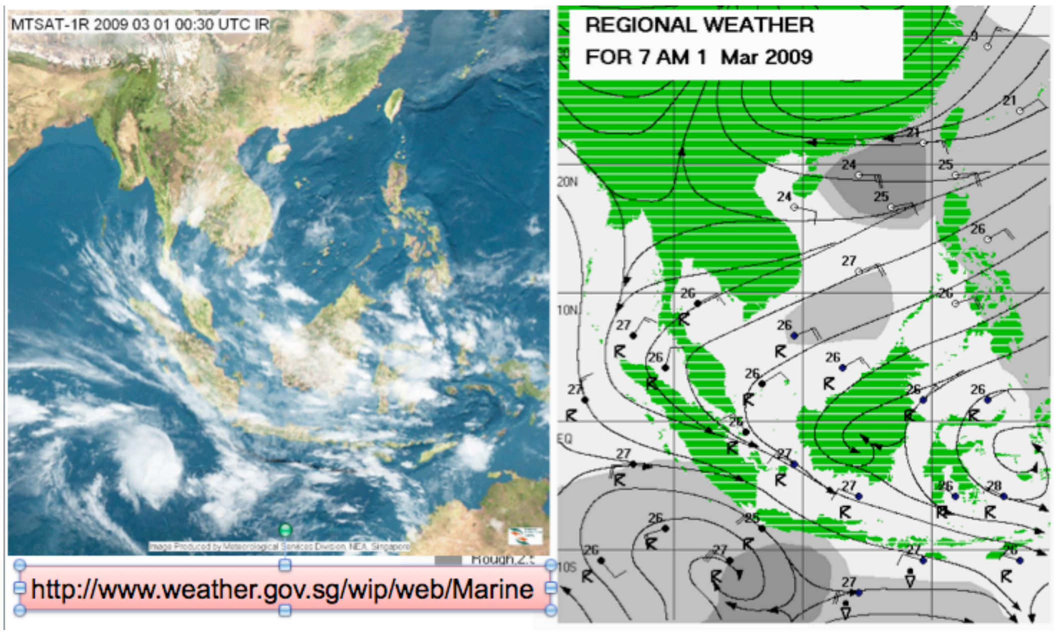
Regional Cruise
Intensive Observational Period 2009
RIOP09
R/V Melville, 27 February – 21 March 2009
Arnold L. Gordon, Chief Scientist
Leg 1 Report
Manila to Dumaguete, 27 Feb to 9 March 2009



Winter monsoon, 2009

I Introduction:

The Regional IOP of 2009 [RIOP09] aboard the R/V Melville began from Manila at 5:30 PM local time on 27 February. We return to Manila on 21 March 2009, with an intermediate port stop for personnel exchange in Dumaguete, Negros, on 9 March. This divides the RIOP09 into 2 legs, with CTD-O2/LADCP/water samples [oxygen, nutrients]; hull ADCP and underway-surface data [met/SSS/SST/Chlorophyll] on both legs, and recovery of 4 PhilEx and 2 Sediment Trap moorings, and possibly an EM-Apex profiler, on leg 2.

The general objective of RIOP09, as with the previous regional cruises is to provide a view of the stratification and circulation of the Philippine seas under varied monsoon condition, as required to support of PhilEx DRI goals directed at ocean dynamics within straits, mostly directed at oceanic mesoscale and sub-mesoscale features.

RIOP09 will investigate the 2009 late winter monsoon conditions, more specifically:

• to reoccupy select CTD/LADCP [Conductivity-temperature-pressure/lowered acoustical Doppler profiler] stations of the prior PhilEx regional cruises [Exploratory Cruise of June 2007; Joint cruise of Nov/Dec 2007; RIOP08 of January 2008] so as to allow for comparison of the winter monsoon to the summer monsoon conditions, and of early/mid-winter monsoon of 2007/2008 to the late winter monsoon of 2009;

• To 'check out' features in the circulation and stratification suggested by model output and remote observations gathered from the PhilEx HF Radar facility on Panay and from satellite derived data products;

• To extend the regional coverage:

§ Leg 1: into the western Pacific adjacent to San Bernardino and Surigao Straits to improve our understanding of the Pacific inflow within these shallow, very tidally active passages, linking the Philippine seas directly to the western boundary regime of the Pacific Ocean.

§ Leg 2: into the southwestern Sulu Sea, to get a sense of the Sulu gyre's equatorial limb and of its eddy field; to evaluate deep-sea ventilating flow through the Sibutu Strait of the Sulu Archipelago; to record the passage of Sulu solitons [noting that we will be in the southern Sulu Sea ~12 March, full moon, when solitons are expected to be large].

II PhilEx

The complexities of the flow within the network of straits and seas composing Philippine waters, subjected to monsoonal seasonal forcing at the sea-air interface, and strong tidal conditions, cannot fully be captured solely by the snapshot views afforded by CTD/LADCP stations and underway data obtained from the ship. But when combined with time series observations from instrumented placed at key sites, from freely moving instrument packages that profile the water column, with remote observations from land based and from earth orbiting satellite; with output from an array of models, and sophisticated ship towed vehicles that obtain high horizontal resolution of sub-mesoscale features, a fuller picture of the Philippine seas oceanography emerges. The PhilEx program components are displayed in Figure 1; description of PhilEx objectives and tools and much more are provided at PhilEx WIKI web site[1].

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[1] http://www.satlab.hawaii.edu/onr/mindoro/wiki/index

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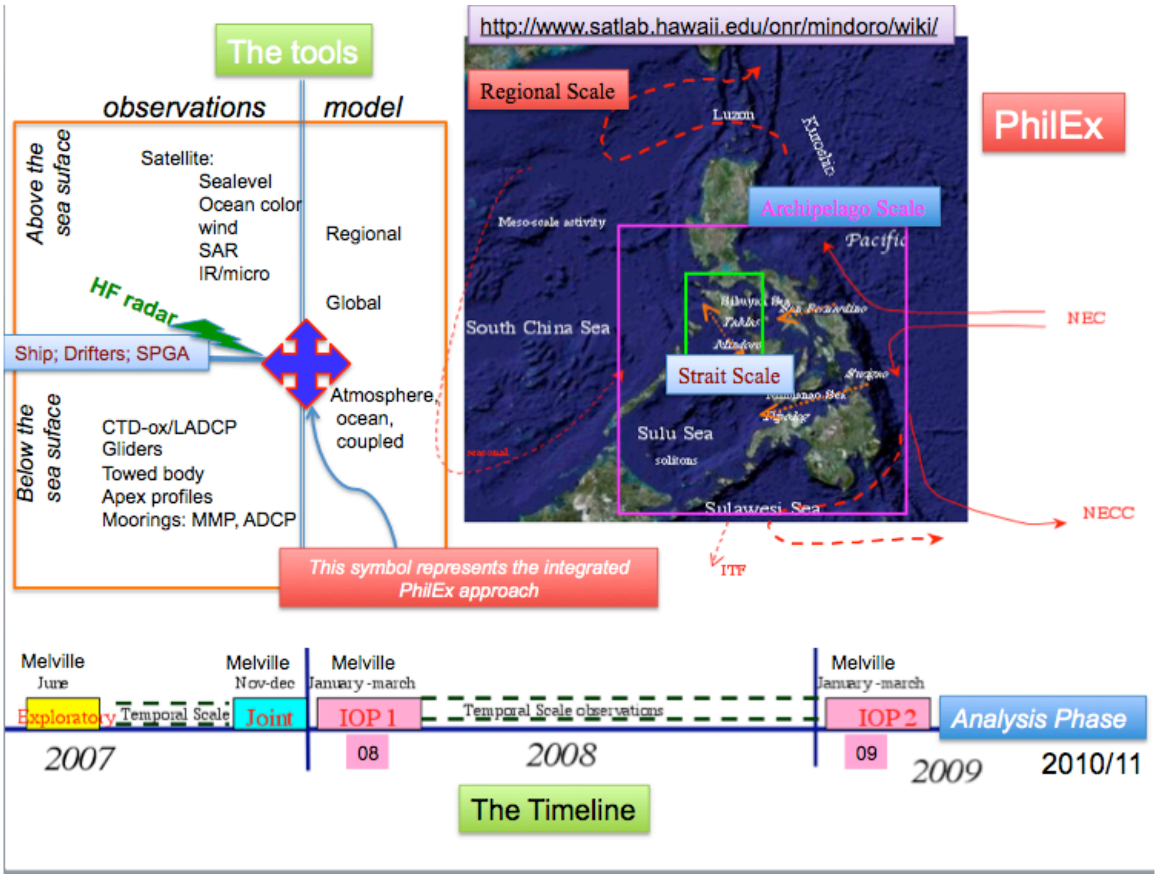


Figure 1: The scales, components and Timetable of PhilEx.

III Leg 1 Personnel

	Last Name	First Name	Employer
1	Cabrera	Olivia	UPD/UPMSI
2	Drushka	Kyla	SIO
3	Ferrera	Charissa	UPD/UPMSI
4	Gordon	Arnold	LDEO
5	Ho	Cheng	LDEO
6	Mele	Philip	LDEO
7	Rab Green	Suzanne	LDEO
8	Senal	Ma. Isabel	UPD/UPMSI
9	Solera	Leilani	UPD/UPMSI
10	Tessler	Zachary	LDEO
11	Tillinger	Debra	LDEO
12	Yñiguez	Aletta	UPD/UPMSI
13	Cole	Drew	SIO
14	Dorrance	James	SIO
15	Cohen	Ben	SIO

16	Anghag	Dioesio	Philippine Navy
17	Cordero	Gerald	Philippine Coast Guard

IV RIOP09 Track/Stations

One needs to find a balance between temporal coverage in which we repeat stations occupied during previous PhilEx regional cruises in order to investigate temporal fluctuations, with coverage that reaches into new areas not sampled on prior PhilEx cruises, in order to improve our regional view of the Philippine seas. A constraint during RIOP09 is that it is only 21 days long, the shortest of the regional cruises, yet we need to recover 6 moorings, 4 PhilEx moorings and two sediment trap moorings of the University of Hamburg.

