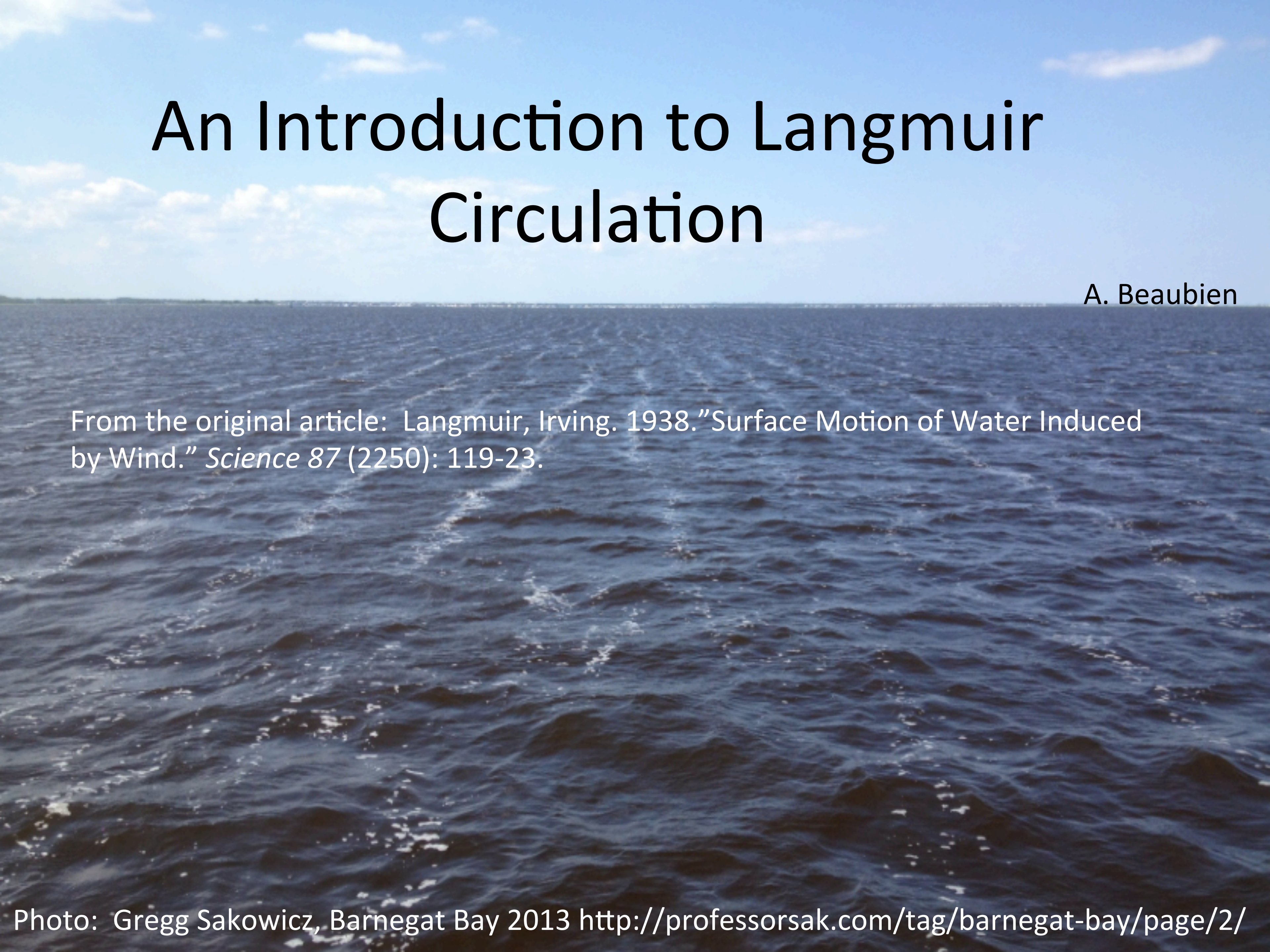


An Introduction to Langmuir Circulation

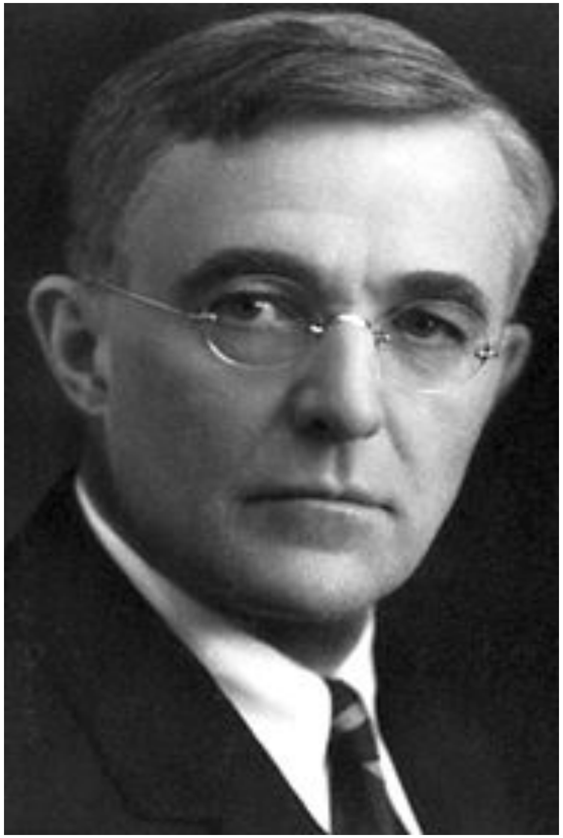
A. Beaubien

From the original article: Langmuir, Irving. 1938."Surface Motion of Water Induced by Wind." *Science 87* (2250): 119-23.

Photo: Gregg Sakowicz, Barnegat Bay 2013 http://professorsak.com/tag/barnegat-bay/page/2/

Historical Note:
Irving Langmuir, 1881-1957, Chemist, Physicist, Inventor

- PhD in Physical Chemistry 1906
- 1909-1950 worked at GE Research Lab
  - Experimentation/study of light bulbs was a continuation of his Ph.D. work
  - he and colleague Tonks improved lifetime of incandescent bulbs by filling the bulb with inert gas and twisting the tungsten filament into a coil
- one of the first scientists to work with plasmas
  - Langmuir & Tonks, electron density waves in plasmas (now known as Langmuir Waves)
  - Invented the atomic hydrogen welding process (first plasma weld ever made)
- Based on Langmuir's work at General Electric, J. B. Taylor developed a detector ionizing beams of alkali metals, (the Langmuir-Taylor Detector)
- Surfactant Chemistry: Nobel Prize in Chemistry 1932, based on 1917 paper on the chemistry of oil films
- Atomic Physics: Helped to define the modern concept of valence shells and isotopes
- Late 1920s-1930s: interest in meteorology/fluid dynamics
  - Refuted claim of entomologist Charles H. T. Townsend that the deer botfly flew at 800 mph (actual speed = 25mph)
  - he discovered a wind-driven surface circulation on bodies of water (now known as Langmuir Circulation)

