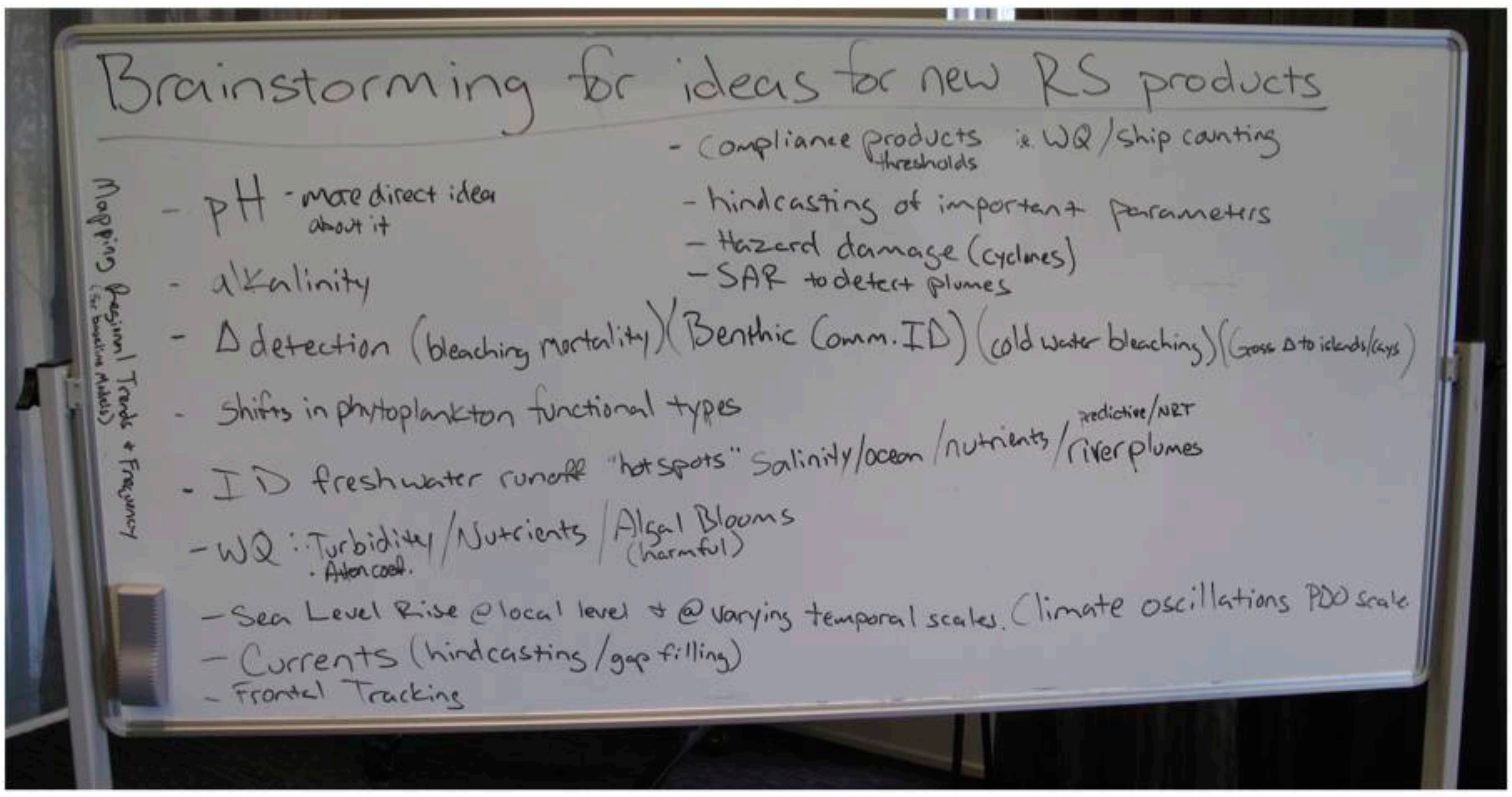
Section III: Workshop Discussions

The workshop discussion sessions provided a useful forum for allowing a variety of thoughts to develop in relation to how remote sensing tools can help managers, what new remote sensing tools would be beneficial, and what work needs to be done on the part of coral reef researchers, remote sensing scientists, and managers. Some interesting revelations from workshop participants included how some remote sensing tools developed by Coral Reef Watch were being used by researchers outside of the coral reef community and how the information form these remote sensing products gives managers credence in the eyes of the public. The following discussions provide a glimpse of the areas of improvement that are needed, the achievements that have been made, and directions that are on the horizon for the remote sensing of coral reefs.

"Brainstorming for ideas for new remote sensing products"

Facilitator: William Skirving

Developing new ideas for remote sensing products was a central goal of the workshop. In the discussion about this topic it was clear that there were many ideas about remote sensing products that would be useful to coral reef scientists and managers. A variety of parameters were mentioned that could be applied at several spatial and temporal scales. At a global scale, participants mentioned that it would be useful to have products that could track and predict climate oscillations, such as the Pacific Decadal Oscillation (PDO). At a regional scale, the monitoring of currents and fronts were mentioned to aid in tracking fisheries. A substantial amount of interest also focused on hindcasting these parameters. The prediction of hazard damage associated with disturbance events, such as storm surge and mixing associated with hurricanes and cyclones, was also a product of interest. At the local level, land based sources of pollution were a prominent topic. One useful product idea was a freshwater runoff tracker that could be used to identify "hot spot" areas, such as delta areas, near coral reefs that may be impacted by salinity changes, using synthetic aperture radar, or increased nutrients and sediment carried by river plumes. The data obtained from these products could then be used to develop compliance products and create baseline models that could be used to monitor trends and frequency of events. For example, if chlorophyll could be used as a proxy for nutrients and attenuation coefficients used for sediment and soil loss, it may be possible to detect if watersheds are exceeding total maximum daily loads. Predictions of flood plume events, using weather forecasts and models for instance, were also mentioned as being useful. A related topic mentioned developing a product that could detect harmful algal blooms (HABs). While NOAA has a HAB operational forecast system (http://tidesandcurrents.noaa.gov/hab/index.html), it is spatially restricted to southern Florida. Additional locations are currently being developed in U.S. coastal waters but their status is experimental. Attendees also mentioned it would be useful to have a product that could detect shifts in phytoplankton functional types and identify other types of cyanobacteria, such as *Trichodesmium*. For coral reefs, potentially useful products include change detection of bleaching mortality and benthic community identification. Change detection of seagrass cover was also mentioned. Effects of climate change and ocean acidification at the local scale also inspired ideas for potential products. Workshop participants voiced an interest in determining sea level rise at varying temporal and episodic scales. Another product of recent interest after the January 2010 cold water-bleaching event in the Florida Keys is a product that could predict cold water bleaching. Related parameters of interest included deriving pH and alkalinity from satellites. Biogeochemical information is important to researchers, especially gross change to islands and keys. Currently an ocean acidification is in an experimental (http://coralreefwatch.noaa.gov/satellite/oa/index.html) phase of research with NOAA's Coral Reef Watch, which may be able to contribute to this effort.



