Global Warming of Lakes is Equally Non-Hypothetical…

Hi Everyone,
So picking up where we left off last time with regards to observed warming rates of streams, this time we'll look at the empirical trends in lake systems. Although stream-climate effects are generally going to be the focus, the importance of lakes for providing fisheries and other recreational activities, combined with last week's blog topic, warrants a brief segue here. I'll preface this post, however, by saying that I'm even more ignorant with regards to water that's not moving than that which is, so take it all with a grain of salt...

As was the case last week, here we're looking at long-term monitoring studies that show past evidence of warming rather than modeling studies that make projections about possible future scenarios. The first studies relate to Philipp Schneider's recent work wherein he & colleagues developed methods for inferring lake surface temperatures from ATSR & MODIS satellite imagery. The imagery is calibrated to individual lakes with a short series of *in situ* lake temperature measurements at which point the surface temperatures of the lake can be estimated accurately and very precisely for the duration of the imagery set available from the satellite.

Key points from the research are that:

1) Surface temperature in 167 large lakes around the globe warmed at the rate of 0.45 °C/decade for the 24 year period from 1985-2009.
2) Lake warming occurred more rapidly in some portions of the globe than others. In general, mid- to high-latitude lakes in the northern hemisphere warmed more rapidly than lakes in low latitudes or the southern hemisphere (which is similar to the trends observed in air temperature increases). In one example specific to the western US, it was found that surface temperatures in 6 large lakes in California & Nevada warmed at the rate of 1.1°C/decade for the 17 year period from 1992-2008.
3) Lake surface temperatures often increased at rates faster than local air temperature increases over the same period of time (graphics below).

Schneider's work provides a nice example wherein a long-term temperature record for the water body of interest is leveraged out of a short-term temperature monitoring record by linkage to a proxy variable (satellite imagery in this case) that's strongly associated with water temperature. Dendro-chronologists have long used similar techniques to reconstruct multi-century stream flow records based on the growth increment of tree rings. And yet others have been applying similar techniques to leverage long-term stream & river temperature records from shorter-term monitoring data (which we'll discuss in the next blog post).

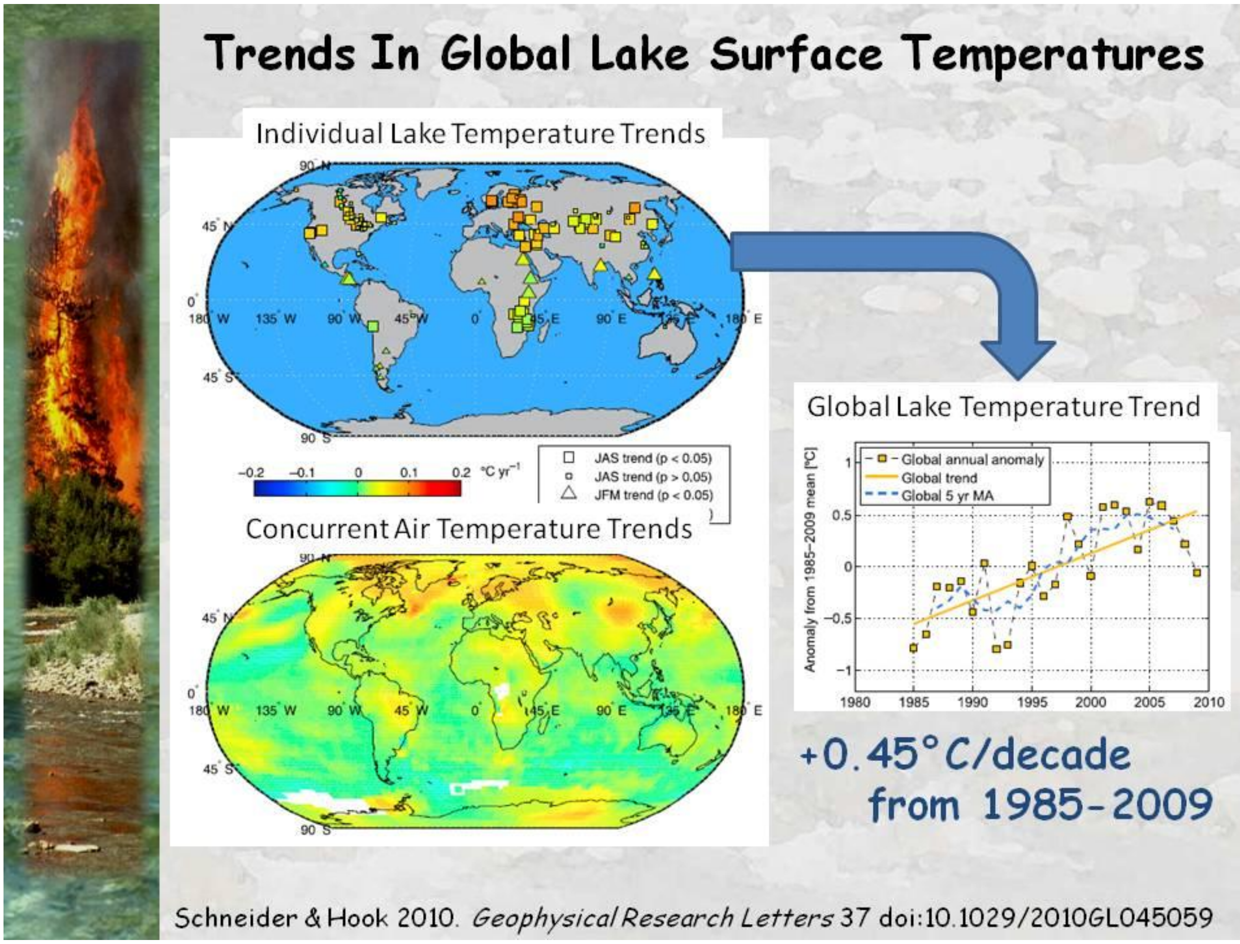
Limitations of Schneider's studies are that the lake warming trends can be inferred back only as far as the satellite imagery exists, which at this point is a few decades. But at the very least, & similar to the Hari et al. 2006 Swiss stream study in the last blog, Schneider's work indicates that lake thermal regimes are responding in a spatially coherent way to climate forcing associated with global warming.

