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MANUSCRIPT REPORT SERIES

No. 39

A Preliminary Tidal Exchange Experiment in Masset Inlet

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Marine Sciences Directorate
Department of the Environment, Ottawa

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Manuscript Report Series No. 39

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Published by
Publié par

Environment Canada
Fisheries and Marine Service

Environnement Canada
Service des pêches et des sciences de la mer

Office of the Editor
Bureau du Rédacteur
116 Lisgar, Ottawa K1A 0H3

Frontispiece CGMV "Cancolim II" in Bute Inlet July 3, 1953
(photo by G.L. Pickard).

Abstract

Concepts of exchange processes are reviewed briefly including a tidal exchange process believed to have been observed in a small tidal inlet in the arctic. The results of a numerical experiment with the latter process in a configuration similar to Masset Inlet are presented and a proposal concerning a field experiment is developed.

Résumé

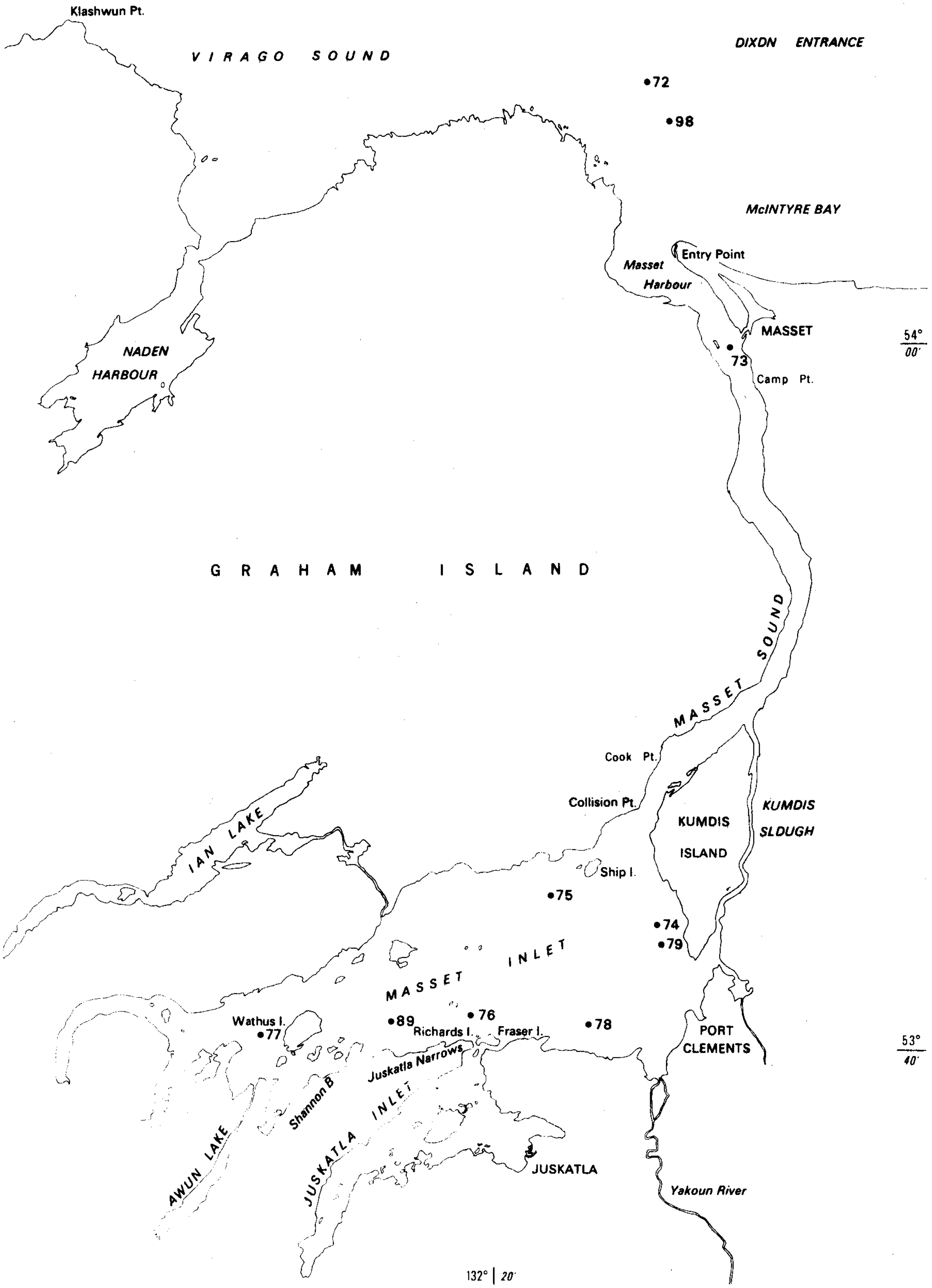
On étudie succintement l'idée d'un processus d'échanges, spécialement un processus d'échange causé par les marées, qui apparemment a pris place dans un fjord affecté par la marée dans l'Arctique. Nous donnons les résultats d'une expérience numérique qui utilisait ce processus d'échange dans une situation semblable à celle de Masset Inlet. Finalement, on propose une vérification sur le terrain.

CONTENTS

1. Introduction

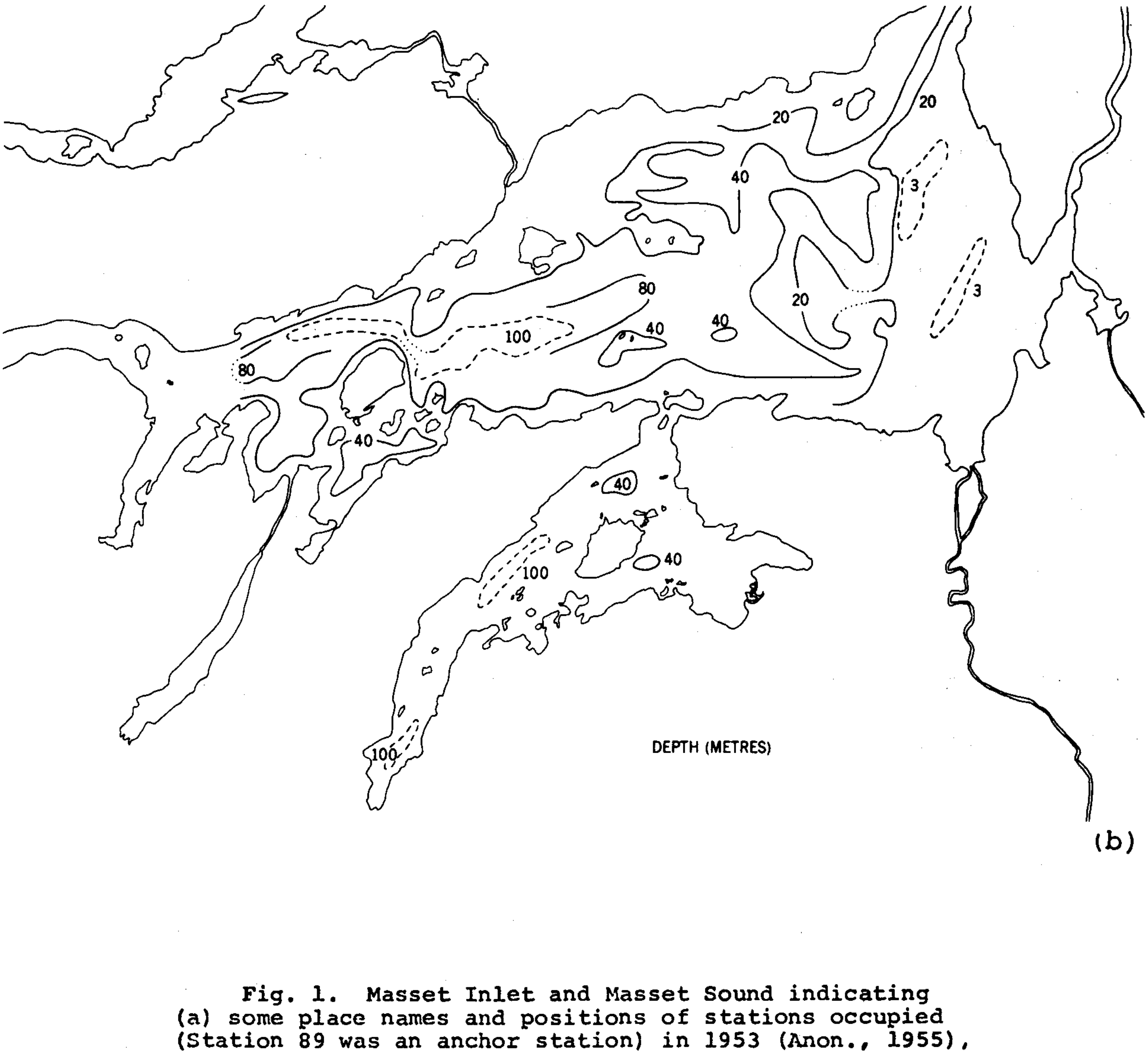
Oceanographic data observed in a small tidal inlet in the arctic, Tuktoyaktuk Harbour, have been reported (Kelly, 1967) and described by Ince (1962) and Barber (1968). In the latter work a hypothesis concerning the occurrence of an exchange between the harbour water and Kugmallit Bay (Beaufort Sea) arising as a secondary tidal influence was developed as an explanation of the distributions observed during the winter under the ice cover. Recently, Barber and Murty (1974) speculated upon the consequence of a perennial ice cover over the water of the Canadian archipelago and provided a model of the tidal exchange mechanism believed to be important to the observations at Tuktoyaktuk. It is the intention here to apply a numerical model to Masset Inlet (Fig. 1) as a step in the assessment of the extent that exchange occurs even during one tidal cycle and to suggest a programme of field observations, a field experiment, which might provide an acceptable measure of the real situation for comparison and further consideration.

