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Atlas of SSM/I Satellite Ice Concentration Interpolated to Operational Ice Model Domains of the Arctic for 1993

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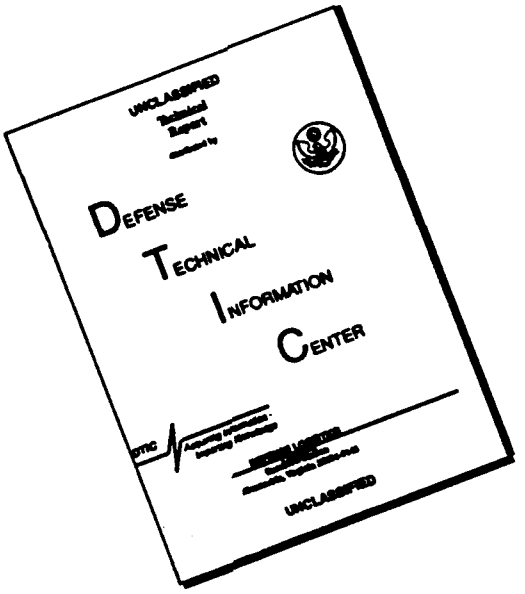

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13. Abstract *(Maximum 200 words).*

The Navy's Polar Ice Prediction System, which is run daily at the Fleet Numerical Meteorology and Oceanography Center (FNMOC), is initialized once each week from ice concentration data derived by the Navy/National Oceanic and Atmospheric Administration National Ice Center (formerly the Joint Ice Center). Ice concentration data, derived by applying the U.S. Navy's algorithm to the Defense Meteorological Satellite Program Special Sensor Microwave Imager (SSM/I) data, have been collected from FNMOC on a daily basis and archived at the Naval Research Laboratory. These data were then interpolated to the operational ice model grids for possible use as a real-time daily update to the operational forecast systems. Collection of data with coverage from the Pole southward to 20° N allows for the observation of ice concentrations for the entire Arctic region and surrounding coastal seas. SSM/I ice concentration data from 1993 are presented for each available day and on each of the operational model grids.

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ATLAS OF SSM/I SATELLITE ICE CONCENTRATION INTERPOLATED TO OPERATIONAL ICE MODEL DOMAINS OF THE ARCTIC FOR 1993

INTRODUCTION

Ice concentration data from the Defense Meteorological Satellite Program Special Sensor Microwave Imager (SSM/I) have been interpolated to the ice model grids of the Navy's Polar Ice Prediction System (PIPS) with the intention of using these concentrations for regular updating of the ice models. These systems are run daily at the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and are currently updated once per week using a digitized data set of ice concentration supplied by the Navy/National Oceanic and Atmospheric Administration National Ice Center (NIC) (formerly the Joint Ice Center). Although the NIC's ice concentration analysis is generated on Wednesday, the information is not usually ready for use by PIPS until Friday, resulting in an update that is 2 days old. The optimal situation would be to have initialization data available daily, as opposed to weekly. SSM/I ice concentration data provides this capability.

DATA

The Naval Research Laboratory (NRL) has been collecting and archiving SSM/I satellite ice concentration data since May 1991 (Lundeen et al. 1993). Ice concentration values are derived from SSM/I brightness temperatures by applying the U.S. Navy's ice concentration algorithm. This algorithm is a streamlined version of the AES/York algorithm as described in Hollinger (1991). NRL collects the data from FNMOC's Environmental Data Repository via an automated data program that retrieves the data from satellite passes or swaths at approximately 25-km resolution. Data values are placed into the repository continuously and are removed after they are approximately 24 h old. Initially the coverage retrieved by NRL was only large enough to cover the PIPS domain, extending from the Pole down to approximately 60°N. In March 1993, coverage was expanded down to 40°N to gain a more complete coverage of the ice forming in the marginal seas, including the Sea of Okhotsk, Hudson Bay, the Labrador Sea, and the Gulf of St. Lawrence. In October 1993, the coverage was extended to 20°N to include coverage of ice forming in the Bohai Bay region. NRL accesses these data files twice per day. The files previously accessed at 1100 and 2300 Pacific Standard Time, were shifted to 1600 and 0400 to provide a more complete data set. Two files together provide sufficient coverage of the Arctic polar region, as well as the marginal seas. The files are large, containing 200,000 to 400,000 data points per file.

INTERPOLATION

Interpolation programs have been generated for each of the operational ice model domains, PIPS (Preller 1985; Preller and Posey 1989), the Regional Polar Ice Prediction System - Barents Sea (RPIPS-B) (Preller et al. 1989), the Regional Polar Ice Prediction System - Greenland Sea (RPIPS-G) (Preller et al. 1990). An interpolation program has also been generated for the domain of the PIPS2.0 ice model (Cheng and Preller 1992) upgrade to PIPS, which is currently undergoing final testing and evaluation at NRL. Since the beginning of 1993, interpolation to the PIPS2.0 model domain has been run on a 360 by 360 grid for improved resolution. All of the interpolation programs work in a similar manner. The SSM/I data files are read in, with the data point latitude and longitude converted to model domain grid point values and the SSM/I ice

concentration values converted to percentages of total ice cover varying from 0 to 100%. The data are then interpolated using a closest point scheme. Those data values which fall within a prescribed distance from the model grid point, are summed and then averaged for an ice concentration at that point. The resolution of the interpolated data are the same as the ice models which is 127 km for PIPS (Fig. 1), 25 km for RPIPS-B (Fig. 2), 20 km for RPIPS-G (Fig. 3) and 17-33 km for PIPS 2.0 (Fig. 4) (this model domain is in spatially varying spherical coordinates).

PROBLEMS

Interpolating the SSM/I data presented several problems most of which were correctable. Early on, it was noted that some of the ice concentration values were indeterminate and some values read greater than 100% concentration. Indeterminate values were removed without any significant loss of coverage due to the large amount of data available. Ice concentrations greater than 100% were reduced to 100%. Another problem was the data void region from 88 to 90°N resulting from the orbit of the satellite. For this region, 100% ice concentration is assumed during interpolation.

Even though two data files provide sufficient coverage for 1 day, there still might be gaps in information due to a variety of causes such as transmission loss, program failure, truncation of the data file, and failure in the data link between FNMOC and NRL. To make SSM/I data useful in regularly updating the ice models, gaps in the data are replaced with the previous day's data. Substitution occurs when zero ice concentration is found at a data point that had 50% ice concentration or higher the previous day. The previous day's values then replace the zero values of the current day. This ensures a smooth continuous ice field from one day to the next.

Another problem was that of spurious ice concentration values in areas where no ice should exist. These values often appear in one of the following forms. As the satellite transitions from land to water, small or low concentrations along the shore may occur. This problem is mostly corrected by converting all ice concentrations below 20% equivalent to zero. The data are adjusted in this way for use in the numerical models. Values less than 15% are treated as open water by the models. Small arcs of concentration may occur mainly in the Greenland and Labrador Seas and occasionally in the Sea of Okhotsk. These arcs are easily distinguishable from the real ice concentrations and their occurrence may be related to passing storms. Another problem was discovered when the coverage was extended to 40°N. Ice would occur in regions between 40 and 60°N in the Sea of Japan, the Pacific Ocean, and the Grand Banks area of the Atlantic Ocean during the summer months from May to the beginning of October. The reason for these erroneous values is unknown at this time but may be due to the treatment of cloud cover and storms in the ice concentration algorithm. Much of this problem has been corrected through the use of monthly ice-ocean masks based on climatology provided by the NIC (Wohl, personal communication). These monthly masks exclude ice in areas that should be climatologically ice free.

To adjust small gaps in the ice concentration data, which results from slight differences between the SSM/I algorithm land boundaries and the ice model land boundaries, a correction routine was added to fill in these gaps with ice concentrations from surrounding grid points. These corrections were to insure the compatibility of the ice model and the SSM/I data in the model initialization process.

RESULTS

The following pages show the results of interpolated SSM/I data for 1993. An interpolation was performed for each day that sufficient data was available. The date appears at the upper right corner in date-time-group format displaying the year, month, day, and hour (always 00 in these plots) in two-digit pairs. The color bar identifies ice concentrations from 20 to 100% in increments of 10%. Each date available for 1993 contains three plots of ice concentration arranged on one page. The top plot is the PIPS 2.0 model domain. The two lower plots are the regional Greenland Sea and Barents Sea model domains. The appearance of spurious ice concentrations was largely corrected through the use of the monthly masks previously mentioned. However, some small amounts of spurious ice located inside of the masks did occur from time to time including the presence of ice arcs in the Greenland Sea. These false ice concentrations are still distinguishable from the real ice on the plot. The following paragraphs contain descriptions of the data based on the results of the interpolations.

The winter months of January, February, and March are a period of ice growth in the Arctic and marginal seas, which is reflected in the SSM/I data. At the beginning of the year, ice is present in the central Arctic and all of the marginal seas including the Greenland, Barents, Kara, Okhotsk, Bering and Labrador Seas, as well as the Gulf of St. Lawrence. The ice sheet continues to gradually expand. Leads appear and disappear in the Kara Sea in a matter of days, most likely tied to major weather events in the area. By the middle of January, ice is filling in the Gulf of St. Lawrence. A tongue of ice called an Odden has begun to form in the Greenland Sea. The Odden will be present, expanding and receding for the next 3 months. On the 20th of January, the Odden is very prominent. The 8th through the 16th and the 21st through 23rd of January display the spurious ice concentration arc in the Greenland Sea and should not be confused with the real ice edge.

By the beginning of February, the ice has continued to expand in the marginal seas. The Gulf of St. Lawrence is completely ice covered. The ice sheet in the Barents Sea is expanding over a broad area. On the 3rd of February, part of the Odden has become detached from the ice pack. A lead around Franz Joseph Land opens and closes. Leads appear from time to time in the marginal seas like the ones in the Bering Sea off the coasts of Alaska and Siberia. There are occasional large scale reductions in ice concentrations at the ice edge such as in the Labrador Sea on the 14th of February. There is a semipermanent feature in the Barents Sea off the coast of Novaya Zemlya that oscillates from open to almost closed during the month. On the 25th of February, it appears that a large weather system has opened up leads in the Kara and Barents Seas that will close by the end of the month.

Early March is the period of maximum ice extent for the Arctic and the marginal seas. The 8th of March is a representative example of the ice maximum. Besides the central Arctic much of the Sea of Okhotsk, the Bering and the Labrador Seas, and the Gulf of St. Lawrence are filled with ice. This period is also marked with the presence of very few leads in the ice. By the middle of the month the Odden has reformed, and the first signs of ice receding in the Sea of Okhotsk appear. Toward the end of the month more leads begin to show in the marginal seas (see March 27th). Leads are present in the Labrador Sea, the Bering Sea, and the Gulf of St. Lawrence, and the ice edge has receded somewhat.

April is marked by a reduction of ice concentration in the marginal seas, especially in the Sea of Okhotsk, the Bering and the Labrador Seas and the Gulf of St. Lawrence. The ice in the Barents Sea will continue to recede and expand along the ice edge. On the 9th, a lead has opened

in the Kara Sea and a remnant of the Odden still exists as an isolated patch of ice in the Greenland Sea. Toward the end of the month much of the ice is gone from the Gulf of St. Lawrence, the Sea of Okhotsk, and the Bering Sea.

During May, the melting of ice in the marginal seas continues to occur. Leads begin to form at the perimeter of the Arctic ice pack. The ice in the Labrador Sea has receded above Newfoundland and away from the southern Greenland coast. By the 5th, leads have formed in the Laptev Sea off the coast of Russia, in the Amundsen Gulf of the Beaufort Sea off the coast of Canada, and in Hudson Bay along the south western shoreline. On the 10th, the ice has almost melted back to the Bering Straits with small amounts of ice remaining in the Bering Sea and the Sea of Okhotsk. A new lead forms on the eastern side of Hudson Bay. Through the rest of the month new leads continue to form and the ice edge recedes. However the ice in the Kara and Barents Seas remains nearly unchanged.

At the beginning of June, the interpolation program was altered to fill in minor gaps in SSM/I data due to the slight differences between ice model land and SSM/I land mentioned earlier. During the first part of June, leads already present continue to expand and new leads form. The Labrador Sea is almost ice free with the ice receding into Baffin Bay. The Bering Straits are open and the Bering Sea and the Sea of Okhotsk are ice free. The ice edge in the Kara and Barents Seas is receding. Toward the later part of June, ice melting continues to accelerate with the Beaufort, Chukchi, and Laptev Seas opening up. The ice along the southern coast of Greenland has receded. Melting is continuing in Hudson Bay and beginning in Baffin Bay (see June 25th).

The month of July is marked by accelerated ice melt and retreat of the central ice pack in the Arctic. The retreat of the ice pack is away from the Siberian and Alaskan coast lines toward the north pole. By the middle of the month, Hudson Bay is almost ice free and only a small amount remains in Baffin Bay. Ice along the southern Greenland coast has almost disappeared. The Alaskan coastline is nearly ice free. A large area of open water has formed off Ostrova Anzou in the Laptev Sea while part of the Siberian coast remains ice bound. By the latter part of the month (see July 25th), much of the Alaskan and Siberian coastline are ice free except for an area in the Laptev Sea. The ice present in the lower Hudson Bay is not real and is part of the problem mentioned previously. By this time, little ice remains in the Kara and Barents Seas as well.

The melting of the central ice pack continues in August. The Chukchi, Beaufort, and East Siberian Seas are open. Little ice remains in the Barents and Kara Seas. By the 10th, the Siberian coastline is almost completely ice free except for some ice in the Laptev Sea. Only small remnants of ice remain in Baffin Bay. Leads have begun to form in the central ice pack. By the latter part of August the ice pack has reached its minimum. Ice only remains in the central Arctic and along the northern Greenland coast. The leads that appeared in the central ice pack have begun to close.

September is marked by a gradual expansion of the central ice pack especially into the Beaufort, Chukchi, and East Siberian Seas. On the 11th, a semipermanent lead near the northern coast of Greenland has begun to close.

October is marked by more accelerated ice growth. The ice pack along the Greenland coast has begun to expand out into the Greenland Sea and move southward along the Greenland coast. There is a rapid expansion of ice in the Barents Sea. Ice in to the Kara Sea begins to expand from the east. Toward the end of the month, ice appears in the northern part of Hudson Bay and begins expanding southward into Baffin Bay. A large part of the Beaufort and Chukchi Seas is ice covered.

In the early part of November, expansion of the ice sheet continues filling in the open water areas of the Arctic. Portions of the Kara and Chukchi Seas, and the Amundsen Gulf (part of the Beaufort Sea) are still open. By the middle of the month (see the 10th), the Beaufort and the Kara Seas are completely ice covered and ice has begun to grow in the northern part of Hudson Bay. Ice in Baffin Bay is starting to extend through the Davis Straits into the Labrador Sea. In the mid to latter part of the month, atmospheric conditions apparently caused ice in the Barents and Kara Seas to recede. By the end of the month, Svalbard is ice free. During this time, ice covers the Chukchi Sea to the Bering Straits by the 20th. On the 26th, ice has begun to appear in the Sea of Okhotsk and Bering Sea. Hudson Bay is nearly covered with ice.

December marks the continued growth of ice in the marginal seas such as the Sea of Okhotsk, the Bering, and the Labrador Seas. By the 14th, the Kara Sea is again ice covered. Ice is present along the Greenland coastline down to the southern tip. Hudson Bay is completely ice covered. Leads along the coast of Alaska appear. By the end of the month the ice has expanded to cover the central Arctic and is present in all of the marginal areas including the Gulf of St. Lawrence, which shows ice for the first time since last winter. Ice has also formed near Murmansk. In the Sea of Okhotsk, the ice is extending southward along the Kamchatka Peninsula and Sakhalin Island. In comparing this ice coverage with the beginning of the year the coverage appears to be about the same with the exception of slightly less ice in the Greenland and the Labrador seas and more in the Barents Sea and the Sea of Okhotsk.

The SSM/I data presented in this atlas will be helpful in updating and improving the ice model's performance. The SSM/I data shown here indicate that large variations in ice concentrations occur over both periods greater than and less than a week. The short time scale variations (i.e., leads) might be missed by weekly updates with the NIC analysis. Having the data available in real time at FNMOC will allow for real-time updates to the ice model systems and more accurate forecasts.

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PIPS MODEL GRID

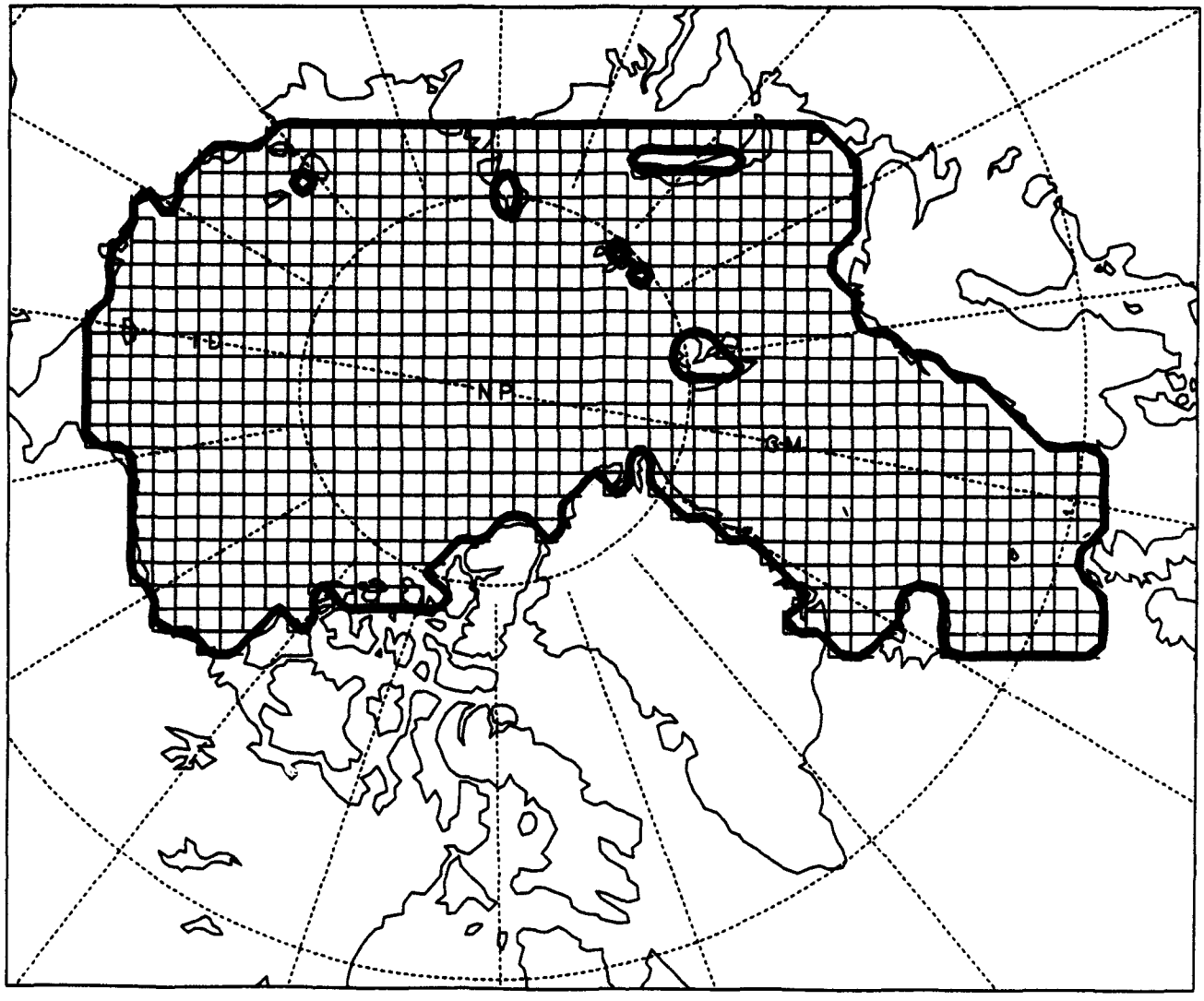

Figure 1. PIPS domain with the 127-km resolution grid overlaid.

RPIPS-B MODEL GRID

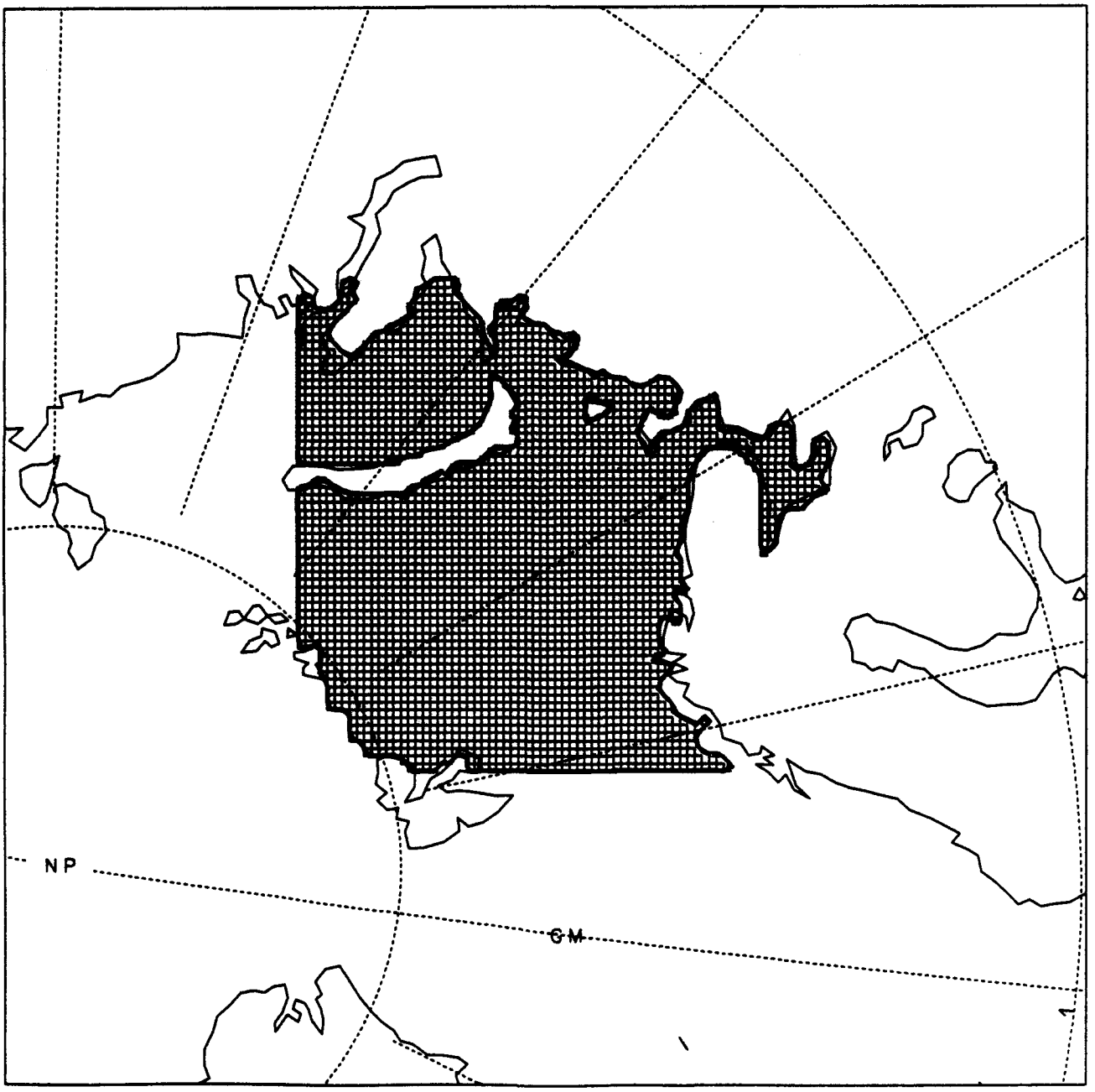

Figure 2. RPIPS-B domain with the 25-km resolution grid overlaid.

RPIPS-G MODEL GRID

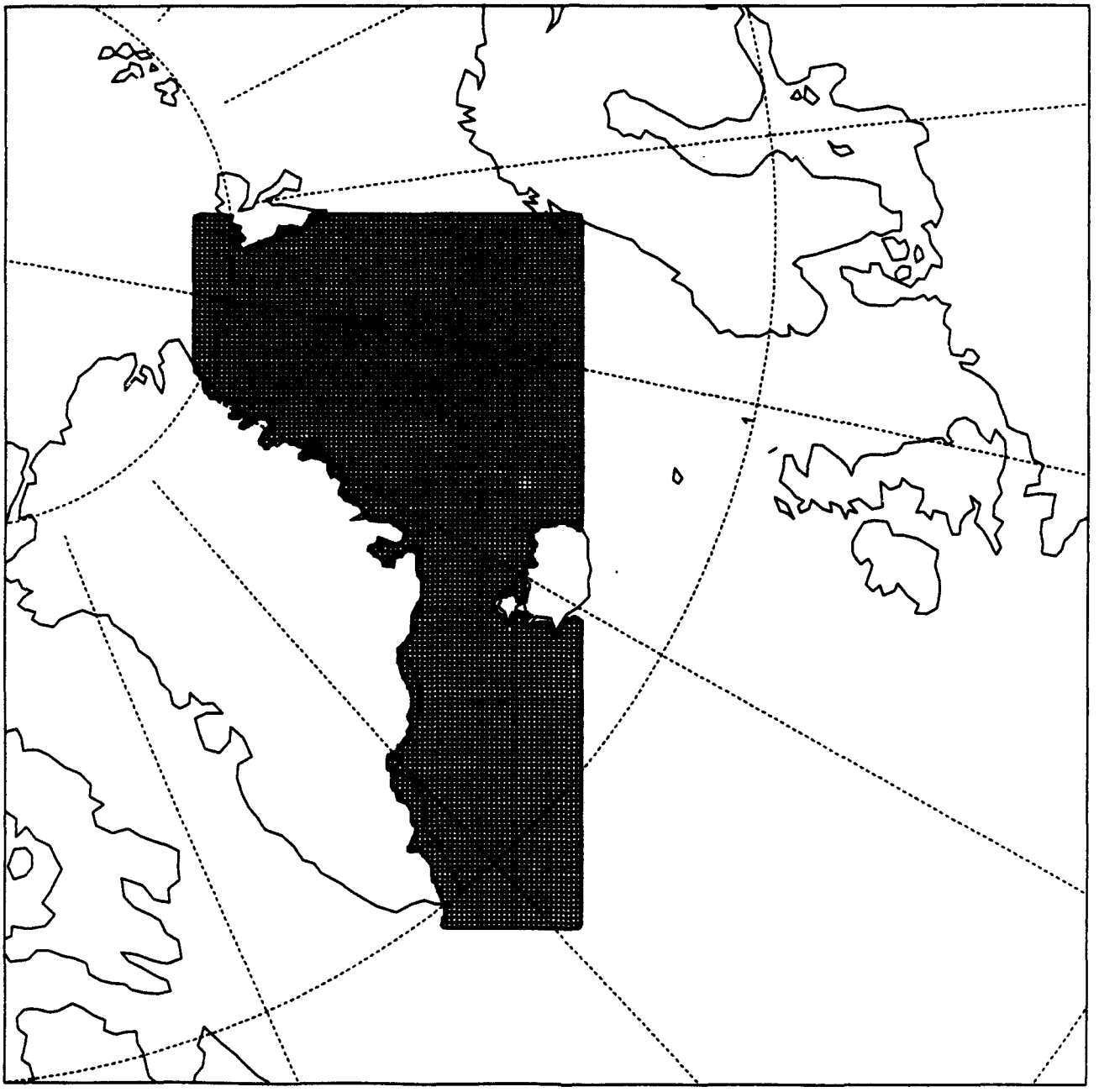

Figure 3. RPIPS-G domain with the 20-km resolution grid overlaid.

PIPS2.0 MODEL GRID

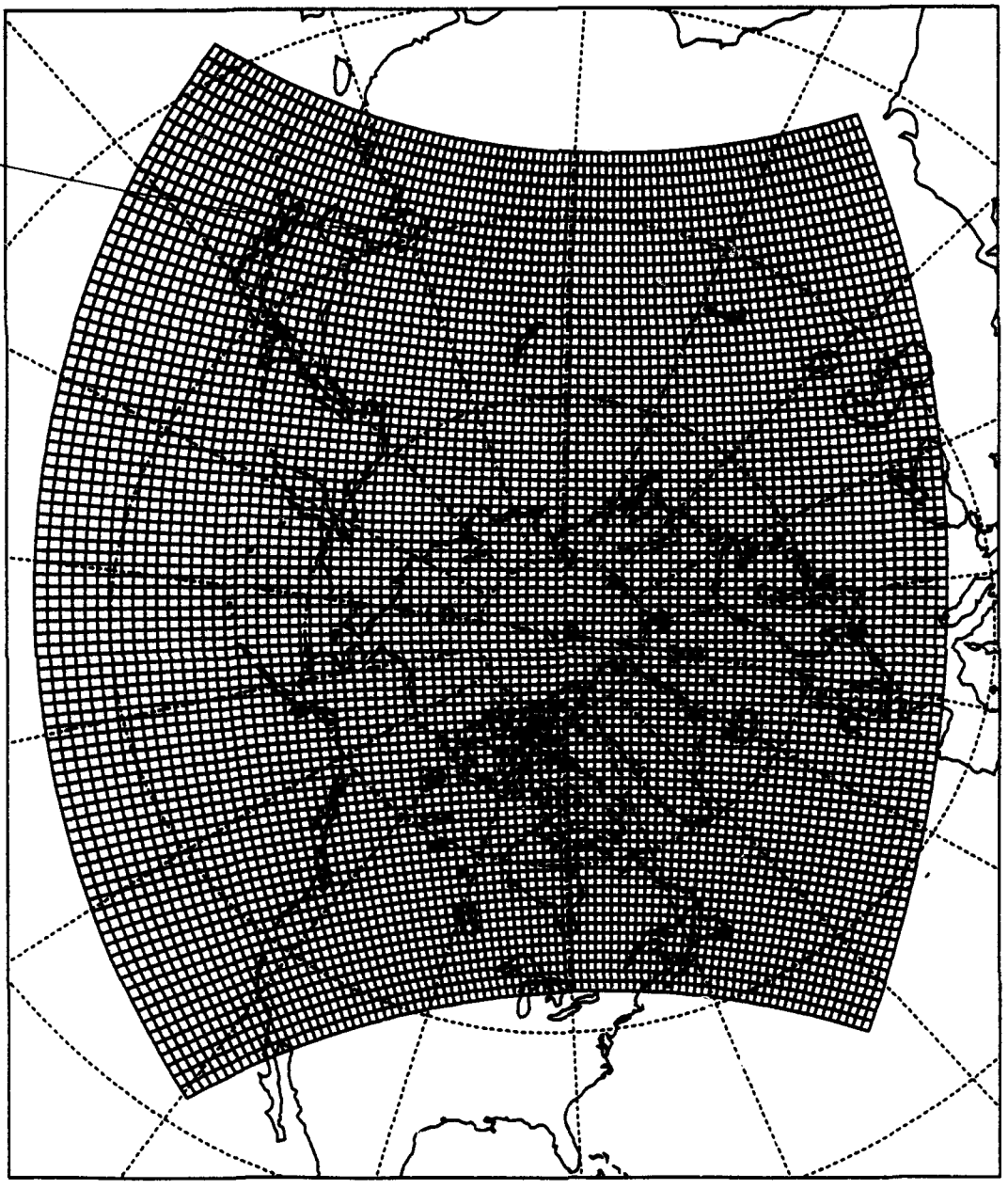

Figure 4. PIPS2.0 domain with the variable resolution grid overlaid. The hatched lines are drawn at every fourth grid point including land points.

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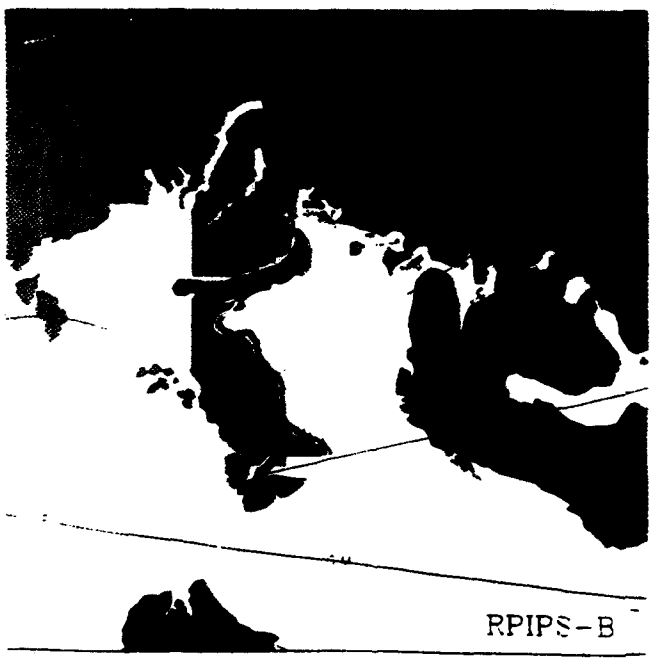

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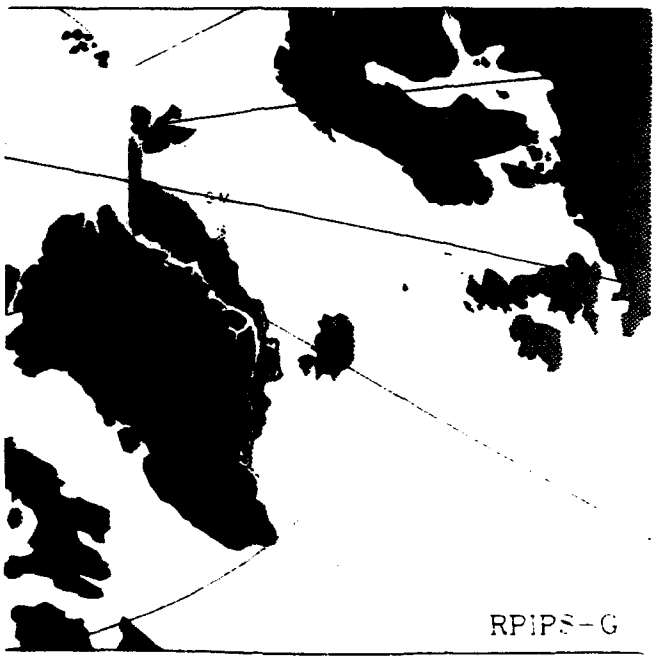

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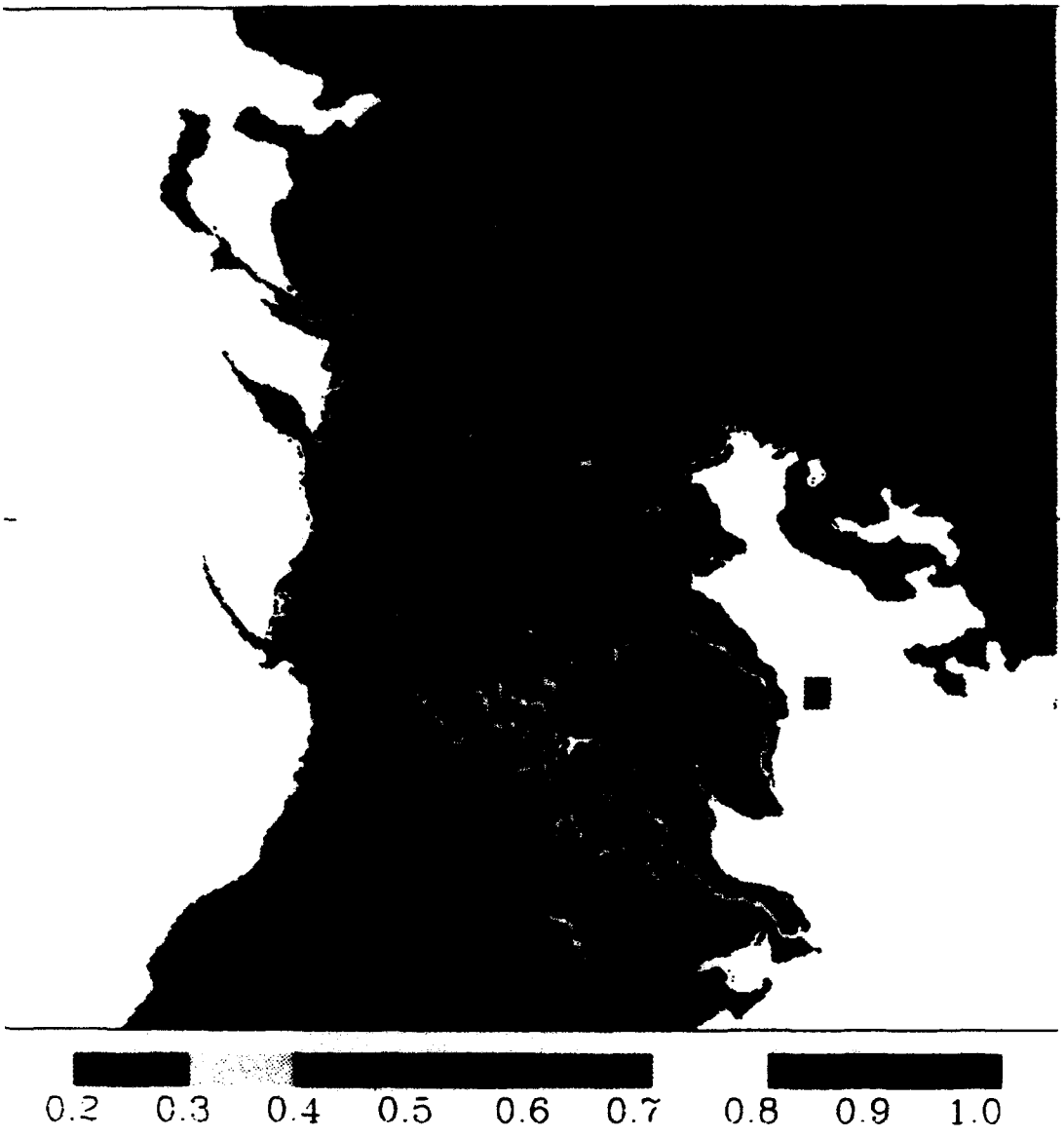

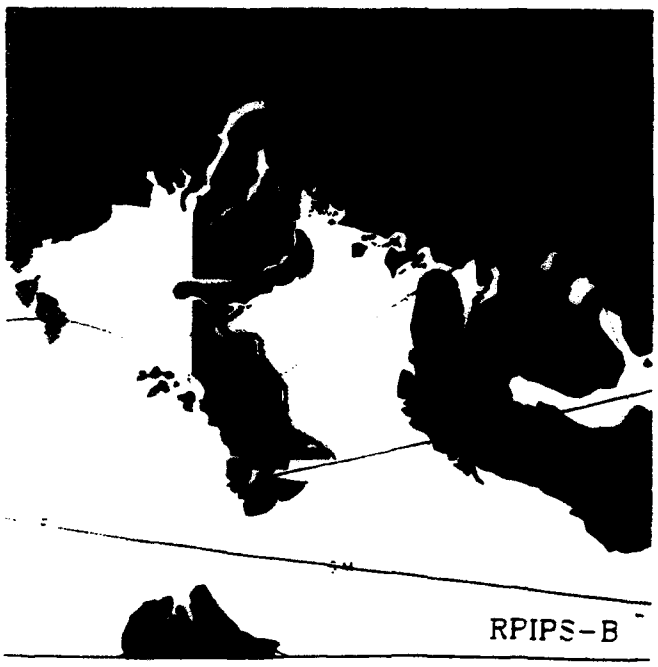

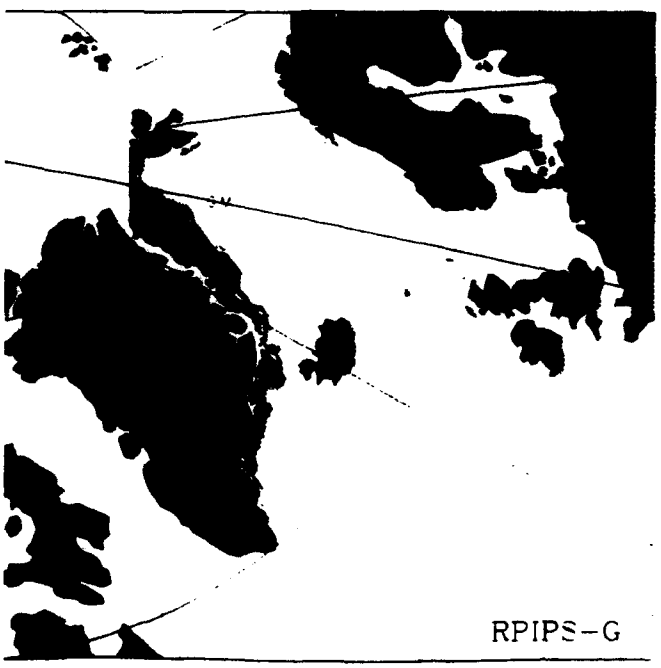

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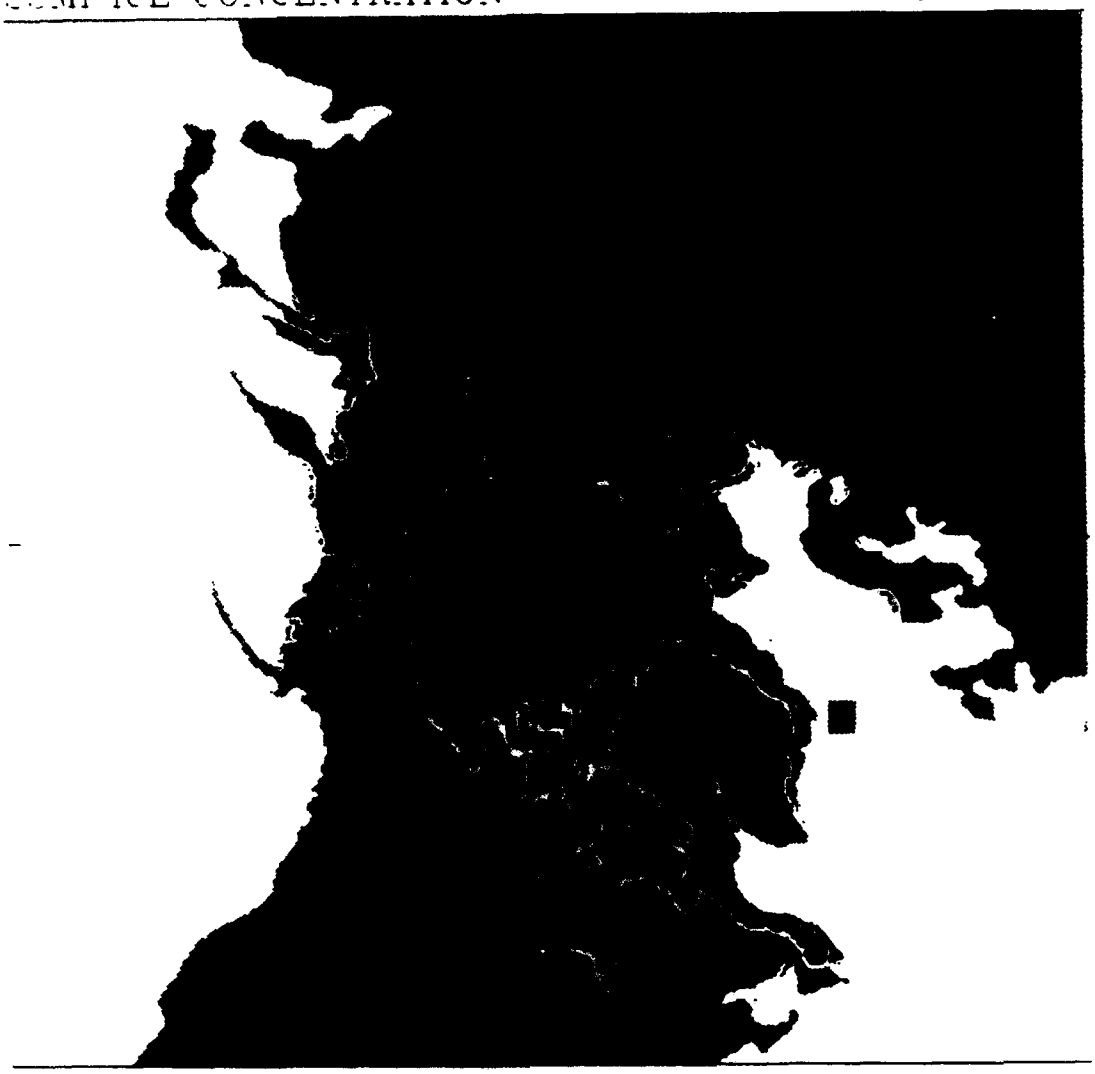

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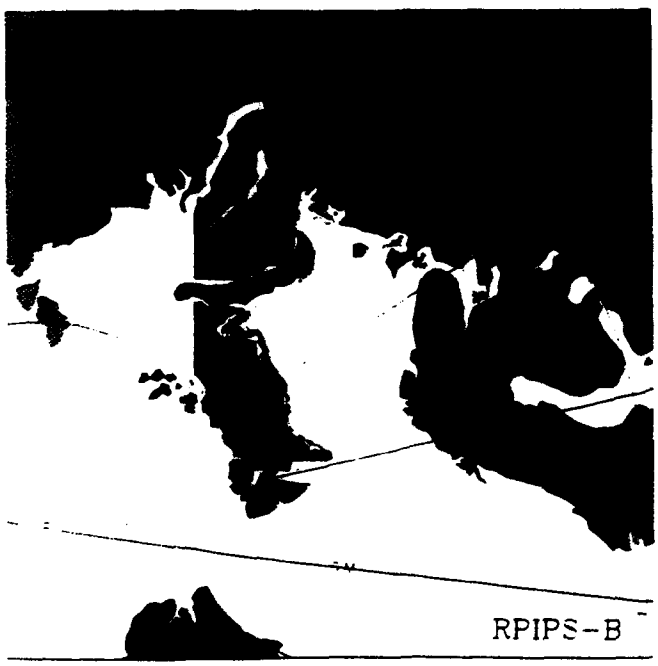

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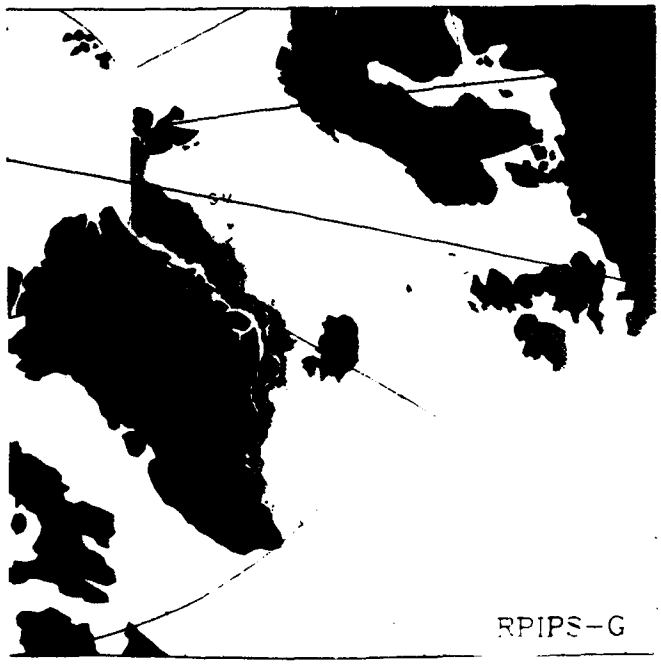

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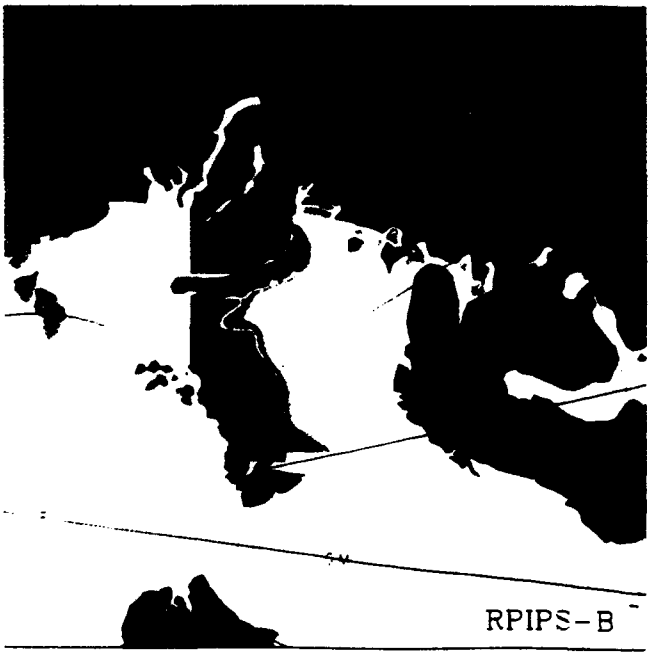

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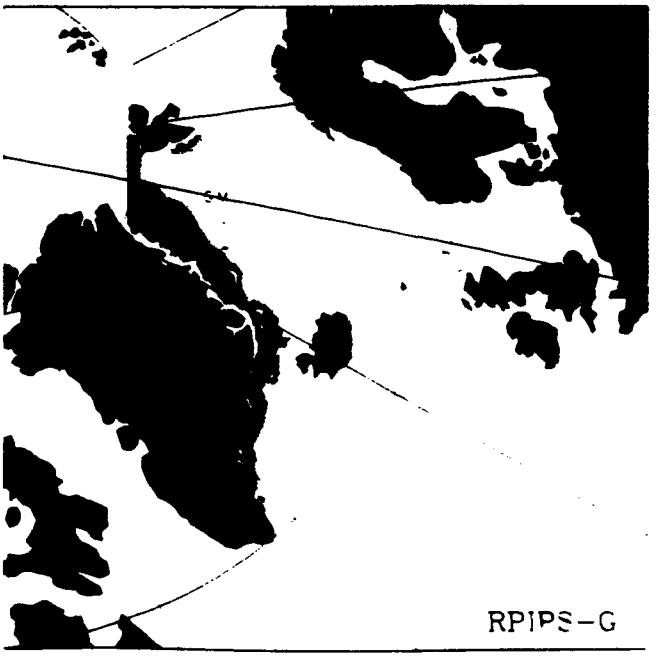

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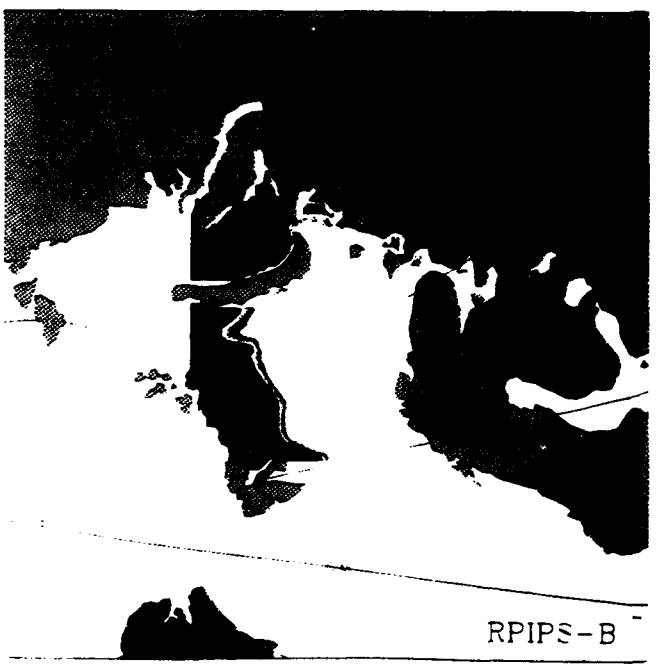
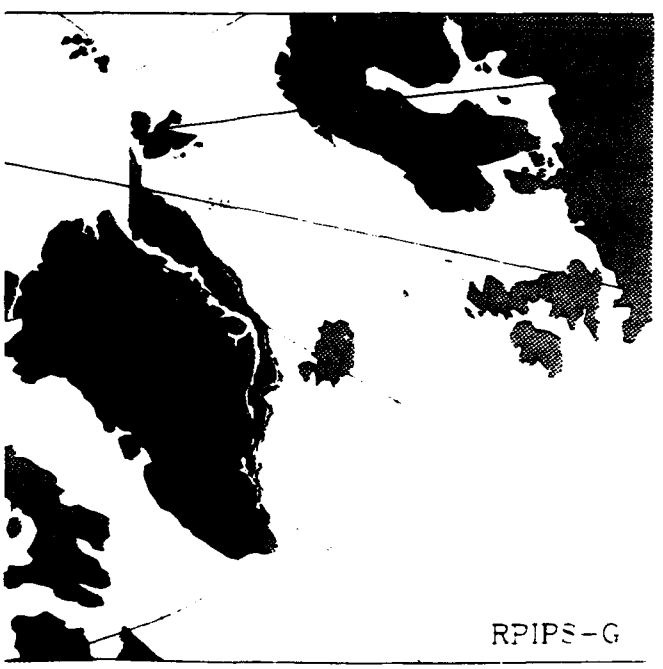


RPIPS-B



RPIPS-G

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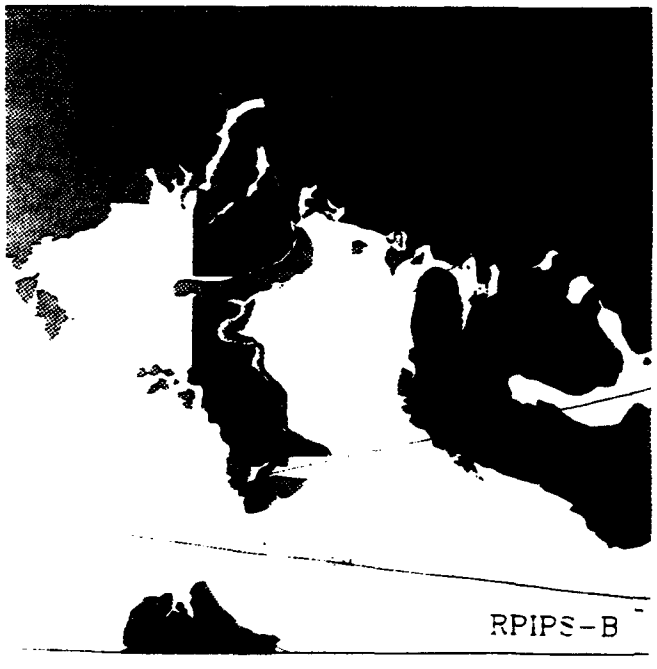
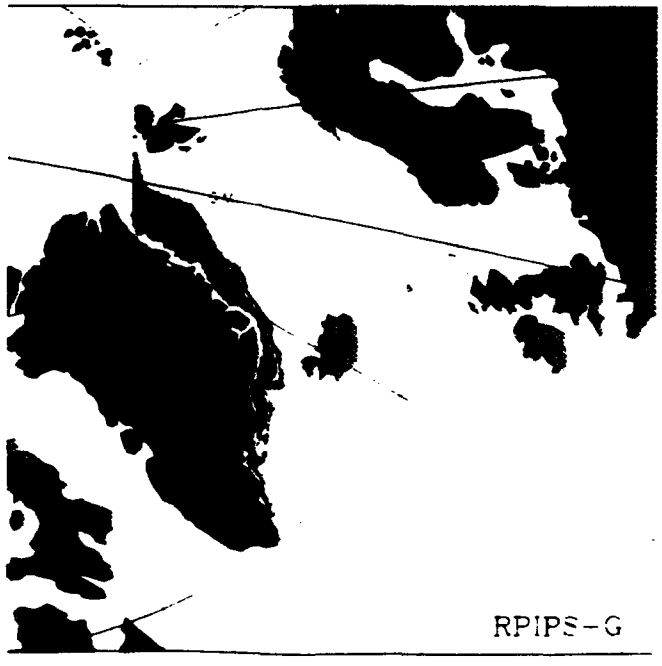
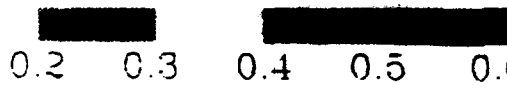
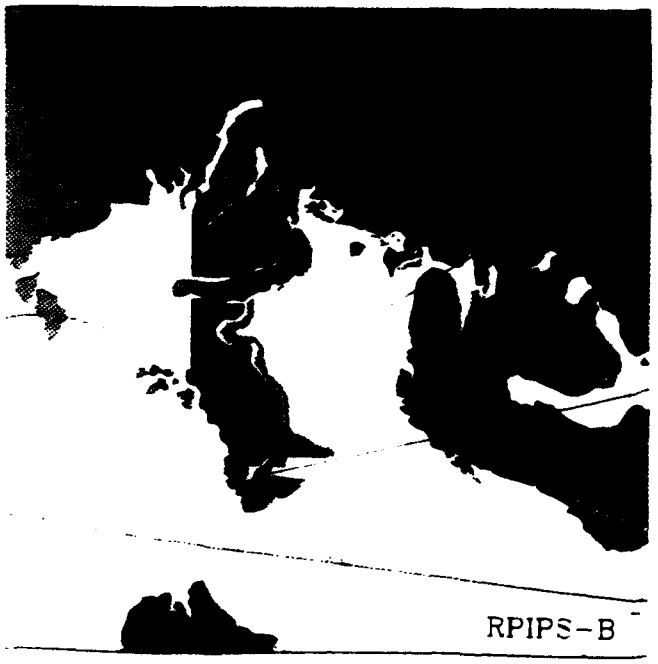
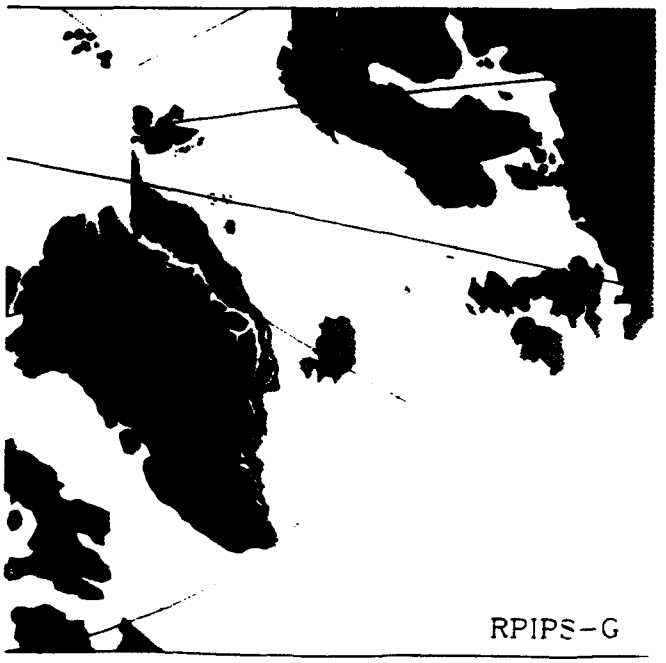




SSMI ICE CONCENTRATION 93010700







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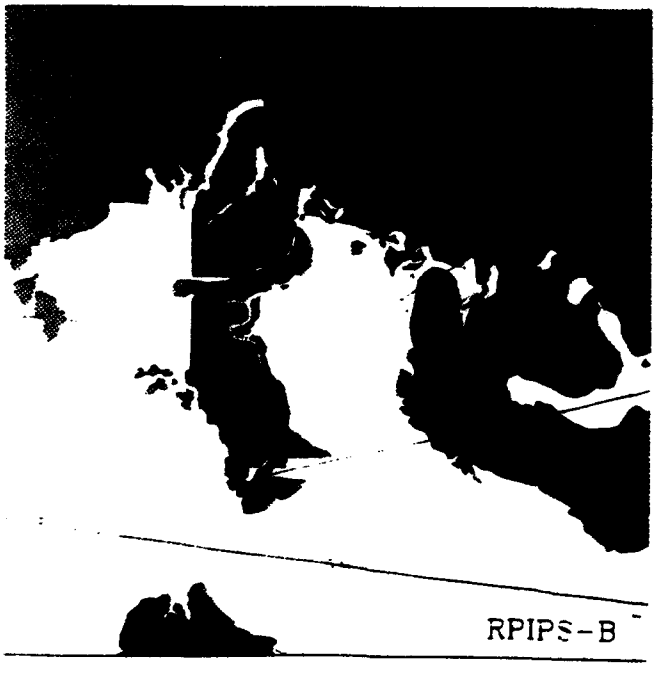
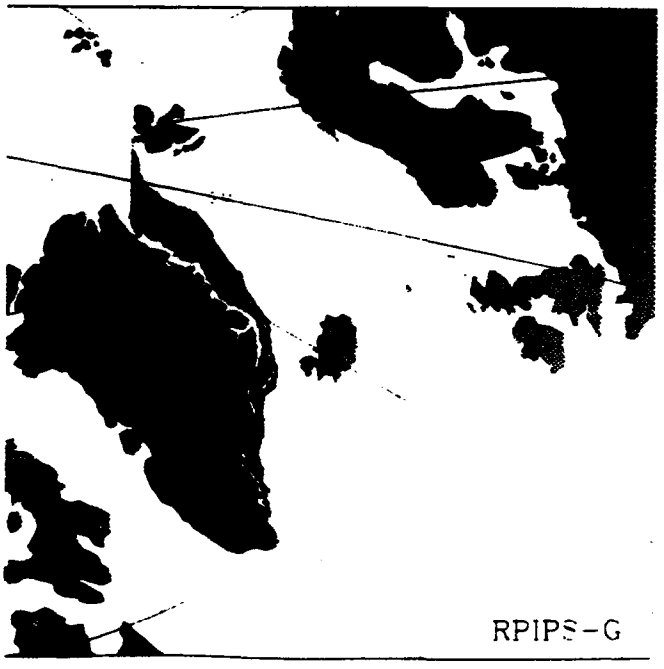


RPIPS-B



RPIPS-G

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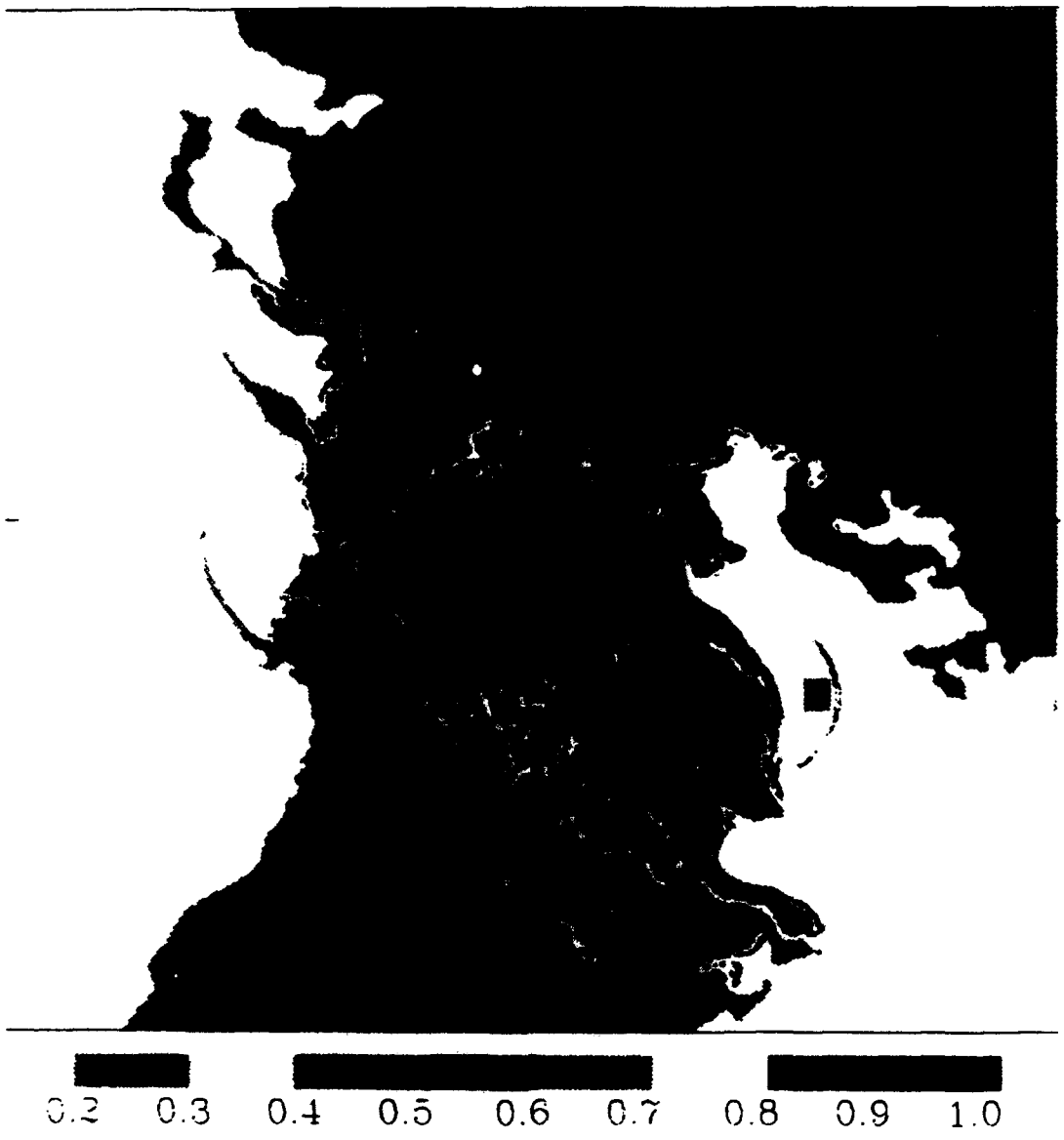

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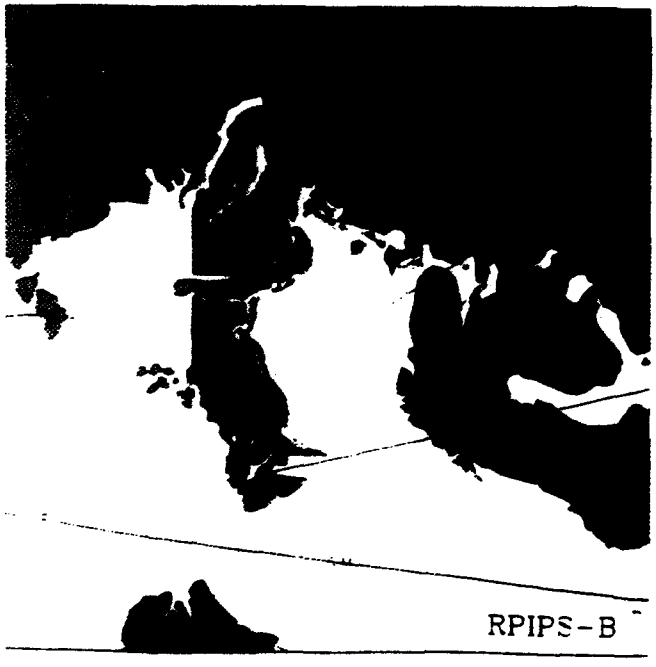

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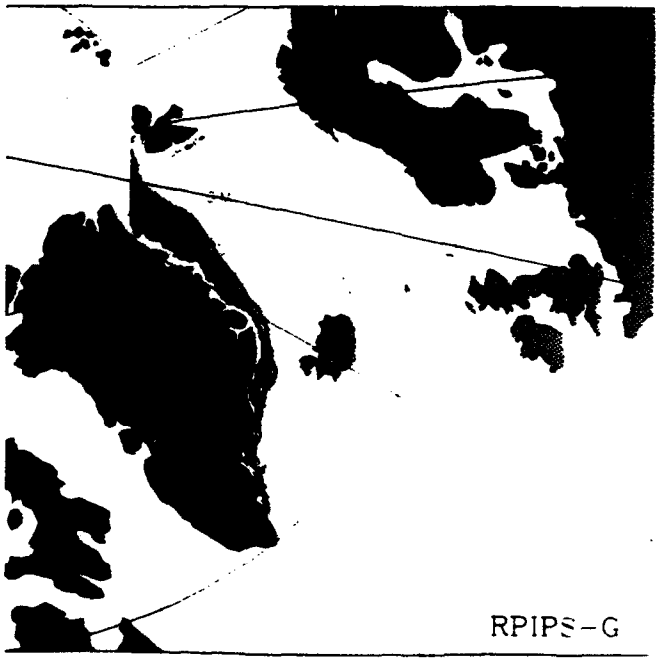

RPIPS-G

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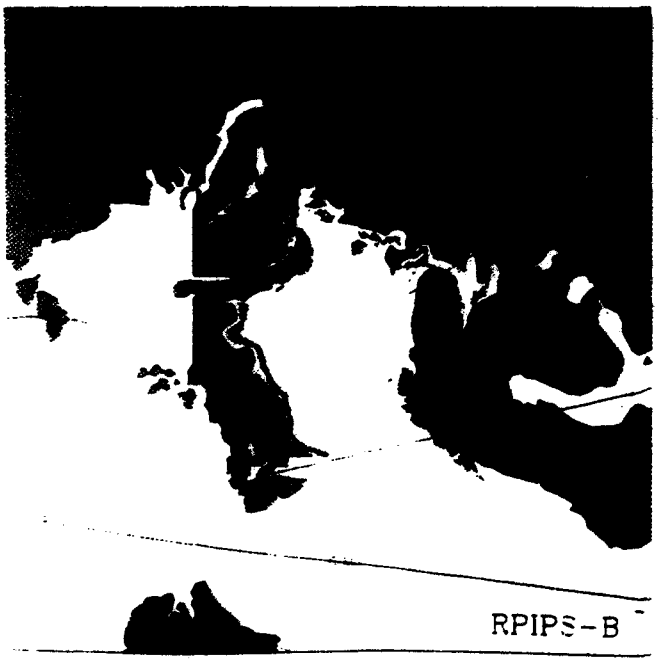
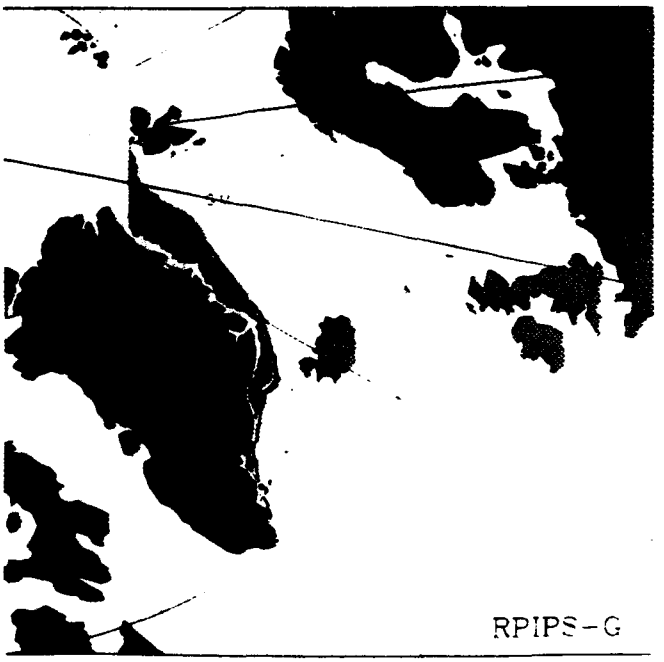


RPIPS-B



RPIPS-G

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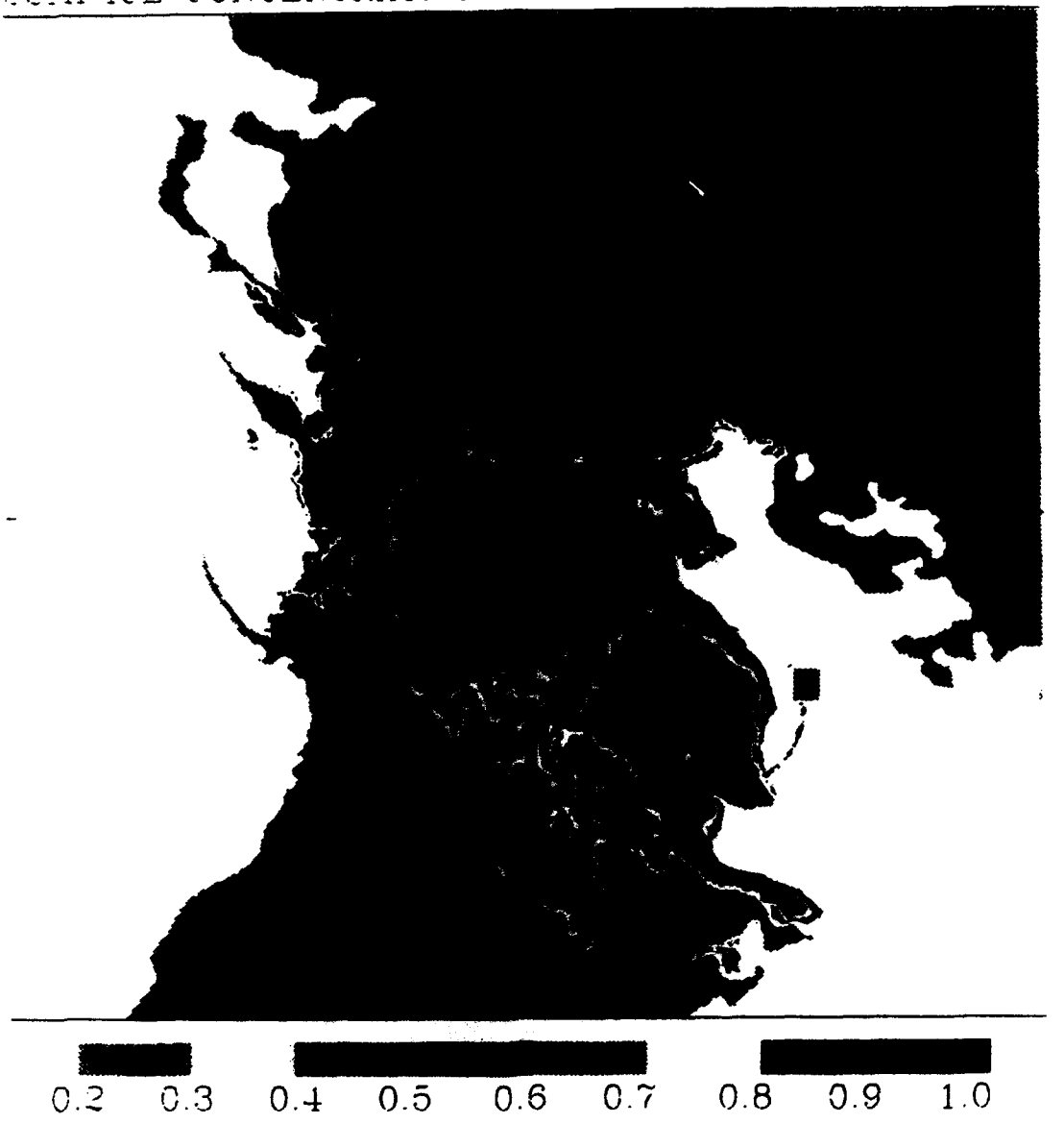

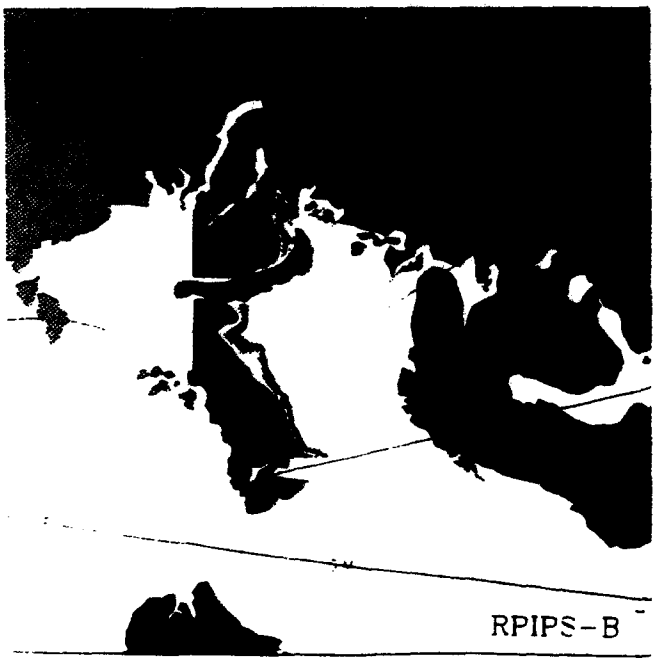

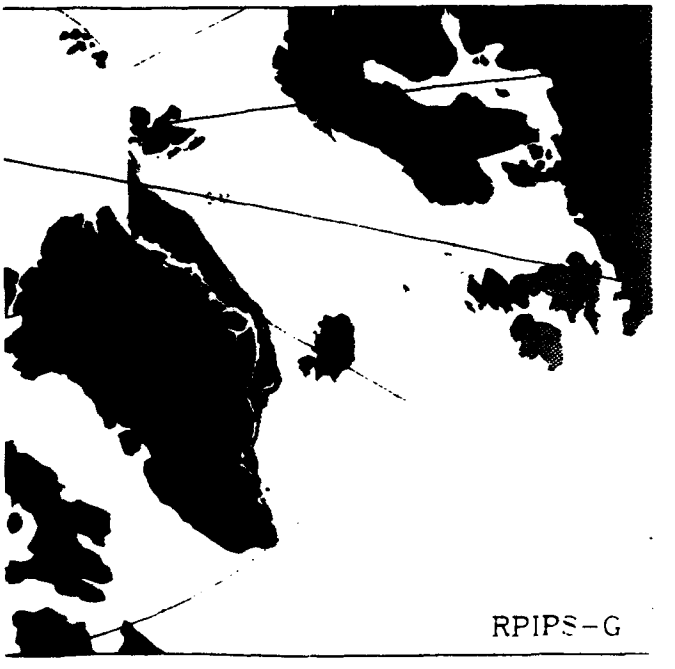

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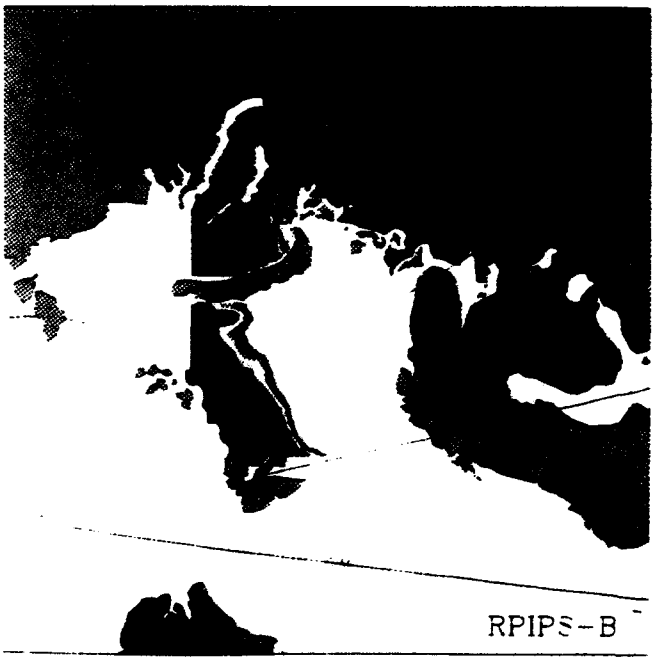

