Are Temporal Changes in Eddy Transports Significant?

Detlef Stammer and Carl Wunsch

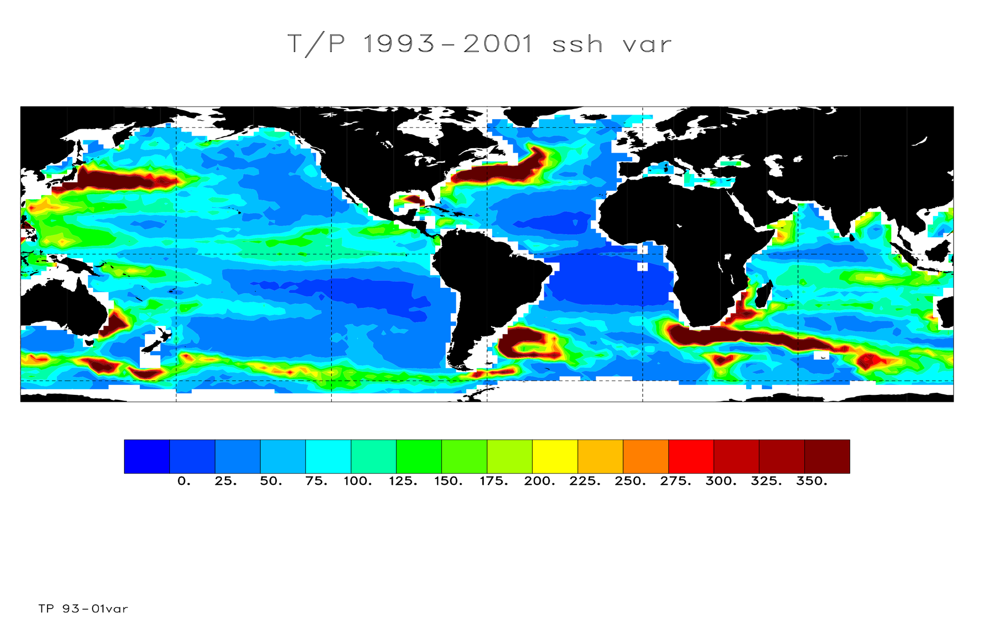
Scripps Institution of Oceanography and Massachusetts Institute of Technology

Summary:

Altimetric sea surface height measurements from the TOPEX/POSEIDON (T/P) mission are used to investigate interannual changes in eddy variability and transports in the ocean. Invoking a "mixing length" hypothesis, an eddy transfer κ for a scalar tracer in the ocean can be estimated from T/P eddy statistics as $\kappa = \alpha K_E T_{bc}$, where α is a scaling factor, K_E is the kinetic energy of the eddy field and T_{bc} is the time scale of the baroclinic eddy field. Changes in T_{bc} on interannual time scales are found to be insignificant. Changes in K_E do exist, but typically remain smaller than 10% of the mean over intervals of 1-2 years. A few regions however, exhibit interannual or longer-term variations in kinetic energy and thus eddy transfers sometimes exceeding 30%. Effects of changing eddy transfers on the general circulation are believed to be negligible however, because those changes usually do not persist over long times, and are found primarily outside of the eddy-active boundary current regions.

Methodology:

Satellite altimetry provides unprecedented information not just about eddy scales, but also about the temporal changes of eddy properties on interannual and longer timescales. A spatially varying eddy mixing/transfer coefficient can be computed from T/P eddy statistics by invoking a "mixing length" hypothesis, with $\kappa = V_{bc} T_{bc} = L_{bc}^2 / T_{bc}$. To do so, we approximate $V_{bc} = \sqrt{K_E}$, where K_E is the eddy kinetic energy obtained from the T/P observations. Our focus here is on expanding the previous estimates of *Stammer* (1997, 1998) by using the full 9-year long data set. These data provide more definitive estimates of eddy kinetic energy and timescales, and permit the investigation of any temporal changes in eddy variability with consequent physical implications. We distinguish changes in eddy variability that are expected from the usual fluctuations of a stochastic process, from those that are sufficiently large to demand a change in underlying statistics. There is no evidence here for the latter; nonetheless, ordinary stochastic variation can, in principle, generate signficant physical changes in the ocean.