With station and underway data, along with information from other PhilEx components [see above section], the regional cruises will greatly improved our description of the stratification and circulation within the Philippine Seas and advance understanding of issues related to PhilEx objectives. However, as typical in science, answering some questions brings up a multitude more. I would have likely to spend more time in any of the areas we surveyed. The inflow passages of San Bernardino and Surigao Straits deserve enough time to decipher the tidal vs. lower frequency fluctuations, to resolve the real throughflow and its variability with season, with ENSO, the impact of intraseasonal events [specifically Pacific Rossby waves]. In other areas I would like to have a followed a finer scale spatial grid, e.g. the southern Mindanao Sea cyclonic eddies, and the routing of the westward surface current or 'jet' within Mindanao Sea [e.g. does it pass to the north or south of Siquijor Island?] as well as its projection into the Sulu Sea. I would have liked to better trace the flow between the small interior seas and their deep ventilation. And no doubt during Leg 2, more questions will arise about Sulu Sea and the complicated junction of Mindoro, Panay and Tablas Straits at the Mixing Bowl.

Cruise objectives that structured the track and station array are listed in the Introduction section. In addition, on Leg 1 we performed a multibeam survey of the Dipolog mooring to allow for improved analysis of the hydraulic control and of the mooring time series at Dipolog Strait [Figure 14 at end of the report- it was added after figure sequence prepare].

The CTD/LADCP stations covered by the four regional PhilEx cruises are shown in Figure 2a, with the specifics of RIOP09 shown in Figure 2b, with a close-up view of the Mindanao coverage as Figure 2c.

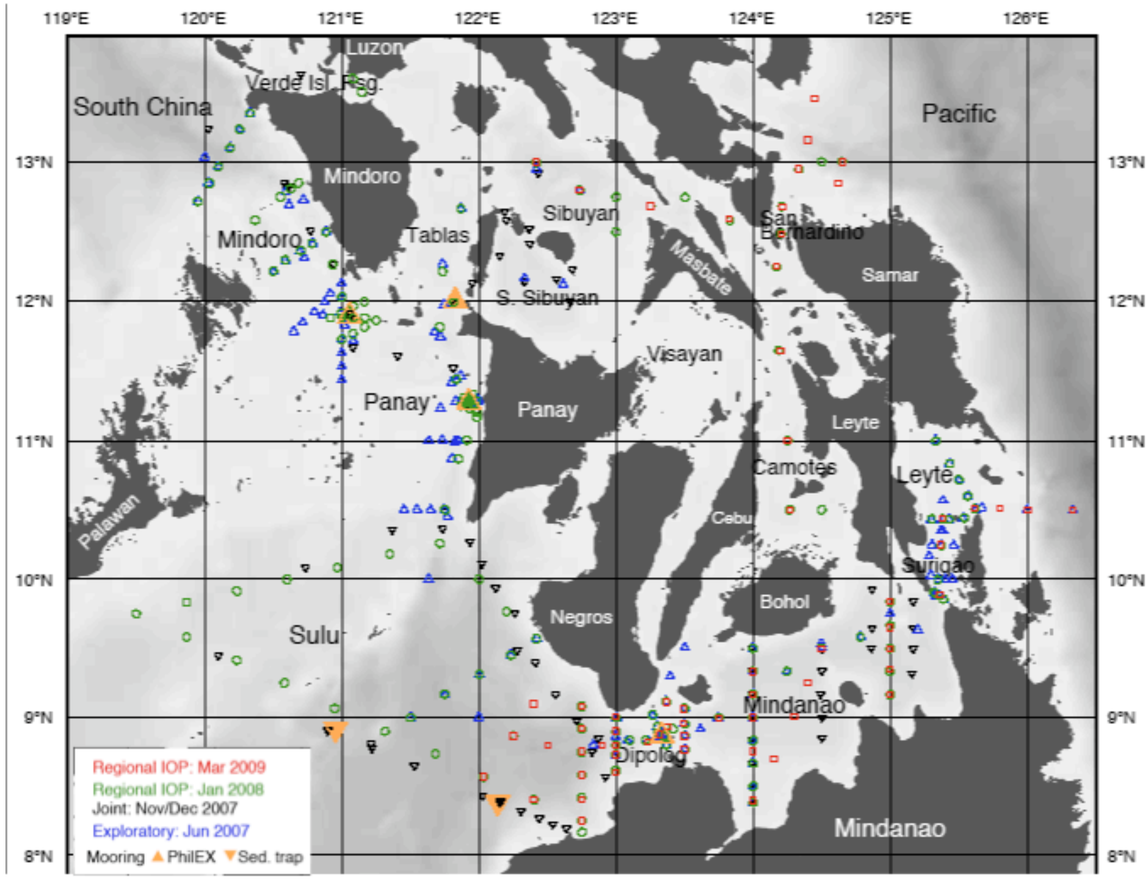


Figure 2a: Map of the Philippine Seas with names referred to in this report and position of CTD/LADCP stations of the four PhilEx cruises: Exploratory June 2007; Joint Nov/Dec 2007, RIOP08 January 2008, and RIOP09 March 2009.

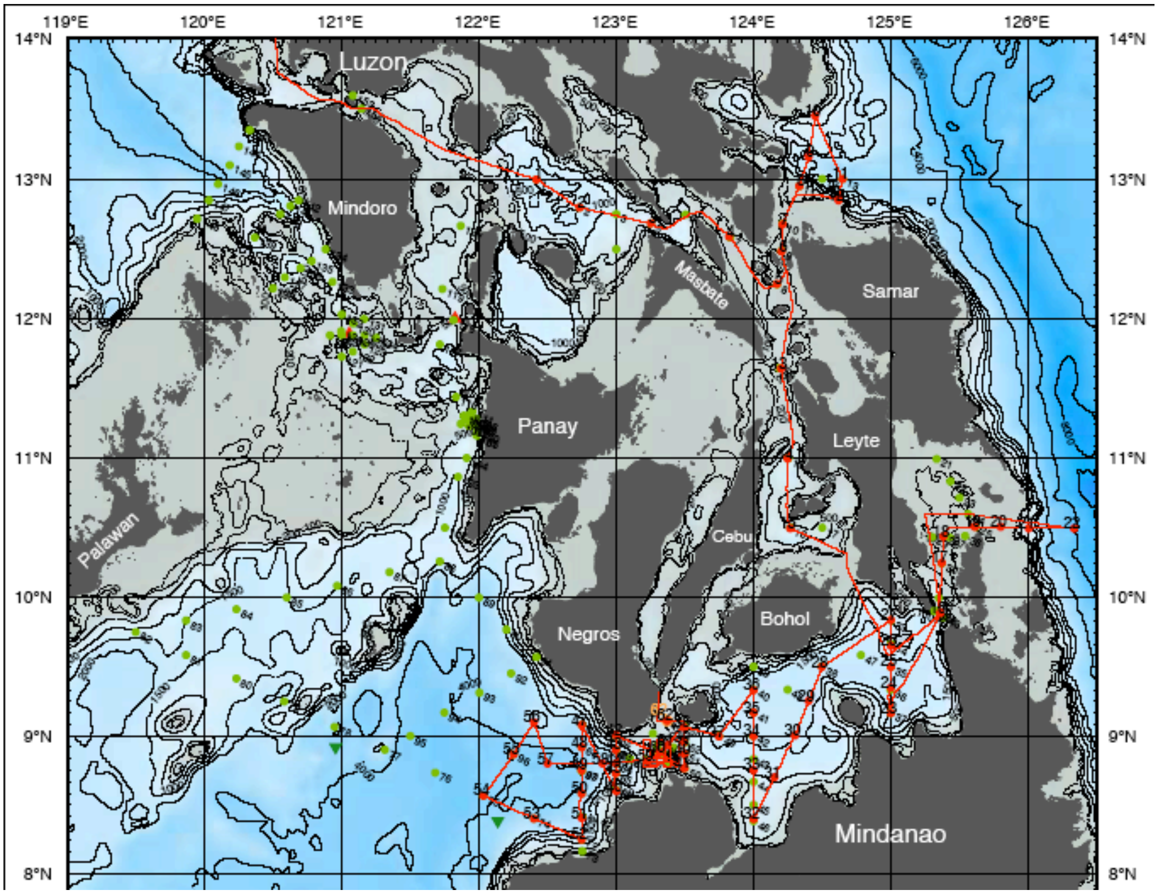


Figure 2b: RIOP09 Track and CTD/LADCP stations [RIOP09 station numbers are slightly larger than prior cruise station numbers].

