EQPAC: A PROCESS STUDY IN THE CENTRAL EQUATORIAL PACIFIC

By James W. Murray, Margaret W. Leinen, Richard A. Feely, J.R. Toggweiler and Rik Wanninkhof

. . . why the equatorial region is not "greener" and more productive.

EQPAC IS the United States-Joint Global Ocean Flux Study (US-JGOFS) process study in the central equatorial Pacific. The first EqPac cruises sailed in January 1992 during a moderately strong El Nino. This was fortuitous for our studies of chemical and biological distributions because El Nino events are difficult to predict, and the lead time for a project of this size is long. There was virtually no previous upper-water-column chemical or biological data for El Nino conditions in the central equatorial Pacific. Now an El Nino has been studied in considerable detail, and it will be easy to sample the extremes in environmental conditions by sampling non-El Nino conditions (including La Nina) in 1993 and the years thereafter. The implementation of EqPac illustrates how difficult it is to mount a large-scale interdisciplinary study of the ocean when the interannual variability is large.

The equatorial Pacific is one of the more-or-less independent ocean "ecosystems" that have 1) characteristic trophic structure, 2) characteristic material cycles, and 3) recognizable boundaries (Barber, 1988). The region has distinct chemical and biological character compared with the tropical waters of the relatively barren, oligotrophic central gyres of the north and south Pacific. Upwelling of nutrient-rich water at the equatorial divergence in the Pacific supports a highly productive phytoplankton community that contributes significantly to global new production (Chavez and Barber, 1987). Vertical motion is constrained to within a degree of the equator (Halpern and Freitag, 1987), and surface divergence of the upwelled water results in a broader band of nutrient-rich water. The resulting nutrient-rich swath straddles the equator and extends across the Pacific basin to at least the dateline. Nutrients are the prime factor governing the large-scale pattern of spatial heterogeneity in productivity of the contemporary ocean and thus also the long-term temporal variations observed in the sedimentary record.

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Until recently primary production in the equatorial Pacific was thought to be supported chiefly by the upwelling of "new nutrients" (Chavez and Barber, 1987), such as nitrate (NO_3^-) as defined by Dugdale and Goering (1967). The new production, driven by these new nutrients was thought to be a large proportion of the total primary production. In oligotrophic regions of the ocean, "regenerated production" driven by nutrients such as ammonia (NH_4^+) and urea is most important. However, the phytoplankton biomass and primary productivity in the equatorial Pacific are not as high as the flux of nutrients could potentially support.

Primary productivity controls many oceanographic biogeochemical processes. Thus, a key to understanding the present and past ocean carbon cycles is to learn the factors that regulate primary and new productivity in this environment and to learn why the equatorial region is not "greener" and more productive (Barber, 1992a).

Previous Studies

The central equatorial Pacific was chosen for EqPac for two reasons: 1) the processes that control primary and new productivity and 2) scale and global mass balances.

Understanding the basic controls or master variables that determine the spatial heterogeneity and magnitude of primary and new productivity is one of the main goals of US-JGOFS (US-JGOFS, 1990). Macronutrients (e.g., NO_3^-) and grazing have long been thought to determine existing large-scale patterns of productivity. Some recent work has shown that the problem is not so simple. For example, Murray *et al.* (1989) showed that surface NO_3^- was a poor predictor of the regional pattern of primary and new productivity in the eastern equatorial Pacific. In addition, the magnitude of primary and new production was anomalously low compared with the nutrient levels present. These observations also apply to the central equatorial Pacific (Cullen *et al.*, 1992) and lead to the question, why?

From the standpoint of chemical and biological oceanography, the equatorial Pacific's most distinguishing feature is the huge tongue of low-temperature, high-nutrient, high-P_{CO_2} water that extends from the eastern boundary to the dateline. A zonal section of temperature, nitrate, and chlorophyll on the equator is shown in Figure 1 (Chavez and Brusca, 1991). Maps of model-predicted surface NO_3^- for the fall and spring seasons are shown in Figure 2. There is a progressive decrease in temperature and an increase in NO_3^- eastward from the date line. Chlorophyll is slightly elevated, compared with adjacent ocean regions but shows no systematic east-west gradients.

The basin-scale distribution of ocean pigment, inferred from Coastal Zone Color Scanner (CZCS) images has given us the best indication of the seasonal variability and has allowed us to select features that should be sampled (e.g., high pigment near 9°N) and those that should be avoided (island effects at 9°S, 140°W) (see Feldman *et al.*, 1992, this issue). Observations that go back to at least 1969 (Barber and Ryther, 1969) have shown anomalous chlorophyll and productivity patterns (e.g., Walsh, 1976; Thomas, 1979; Chavez and Barber, 1987; Pena *et al.*, 1990; Cullen *et al.*, 1991). In addition, the food web is dominated by small phytoplankton (Chavez, 1989) with a unique taxonomic composition dominated by relatively few groups in the pico- (0.2–2 μm) and nanoplankton (2–20 μm) size ranges (Chavez *et al.*, 1990).

