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Résumé de l'article

L'auteur emploie les données aérologiques des deux saisons hivernales 1956-57 et 1957-58 pour estimer le bilan d'humidité.

Il évalue la divergence du flux de vapeur d'eau entre la surface et 500 mh. suivant deux méthodes. La première consiste à déterminer la divergence horizontale à partir de cartes des composantes du flux (en employant une grille latitude — longitude). Il y a une bonne corrélation entre la répartition des précipitations mensuelles en hiver et les cartes de divergence de flux quoique, sauf dans le sud-est, les pertes par évaporation semblent trop faibles. La seconde méthode, basée sur les relevés à huit niveaux dans le triangle Stephenville - Goose - Sept-Iles donne de moins bons résultats.

L'auteur compare ensuite la divergence turbulente du Hux de vapeur d'eau, suivant la première méthode, avec une évaluation de la différence entre les précipitations et l'évaporation ; la corrélation entre les évaluations aérologiques et de surface dans le Labrador - Ungava n'est pas aussi bonne qu'on aurait pu l'espérer.

VAPOUR FLUX DIVERGENCE AND MOISTURE BUDGET CALCULATIONS FOR LABRADOR-UNGAVA

by

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INTRODUCTION

One approach to moisture budget estimates is through aerological data. The moisture budget can be written

$$P\text{-}E = F_{\bar{V}} + F_{\bar{L}} + F_{\bar{U}} + \Delta(V+L)$$

where P = precipitation
E = evaporation
$F_{\bar{V}}$ = the vapour influx through the vertical walls of a unit column of air
$F_{\bar{L}}$ = the liquid influx through the vertical walls of a unit column of air
$F_{\bar{U}}$ = vapour influx through the upper face
Δ = difference over a time interval.

$F_{\bar{L}}$ and ΔL may be neglected for large-scale space and time averages and so may $F_{\bar{U}}$ if a sufficiently high upper data level is selected. This approach has been used for studies for hemispheric and continental water balances (Peixoto and Crisi, 1965, Benton and Estoque, 1954 and Rasmusson, 1967) as well as for regional determinations (Hutchings, 1957, Söderman and Wesanterä, 1966). The present paper follows similar lines for the Labrador-Ungava peninsula.

METHOD

Two winter seasons, November 1956 — February 1957 and November 1957— February 1958 are investigated. The details of the computations of the vapour content and flux between the surface and 500 mb for 20 stations in north-eastern North America have already been reported elsewhere (Barry, 1967). The divergence analysis is limited to the area between about 45-60°N and 55-95°W to reduce uncertainty toward the boundaries.

The horizontal divergence of vapour flux, determined with reference to a latitude — longitude grid, is

$$\Delta . \mathrm{Vq} = \frac{\delta(\mathrm{uq})}{\delta \mathrm{x}} + \frac{\delta(\mathrm{vq})}{\delta \mathrm{y}} - \frac{\mathrm{vq} \tan \phi}{\mathrm{R}} \qquad (1)$$

where uq = eastward component of the flux
vq = northward component of the flux

ϕ = latitude
R = radius of the earth

The terms $\delta(uq)/\delta x$ and $\delta(vq)/\delta y$ are evaluated from separate maps of the flux components by finite differences methods, using a length unit of 5° latitude (555 km) at 2½° intervals. The third term on the right is a correction for the convergence of the meridians towards the pole.

The divergence of the mean total vapour flux for a given time period can be regarded as consisting of an advective (or mean) component and an eddy component.

$$\nabla\cdot\overline{\mathbf{V}q} = \nabla\cdot\overline{\mathbf{V}}\,\overline{q} + \nabla\cdot\overline{\mathbf{V}'q'} \quad (2)$$

where the bar denotes a time mean, and the prime a deviation from the mean. The advective flux itself comprises a geostrophic and an ageostrophic component. Assuming horizontal geostrophic flow, so that $\nabla\cdot\overline{\mathbf{V}} = 0$, (3)

$$\nabla\cdot\overline{\mathbf{V}}\,\overline{q} = \overline{\mathbf{V}}\cdot\nabla\overline{q} \quad (4)$$

Figure 1 shows the advective flux-divergence for the 850 mb level in January 1957 as determined from the calculated advective fluxes ($\nabla\cdot\overline{\mathbf{V}}\,\overline{q}$) and from the mean wind components and mean specific humidity gradients ($\overline{\mathbf{V}}\cdot\nabla\overline{q}$). The ageostrophic component of the advective flux-divergence is generally an order of magnitude smaller than the geostrophic term for time averages of about a month and figure 1 confirms that there is good agreement between the two estimates of the advective flux-divergence. Nevertheless, the fact that the flux-divergence is generally a small residual from two large terms (equation [1]) of similar magnitude and opposite sign, and the known correlation between the moisture and wind fields, make the estimates of advective and also total flux-divergence uncertain.

