

“SECONDHAND” MOSSFA IN THE DEEP GULF OF MEXICO – A SMOKING GUN



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Crew of the Point Sur



Firsthand MOSSFA ~May 2010

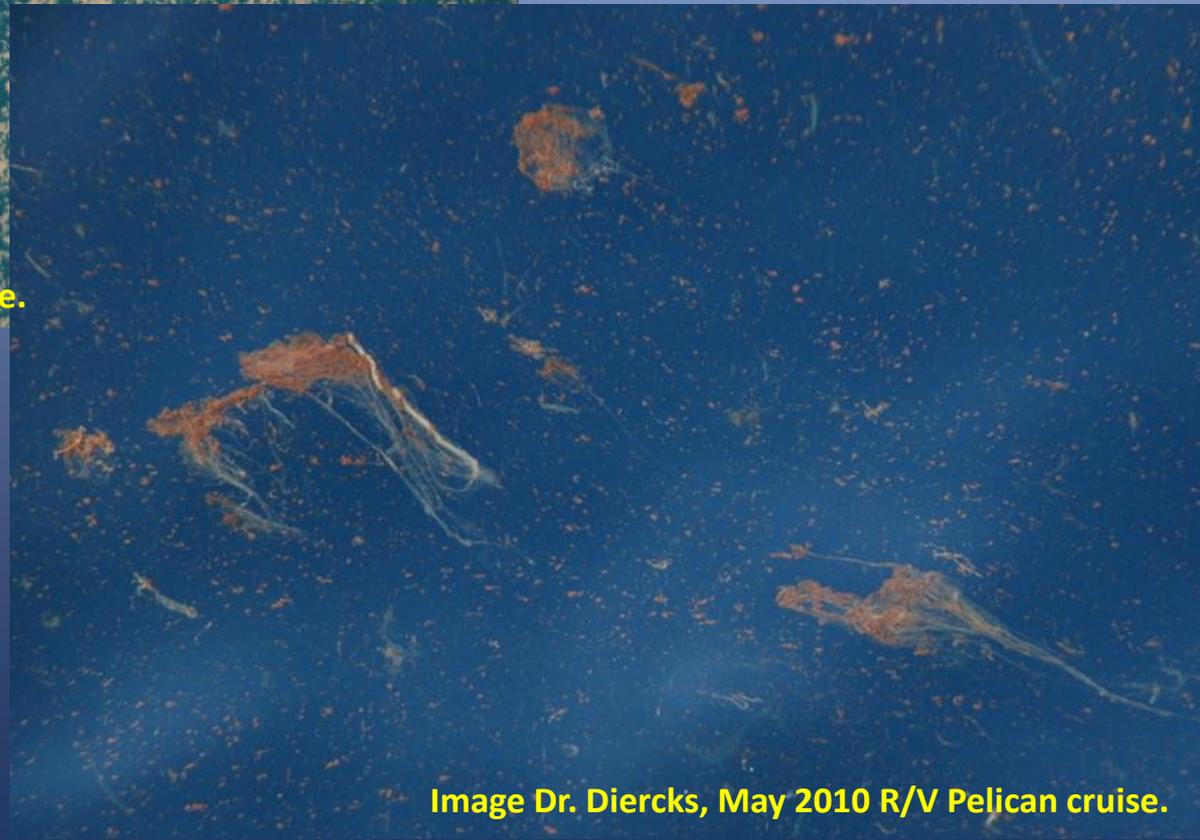


Image Dr. Diercks, May 2010 R/V Pelican cruise.

MOSSFA

Marine

Oil

Snow

Sedimentation and

Flocculent

Accumulation

Image Dr. Diercks, May 2010 R/V Pelican cruise.

2013 MOSSFA WORKSHOP

Hydrography and its Implication to Resuspension of Sediments in the Northern Gulf of Mexico

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- 1) Can we find these oil deposits along the 800 – 1,200m isobath? (“Dirty Bathup”)
- 2) Can these sediments be re-suspended?
- 3) Where will this material end up, if it is re-suspended?



Above: Bathymetry from NOAA vessel Okeanos Explorer (50m/px) and additional data from the General Bathymetric Chart of the Oceans (GEBCO; <http://www.gebco.net/>) at 3 arc sec / pixel. Yellow lines indicate modeled drainage pathways. Red square shows the location of the Eagle Ray AUV survey near the Macondo Wellhead. Within ECOGIG this site is called OC26. It is located in BOEM D1 and Gas Lease Block Mississippi Canyon 297.



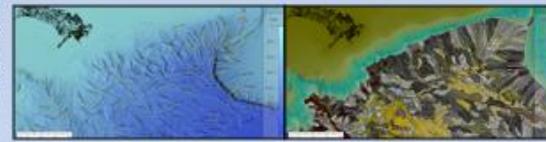
Above: Bathymetry from NOAA vessel Okeanos Explorer (50m/px) and the General Bathymetric Chart of the Oceans (GEBCO; <http://www.gebco.net/>) (3 arc sec/px). Yellow lines are modeled drainage paths and depend strongly on the resolution of the available bathymetry for flow prediction. Red star indicates position of the Macondo Deepwater Horizon Wellhead. The dark horizon indicates the “dirty bathtub ring”, suggested as potential zone for deposition of oily sediments originating from the deep hydrocarbon rich plumes. In this map the center of the “Dirty Bathub Ring” is set at -1,000m extending up and down 200m. This range was chosen based on the CTD data obtained during the 2010 R/V Pelican cruise. Note, that this ring is not an indication that the oily snow from the deep plumes actually was deposited at these sites, but strictly a graphical aid to show the potential interception of these plumes with the continental slope if the material staid at the depth and was transported laterally.



Overview map of ECOGIG main study sites. Bathymetry based on GEBCO data. Macondo Wellhead is not pictured as it is too close to site OC26 for proper presentation.



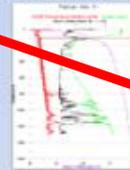
Top: High resolution Bathymetry created from data the NIUST AUV Eagle Ray (ER) collected using its EM2000 MBES while flying 50m above the local terrain. Individual survey lines can be identified as parallel lines running SW-NE in the image. Line spacing is approximately 175m. MBES data collected from this close to the terrain produce data at a resolution of 1m or less per pixel. In the western corner of the ER multibeam survey, star marks (red arrows) are visible that follow the yellow lines, which indicate the modified drainage pathways.



Top: Drainage paths modeled after terrain. Numbers Top: Coverage of individual areas that drain into the are giving an estimate of the amount of area each of modified pathways. Color is an indication of areal these pathways is draining.



Top: Bathymetry obtained from NOAA vessel Okeanos Explorer (OE) using their EM302 MBES. (25 to 50 m per pixel). Yellow lines indicate modeled drainage pathways, using a watershed analysis of the OE bathymetry. Data from the EM302, is the highest resolution bathymetry data we currently have that covers a large continuous area around the well head.



The hypothesis of having a “bathtub ring” of oil snow deposit being deposited after the oil spill, without leads to some very interesting questions. If we are trying to understand the final fate of the oil on the seafloor

- 1) Can we find these oil deposits along the 800 – 1200m isobath?
- 2) Can these sediments be re-suspended?
- 3) Where will this material end up, if it is re-suspended ?

Answers:
 1) Yes we do find these layers in some of the CTD profiles.
 2) Resuspension experiments are being done by Ziervogel to measure the necessary shear stress generated by currents to mobilize these oily sediments. Results of this work are being presented in a different poster and are promising to explain resuspension events noticed in camera and sediment trap data presented in additional posters at this meeting.
 3) A very simple approach to take a look at impacts of advection is to use the information about the seafloor terrain we have. Using bathymetric datasets from GEBCO and most recently NOAA Okeanos Explorer and Eagle Ray multi-beam echo sounder data, a watershed analysis offers some insight into the fate of potentially re-suspended material.

Top: One of several CTD Profiles taken during the first research cruise on site of the Macondo spill. In May 2010, CTD profiles taken on the R/V Pelican near the wreck site indicated a subsurface plume of increased CDOM fluorescence, increased beam attenuation and decreased oxygen concentration.

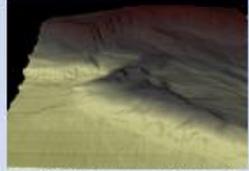


Top: Oil snow observed at the spill site on 5/11/2010. For size comparison note the Portuguese Man-of-War in the center of the image. This is not the kind of oil snow that is part of the Bathub Ring.

