Freshwater Ice and Water SOPs:
Ice-On/Off Dates, Ice Thickness, Water Temperature

Top Results

Freshwater Ice On/Off Dates

Manuals:

- (PDF) New Brunswick River Ice Manual (2011)
- (PDF) EPA 2016 "Technical Documentation: Lake Ice"

Methods mentioned in research papers:

- moderate resolution imaging spectroradiometer (MODIS), advanced very high resolution radiometer (AVHRR), aerial surveys, satellite imagery, visible infrared imaging radiometer suite (VIIRS), shallow water ice profiler (SWIP), webcam, ENVISAT ASAR wide swath data, visual/volunteer observations

Databases:

- (Link) NSIDC Global Lake and River Ice Phenology database
- (Link) NOAA Great Lakes Ice Atlas - Ice Charts - 1973-2002
- (Link) Charts of Freeze-up, Break-up for Northern Canadian Waters

Freshwater Ice Thickness

Manuals:

- (PDF) Korhonen (2015) Measuring Ice Thickness: Finnish methods
- (PDF) 2013 “Best Practices for Building & Working Safely on Ice Covers in Alberta” cited in (PDF) Prospectors & Developers Association of Canada

Methods mentioned in research papers:

- Ice auger, drill holes, SWIP, ground penetrating radar (GPR) ice profiling equipment, electromagnetic subsurface profiling (EM sensors, sled-mounted), reflectometers, magnetostrictive delay line, MODIS, advanced microwave scanning radiometer-earth observing system (AMSR-E) brightness temperature measurements, synthetic aperture interferometric radar altimeter (SIRAL)

Databases:

- (Link) Canadian Ice Service Great Lakes Regional Ice Charts, Forecasts, and Bulletin - Canada Ice & Iceberg Charts (Stage of Development shows thickness)
- (Link) Canadian Ice Thickness Program - 1947-2002, 2002-2016

Temperature Measurement & Depth

Manuals:

- (PDF) UNEP/WHO (1996) “A Practical Guide to the Design & Implementation of Freshwater Quality Studies & Monitoring Programmes”
- (PDF) USGS 2006 Field Manual Temperature-measurement
- (PDF) EPA 2014 "Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams"

Devices mentioned:

- Data loggers, thermistor thermometers, handheld meters, temperature loggers

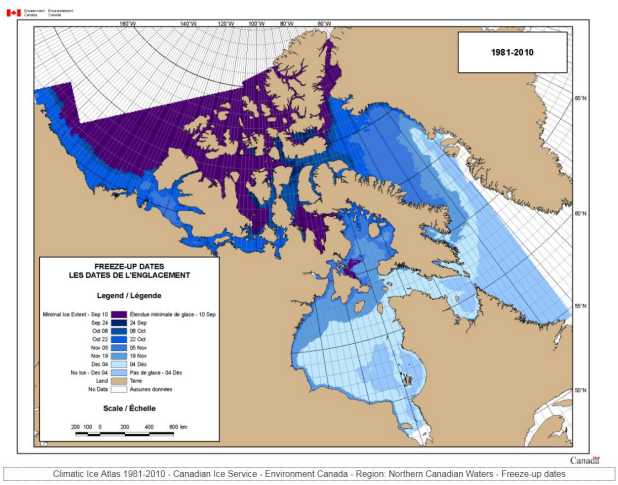
Databases:

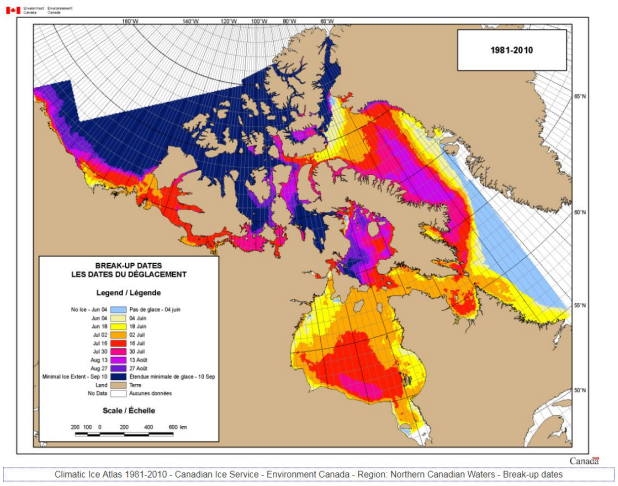
- (Link) Polar Data Catalogue - 1954-2012 Physicochemical Lake Profiles (temperature vs. depth AND includes snow depth and ice thickness)
- (Link) NSF Arctic Data Center - Bathymetric depth soundings

Freshwater Ice-On/Off Dates: Methods & Databases (59)