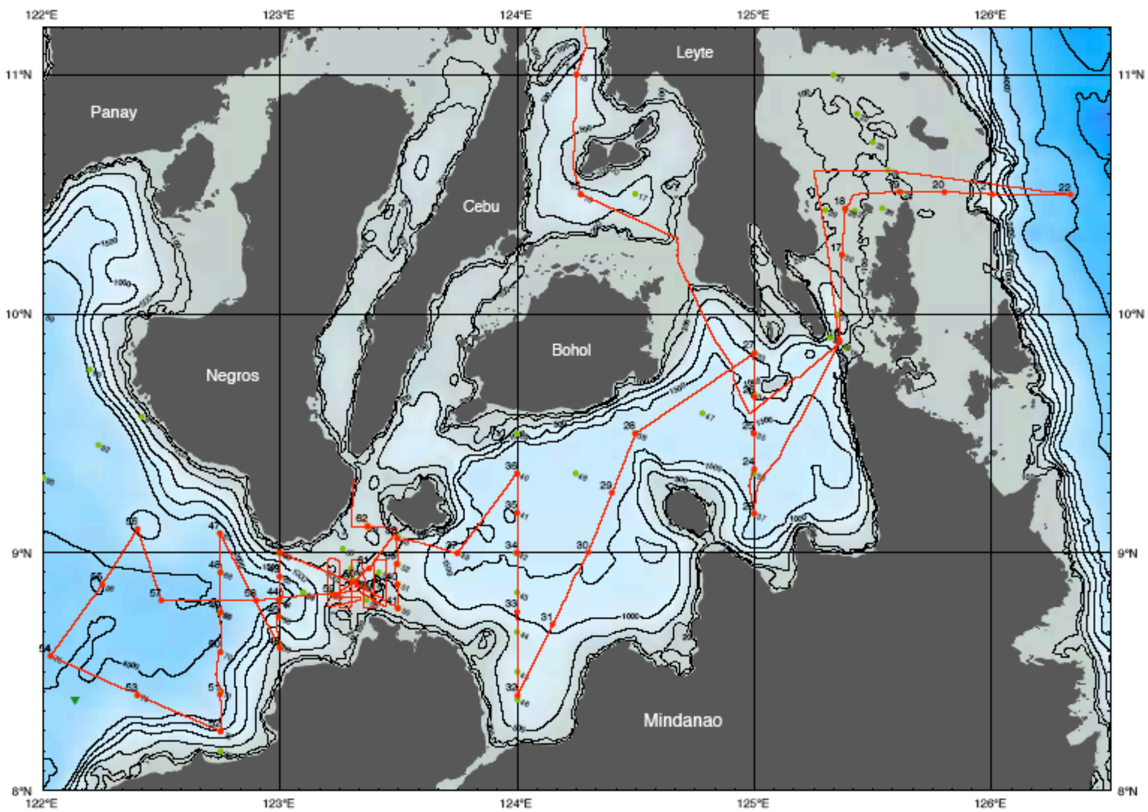
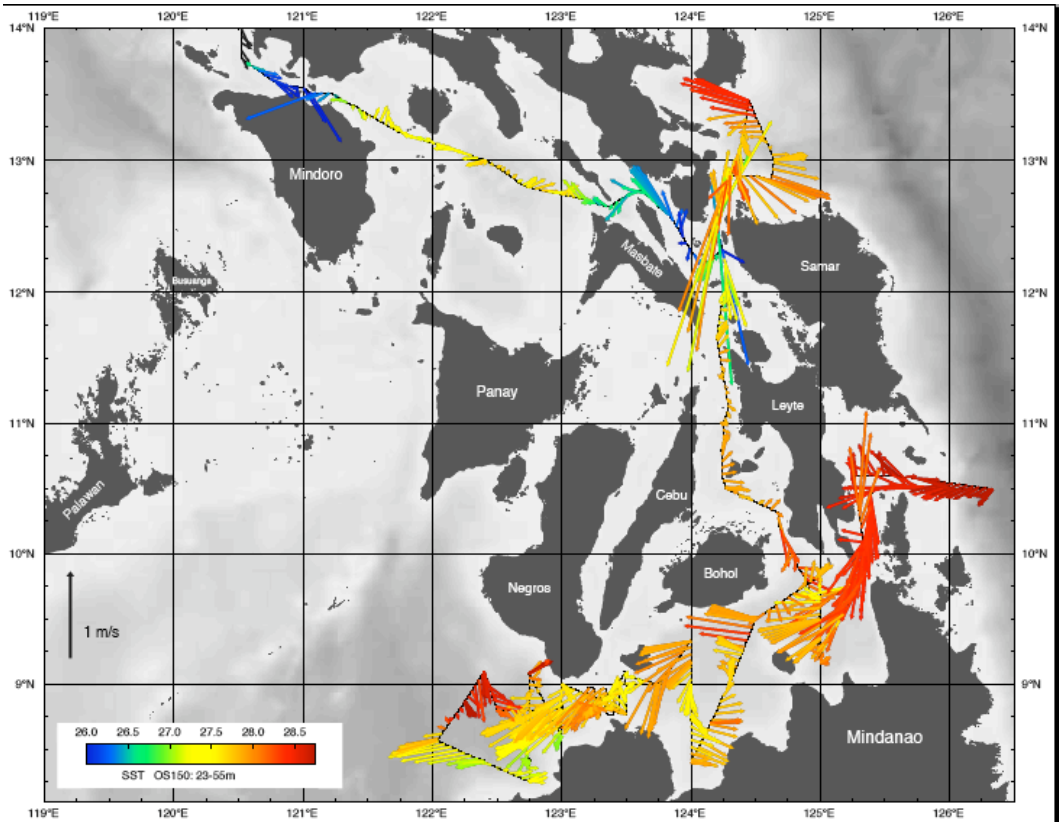


Figure 2c: Close-up view of Mindanao Sea region RIOP09 Track and CTD/LADCP stations. The grid near 123.3E is the multibeam track over the Dipolog mooring site.


Mindoro
Masbate
Samar
Busuanga
Panay
Leyte
Palawan
Cebu
Bohol
Negros
1 m/s
Mindanao
26.0 26.5 27.0 27.5 28.0 28.5
SST OS150: 23-55m

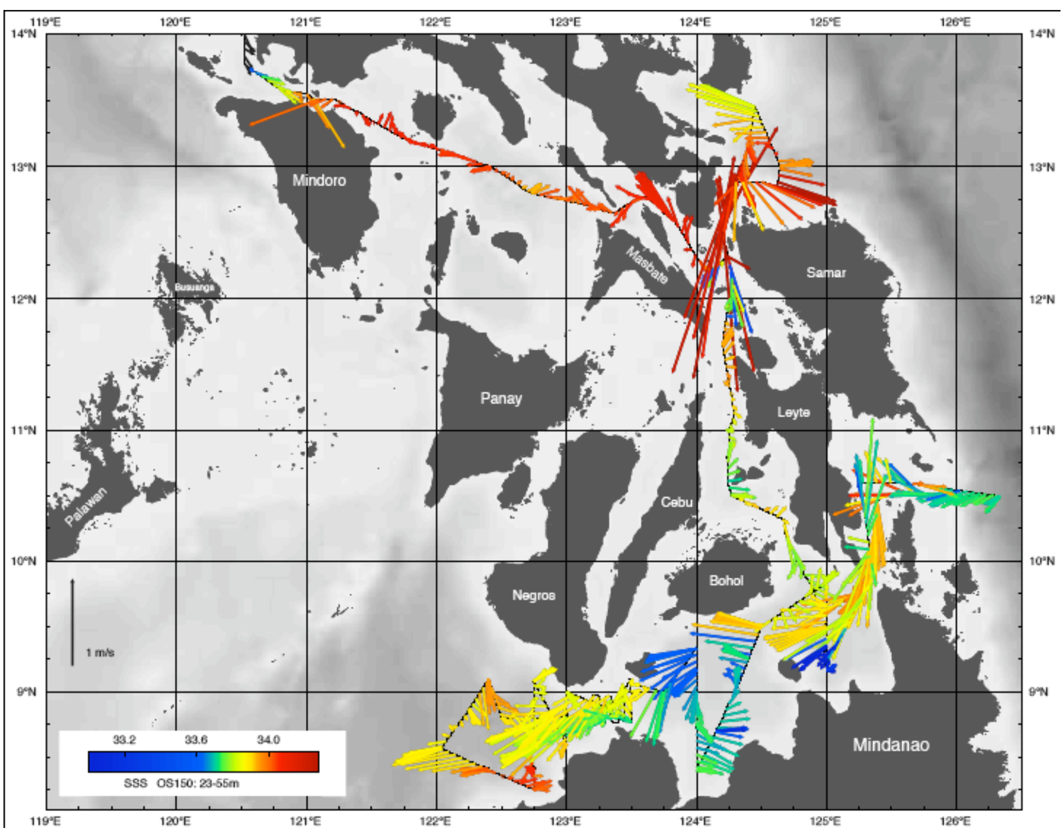

Mindoro
Masbate
Samar
Busuanga
Panay
Leyte
Palawan
Cebu
Bohol
Negros
1 m/s
Mindanao
33.2 33.6 34.0
SSS OS150: 23-55m

Figure 3: Surface layer, 23-55 m, currents, color-coded for sea surface temperature SST [upper panel] and sea surface salinity SSS [lower panel] of RIOP09 Leg 1. This map was constructed before the track between Siquijor Island and Negros was completed [to be added after Dumaguete port stop]

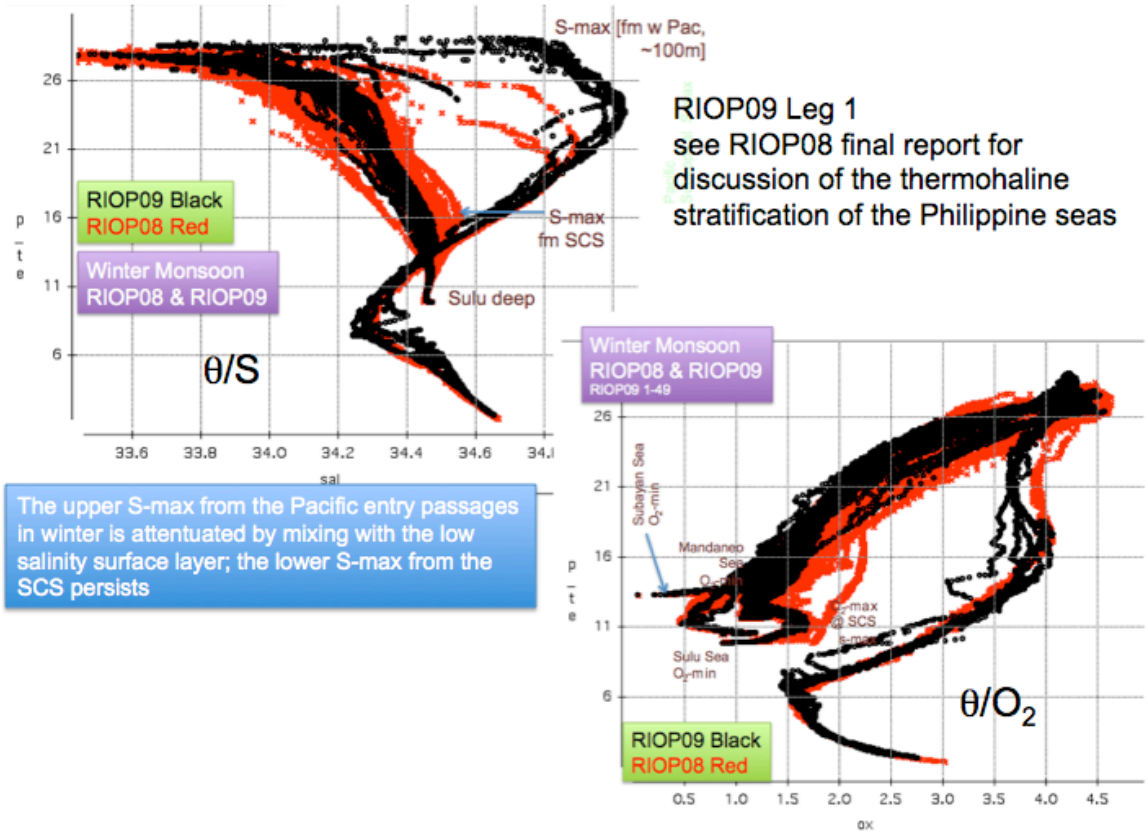


Figure 4: Property-Property plots of RIOP09 Leg 1 and of the RIOP08 coverage for the same areas: Potential Temperature [θ°C] vs. salinity [S] and Oxygen [O_2]

V Preliminary Data Analysis:

The reader is referred to the final report of the January 2008 RIOP08[2] for a discussion of many aspects of the Philippine Sea oceanography. Here I will touch briefly on only a few topics that were either not discussed in the RIOP08 report, or topics that can be addressed differently with the RIOP09 data. The most significant discussion is directed at San Bernardino and Surigao Straits.