A watershed analysis provides information as to how much area is drained into which direction by simple gravity flow based on the local terrain. The information this analysis provides can be used for selecting future sampling sites. Areas of main flow, the yellow lines in the above figure, are erosional valleys and transport material along the main flow lines. Hiatuses within the directional flow lines can have two reasons, not enough data at high enough resolution, or the terrain shallows out for long enough that the parameters to induce a flow in the watershed analysis are no longer valid. Areas with no or very little slope, or geographical traps, areas where there simply is no drainage and thus pooling of material might occur with no immediate erosion by bottom flow can be detected this way as well. Regions with high flows of bottom water leaving visible scouring marks on the ocean floor could explain thinner layers of oily sediment even closer to the spill site. See the small figure on the left column showing ER high resolution MBES data with track scouring marks observed around OC26.



Top: 3D- view of the area of interest in the deep Gulf of Mexico looking north. Note the “Codew Mound” in the picture and locate it on the large map to reference the view. This 3D view illustrates the morphology of the area to show how the area is sloped towards the East furnishing the deep water flow towards the eastern side of the abyssal Gulf of Mexico.



Top: GEBCO bathymetry with Bathub Ring interception of seafloor indicated by darker colors. Bathymetry Data acquired by Eagle Ray AUV.



Top: Marine Snow Camera image taken on the Walton Smith Cruise in 2010 showing the marine snow blizzard at the depth of the plume. See additional posters by Asper and Dike.

“SECONDHAND” MOSSFA

- What is “secondhand” MOSSFA? (**re**-suspended – **re**-distributed – **re**-deposited)
- How do we know we have secondhand MOSSFA?
- How do we differentiate between primary flux and secondhand flux in our data?
- Lateral Transport of resuspended MOSSFA.
- Secondary deposition and potential effects on benthic communities.

**What is “secondhand MOSSSFA”?
resuspended – redistributed – redeposited
snow aggregates
Resuspension, Nepheloid Layers**

Images: Dr. Diercks, 2016, Marine Snow Profiling Camera System

Normal Marine Snow Image

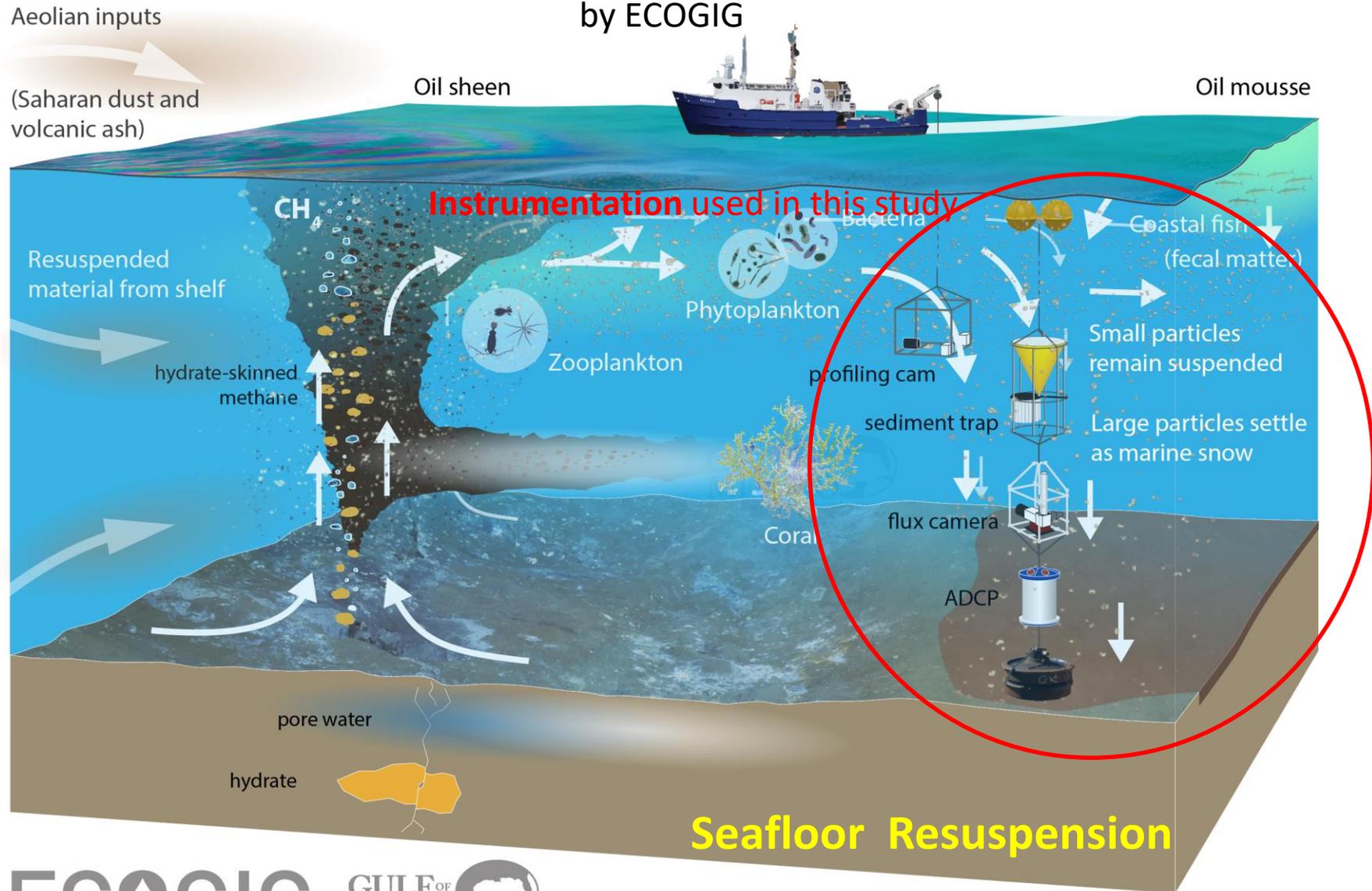


Time between images 6 seconds. Camera frame set down on the seafloor, due to pinger malfunction.



Marine Snow, Oiled Marine Aggregates (OMA), and Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA)

Early conceptual diagram to explain deep sea processes associated with the oil Spill, developed by ECOGIG



How do we know we have “secondhand” Flux?

We look at data from: Time Series Sediment Traps
 Flux and Profiling Marine Snow Cameras
 Current Measurements (ADCP & Current Meters)

Flux specific data from two stacked time series sediment traps were combined with size-specific in-situ settling speeds of settling aggregates obtained by moored flux cameras, particle size distributions from a lowered profiling camera, current speed and directions from moored current meters were combined with to identify resuspension events of different scales and magnitudes in the deep Gulf of Mexico.

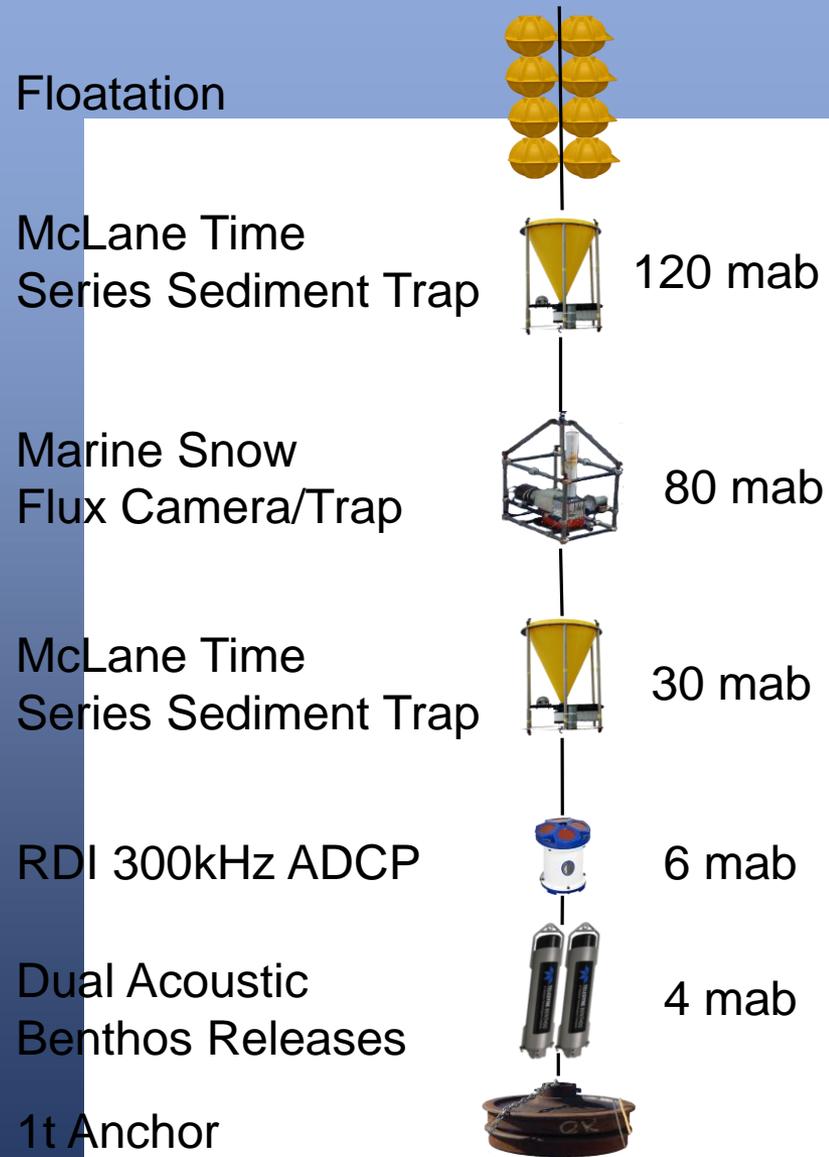
We defined three categories of deep (> 1,000 m) resuspension :

