USES OF AERIAL PHOTOGRAPHY IN STUDYING COASTAL AREAS

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This is not intended to be a complete survey of uses of aerial photography in coastal oceanography and hydrography. Such a paper might be useful to write, but there are so many examples that could be chosen, reflecting interests in many different specialities, that the end product would probably be difficult to follow and dull to present. I would prefer to pick out a few specific examples and discuss them in more detail.

Aerial photography is clearly a valuable mapping and reconnaissance tool, and any group of scientists studying the sea can probably benefit at some time by having access to aircraft and cameras. We have had a number of requirements at Ocean and Aquatic Sciences, Pacific Region (now the Institute of Ocean Sciences, Patricia Bay) which show a need for both standard mapping photography - the 9 inch square format normally provided by air photo companies - and also for a variety of small format 70 and 35 mm photographs for special purposes. In several cases the photographic work has pointed up the need for more specialized remote sensing techniques, and an example of thermal scanning imagery is shown below.

One example of a requirement for the 9 inch mapping photographs is in air photos to assist in chart construction for shoal detection and shoreline mapping. This is a requirement that we expect to increase as a result of a programme which is currently investigating the application of special purpose stereophotography to measurement of shallow water depths.

In a recent example of a smaller project, it was necessary to know whether a particular coastal marsh was accreting or eroding and what area of the marsh was under water at a given level of high tide. This is not exactly an oceanographic problem, but it seems to be the kind of problem that falls on the oceanographic community from time to time, at least in Canada. For answering the first question, historical mapping photography was available for the area from the B.C. Government's Air Photo Division. This photography showed the outline of the marsh on 3 past occasions at roughly 7 year intervals. For an estimate on how much of the marsh was water covered at high tide, however, special photography was needed. Down-looking photographs cannot show up water over mud or among plant life in the marsh, but hand held oblique 35 mm photographs from a light aircraft showed up the bright sky reflections from open water and gave a quick estimate of the water covered area.

There are 3 main examples, each connected with programs at our institute, that I want to discuss in this talk.

The first concerns a numerical model of the Georgia Strait. This is the body of water between Vancouver Island, on which our institute is located, and the mainland. The Fraser River flows into the Strait just south of the city of Vancouver on the mainland, bringing in a large volume of fresh silty water and strongly affecting the properties of water in the Strait. For this reason the distribution and mixing of Fraser River water is being studied as one of the boundary conditions of the numerical model.

Imagery from the LANDSAT-1 satellite can show the overall distribution of Fraser River water on the surface of the Georgia Strait. Figure 1(a) shows part of a frame fro July 30, 1972 at a time of ebbing tide and Figure 1(b) shows the same scene on September 4, 1972 during a flood. Part of Vancouver Island and the Guld Islands are visible in the lower left side of the scene, with the plume of the Fraser River lightening the otherwise dark water of the Georgia Strait in the centre of the scene. The City of Vancouver is north of the Fraser delta at the top right, with the characteristic shape of the Stanley Park peninsula clearly visible.

These pictures would be ideal for supporting a ship operation by showing the overall form of the river's plume at a given time. From a ship it is impossible to see the large scale features of the silt distirbution, so that it is difficult to relate current drogue measurements or STD casts to the general form of the plume. Unfortunately these pictures suffer the very strong disadvantage of being available only every eighteen days and then only if the weather is completely clear. The combination of these two limits, results in there being only about 3 or 4 pictures of the quality of these examples per year for this area, whereas the requirement, to support a ship study of the area, is for several pictures per tidal cycle on the specific days when the ships are working.

Standard aerial photography requires many photographs to cover the area even when taken with a wide angle camera from high altitudes, and good weather is again necessary. Figure 2 shows a picture taken at 31,000 ft. over the mouth of the Fraser River south of Vancouver, with a focal length of 88.5 mm or roughly 3.5 inches. The original picture is imaged onto a piece of film 9 inches square, which for this short focal length implies that the scene is being photographed out to about 60^{o} away from the nadir with only very small geometrical distortions. This is the so-called "super wide angle" lens, the widest angle available for mapping purposes which, from 31,500 ft. means that the photograph covers a little over 13 miles square.

To map the plume using this high altitude photography, however, still requires cloud free weather and is also an expensive operation. Figure 2 was taken by the canada Centre for Remote Sensing using a Falcon Fanjet aircraft. To provide coverage of about 80% of the plume area took about 20 photographs flying a total of 70 line miles.

The centre charged $14.00 per line mile in 1975 and estimated that this recovered about 50% of their costs, so that the full cost of a single mosaic of the plume area would be around $2,000.

To reduce the dependence on clear weather, we experimented with taking pictures from a lower altitude using a fisheye lens in a 35 mm camera. The lens receives light from an angle of 220°, that is, up to 20° above the horizon in all directions when the camera is pointed vertically downwards. Figure 3 shows such a picture taken from a light aircraft over the First Narrows at the entrance to Vancouver Harbour. Stanley Park is visible to the left, connected by the First Narrows bridge to the North Shore with its mountains foreshortened on the skyline to the right.

