APPLICATIONS OF ISES FOR THE OCEANS*

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I will discuss my interests in oceanography and acquaint you with how some oceanographers feel concerning the need for direct broadcast, why, and what type.

I am particularly interested in the role of the ocean in carbon storage in sequestering. Through fossil fuel burning, approximately 5 to 6 gigatons of carbon are emitted into the atmosphere each year. Half of that amount stays in the atmosphere, and it is thought that about half of the remaining carbon goes into the oceans. The ocean biota represent a small pool, but they overturn very rapidly. In fact, this very small pool of carbon represents a mechanism that has sequestered over geological time 99.99 percent of the carbon on Earth. If you have read any of the Earth Observing System (Eos) literature, you have seen a figure of the carbon cycle. Most of the carbon reservoir is in sediments of marine origin, and our main interest is the ocean phytoplankton that is typically studied through ocean color. Phytoplankton represent a small biomass, but through eons of fixing carbon particles and sinking in the deep ocean, most of the carbon on Earth has ended up in marine sediments. Although the annual input is very large because of such processes as dissolution of carbon and deep water formation, the signal that represents this deep carbon storage is very small. We are looking at a very small signal difference between very large signals. To determine this difference really requires time series and comprehensive observation, as well as a great deal of in situ work understanding these processes; this entails ships out in the ocean and moored instruments. Many magnifiers of global processes exist, such as enhanced production in deep ocean due to aerosols (i.e., continental aerosols, Asian dust, and Saharan dust, which has a lot of iron). These magnifiers fulfill some nutrient limitations. A particular species or a group of species of phytoplankton called coccolithophores produce dimethyl sulfide, and it is thought this parameter might play a role in cloud formation. Due to eutrophication of estuaries and rivers, we are seeing enhanced production in coastal regions, which again affects or magnifies anthropogenic effects and carbon cycling. This observation is especially interesting because ocean colors are flow visualizers and signify mixing changes.

We have been processing Coastal Zone Color Scanner (CZCS) data and were able to generate a composite representation of 32 months of observations. We can see upwelling at the equatorial region, high productivity in the Northern latitudes, large production in the Southern oceans due to mixing, upwelling along the coasts of Africa, Peru, and the Western U.S., Amazon river outflows, and monsoonal areas. This composite basically represents the general picture that we had before satellite data. Things become interesting when we look at interannual variability. By transforming data like these, we can estimate the total zonal production and how much carbon is fixed (as a function of latitude). From this we calculate how much carbon is going into the ocean biomass, with time. The data set contains 32 months of data beginning when Nimbus 7 was launched; from this we can estimate a total carbon fix per day, which is equivalent to approximately 60 gigatons of carbon per year. The anthropogenic output is one-tenth of that amount. If one-tenth of this gets fixed by phytoplankton and ends up in the deep ocean, then all the fossil fuel CO_2 is used up and there is nothing to worry about. But it is unlikely that the number is that high; it is probably closer to 1 percent. Notice that there is a hint of a secular trend.

What we measure with the satellite is radiance in four spectral bands, and from that we look at color shift in an empirical relationship between the water-leaving radiance and the amount of chlorophyll pigment. Chlorophyll pigment is used as a measure of biomass. It is also the primary photosynthetic pigment, and these chlorophyll concentrations are a good indication of how fast the plants are growing. Plants in the ocean are not like plants on land. If you look at plants in the forest, you see only carbon trunks. The carbon stays around for a long time. But, the plants in the ocean are unicellular; they have no support structure. They divide once a day so the biomass is a good measure of how strong they are

*Paper taken from workshop recordings.

growing. If they are not growing, they are sinking to the bottom or they are being eaten. There is a very simple relationship therefore between the chlorophyll concentration and the total carbon fix.

We can see trends, and for the first time, we can look at interannual variability. For example, we see the difference in CZCS data between winter and spring. In spring you get more sunlight, plants grow faster, the water column stabilizes, and the nutrients are fixed. Between winter and spring there is a tremendous increase in biomass and phytoplankton in the ocean, and a substantial fraction of that will sink in the deep ocean, be removed from contact with the atmosphere, and represent a short-term repository for carbon. One-tenth to one percent will get incorporated into the sediments and then enter a pool that is on a geological time scale. It is apparent from 1979 data that there is a spring bloom and a fall bloom (we see a much smaller spring bloom in 1980, a much larger fall bloom in 1981, and a spring bloom in 1981). This delineates some of the interannual variability that we see, which represents anthropogenic carbon input. So the variability in the ocean is large with respect to how much anthropogenic carbon is going in. The southern oceans receive outflow from rivers, where the winds are more constant and show very little interannual variability. The name of the game is how variable is the ocean, and for the first time, with satellite data sets, we can look at interannual variability. We have never been able to do that on these scales before from ship data.