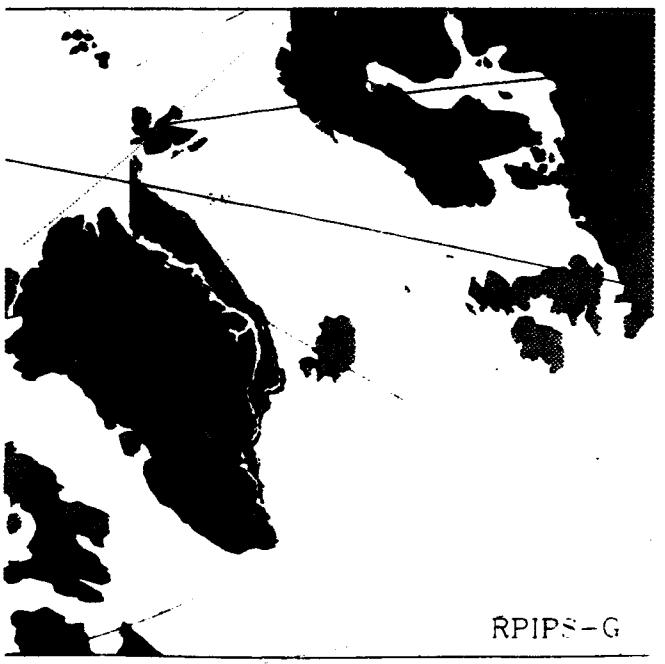

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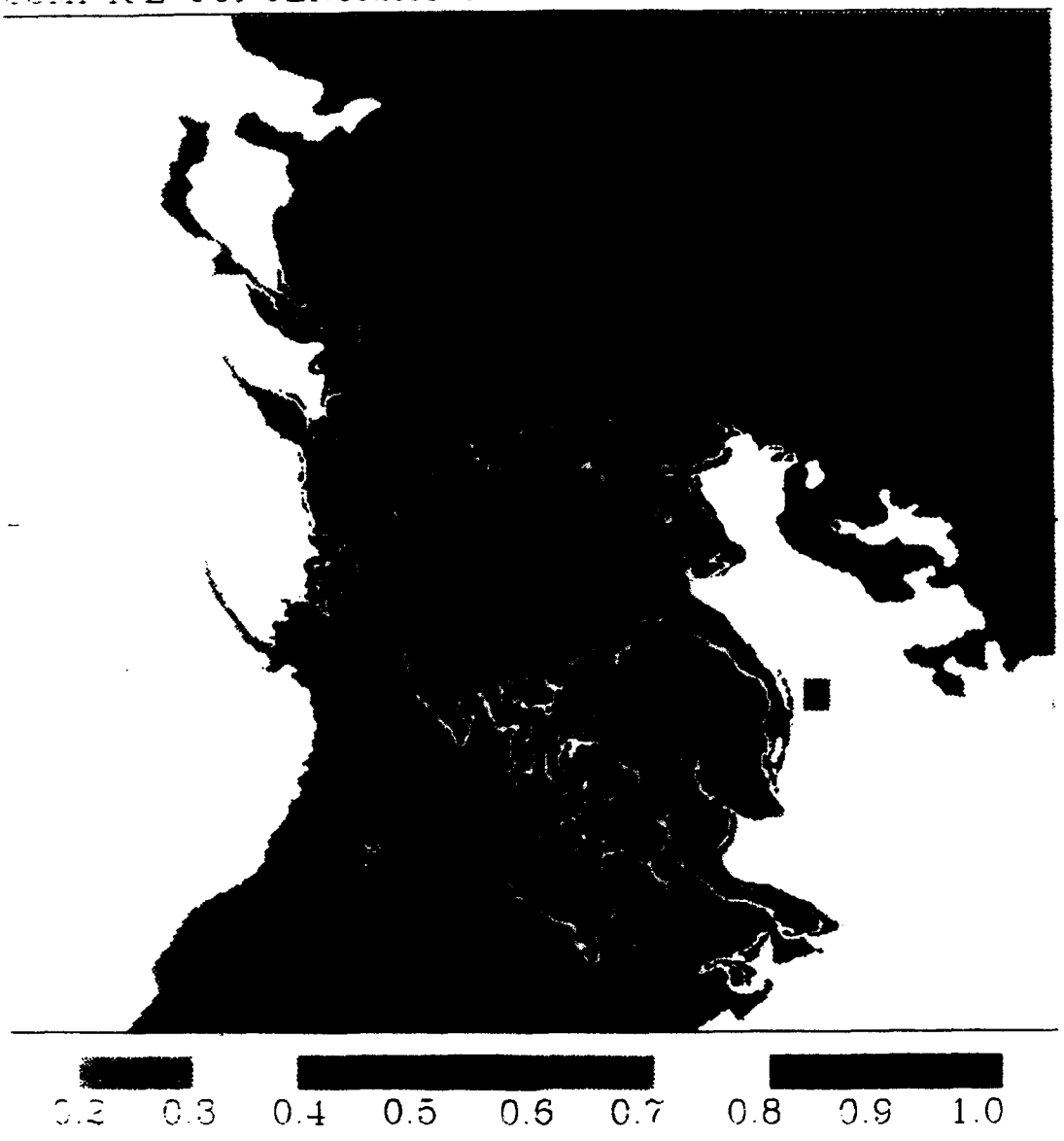

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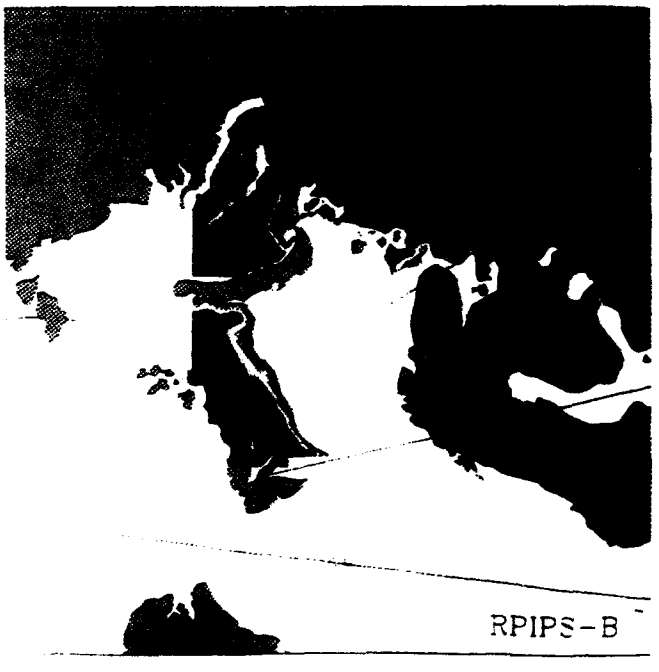

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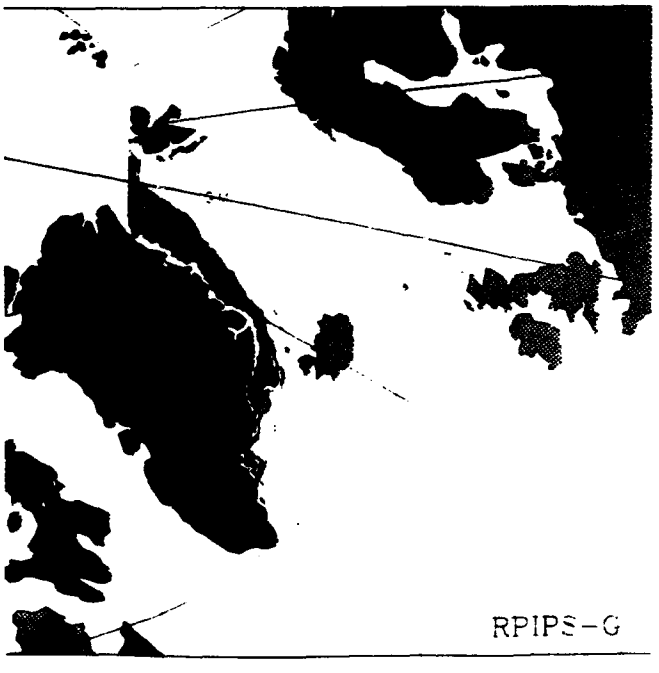

RPIPS-G

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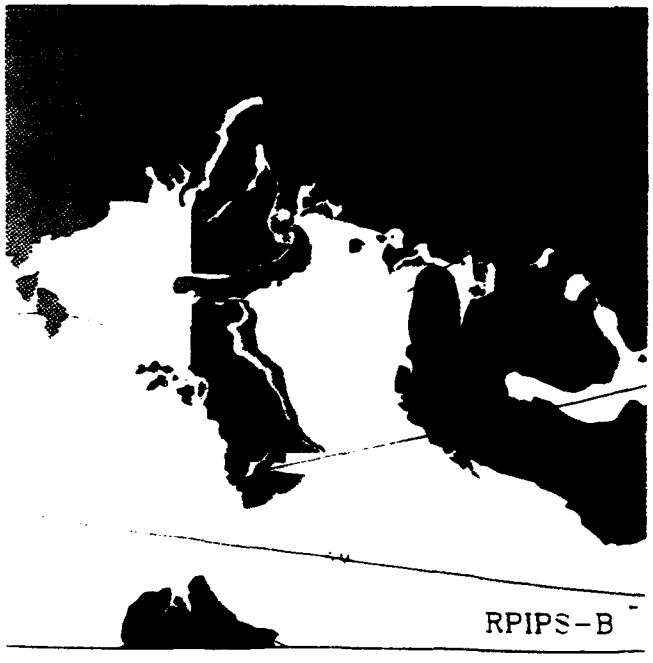

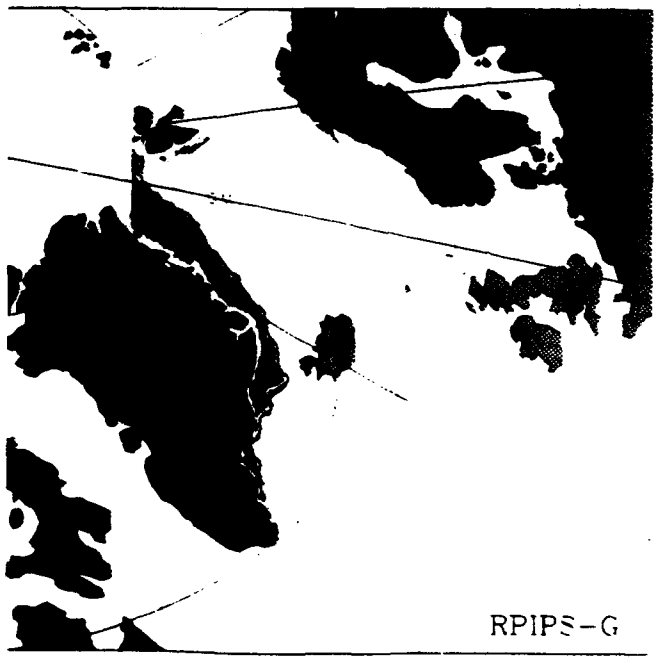

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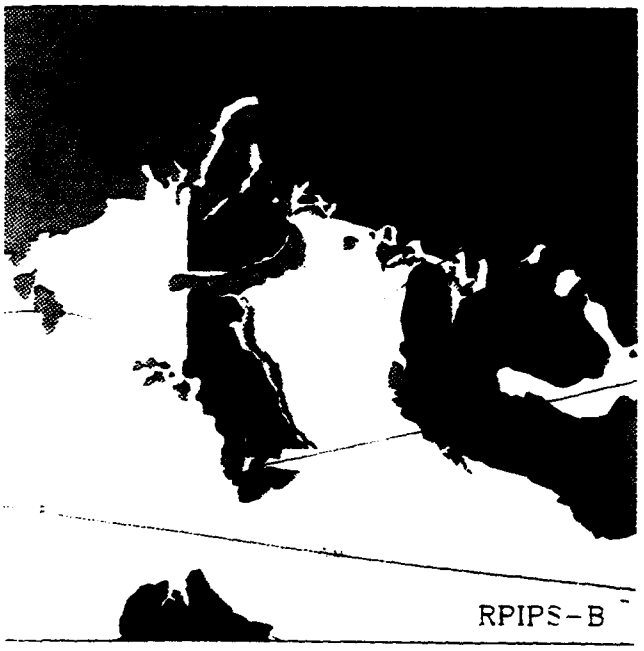
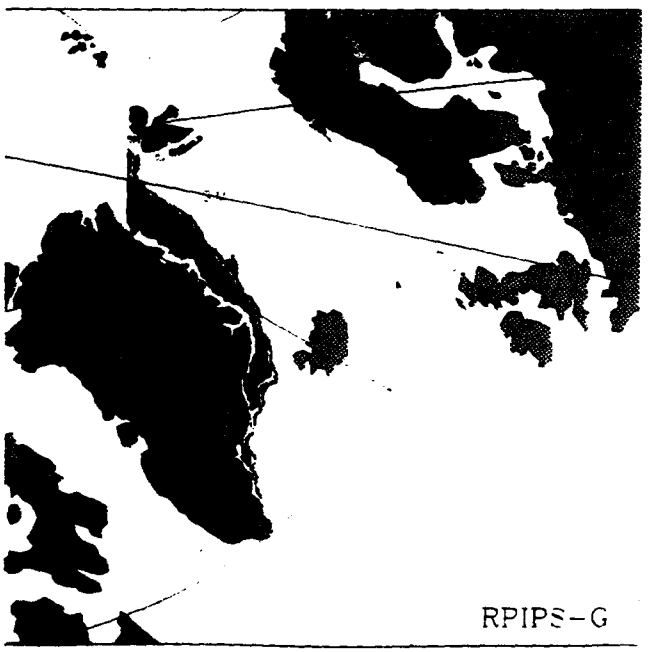


RPIPS-B



RPIPS-G

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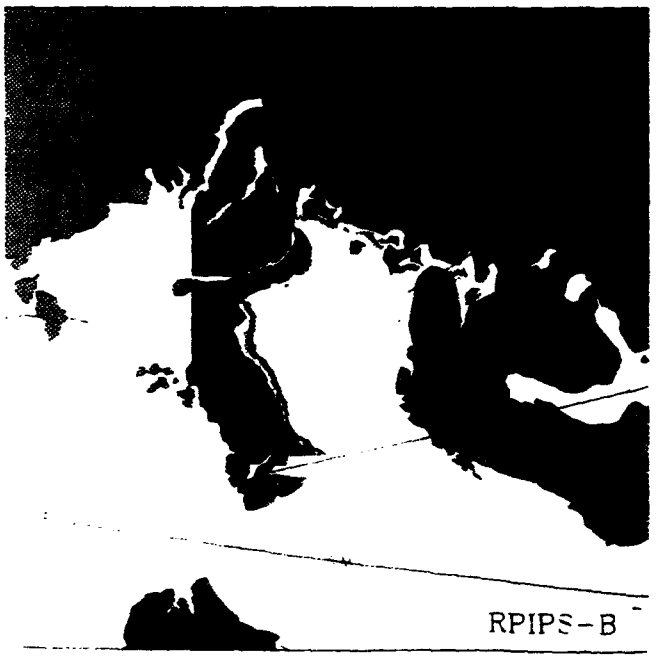
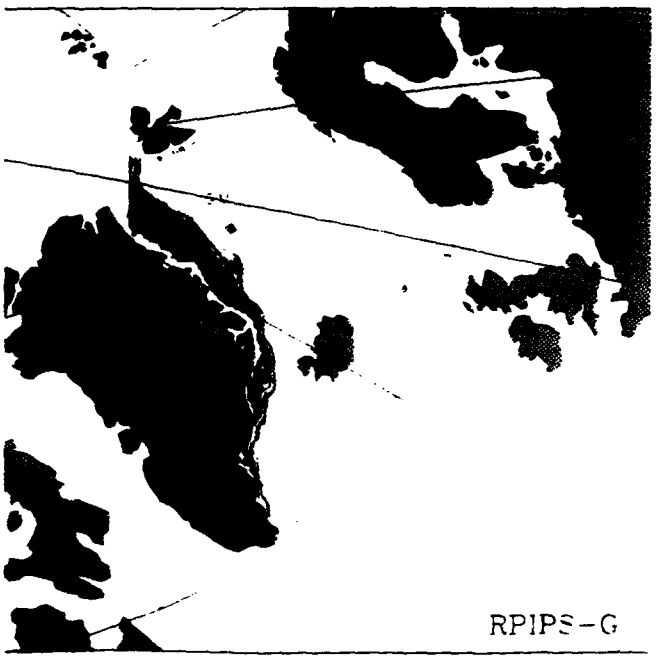


RPIPS-B



RPIPS-G

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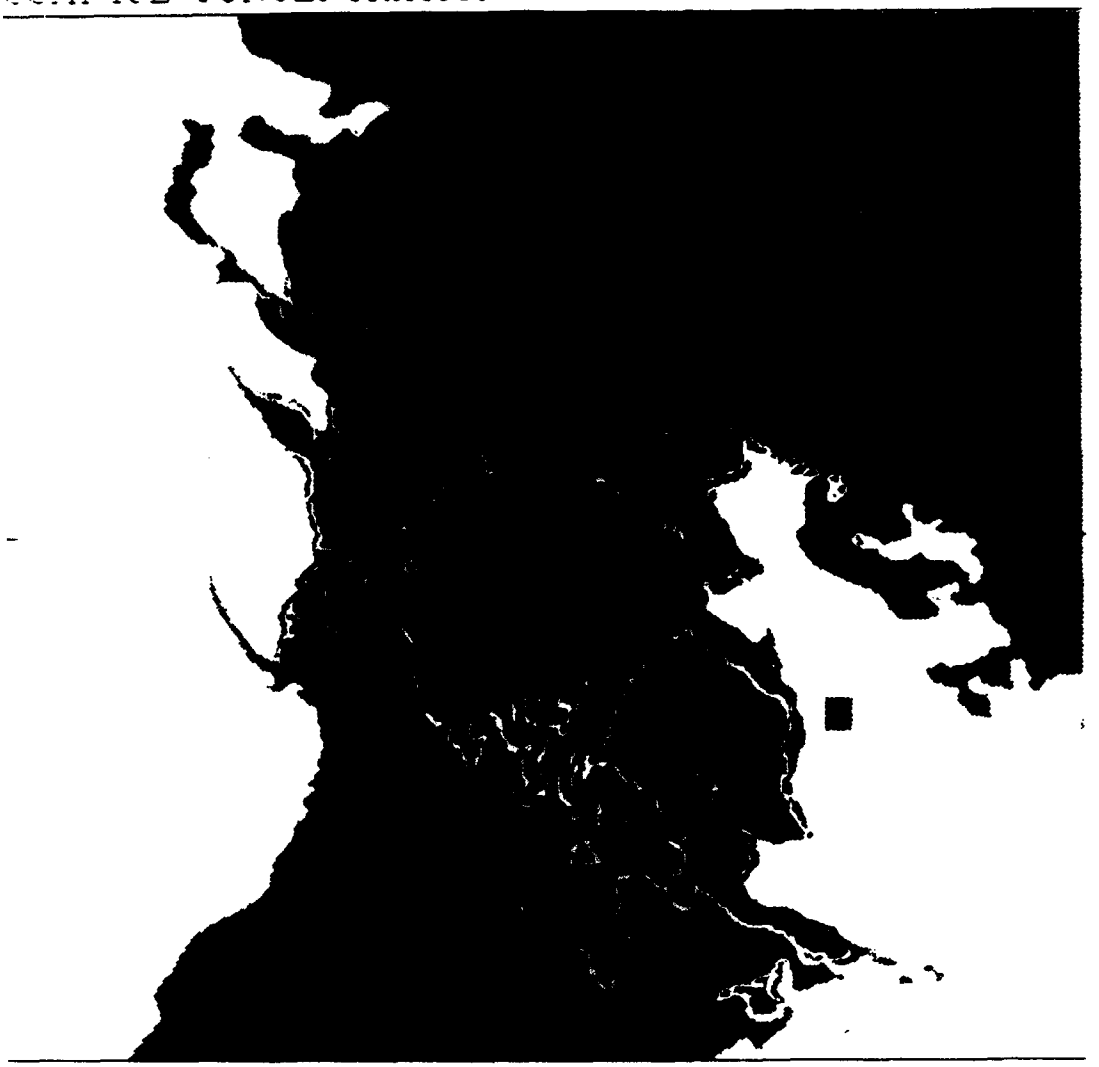

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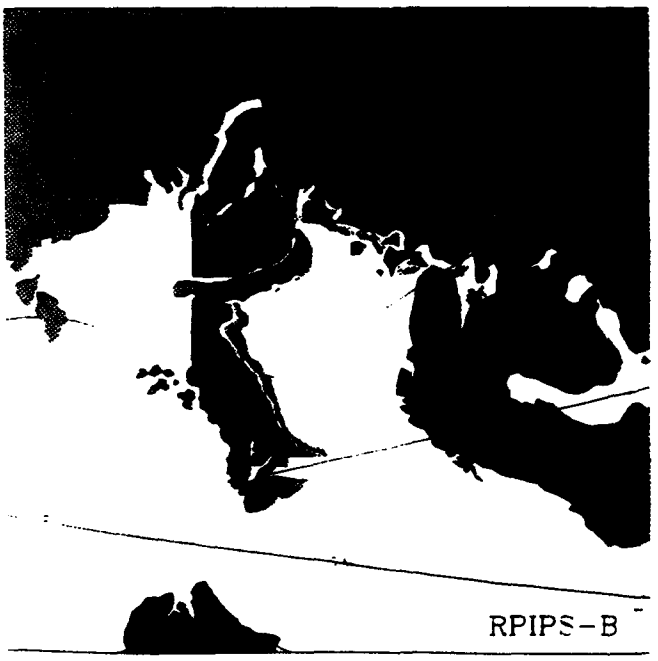
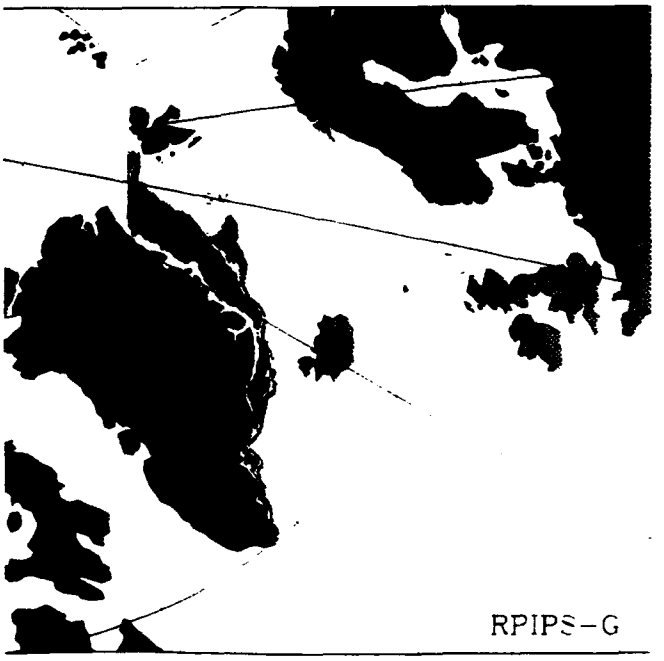


RPIPS-B



RPIPS-G

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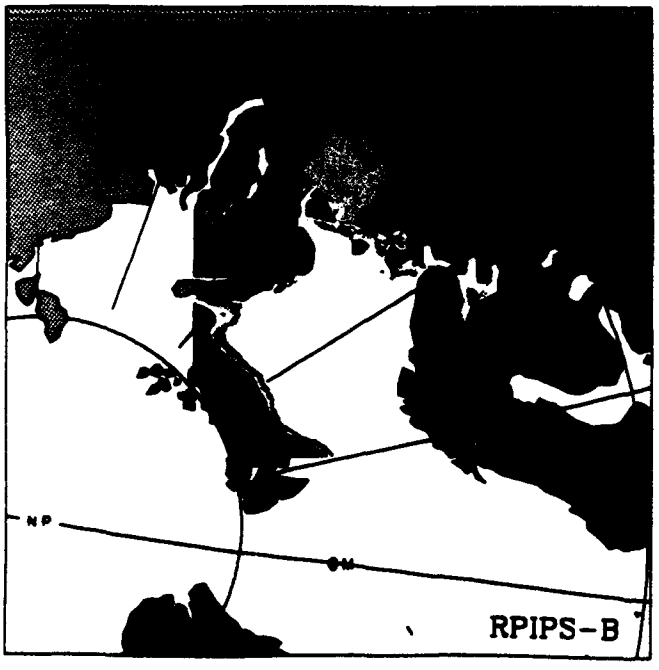

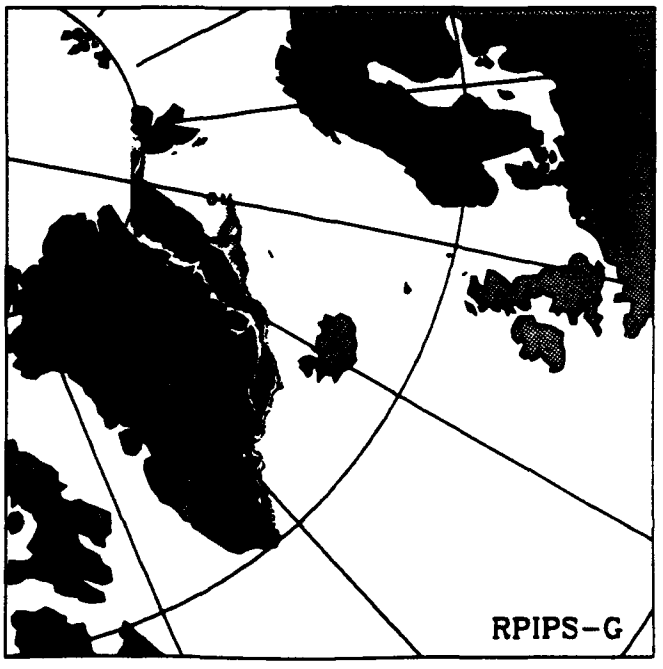

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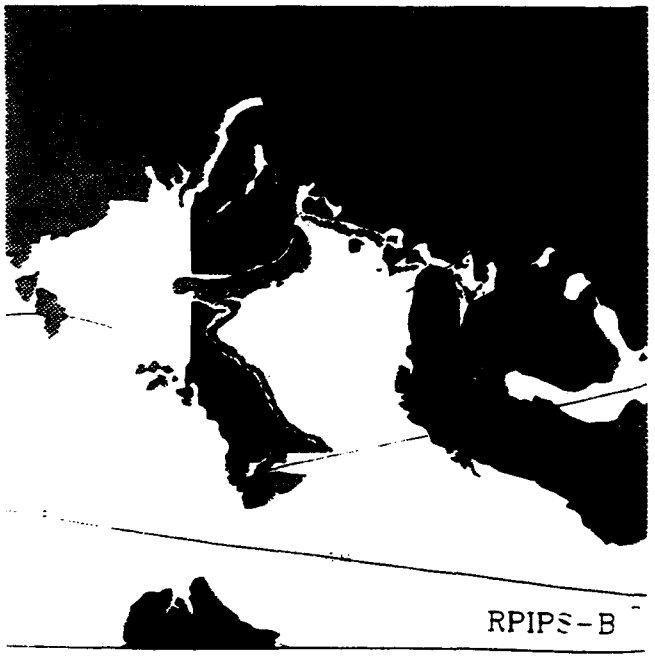
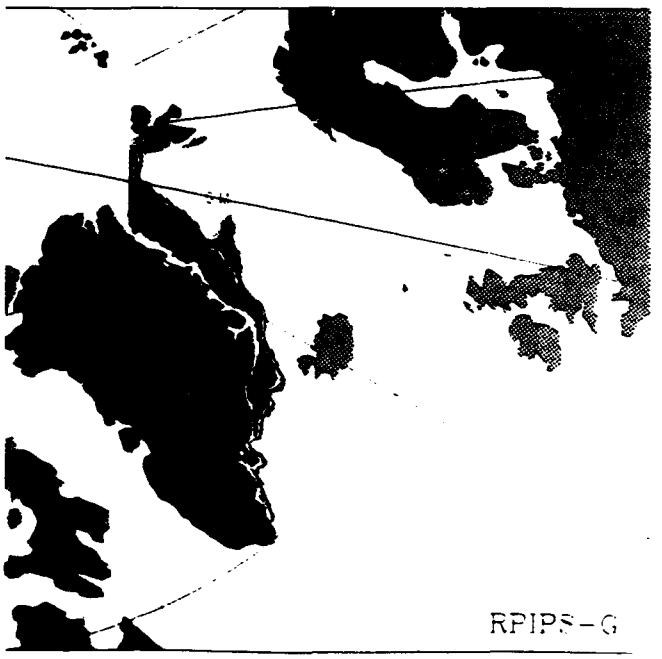


RPIPS-B



RPIPS-G

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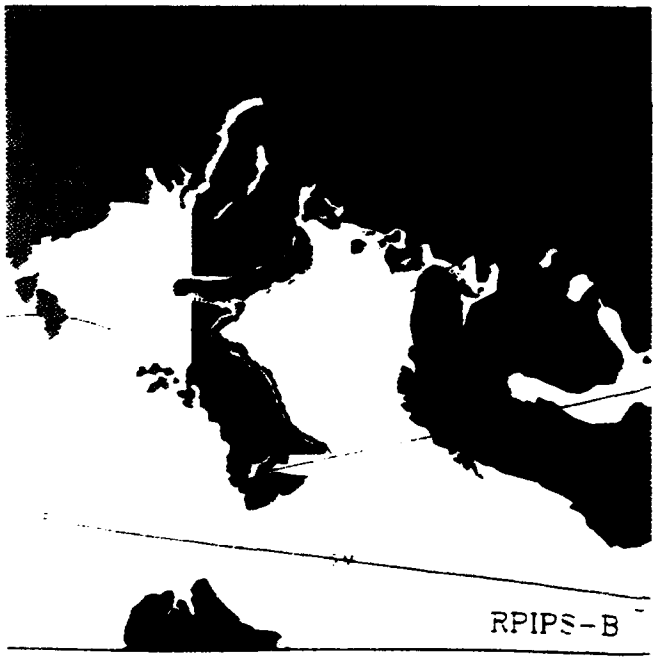

RPIPS-B

RPIPS-G

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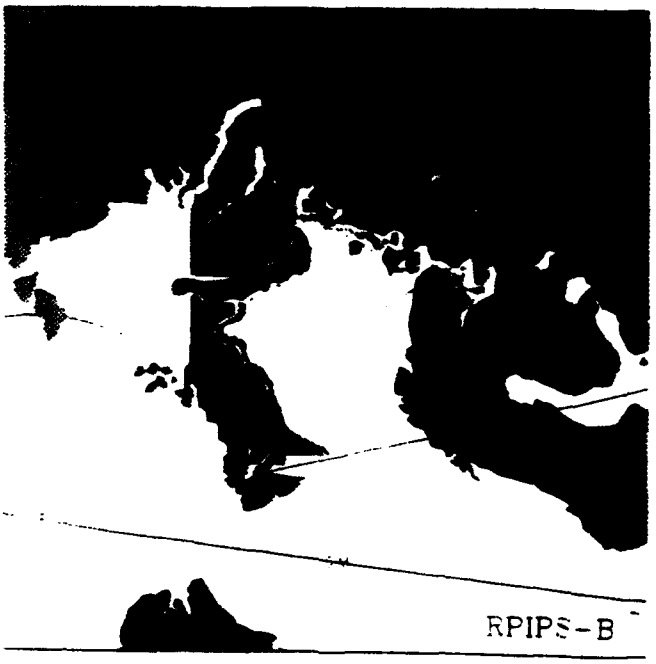

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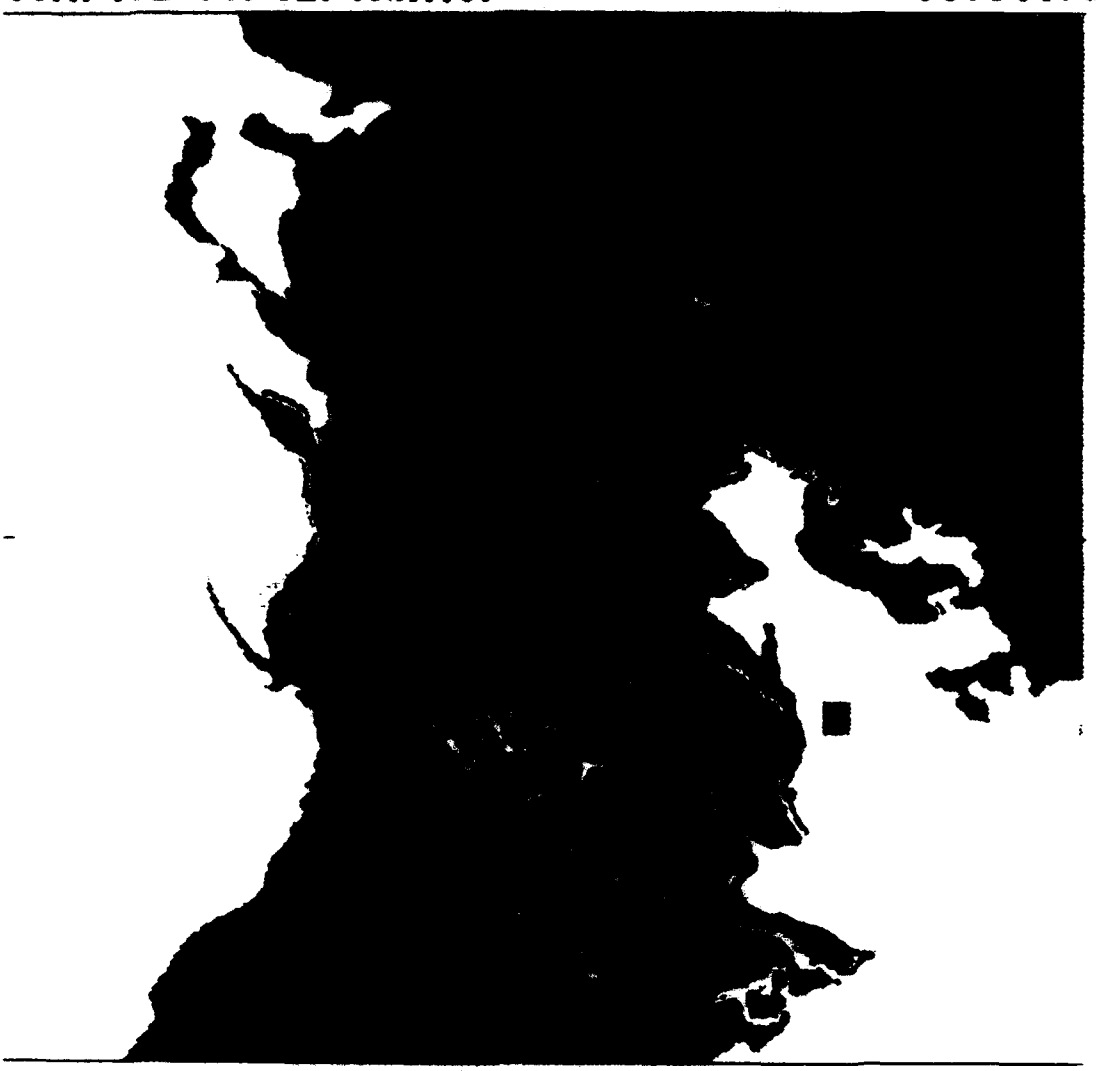

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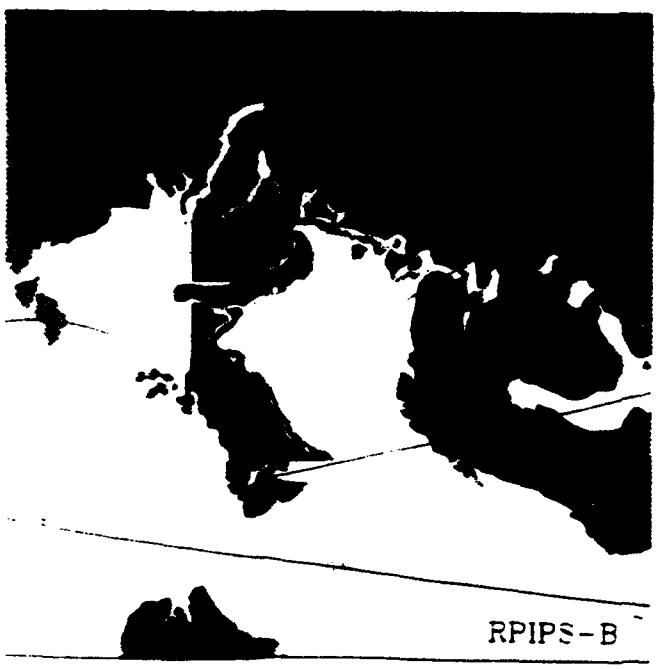

RPIPS-B

RPIPS-G

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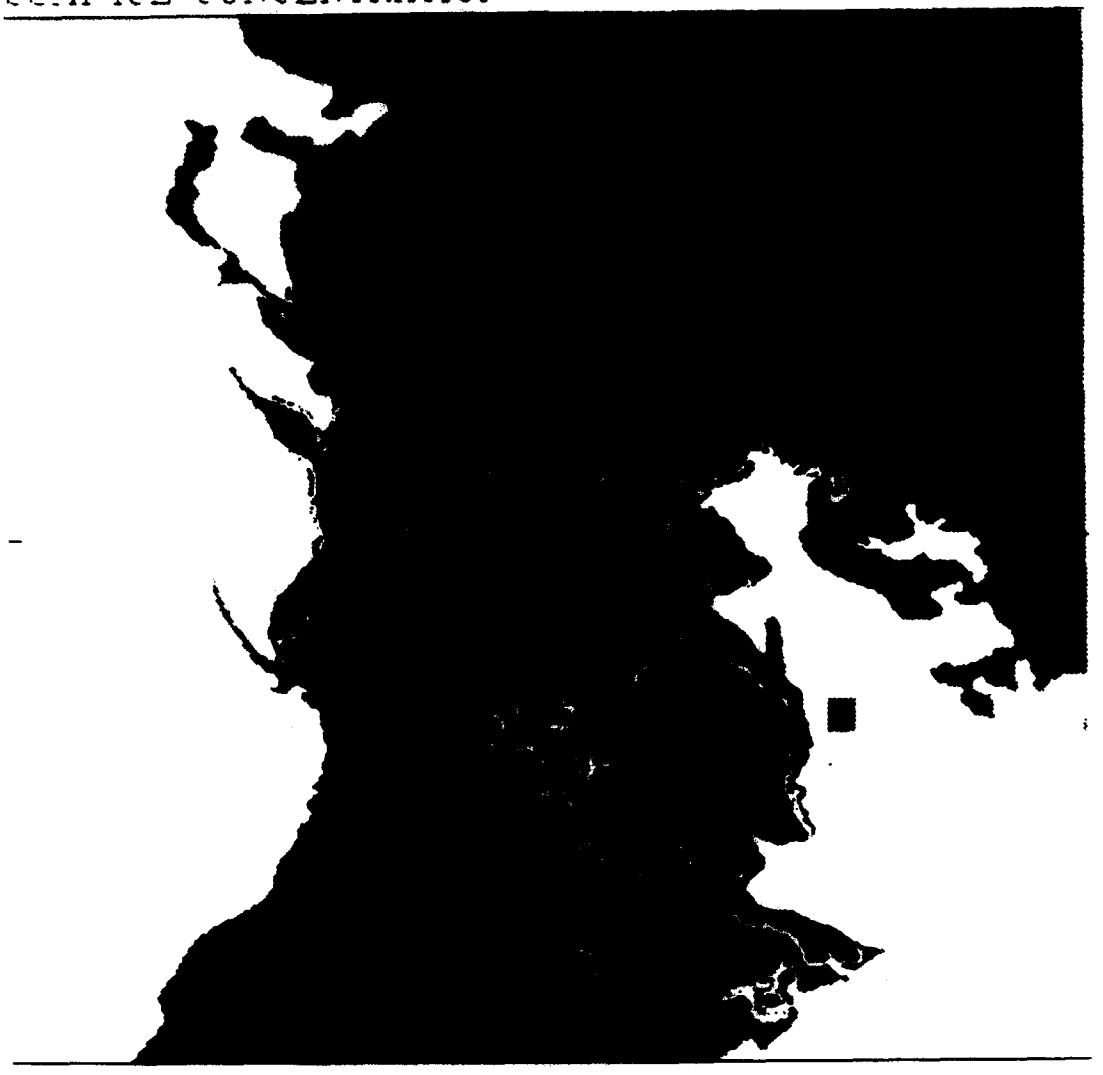

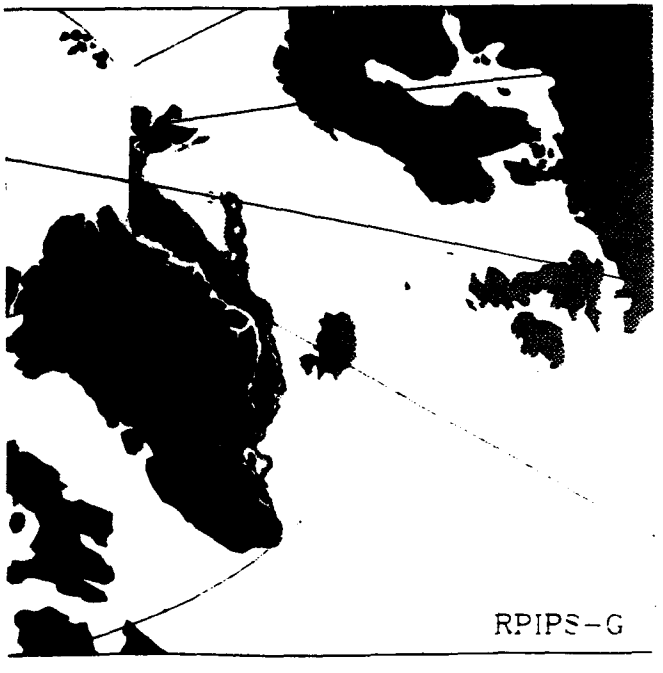

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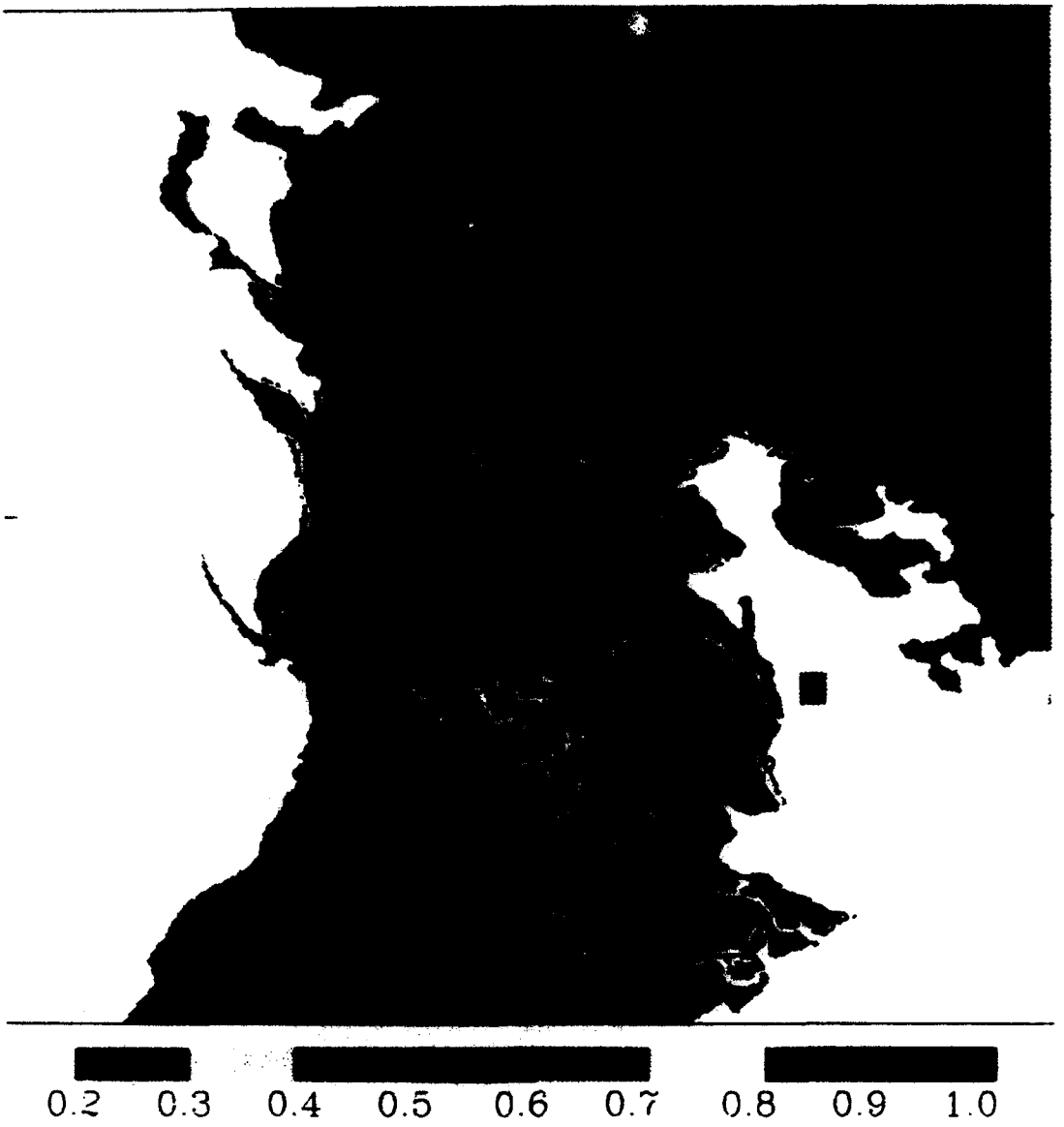

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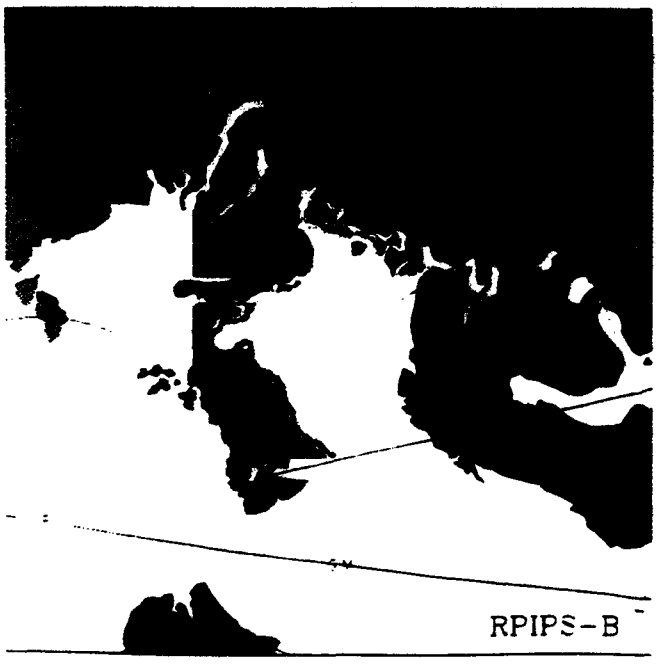
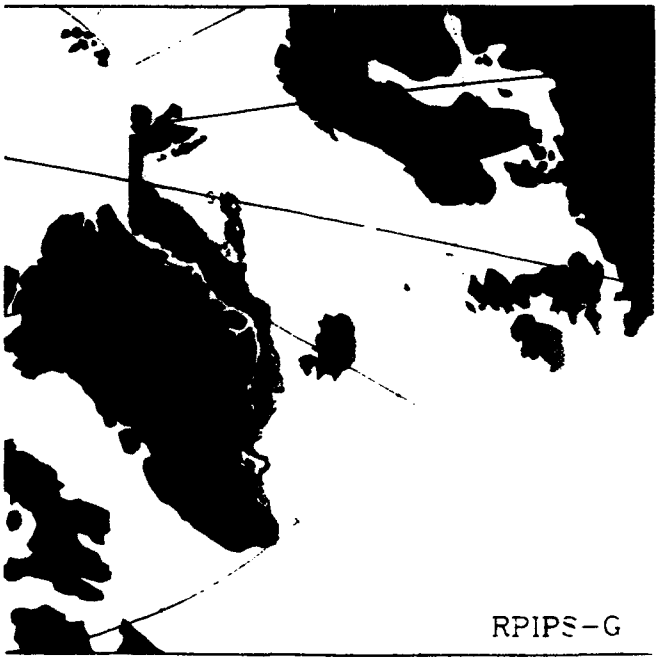


RPIPS-B



RPIPS-G

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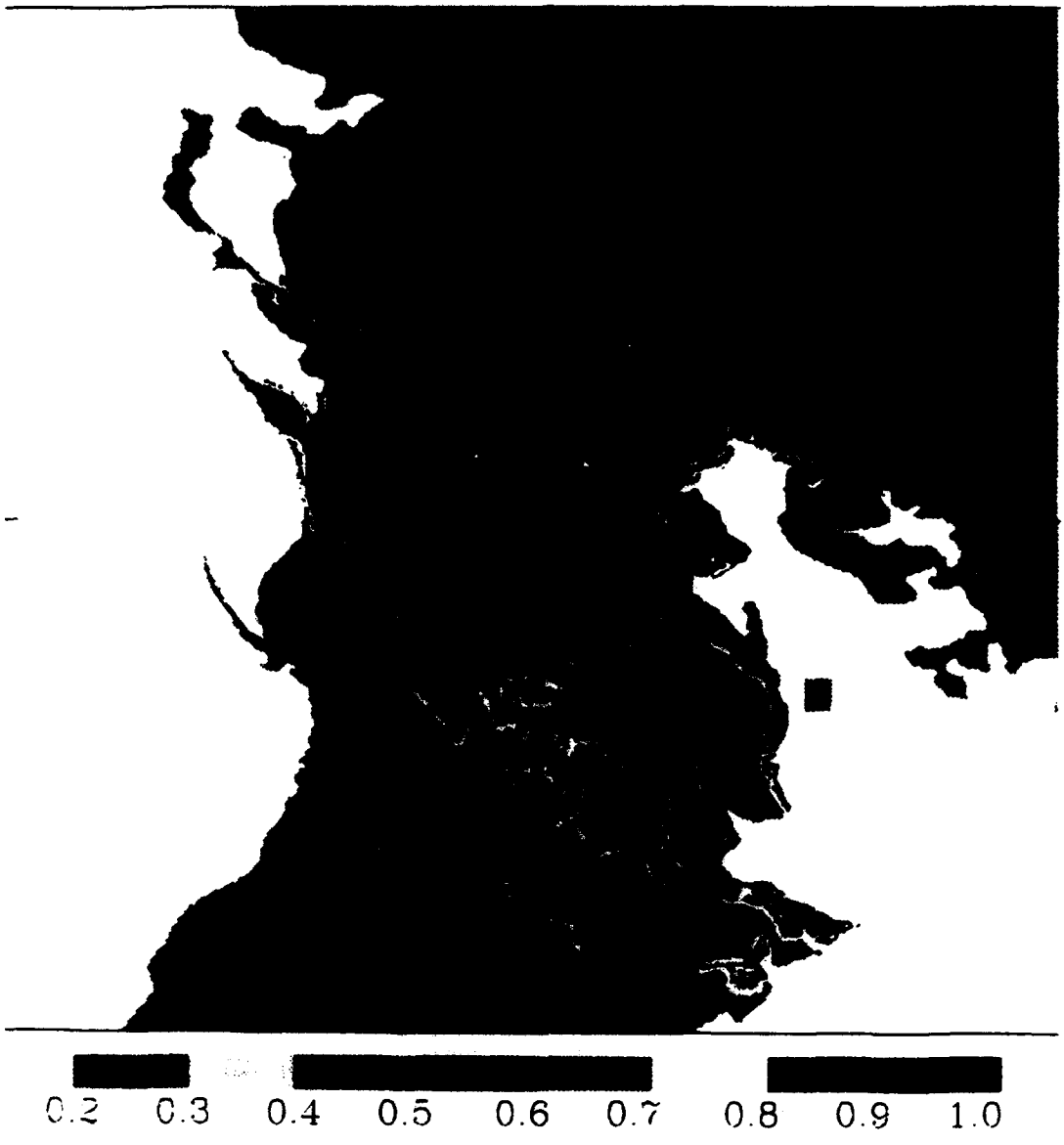

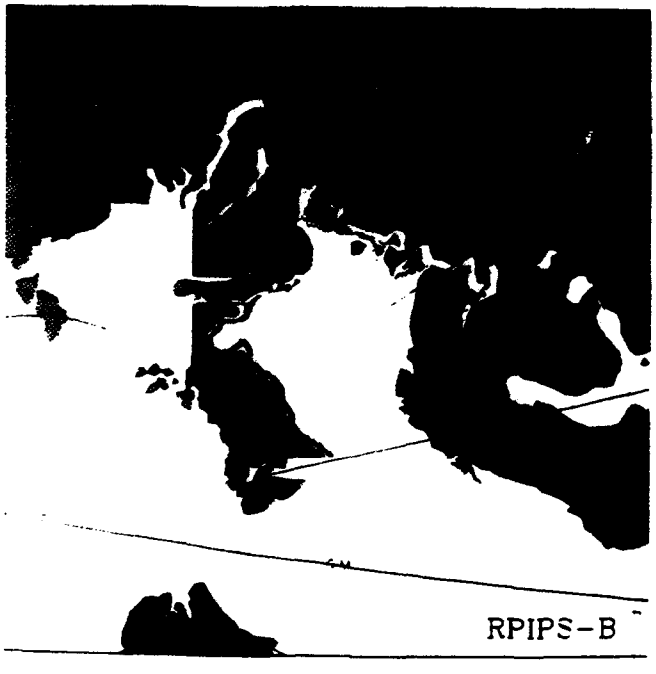

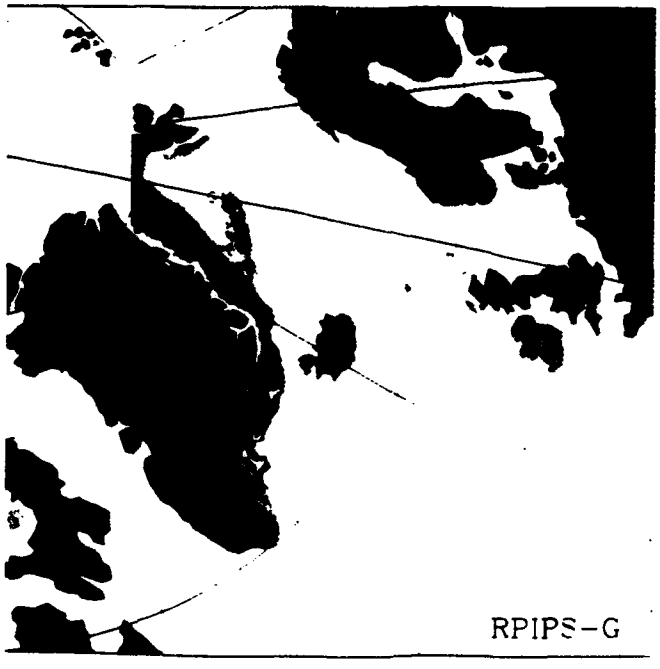

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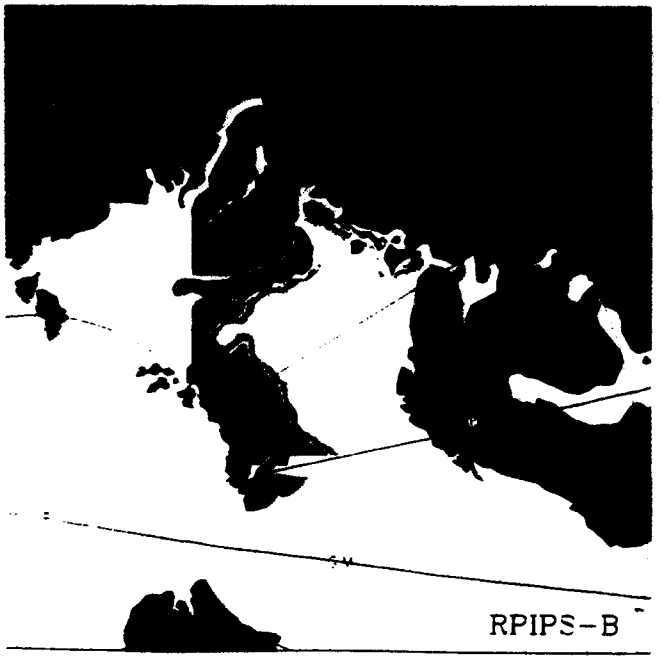
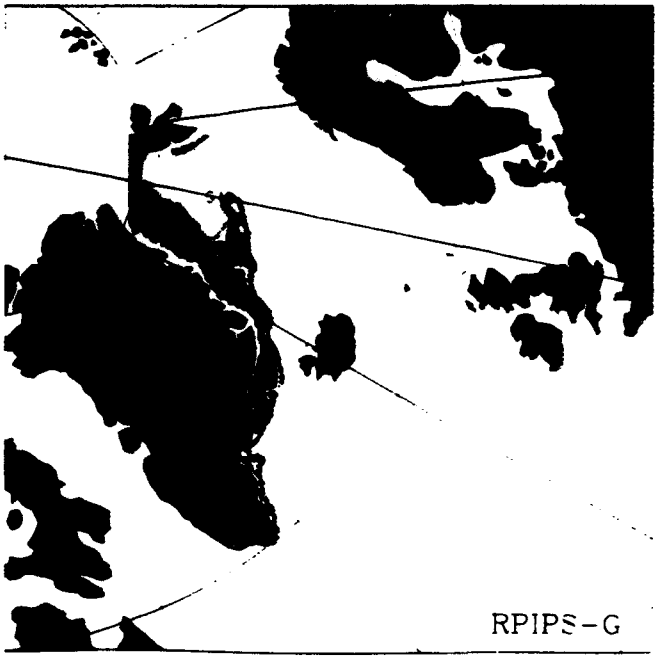


RPIPS-B



RPIPS-G

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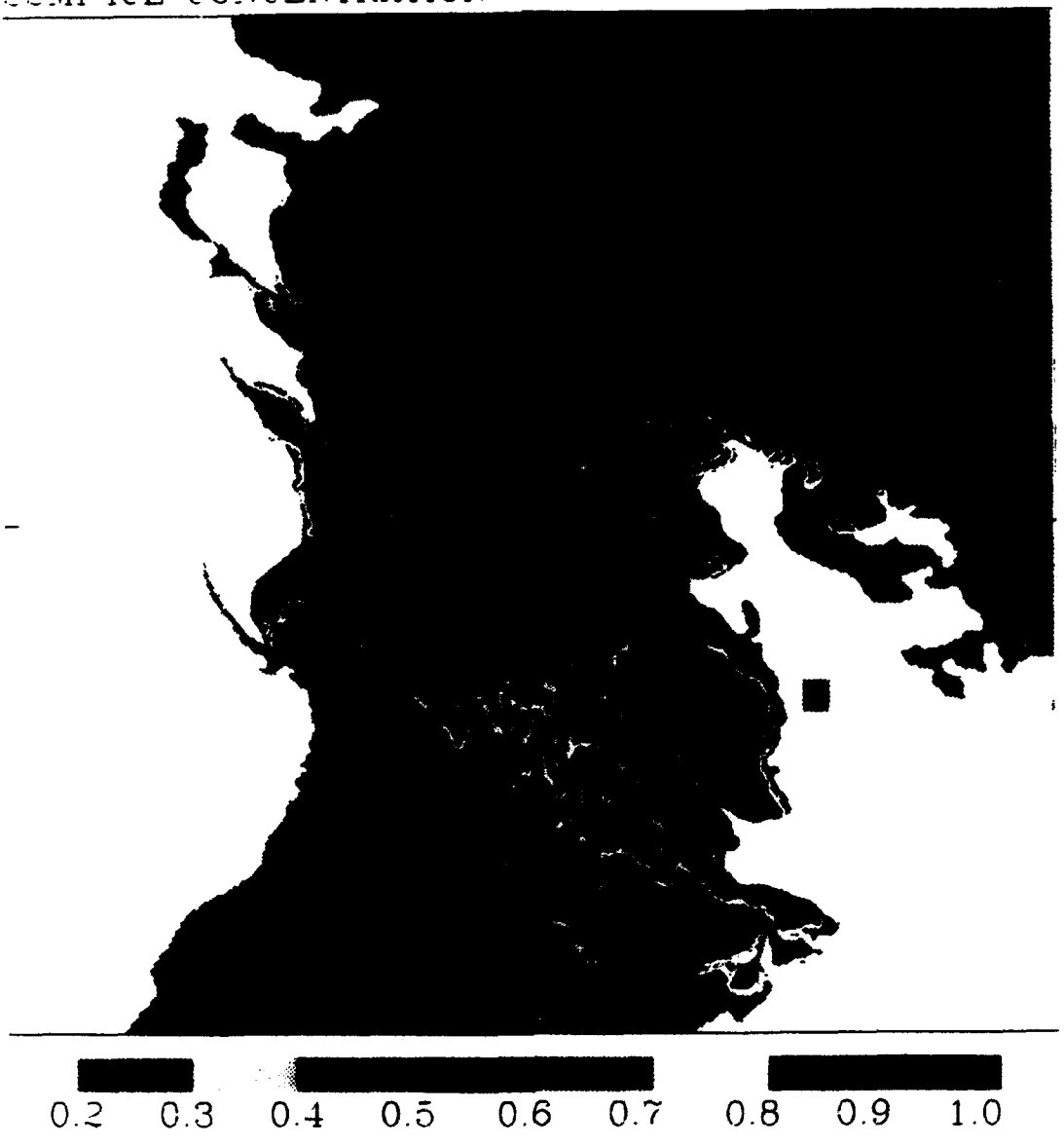

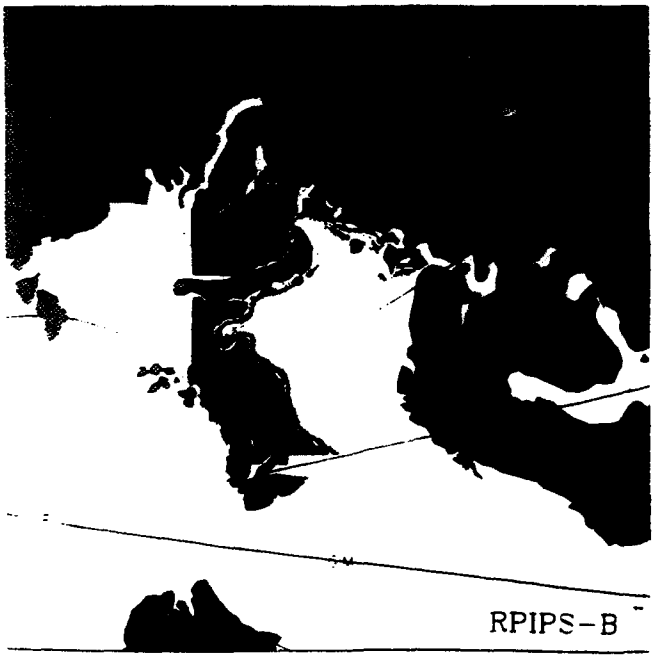

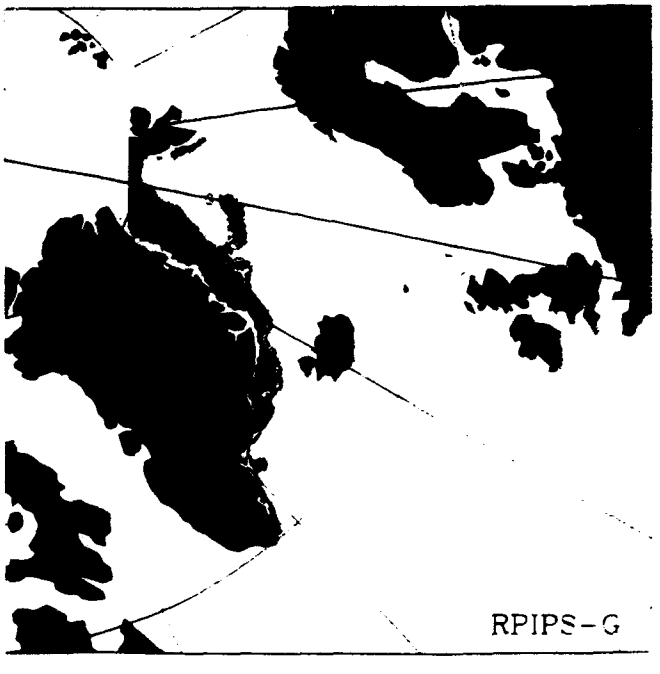

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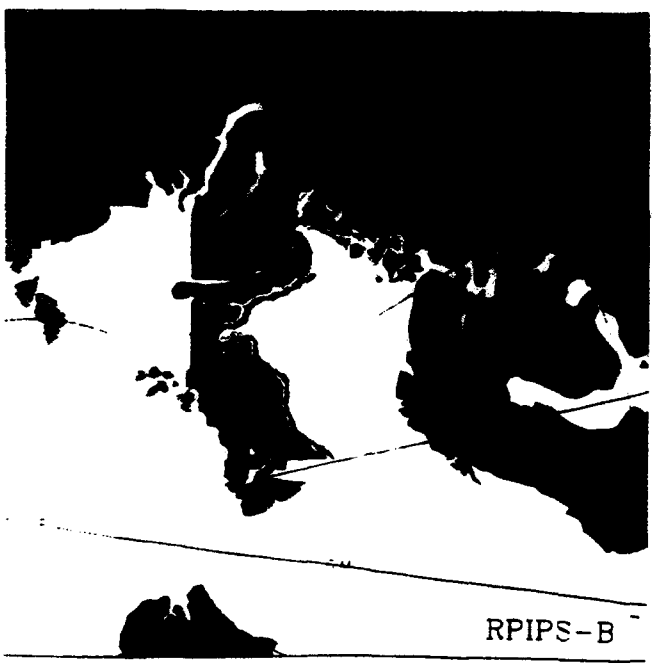
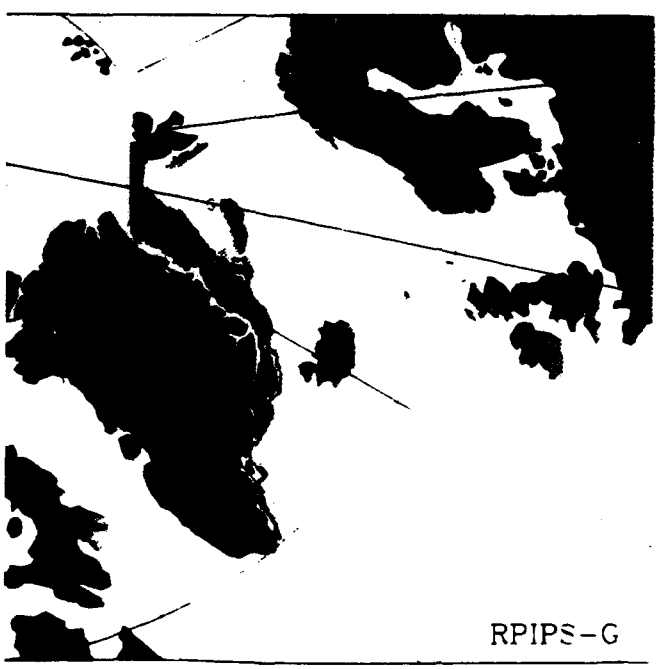


RPIPS-B



RPIPS-G

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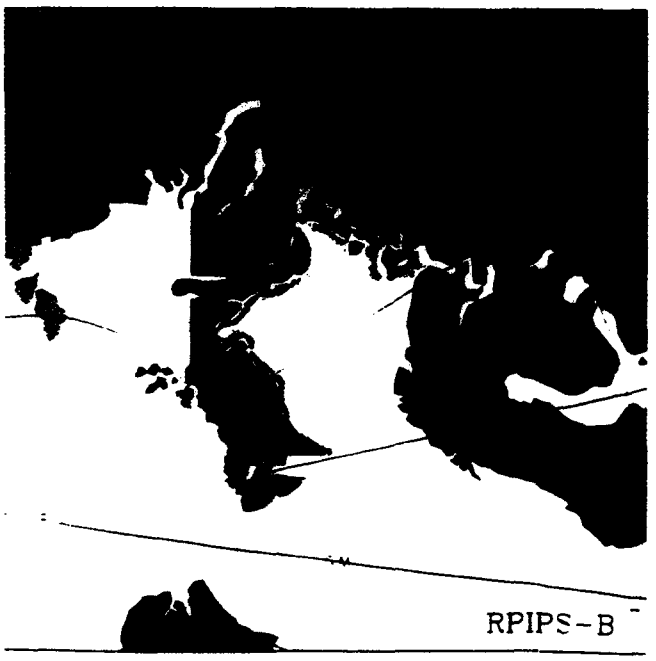

RPIPS-B

RPIPS-G

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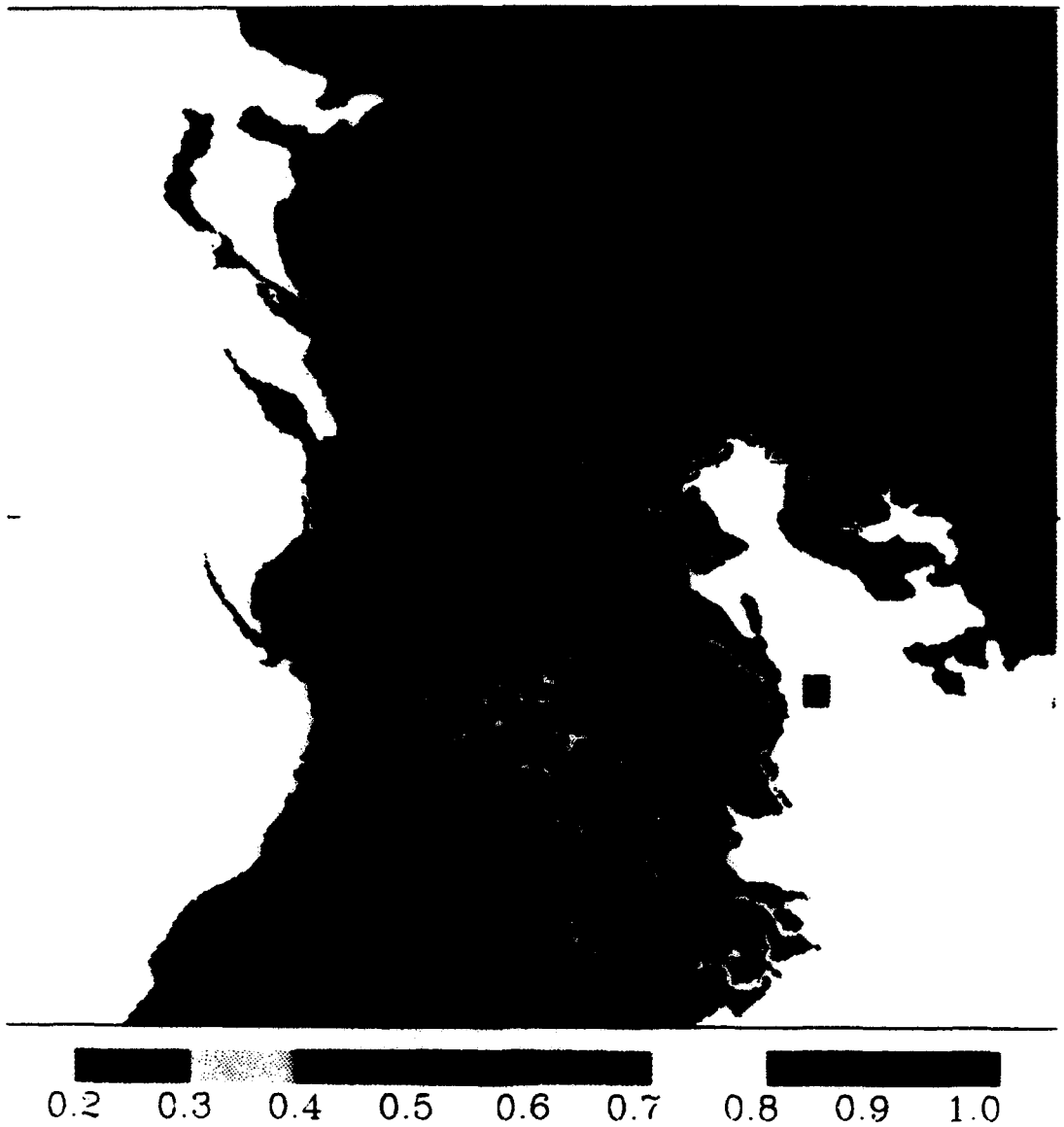

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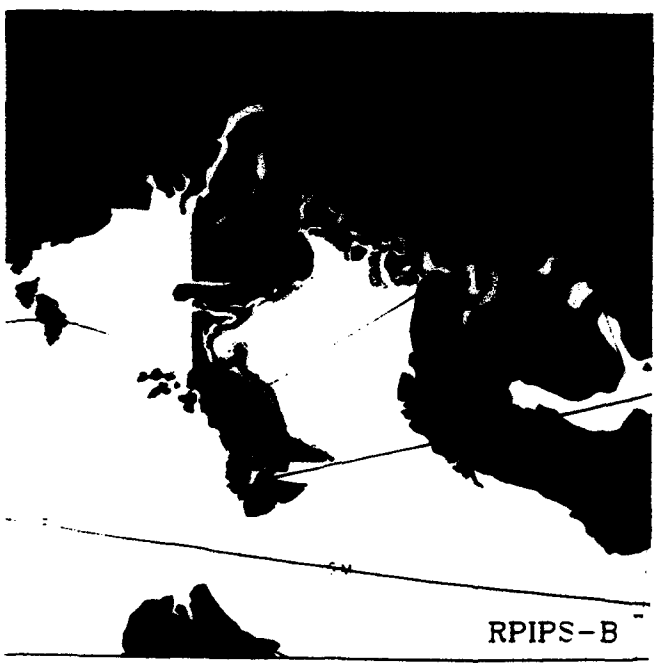
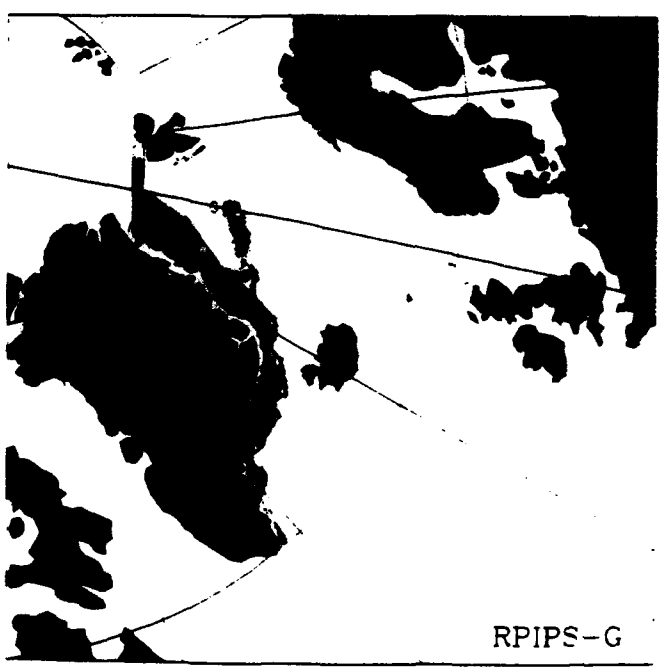


RPIPS-B



RPIPS-G

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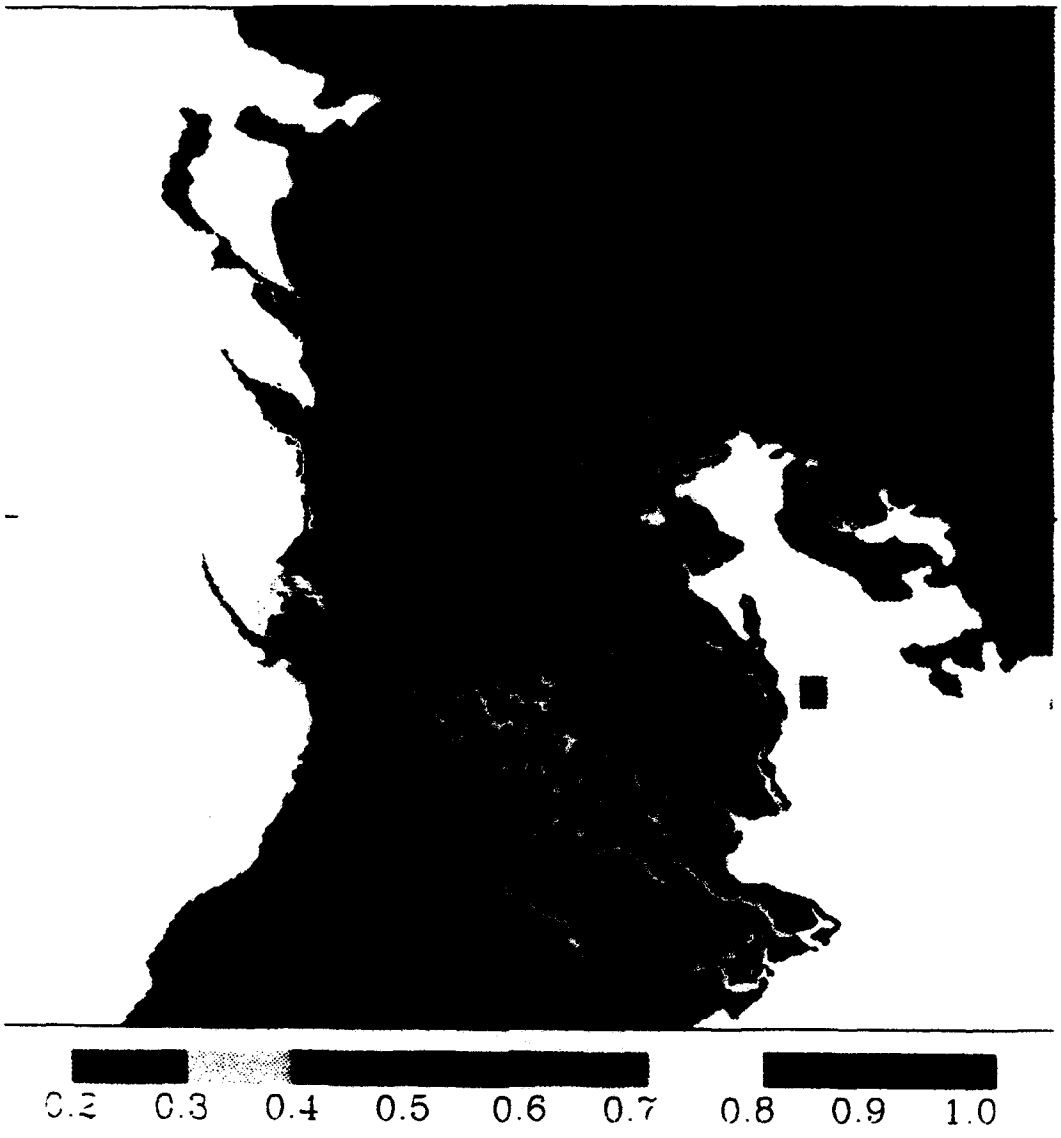