There are several possible explanations for the nutrient and productivity distributions, but grazing control (e.g., Walsh, 1976; Banse, 1992; Cullen *et al.*, 1992) and iron limitation (e.g., Martin *et al.*, 1989) have received most attention. Frost and Franzen (1992) used a simple chemostat model to show that grazing control is essential to reproduce the present conditions of high nutrients, low phytoplankton biomass, and high phytoplankton-specific growth rate observed in the equatorial upwelling zone. Iron limitation is hypothesized to play a dual role by limiting nutrient utilization and influencing plankton species composition (Price *et al.*, 1991). For example, large diatoms, which have elevated iron requirements, are one of the main groups conspicuously absent from the equatorial food web. The iron deficiency appears to be more pronounced east of ~140°W, where the rate of primary productivity is independent of the subsurface nutrient composition (Barber and Chavez, 1991). Low supply of eolian iron to this remote location may be the explanation.

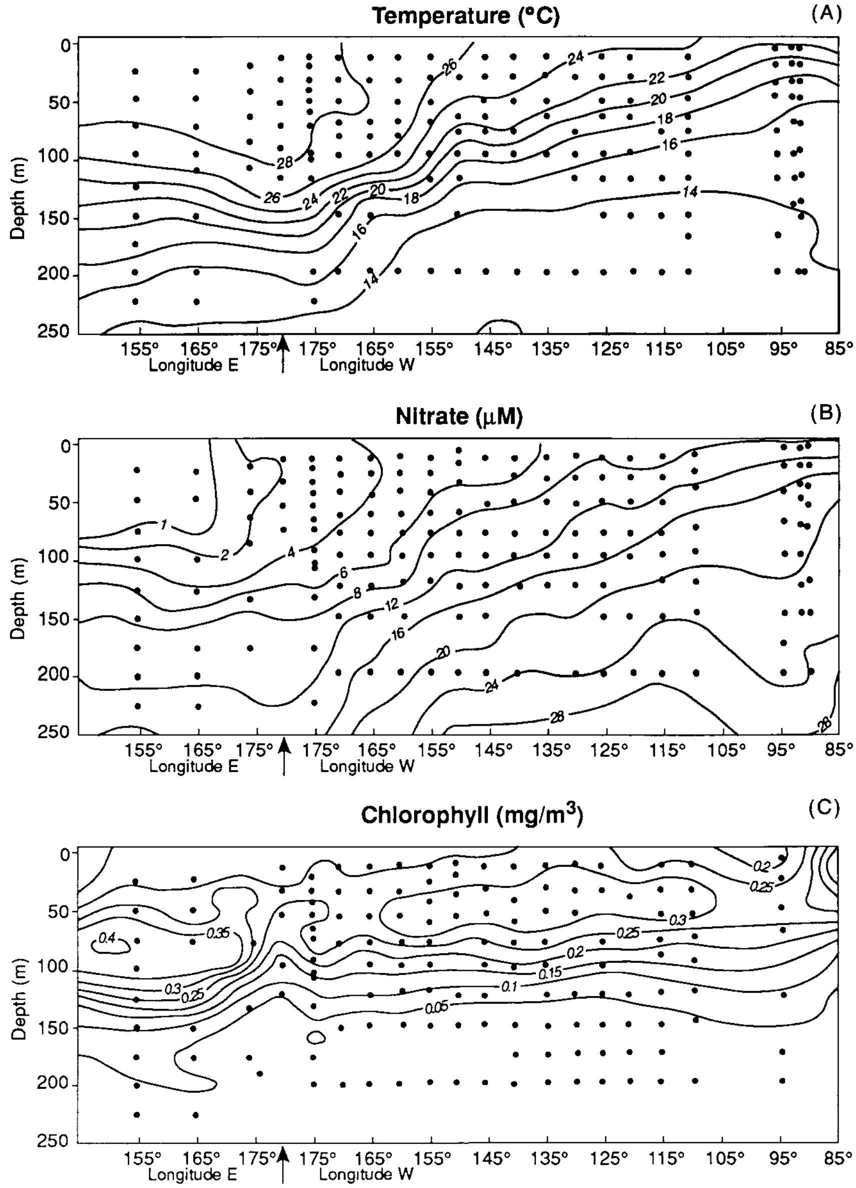

*Fig. 1: Zonal sections of (**A**) temperature, (**B**) nitrate, and (**C**) chlorophyll on the equator in the Pacific from 145°E to 85°W (Chavez and Brusca, 1991). The thermocline and nutricline shoal east of the date line, and the chlorophyll concentrations remain relatively uniform.*

Other large ocean areas such as the southern ocean (Mitchell *et al.*, 1991) and sub-arctic Pacific (Miller *et al.*, 1991) have been shown to have similar nutrient-productivity relationships. These regions are referred to as having high-nutrient, low-chlorophyll (HNLC) distributions (Chisholm and Morel, 1991; Cullen, 1991). An important long-range goal of US-JGOFS will be to see whether we can generalize the results of EqPac to these other regions.