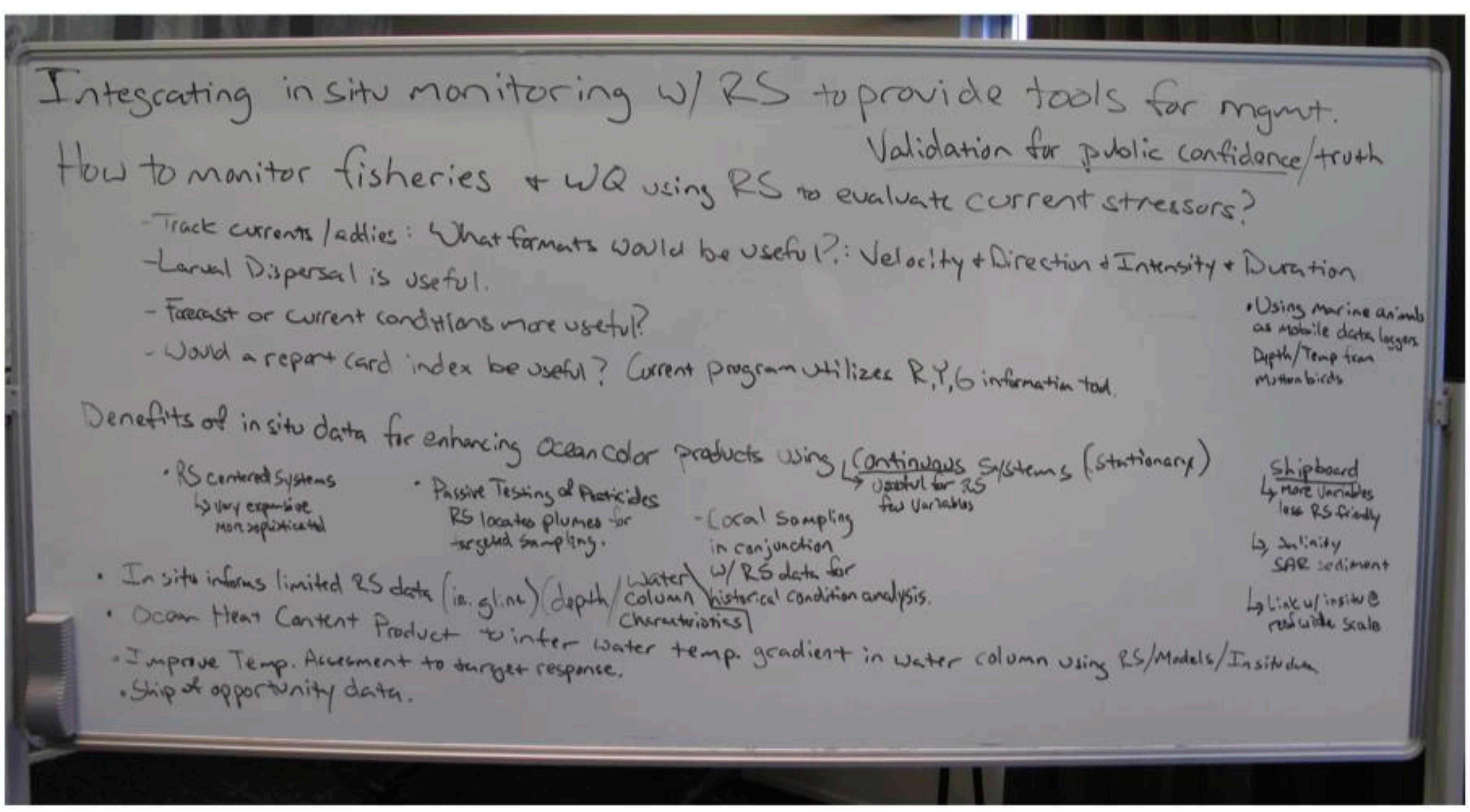
<u>"Integrating *in situ* monitoring with remote sensing to provide tools for management"</u>

Facilitator: Billy Causey

Because some remote sensing data comes from distant platforms, scenes often display data that is not of use to researchers investigating coral reefs, such as atmospheric aerosols and sunglint, which can interfere with the actual conditions of the observed environment. To correct for some of these disturbances it is necessary to calibrate and validate what the sensors are viewing using *in situ* data. This information is not only useful to remote sensing scientists, but also to managers, who use this information to make decisions and inform the public. Managers gain credibility from stakeholders when their information accurately reflects events taking place in the area. Managers walk a fine line between a populace and media that often minimize a job well done and thoroughly expose situations where managers are wrong. Oftentimes the media's depiction of an event is the last word. In these cases managers want to be sure they are on the right side of a portrayal, for example coral bleaching. Calibrated and validated remote sensing data derived from *in situ* data aid by making sure managers are equipped with accurate data. Various *in situ* parameters, such as SST, chlorophyll *a* and turbidity measurements, are currently monitored to inform remote sensing analysts. This discussion sought to identify other parameters that would be useful to managers in order to calibrate and validate remote sensing data.

Methods of obtaining *in situ* data are numerous and include stationary and mobile monitoring platforms that may be manned or unmanned. Stationary buoys, jetties, and piers have the advantage of gathering various types of data, such as wind speed, sea surface temperature, water column temperature at varying depths, air temperature, and in some cases turbidity and chlorophyll *a*. Stationary platforms have the ability to gather data over a long period of time in a specific, geographically fixed area with little or no maintenance. Because buoys, jetties and piers are spatially fixed it means they are easy to link with remote sensing data. Some important parameters cannot be obtained with stationary platforms, however, such as currents, and are tracked with drifters equipped with GPS units to display the patterns of currents and eddies. Some studies even use data loggers attached to animals, such as birds, whale sharks, and tarpons to derive their movement and associated data, for example temperature at varying depths. Research ships also obtain a substantial amount of data but often these data are more difficult to link to remote sensing data due to the variability of the data to be georeferenced.

Some of the physical parameters of interest to researchers and managers at the workshop were data pertaining to velocity, direction, intensity and duration to monitor larval transport of coral and other marine organisms. Water quality data is another important set of parameters that researchers are interested in deriving from satellite data. One useful parameter that researchers want to examine is salinity, which can be derived, even during cloudy conditions, with synthetic aperture radar. However, much of the information researchers are interested in is found in coastal waters, which are currently difficult to analyze due to the technical designs of current satellite platforms that were designed for the open ocean, not for highly turbid and shallow coastal areas.



A substantial amount of technical effort, such as training, calibration, validation data, and *in situ* measurements are necessary throughout the world if coastal areas are to be accurately analyzed for water quality attributes such as chlorophyll *a,* turbidity, and other parameters, such as total nitrogen and phosphorous, that may be obtained through proxy relationships using remote sensing. Once these parameters are able to be measured with accuracy it will be possible to develop other information tools, such as report cards, and models that will be capable of determining forecasts and trends.

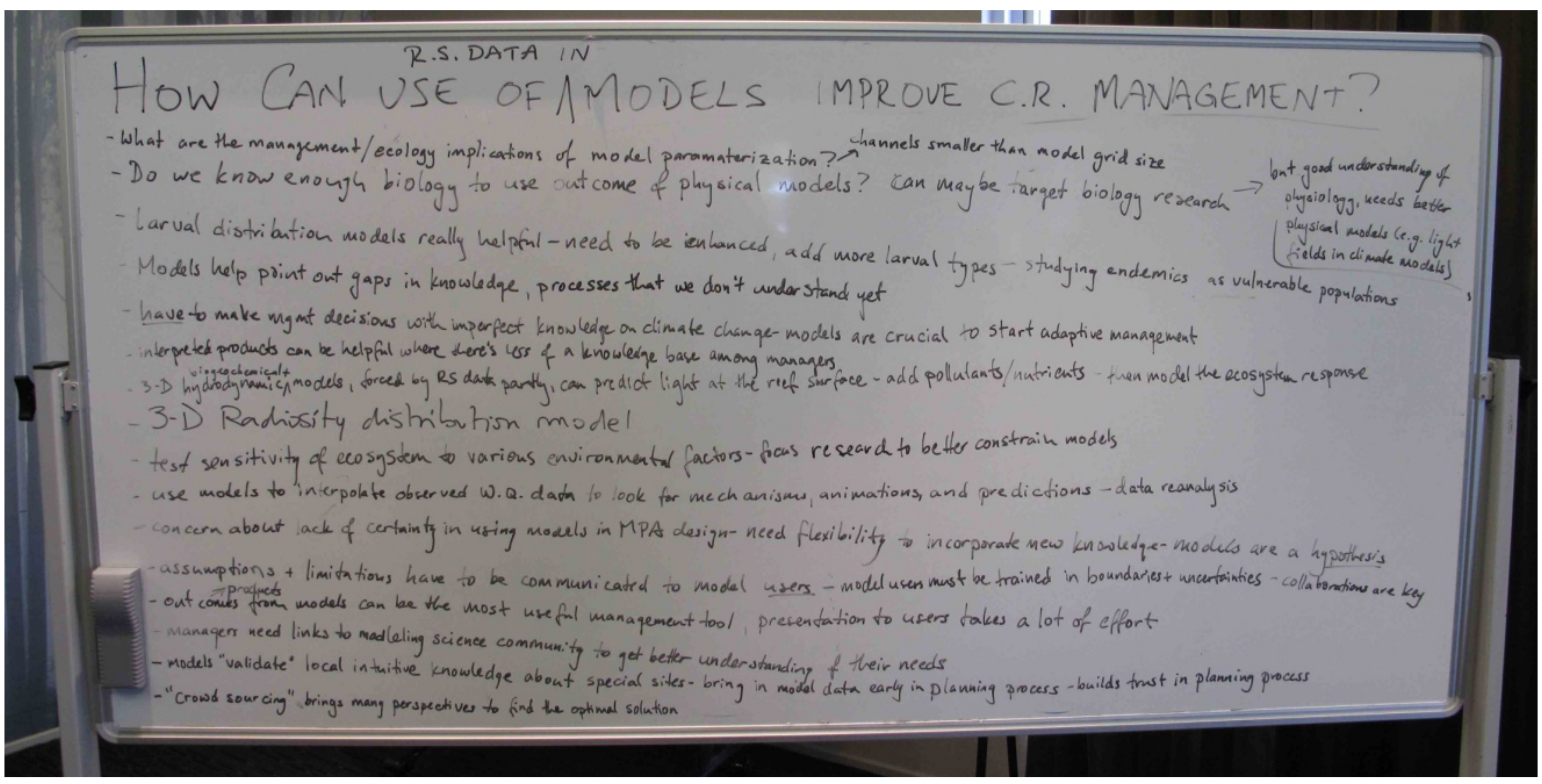
"How can the use of remote sensing in models improve management of coral reefs?"

