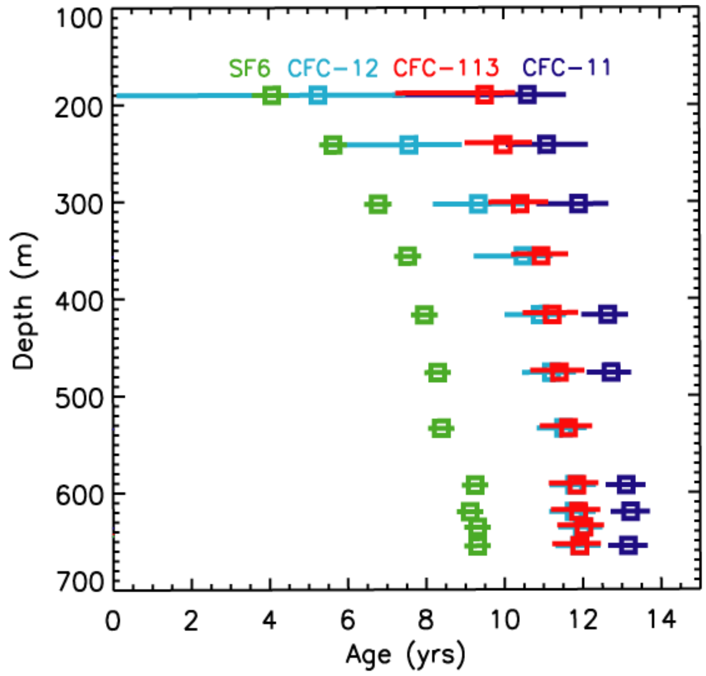
Transit Time Distributions in Lake Issyk-Kul

[See Waugh et al. 2002 for details.]

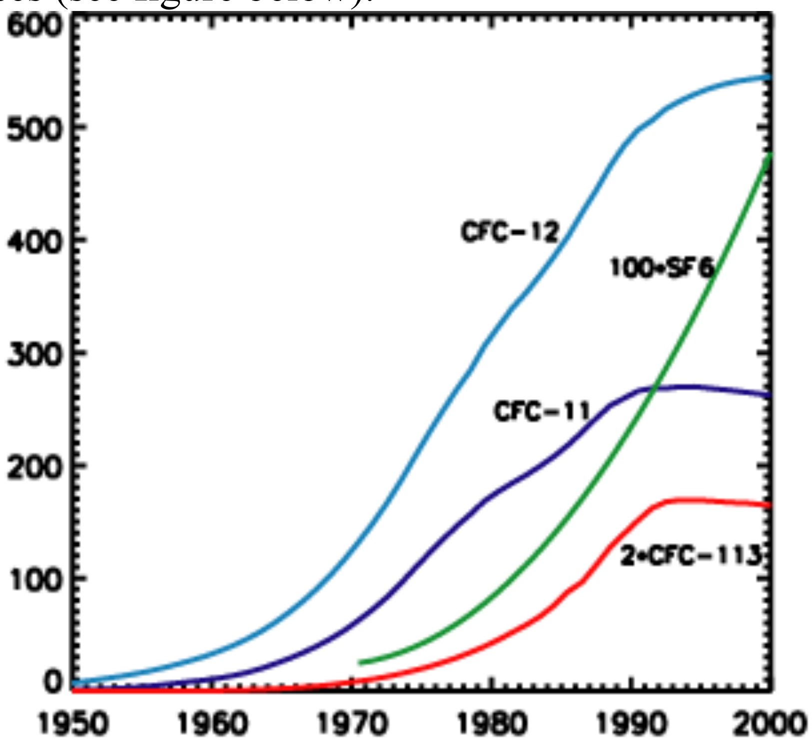
Measurements of SF_6, CFC11, CFC12 and CFC113 were made in Lake Issyk-Kul, Kyrgyzstan in September 2000 [Vollmer et al., GRL, 2002]. These measurements can be used to constrain the distributions of surface-to-interior transit times in the lake.

As shown below, the ages (elapsed times since surface concentrations equal measured values) derived from the measurements differ among the tracers.