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The equatorial Pacific plays a significant role in global carbon balances, because it is such a large area of the world ocean. Calculations by Chavez and Barber (1987) showed that the equatorial Pacific has the potential to produce as much as 1.9 gigatons (1 Gt = 10^{12} metric tons) new production

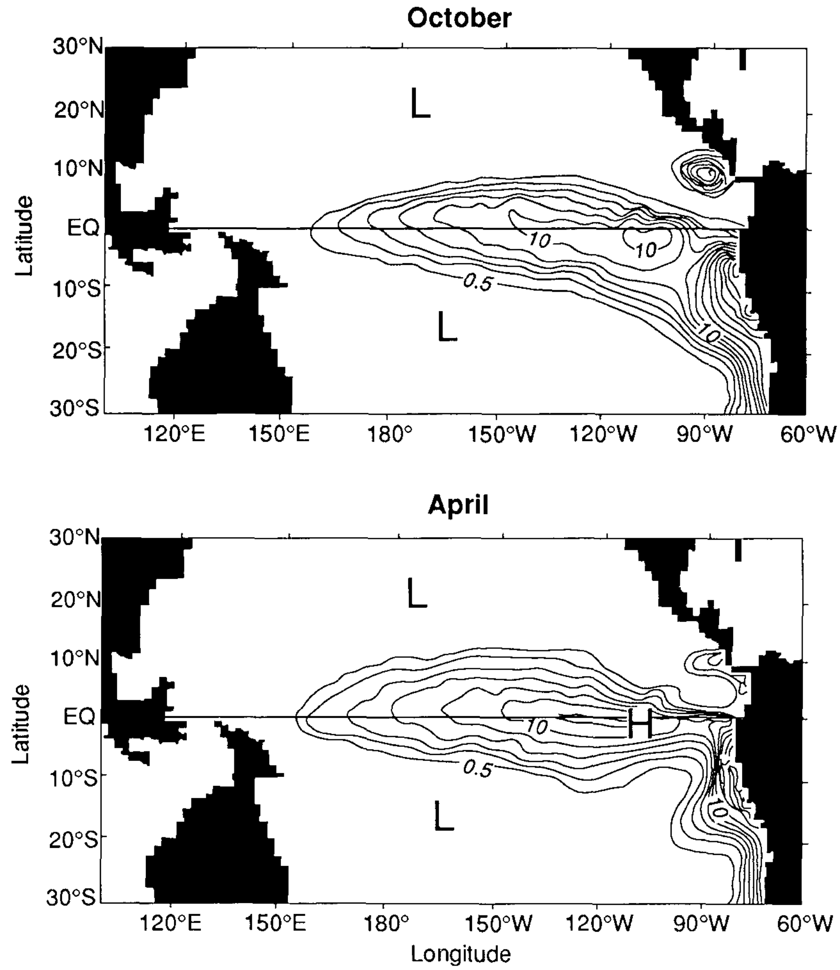

Fig. 2: Charts of surface nitrate (μM) during the months of October (top) and April (bottom) in the surface water of the tropical Pacific as predicted from the Princeton/Geophysical Fluid Dynamics Laboratory three-dimensional model that couples physical circulation, biochemical cycling, and food-web dynamics (J.R. Toggweiler, H.W. Ducklow, J.L. Sarmiento, and R. Slater, personal communication).

Ultimately carbon fixed in surface waters is recycled . . .

per year. This would be a significant fraction of the global new production, estimated by Eppley and Peterson (1979) to be between 3.4 and 4.7 gigatons per year.

The cold tongue of upwelled water in the equatorial Pacific is characterized by high partial pressures of CO_2 (P_{CO_2}) (Keeling, 1968). It is the largest natural source of CO_2 to the atmosphere, if CO_2 sources are averaged over an annual cycle (0.6 to 1.0 Gt y^{-1}) (Gammon *et al.*, 1985; Feely *et al.*, 1987). Major spatial and temporal gaps in knowledge about the distributions of CO_2 in surface waters need to be filled (Murphy *et al.*, 1991). Finally, simple mass-balance calculations suggest that much of the carbon fixed by primary productivity may ultimately be exported from the region as dissolved organic carbon (DOC) (Bacastow and Maier-Reimer, 1991; Najjar *et al.*, 1992). Barber and Ryther (1969) observed that recently upwelled water was lower in DOC than the water to the north and south, although the horizontal gradients were small. Their surface DOC values (66 μm/l) are about one-half those recently reported by Martin and Fitzwater (1992) but are consistent with those reported from north of Hawaii by Benner *et al.* (1992). Evaluating the importance of DOC export will allow us to determine the role of the equatorial Pacific in global carbon budgets.