The eddy flux-divergence term is not affected by these factors so that the eddy patterns are more reliable. Fortunately, the calculated eddy flux-divergence appears in most of the months to contribute significantly to the calculated total flux-divergence as shown in table 1. This result is further illustrated by figures 2 and 3 showing the average total and eddy flux-divergence for the two winter seasons (excluding November). Comparison of figure 2 with maps of mean monthly precipitation in winter shows broad agreement as to general pattern (Department of Transport, 1967), although after allowing for evaporation losses the estimated amounts still appear to be too low except in the south-east. Winter precipitation totals and total flux-convergence estimates, in brackets, for three stations are Harrington Harbour 32 cm (33 cm), Sept-Îles 24 cm (12 cm) and Goose 20 cm (16 cm).

A second method of estimating flux-divergence averaged over an area is the triangle technique of Bellamy (1949), which has been applied to vapour flux by Hutchings (1957). A slightly modified approach is used here. The formulation assumes that the wind components u and v, and the specific humidity, comprise three linear fields over a triangle with its vertices at three observation points. The triangle Stephenville — Goose — Sept-Îles is used in the present analysis. Table 2 summarises the results obtained by this method for the centroid of the triangle. The vertically integrated total is based on determinations at eight levels. In nearly all months there is a maximum convergence of about 900-850 mb. The totals differ considerably from those obtained by the isopleth method, whereas in a similar

Table* 1 *Percentage contribution of the eddy component to the total vapour flux-divergence

		50°N	*55°*	*60°*	*50°N*	*55°*	*60°*
		70° Meridian			*90° Meridian*		
1956	November	23	—	33	6	100	75
	December	>100	>100	100	50	100	—
1957	January	—	—	10	80	100	0
	February	>100	—	0	—	100	>100
	November	50	0	60	>100	>100	—
	December	>100	—	67	70	>100	100
1958	January	—	>100	80	>100	>100	>100
	February	100	>100	>100	>100	—	—

A dash indicates that the two quantities are of opposite sign.

Table* 2 *Total flux-divergence over south-eastern Labrador-Ungava

g (cm^2 100 mb month)$^{-1}$

	1956		*1957*				*1958*	
	Nov.	*Dec.*	*Jan.*	*Feb.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*
Surface	−1.1	−2.8	0.8	0.0	−0.7	−2.0	−0.3	0.6
950 mb	−4.6	−4.4	−0.7	−1.7	−2.9	−8.1	−3.1	−0.6
850	−6.4	−5.0	−2.7	−2.2	−2.3	−10.7	−2.0	−0.9
70	−3.2	−3.3	−1.8	0.2	−0.8	−4.5	0.9	2.1
500	−0.4	−1.9	−0.5	0.5	0.2	−1.8	0.4	1.1
TOTAL g(cm^2 month)$-^1$	−18.0	−17.5	−7.3	−2.7	−6.1	−30.9	−2.4	3.7
Isopleth Method	−6	−6	−5	−5	+9	−11	−6	−12

Table* 3 *Aerological and Surface Moisture Budgets Estimates for Central Labrador-Ungava (cm).

	1956		*1957*				*1958*	
	Nov.	*Dec.*	*Jan.*	*Feb.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*
P	4.3	2.5	1.0	2.9	5.2	8.1	6.9	4.4
E	0.4	0.2	0.2	0.2	0.4	2.5	2.0	0.2
P-E	3.9	2.3	0.8	2.7	4.8	5.6	4.9	4.2
Storage change	−0.3	−0.1	0.0	−0.1	−0.5	−0.3	0.5	−0.4
Total flux-convergence	0	2	2	0	−6	−3	4	5
Eddy flux-convergence	2	4	−1	2	−3	5	12	5