Facilitator: Scott Heron

The purpose of this discussion was to examine how remote sensing might be combined with models in order to make predictions in relation to items of interest for managers. Much of the work in developing remote sensing products has focused on near-real-time observations and studies in the past using ancillary information, such as climatologies and *in situ* data, from the past. Models are informative on a variety of levels, for instance they let the researcher know when they have enough data but they also let them know that they don't have enough and are missing another important variable that would otherwise allow them to generate a reasonable depiction of an item of interest. A point made by Claire Spillman was that models could be used to design biology data collection programs because they interact both ways, you can feed them data or they can suggest the data researchers need. Difficulties of modeling include that sometimes we do not know enough about the biological systems we are studying, for instance if the resilience of some coral reefs is due to local adaptation or differences in the clade types of *Symbionts*, to use models effectively. Furthermore, many of the parameters we are interested in are changing at such a rapid pace that it is difficult to collect all these data and develop accurate models before conditions have changed again. There are also other management and ecological implications of model parameterization, for instance pixel sizes of remote sensing data may be smaller than model grid sizes.

A biological modeling area of interest included modeling coral reef thermal capacitance, although this is relatively limited by our biological understanding of coral reef resilience as mentioned above. Another biological feature of interest is modeling larval transport using current and weather data. Water quality data was another potential area for modeling. This included the development of hydrodynamic models that incorporate variables like light, chlorophyll *a*, nitrogen, phosphorous, sediment and other stressors to determine how coral reefs are affected in their environments. The modeling of coastal discharge points to determine how salinity changes and where using forecast information and previous flow data was another interesting area of interest. Light stress is another area of modeling interest, which can be determined through the use of 3D radiosity distribution models that depict how light fields interact with coral reefs.

Education and outreach of modeled products cannot be underestimated. Regardless of the quality of the data derived from some models, in some cases managers have to make decisions about resources with imperfect knowledge. From a pragmatic standpoint, Ray Berkelmans pointed out that it is better to handle model product design as an adaptive management process where researchers utilize the data and knowledge available at the moment and trial the models to determine whether they work or not, rather than spend unnecessary time collecting more and more data. It should be emphasized that models are a hypothesis, not a fact or theory. Individuals using models need to be aware of the assumptions, limitations, and lack of certainty that are part of any model, especially ones that incorporate environmental data, such as those used in MPA design. Because ecological knowledge, ideas, theories and data are always changing, models should be designed to be as flexible as possible to incorporate new variables and cofactors. Therefore, it is important to foster strong collaborations between model designers and end users so they understand the boundaries and uncertainties inherent in the models or products and to include others to contribute through events such as "crowd sourcing." In relation to coral reef conservation, it is important that links be established between coral reef managers and the scientific modeling community to better understand their needs and how they can implement products. For instance, climate models are crucial to start adaptive management. Although the production, education, and outreach associated with modeling products takes substantial effort the products derived from models can be invaluable management tools.



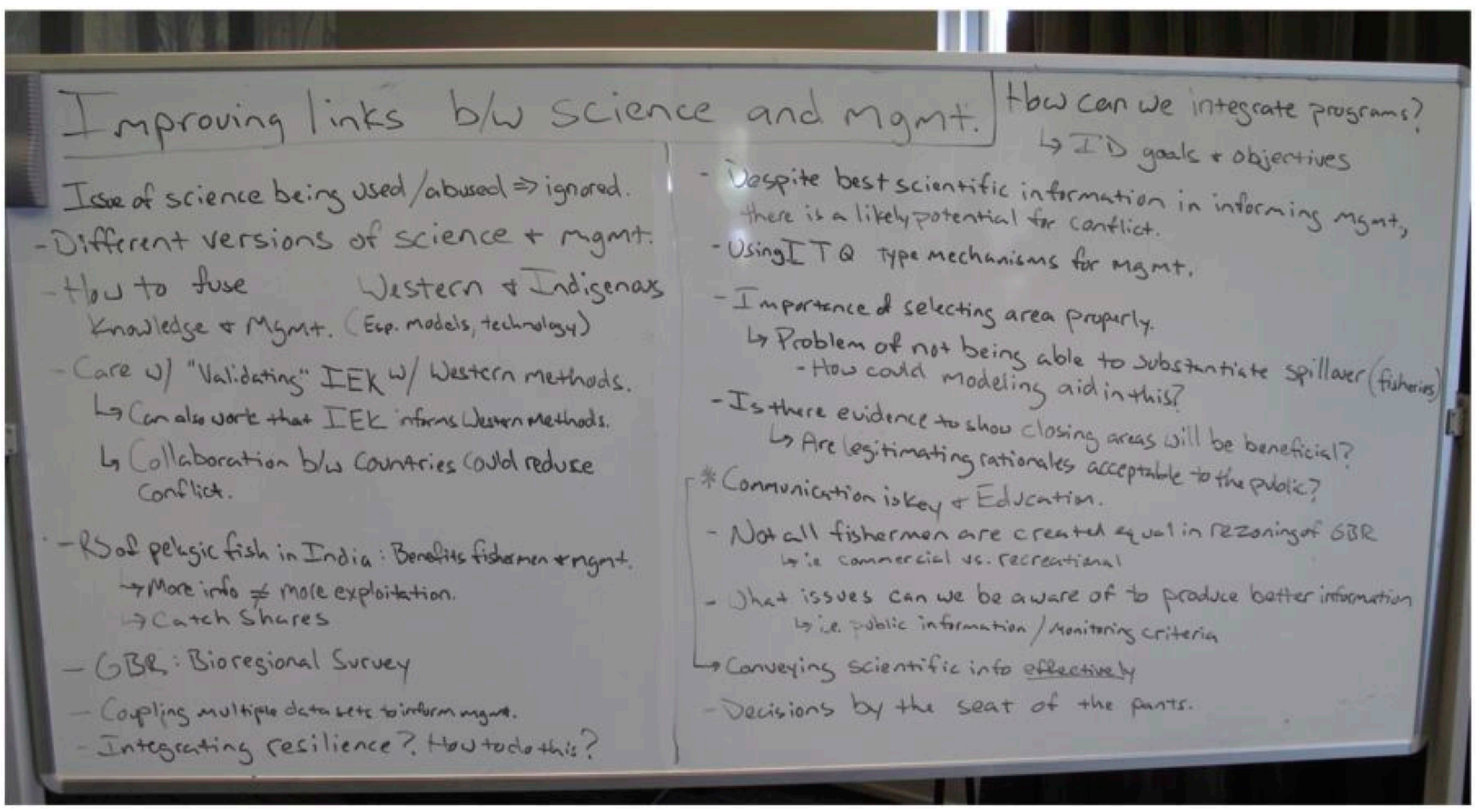
"Improving links between science and management"

Facilitator: Mark Eakin

In the discussion on Improving Links Between Science and Management, communication was a central theme. Expanding on a previous example, Mark Eakin explained how in the case of the establishment of Papahānaumokuākea Marine National Monument (PMNM) a lack of effective communication between policy makers in the White House and scientists in the midst of collecting data for the designation of a marine protected area in the NWHI led to uncertainty about the course of action that would be determined in the designation of the protected area. While acting managers had consulted the public and scientists to determine what kind of management area would be best suited for implementation in the NWHI, the 2006 Bush administration decided to designate the area with the stroke of a pen, resulting in confusion and concern over what the reserve area would include, how it would function, and who would be in charge of it. While the PMNM eventually took the form that the public process had wanted, the uncertainty of the top-down method led to concern as a result of a lack of communication between the former administration and stakeholders of the PMNM. This example led to a broader discussion of how management areas are implemented in other locations throughout the world and what are the most effective ways to communicate with stakeholders to ensure all perspectives are recognized. One situation mentioned the management complexities occurring in American Samoa where there is an indigenous management framework that exists and there are efforts to overlay a western management system. In this case numerous participants noted the importance of not discounting indigenous management methods by validating them with western science. One proposed alternative was to find a new way to move forward that prioritizes the indigenous management methods and incorporates western science if management authorities see a need for it. For example, in the Coral Triangle Initiative, Indonesia, Malaysia, the Philippines, Papua New Guinea, Timor Leste and the Solomon Islands are working together to address these issues collectively. An example from India explained how authorities are using remote sensing to identify where pelagic fish stocks are in order to conserve fish stocks. This may sound counter intuitive, but the data is given to fishermen to fish efficiently through reduced fuel use. Prior to this information fishermen overfished inshore fish populations, which may be linked to pelagic fish populations, used excess gas and time and were not provided with a certain catch. In addition, the information service is shut down during spawning times in order to allow fish to propagate and the fishermen to maintain their fishing equipment. In this case more data does not always mean that the stock will be depleted and it may lead to more sustainable fishing practices.