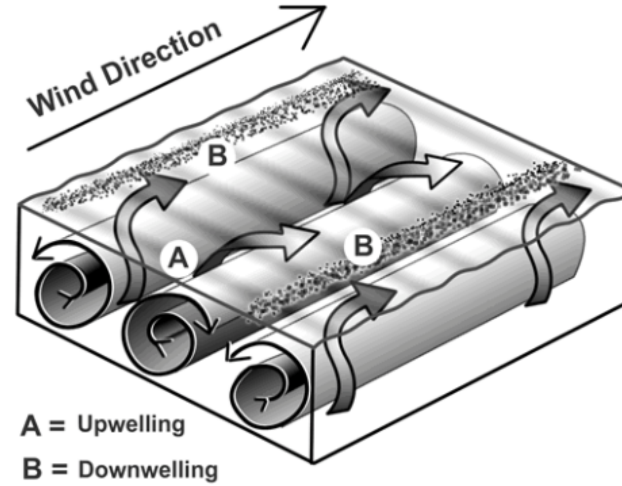


http://en.wikipedia.org/wiki/Irving_Langmuir

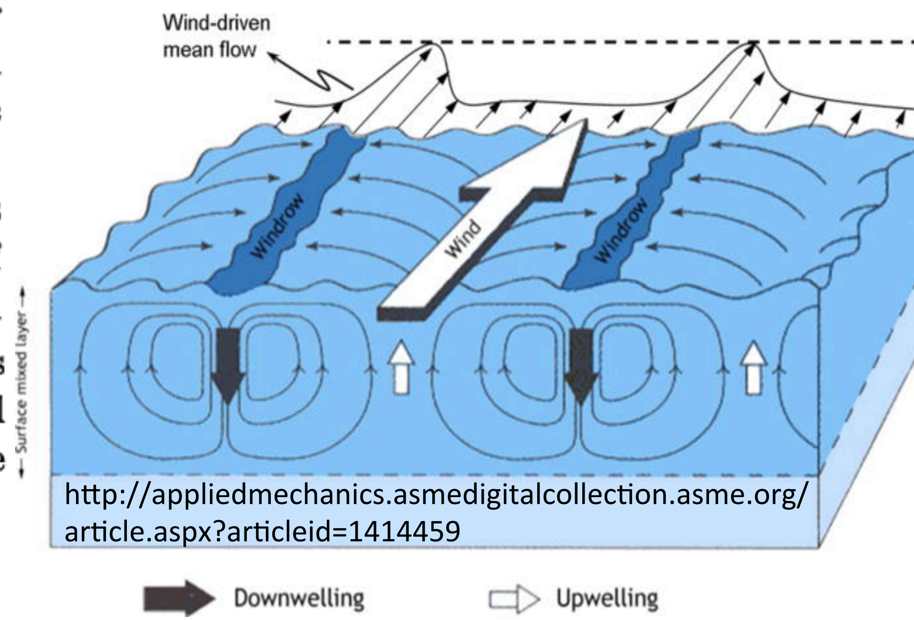
What is Langmuir Circulation (observation from L38)

On August 7, 1927, when about 600 miles from New York on an Atlantic crossing to England I noticed that there were large quantities of floating seaweed, most of which was arranged in parallel lines with a somewhat irregular spacing ranging from 100 to 200 meters. These lines, parallel to the wind direction, which I shall call streaks, often had lengths as great as 500 m. Between these larger streaks, which contained vast quantities of seaweed forming continuous bands 2 to 6 m wide, there were smaller streaks which were made up of detached masses of seaweed along nearly straight lines. At this time the wind was from the north with a velocity of approximately 10 m/sec (22 miles/hr) and the waves roughly 4 m high.

A day later the waves were larger and the streaks of seaweed were still abundant. On the afternoon of this day a sudden change of wind direction occurred (of about 90°); within 20 min all the seaweed was arranged in new streaks parallel to the new wind direction, although the waves continued to move in the old direction.

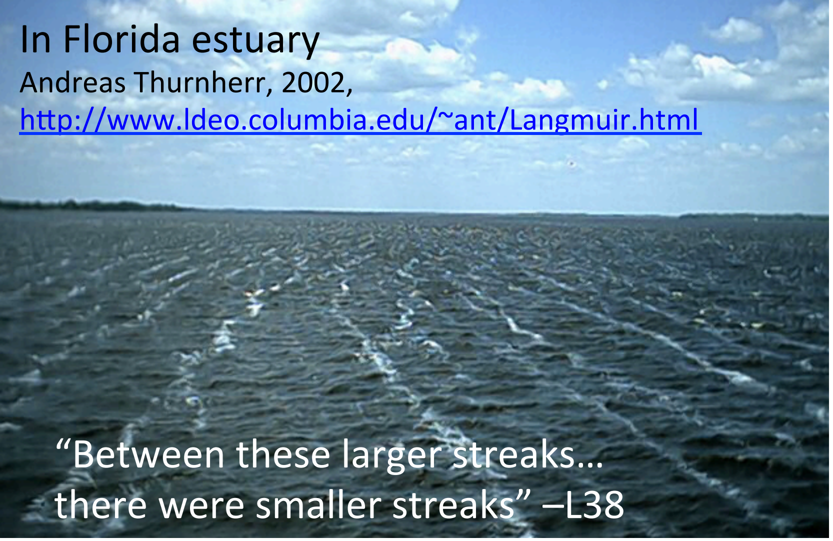


http://www.lmvp.org/Waterline/winter2002/langmuir.htm



http://appliedmechanics.asmedigitalcollection.asme.org/article.aspx?articleid=1414459

In Florida estuary
Andreas Thurnherr, 2002,
http://www.ldeo.columbia.edu/~ant/Langmuir.html



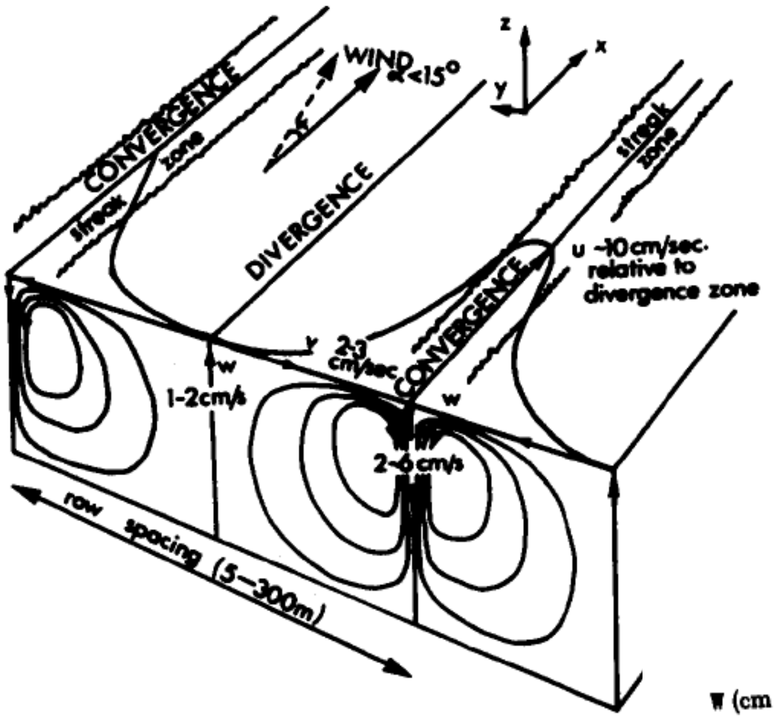
"Between these larger streaks… there were smaller streaks" –L38

Where Langmuir Circulation Occurs

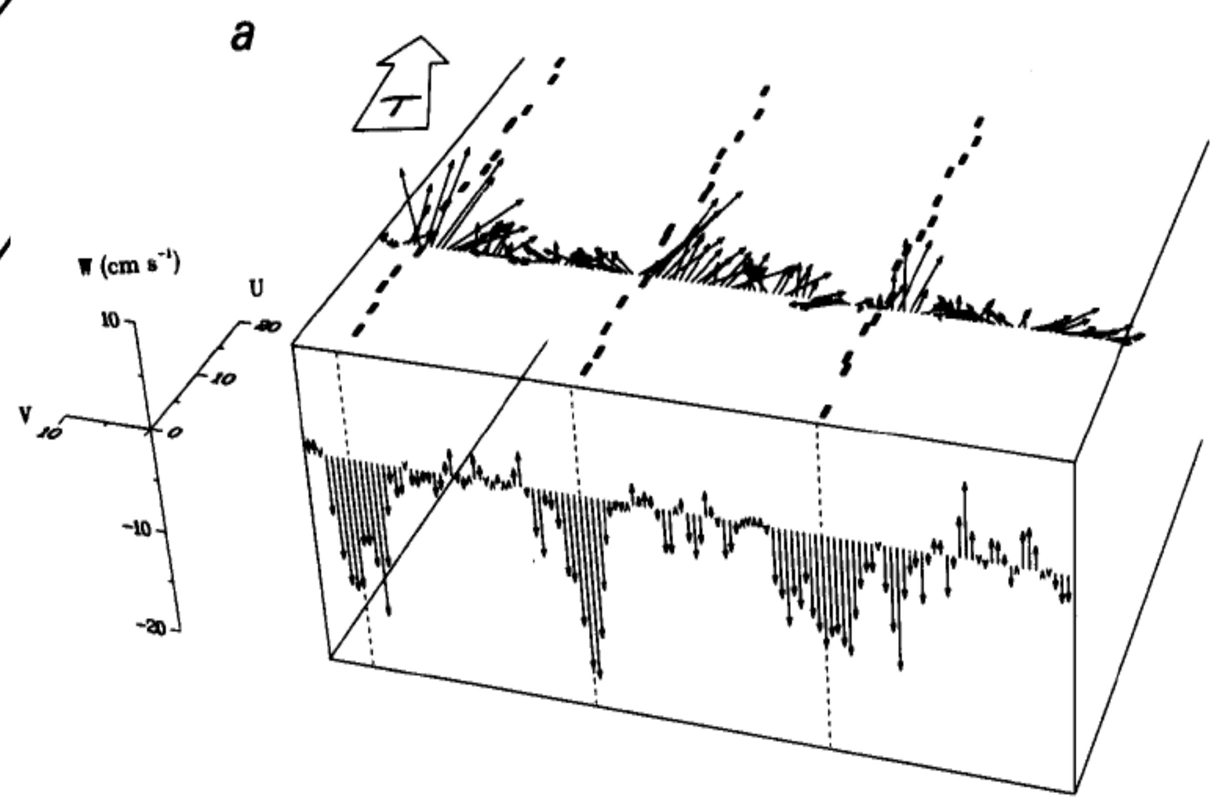
On Rivers: Brian Tang, 2005, Charles River near MIT
http://www.wunderground.com/wximage/btangy/0?gallery=