Small-scale-local events

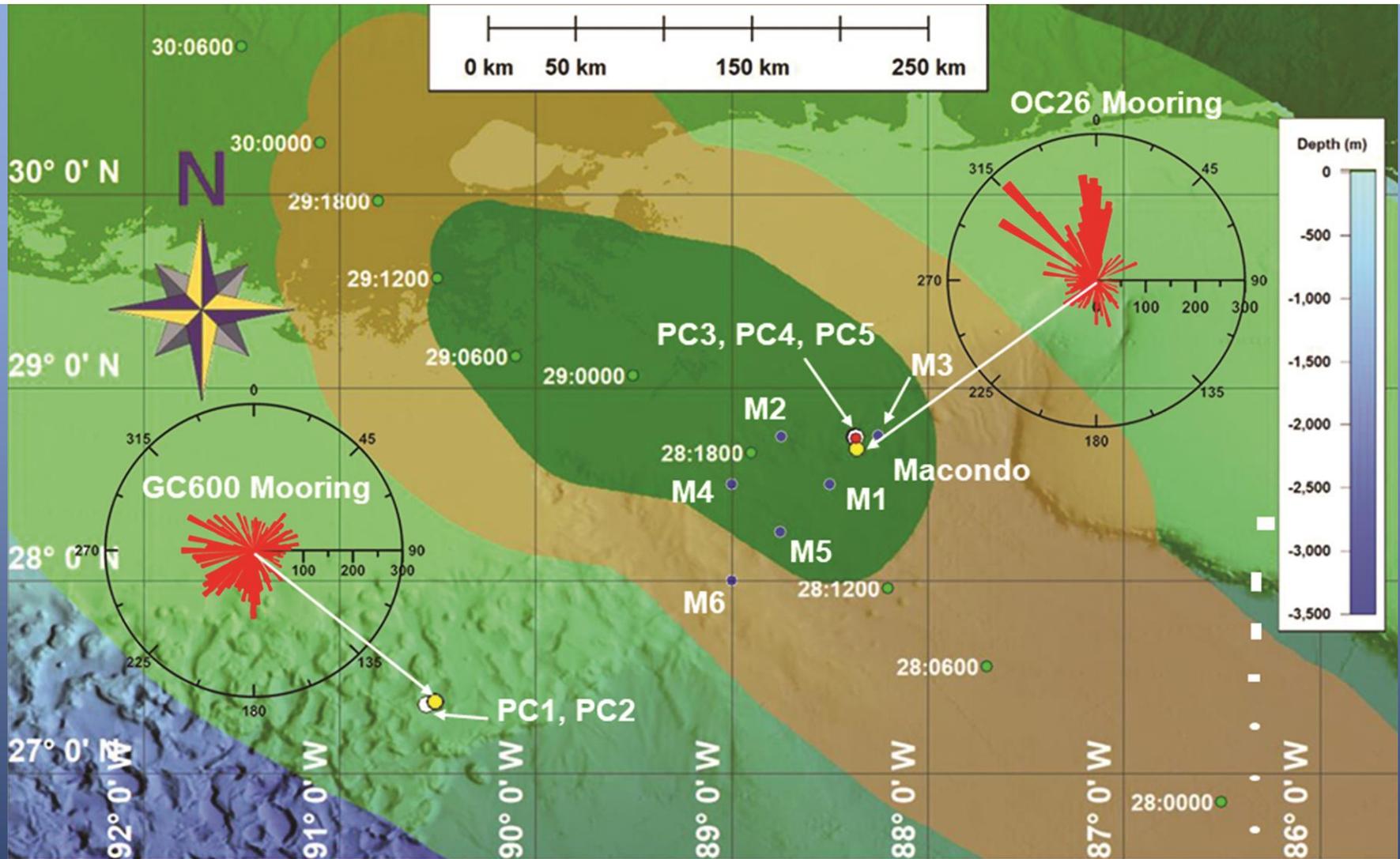
Small-scale-far-field events

Large or hurricane-scale events

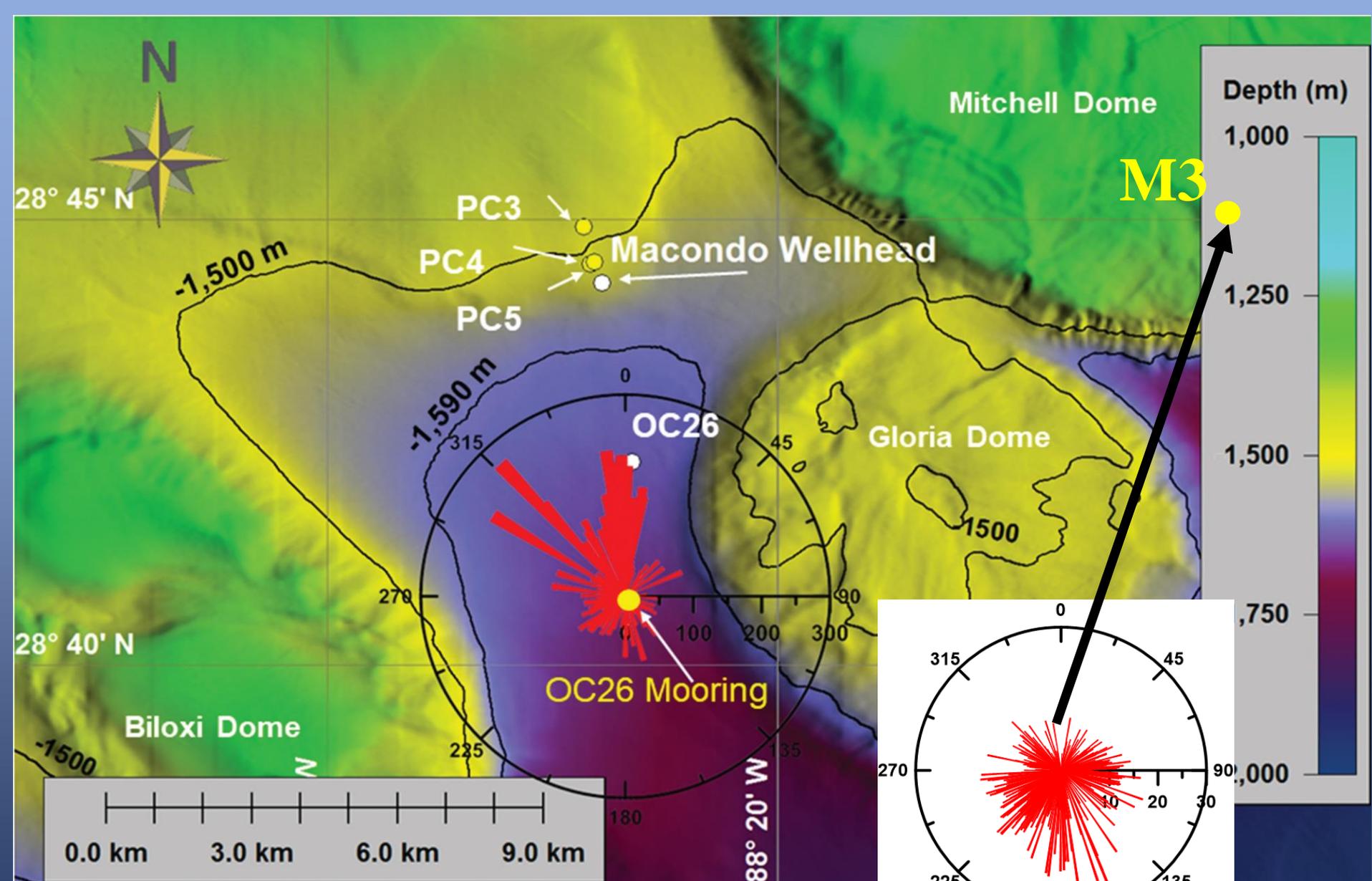
Time Series Sediment Trap mooring array with Flux camera and RDI ADCP