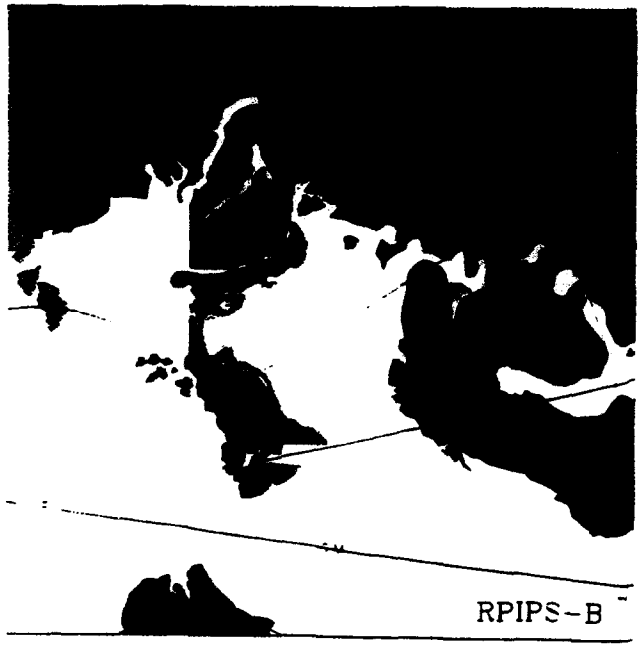

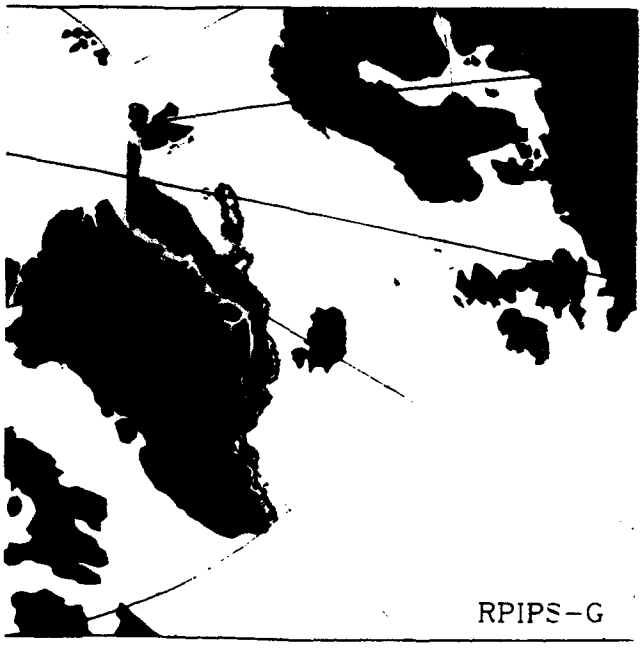

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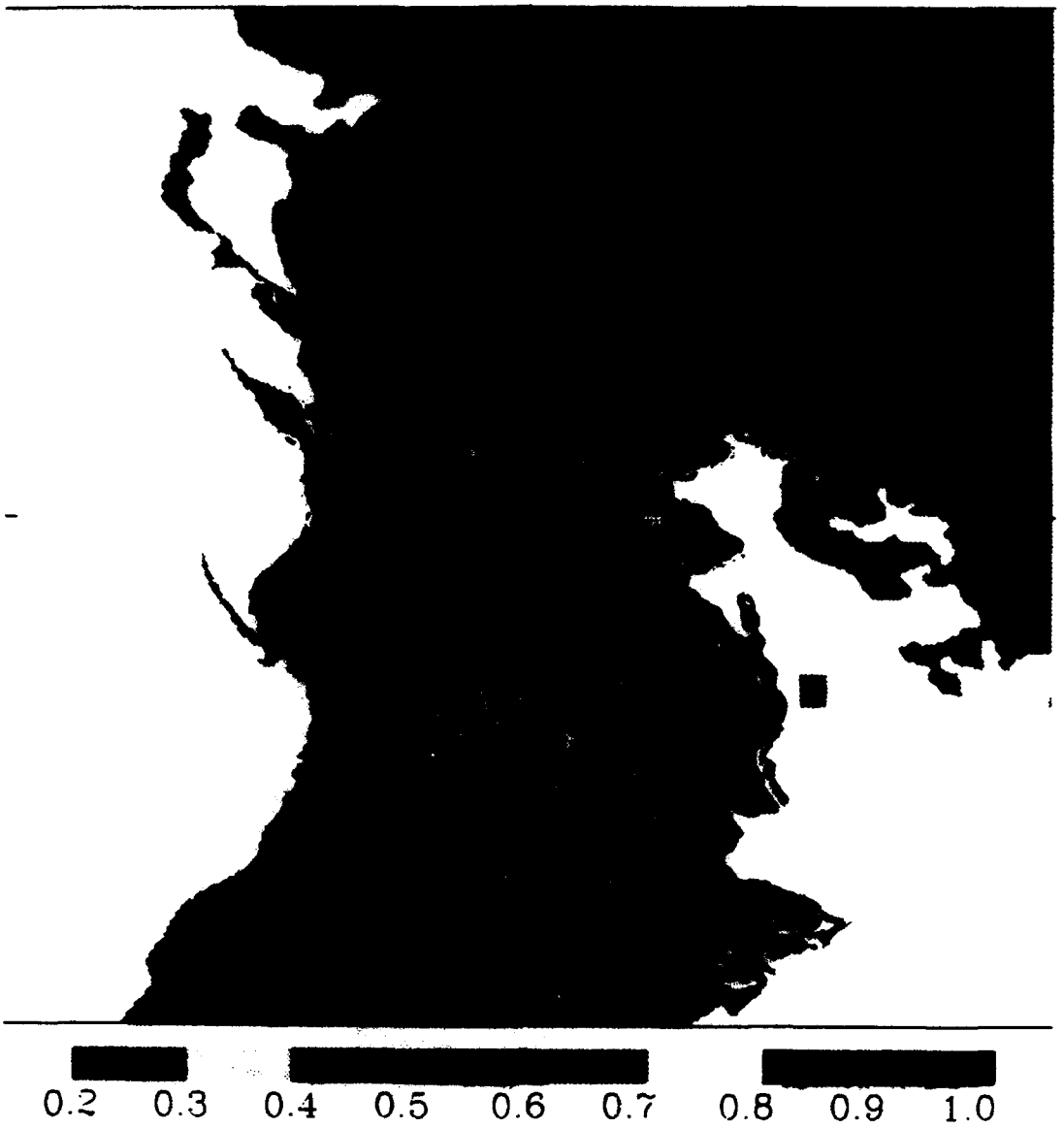

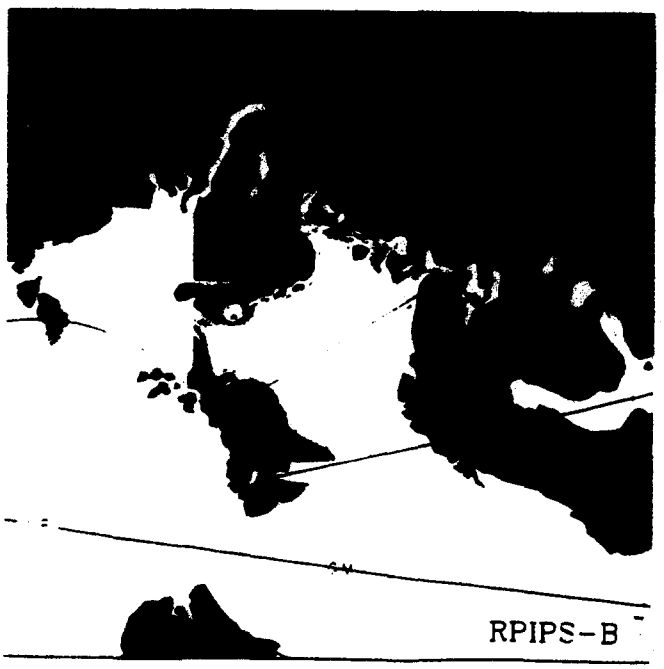

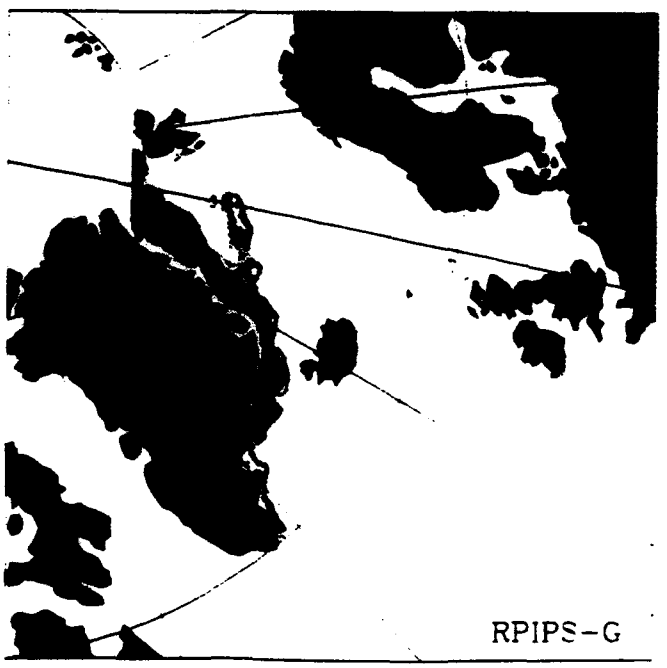

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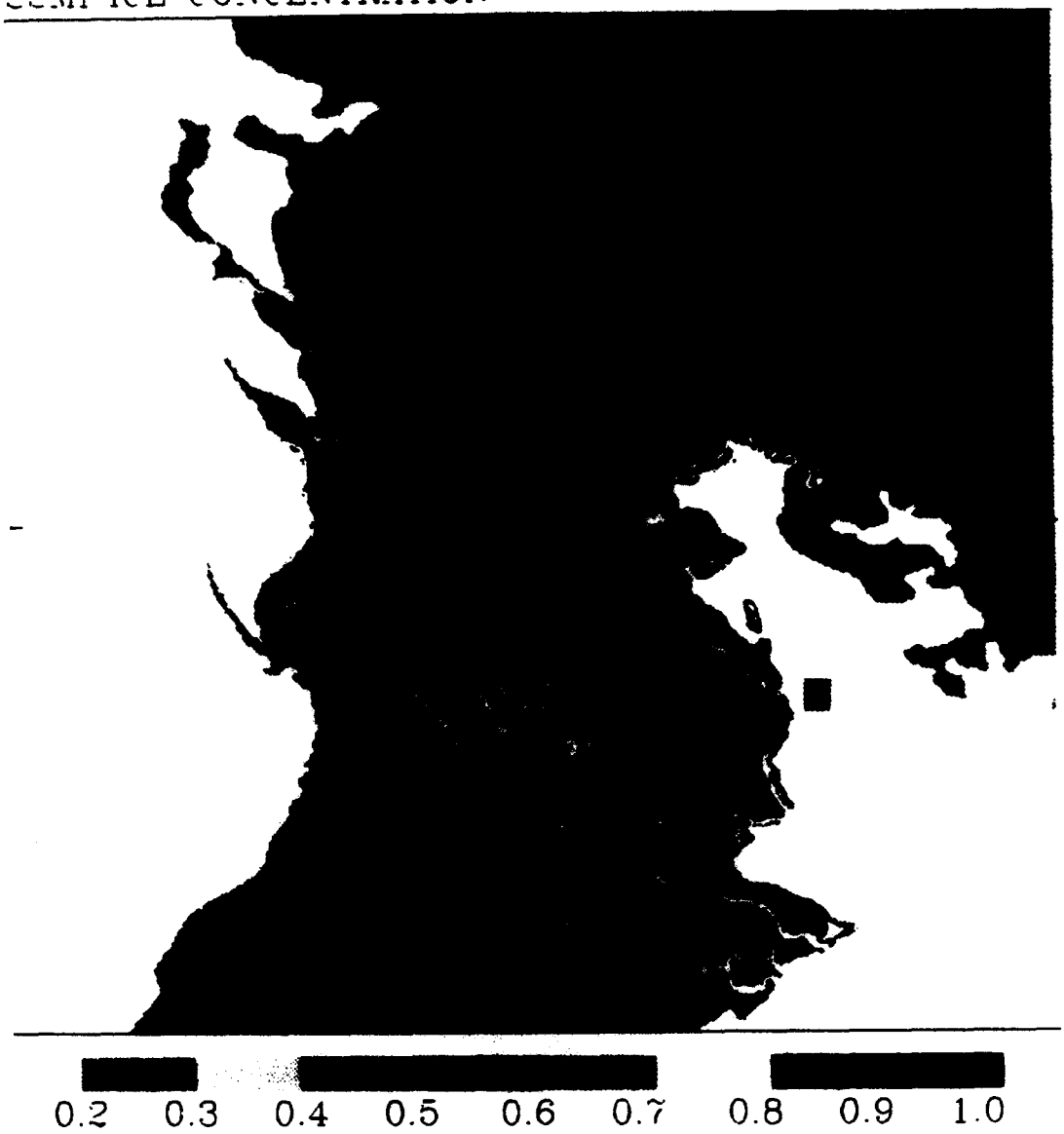

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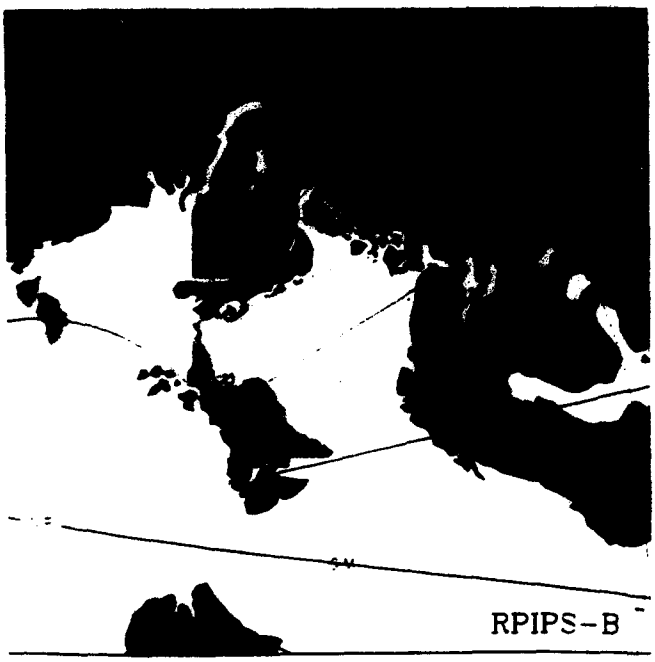
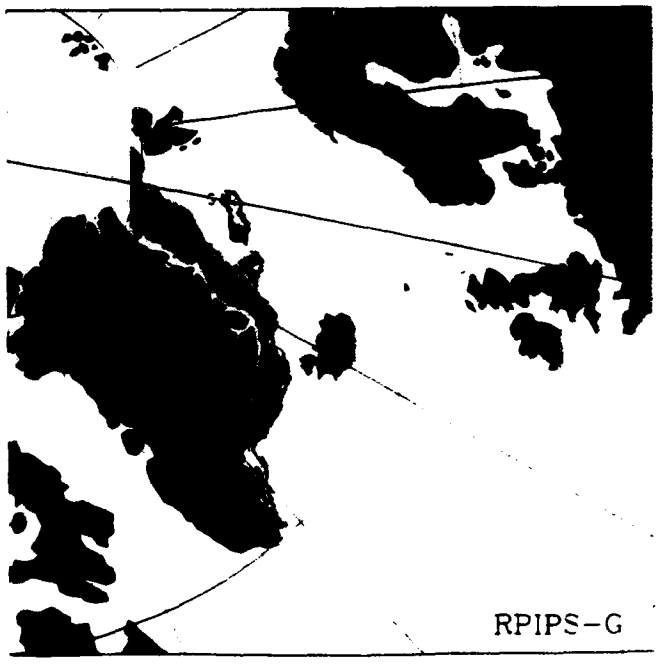


RPIPS-B



RPIPS-G

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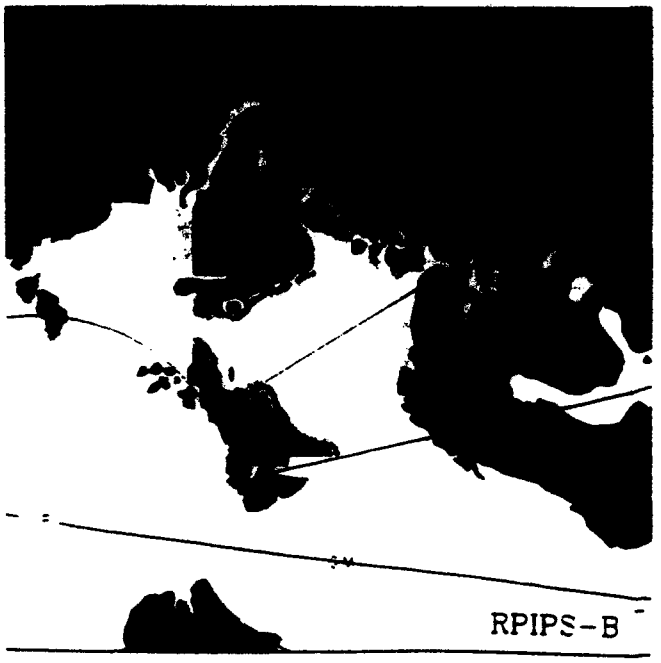
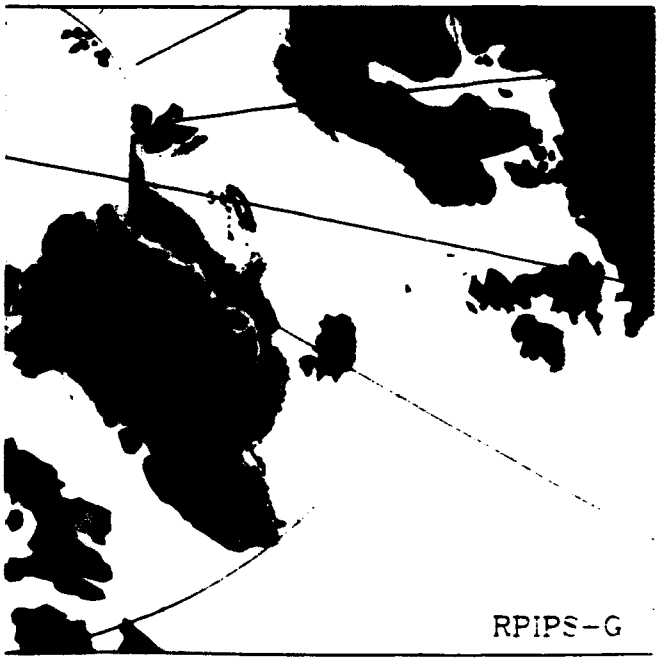


RPIPS-B



RPIPS-G

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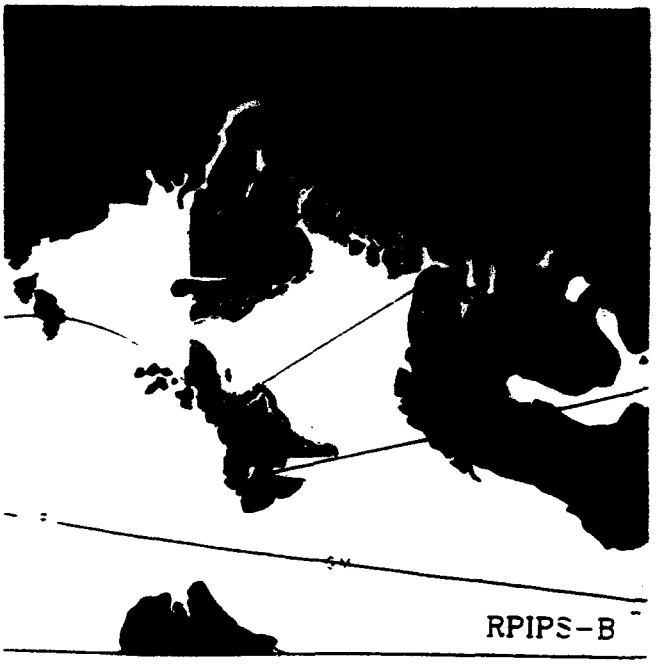

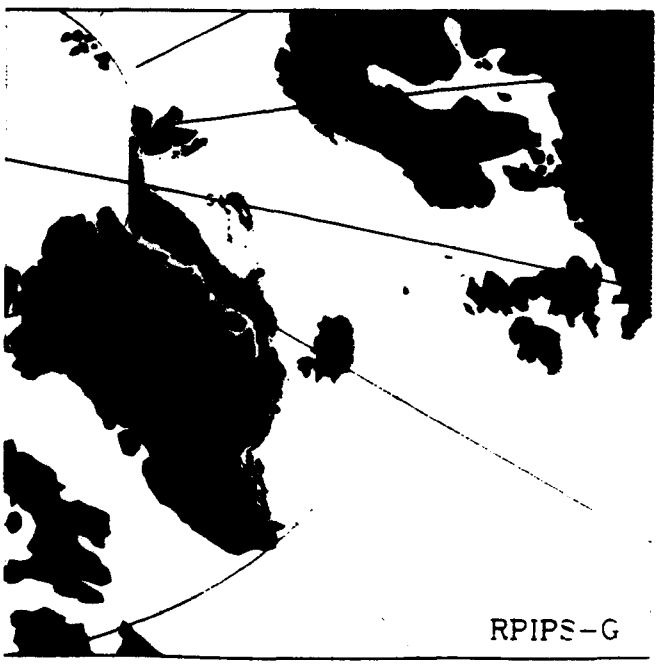

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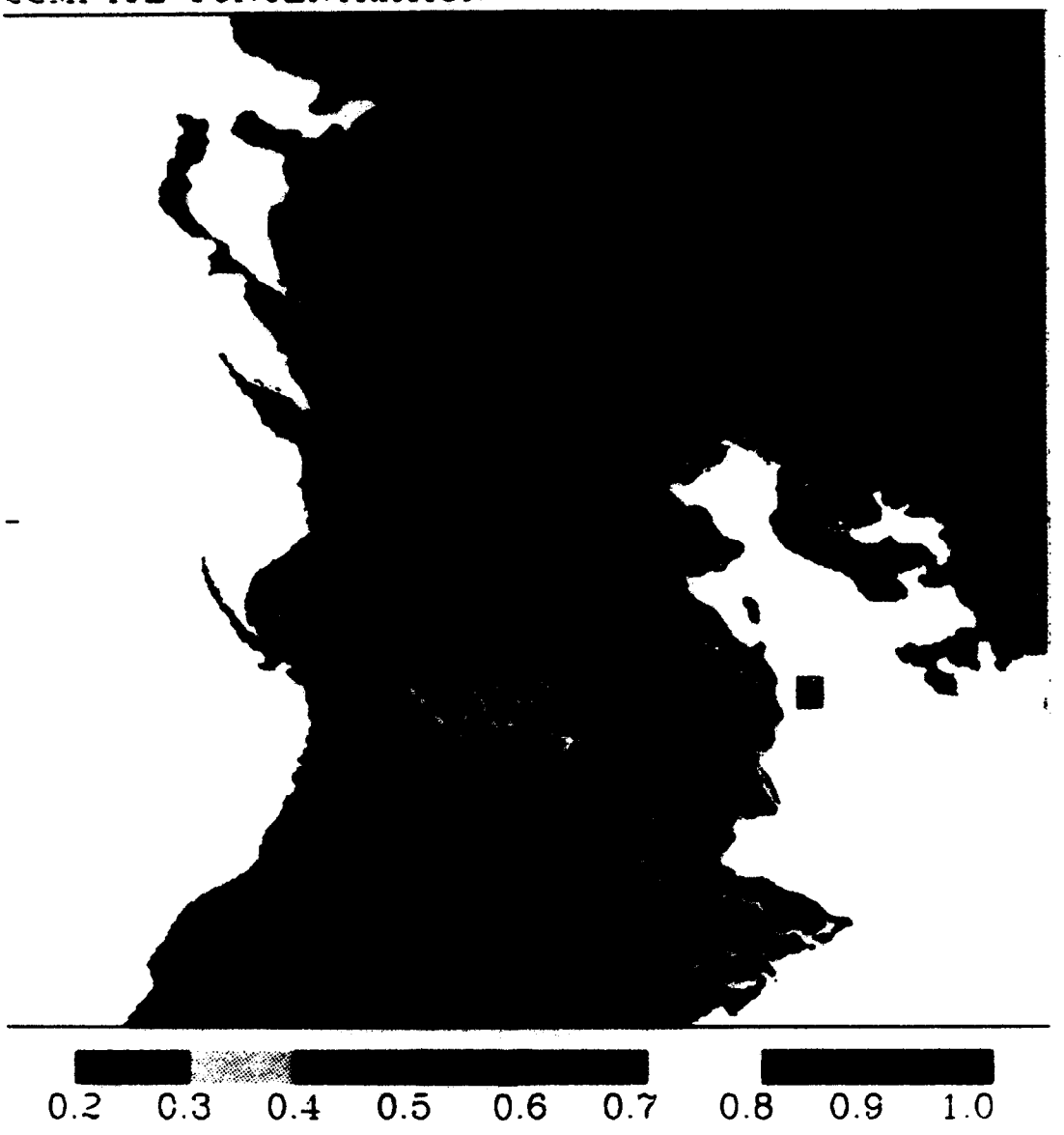

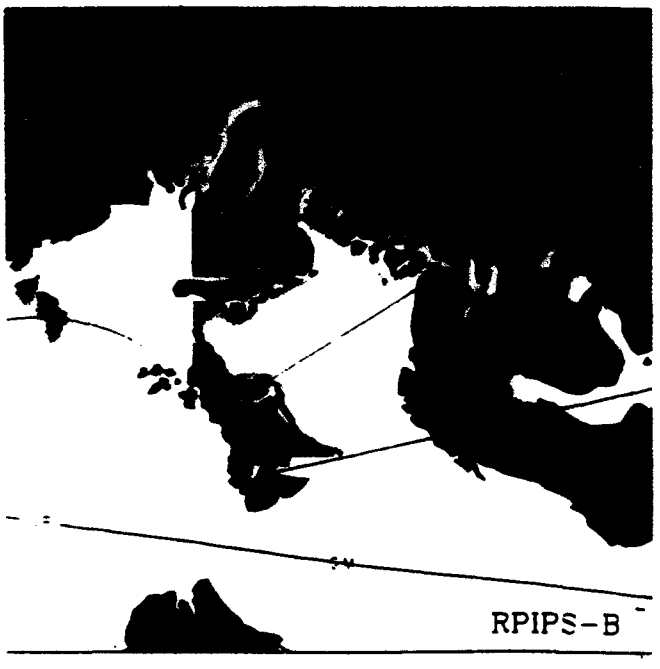

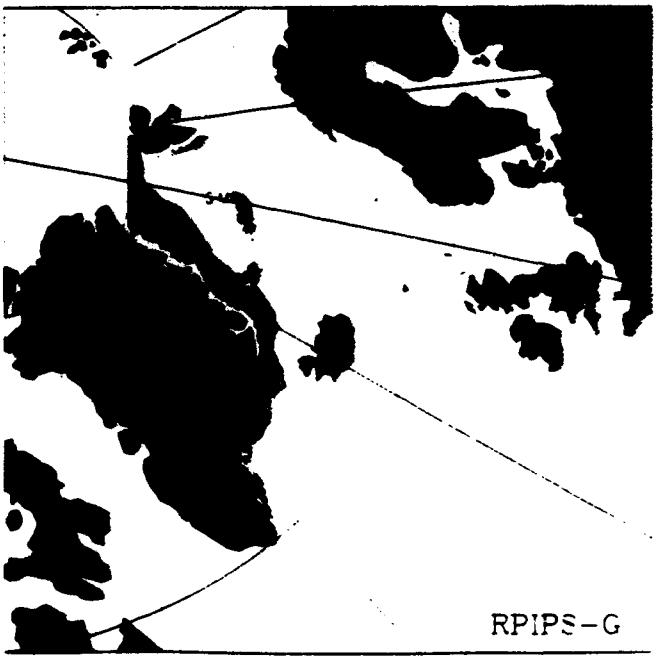

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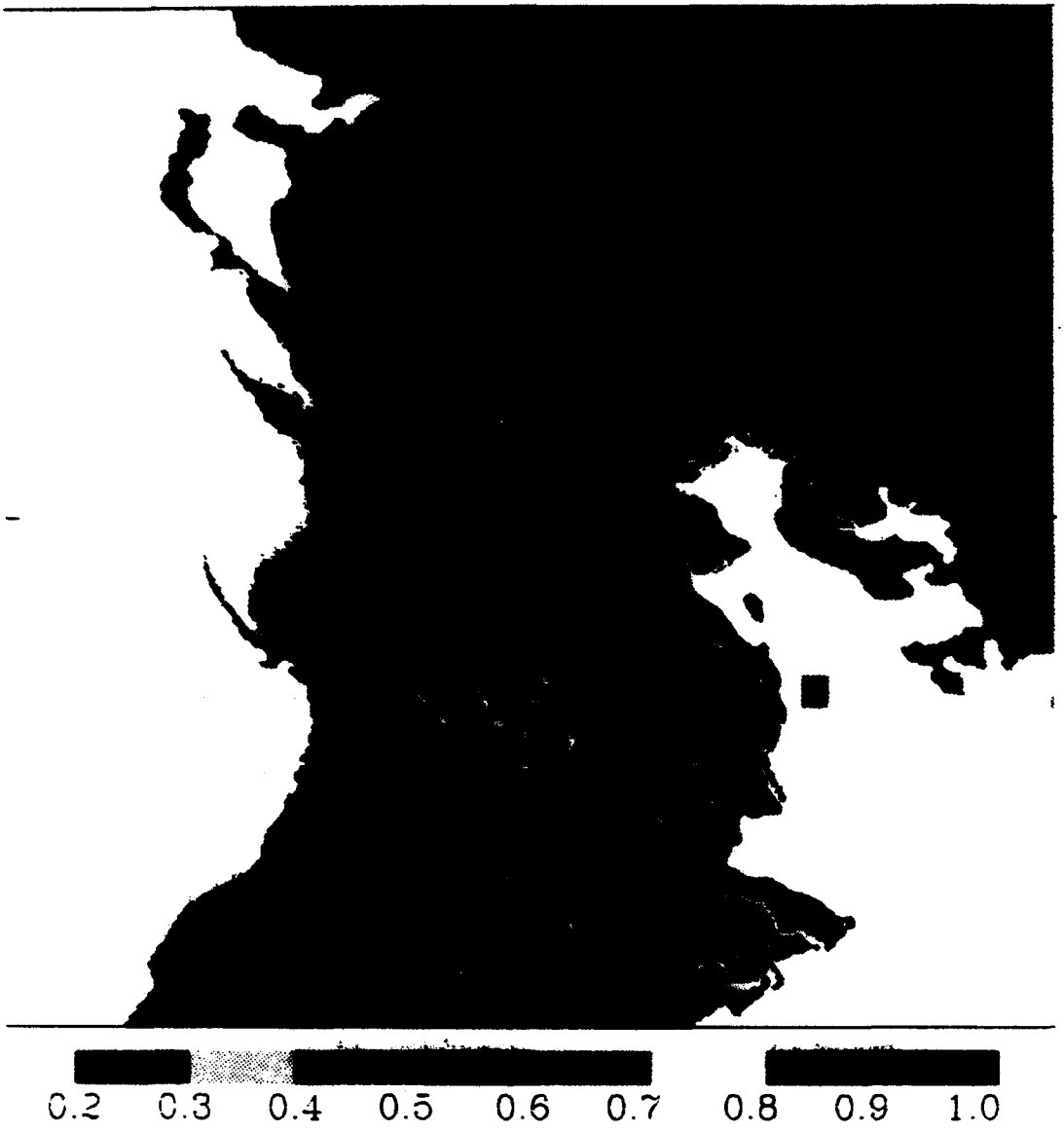

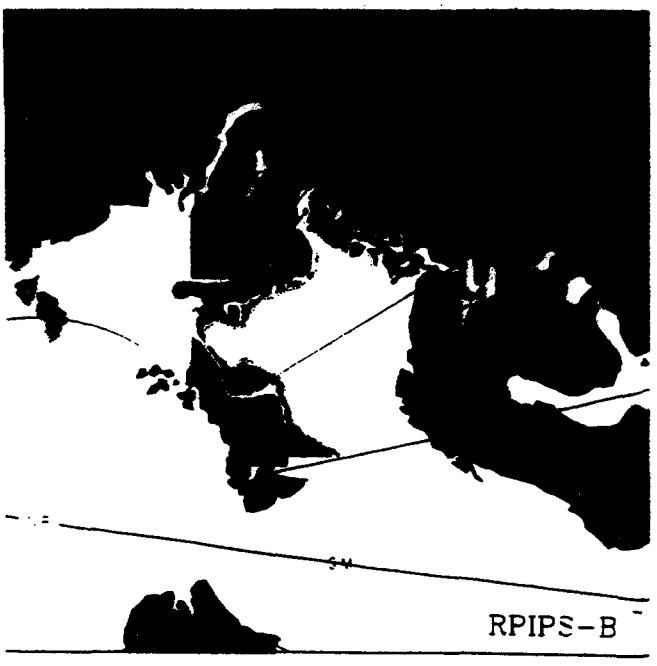

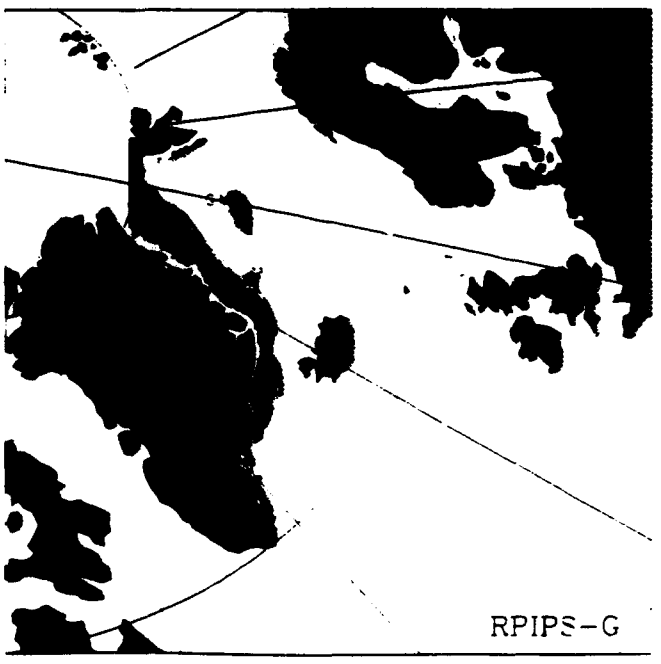

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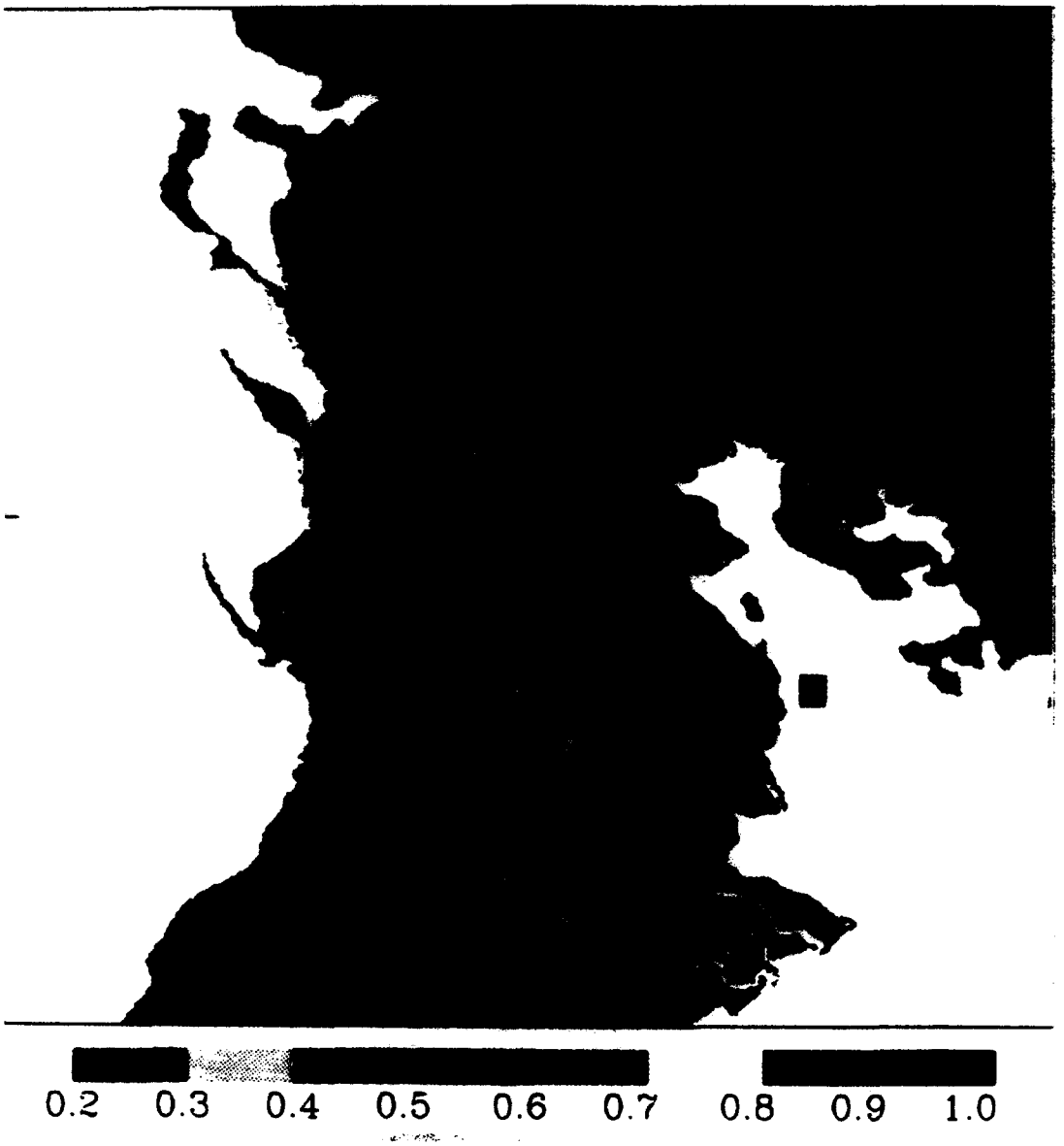

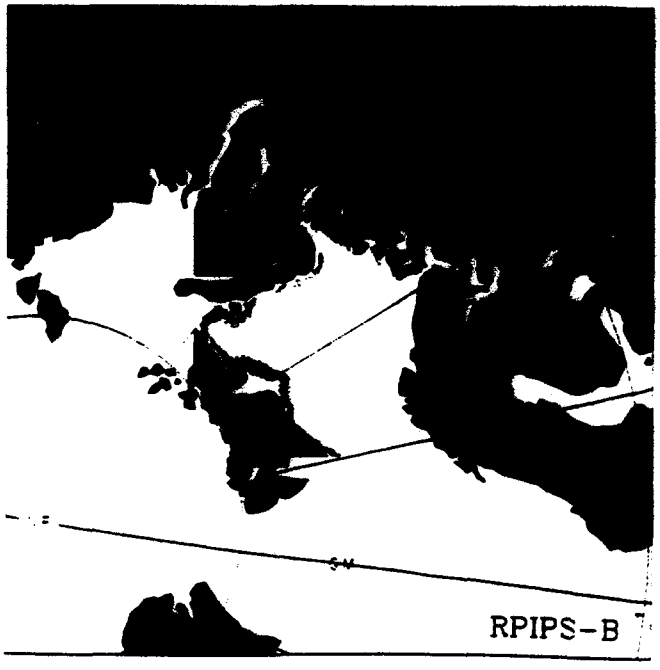

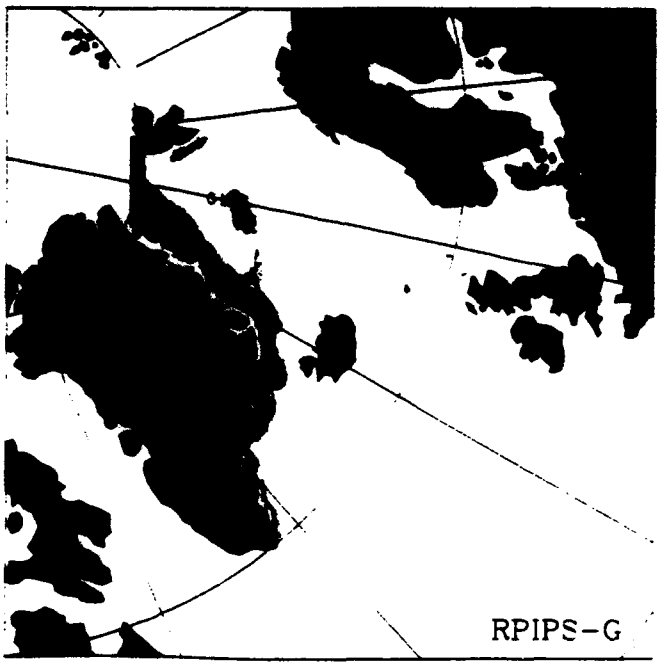

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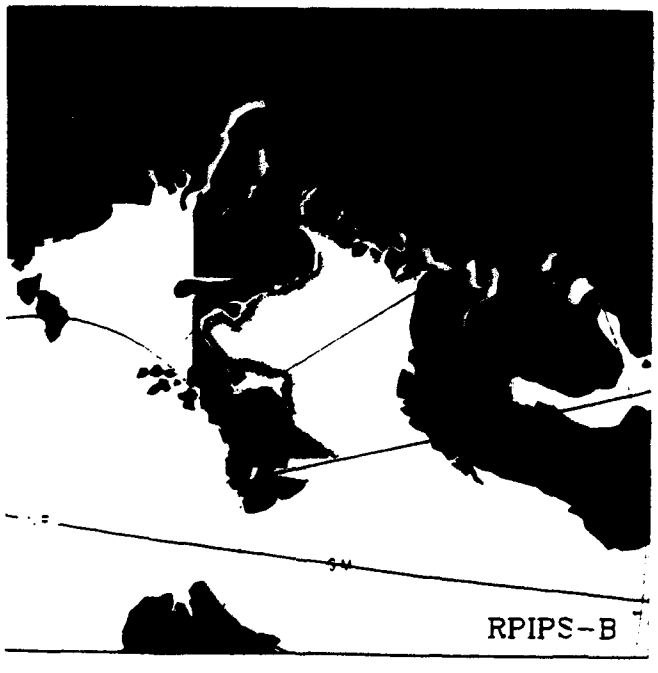

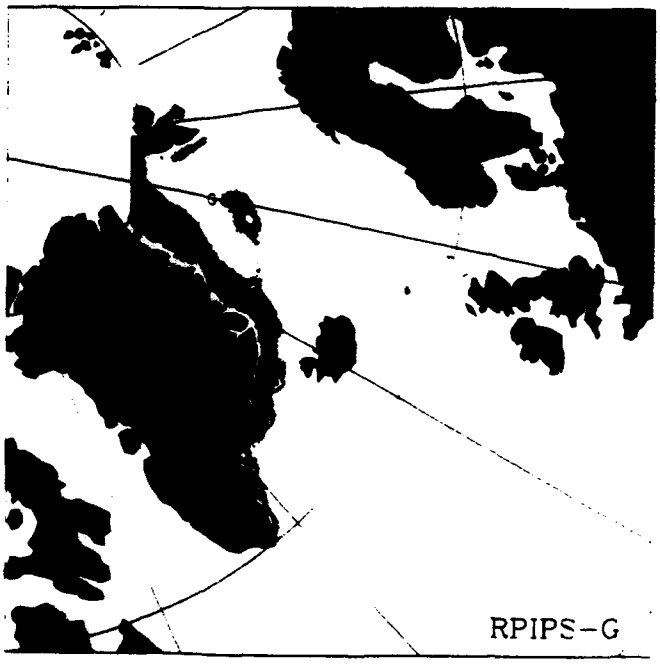

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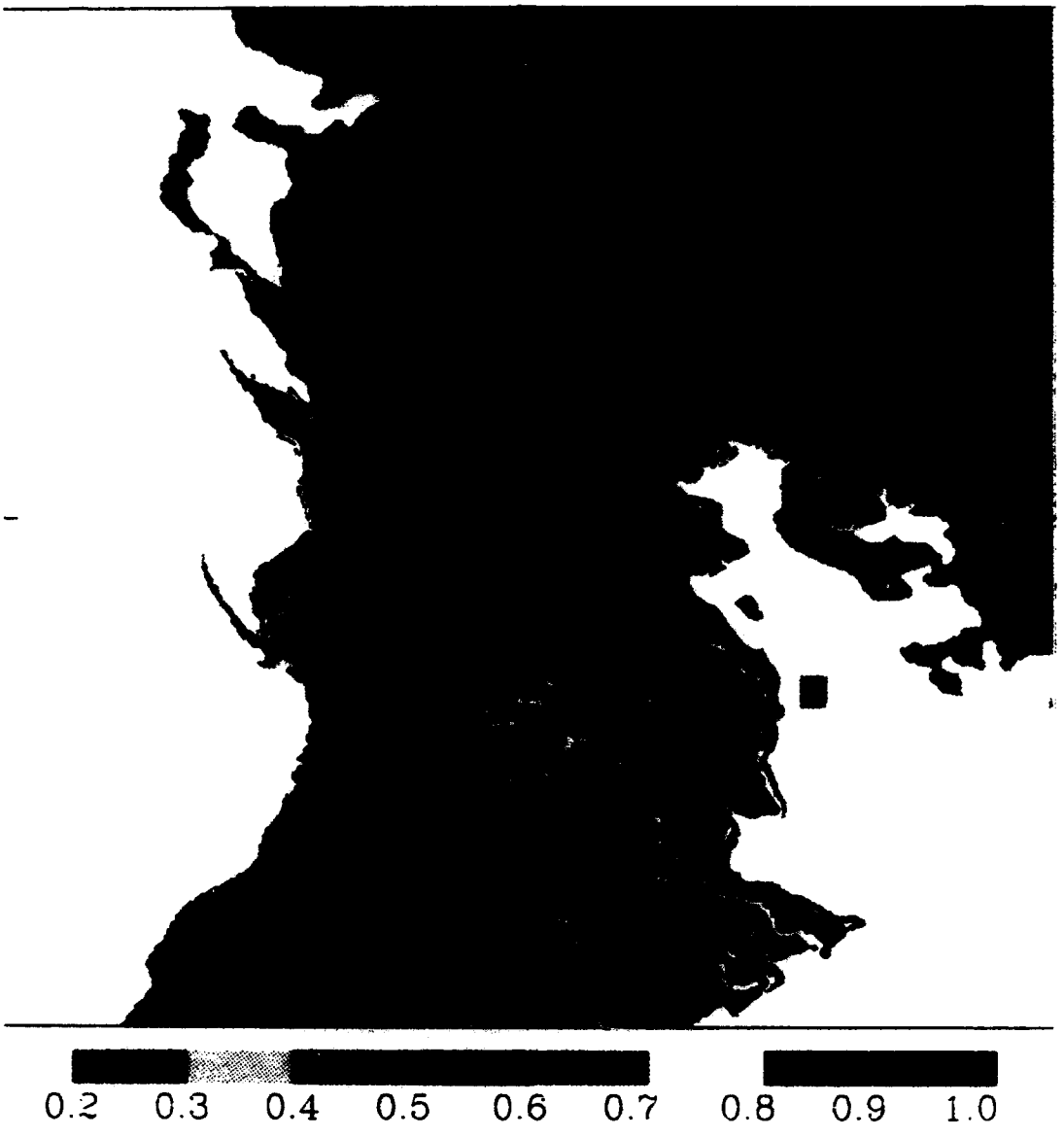

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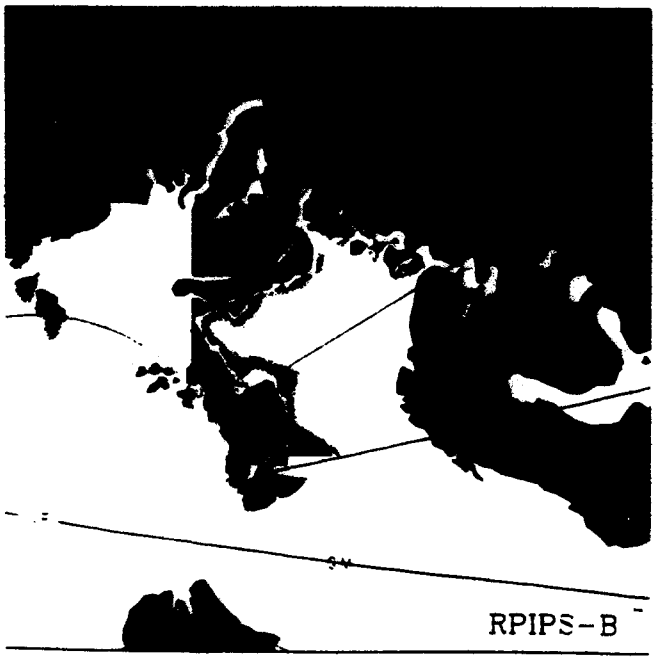
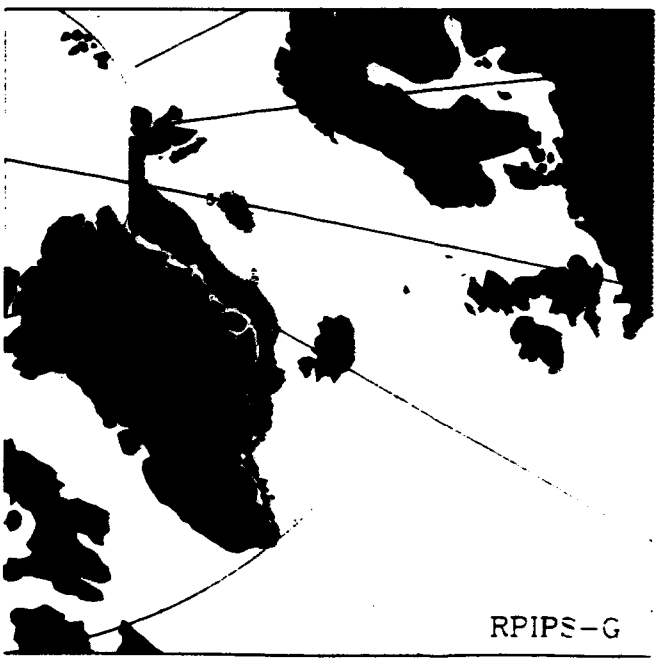


RPIPS-B



RPIPS-G

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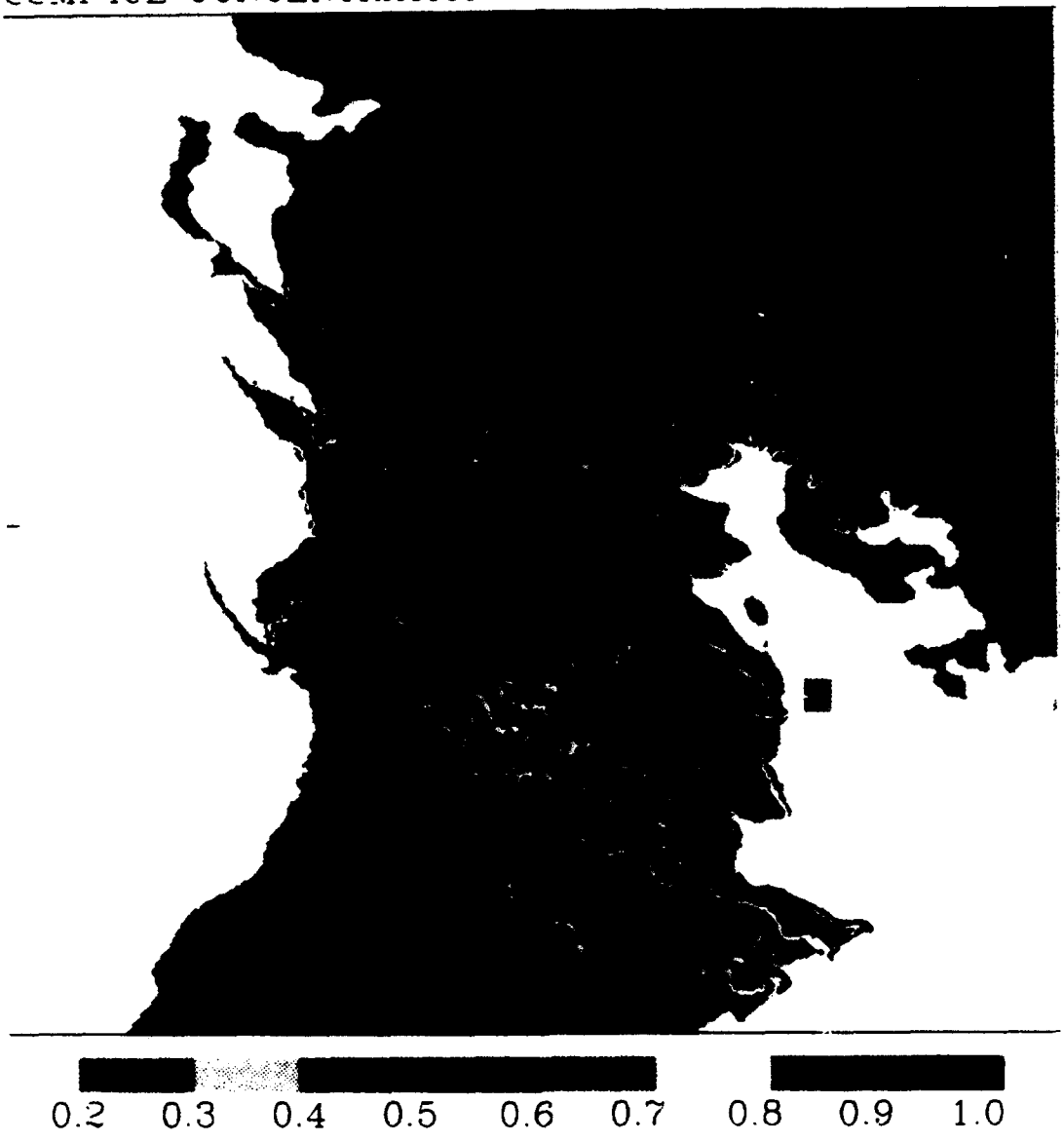

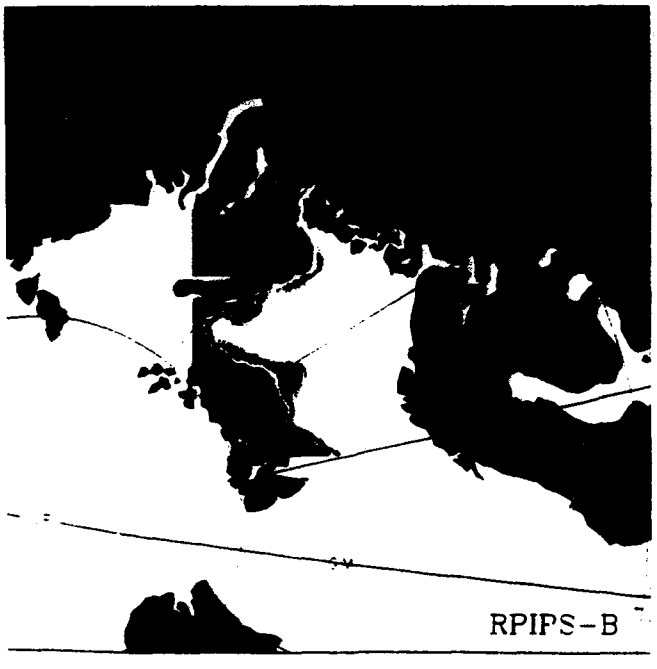

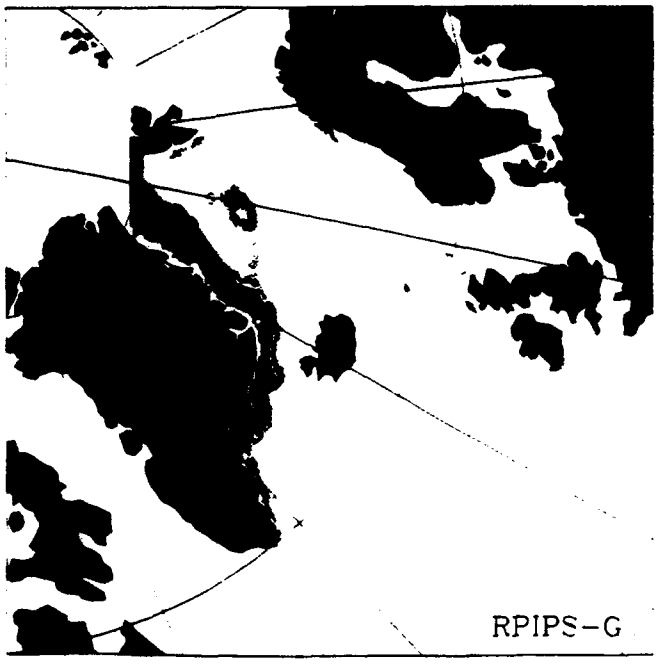

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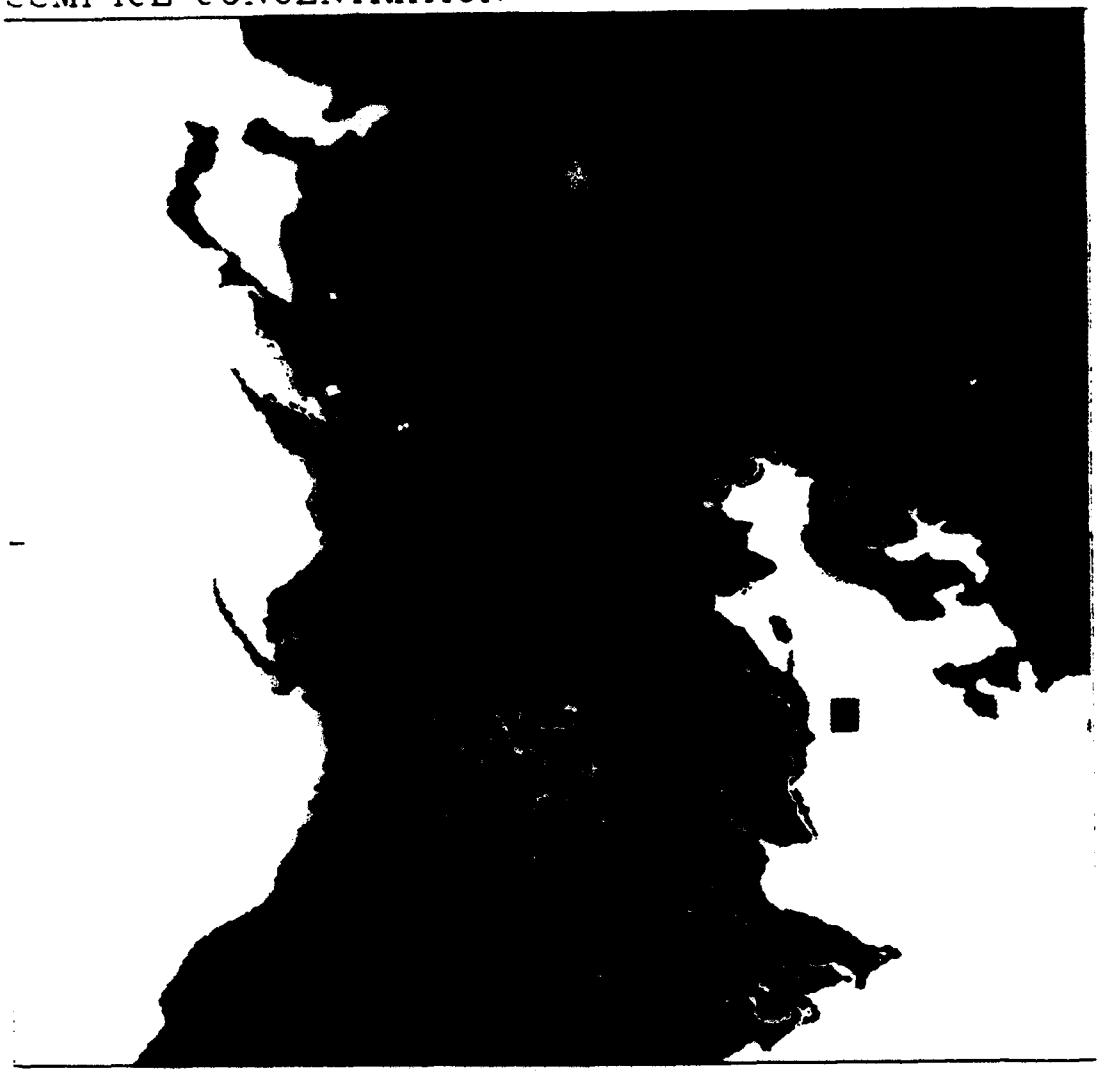

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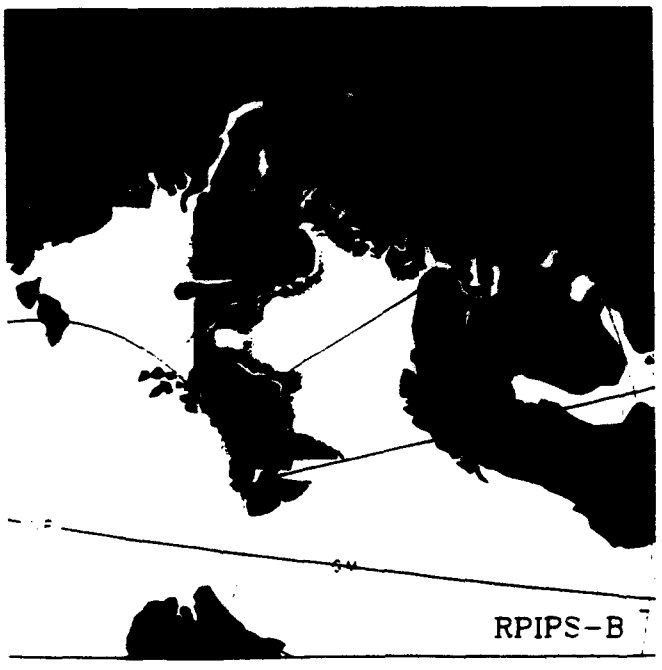
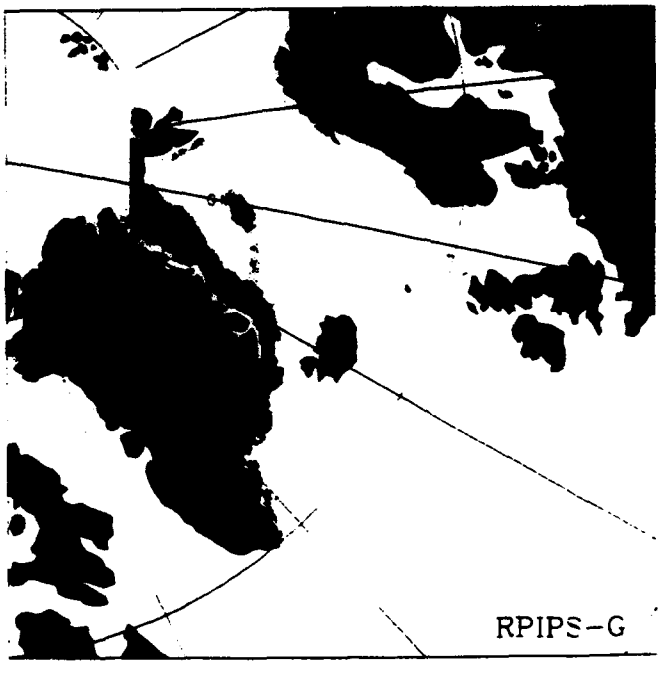


RPIPS-B



RPIPS-G

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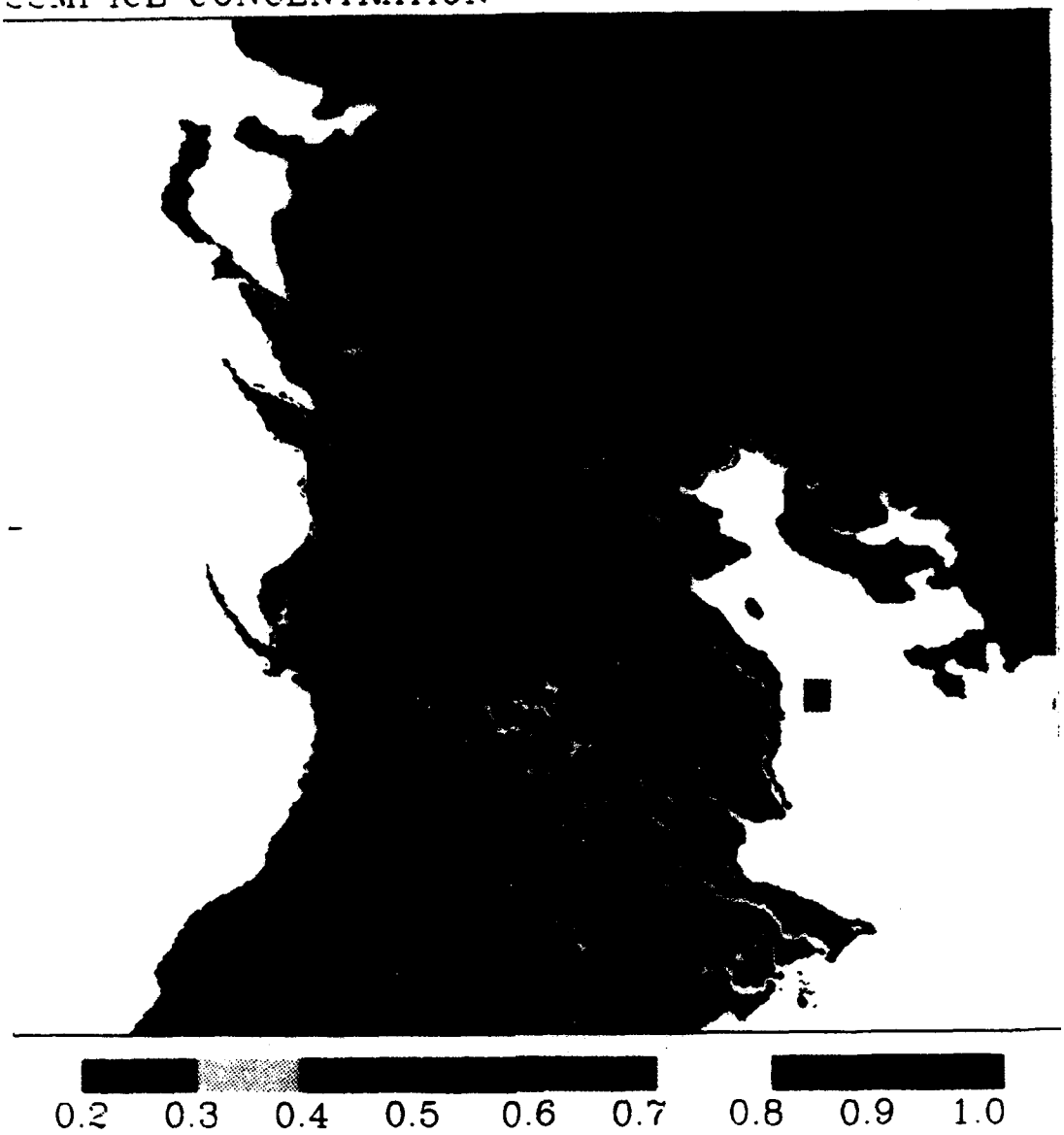

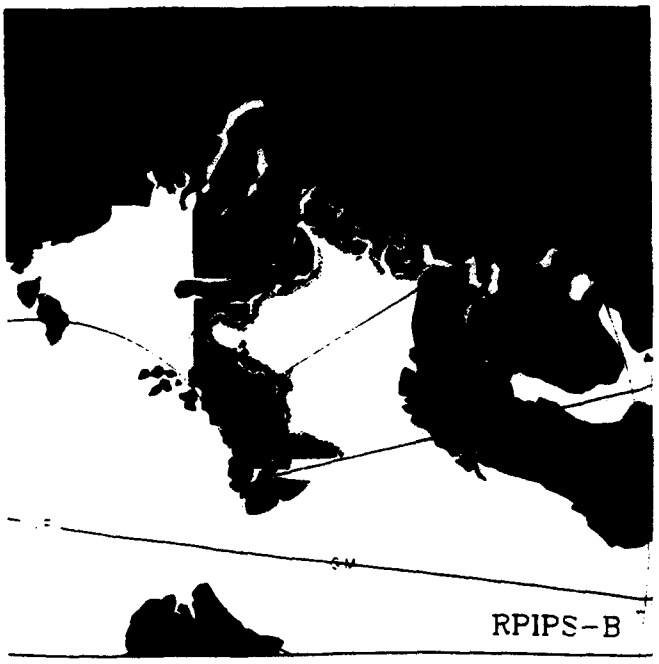

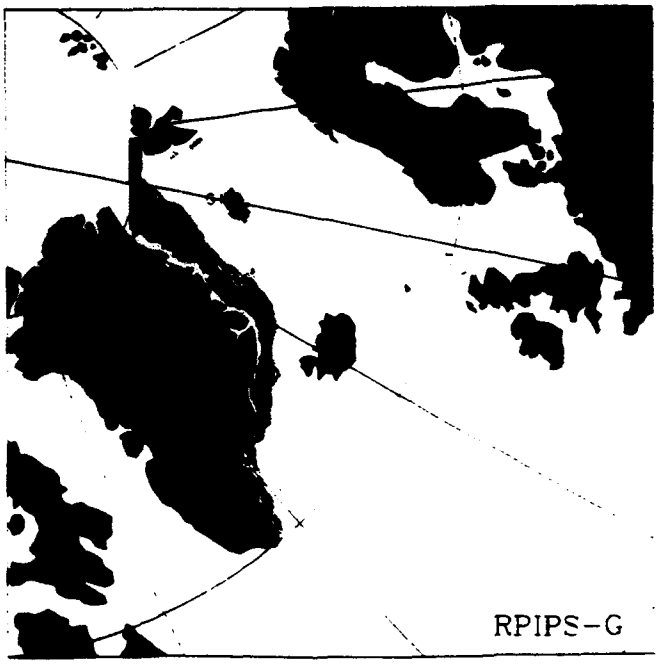

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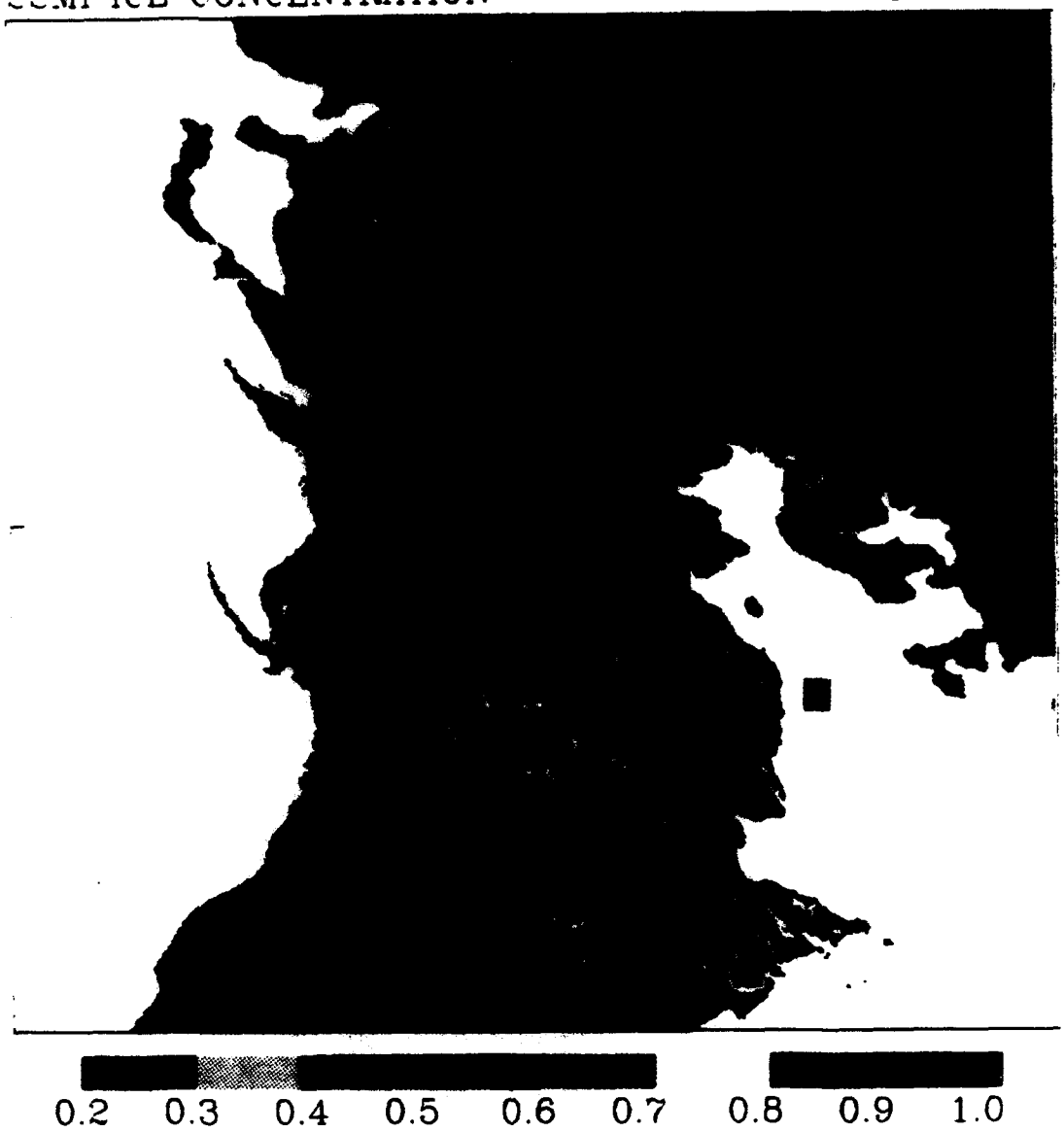

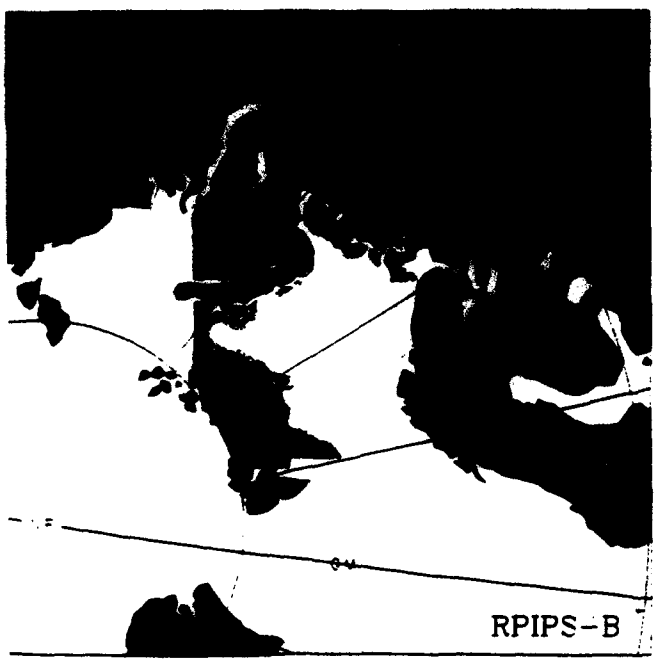

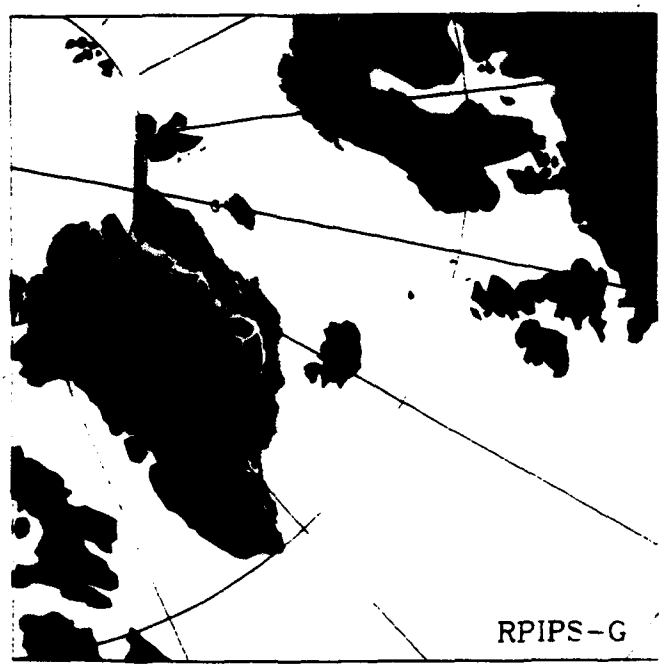

SSMI ICE CONCENTRATION 93021500

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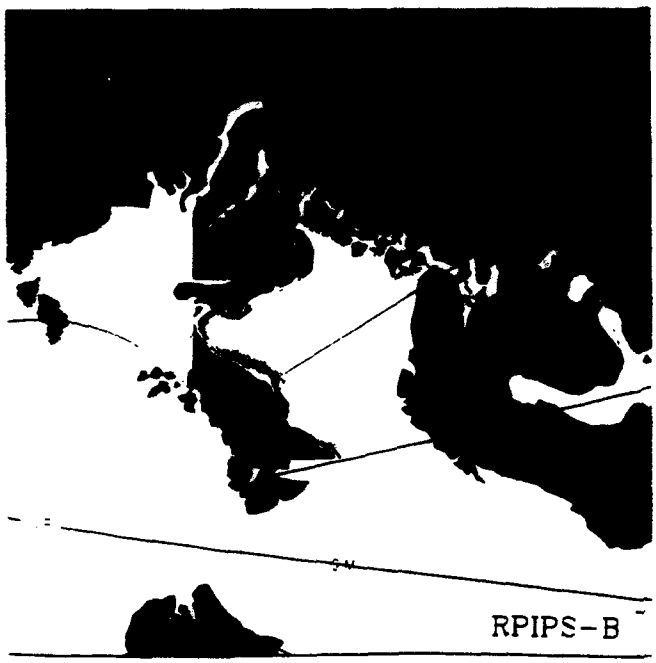