In summary, our ocean estimate is 61 gigatons of carbon; compare that to 6 gigatons of carbon output by fossil fuel. The new production, which is the production that is due to nutrients coming up from underneath the ocean due to upwelling, is approximately 23 gigatons. We would expect that an equivalent amount of carbon gets sunk with residence times on the order of decades to centuries, and if 10 percent of that gets buried, then we have essentially solved the missing carbon problem. I don't believe any of the carbon budgets, but understanding the process of what you see in the satellite image and relating it to what happens to the carbon inside the ocean are the subjects of a major international effort called the Global Ocean Flux Program. Currently, there are field pilot studies occupying a transect from Iceland down past the Azores. If you understand the onset of the spring bloom and how much carbon goes deep into the ocean, you understand that the winter nitrate concentration is the primary limiting nutrient of phytoplankton production. Another issue is how deep the water mixes, because this is a prime forcing function. We are interested in wind stress and mixed layer calculations and running physical models in order to set up a physical regime with which to determine the biology. To give you an idea of the scale of this, consider the area that is occupied by this field experiment. The bloom starts first in the south. The U.S. was there in April, and now as time goes on, the bloom progresses north so the activity shifts toward the north. The Germans are there, our P3 aircraft is there, along with one Canadian vessel and the British who come and go. A Netherlands ship was also involved. My point is that this occupies a very large area of the world, and right now we have no way of determining what is happening on a regional basis. To look at some of the historical data, we need to know where to put stations. These stations were chosen because they were close to the European support and because they had past moorings there. One might move those stations if real-time information were available.

Since I was first asked to consider direct broadcasting, we have had follow-on studies for ocean color sensors to look at, some of which include direct broadcast and some not. I can see four reasons for support. 1) We need to back up single point failures, such as the Tracking and Data Relay Satellite (TDRSS), EosDIS, and a central data handling facility. 2) Obviously, we need real-time observations in support of field studies. The ocean does not stay fixed, and the name of the game is to get a ship to one of the bloom areas or plumes. We need data within a day. It is not obvious that the EosDIS will be able to deliver that. 3) We would like to experiment with onboard processing and selection of data for direct broadcast. 4) We need to develop future operational NOAA systems.

I'm concerned about all these areas. It seems we have a choice of three data rates. High data rate, X-band (I call high data rate anything above 20 megabits per second) will require a large ground station (there are going to be a few of them), lots of dollars, and some screening of data, because you still can't handle all of Eos and therefore must select which data and what day you put it out. It is going to require on-site processing at the ground station, and this will be a major effort. You still have a problem of how to get it out to the ships at sea. Oceanographic Principal Investigators (PI's) tend to go to sea: they take their act with them. For medium data rate (such as the L-band for the High-Resolution

Picture Transmission (HRPT) or S-band), there are lots of ground stations. Screening or selection of data (that is, which bands from which sensors) is needed. Many of these HRPT stations are within the PI domain, but you still have the problem of distribution to the field sites. There is also low data rate, in which you experiment with onboard data processing and produce a geophysical product.

There are potentially a large number of ground stations, and it is very foreseeable to have a station on every major or even minor oceanographic research ship with a PC to do processing. It really requires a selection of data. Which data do you send? For the most part, the PI would rather have the raw data, not a geophysical unit. The field party gets the data directly (that is, there are no problems in up-linking again to a satellite to get it out to a ship).

Concern about research for operational use is based on my own point of view, which is mostly for research needs. Does a scientist have a VAX or access to a supercomputer or does he just want information to show where to take a dory? We have considered the high- and low-data rate reception capability, but we should not forget the regional "value added" processing and routing. I mention this because commercially there is a great deal of interest in fisheries' broadcasting, in which a number of businesses have been set up to take ocean color and sea surface temperature data, process it (based on their previous knowledge of ocean conditions and topography), and forecast where the mackerel, squid, or other fish will be. That procedure requires that you get data to the fisheries and that they distribute a product to the ultimate user.

Another topic is cruise activity and planing for algorithm development. We hope to have more sophisticated algorithms making use of the multi-bands than were possible with CZCS. When you are at sea trying to validate a model, it is nice to know what the ocean is doing rather than use pigment as a predictor of some other species or pollution event and make your correlative measurements. It is nice to have that data in hand to find where the hot spot is. A hot spot in a general pigment measurement is not necessarily the hot spot of a coccolithophore bloom; they have different spectral signatures. This area is intended for tailored algorithm development and validation studies. The instrument scientists have a real need to get the data down to look at it to find out if their sensor is working right, i.e., sensor performance.

We use an ozone product to atmospherically correct our data in the final processing. Currently we have the Total Ozone Measurement Satellite (TOMS) data because we are doing it retrospectively now. With TOMS, we get approximately a 25-percent improvement in the results. With the present scenario we are going to have to wait approximately 5 days in order to get an ozone product unless it is from MODIS itself. You can read in wind speed because there will be glint corrections. The point is, there is a need for ancillary data. If it were possible to get that data on the ground quickly, to a first approximation (even though the people studying the ozone might not be satisfied, it could be a preliminary product for them), then all we need is a 90-percent-accurate ozone number to form a crude correction because it doesn't affect the CZCS data by more than one-third count. You will never see it using a correction term. I think there are other analogies in which quick data could be very useful in routine data processing.