Mooring designed and operated
by the ECOGIG consortium



White dots indicate locations of profiling camera casts PC1 to PC5. Yellow dots indicate locations of sediment trap moorings. Red dot indicates the location of the *Macondo* wellhead. Brown area indicates Hurricane Isaac wind swath with wind speeds > 64 mph; brown, wind speeds > 49.33 mph; and light green, wind speeds of. > 39 mph. Locations of the center of the hurricane eye are plotted as green dots with day and time in August of 2012 Blue dots mark the M1 to M6 mooring locations where the Gulf Integrated Spill Research (GISR) consortium deployed single-point current meters. Polar diagrams depict ADCP current measurements from the sediment trap moorings from 25 August 2012 to 15 September 2012, the passage of Hurricane Isaac. Currents are plotted with the indicator point from the center in the direction of the flow



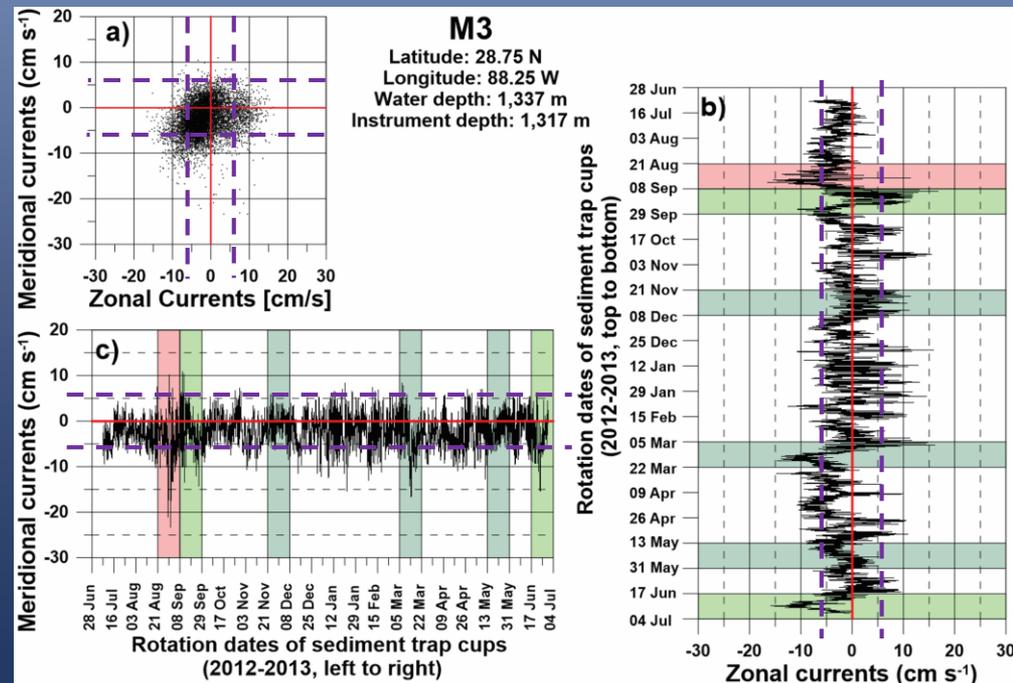
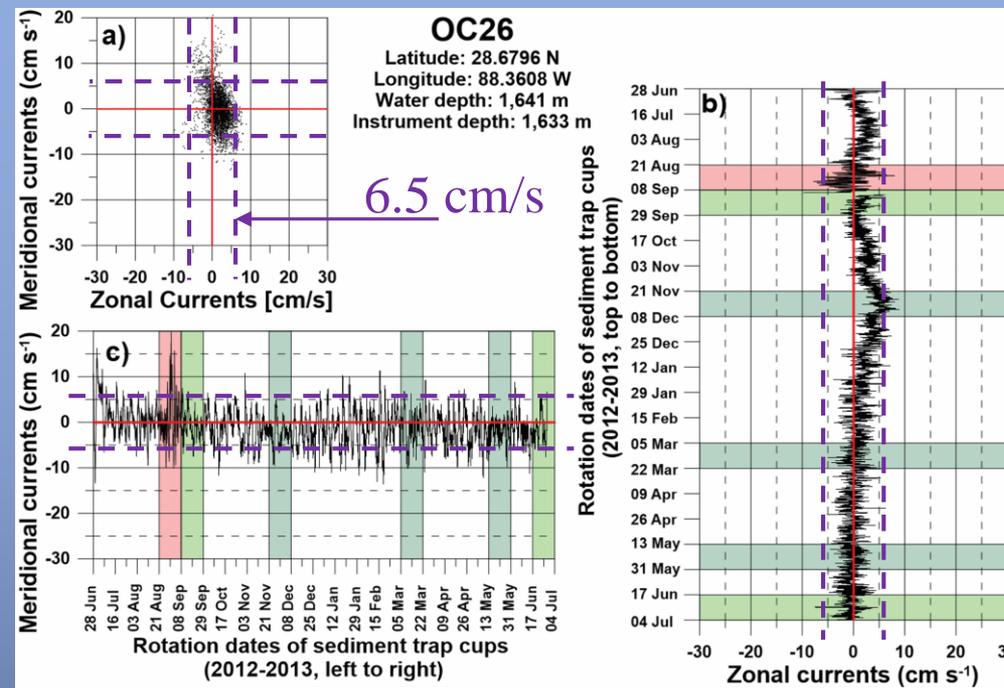
Diercks, A.-R., C. Dike, V.L. Asper, S.F. DiMarco, J.P. Chanton, U. Passow. (2018) Scales of methane seepage from the northern Gulf of Mexico. *Elem Sci Anth.* 2018;6(1):32. DOI: <http://doi.org/10.1525/elementa.285>

Zonal and meridional flow at OC26 and M3

Panel a) presents meridional versus zonal flow at the site from 28 June 2012 to 4 July 2013, covering the sediment trap deployment period.