At Tuktoyaktuk an exchange of water was observed during a period that a net transport did not occur. A measure of the exchange became possible as the type of water in the approach to the harbour, i.e. in Kugmallit Bay, was markedly time-dependent, and varied between an ocean water in summer (to 31°/₀₀) and a river water in winter (from the nearby Mackenzie River). It was estimated from field observations over the winter that about 8% of each tidal volume was exchanged each tidal cycle and subsequently a model was developed which



(a)

Fig. 1. Masset Inlet and Masset Sound indicating (a) some place names and positions of stations occupied (Station 89 was an anchor station) in 1953 (Anon., 1955), and (b) the depth (m) in Masset Inlet.



(b)

Fig. 1. Masset Inlet and Masset Sound indicating (a) some place names and positions of stations occupied (Station 89 was an anchor station) in 1953 (Anon., 1955), and (b) the depth (m) in Masset Inlet.

supported the estimated value of the exchange, but again over a relatively long time interval, i.e. of about one month. The model, modified from Fischer (1972a), envisaged the "diffusion" of a volume of water into a larger volume by shear effect, or shear dispersion, which occurs in the presence of velocity gradients (Pritchard et al., 1971) in currents of any kind. The process seems not to be generally accepted as being significant, presumably as an unambiguous assessment of it is not available. Furthermore, it is likely that other mechanisms are important - Fischer (1972b, p. 685) grouped them under the phrase, "boundary-induced circulation" - including Coriolis acceleration and the shape of the basin. It is our view that these mechanisms would receive more attention were a quantification of their influence assessed over one tidal cycle in a locality where the value of the exchange was as large as natural situations would allow.

It has also been the view that a tidal exchange process was rather more important to distributions on and inshore of continental shelves than is generally acknowledged, but it has been only in the arctic situations, e.g. Fury and Hecla Strait (Barber, 1965) and Tuktoyaktuk, that the usual type of field data are instructive. This is largely due to the arctic climate, which can produce well-defined time-dependence (annually) in such features as runoff and ice cover. This, as well as the existence of very small tides in some areas, provides regions of little mixing so that other influences of tidal currents can be recognised. However, having recognised the general process, it is believed that the rather extreme situation of Masset Inlet, where a relatively large body of water (the inlet) is coupled to the ocean (Dixon Entrance) by a relatively restricted connection (Masset Sound), could provide useful data concerning the volume exchanged.

It will be shown that salt water occurs throughout Masset Inlet, but at lower salinity than in the adjacent ocean, and that tidal activity is pronounced. It will also be shown that nearly all of the water in Masset Sound at low water slack probably enters Masset Inlet during the following flood. Of course this water participates in the flood because it is already in the sound. As no similarly strong constraint applies to the water of the ebb, other than it be in Masset Inlet, it is envisaged that a significant fraction of the ebb from the inlet did not enter the inlet on the previous flood. There are numerous localities where the experiment described here might be performed, but it is for the foregoing reason that the Masset system appeared the most suitable.

The interpretation of the Tuktoyaktuk experience is that the fraction exchanged was not due to "tidal mixing", but rather to volume exchange in the absence of net transports. The nature of such exchange must therefore be related to inertial elements of the purely tidal motion in the particular situation of topography and tide. The resultant velocity field is the feature that, if known throughout a tidal cycle, would provide direct information concerning the occurrence and amount of the exchange. As it is not yet possible to observe this field directly in adequate way, a tagging experiment using dye is proposed and described in later section.

2. Masset Inlet

A number of stations were occupied in the Masset system and nearby in Dixon Entrance during a summer survey in 1953 in CGMV "Cancolim II" (frontispiece) from which the data have been reported (Anon., 1955). It is known that the salinity of the surface water of Dixon Entrance varies with annual period (Crean, 1967, his figure 15), such that seaward of Masset Sound a minimum of about 29.5°/₀₀ occurs in spring and values to 31.5°/₀₀ can be expected at other seasons. The T-S curves (section 2.3) for the data observed in 1953 indicate the water in the inlet during that summer to be at much lower salinity than surface water of McIntyre Bay, i.e. of Dixon Entrance. One concludes that, while the shallow depths in the seaward approach to the sound limit the influence of Dixon Entrance to that of the relatively low salinity water there, considerable mixing with freshwater from runoff must occur within the system.

2.1 Hydrography, including tides and tidal streams

A description of Masset Inlet and adjacent waterways is available in the Pilot (Anon., 1974) and on charts of the Canadian Hydrographic Service, e.g. CHS chart 3805 titled Masset Sound and Inlet, edition 1974. The inlet has an area of about 220 km^2 and a maximum depth of about 100 m (survey of the inlet is not yet complete). Juskatla Narrows connects the inlet to Juskatla Inlet which is somewhat smaller but about the same maximum depth. Masset Inlet is connected to McIntyre Bay, Dixon Entrance by the long (38 km), narrow (0.9 to 1.5 km) and shallow (22 m) Masset Sound. In the seaward approach to the sound a threshold depth in the range 4 to 6 m exists and in the sound abeam of Cook Point a decrease of width occurs to less than 0.4 km.

