Assessing Climate Change Within Lake Champlain (NY, VT, QC)

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ABSTRACT GC21D-1130

SUMMARY

We evaluate climate change within Lake Champlain using a combination of atmospheric and limnological observations. Long-term monitoring has revealed a summertime warming trend of surface waters of about 0.9°C dec^{-1}. Climate change is an important component in the development of management programs (LCBP, 2015; Zia et al., 2016). However, Lake Champlain is dynamic and large temperature fluctuations can be expected on synoptic timescales.

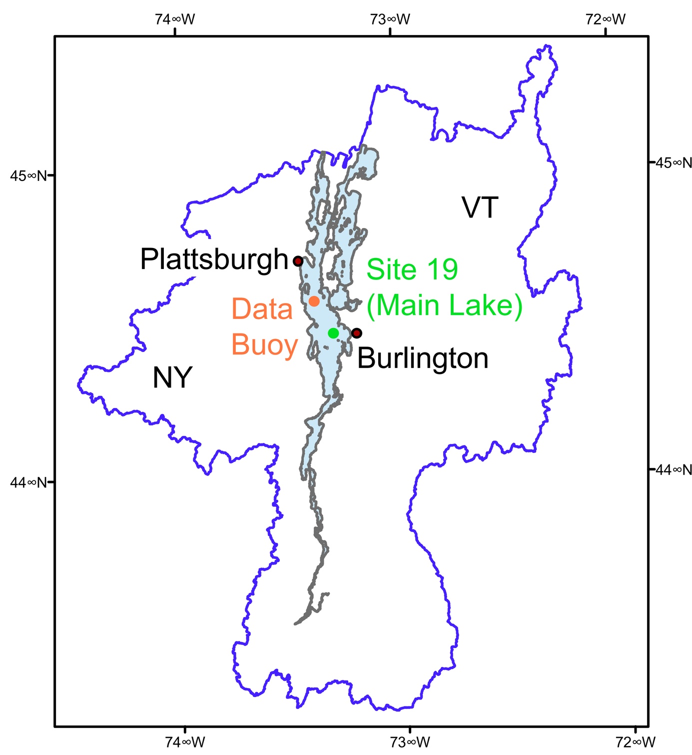
A data buoy deployed within Lake Champlain during the 2016 warm season is used to quantify synoptic variations of the thermal structure. Observed trends in August and summer mean near-surface water temperature have risen beyond the uncertainties of synoptic and interannual variability.

Despite their importance to the ecology of Lake Champlain, the NY/VT long-term monitoring program cannot provide meaningful guidance regarding changes in mixed layer depths or temperature within the metalimnion because of large variability associated with internal waves and mixing.

Principal component analysis of the lake's thermal structure reveals a primary mode associated with wind mixing, potentially allowing prediction and reanalysis of observed data. However, it is recommended that high-frequency sampling of the thermal structure be continued and expanded.

1. Long-term Monitoring of L. Champlain

Lake Champlain lies at the border of the states of New York and Vermont, and the province of Quebec (**Figure, right**). A long-term measurement campaign (LTM) of the biological, chemical, and physical properties of the lake began in 1992, with inconsistent and scattered measurement programs extending into the 1960s.



The LTM program records 2-4 vertical profiles per month of lake conditions at ~15 locations. We analyze 'Site 19', which is within the main trunk of Lake Champlain (depth:100 m; green dot on map).

The **Table below** shows the 25-year trend in near-surface water (1 m) obtained from the LTM observations. Significant trends exist in the summer, led by August (see **Figure below, right**), and the shoulder seasons. Trends weaken if data completion requirements are added (right column.)

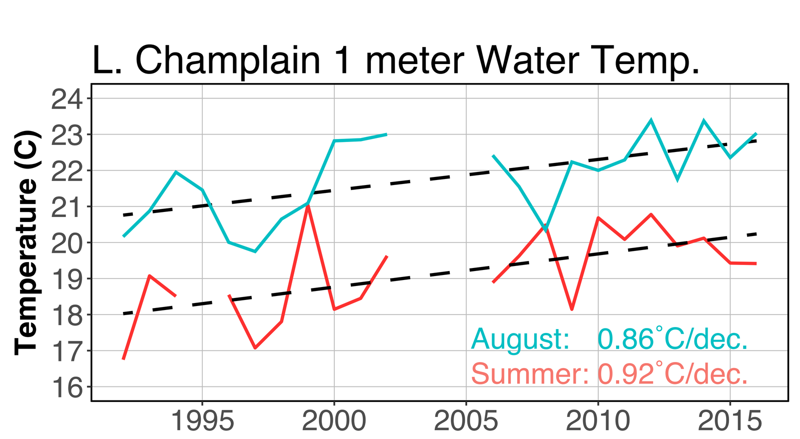
Observed 1992 - 2016 Temp. Trend (˚C dec^{-1})