Pictures of the Fraser River plume were taken from a light aircraft at altitudes that varied during the ship operation between 500 and 4,000 ft. In fact, only one day was sufficiently cloud free for high altitude photography to have been possible. The lens was mounted on a 35 mm camera with motorized film drive, and pictures from a second camera having a conventional wide angle lens were taken at the same time. The fisheye lens allows the widest possible view to be recorded of the water and has the additional advantage that, since the horizon can be seen, the position of the aircraft can be deduced at any time from the angular spacings of landmarks. Similarly any aircraft pitch or roll can be detected and their effects estimated.

Figures 4a, b and c show a sequence of fisheye pictures of the edge of the plume. The aircraft positions deduced from the photographs locates this edge geographically and the main plume area can be mapped in outline from a flight that follows this edge across the Gulf of Georgia. The wide angle pictures (Figure 4d) record features of this edge with considerably more detail, and here shows internal wave patterns in a cusp of silty water south of Bowen Island. Accuracy of the positions deduced in this way depends strongly on the distribution of suitable landmarks. At flying heights above 1000 ft, the aircraft's position could be deduced to better than 0.5 nautical miles accuracy, corresponding to bearings measured to about 1°C of landmarks up to 15 miles away. This accuracy was sufficient for outlining the plume and showing changes after a few hours interval.

The product is not nearly as simple to use as a mosaic of high level photographs would be, but the method does give usable pictures in marginal weather conditions, and since a light aircraft is used (in this case a Cessna 180 aircraft) it is relatively inexpensive.

Any of these methods of producing a picture of a river plume from the air will only be mapping the surface distribution of silty water and will not be showing the velocity or volume of fresh water or the rate at which this water mixes with the salt water beneath. STD casts from a ship can provide more information in a few points, and it is the combination of ship and aircraft measurements that is needed to give useful results. Problems still remain in relating the two types of data however. We have found examples where the plume, strongly visible from the air, was too thin (less than 1 m) to show on a standard STD cast.

The second example of a requirement for aerial work, connected with the previous one, is in the measurement of surface currents and the distribution and variation of currents over a particular area. Here what is required is simultaneous current measurements at many locations. Current meters are expensive and near the surface are liable to be damaged or removed by ship traffic. Several studies have been carried out on the west coast using freely floating drogues of various types. The most recent work has used drogues that can be tracked by standard ship's radar. Each drogue has a radar reflector and a sail at some selected depth in the water and is set out and retrieved during the study by one or more launches. The radar is mounted on as steady a platform as is available, ideally on land, and photographs of the radar display show the drogues movement day and night in all weather except heavy rain.

This method has been very successful, and movies derived from the consecutive radar screen displays provide an impressive and quantitative picture of surface water movements. The radar reflector will however cause the drogue to be affected by the wind and it is also difficult to design a drogue that will respond to the movement of the top surface layer of the sea less than 1 m deep. There is therefore still a use for aerial photography of floating sheet targets and water colour boundaries especially in studies designed to duplicate the motion of oil slicks.

In a study of water movement in Burrard Inlet, that took place in June of this year, a combination of current meters and radar tracked drogues were used to monitor currents in the Inlet while a current meter array was used to measure the deep water flows across the entrance to the Inlet. Figure 5a shows an aerial photo (original in colour) that was taken during this study. Silty water from the Fraser is visible in the lower left and water entering from the east through First Narrows (top right) is faintly visible as it moves into an anti-clockwise eddy in English Bay. Figure 5b was taken 8 hours later during the following flood. From single pictures such as these one cannot make unambiguous current estimates, but the instantaneous picture of water colour variations in the Inlet shows the full distribution of Fraser River water at this time and can act as a check on the *in situ* measurements as well as a way of interpolating spatially between them.

Another source of data available from the same flight is imagery from a thermal scanner. This device senses temperature variations of the land or sea surface and converts them into a black and white image. Apparent land temperatures in summer sunlight generally fall between 10 and 40°C and a scanner is therefore set to receive this range of temperatures in studies of land targets. Water temperatures, especially in well mixed areas, cover a much smaller range, and in the images shown in Figure 6a and Figure 6b temperatures from 8 to 12°C are converted by the scanner to the full black to white range of the picture so that temperature changes of less than 0.25°C can be distinguished. Figures 6a and 6b were taken at the same time as Figures 5a and 5b respectively. In Figure 6a colder water can be seen moving out to the west through First Narrows as the tide ebbs. In Figure 6b the incoming tide pushes a jet of warmer water through First Narrows into Vancouver Harbour.

In Figures 7a and 7b the grey scale of the picture has been quantized electronically in steps corresponding to 0.67 and 1.0 degrees centigrade respectively. The apparent temperatures corresponding to each step can be deduced from thermal references built in to the scanner.

