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COMPUTATION OF ICE POTENTIALS AND HEAT BUDGET IN THE
GULF OF ST. LAWRENCE

AUTHORSHIP

L. M. Lauzier and R. D. Graham

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INTRODUCTION

A method of predicting the date of ice formation and of forecasting the growth of ice can be of considerable importance in an area like the Gulf of St. Lawrence and the Estuary where the navigation stops during the winter months because of ice conditions. Lee and Simpson (1954) have formulated a forecasting technique of computing the ice potentials and the potential heat loss. In order to calculate the date of ice formation from the potential heat loss, one must compute from meteorological conditions the effective heat loss at the air-sea boundary. These computations were made according to the method suggested by Jacobs (1942).

MATERIAL

Oceanographic data, collected in the northwestern Gulf and the Gaspe Passage in the autumn 1955 and 1956, during the "Sackville" cruises S-29 and S-35, have been used to calculate the potential heat loss according to Lee and Simpson's method. Meteorological data, supplied by the Meteorological Service, from regular weather stations surrounding the area were used for computations of the effective heat loss from the sea to the atmosphere. Average monthly values of meteorological conditions at Harrington Harbour, Natashquan, Seven Islands, and Mont Joli, Que. were used.

Data on average insolation during cloudless days were taken from Mateer (1955).

<div align="center">RESULTS</div>

Ice Potentials

The potential heat loss for ice formation was calculated for each station. The locations of the stations are indicated in Figure 1. Average values of the potential heat loss were taken for three sectors of the Gulf area: along the Gaspe Peninsula, in the center, and along the North Shore and Anticosti Island. An overall average was also taken as indicative of general conditions. The same procedure was followed to determine the potential heat loss associated with the formation of 30, 60, and 100 cms. of ice. The results, given in Tables I and II, show that the ice potentials have minimum values along the Gaspe Peninsula during both years. The maximum values of ice potentials were recorded for either the center sector or along the North Shore and Anticosti Island. The overall averages show that the potential heat loss prior to ice formation, as well as for ice thickness of 30, 60, and 100 cms., had higher values in 1955-56 than in 1956-57. This indicates that less heat transfer from water to air was required in 1956-57 than in 1955-56 in order to form ice.

The same computations gave the thickness and the salinity of the mixed layer when the ice starts to form and grows to various thicknesses. The results, given in Tables III and IV, show that the thickness of the mixed layer was always minimum along the

Gaspe Peninsula and was generally maximum in the center of the Laurentian Channel. The overall average of the thickness of the mixed layer was greater in 1955-56 than in 1956-57. The increase in salinity, within the mixed layer, due to ice formation had a tendency to be greater along the Gaspe Peninsula than in the center or along the North Shore. If the ice were to reach a calculated thickness of 60 cms., the average salinity within the mixed layer should have increased by $0.8^{\circ}/oo$ in 1956-57, and $0.6^{\circ}/oo$ in 1955-56.

Comparison of observed and calculated values of the thickness of the mixed layer and of the salinity increase from autumn to winter, should give an index of reliability of such computations for this area. It should be pointed out that in the computations, it was assumed that there was a minimum of interchange of water types. This may or may not be a reasonable assumption.

In the two years of observations, the maximum increase of salinity from autumn to winter occurred along the Gaspe Coast where the observed increase was higher than the calculated. In the other sectors, in the center and along the North Shore and Anti-costi Island, the observed increase of salinity in 1956 was lower than the calculated one, and in 1957, it was higher.

The thickness of the mixed layer in the winter is taken as that of the depth of the -1.0° isotherm, Lauzier (MS, 1958). During the two winters, 1956 and 1957, the observed thickness of the mixed layer was always greater than the calculated thickness for the amount of ice encountered during the winter survey. This difference was greater in 1956 than in 1957 when the observed

thickness was more than twice the calculated thickness.

The difference between observed and calculated values seems to indicate that some of the ice formed in the area drifted away to the southwestern Gulf presumably while the continuing ice formation process would further thicken the mixed layer.