This led to a discussion on the establishment of no-take areas and catch share fishing practices on the GBR. The process involved in designating these areas has its challenges, such as policy structures and stakeholder support. The challenges associated with the policy structure means that rezoning and other adaptive management techniques can only be changed by an act of Parliament. Stakeholder support is also another challenge when resources are being restricted. In some cases stakeholders were very proactive in particular areas of the GBR, in others it depended on what type of fishermen they were, for example commercial fishermen were against the rezoning while recreational fishermen were for it. One tool that facilitated communication and involvement between stakeholders and managers was called "Trader," which divided the GBR into polygons based on bio-movement so stakeholders could participate in moving and negotiating for areas they would be willing to trade for other areas. Future improvements in consideration include short-term flexible arrangements and efforts to integrate resilience into the management regiment.

Another item that has the potential to advance communication between managers, scientists, and policy makers is additional biological understanding. Because limited information is not fully supported or accepted by stakeholders or policy makers, enhanced biological understanding has the potential to make scientists and managers more credible. In one case example it was mentioned that scientific studies should attempt to answer questions in relation to management in order to legitimate management decisions, such as the effectiveness of no take zones in enhancing fish communities. Fishermen in the Florida Keys often suggest that permanent closure areas are not effective at this and little research has been shown to say that they are. Again, communication is key to these relationships and interest on the part of scientists was voiced in relation to understanding the questions managers have, their priorities, and how scientists can help them build credibility. One alternative mentioned is to approach stakeholders with perspectives that are not rooted in science, such as biodiversity, but in concepts related to them, such as allowing the field (sea) to lay fallow in order to enhance crop yield (fish biodiversity). Despite efforts such as these, in the case of the rezoning of the GBR it was pointed out that even though an adequate amount of established science was used in the process, stakeholders were still critical of the rezoning effort. Communication between managers, scientists and stakeholders needs to start with an understanding of the goals and objectives of each party and the desired outcomes of those parties. Currently there is a lack of understanding on the part of scientists regarding the day-today needs of managers and this was one area where participants said they could move forward.



"Use of water quality and light over coral reefs for future management products"

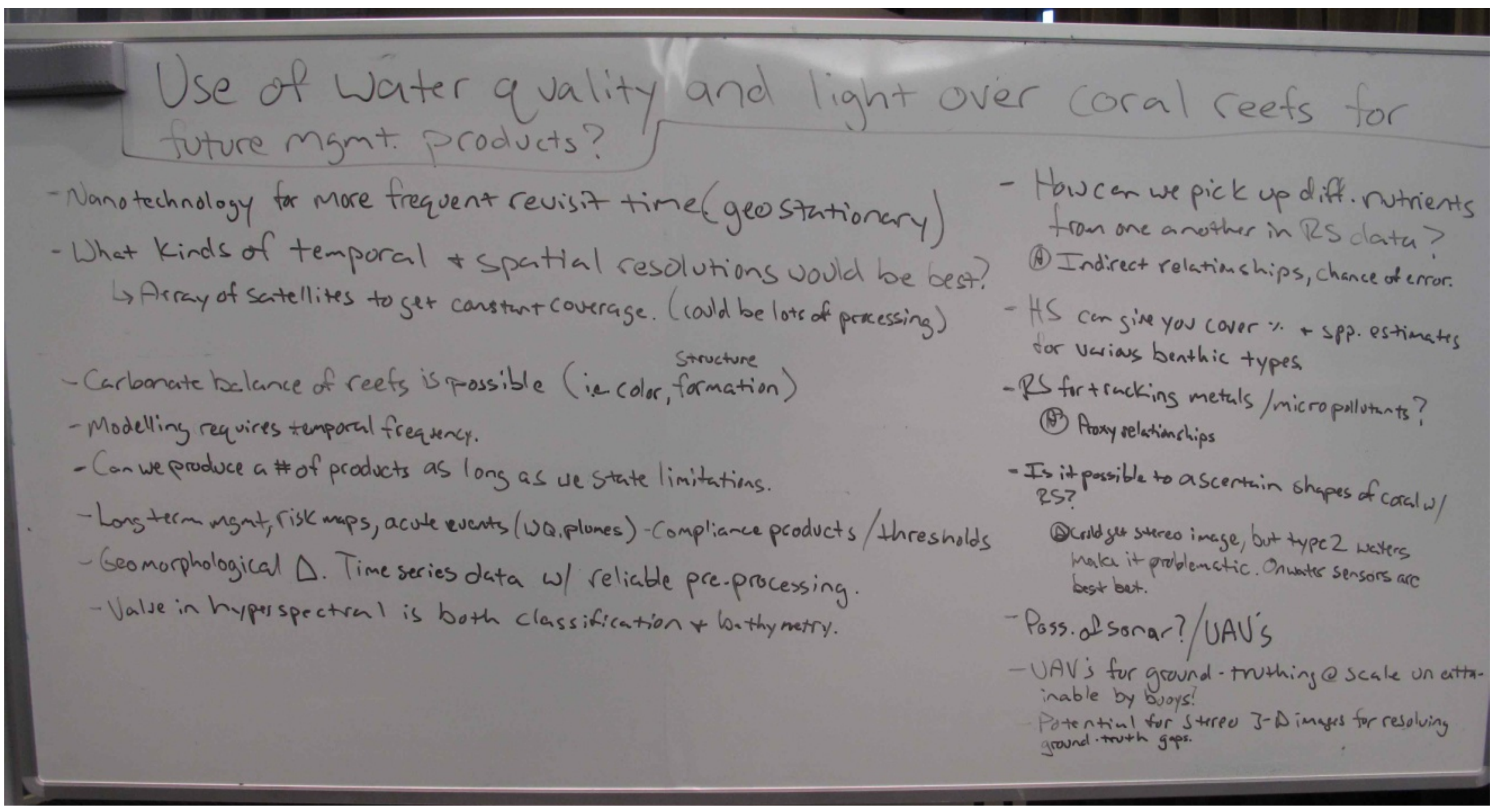
Facilitator: Arnold Dekker

Workshop discussions ranged from developing capacities that are available given current technologies to the discussion below, which focused on how to observe parameters of interest to managers using innovative techniques or technologies that have yet to be developed. The discussion began with a dialog related to sensor platforms and which ones would be useful given constraints of current platforms. Primary restrictions of current satellites include environmental interferences, such as cloud cover, large pixel sizes of geostationary satellites, long revisit times of polar orbiting satellites and the lack of spectral band combinations that are useful in coastal waters or coral reef applications. Alternative platforms and sensors that were discussed and could possibly achieve these interests included:

- Blimps and towers that could provide data with minimal atmospheric effects.
- Geostationary nano-sensors that could be deployed in a specific area at a height below cloud cover for repeat coverage with minimal atmospheric effects.
- Satellite constellations with optimal spectral and spatial resolutions that would be capable of frequent revisit times. Intensive amount of processing could be a caveat.
- Unmanned Aerial Vehicles (UAVs) that are capable of longer flight times, obtaining multiple scale data, and collecting 3-D images for resolving ground-truth gaps.