On lakes: Michael Mikkelson, 2010, Univ.Wisconsin Lake Mendota
https://www.flickr.com/photos/m2creativedesign/7910681674/in/photostream/

Langmuir Circulation, Diagram and Observation from Weller, Price, 1988



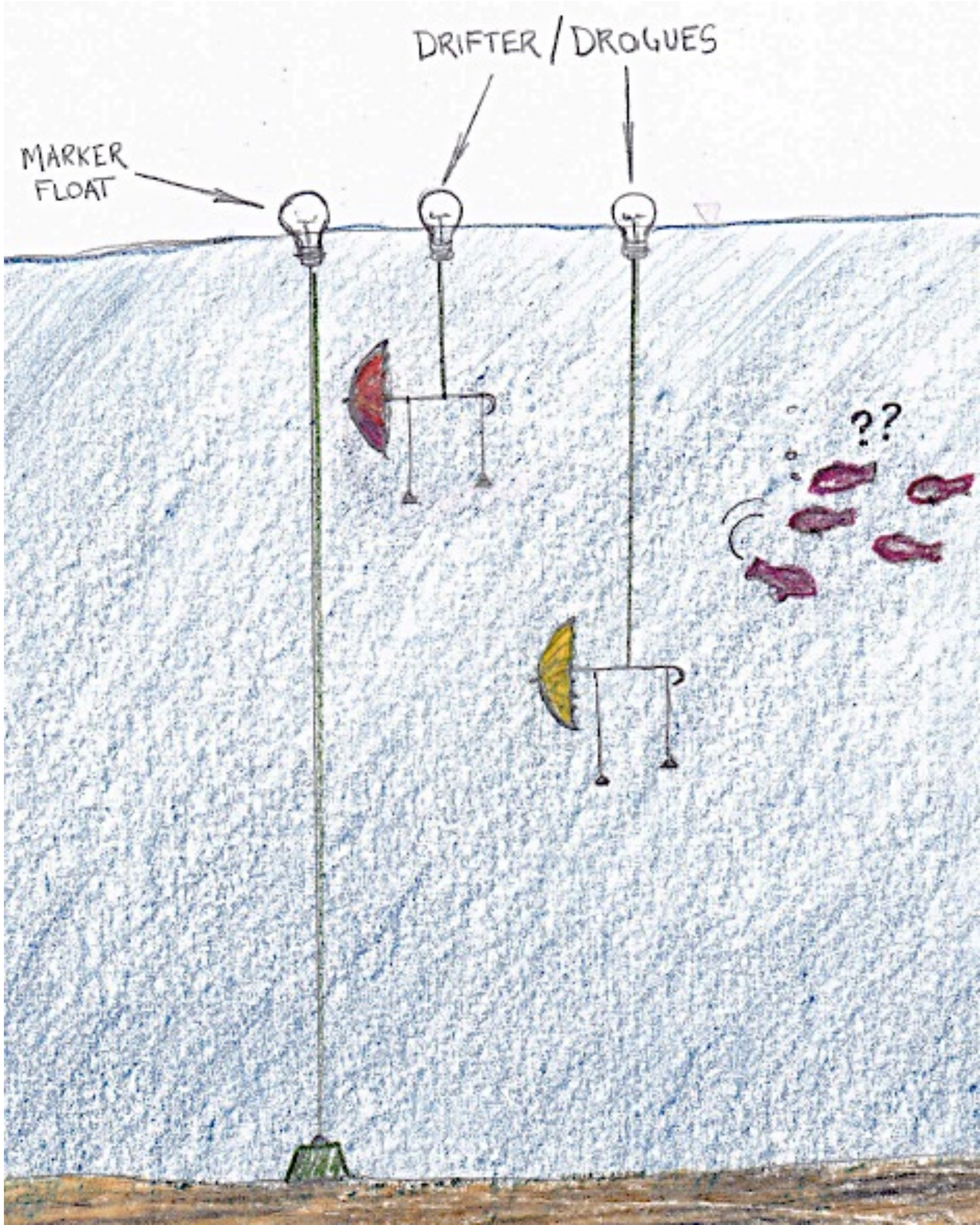
R.T. Pollard, 1977



WP88

L38: Original Lake George LC experiments used these items as tracers/instrumentation:

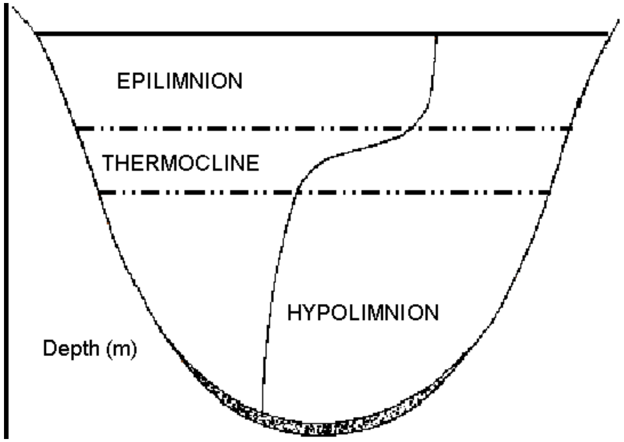
-olive oil
-floating leaves
-fluorescein solution
-2mm white cord with small fragments of cork spaced at 10cm
-To measure vertical velocities, plates of aluminum were suspended in a horizontal plane, made neutrally buoyant with lightbulbs and weights
-to measure below surface current 5-30m Below surface, umbrellas (60cm diam), suspended by light cords from small lamp bulbs floating at the surface, with a bulb at the surface as a marker buoy (perhaps 1st underwater drogues)



Key Observations from L38 Lake George Experiments

- Water velocities (u,v,w) were highest in the convergence zones (where v is in-line with the wind and w is the vertical velocity): ”water rising from deeper levels have a low forward velocity but this increases steadily through the action of the wind so that when the water reaches the streak it has it’s maximum velocity” –LC38
- Cell “spacings are approximately proportional to the depths to which they penetrate”
- several scales of streaks/LC cell spacings—there was a larger scale of windrow spacing and sometimes a smaller one inside that.
- Surface streaks changed direction as the wind changed direction—they aligned themselves with the wind, sometimes there was a lag 10-20 min but the streaks always aligned with the wind.
- “patterns of the streaks…are slowly changing; some growing, others dying out. On some days the streaks are much more regular than on others.”
- There is a specific circulation cell structure beneath the windrows:
  – “longitudinal and transverse velocities of the water in the vortices have their maximum values at the surface and gradually decrease to zero at the thermocline. Thus the vortices are unsymmetrical in respect to depth being increasingly diffuse at greater depths.”
- Momentum delivered to the water by the force of the wind is distributed in the mixed layer (but it is not always evenly distributed—there may be a pile-up of wind driven water on one side of the lake from a one-directional wind)
  – Langmuir calculates momentum as the integral of $(v-v_o)$ dz from the surface down to 6 m depth
  – Also calculates how much momentum the wind stress imparts per unit area as the integral of the windstress*dt over a certain time period.