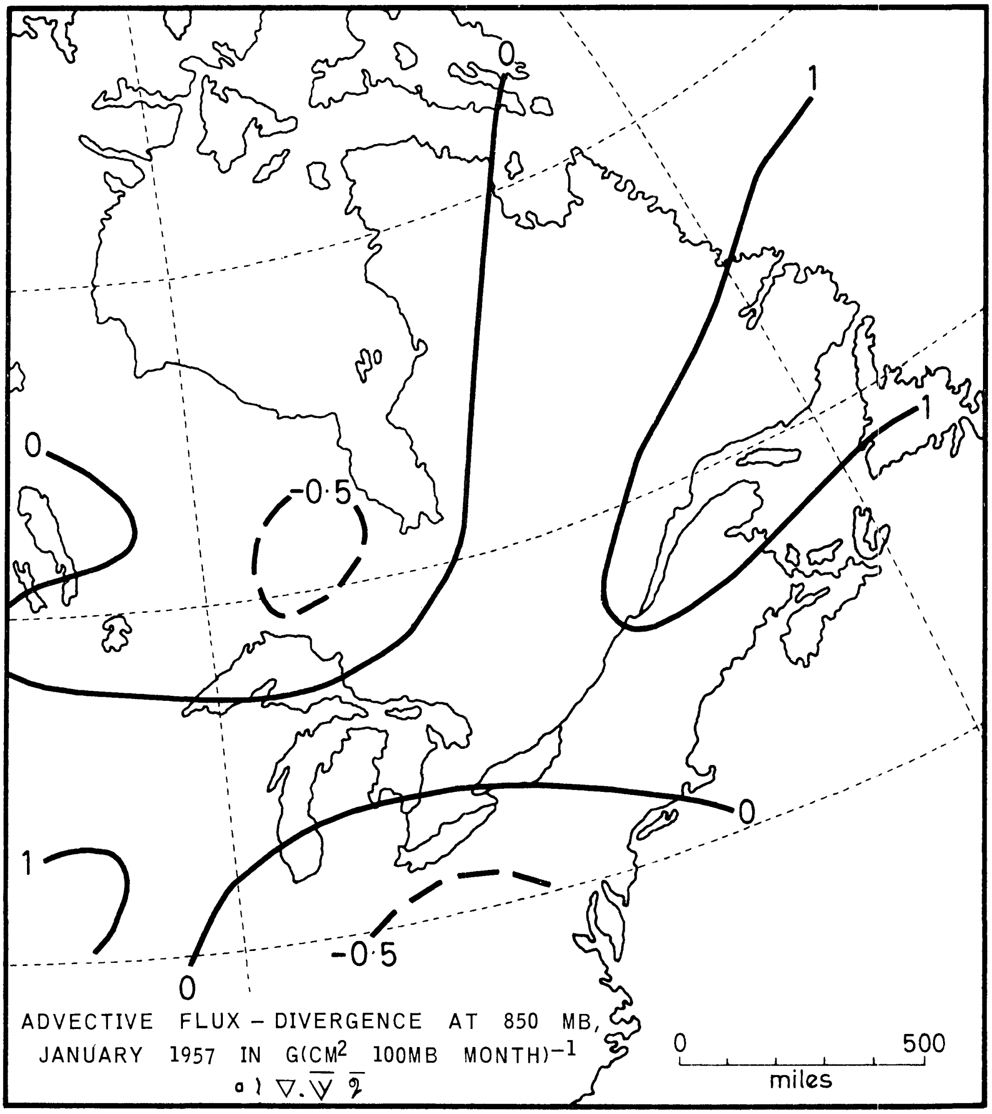


Figure 1a Advective flux-divergence at 850 mb, January 1957 in g (cm^2 100 mb month)
(*a*) $\underline{\nabla}, \overline{\overline{\mathbb{V}}q}$
(*b*) $\overline{\mathbb{V}}. \nabla q$

study for the British Isles, Bannon, Matthewman and Murray (1961, p. 509) state that the two techniques gave comparable values of flux-divergence. The discrepancies in the present work may be attributable to several factors: the effect of missing data on the calculated fluxes; uncertainties in the isopleth analysis of the flux-components; general non-linearity of the wind and moisture fields; and specific topographic influences on the flux at Sept-Îles.