Databases/sets (11)

1. (Link) NSIDC Global Lake and River Ice Phenology **database**
    a. Pro: data aggregation, spatio-temporal coverage, sort by country, lake, river, date
    b. Con: does not list methodology or ice-on/off definitions behind each data point
2. (Lake Ice In, Lake Ice Out) Minnesota Department of Natural Resources - **maps & dates**
    a. Contacts same individuals each year to maintain consistent record for each lake
    b. Depending on the lake, ice-off could mean 100% free of ice, 90% free of ice, or navigable from point A to B. For ice-on, ideally report when entire lake freezes for first time to stay frozen throughout rest of winter
3. (Link) Canadian Ice Service Great Lakes Regional Ice Charts
    a. Has animation of ice concentration last 10 days
4. (Links) Great Lakes Surface Environmental Analysis GLSEA
    a. (Link) Last 10 day analysis from 07/02/2018
5. (Link) IceWatch - need to sign up to download data
6. (PDF) Canadian Ice Service “Lake Ice Climatic Atlas: Great Lakes 1981-2010”
    a. Has ice on/off and thickness
7. (Link) Charts of Freeze-up, Break-up for Northern Canadian Waters
8. (Link) **Global Lakes Wetlands Database** - lakes to track/measure (used in (PDF) Brooks et al. (2013) “Quantifying Northern Hemisphere Freshwater Ice”)
9. (Link) Scott Polar Research Institute - World Data Center for Glaciology - search for floating ice, sea, lake, and river - or land ice, glaciers, and ice shelves
10. (Link) Lake Ice Analysis Group - North Temperate Lakes
    a. has data protocol, and workshop from **1996**
11. (Link) NOAA Great Lakes Ice Atlas - Ice Charts - **1973-2002**





Left: North Canadian chart of Freeze-up dates**. Right:** North Canadian chart of Break-up dates.

Practices & Procedures

Manuals & Standards (9)

12. (PDF) New Brunswick **River Ice Manual** (2011)
    a. Location of stations, frequency of freezeup, pre-breakup, breakup observations
    b. Satellite vs. ground-based vs. aerial surveys
13. (Link) **WMO** Colour Code: (Link) Concentration (Link) Stage of Development - Lake Ice
14. (PDF) **EPA** 2016 **"Technical Documentation: Lake Ice"**
15. (PDF) Assel & Herche (1998) "Ice-on, ice-off, and ice duration for lakes and rivers with long-term trends"
    a. Incorporated in "**Ice in Surface Waters: Proceedings of the 14th International Symposium on Ice**," H. Shen, Ed. (Netherlands, 1998), pp. 147–151.
16. (Book) Gray and Prowse, in **Handbook of Hydrology**, D. Maidment, Ed. (McGraw-Hill, New York, 1993), pp. 7.1–7.54.
17. (PDF) Kuusisto 1993 in Snow Watch 92—**Detection Strategies** for Snow and Ice
18. (Link) Closa et al. (2003). "The **ASAR Wide Swath** Mode products"
    a. Geoscience and Remote Sensing Symposium. IGARSS '03. Proceedings. 2003 **IEEE** International (Toulouse), vol. 2, 1118–1120.
19. (PDF) Assel (2004) **GLERL Technical Report** - Lake Erie Ice Cover Climatology - Basin Averaged Ice Cover winters **1898-2002**
20. (Link) **IPCC** 2007 Working Group I: Changes in Freeze-up and Breakup Dates

Research Papers

Reviews/Historical Studies (24)

21. (PDF) Turcotte & Morse (2013) "A global river ice **classification** model"
22. (PDF) Prowse et al. (2007) "River-ice break-up/freeze-up: a review of **climatic drivers**, historical trends and future predictions"
    a. **Definitions** of ice-on/off dates vary among sources
    b. It can take up to 4 weeks for ice-off process to complete (de Rham 2006)
23. (PDF) Brown & Duguay (2010) "The response and role of ice cover in lake-climate interactions"
    a. "Ice **phenology** trends have typically been associated with variations in air temp"
24. (Link) Prowse et al. (2012) Past and Future Changes in Arctic Lake and River Ice
    a. Later freeze-ups earlier breakups and declining ice thickness in future projections
25. (PDF) DeBeer et al. (2016) "Recent changes over interior of western Canada"
    a. See pg. 1586 for section 7- Freshwater Ice Cover
    b. "Some useful reviews on the climatic controls, historical trends, and future projections of river ice formation and break-up are provided by Prowse and Beltaos (2002), Beltaos and Burrell (2003), Prowse and Bonsal (2004), Prowse et al. (2007), Beltaos and Prowse (2009), and Prowse (2012)."
26. (PDF) Takacs et al. 2013 "Impacts of anthropogenic effects on river ice **regime**: examples from Eastern Central Europe"
27. (PDF) Livingstone et al. 2010. Lake ice phenology. In: George, D.G. (ed.). The impact of climate change on European lakes. Aquatic Ecology Series 4:51–62.