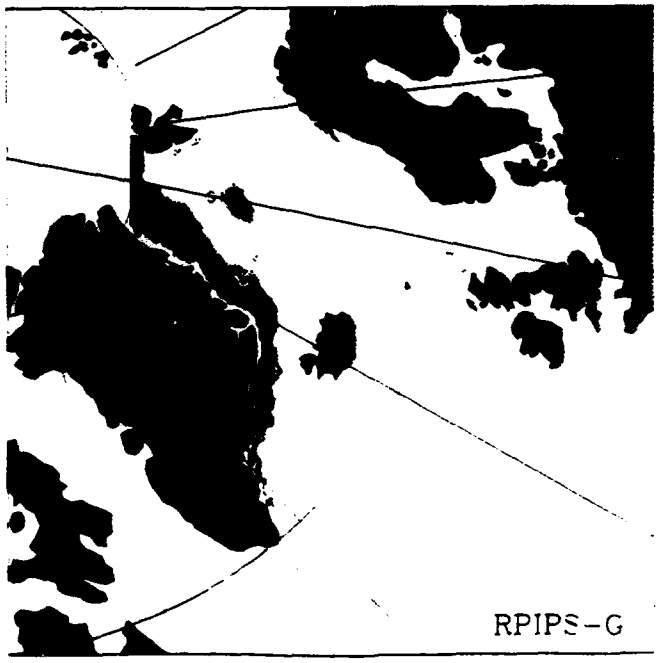

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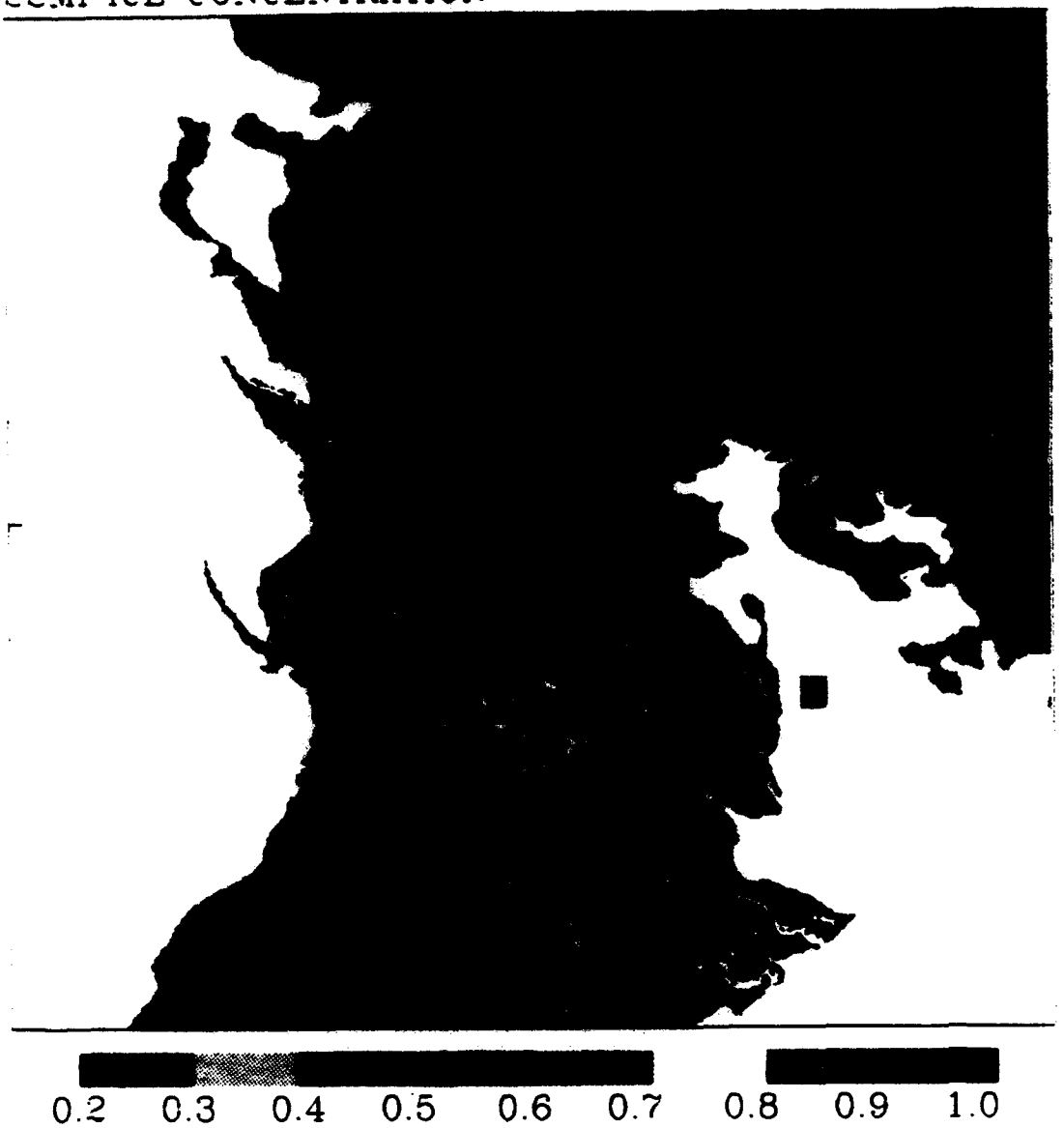

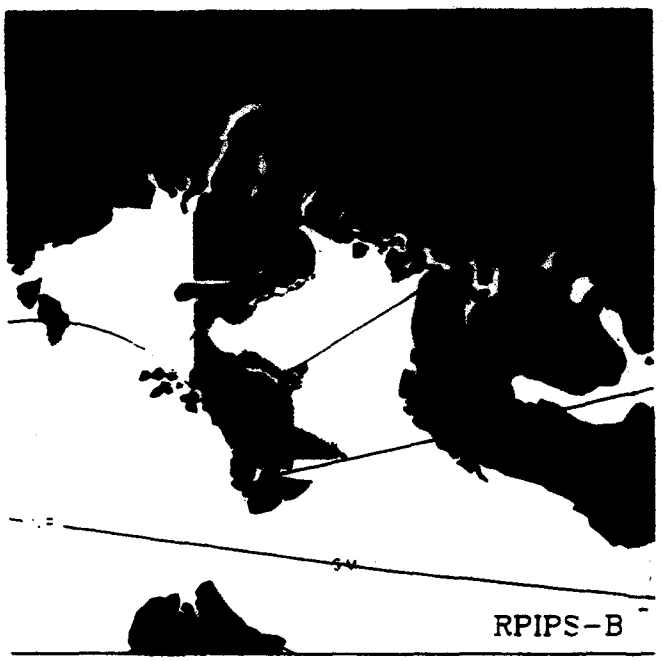

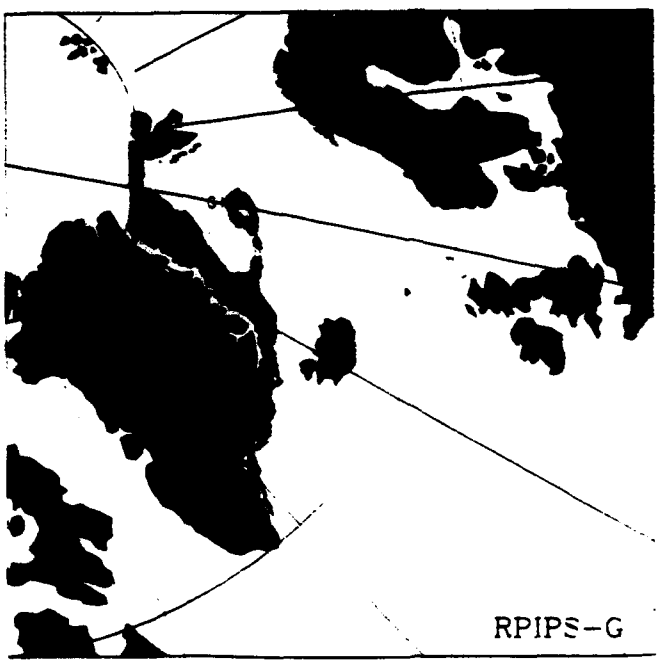

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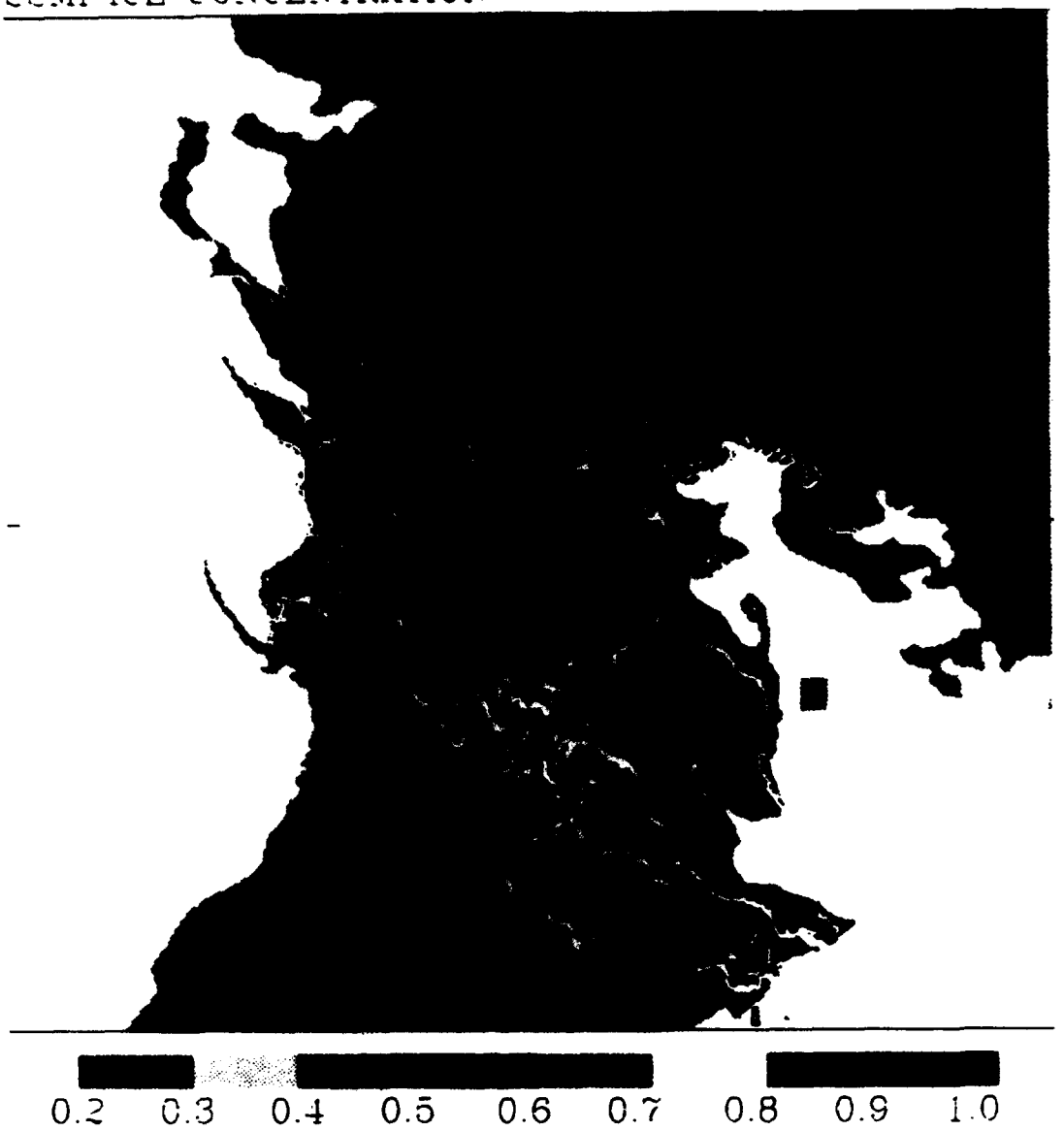

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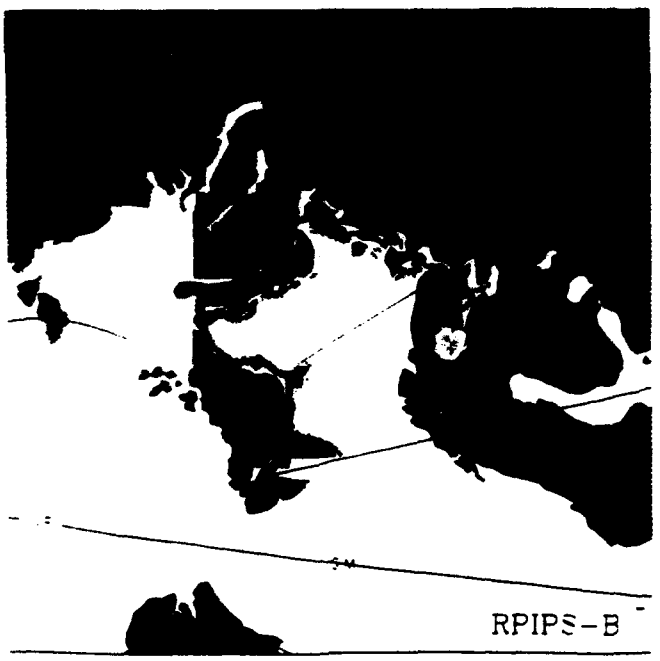
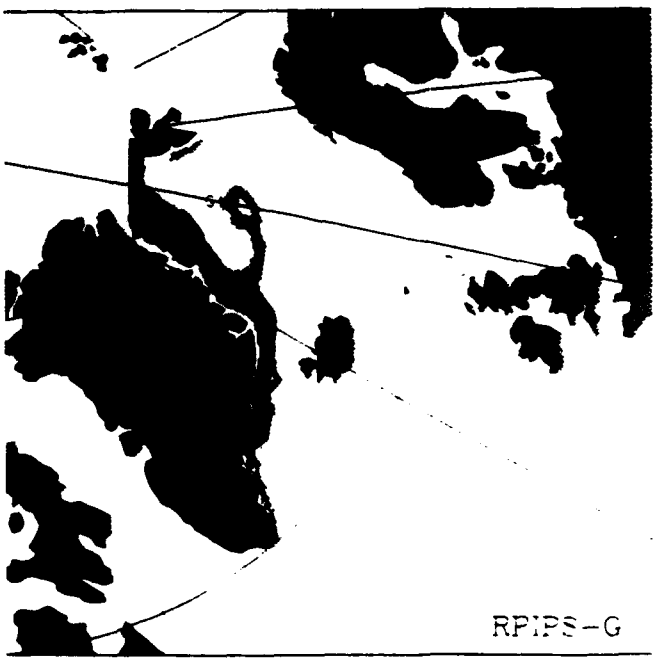


RPIPS-B



RPIPS-G

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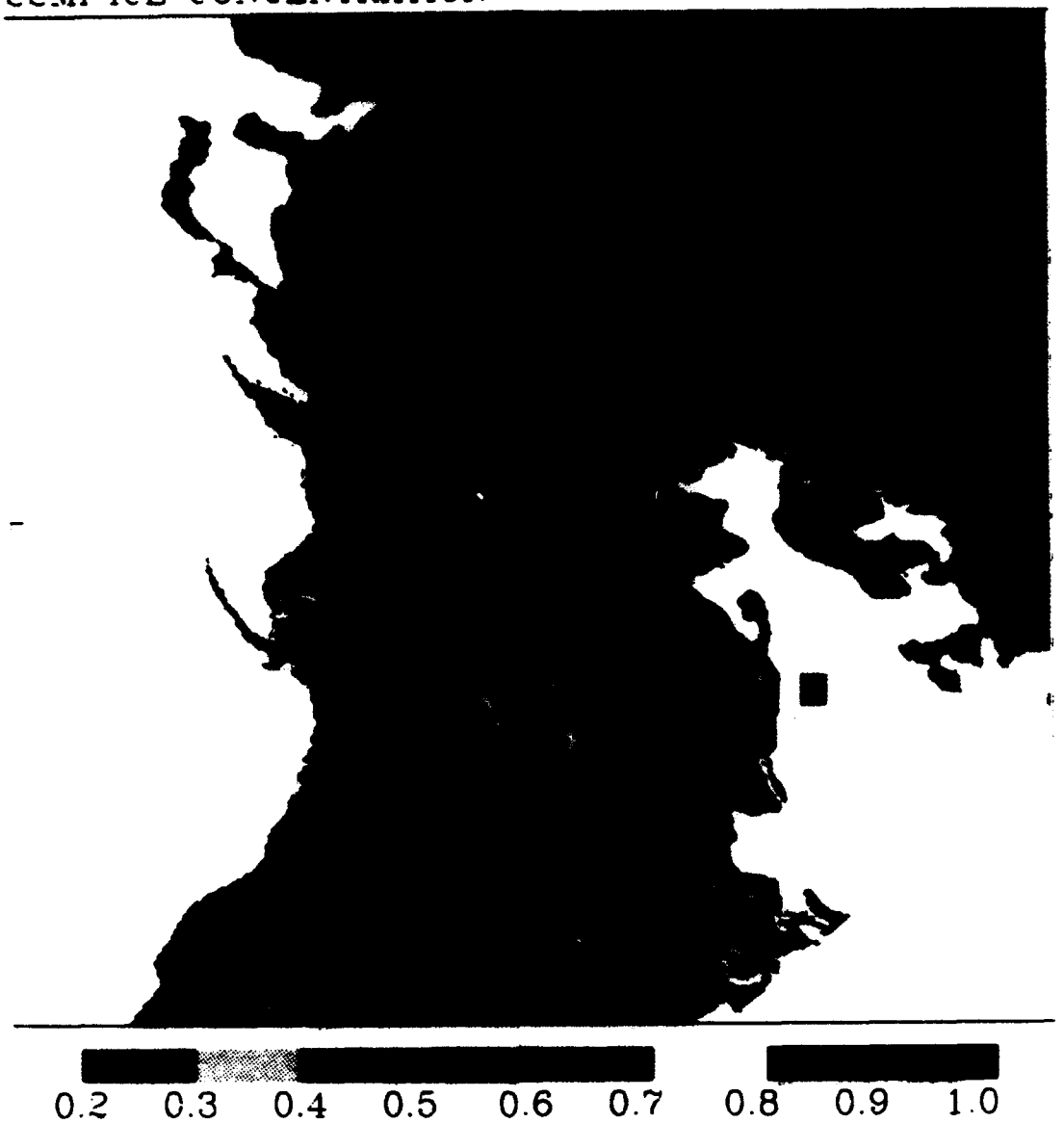

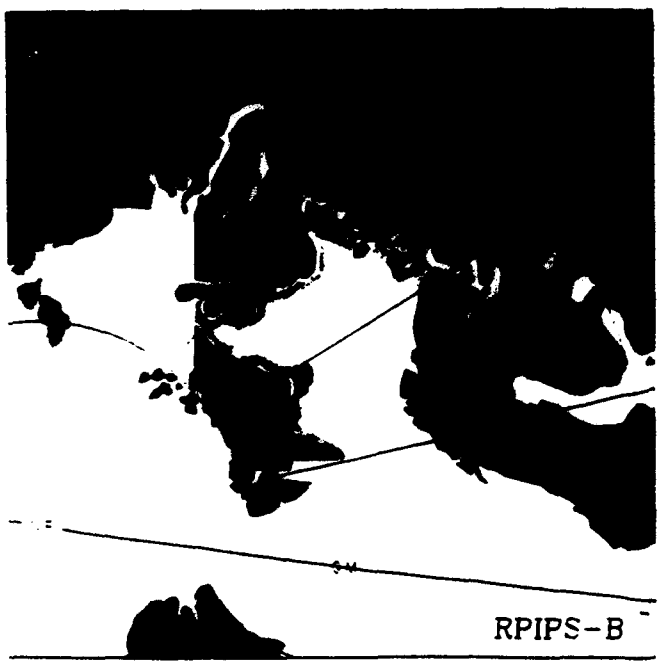

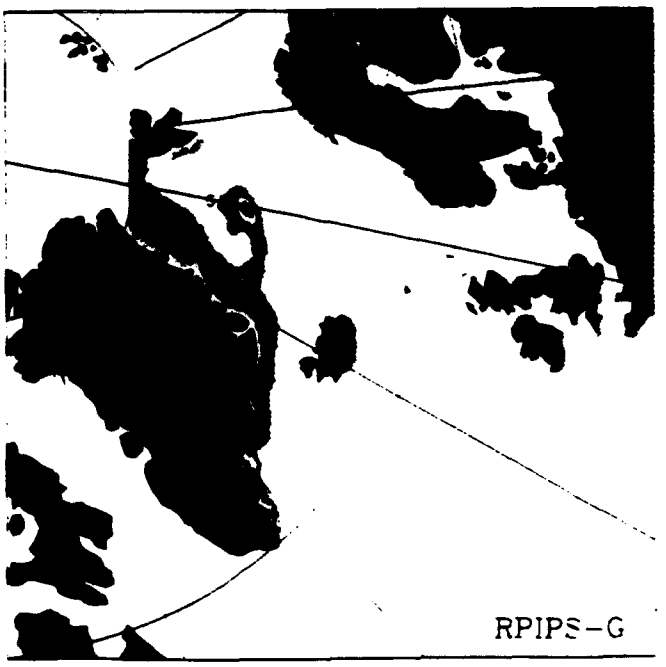

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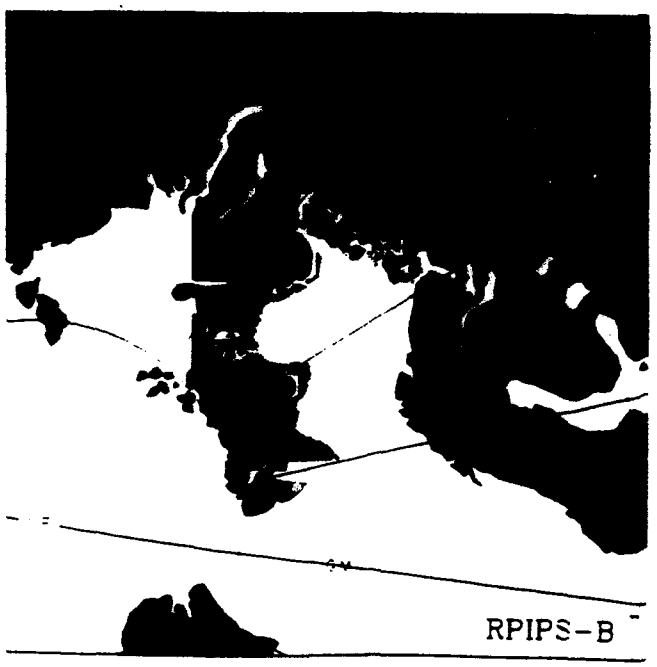

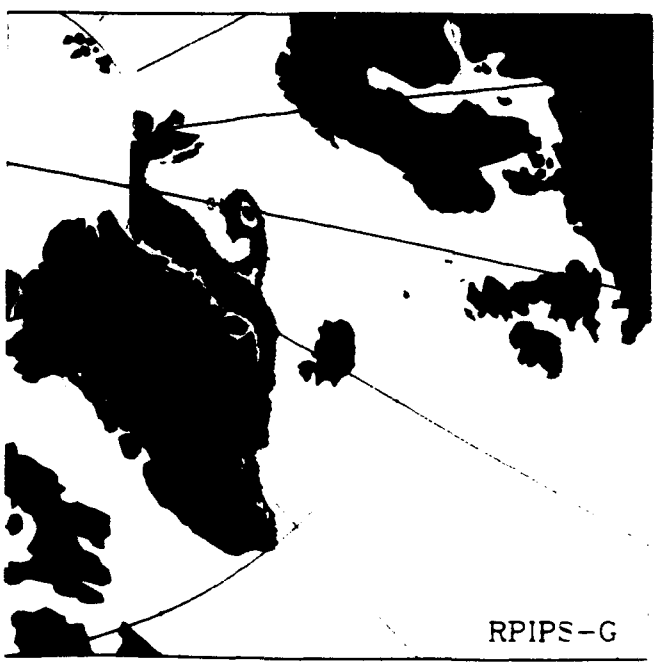

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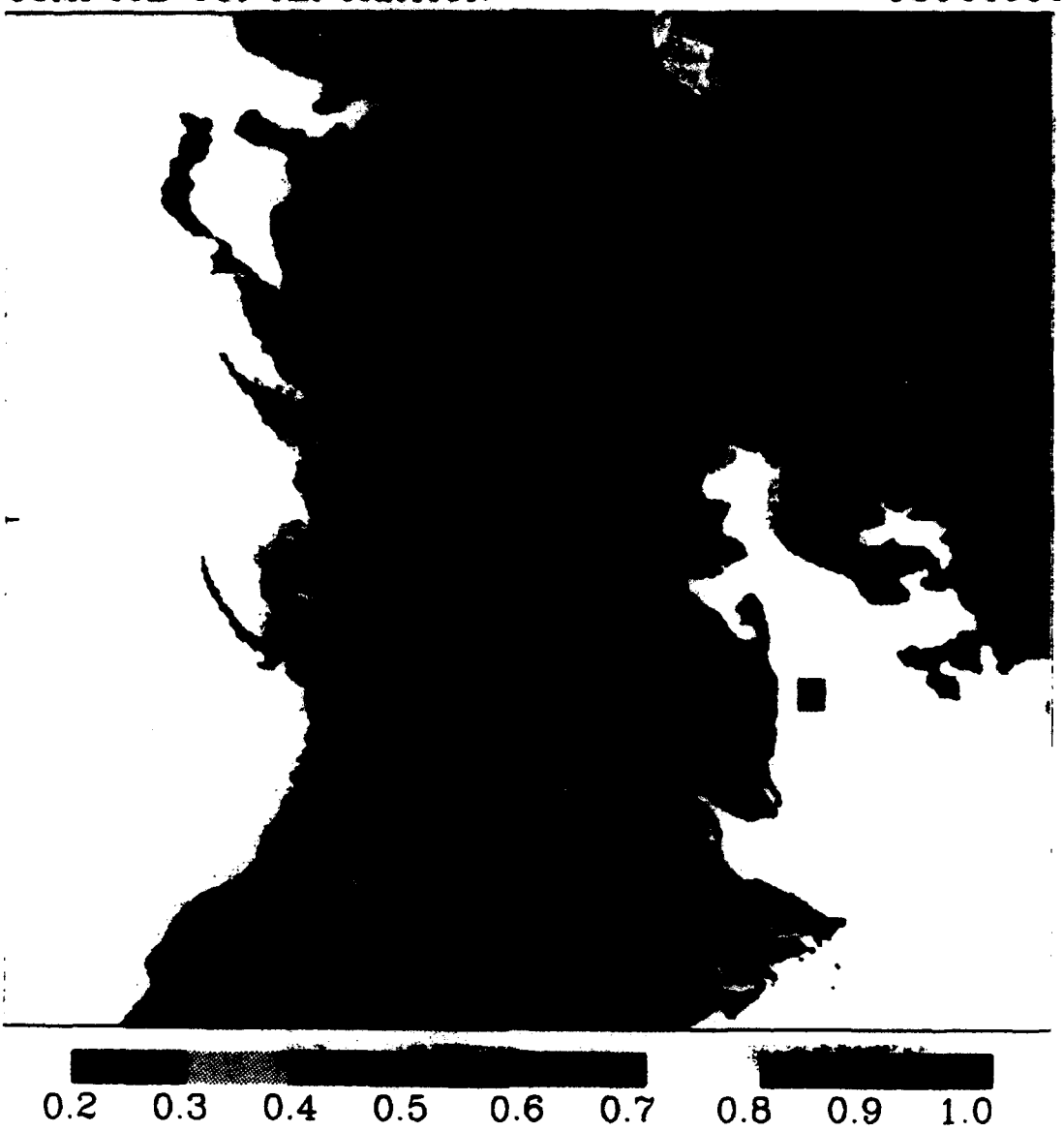

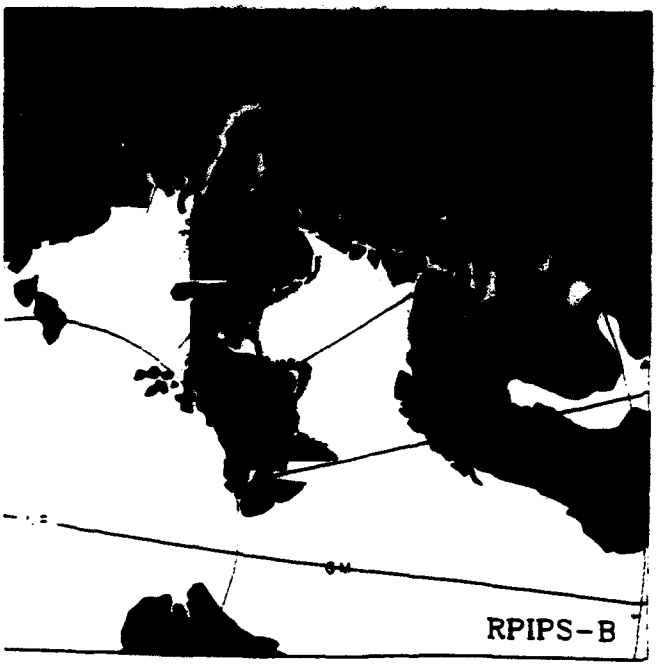

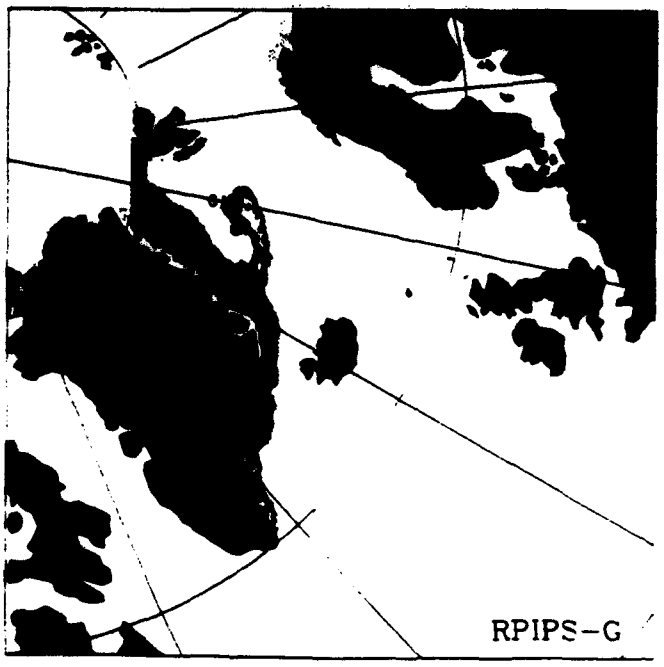

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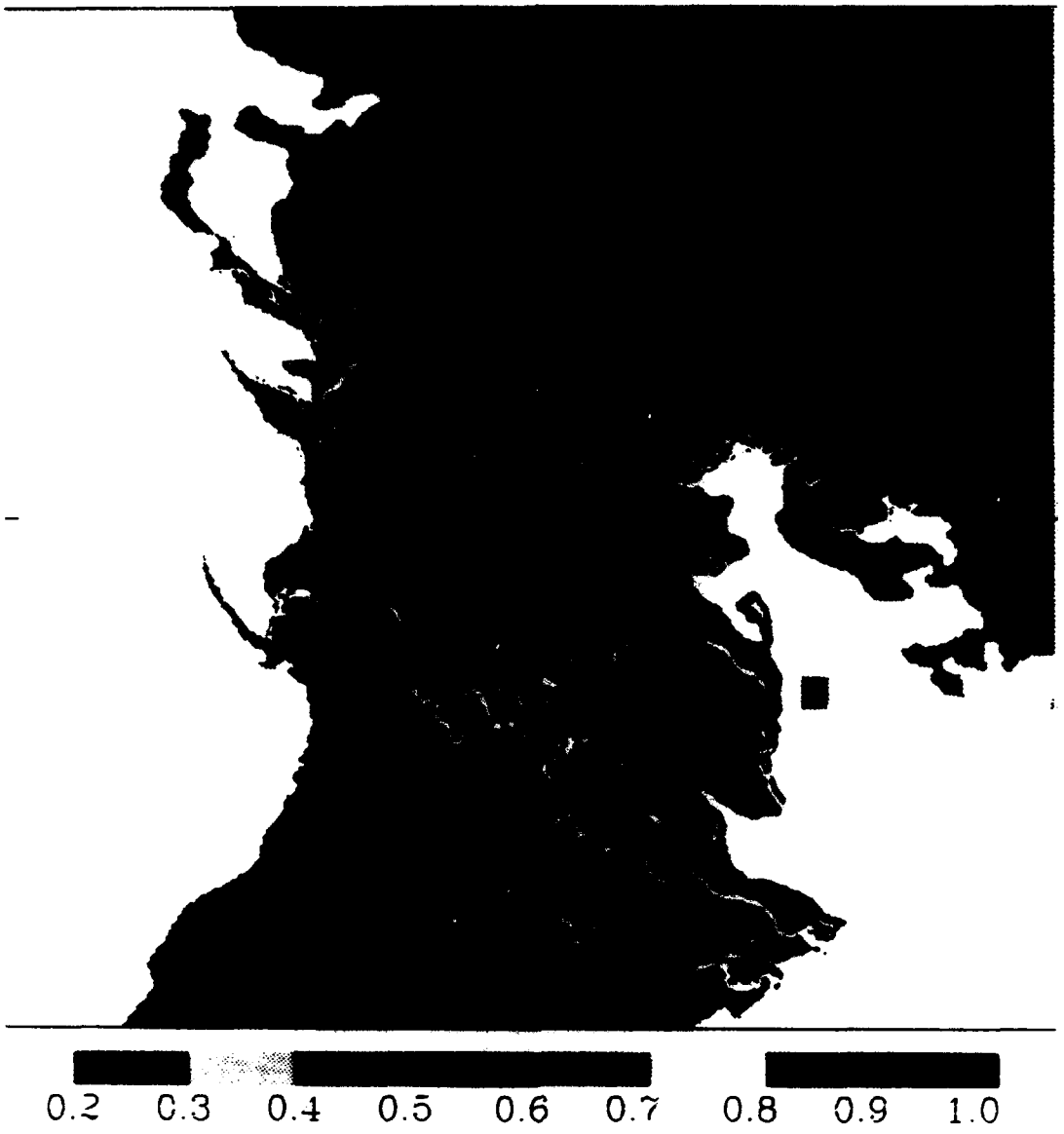

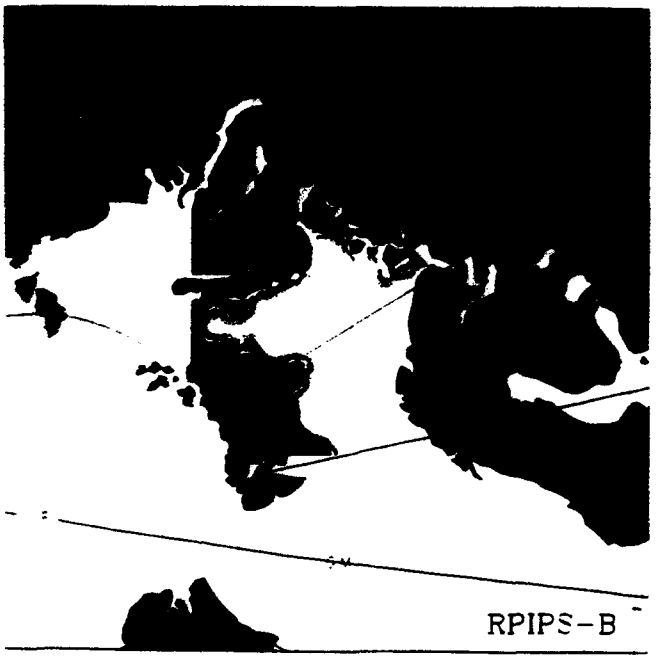

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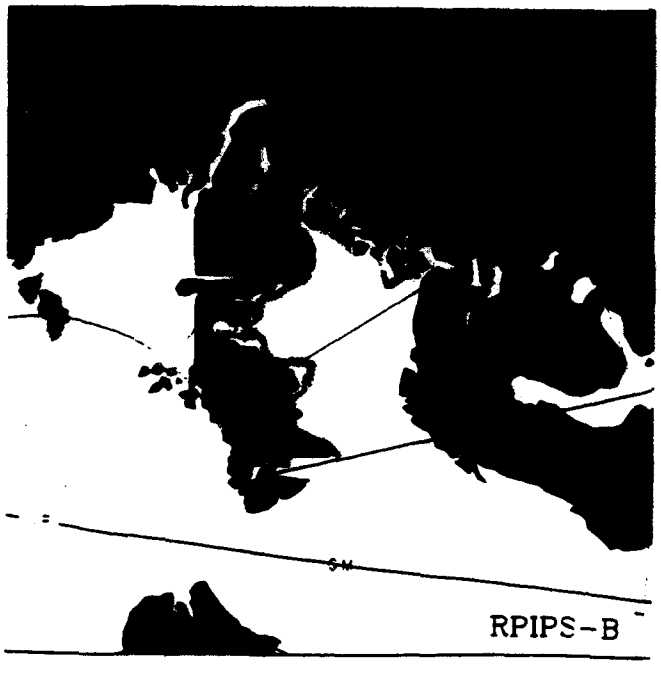
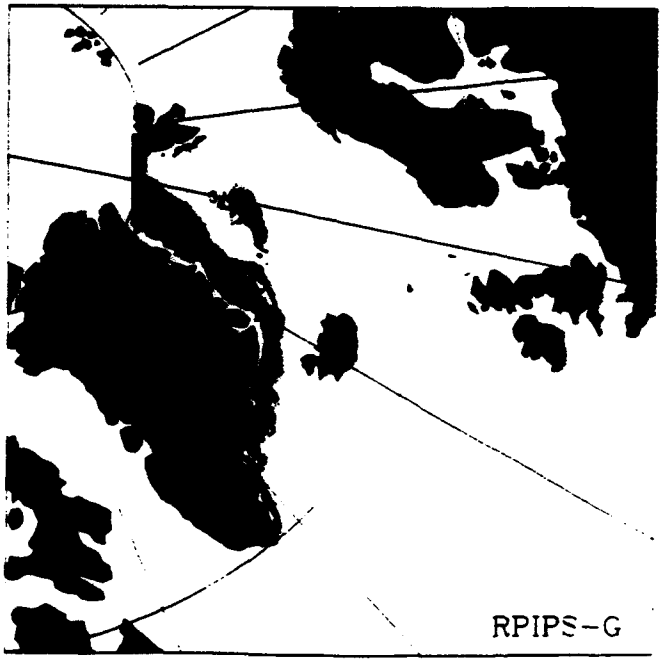


RPIPS-B



RPIPS-G

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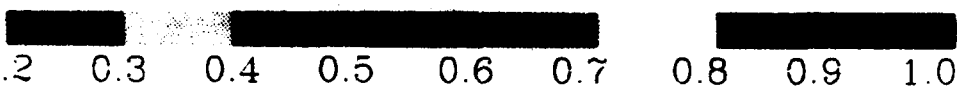

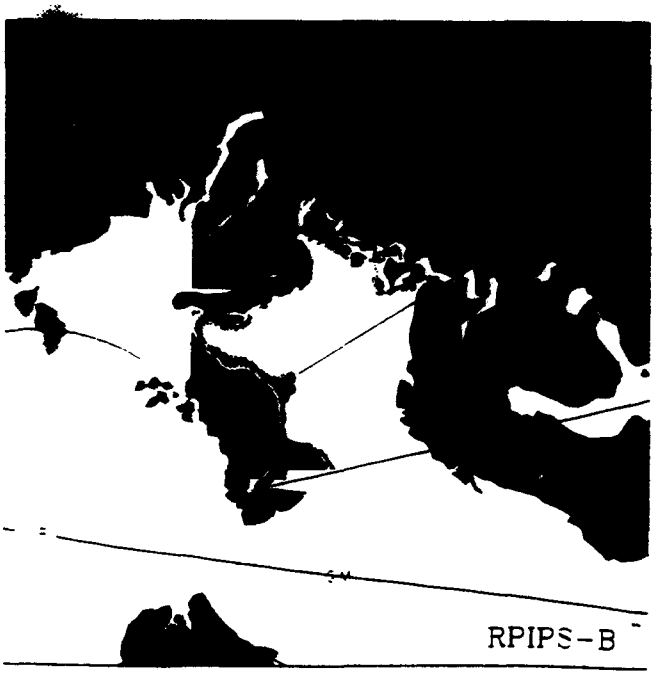

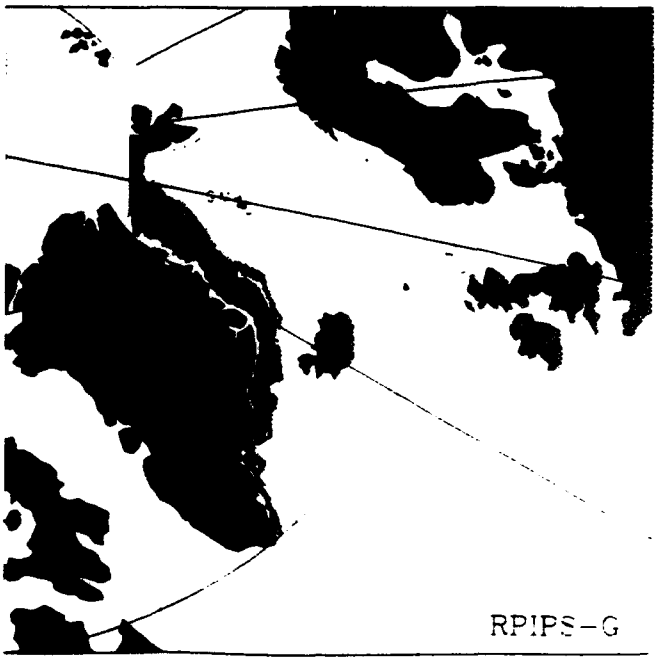

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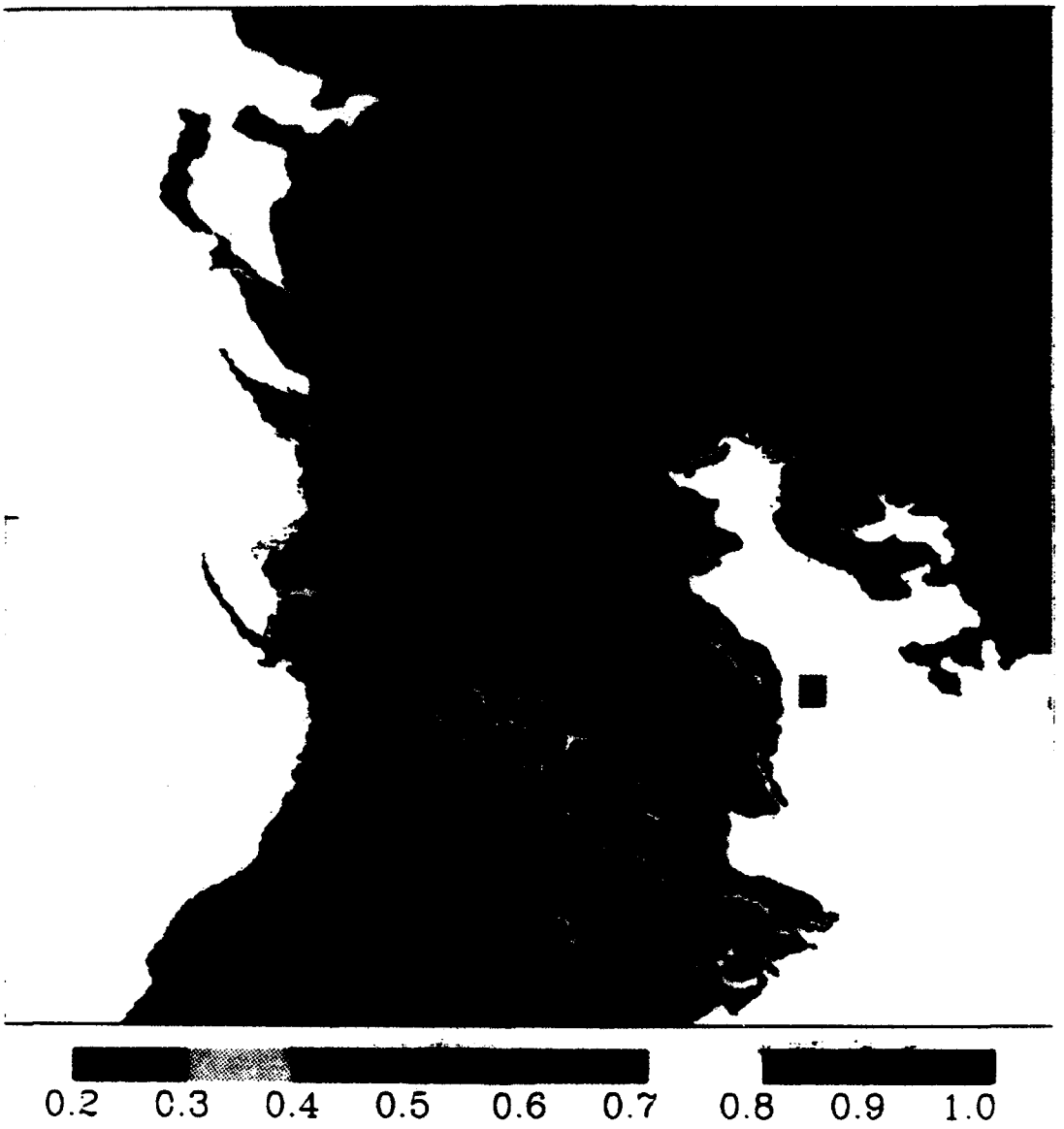

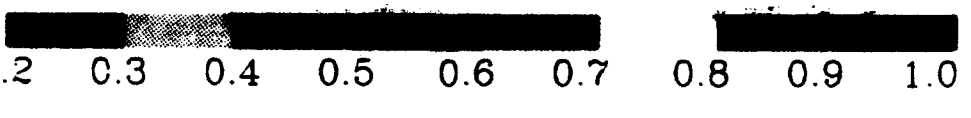

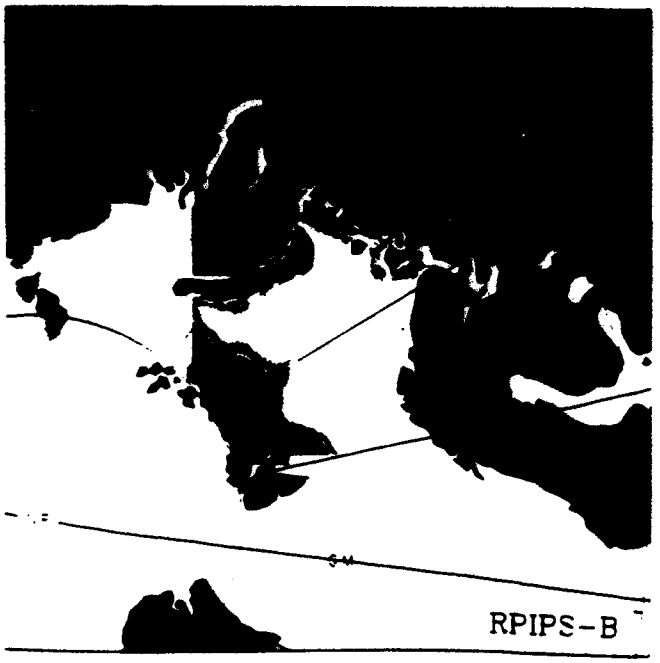

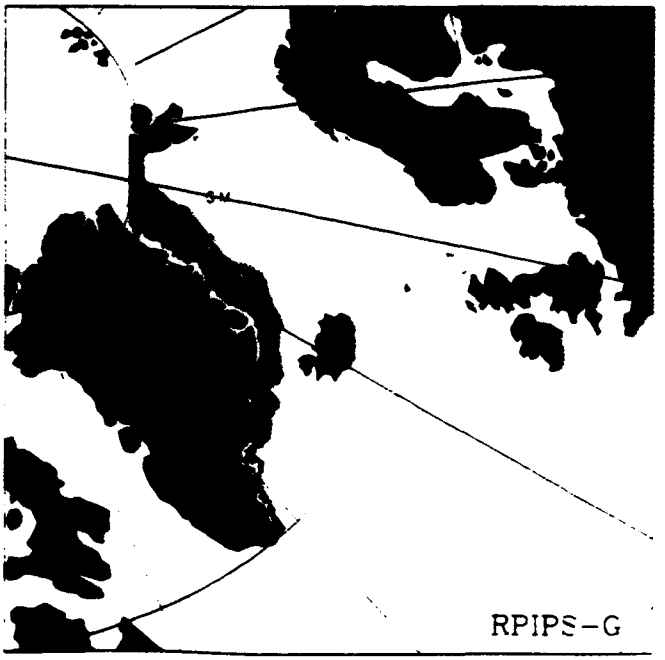

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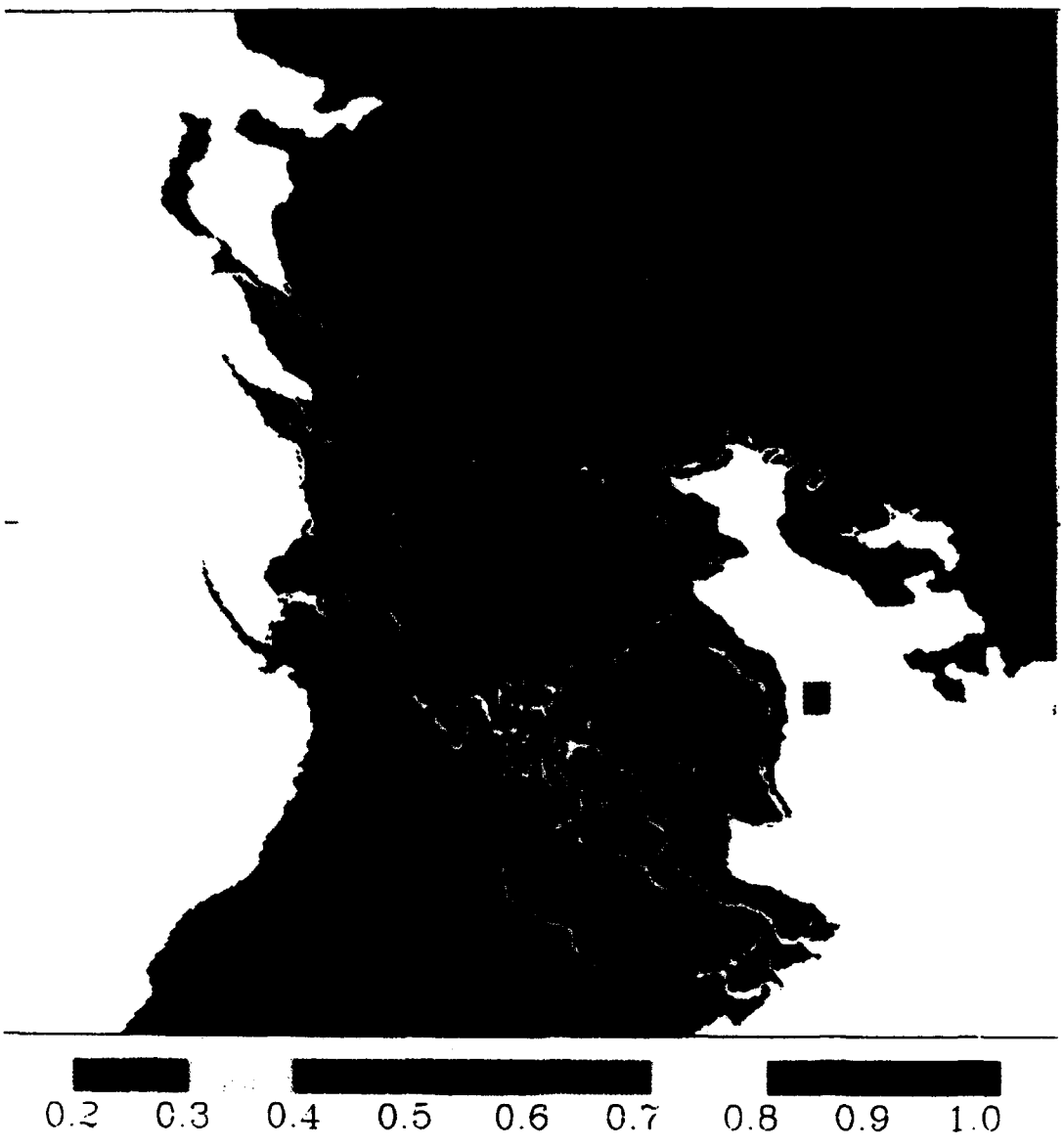

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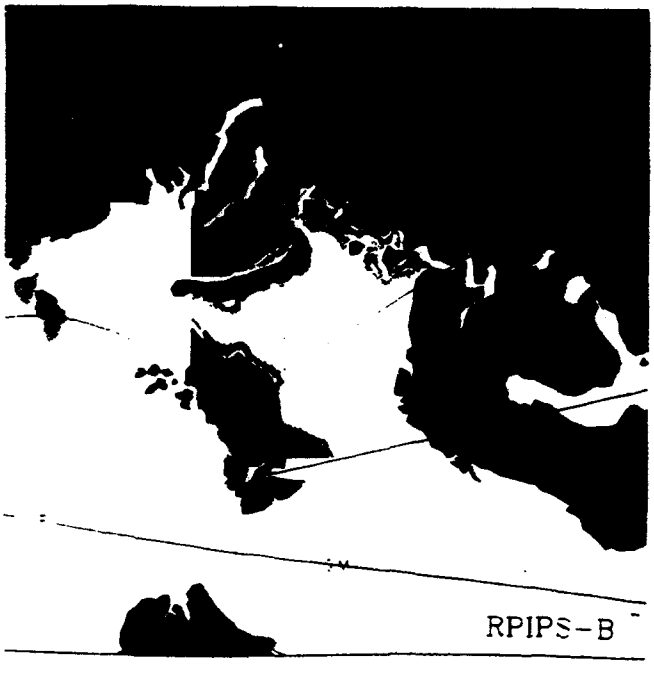

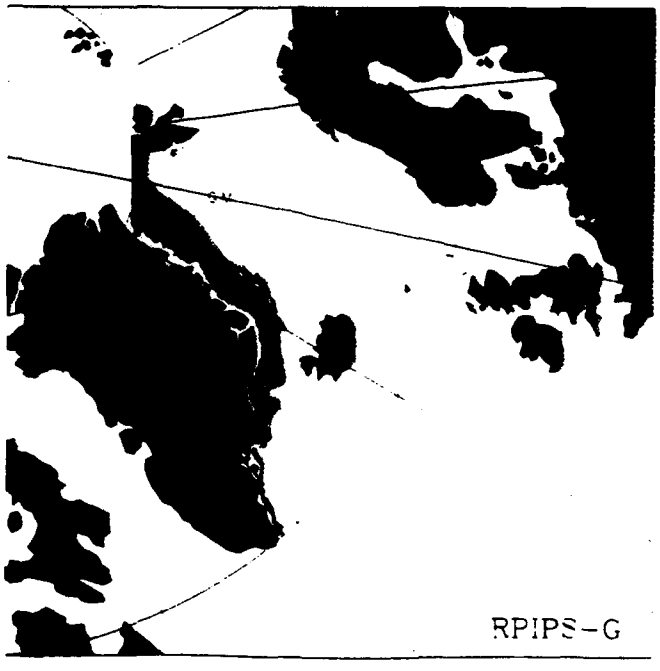

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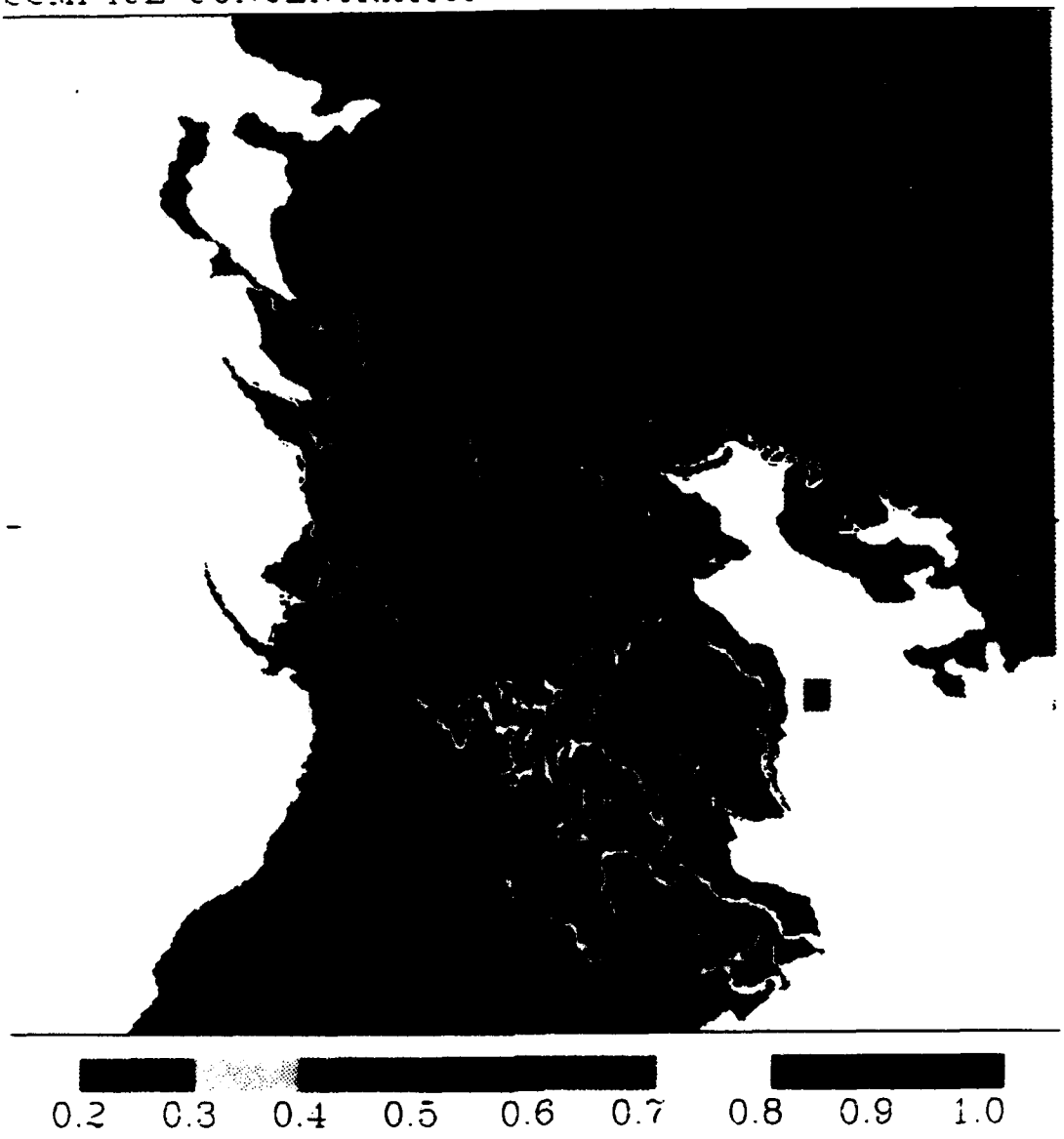

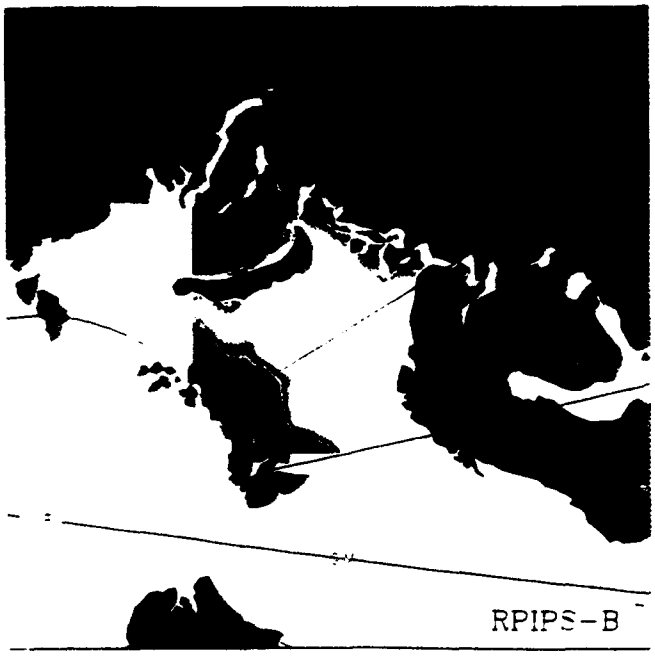

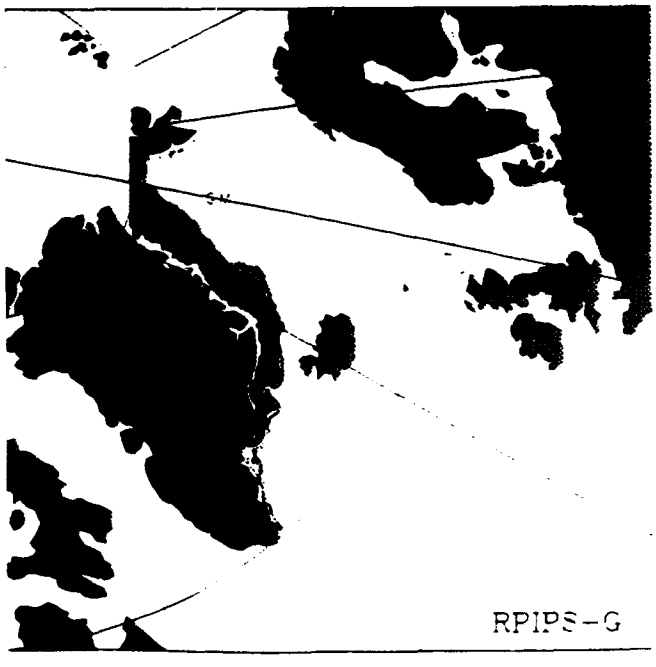

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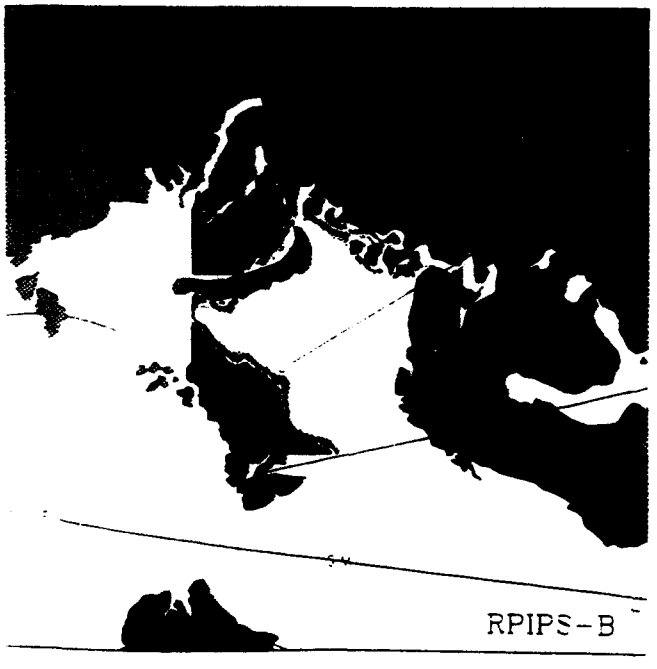

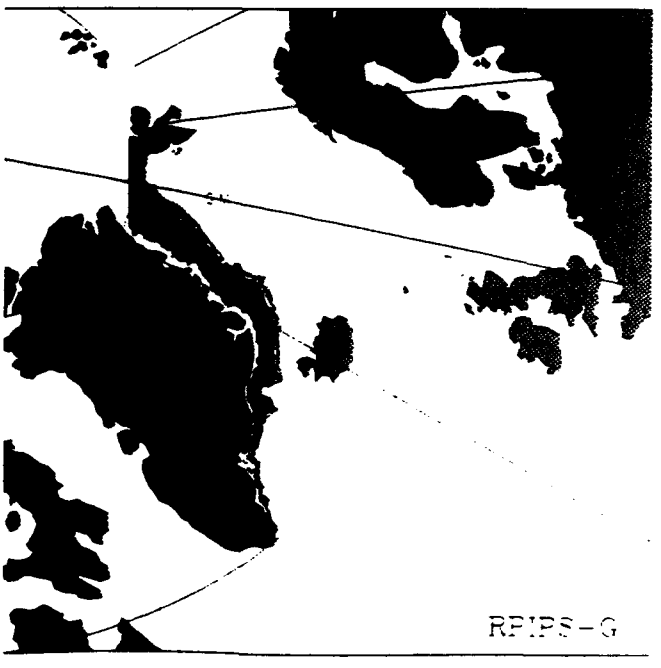

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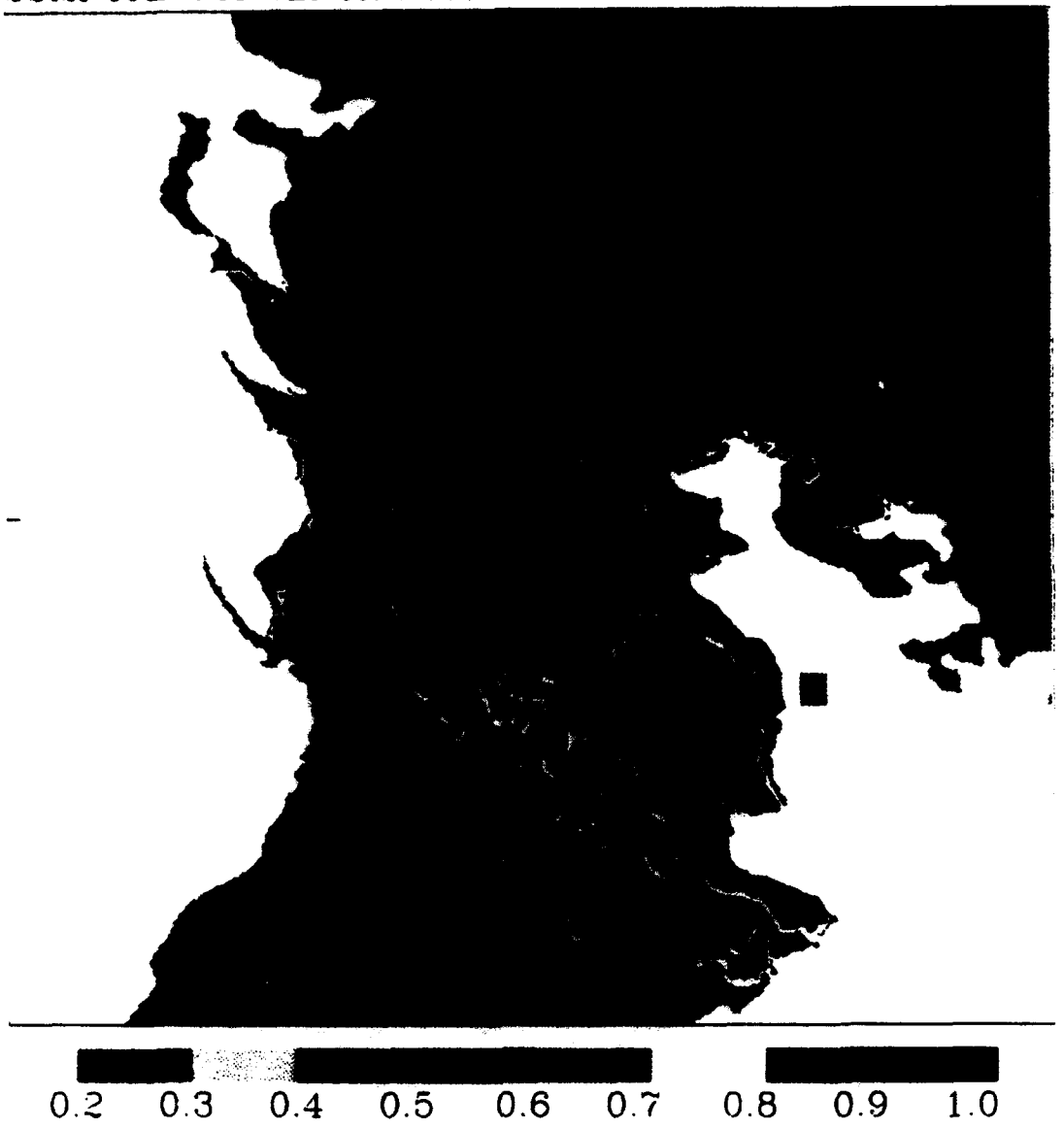

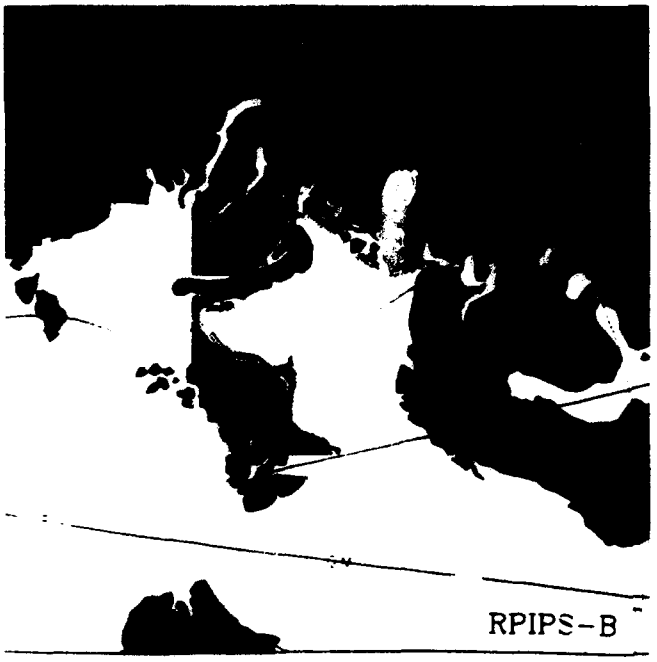

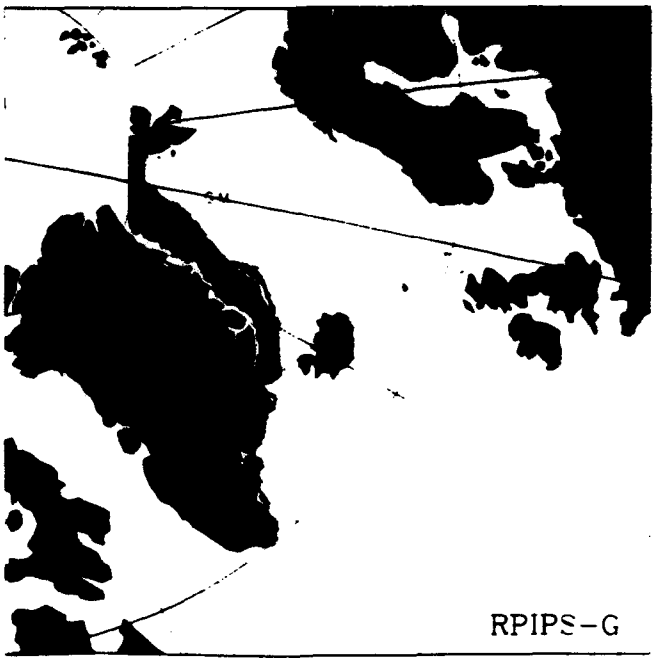

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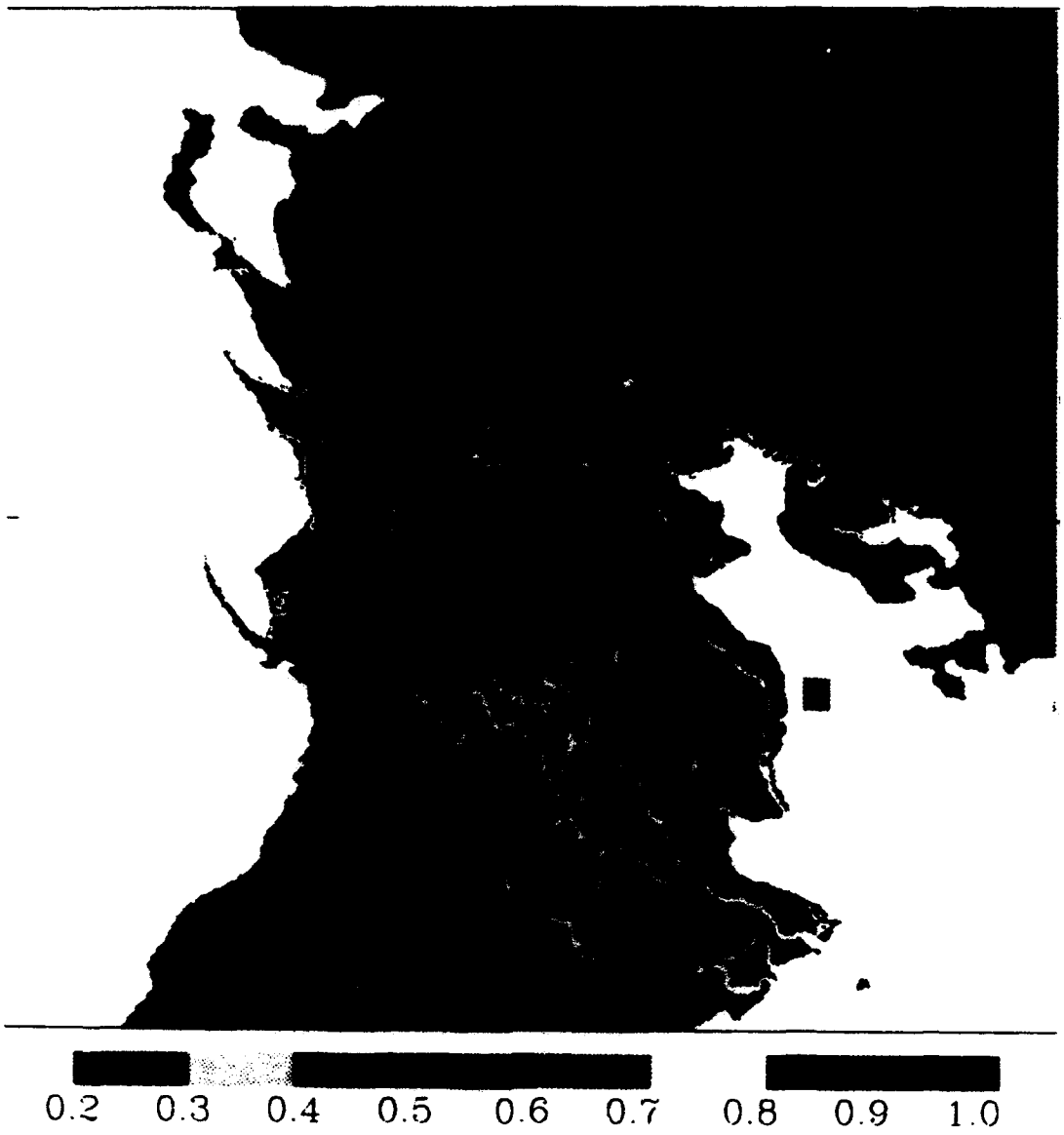