Heat Exchange

The monthly values of the various computed factors of heat exchange between the atmosphere and the sea for the periods November to April, 1955-56 and 1956-57, are listed in Table V. The computations show that more heat was given up by the sea to the atmosphere during 1956-57 than in 1955-56. However, this does not imply that the heat was given up entirely by the same water masses. Temperature measurements of the water column indicate the amount of cooling in the area between November-December and February-March. In 1956-57, the measured amount of cooling, $Q\theta$ (Table VI) is less than the amount of heat given up to the atmosphere. This indicates, in part, addition of warmer waters to the area, these warmer waters were losing heat to the atmosphere only after mixing, and thus slowing down the process of cooling in the area. Table VI shows that the amount of heat brought into the region by currents or by mixing was much greater in 1956-57 than in 1955-56. It has been observed that the deep layer, of salinity greater than $34.0°/oo$, had a greater volume in the winter 1957, than in 1956, and was also warmer in the winter 1957, as compared to 1956. There are indications as well that those waters of the boundary zone, of salinities $33.0°/oo$ to

$34.0^{\circ}/oo$, were transporting more heat to the area in the winter 1957 than in 1956.

Another factor has to be considered in the heat budget during the winter season. It is the heat loss due to ice formation, $Q\theta_i$, of Table VI. We estimated that $Q\theta_i$ in 1957 was roughly three times greater than in 1956 with respective values of 3 and 1 Kg cal./cm^2. With ice coverage, the heat exchange between the sea and the atmosphere cannot occur as freely as it does at the air-water interface. The cooling of the body of water underneath the ice cannot be related directly to the sensible heat loss as calculated from meteorological factors. The development of the mixed layer becomes a function of the cooling of the column of water, ice coverage, age and thickness of ice, as well as snow cover. It is further complicated by entrance of other water masses into the area. The intermediate cold-water layer, found during the spring and summer seasons, is, in part, the product of the development of the mixed layer during the previous winter.

The immediate application of ice potential computation is to determine the amount of sensible heat which must be transferred from the water column to the atmosphere before ice is formed. This heat loss integrated into the heat budget, in the main, determines the date of ice formation. The calculations indicated that the initial formation of ice in the northwestern Gulf and the Gaspe Passage would occur on December 13th, 1956, and on December 29th, 1955. However, due to too many unknown factors, the ice growth and the date of various ice thicknesses was not computed.

The method used in the study of the heat budget of some
of the waters of the Gulf of St. Lawrence, the northwestern Gulf
and Gaspe Passage, requires additional consideration. The
preliminary work reported upon, suggests that the method might
be of considerable value to winter navigational problems. In any
event, it leads to a better understanding of some of the processes
involved in the production of the cold-water layer of the area.

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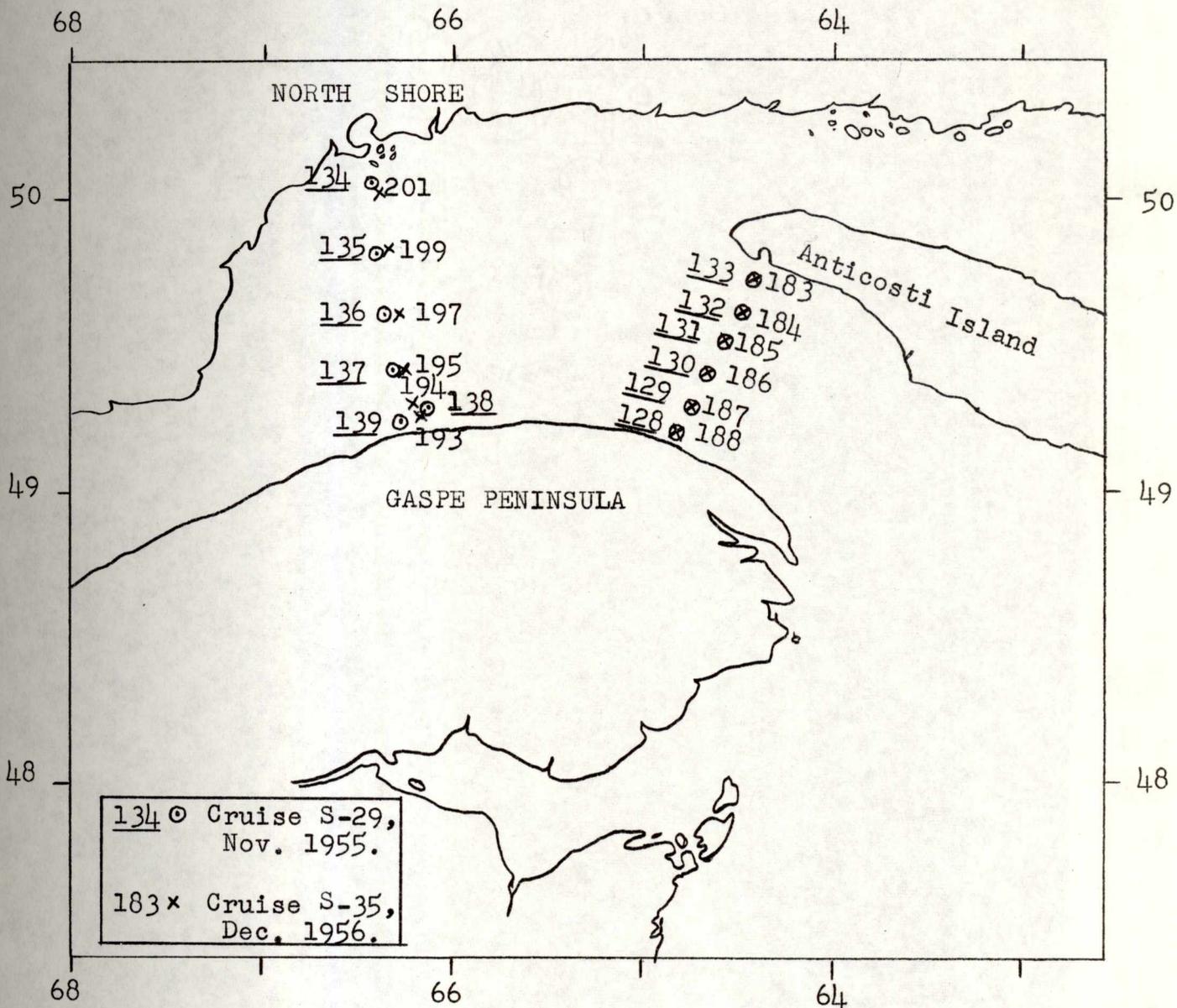days. Can. J. Tech. Vol. 33, pp. 12-32.