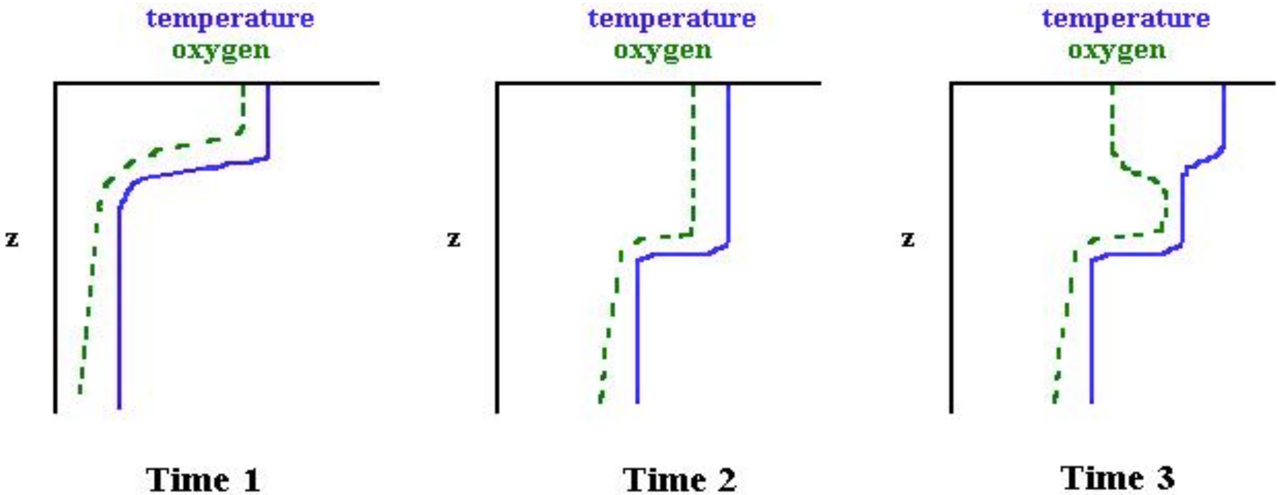
More Observations from Lake George and some limnology



http://www.gfredlee.com/intake.html

Depth and horizontal spacing of the cells is limited to the base of the mixed layer (epilimnion) and/or beginning of the thermocline

- -where several mixed layers occur (a steppy temperature profile) the LC cells go to the base of the mixed layer
- -The thermocline acts as a rigid bottom to limit size of the circulation cells
- -Surface wind and thermal convection both important

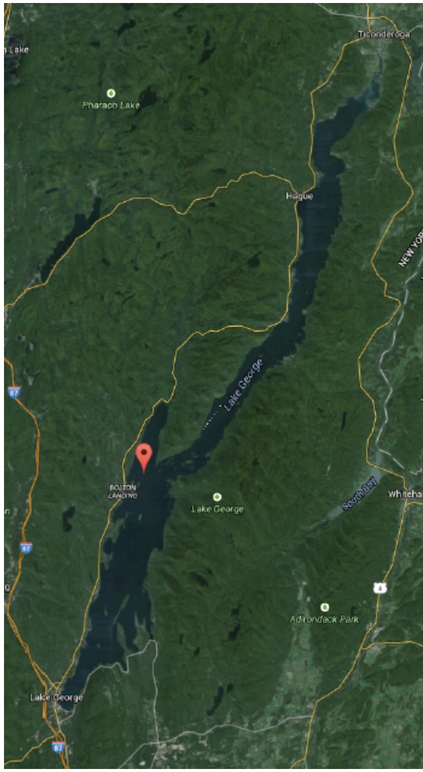


Most like summer (or little to no wind)

most like late autumn/winter (steady wind/deep convection)

most like early autumn/spring (wind events/ periods of deep convection and warming)

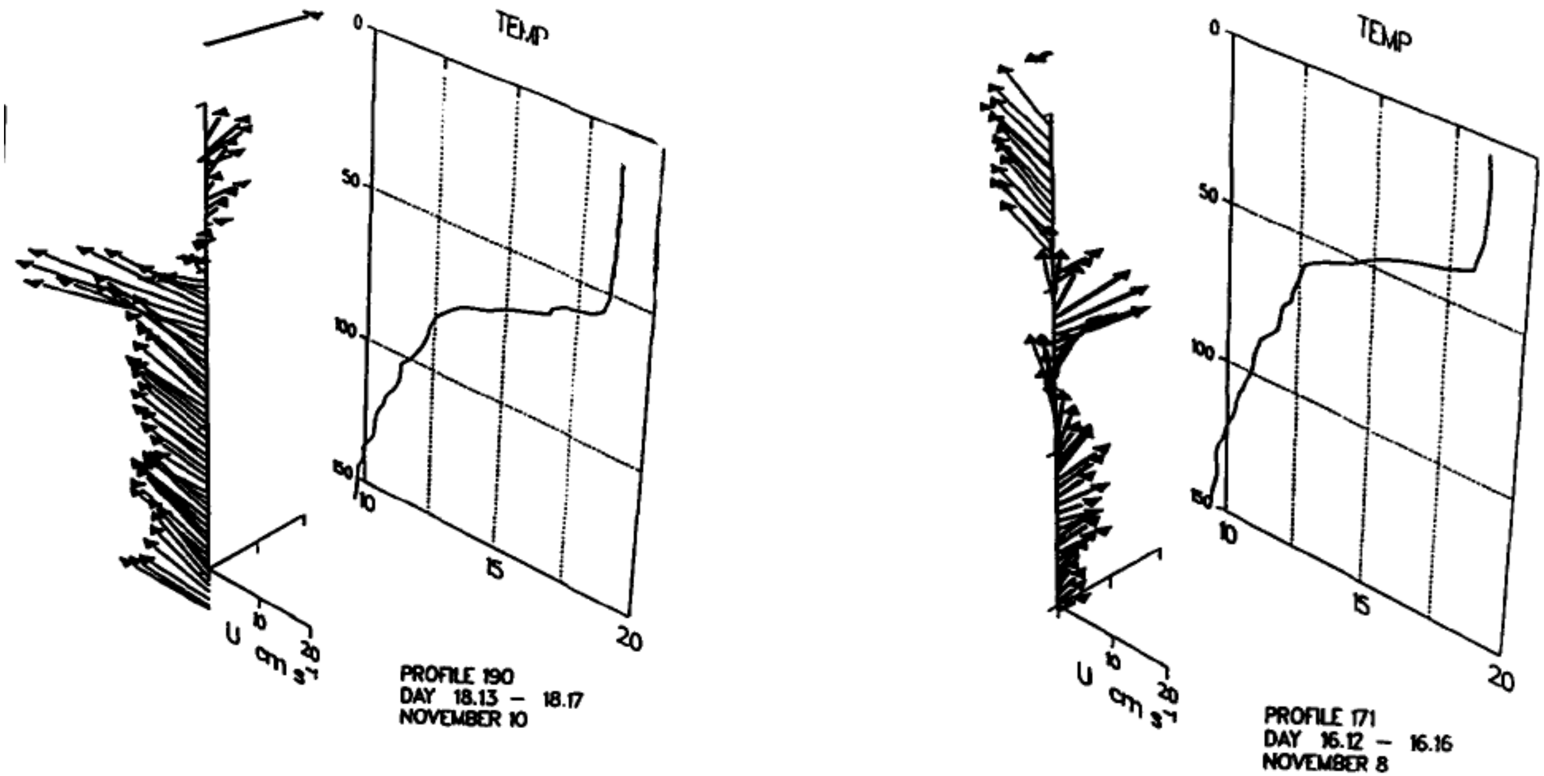
http://www.esf.edu/efb/schulz/Limnology/Oxygen.html



