Response to issues raised by SSC-12 (Miami, January 2005)

We appreciate very much the attention the SSC has given to the PUMP project, and again note that CLIVAR comments have contributed greatly to the shaping of PUMP.

The following responses are organized according to the assessment prepared by the SSC.

Feasibility: We agree with the SSC that the mixing element of PUMP is "higher risk science", and that the appropriate tack is to ensure that the mixing tasks be opened as widely as possible to the community, with the idea that many PIs will propose a variety of approaches. In fact the technology of sampling mixing and microstructure has advanced greatly since the last equatorial experiment (1991), and there are now moored and Lagrangian instruments, as well as much-improved doppler current profilers in use (see below). Further, the theoretical basis for hypotheses about how the mixing works has also advanced with the digestion of data from the previous experiments, making the observational targets much clearer (the generation, propagation and breaking of near-N internal gravity waves, and the dependence of the waves on the background shear). We can expect a vigorous response to a call for proposals in this area.

Five pre-PUMP projects that will contribute to refining the observational plan and increasing its feasibility are already funded or bootstrapped:

1) Tests of moored mixing samplers: Moored microstructure instruments will be tested on the TAO mooring at 0°, 140°W this year. These are essentially fast-response thermistors recorded at high data rates. They yield frequency spectra of mean, internal wave and turbulence fields, and ultimately, time series of heat fluxes at a point. Multiple samplers on a mooring provide the heat flux divergence, or heating rate of a water parcel. If this works, it will allow us to produce year-round time series of microstructure at low cost and over greater geographical extent than has been possible from a ship.
2) OSSE experiments: An OGP-funded postdoc will arrive at PMEL this summer to study array design and estimate space and time-scales of variability. While the OGCMs are clearly not perfect, they should represent the dynamical balances well enough to improve our guesses at the errors to be expected in calculating both primary and derived quantities from PUMP sampling.
3) Tests of very-near-surface velocity measurements: 5 point-sampling Doppler current meters have been deployed in the upper 25m of a PMEL engineering test mooring at 2°N,140°W over the past year. For technical reasons neither downward-looking shipboard profilers nor upward-looking moored profilers sample the upper 20-25m, so this is the first time that the poleward limb of the diverging meridional circulation has ever been measured. The mooring was recovered last month and the data are being processed. We will analyze these velocities and write up the results this summer. These data will inform the design of PUMP moorings.
4) Engineering tests of subsurface buoy communication: At present subsurface current meter moorings provide no realtime data and in fact no indication that they are working. Therefore it is essential to pull them up for servicing at least once/year, if only to ensure that large amounts of data aren't lost. PMEL engineering is now testing acoustic modems that would let a passing ship listen to the subsurface mooring and download data. If this works, then a single mooring deployment could remain in service for 3 years, and would in fact be cheaper than the planned PUMP 2-year deployment with present (refurbish-annually) technology.

5) Neutrally-bouyant Lagrangian floats that measure turbulent dissipation rates were successfully deployed in the equatorial Pacific late last year by investigators at APL/UW. These instruments will provide the capability to expand sampling in a wide region around the PUMP focus longitude, increasing confidence in the representativeness of our sampling. In addition, this Lagrangian sampling will complement and check the interpretation of the Eulerian sampling from moorings and stationary ships.

The result of all these pre-PUMP activities will, over the next 1-2 years, allow us to devise a sampling strategy with a much stronger basis than at present.

Applicability/Importance:

1) Narrow geographical scope of experiment relative to phenomena.
This issue has been prominent in discussions of PUMP since the beginning, and was again raised by modelers at GFDL in a recent visit. It appears that the OGCMs do a "better" job at 140°W, while producing larger SST errors at 110°W, therefore we were strongly encouraged to revisit this question. Of course, the fact that the SST errors are larger in the east does not necessarily mean that the solution is also to be found there (if the processes are the same then the argument could be made that we should go where the observations are most convenient). The OSSE work that will be conducted at PMEL this year (see discussion above) will be used to further explore this problem, in collaboration with GFDL. There are two possibly-conflicting goals here: one, we assert that what is needed is to understand processes to provide the basis for developing new parameterizations; two, we want to "oversample" the region for a limited time to make a complete as possible diagnosis of the evolution. One can be done in a single meridional section (based on the OSSE work that will establish the region over which it is representative), the other suggests a broader target. We will use the OSSE work to rethink this problem and attempt to come to a conclusion.