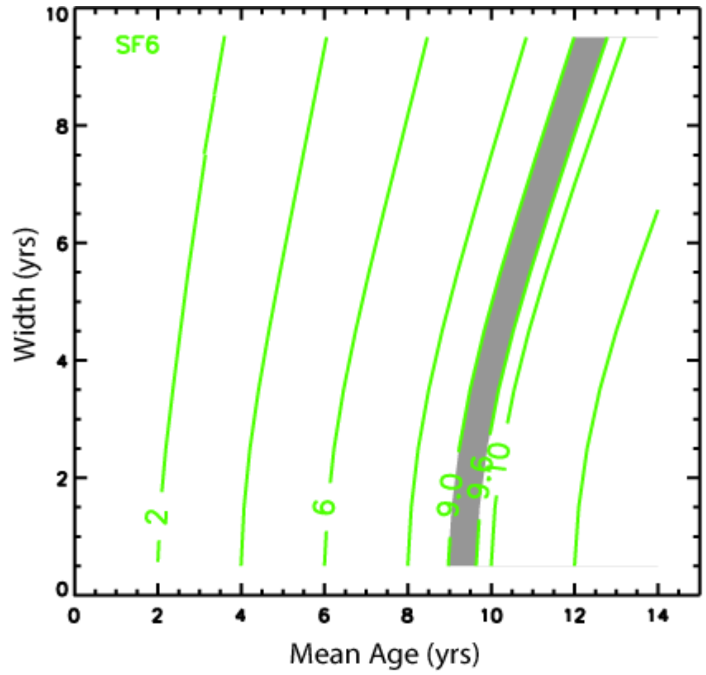
Vertical profiles of tracer ages derived from measuements in Lake Issyk-Kul (Vollmer et al. 2000).

As discussed in the Transient Tracers and Tracer Ages section, these differences are related to different atmospheric histories of the gases (see figure below).



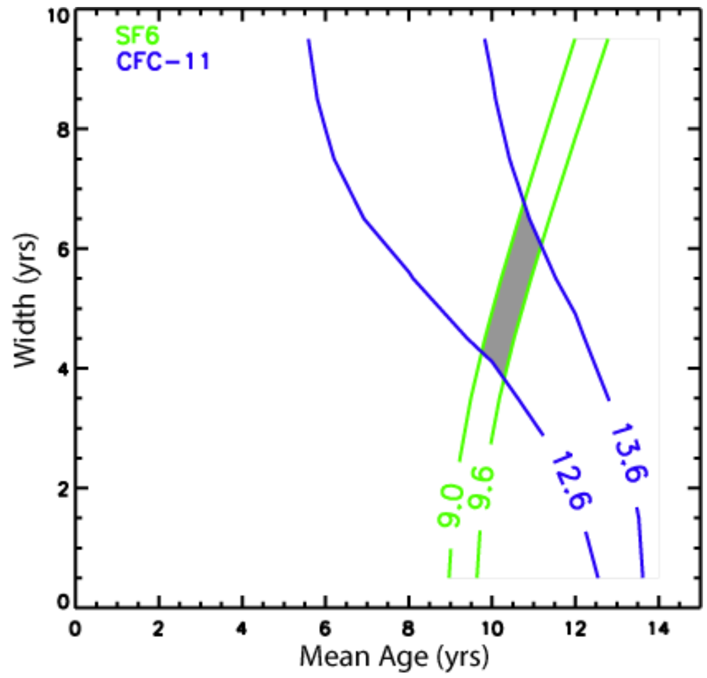
Time series of atmospheric concentrations, for background air in northern hemisphere troposphere, of CFC-11, CFC-12, CFC-113 and SF_6.

These differences in tracer ages can be used to constrain the transit time distributions (TTDs) in the lake. Assuming that the TTDs can be modeled as Inverse Gaussian distributions the age from a single tracer constrains the first two moments of the TTD (mean Γ and width Δ) to a range of values, which correspond to different amounts of mixing. This illustrated below where the region of Γ-Δ space consistent with the measurement of SF_6 at 655 m is shaded.