Concerning timeliness, for research cruise planning, approximately a 12-hour response will be needed to be useful. The ocean community has been over this time and time again with no justifying need for real-time data distribution, and they have settled on 12 hours as a satisfactory number. We would like it sooner, but 12 hours is enough time to set up next day activities on the vessel.

It is certainly possible to consider doing the sea surface temperature (SST) processing onboard the satellite even though that method would have pluses and minuses. Currently it is done in a hands-off mode; it takes a bit of "number crunching," approximately 2 minutes on a micro-VAX 3 size instrument. Doing the CZCS pigment type algorithm onboard Eos might be feasible. It is not trivial; it takes on the order of 20 minutes on a micro-VAX 2 to process a 2-minute scene. It is an intensive task even with nearly optimized code. You have to know the ephemeris, calculate the Sun sensor geometry, store large look-up tables for the Rayleigh correction, make some assumptions concerning an ozone field, use a red color pixel to estimate aerosols and assume a default aerosol type, and use one of the channels to identify clouds, land, and glint.

One scene is approximately one-fourth of a megabit. The look-up tables for the atmosphere correction, where you have already solved the multi-scatter radiative transfer model, are typically done on every 32 pixels. You then interpolate within the look-up table. All of the data we have generated was essentially done in a hands-off mode. A number of us looked at the output to determine if it worked or didn't, and threw out what didn't work. It is not interactive in the sense that we are refining a coefficient. We know there are errors when you change from a marine to a continental aerosol model around Africa. Some of the errors can be estimated, and that is what we do. We don't have the information within the CZCS to make decisions as to what their corrections should be; therefore, MODIS final products certainly would be much better for quick results. People who are in favor of onboard processes would be delighted with something like that.

What I'm suggesting is that the way we process CZCS data today requires none of those corrections. There will be an ozone channel on MODIS. As for the research algorithms that people expect to have developed and ready to do MODIS ocean color, they are at the same stage that ISES is right now. We must answer these questions: what can we correct for, where do we get the data, and how do we code an algorithm? I think it is unrealistic to expect to come up with a consensus in time to help with the present algorithms and processing methodology that can be done. It's going to take a good deal of onboard storage and encoding software. There is no way that I would recommend that you get into the next-generation algorithm development for onboard processing. There are applications that haven't even used real-time wind speeds to do a good glint correction, for example. Atmospheric pressure is needed to recompute and solve the Rayleigh scattering model on a regional basis each time, because with the expected precision of MODIS, which we presently just ignore with CZCS, the atmospheric effect will be very evident in the research data product. Even the sea surface temperature, the multi-channel SST that NOAA does routinely, is not perfect. Many people find it has problems, but it is extremely useful for fishermen or setting up regional field studies. If it were available in real-time over a simple data link, that would be good. To me, one of the real challenges would be to control the selection of data from the various instrument types and output that through several channels of the HRPT.

The SST is a lot simpler than ocean color because it is just a simple difference or ratio between two channels; you multiply it by some coefficients to get approximately a degree and one-half accuracy. The atmospheric correction is extremely simple. You don't require people to use look-up tables or make extensive calculations. It can be done with a microprocessor by using a couple of channels and putting out a product of known performance. People are used to it and it is available in real-time. You don't have to go through Goddard and wait 3 days. You don't have to wait for the NOAA satellite. Suppose the NOAA satellite fails, we still have the data.

I see a couple of ways to handle the process for chlorophyll. You could have the ability to select MODIS visible channels. You could select up to 8 or 10 channels, maybe have a switch to select which ones are useful for oceanographers and land scientists, put them into a HRPT format, and direct broadcast to any current NOAA HRPT station. The Navy and universities will then have that data. It won't be all the data they will ultimately want, but it will be enough to tell them what to do tomorrow.

One of the main problems I see is that you still have to do onboard selection to choose what data to put into the data stream unit; you may be sending down the wrong data. Who gets to decide what and when would be a key issue. If I'm planning an experiment, how much lead time will I have to get a commitment from NASA that my data will be there when needed? It would not be good if I planned a multi-national effort and found that SAR data was scheduled to be taken that week; that does me no good at all. So the important thing is who controls the sensor outputs. If we have several selectable channels, such as an ocean channel, a land channel, a vegetation channel, a desert channel, and an atmospheric channel, which could be relied on, then it would make planning for field efforts much easier.

In conclusion, it would certainly be desirable to have a direct broadcast capability to support research ships at sea, as well as other activities. The format may include a selected number of raw data channels from some of the instruments, or it may contain fully processed geophysical parameters. The selection would be dependent upon the application, however, and a guarantee of availability when needed would be essential. Because the algorithm development for the MODIS data products is still an active issue, it is perhaps too early to state exactly what real-time products are needed and what mix of onboard and ground data processing is desirable.