Jet Propulsion Laboratory
California Institute of Technology

Lake Water Temperature Trends from LST

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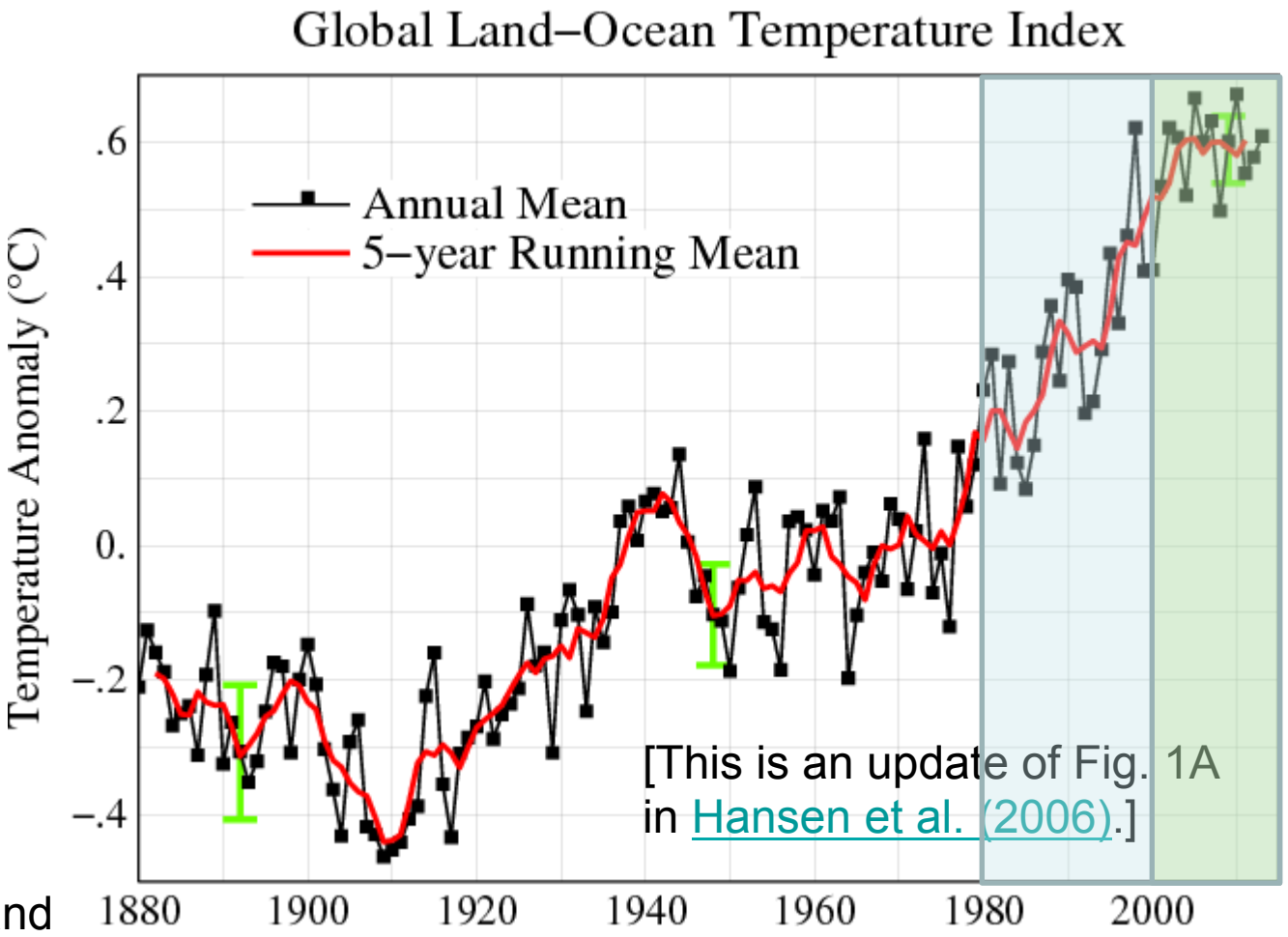
Mono Lake, California, October 2009

Outline

- Background and previous work
- Data and Methods
- California Case Study
- Ecological consequences
- Summary and Conclusions

Background

Line plot of global mean land-ocean temperature index, 1880 to present, with the base period 1951-1980. The dotted black line is the annual mean and the solid red line is the five-year mean. The green bars show uncertainty estimates.



Air temperature over land
Buoy and satellite retrievals over oceans

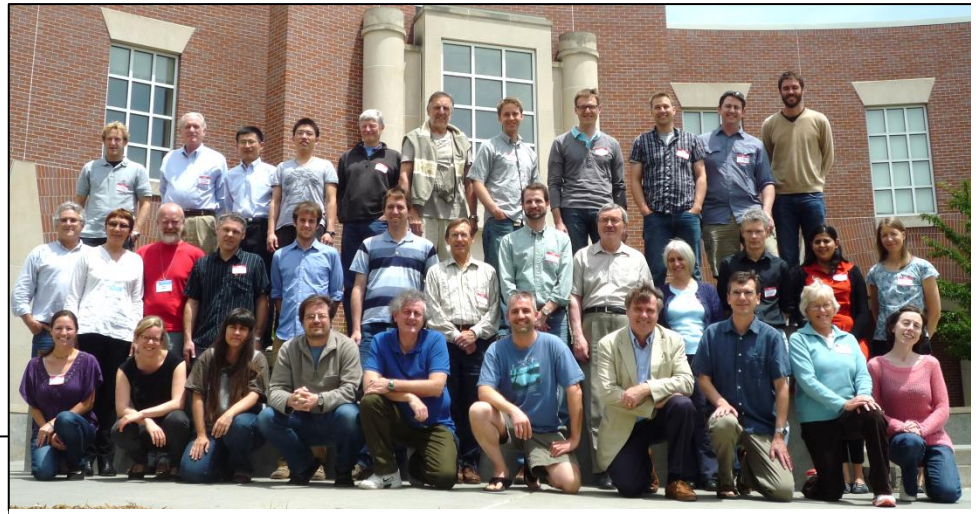
Previous Work

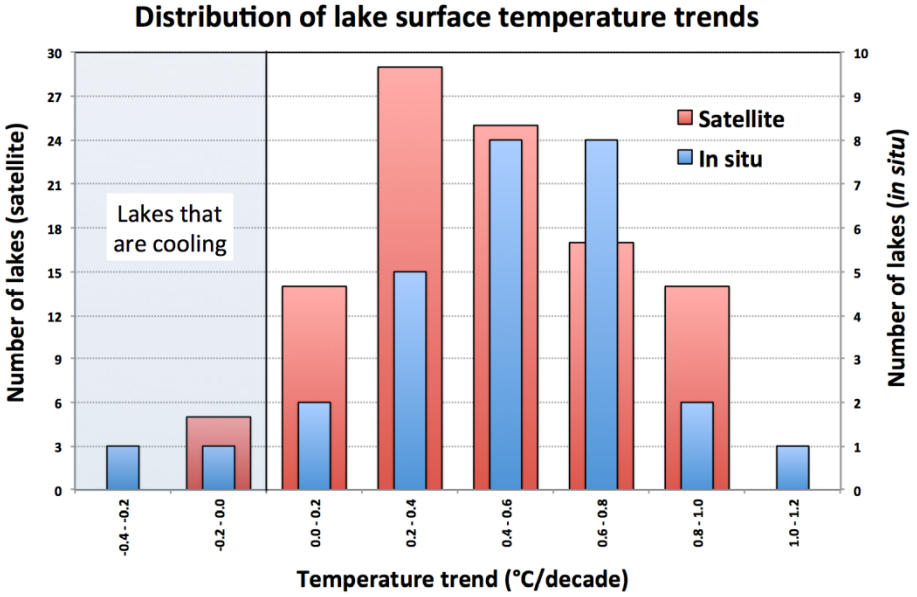
GLTC Global Lake Temperature Collaboration

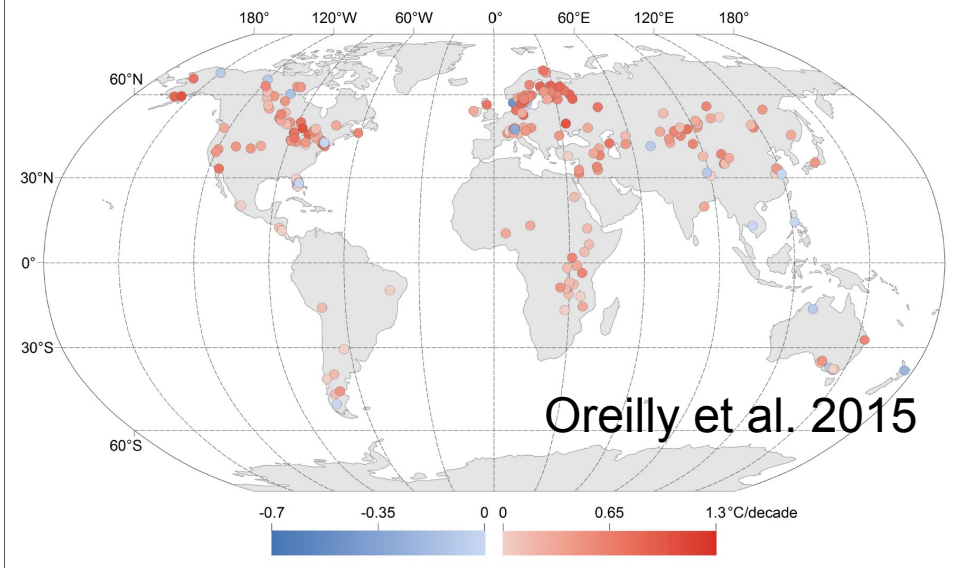
http://laketemperature.org/

Global Lake Temperature Collaboration (GLTC):

What are the patterns, mechanisms, and impacts of global lake warming / cooling?