28. (PDF) Magnuson et al. (2000) "Historical trends in lake and river ice cover in the Northern Hemisphere" Science 289:1743–1746.
29. (PDF) Hewitt et al. (2018)!! "Historical Trends, Drivers, and Future Projections of Ice **Phenology** in Small North Temperate Lakes in the Laurentian Great Lakes Region"
30. (PDF) Benson et al. 2012 "Extreme events, trends, and variability in Northern Hemisphere lake-ice **phenology** (**1855-2005**)" - cited in Hewitt et al.2018
31. (PDF) Cleve & Martin ed. **1991** "A network of research sites: long-term ecological research in the U.S."
    a. mentions ice free between June-Sept
32. (PDF) Arp et al. (2015) "Depth, ice thickness, and **ice-out timing** cause divergent hydrologic responses among **Arctic lakes**"
33. (Link) Bartsch et al. 2017 "Circumpolar mapping of ground-fast lake ice"
    a. Got lots of good references from this one
34. Need HOLLIS Access - (PDF) Jeffries et al. (2013). “Ice characteristics and processes, and remote sensing of frozen rivers and lakes”
    a. Was included in American Geophysical Union
35. (PDF) Korhonen, J. (2006) Long-term changes in lake ice cover in **Finland**, Nordic Hydrology 37, 347–363.
36. Skinner, W. R. (**1986**) The break-up and freeze-up of lake and sea ice in Northern **Canada**. Can. Climate Centre rep. 86–8, Atmospheric Environmental Service, Downsview, Ont., 62 pp. (unpubl.ms.)
37. (PDF) Williams, G. P. (**1971**) Predicting the date of lake ice break-up. Water Resources Research 7, 323–333.
38. (PDF) Livingstone **1999** ice breakup Lake Baikal **Siberia** North Atlantic Oscillation "uninterruptedly recorded" since **1869**
39. (PDF) Hodgkins 2010. Historical ice-out dates for 29 lakes in New England, **1807–2008**. U.S. Geological Survey Open-File Report 2010-2014.
40. (PDF) Hodgkins 2013. The importance of record length in estimating the magnitude of climatic changes: an example using **175 years of lake ice-out** dates in New England. Climatic Change 119:705–718.
41. (PDF) Takacs & Kern (2015) "Multidecadal changes in the river ice **regime** of the lower course of the River Drava since AD **1875**"
    a. "more than **130-year-time-series** of ice-on and ice-off, and freeze-up and break-up dates was analysed from 4 selected hydrological stations along the lower course of the River Drava"
42. (PDF) Lind et al. 2016 "Hydro & thermal controls of ice formation in 25 boreal streams"
    a. Again: ice types rather than dates, but mention of freeze up and breakup
43. (PDF) Jensen et al 2007. Spatial analysis of ice phenology trends across the **Laurentian Great Lakes** region during a recent warming period.
44. (PDF) Beltaos and Prowse (2000-01) "Climate impacts on extreme ice jam events in Canadian rivers"
    a. In contributions to IHP-V by Canadian Experts, **UNESCO- International Hydrological Programme, IHP-V Technical Documents in Hydrology**, No. 33 (United Nations Educational, Scientific and Cultural Organization, Paris, 2000)

Satellite/Remote Sensing (8)

45. (Link) Karetnikov (2017) “Journal of Great Lakes research: A time series of over 100 years of ice seasons on Lake Ladoga”
    a. “Lake Ladoga ice conditions were examined for the period 1913–2015 based on weather data and **Finnish ice data (1913–1937)** and **Soviet/Russian airborne and satellite surveys (1943–2015).** The data from the time series included the evolution of the ice concentration each winter, and occasionally of **ice thickness**. The **mean freezing and breakup dates** were November 26 and May 15, respectively. The annual frequency of complete freeze-over of the lake was 0.83.”
46. (PDF) Moore & Gregory (1980s or so) “Use of Satellite Imagery for Monitoring Ice Break-up along the Mackenzie River, N.W.T.” - covers years 1975-77
47. (Link) Stalder et al. (2016-2018) “Integrated Monitoring of Ice in Selected Swiss Lakes”
    a. Integrates remote sensing **(VIIRS)** and **webcam imagery** into lake ice on/off dates with in-situ measurements of temperature profiles -- enhances resolution from previous **MODIS & AVHRR** (Advanced Very High Resolution Radiometer)
48. (PDF) Latifovic & Pouliot (2007). Analysis of climate change impacts on lake ice phenology in Canada using the **historical satellite data** record.
49. (PDF) Surdu et al. (2015) "Ice Freeze-up and Break-up detection of shallow lakes in Northern **Alaska** with **Spaceborne SAR**"
    a. **ASAR Wide Swath, RADARsat ScanSAR**
50. (Link) Bartsch et al. 2008 "Detection of permanent open water surfaces in central **Siberia** with **ENVISAT ASAR wide swath** data with special emphasis on the estimation of methane fluxes from tundra wetlands"
    a. Open water surfaces, ASAR wide swath
51. (PDF) Duguay et al (2002). **RADARSAT** backscatter characteristics of ice growing on shallow sub-Arctic lakes, Churchill, Manitoba, Canada.
    a. Very technical
52. (PDF) Jones et al. (2013). Classification of freshwater ice conditions on the Alaskan Arctic Coastal Plain using **ground penetrating radar and TerraSAR-X satellite data**.
    a. GPR + TerraSAR-X satellite