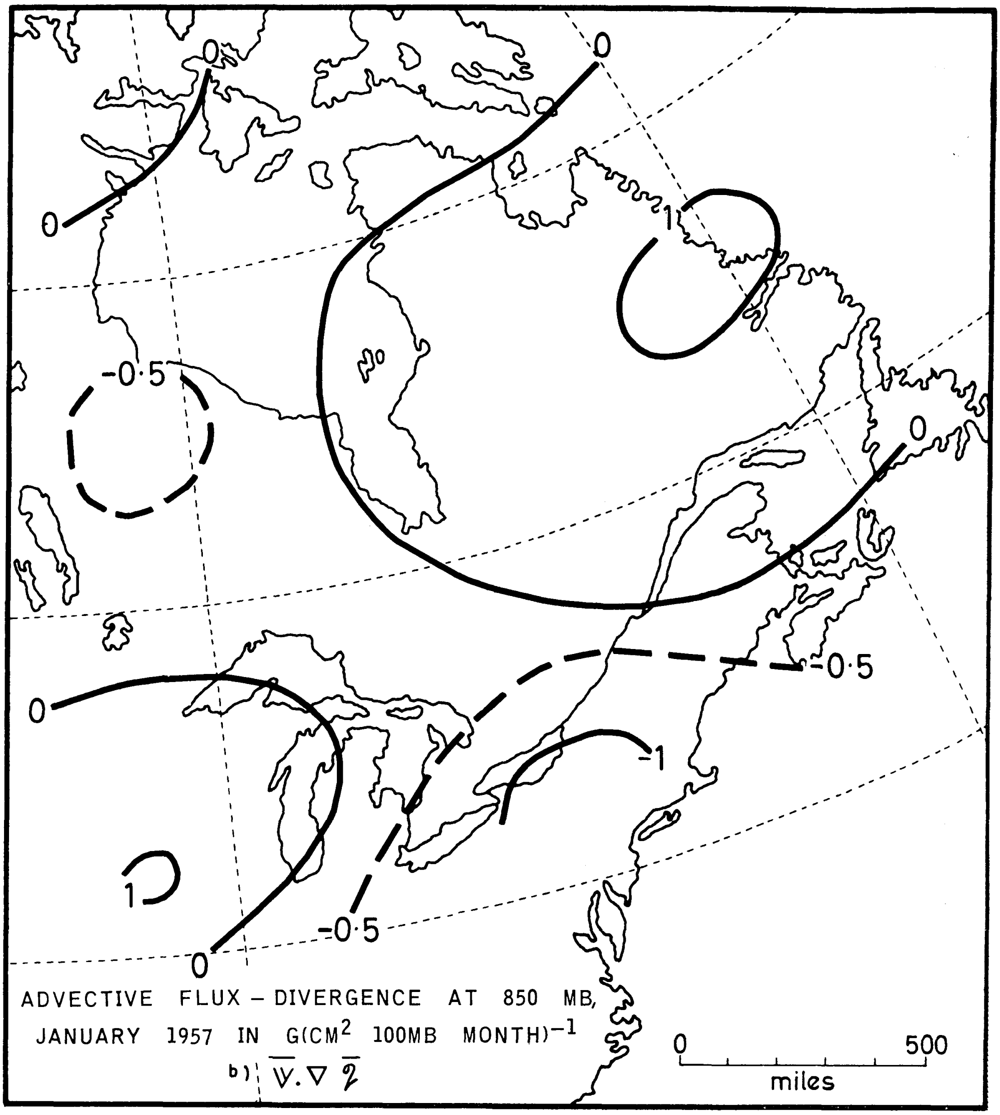


Figure 1b

Further analysis has been concentrated on the isopleth maps since these offer scope for other investigations.

MOISTURE BUDGET ANALYSIS

Estimates of the total flux-divergence determined by the isopleth method are now compared with precipitation minus evaporation estimates. Winter evaporation from snow is problematical. Measurements of snow evaporation reported by

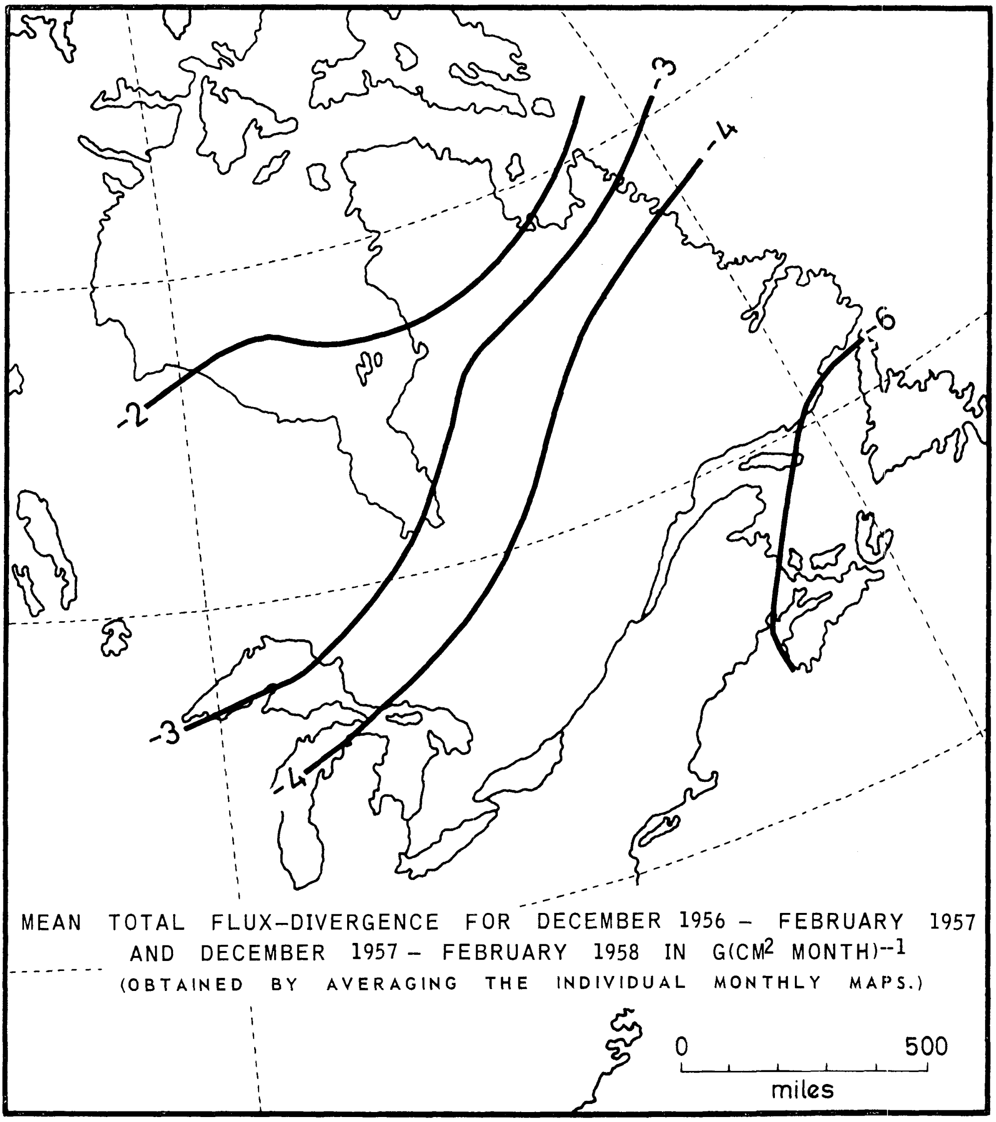


Figure 2 Mean total flux-divergence for December 1956 — February 1957 and December 1957 — February 1958 in g (cm^2 month)$^{-1}$, obtained by averaging the individual monthly maps.