	Atmos.	1m Water Temp.	
	Burlington VT	Any #	> 1 Obs. per period
Annual	0.6* (24)	N/A	N/A
DJF	0.6 (23)	N/A	N/A
MAM	0.7 (24)	N/A	N/A
JJA	0.3 (24)	0.9** (20)	0.6 (12)
SON	0.8** (23)	N/A	N/A
Jan.	0.8 (24)	N/A	N/A
Feb.	0.4 (25)	N/A	N/A
Mar.	0.7 (24)	N/A	N/A
Apr.	0.3 (24)	0.1 (5)	0.1 (5)
May	1.0* (24)	2.1* (21)	2.3 (13)
Jun.	0.0 (24)	1.6* (23)	1.3 (15)
Jul.	0.5 (24)	0.4 (23)	0.6 (15)
Aug.	0.5 (24)	0.9** (21)	0.8** (16)
Sep.	0.7 (24)	0.5 (22)	0.5 (11)
Oct.	0.1* (24)	0.1* (16)	0.1* (9)
Nov.	0.6 (24)	N/A	N/A
Dec.	0.4 (20)	N/A	N/A

* - Trend significant at 95%
** - Trend significant at 99%
( ) - Number of years with valid observations

Interannual variability prevents atmospheric warming (homogenized record from NASA GISTEMP) in nearby Burlington, VT from being significant over this short time period, except for the shoulder season and annual means.

Shoulder season warming can be interpreted as a lengthening of the warm season and a potential source of lake warming. However, analysis shows little connection between lake temperatures and monthly/seasonal-scale atmospheric temperature variability. Indeed, minimal predictive power is offered by atmospheric conditions even when considering a lead-in lag.



2.2016 Data Buoy Observations

The Lake Champlain LTM program provides only 1-4 temperature measurements per month for each site. Is the existing LTM program sufficient to detect climate change? To what degree do the surface water temperatures vary?

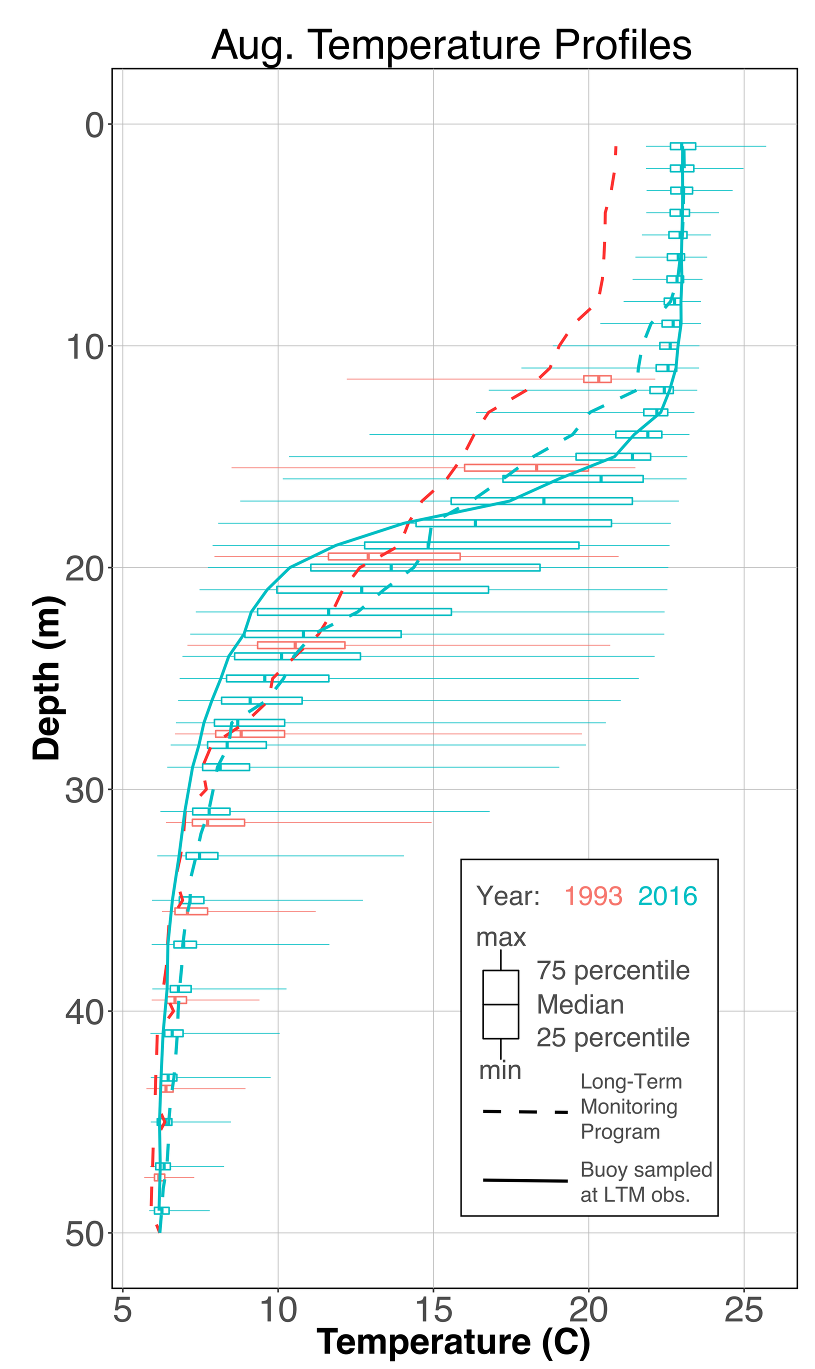
A data buoy (**image, above right**) was deployed during the 2016 field season near Valcour Island, just north of the Main Lake 'Site 19' discussed in **Section 1**. The data buoy measured surface air temperature, wind speed and direction, and air pressure, while also observing water temperatures between the surface and 50 m depth with 1 m resolution.