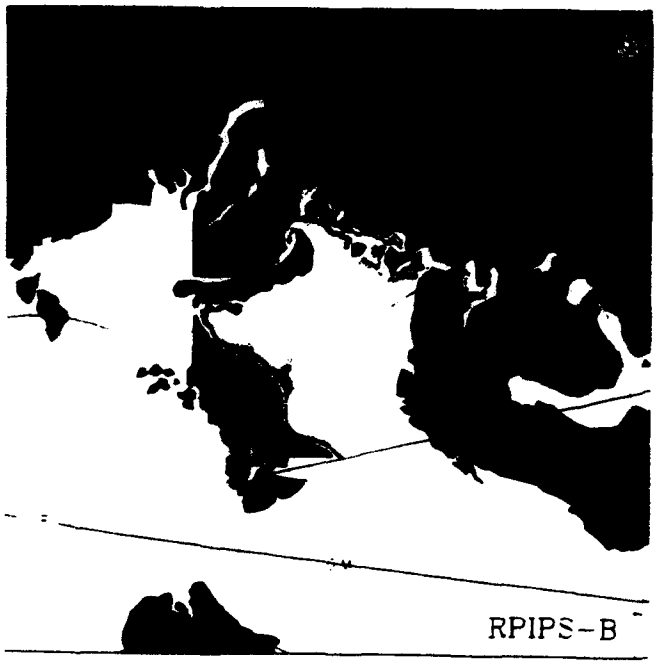

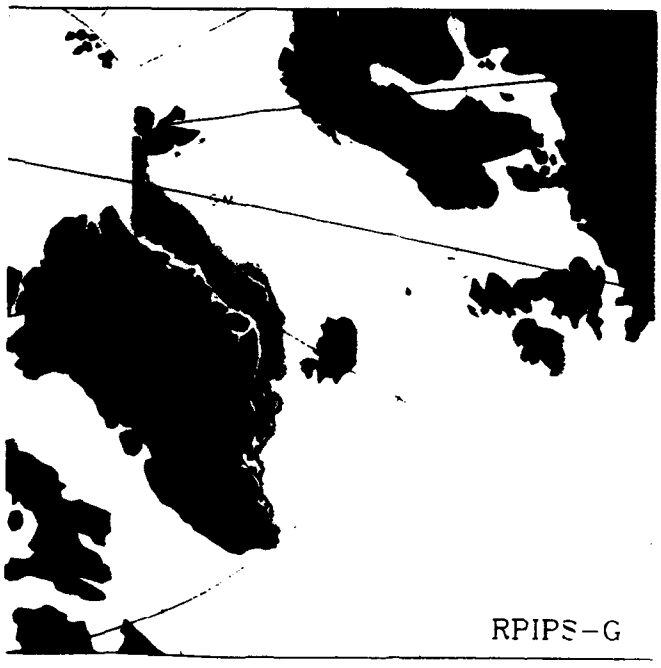

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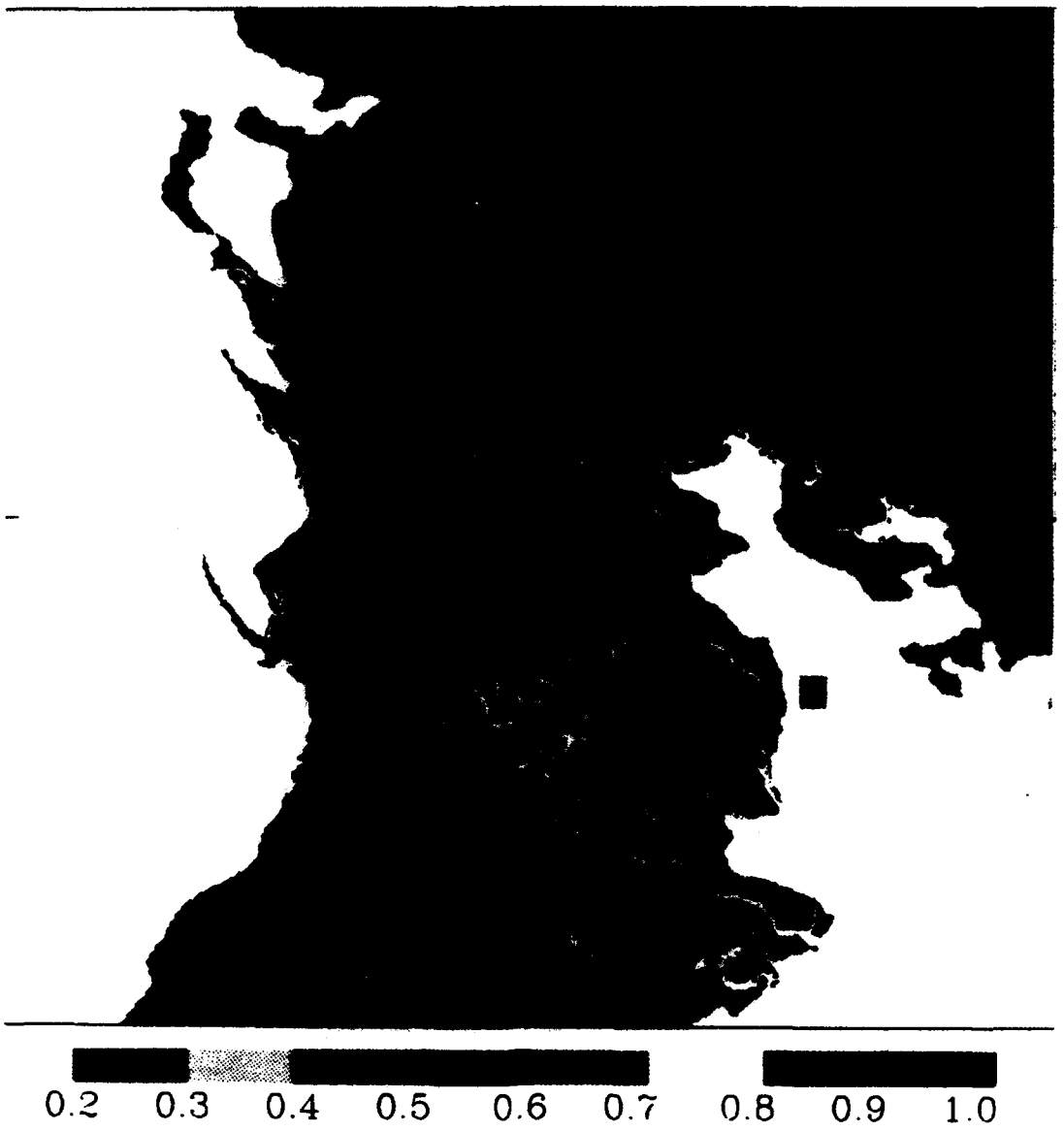

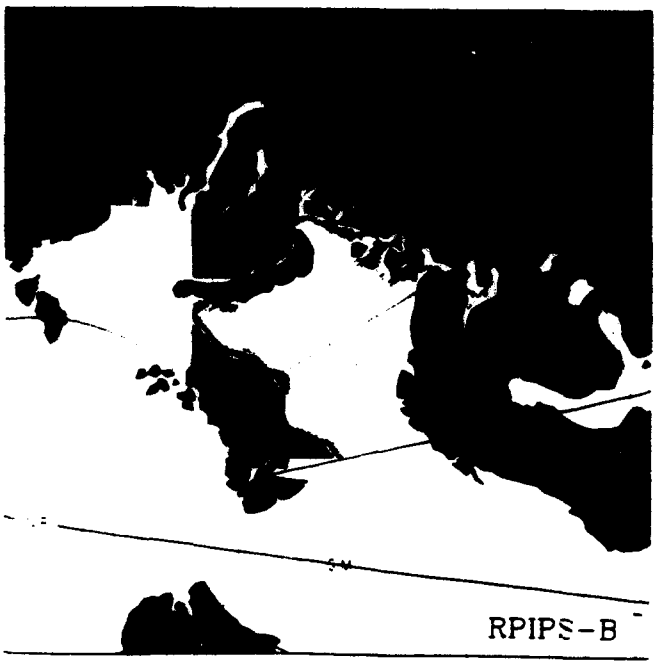

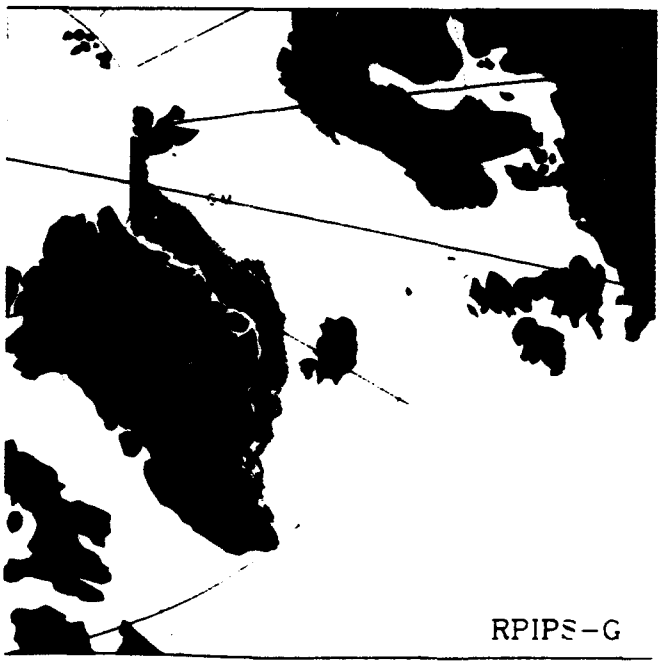

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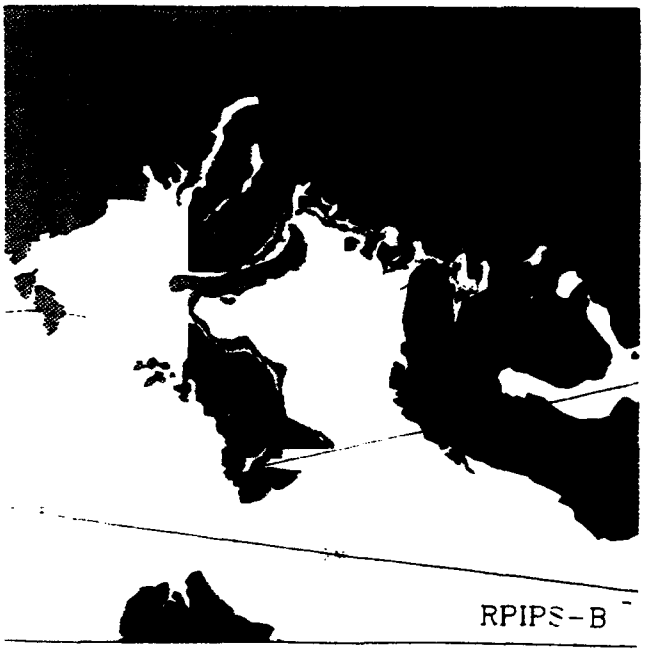
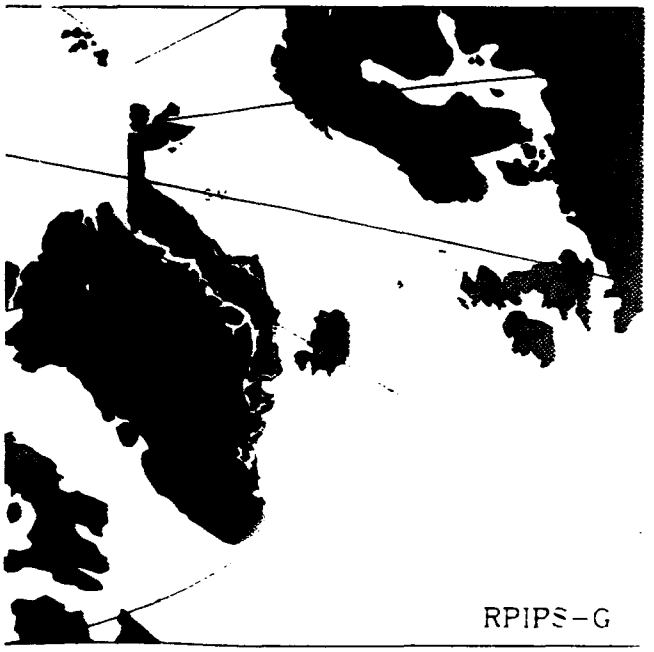


RPIPS-B



RPIPS-G

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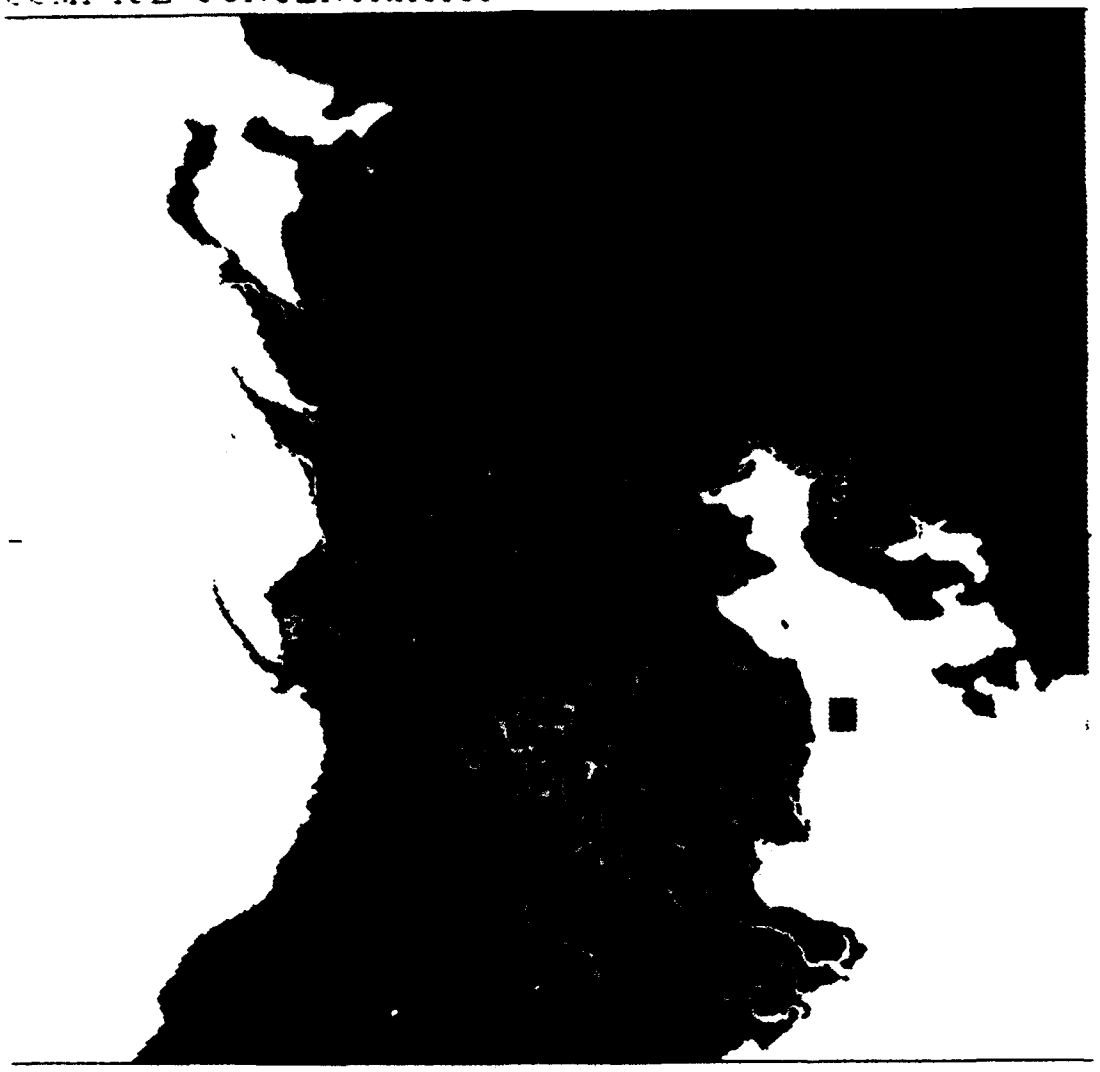

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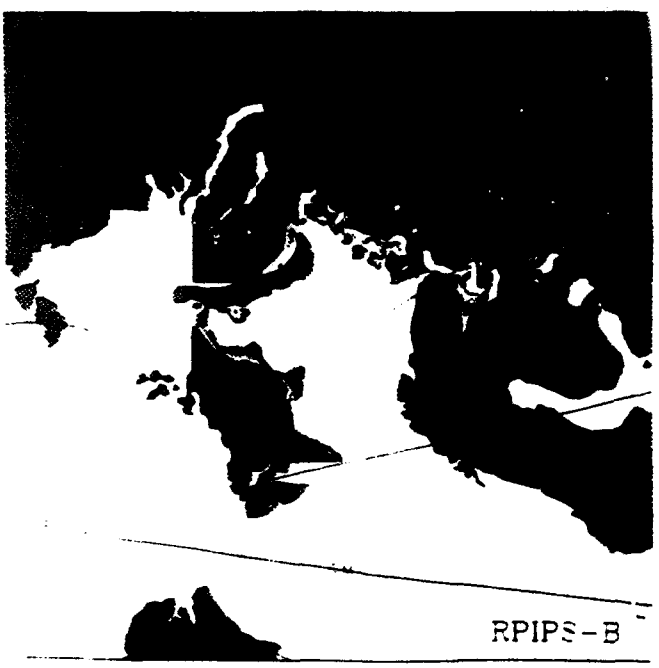

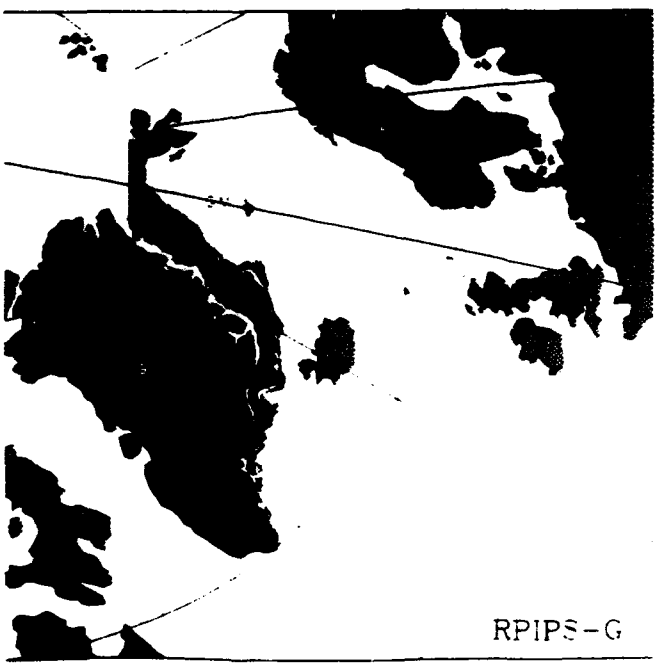

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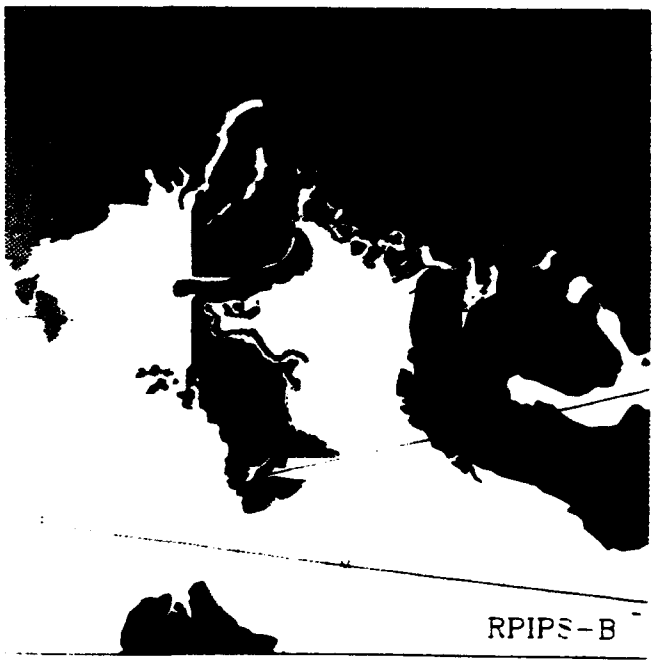
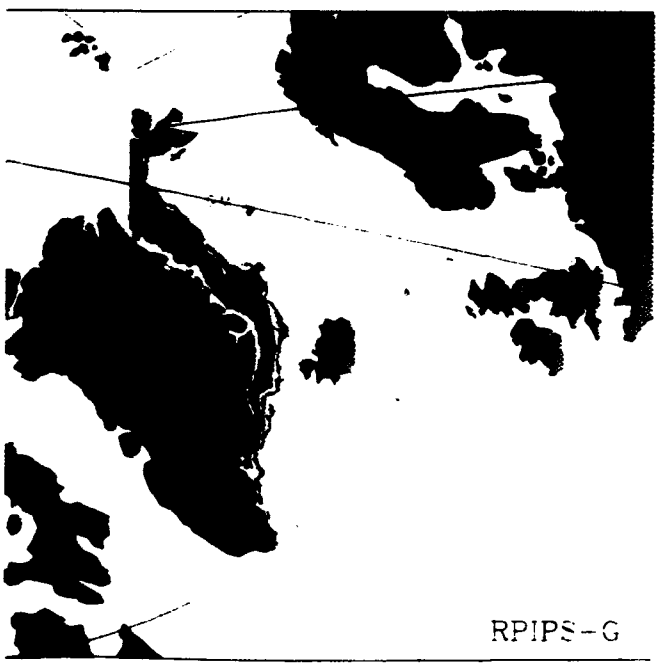


RPIPS-B



RPIPS-G

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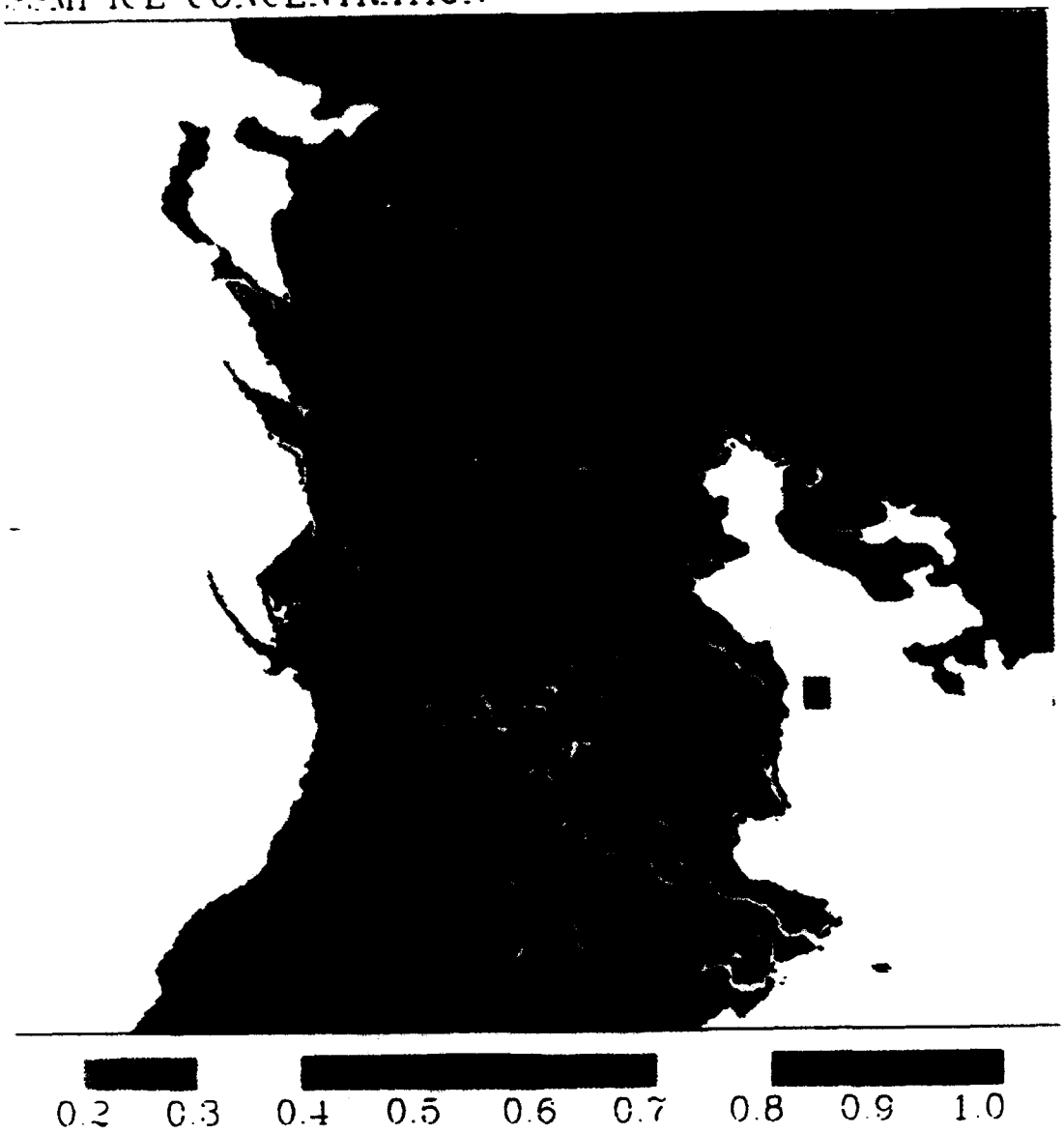

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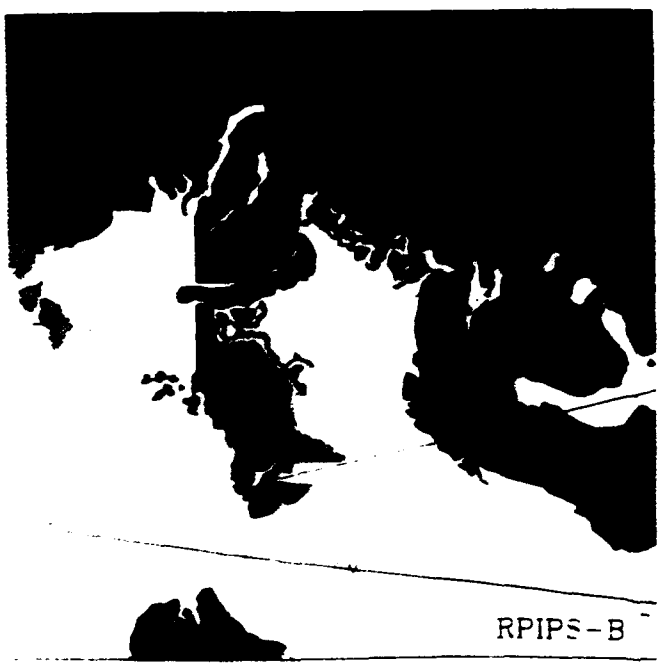
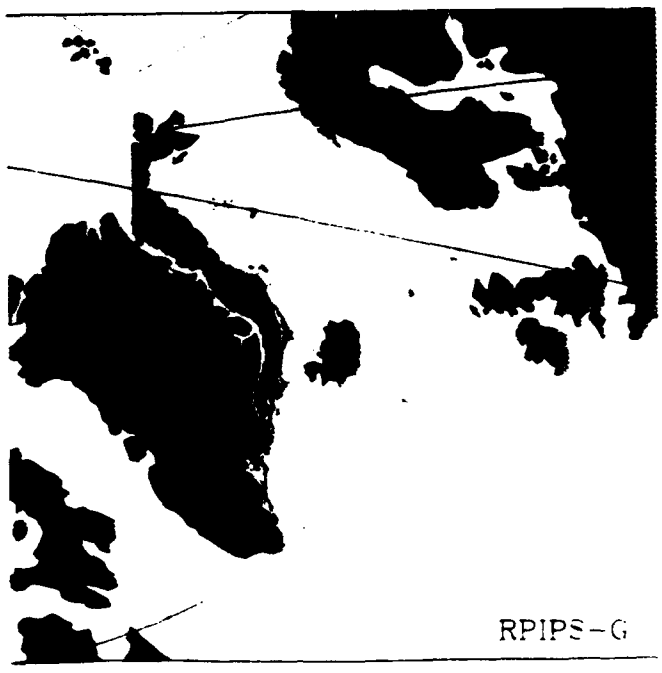


RPIPS-B



RPIPS-G

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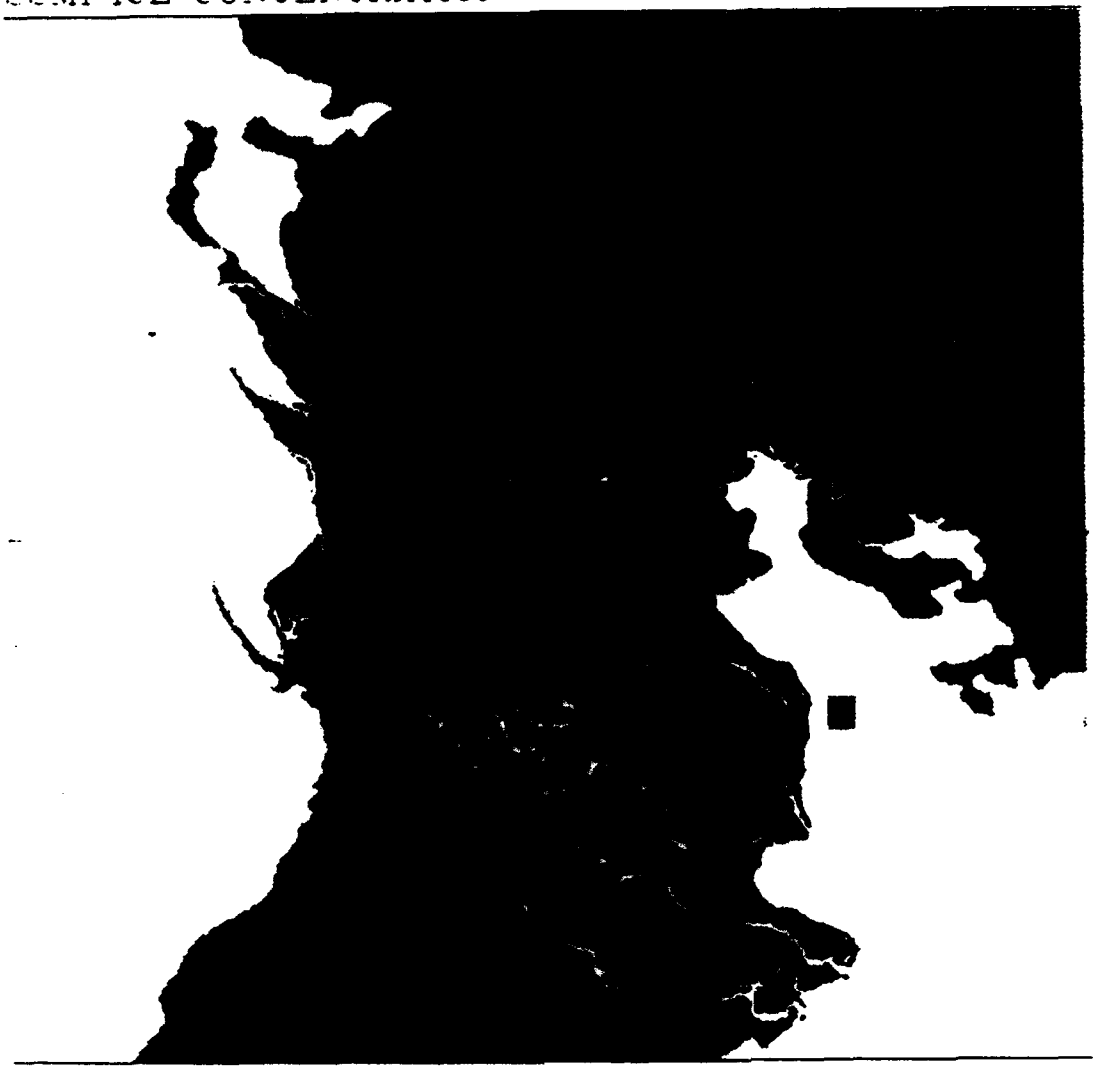

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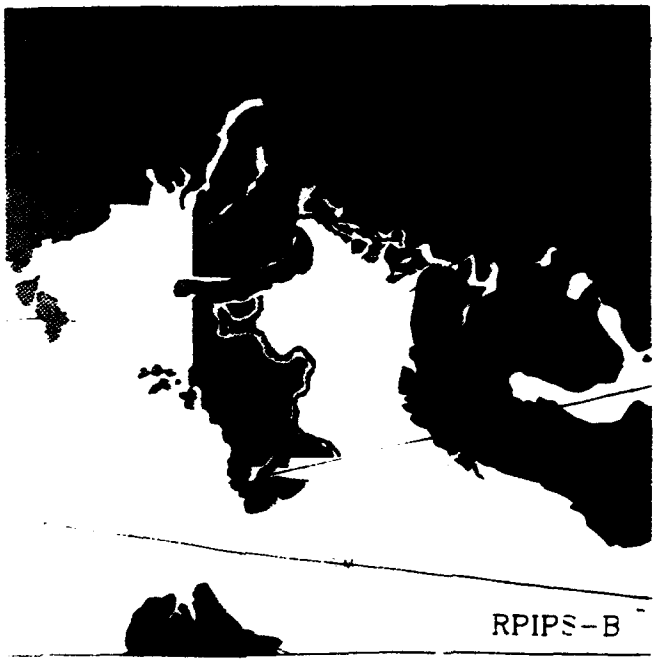
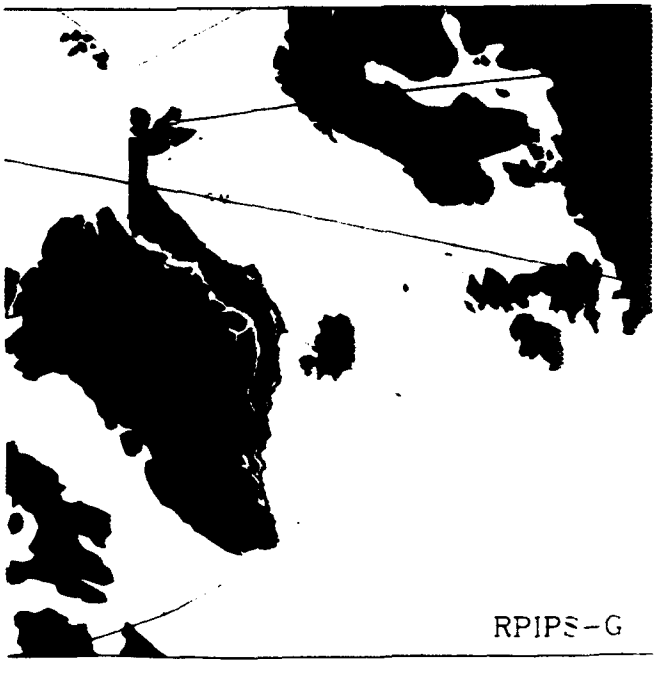
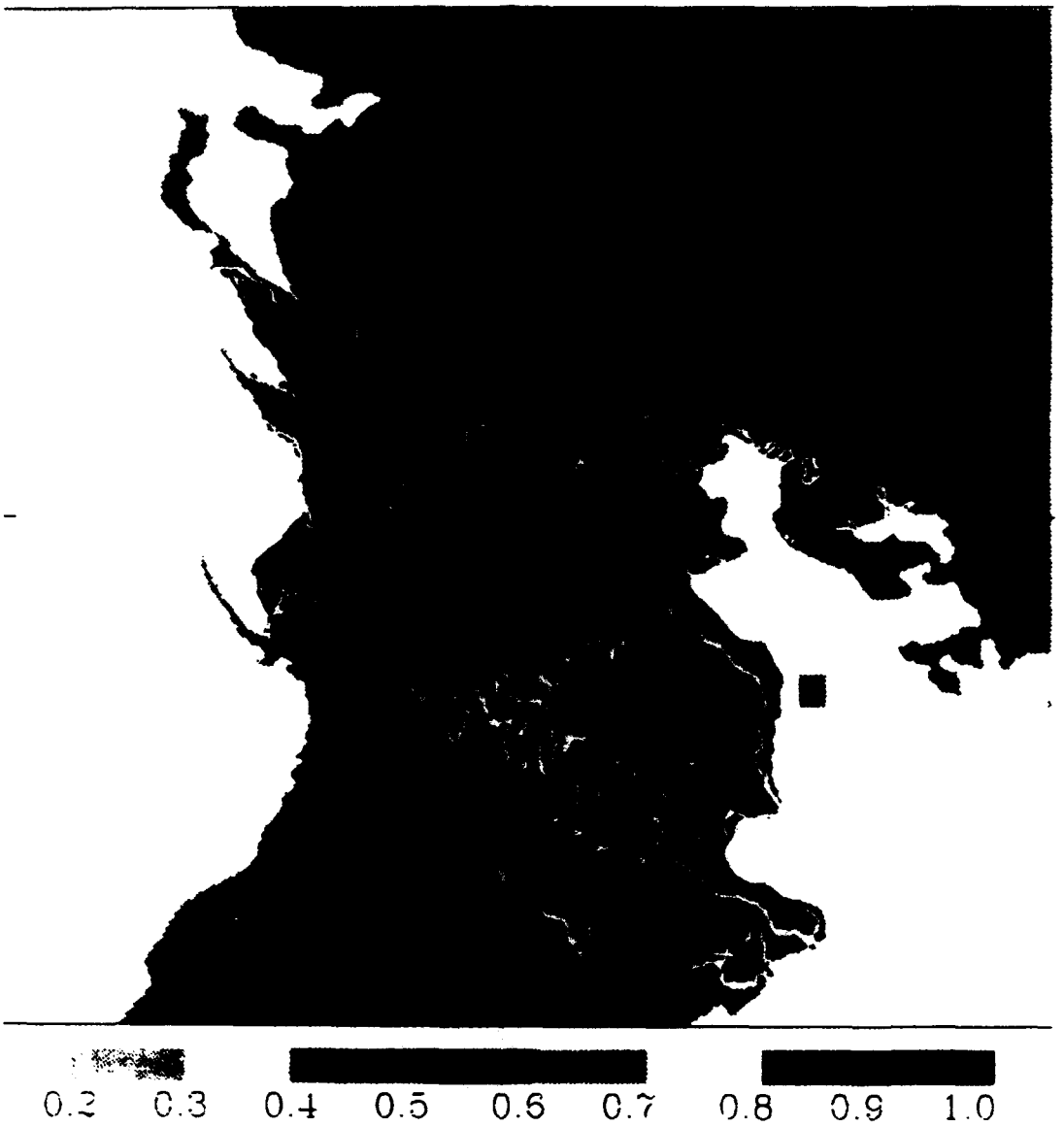


RPIPS-B



RPIPS-G



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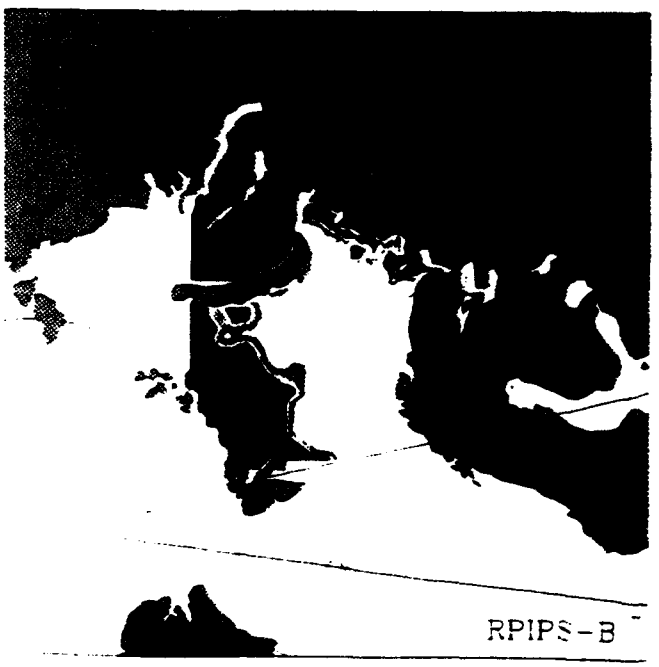

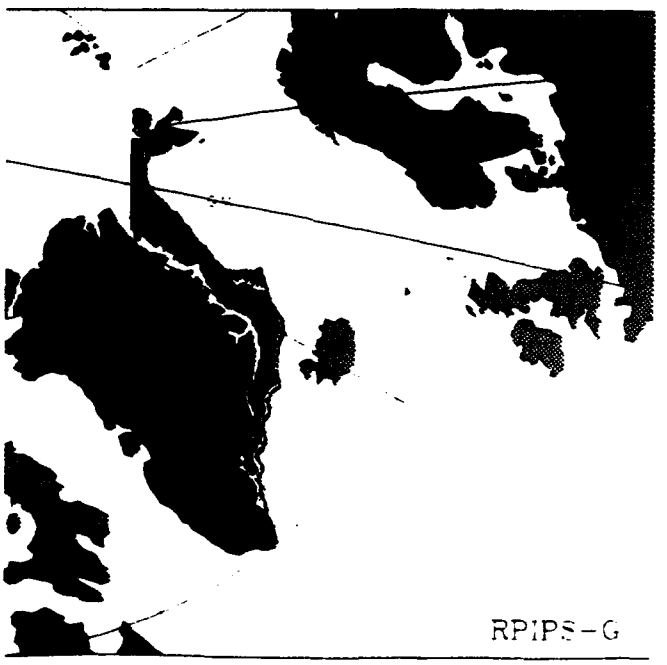

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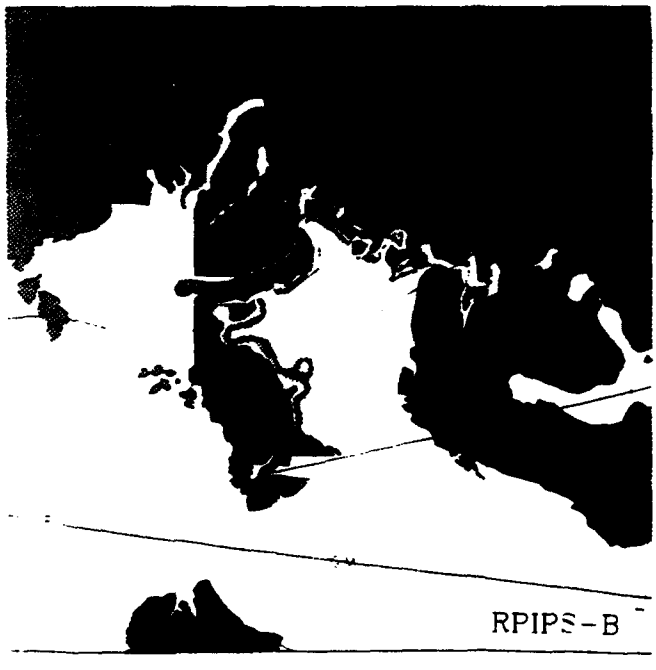
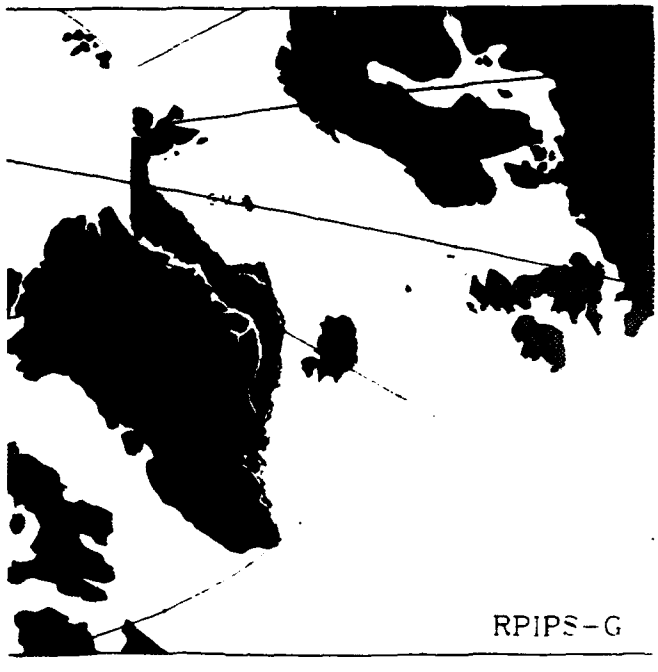


RPIPS-B



RPIPS-G

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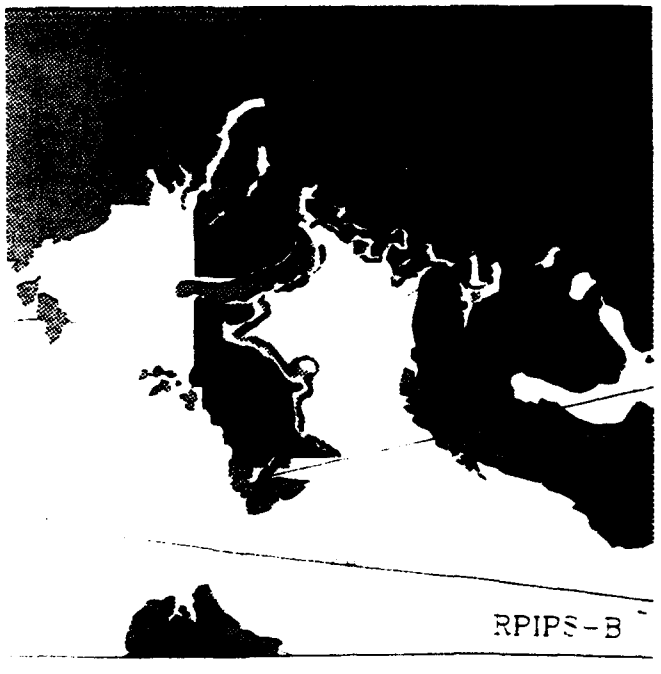
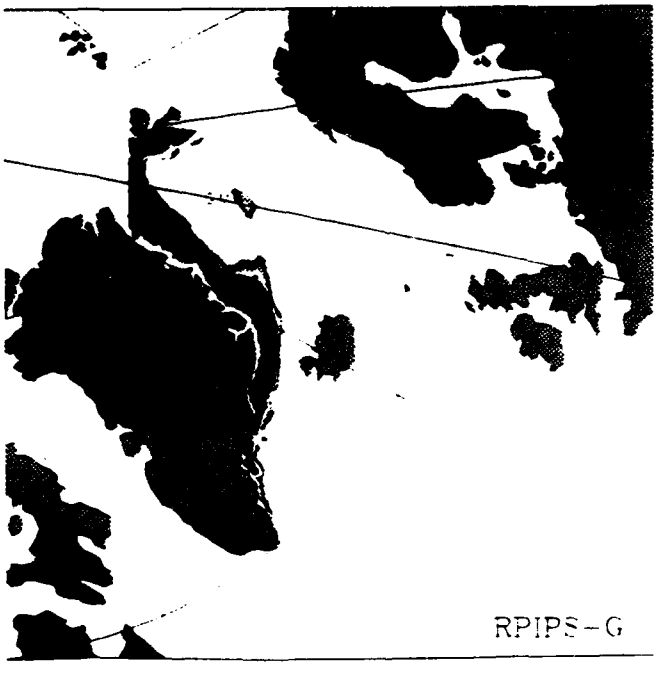


RPIPS-B



RPIPS-G

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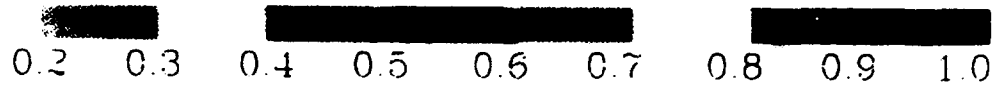

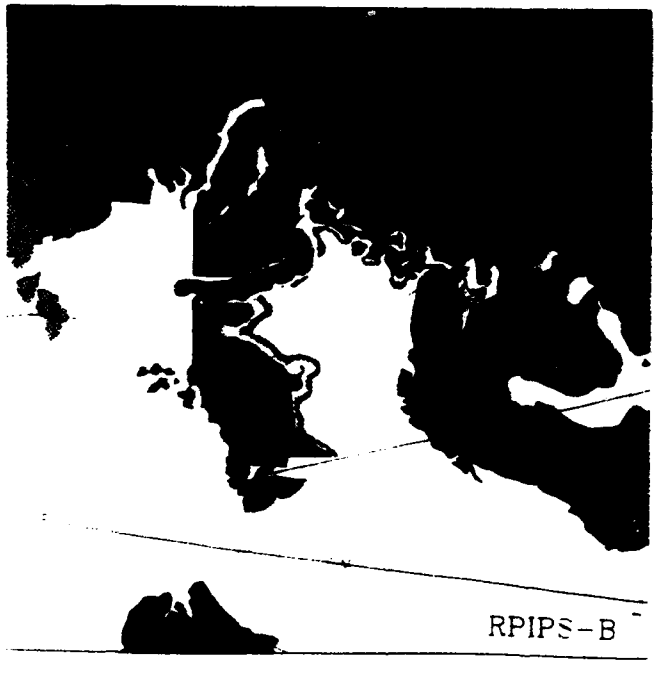

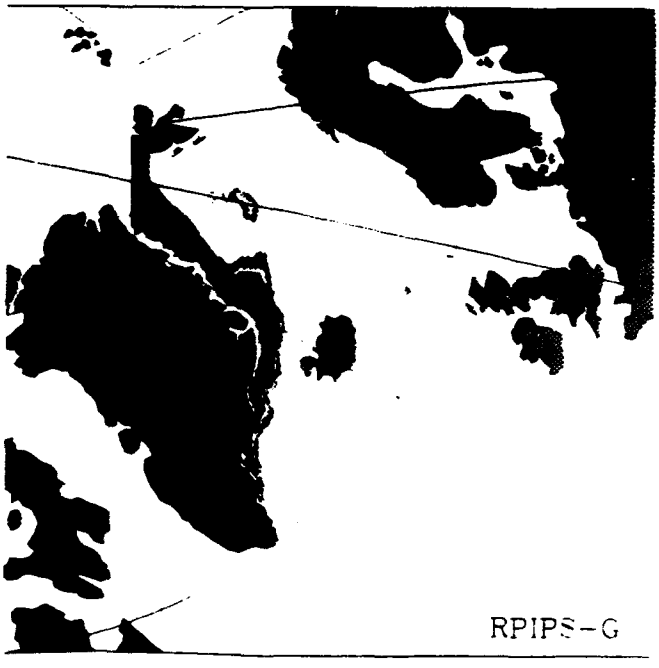

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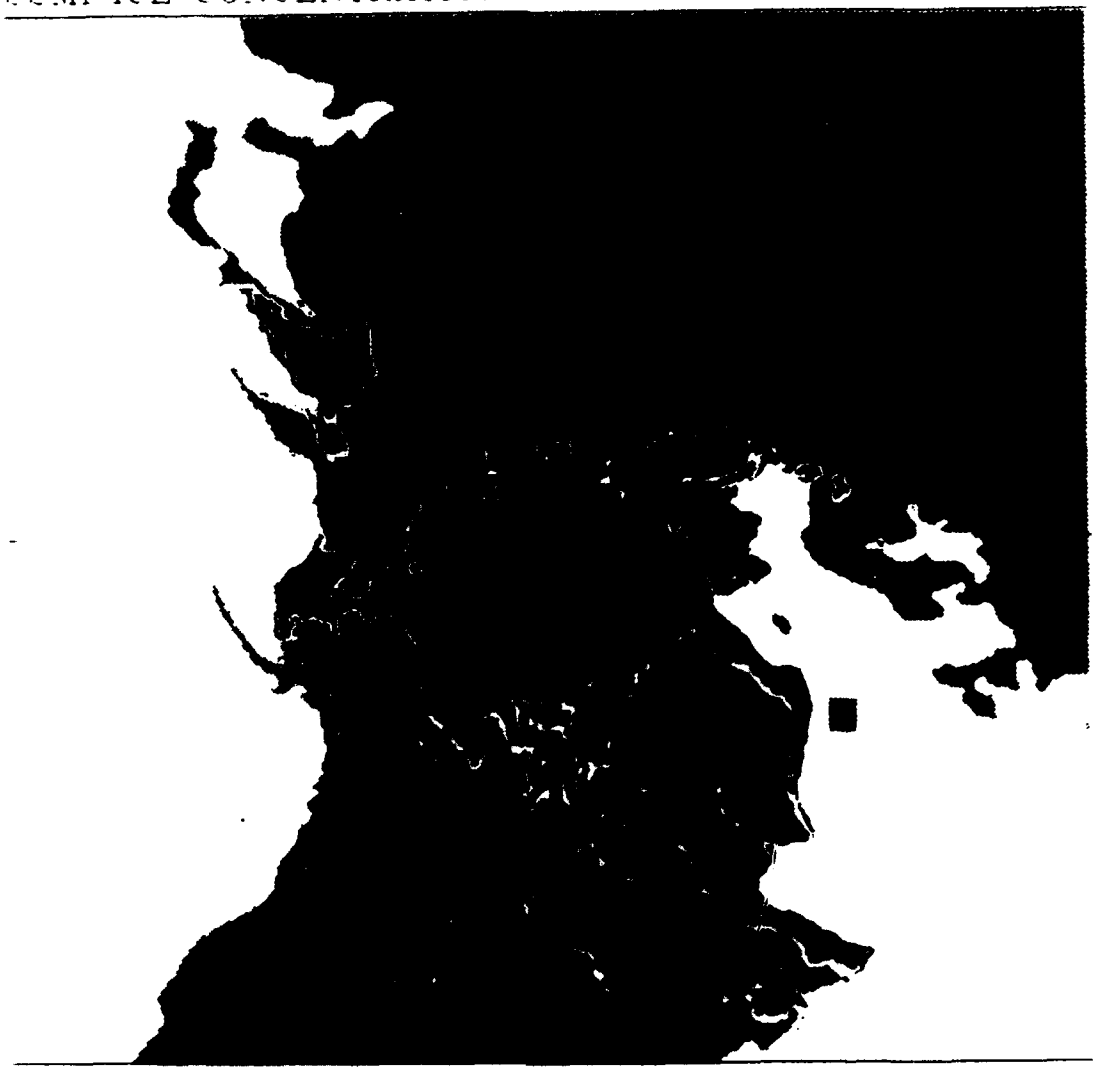

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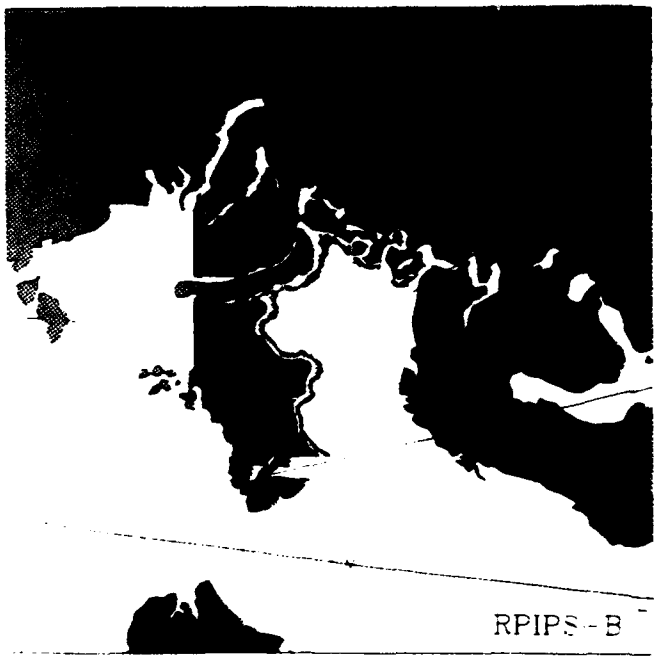

RPIPS-B

RPIPS-G

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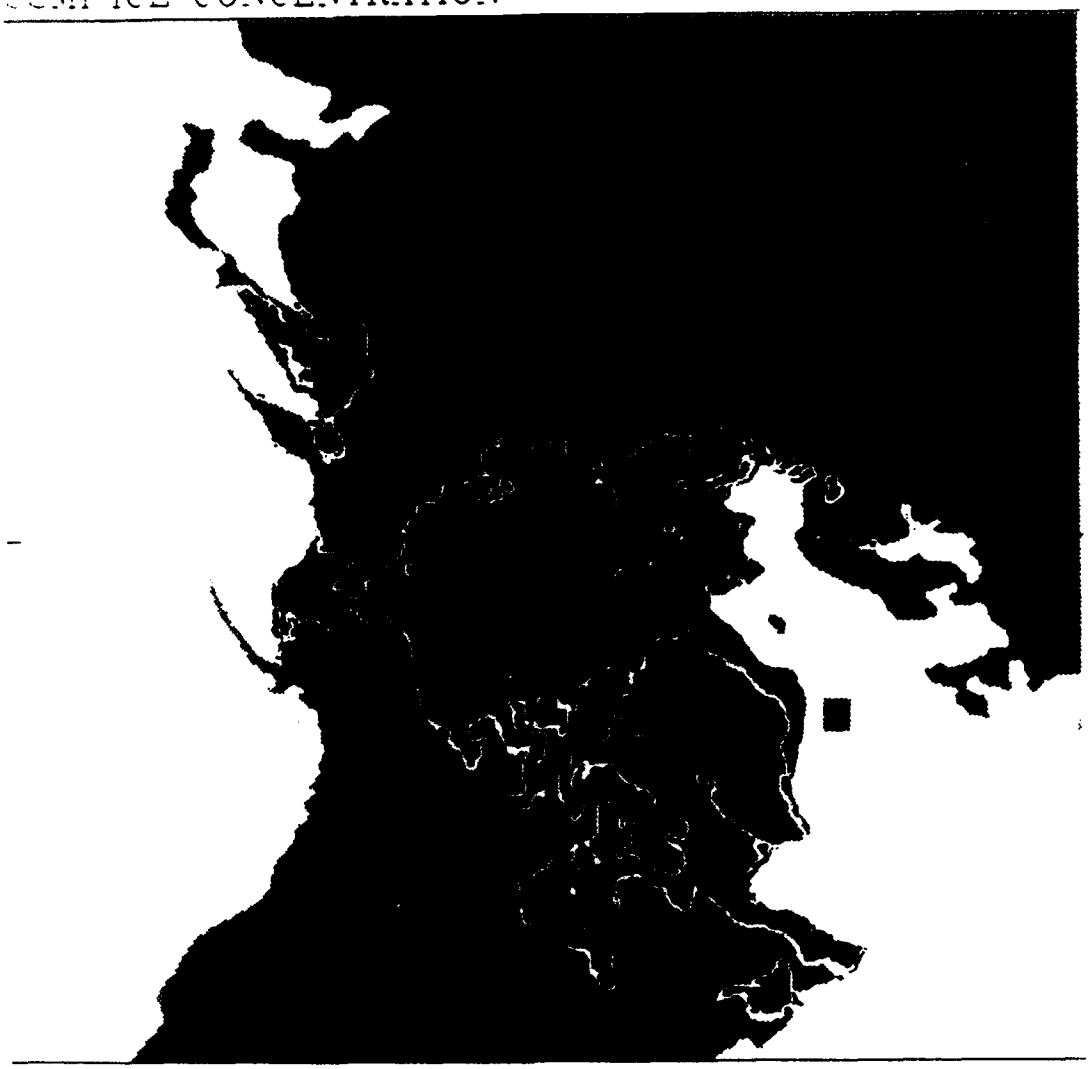

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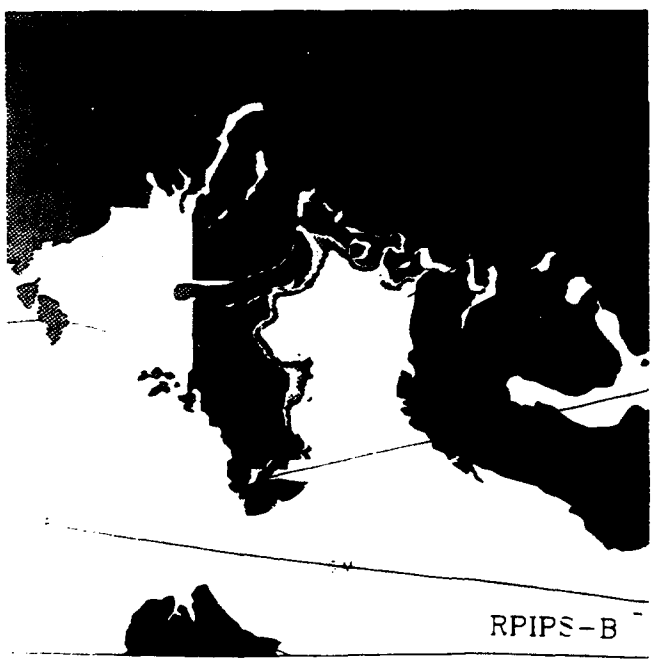
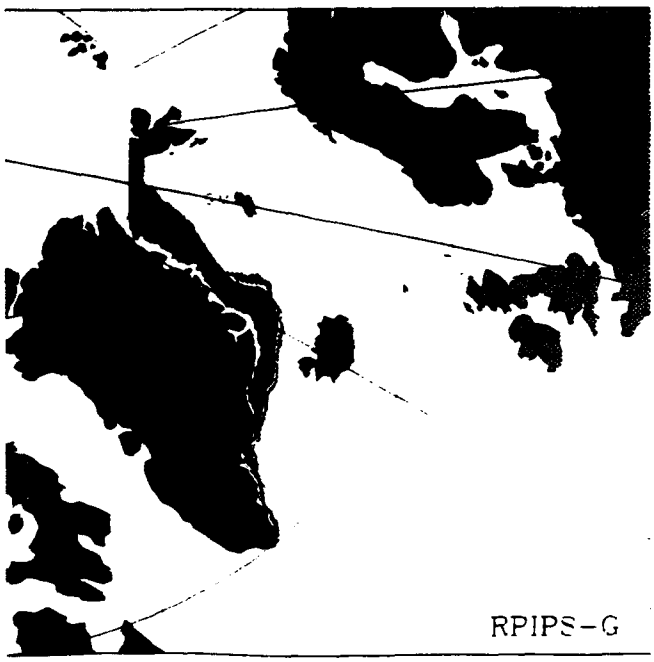


RPIPS-B



RPIPS-G

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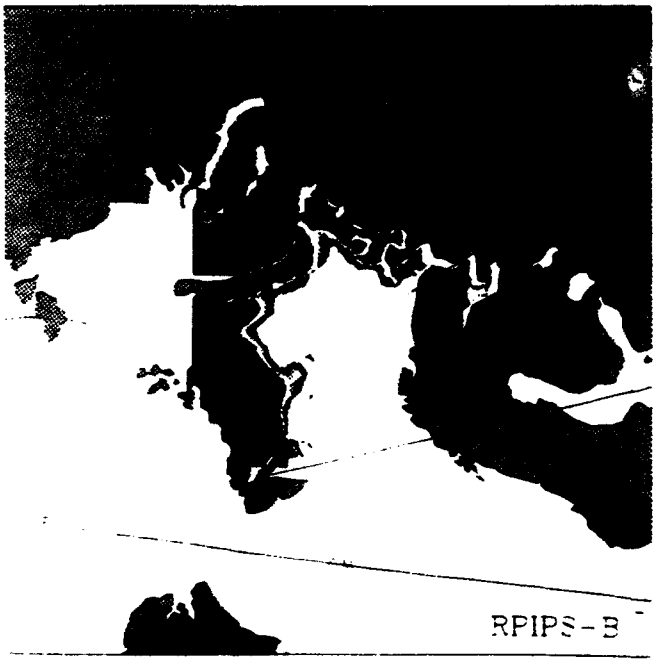

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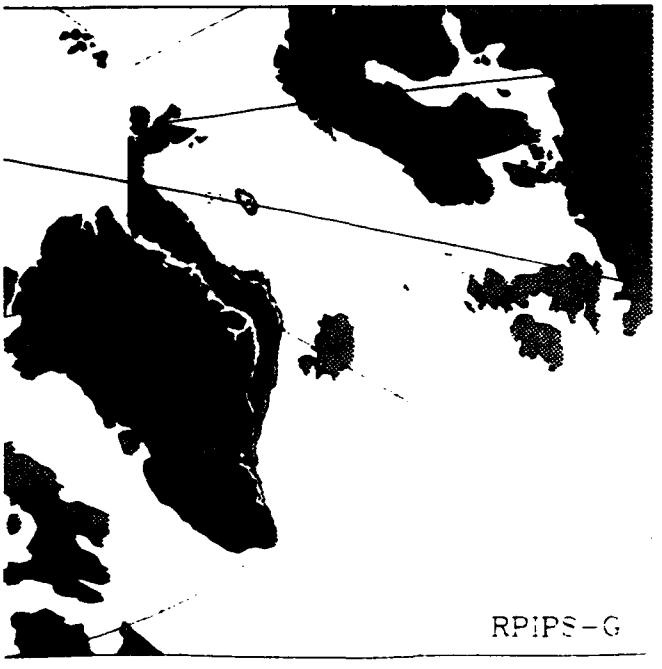

RPIPS-G

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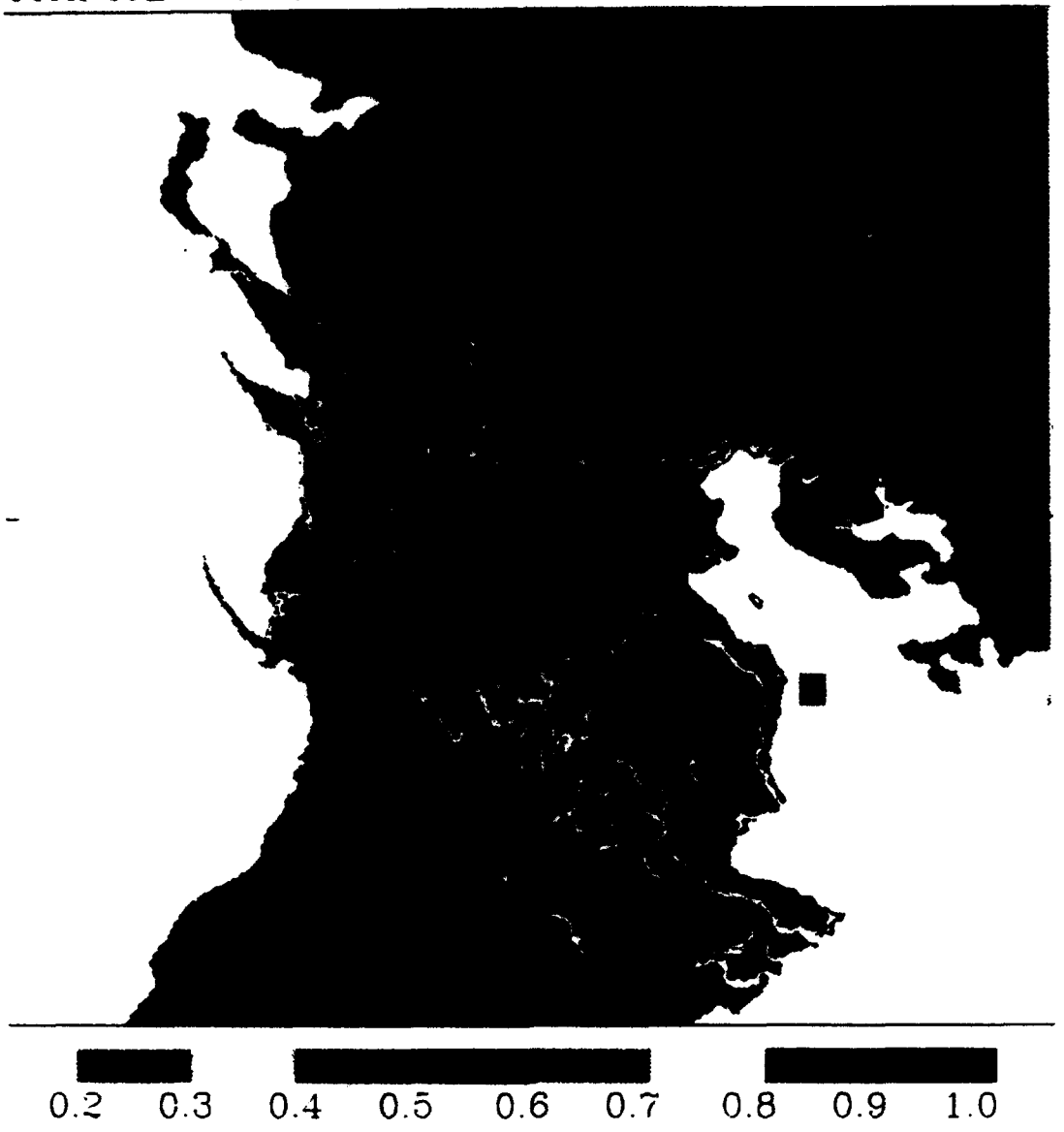

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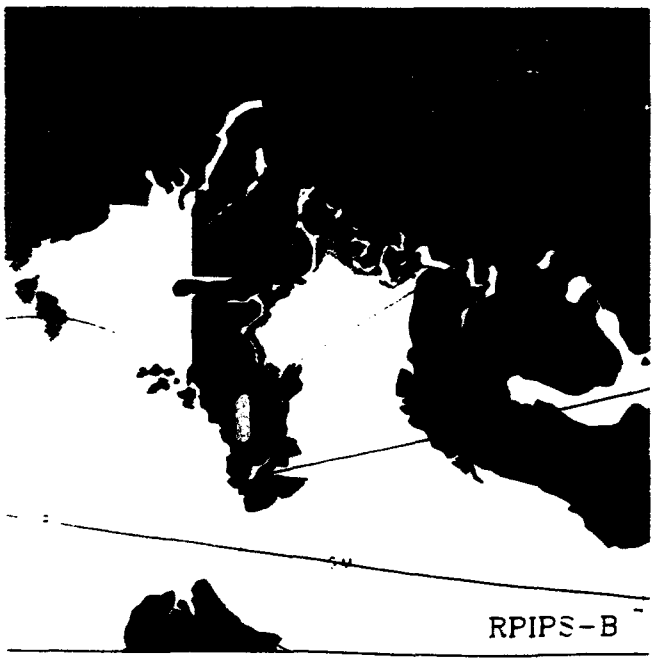

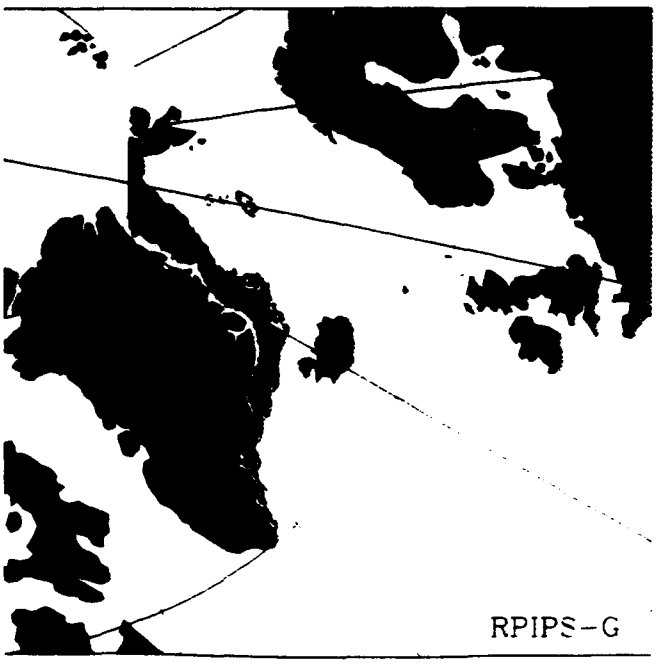

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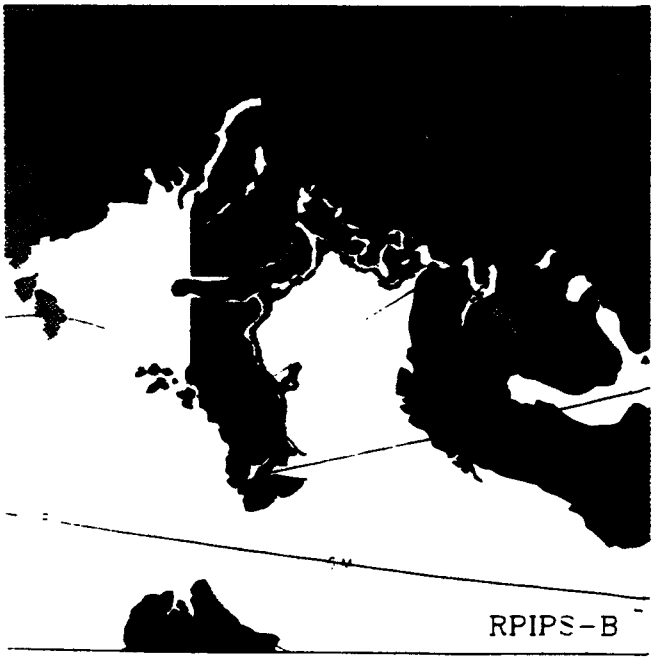
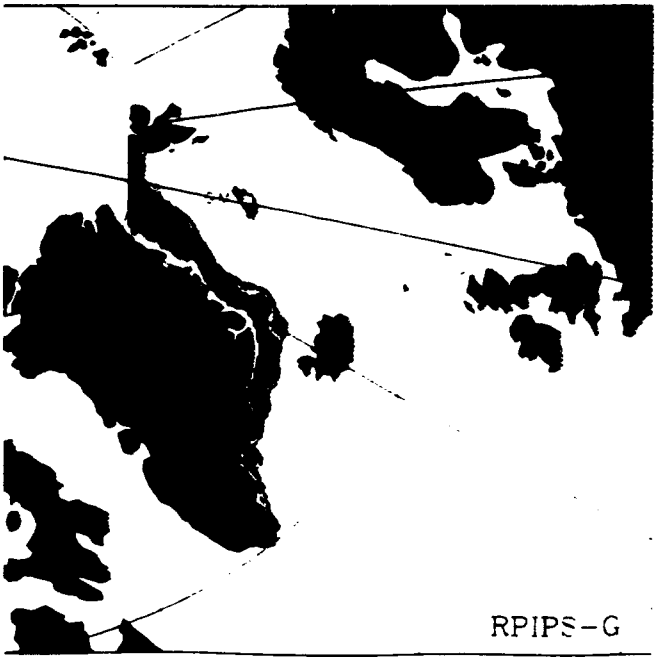


RPIPS-B



RPIPS-G

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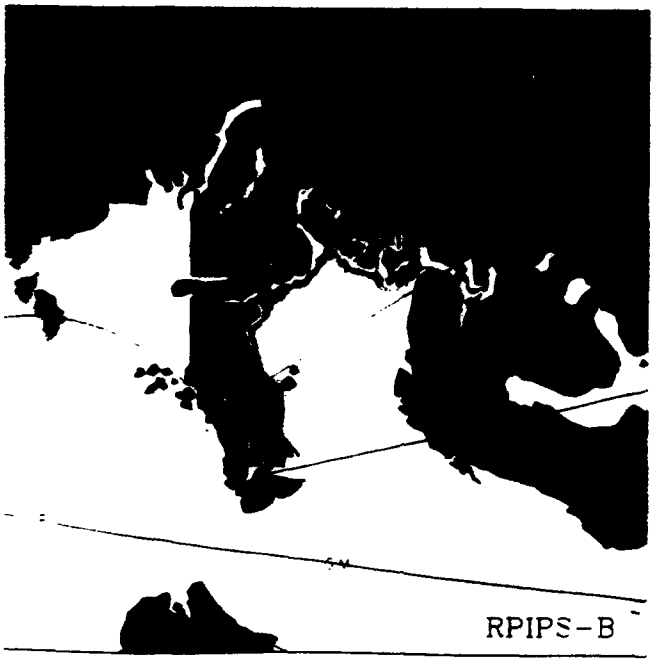
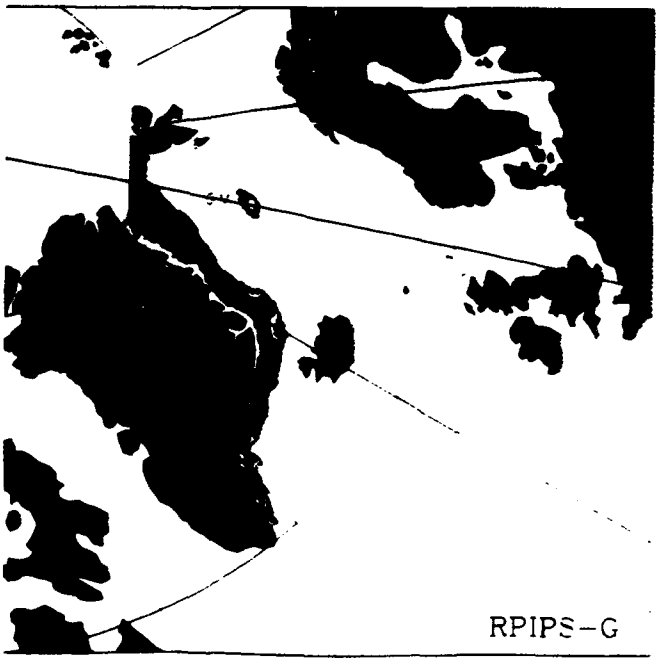


RPIPS-B



RPIPS-G

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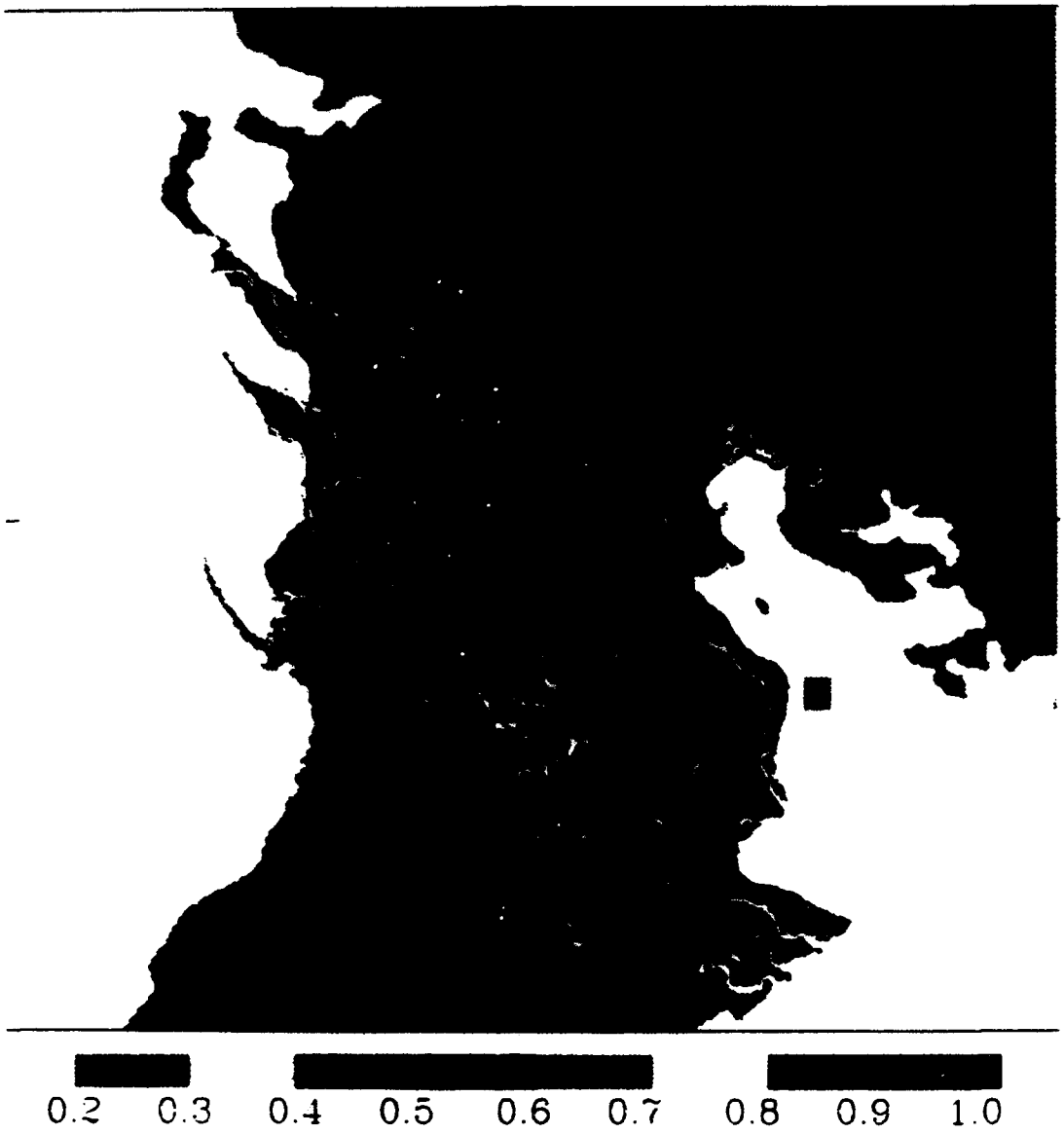