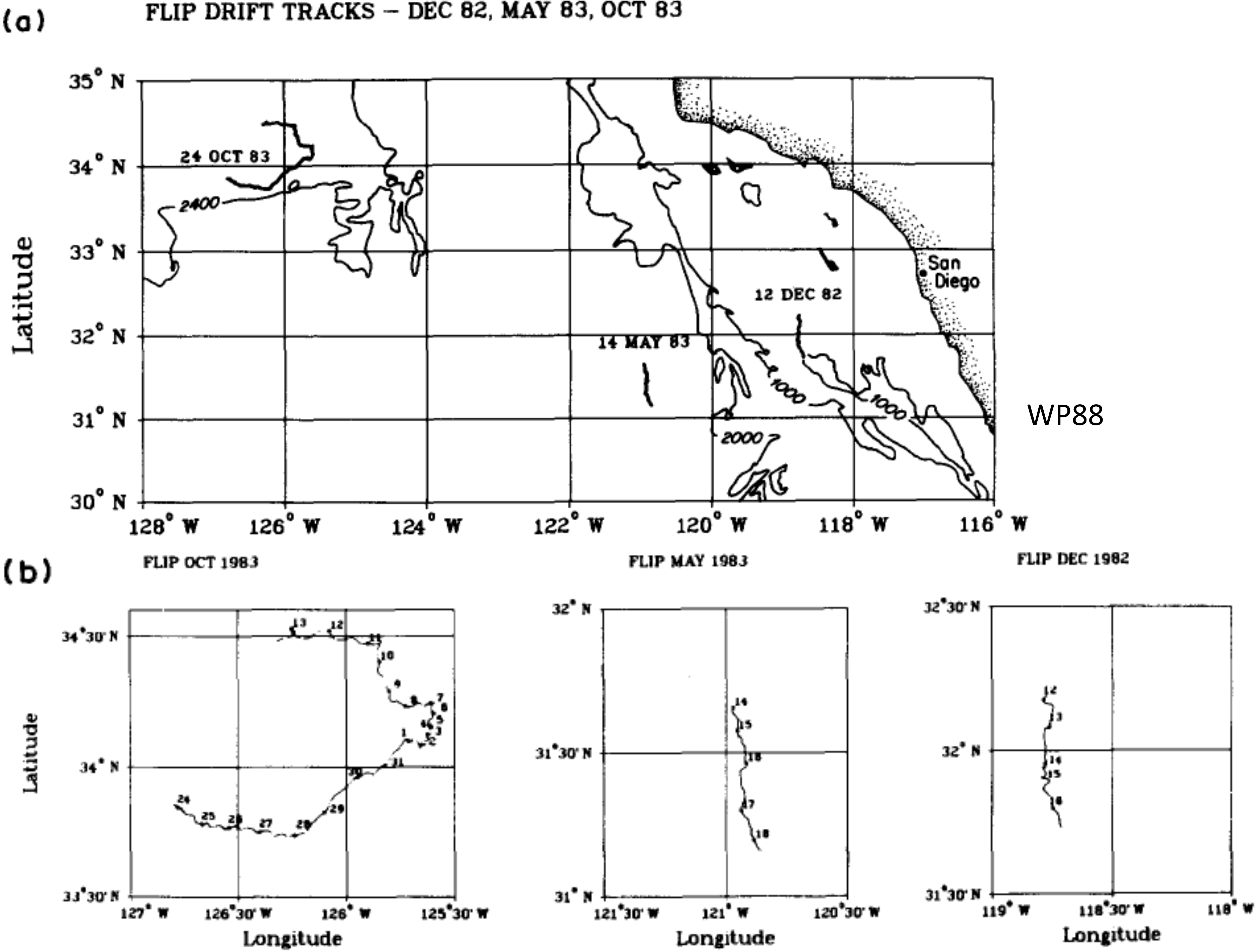
Lake George, Google Maps

From Langmuir “the helical vortices set up by the wind extend to the depth of the epilimnion but do not penetrate through the thermocline…The thermocline, however, is practically a fixed surface like that of a lake bottom for it is not set in motion by the overlying layers.”

“in May or June…when the epilimnion is shallow or is not strictly isothermal, the streaks are close together (5 to 10m), while in October and November well defined streaks usually have spacings of 15 to 25 m. The spacings are presumably approximately proportional to the depths to which they penetrate.” --Langmuir



Oceanic Mixed Layers from Weller and Price 1988, Comparison of two different days, different surface wind speeds, different mixed layer depths, LC was occurring on these days


(a)
FLIP DRIFT TRACKS – DEC 82, MAY 83, OCT 83
35° N
34° N
33° N
32° N
31° N
30° N
Latitude
128° W
126° W
124° W
122° W
120° W
118° W
116° W
24 OCT 83
2400
San Diego
12 DEC 82
14 MAY 83
1000
1000
2000
(b)
FLIP OCT 1983
FLIP MAY 1983
FLIP DEC 1982
34°30' N
34° N
33°30' N
127° W
126°30' W
126° W
125°30' W
32° N
31°30' N
31° N
121°30' W
121° W
120°30' W
32°30' N
32° N
31°30' N
119° W
118°30' W
118° W
Latitude
Longitude
Longitude
Longitude

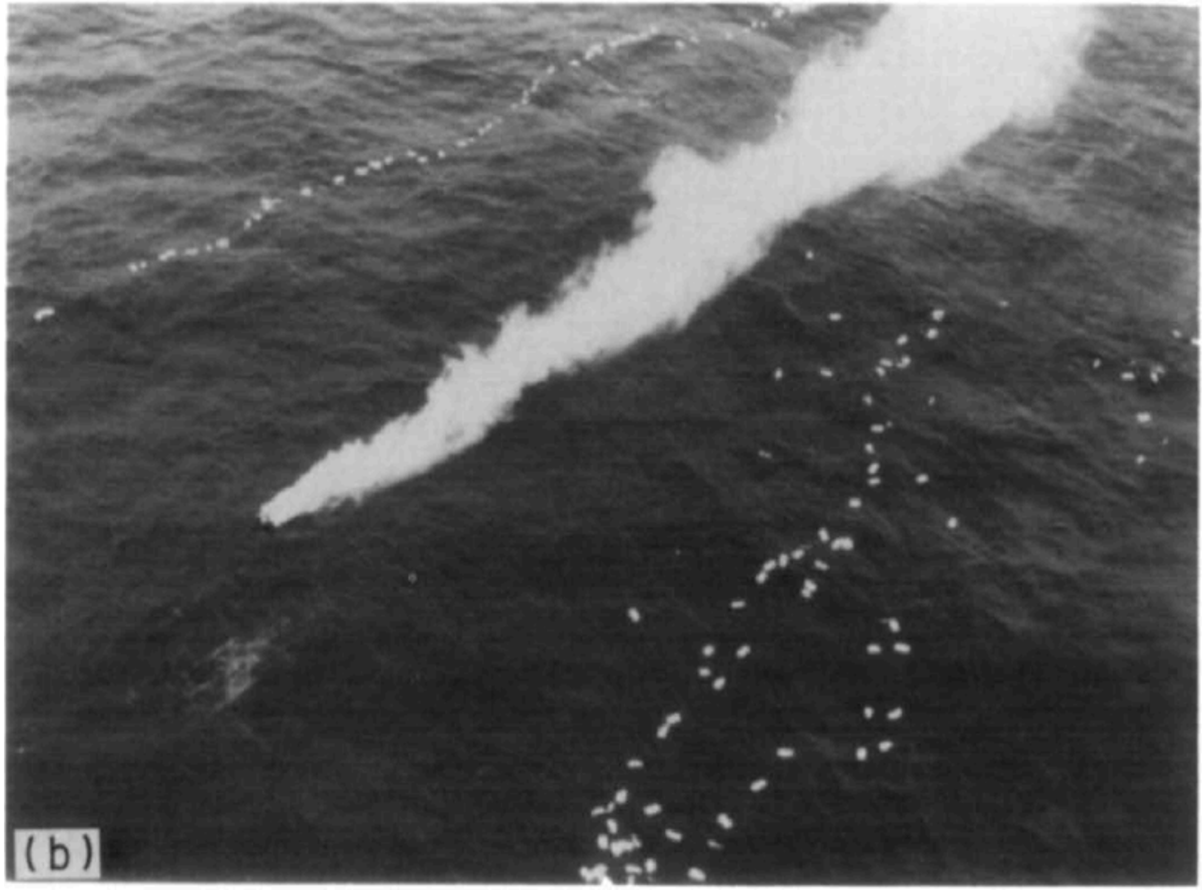
WP88

Experiments from WP88 used these tracers:

-smoke

-the tears of grad students (computer punch cards)

-and…

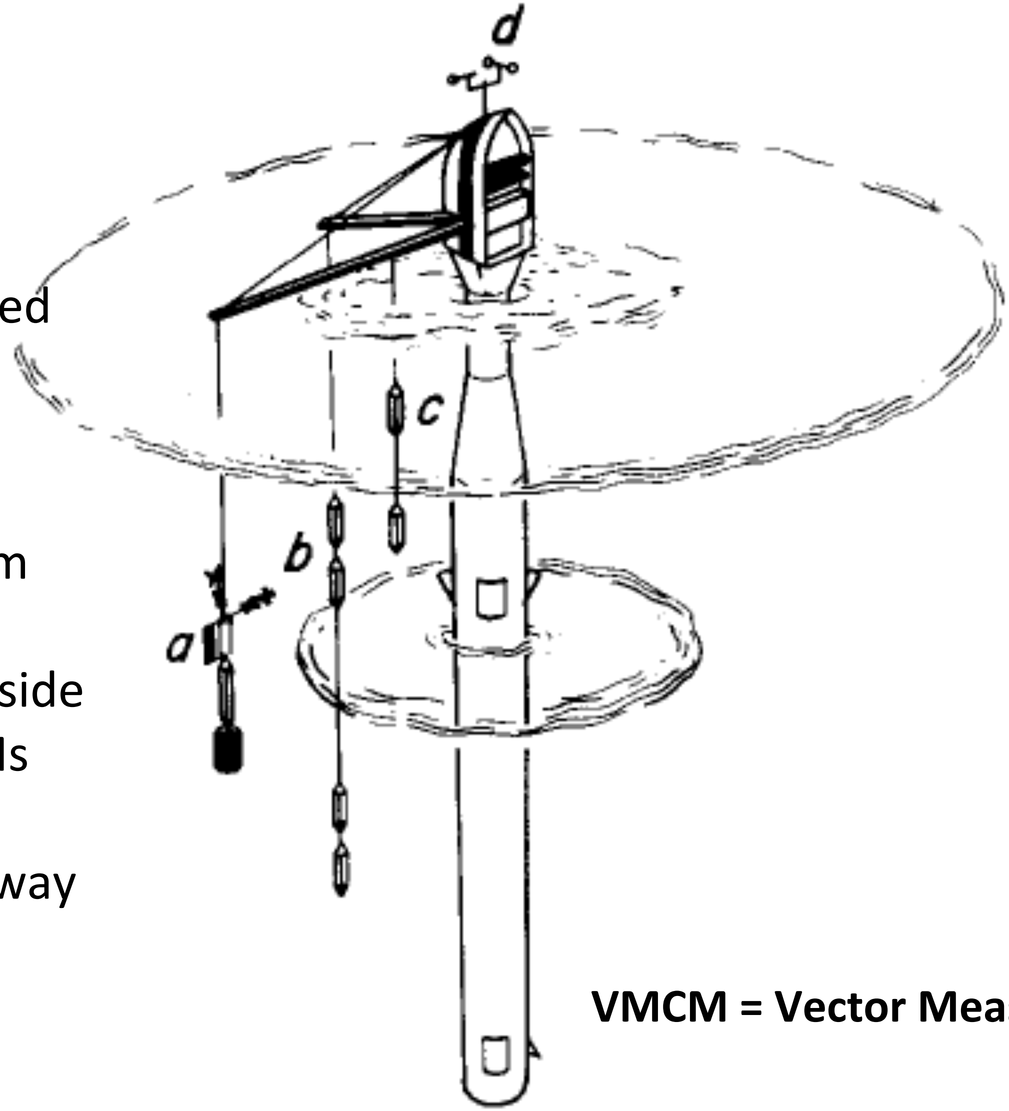


WP88

RP FLIP (total length 355 ft, draft = 300 ft)

Outfitted with:

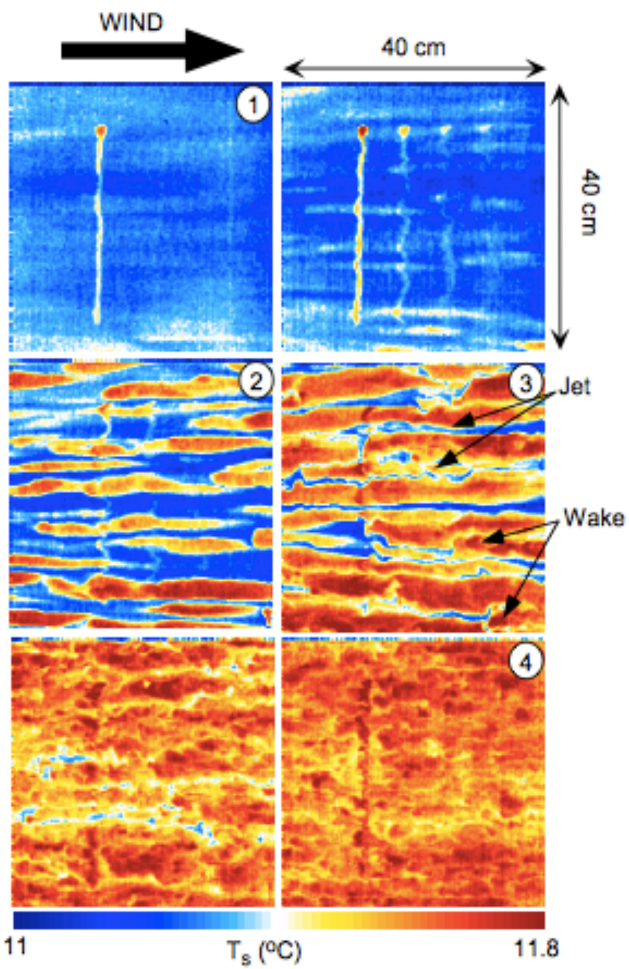
(a) Real Time Profiler (RTP) deployed off 15 m boom
(b) Automatically profiling VMCMs deployed from a 10 m boom angled slightly forward off the port side
(c) Fixed level VMCMs and the second RTP were deployed part way out the 15 m boom
(d) Met station