The predicted time and height of the tide as well as predicted current information are available in tables for each year (e.g. Anon., 1966). Dohler (1964, his figure 9) indicated the tide in the area to be "mixed: mainly semidurnal". The average range of the tide at Port Clements (Anon., 1966 p. 16) is 2.1 m and the range for large tides is 3.0 m. The spring strength of the flood in the sound attains 5 knots, the rms value is likely about 3.2 knots (5.8 km hr^{-1}), where the area in cross-section is about* 1.8×10^4 m^2. The flood volume then would be (about $5.8 \times 10^3 \times 1.8 \times 10^4 \times 6$ hours cubic metres) sufficient to raise the level over the area (220 km^2) of Masset Inlet by about 2.8 m. As this value is near to the observed range of large tides (2.9 m) at Port Clements it would seem likely that change of sea level of tidal period in Masset Inlet is due largely to the flood and ebb in Masset Sound and that interior modes of circulation do not contribute significantly.

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* Width 900 m and depth 20 m.

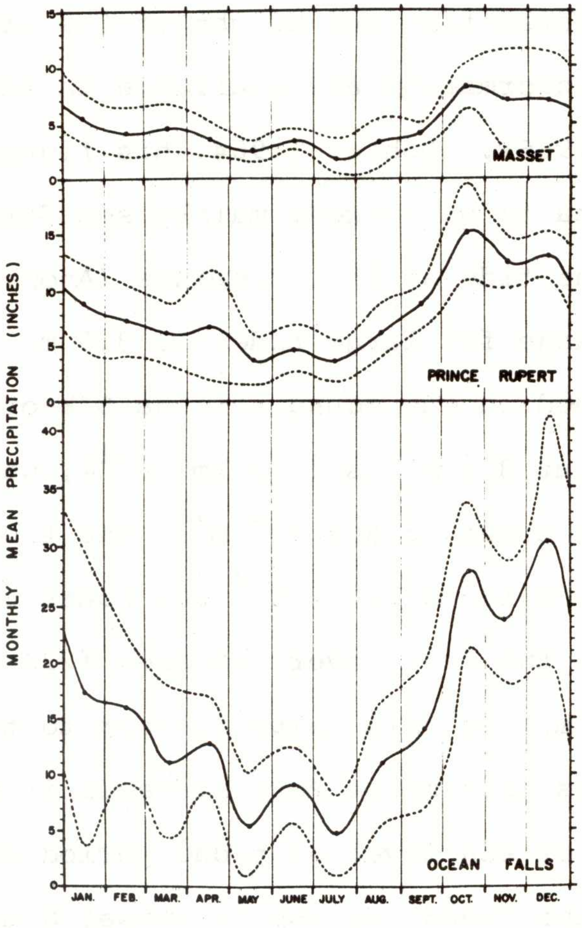


Fig. 2. From Crean (1967, figure 5) where it was captioned, "Monthly mean precipitation in inches and standard deviations at Masset, Prince Rupert, and Ocean Falls, 1956 through 1963."

2.2 Precipitation and runoff

The mean annual precipitation at Masset is 142 cm (Kendrew and Kerr, 1956). According to Crean (1967) "the mean monthly precipitation averaged over the years 1956-63 is characterized by an annual cycle of relatively small amplitude". The peak value occurs in October (Fig. 2) and the smallest value in July. It is characteristic of small rivers and streams on the coast that two maxima occur in the rate of runoff over a year: one in association with the spring thaw, the other with the direct runoff of the relatively large precipitation occurring in the autumn (Pickard, 1961).

There are several relatively large lakes nearby which drain into the inlet. A significant runoff into the inlet at all times of a year probably occurs due to this storage and to direct precipitation. Thus, a net transport out of Masset Inlet through Masset Sound throughout a year may be anticipated. The fact that salt occurs in the inlet indicates that exchange with water in Dixon Entrance occurs. The nature of this exchange has not been described but it seems certain that, because of the restriction of the sound, the amount of the exchange would vary inversely as the net transport.

The relative depth of sound and inlet indicates that a portion of the salt water entering the inlet from seaward must sink. The extent and timing of this sinking is likely related to the surface salinity in the seaward approach to the sound, the amount of runoff into the inlet and the sequence of the temperature variation. As the temperature of the water at

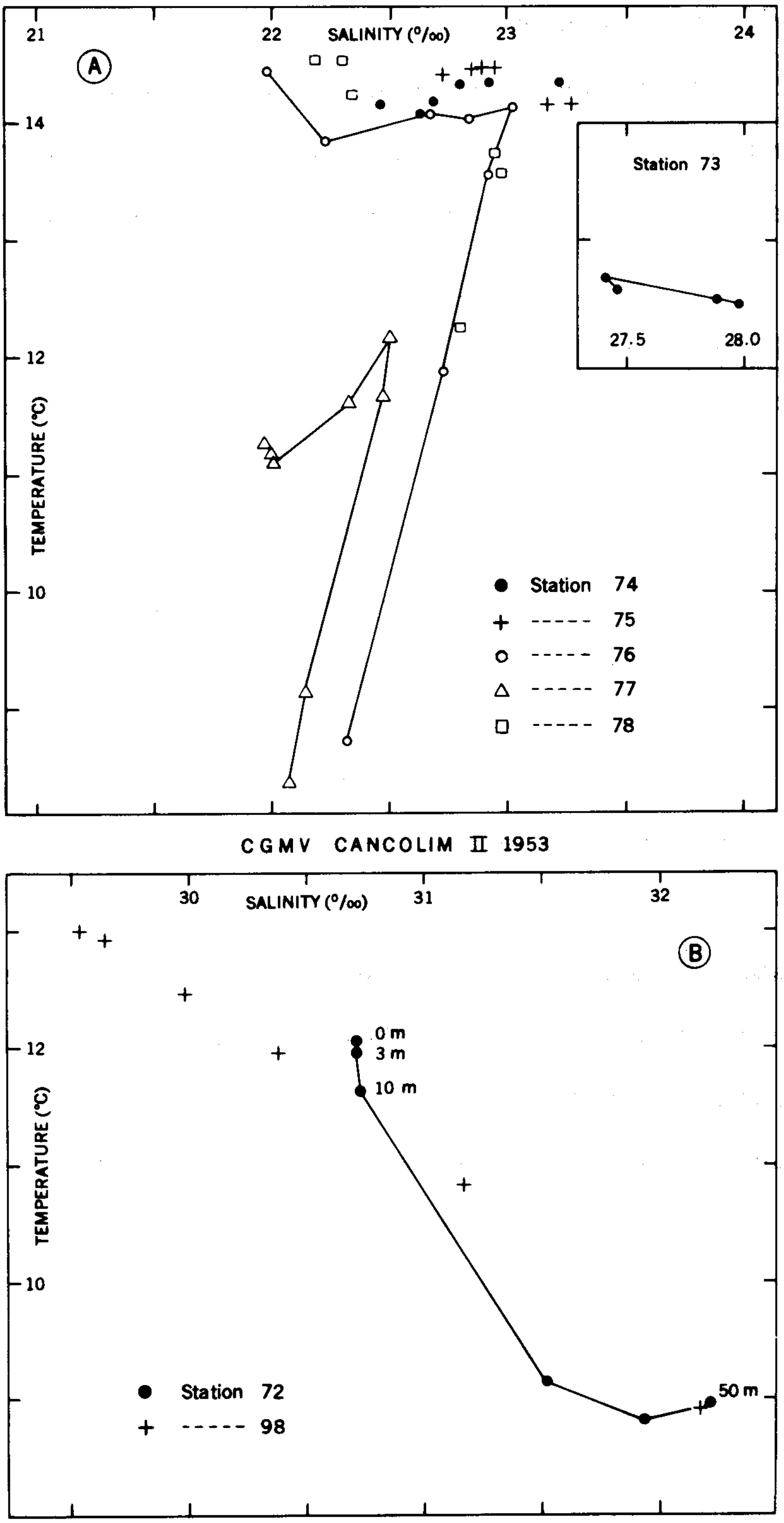


Fig. 3. The T-S relationship of some of the serial data observed at "Cancolim II" stations 72 to 78 and 98 (see figure 1 for positions). Station 98 was occupied July 29 and the others on July 20. (a) Stations 74 to 78 in Masset Inlet with inset Station 73 in Masset Sound. (b) Stations 72 and 98 in the seaward approach to Masset Sound.

depth is colder than the summer surface water it seems that the deeper water is formed at some time other than summer, i.e. the sinking does not occur in summer.