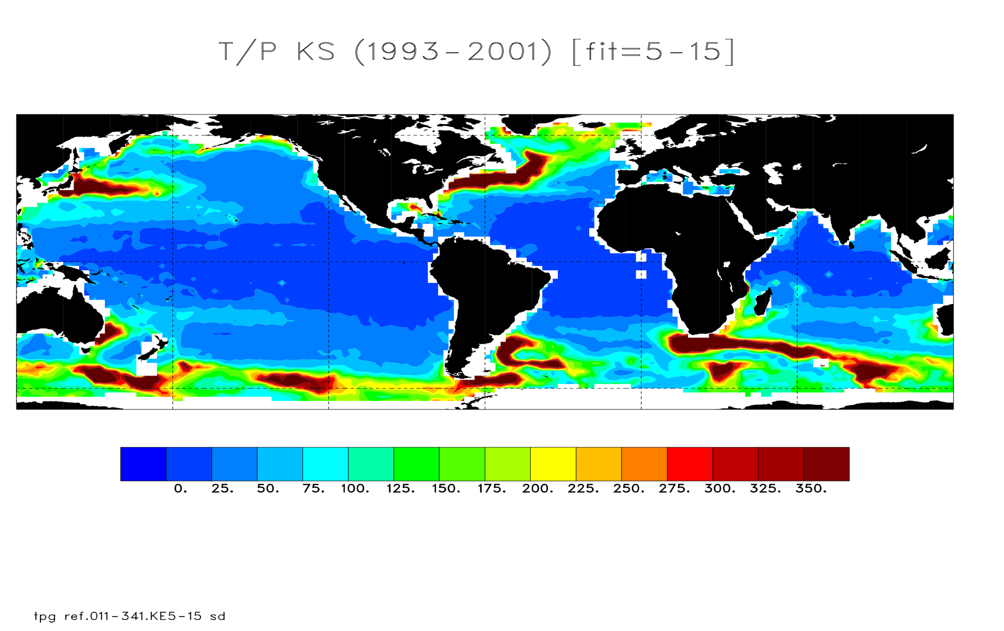
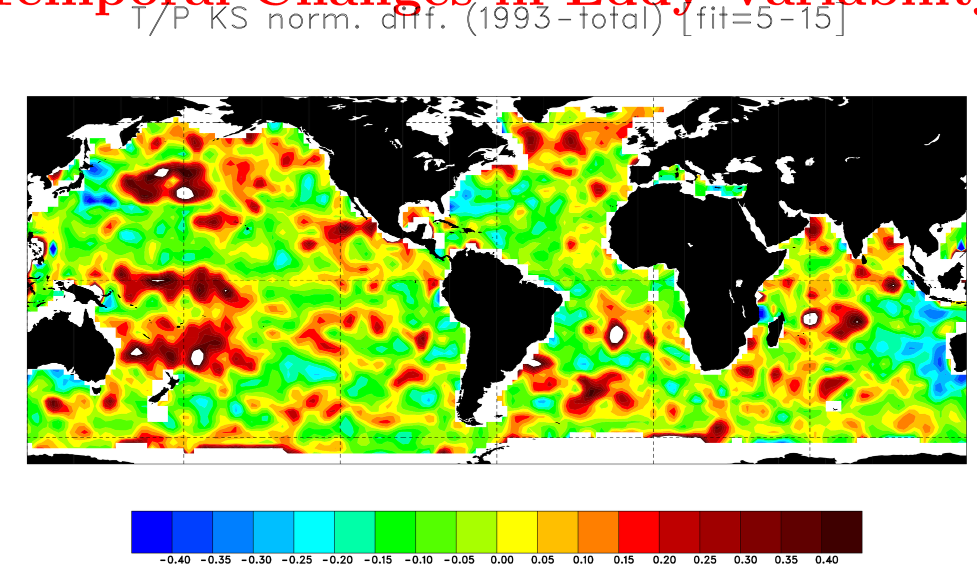


Fig. 1: Estimates of the SSH variance and of slope variance over the time interval 1993 - 2001. Slope variance is defined here as in *Stammer* (1997) as

$$K_S = \left(\frac{g}{f}\right)^2 < v_s^2 >, \tag{1}$$

where $v_s = \partial\eta'/\partial s$, η' the along track SSH anomalies (relative to the 9-year mean) and s is the along-track distance. Note that the eddy kinetic energy follows from (1) as $K_E = K_S \sin^2(\phi)$, with ϕ being latitude. The K_S field shown here was computed from the along-track η' data by fitting a straight line over several alongtrack data points. The associated fitting distance was varied from 150 km near the equator to 50 km around 60° N to account for meridionally varying eddy scales and a higher noise sensitivity near the equator.