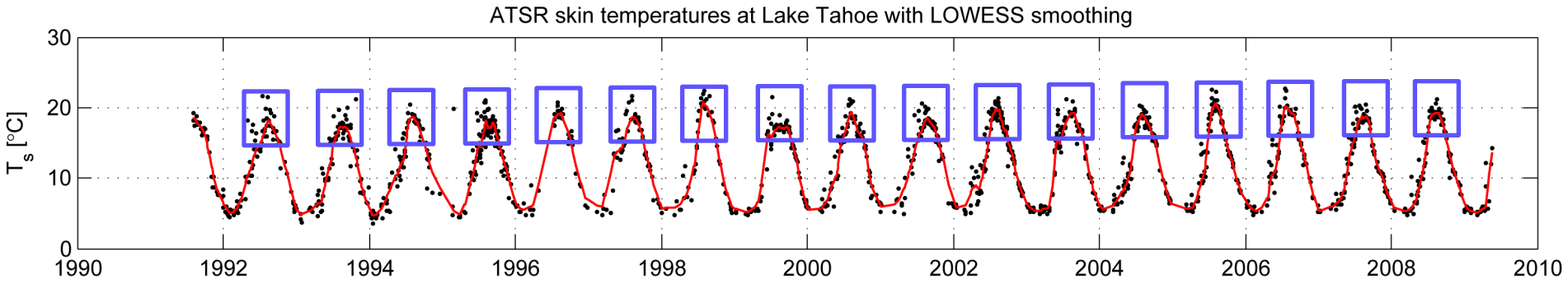






Data and Methods

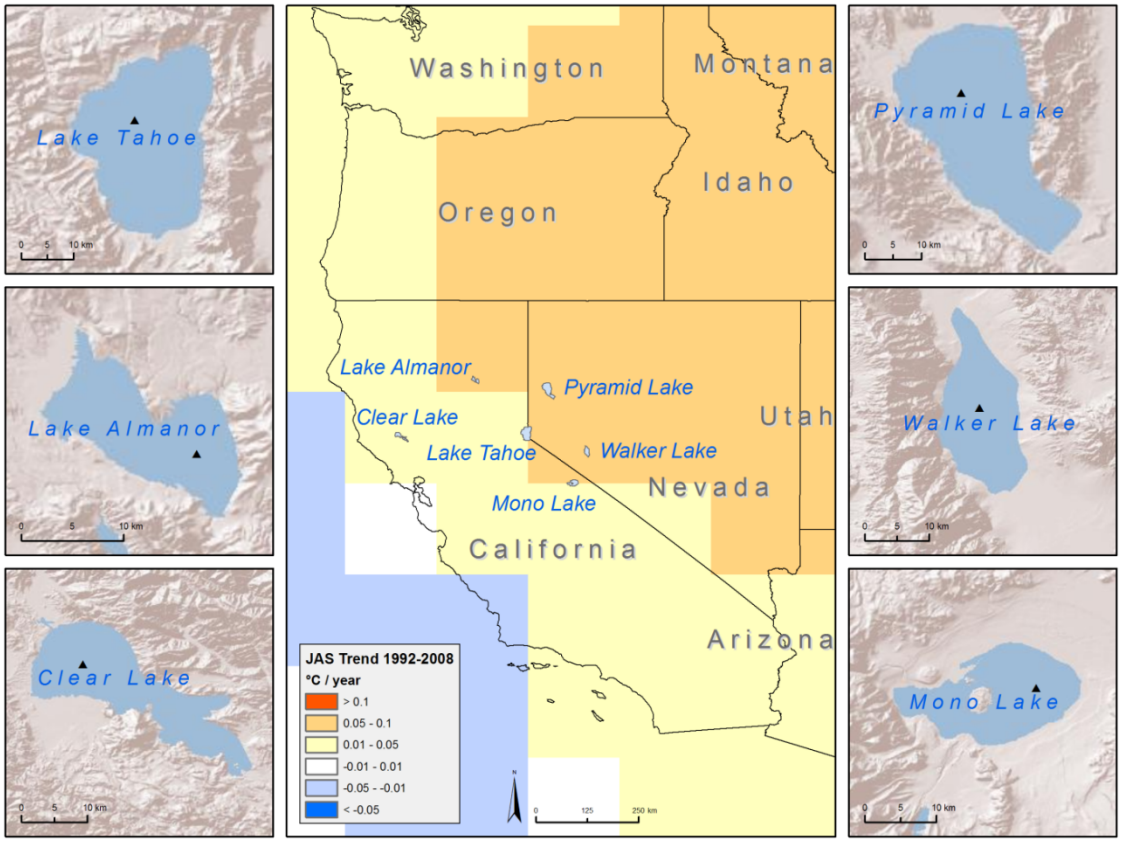
- Thermal infrared data from four sensor series
  - Advanced Very High Resolution Radiometer (AVHRR) 1982-present
  - Along-Track Scanning Radiometer (ATSRx) 1991-2011
  - Moderate Resolution Imaging Spectroradiometer (MODIS) 1999-present
  - Visible Infrared Imaging Radiometer Suite (VIIRS) 2011-present
- Data extraction
- Cloud masking
- Atmospheric correction
- Computation of summer time (JAS) means
- Weighted linear regression analysis and uncertainty analysis



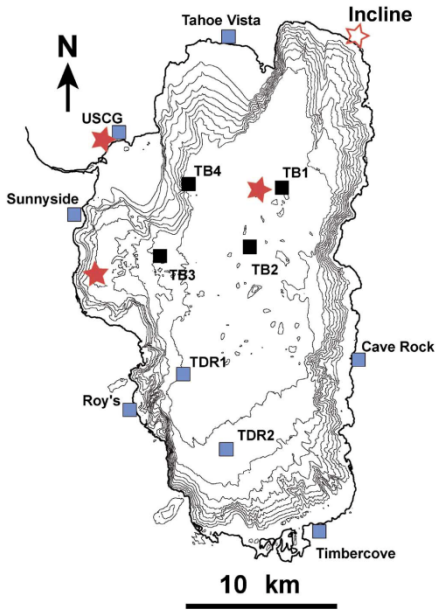
Processing Criteria for MODIS (Terra & Aqua)

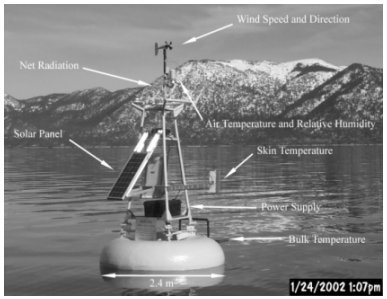
Location	3 x 3 pixel window (1 km pixels)
Minimum points in JAS Range	20
Smoothing	LOWESS interpolation
Image Time	Night
Range from Target Coordinates	< 1 km
Standard Deviation of Temperatures in 3 x 3	< 0.5 K
Sensor Zenith Angle	< 45°
Cloud Masking	Cirrus Cloud Test High Cloud Test Thermal Test
Temperature Range	<= 308.15 and >= 237.15 K

California/Nevada case study



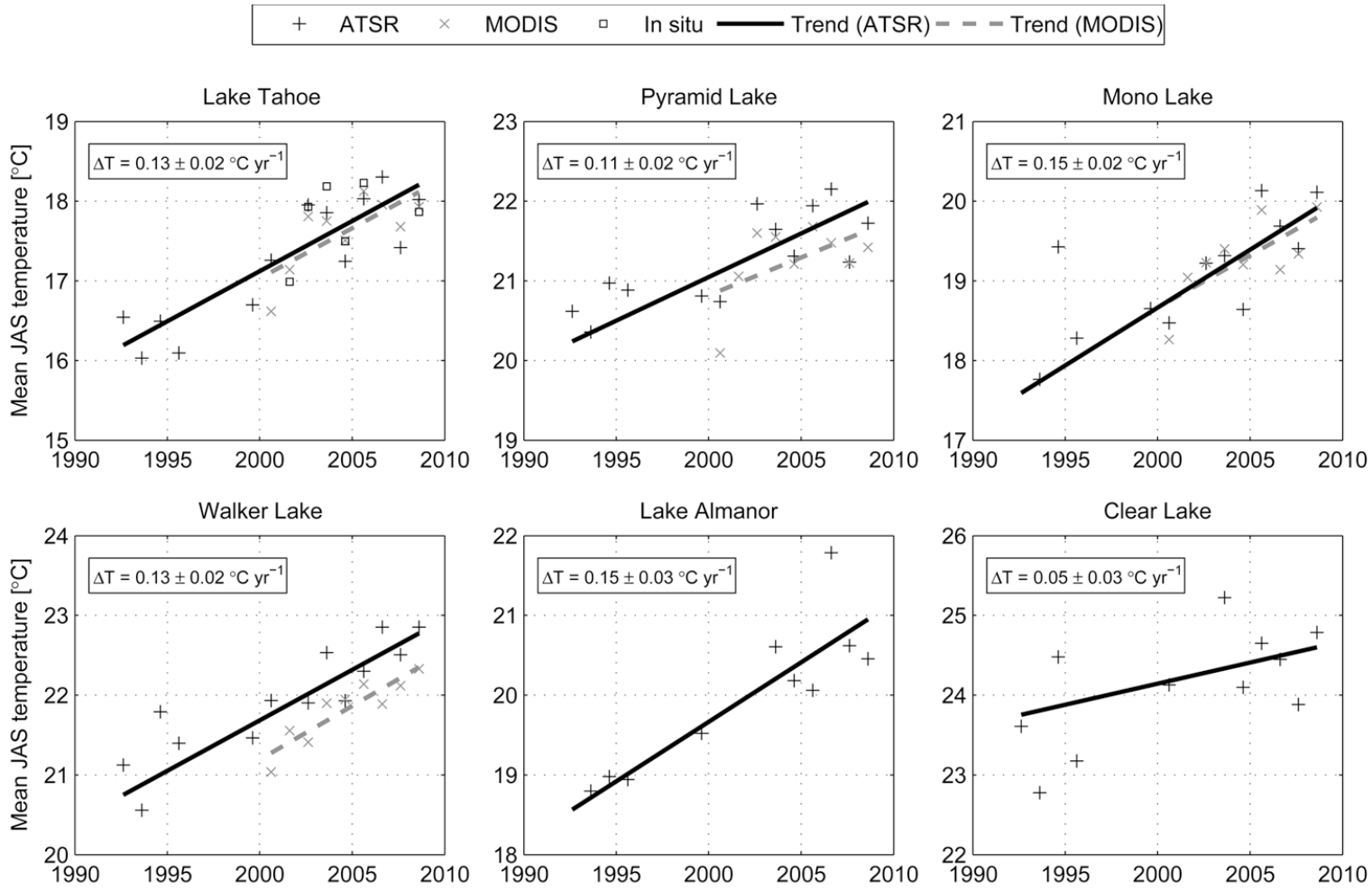
A preliminary case study was carried out for six lakes in California and Nevada. The center panel shows the lake locations and the GISTEMP (Hansen et al., 1999) summertime temperature change between 1991 and 2008.