[A] Ventilation of the Sibuyan Sea [see Figure 2a for place names]

The Philippine seas are composed of numerous deep basins. There is the open Pacific Ocean to the east; there are the relatively large seas to the west of the Philippines, as the Sulu Sea, South China Sea and Sulawesi Sea; and there are the smaller interior seas, most notably the Mindanao or Bohol Sea and the Sibuyan Sea, and the still smaller Visayan, Camotes Seas, and others. These seas are ventilated by inflow of dense waters from surrounding seas that descent to the depths replacing resident water made less dense by vertical mixing, most likely due to tidal dissipation. The residence water is lifted upward as it is replaced by denser overflow gravity currents, and is subsequently exported to the surrounding seas. As these waters are reduced in oxygen by the rain of organic material from the sea surface, their spreading can be traced as an oxygen minimum. For example the Mindanao oxygen minimum near 12°C [Figure 5; referred to as the pervasive oxy-min in the RIOP08 report] is observed near 300 m throughout the Sulu Sea.

The oxygen minimum of the Sibuyan Sea is not drawn from the oxygen minimum of the Mindanao Sea via the interior Camotes Sea or by way of the Tablas Strait [as I suggested in my RIOP08 report], as the Sibuyan oxy-min thermohaline characteristics don't match that of the Mindanao oxy-min layer and there may not be a deep enough interior routing from the Mindanao to the Sibuyan Sea. It is concluded that the Sibuyan oxygen minimum is of local origin. The oxy-min of the Sibuyan Sea serves as the ventilating water source for the South Sibuyan Sea, accounting for the super-low oxygen of the southern Sibuyan Sea bottom water, <0.3 ml/l.

[2] RIOP08_Repts_ALL.pdf on the PhilEx WIKI site @ http://www.satlab.hawaii.edu/onr/mindoro/cruises/gordon_january_08/

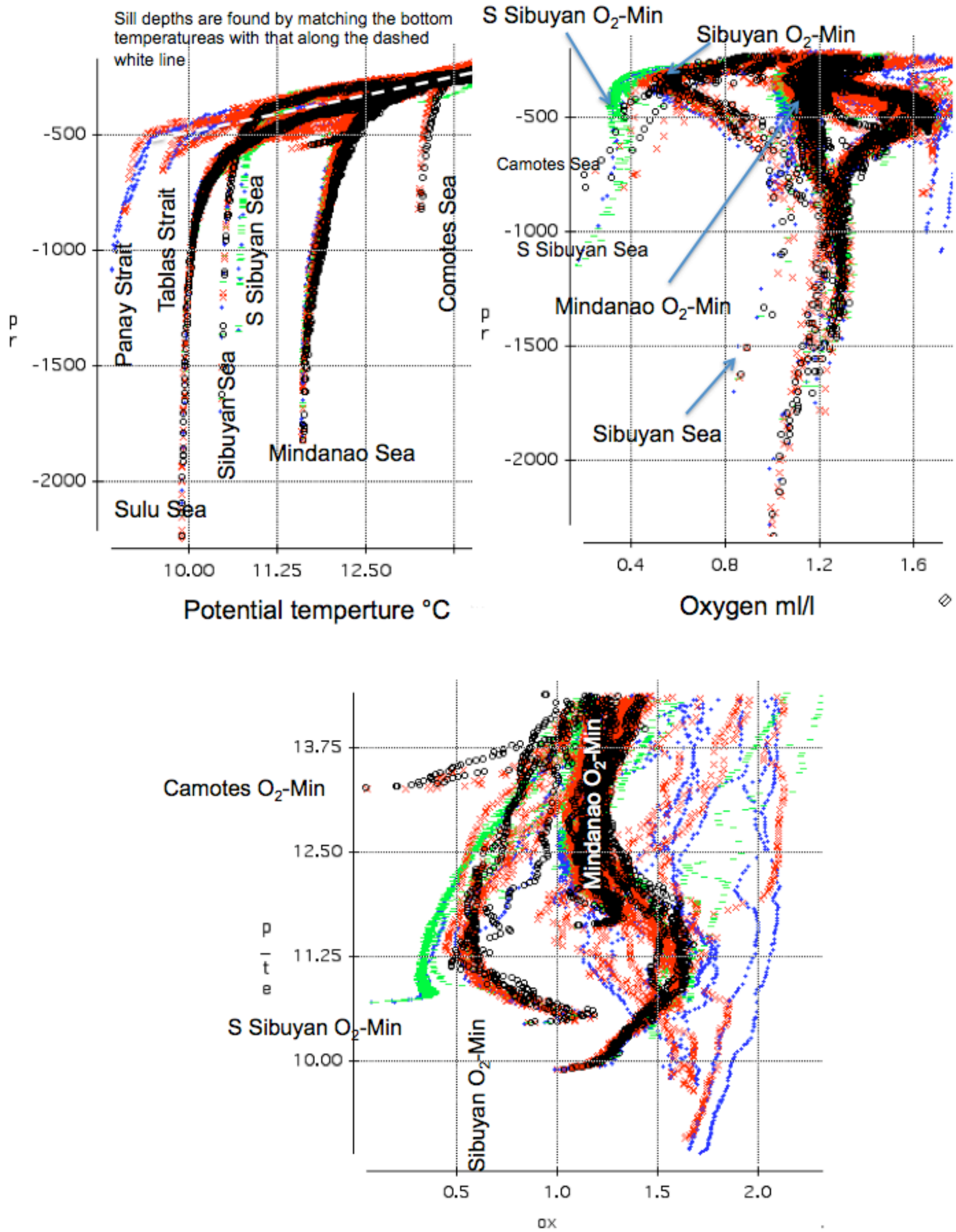


Figure 5: Potential Temperature and oxygen depth profiles in the interior seas of the Philippines [upper panel]; θ/O$_2$ [lower panel]

[B] San Bernardino and Surigao Straits

The direct connection of the Philippine Seas to the western Pacific is through the San Bernardino and Surigao Straits [Figure 6]. These straits are shallow, 50 to 100 m, and exhibit strong tides that induce vigorous mixing that attenuates the Pacific stratification. The sill depth for Surigao is near 50 m, at San Bernardino the sill depth is a bit more uncertain, ~80 m.