Water Temp. Std. Deviation (˚C)

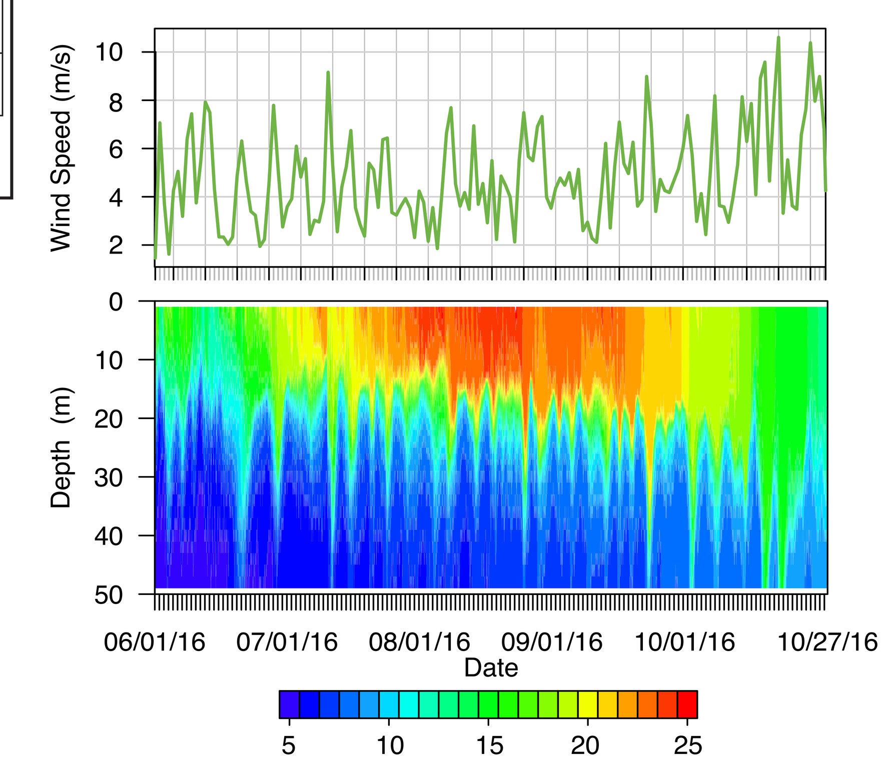
	1m	10m	20m	30m	40m	50m
Jun.-Oct.	3.4 (0.7)	3.6 (0.6)	4.1 (3.0)	2.5 (1.8)	1.7 (1.0)	1.4 (0.7)
June	2.2 (1.2)	2.3 (0.9)	2.6 (2.5)	1.6 (1.4)	0.9 (0.8)	0.6 (0.4)
July	1.3 (0.7)	1.3 (0.6)	3.2 (3.0)	1.4 (1.2)	0.7 (0.5)	0.5 (0.3)
August	0.6 (0.5)	0.6 (0.5)	4.2 (4.0)	1.4 (1.3)	0.5 (0.4)	0.3 (0.3)
September	1.3 (0.4)	1.2 (0.3)	3.5 (3.2)	2.6 (2.6)	1.3 (1.2)	0.7 (0.6)
October	1.9 (0.4)	1.9 (0.5)	2.3 (1.3)	2.4 (2.0)	2.0 (1.6)	1.7 (1.3)

( ) - Standard deviation after removal of 10-day running mean to isolate mixing events

The **Table above** shows the importance of wind mixing events. Removing seasonality, through a 10-day moving average, reveals that variability from mixing contributes more than 50% of overall variability.