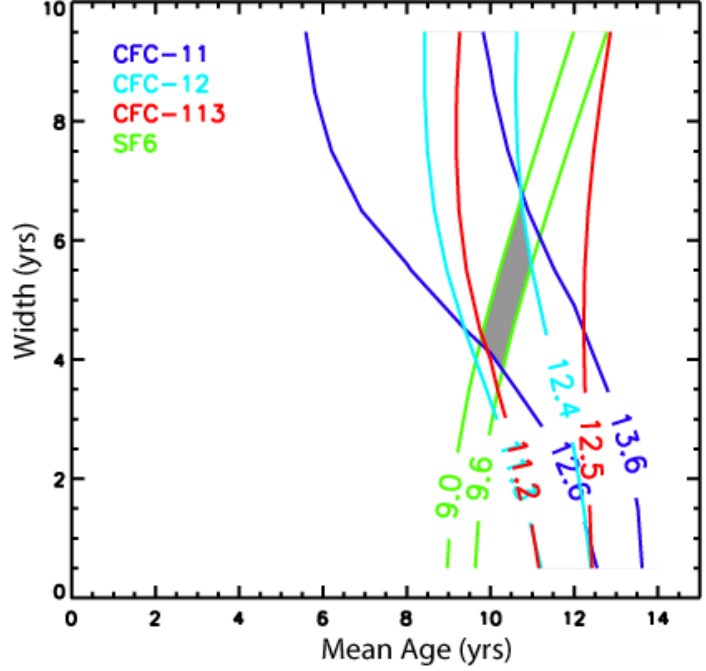
Variation of SF_6 age with mean age and width. The shaded region corresponds to the region ages are consistent with the measurement at 655m.

The age from a second tracer will in general constrain Γ and Δ to a different range of values, and there will be a limited range of Γ and Δ producing both tracer ages. This is the case of CFC11 measurements, as shown below.



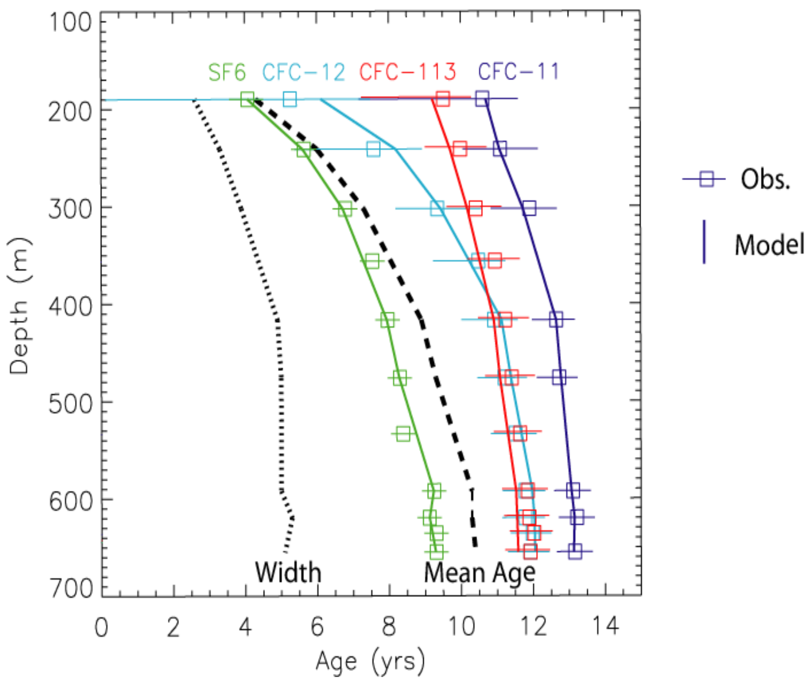
Variation of SF_6 and CFC11 ages with mean age and width. For each tracer two age isopleths are shown, one corresponding to the lower limit and the other to the upper limit of the measured age at 655m. The shaded region shows the region where both ages are consistent with the measurements.