2.3 The data

As has been mentioned the water in Masset Inlet in July was brackish throughout, but over the relatively small range from 22 to 23.3°/oo (Fig. 3a). Temperatures varied from about 8 to 14.6°C. At station 73 in Masset Sound somewhat higher salinities occurred, 27.5 to 28°/oo, at a temperature of 12.5°C. At stations 72 and 98 (Fig. 3b) in the seaward approaches, observed salinity varied from 29.5 to 32.3°/oo and observed temperature from 9 to 13°C. Within the inlet a salinity inversion at about 20 to 30 m occurred at most positions and toward the head at station 77, a mid-depth temperature maximum was observed.

Other data include surface temperatures at Shannon Bay in 1938 and daily surface temperature and salinity at (New) Masset in 1940 (Anon. 1948a; b). The latter indicate little seasonal change in salinity but quite a large change in temperature. The observations at Shannon Bay indicate a relatively high surface water temperature there, close to 24°C (75.2°F, p. 130), for a short period in summer.

3. Concept of tidal exchange

Tully (1958 p. 525) in a consideration of flushing associated with tides remarked, "the inflow and outflow are usually asymmetric" so that the water of the ebb may not be entirely that of the flood. As well, he noted (p. 526) that it is difficult to distinguish between the "purely tidal flushing" and the freshwater transport mechanism. It is implicit in descriptive work, e.g. Cameron and Pritchard (1963), that tidal exchange can occur, but it is explicitly ruled out in dynamical treatment through the assumption that the tidal velocity terms are simple harmonic functions (Cameron and Pritchard, 1963 p. 318). Preddy (1954 p. 646) seems to have recognised this, although he emphasized that dispersal of water was due to the mixing which depended only partly on "the difference in the pattern of flow between the flood and ebb tides". The turbulent eddy diffusivity defined by Stommel (1953) and the "mixing parameter or exchange parameter" of Dorrestein (1960) include the influence of exchange due to asymmetry of tidal movements, i.e. due to inertial effect. Cameron and Pritchard (1963 p. 311) indicated that the inertial effect "is probably of secondary importance compared to the effect of the flux of momentum associated with turbulence". Others who have commented on an asymmetry in tidal flows include Bowden and Gilligan (1971), Fischer (1972a) and Leendertse and Gritton (1971), while Pritchard (1969) described a mechanism of dispersal due to fluid "entrapment" in shoreline indentations in the presence of reversing tidal currents. Bowden (1965) showed that horizontal mixing could be produced by the existence of a shear in currents, including tidal currents which again were considered to oscillate harmonically. Fischer (1972b) apparently recognised that tidal exchange occurs, but developed as the basis for his model a diffusion expression in which mixing was necessary; the mixing was due to shear dispersion. By a suitable choice of the "mass transfer coefficient" he was able to predict the "movement and dispersion of a pollutant in a tidal embayment". We (Barber and Murty, 1974) used the Fischer model and were able to hindcast the observed increase in freshwater in Tuktoyaktuk over the winter. However, we have come to believe that at the scales considered here, our process is one of exchange rather than mixing.

Certainly the evidence from Tuktoyaktuk is that mixing is not a major part of the exchange process there. Initially therefore we need not discuss such processes which include turbulent mixing, molecular mixing, diffusion or self-diffusion. The latter term was utilized (Elder, 1959) in the situation that the fluid was homogeneous, i.e. no portion of it was "hydrodynamically distinguishable" from another. This suggests that the phrase "self-exchange" might be applicable to our concept, in which a fraction of a flood volume, quantitatively equivalent and hydrodynamically indistinguishable from an ebb volume, becomes exchanged. Thus self-exchange is visualized as dispersive, i.e. as being due to variations of transport, at time scales not greater than tidal, arising from an asymmetry in the spatial distribution of velocity (Holley, 1969).

It is also visualized that in Masset Sound the spatial variation in velocity is relatively small, due to its uniform shape. In the inlet, however, the flood velocity will reflect to considerable extent the character of the inflow, particularly in sections close to the outlet where, during parts of the flood a relatively high momentum would give the character of a jet. Thus a spatial variation of velocity would exist both horizontally and vertically. On the other hand during the ebb the velocity distribution would reflect the pressure gradient toward the outlet, the sound, so that movement would occur rather evenly throughout any cross-section, i.e. similar to a potential sink flow (Fischer, 1972a). The self-exchange mechanism exists because the inertial elements of the tidal motion cause an asymmetry over a tidal cycle in the pattern of velocity at a point and thus to the time variations of transport noted above.

It is foreseen that this asymmetry is strongly related to depth change, between the sound and inlet, but it has been customary in estuarine studies to include depth variations through vertical integration of the equations of motion. This approximation is quite satisfactory for such long wave problems as tsunamis and storm surges. However, the approximation does not allow topography to play its adequate role because the shear generated by topography is not properly accounted for. The rationale in the use of simplified models is according to Leendertse (1970):

> At present, computational techniques are inadequate to deal with three-dimensional computations of fluid flow, and problems with the complicated boundaries of estuaries are beyond the capabilities of present computers. In the approach presented here, vertical integration of the equation of motion and continuity is used to reduce the problem to a two-dimensional one.

Simons (1973) pointed to the pit-falls in using the flow computed from vertically integrated equations in place of local flow. He stated in part:

> Although such one-layer models may be useful for the prediction of storm surges and the study of the winter circulation of the lakes, they are subject to severe limitations. Thus, under homogeneous conditions, the vertical mean flow as computed from the integrated models is indeed essentially correct, but this mean flow does not necessarily give an indication of the actual velocities to be found in the lake in particular, the time variations of local currents bear hardly any relationship to the integrated volume transports.

Clearly, if we are to model the self-exchange process a three-dimensional model is required; however, there are other factors which could lead to exchange, including Coriolis force and variations of shape, shoreline and depth within a water body. It was decided as a next step in our approach to the problem, to conduct a number of numerical experiments with an Eulerian two-dimensional model.

4. Numerical experiment

Consider a cluster of distinguishable water particles, or "markers" scattered across Masset Sound at some point along its length at low tide and assume that the cluster extends from one side of the sound to the other and is close enough to the entrance to Masset Inlet to be pumped fairly far into the inlet at high tide. We wish to trace the path of this cluster over one or more tidal cycles to see if it returns to its original shape and position at each successive low tide, or whether it becomes progressively distorted or dispersed, perhaps even extending partially into the inlet at low tide. Also, if there is progressive distortion we would like to separate and roughly estimate the importance of several of its possible causes. Here we are dealing solely with the deterministic effects of the hydrodynamic equations upon the particles of water. We ignore diffusive effects altogether.