Ultimately carbon fixed in surface waters is recycled to the atmosphere, back into seawater, or is buried in sediments. Studies of the factors controlling burial will allow us to understand the sedimentary record of carbon burial. This, in turn, will allow us to study the response of ocean productivity to global climate change. Organic carbon and biogenic silica in surface sediments have higher concentrations at the Equator (Cwienk and Leinen, 1985; Fig. 3). The geological record in the underlying sediments contains a detailed, but complicated, history of how this system has changed in the geological past (e.g., Pedersen, 1983; Lyle *et al.*, 1988; Pisias and Rea, 1988). This record represents ~0.1% of the carbon originally fixed by photosynthesis that is not recycled in the water column or at the sediment-water interface. Benthic fluxes from 15°S to 11°N at 135°W are ~1–2% of the primary production (Martin *et al.*, 1991). The zonal variation in organic-carbon degradation rates was similar to the surface-water pattern of primary production. The rates for silica degradation were significantly different, perhaps due to differences in the composition of the particulate flux (e.g., diatom abundance). Sediment mixing by benthic deposit feeders plays an important role in organic carbon diagenesis and Smith (1992) has predicted that a 10-fold decrease in bioturbation rate occurs between the Equator and 10°N at 140°W. Calcium carbonate preservation has varied significantly over geological time (Farrell and Prell, 1989), and this may be due to variations in primary productivity and the organic-carbon rain rate (Archer, 1991).

The circulation of the equatorial Pacific is complicated but has been studied intensely as part of the Hawaii–Tahiti Shuttle (NORPACS) and the Tropical Ocean Global Atmosphere (TOGA) studies called Equatorial Pacific Ocean Climate Study (EPOCS), Tropic Heat and Tropical Atmosphere-Ocean (TAO). The physical circulation models for the equatorial Pacific are among the best and most realistic of any ocean region. The design of EqPac was influenced by a three-dimensional model for the equatorial Pacific that coupled circulation, biochemical cycling and food-web dynamics. In this exercise a seven compartment version of the Fasham *et al.* (1990) food-web model was imbedded in the Philander *et al.* (1987) equatorial Pacific circulation model. The coupled model predicts phytoplankton biomass and primary production as a function of *in situ*

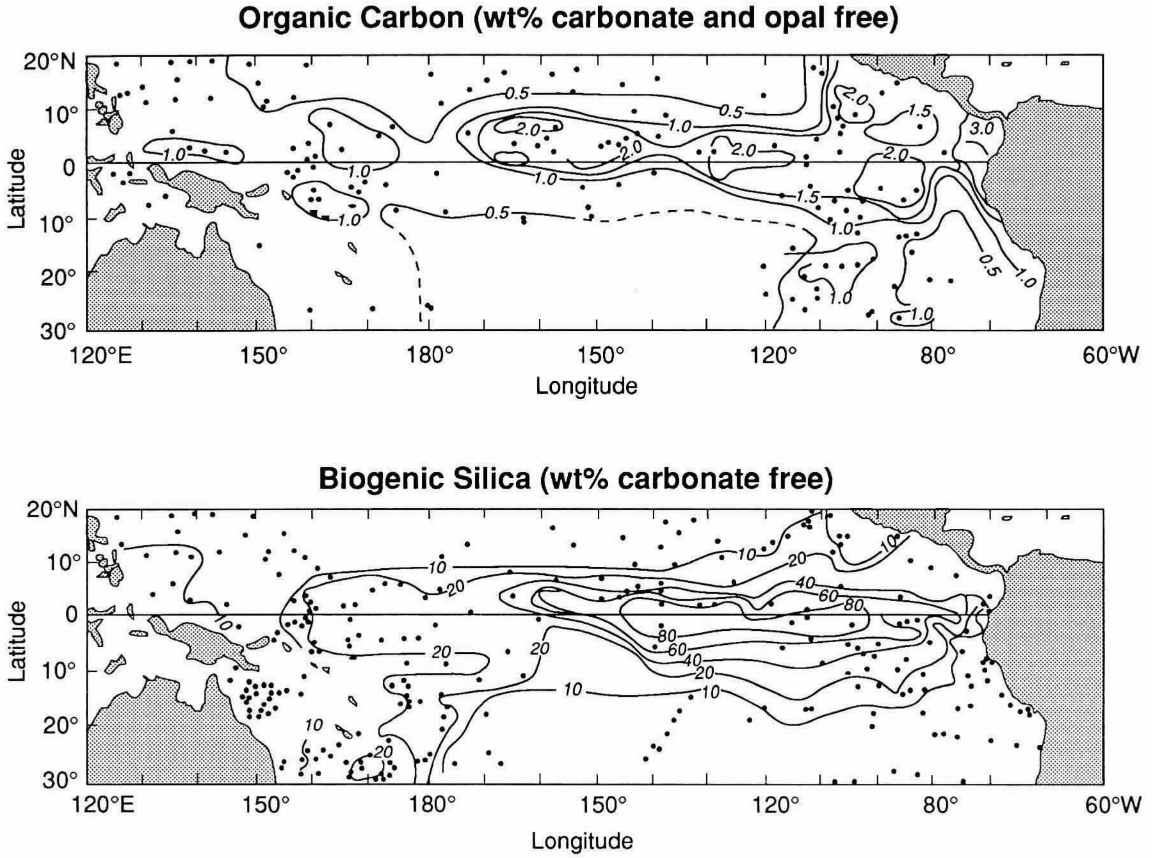

Fig. 3: Organic carbon and biogenic silica concentrations in equatorial Pacific surface sediments (Cwienk and Leinen, 1985).

There is virtually no biological data . . . for El Nino conditions.

irradiance and nutrient availability. The seasonal changes in surface nitrate concentrations predicted by the model are especially evident at ~110°W (Fig. 2). The cruise tracks of the National Oceanic and Atmospheric Administration (NOAA) component have been designed to verify this predicted difference (Fig. 4).