The **Figure below** shows the evolution of the thermal structure throughout the 2016 warm season. There is significant variability in water temperature at all levels (**Table, left**), which is generally related to wind mixing events (**top graph of Figure below**; also see **Section 4**).



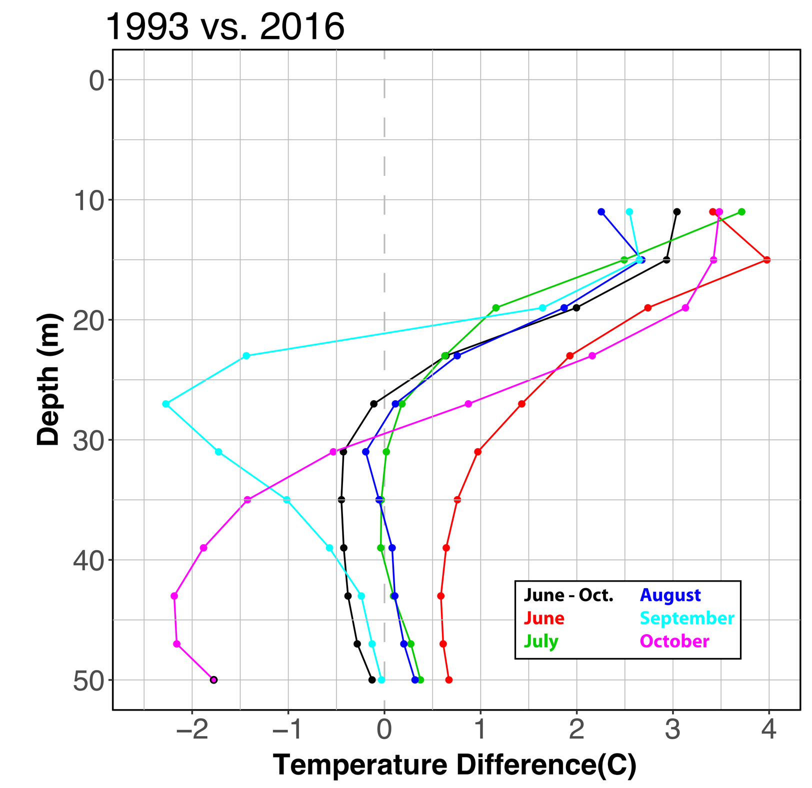
The **Figure to the left** shows observations from August 2016 (cyan), including measurements by the data buoy (box-whiskers), LTM program (- - - - - - line; two August visits to 'Site 19' each year), and the data buoy sampled at the timing of the LTM observations.

The difference between the LTM and buoy data sub-sampled to the date/time of the LTM observations is small near the surface (<0.3°C), but sizable between 20-30m.

In general, natural interannual and synoptic scale variability of water temperatures obscures the climate change signal. The exception is, as noted in **Section 1**, near surface water when the thermocline is well-established (August) and limited variability from mixing arises.

3. 1993 vs. 2016 Data Buoy Observations

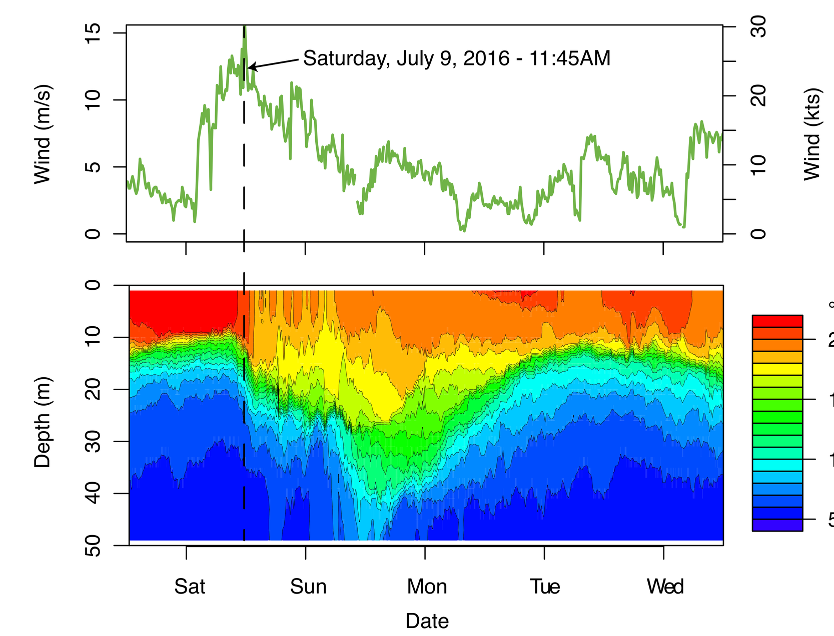
The **Figure at the bottom of the second column** also contains data buoy observations collected by Tom Manley (Middlebury College; Manley et al., 1999) in 1993 (red). The locations of the two data buoys (Middlebury and Plattsburgh) are very similar, although more than two decades apart in time. It is clear that the LTM profiles (- - - - - - line) are also a poor representation of the monthly values compiled from hourly observations.



