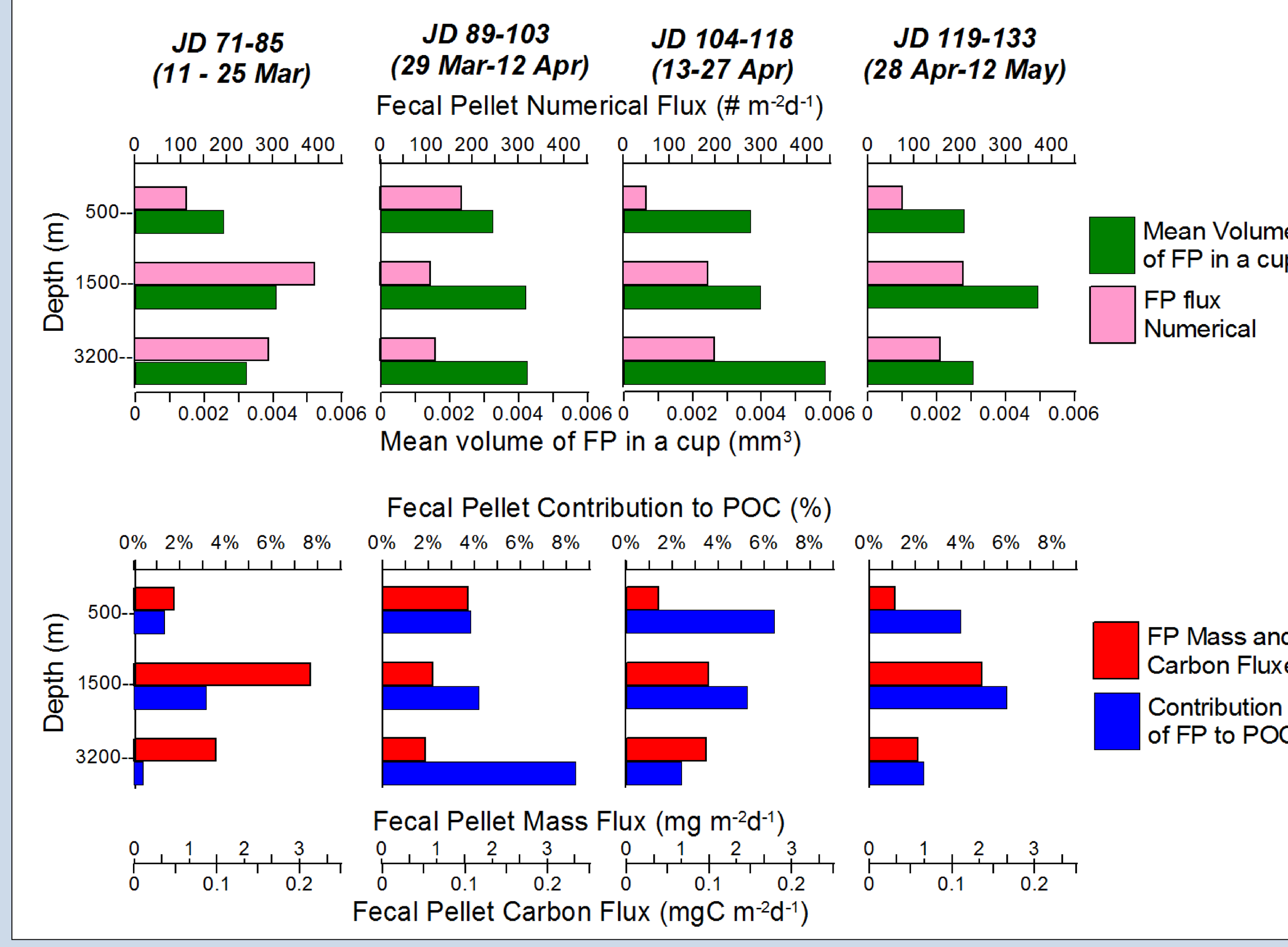
Maps of Sea Level Anomaly (SLA) from TOPEX satellite data for time periods in 2007 when mesoscale eddies passed through the vicinity of OFP site (SLA data products from Colorado Center of Astrodynamics Research). The star indicates the location of the OFP mooring (31°50'N, 64°10'W). Images chosen represent closest passage of the respective eddies over the OFP mooring.

FECAL PELLET SIZE DISTRIBUTIONS



Temporal variability in size frequency distribution parameters of fecal pellet flux at 1500m depth: Size frequency distributions of the fecal pellets were modeled using a 4-parameter gamma probability distribution function. The size frequency distributions shown at left illustrate the relationship between the skewness parameter of the model distribution and fecal pellet size distributions. Smaller mean size and increased skewness of the fecal pellet distribution during the cyclonic eddy is indicative of a younger zooplankton population and is consistent with increased secondary production in the eddy. Decreased skewness and greater mean size of the fecal pellets during the passage of the mode water and anticyclonic eddies suggests dominance of larger zooplankton taxa in these eddies. Any seasonal trend in size distribution was overshadowed by the non-seasonal influence of the eddies.

DEPTH VARIABILITY OF FECAL PELLET FLUX



Vertical profiles of fecal pellet flux show no consistent changes with depth. The time period shown spans the transition from C eddy to M eddy influence. The absence of any systematic trends in fecal pellet flux or size distribution provides evidence for a dynamic deep-sea environment where high turnover and *in-situ* grazing control fecal pellet flux and composition within the water column.

CONCLUSIONS

- **Intact** fecal pellets are a small contribution to mesopelagic POC flux (3-12%).
- Non-seasonal mesoscale physical forcing significantly outweighs the effects of the seasonal cycle on mesopelagic particle flux.
- Fecal pellet size distributions are continuous and strongly skewed. Changes in the distribution reflect changes in production and processing in the water column.
- No apparent depth trends in fecal pellet flux or size distribution indicate a dynamic deep-sea environment and rapid turnover of the fecal pellet pool.
- Quantitative image analysis of digital microphotography is a new, valuable, non-destructive method to understand particle flux dynamics and holds great potential for future studies.

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