Parameters of interest to researchers at the workshop were representative of a variety of tropical marine ecosystems. Seagrass was a recurrent ecosystem of interest to researchers given its limited amount of remote sensing analysis when compared with the remote sensing of coral reefs. Seagrass parameters of interest to researchers included productivity and seagrass cover. One idea for a product was to combine seagrass cover and species type so it is possible to estimate biomass. Characterizing benthic properties was the dominant conversation and discussions included a variety of topics. Coral reef parameters of interest included productivity, cover, complexity, roughness, and rugosity. It was noted that hyperspectral satellites could provide percent coral cover, species estimates, benthic classification and shallow bathymetry. From a geomorphological standpoint, researchers were interested in whether it is possible to track coral reef change via carbonate balances. One idea was to track this by coral reef color and structure formation using high spatial resolution data with *in situ* validation. While potentially useful, it was noted that it would be difficult and expensive to track live to dead cyanobacteria cover. Topological complexity was another area of interest. Researchers would like to distinguish between branching and boulder coral but this is unlikely to obtain because submerged shapes need to be obtained via a stereo imaging device, not an overhead device like most remote sensors. Obtaining this data from satellites would require using two satellites obtaining optical data from off-nadir views. This would make processing difficult, especially in case two waters. The best alternative to this that was mentioned is to use ocean surface detection using a stereo sonar system onboard a ship or boat.

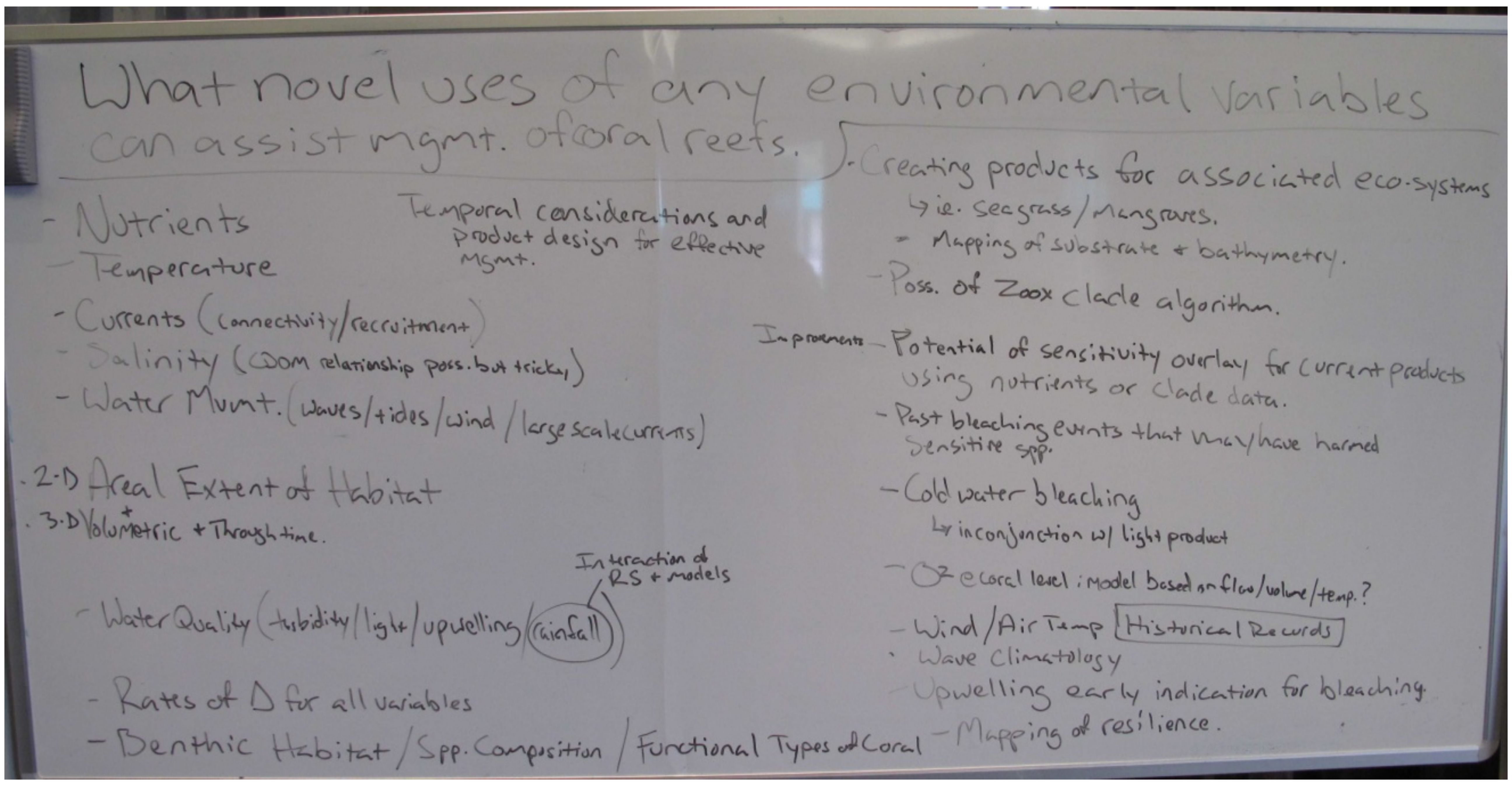
Water quality parameters that adversely affect coral reefs were also a central theme of discussion. The central question in this discussion consisted of "how do we pick up different nutrients form one another is remotely sensed data?" While some water quality parameters are capable of being identified using remote sensing instruments in clear, case one waters, such as turbidity and chlorophyll *a*, identification of these same water quality parameters in coastal (case two waters) areas are challenging due to the effects of atmospheric aerosols and optically shallow waters that create a backscattering effect when the benthic substrate is visible. While researchers are working on these complicating features more work is to be done, especially if we are to determine more specific parameters such as nitrogen and phosphorous levels. Some researchers have suggested that these, in addition to other parameters such as metals and micropollutants, can be determined by indirect or proxy relationships with other parameters, such as chlorophyll *a*. Despite the possibilities, there is a substantial chance of error if these parameters were obtainable. Furthermore, technical hurdles for accurately assessing water quality in case two waters still lie ahead of any analysis of this kind. However, the possible products that could be obtained, should these analyses become possible, include risk maps, acute event maps, and compliance products. With biologically established thresholds, high temporal frequency modeling, substantial *in situ* water quality data for characteristic reef areas throughout the world and technical advancements, this information could be compiled into remote sensing products of great value to coral reef managers.



<u>"What novel uses of any environmental variables can assist management of coral reefs?"</u>