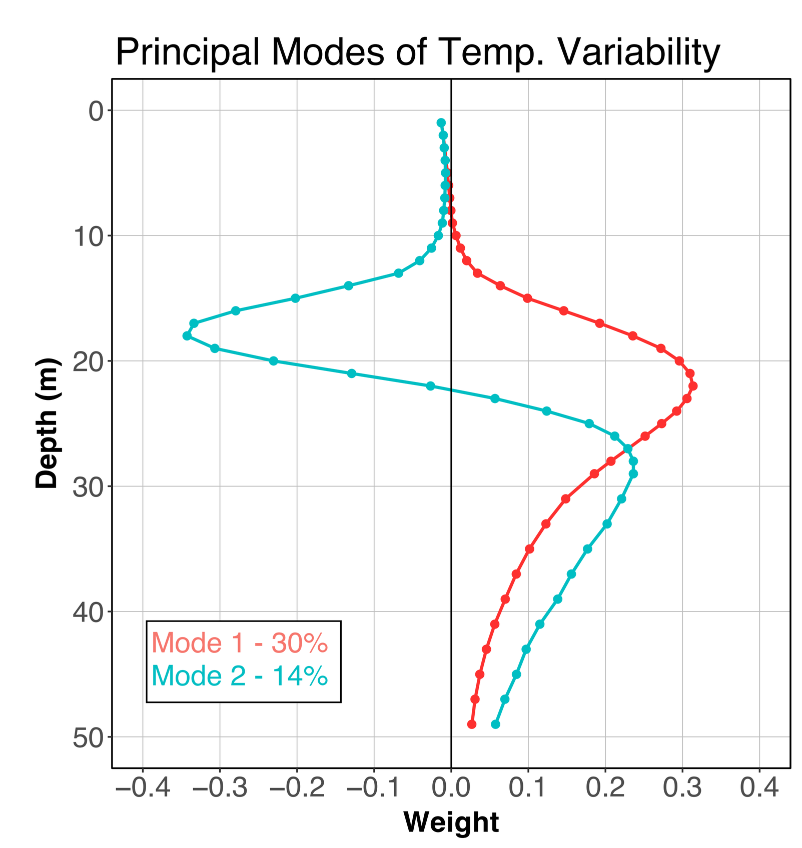
The **Figure to the right** shows the difference between August mean temperatures at depth in 1993 and 2016. Temperature measurements began at a depth of 11 m on the Manley data buoy. While the LTM data cannot adequately compare 1993 and 2016, the two buoy datasets show significant differences, including a tendency towards increased stratification at lower depths, particularly later in the warm season. This type of comparison is not possible from the existing LTM dataset.

4. Predictability of Subsurface Temps.

The thermal structure of the lake may be somewhat predictable since there are two principal sources of variability:
1) the progression of the seasons and 2) wind-forced mixing. The **Figure to the right** shows an example of a wind mixing event in which a storm incites warmer temperatures at depth and cooling near the surface.



The impact of seasons can be removed through a moving average (10-day). The resulting time series was subjected to a principal component analysis to isolate the major modes of variability.



The **Figure to the left** shows the first two principal modes. The first mode (barotropic) accounts for more than 30% of the lakes thermal structure, with the second mode (baroclinic) adding another 14% of explanatory power. The first mode represents the local wind mixing, while the second mode represents the progression of internal waves along the thermocline. Indeed, analysis of the event in the **Figure above** reveals an excitation of the first mode, followed by the second mode the following day.

Further analysis shows both modes are somewhat correlated to the wind speed integrated between a given time and 34 hours ahead. This predictive capability may provide a new method to analyze long-term changes in the thermocline region as the climate warms.

Acknowledgements:
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