In situ measurements at 4 buoys at Lake Tahoe were used to develop algorithms and validate the results

Summertime (JAS) trends since 1991-2008



Schneider et al. (2009). Satellite observations indicate rapid warming trend for lakes in California and Nevada. *Geophysical Research Letters*

Listed trends are derived from ATSR data (1991-2008)

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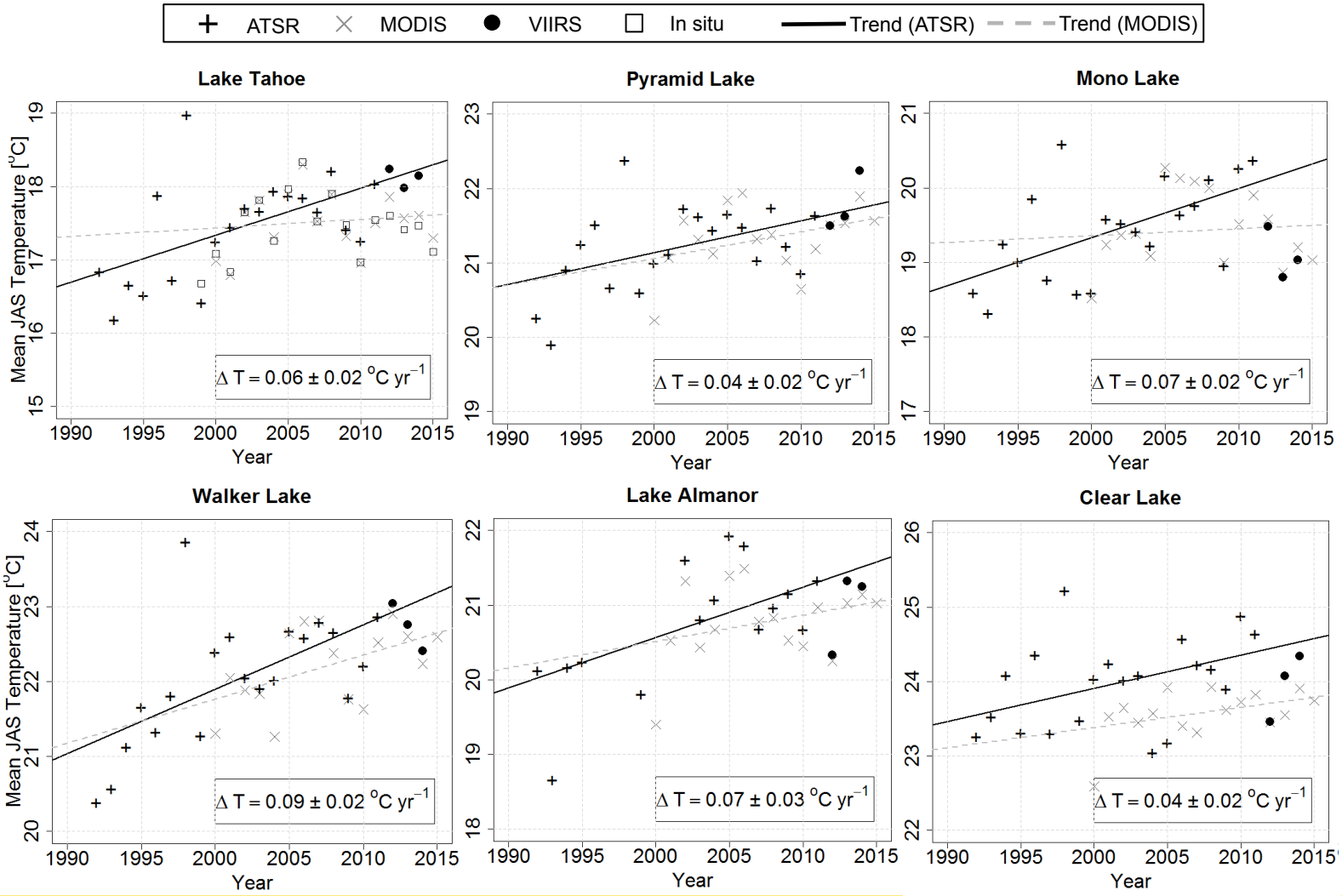
Summertime (JAS) trends since 1991-2015



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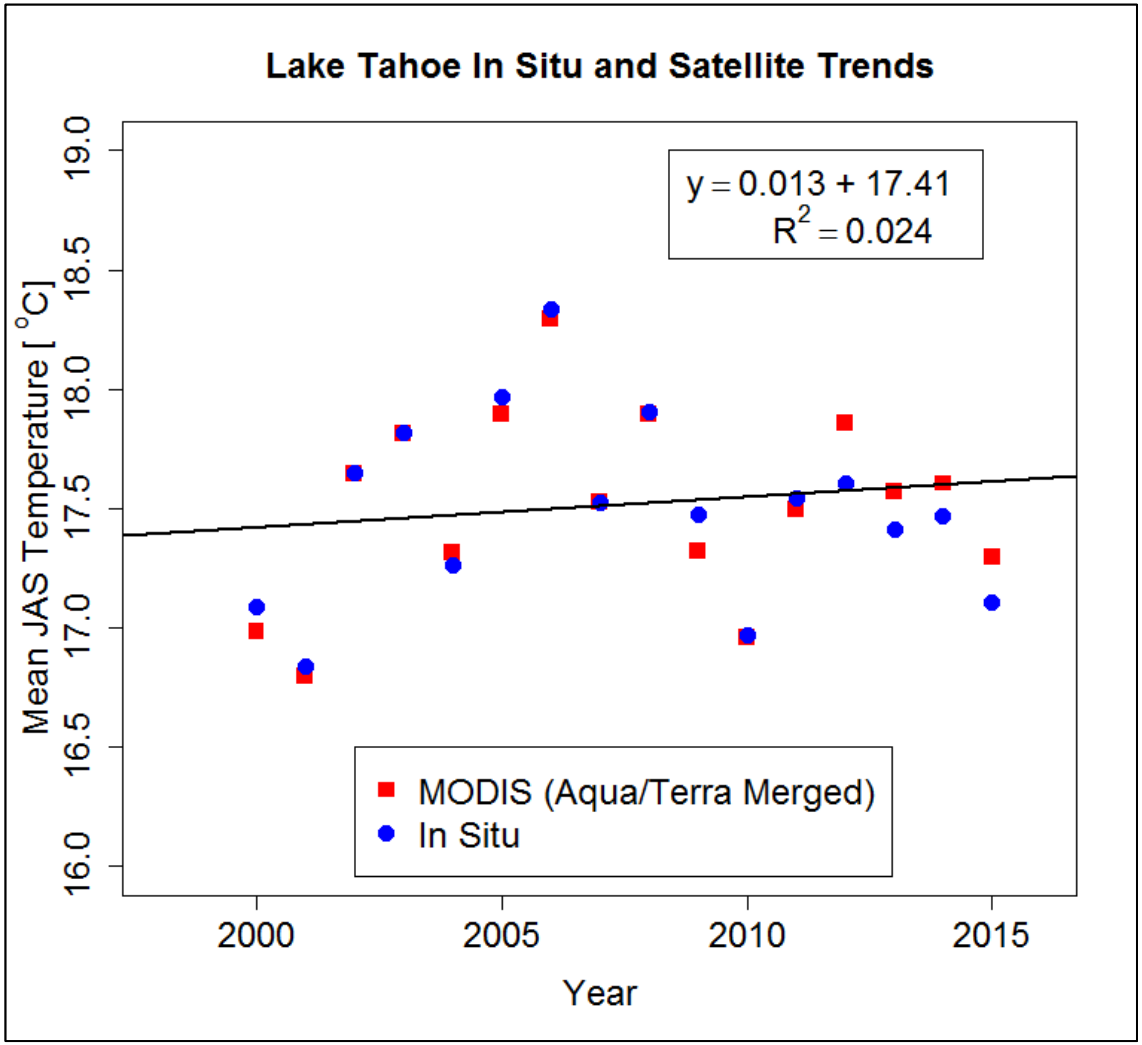
The Importance of Record Length