The other potential limitation is that lake surface temperature trends may not be representative of trends at other depths, given that most lakes stratify for significant parts of the year and it could be that surface thermal gains may not translate below the first few meters. To address this limitation, therefore, we need a good long-term, multi-depth monitoring study. Not surprisingly, there're not many such beasts out there, but there are a few & here again, some of the best data come from Europe. The study we'll look at is by David Livingstone on Switzerland's Lake Zurich where he & his predecessors have been measuring monthly temperature profiles in this 135m deep lake since 1936.

Key points from the research are that:

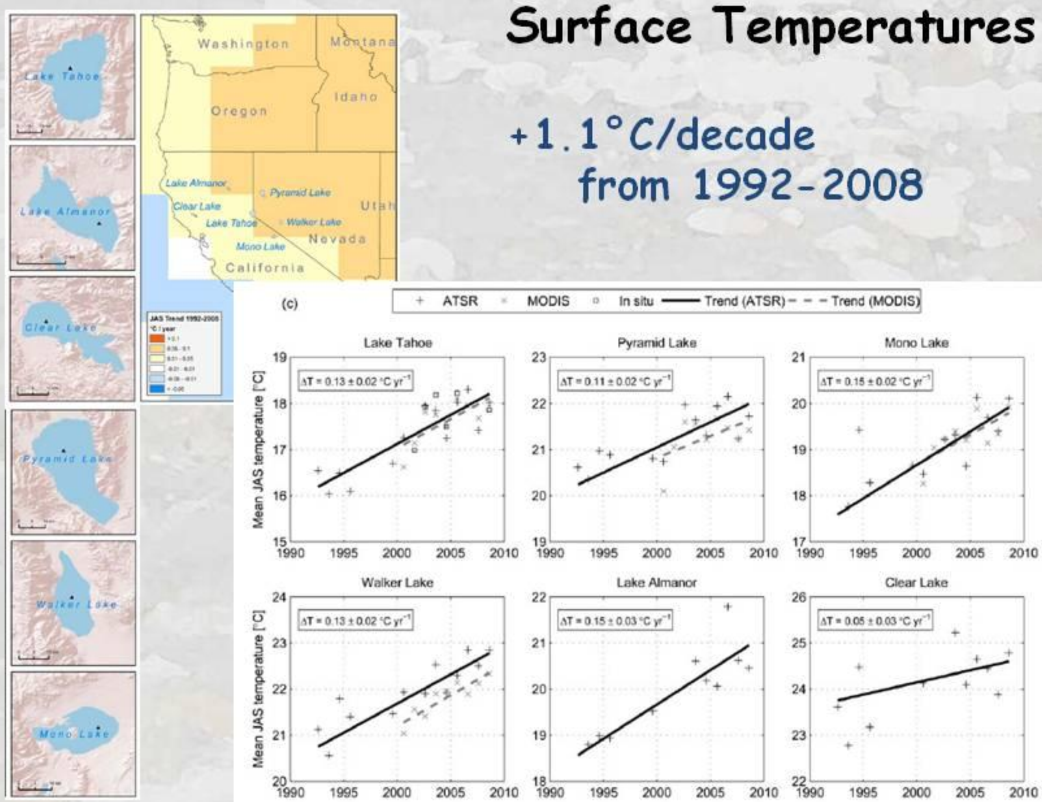
1) All lake depth strata (surface, epi/metalimnion, and hypolimnion) show warming trends in recent decades.
2) Warming trends in the deepest part of the lake (hypolimnion 20-136m) appeared to lag trends at shallower depths by more than a decade, but once warming began, it proceeded at the same rate as other depths.
3) Trends in lake temperatures generally tracked local air temperatures.
4) Lake thermal trends were associated with strong trends in annual days of lake stratification (increased), days of homothermy (decreased), date of transition to stratification (advanced), and date of transition to homothermy (retreated; graphics below)