There is significant interannual variability in surface temperature and nutrients associated with the El-Nino-Southern Oscillation (ENSO) (Enfield, 1989). There is virtually no biological data from the central equatorial Pacific for El Nino conditions. A set of biological data collected from 2°N to 2°S along 95°W by Barber and Kogelschatz (1990) during the 82/83 El Nino found that the primary and new productivity were drastically reduced. Some chemical data were reported for the 82/83 El Nino by Feely *et al.* (1987). They observed that the calculated net flux of CO_2 across the air-sea interface was essentially zero during that period. Dymond and Collier (1988) observed that the biogenic particle fluxes to the deep sea were greatly reduced at the Equator during the 82/83 El Nino. They were anomalously high at 11°N during this same period.

Based on previous observations, we expected the following scenario for a "typical" strong El Nino (after Feely *et al.,* 1987; Barber and Kogelschatz, 1990; Siegenthaler, 1990; Barber, 1992b). The equatorial trade winds are still easterly and strong in the central Pacific and upwelling continues from the 50- to 100-m depth range. The sea-surface temperatures (SST) are elevated and the thermocline is depressed compared with non-

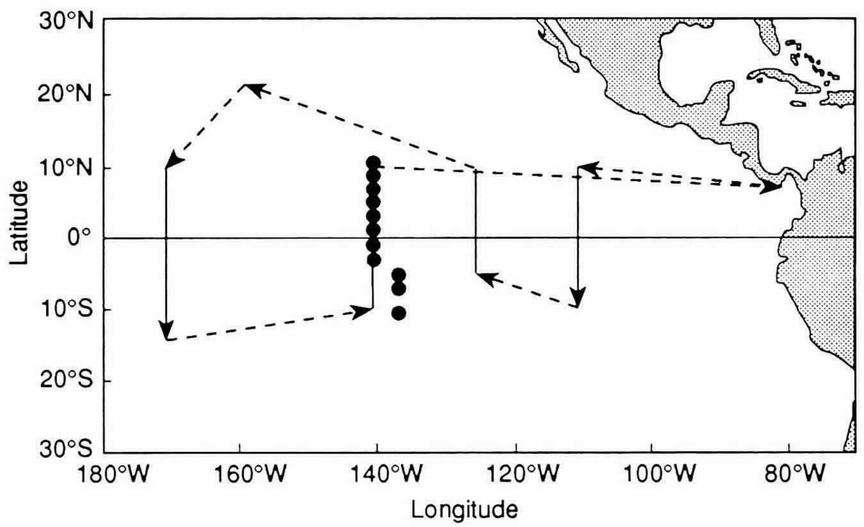

Fig. 4: Tentative EqPac station locations. The solid symbols along 140°W show the station locations of the NSF Survey Cruise. The NSF Time-Series cruise will spend most of its station time at the equator. The dashed and solid lines show the cruise track of the R/V Baldridge in the spring of 1992. In the fall of 1992 the meridional section at 170°W will be moved to 95°W.

Table 1

Scientific goals of EqPac, the US-JGOFS Process Study in the central equatorial Pacific. Indication is given below regarding the relative importance of each goal in terms of the respective cruise plans

1. To determine how large a role the equatorial Pacific plays in global biogeochemical cycles. (NSF and NOAA)
2. To determine the relationship between environmental variables (e.g., temperature, nitrate, and light) and the structure of the biological food web and the magnitude of primary and new productivity. (NSF)
3. To evaluate how midwater, deep-water, and benthic processes control the recycling of carbon and related elements and determine the ultimate removal of biological components to the deep ocean and burial in marine sediments. (NSF)
4. To determine how the region responds to interannual variability (El Nino, La Nina, etc.). (NSF and NOAA)
5. To construct budgets for carbon and nitrogen and evaluate the role of dissolved organic carbon and nitrogen (DOC/DON) and sinking particle fluxes in the biochemimical cycles. (NSF and NOAA)
6. To establish a three-dimensional understanding of how carbon and nitrogen enter and leave the equatorial region by combining multiple meridional sections together with coupled physical-circulation and biological-food-web models. (NOAA)

The NSF cruises focus on the region around 140°W . . .

El Nino conditions, due to migration of a Kelvin wave from west to east. Surface NO_3^- is lower than normal because upwelling delivers warm nutrient-depleted water. Chlorophyll is lower than normal and, as a result, the euphotic zone is deeper. Primary production and new production may only be 25 and 5% of their normal values, respectively. There may be major changes in the phytoplankton species assemblages with decreased abundance of diatoms and increased coccolith concentration. The flux of CO_2 to the atmosphere is close to zero or at least much less than its normal value. Because of the fortuitous timing of the 91/92 El Nino, EqPac will be able to verify whether these predictions are valid.

