

# A COMPARISON OF ACOUSTIC THERMOMETRY, XBT, TOPEX, AND HOT OBSERVATIONS OF OCEAN TEMPERATURE IN THE NORTHEAST PACIFIC OCEAN

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**Abstract** - Acoustic thermometry offers naturally integrating observations of large-scale temperature with unrivalled accuracy and precision. These temperature measurements have no calibration drift. In a world of a climate signal of order 0.01 °C/yr and high-wavenumber (mesoscale) noise of order 1 °C rms, spatial low-pass filtering is needed to pull out the climate signatures.

Timeseries of temperature have been measured using long-range acoustic transmissions in the Northeast Pacific as part of the Acoustic Thermometry of Ocean Climate (ATOC) project (The ATOC Consortium, 1998; Dushaw, et al., 1999; Dushaw 1999; Worcester et al., 1999). In this paper, these timeseries are compared with other available data types. The acoustic timeseries of transmissions from a source off the coast of central California began in early 1996, while the timeseries from a source north of Kauai, Hawaii began in late 1997. As a result of marine mammal protocols, the timeseries are intermittent. The California source was turned off in Fall 1998 after 24 months of operation in accord with permit requirements. Transmissions from the Kauai source continue to the present time.

Assuming that the variations in sea surface height observed by TOPEX/POSEIDON are caused solely by thermal expansion in the upper 100-m of ocean, the amplitude of the annual cycle of heat content derived from altimetry is considerably larger than that found by the acoustic data, Levitus climatology, and monthly maps of ocean temperature derived from XBT's of opportunity (XBT maps courtesy of White, 1999). Averages of the altimeter and XBT data are calculated along the acoustic paths for these comparisons. The "anomalies," or deviations of temperature from the annual cycle, are the essence of the climate problem. The heat content "anomalies" determined by the XBT maps are comparable in size to the differences between the XBT and acoustically derived heat content. These differences may be due to undersampling in space or time by the XBTs, errors in the XBT maps as a result of such things as fall rate errors, aliasing of internal wave or mesoscale variability, or the deeper sampling (below 400 m) of the acoustic data. The 12-year timeseries of temperature derived from the Hawaiian Ocean Timeseries (HOT) data set (monthly CTD casts), highlights the problem of mesoscale noise in sampling at a single point (Figure). However, thermal variability at 100-day timescales is observed in the acoustic data obtained between Hawaii and California using the Kauai source with no corresponding variability in the TOPEX data (and certainly not in the heavily-smoothed XBT maps). Acoustic thermometry is complementary to altimetry and hydrography.

A global acoustical array may eventually be feasible, effective, and affordable (Acoustic Tomography White Paper, 1999; SCOR, 1994). Regional tomographic observations will become more common and opportunistic. Both the large-scale or basin-wide observations and regional (process-oriented) experiments can make contributions to learning about the climate variations of the world's oceans. Observing systems such as the proposed "Deep Earth Observatories on the Seafloor" (DEOS, 1999) system may include receivers for tomography on deep-ocean moorings; such receivers would greatly expand the coverage of acoustic sampling. We are working to reduce costs by redesigning sources and receivers to take advantage of technological developments. Presently, one of the greatest impediments to implementing greater coverage of the oceans by acoustic tomography is the high upfront cost of the instrumentation (primarily acoustic sources). Once instrumentation is in place, the operational costs of