For the purpose we used a hydrodynamic numerical model of the Masset system forced by an M_2 tide at the mouth of the sound. At small intervals of time over a full tidal cycle we saved the u and v fields, i.e. the currents in the x and y directions, on magnetic tape. Then we used these velocity fields to determine the motion of a cluster of markers set down in Masset Sound near Cook Point at low tide. This procedure was used for a model with the actual Masset geometry and for a series of simplified models run in an attempt to isolate the causes of the distortion of the cluster.

The model is of the standard two-dimensional, time-dependent type, allowing for arbitrary shoreline and bottom configuration and with the currents averaged over depth. The equations include the effects of surface gradient, Coriolis force and quadratic bottom friction, while at shoreline boundaries the normal current is set to zero. The equations were solved by finite differences using a uniform rectangular grid of standard type with a Z (water height) point at the center of each double grid rectangle, u values to the right and left and v values above and below. The outline of the grid used for the

Masset model can be seen from Figure 4a. The total grid size is 61 x 43, with $\Delta x = 1.10$ km and $\Delta y = .55$ km. The sound is just one double grid space ($2\ \Delta y$) in width.

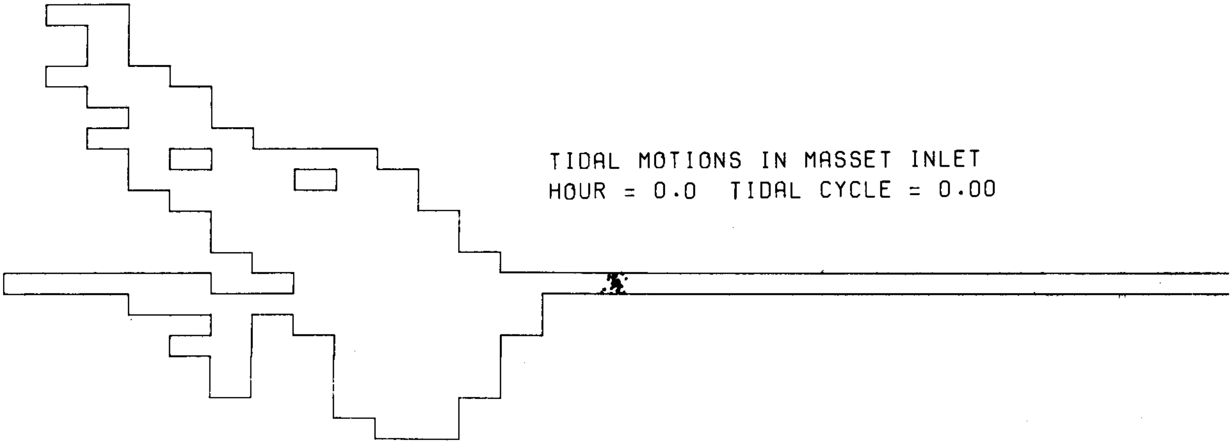
The tide at the mouth of the sound was a sinusoid of period 12.42 hours, and we adjusted the amplitude to give a tidal range of 9.2 feet (the known average tide) at Camp Point in Masset Harbour. Also we adjusted the bottom friction coefficient and the depth of the entrance to Juskatla Inlet to get agreement with other tidal measurements in the Masset system. The friction coefficient used was .0032, which is slightly larger than the customary value of .0025. The model was run for several tidal cycles until the transients had died away, then for the last cycle the u and v fields were stored for later use on magnetic tape at time intervals of 1/200 of a tidal cycle.

The equations governing the motion of a water particle are:

$$\frac{dx}{dt} = u(x,y,t), \qquad \frac{dy}{dt} = v(x,y,t).$$

We used simple forward differences to integrate these equations numerically over one or more tidal cycles. A time step of 1/4000 tidal cycle was found to give good convergence and with the u and v fields as generated above, we interpolated u and v to any required x, y, t values as follows:

(i) No interpolation was used in time; we merely used the u, v field nearest in time to t. This rather crude procedure was checked and found to be adequate.



(a)

Fig. 4. **Actual Masset geometry showing the position and configuration of markers at various stages of the tide. (a) Initial configuration at low tide. (b) After half a tidal cycle. (c) After a complete tidal cycle. (d) After 9½ cycles. (e) After 10 cycles.**

(ii) To get u at a point x, y we used "warped plane" interpolation, based on the values of u at the four corners of the double grid rectangle containing the point x, y. The interpolating equation is of the form:

$$u(x,y) = a + bx + cy + dxy$$

This technique has the advantage of maintaining continuity of u across grid lines. In regions near the shore some of the four surrounding u values will usually be missing, and special care must be taken to avoid currents through the shoreline and deadwater areas. We won't go into this in detail. However, one important result is that the current along the sound is constant across any given section (at a given time) and equal to the value of u linearly interpolated along the center line from the nearest two u grid points. This is necessary to maintain proper volume transports. Interpolation of v is similar to that of u.

Initially we set down a cluster of 50 markers, or water particles, scattered across Masset Sound at Cook Point at low tide. Cook Point is about 10% of the way along Masset Sound from the entrance to Masset Inlet and about 70% of the water in the sound appears to be moved into the inlet at high tide by our model. So the cluster should get fairly well into the inlet. Figure 4a shows the cluster of 50 water particles initially at Cook Point at low tide. Figure 4b shows the cluster after half a tidal cycle. It has been propelled into the inlet and stretched into a long string of particles. If these particles were actual markers on the surface of the water then presumably