Planning

When the first EqPac sediment-trap-deployment cruise departed Honolulu on January 12, 1992, it had been almost four years since the US-JGOFS Pacific Planning Meeting in Monterey during February 1988. The reports presented during that workshop (US-GOFS, 1989) and input from a large number of interested scientists led to the development of a science plan for the process study (Leinen and Murray, 1990). Approval from both the JGOFS and US-JGOFS steering committees in January 1990 followed these preliminary plans. The process study evolved to include components supported by both National Science Foundation (NSF) and Na-tional Oceanic and Atmospheric Administration (NOAA). The proposal solicitation for both NSF and NOAA was open with the only stipulation being that the problems and hypotheses in the EqPac science plan be addressed. The entire planning process benefitted greatly from the experiences of the JGOFS pilot study in the North Atlantic, called the North Atlantic Bloom Experiment (NABE) (US GOFS, 1986).

Field Program

The EqPac Science Plan (Leinen and Murray, 1990) addressed the goals shown (Table 1) by identifying seven scientific problems (Table 2). Each of these problems is the focus of several alternative hypotheses that will be tested as part of both the NSF and NOAA components of EqPac. The scope is wide ranging—from the euphotic zone, through the upper and deep water column to the sediments.

The NSF strategy is a detailed process-oriented investigation at a few locations. The NOAA component addresses some questions on a regional scale. As a result, the NSF and NOAA cruise plans are different (Table 3; Fig. 4). The NSF ship schedule on the Research Vessel Thompson consists of survey, time-series and benthic cruises as well as the moored-sediment-trap recovery in 1993. Moored sediment traps were deployed from a separate cruise on the Research Vessel Wecoma. The NSF cruises focus on the region around 140°W from 12°N to 12°S (Fig. 4). The station latitudes for the survey cruises are 12°, 9°, 7°, 5°, 3°, 2°, and 1°N, and 0°, 1°, 2°, 3°, 5°, 7°, 9°, and 12°S. The stations south of 5°S are moved to 135°W to avoid island effects (see Feldman *et al.,* 1992). The time-series cruise will spend ~18

Table 2

Scientific problems to be addressed by EqPac (Leinen and Murray, 1990)

1. What is the relationship between physical forcing and upper ocean biogeochemical cycles?
2. Why are the levels of primary productivity and chlorophyll lower than expected based on ambient nutrient levels?
3. Why does the magnitude of the import and export for new productivity appear to be lower than expected based on ambient nutrient levels?
4. What are the processes responsible for transport and regeneration of particulate and dissolved nutrients?
5. What are the processes responsible for the formation and transport of dissolved organic matter?
6. What are the relationships of seafloor remineralization and burial rates to primary and new production?
7. What is the response of equatorial Pacific circulation and productivity to short- and long-term climate change?

Table 3
1992 EqPac cruise schedule showing both NSF and NOAA sponsored cruises

Cruise	Chief Scientist	Ports	Dates
Research Vessel Thomas G. Thompson (NSF)			
Spring Survey	J.W. Murray (University of Washington)	Honolulu-Papeete	1/29–3/13
Spring Time-Series	M. Roman (Horn Point Environmental Lab.)	Papeete-Honolulu	3/17–4/20
Fall Survey	R.T. Barber (Duke University)	Honolulu-Papeete	8/5–9/18
Fall Time-Series	M. Bacon (Woods Hole Oceanographic Lab.)	Papeete-Papeete	9/22–10/25
Benthic	M. Leinen (University of Rhode Island)	Papeete-Honolulu	10/29–12/12
Trap Recovery	R. Collier (Oregon State University)	to be scheduled in early 1993	
Research Vessel Wecoma (NSF)			
Trap Deployment	J. Dymond (Oregon State University)	Honolulu-Honolulu	1/2–2/2
Research Vessel Baldridge (NOAA)			
Spring Leg 1	R. Wanninkhof (Atlantic Oceanographic and Meteorological Lab.)	Balboa-Honolulu	2/17–3/19
Spring Leg 2	D. Atwood (Atlantic Oceanographic and Meteorological Lab.)	Honolulu-Papeete	3/25–4/10
Spring Leg 3	R. Feely (Pacific Marine Environmental Lab.)	Papeete-Balboa	4/16–5/17
Research Vessel Discoverer (NOAA)			
Fall Leg 2	TBA	Hilo-Hilo	8/3–8/27
Fall Leg 3	R. Feely (Pacific Marine Environmental Lab.)	Hilo-Manzanillo	9/3–10/5
Fall Leg 4	R. Wanninkhof (Atlantic Oceanographic and Meteorological Lab.)	Manzanilla-Panama	11/16–12/10
Fall Leg 5	P. Murphy (Atlantic Oceanographic and Meteorological Lab.)	Panama-Seattle	10/12–11/10

days at the equator. This is approximately the time scale of the tropical instability waves. The extremes in physical forcing occur in the boreal spring and fall, so the cruise plan has a survey cruise from 12°N to 12°S and a time-series cruise near the equator in approximately both seasons. This approach will evaluate the variability in carbon cycling due to seasonal forcing. There will be one benthic cruise in November 1992 that will take advantage of the year-long record of deep-ocean sediment-trap fluxes that will precede the benthic-flux measurements on that cruise. Sediment-trap and benthic-cruise stations are at 9°, 5°, and 2°N, 0°, 2°, 5°, and 12°S. The 12°S station is at 135°W and all the rest are at 140°W.