Williams (1961) indicate modal values of 0.050 – 0.075 cm day^{-1} at Ottawa and 0 – 0.012 cm day^{-1} at Fort Frances, Ontario. The equivalent monthly losses would be about 1.8 cm and 0.2 cm, respectively. Use of Penman's equations with an appropriate albedo for data from Knob Lake for December 1957 gives a negative radiation term exceeding the term involving γ **E**a.

Neglecting the former and using only $\gamma \mathbf{E}a/\Delta+\gamma$

where **E**a = a term involving a wind function and mean saturation deficit of the air,

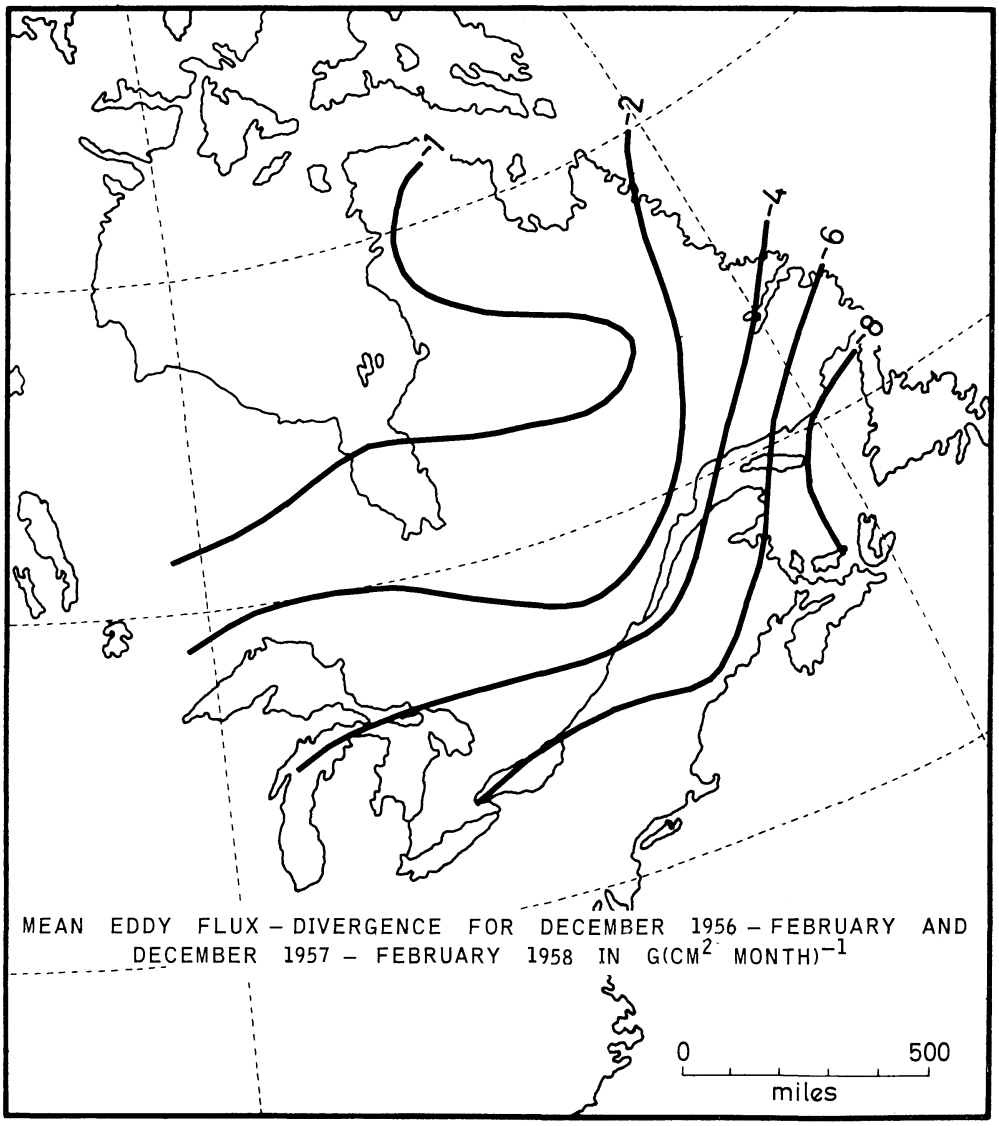
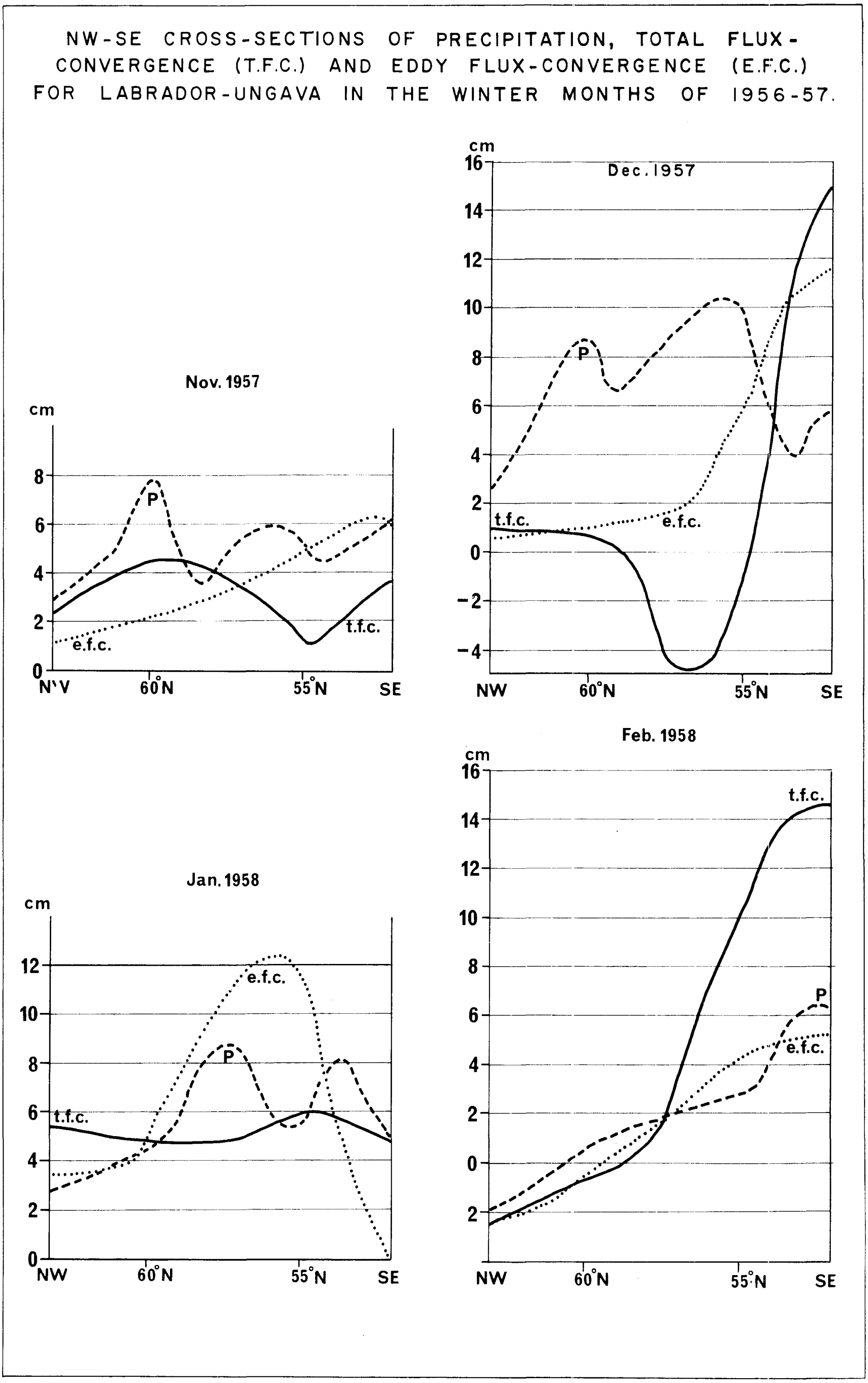