North American Lakes
MODIS (Aqua &Terra) Trends - Top Ten

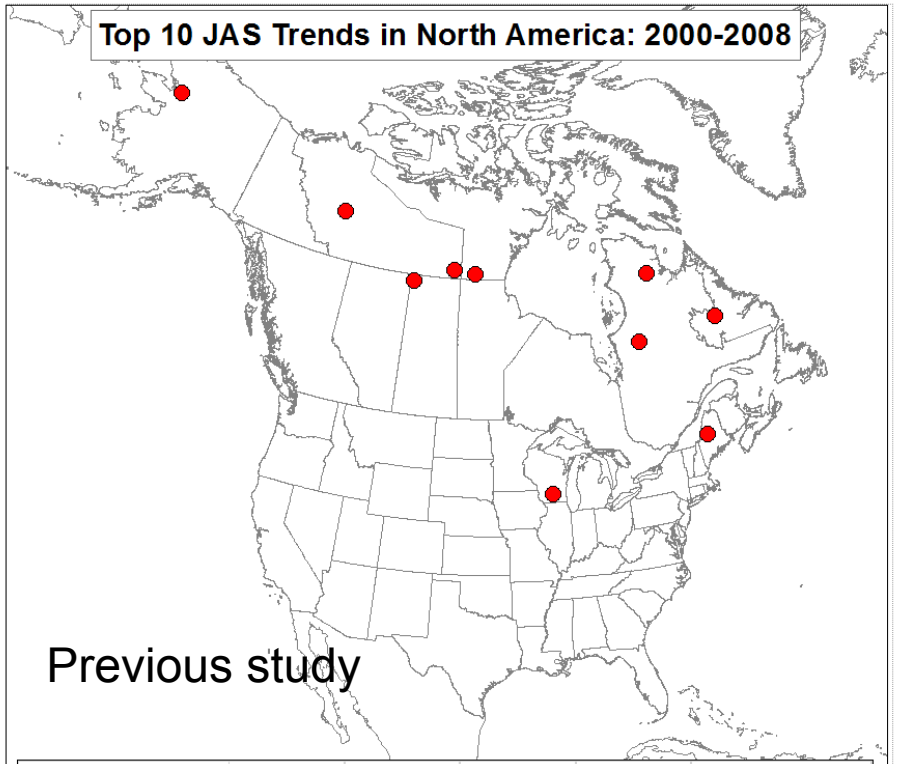
2000-2008

Name	Slope	Intercept	R^2	p value	standard error	Rank
Mendota	0.396	293.411	0.702	0.078	0.179	1
Athabasca	0.321	283.330	0.382	0.397	0.347	2
Lac Fairbault	0.298	280.091	0.407	0.365	0.299	3
Snowbird	0.276	282.022	0.324	0.478	0.361	4
Le Grande Riviere	0.254	283.139	0.445	0.269	0.209	5
Blackwater	0.252	283.017	0.737	0.059	0.103	6
Nueltin	0.249	280.896	0.275	0.551	0.389	7
Inland	0.233	284.202	0.394	0.381	0.243	8
Smallwood	0.171	282.423	0.405	0.368	0.173	9
Moosehead	0.136	290.510	0.466	0.206	0.097	10

2000-2015

Name	Slope	Intercept	R^2	p value	standard error	Rank Change Since 2000-2008
Athabasca	0.130	284.385	0.398	0.126	0.080	↑
Nueltin	0.130	281.240	0.322	0.283	0.116	↑
Blackwater	0.126	283.637	0.553	0.040	0.055	↑
Moosehead	0.091	290.631	0.544	0.029	0.037	↑
Snowbird	0.074	282.809	0.214	0.462	0.098	↓
Inland	0.069	284.772	0.273	0.390	0.077	↑
Smallwood	0.050	282.760	0.193	0.548	0.080	↑
Mendota	0.049	294.764	0.168	0.584	0.086	↓
Le Grande Riviere	0.038	284.124	0.145	0.606	0.071	↓
Lac Fairbault	-0.087	281.682	-0.232	0.493	0.122	↓

North American Lakes Trends - Top Ten



Previous study

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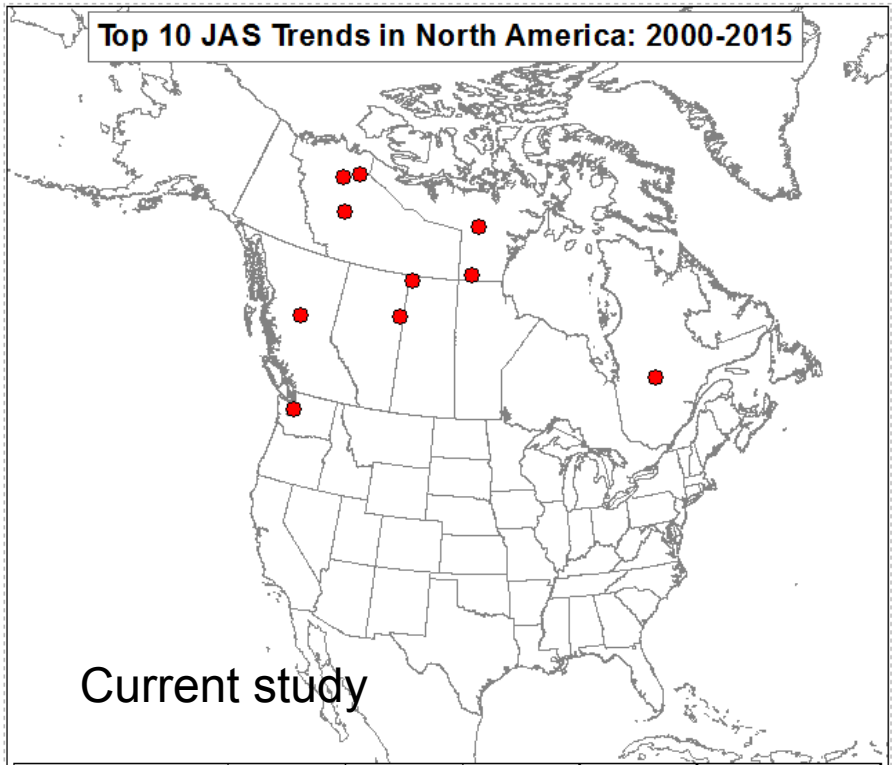