MODIS & AVHRR (4)

53. (PDF) Muhammad et al. (2016) “Monitoring ice break-up on the Mackenzie River using **MODIS** data” MODIS = Moderate Resolution Imaging Spectroradiometer
    a. Fills gaps in ground-based hydrometric observations with **remote sensing** data
    b. Compares ice-off to snow-off for thermally & dynamically driven melt processes
    c. Finds that channel morphology has significant impact on ice break-up patterns
54. (PDF) Reed et al. (2009) “Integration of **MODIS-derived** metrics to assess interannual variability in snowpack, lake ice, and NDVI in southwest Alaska”
    a. “The start of the lake ice season lagged the snow season by 2 to 3 months. Within a given lake, freeze-up dates varied in timing and duration, while break-up dates were more consistent.”
55. (Link) Gou et al. (2017) “Lake ice phenology of Nam Co, Central Tibetan Plateau, China, derived from multiple MODIS data products”

   a. “we present a **new automated method** to extend the interpretation of existing in-situ lake ice records, using **multiple MODIS data products**. Our results showed **strong agreement with the in-situ data** at Nam Co (Co means lake in Tibetan language) on the central **Tibetan Plateau**.”
56. (PDF) Nonaka et al. “Relationships between ice breakup dates of lakes and local air temperature on the Eurasian continent”
   a. ice breakup dates on 18 Eurasian lakes from 2001 to 2003 estimated by **MODIS**
   b. ice breakup dates on Lake Khanka since 1984 estimated using **AVHRR** data

Field & Simulations (2)

57. (PDF) Fang et al. 1996 "Simulation & observation of ice formation (freeze-over) in lake"
58. (PDF) Timalsina et al. 2013 "Simulation of the ice **regime** in a Norwegian regulated river"
   a. regime is not phrenology, but related for identification of ice cover presence

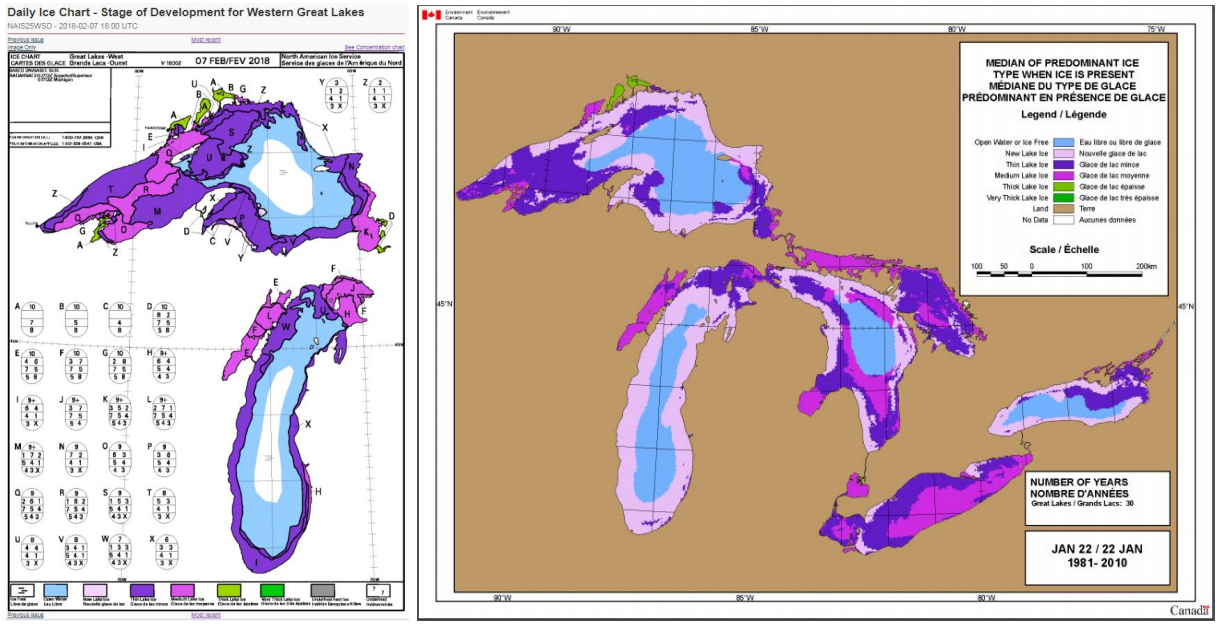
SWIP (1)