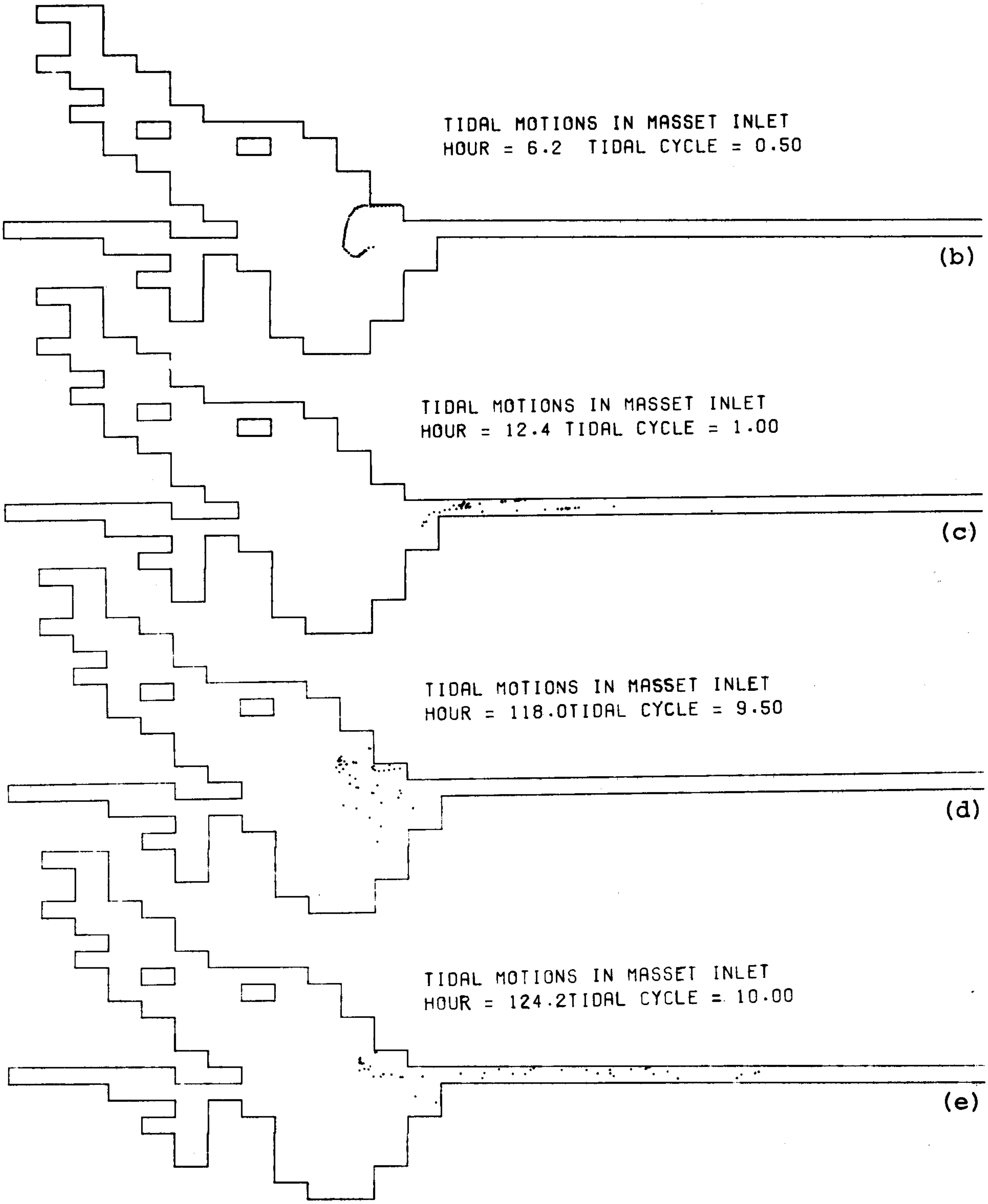


Fig. 4. Actual Masset geometry showing the position and configuration of markers at various stages of the tide. (a) Initial configuration at low tide. (b) After half a tidal cycle. (c) After a complete tidal cycle. (d) After 9½ cycles. (e) After 10 cycles.

they would actually be propagated further into the inlet than the model indicates, for as noted we used depth averaged velocities, and the surface water will evidently move faster than deep water. Figure 4c shows the configuration at low tide after a full cycle; the cluster definitely does not return to its original shape and there is considerable exchange of water over the tidal cycle. Figures 4d and 4e show the results after 9½ and 10 cycles.

There are at least two apparent limitations to this model. First and as mentioned, the averaging of currents over depth masks the variation of current with depth. Second, Masset Sound, as modeled, is only 2 Δy in width. This means that the only non-zero current grid points are a line of "u" values along the central line of the sound. That is, there is no possibility of variation of the current in the sound between the edges and the center. A model with variable grid spacing could possibly overcome this.

If the model were perfectly linear and the currents were in phase at all points in the system, then evidently a water particle would return exactly to its original position at the end of each tidal cycle. With this in mind, it is perhaps worthwhile to note the phases of the tides in Masset, as determined by our model: taking the tide at Camp Point as our origin, the phase lag is 63° at Cook Point, 78° in Masset Inlet and 113° in Juskatla Inlet.

In an attempt to illustrate the effects of Coriolis force, depth variation and shoreline configuration of the inlet

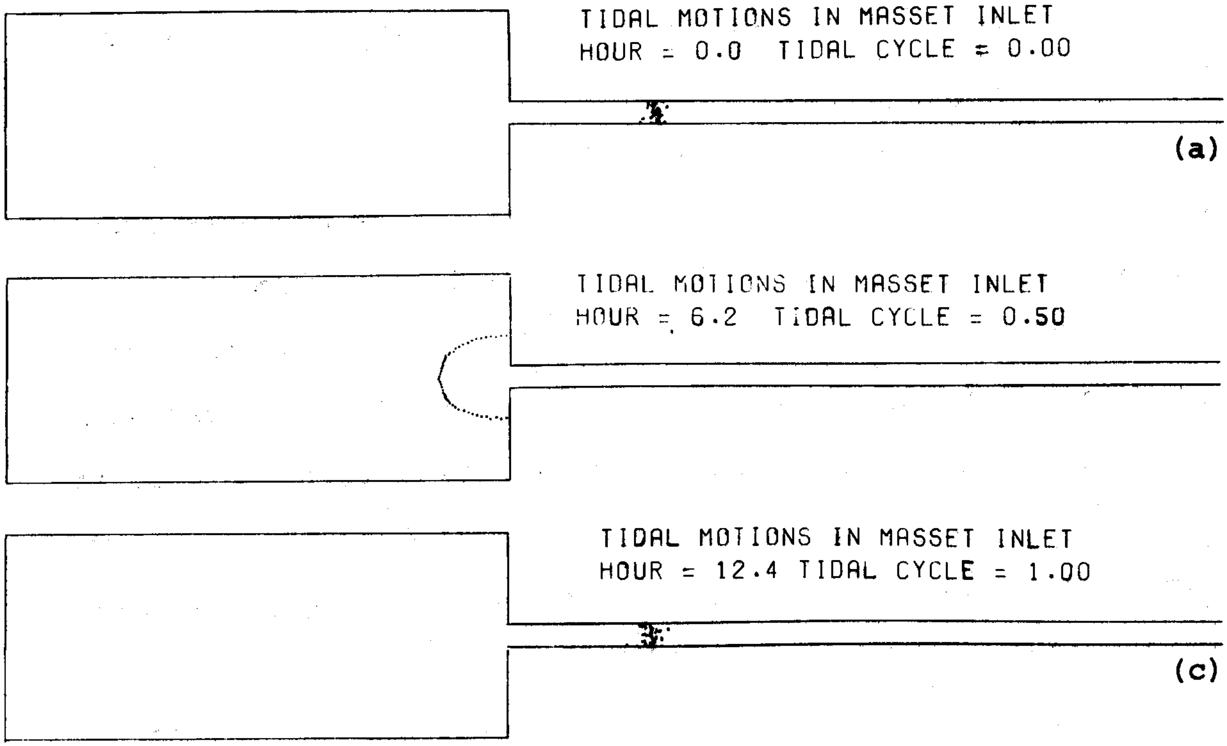


Fig. 5. Control run of the simplified model showing markers at different stages of the tide. (a) Initial configuration. (b) After half a tidal cycle. (c) After a full cycle.

upon the dispersion of the cluster of water particles, we made another numerical model with Masset and Juskatla Inlets combined into a single basin of rectangular shape and constant depth, with approximately the same surface area and volume as the original. The sound joins this inlet symmetrically at one end; Figure 5a shows the shape of this model. First we set the Coriolis force to zero and ran the model through a tidal cycle. This is the control run. The results at 0, ½ and 1 cycle are shown in Figure 5b. Figure 5c shows that there is very little dispersion after one tidal cycle.

Next we reset the Coriolis parameter to its proper value and reran the model. Figure 6a, at one cycle shows marked dispersion of a definite pattern. Figures 6b and 6c show how this has progressed after 2 and 3 cycles.

Then we reset the Coriolis force to zero, but made the bottom of the inlet trough shaped rather than flat (leaving the sound as is). The trough extends lengthwise along the inlet. It has zero depth at the edges and twice the previous flat depth along the central axis of the inlet, thus preserving the total water volume. Figure 7 shows the pattern of the markers after one tidal cycle and again there is a definite pattern of dispersion, but it is distinct from that produced by Coriolis force.