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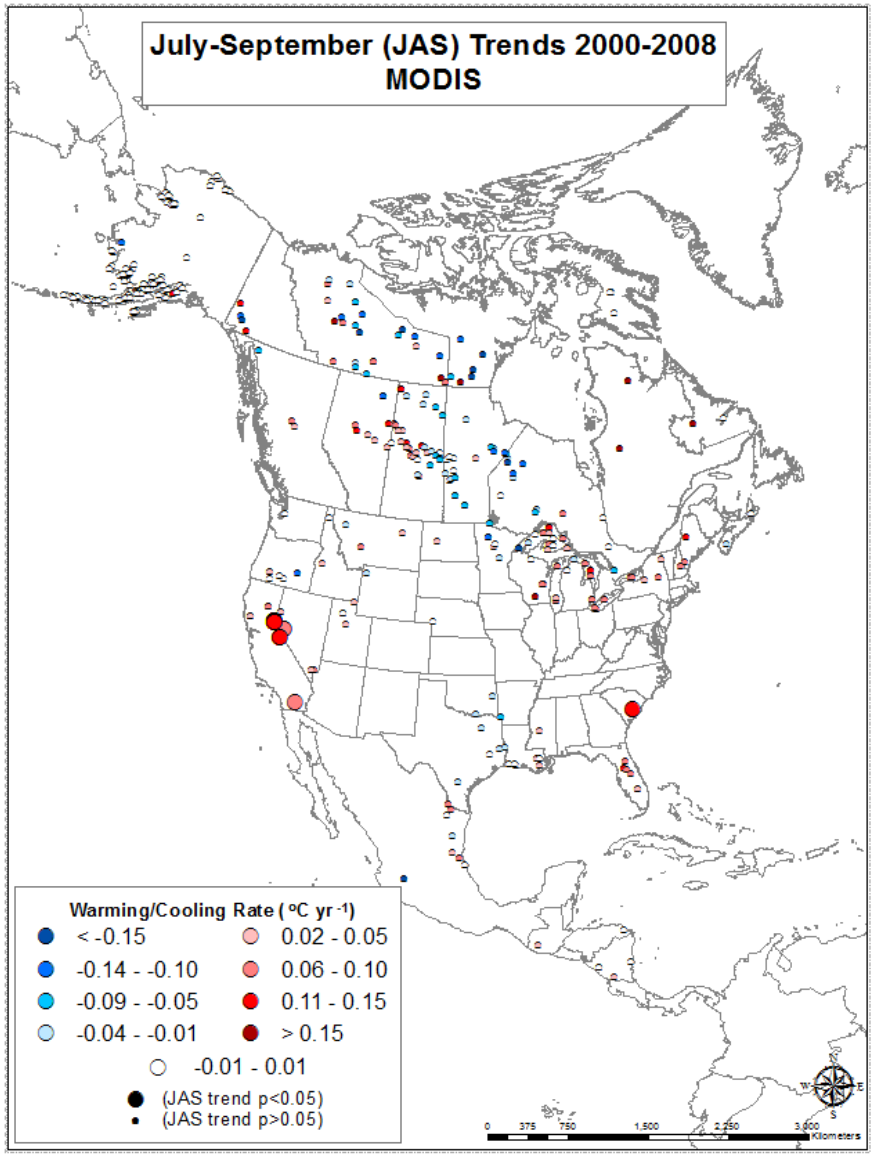
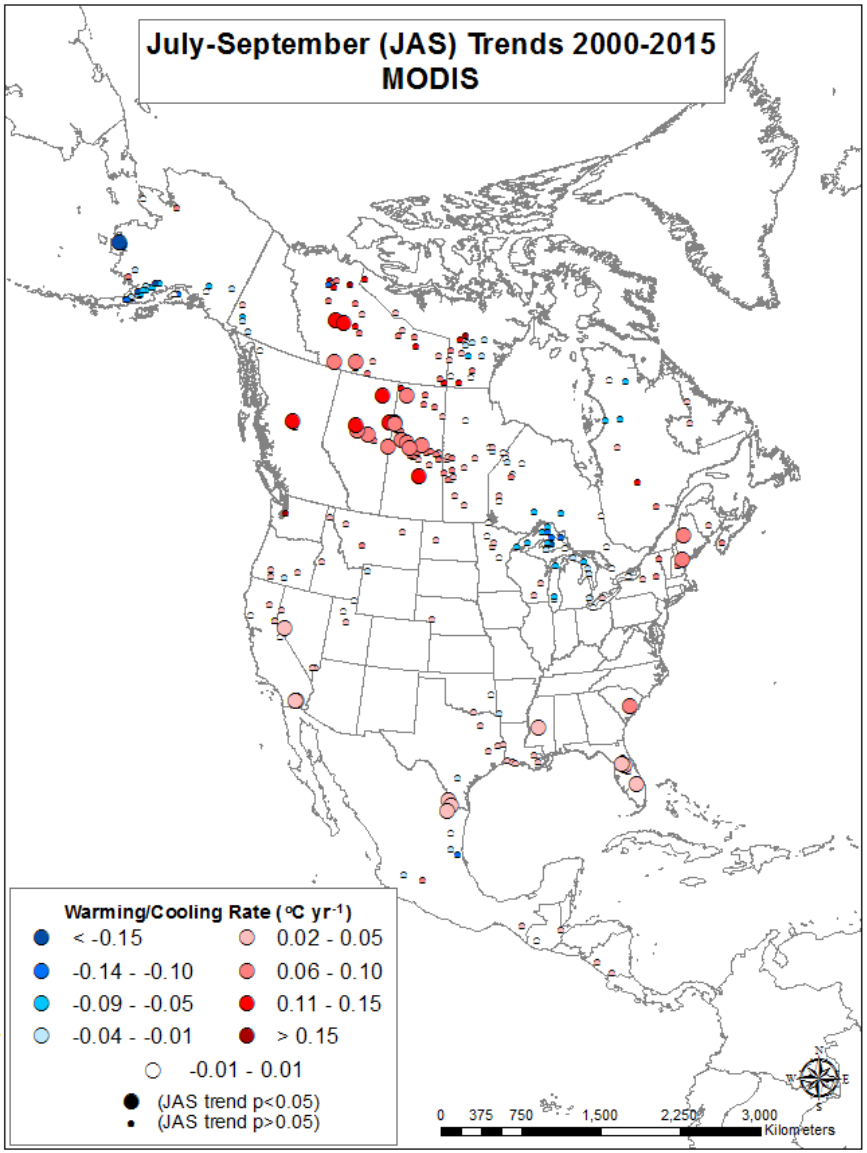
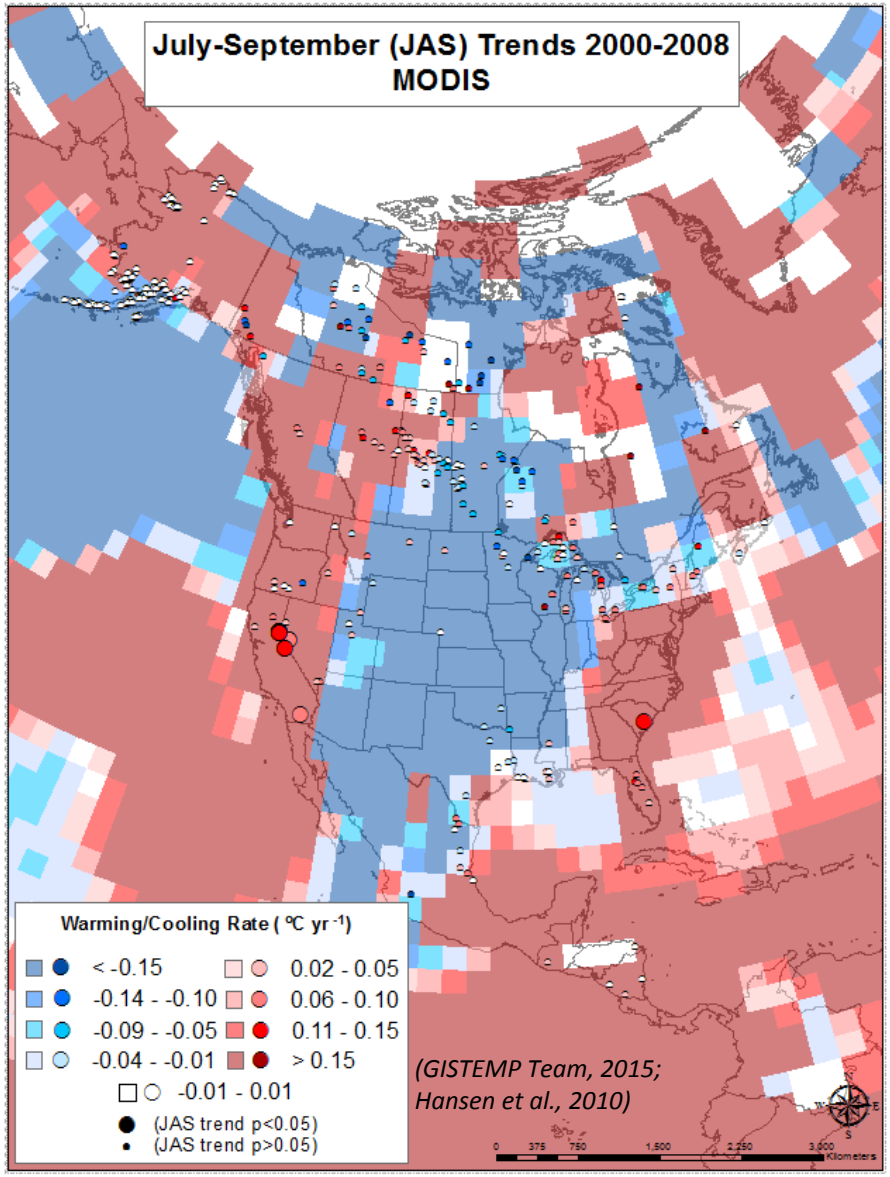
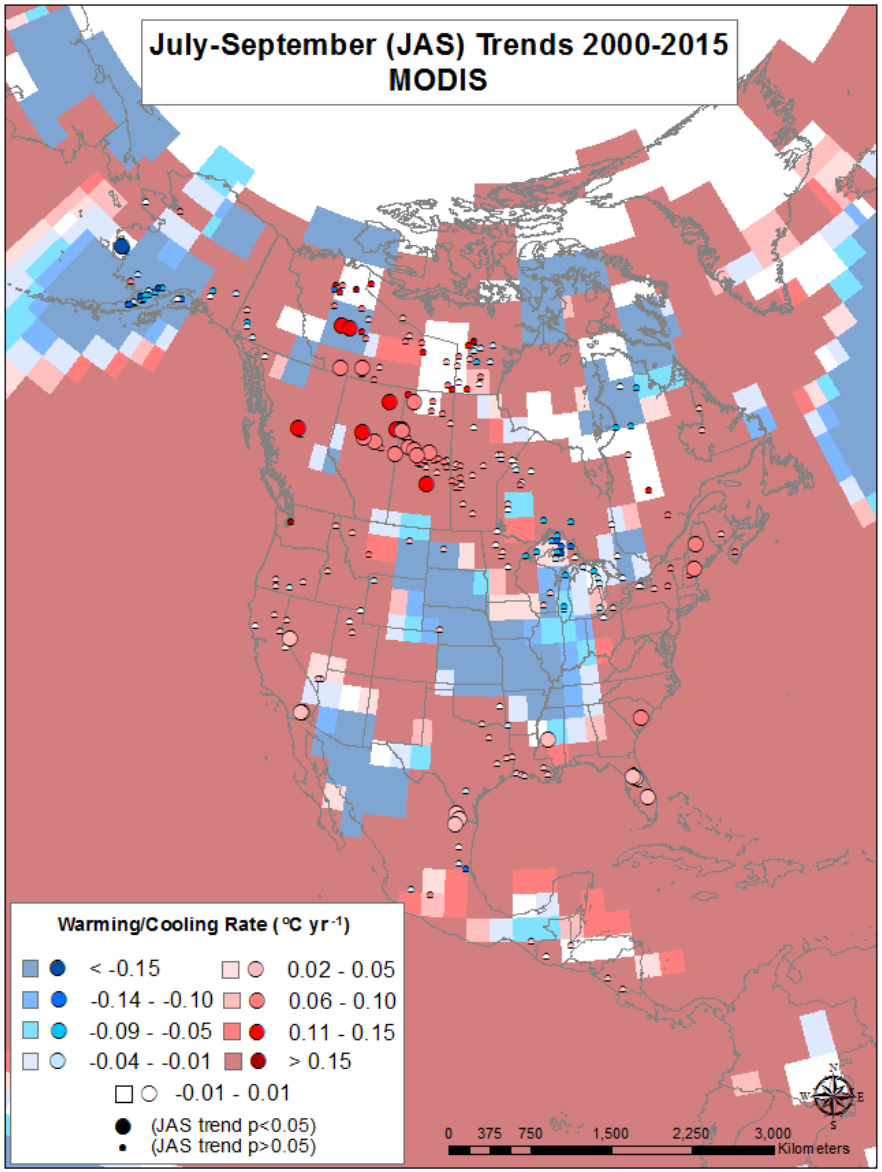
North American Lake Trends