Panel b) displays the hourly meridional flow of the measured currents

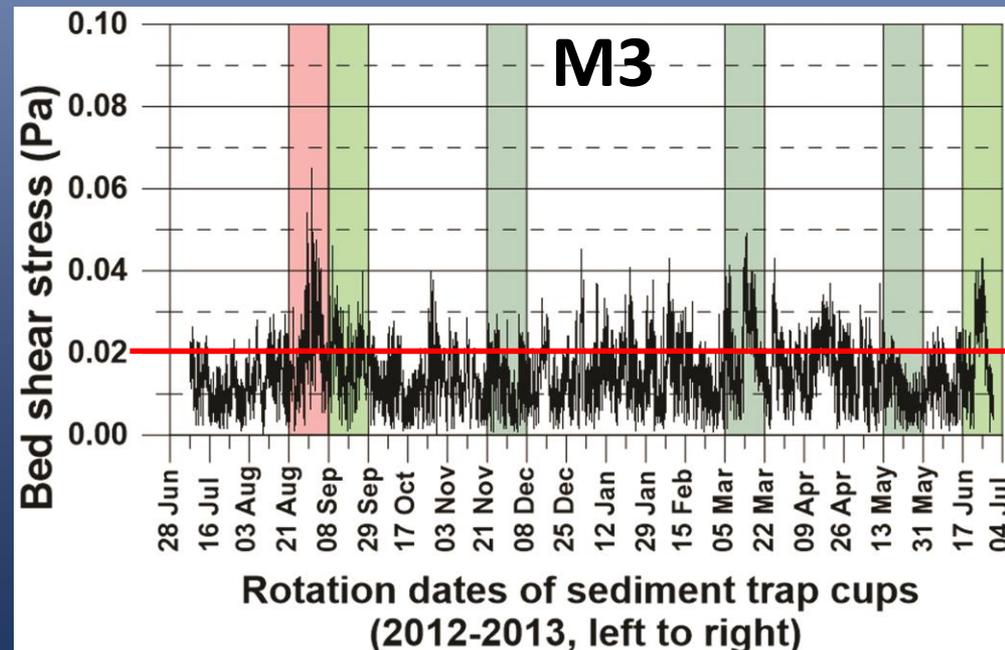
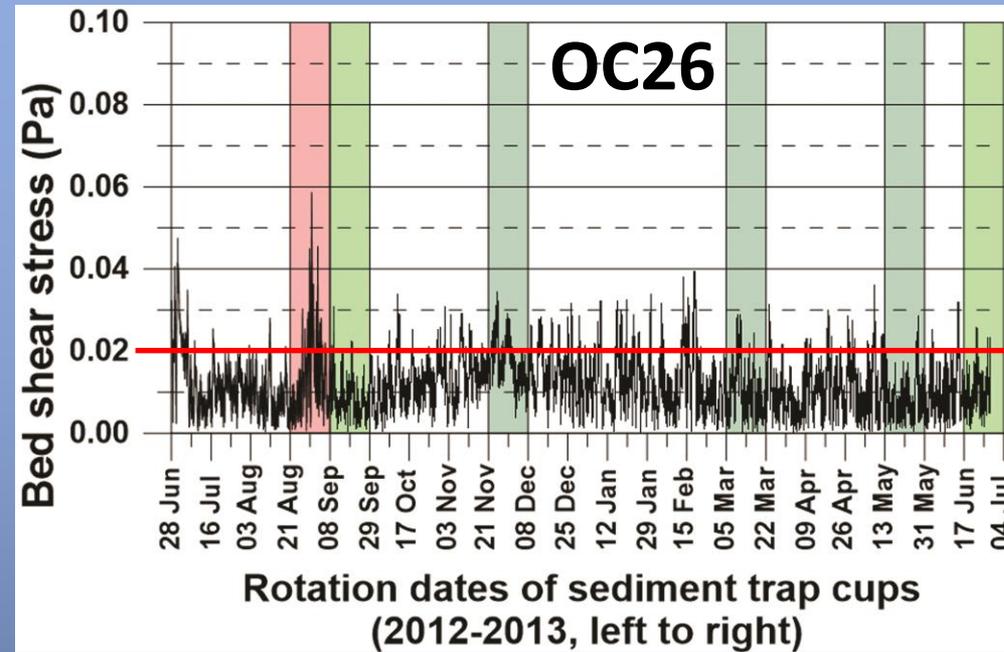
Panel c), the zonal currents.



- Time intervals are marked corresponding to the trap schedule.
- Red = large-scale resuspension
- Light green = small-scale near field resuspension
- Dark green = small-scale far field resuspension

Bed shear stress at OC26 and M3

Bed shear stress was calculated using actual current measurements, kinematic viscosity of seawater at 4°C, and the height of the single point current meter above the seafloor (20 mab) at M3 and the height of the first bin of the ADCP measurement (18 mab) at OC26



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Large or hurricane-scale events

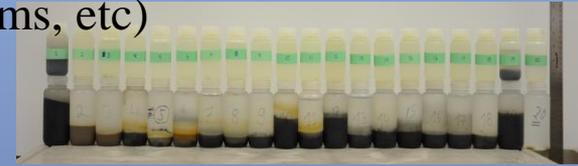
Diercks, A.-R., C. Dike, V.L. Asper, S.F. DiMarco, J.P. Chanton, U. Passow. (2018)
Scales of seafloor sediment resuspension in the northern Gulf of Mexico.
Elem Sci Anth. 2018;6(1):32. DOI: <http://doi.org/10.1525/elementa.285>

Two types of information from our stacked sediment traps:

1. Individual Cups from each trap give us a time series data set

Individual cups provide time series of total vertical flux over time.

Example: high flux events (spring plankton bloom, storms, etc)
 low flux times are winter months



2. Comparison of cups from the same time between trap will provide information about source of material or mechanism

POC / DW ratio:

High → primary input from surface

Low → resuspended material from seafloor

LSi flux comparison between upper and lower trap

If different → different sources or forcing factors

How do we differentiate between primary flux and secondhand (re-suspended) flux?

Re-suspension events were characterized within sediment trap samples by comparing the POC content against sample dry weight and lithogenic silica (LSi) flux.

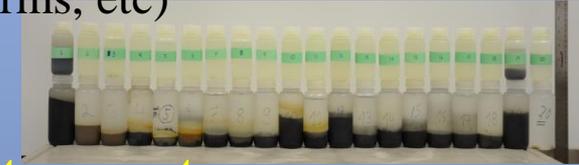
The ratio of POC to Sample Dry Weight was identified as an indicator for material collected in the sediment traps originating from resuspension events.

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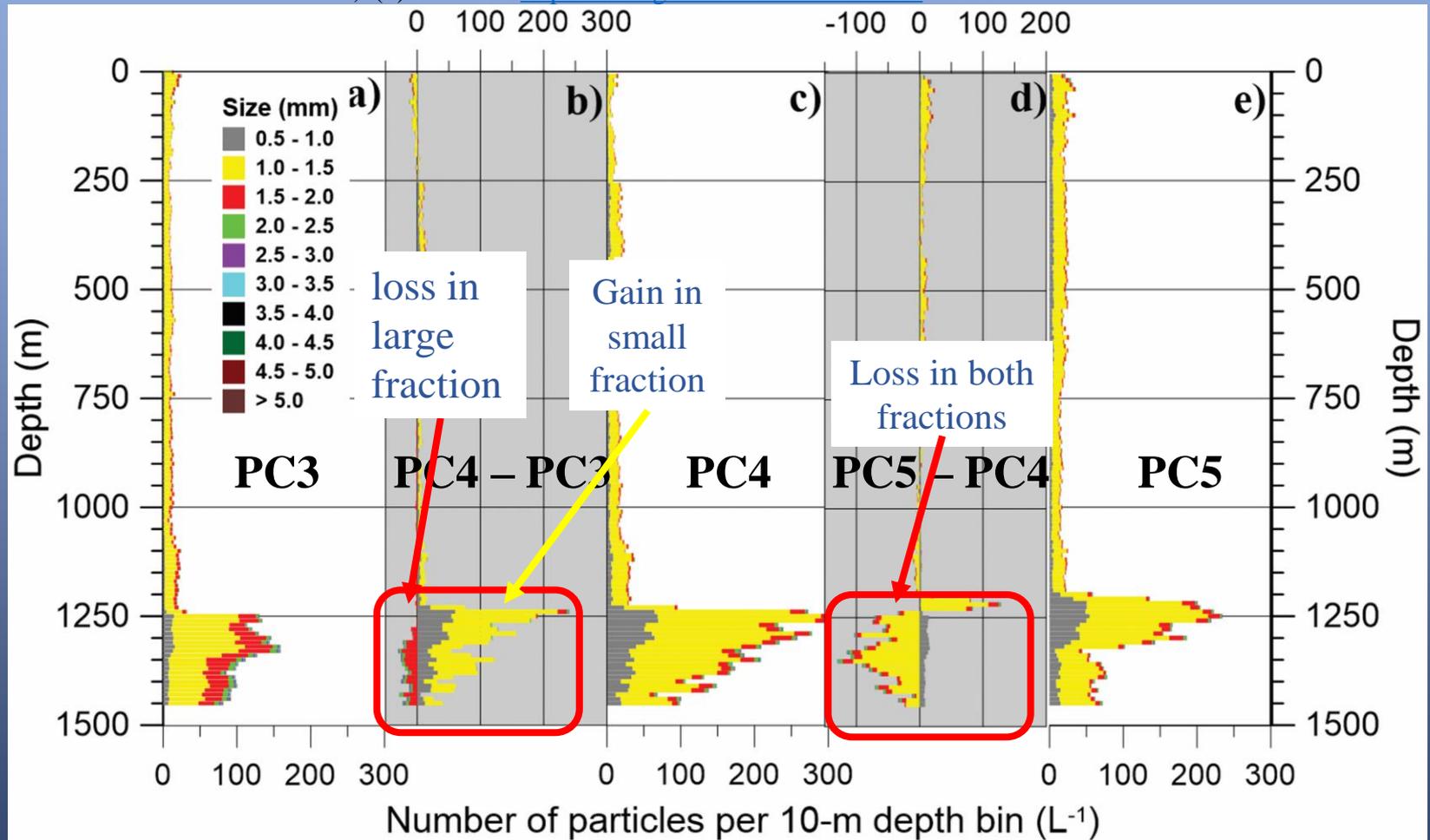
Far-field small scale if only in upper trap