Using the measurements of all 4 tracers a tight constraint can be placed on Γ and Δ, e.g.,



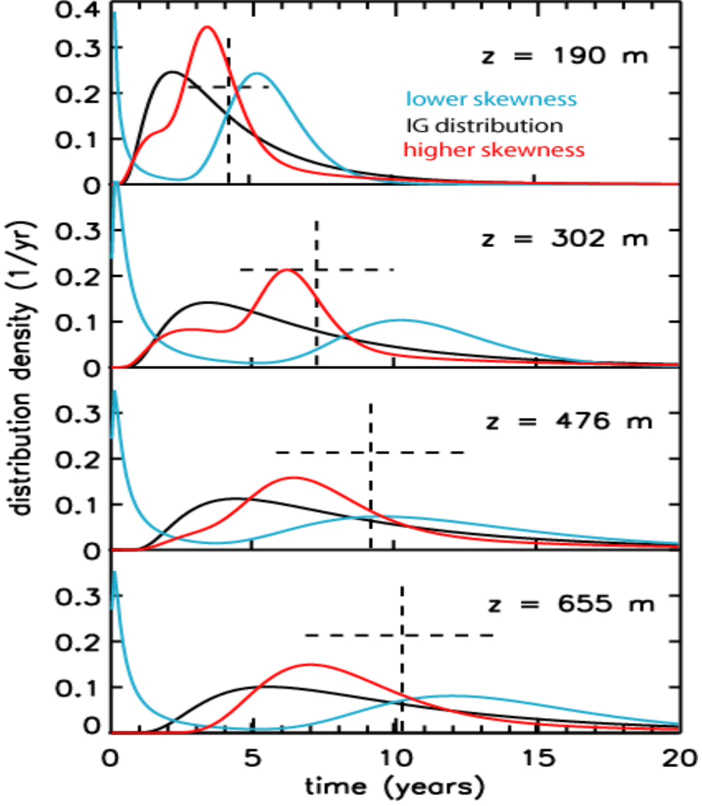
Variation of tracer ages with Γ and Δ, for CFC-11, CFC-12, CFC-113 and SF_6 ages at 655 m. For each tracer two age isopleths are shown, one corresponding to the lower limit and the other to the upper limit of the measured age. The shaded region shows the region of (Γ, Δ) space where all ages are consistent with the measurements.

At each depth the pair of Γ and Δ that minimizes the weighted sum of the square of differences between the TTD and observed ages of all four tracers can be calculated. These are shown in the figure below. Both Γ and Δ increase with depth, and Γ is bounded by the SF_6 and CFC12 ages.



Vertical profiles of tracer ages, and mean and width of TTDs in Lake Issyk-Kul. The squares and horizontal lines show the observed ages plus and minus the uncertainty. The curves show the tracer ages (solid), mean (dashed) and width (dotted) of the best-fit TTD.

The ratio Δ / Γ is around 0.5 at all depths. This corresponds to broad TTDs, with a large ranges of transit times to each location, e.g.,



TTD at depths between 190 and 655 m. Dashed vertical (horizontal) lines show the mean age (standard deviation) at each depth. The black curves show IG distributions whereas the blue (red) curves show ``two-IG" with lower (higher) skewness. The tracer ages from each TTD are consistent with the observed values.

The three TTDs shown at each depth in the above plots have different shape but have the same Γ and Δ and all match the tracer data. This shows that the estimates of Γ and Δ are insensitive to assumed shape of the TTDs.

Summary

As sulfur hexafluoride (SF_6) and the chlorofluorocarbons CFC11, CFC12, and CFC113 have different tropospheric histories the simultaneous measurements of these tracers can be used to tightly constrain the timescales for deep-water renewal in Lake Issyk-Kul. In particular, from these measurements the mean, Γ, and width, Δ, of the distributions of transit times since water made last contact with the surface can be tightly constrained. Γ is older than the age determined from SF_6 and younger than the ages from the CFCs, and increases from around 4 yrs at 200 m to around 10.5 yrs at the deepest location (655 m). Δ also increases with depth and equals around 0.5 Γ, which corresponds to large ranges of transit times, and implies mixing processes play a major role in the transport.

For more details see Waugh et al. 2002 .

Back to Transit Times in Geophysical Flows.