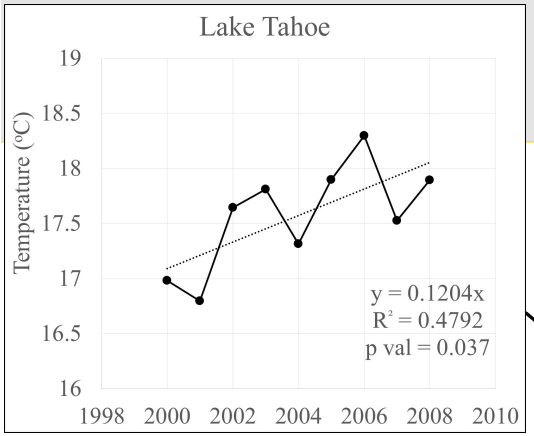


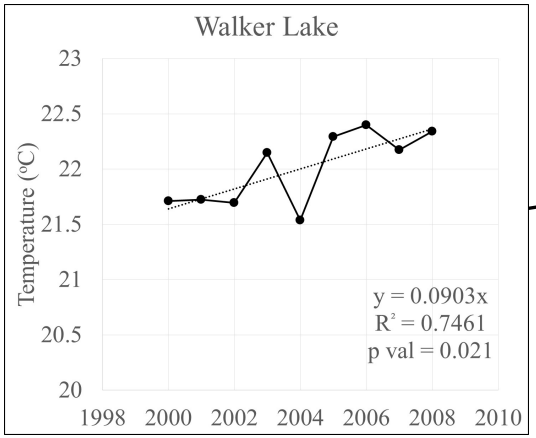
North American Lake and Air Temperature Trends