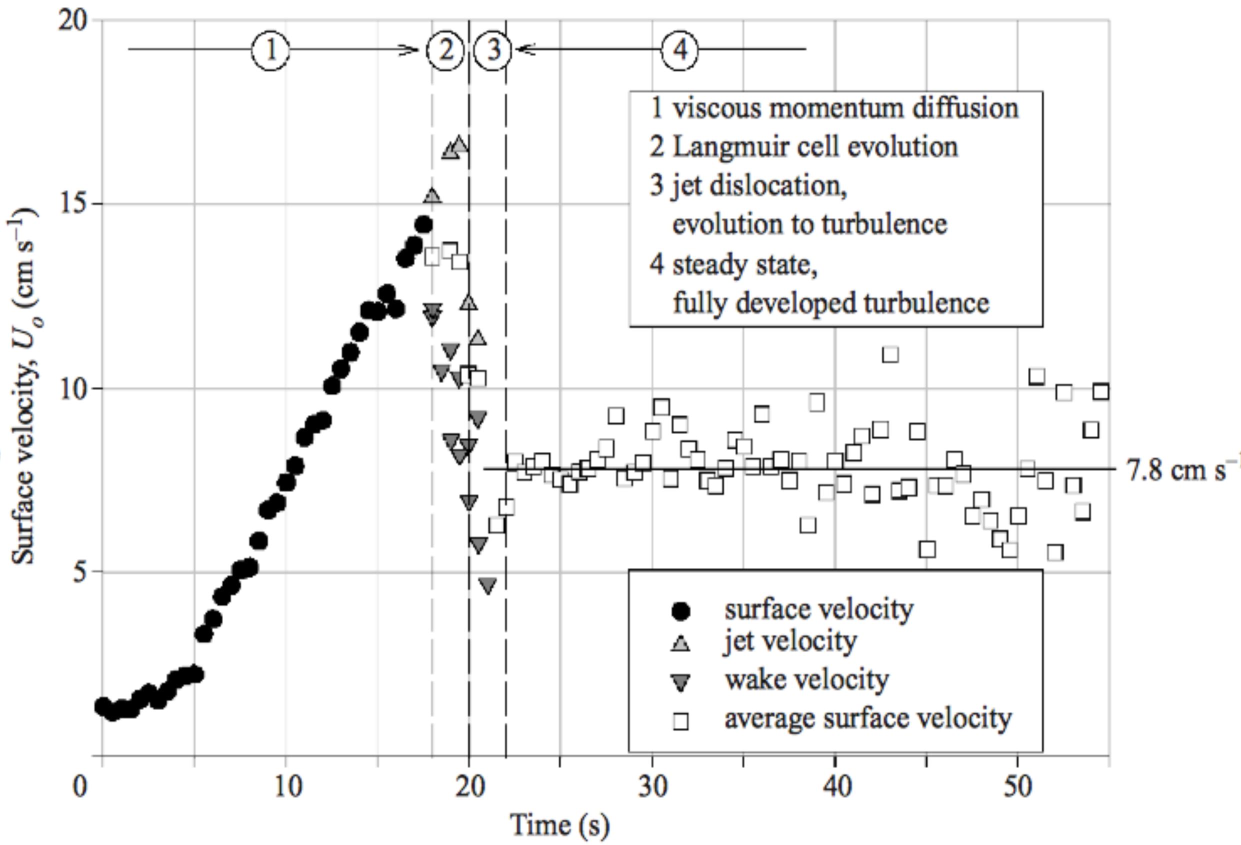


VMCM = Vector Measuring Current Meters

WP88

Modern Technology to visualize LC: infrared imaging in wave tank

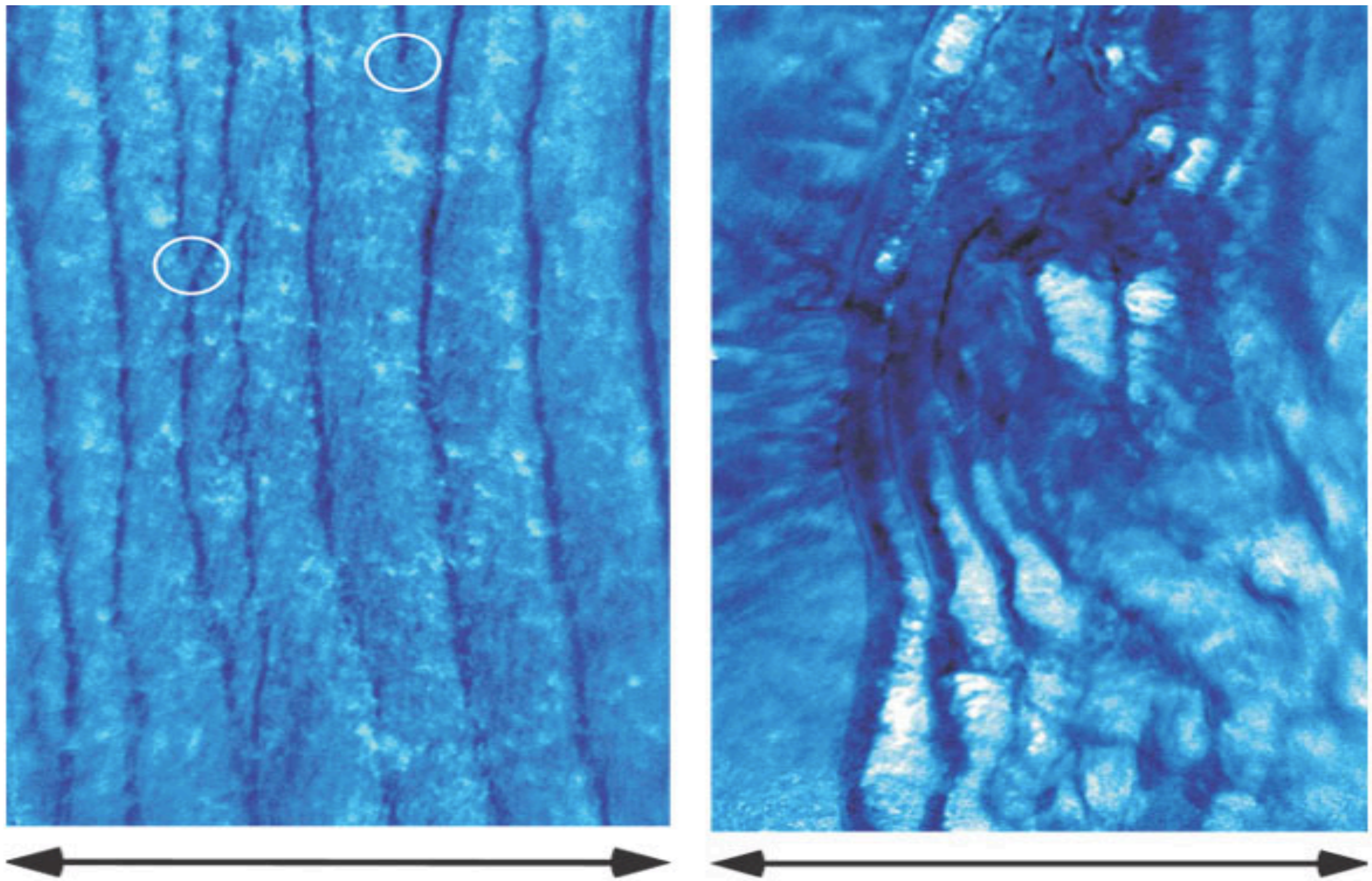




(Veron and Melville, 2001).

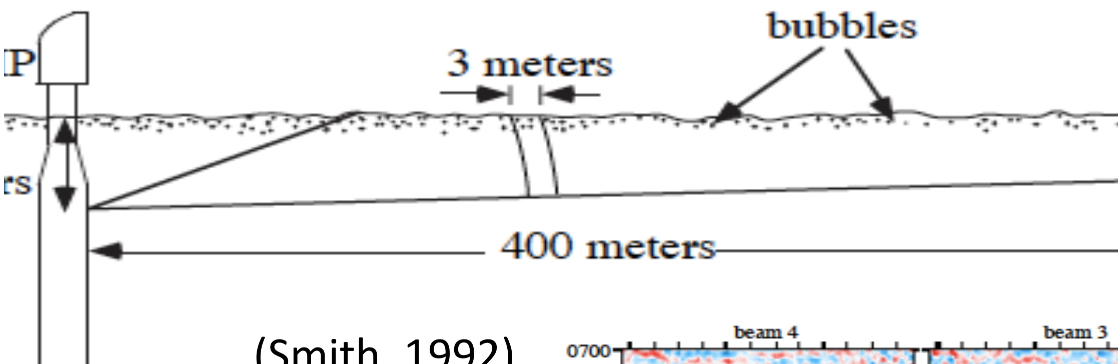
Observing LC/IW: Infrared Imaging

"the patterns of streaks on the lake surface are slowly changing; some growing, others dying out. On some days the streaks are much more regular than others" –Langmuir, 1938



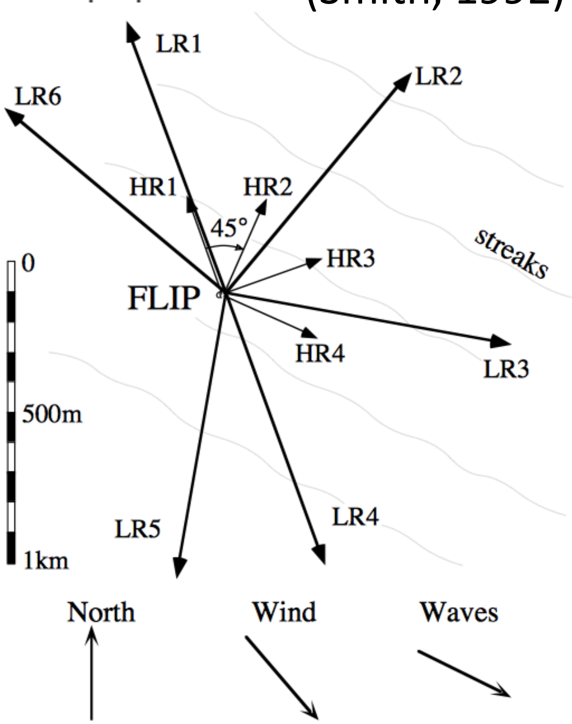
LC at left with wind speed 5m/s, IW at right with wind speed 1 m/s (Marmorino, 2004).