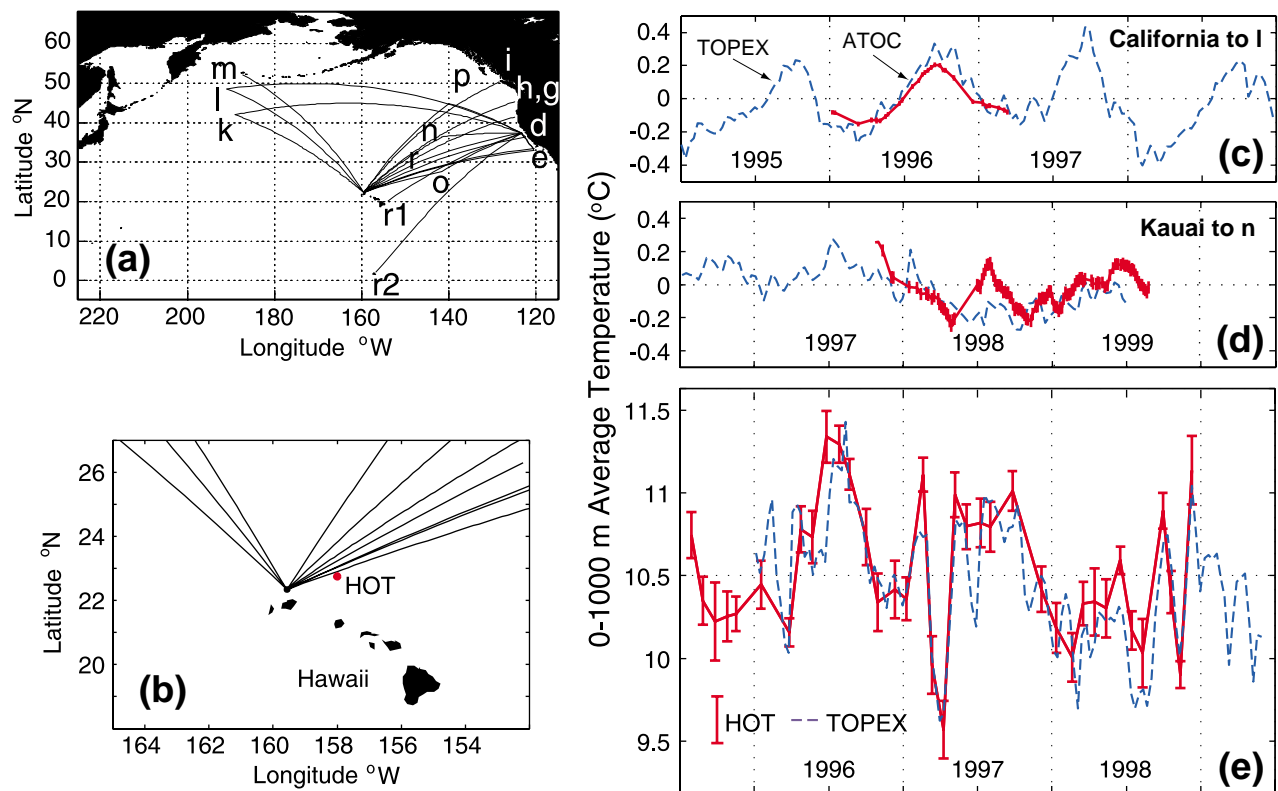
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long-term observations is minimal. The amortized cost of the technique is attractive.

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A comparison of line-integral and point data. (a): The ATOC array. (b): The HOTS site. (c) and (d): Acoustic thermometry (solid line) compared to TOPEX altimetry (dashed line) for two acoustic paths as indicated. The error bars on the acoustical results in (c) are small. The annual cycle was removed from the TOPEX data in (d); the acoustic data on this path sample below the seasonally-varying surface layers and hence do not observe the annual cycle. (e): A similar comparison of 0-1000 m averaged temperature derived from HOTS hydrographic data (error bars are RMS of 10-20 CTD casts) and TOPEX. All timeseries have the same scale for both axes. In (e), a nearly identical result is found when comparing dynamic height and altimetry. The differences between the temperature inferred from TOPEX and the direct measurement at HOTS (a point measurement) are comparable to the temperature signal observed in the line-integrating data. The error bars of the hydrographic data are comparable in magnitude to the signal observed in the line-integral data, and the hydrographic data is dominated by mesoscale variability.