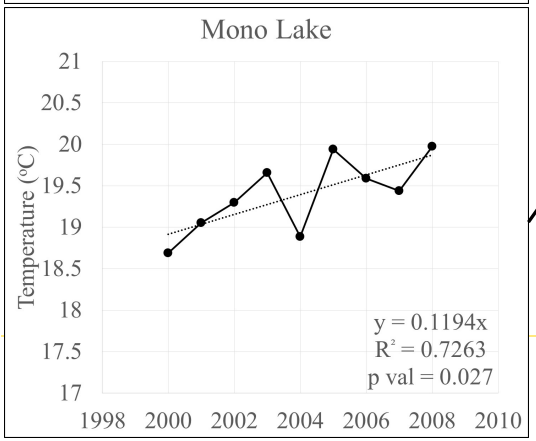


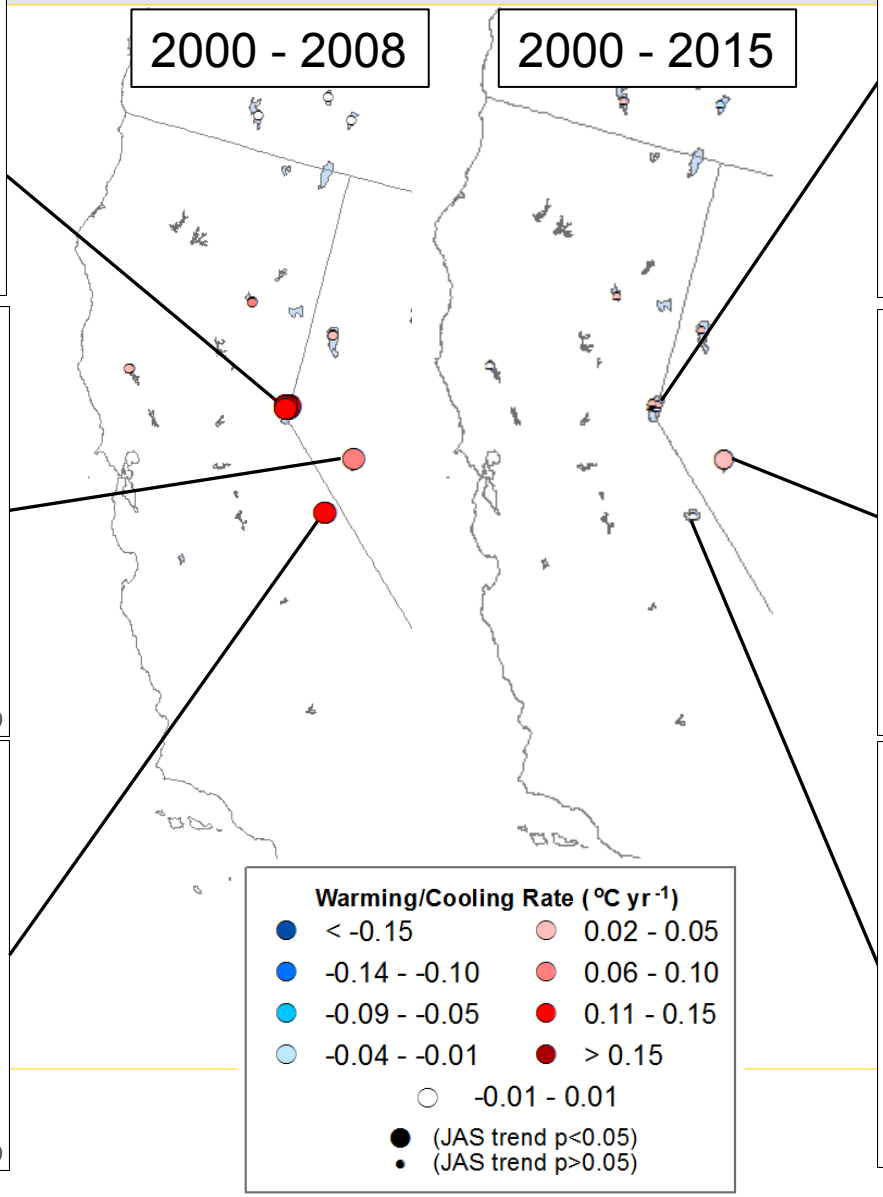


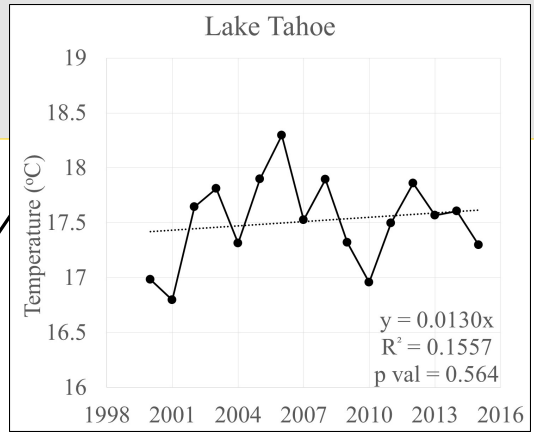
Latest Trends

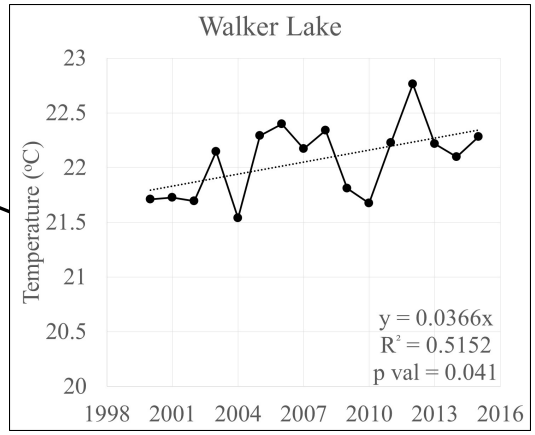


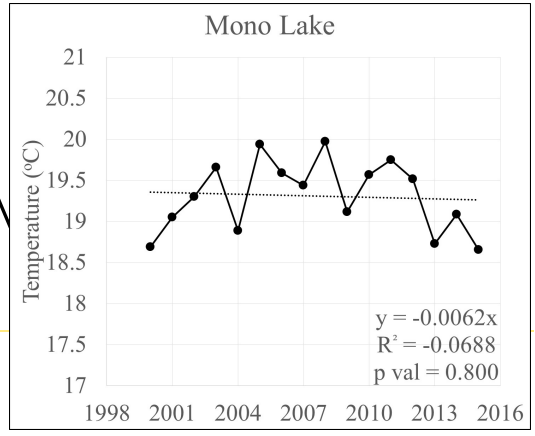






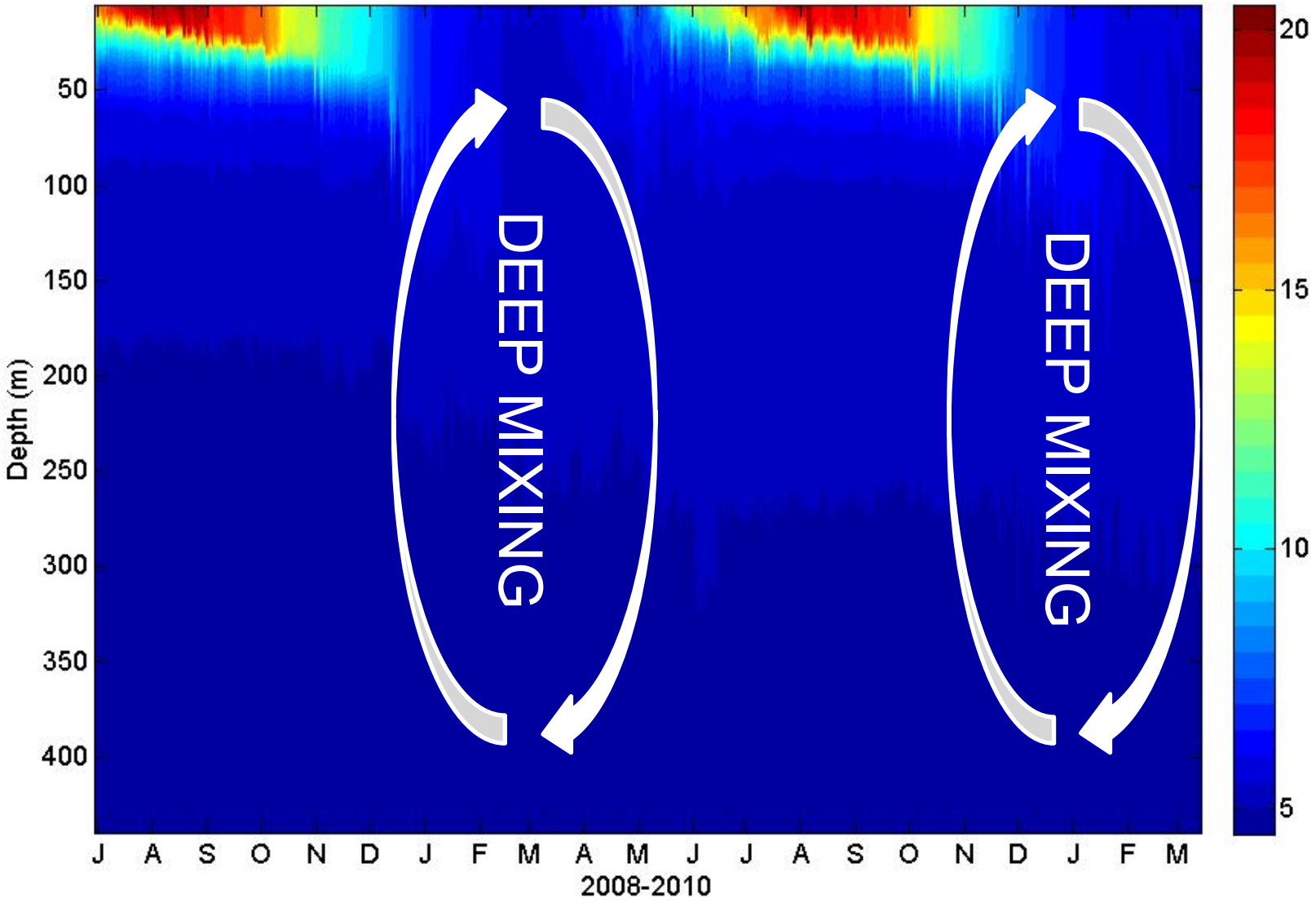






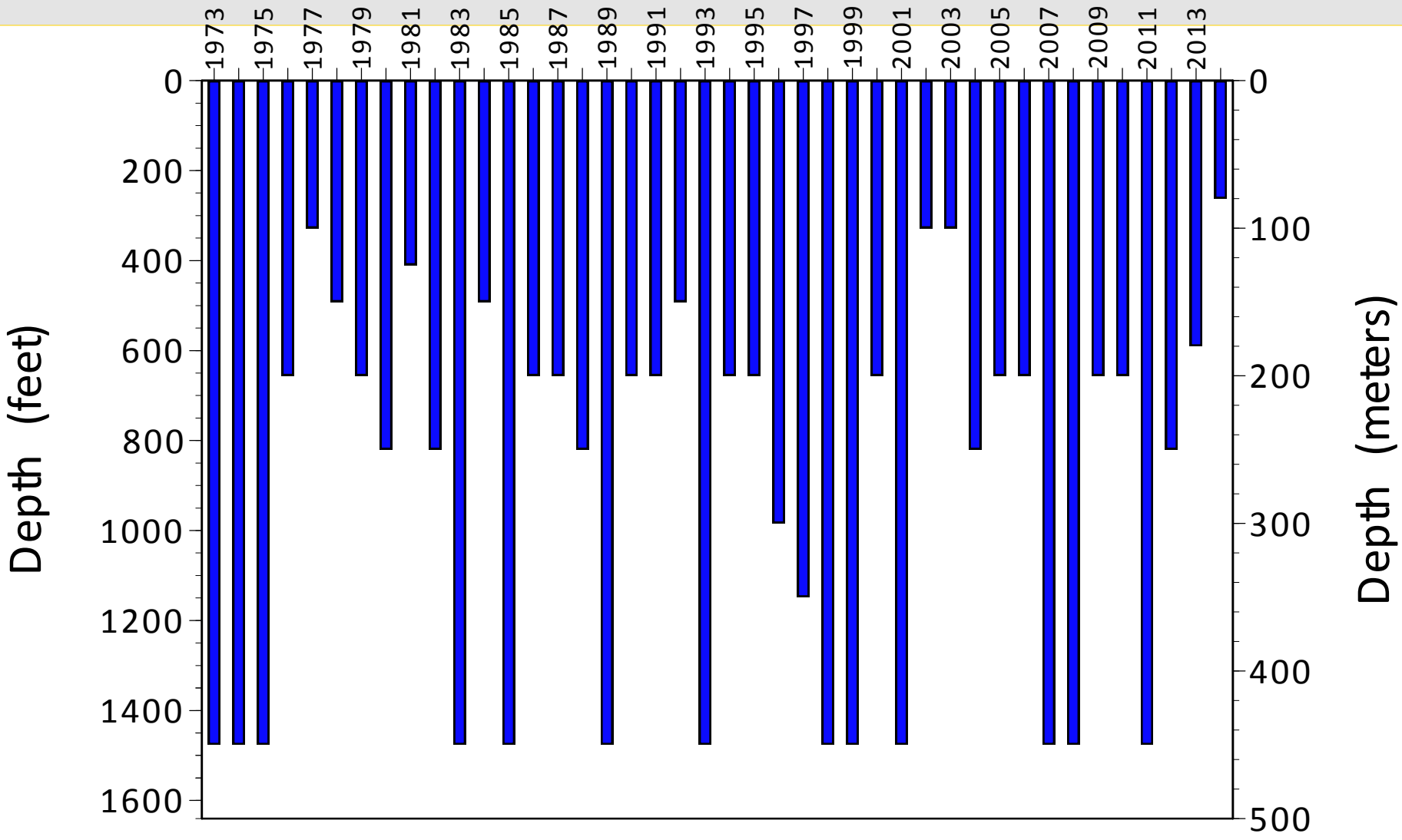
Typical Thermal Stratification Pattern

Deep mixing



Courtesy G. Schladow – UC Davis

Last 41 Years – Depth of Winter Mixing



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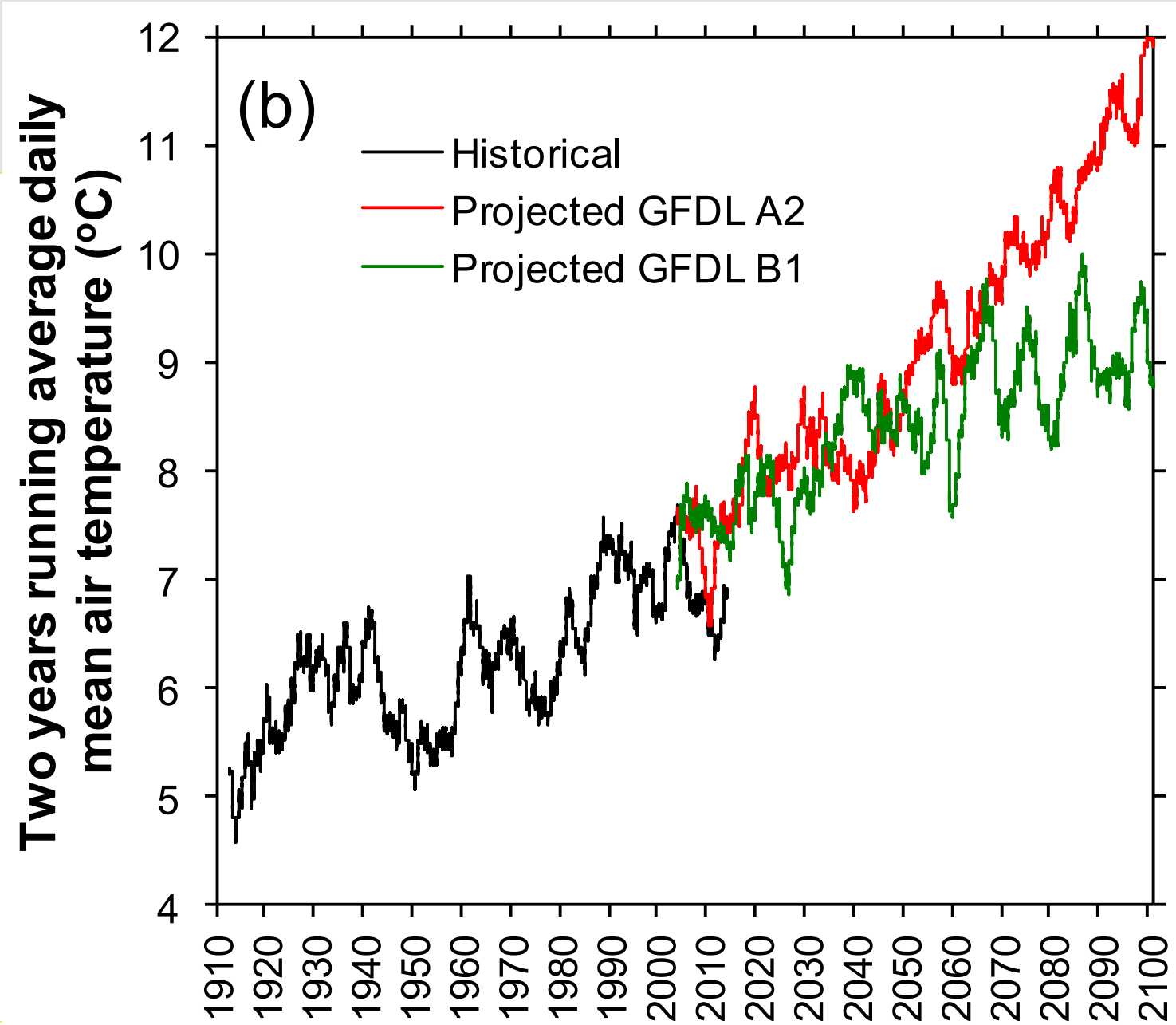
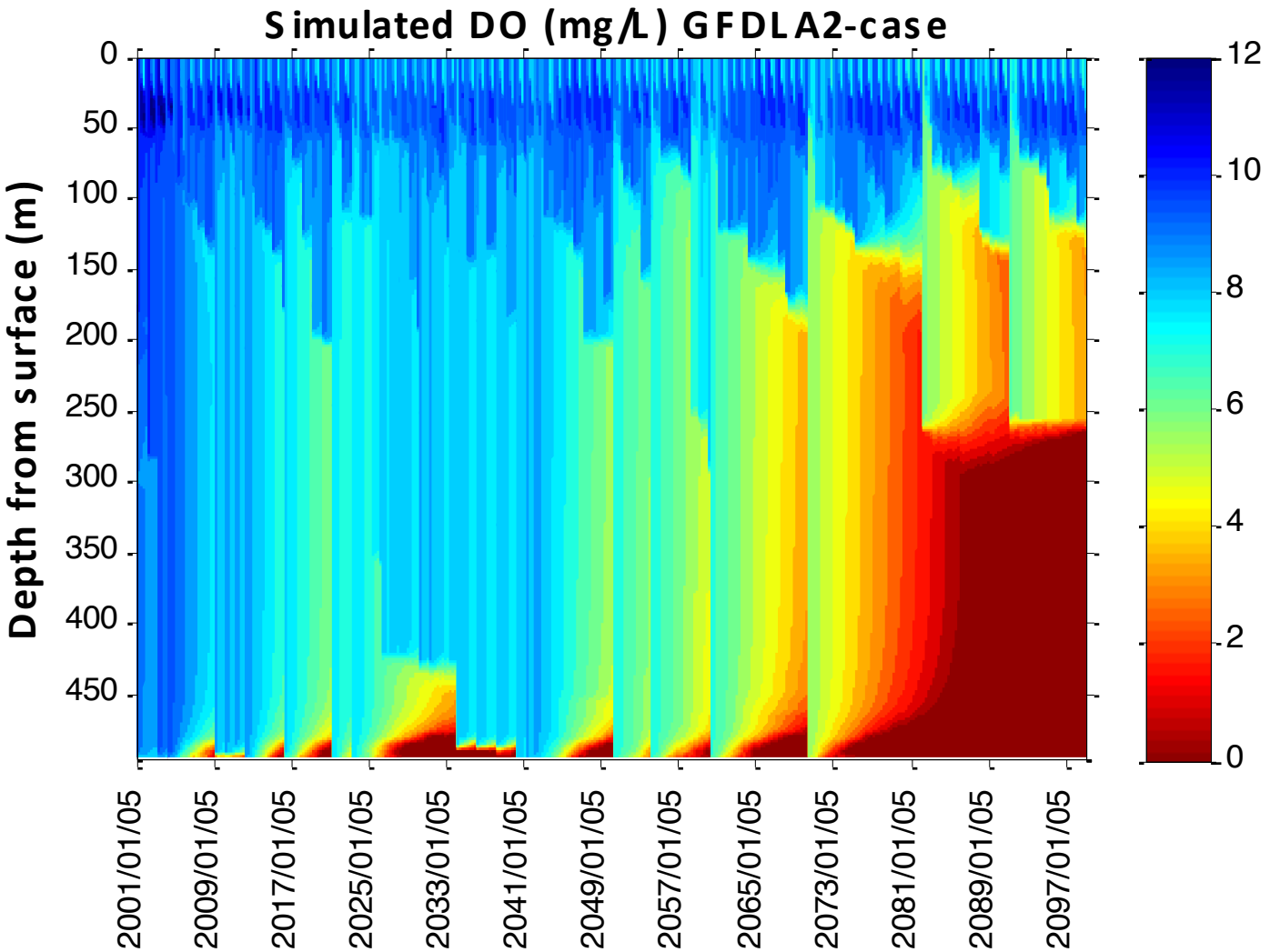


Courtesy G. Schladow – UC Davis

DO in the Next 85 Years? Hypoxia at Lake Tahoe?