Figure 1. Locations of stations.

TABLE I

Potential Heat Loss

Northwestern Gulf and Gaspe Passage - 1955-56

from data collected on December 2-3, 1955 (Cruise S-29)

	Station	Ice Formation	30 cm.ice	60 cm.ice	100 cm.ice
	134 (North)	14.	24.	29.	35.
	135	14.	19.5	23.	30.
Northwestern	136	12.	20.	24.5	35.
	137	22.	30.5	34.	40.
Gulf	138	29.	40.	46.	55.
	139 (South)	2.5	9.	14.	19.
	133 (North)	7.	14.5	20.	
	132	11.5	21.	25.	
Gaspe	131	10.	18.5	21.5	26.
Passage	130	12.	19.	22.	26.
	129	21.5	31.5	35.	39.
	128 (South)	4.	11.5		

Averages

	Ice Formation	30 cm.ice	60 cm.ice	100 cm.ice
Along North Shore and Anticosti	12.	19.	24.	32.5
Center	17.	25.5	29.5	37.
Along Gaspe Coast	3.	10.	14.	19.
Overall Average	13.	21.	27.	34.

TABLE II

Potential Heat Loss

Northwestern Gulf and Gaspe Passage - 1956-57

from data collected on November 15-16, 1956 (Cruise S-35)

	Station	Ice Formation	30 cm. ice	60 cm. ice	100 cm. ice
	201 (North)	10.	18.	28.	40.
	199	9.	16.	19.	24.
	197	12.	18.	21.	26.
Northwestern Gulf	195	10.	18.5	21.5	25.
	194	10.	20.	24.	30.
	193 (South)	5.	13.	17.5	24.
	183 (North)	14.	19.	22.5	30.
	184	8.	14.	18.	23.
Gaspe	185	11.	17.5	22.	24.
Passage	186	11.	13.	19.	24.
	187	15.	21.	24.5	28.
	188 (South)	8.			

Averages

	Ice Formation	30 cm. ice	60 cm. ice	100 cm. ice
Along North Shore and Anticosti	14.	17.5	23.	31.
Center	11.	17.5	21.5	26.
Along Gaspe Coast	6.5	13.	17.5	24.

Overall Average   10.   17.   21.   27.

TABLE III

Thickness and Salinity of Mixed Layer
Northwestern Gulf and Gaspe Passage, 1955-56
from data collected on December 2-3, 1955 (Cruise S-29)

	Station	Ice Formation		30 cm. ice		60 cm. ice		100 cm. ice	
		Thickness	S°/oo	Thickness	S°/oo	Thickness	S°/oo	Thickness	S°/oo
Northwestern	134 (North)	36 m.	31.4	46 m.	31.7	55 m.	32.0	70 m.	32.2
	135	41	31.2	47	31.3	51	31.5	65	32.1
	136	34	31.6	42	31.8	49	32.1	60	32.3
	137	57	31.5	61	31.6	64	31.8	70	31.9
Gulf	138	83	31.3	85	31.4	88	31.6	100	31.8
	139 (South)	11	29.2	25	29.8	33	30.1	40	30.5
	133 (North)	31	32.4	45	32.7	51	32.8		
Gaspe	132	51	32.2	76	32.4	83	32.5		
	131	55	32.1	60	32.2	64	32.2	70	32.6
	130	40	31.8	51	31.9	54	32.1	60	32.4
Passage	129	62	31.5	68	31.7	71	31.8	75	32.0
	128 (South)	17	29.2	27	29.6				