The apparent temperatures of the water, as measured by the scanner, will be affected by atmospheric absorption, which causes a change of several degrees for observations from high altitude. For these flights water surface temperatures, measured at a variety of locations, showed that airborne temperature measurements deduced from Figures 7a and 7b were 3.5 and 2.5°C. too cold respectively. More detailed comparisons show that the difference is equivalent to approximately 30% absorption of the radiation in an atmosphere (or, more correctly, water vapour in the atmosphere) having a temperature of about 3°C.

The thermal radiation that is being measured by the scanner originates in a very thin (less than 1 mm) surface layer of the water which can sometimes differ in temperature from the bulk of the water beneath. Simultaneous low level radiation measurements on the second flight show that, in Figure 7b at least, this effect is small.

Quite apart from the indications the figures give of the water circulation patterns, the distribution of surface water temperatures are plainly visible.

I must thank the Coast Guard, Ministry of Transport and Greater Vancouver Sewage and Drainage District authorities who supplied water surface temperature measurements to me for the times of these flights.

The colour and temperature patterns shown in Figures 5, 6 and 7 vary during a tidal cycle and in response to other influences such as wind and fresh water runoff, and it would be useful to repeat aerial imagery at regular intervals to show these changes. To follow tidal variations the repeat time would need to be one or two hours, and in fact photography was taken on two good days during the Burrard Inlet Study at two hour intervals during daylight, using the ligh aircraft with the same fisheye/wide-angle 35 mm camera combination as described previously.

The ideal platform for studying this type of variation would be one that hovered at a point from which the entire scene is visible. A high resolution sensor in a geostationary satellite would view Canadian waters at an oblique but, for southern Canada, acceptable angle and may one day be available. A satellite in an eccentric orbit could also give continuous day-time coverage of Canada.

In the meantime, cheaper alternatives have to be used. For Burrard Inlet the mountains to the north provide a viewpoint from which this area can be seen at a glancing angle of from 5 to 15°. As part of the current study a small Super 8 mm movie camera was fixed on a tree at 2100 ft altitude recording the orientations of the ships at anchor in the Inlet at 5-minute intervals. The resulting movie provides an indication of current directions in the area of where the ships themselves block radar returns from the drifting targets described earlier. Since the pictures are taken from a fixed location, they are simple to analyze. The small scale film size (8 mm) gives considerably less detail than the 35 mm picture shown in Figure 8, but is still sufficient to show ship orientations to ± 20°. On windy days the ships will be pushed out of line with the currents since they are empty and riding high in the water. Air photos on past occasions, when a dock strike has increased the number of anchored ships to 15 or 20, have shown up the single and multiple gyre patterns which occur in this area.

The final example of air photo application concerns Rupert Inlet at the north end of Vancouver Island, where a copper mine has been discharging tailings into the water. The tailings are mixed with bottom water from the inlet so that they should stay deep, and the long-term plan has been to fill the Inlet about one-third full of tailings without affecting its present surface water or shoreline. Unfortunately, the Inlet is joined to the sea by Quatsino Narrows which has tidal currents up to 7 knots that stir the water in Rupert Inlet sufficiently to bring these tailings to the surface. The stirring only occurs on the incoming tide and depth of water affected depends strongly on the salinities and temperatures of the water inside and outside the Inlet, which vary greatly during the year and with the shorter term weather.

Air photographs and sightings by a number of agencies have suggested in the past that the upwelling of tailings is getting worse as the mining operation proceeds (Figure 9). It is now in its 4th year out of an expected total of 20 years. Because of the variability in the amount of tailings being brought to the surface, it has been difficult to follow the increase or to say in what areas of the Inlet the problem will be worst.

To try to answer these questions, series of pictures have been taken from two different photo platforms. In one case a camera was attached to a tree at the top of a nearby hill, and set to take pictures once every 10 minutes. The camera was again Super 8 mm with automatic exposure control and with this setting could continue to run for about 3½ weeks. Unfortunately, the hills surrounding Rupert Inlet are low and provide a very shallow look angle at which only the strongest water colour changes in bright sunlight are visible.

A very useful viewpoint for this study was, however, obtained from a balloon. (Figures 9a and 9b). The balloon is about 30 feet long and 15 feet in diameter, and when filled with helium provides about 60 lbs. of lift. The balloon had been used in making atmospheric measurements by Dr. Miyake's group at the University of British Columbia and they were contracted to provide a series of 35 mm air photos over the inlet. The balloon was inflated at the copper mine with the cooperation of mining company officials, (Figure 9a) and was then flown above a launch using 4000 feet of 600 lb. line on a motor driven winch. Written permission was obtained from the Ministry of Transport to fly the balloon in daylight hours, below, but not in cloud, on days when visibility was over 3 miles. The line was marked with 3 ft square red flags at intervals of 100 ft and pilots were warned of the operation through the standard "notice to airmen" procedure of the M.O.T.