59. (PDF) Brown & Duguay (2011) “A comparison of simulated and measured lake ice thickness using a **Shallow Water Ice Profiler**”
   a. Collects in-situ ice cover and thickness measurements using SWIP on lake floor, a **digital camera** on shore, and **field measures** of snow depth, ice thickness
   b. Identifies ice-on/off dates and simulates how snow cover affects ice-on dates

Freshwater Ice Thickness: Methods & Databases (53)

Databases/sets (8)

1. (Link) NOAA/Great Lakes Environmental Research Laboratory (GLERL) (1995). “GLERL Great Lakes Ice Thickness Data Base, 1966-1979, Version 1”
    a. Weekly ice thickness and stratigraphy data at ~90 stations in the winters of 1965/66 through 1976/77 on the Great Lakes. Data include station name, latitude, longitude and period of record as well as thickness of up to six ice layers, total ice thickness, snow depth (on top of ice), snow condition, ice condition, and ice type code. “Sensors” are **ice augers and visual observations**
2. (Link) Canadian Lake Ice Database (Polar Data Catalogue)
    a. Unsure how the data is visualized, but it can be downloaded in “.lst” format
3. (Link) Canadian Ice Service Great Lakes Regional Ice Charts, Forecasts, and Bulletin - Canada Ice & Iceberg Charts
    a. Stage of Development shows thickness
    b. Ex. Feb 2018 Great Lakes-West Stage of Development (latest) depicts open water, ice free, new lake ice, think, thick, and very thick lake ice
4. (PDF) Canadian Ice Service “Lake Ice Climatic Atlas: Great Lakes 1981-2010”
    a. Has ice on/off and thickness
5. (Link) Polar Data Catalogue - 1954-2012 Physicochemical Lake Profiles
    a. Includes snow, ice thickness, temperature, depth
6. (Link) Russian river ice thickness measurements and freeze up from 50 stations
7. (Excel) Alaskan North Slope (1962-2017) lake ice thickness
8. (Link) Canadian Ice Thickness Program - 1947-2002, 2002-2016



Left: Regional Ice Charts (Stage of Development). **Right**: Lake Ice Climatic Atlas- Median of predominant ice thickness (low, medium, high) when ice is present on Jan 22 from 1981-2010.

Practices & Procedures

Manuals & Standards (6)

9. (PDF) Prospectors & Developers Association of Canada (n.d.) “e3 Plus: Framework for Responsible Exploration: Excellence in Health and Safety: Snowmobiles”
    a. Acknowledges traditional practice of drilling holes with an **ice auger**
    b. Recommends using **ground penetrating radar (GPR) ice profiling equipment** for accurate determination of thickness, variations, hidden cracks and features
    c. > 10cm thick before crossing on foot (15cm safer) and > 18 cm for snowmobile (these recommendations come from “Best Practices for Building and Working Safely on Ice Covers in Alberta” (2013) (PDF)
10. (PDF) Korhonen (2015) Finnish methods
11. (Book) River Ice Data Instrumentation
12. (Link) Wadhams 2012 NCBI review of current techniques
    a. mostly for Arctic sea ice
13. (Link) Minnesota Ice Thickness Guidelines
14. (PDF ppt) Menge 2016 overview of methods for sea ice

Research papers

Reviews / Historic Case Studies (9)