Temporal Changes in Eddy Variability



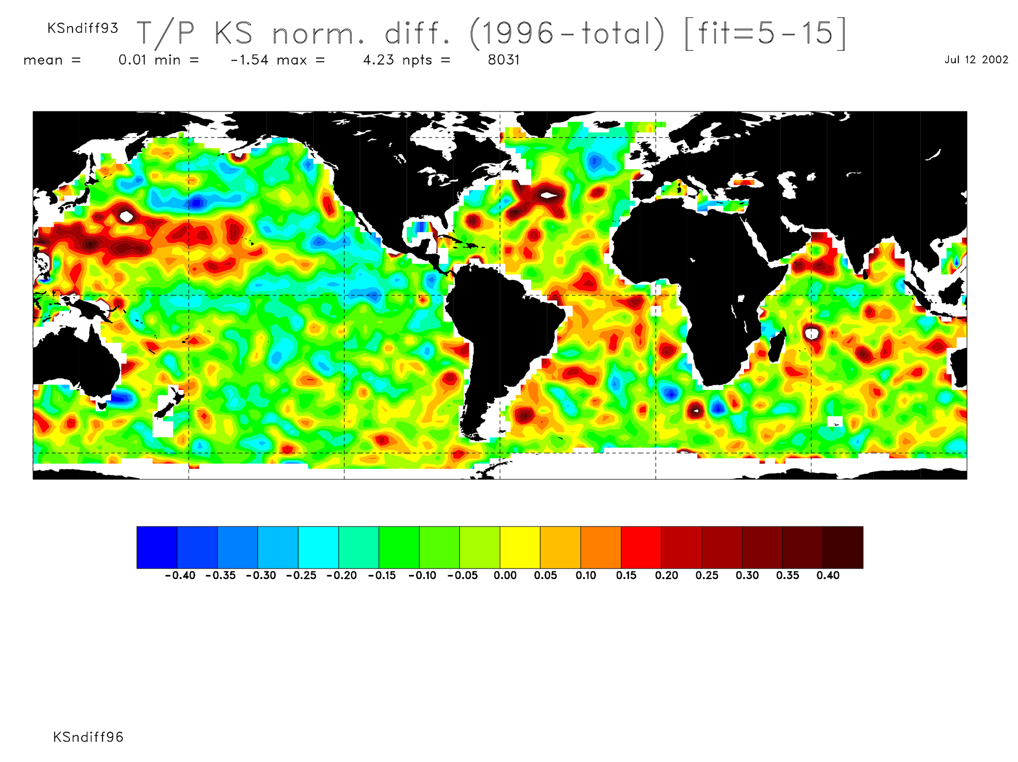


Fig. 2: Two examples of interannual variability in kinetic energy. The figure displays normalized annual K_S anomalies for 1993 and for 1996. These values are expected to fluctuate around the true mean value with amplitudes dependent upon the number of degrees of freedom. Whether or not the changes demand a shift in underlying statistics, the finding of changes of 30% or more in K_E on large spatial scales suggest that significant physical effects could occur depending upon both the absolute magnitude and its ratio to "mean" quantities, as well as the duration of the anomalies.