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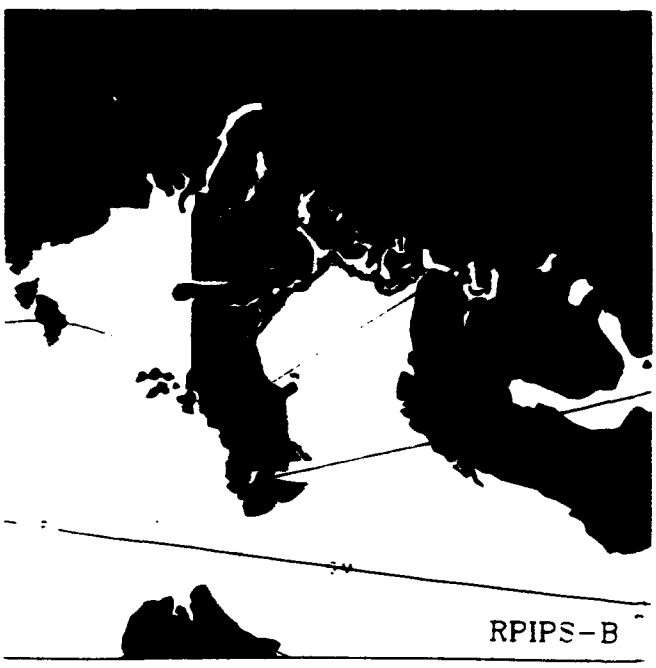

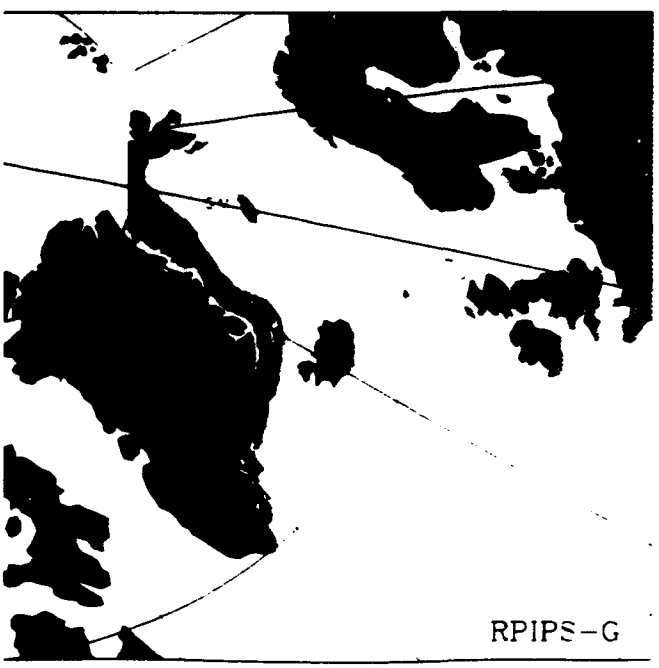

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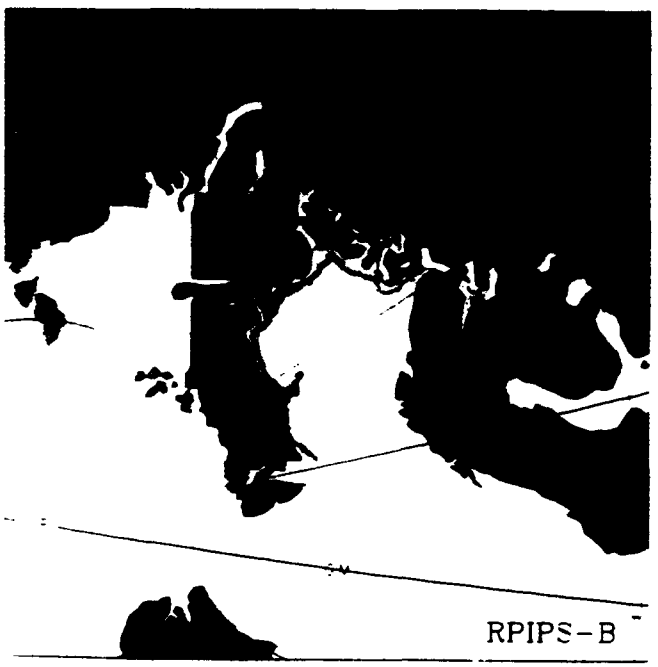
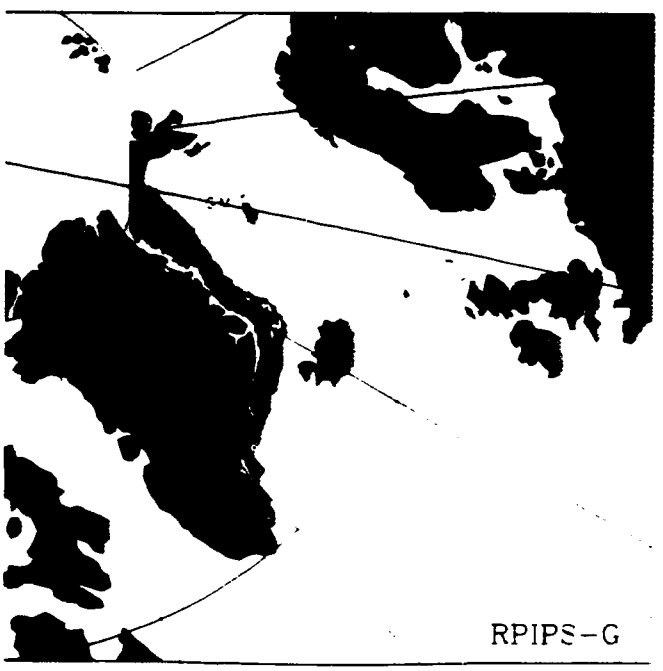


RPIPS-B



RPIPS-G

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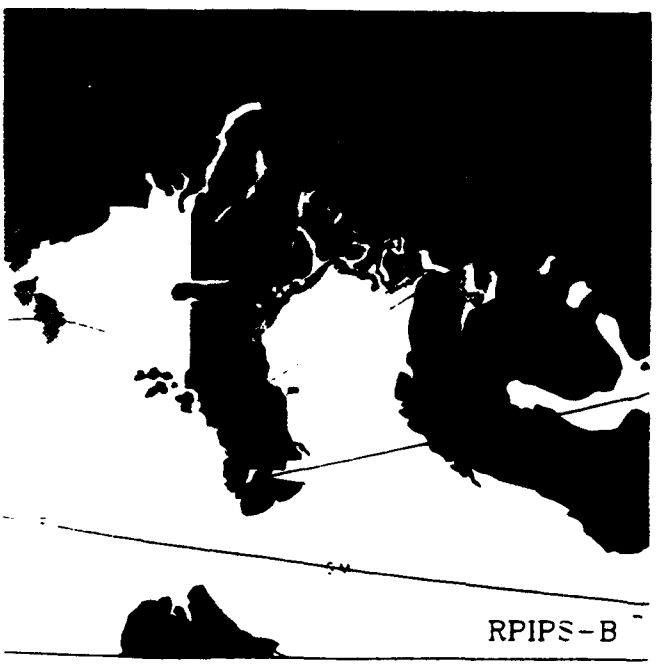

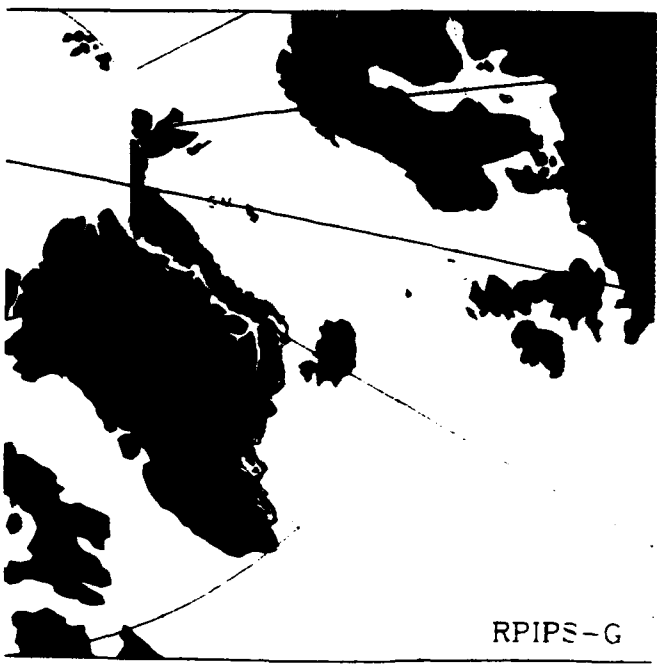

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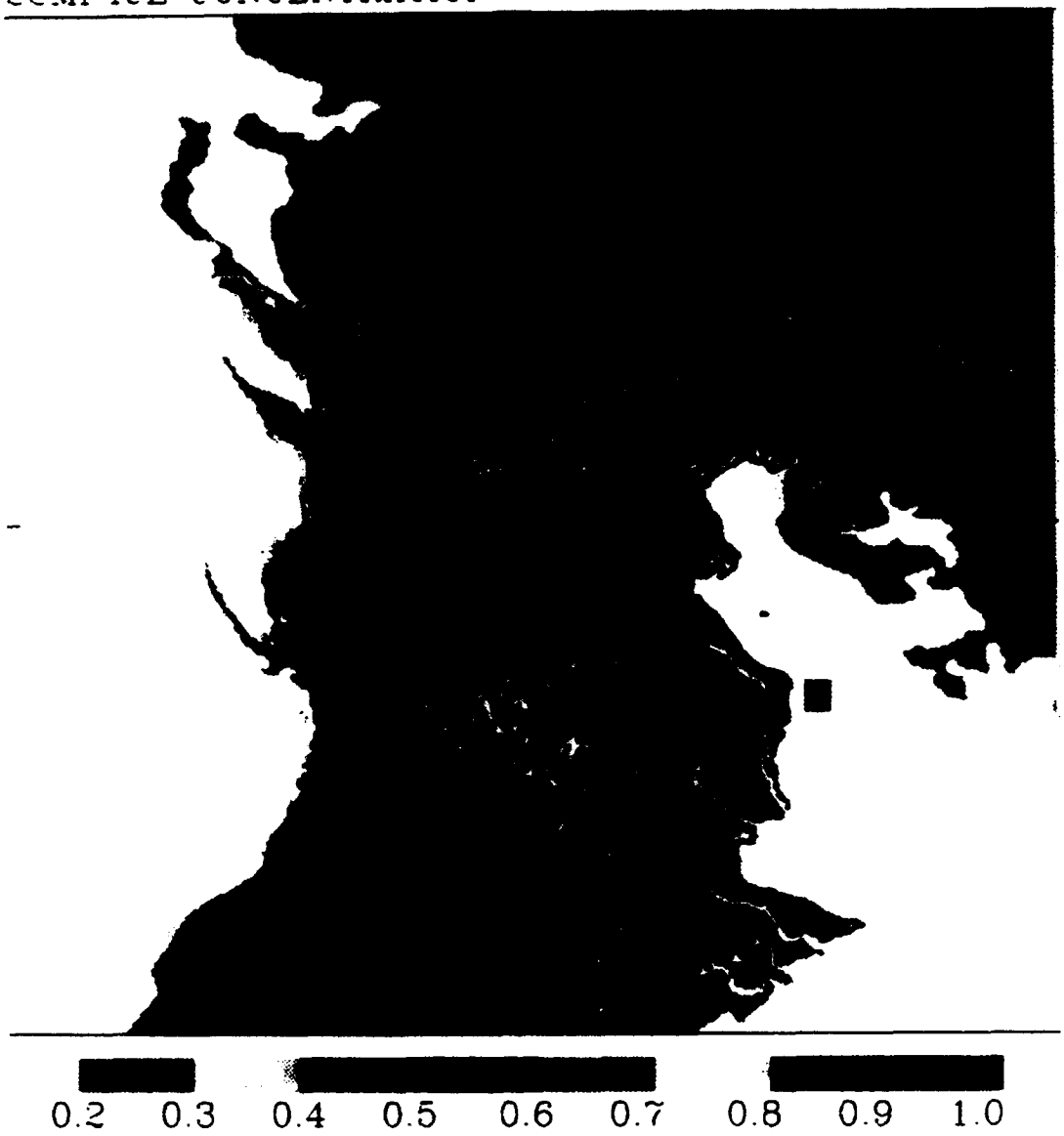

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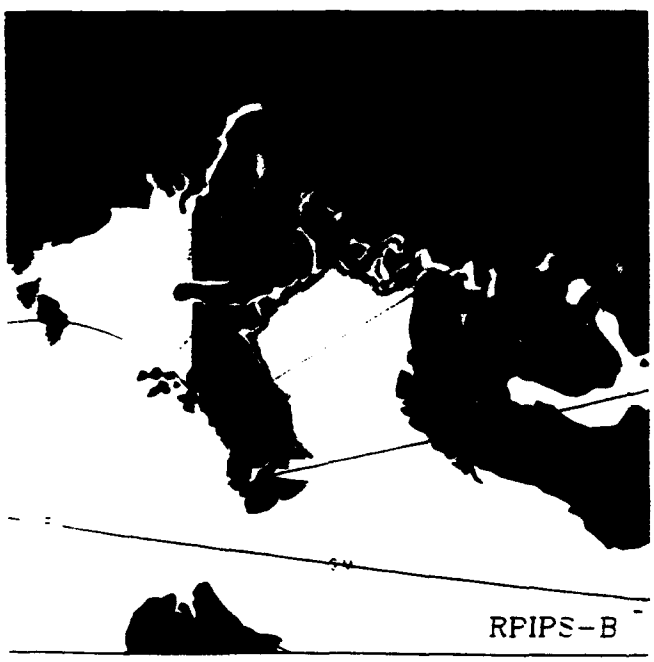
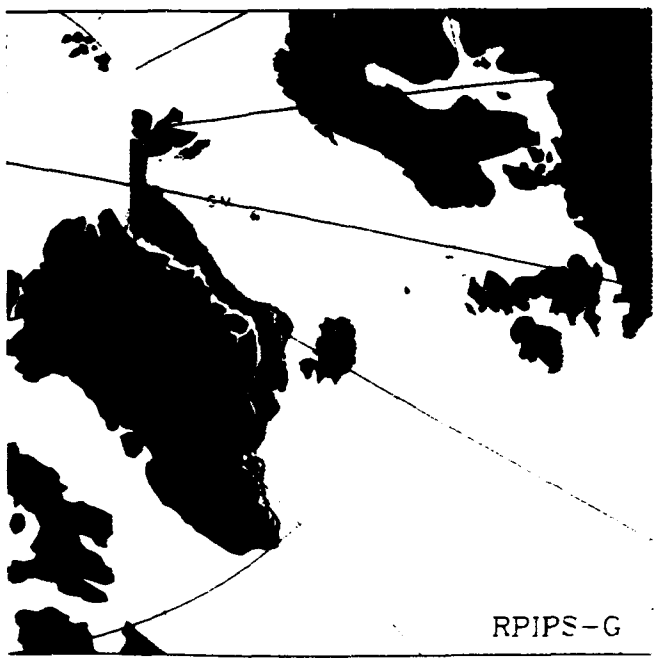


RPIPS-B



RPIPS-G

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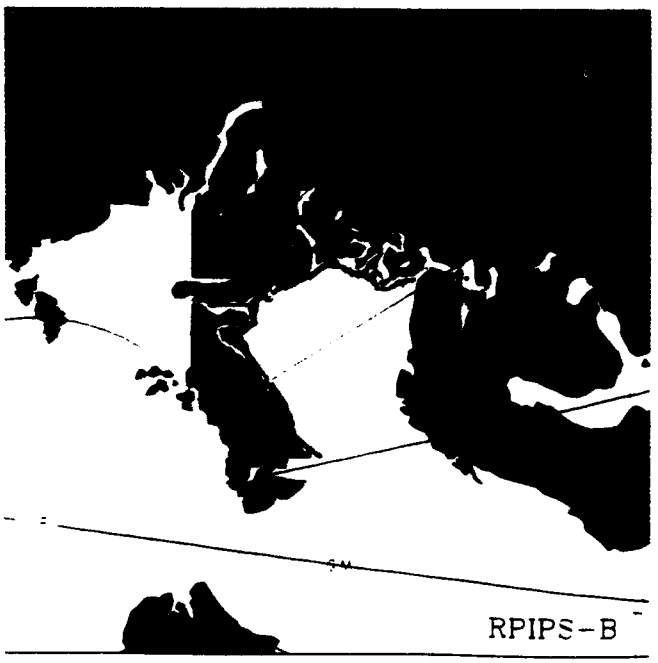
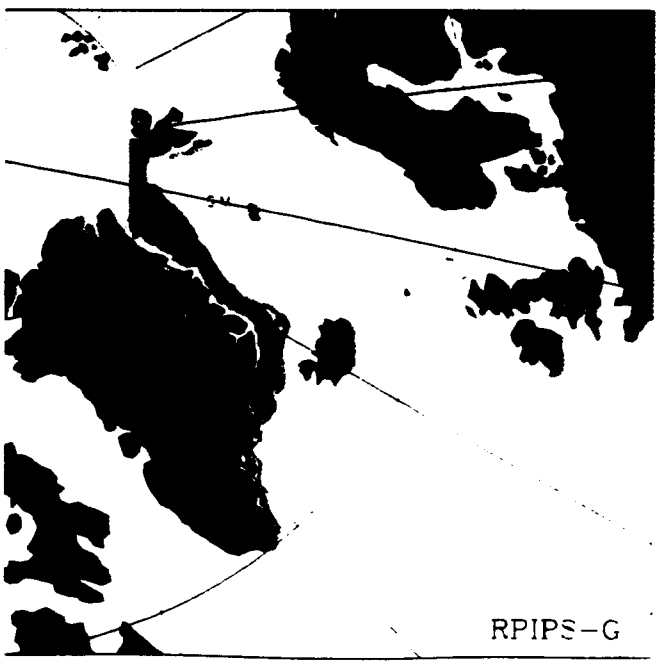


RPIPS-B



RPIPS-G

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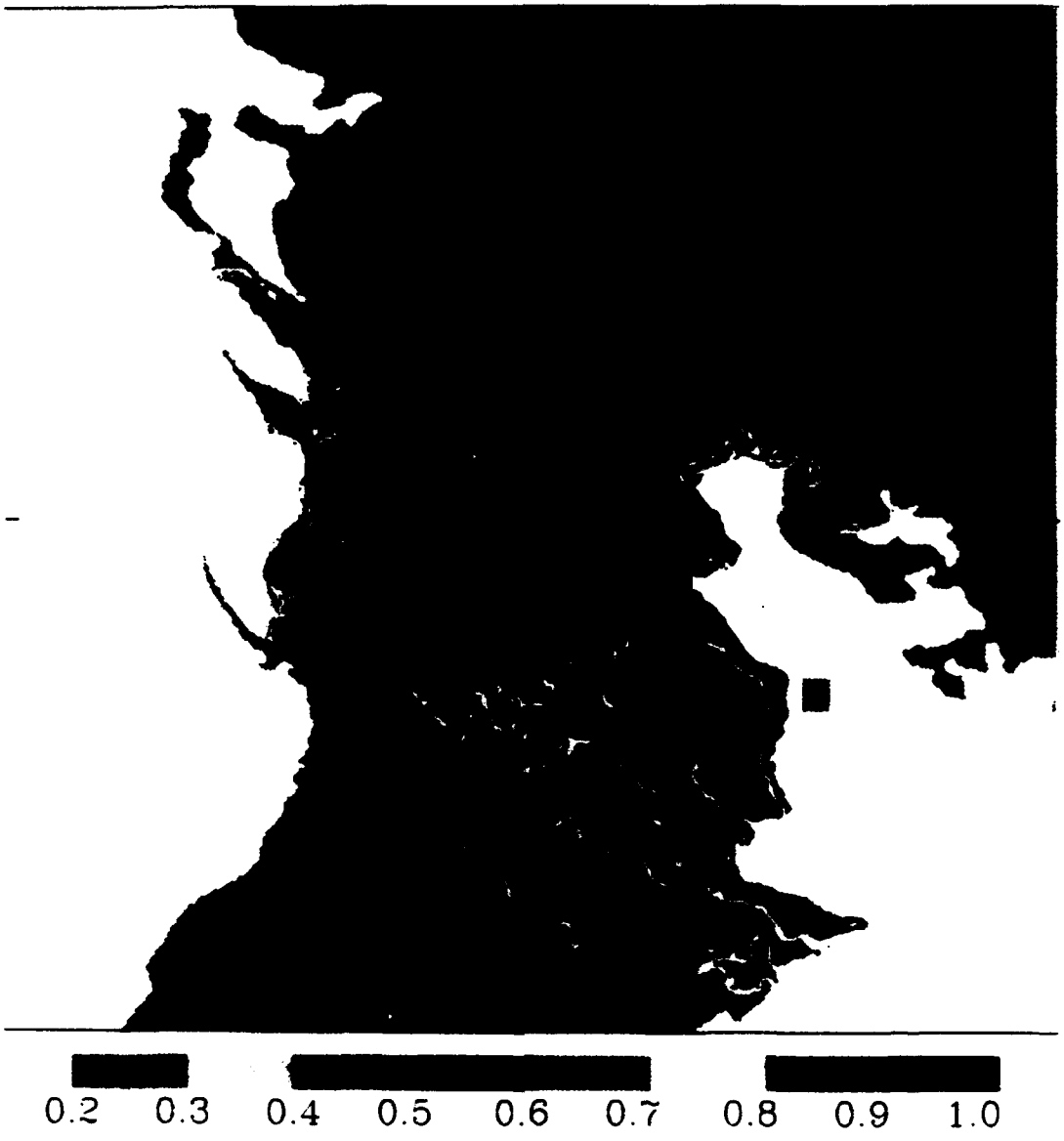

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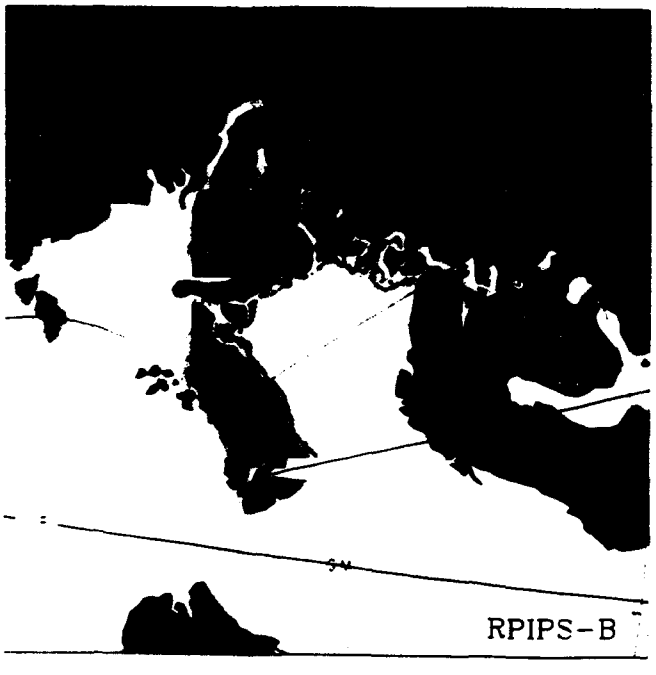

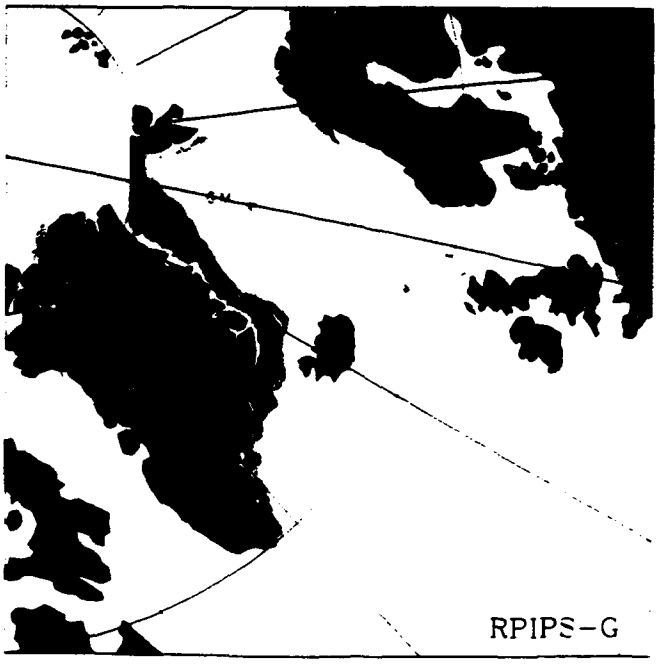

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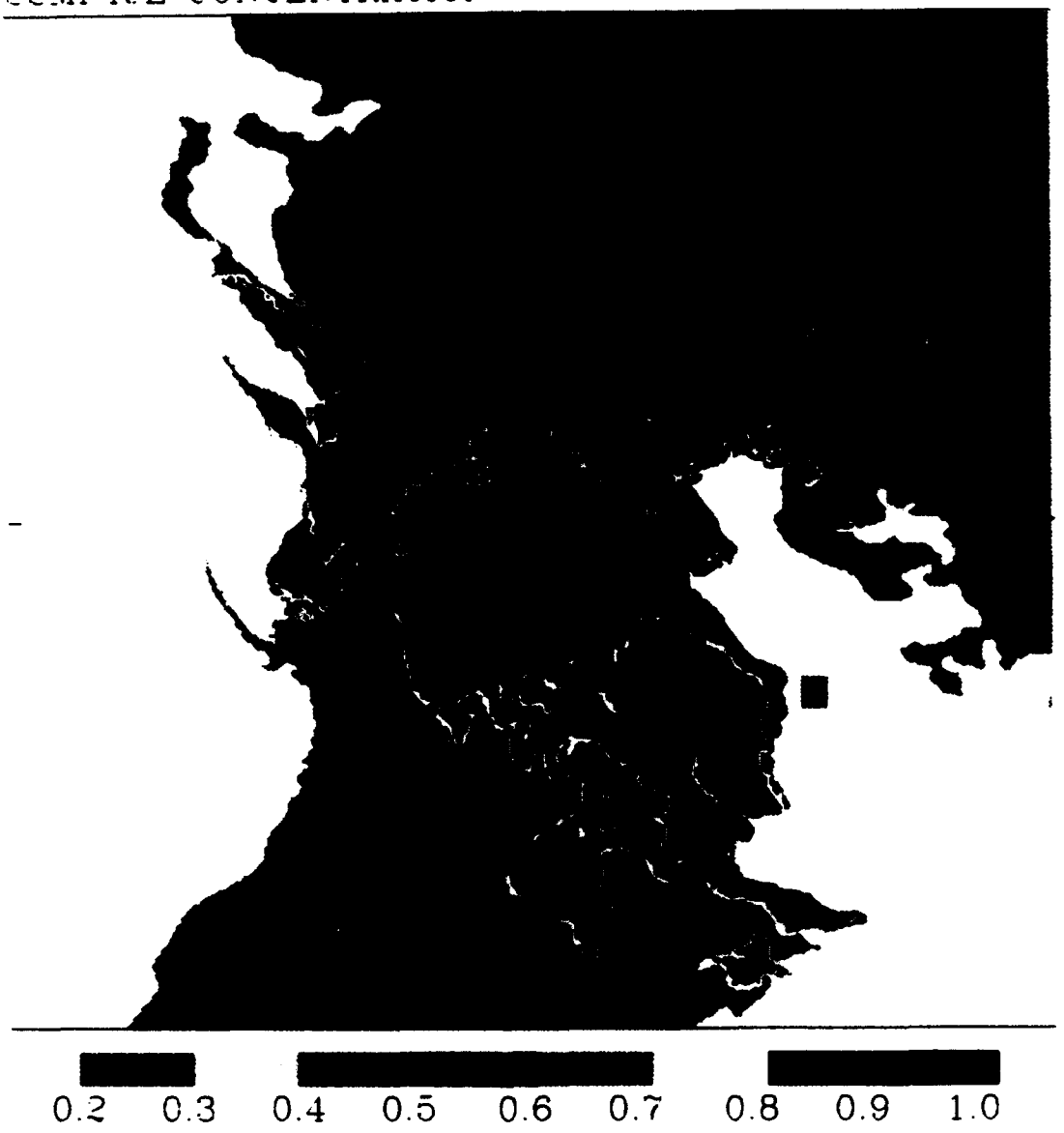

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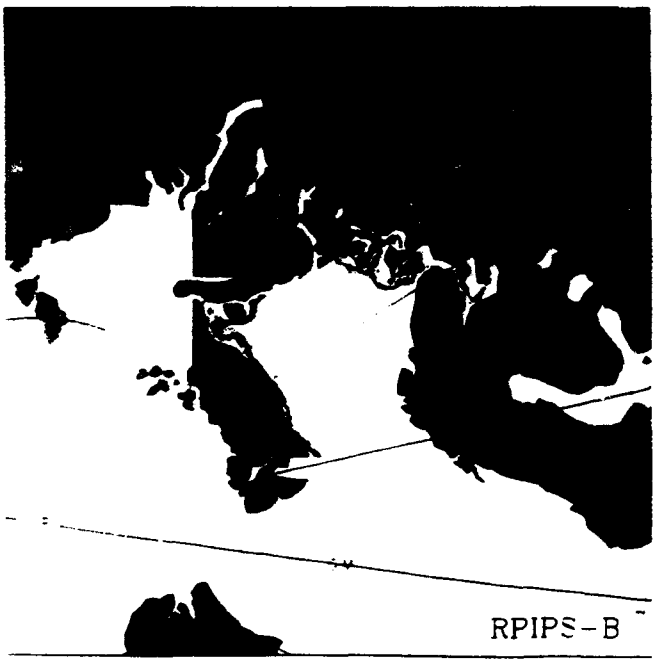

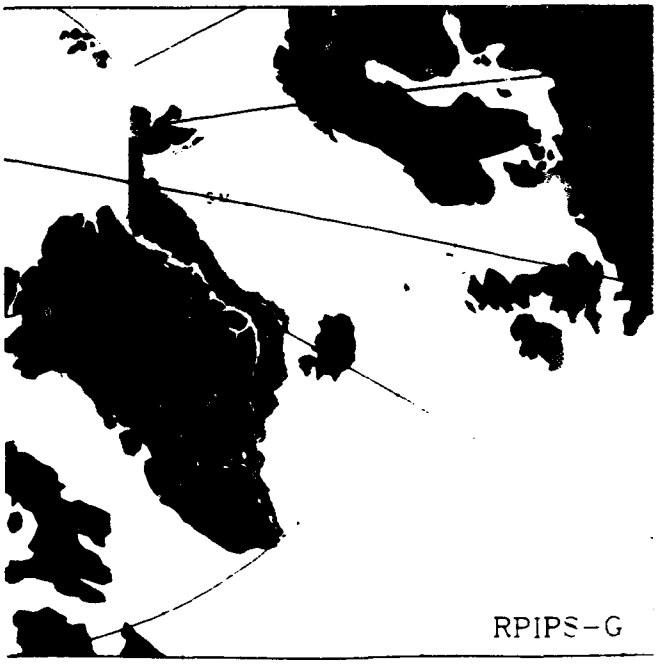

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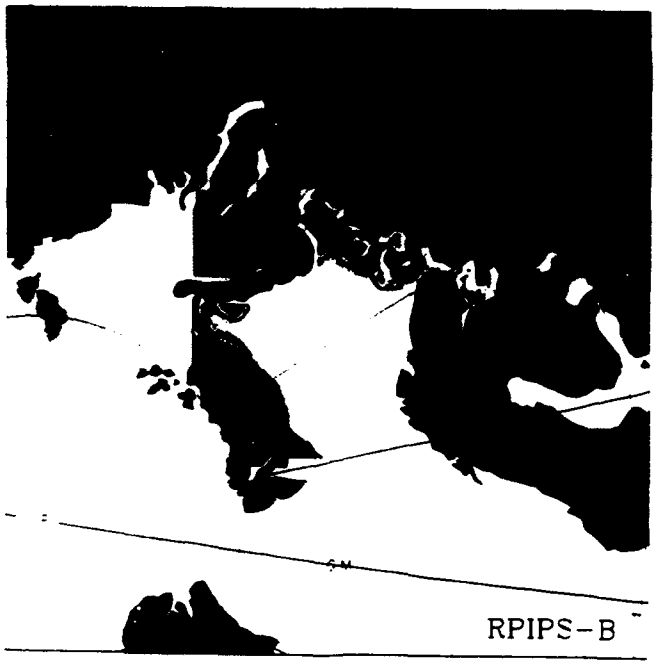
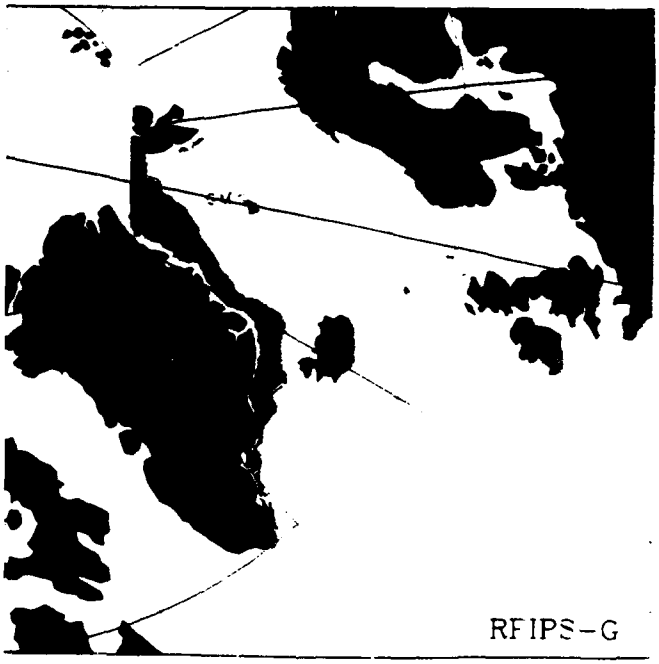


RPIPS-B



RFIPS-G

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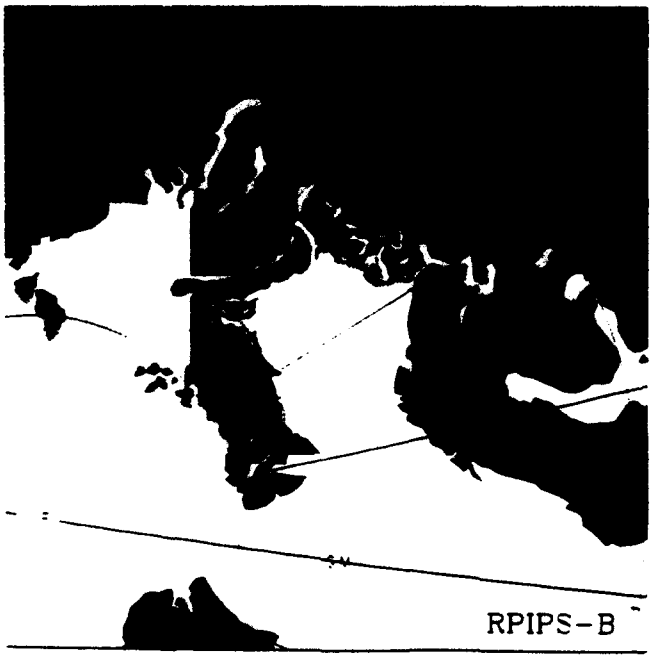
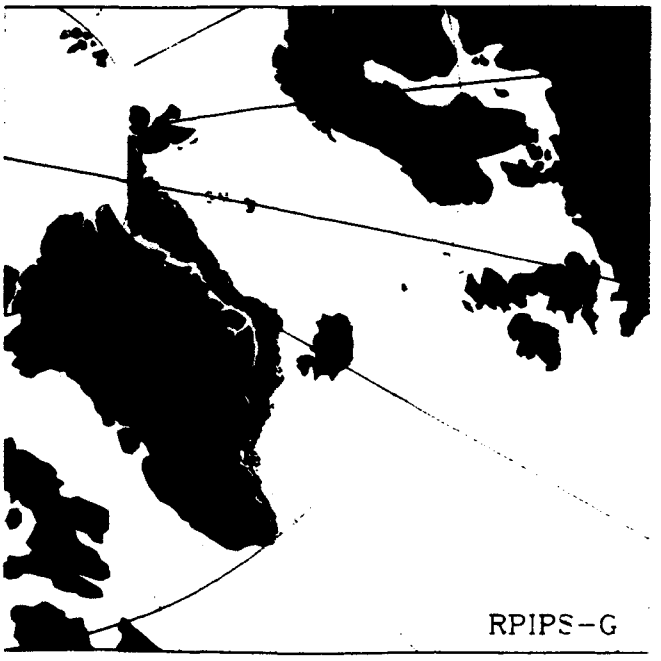


RPIPS-B



RPIPS-G

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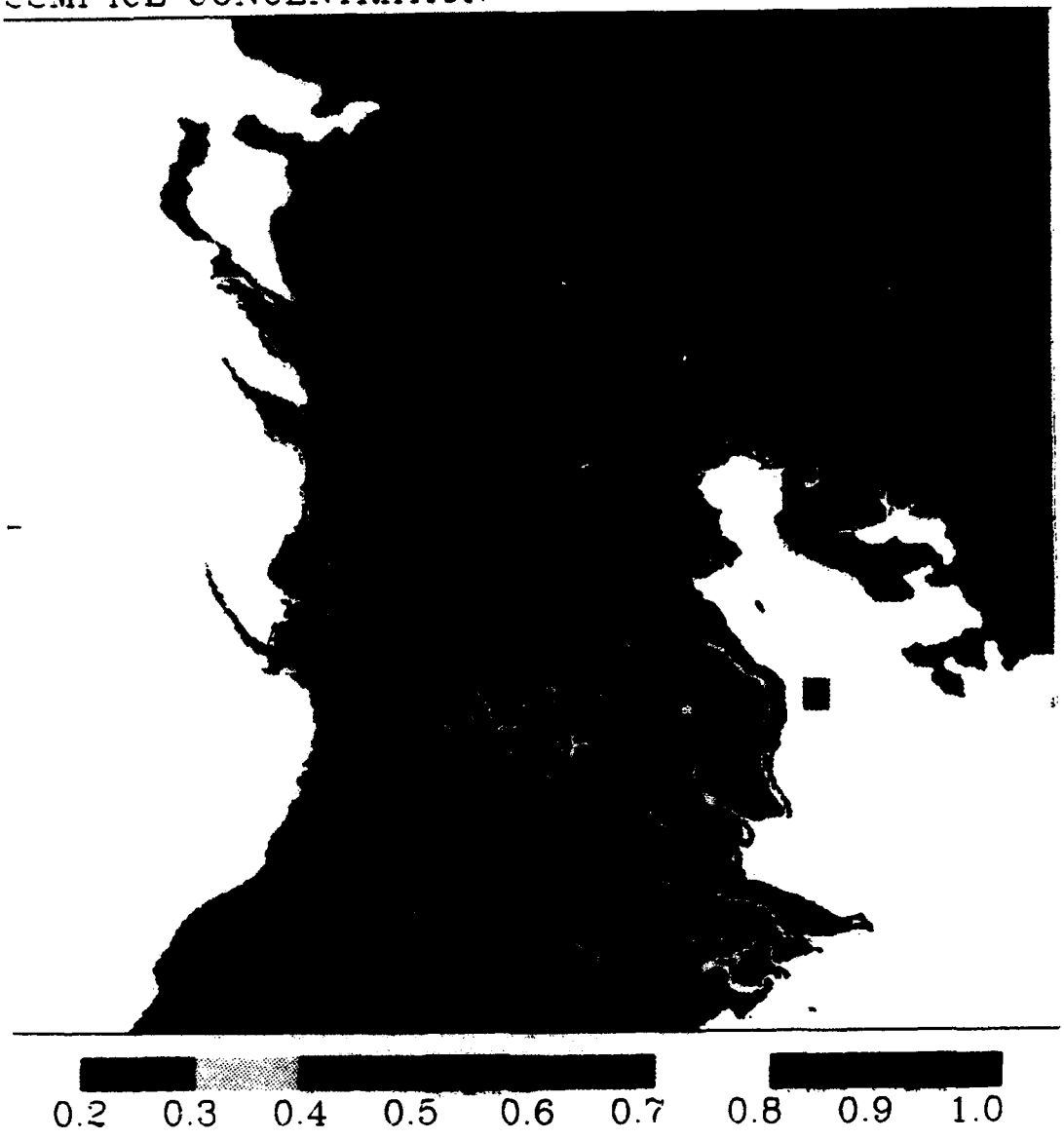

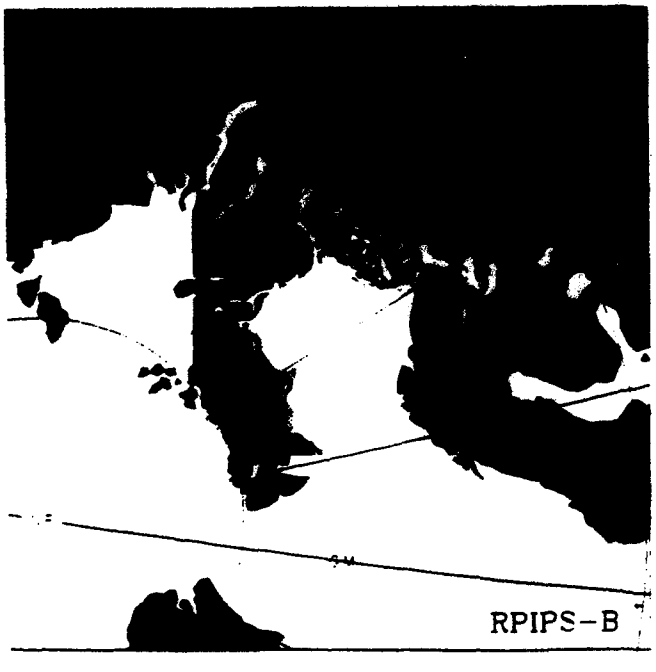

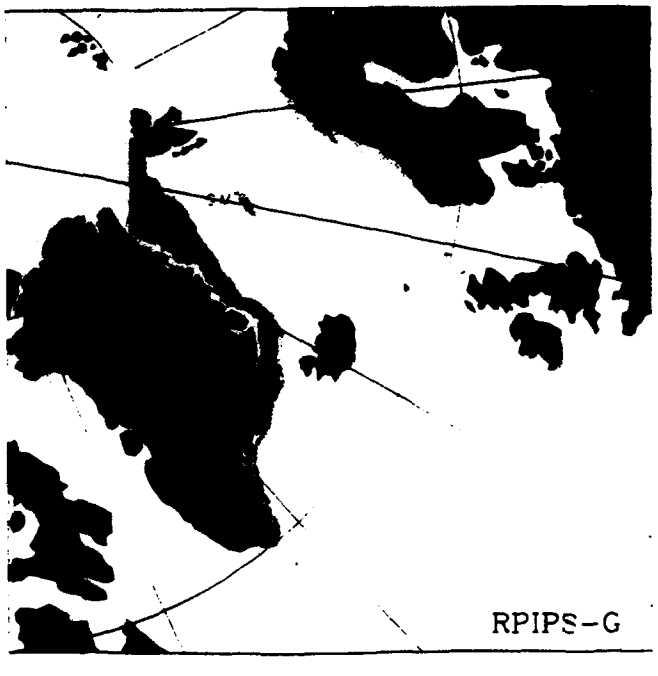

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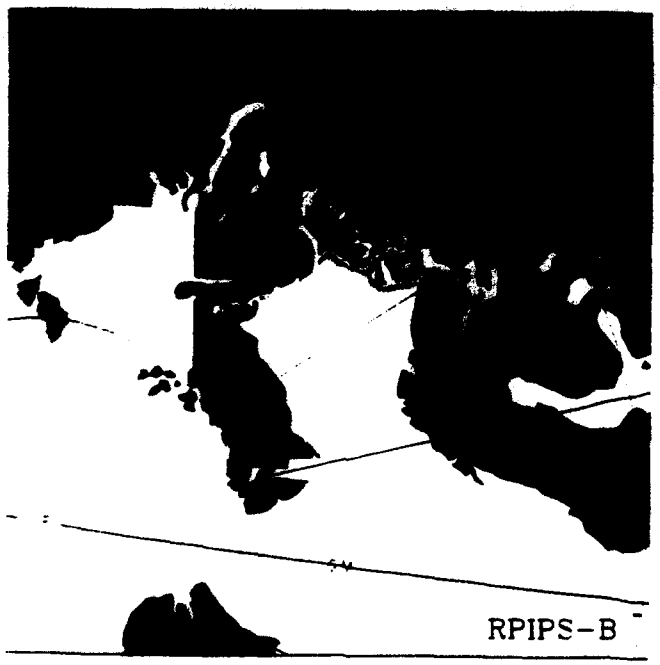
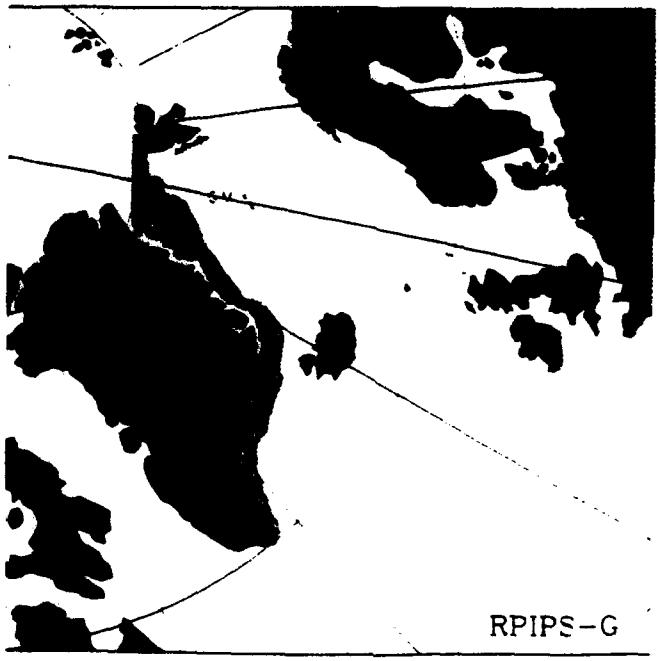
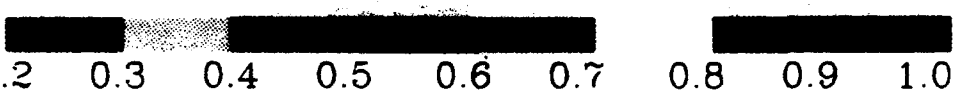


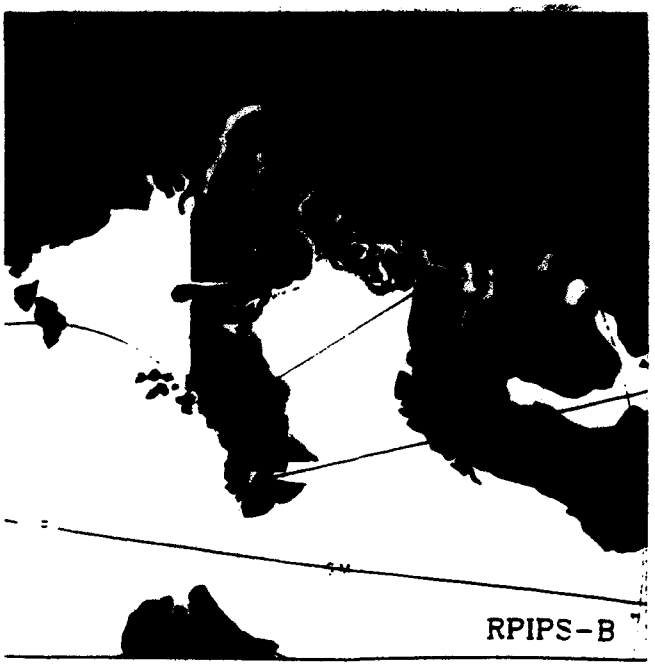
RPIPS-B

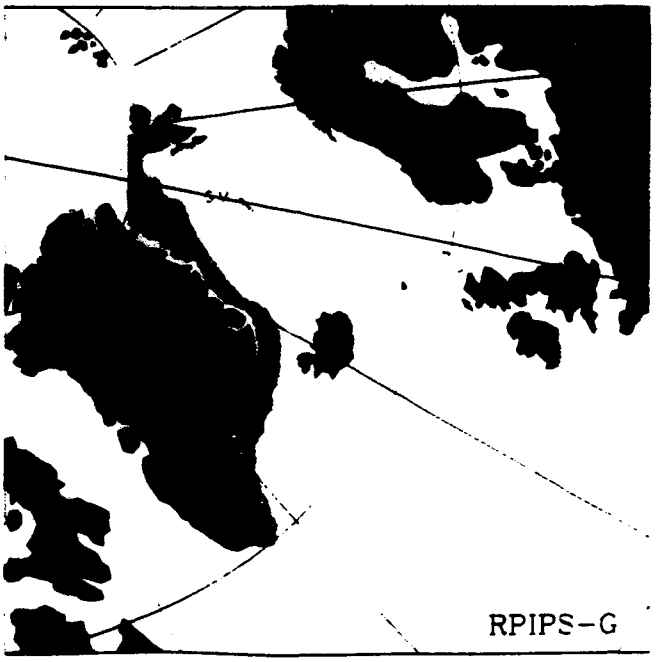


RPIPS-G

SSMI ICE CONCENTRATION 93040100







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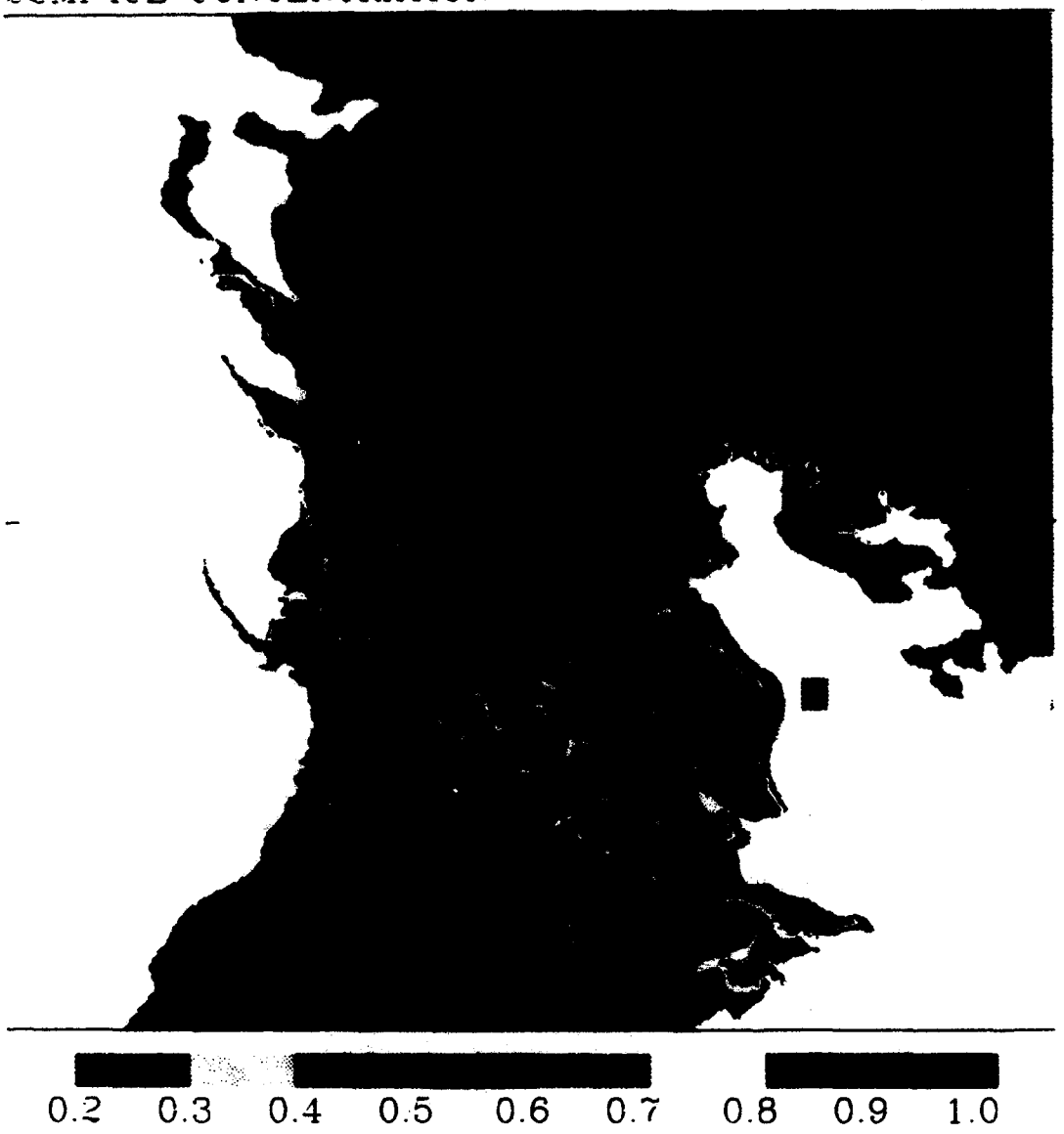

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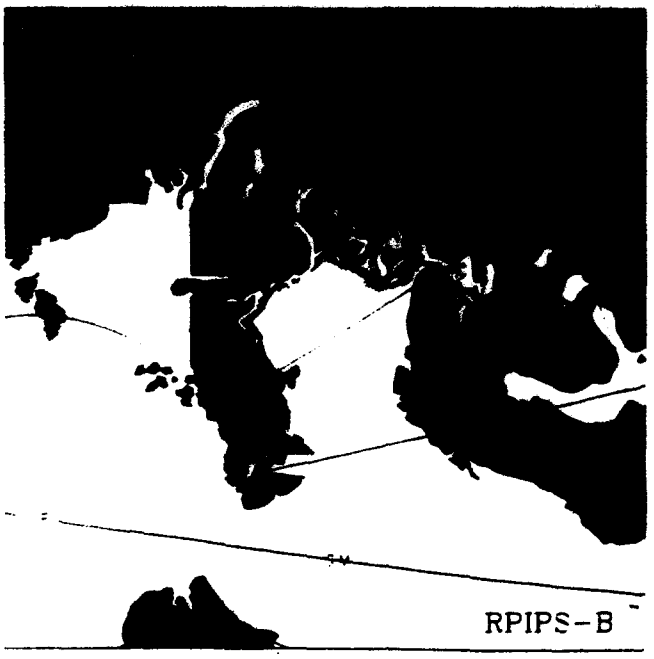
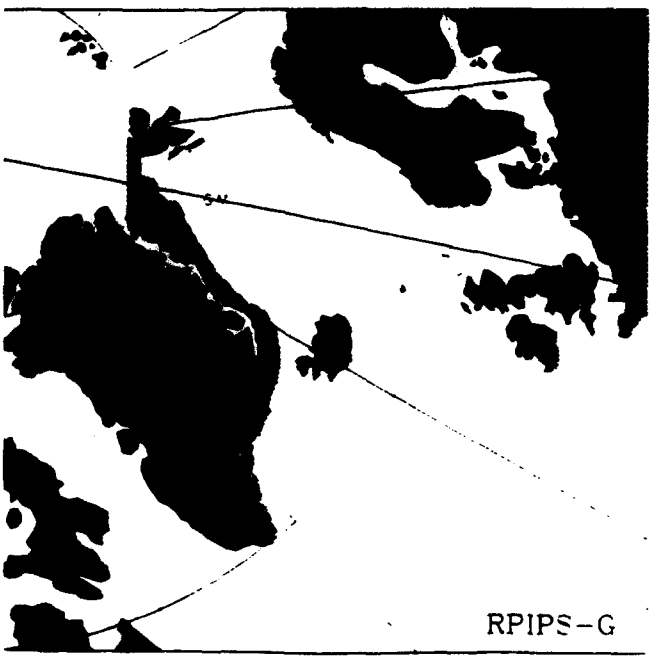


RPIPS-B



RPIPS-G

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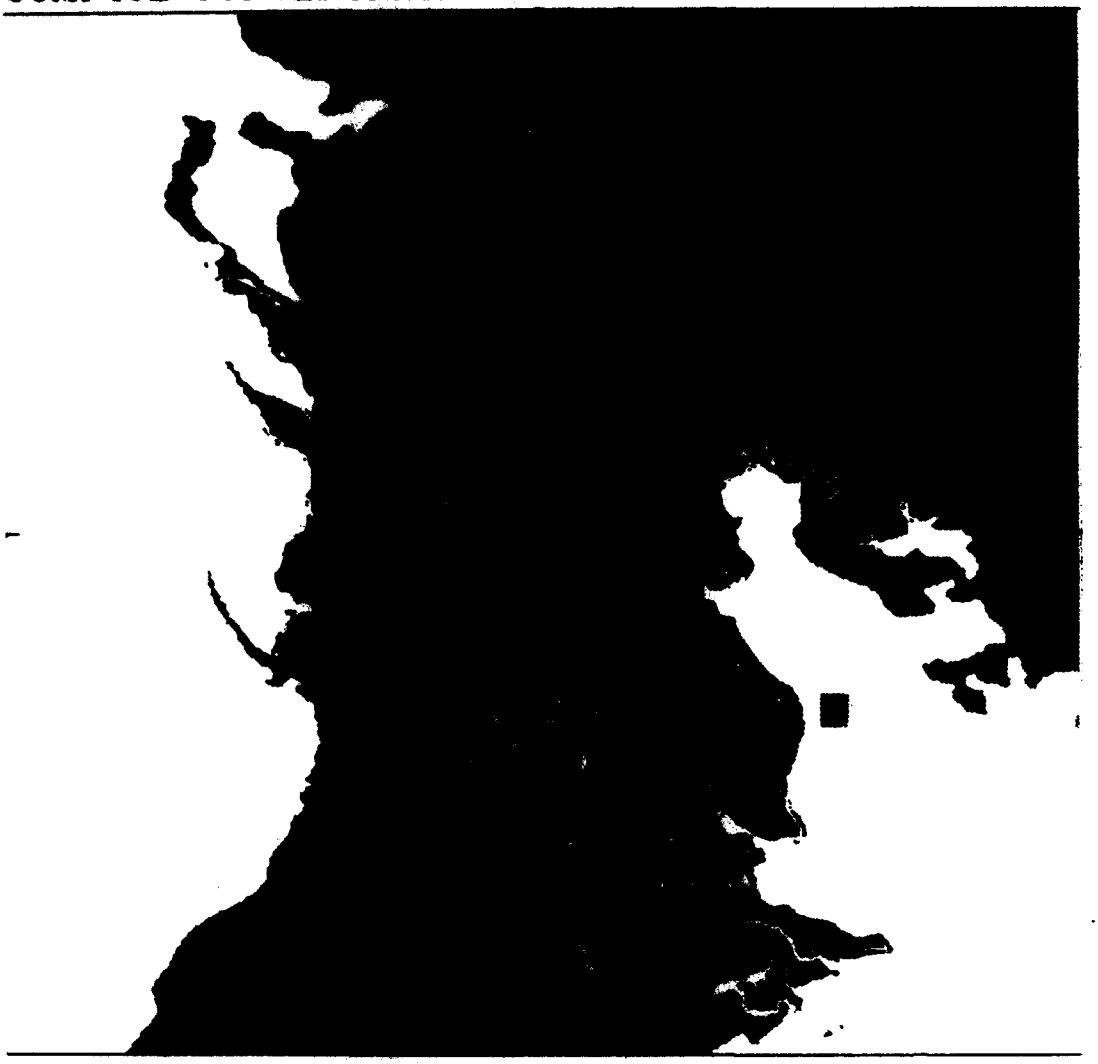

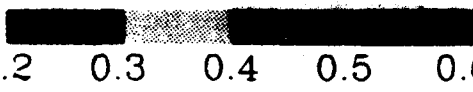

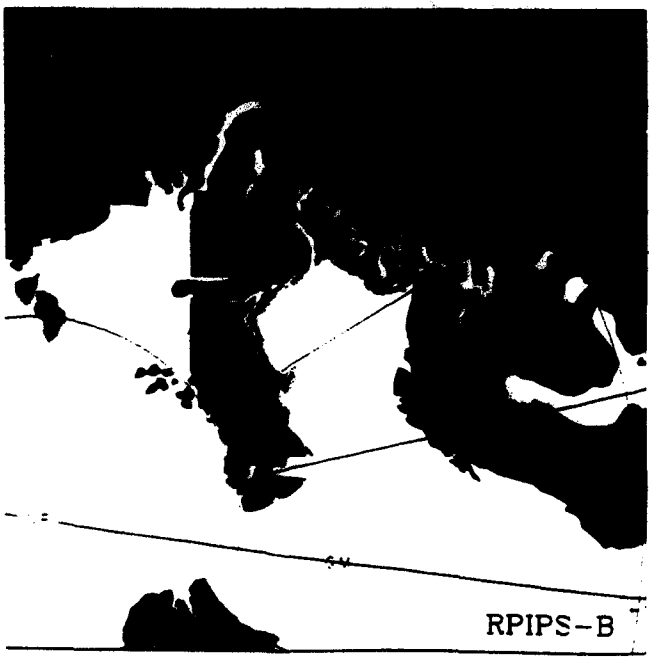

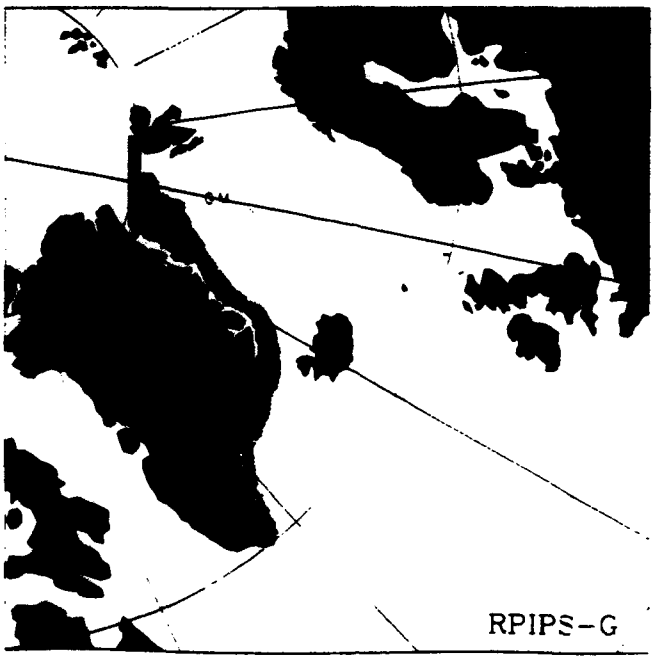

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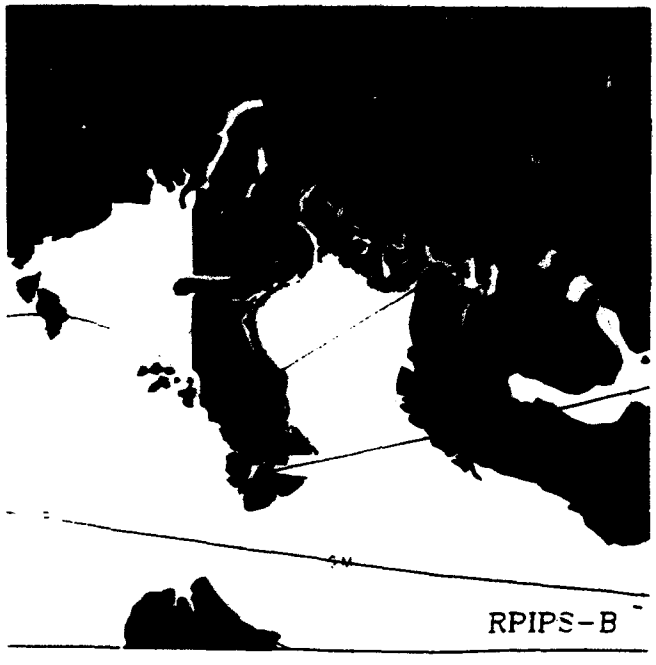

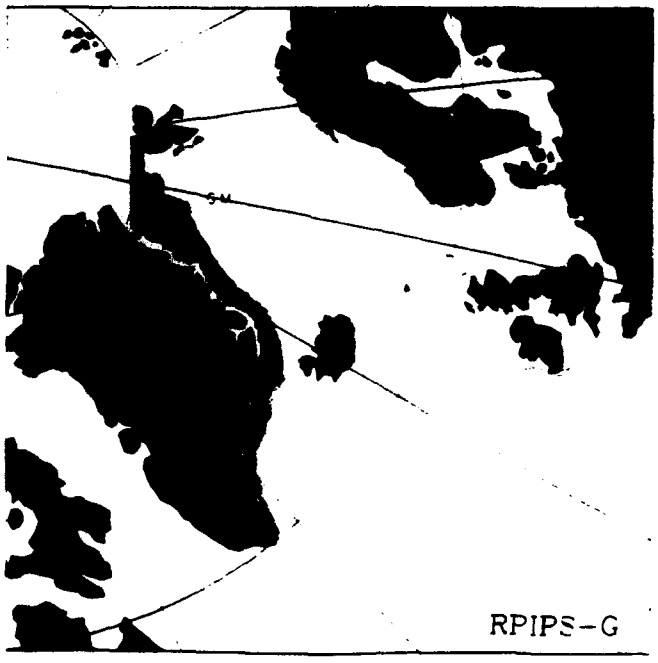

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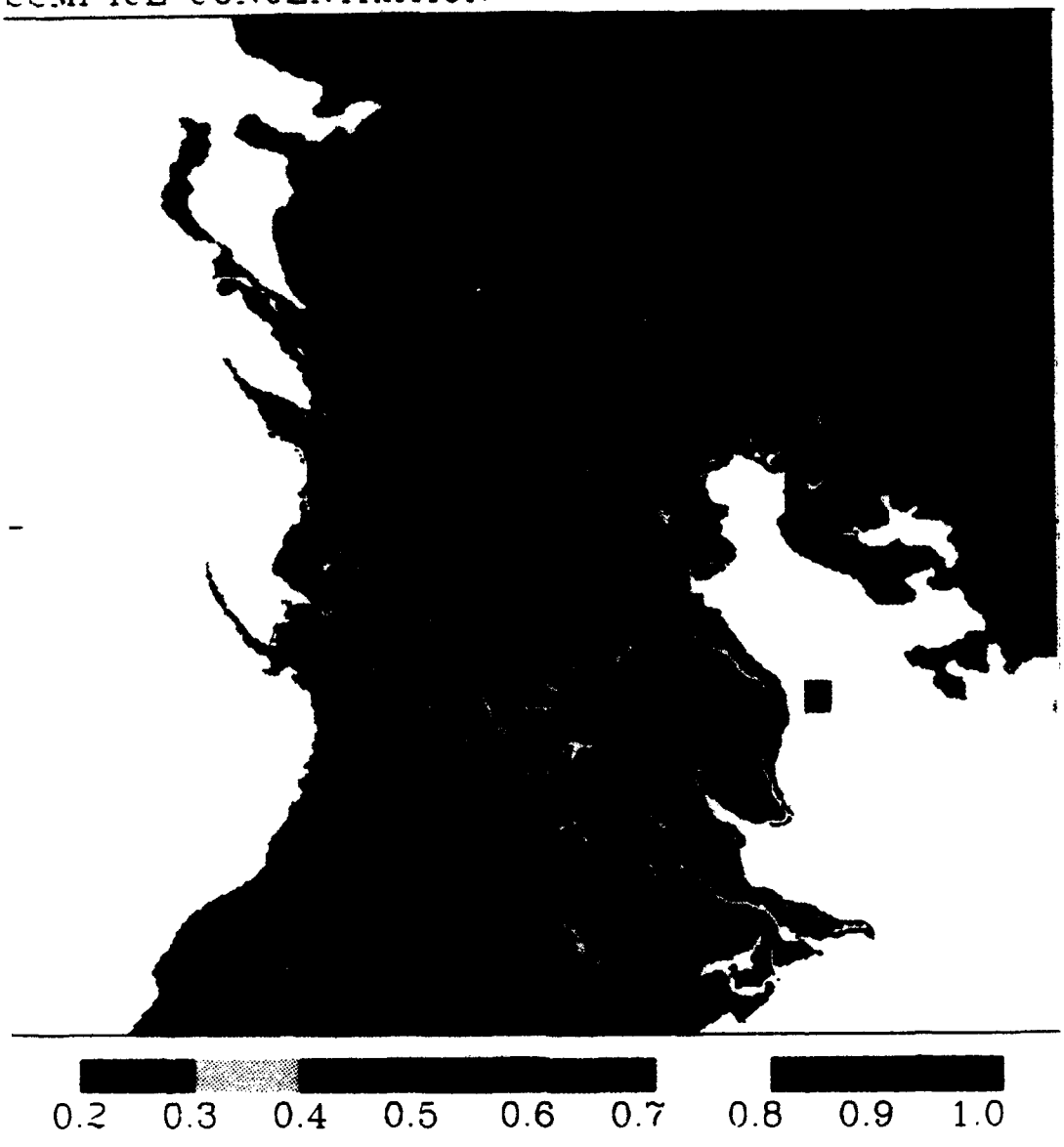

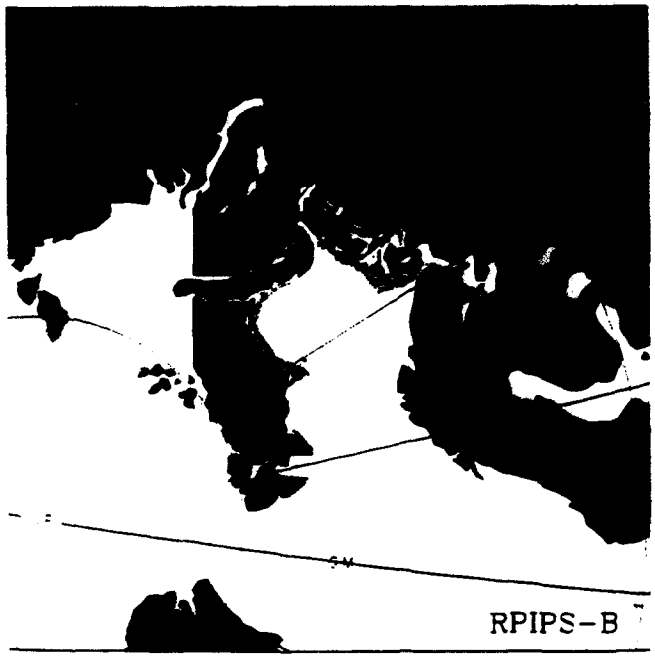

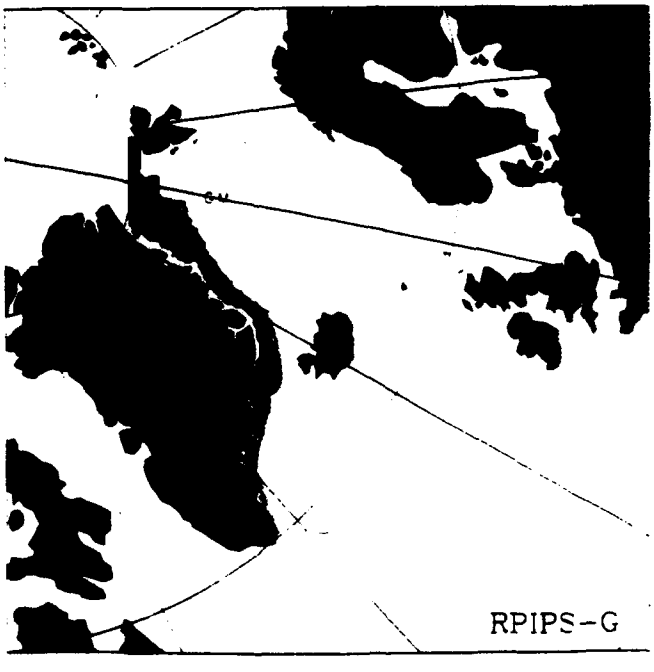

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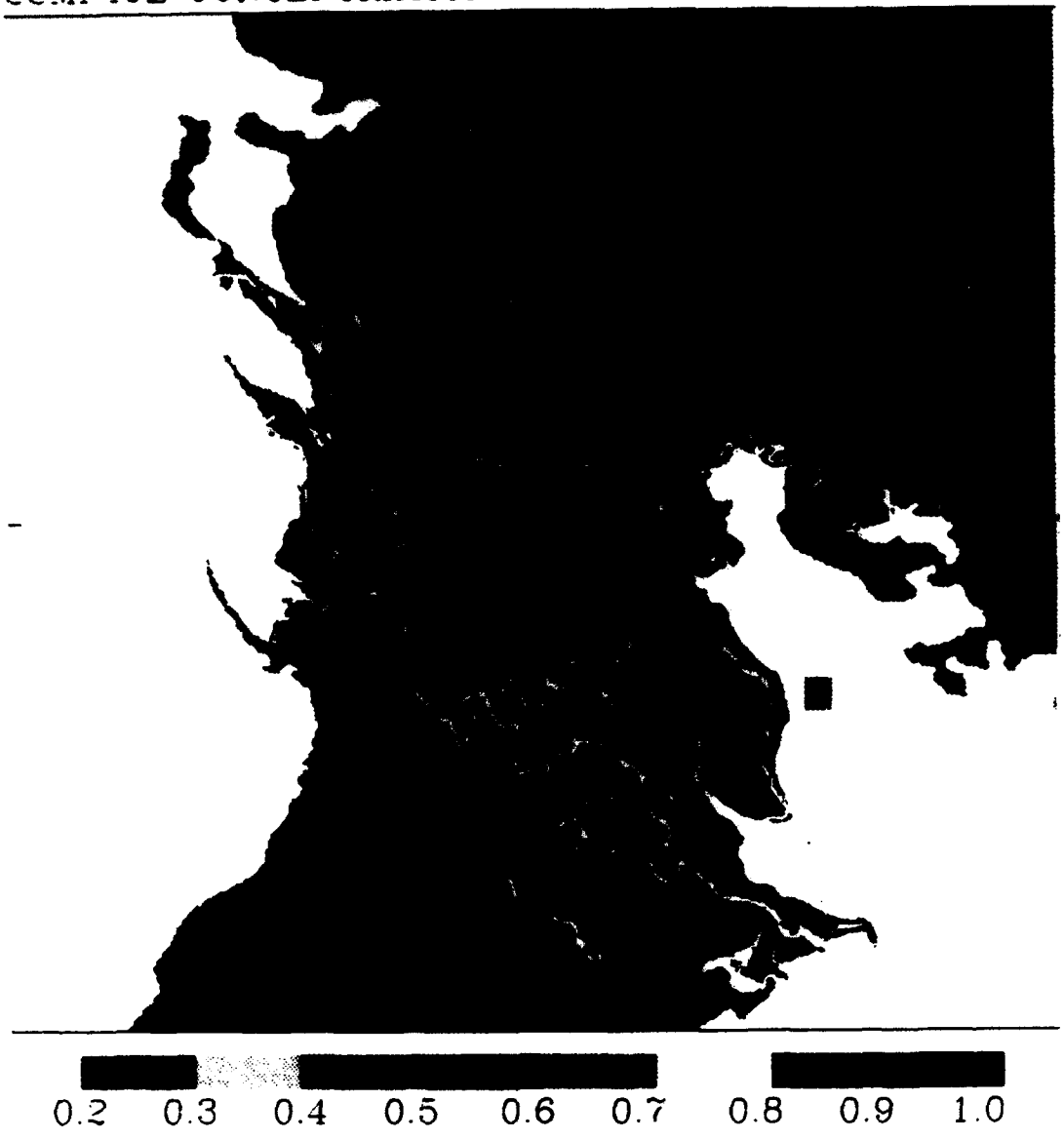

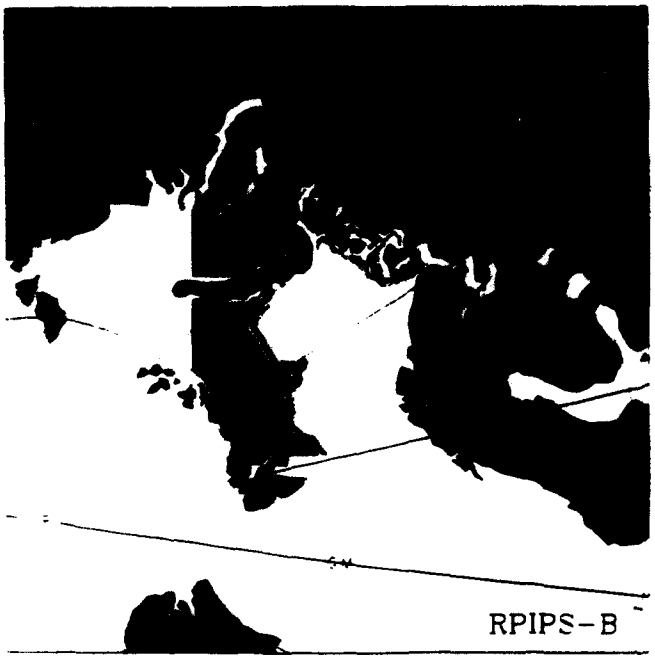

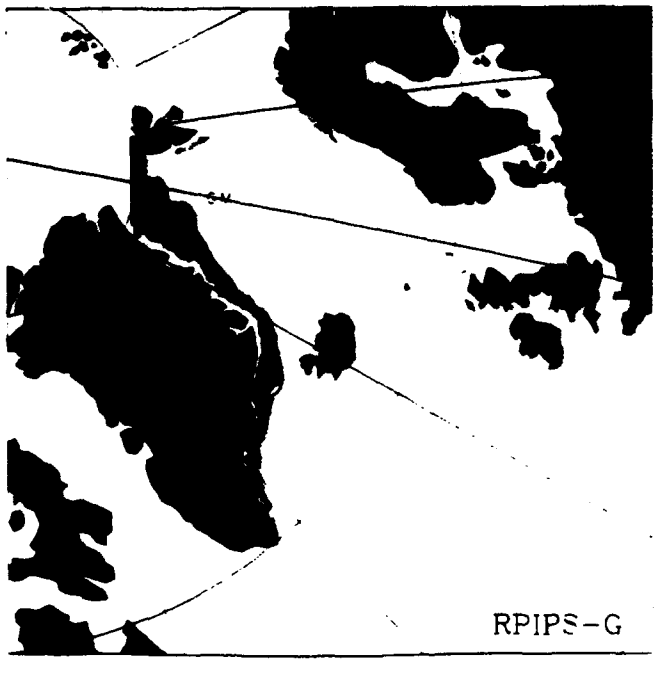

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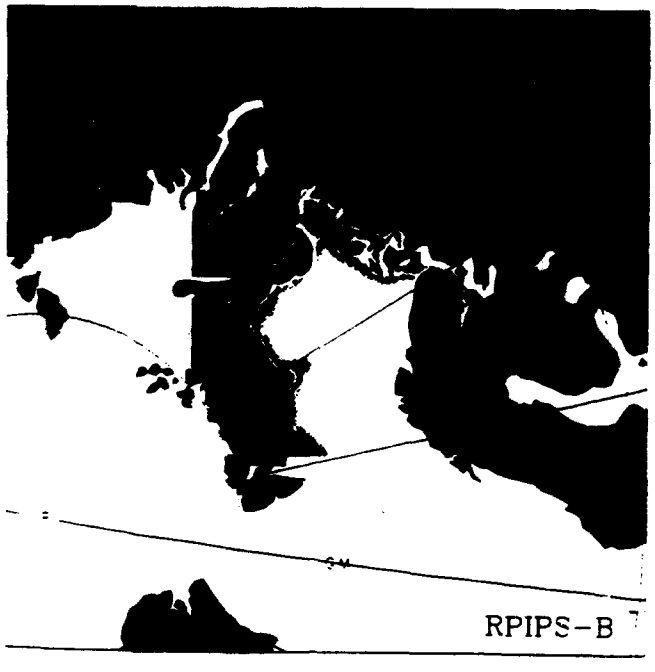