15. (PDF) Nordell & Westerström (1994) “Method for continuous measurement of ice cover thickness” References older methods in intro: measurement stick, temperature measurements by evenly spaced gauges, floats in boreholes filled with kerosene, radar measurements. Introduces a **bucket method** (preliminary lab test)
16. Fransson, L., 1991. **Methods** to measure **ice cover thickness** (Metoder att mata istjocklek). Coldtech 91:2, Department of Structural Engineering, Lule~ University of Technology (in Swedish).
17. (PDF) Brown & Duguay (2010) “The response and role of ice cover in lake-climate interactions”
    a. “**ice thickness** trends tend to be associated more to changes in **snow cover**”
18. (Link) Prowse et al. (2011)
    a. Later freeze-ups earlier breakups and declining ice thickness in future projections
19. (PDF) DeBeer et al. (2016) “Recent changes over interior of western Canada”
    a. See pg. 1586-7 for section 7- Freshwater Ice Cover
    b. “Spatially, ice thickness ranges from skims in more temperate southern parts of this region to several metres in colder northern parts, while ice cover duration ranges from being a transient feature to existing for over 6 months of the year (Prowse, 2012)” (p. 1586)
    c. “Prowse (2012) noted that the CID observations of Lenormand et al. (2002) over Canada do not show any obvious trends in ice thickness over the latter part of the 20th century” (p. 1587)
20. (Book) Prowse, T. (2012) “Lake and River ice in Canada” in: Changing Cold Environments: A Canadian Perspective, 1st edition, edited by: French, H., and Slaymaker, O., John Wiley & Sons, 163–181.

21. (PDF) Arp et al. (2015) "Depth, ice thickness, and ice-out timing cause divergent hydrologic responses among Arctic lakes"
22. (PDF) Brooks 2012 thesis quantifying peak freshwater ice in N hemisphere
23. (PDF) Brown et al. 2002 Freshwater ice monitoring in Canada - assessment of contributions to global climate monitoring - mentions AVHRR and RADARSAT

Ground-based Sensing Methods (14)

24. Chang & Dou 2011 电容感应式冰厚检测系统的冰厚判别方法研究 - The Study on the Methods of Identifying Ice Thickness in the **Capacitive Sensor Measuring System** From 太原理工大学学报 [1007-9432] yr:2011 vol:42 iss:1 pg:47-50
25. (PDF) Kang et al. (2014) “Estimation of ice thickness on large northern lakes from **AMSR-E** brightness temperature measurements”
    a. **Advanced Microwave Scanning Radiometer-Earth Observing System**
    b. “The root-mean-square-error in estimated ice thickness is ~ 18 cm … Linear regression equations are used to generate monthly lake ice thickness maps”
26. (PDF) Prinsenberg & Holladay 2009 International Society of Offshore and Polar Engineers (ISOPE) “Ice Thickness Measurements with a **Miniature Electromagnetic Sensor Sled**”
    a. An electromagnetic sensor was attached to a sled and tested in 2008 as an intermediate measurement between **auger ice holes and helicopter sensors**
27. (Link) Campbell & Orange (1974) **impulse radar** and shallow subsurface exploration **"Electromagnetic Subsurface Profiling" - sled mounted**
28. (PDF) Prinsenberg et al. (2011) Lake Melville Canada
    a. **EM sensor for ice**, GPR sensor for snow
29. (Link) Canada Bedford Institute of Oceanography **GPR** System
30. (Link) Gunn et al. (2017) **FMCW radar vs. SWIP**
31. (Link) Annan & Davis (1977) **Impulse radar** for ice thickness and bathymetry
32. (PDF) Whitaker et al. (2015)
    a. **reflectometer sensors** of soil water content for lake ice depth
33. (Link) Joseph et al. (1994) portable **vector reflectometer** for thickness and permittivity
34. (Link) Yang et al. 2013 **Magnetostrictive Delay Line** monitoring apparatus
35. (PDF) Dou & Chang 2012 **Magnetostrictive Delay Line**
    a. in-situ capacitive sensor for automatic monitoring
36. (Link) Canada Bedford Institute of Oceanography **EM** probe
37. (Link) Svalbard ice thickness Arctic lakes **MODIS & ASMR-E** data assimilation

Shallow Water Ice Profilers (3)

38. (PDF) Blazevic (2009) “The Nunavik Lake Ice Service: Integration of Inuit Traditional Knowledge and Remote Sensing for monitoring of Char Resources”
    a. Mentions **ice thickness** measurements from a **shallow water ice profiler (SWIP),** Inuit ice cores from lakes and rivers to validate remote sensing
    b. Gives chart of **ice on/off** trends in specific regional lakes/rivers (slide 25)
39. (PDF) Brown & Duguay (2011) “A comparison of simulated and measured lake ice thickness using a Shallow Water Ice Profiler”
    a. Measures lake ice thickness from the bottom of a lake using an upward looking **Shallow Water Ice Profiler (SWIP)** and via **field measurements & simulations**

40. (PDF) Ocean Networks Canada (2011). Operator Manual, **Shallow Water Ice Profilers**
    a. printable brochure, technical papers and equations/schematic for calculating ice draft (**real-time acoustic ice thickness**) at ASL Environmental Sciences

Satellite / Remote Sensing Methods (8)