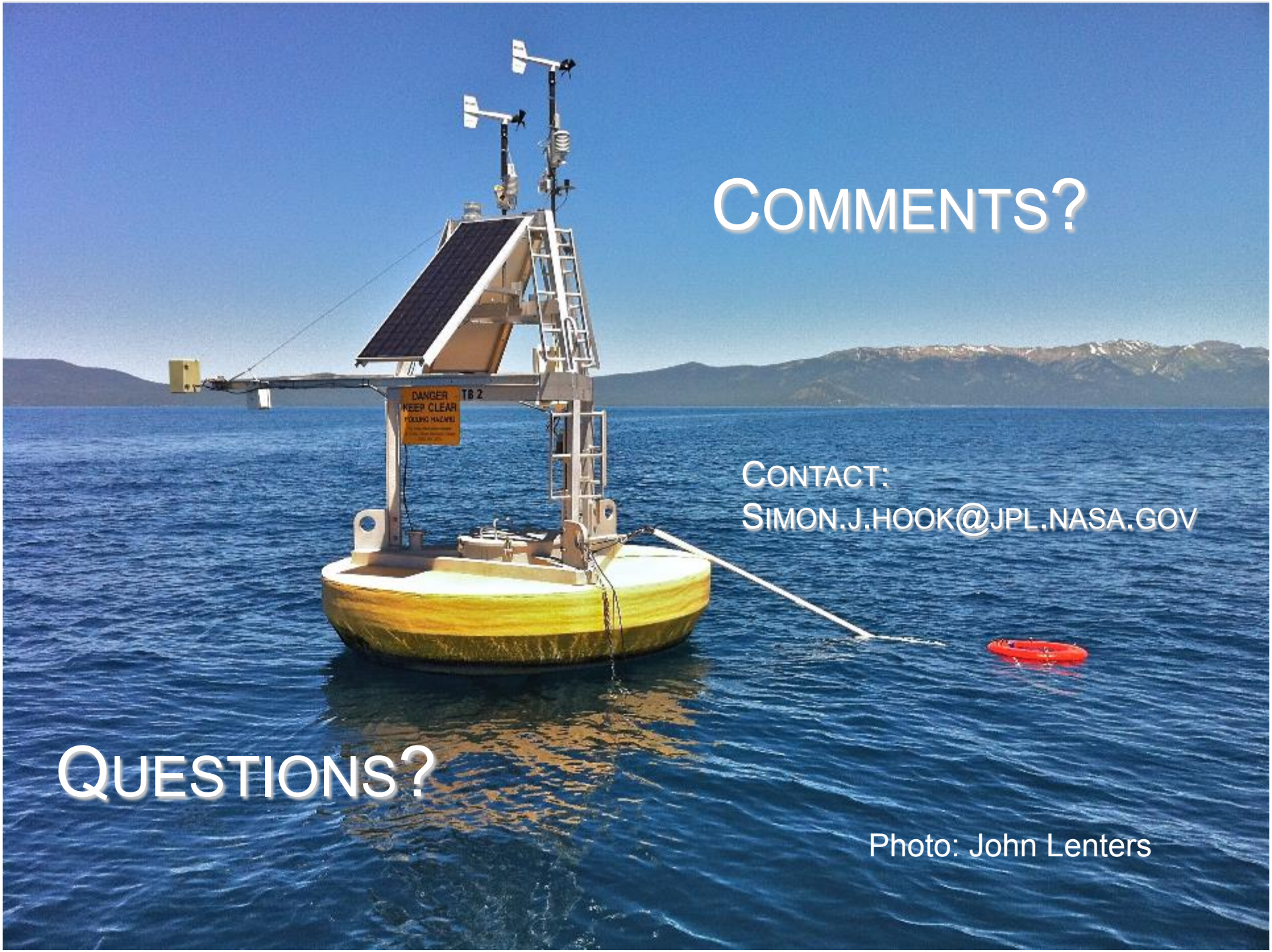


Courtesy G. Schladow – UC Davis

SOD 0.04 g-O_2 m^{-2} d^{-1} Marc Beutel

Summary and Conclusions

- Satellite thermal data provides a rich record of changes in surface temperature since 1980.
- Currently extending time series first created in 2009 to present day (AVHRR, ATSRx, MODIS, VIIRS).
- In Western USA warming rates have been lower from 2009-present
- Relating changes in the thermal behavior of the water bodies to changes in surface air temperature data.
- Exploring ecologically consequences of warming



COMMENTS?

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QUESTIONS?

Photo: John Lenters