Figure 3 Mean eddy flux-divergence for December 1956 — February and December 1957 — February 1958 in g (cm^2 month)$^{-1}$

γ = 0.27 mm Hg °F.$^{-1}$,

Δ = slope of the saturation vapour-pressure curve at mean air temperature. The evaporation in December 1957 is 0.07 cm. A mid-winter value of 0.2 cm month^{-1} is therefore assumed to apply for the central area of the peninsula. However, in December 1957 and January 1958 there were undoubtedly greater losses due to incursions of the Atlantic air with temperatures above freezing. For example, the



NW-SE CROSS-SECTIONS OF PRECIPITATION, TOTAL FLUX-CONVERGENCE (T.F.C.) AND EDDY FLUX-CONVERGENCE (E.F.C.) FOR LABRADOR-UNGAVA IN THE WINTER MONTHS OF 1956-57.

Nov. 1957

Dec. 1957

Jan. 1958

Feb. 1958

Figure 4 NW-SE cross-sections of precipitation, total flux-convergence (t.f.c.) and eddy flux-convergence (e.f.c.) for Labrador-Ungava in the winter months of 1956-57. See text for details.

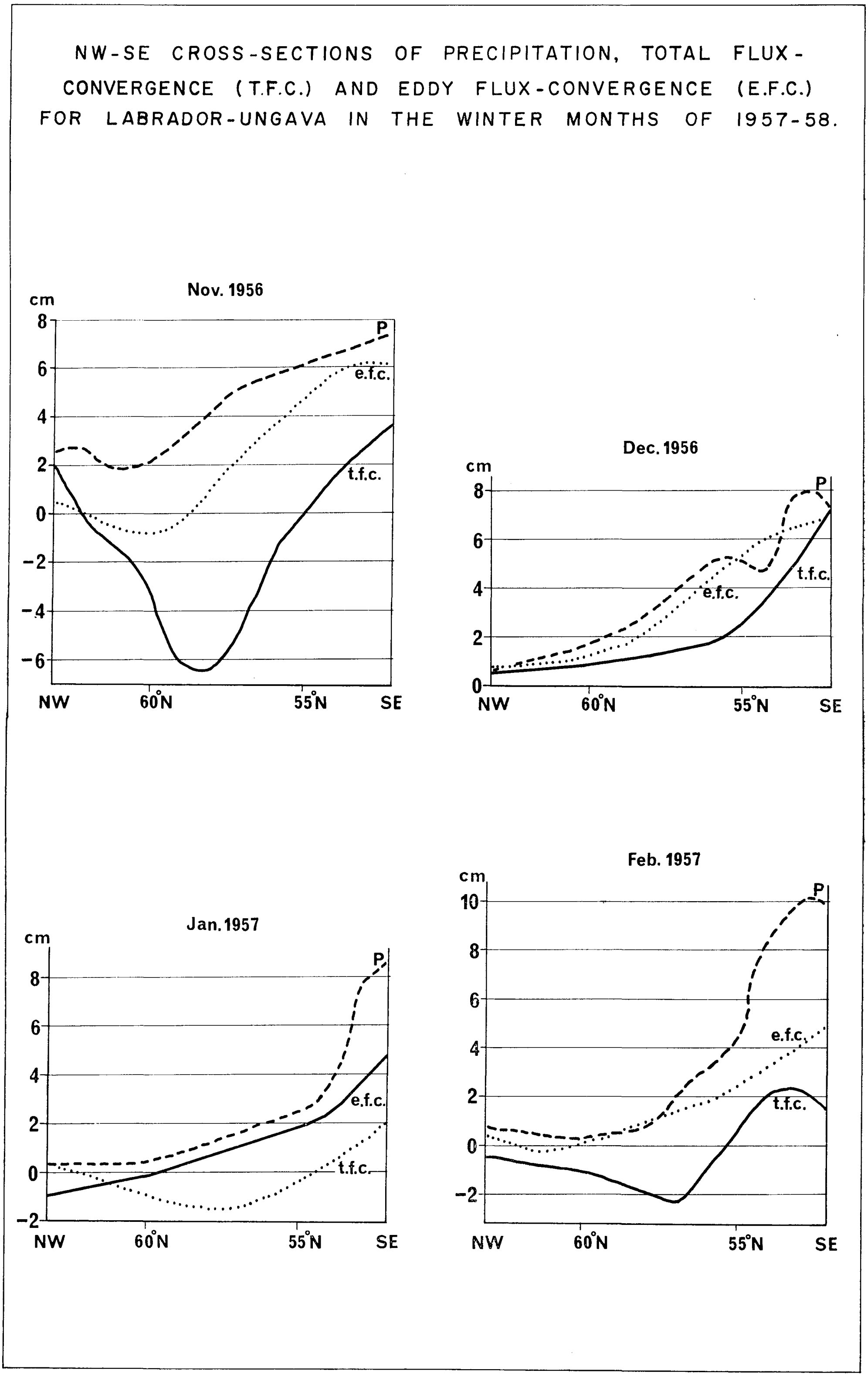


Figure 5 As figure 4 for the winter months of 1957-58.

observed snow-depth at Knob Lake decreased by 9 inches (about 2 cm water equivalent) between 19-21 December, 1957 and again by 7 inches (about 1.5 on water equivalent) between 17-19 January 1958. The evaporation estimates for these months are adjusted accordingly.

Table 3 shows estimates of precipitation, evaporation, storage change in the air column and the total and eddy flux-convergence at 56.0°N., 66.5°W. The precipitation amounts are arithmetic means of the monthly totals at Knob Lake (54.6°N., 66.6°W.), Nitchequon (53.2°N., 70.9°W.) and Lake Eon (51.9°N., 63.3°W.). It is worth noting however, that snow-course surveys made subsequently at Knob Lake (Adams *et al.* 1966) show that the conventional measurements in the Nipher gauge are 25 per cent low. The storage change in the atmosphere over each month refers to the aerological data at Nitchequon. It is virtually negligible in all the months.

There is reasonably good agreement between total flux-convergence and P – E in December 1956, January 1957 and January and February 1958. In November 1956, February and December 1957 the eddy flux-convergence is a reasonable estimate of P – E, but in November 1958 both terms are negative i.e. flux-divergence. This may be a result of anomalous fluxes at Sept-Îles, arising from the effects of topography.

Further comparison of flux-divergence and precipitation amounts is made by means of generalised cross-sections of monthly precipitation totals from the small-scale maps in the *Monthly Record* (Meteorological Branch, Department of Transport). These show isohyets at 1 inch (2.5 cm.) intervals. Reference has been made to station data in areas where the total is less than 1 inch and where maxima or minima would occur on the graphs (Figures 4 and 5). The cross-section line from Cape Wolstenholme (62.6°N., 77.5°W.) to Battle Harbour (52.3°N., 55.6°W.) is chosen to illustrate approximately the maximum range of precipitation and flux-divergence values.[1]

Figures 4 and 5 show a limited measure of agreement between flux-divergence and precipitation, particularly in the north-west, but with the exception of January 1957 such agreement as occurs is mainly between the eddy flux-divergence and precipitation. In January and February 1957 and January 1958 the flux-divergence is much smaller than the precipitation in the south-east. This may to some extent reflect evaporation losses in January 1958, but not in January and February 1957. The cross-sections for November and December 1957 and January 1958 suggest that the station network is too sparse to provide appropriate « detail », although other factors may equally be responsible. The probable importance of evaporation in December 1957 has already been referred to.