A fisheye lens was used on the camera so that even at low altitudes down to 200 ft the entire affected area, about a mile across, could be seen and the position and orientation of the camera could be deduced from landmarks. This turned out to be extremely useful, since clouds often restricted the balloon's weight and the movement of the balloon and camera caused by the wind would have made the pictures impossible to orientate without landmarks being visible on the pictures. Series of colour photographs were taken on 4 separate days with the camera being triggered by a small attached intervalometer and showed the upwelling very clearly. The balloon, launch and camera could be operated by two people. The balloon remained in flight at all times and could be pulled by the launch at full speed on to and off station. Its streamlined shape allowed it to stay near vertical in most wind or slipstream conditions, though drag on the line pulled this well away from vertical until on the highest flight with about 1200 ft of line out when the lower end of the line was under reduced tension, the line was paying out horizontally. Optimum height for photographing the required area was 6-800 ft.

The balloon was pulled down to near the launch to service the camera and was left overnight held down by about 50 ft of line anchored on shore. It was this mooring arrangement that resulted in eventual disaster during a storm, when it was blown to the ground and ripped.

The photographs obtained, however, showed that a balloon can be extremely appropriate for a variety of coastal studies when a continuous sequence of pictures from low altitude is required. Figures 11a, b and c show part of one sequence in which the surface plume can be seen extending from Quatsino Narrows (lower left) almost to Hankin Point (top). The line tethering the balloon cuts across the right half of the picture.

CONCLUSIONS

The above examples of aerial photography show some, but by no means all, of the variety of techniques that can be applied to coastal oceanography.

I would like to thank fellow workers at the Institute of Ocean Sciences, Patricia Bay for advice and discussions in planning these projects.

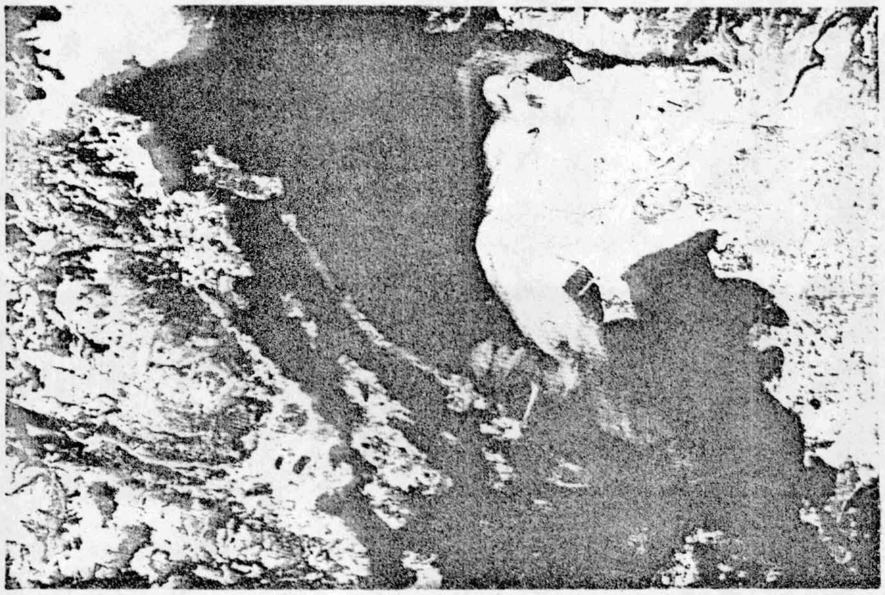


Figure 1a. Part of the LANDSAT-1 scene for July 30, 1972 showing (centre) the silty plume from the Fraser River against the dark, clearer, water of the Georgia Strait.

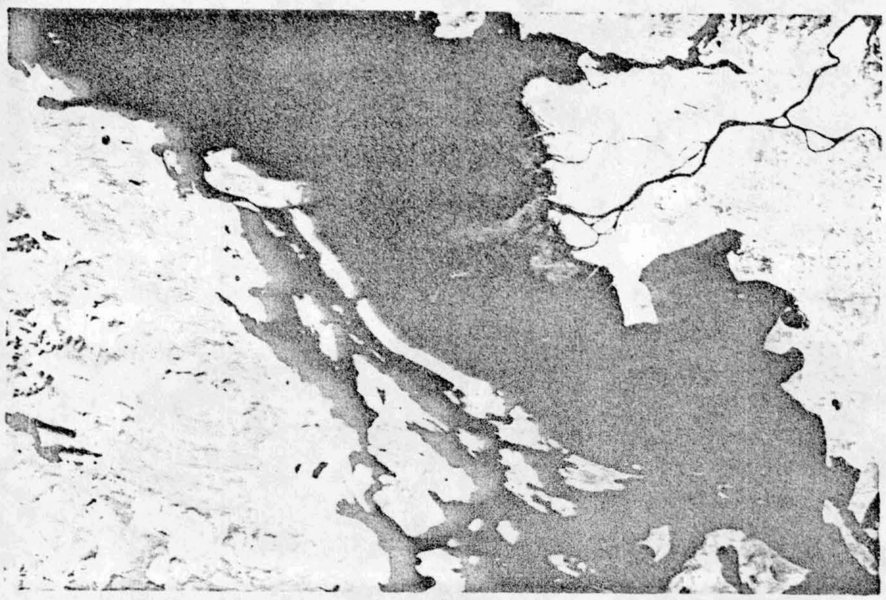


Figure 1b. A similar scene for September 4, 1972.