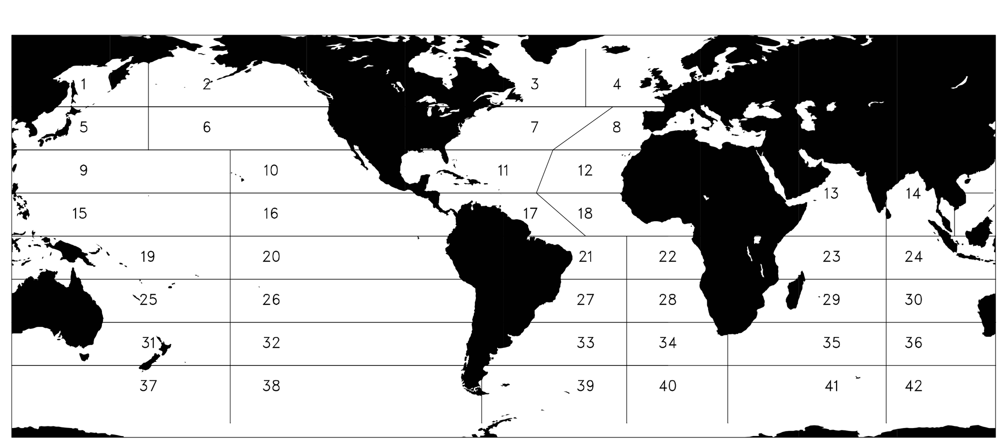


Fig. 3: For a quantitative description of temporal changes in eddy variability, frequency spectra, and area-averaged variances were computed from alongtrack SSH and slope data in the regions depicted in the figure. To highlight the variations of the short-period slope variances, the variance of the slopes was determined for each repeat cycle over the areas shown. Results are presented in Fig. 4.