Near field small scale if only lower trap

Large scale if in both traps

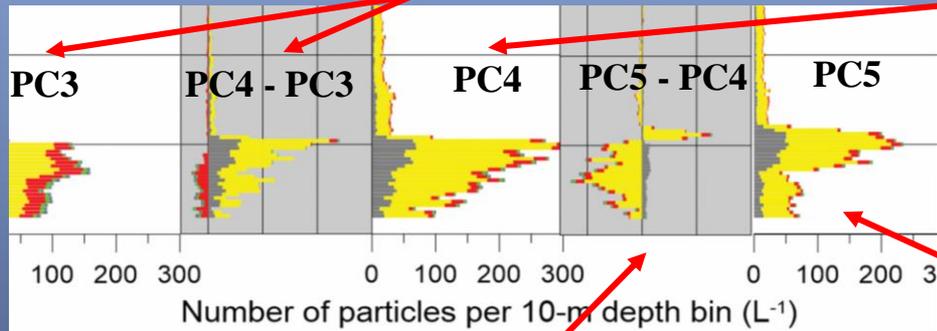
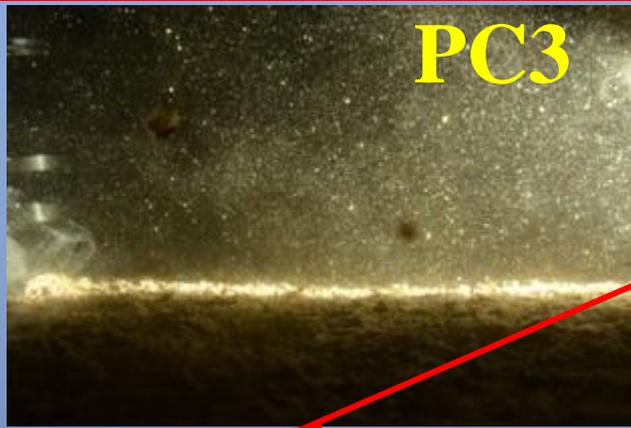
Small Scale Resuspension Event: Particle abundance profiles of PC3 to PC5

Diercks, A.-R., C. Dike, V.L. Asper, S.F. DiMarco, J.P. Chanton, U. Passow. (2018) Scales of seafloor sediment resuspension in the northern Gulf of Mexico. *Elem Sci Anth.* 2018;6(1):32. DOI: <http://doi.org/10.1525/elementa.285>

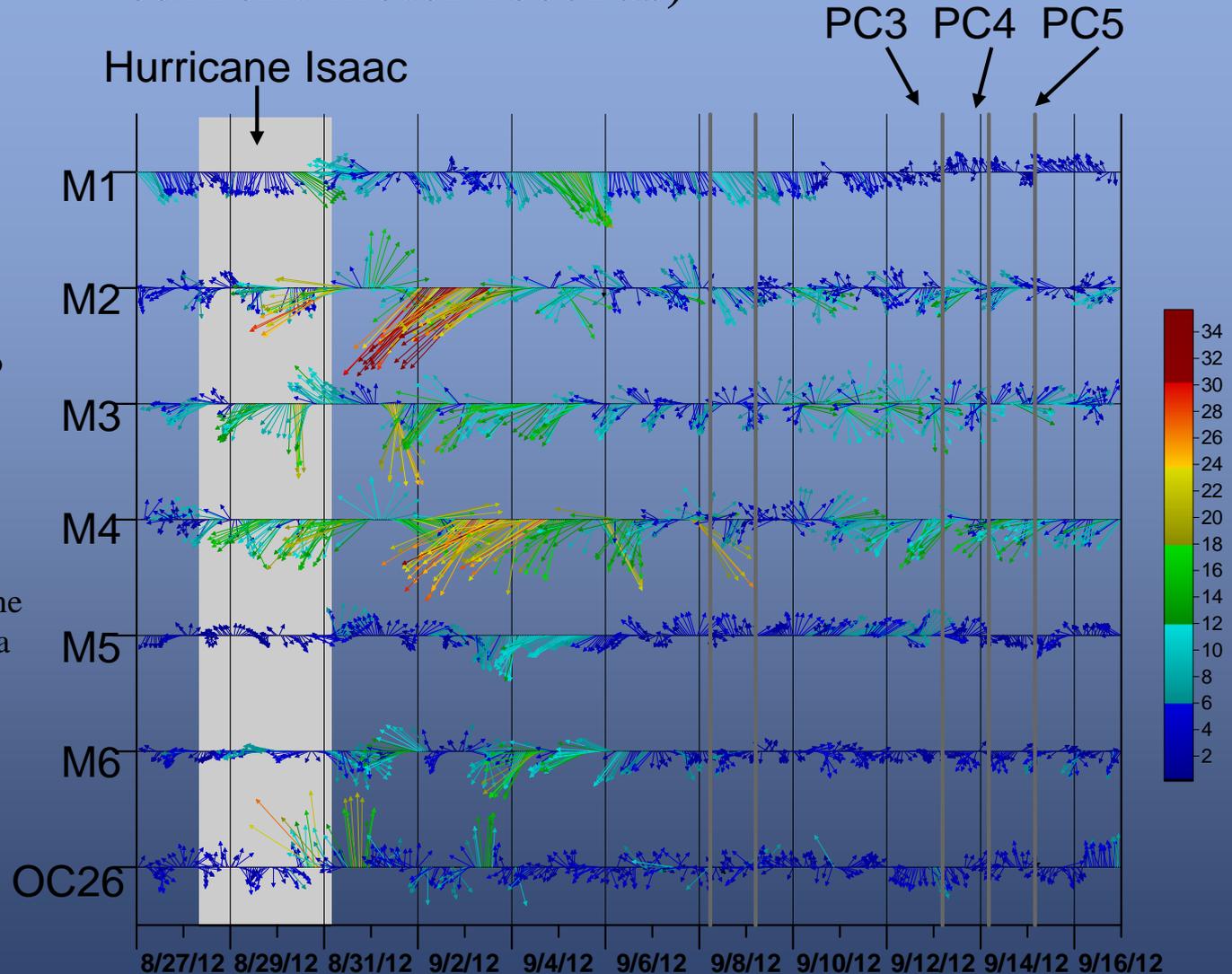


Colored bars present the 10m vertically binned size specific particle concentrations of PC3 (a), PC4 (c) and PC5 (e) and the changes in particle distribution between PC3 and PC4 (panel b), PC4 and PC5 (panel d). Strong changes below 1,300m are visible with an apparent loss of particles >1.5 mm, even though total number of particles had increased. Temperature and salinity data taken during the three casts indicate that no changes in water mass had occurred.

Conceptual model



Lateral Transport (Redistribution, based on seafloor morphology, current meter records)



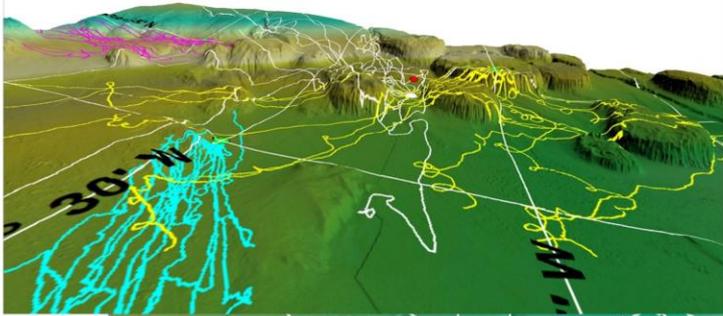
Current vectors at sites M1 to M6 and OC26, 26 August to 16 September 2012. Shaded grey box marks the period when Hurricane Isaac moved across the moorings. Vertical grey bars mark the times of the five different profiling camera casts PC3, PC4 and PC5.

Diercks, A.-R., C. Dike, V.L. Asper, S.F. DiMarco, J.P. Chanton, U. Passow. (2018) Scales of seafloor sediment resuspension in the northern Gulf of Mexico. *Elem Sci Anth.* 2018;6(1):32.