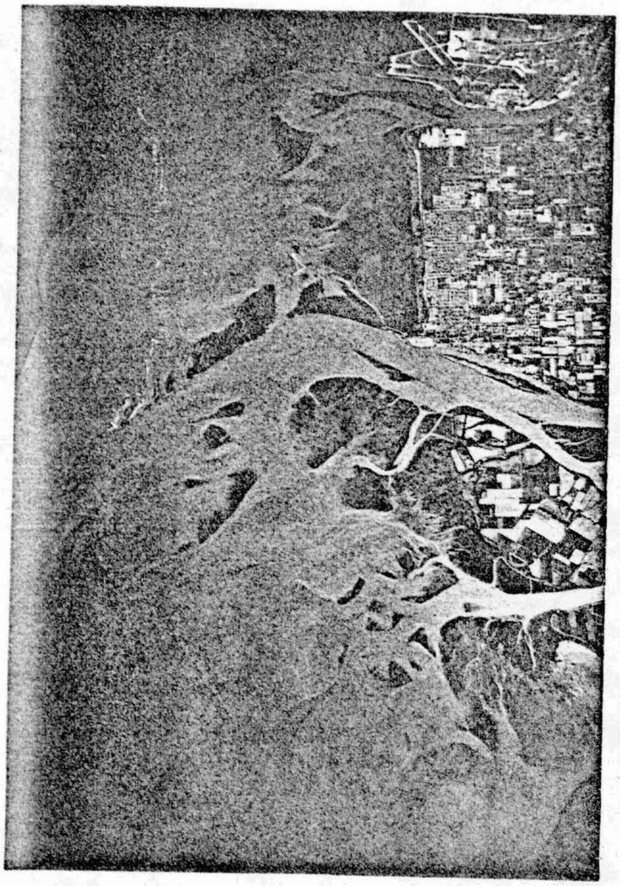


Figure 2.

A high level air photograph of the mouth of the Fraser River south of Vancouver, taken from 31,500 ft. with a super wide angle lens.

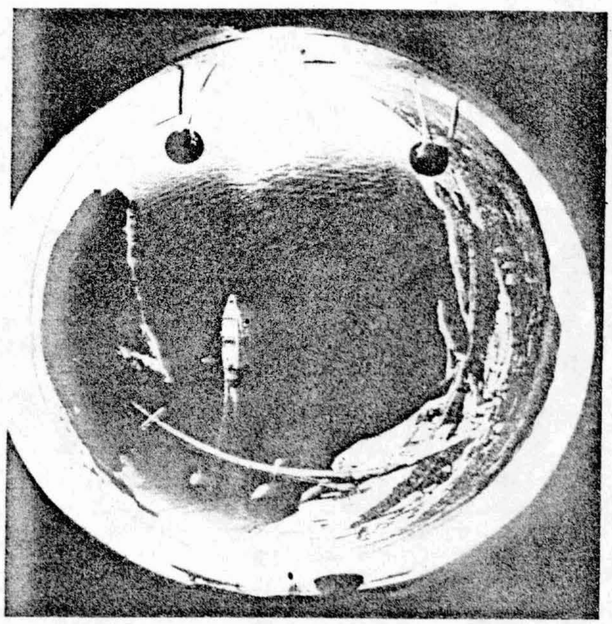
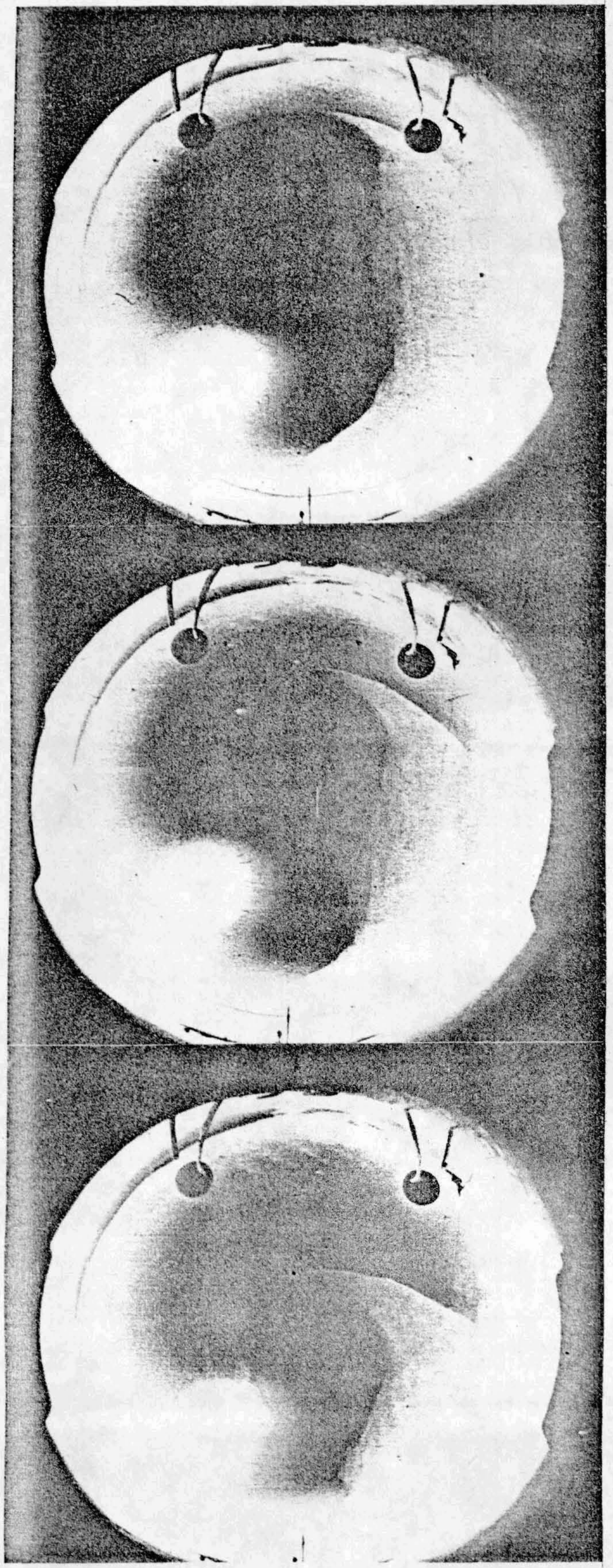