Facilitator: Tyler Christensen

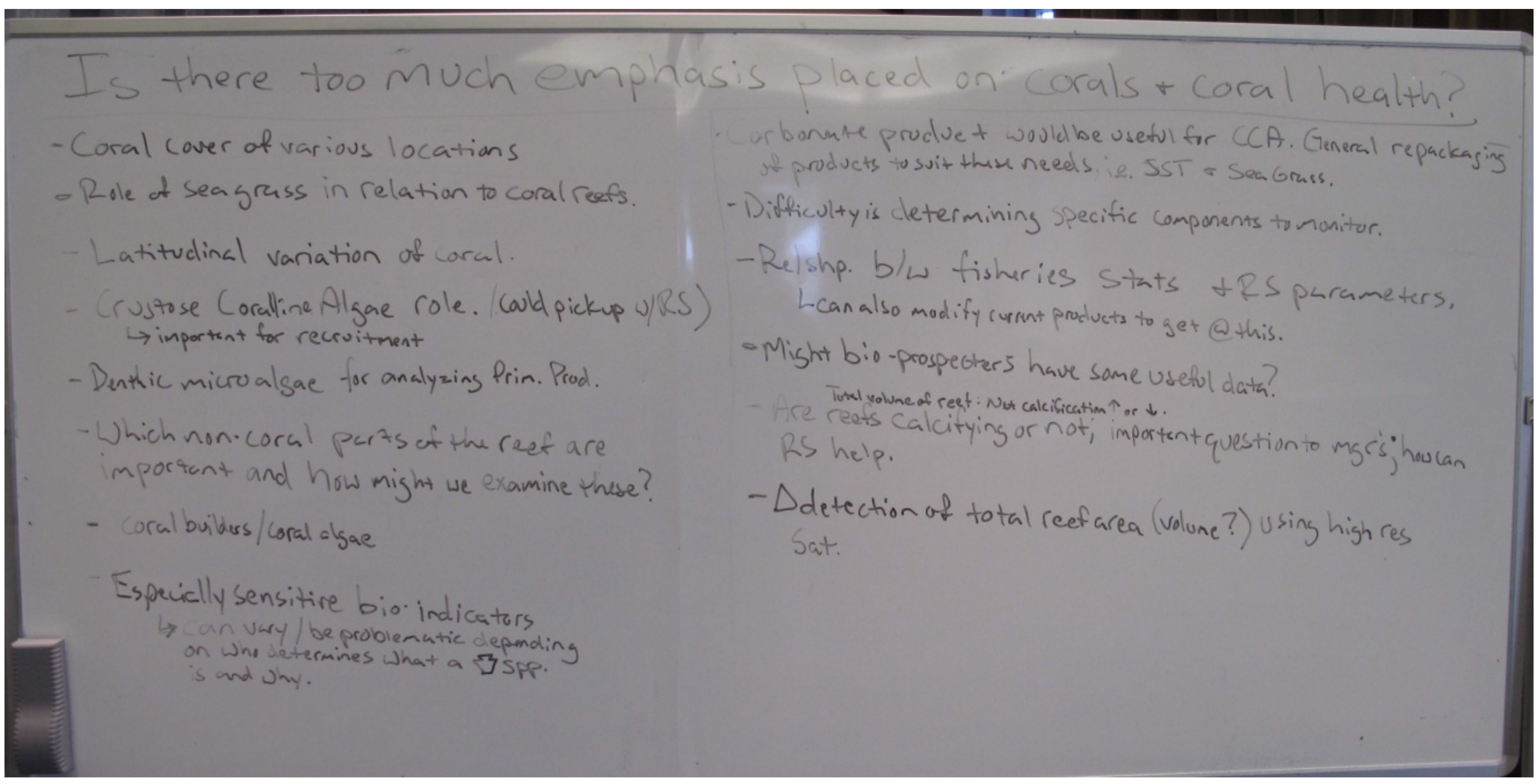
This discussion focused on considering environmental variables broader than water quality variables. The discussion began with an overview of previously discussed topics, such as nutrients, loss of coral cover, water movement, waves, tides, currents and winds to understand how these affect temperature, oxygen depletion, connectivity and recruitment, and areal / volumetric extent of coral reefs (3D / 4D) through time. Additional parameters of interest that were mentioned included water clarity as indicated by degree of turbidity, origins of nutrients, for example from upwelling or terrestrial input, and the rate of change for all of these variables. While many of these parameters can be measured on the ground, finding automated ways of monitoring these would be beneficial. Precipitation was another parameter that would be useful as an indicator of a water quality event from land-based sources of pollution. One idea was to combine remote sensing with modeling to more thoroughly understand rainfall events due to the limited capacity of remote sensing data to observe these events as a result of cloud cover. A commonly held observation of coral reefs, which is validated with the list of parameters mentioned above, is that there are a number of complex interactions that affect coral reefs. One idea for depicting this using remote sensing data was to develop an overlay of coral reef sensitivity based on the interactions of relevant parameters. While biological understanding and the linkages between parameters and the effects these have on corals are not thoroughly understood, with more advancement in these areas it would be possible to explain quizzical phenomenon, such as when researchers think coral reefs should be bleaching due to elevated temperature but they are not. One comment suggested that it may be more important to focus efforts on determining the type of coral for now, which is currently being done in limited spatial scales, and focus on zooxanthellae clade identification later. Salinity is another parameter of interest, which can be remotely sensed by two current satellites, the European Space Agencies SMOS satellite that has a 200 kilometer (km) spatial resolution and the National Aeronautics and Space Administration, Aquarius satellite that will be launched in 2011 that has a 100 km spatial resolution. Unfortunately both of these sensors deliver data at a resolution and accuracy that are not beneficial for coral reef research. While flood plumes can act as a proxy for salinity levels, determining salinity levels around islands with rainfall runoff can be more difficult to ascertain. The occurrence of the 2010 cold-water mortality event in the Florida Keys led to numerous discussions about developing a cold-water mortality product. A couple of the participants had noted that this would be of interest and that there was field and lab data available that could aid in determining thresholds in areas like the Great Barrier Reef. Oxygen was another parameter of interest for developing thresholds and remote sensing products. Corals are very tolerant of low-oxygen conditions but associated organisms in these areas may benefit from a product like this. Flow and volume of water in these areas, detected by buoys and incorporated into models, may lend enough information to develop a product that raises warnings for managers. Given the complexity of this issue, it was noted that other parameters should be considered such as overfishing leading to zooplankton consumption and changes in wind and upwelling conditions. Long-term records of wind and direction, air temperature and wave climatology would also be beneficial. But it is important to note that localized phenomena can stand out from regional trends. In an example from Ray Berkelmans it was pointed out that upwelling has been one indicator of early bleaching in some locations on the Great Barrier Reef. It is suspected that this is the result of the East Australian Current speeding up during doldrum conditions but there is some debate as to whether this is upwelling in a strict definition of the word. Resilience was another concept of interest that would be of use to managers if it were possible to map out these areas using parameters derived from remote sensing to illustrate resilient and vulnerable areas. For these products to be useful to managers it is important that the scales, both spatial and temporal, are aligned with the events taking place in order to be useful to managers. The issue of past thermal histories affecting coral reefs was one of the final topics. The question was posed of whether corals that are exposed to more variable conditions may be more resistant to bleaching? In general a lack of consensus was expressed with the prevailing thought being that due to variability, multiple stressors, and numerous species of coral it is too difficult to determine a threshold that would be accurate enough to apply to a broad amount of coral species. Ideas for the future included looking at where future habitats may be based on different variables, which is supported by one study that found edge areas in marine environments have been important in the evolution of coral reefs in the past (Budd and Pandolfi, 2010). Another idea was to investigate the possibility of a zooxanthellae clade algorithm that could be used in previous and current products.



<u>"Is there too much emphasis placed on corals and coral health?"</u>

Facilitator: Mark Eakin

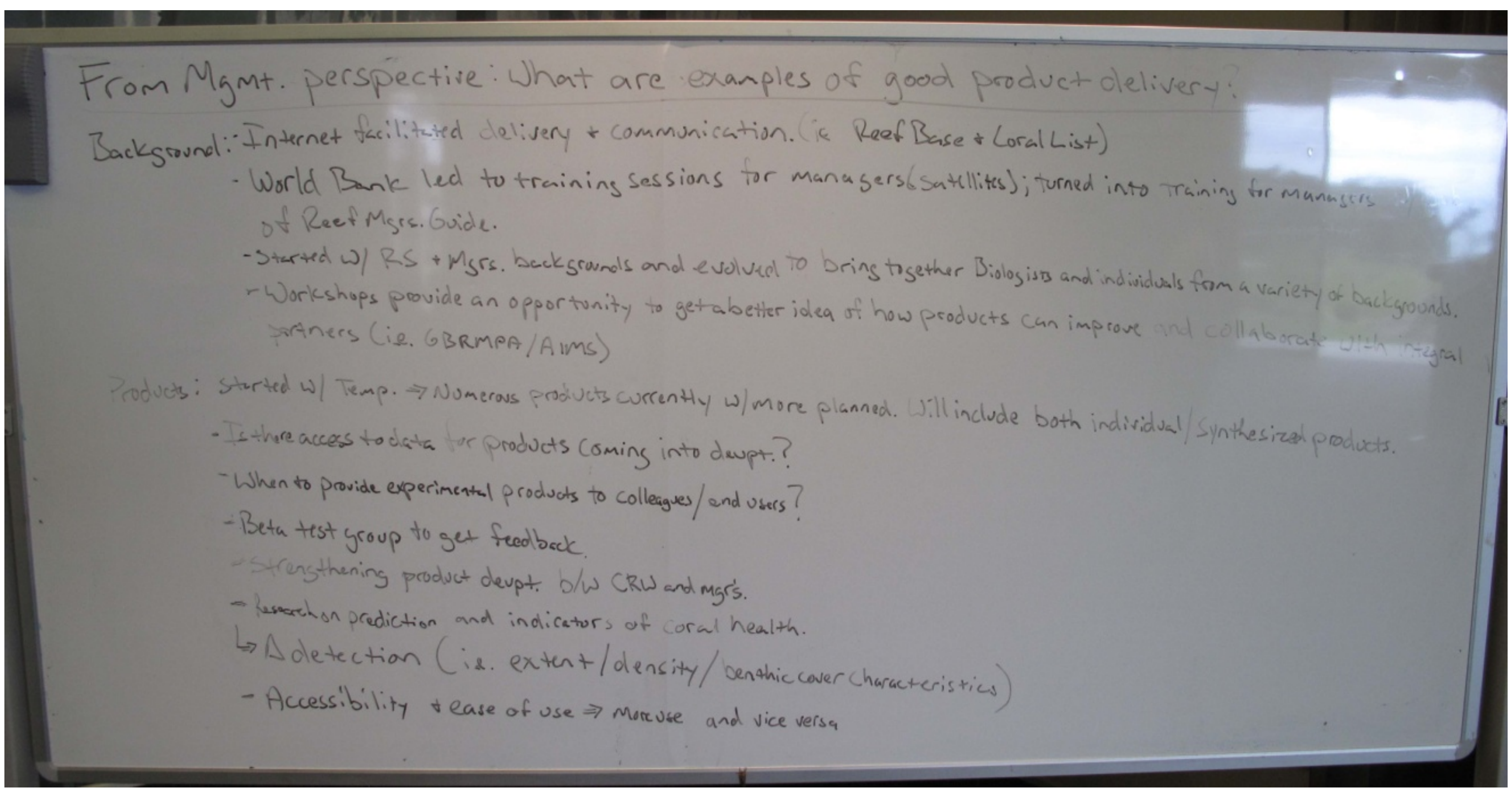
In this discussion the emphasis was on determining non-coral products that are capable of assisting with the management of coral reefs. In order to obtain this information, participants mentioned that it would be beneficial to determine the percentage of coral within areas in order to ascertain the remainder of benthic habitats within those areas, such as sand, and seagrass. An emphasis was placed on looking at the entire ecosystem because this would allow researchers to observe linkages between associated ecosystems and how these interact and influence one another. While percentages of coral and associated habitat were noted as important criteria for informing managers, calcification rates of coral reef growth or decline were also mentioned as information of interest to managers. If satellites could obtain standing stock of calcium carbonate over a large scale to estimate changes in the volume of reefs over time managers would be able to use net increase or decrease in calcification as an indicator of reef health or reef condition. These same products could be repackaged to develop products for non-coral substrate types like crustose coralline algae. The interconnectedness of these ecosystems necessitates an understanding of areas that are dominated by non-coral species. As Billy Causey pointed out, crustose coralline algae provides a base for recruitment and increased sea surface temperatures not only affect coral but also reef fish, which can be susceptible to disease during these times. Seagrasses were another area of interest researchers pointed out. Researchers explained how it would be helpful to have a morphological descriptor that described the location of seagrass in relation to coral reefs. From a broader perspective it was noted that there was little agreement regarding the main actors on the reef and possible bioindicators, keystone species, or thresholds. This is one area that may be contentious amongst biologists but needs to be addressed and agreed upon if science and management is to inform policy. Additional components included considering latitudinal orientation in regard to crustose coralline algae and the effects of ocean acidification on high-latitude coral reefs. One challenging aspect of differentiating between coral and crustose coralline algae with current remote sensing satellites are the similarities in their spectral signatures, which makes classifying, and therefore separating the two substrate types, difficult. Benthic microalgae, however, are everywhere and has a different spectral signature, which can be picked up in order to gauge primary productivity. According to one participant, the European Space Agency is working to produce high-resolution products for coral reefs sometime in the near future. Additional organisms that were mentioned include sponges, urchins, seaweeds, and sensitive species. One suggested method that would allow researchers to broaden our understanding of environmental stressors of associated species, for example sponges, is by collaborating with the bioprospecting community to know what they look for. Another useful product currently in use that received interest was using change detection with coral reef areas to estimate healthy or unhealthy trends. Other suggestions for products included the mapping of fish related disease outbreaks as a result of temperature and an information tool that would suggest when fishing quotas should be reset.