41. (PDF) GMES (2012) “Sea Ice Monitoring: GMES services, **Finnish** experience and user requirements” EC presentation from workshop on sea ice monitoring
42. (PDF) SATCOM (2016) “**Satellite Communication** to support EU Security Policies and Infrastructures” Has notes on sea ice monitoring (p. 68)
43. (PDF) EC (2012) “Space and the Arctic”
    a. “The **CryoSat mission, launched by ESA in April 2010**, is assessing the ability of satellites to measure ice thickness. Its **Synthetic Aperture Interferometric Radar Altimeter (SIRAL)** has been specifically designed for measuring ice thickness changes over time. CryoSat measures the height of the sea ice above the water line, known as the freeboard, to calculate the **ice thickness**. The first CryoSat ice thickness map of the Arctic was generated from January and February 2011 data, as the ice approaches its maximum.”
44. (PDF) Hirose et al. 2008 "Bottomfast Ice mapping and the measurement of Ice Thickness on tundra lakes using C-band **Synthetic Aperture Radar remote sensing**"
45. (PDF) Hall et al. (1981) **passive microwave sensors** for freshwater ice thickness
46. (Link) Beckers et al. 2014 **ESA Cryosat-2 retrievals** of freshwater lake ice thickness
47. (Link) Lalumiere **airborne GPR** for oil in ice detector and ice thickness
48. (Link) Gunn et al. 2015 **ground and space based radar data** for freshwater lake ice containing bubbles

Field & Models (5)

49. (PDF) Gold (1960). “Field study on the **load bearing capacity** of ice covers”.
    a. Archived in National Research Council Canada, referenced in blog
50. (PDF) Ashton et al. (2011) "River and lake ice thickening, thinning, and snow ice formation" - **Drill hole data set**
51. (PDF) Kamari et al. (2017) "Spatial variation of river-ice thickness in a meandering river" - **GPR radar data and ground truth ice thickness** measurements.
    a. Mean abs error +-3cm
52. (PDF) Dibiasio et al. (2017) Measurement Device Design
53. (PDF) Bruijn et al. 2014 intercomparison study of **Netherlands ice thickness models**

Water Temperature Standard Operating Procedures (SOPs) (39)

Databases (5)

1. (Link) Polar Data Catalogue - 1954-2012 Physicochemical Lake Profiles
    a. Includes snow, ice thickness, temperature, depth
2. (Link) “Globally distributed lake surface water temperatures collected in situ and by satellites; 1985-2009” values.csv
3. (Link) NSF Arctic Data Center - Bathymetric depth soundings
4. (Link) New Zealand Measurement Standards Laboratory - Technical Guides
    a. no water temperature but lots of various thermistor thermometers
5. (Link) USGS Current Conditions Water Quality 2018 temperature for rivers, creeks, lakes

Practices & Procedures

Manuals & SOPs

International (7)

6. (PDF) IEEE/OES (2005) 8th Working Conference on Current Measurement Tech “Instruments for the Measurement & Recording of Flows Under Ice”
    a. Has temperature sensor specifications for under-ice measurement devices
7. (PDF) UNEP/WHO (1996) “Water Quality Monitoring - A **Practical Guide** to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes”
    a. “If it is not possible to measure the temperature in situ, a sample must be taken from the correct location and depth of the sampling station and its temperature measured immediately it is brought to the surface.”
    b. “When an electronic thermometer having a probe with long leads is used, lower the probe to the required depth. Hold it at that depth until the reading on the meter is constant. Record the temperature to the nearest 0.1 °C and the depth to the nearest 10cm. Lower (or raise) the probe to the next measurement point for the next reading.”
8. (Link) ASTM International has **temperature measurement standards**
    a. The PDFs are on sale, and not specific to water testing -- they appear to cover standard practices for reporting thermometer calibrations, inspecting and verifying thermometers, standard specifications for ASTM thermohydrometers
9. (cited in UNEP/WHO 1996) WHO 1992 GEMS/WATER **Operational Guide**. Third edition, Unpublished WHO document GEMS/W.92.1, Geneva
10. (Link) Hutton, L.G. 1983 **Field Testing of Water** in Developing Countries. Water Research Centre, Medmenham.
11. (Link) Hach Company 1989 Hach **Water Analysis Handbook**. Hach Company, Loveland, CO.
12. (PDF) Globe 2014 Hydrosphere: "Water Temperature Protocol for Thermometer Probes: Field Guide"

National (8)