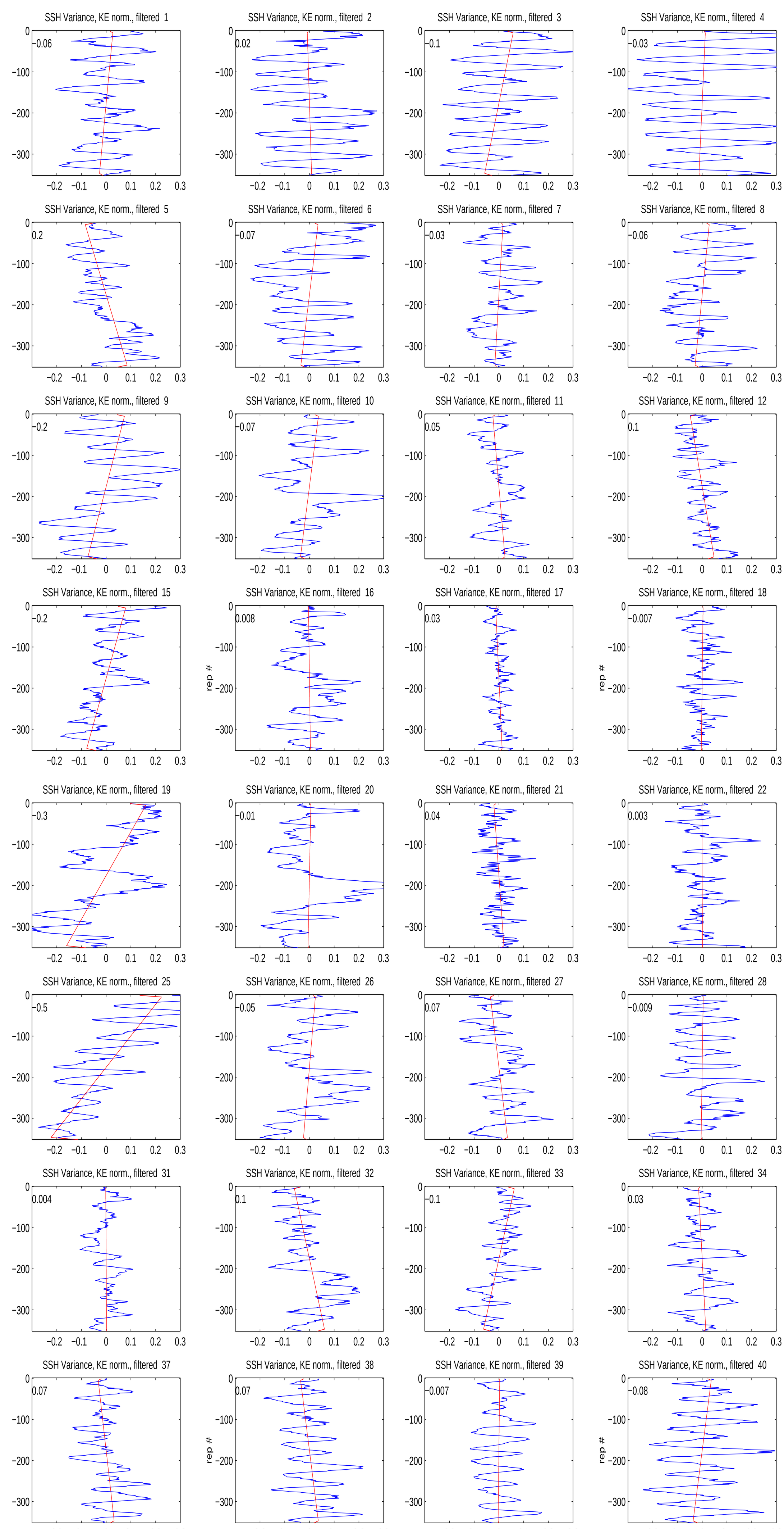


Fig. 4: Results for the Pacific (left two columns) and the Atlantic (right two columns) after normalization with the mean variance from the entire period. Timeseries for the eddy slope variances essentially accord with those from SSH eddy variances, and with results obtained from a spectral analysis (not shown). The slope variances show changes on seasonal and interannual time scales, and display secular trends—shown as red lines—from a least-squares fit.

Over the nine years, the subpolar North Atlantic appears to decline in eddy variability, most strikingly over the Labrador Sea. In contrast, the subtropical North Atlantic shows some increase in variability as do parts of the South Atlantic. Most noticeable, however, is the steady decrease of eddy variability over much of the subtropical and tropical Pacific Ocean in both hemispheres, and a steady increase of eddy variability over the eastern Indian Ocean (not shown).

Temporal Changes in Eddy Scales

To gain insight into temporal variability we computed eddy timescales T_{alt} over a sliding 3-year long window as the temporal eddy SSH decorrelation time scale.

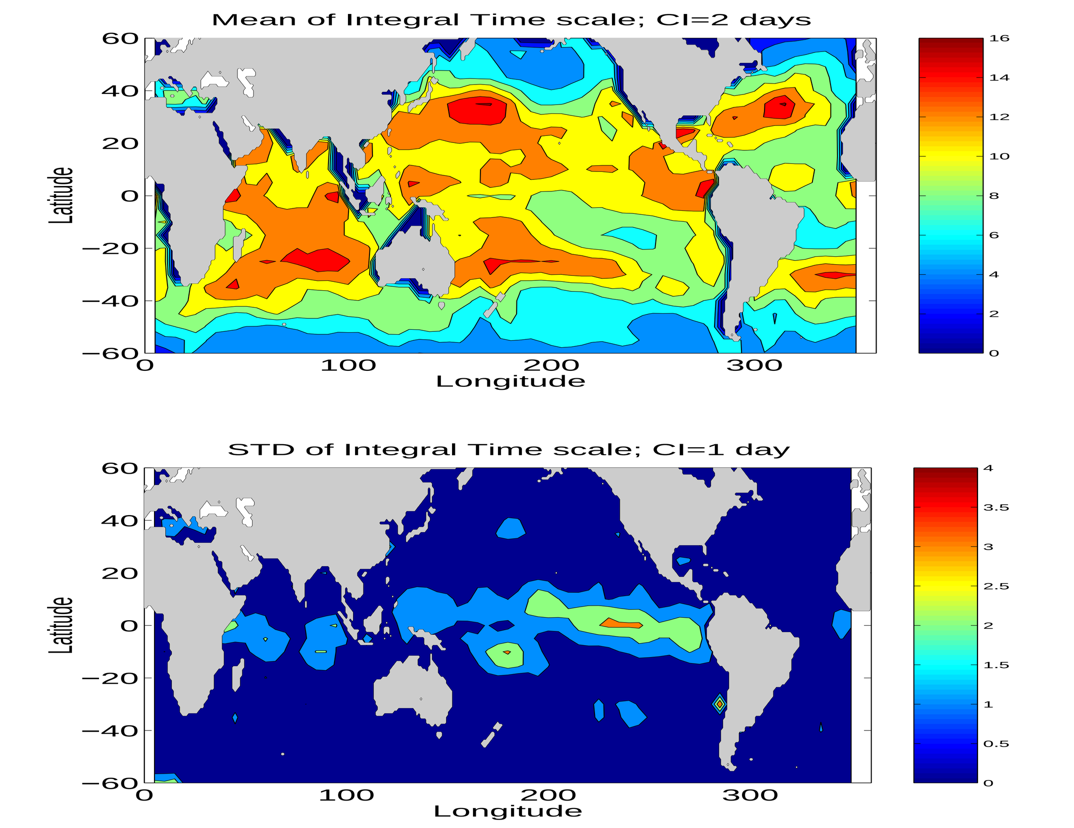


Fig. 5: Mean (top) and standard deviation (bottom) of T_{alt} computed from the 9-year long T/P timeseries split into sliding 3 year-long windows. Results agree basically with *Stammer* (1998). Temporal variations of T_{alt} are insignificant outside the tropical region where ENSO events are the dominant source of changes.