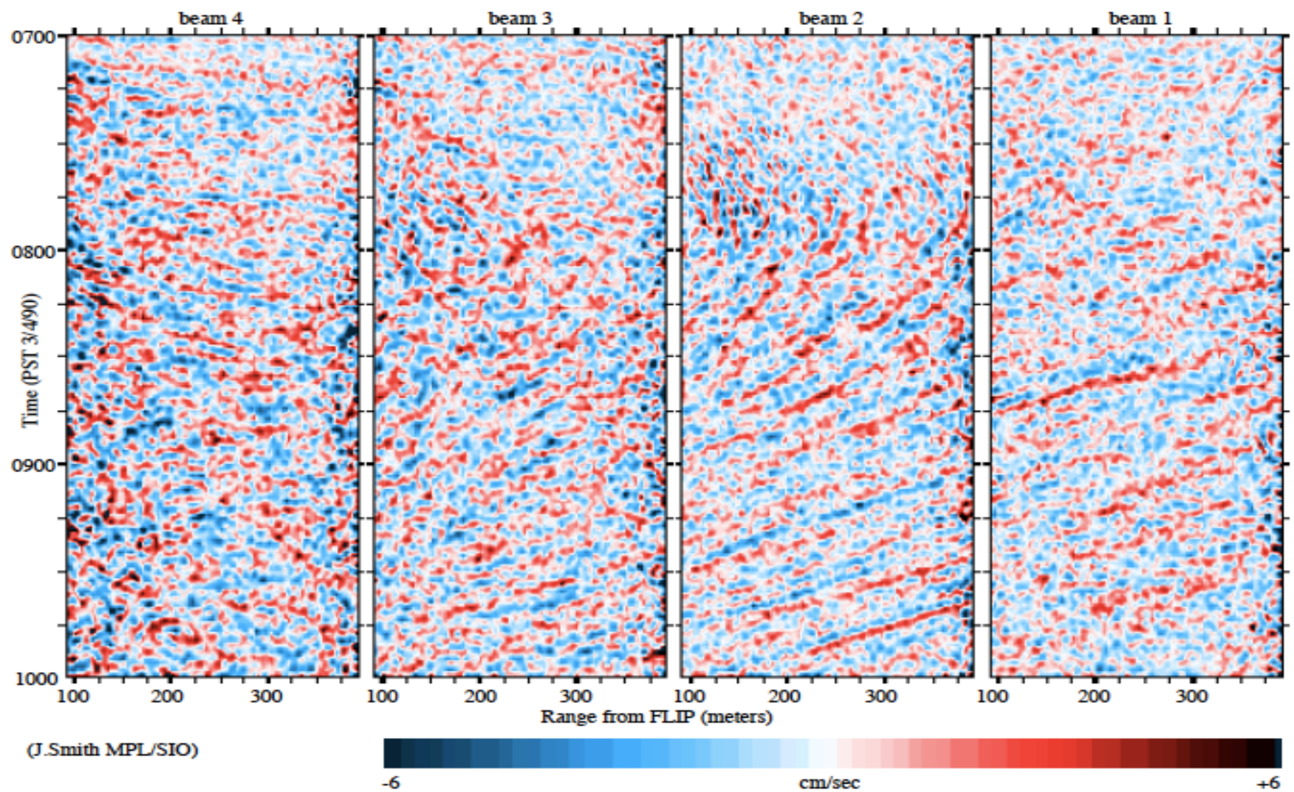
High Resolution Doppler Sonar (used in the 1990s SWAPP experiment)



Velocity in cm/s for each beam of high resolution Doppler sonar (Smith, 1992)

(Smith, 1992)





References

L38 = Langmuir, Irving. 1938."Surface Motion of Water Induced by Wind." *Science 87* (2250): 119-23.

Marmorino, G.O., G.B. Smith, and G.J. Lindemann, High Resolution Infrared Ocean Imaging, Remote Sensing Division, Naval Research Laboratory, 2004, website: http://www.nrl.navy.mil/research/nrl-review/2004/remote-sensing/marmorino/

Smith, J.A., Observed Growth of Langmuir Circulation, *J.Geophys.Res.,97*(C4), 5651-5664,1992.

Veron, F., W.K. Melville, 2001: Experiments on the Stability and Transition of Wind-Driven Water Surfaces. *Journal of Fluid Mechanics*, **446**, 25-65.

WP88 = Weller, Robert A, and James F Price. 1988. "Langmuir Circulation Within the Oceanic Mixed Layer." *Deep Sea Research Part a. Oceanographic Research Papers 35* (5). 711-47.

A few more limnology tidbits (ice, etc)

- Some lakes can have a mixed layer extend all the way to the bottom, happens more frequently in shallower lakes.
- A few lakes are so deep and store enough heat, despite being very cold, that they do not freeze over the top completely even in winter (lake Tahoe)
- What a complete ice cover does to the thermal structure of a lake:
  - Before Melting
  - During Thaw

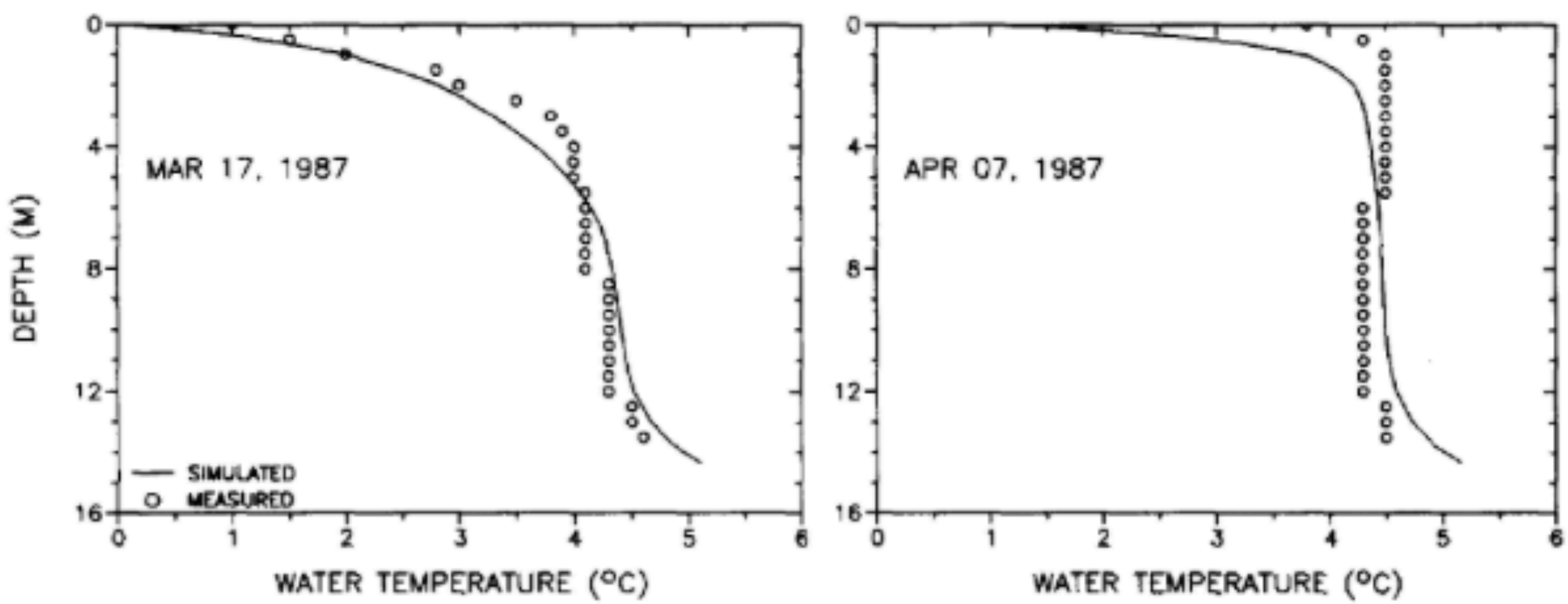


Fig. 6. Simulated and measured water temperature profiles for Thrush Lake, Minnesota, from 1986 to 1987.

X. Fang, H.G. Stefan / Cold Regions Science and Technology 24 (1996) 289–304