Finally, returning to constant depth and no Coriolis force, we moved the junction of the sound and inlet to an asymmetric point on the end of the inlet. Figure 8 shows that there is some dispersion, but not as much as in the two previous cases. This run was a rather mild attempt to see the effect of

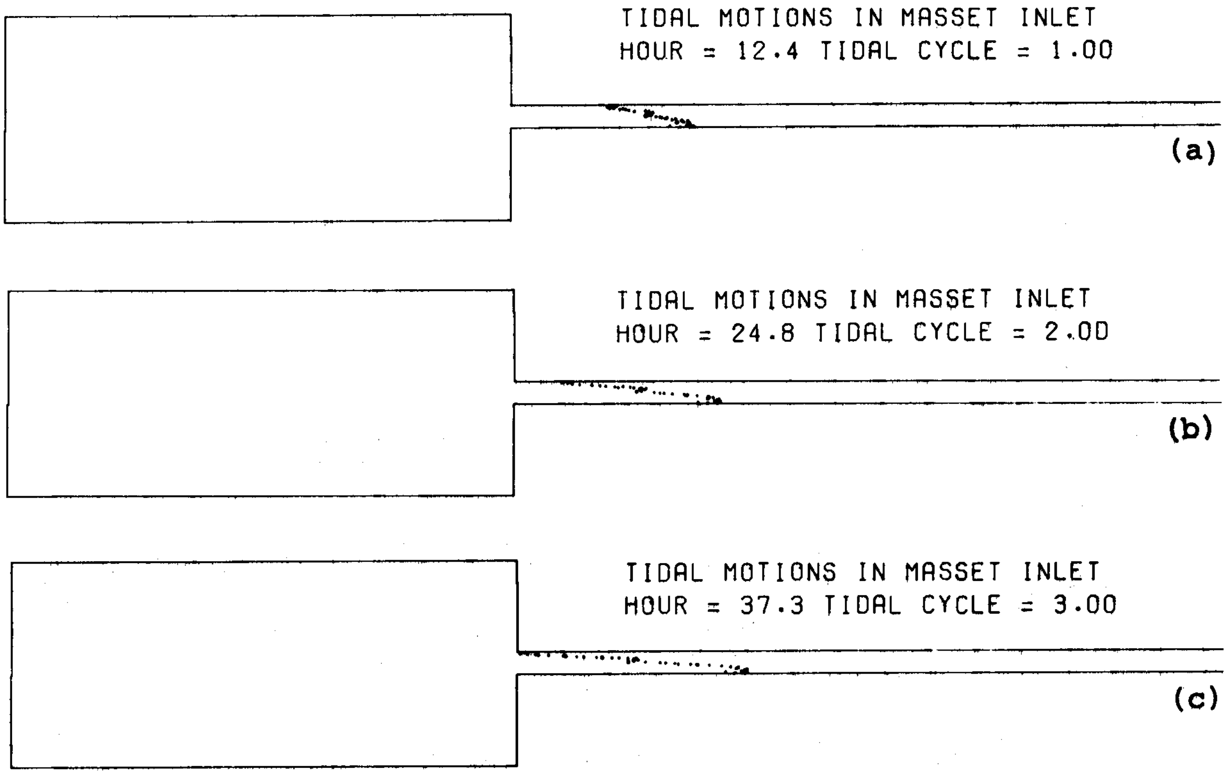


Fig. 6. Effect on dispersion of Coriolis force. (a) After one cycle. (b) After two cycles. (c) After 3 cycles.

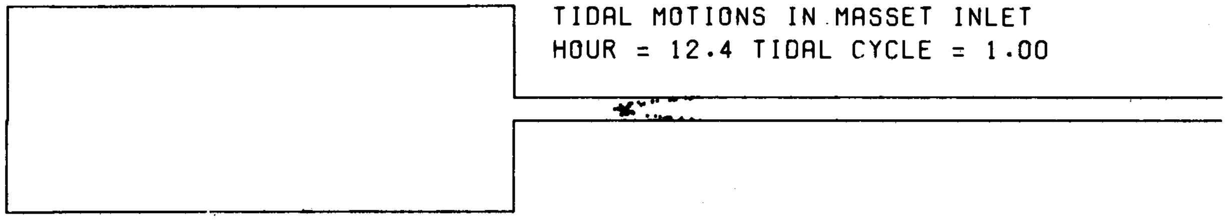


Fig. 7. Effect on dispersion of the depth variation within the inlet.

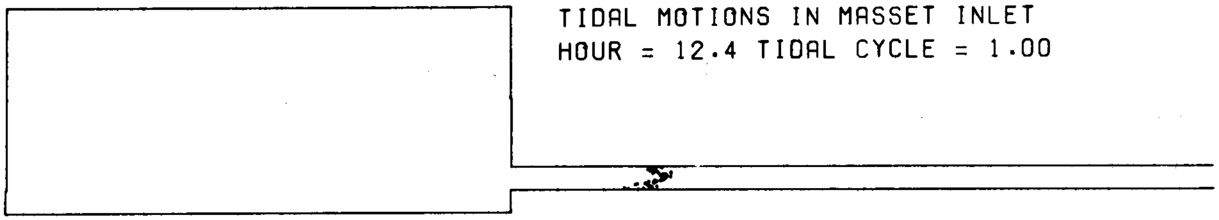


Fig. 8. Effect on dispersion of shoreline asymmetry.