Figure 3.

A photograph taken through a fisheye lens at 1000 ft. over First Narrows, Vancouver.



Figures 4a,b,c

A series of fisheye photographs taken from a light aircraft flying over an edge of the Fraser River plume on June 4, 1974.

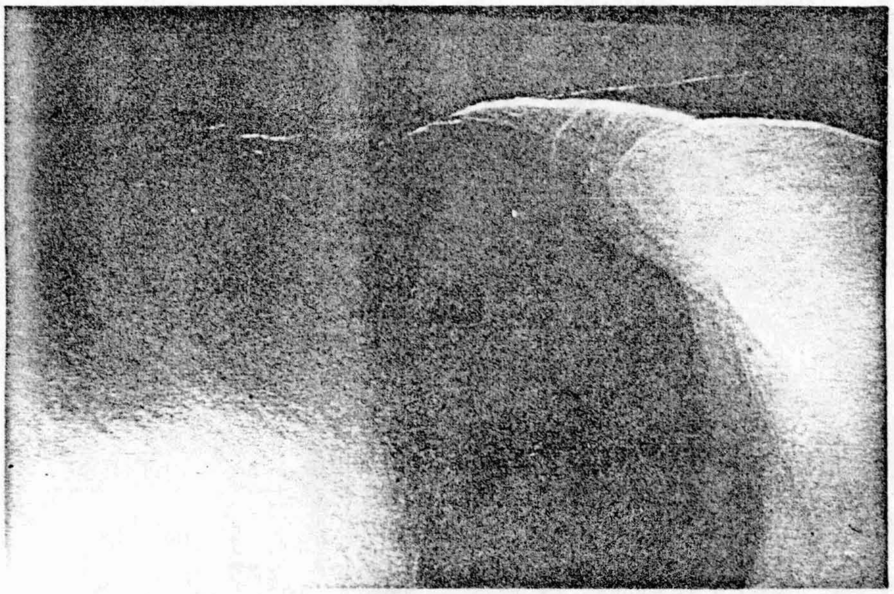


Figure 4b. The wide angle photograph taken at the same time as Figure 4c and showing the cusp of silty water with higher resolution and without the geometrical distortions of the fisheye lens.

Figure 5a

Figure 5b

High level air photographs showing Burrard Inlet and Vancouver at 1100 and 1900 PDT on June 11, 1975, during an ebbing and a flooding tide respectively.