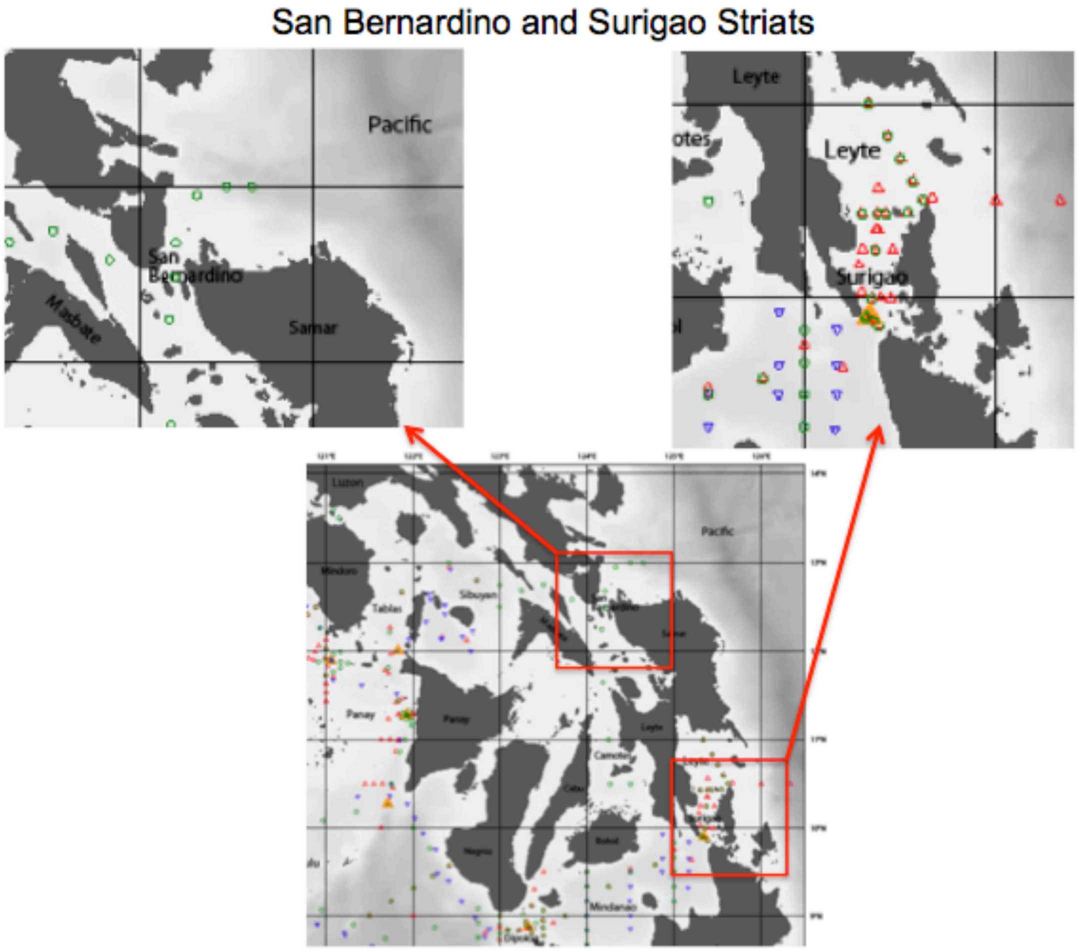
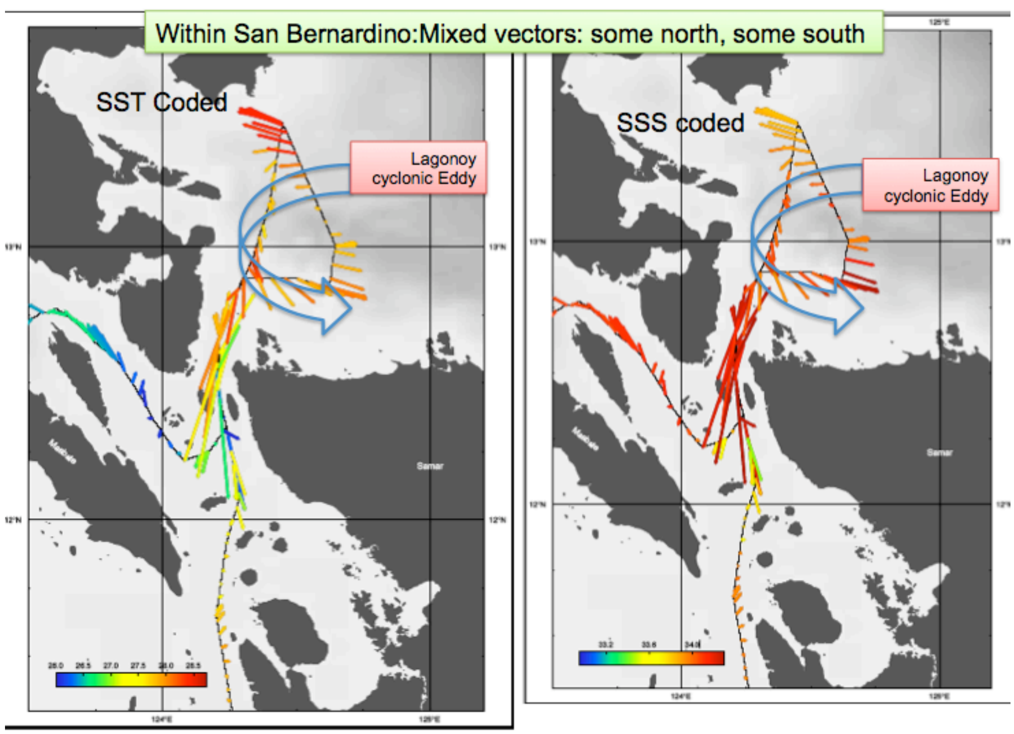


Figure 6: Map of the San Bernardino [left panel] and Surigao [right panel] Straits.

San Bernardino Strait connects the Gulf of Lagonoy with the Samar Sea [just west of Samar Island], which in turn connects with the interior seas: Sibuyan, Visayan and Camotes. The hull ADCP indicates a cyclonic flowing circulation within the Gulf of Lagonoy [Figure 7], which delivers low salinity surface water into the San Bernardino northern entrance. Vigorous mixing brings up higher salinity deeper water [Pacific water spreading over the sea floor of the Gulf of Lagonoy] boosting the surface salinity, as suggested in the upper right panel of Figure 7 and in the profiles shown in Figure 8.

Continuity [throughflow pathway] of the San Bernardino water into the interior seas is not evident [Figure 7, lower panel], though tidal currents are likely to obscure the throughflow pattern. However, there is not the expected strong westward flow in the

Sibuyan Sea or of southward flow in the narrow passage between Masbate Island and the NW tip of Leyte Island, that would be needed to feed continued southward flow in the Camotes Sea or entry into the Visayan Sea, from which the San Bernardino water can spread westward into the Sibuyan Sea or south Sibuyan sea to eventually enter into Tablas Strait, either to the north or south of Tablas Island. Various PhilEx models suggest substantial San Bernardino throughflow connected to westward flow within the Visayan Sea to the passage south of Tablas Island. Based on observations from RIOP08 and from RIOP09 the continuity of the San Bernardino throughflow into Sibuyan routed either north or south of Masbate Island is not evident, nor is the continuity with southward flow in Camotes Sea. Perhaps at the time of RIOP08 and RIOP09 the San Bernardino throughflow was small, or that we missed a narrow connection with the western routing. A time-based survey of these interior seas is suggested.



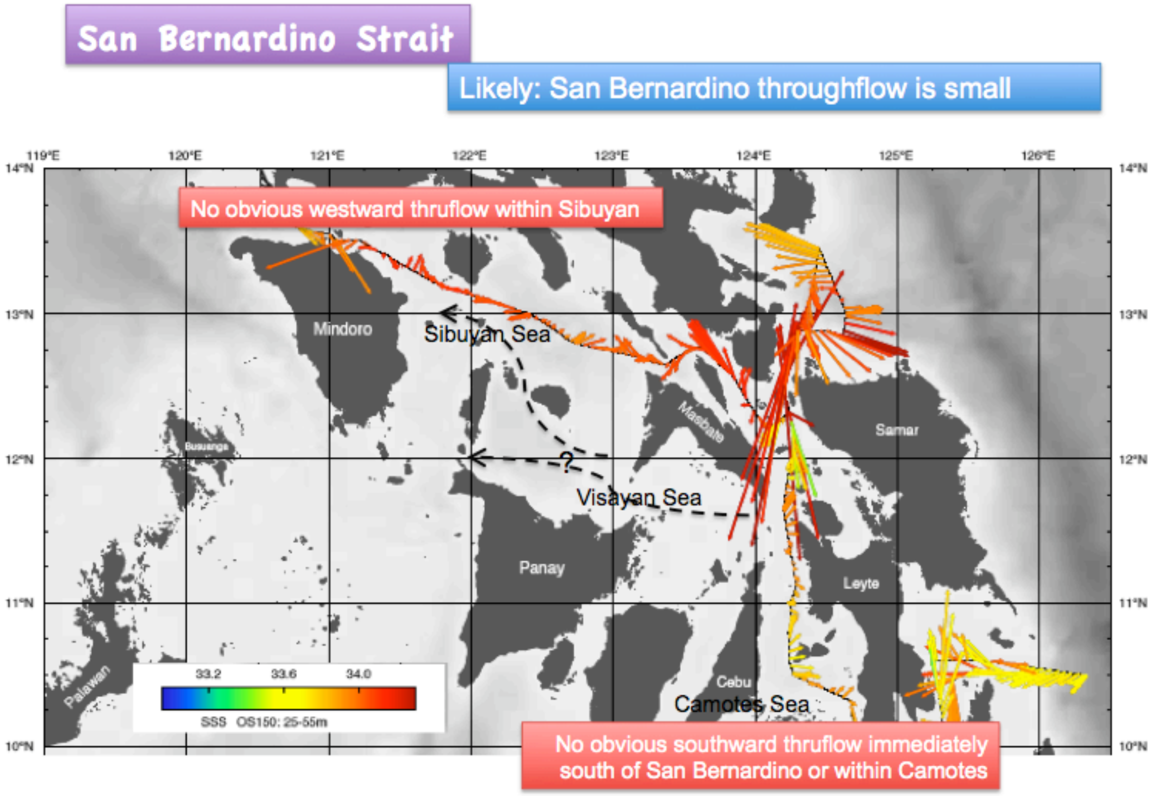


Figure 7: Hull ADCP vectors within San Bernardino Strait [upper panel] and for the larger region including the Sibuyan and Camotes Seas [lower panel]. The continuity of the San Bernardino throughflow into Sibuyan routed either north or south of Masbate Island is not evident, nor is the continuity with southward flow in Camotes Sea. Model results favor the path south of Masbate, within the Visayan Sea.