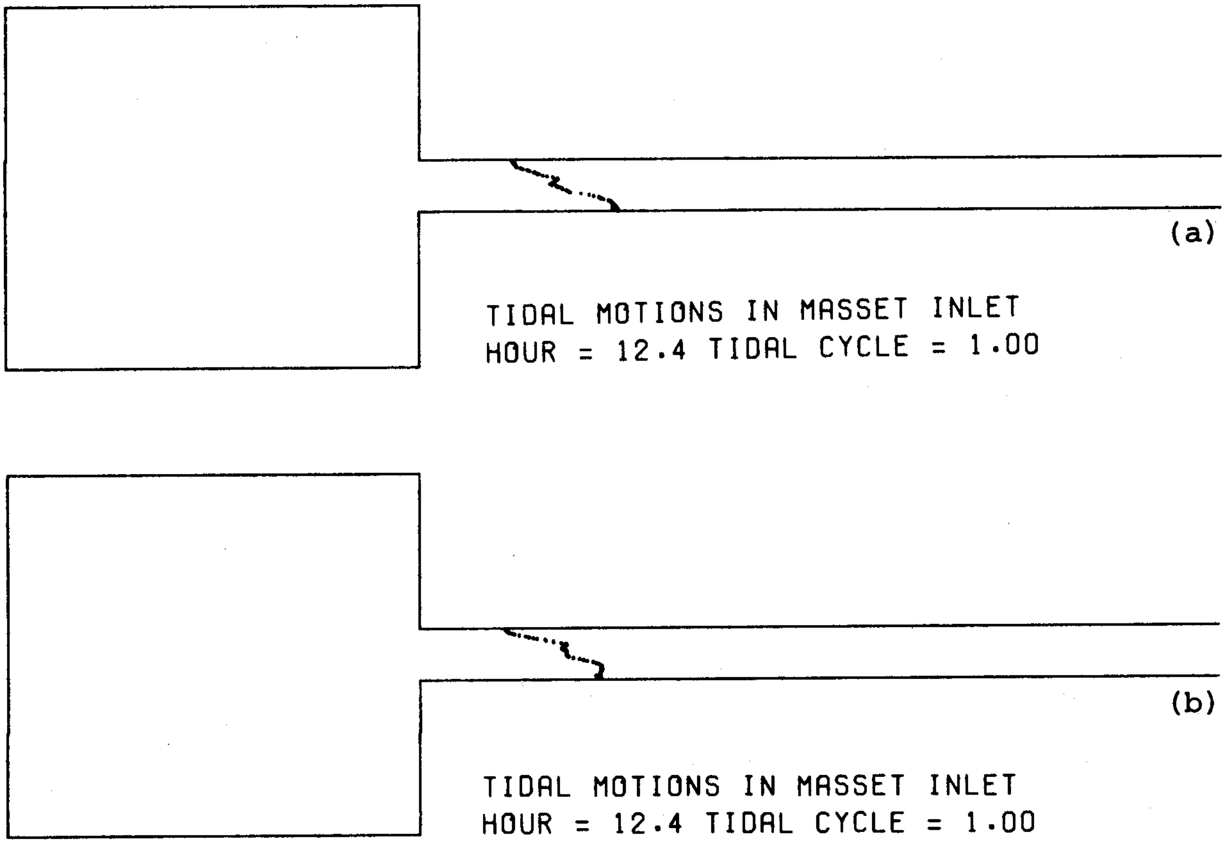


Fig. 9. Effect of grid size on dispersion due to Coriolis force. (a) Coarse grid after 1 cycle. (b) Fine grid after 1 cycle.

irregular shoreline on the dispersion. Perhaps more severe irregularity would produce greater effect.

The results seem to show clearly the effect of Coriolis force and depth variations upon the dispersion of the water particles. The effect of irregular shoreline has not been shown as clearly.

It is perhaps worthwhile to mention briefly three test runs made to check the correctness of our model. In the first we used a model consisting of a sound with depth variable along its length, closed at one end (no inlet) and forced by the tide at the other end. At the end of one tidal cycle all markers returned to their original position as they should.

Next we used a model similar to that in Figure 5, but made the tidal cycle very long, thus making the phases nearly constant over the whole system. The markers all returned correctly to their original positions after one tidal cycle.

Finally we constructed a series of models somewhat similar to those described above and shown in Figures 5 through 8, but with a coarser grid spacing. These we ran for one tidal cycle. Then we refined the grid by a factor of two and reran the models. Now the finite difference technique used in our model has second order accuracy, so presumably cutting the grid spacing in half would reduce numerical errors due to the finite grid size to one quarter. We found that the results with the coarse and refined grids showed the same general features, though they differed in some of the small scale features. As an example we show in Figure 9 the effects of Coriolis force using the coarse and the refined grid. The general pattern of dispersion is evidently the same in both cases. So it appears that our results are genuine and cannot be explained by numerical dispersion.

5. Discussion and proposal

The real interest in the present problem is the quantitative significance of the self-exchange process, i.e. in the absence of other transport mechanisms what fraction of the water of the flood into the inlet does not participate in the ebb? It seems likely that further numerical experiments with a three-dimensional model could provide a value and it is anticipated that it will be possible to continue with such an examination. At this point however it seems that a field experiment would be appropriate and in the following a relatively simple experiment is outlined. Other experiments based on the concept could be described, but these seem now to be rather secondary.

The essential idea is to tag with dye a known volume of water entering the inlet during the flood and to determine the distribution of the tagged volume at the end of the ebb. The strength of the flood and the resulting turbulence suggest that this should be possible. In an initial trial, a known amount of dye would be introduced into the sound after low water slack in a section just north of Cook Point at a rate and over a time interval sufficient to tag a kilometre long length of water, with the distribution of dye at the end of the following ebb being estimated visually and from photographs. Should this indicate that significant self-exchange occurs, then during another trial, measurements would be attempted to determine the quantitative distribution of the dye at the end of the ebb. Two types of measurement are proposed. One, at a location close to the point of dye injection, would comprise the continuous measurement at about 10 m depth of dye concentration over the period of the ebb as well as a determination of the transport. These data would provide an estimate of the amount of dye returned to the point of injection. The second would comprise a synoptic sampling at the end of the ebb using a towed sensor at one depth (10 m). These data would have to be reconciled with the measurement in the sound and with likely amount of dye lost through other processes.

The location and timing of dye introduction is determined by the requirement that the dye be thoroughly mixed into the desired portion of the flood. The extent to which this occurs is in part a function of the turbulence within the sound and the length of time the dye and water undergoes mixing from the turbulence. There can be no doubt but that the above requirement will not be met completely so that the extent to which the experimental result will be degraded must be assessed. Of course there exist a number of other limitations in the experiment; some relate to the particular location of the experiment, others to the use of dye. A useful publication with regard to the latter aspect is that of the Lamont Geological Observatory (Ichiye, 1965) and it is mainly on the basis of the experience described there that the overall experiment in Masset Inlet was determined. During the ebb it is anticipated that the measurement at one depth (10 m) abeam of Cook Point as well as a measurement of the speed will permit an acceptable measure of the amount of dye contained in the ebb. This quantity with certain corrections would with the quantity entering the inlet provide the quantitative result sought for each trial. Corrections include dye loss during the experiment. Gunnerson et al. (1965) briefly described the nature of these losses and indicated the need for field calibration (see also Carpenter, 1960).

The evidence is that a net transport out of Masset Inlet occurs throughout the year due to freshwater from runoff. As the water is brackish throughout it is assumed that freshwater storage occurs and, as a result, the time of least net transport would lag the time of least runoff. It seems likely that the least net transport occurs in the late summer and early autumn. It is estimated that this transport could comprise up to about 2% of a flood volume and would therefore decrease the self-exchange.

6. Summary

Certain selected observations supported by preliminary numerical experiment indicates that a self-exchange process associated with tidal currents in the absence of other transport mechanisms can lead to significant exchange. Consideration of the hydrography of the Masset Inlet system has in turn led to the definition of a field experiment there which would contribute to the quantitative assessment of the process.

7. References

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8. List of figures

Frontispiece. CGMV "Cancolim II" in Bute Inlet July 3, 1953.

Figure 1. Masset Inlet and Masset Sound indicating (a) some place names and positions of stations occupied (Station 89 was an anchor station) in 1953 (Anon., 1955), and (b) the depth (m) in Masset Inlet.

Figure 2. From Crean (1967, figure 5) where it was captioned, "Monthly mean precipitation in inches and standard deviations at Masset, Prince Rupert, and Ocean Falls, 1956 through 1963".

Figure 3. The T-S relationship of some of the serial data observed at "Cancolim II" stations 72 to 78 and 98 (see figure 1 for positions). Station 98 was occupied July 29 and the others on July 20. (a) Stations 74 to 78 in Masset Inlet with inset Station 73 in Masset Sound. (b) Stations 72 and 98 in the seaward approach to Masset Sound.

Figure 4. Actual Masset geometry showing the position and configuration of markers at various stages of the tide.

(a) Initial configuration at low tide. (b) After half a tidal cycle. (c) After a complete tidal cycle. (d) After 9½ cycles. (e) After 10 cycles.

Figure 5. Control run of the simplified model showing markers at different stages of the tide. (a) Initial configuration. (b) After half a tidal cycle. (c) After a full cycle.

Figure 6. Effect on dispersion of Coriolis force. (a) After one cycle. (b) After two cycles. (c) After 3 cycles.

Figure 7. Effect on dispersion of the depth variation within the inlet.

Figure 8. Effect on dispersion of shoreline asymmetry.

Figure 9. Effect of grid size on dispersion due to Coriolis force. (a) Coarse grid after 1 cycle. (b) Fine grid after 1 cycle.