Best regards,
Dan

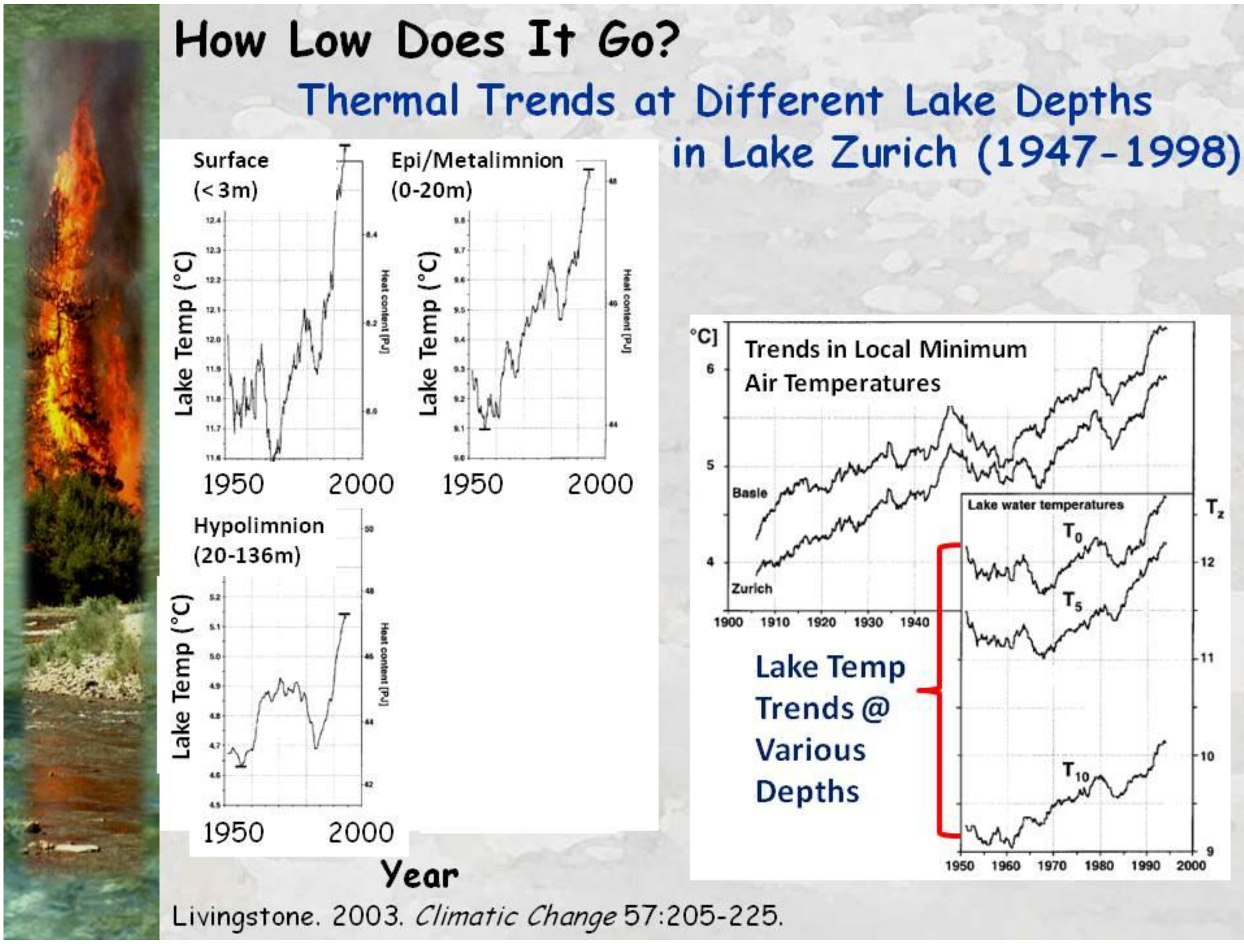

Trends In Global Lake Surface Temperatures
Individual Lake Temperature Trends
JAS trend (p < 0.05)
JAS trend (p > 0.05)
JFM trend (p < 0.05)
°C yr⁻¹
Concurrent Air Temperature Trends
Global Lake Temperature Trend
Global annual anomaly
Global trend
Global 5 yr MA
Anomaly from 1985–2009 mean [°C]
+0.45°C/decade
from 1985-2009
Schneider & Hook 2010. Geophysical Research Letters 37 doi:10.1029/2010GL045059

Trends In Western US Lake Surface Temperatures

+1.1°C/decade from 1992-2008

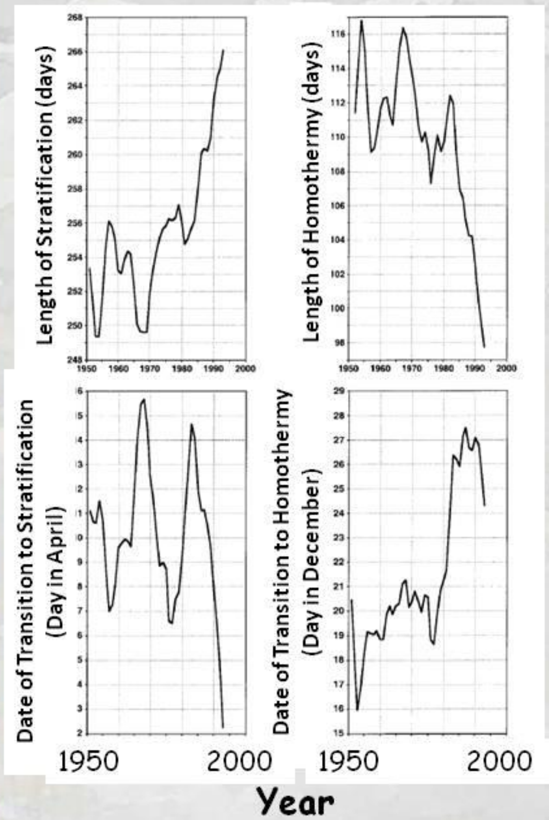


Schneider et al. 2009. *Geophysical Research Letters* 36doi:10.1029/2009GL040846



How Low Does It Go?
Thermal Trends at Different Lake Depths in Lake Zurich (1947-1998)
Surface (< 3m)
Epi/Metalimnion (0-20m)
Hypolimnion (20-136m)
Lake Temp (°C)
Heat content [PJ]
1950
2000
Year
°C]
Trends in Local Minimum Air Temperatures
Basle
Zurich
1900
1910
1920
1930
1940
Lake water temperatures
T0
T5
T10
Tz
1950
1960
1970
1980
1990
2000
Lake Temp Trends @ Various Depths
Livingstone. 2003. Climatic Change 57:205-225.

Trends in Other Parameters for Lake Zurich (1947-1998)



Livingstone. 2003. *Climatic Change* 57:205-225.