Averages

	Ice Formation		30 cm. ice		60 cm. ice		100 cm. ice	
Along North Shore and Anticosti	39	31.7	46	31.9	52	32.1	68	32.2
Center	55	31.7	63	31.9	69	32.0	72	32.2
Along Gaspe Coast	14	29.2	26	29.7	33	30.1	40	30.5
Overall Average	43	31.2	53	31.5	60	31.8	68	32.0

TABLE IV

Thickness and Salinity of Mixed Layer

Northwestern Gulf and Gaspe Passage, 1956-57

from data collected on November 15-16, 1956 (Cruise S-35)

	Station	Ice Formation		30 cm. ice		60 cm. ice		100 cm. ice	
		Thickness	S^o/oo	Thickness	S^o/oo	Thickness	S^o/oo	Thickness	S^o/oo
	201(North)	26 m.	31.5	41 m.	31.9	66 m.	32.1	90 m.	32.3
	199	31	31.4	35	31.7	39	32.0	45	32.3
Northwestern	197	32	31.5	37	31.5	41	32.0	45	32.4
	195	35	31.5	41	31.7	44	32.0	50	32.3
Gulf	194	25	31.1	40	31.5	45	31.7	50	32.0
	193(South)	22	29.1	26	29.3	28	29.8	35	30.5
	183(North)	25	30.9	30	31.3	34	31.6	40	32.0
Gaspe	184	22	30.2	27	30.5	30	31.0	35	31.4
	185	26	30.9	39	31.3	44	31.5	50	31.8
	186	29	29.2	32	29.3	36	29.7	38	30.3
Passage	187	35	29.1	46	29.3	49	29.5	55	30.1
	188(South)	20	28.8						

Averages

	Ice Formation		30 cm. ice		60 cm. ice		100 cm. ice	
Along North Shore and Anticosti	27	31.3	35	31.6	46	31.9	58	32.2
Center	29	30.5	37	30.7	41	31.1	46	31.5
Along Gaspe Coast	21	28.9	26	29.3	28	29.8	35	30.5
Overall Average	27	30.4	36	30.8	42	31.2	48	31.6

TABLE V

Heat Exchange

November–April, 1955-56 and 1956-57

Year	Month	Q_i	Q_r	Q_b	Q_e	Q_c	$Q_i-Q_r-Q_b-Q_e-Q_c$
1955	November	82.9	4.1	87.	63.5	0	-71.7
	December	77.4	3.9	124.	207.	268.	-525.5
1956	January	79.0	4.0	91.5	114.	87.5	-218.
	February	161.0	8.0	138.	198.	250.	-433.
	March	320.0	16.0	175.5	210.	185.	-266.5
	April	317.0	15.8	110.	67.8	-26.2	+149.6
1956	November	110.0	5.5	130.	104.	6.5	-136.
	December	80.4	4.0	135.	217.	332.	-607.6
1957	January	119.0	6.0	161.	230.	491.	-769.
	February	165.0	8.2	142.	203.	278.	-466.2
	March	236.0	11.8	111.	115.	35.6	-37.4
	April	358.0	17.9	129.	94.5	0	+116.6

Q_i – solar radiation with average cloud cover taken into consideration (g. cal./cm^2/day)

Q_r – heat energy reflected from the sea surface (g.cal./cm^2/day)

Q_b – total back radiation   "

Q_e – heat loss due to evaporation   "

Q_c – heat loss due to conduction   "

TABLE VI

Total Heat Exchange from Autumn to Winter

		1955-56 December to March	1956-57 November 15 to March
$Q_i - Q_r - Q_b - Q_e - Q_c$		35.5 K cal./cm^2	57.6 K cal./cm^2
Q_θ	$Q_{\theta w}$	35.5	26.9
	$Q_{\theta i}$	1.0	3.0
Q_v		-1.0	27.7

Q_θ — heat required locally to change temperature of water column, $Q_{\theta w}$ water, $Q_{\theta i}$ ice formation.

Q_v — heat brought into region by currents, or processes of mixing.