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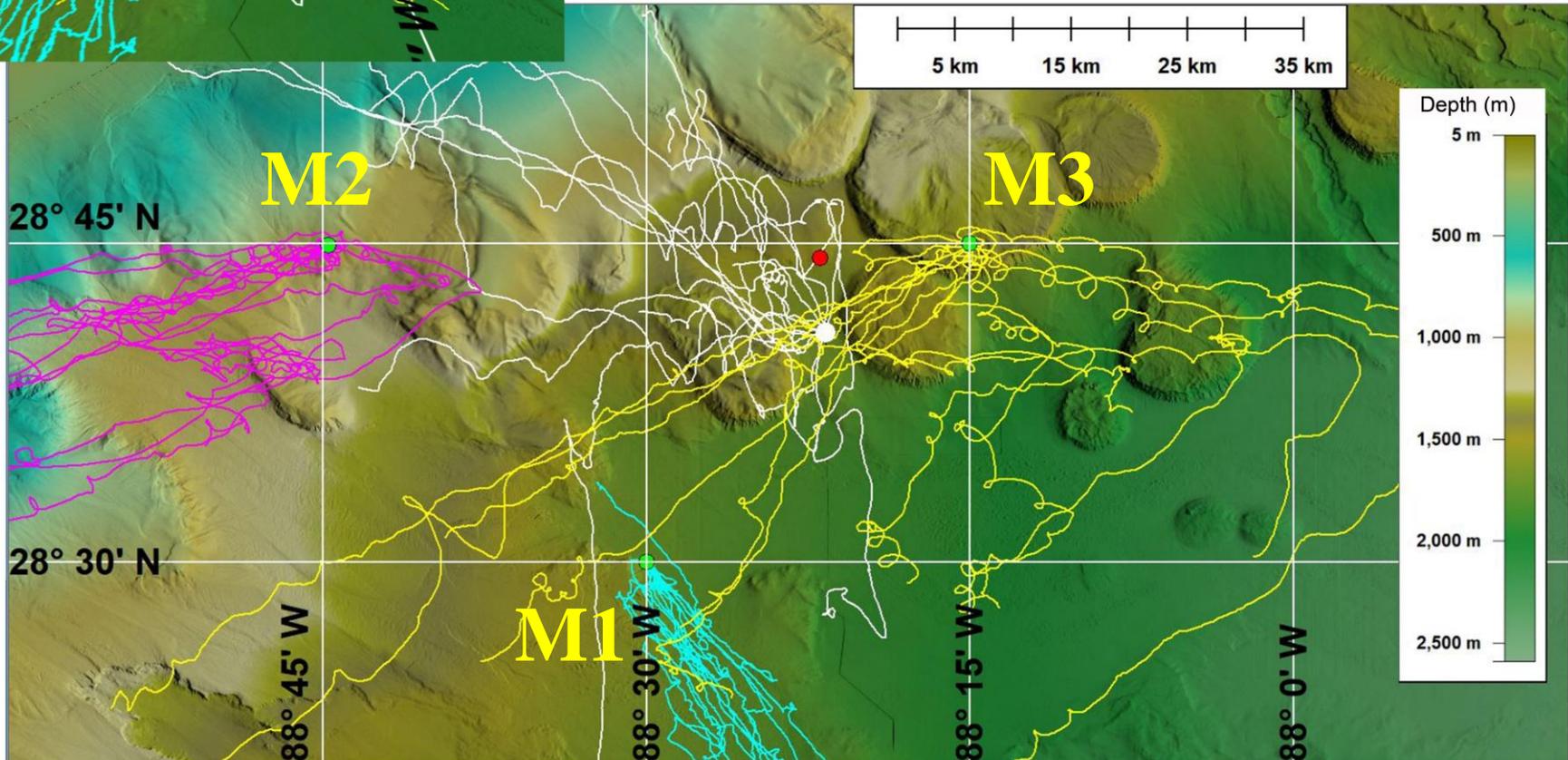
Diagram of seafloor around DWH

3D Block Diagram of seafloor morphology.



Lines represent 18 days of current meter measurements, linked to the length of the sediment trap schedule. Currents are plotted as flow towards the mooring, presenting the flow in relation to the diverse morphology of the area potentially supplying material to the trap.

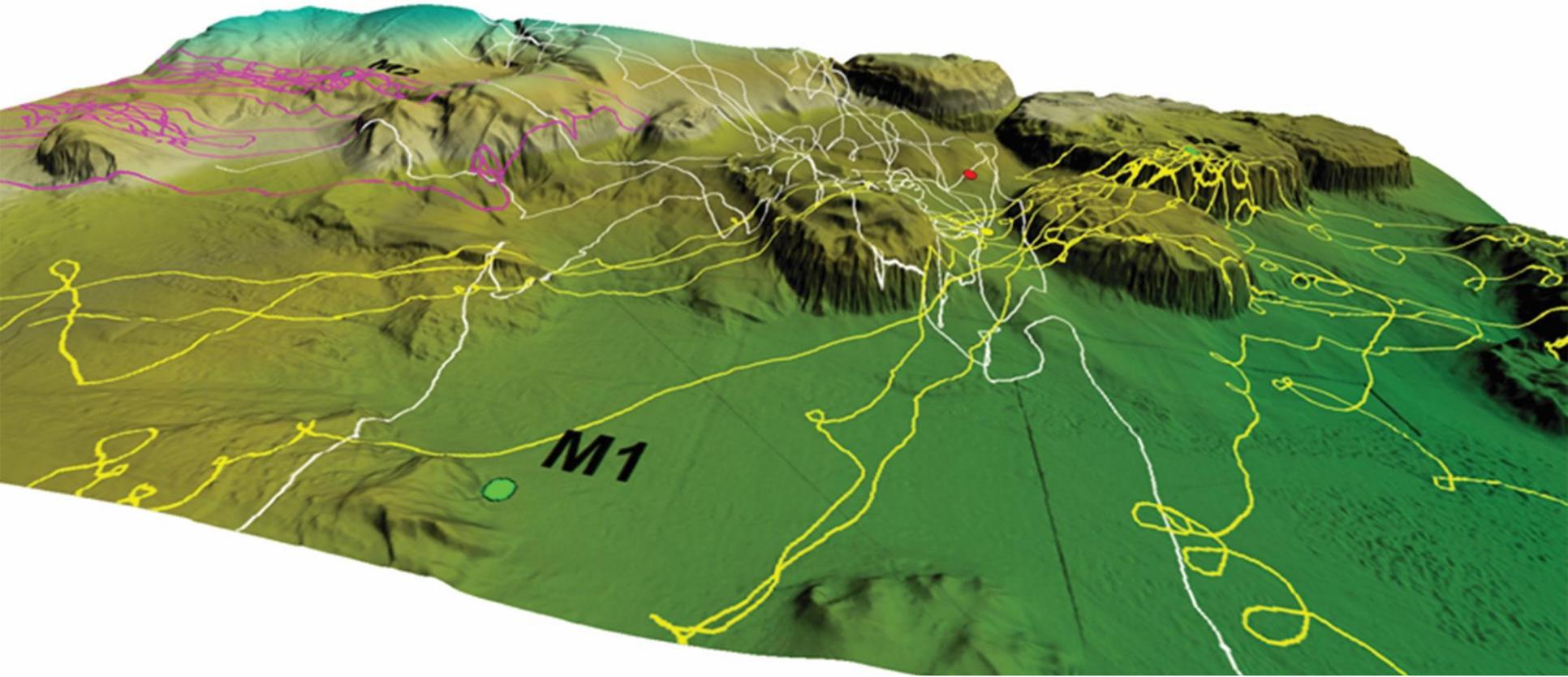
Base map : <https://eos.org/project-updates/a-1-4-billion-pixel-map-of-the-gulf-of-mexico-seafloor>