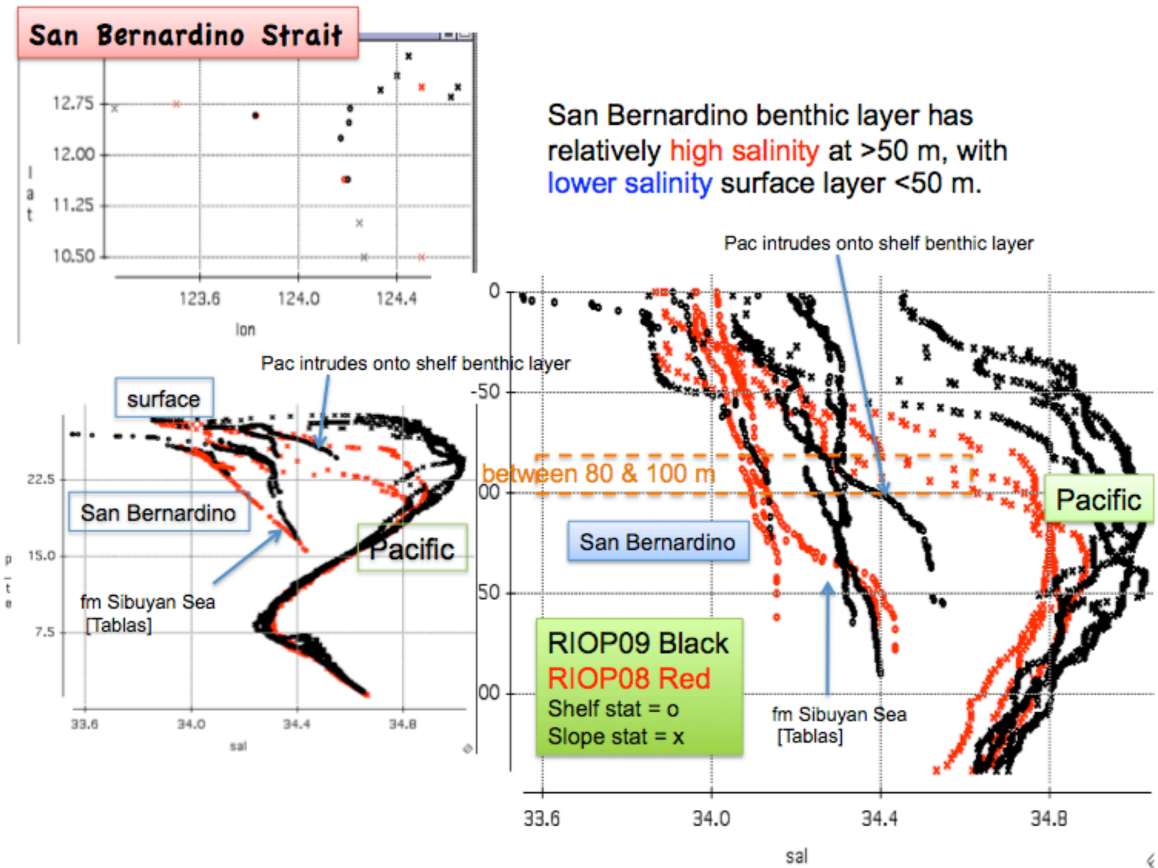


Figure 8: Potential temperature:salinity relationship [left panel] and salinity profiles [right panel] for the San Bernardino Strait. Signs of intrusion of salty Pacific water over the seafloor in the Gulf of Lagonoy are evident. This water provides the salt to attenuate the low SSS of the Gulf of Lagonoy inflow to San Bernardino Strait.

A similar situation is evident in Surigao Strait [Figures 9, 10], though there the indications of a substantial throughflow are stronger, with Surigao surface layer feeds into the westward surface layer flow that tracks along the northern Mindanao Sea [see RIOP08 final report]. The Pacific water passes into the Leyte Sea and eventually into the Surigao Strait between Homonhon Island and the NE tip of Mindanao [this is based on RIOP08 data], with a sill depth of 50 m or slightly larger than 50 m. The Pacific water executes a sharp turn to the south to pass through the Surigao Strait [Figure 9] and feeds into the Mindanao Sea westward directed surface current [RIOP08 Report and Figure 3].

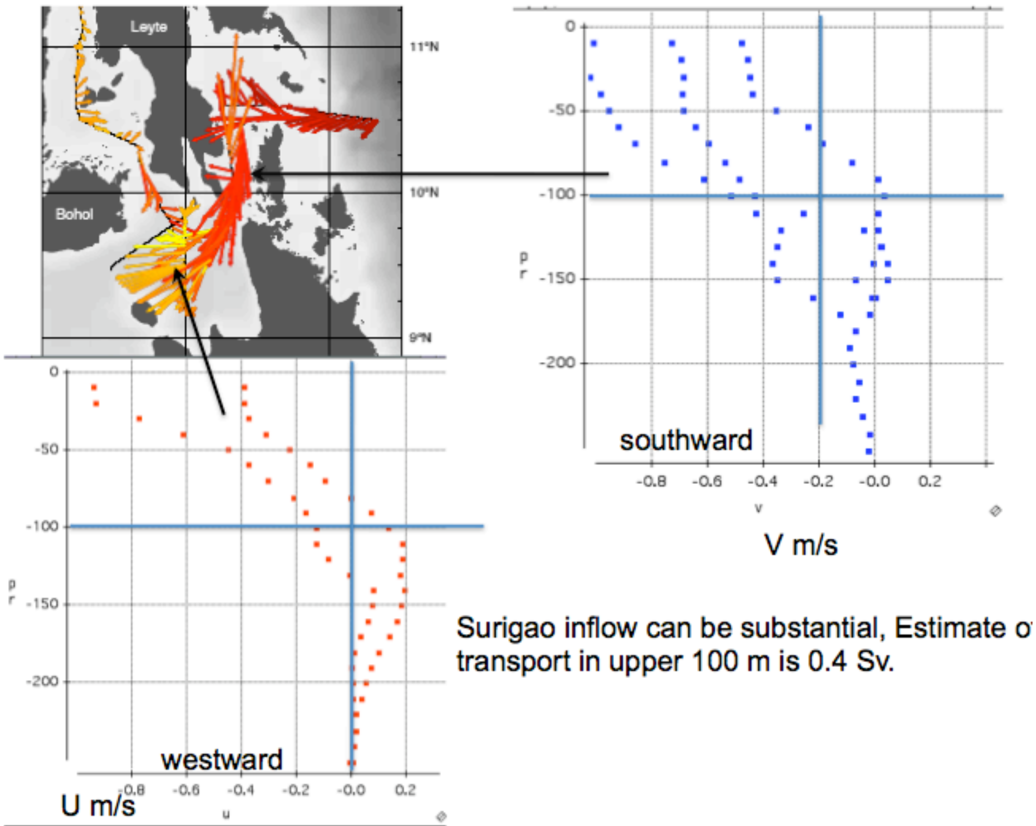


Figure 9: Vectors of flow at 23-53 m, color coded for SST [upper left panel]. The profiles of zonal [red] and meridional [blue] speed from the Lowered ADCP are shown in accompanying panels.

The hull and lowered ADCP suggest a Surigao throughflow as high as 0.4 Sv [Figure 9]. This includes the benthic intrusion of salty Pacific water, as evident by station #20 [Figure 10].

Schematics of the oceanography of the San Bernardino and Surigao straits are offered in Figure 11.

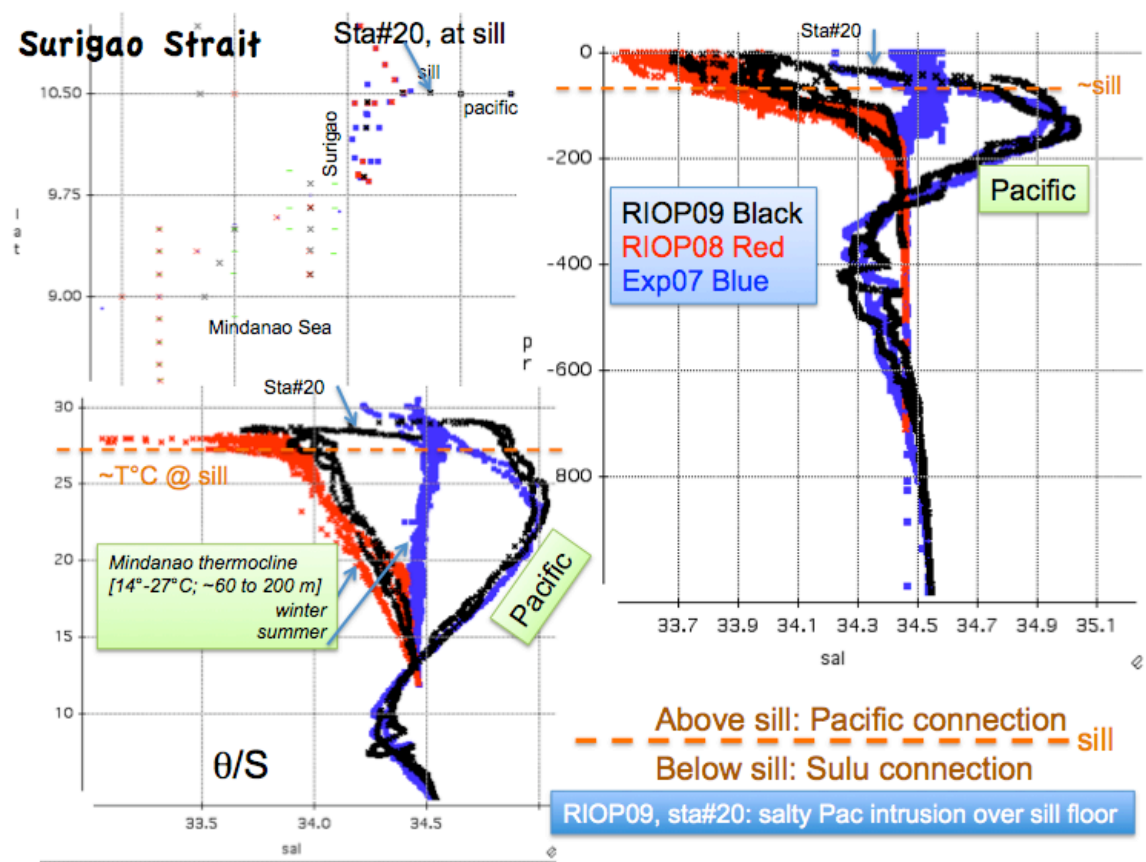
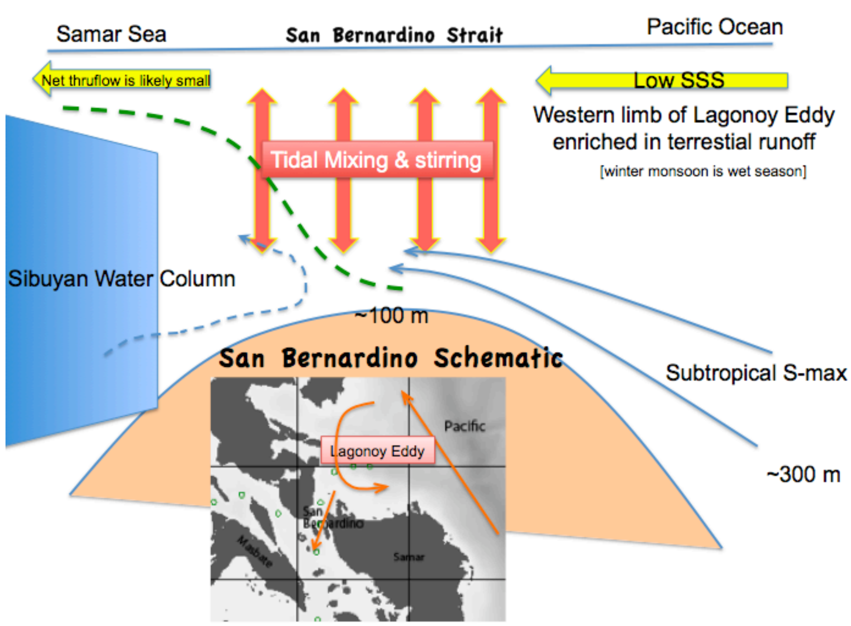


Figure 10: Stratification at Surigao Strait. Station 20, close to the topographic sill separating the Pacific from the Mindanao Sea, reveals intrusion of Pacific water along the sea floor.