"From the management perspective, what are examples of good product delivery?"

Facilitator: Randy Kosaki

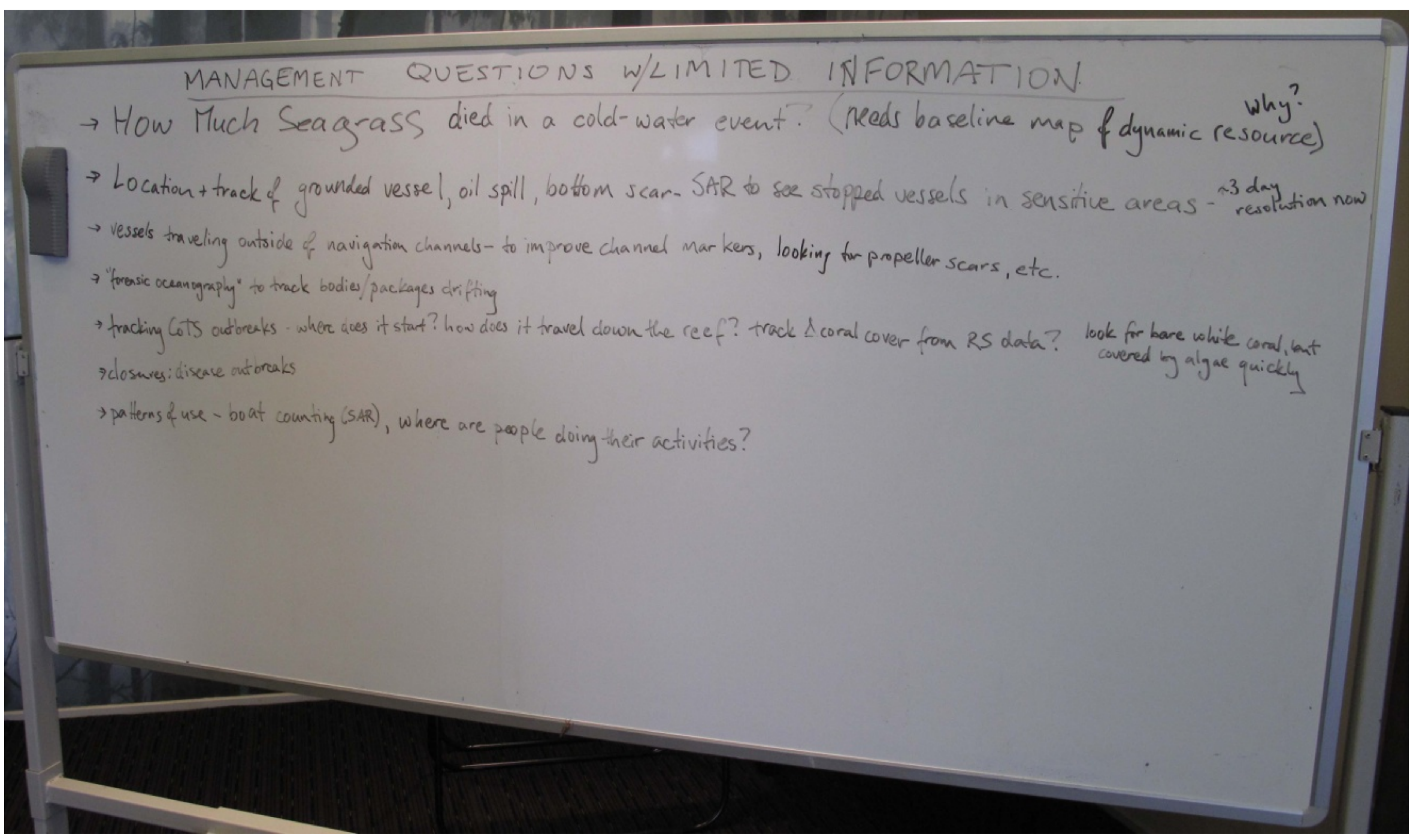
In this discussion workshop participants focused on how product delivery of remote sensing products could be improved. Associated questions included "What could / should be developed to help managers ingest satellite data?" and "How to best help managers with uptake of the use of satellite products?" In order to provide a context, the historical origins of delivering remote sensing data to managers was described by Al Strong, who is the founder of Coral Reef Watch. He explained how the Internet facilitated the dissemination of Coral Reef Watch bleaching products in addition to e-mail exchanges that allowed both outreach, through awareness, and dialogue, through comments and conversations in Listserv forums such as Coral-List and ReefBase. A coordinated effort was undertaken by individuals like Billy Causey and Jim Hendee to create databases of coral bleaching, and with increased awareness of the effects of climate change, funding was available through the World Bank for supporting the first of these coral bleaching workshops. Al Strong's experience with meteorology and his familiarity with meteorology's development of products inspired him to innovate new climate change products that could aid in the monitoring of coral bleaching events. This was a primary emphasis of the first workshop. In conjunction with Peter Mumby in Palau, the strategy was to use the Centers of Excellence to provide training on Coral Reef Watch products, which were developed in the U.S. and were conceptually similar to other weather service products. As William Skirving pointed out, in the beginning the emphasis was on the satellite, remote sensing side of the CRW tools, but managers were asking how they would be able to better manage reefs under the influence of climate change. As a result, a Reef Managers Guide was published which was built upon providing managers with the next steps they could implement to protect coral reefs from climate change. Workshop attendees worked with GBRMPA and received funding from the CRCP to build a curriculum of which satellite tools were a small part. With feedback from participants over the years the curriculum has changed and grown. A comment echoed by multiple Coral Reef Watch participants is the culture of developing tools for multiple audiences, and education and outreach has been a central component of this effort. This understanding is gained through interactions and integration with managers and it was central in the development of the Reef Manager's Guide with collaborations with people like GBRMPA's Paul Marshall. CRW products started with temperature but are currently trying to capture a lot of the complicating factors, such as light, and nutrients. Developing accurate, operational products of some of these parameters are possible and some are not. Another question was whether some of these parameters can be combined or if they are stand-alone products. Some of the products that CRW is currently working on, such as the light stress damage, can be used not only with coral reefs but also other aquatic plants. One challenging issue was how to develop thresholds for some of these parameters, such as water clarity, where it is not as clearly tied to reef impact. For remote sensing scientists it is important to have substantial past data for previous events and biological thresholds that can be used to train and calibrate remotely sensed data. These data are largely collected by managers and biologists and can only be useful in satellite products if these data are known. If these data are known it is possible to develop experimental products and a couple of questions were raised as to how and when to release these experimental products. Ideal conditions included having Beta testing groups that would involve scientists, managers and product developers who would test and use experimental products on the Internet and provide feedback. Unfortunately this group of users is extremely busy and it is difficult to get consistent support. Another issue with new or experimental products is the issue of conflicting reports with other systems. For example, there was an instance where the CRW outlook for an area of interest to GBRMPA was in disagreement with the POAMA outlook. While these were acknowledged as problematic features of experimental products, coral reef managers explained that they would rather have false starts and areas where data didn't match up as long as the developers of the product were ready to explain and provide managers with reasons why the products were not depicting actual conditions on the ground. Managers also explained that in-person introductions of experimental products would be more informative than e-mails introducing new products on the Internet. A product of interest to coral reef managers is an ocean color product that is capable of indicating sediment plumes and chlorophyll *a* concentrations in coastal areas near and over coral reefs. Unfortunately technical constraints have made this difficult data to accurately obtain. The first step is to obtain this data using plane-based hyperspectral data, develop water quality products, and then apply the effective algorithms to satellite sensors. This data processing can be used in associated ecosystems, such as seagrass beds to look at changes in extent and then bed thinning. Another important parameter in seagrass ecosystems is sediment type, specifically dark versus white sediment. A substantial amount of data has been gathered for this in Puerto Morelos, Mexico. While some members were skeptical about the ability to spectrally distinguish what was in the water column and what was on the surface of the bottom, it was pointed out that while there are limitations, if the spectral signatures are distinct there are ways of obtaining this data. The question was raised as to where we are at in regard to informatics tools that would aid in analyzing these changes automatically. Vic Ciesielski noted that blatantly different surface types would not take much machine learning to detect, but subtle changes are more difficult to detect and determining when that change is significant can be a tough task. In general the two primary types of products managers are interested in are predictive and change related remote sensing tools. Managers noted that anything that can gather information without having to schedule and pay for a cruise is beneficial. Furthermore, the more accessible a tool is, the more it will be used.