The NOAA cruises on the R/V Baldridge in the spring and the R/V Discoverer in the fall will make four crossings of the equator (Fig. 4). In the fall the section at 170°W will be moved to 95°W to investigate seasonal differences in the distribution of carbon and nitrogen species to the south and into the Peru upwelling region (Fig. 2).

The project's principal investigators (PIs) and research programs for the NSF component and NOAA component are shown in Tables 4 and 5, respectively. There are a total of 53 PIs in the NSF component and 10 PIs in the NOAA component.

Three additional projects that are closely associated with EqPac will be conducted in the equatorial Pacific region at 140°W. Drs. Frank Hoge of The National Atmospheric and Space Administration (NASA) and James Yoder (University of Rhode Island) have organized long-range P3B aircraft overflights of the study area for late August 1992. These flights have been scheduled to coincide with the period when the Thompson will be on station at the equator. In the absence of an ocean-color satellite the aircraft sensors will provide snap-shots of the regional-scale distribution of chlorophyll, phycoerythrin, dissolved-organic-matter fluorescence, passive upwelled irradiance, and sea-surface temperature. Drs. John Martin (Moss Landing Marine Laboratory) and Neil Tindale (University of Rhode Island) have organized an Office of Naval Research (ONR) sponsored study of atmospheric dust sources of iron and their effect on ocean primary productivity. Atmospheric dust samples will be collected on the Research Vessel Wecoma and transferred to the Research Vessel Thompson for seawater enrichment experiments during the spring time-series cruise. Finally, Drs. Tim Bates (NOAA/Pacific Marine Environmental Lab) and Eric Saltzman (University of Miami) are coordinating a NOAA/NSF-sponsored study of atmospheric and ocean carbon, nitrogen, and sulfur trace-gas chemistry at 2° and 12°S. This cruise will overlap with the EqPac spring survey cruise.

The NOAA cruises . . . will make four crossings of the equator.

Table 4
NSF-sponsored EqPac principal investigators and topics of research

Investigator	Topic of Research
Survey cruises	
James Murray (University of Washington)	Hydrography
	Floating traps, flux of scavenging isotopes and trace elements
Jan Newton (University of Washington)	Floating traps, flux of C, N, P, and pigments, growth rates
John Hedges (University of Washington)	Floating traps, flux of organic compounds
Paul Quay (University of Washington)	Stable carbon isotopes
Jim Swift (Scripps Institution of Oceanography)	Salinity and oxygen
Dick Barber (Duke University Marine Lab.)	Primary productivity using ^{14}C
Jim McCarthy (Harvard University)	Nitrogen cycling and new productivity using ^{15}N
Chris Garside (Bigelow Laboratory)	Nitrogen cycling, core nutrients and pump profiling
Jim Bishop (Lamont-Doherty Geological Laboratory)	*In situ* pump filtration, elemental composition of particulate matt
Dave Archer (Lamont-Doherty Geological Laboratory)	Carbonate system analyses (PCO_2, total CO_2, and alkalinity)
Chuck Trees (San Diego State University)	*In situ* optics
Jim Aiken (Plymouth Marine Lab.)	*In situ* optics
Bob Bidigare (University of Hawaii)	Biological tracer pigments by high-pressure liquid chromatography
Mike Landry (University of Hawaii)	Microzooplankton biomass and grazing rates
Dave Kirchman (University of Delaware)	Bacterial biomass and production
T.-L. Ku (University of Southern California)	Th and Be isotopes
Hans Dam (University of Connecticut)	Mesozooplankton biomass and grazing rates
Mike Roman (Horn Point Environmental Lab.)	Mesozooplankton biomass and grazing rates
Edward Peltzer (Woods Hole Oceanographic Institution)	Dissolved-organic-carbon analyses
Greta Fryxell (Texas A&M University)	Plankton speciation
Barney Balch (University of Miami)	Calcification
Time-series cruises	
Mike Bacon (Woods Hole Oceanographic Institution)	*In situ* pump filtration and scavenging isotopes
Catherine Goyet (Woods Hole Oceanographic Institution)	Carbonate system analyses (PCO_2, Total CO_2, and alkalinity)
Robert Olson (Woods Hole Oceanographic Institution)	Cyanobacteria, prochlorophytes
Penny Chisolm (Massachusetts Institute of Technology)	Cyanobacteria, prochlorophytes
Kirk Cochran (State University of New York)	*In situ* pump filtration and scavenging isotopes
Dick Barber (Duke University)	Primary productivity using ^{14}C
Michael Bender (University of Rhode Island)	Gross primary production using oxygen isotopes
Michael Sieraki (Bigelow Laboratory for Ocean Sciences)	Microzooplankton biomass and grazing rates
Peter Verity (Skidaway Institute of Oceanography)	Microzooplankton biomass and grazing rates
Diane Stoecker (Horn Point Environmental Lab.)	Microzooplankton biomass and grazing rates
Mike Roman (Horn Point Environmental Lab.)	Mesoplankton biomass and grazing rates
Hans Dam (University of Connecticut)	Mesoplankton biomass and grazing rates
Hugh Ducklow (Horn Point Environmental Lab.)	Bacterial biomass and production
Pat Wheeler (Oregon State University)	Nitrogen cycling using ^{15}N, core nutrients
Jim Swift (Scripps Institution of Oceanography)	Salinity and oxygen
Curtis Davis (Jet Propulsion Lab.)	*In situ* optics
Mike Landry (University of Hawaii)	Microzooplankton grazing
Bob Bidigare (University of Hawaii)	Biological tracer pigments
Alan Mix (Oregon State University)	Stable carbon isotopes
Wilf Gardner (Texas A&M University)	Particulate matter and aggregate studies
Mary Jo Richardson (Texas A&M University)	Particulate matter and aggregate studies
Ian Walsh (Texas A&M University)	Particulate matter and aggregate studies
Vernon Asper (University of Southern Mississippi)	Particulate matter and aggregate studies
Greta Fryxell (Texas A&M University)	Plankton speciation
John Martin (Moss Landing Marine Lab.)	Iron-enrichment experiments, trace-metal profiles
James Murray (University of Washington)	Hydrography
Benthic Cruise	
Margaret Leinen (University of Rhode Island)	Sediment composition and deposition rates
Doug Hammond (University of Southern California)	Benthic fluxes
Will Berelson (University of Southern California)	Benthic fluxes
Dave DeMaster (North Carolina State University)	Sediment/water interface: isotope studies
Craig Smith (University of Hawaii)	Sediment/water interface: benthic biology
Fred Dobbs (University of Hawaii)	Sediment/water interface: benthic biology
Bob Anderson (Lamont-Doherty Geological Observatory)	Sedimentary radionuclides
Cindy Lee (State University of New York)	Organic-matter diagenesis and burial fluxes
Dave Kadko (University of Miami)	Sedimentary radionuclides
John King (University of Rhode Island)	Sedimentary accumulation rate
Kuo Yen Kuei (Yale University)	Paleoceanography
Moored Sediment Trap Cruises	
Bob Collier (Oregon State University)	Moored sediment traps
Jack Dymond (Oregon State University)	Moored sediment traps
Nick Pisias (Oregon State University)	Settling foraminifera
Susumo Honjo (Woods Hole Oceanographic Institution)	Moored sediment traps
Stuart Wakeham (Skidaway Institute of Oceanography)	Flux of particulate organic compounds