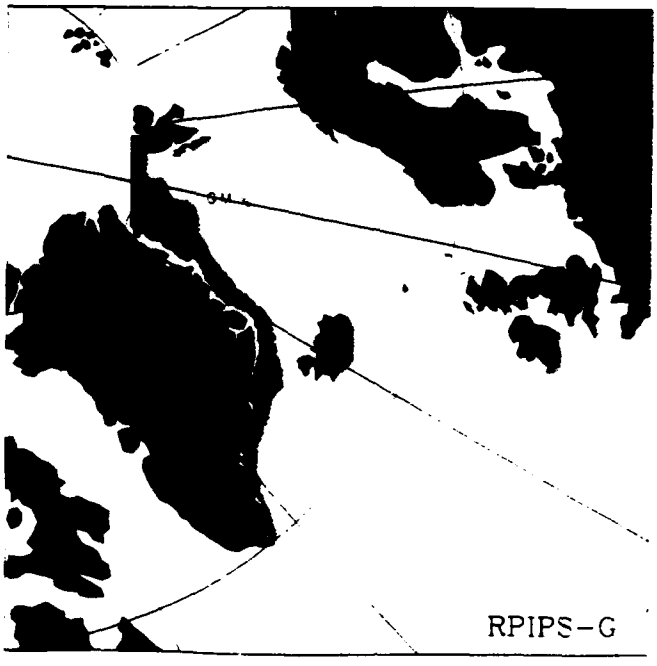

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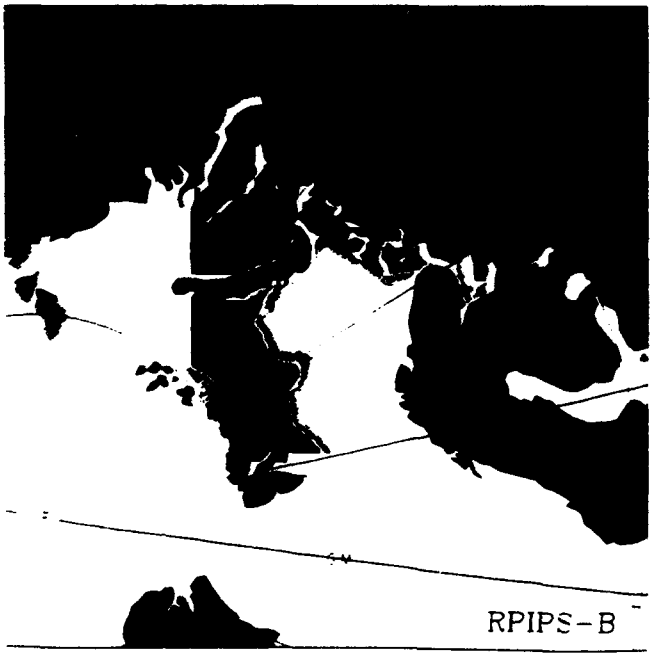

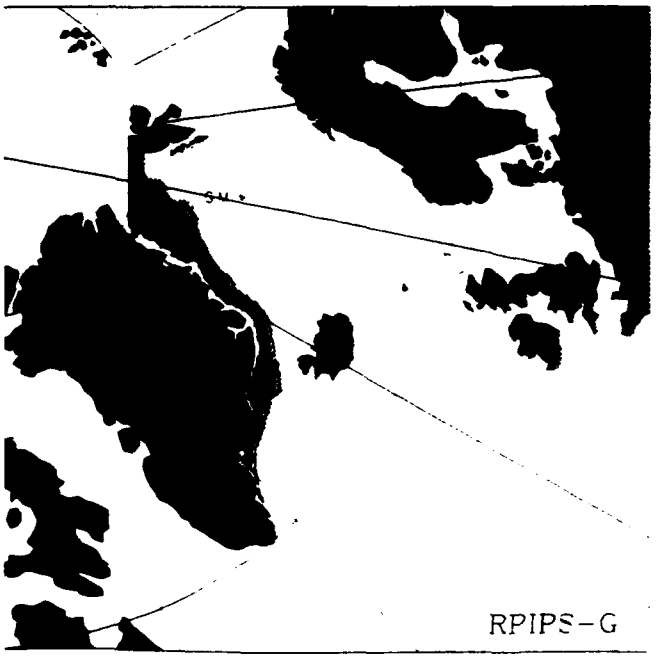

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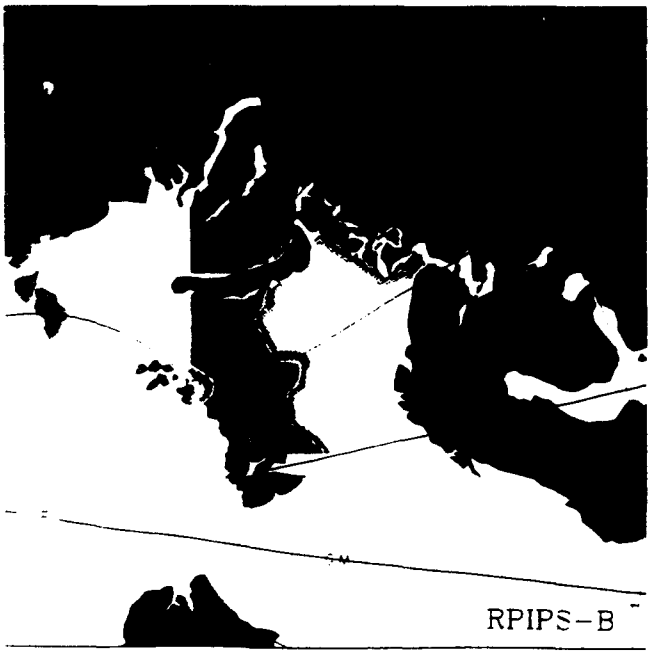
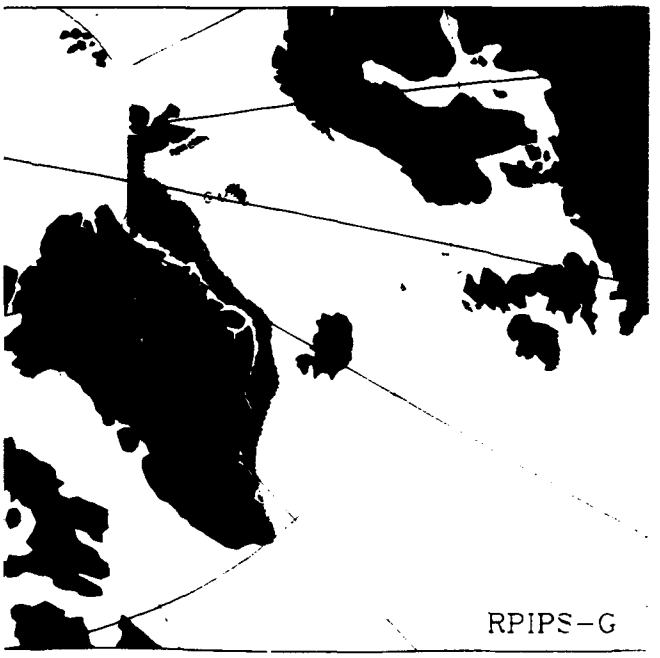


RPIPS-B



RPIPS-G

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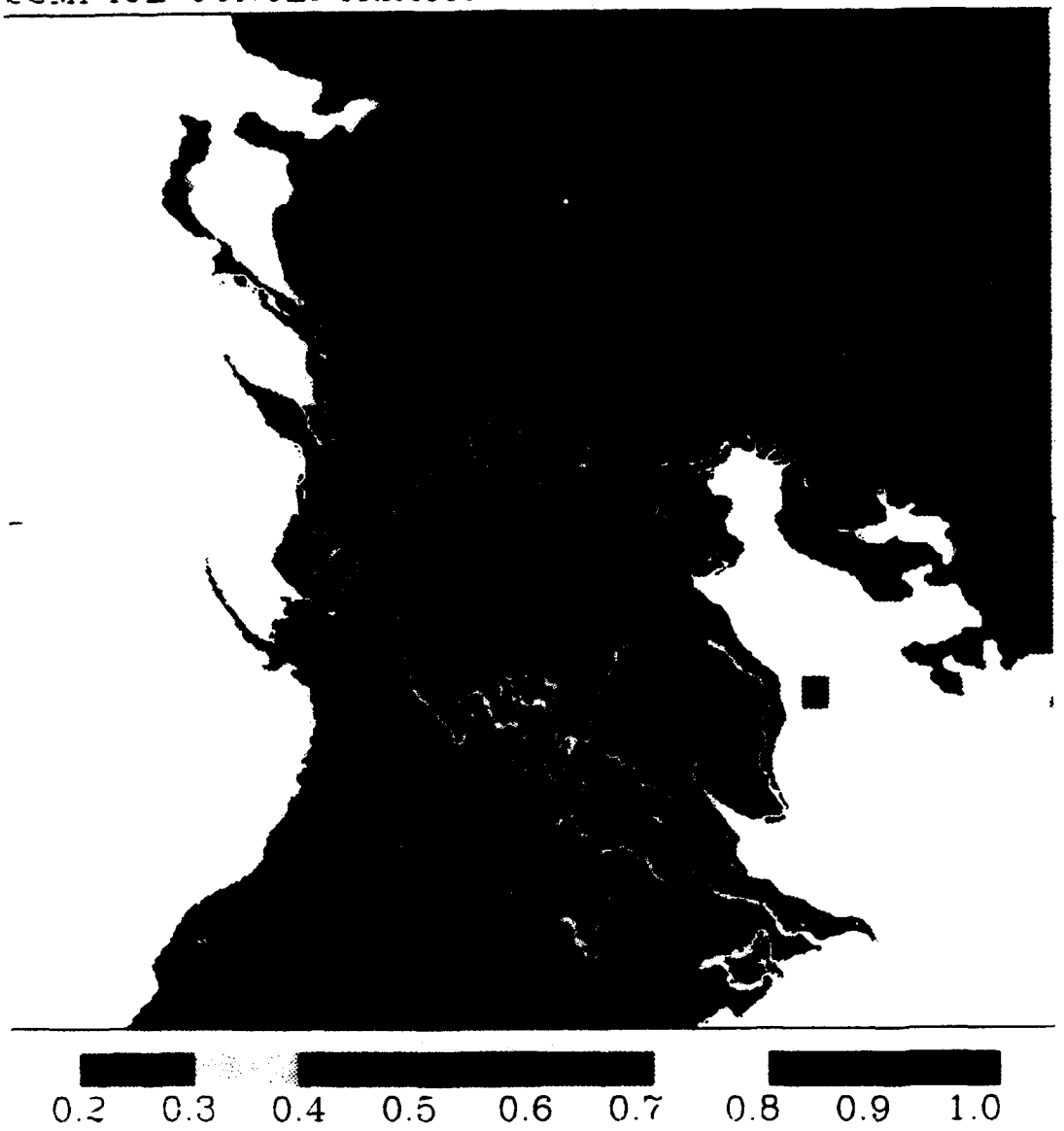

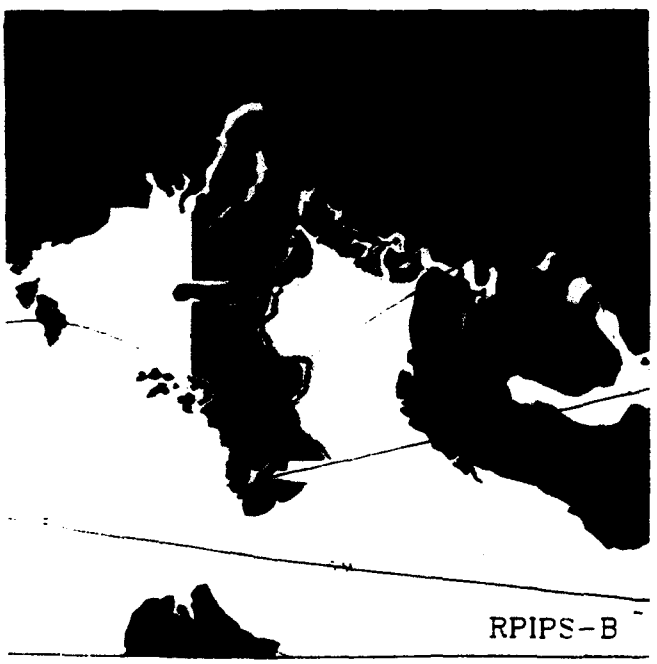

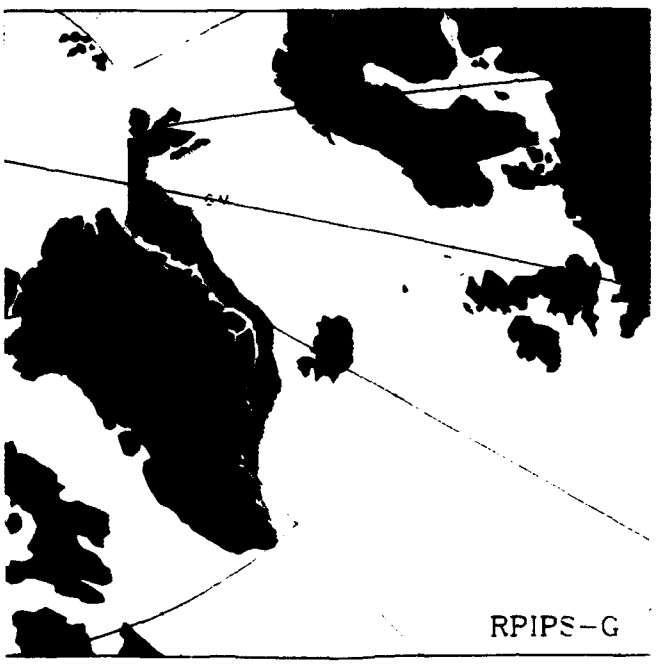

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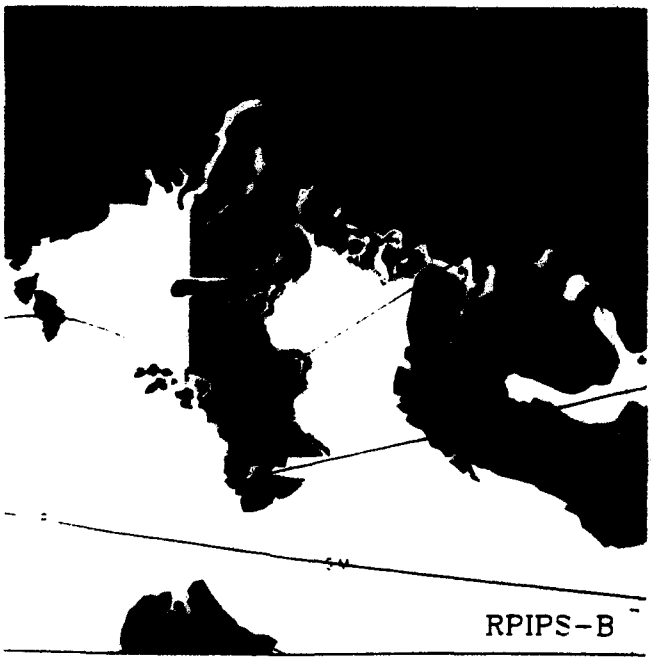
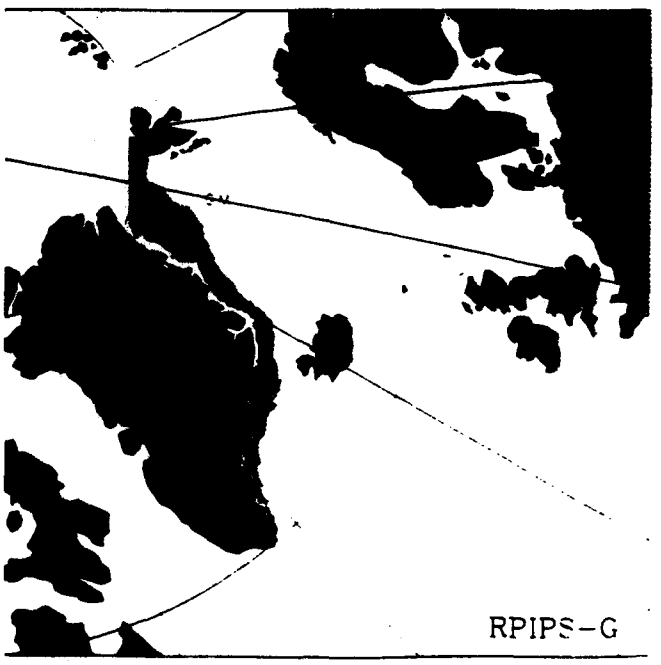


RPIPS-B



RPIPS-G

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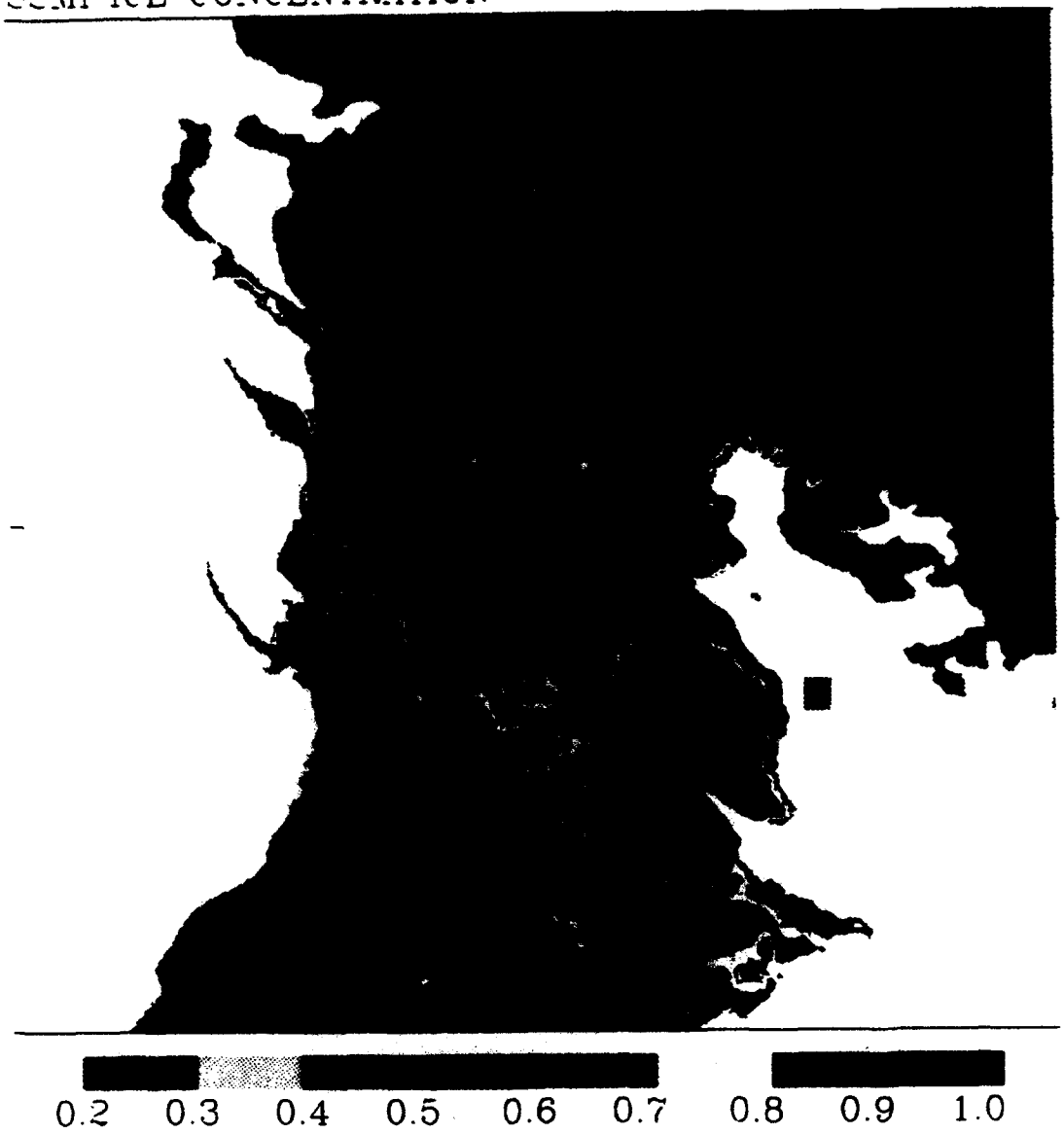

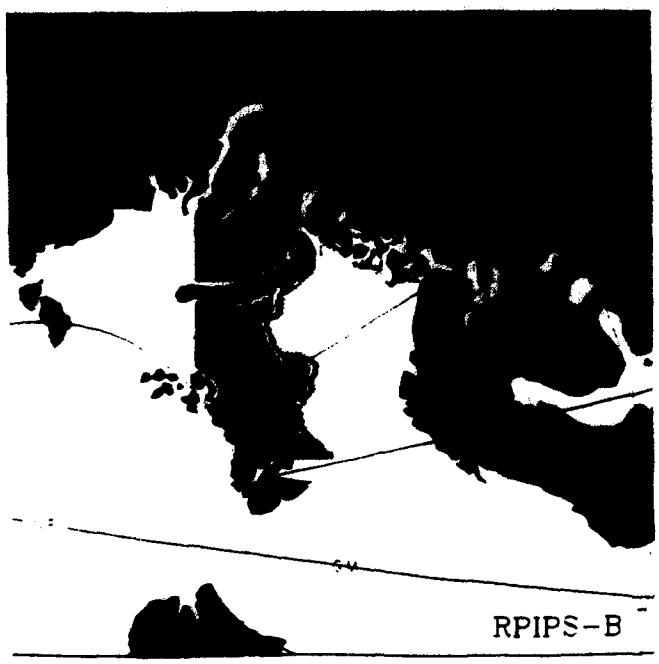

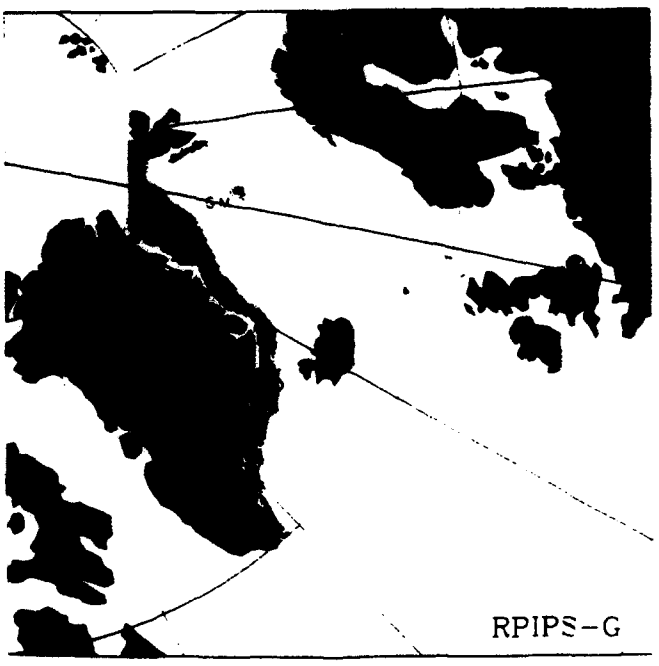

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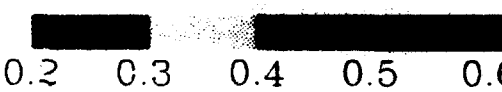

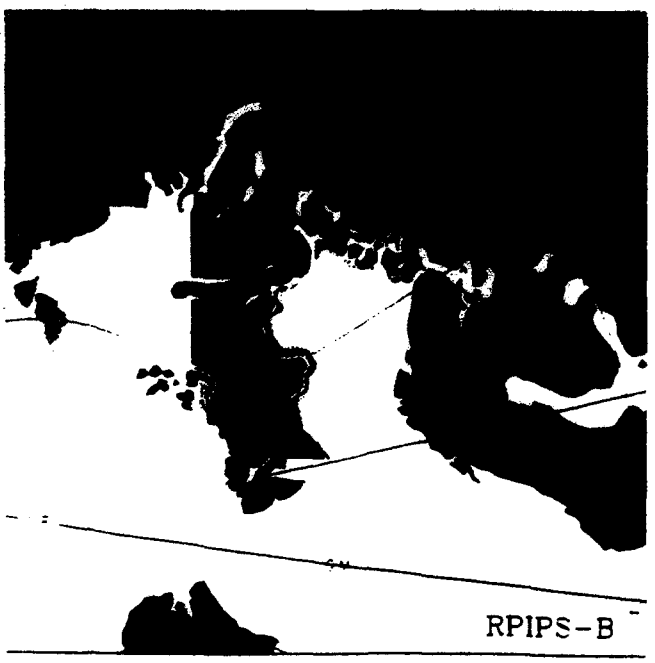

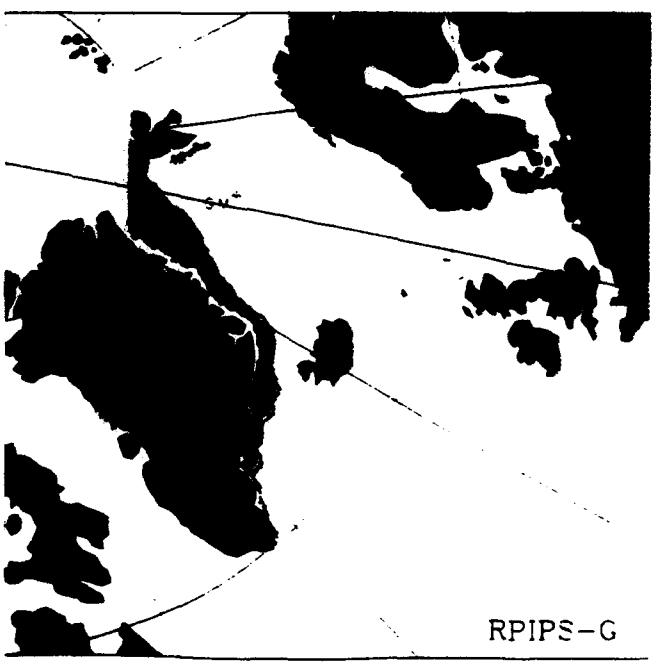

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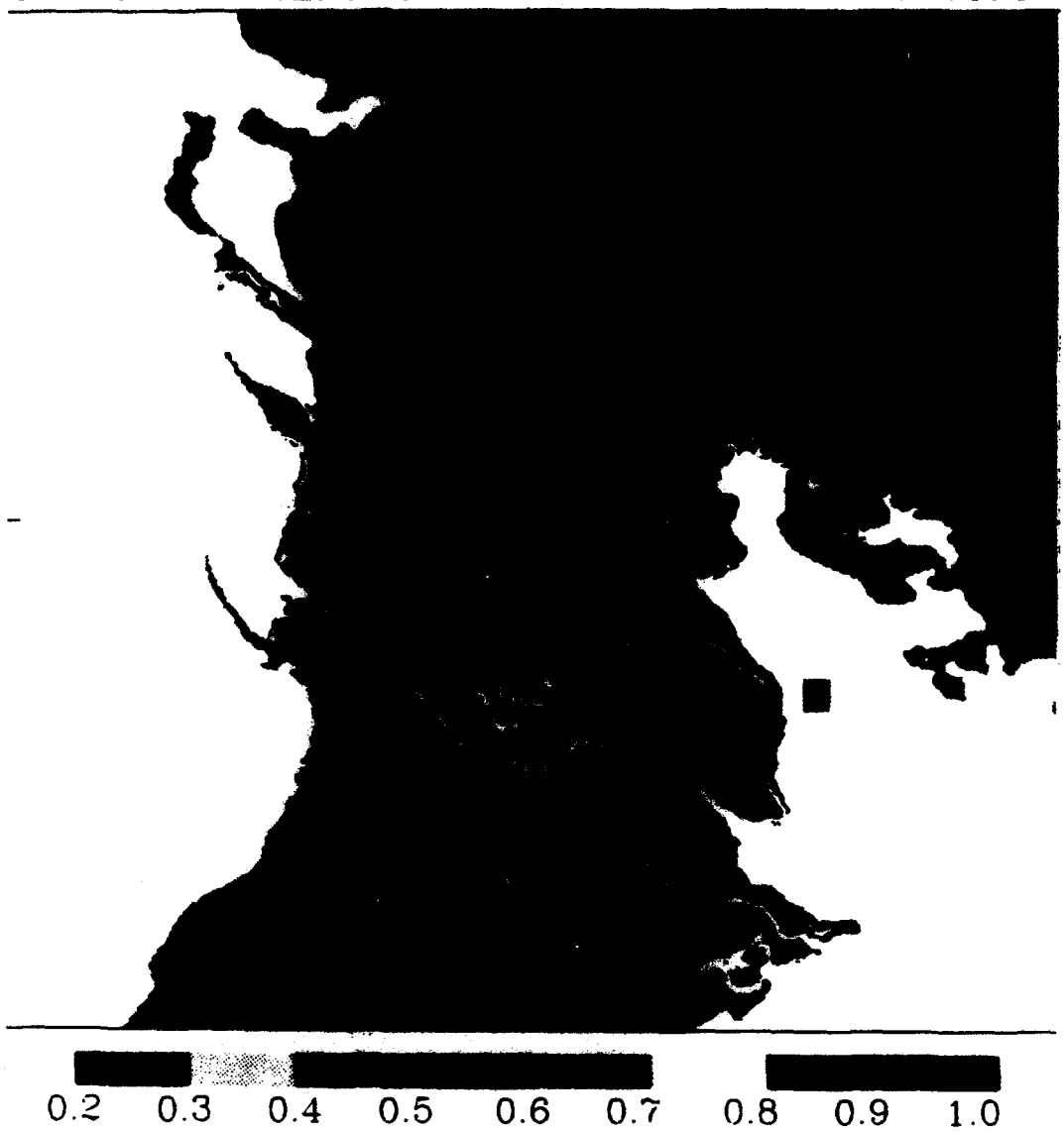

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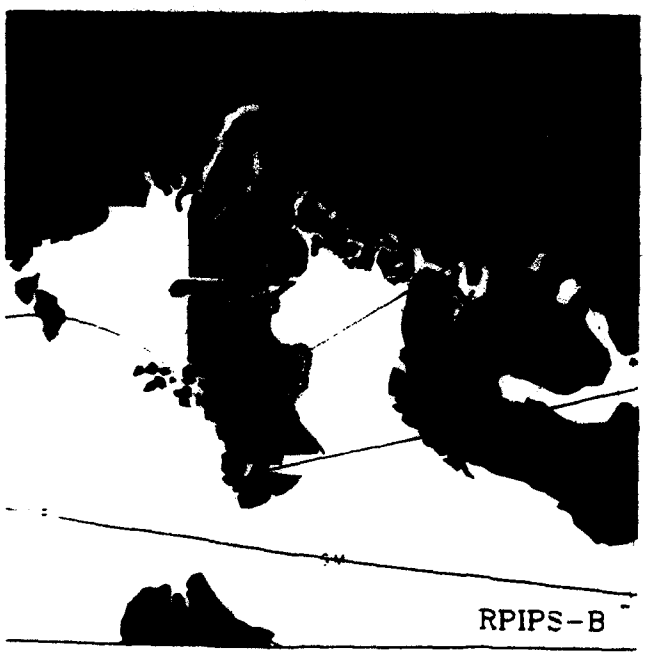

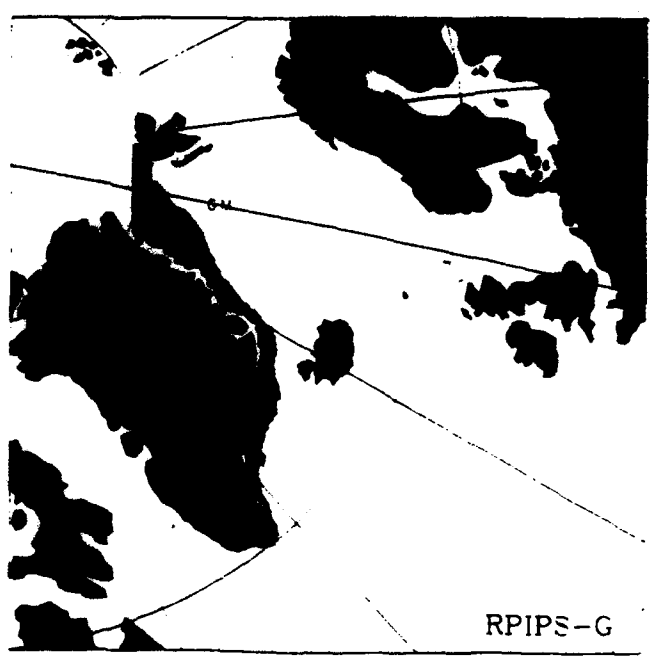

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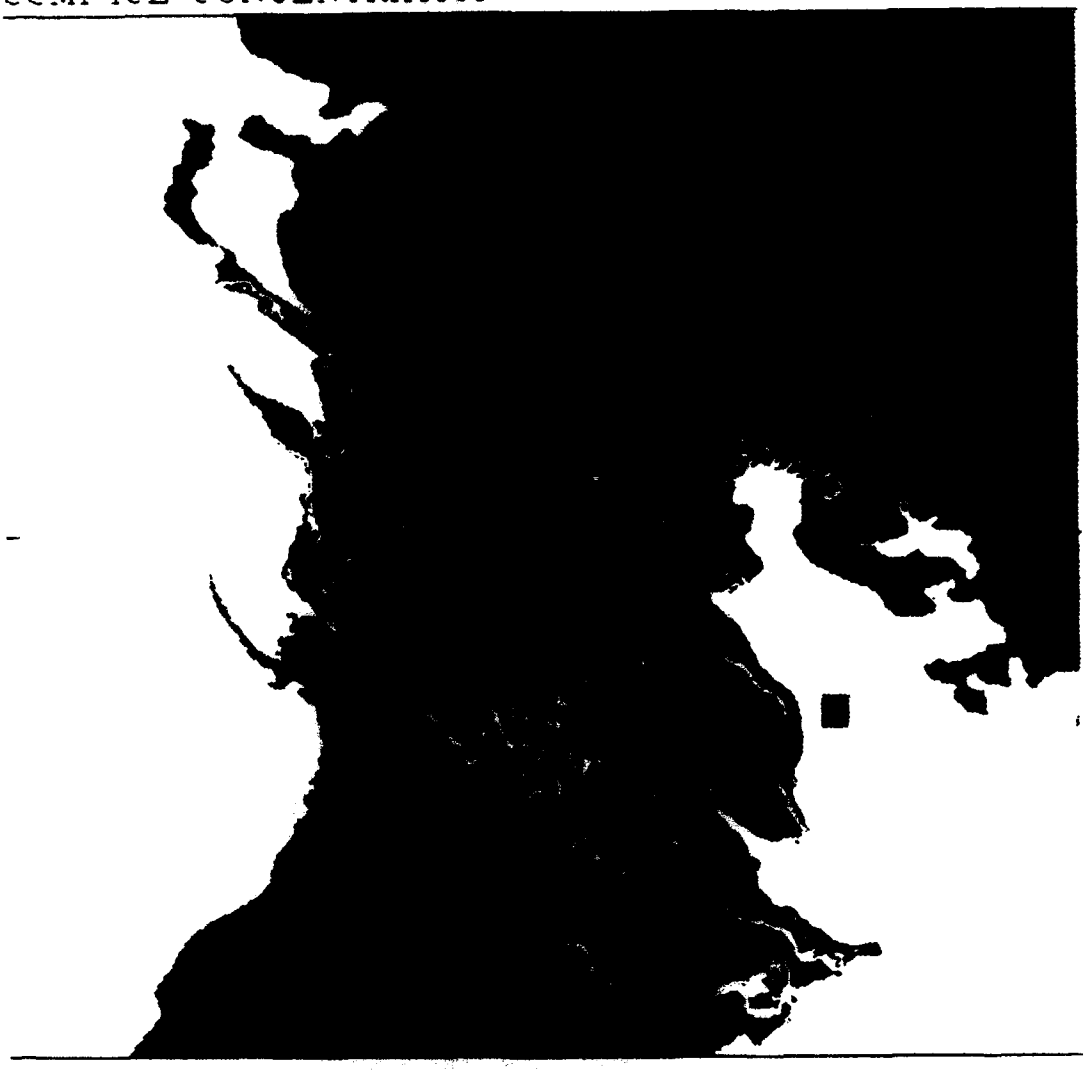

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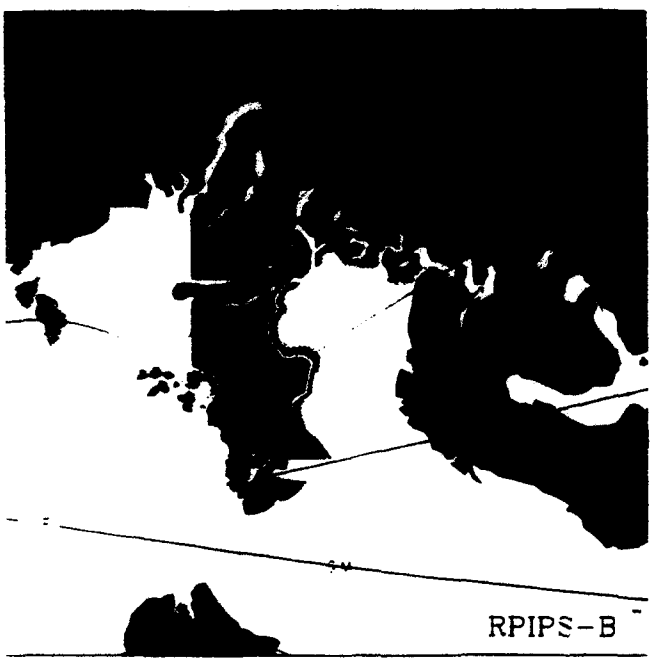
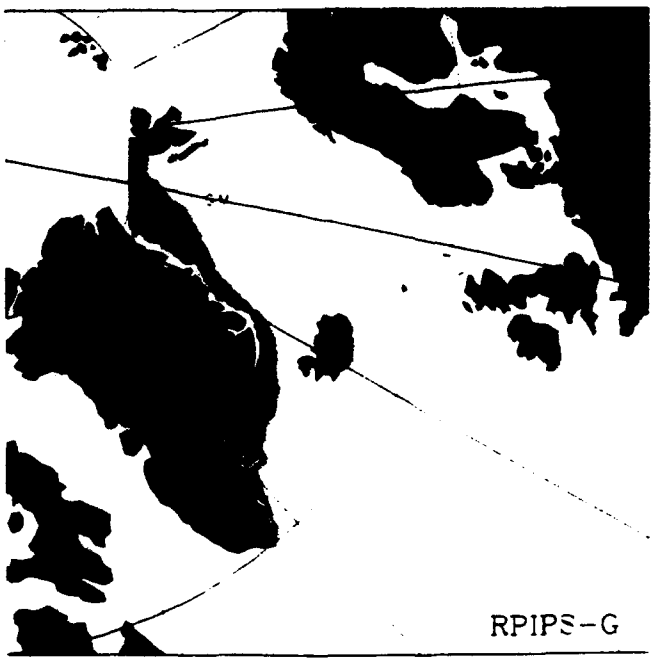


RPIPS-B



RPIPS-G

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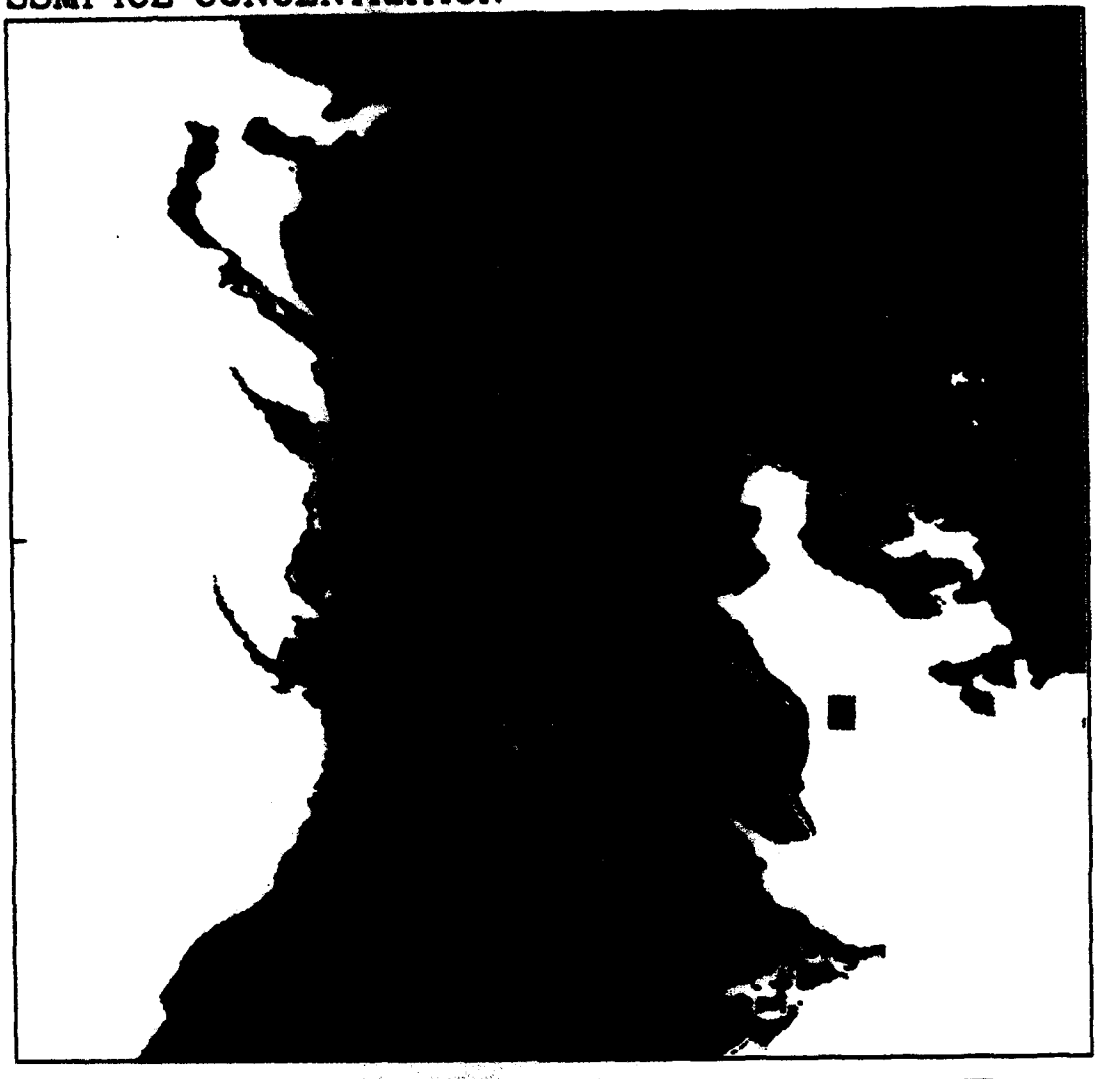

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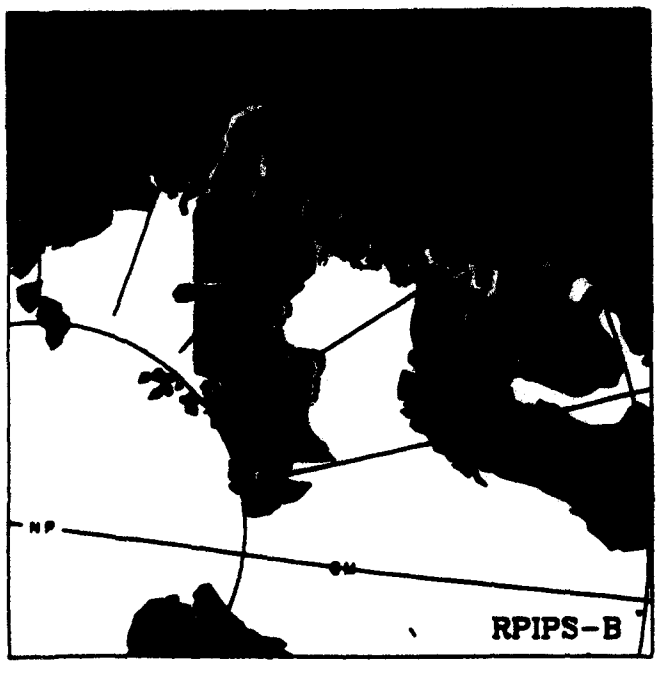

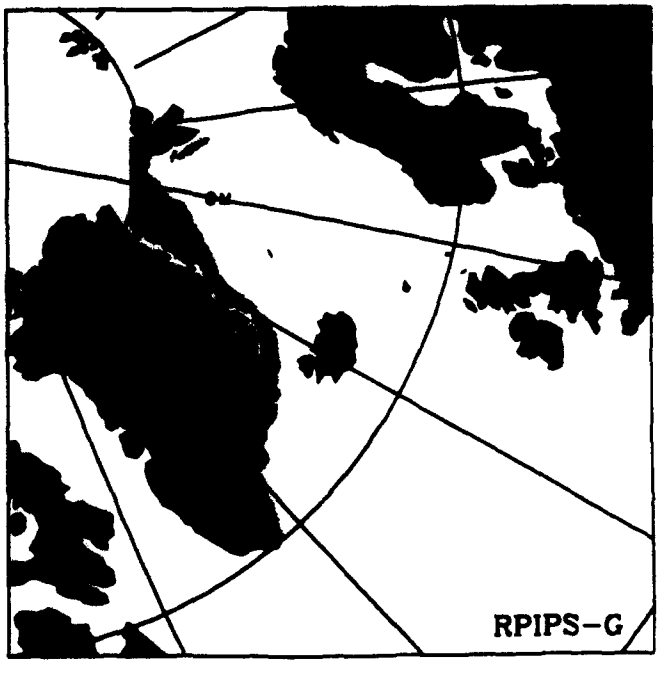

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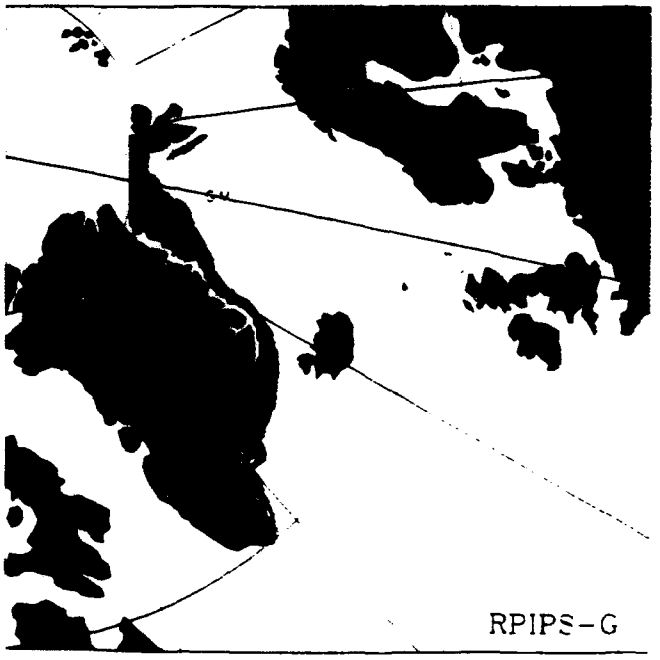

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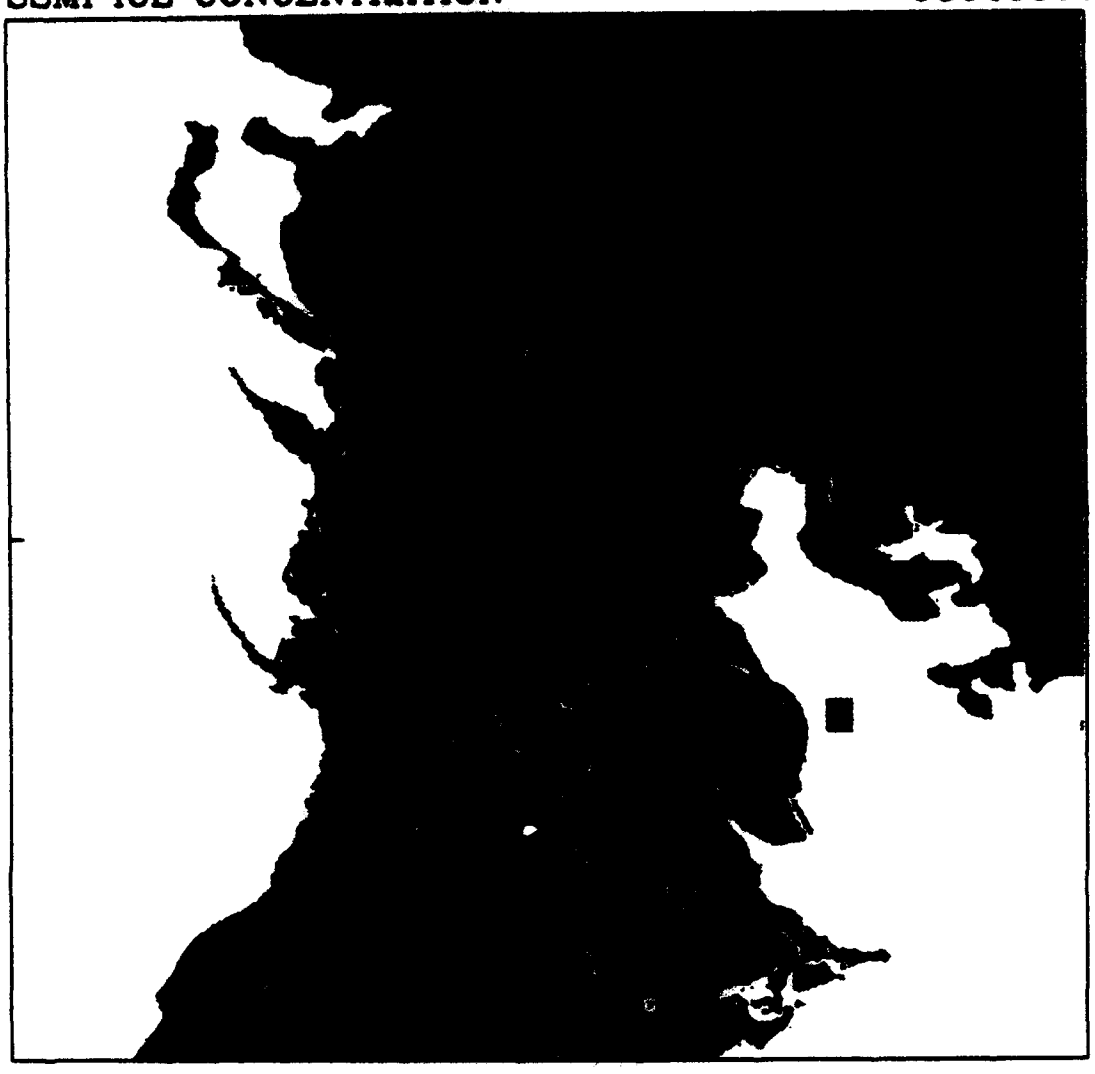

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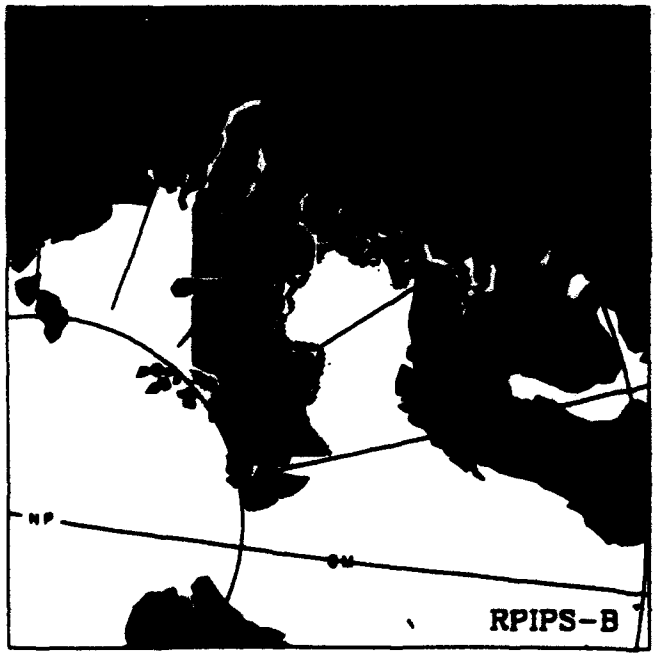

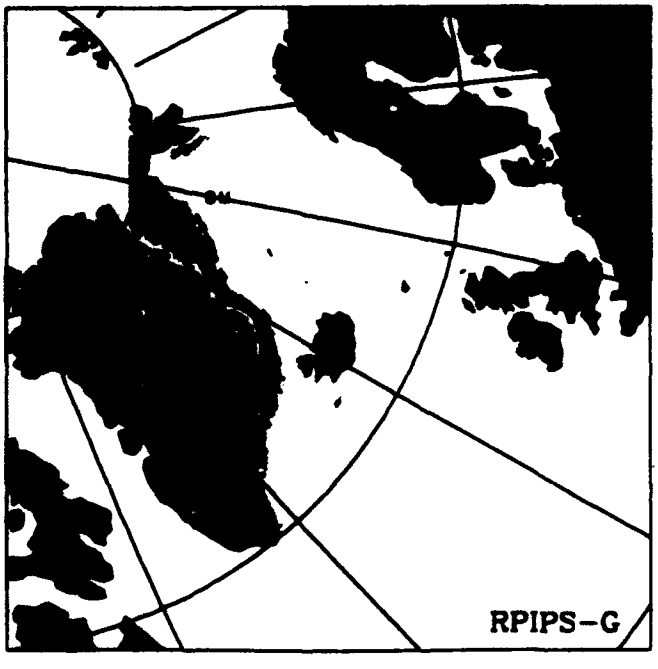

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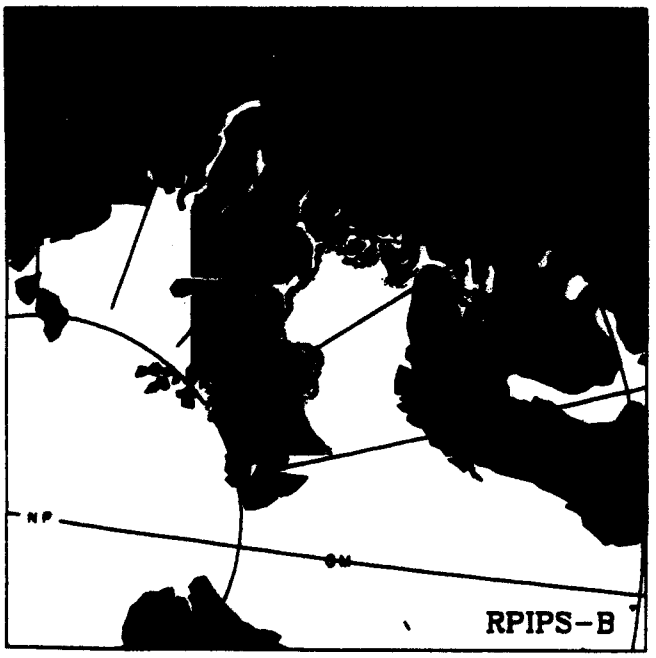

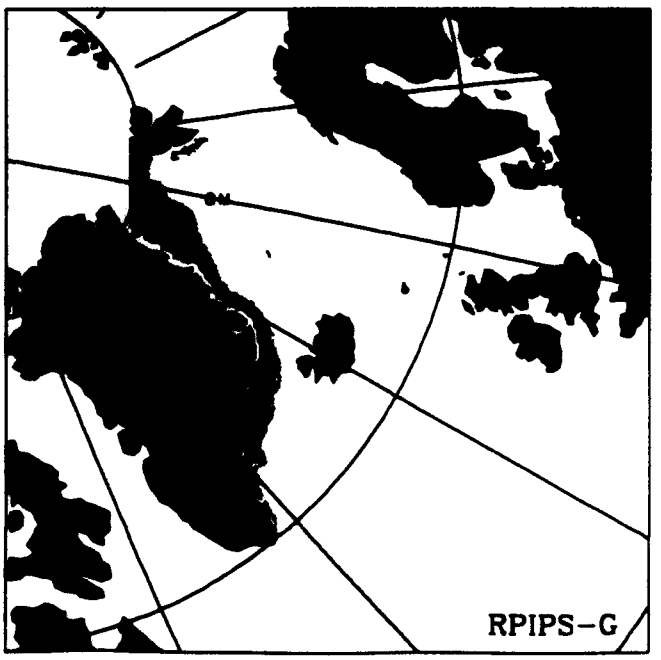

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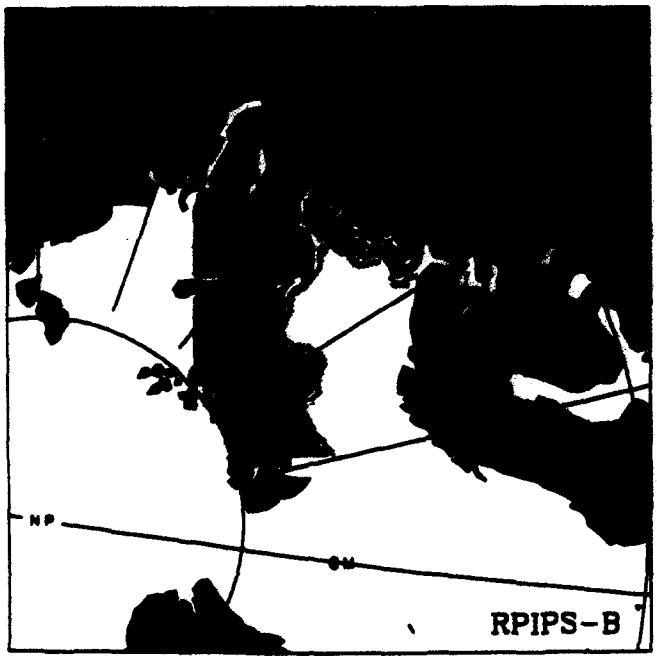
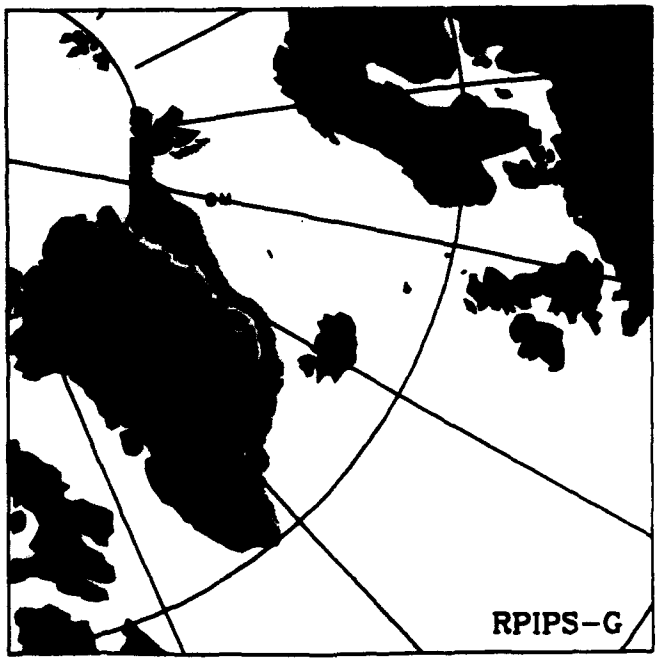
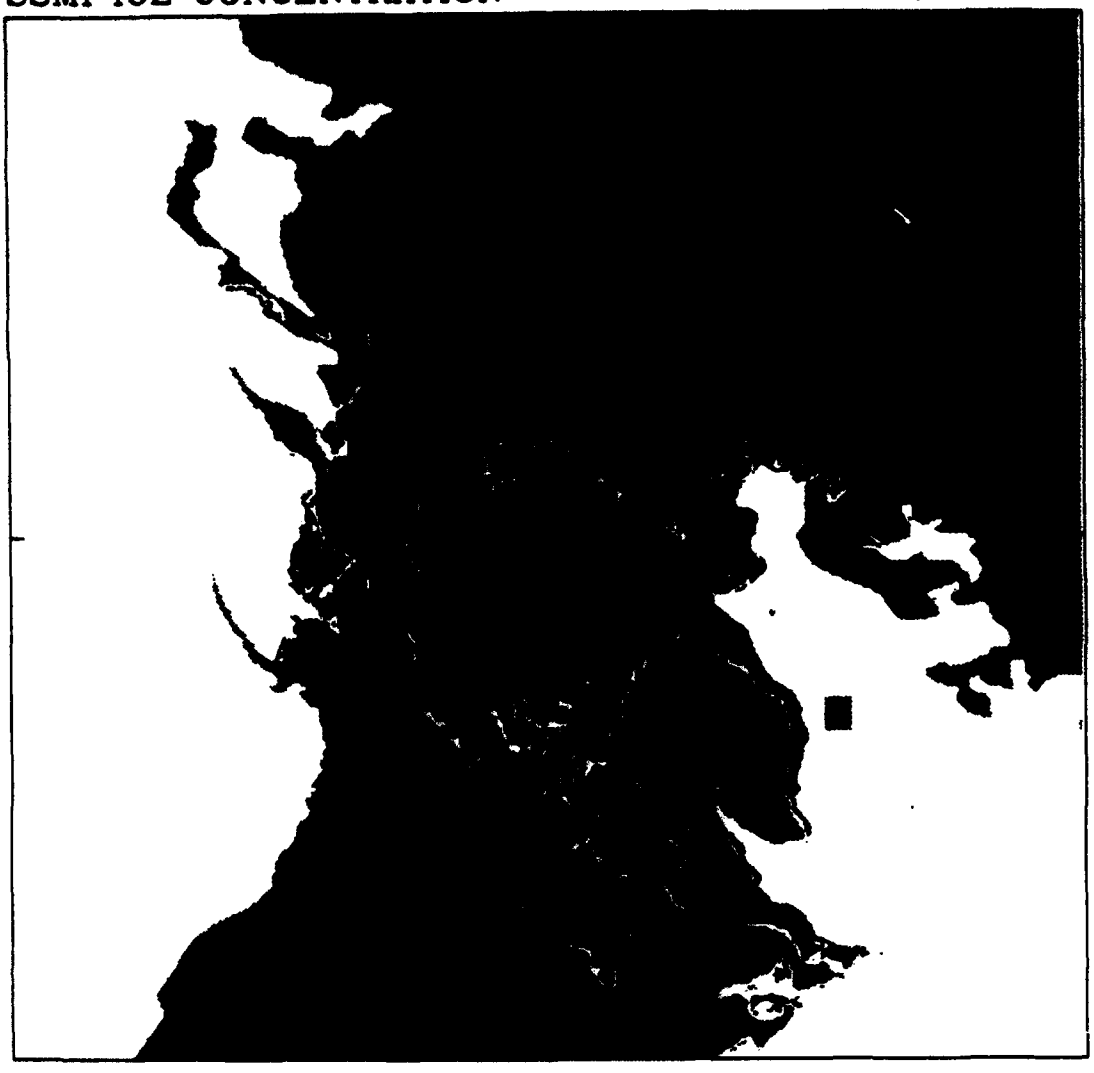




SSMI ICE CONCENTRATION 93042100



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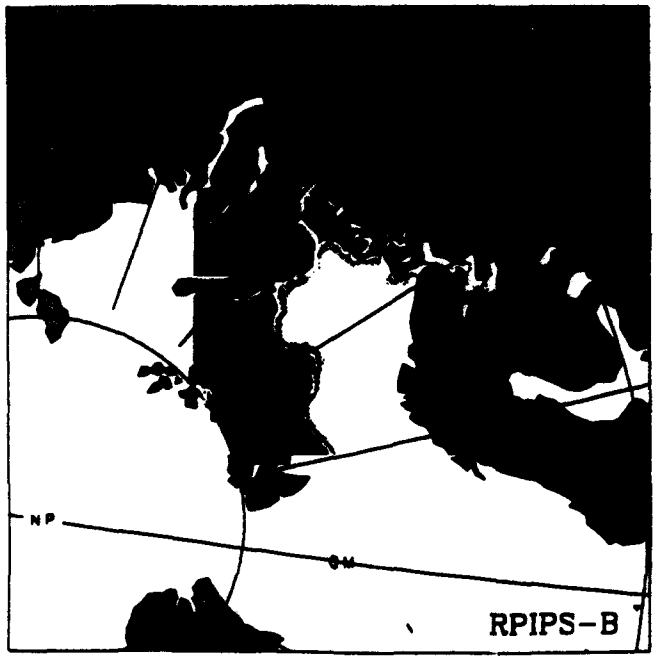

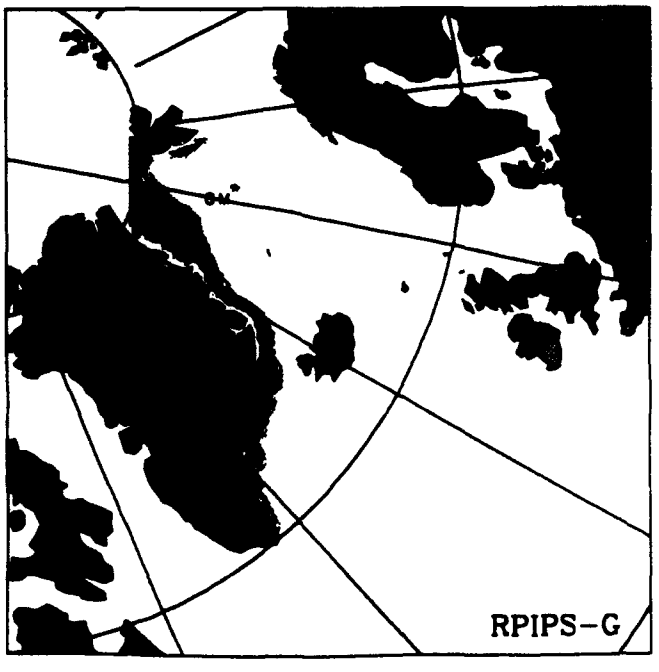

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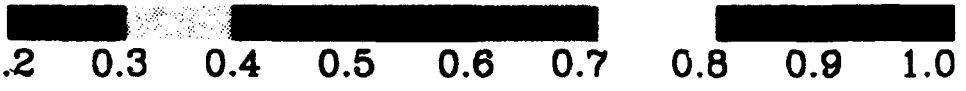

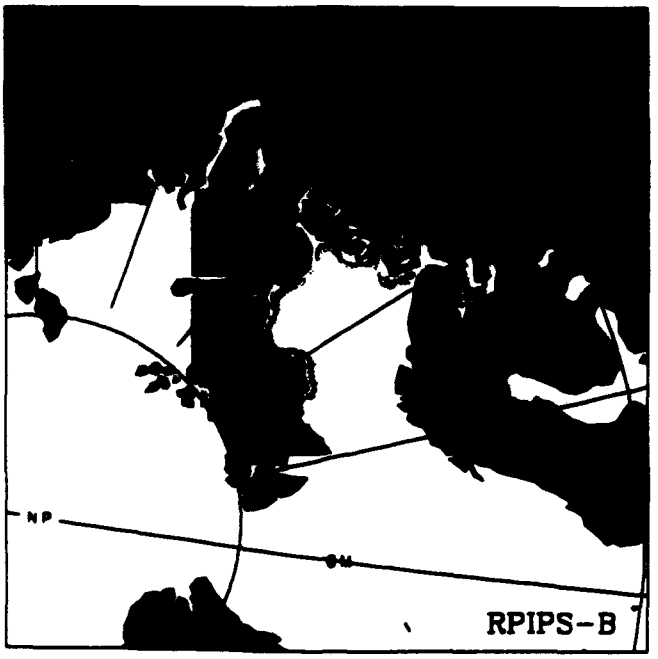

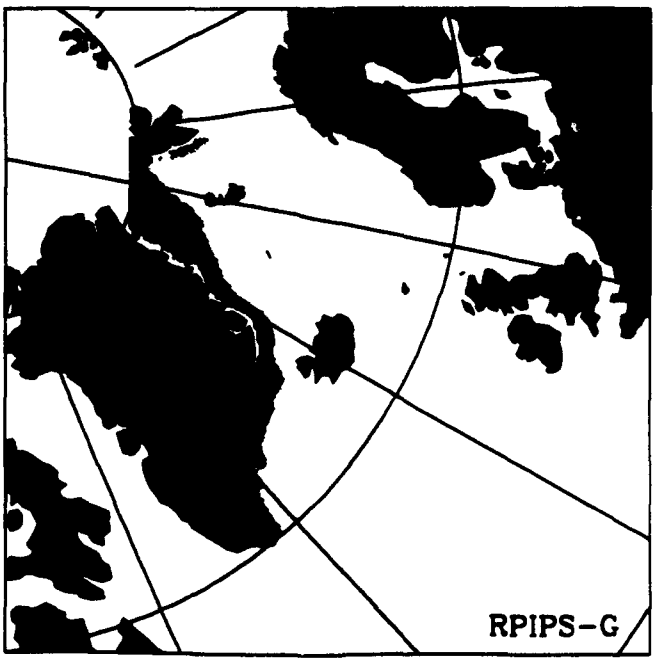

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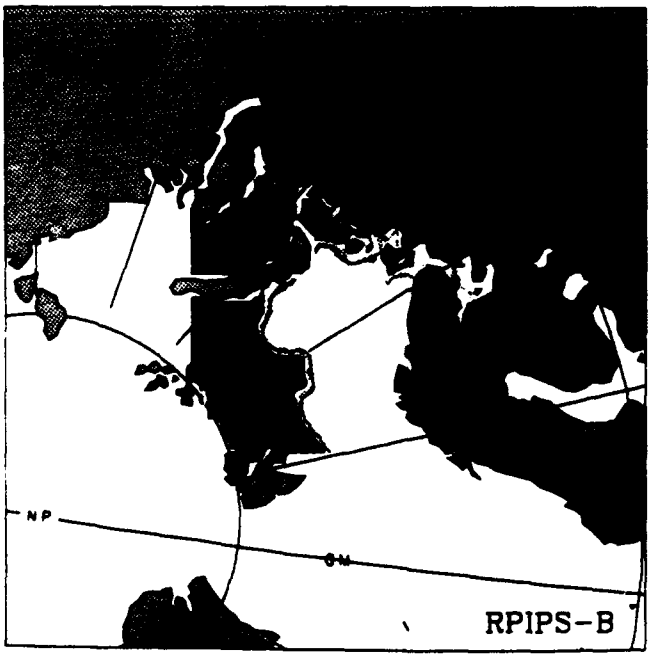

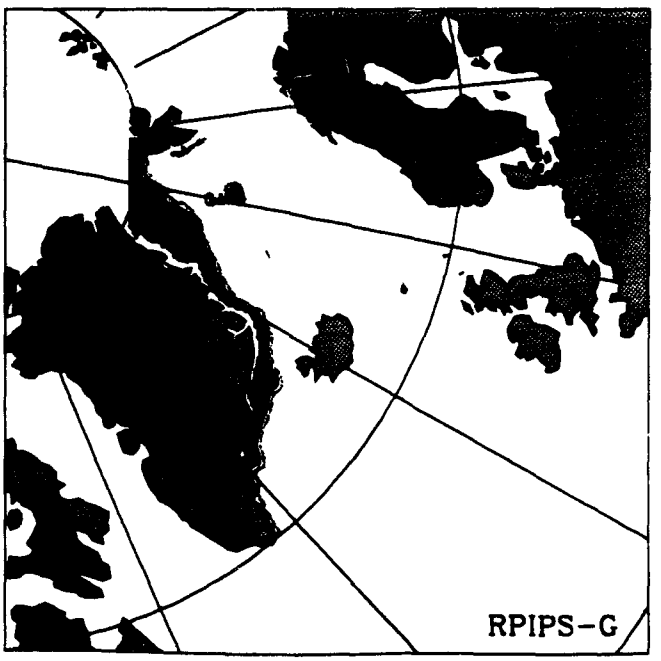

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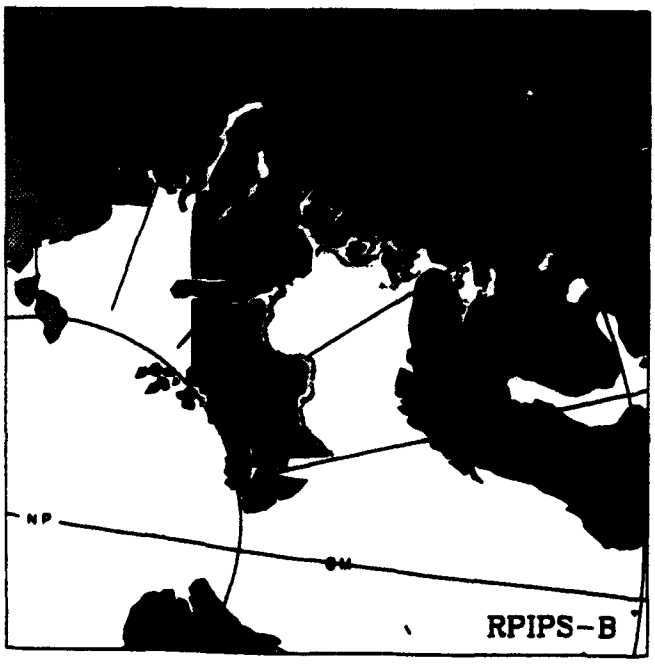

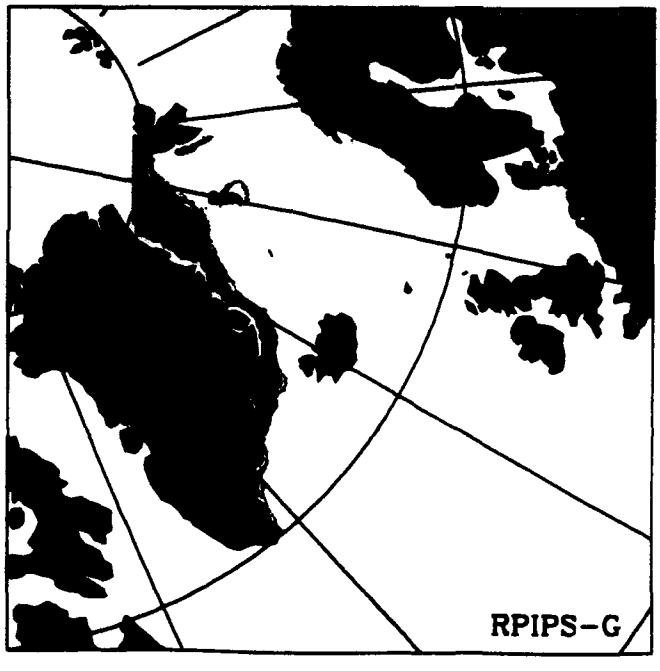

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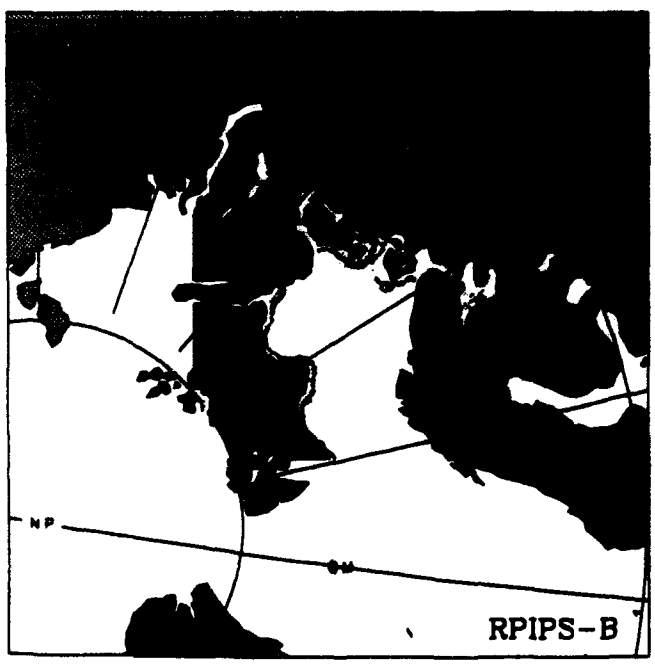

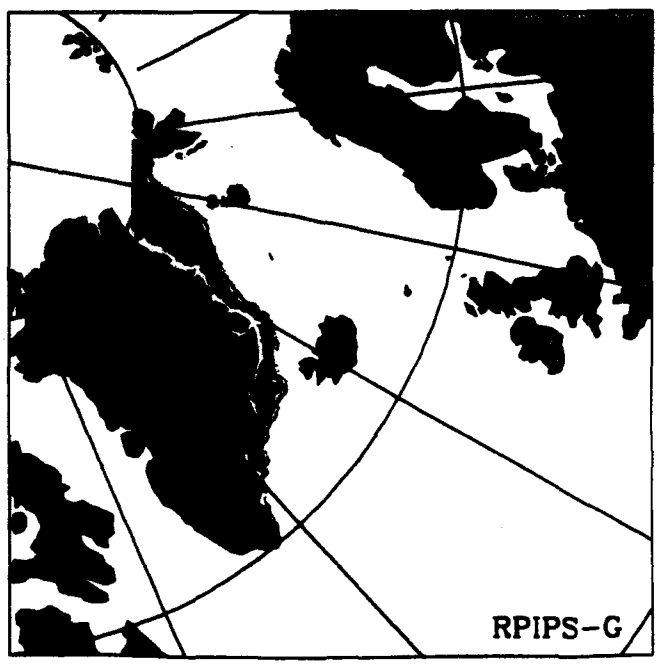

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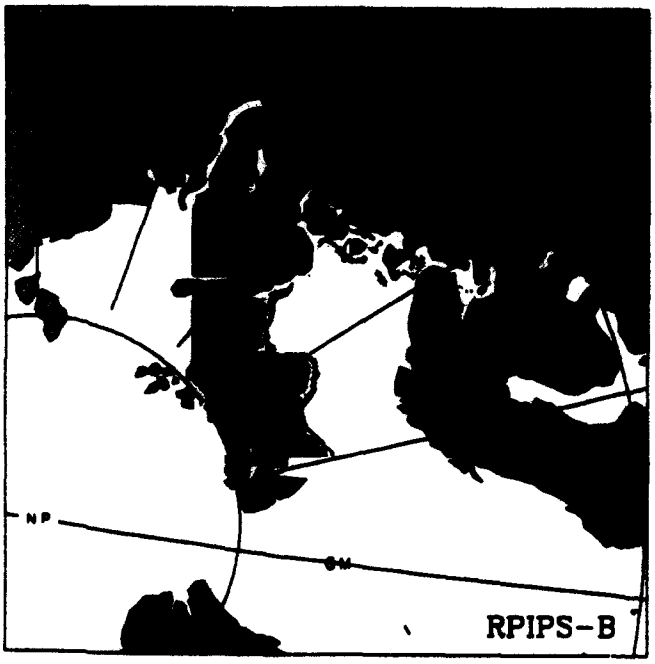