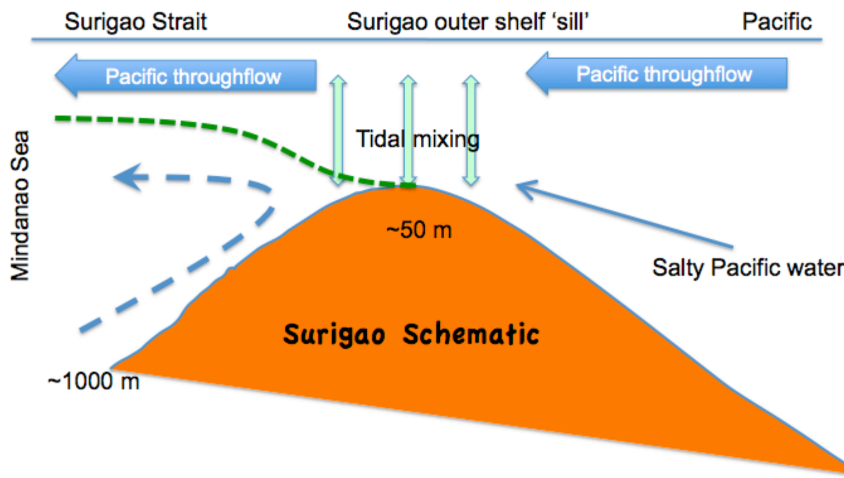


Figure 11: Schematics of oceanographic stratification and processes within San Bernardino [upper panel] and Surigao [lower panel]. The inflow of Pacific water is well mixed by local tidal energy and overrides denser sub-sill water within the interior seas of the Philippines, which are drawn from the Mindoro/Panay/Tablas Straits to the west.

[C] Western Mindanao Sea and the Dipolog Strait [See the RIOP08 Report for discussion of the Mindanao Sea horizontal and overturning circulation, a summary schematic is shown in Figure 12]

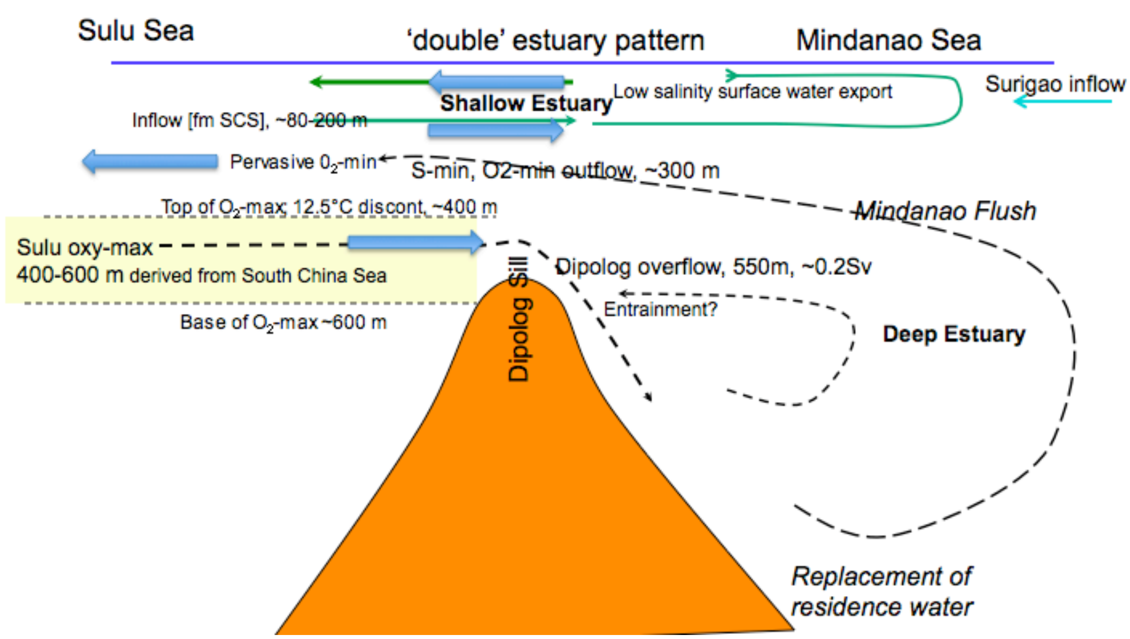


Figure 12: Schematic of the flow patterns in the western Mindanao Sea and Dipolog Strait.

Topics-

§ <u>Deeper thermocline in March 2009 relative to January 2008</u>: One of the most noticeable differences within the Dipolog Strait between the data we are collecting now vs. Jan 2008 data is the presence of a thicker surface layer in 2009, which has the effect of inducing a deeper thermocline [Figure 13]. Perhaps the change is just due to the 2 month difference of RIOP09 and RIOP08 as a sign of the maturing of the winter monsoon stratification, but interannual effects may also be possible: the RIOP08 occurred during the wettest winter in over 30 years. The lower surface salinity in that year relative to winter 2009 may have limited the downward mixing of surface water, leading to a shallower pycnocline. [I've not checked the rainfall conditions in winter 2009, so this remark is speculative.]

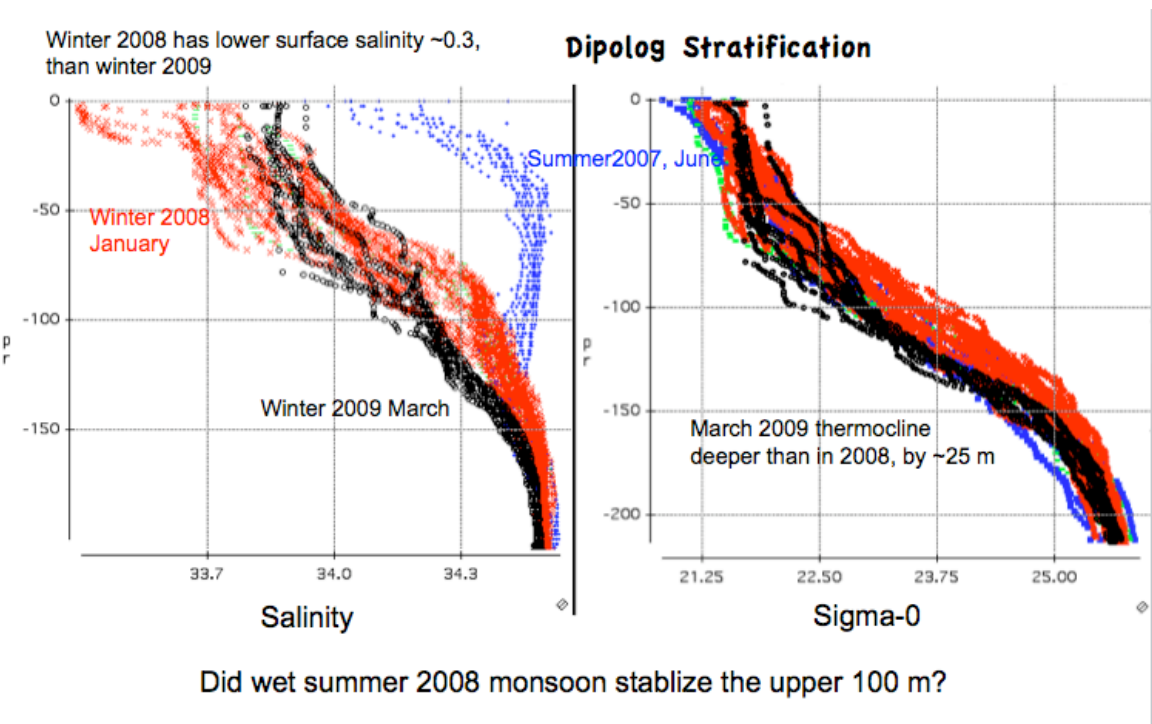


Figure 12: Salinity and density profiles in the Dipolog Strait from RIOP08 and RIOP09

§ <u>Routing of the Mindanao surface flow into Dipolog Strait</u>: Another issue is the routing of the Mindanao Surface Jet into Dipolog Strait. Does it pass to the north or to the south of Siquijor Island [Figure 13]? The RIOP09 hull ADCP clearly shows that at the time of RIOP09 presence the Mindanao surface current jet passes between Siquijor and Negros. The branch of the Mindanao surface current jet that curls to the south along the east side of Siquijor is part of the cyclonic gyre centered near 123°E. Which may be referred to as the Iligan Gulf gyre.