The development of instruments to make Lagrangian and moored mixing estimates (see above), and also of gliders that could provide wider sampling of **u** and T, opens the field up to the possibility of accomplishing both goals.

2) Brief sampling of the IOPs.
This issue has also been a continuing source of discussion and poses an obvious problem of representativeness. Moored mixing instruments will be tested on the TAO mooring at 0°, 140°W this year (see above). If this works, then it will allow us to produce year-long time series of microstructure at low cost and greater geographical extent. However, at least until new technologies such as this reach maturity, the IOPs will remain necessary to provide irreplaceable detailed process studies that can only be achieved with instrumentation such as turbulence profilers and SeaSoars, together with real-time at-sea decision making.

3) Limited information about interactions with the atmosphere.
Present PUMP plans would provide time series of surface flux components from moorings, but no direct description of changes in the PBL that are known to occur across the SST front. It would be possible to deploy balloon soundings from the mooring service ships that would enable diagnosis of the PBL a few times a year, and we have been in contact with PIs who are interested in doing this in collaboration with PUMP. We will continue to explore these possibilities.

4) Possible third year of deployment.
The main reason to want a third year is to avoid the problems that would occur if the experiment occurred in a situation like 97-98, when strong anomalies extended over 2 years. There's a roughly 1 in 4 chance of having an El Nino in any given year (though probably not an event as strong as 97-98). Even without ENSO, since PUMP is in many cases the first sampling of some of these quantities, an extra seasonal cycle would produce a significant increase in information. We estimated that extending the moorings to 3 years from 2 would increase the cost of the array by about 1/8th using present technology. However, if the new methods of communicating with subsurface doppler current meter moorings (see item 4 under feasibility above) prove practical then the third year would cost virtually nothing extra. We will keep close track on the emerging technology.

5) Integration of mixing into the overall observational program.
The integration of the mixing observations into the moored array context is the key difference between PUMP and previous programs. Our aim is the characterization of mixing as a function of properties the models can already reproduce with reasonable fidelity: vertical profiles of **u** and T. Therefore this integration is absolutely fundamental to PUMP's success. However, the mixing observations are more than that. These observations are essential for the dissection of the physical processes from internal waves through instability to irreversible mixing. The development of parameterizations requires not just a statistical relationship between the larger scale fields and mixing, but a fundamental understanding how and why the mixing occurs. Without that understanding, it will be impossible to develop parameterizations that can be applied to climate regimes that we are not directly sampling.

It is obvious that this integration is a major challenge for PUMP, requiring two communities that have not necessarily communicated well to work in concert. However, the enthusiastic response of the mixing and large-scale communities to the possibilities of making major progress in both areas suggests that PUMP is an opportunity to move beyond the barriers that have made this integration difficult in the past.

Timeline:
The SSC comment that we have not planned for sufficient digestion time for the data is correct. This is even more true when the need to conduct model parameterization tests is considered. The post-field-program analysis phase will be 2-3 years, and revised planning documents will reflect this

As called out by the SSC, the PUMP plan requires 3 ships working at one time during the IOPs. Given the need to have a SeaSoar bridge the scale gap between the microstructure sampling and the moorings, this is inherent in the demands of the sampling. Though challenging, this is not impossible, as there were at least 3 ships out for longer periods during COARE, which was further from the U.S. We will explore opportunities for international participation to achieve this objective at lowest cost.

Data synthesis/assimilation:
What assurance do we have that PUMP will lead to better parameterizations? Since there is no algorithm that shows how to develop a mixing parameterization, there is no guarantee. What is

assured, however, is that without these integrated observations, parameterization development will continue to be a matter of trial and error. Recent discussions with modelers at GFDL suggests some promising directions. Given the likelihood that internal wave fluxes are essential to balance the zonal pressure gradient in the EUC, we will look into developing a vertically non-local (but single column) turbulence model that could be introduced into the models. Unlike the rest of the interior ocean, the equatorial internal waves seem to be largely locally-generated, raising the possibility of a simplified closure model (omitting horizontally-propagating influences). In collaboration with GFDL, we will experiment with such models, in time to be able to test these ideas in the water. Based on these interpretations of results from previous work, PUMP is more than a mapping expedition; working with modelers anxious to improve their product we have concrete ideas to evaluate.

Resource issues:
As the SSC notes, PUMP is a resource-intensive project (about as large as other recent oceanic process studies such as EPIC or HOME, but significantly smaller than TOGA-COARE). We will keep abreast of all opportunities to share resources with other programs, and would appreciate the SSC and IAG continuing to bring such opportunities to our attention.