Eddy Transport Variations

An estimate of a diffusion coefficient was obtained as,

$$\kappa = \alpha K_E T_{alt}, \tag{2}$$

where K_E is an estimate of near surface eddy kinetic energy from T/P, $T_{bc} = T_{alt}$ was provided on a 5° geographical grid, and $\alpha = 0.1$ is a correlation coefficient determining the efficiency of the ability of individual eddies to mix tracer particles.

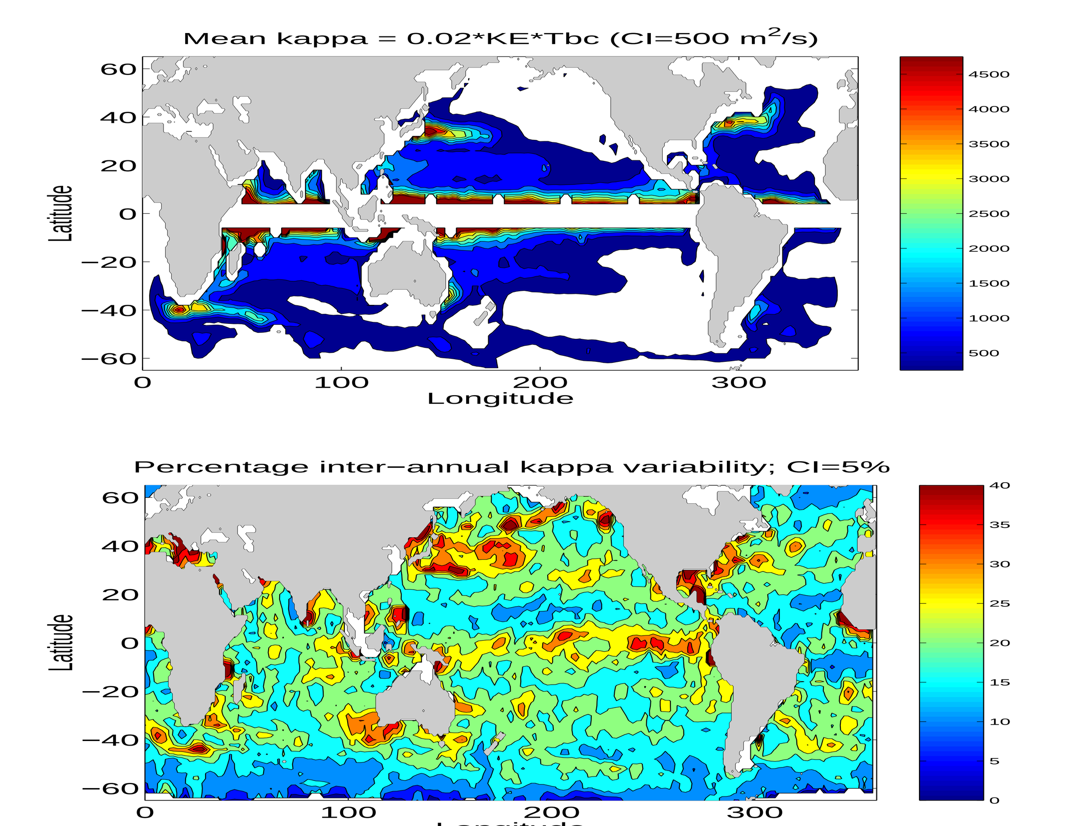


Fig. 6: The mean κ field resulting from the 9-year long estimates is shown in the top panel. In the lower panel is shown the percentage temporal change in κ on interannual time scales. Only in a few regions do changes reach 30% of the mean; most of those places are areas of sufficiently weak eddy energy that the shift in eddy fluxes is unlikely to have any major physical consequences.

References

[1] Stammer, D., 1997: Global characteristics of ocean variability from regional TOPEX/POSEIDON altimeter measurements, *J. Phys. Oceanogr.*, 27, 1743–1769.

[2] Stammer, D., 1998: On eddy characteristics, eddy transports and mean flow properties, *J. Phys. Oceanogr.*, 28, 727–739.

[3] Stammer, D., and C. Wunsch, 2002: Are temporal changes in eddy transports significant? To be submitted for publications.