13. “LAWA (1987) Grundwasser - Richtlinien für Beobachtung und Auswertung - Teil 2: Grundwassertemperatur (Groundwater – **Guidance for monitoring and assessment** – part 2: groundwater temperature).” found in the EU 2000/60/EC “Guidance Document No. 7 - Monitoring under the water framework directive”
14. (PDF) U.S. Department of the Interior and U.S. Geological Survey (2006) “Guidelines and **Standard Procedures** for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting: Techniques and Methods 1-D3”
    a. Covers depth of use, calibration, and quality control of field temperature sensors
15. (PDF) EPA (2017). “**Standard Operating Procedure** Calibration of Field Instruments”
    a. 5 steps to verify accuracy of temperature sensor (p. 6-7)
16. (PDF) USGS 2006 **Field Manual** Temperature-measurement
17. (PDF) USDA 2005 Measuring Stream Temperature with Digital Data Loggers: A **User's Guide**
18. (PDF) EPA 2014 "**Best Practices** for Continuous Monitoring of Temperature and Flow in Wadeable Streams"
19. (PDF) UK National Physical Laboratory 2012 - "**Beginner's Guide** to Temperature Measurement: **Measurement Good Practice Guide** No. 125" see pg. 29
20. (PDF) Australia DEHP 2009 **monitoring and sampling manual** for in situ water quality instruments & measurements

State (U.S.) (6)

21. (PDF) California Water Resources Control Board (2010). “**Standard Operating Procedure** (SOP) 3.1.2.2: Measuring Temperature with a Thermistor Thermometer”
    a. For measuring temperature in surface water, choose proper sampling method, make sure conditions are representative, immerse for > 60 seconds at correct depth (weighted cable if necessary) until thermal equilibrium. Once readings stabilize within 0.2°C, record median of ~5 values
22. (PDF) Colorado Water Quality Control Division (2015). “**Standard Operating Procedures** for the Collection of Stream Water Temperatures Utilizing the Deployment of Temperature Data Loggers”
    a. Specifies the Tidbit v2 Temperature Logger by Onset Computer Corporation
    b. “Make sure that the water depth is enough so that the loggers do not dry out in the summer months and freeze in the winter….” (p. 6) Record depth
23. (PDF) Red Lake Watershed District, Minnesota (2012) “**Standard Operating Procedures** for Water Quality Monitoring in the Red River Watershed”
    a. Figure 4. Ideal sampling depth and location (3/5 depth) (p. 42)
    b. For multiparameter sondes, “The depth goal should be to get the probe to a point that is approximately 3/5 of the total water depth below the surface or 2/5 of the total water depth above the streambed.”
24. (PDF) Montana Department of Environmental Quality (2005). “Temperature Data Logger Protocols **Standard Operating Procedure**”
    a. Addresses sampling technique and data handling, in particulaR
25. (PDF) Washington State 1991 Citizen's Guide to Monitoring Lakes and Streams
26. (PDF) USGS 2014 "Guidelines for the Collection of Continuous Stream Water Temperature Data in Alaska"

Research papers

Reviews / Historic Case Studies (6)

27. (PDF) Šporka et al. (2006) Water temperatures and ice cover in the lakes of the Tatra Mountains, Biologia 61(Suppl. 18), S77–S90
28. (PDF) Bower & Kendra 1990 Citizen-Volunteer 25 Lakes Washington State
    a. for temp v depth see pg. 72-113
29. (PDF) Baylosis et al. USGS 1997 SF Bay California regional monitoring results
    a. temp v depth p. 22-215 - sampling system p.9 "p.4")
30. (PDF) Clifton USGS 1982 Water quality data for Smith and Bybee Lakes Oregon
    a. p.12-13 for temp v depth profiles
31. (PDF) Ludovicus et al. 2012 Physically based model of global freshwater surface temp
32. (PDF) Sharma et al. 2015 Global database of lake surface temperatures collected in situ and satellite from **1985-2009**

Field Project Protocols (7)

33. (PDF) specifies Tidbit v2 Temperature Logger by Onset Computer Corporation
34. (PDF) Maine Department of Environmental Protection (2009) "**Standard Operating Procedure** Maine Volunteer River Monitoring Program Methods for Using the YSI DO200 Handheld Meter in Rivers and Streams"
    a. Refers to **Operational Procedures** listed in Manufacturer's Manual (2012) (PDF)
35. (PDF) Data Sheet for HOBO 30-Foot Depth Water Level Data Logger (Link)
    a. "This data logger is ideal for recording water levels and temperatures in shallow wells, streams, lakes and freshwater wetlands. For saltwater deployments, such as brackish wetlands and tidal areas, see HOBO U20 Water Level Titanium."
36. (Link) Durable Underwater Temperature Logger - Star Oddi - oceans, rivers, lakes
37. (Link) Water Level Temperature Meter Model 201 Data Sheet by Solinst
    a. measuring static water levels, profiling temp in wells, boreholes, open water
38. (Link) Student lab - temperatures at different depths procedure
39. (Link) Mississippi Water Temperature Project 2006 - volunteer measurement methods