Opportunities for early studies to refine and sharpen the experimental design of PUMP

The following are ideas for near-term pre-PUMP studies that would help focus and refine the observational and modeling work for the proposed PUMP experiment. They include theoretical and modeling studies, small-scale observational work, and data mining. Some of these might be suitable for a specific item in an Announcement of Opportunity, while others could be done by a single PI. We have tried to be as specific as possible, pointing to work that could be completed in a 2-yr period so as have results available for guiding PUMP, and that would generate hypotheses to be tested during PUMP fieldwork. A principal aim of suggesting these ideas is to broaden community awareness of PUMP, bringing a larger spectrum of ideas to the planning process, and we therefore seek a wide dissemination. Note that none of these is a request to fund any specific PI or group; our intention is explicitly to open this work to broad competition. Any publicity that these ideas could gain through CLIVAR or through the IAG program managers would be of great benefit towards focusing the PUMP program, increasing its likelihood of meeting its goals, and decreasing its costs.

1. Data recovery and reanalysis for the Tropic Heat 1, 2 and TIWE experiments.

The fieldwork that produced our knowledge of the equatorial mixing environment was conducted in 1984, 1987 and 1991. The initial interpretation of results was highly influential in constraining the mixing parameterizations of current-generation OGCMs; unfortunately, the original data have languished and now exist only on old tapes and in old formats. The TIWE experiment in particular was like a mini-PUMP in including both moored estimates of velocity divergence and microstructure surveys, but these two data sets have only been examined in isolation. In addition to getting additional value from the Tropic Heat and TIWE fieldwork, reanalysis of these observations as a joined picture would begin to show the interdependence of upwelling and mixing that is the target of PUMP. This would aid the planning of PUMP and provide a historical background for it.

Work would be required to recover the data (and metadata) from old media and paper records, and present it in modern formats. The reanalyzed findings could then be used to compare and validate hindcast experiments run with modern OGCMs.

We regard this item as the one piece of work that is absolutely essential to accomplish in planning PUMP.

2. Multi-model comparisons of the meridional circulations in OGCMs.

A large literature exists comparing OGCMs' SST and their vertical structures of u and T along the equator, but relatively little is known about the models' representations of the equatorial upwelling cell. These cells appear to differ widely among models, which has important implications for the spinup of the model circulations in response to wind anomalies, and therefore for the mechanisms by which the models produce SST variability. The meridional, vertical and temporal scales of variability of the model upwelling cells as the wind varies in magnitude and direction will likely be partly a function of the thermocline stratification and EUC strength (which therefore implies the influence of basin-scale, not just local, winds). Comparison and diagnosis of these cells in different types of model configurations (z-level and isopycnal coordinate, varying vertical and horizontal resolution, level of lateral mixing), and their dependence on the type of mixing parameterization used, would provide insight into how the models' equatorial circulations work and suggest the range of possibilities PUMP observations might encounter, as well as indicating the magnitude of the task of improving the models. These analyses will be essential background for the development and testing of new mixing parameterizations.

3. Development of models for vertical wave momentum flux.

In analogy to the role of gravity wave drag in the equatorial stratosphere, observations suggest that internal wave momentum fluxes are essential to balance the zonal pressure gradient in the equatorial undercurrent. A symptom of this is the emerging view that purely Ri-dependent parameterizations apparently cannot be tuned to encompass both the EUC and the shears in deep overflows.

Unlike the rest of the interior ocean, equatorial internal waves seem to be principally vertically-propagating and hence locally-generated, raising the possibility of a simplified closure scheme omitting horizontally-propagating influences. Again in analogy to the atmospheric GCMs, a vertically non-local (but single column) model might be able to parameterize this process. Experiments in idealized, LES and basin-scale GCM models could be used to develop and test such schemes. This work would both focus attention on physics missing from the Ri-based parameterizations and provide quantitative hypotheses for the impacts and locations of internal wave momentum flux convergence that could be tested during PUMP fieldwork.

4. Instrument testing and quantification of scales of variability in the cold tongue.

While the long histories from the TAO array provides substantial information about temporal variability right at the equator, the near-equatorial meridional structure remains poorly sampled. Since the divergence that produces vertical velocity depends on the gradient of horizontal velocity, the present vagueness about the vertical/meridional scales of velocity variance leads to uncertainty about how to reliably sample it to estimate w. In addition, recent observations during EPIC have shown the sharpness of the front near 2°N and suggested the importance of frontal circulations in the heat and property budgets. New instrumentation (e.g., gliders and Lagrangian floats) is available that could begin to quantify these scales in preparation for PUMP, which would also provide useful guidance to their capabilities in the regional conditions. The early sampling gained from such testing would help to justify or suggest alternatives to the proposed PUMP mooring array spacing.

5. Theoretical and modeling studies of fronts and their secondary circulations near the equator.

Observations during EPIC have shown the intense front that bounds the cold tongue to the north, but the reasons for the sharpness of this front remain unclear. Further, it appears that the front is associated with secondary circulations that produce significant meridional fluxes of heat, salt and momentum. It has also been shown to strongly affect the atmospheric boundary layer winds, raising the possibility of coupled feedbacks. Since the front is and will remain subgridscale in the climate models, parameterization of these fluxes is a key challenge for the representation of the equatorial momentum and property budgets. Building on mid-latitude frontal results, theoretical and both idealized and realistic modeling studies should determine the vertical and meridional scales of the secondary circulations, estimate the associated fluxes, and work towards parameterizations of these in coarse-grid models. The studies should point to observations that could be taken during PUMP fieldwork to test these hypotheses.

6. Theoretical and model diagnoses of the transition of the Ekman layer near the equator. Observations and models suggest that the poleward diverging limb of the equatorial upwelling cell occurs in a thin (20-30m) near-surface layer; however the thinness of this flow is a challenge both to observe and to model. Existing theory provides little guidance as to how the "Ekman layer" should be expected to change as the equator is approached; such guidance would both aid in developing a PUMP sampling strategy and provide a target for model diagnoses. In addition, development of a dynamical foundation for the near-surface equatorial circulations would help in understanding the vertical and meridional scales and structure of the cross-equatorial cells seen in the eastern Pacific that pull the upwelling to the south. Basin-scale OGCMs and sparse observations suggest large-zonal-scale subduction of the poleward flow near 3°-4°N. This could be related to frontal processes (and would itself contribute to sharpening the front) but also is implied by Ekman pumping due to the rapid decrease in the magnitude of the Coriolis parameter with latitude. This complex of near-equatorial surface layer processes has been glossed over in existing theories but is ripe for reexamination, which would help focus the target for PUMP in the off-equatorial transition regime, and provide guidance for the model resolution necessary to properly represent this important feature.