Figure 6a

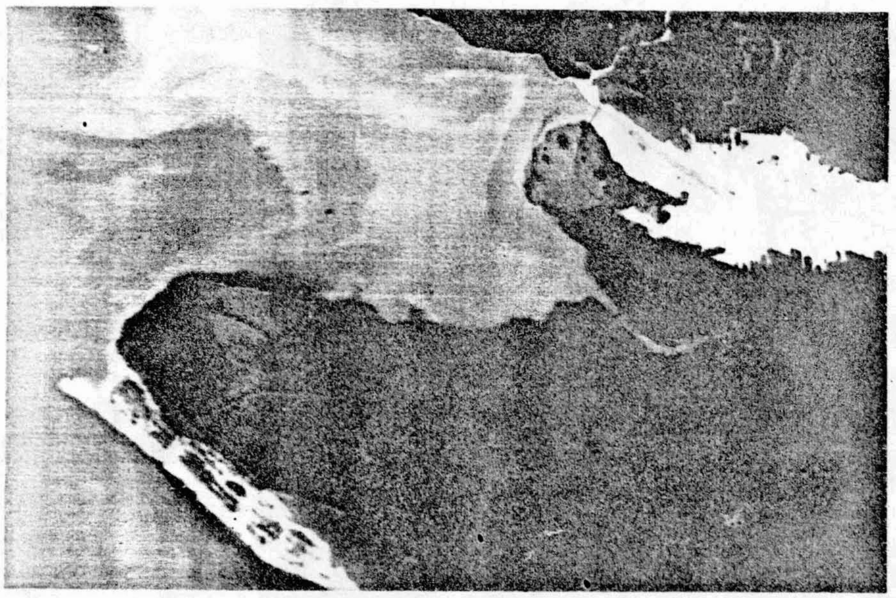


Figure 6b

Thermal scanner imagery of the same area as Figure 5a and 5b taken at the same times. Warmer areas (15^{o}C) are black and colder areas (11^{o}C), white. In Figure 5a the tide is ebbing, and in Figure 5b the flooding tide sends a jet of water into the colder Vancouver harbour.