Diercks et al. (2018) DOI: <http://doi.org/10.1525/elementa.285>

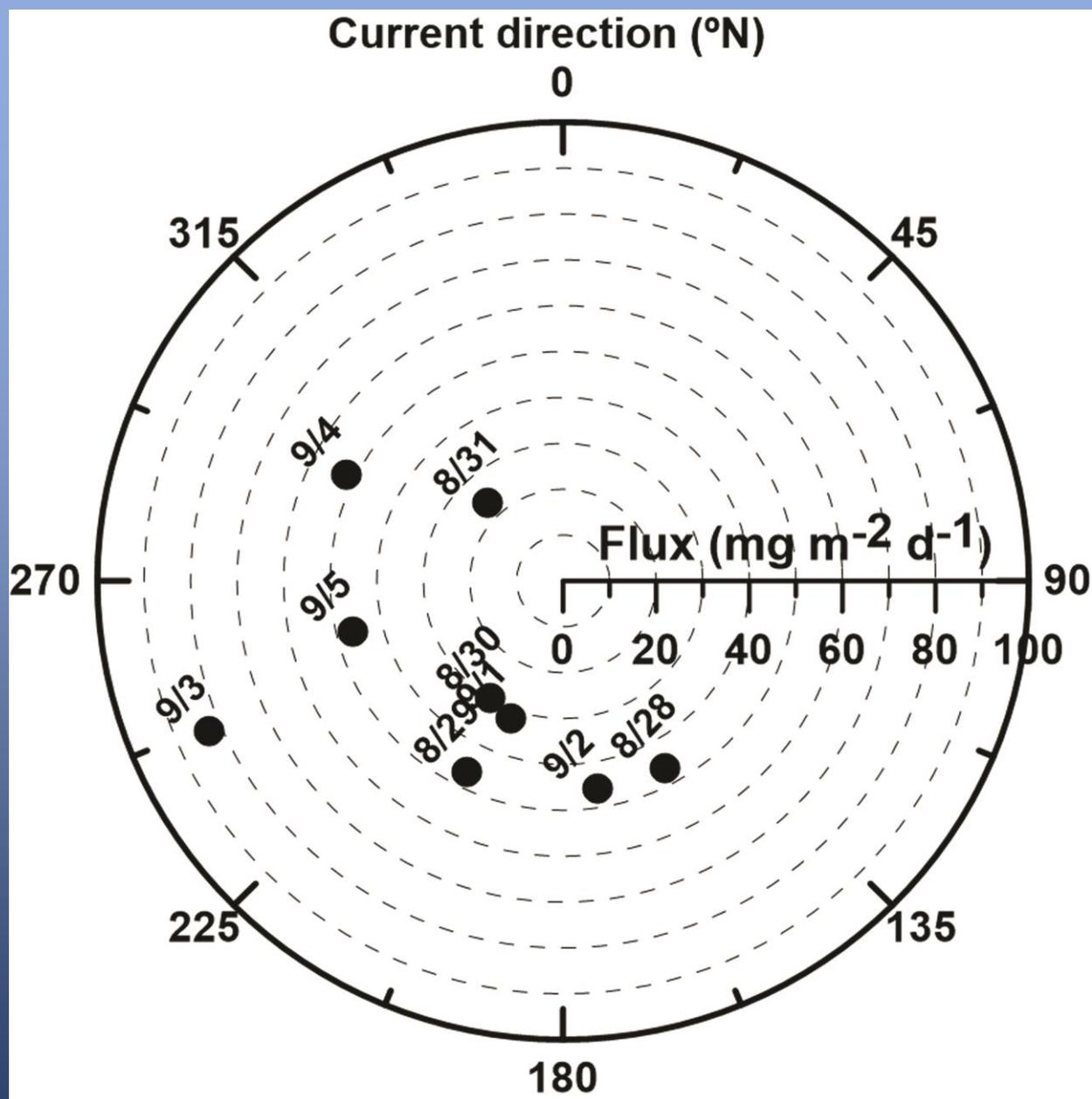
Block Diagram of seafloor around DWH (Red Dot)

Potential source areas for resuspended material collected in a sediment trap



Block Diagram of seafloor topography in the vicinity of Macondo Well with current meter data overlain as vector addition. Presenting the potential source areas for resuspended material collected in a sediment trap and imaged by the flux camera deployed approximately 5 km south of the Macondo well (yellow dot). Lines represent 18 days of current meter measurements. Currents are plotted as flow towards the mooring, presenting the flow in relation to the diverse morphology of the area potentially supplying material to the trap samples.

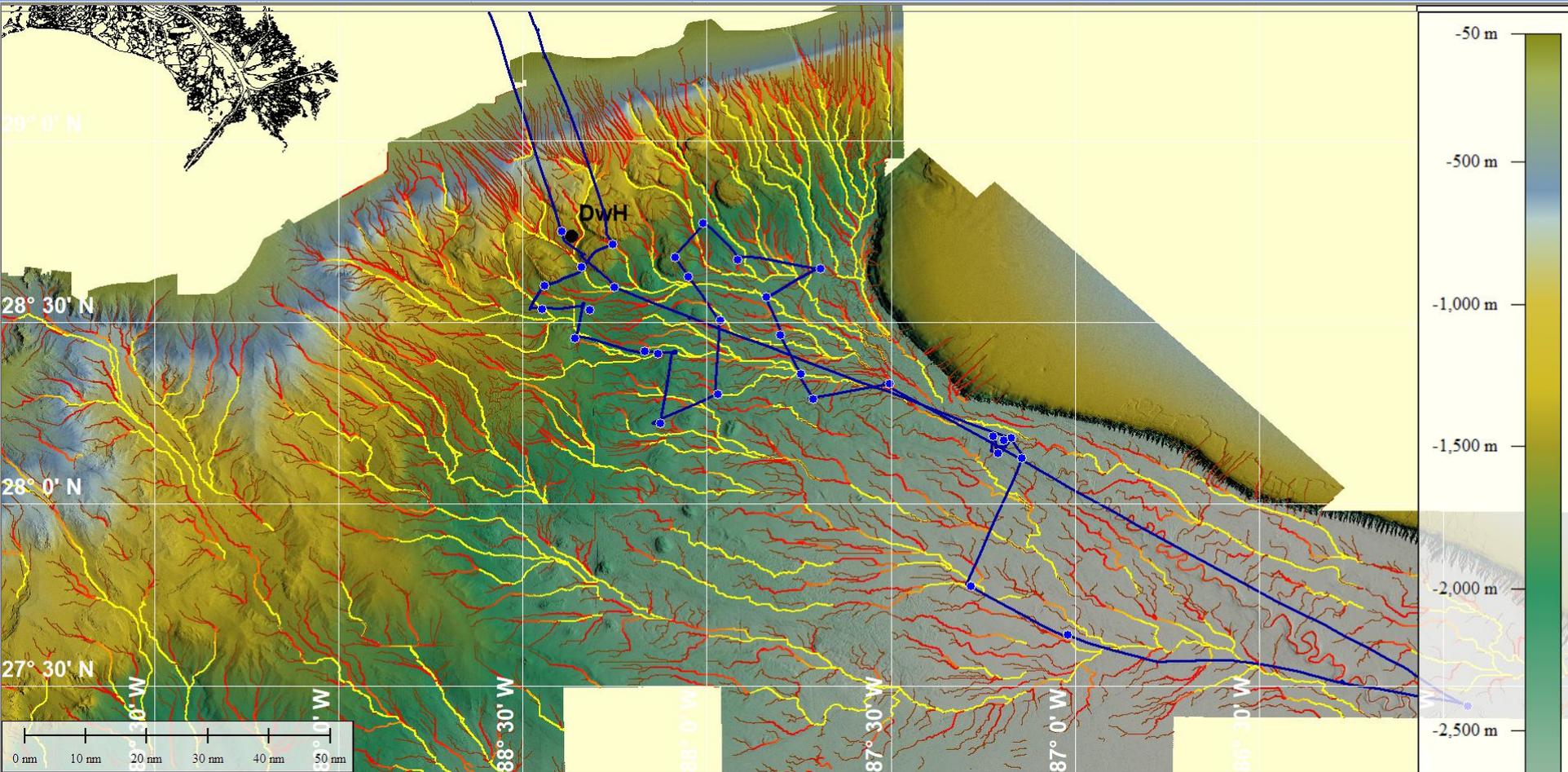
Polar diagram of daily mean particle flux calculated from camera data versus daily mean current direction



Diercks, A.-R., C. Dike, V.L. Asper, S.F. DiMarco, J.P. Chanton, U. Passow. (2018) Scales of seafloor sediment resuspension in the northern Gulf of Mexico. *Elem Sci Anth.* 2018;6(1):32.

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Watershed analyses presenting major drainage pathways, modeled for the GOMRI funded Resuspension, Redistribution and Deposition of DwH Recalcitrant Hydrocarbons to offshore Depocenters project
Diercks (2018, unpublished data)



Base map: Kramer and Shedd: <https://eos.org/project-updates/a-1-4-billion-pixel-map-of-the-gulf-of-mexico-seafloor>.

Summary

We know we have resuspension events that remobilize material from the seafloor in the area of the initial deposition of the MOSSFA event.

We also have data that support the redistribution.

We have indication from an independent study (Charles Fisher's group) that point to a potential secondhand exposure of corals near MC344.

We have a large area of seafloor >87% in our study area, that has small slope gradients and an intricate drainage system that is receiving remobilized material from the high energy slopes in the area of the oil spill.

Too early to say what the final outcome of the redistribution of the secondhand MOSSFA will be, but preliminary data do show that we have redistribution of this material in our core samples collected to the SE of the DwH site.

ACKNOWLEDGEMENTS

- US National Oceanic and Atmospheric Administration - NOAA
- US National Science Foundation - NSF
- We also thank the Captains and crews of the R/V *Pelican*, R/V *Point Sur* and R/V *Endeavor* for all their efforts to make this such a successful trip.
- This research was funded by a grant from the Gulf of Mexico Research Initiative



Questions?