"What issues are managers having to respond to in short time frames with little information?"

Facilitator: William Skirving

This discussion focused on ways that satellite remote sensing data could assist in providing information to managers in cases where they were required to make decisions with limited information and time. The first topic of interest was how much seagrass had died off in the cold-water event in Florida of 2010. Questions arose over how to determine a baseline due to the yearly changes seagrass beds experience. The second topic focused on vessel groundings, which require an immediate response. Useful data would include vessel location, path, track and spills. Once the vessel is removed, scar extent and recovery could be assessed. Useful platforms and sensors that would provide this data include Landsat data, and during cloudy conditions, synthetic aperture radar (SAR) could be used to track this and report if ships enter or stop in a sensitive area. Even MODIS data can be used if the spill is large enough, as was seen in the 2010 Deepwater Horizon oil spill in the Gulf of Mexico. High-resolution satellite data and aerial photos were also mentioned to be of use if ships were navigating outside prescribed channels and if they possibly damage seagrass beds and reefs. A forensic use of the data could be to track drugs and bodies if satellite and current models were used in conjunction. Another use that would require a frequent temporal revisit time is the outbreak of Crown of Thorns Starfish (COTS). It would be useful to track the outbreak of COTS in addition to the pattern of the outbreak, but it would require a platform capable of a frequent revisit time due to affected areas only staying white for two to three days. Additional items included monitoring events that led to closures, such as coral disease outbreaks and use patterns of locations where people conduct their activities.



<u>"What other variables, tools, and information would be useful for managing coral reefs?"</u>

Facilitator: Roberto Iglesias-Prieto

In the final discussion of the workshop participants discussed many creative ideas for developing products that would be of use to managers. One idea was to build on the projects mentioned in the presentation by Jane Hunter that would build a central data integration repository for collecting science data, information, photos and citizen science data. Through the use of data networking websites people could have a forum where they could provide information on environmental events by uploading pictures from their Smart Phones and other devices. Another idea was to use something like facial recognition software to assist researchers and participants with the identification of coral species or diseases. While machine learning capabilities of discerning numerous images taken under a variety of conditions may be difficult, image retrieval was recommended as a suitable alternative that would retrieve images that are closest to an unknown image and then the user can determine which image/example is the one in their image. Tools such as these can be incorporated into a Smart Phone application that could be used in the field. Then the data can be uploaded to a site that makes the information available to other users through the data sharing/networking framework mentioned by Jane Hunter. The utilization of outreach tools for influencing policy was also mentioned. Outreach tools that were discussed included time-lapse video, animations, or pictures of how water quality or reef conditions (good, moderate, and bad) have changed over time. In pictures or video where changes occur, but are not noticeable to the untrained eye, specific areas could be modified with color to highlight the affected areas. These materials could then be posted onto media outlets, such as You Tube. One concern is the interpretation of remote sensing imagery as abstract. One way to address this was to have pictures or video from a particular location next to a remote sensing image with the location indicated. If the remote sensing image and the water quality image were placed next to one another in a video or poster it would be possible to illustrate, for example, how sediment plumes can be spotted on remote sensing images, in addition to how the water quality conditions change. There is an abundant amount of technology for these purposes from security and other businesses. Cameras are currently available with fluorometers for showing *in situ* chlorophyll and some cameras have options like 360-degree views and windshield wipers for removing material from the lens. Some of these technologies are near implementation and one example from the workshop mentioned a project that will place a camera on a beach to record the accumulation of beach marine debris over time. Another topic of interest involved the circulation of water around coral reefs. Satellite data could show distribution of wind, wave direction and energy levels at virtual stations. When combined with tidal and climatology data, for instance blended wind products with IMPACT wind climatology, this information could show unusually calm periods. This information would be useful for examining parameters like doldrums that contribute to bleaching events and for tracking coral spawning events and oil slicks. One challenge with tracking coral spawning events is that coral larvae do not float on the top of the water. Furthermore, only a limited amount of wind energy influences surface currents (roughly 3%) and low wind speeds are more accurate in accurately depicting where coral larvae go than high wind speeds. Therefore, one suggestion was that high-resolution hydrodynamic models are needed in conjunction with good bathymetry to best analyze larval dispersion. Ocean acidification was also mentioned as a useful tool. One of the primary challenges of developing this product that participants mentioned is the lack of *in situ* data. While more monitoring efforts are being implemented from a variety of platforms, such as *in situ* monitoring stations on the Great Barrier Reef and NOAA vessels. While having these additional platforms is beneficial, the data collected are relatively limited spatially. This information is useful for scientists interested in a specific location. But for managers who may be interested in a broader spatial area, the data are most useful when looking for hotspots of ocean acidification, which can aid in making water management decisions. Because ocean acidification is such a subtle and unseen environmental problem by the public, this data is also useful to managers for outreach and awareness. The disease algorithm that is being created by Coral Reef Watch will be able to give a seasonal outlook based on winter conditions and also near-real-time risk maps in the summer once it is improved. The hope is to provide managers with an advanced warning system for coral diseases so managers can target their surveys. Because some diseases are not related to temperature the disease product will only work with some disease outbreaks. However, those diseases that are associated with temperature will be predictable. This link between temperature and coral disease prompted thought on whether previous years in which the Florida Keys experienced warm winters allowed diseases to continue into following years and whether the 2010 cold front would constrain diseases in 2010. Fresh water is also known to cause disease outbreaks in some Australian locations, like Magnetic Island. One idea for a product was to include coastal runoff events as an additional stress that influences coral disease. In summary, there are a variety of remote sensing products that can aid managers and researchers in understanding the threats that coral reefs face. In order to make them as accurate as possible the scientific community has a long road ahead that requires a substantial amount of biological, physical, and remote sensing research.