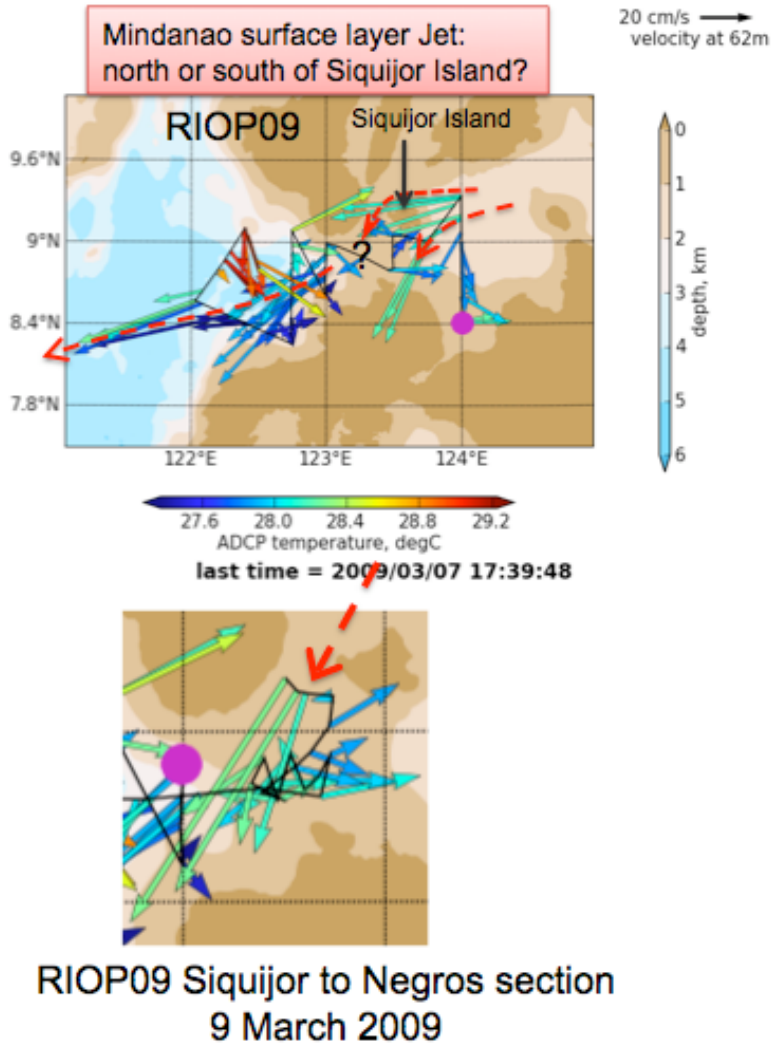


Figure 13a: The Westward flowing surface layer (<80 m in thickness) in Mindanao Sea, the "Mindanao Surface Jet" can approach Dipolog Strait by passing either south or north of Siquijor Island. The observations and model results favor the north routing, but the route may be time dependent. The lower panel obtained on the way towards Dumaguete reveals strong southward flow within the Siquijor/Negros Passage. Western intensification is evident. The vectors shown are from the ship board hull ADCP NB150 and OS75 ADCP Data web page. Figure 13b for vectors for a shallower 23-55 layer.

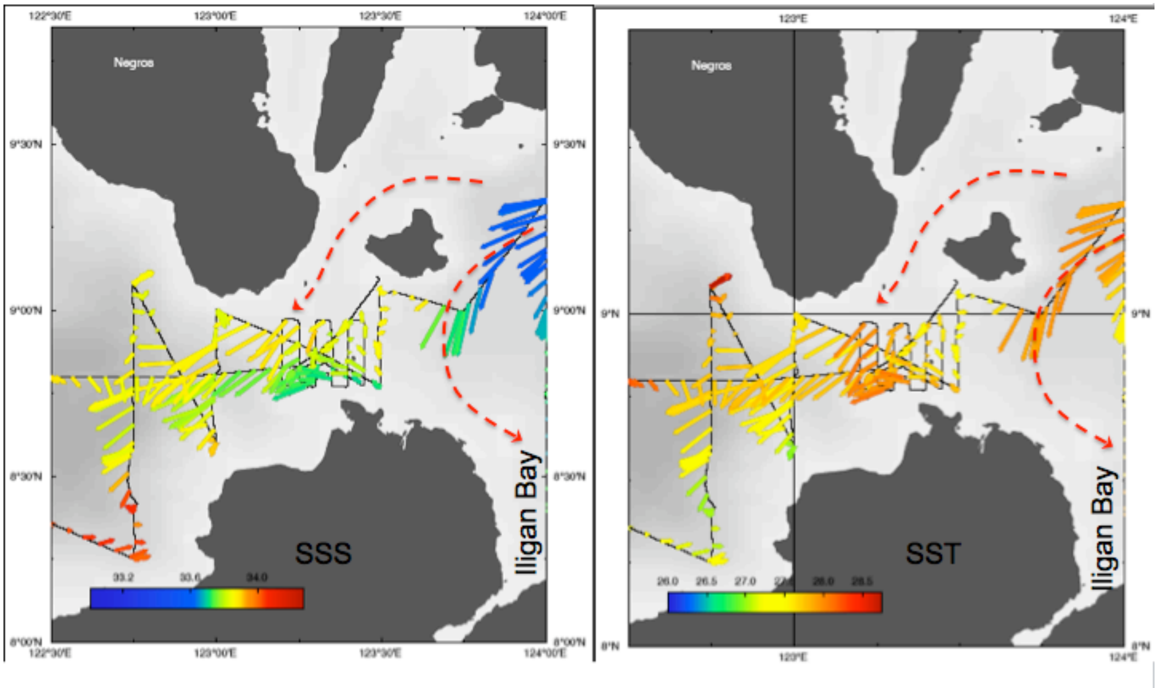


Figure 13b: Hull ADCP color codes for SST [right panel] and SSS [left panel]. Vectors are 23-55 m average. For vector scale see figure 3. This figure was constructed before the ship did the track between Siquijor Island and Negros [to be added after Dumaguete], but the dashed red arrow in the Siquijor/Negros passage is taken from figure 13a. The Mindanao surface jet that does not pass to the north of Siquijor is likely the west limb of the cyclonic gyre in the Iligan Bay region [see Figure 3].

§ Silino Island: About 5 nm east of the Dipolog mooring is the flat island of Silino, sitting on the southeast side of a coral plateau [reef] of 3 nm diameter. As the surface layer flow is strong towards the west, it is expected that the coral platform will generate eddies, perhaps much like Apo reef in Mindoro Strait. Alighay Island is a similar flat island 4 nm to the south of the Dipolog mooring site.

Multibeam figure

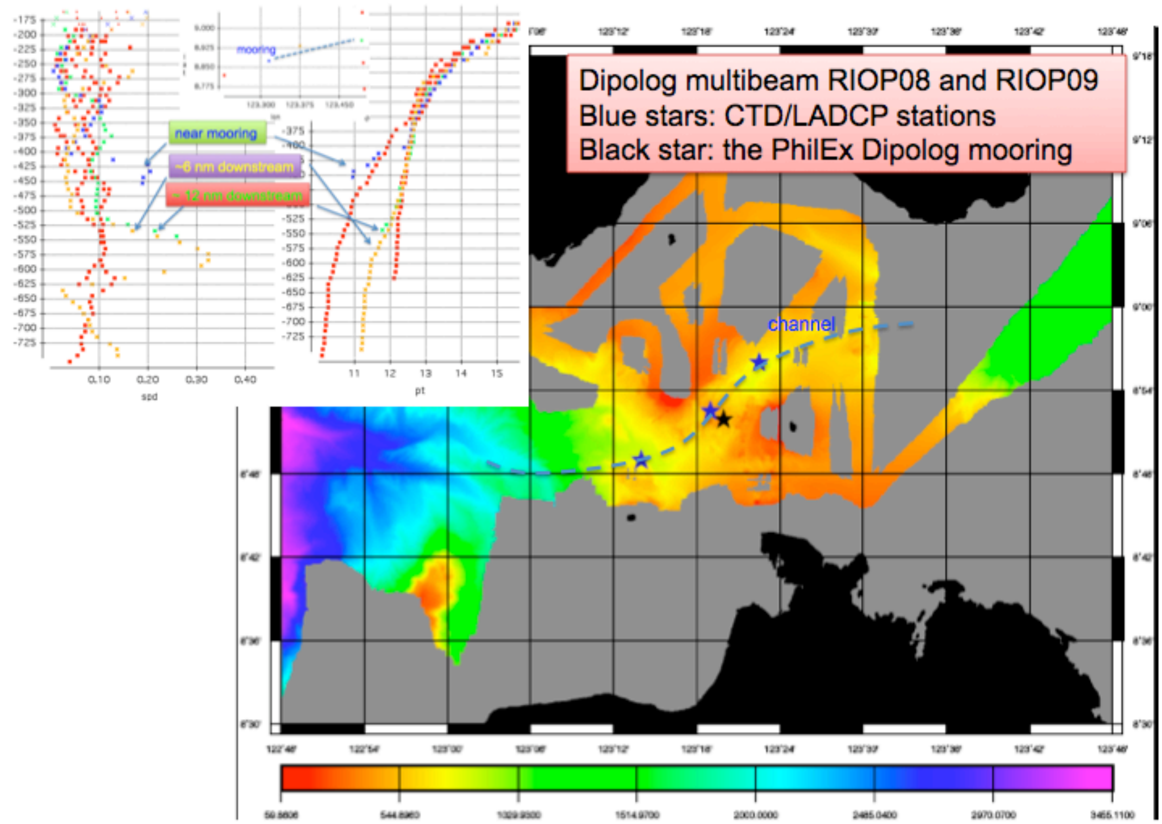


Figure 14 [added after figure sequence prepared]: Sea floor depths from RIOP08 and RIOP09 multibeam surveys. The blue stars mark the CTD/LADCP stations along the deep passage. The dashed blue line marks the approx channel axis. The black star is the position of the PhilEx Dipolog ADCP mooring, at 490 meters depth. The profiles of speed and temperature are shown in upper left panel. At the stations ~6 nm downstream of the moorigns the speed maximum near 590 m is about 150 m above the sea floor, indicating that the overflow at least at times does not slide along the sea floor to great depths in the Mindanao Sea, perhaps a tidal effect?

The topics discussed above are based on a first look at the data collected during RIOP09 Leg 1. A more complete description of the regional oceanography is provided in my report from RIOP08. The above comments, as well as those from RIOP08 are preliminary, and detailed study during the PhilEx evaluation phase will no doubt alter the picture. It is offered in this cruise report and in the RIOP08 report [and Exploratory June 2007 Cruise report] to encourage consideration and collaboration between the many components of PhilEx.

Acknowledgements are reserved for the report after Leg 2. But here I want to state my appreciation for the tremendous help, provided so cheerfully, by the wonderful officers and crew of the Melville, and of the Scripps technical support.

ALG - 9 March 2009