In addition, Mark Altabet (Woods Hole Oceanographic Institution) and Miriam Kastner (Scripps Institution of Oceanography) will analyze samples collected by others for nitrogen and neodymium isotopes, respectively. Tom Dickey (University of Southern California) is conducting optical measurements in collaboration with the NOAA TOGA/TAO long-term moorings. Pierre Flament (University of Hawaii) is processing the remote-sensing sea-surface temperature data.

Table 5
NOAA-sponsored EqPac principal investigators and topics of research

Investigator	Topic of Research
Richard Feely (Pacific Marine Environmental Lab.)	Total CO_2, PCO_2, hydrography
Rick Wanninkhof (Atlantic Oceanographic and Meteorological Lab.)	Total CO_2, PCO_2
Don Atwood (Atlantic Oceanographic and Meteorological Lab.)	Core nutrients
Robbie Toggweiler (Geophysical Fluid Dynamics Lab.)	Natural ^{14}C distributions, basin-scale modeling
Francisco Chavez (Monterey Bay Aquarium Research Institution)	Primary productivity using ^{13}C
	Pigments, particulate carbon/nitrogen
Ken Buesseler (Woods Hole Oceanographic Institution)	^{234}Th studies
Ed Peltzer (Woods Hole Oceanographic Institution)	Dissolved organic carbon
Frank Millero (University of Miami)	Alkalinity, pH
Robert Byrne (University of South Florida)	Alkalinity, pH
Paul Quay (University of Washington)	Carbon isotopes
Pat Wheeler (Oregon State University)	Nitrogen cycling and new productivity using ^{15}N (Fall Cruises Only)

Concluding Remarks

The US-JGOFS Process Study described here is the result of a co-operative effort by the US-JGOFS Steering Committee and members of the US ocean-sciences community. It is the result of a large number of meetings and workshops and is only one component of an International Equatorial Pacific Program (JGOFS 1990a,b). The field work will lead to an integrated understanding of equatorial ocean carbon and nitrogen cycles.

The issues of central equatorial Pacific productivity and carbon cycling involve the relationship of the biology and CO_2 chemistry to predictive variables like sea-surface temperature and nutrient concentrations. The goal of EqPac is to understand the processes controlling the relationships so that we can parameterize and model primary and new productivity and their relationships to the structure of the biological food-web. The research plan should enable us to evaluate the relative importance of remote atmospheric winds, which regulate basin-wide upper-ocean heat storage, and local winds, which drive upwelling (Barber, 1990). With that understanding we will be able to construct predictive models of deep-ocean and benthic processes and decipher the long-term oscillations in the sedimentary record.

The field work will lead to an integrated understanding of equatorial ocean carbon and nitrogen cycles.

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