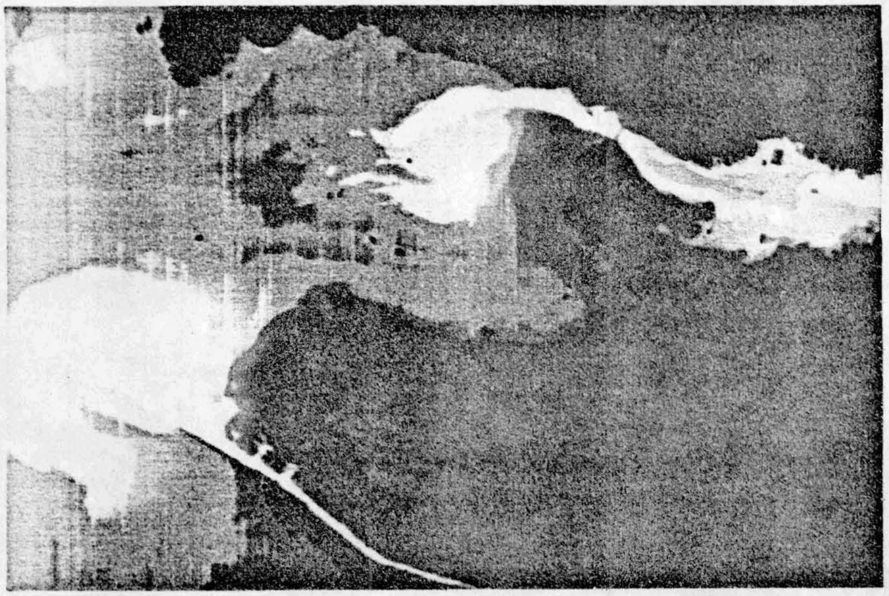


Figure 7a

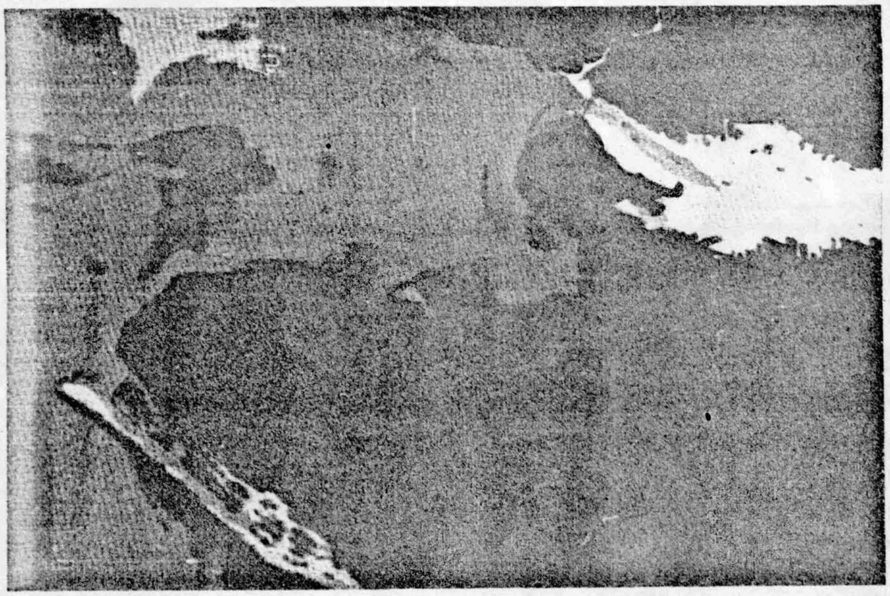


Figure 7b

The thermal scanner imagery of Figures 6a and b with the grey scales quantized at $0.6^{\circ}C$ intervals in Figure 7a and at $1.0^{\circ}C$ intervals in Figure 7b. The apparent temperatures corresponding to the different grey levels can be found from the known temperatures of the scanner's reference sources.

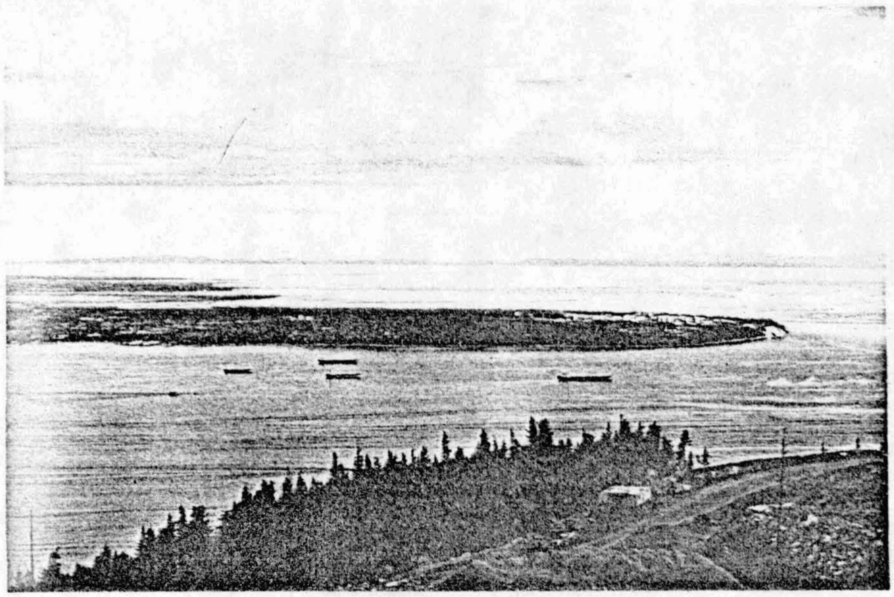


Figure 8. Ships moored in Burrard Inlet with their orientations indicating the incoming tidal current. Aerial photographs on past occasions have shown the presence of complex gyres in this area.

Figure 9. An oblique air photograph from 1500 ft. showing upwelling of mine tailings opposite Quatsino Narrows in Rupert Inlet.

Figure 10a. The balloon during inflation on the shore of Rupert Inlet.

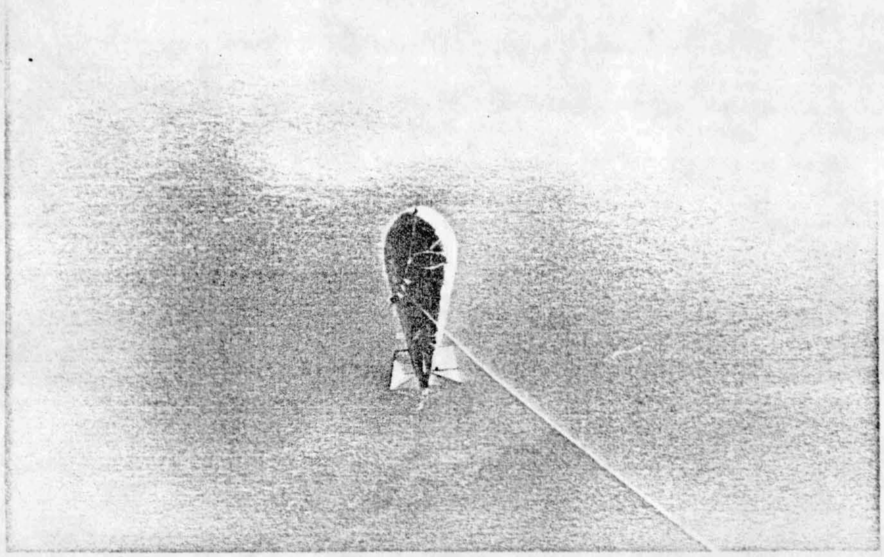


Figure 10b. The balloon flying overhead at 600 ft. altitude with the camera package (the small black rectangle) hanging underneath.

Figure 11a,b,c

A series of 3 photographs of the upwelling mine tailings in Rupert Inlet taken with a fisheye lens from the balloon at a height of 600 ft. These are part of a longer sequence taken at 10 minute intervals and covering most of the period of incoming tide.