CONCLUSIONS

The results show that the correspondence between aerological surface estimates of P – E in Labrador-Ungava is not as satisfactory as might be hoped. However,

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[1] Note that for convenience the sections show flux-convergence as positive. Strictly, flux-divergence is positive, flux-convergence negative.

this may be due in part to data limitations in the present study. Further detailed work would appear therefore to be worthwhile. Certain pointers for such future investigations have been established. Finite difference analysis looks more promising in this area than the triangle methods. It is of interest that the eddy component of the flux-divergence appears in some months to provide a better estimate of P−E than total flux-divergence. Study of the synoptic characteristics of such months would be useful.

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RÉSUMÉ

L'auteur emploie les données aérologiques des deux saisons hivernales 1956-57 et 1957-58 pour estimer le bilan d'humidité.

Il évalue la divergence du flux de vapeur d'eau entre la surface et 500 mb. suivant deux méthodes. La première consiste à déterminer la divergence horizontale à partir de cartes des composantes du flux (en employant une grille latitude – longitude). Il y a une bonne corrélation entre la répartition des précipitations mensuelles en hiver et les cartes de divergence de flux quoique, sauf dans le sud-est, les pertes par évaporation semblent trop faibles. La seconde méthode, basée sur les relevés à huit niveaux dans le triangle Stephenville – Goose – Sept-Îles donne de moins bons résultats.

L'auteur compare ensuite la divergence turbulente du flux de vapeur d'eau, suivant la première méthode, avec une évaluation de la différence entre les précipitations et l'évaporation ; la corrélation entre les évaluations aérologiques et de surface dans le Labrador – Ungava n'est pas aussi bonne qu'on aurait pu l'espérer.

SUMMARY

For the two winter seasons 1956-57 and 1957-58, the author uses aerological data to estimate the moisture budget for the Labrador – Ungava peninsula.

Two methods of estimating the vapour flux-divergence between the surface and 500 mb. are described. In the first, the horizontal divergence is determined from separate maps of the flux components with reference to a latitude – longitude grid. A comparison of the resulting maps of flux-divergence with the winter maps of mean monthly precipitation show an agreement in pattern, although allowing for evaporation losses, the amounts appear to be generally too low except in the south-east. The second method, using a triangle technique (Stephenville – Goose – Sept-Îles) at eight levels proved less reliable.

A detailed comparison is made of estimates of the total and eddy flux-divergence (based on the first method) and precipitation minus evaporation estimates, and significant differences are discussed. The results show that correspondence between aerological

and surface estimate of precipitation minus evaporation a Labrador – Ungava is not as satisfactory as might be hoped.

REFERENCES

ADAMS, W. P., *et al., Snowfall and snow cover at Knob Lake, central Labrador-Ungava.* McGill Sub-Arctic Research Paper No. 22, 1966, pp. 114-140.

BANNON, J. K., KATTHEWMAN, A. G., and MURRY, R., *The flux of water vapour due to the mean winds and the convergence of this flux over the Northern Hemisphere in January and July. Quaterly Journal of the Royal Meteorological Society, 87,* 1961, pp. 502-12.

BARRY, R. G., *Variations in the content and flux of water-vapour over north-eastern North America during two winter seasons. Quarterly Journal of the Royal Meteorological Society, 93,* 1967, pp. 535-43.

BELLAMY, J. C., *Objective calculations of divergence, vertical velocity and vorticity. Bulletin of the American Meteorological Society, 30,* 1949, pp. 45-9.

BENTON, G. S., and ESTOQUE, *M. A., Water vapour transfer over the North American continent. Journal of Meteorology, 11,* 1954, pp. 462-77.

DEPARTMENT OF TRANSPORT, *Climatic maps, Mean Monthly Amount of Precipitation, Sheets 1 and 6.* Meteorological Branch, Toronto, 1967.

HUTCHINGS, J. W., *Water vapour flux and flux-divergence over southern England ; summer 1954. Quarterly Journal of the Royal Meteorological Society, 83,* 1957, pp. 30-48.

PEIXOTO, J. P., and CRISI, A. R., *Hemispheric humidity conditions during the IGY,* Sci. Rep. No. 6, Meteorology Department, Massachusetts Institute of Technology, Contact A. F. 19 (628) — 1965, 166 pages.

RASMUSSON, E. M., *Atmospheric water vapor transport and the water balance of North America. Monthly Weather Review, 95,* 1967, pp. 403-426.

SÖDERMAN, D., and WESENTERÄ, J., *Some monthly values of evapotranspiration in Finland computed from aerological data. Geophysica, 8* (4), 1966, pp. 281-90.

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