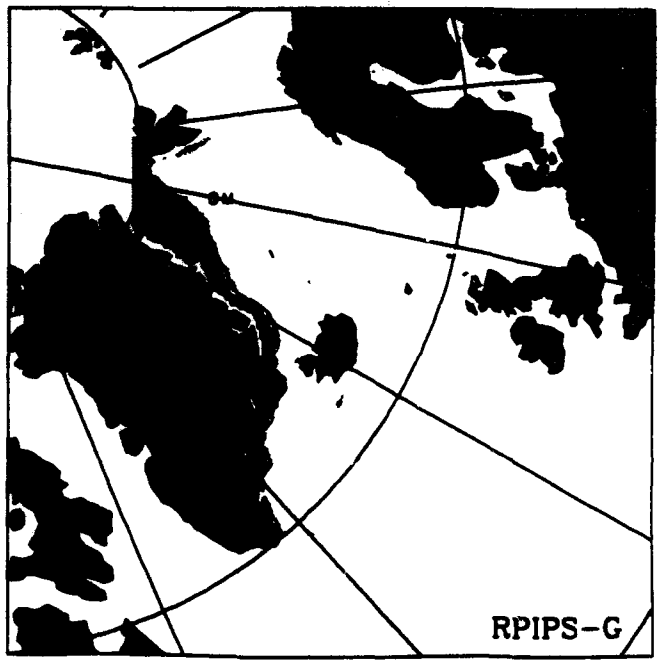

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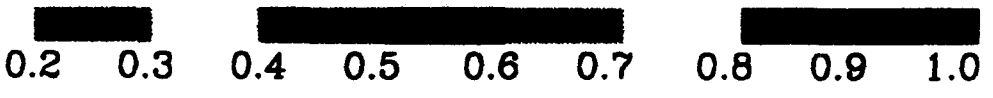

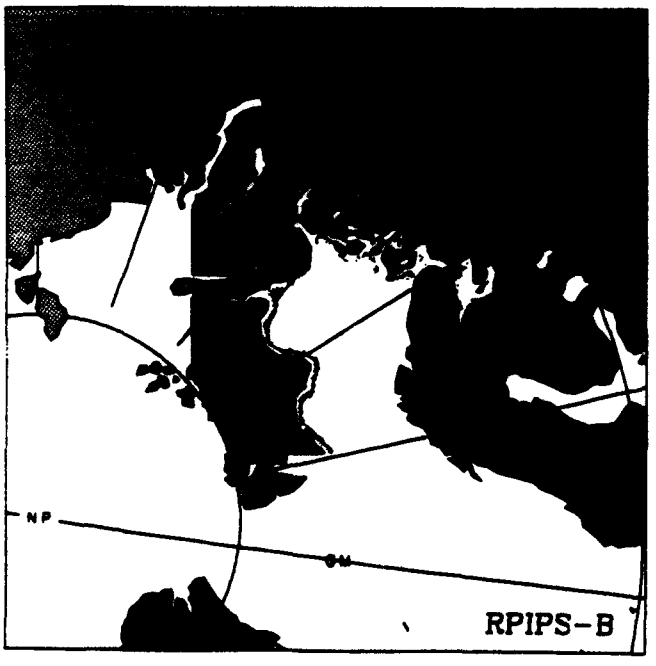

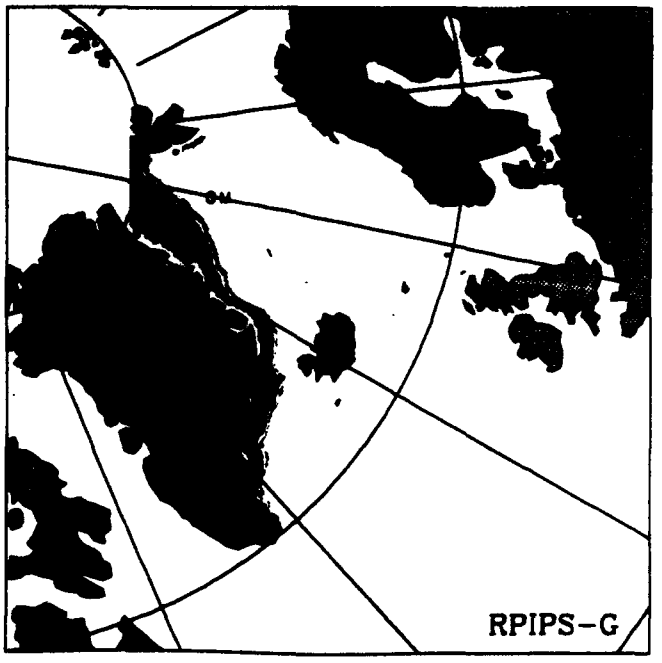

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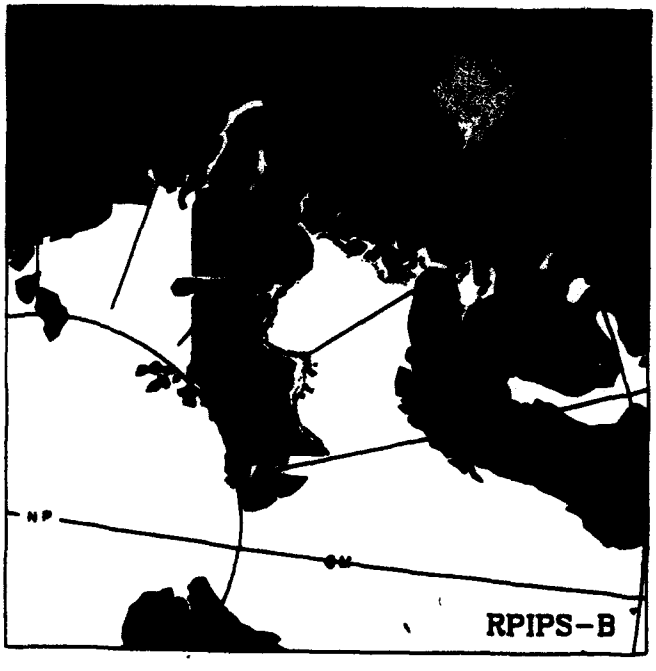

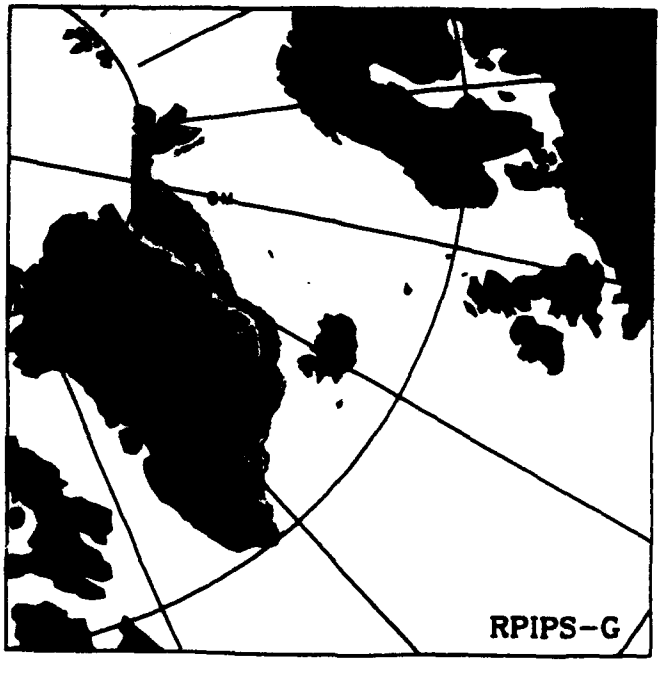

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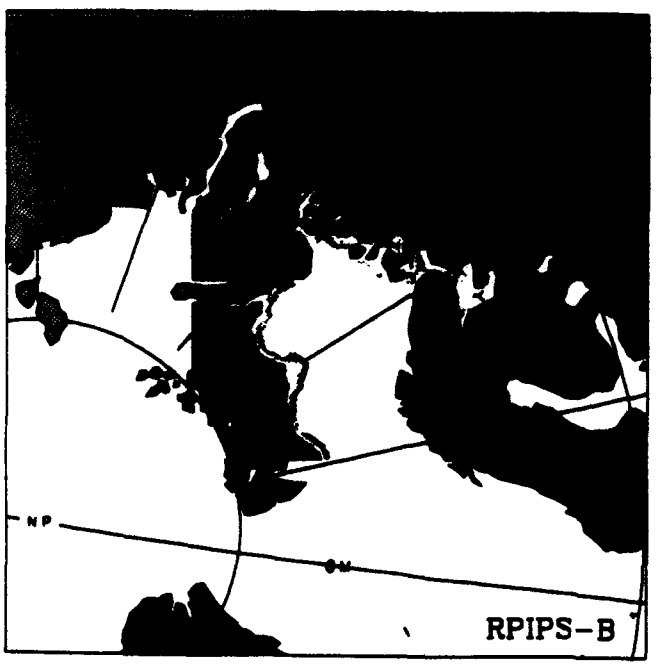

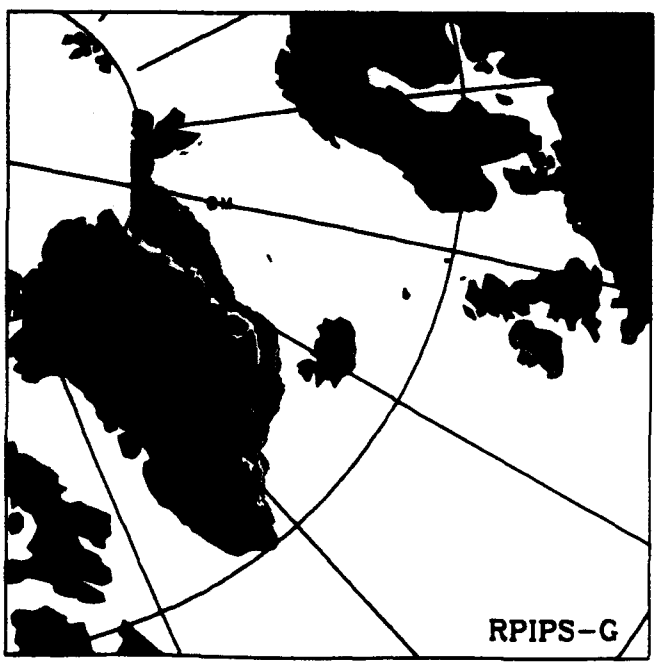

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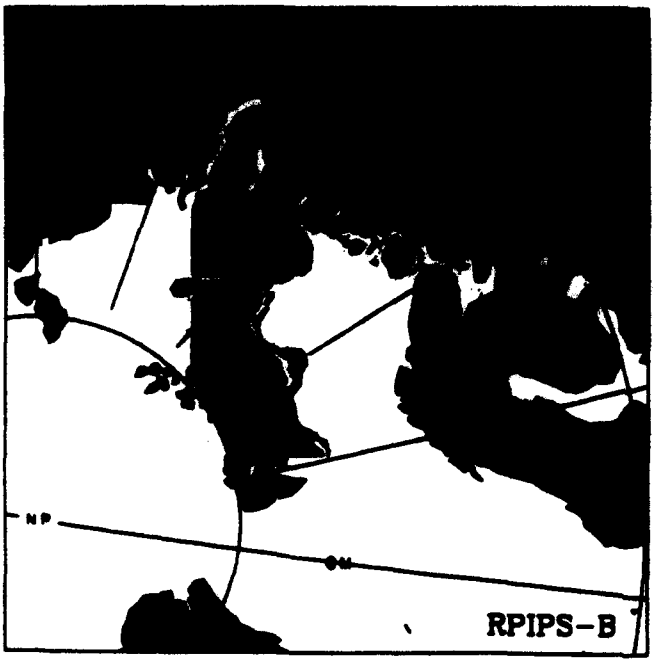

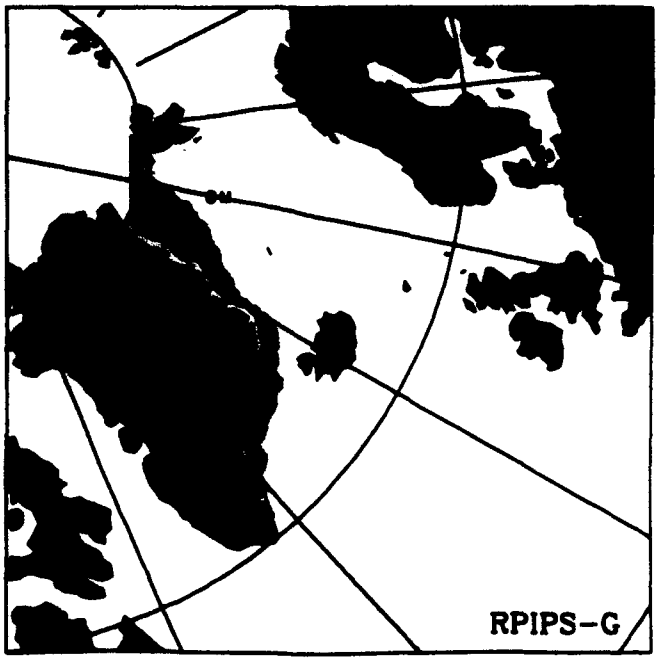

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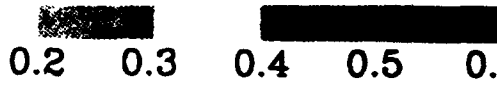

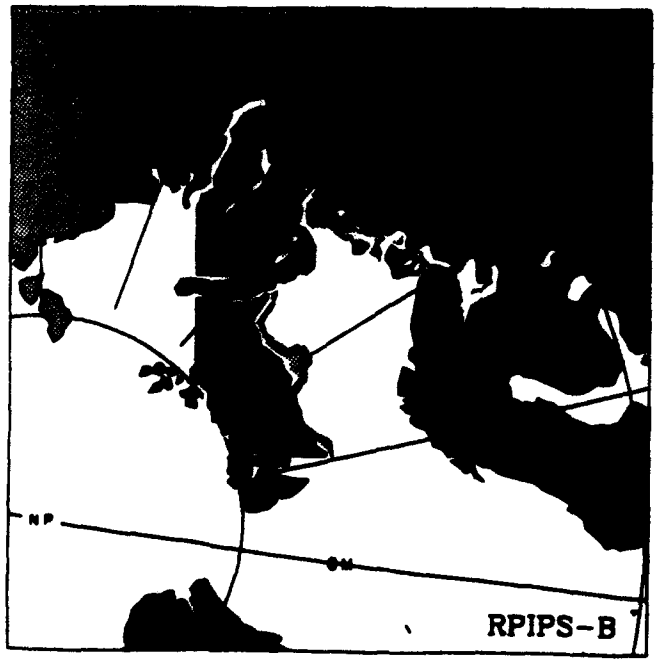

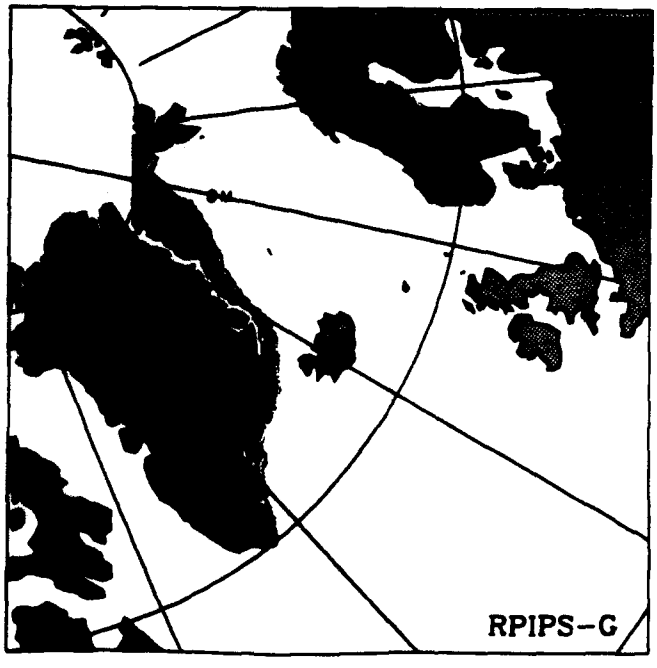

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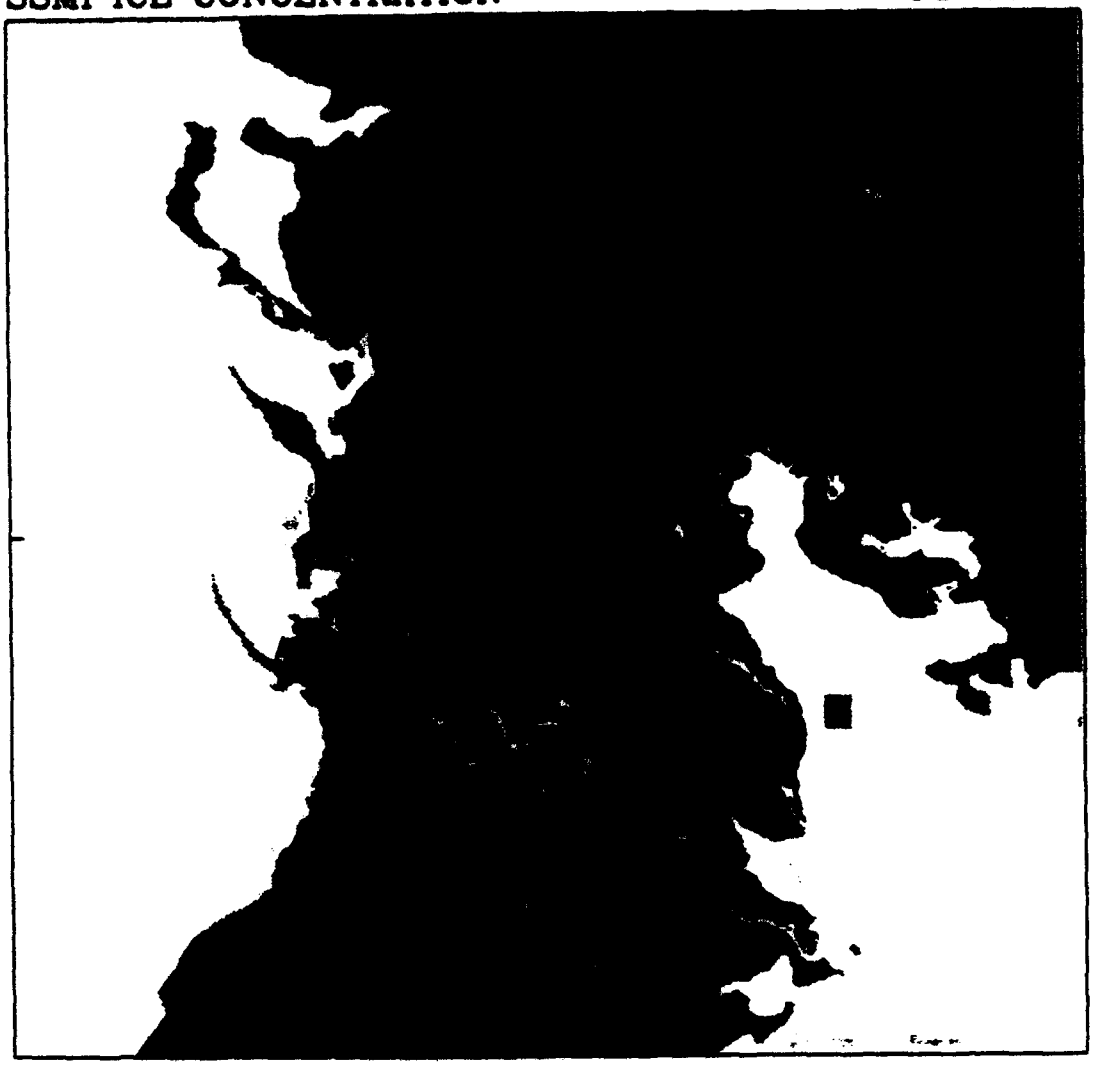

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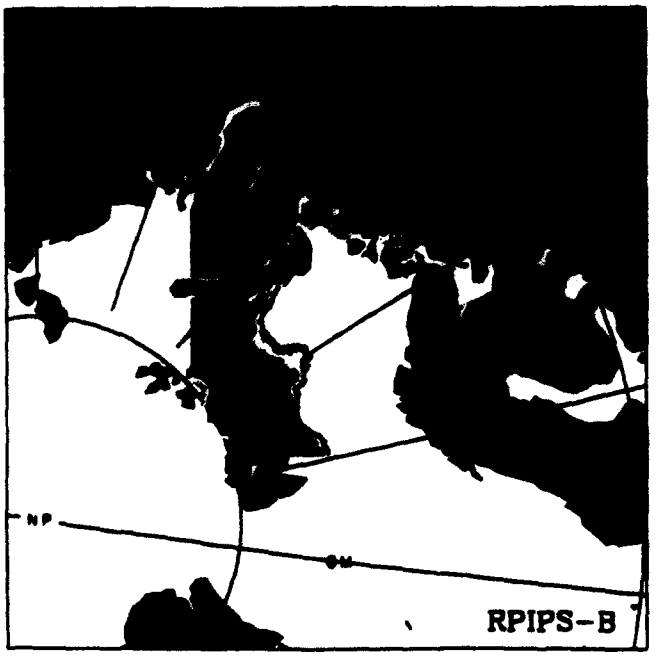

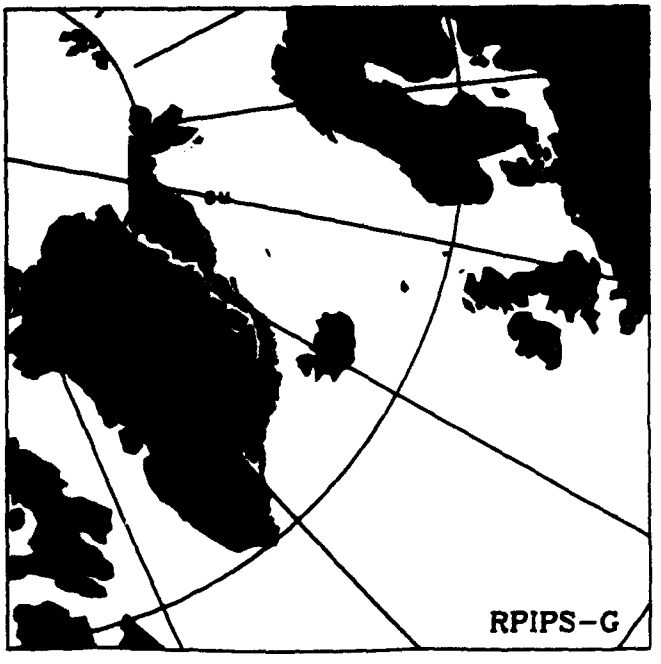

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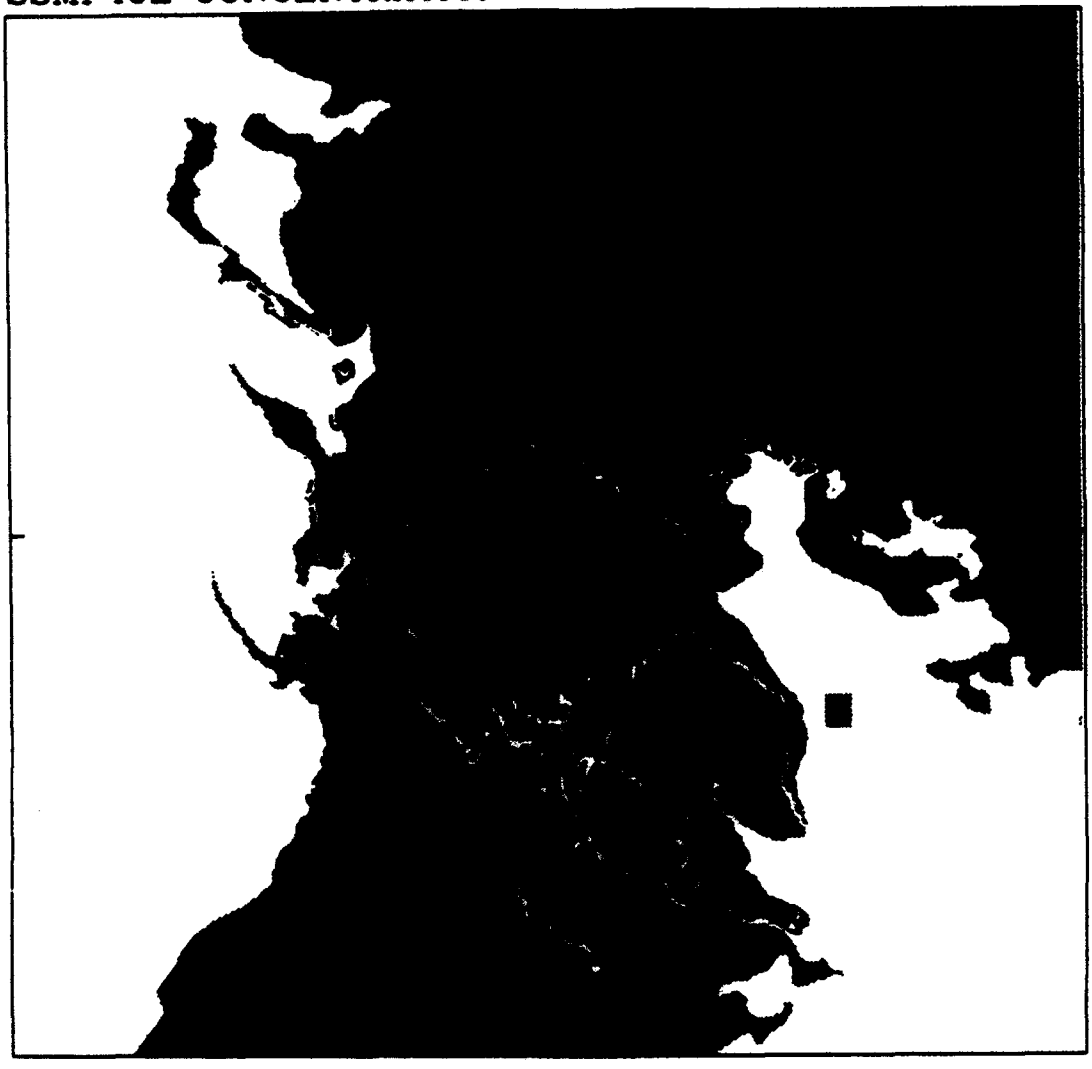

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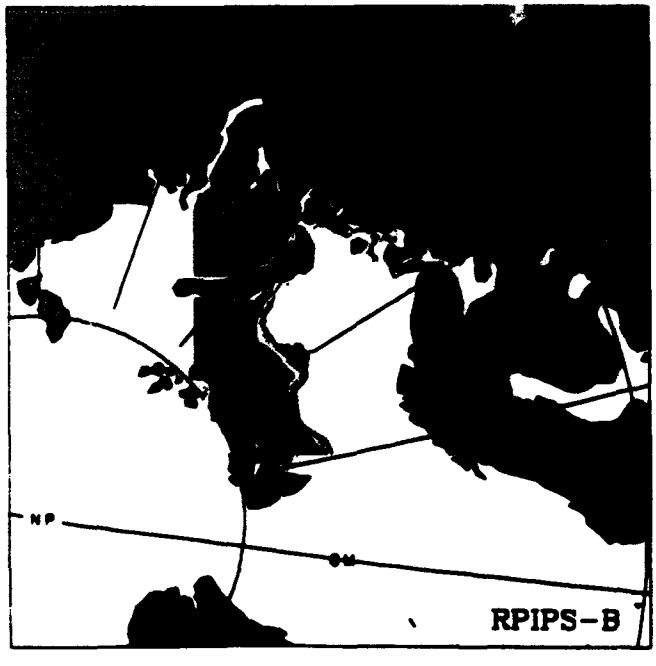

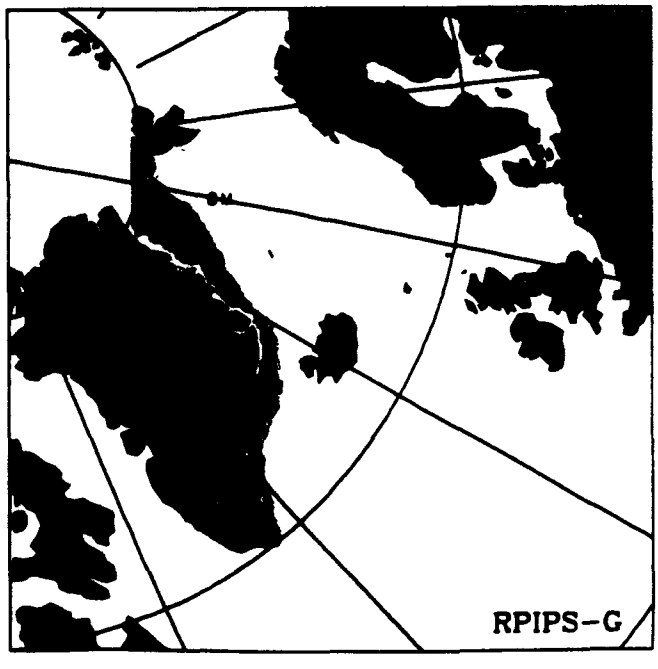

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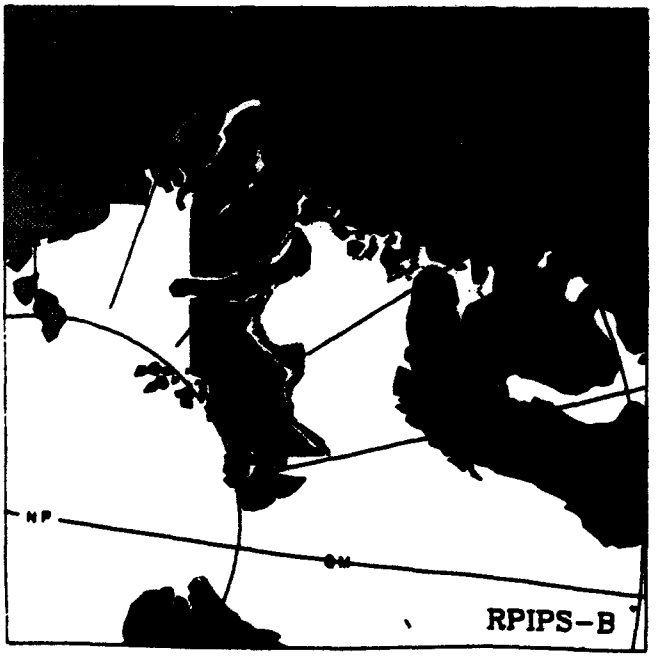

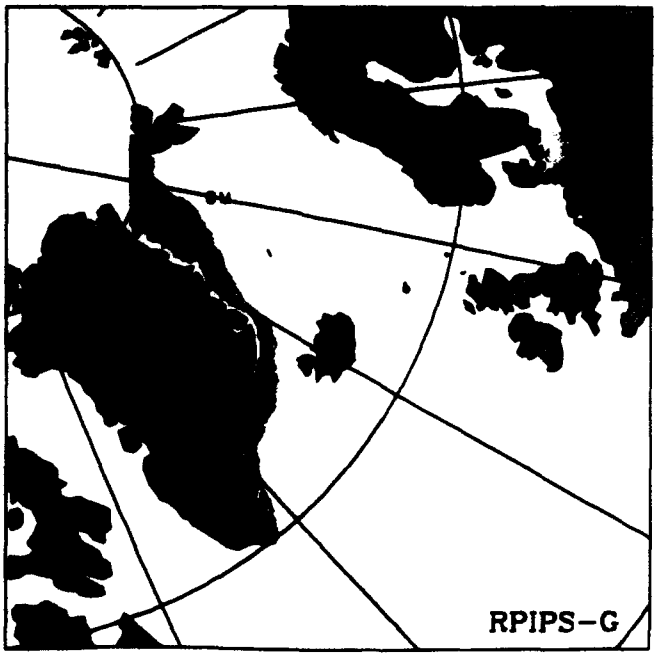

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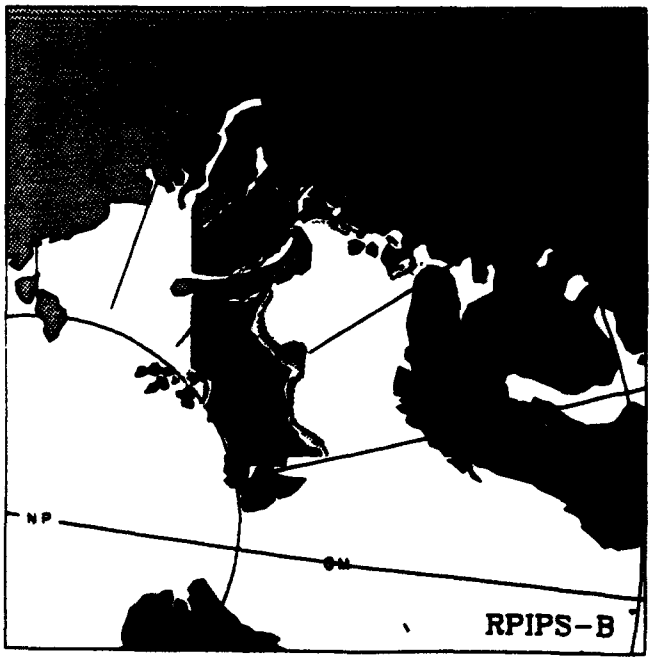

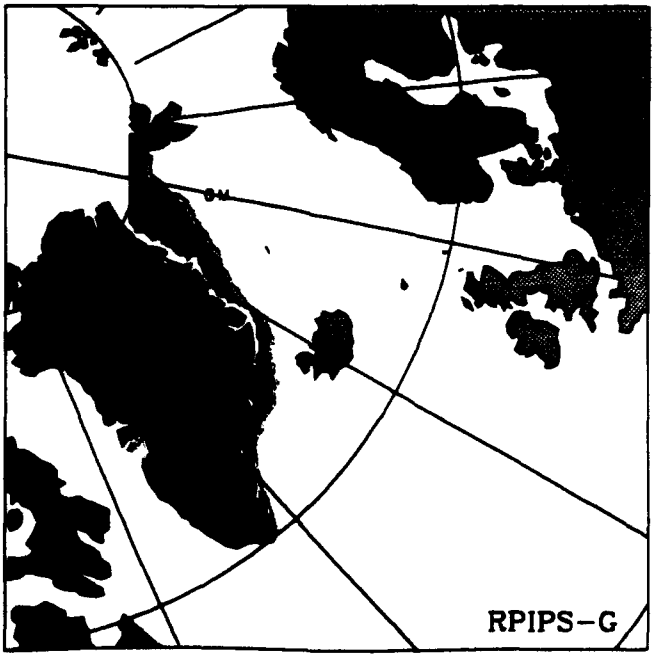

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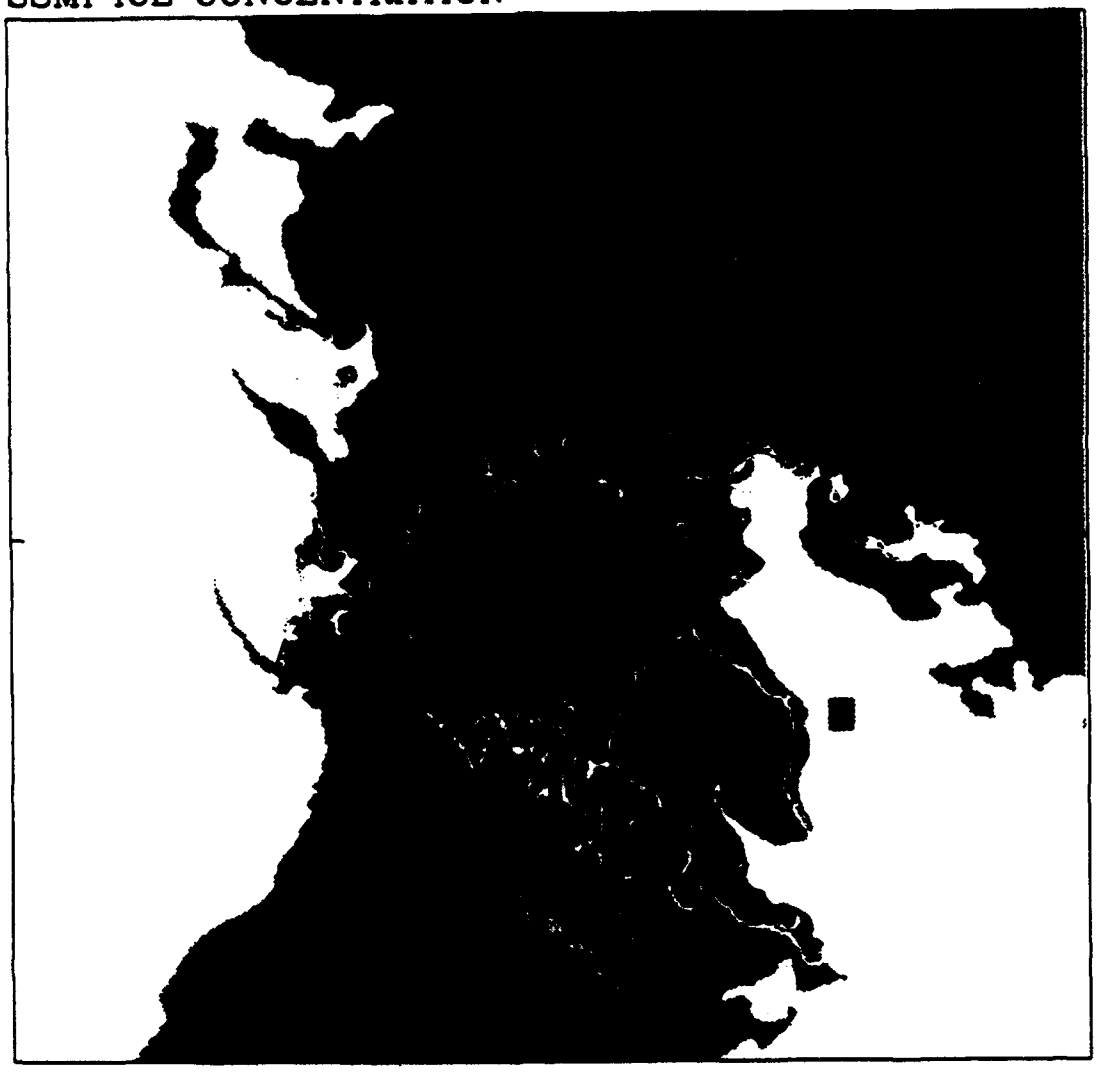

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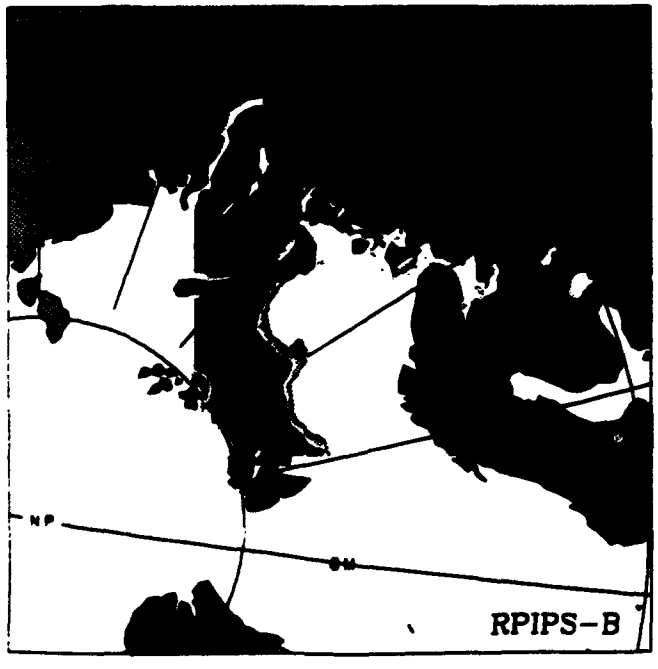

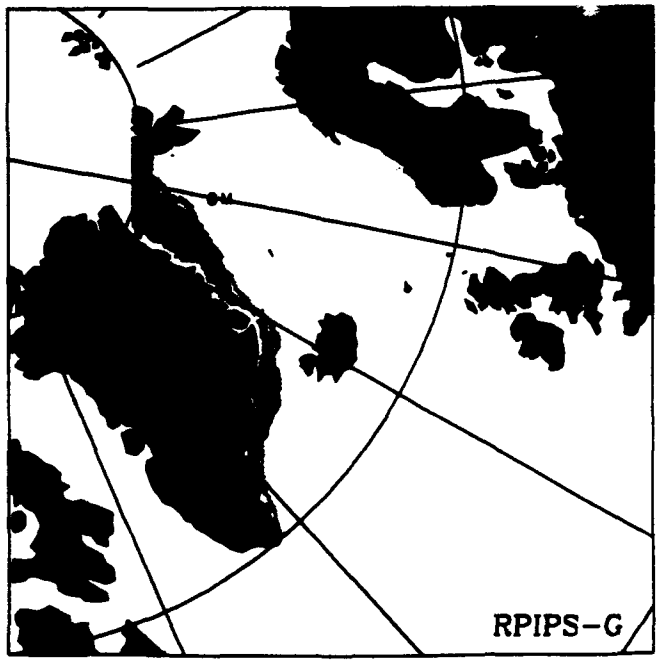

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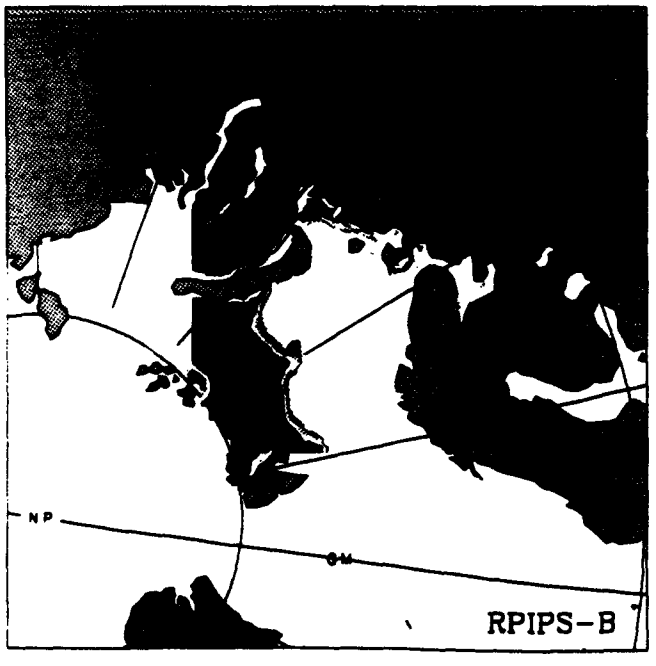

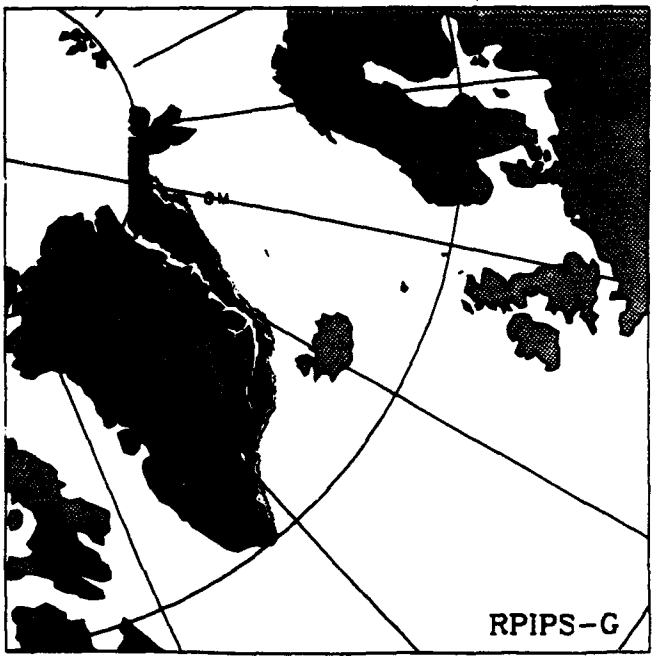

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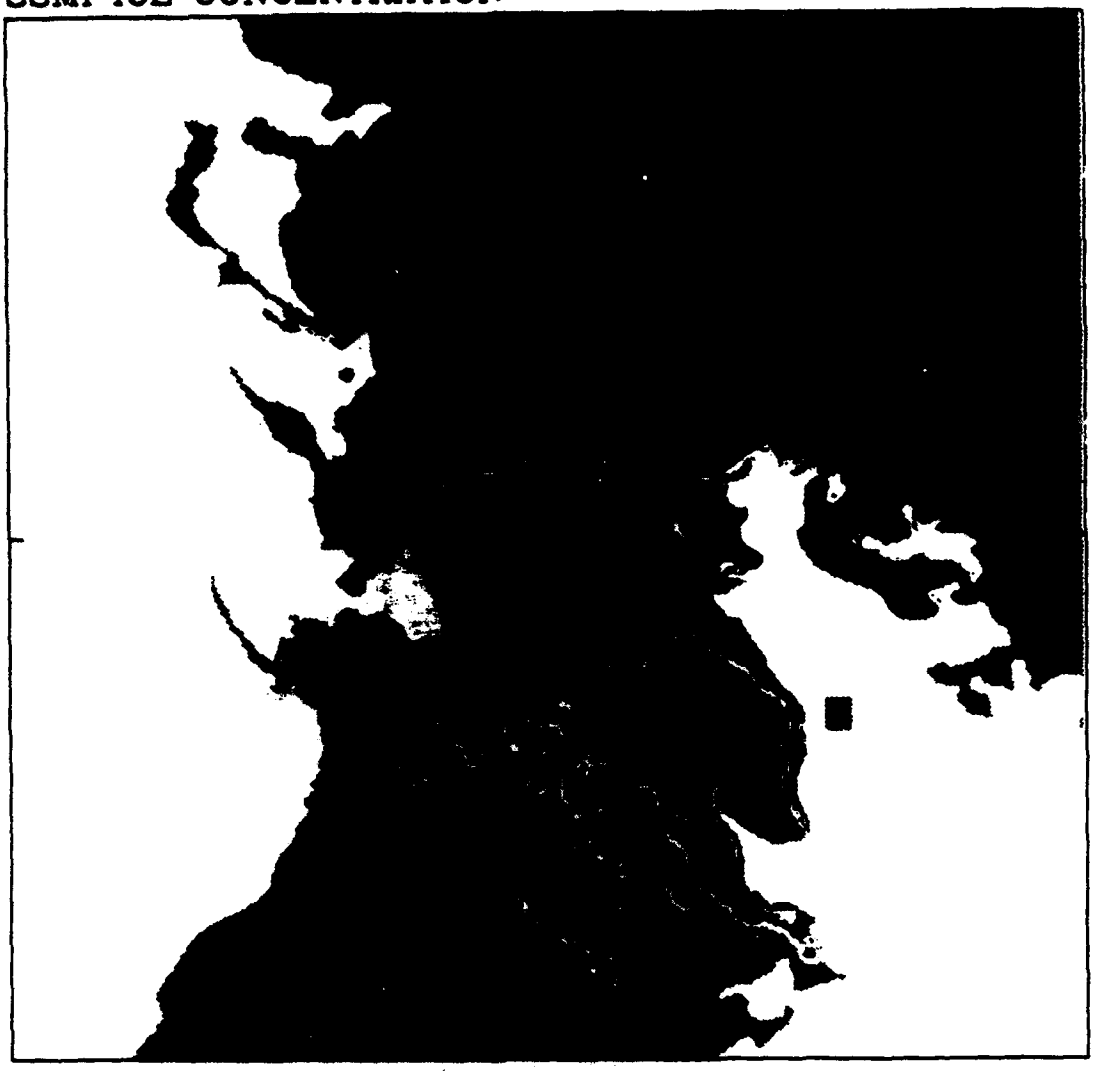

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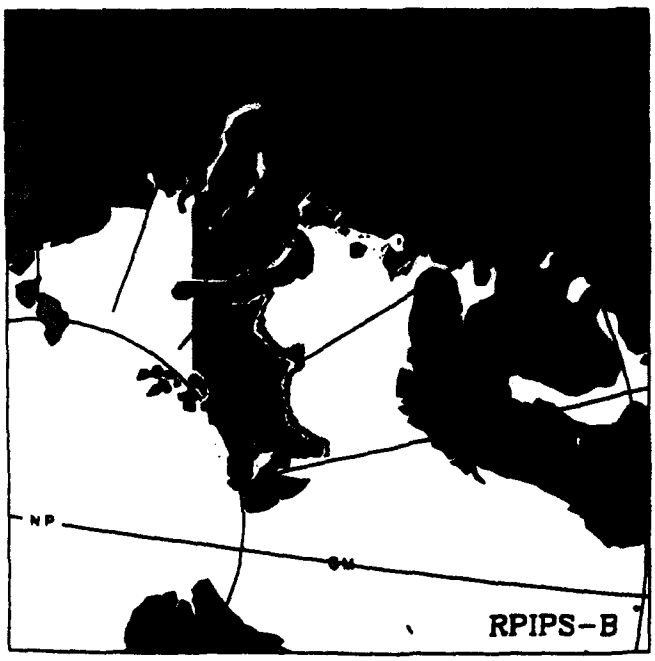

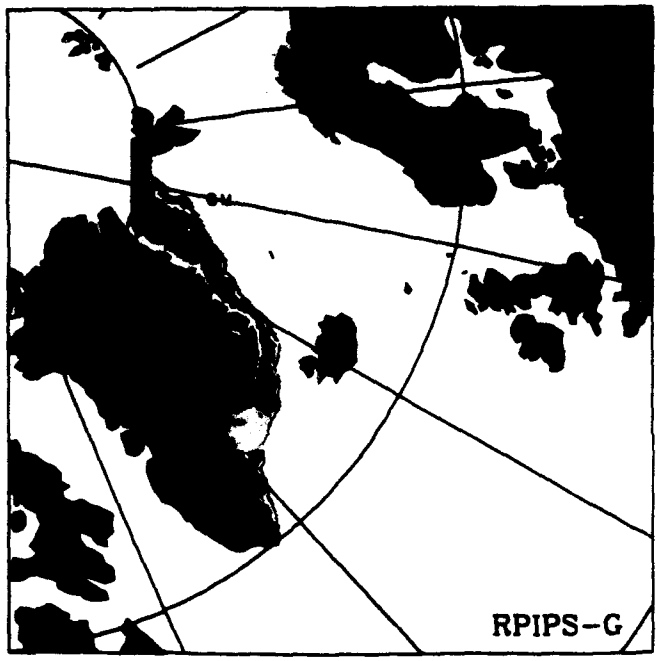

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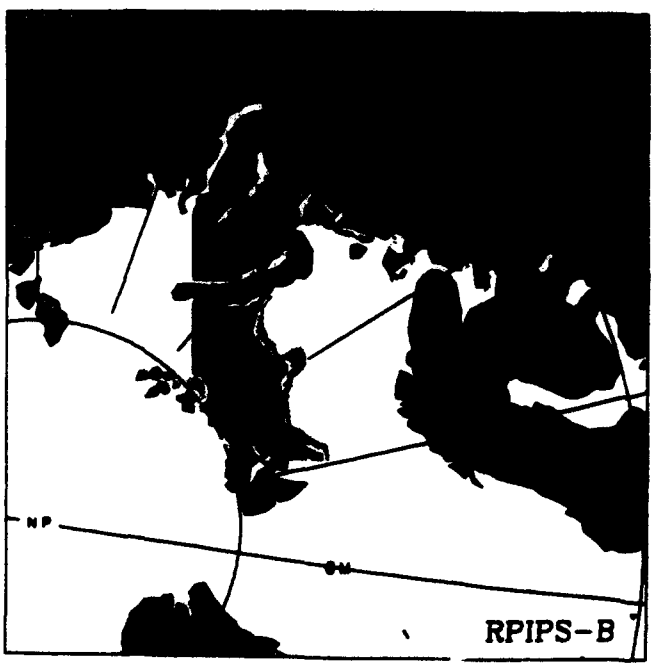

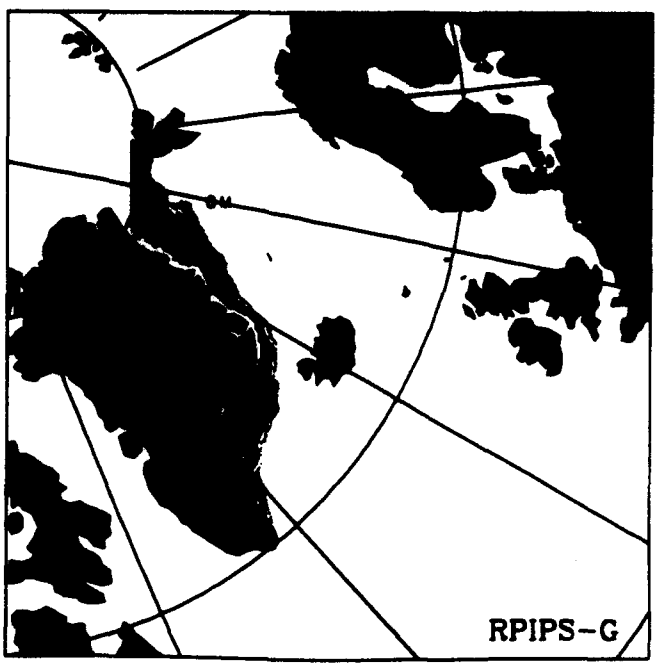

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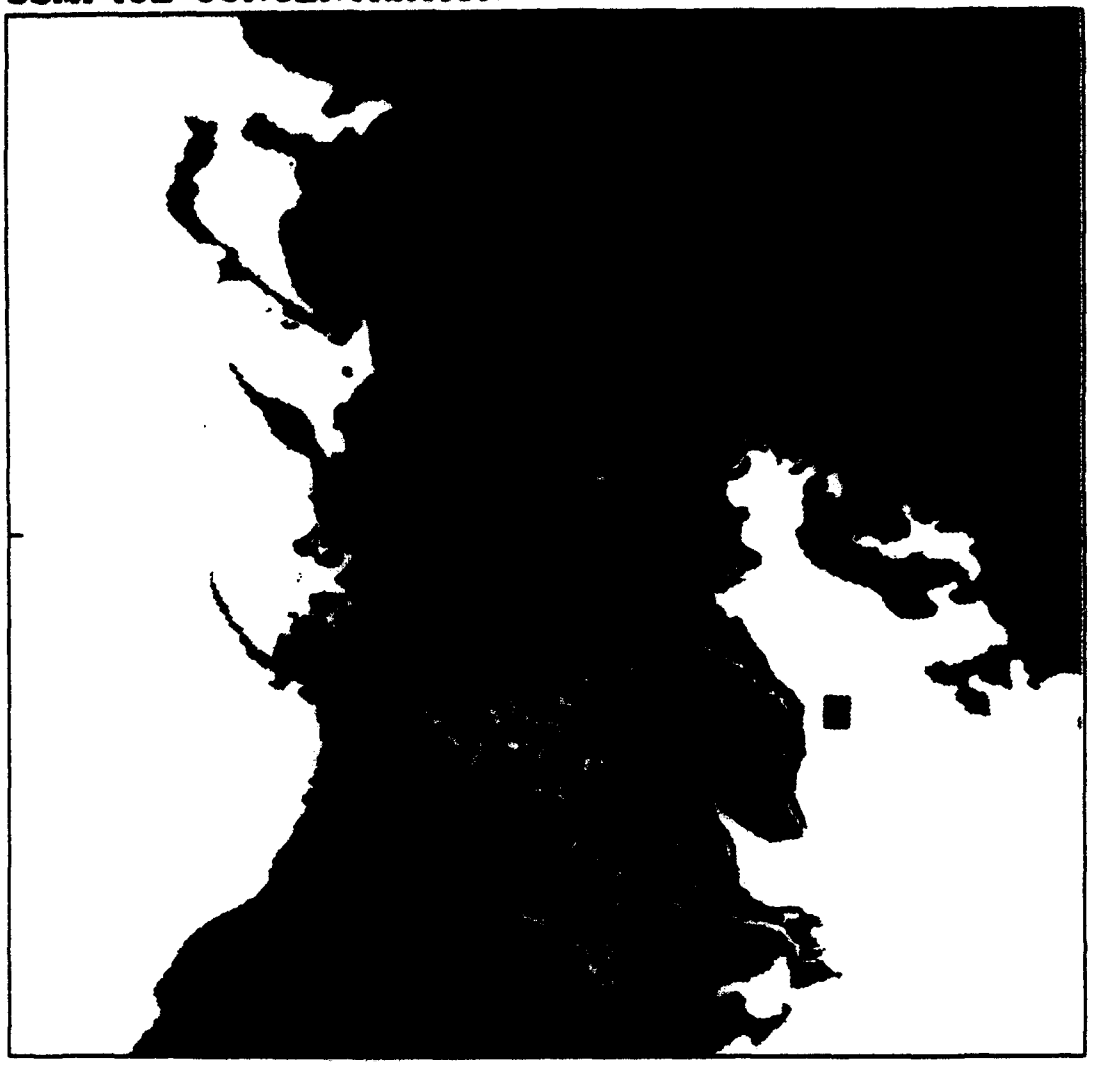

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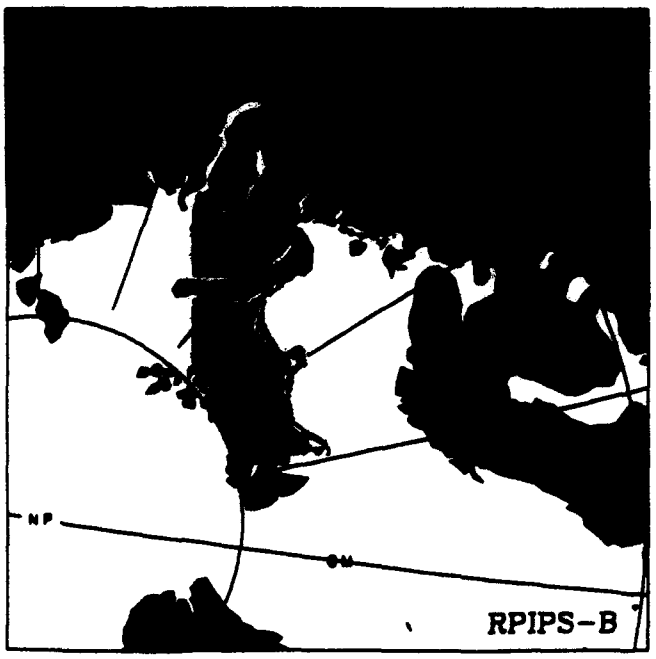

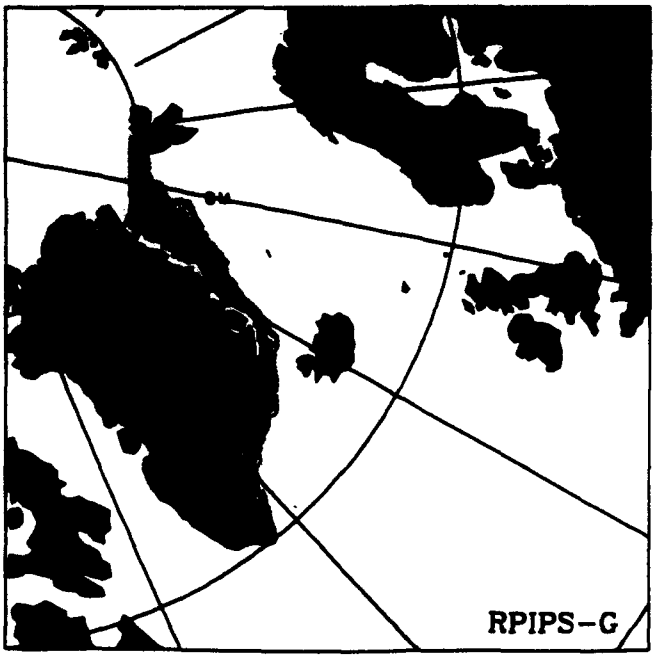

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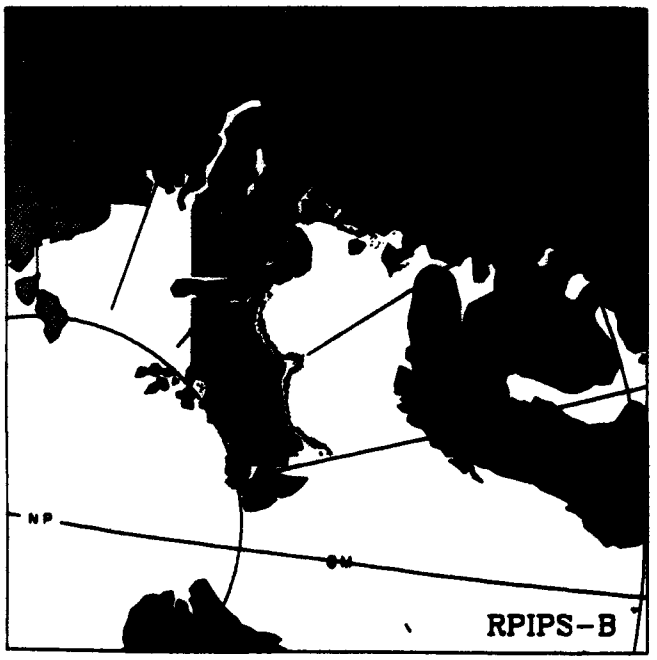
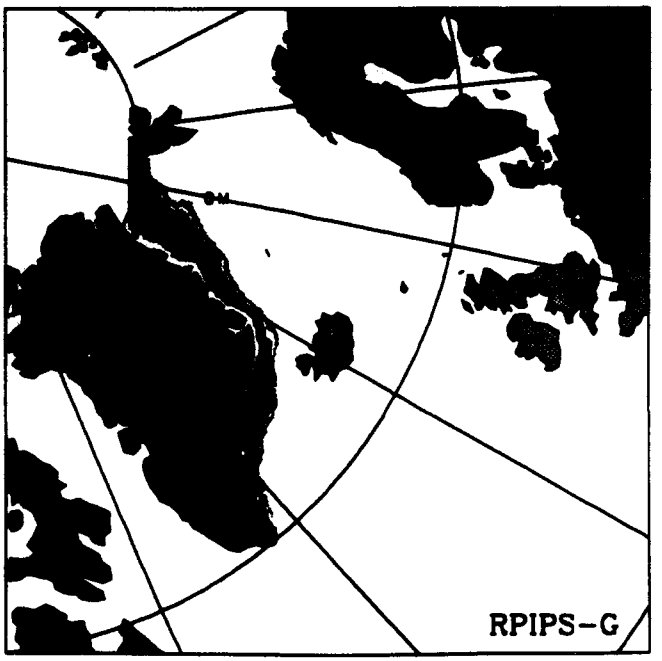
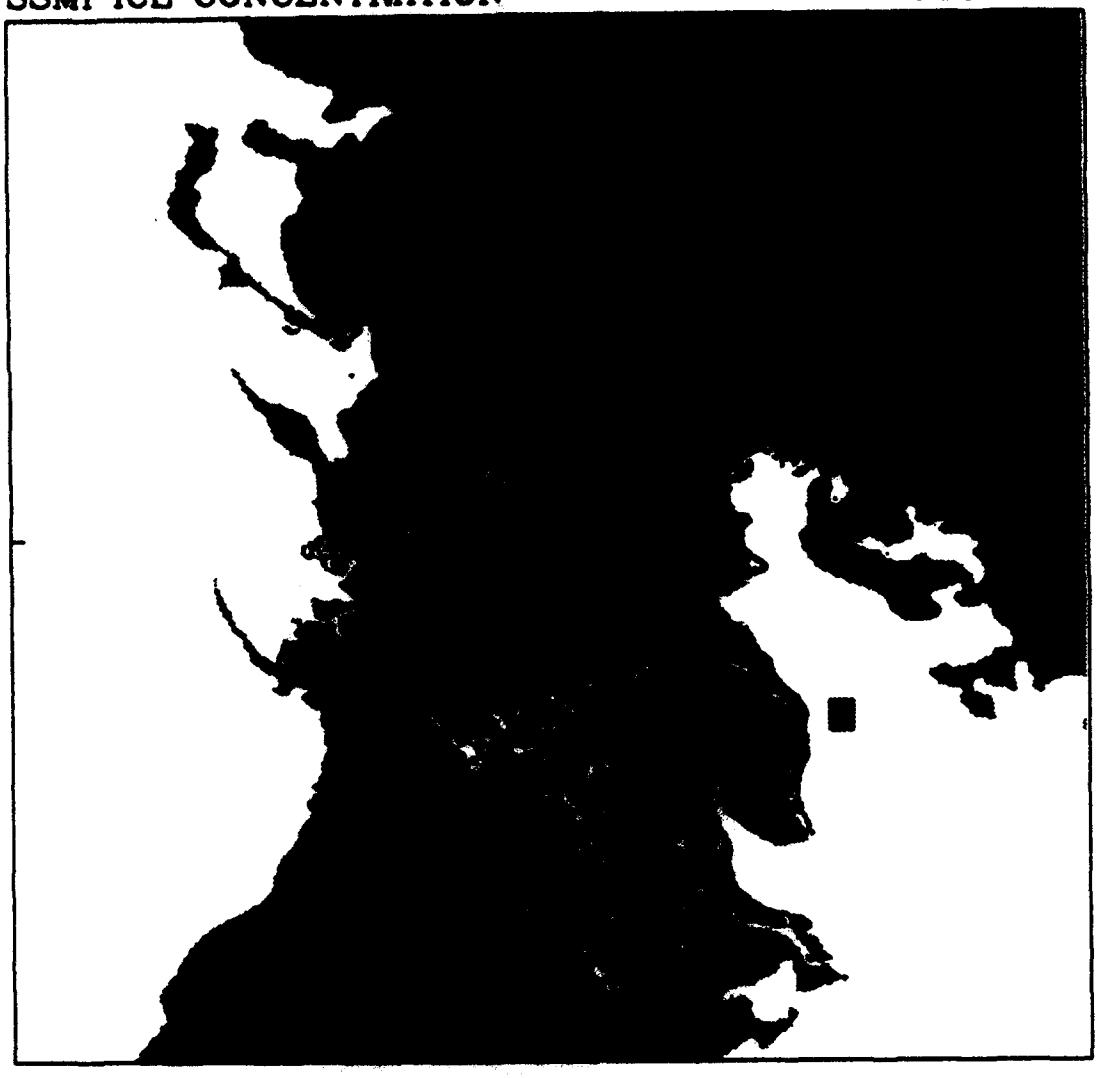




SSMI ICE CONCENTRATION 93051300



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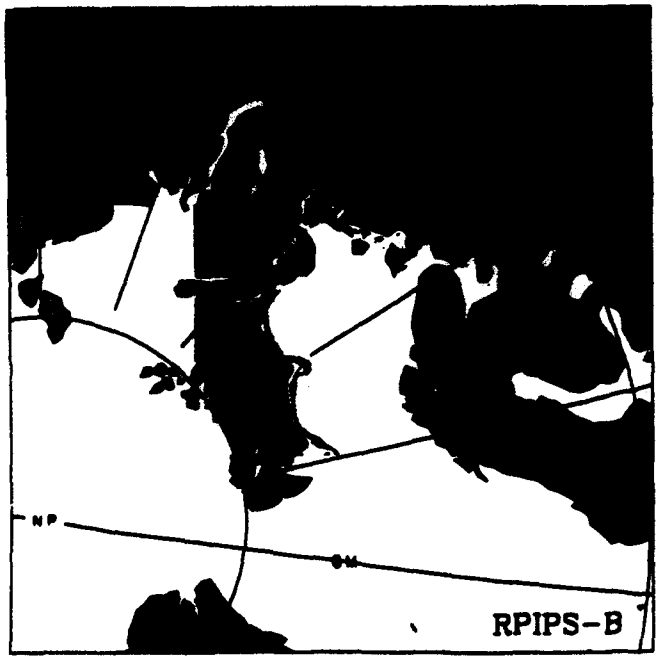

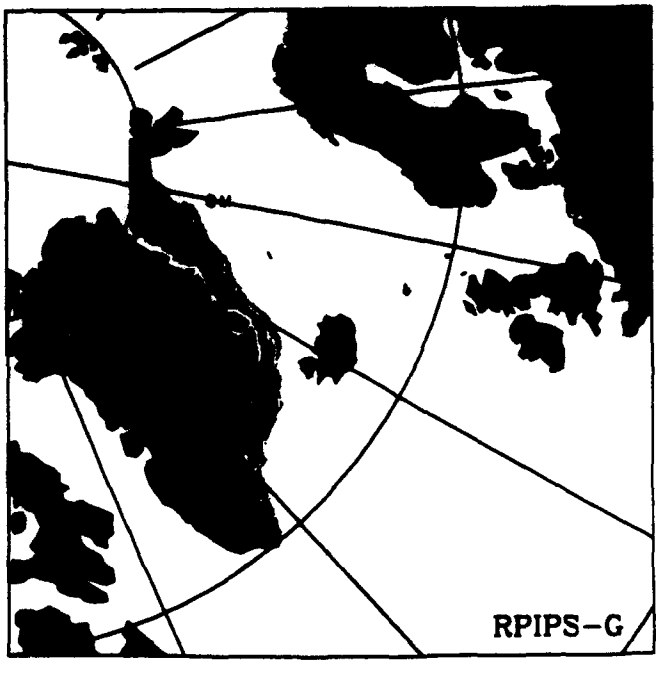

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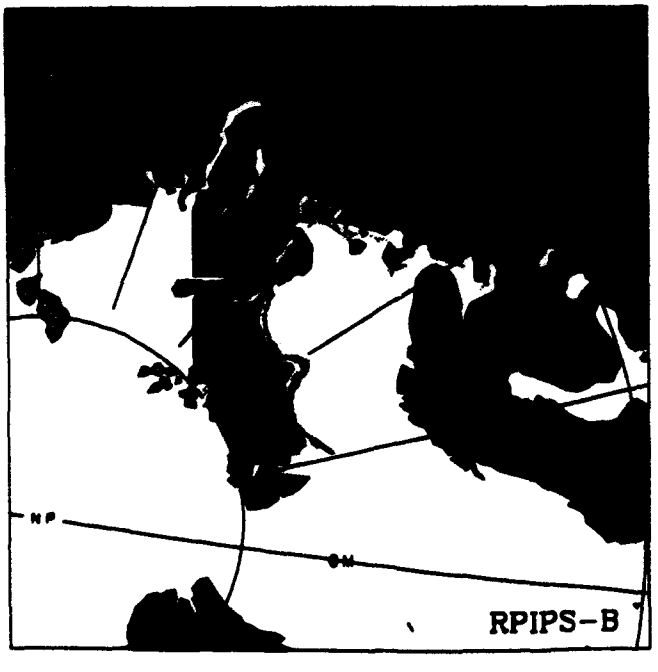

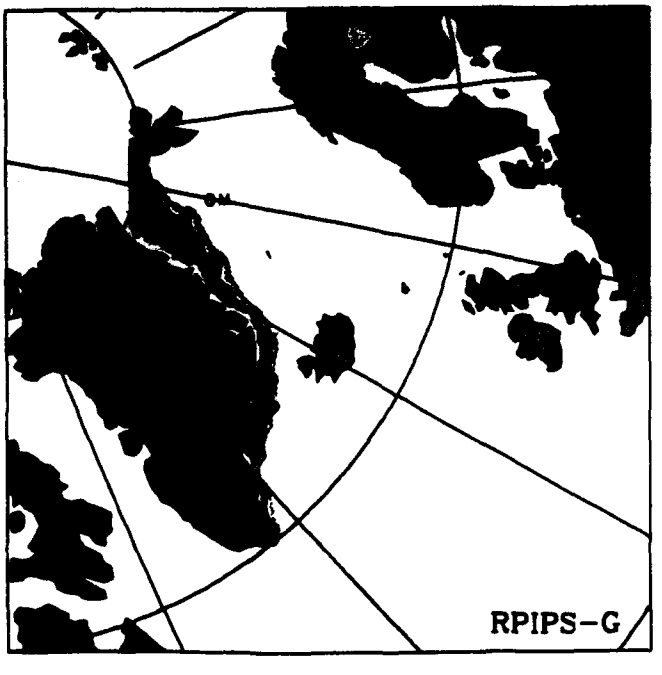

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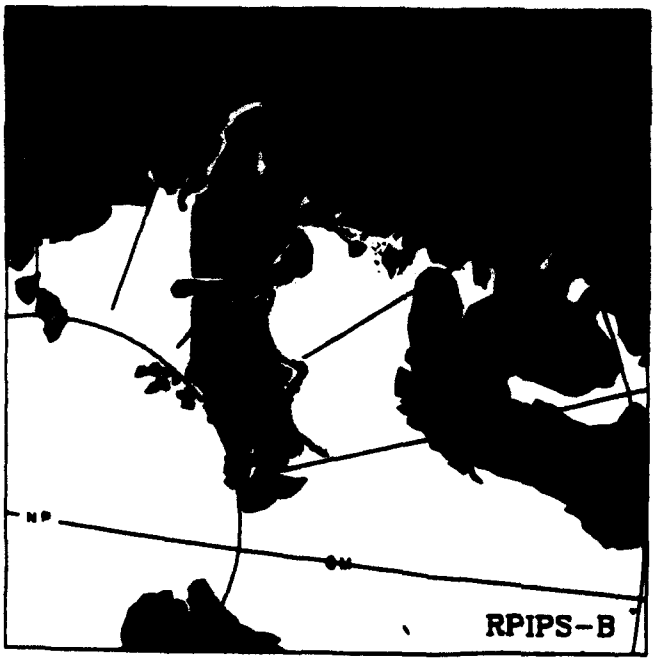

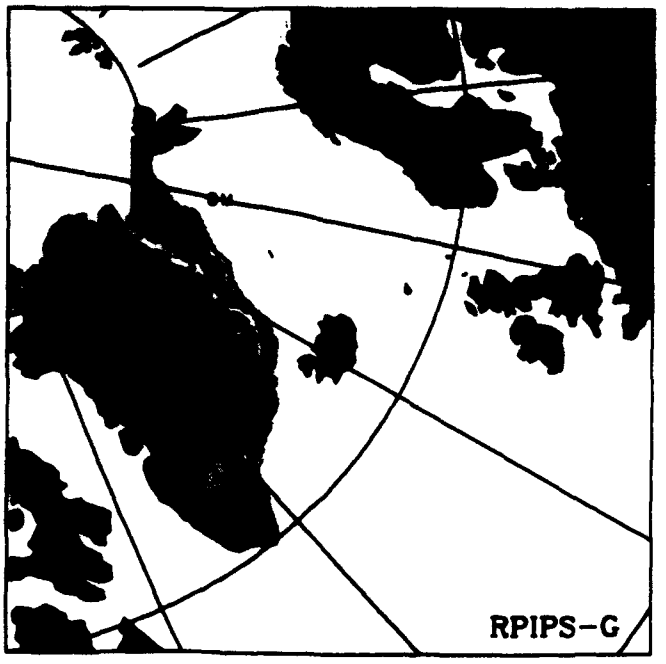

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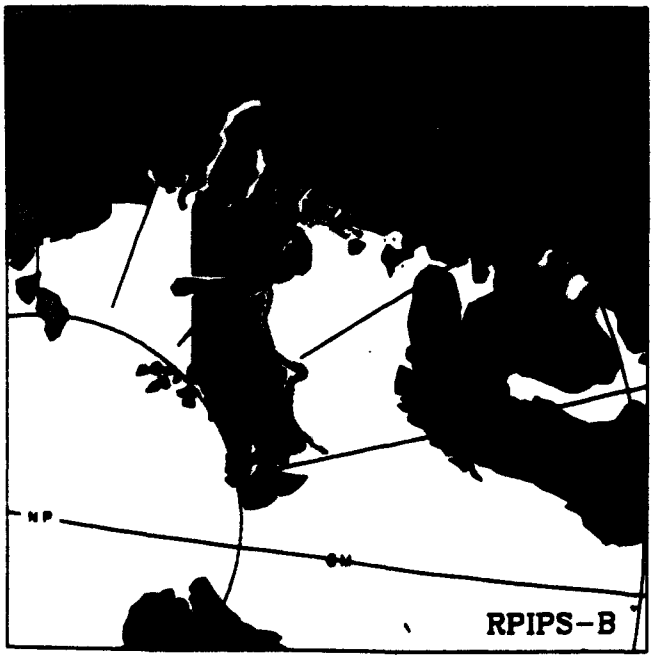

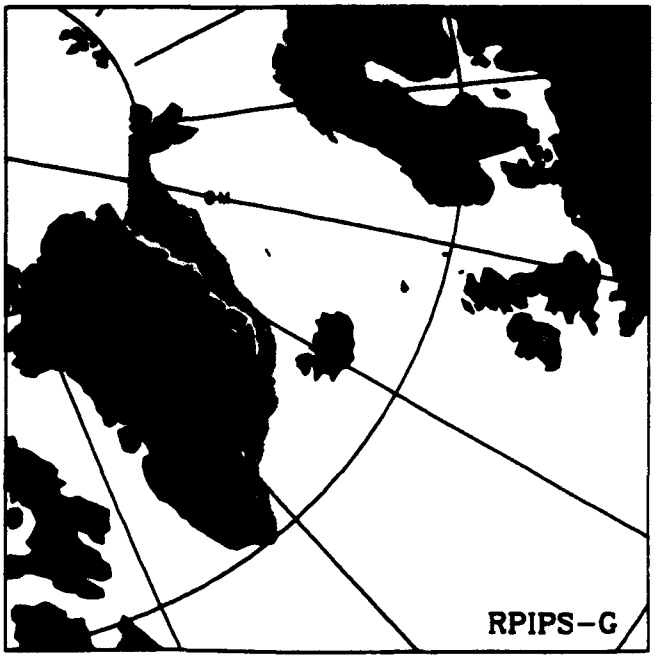

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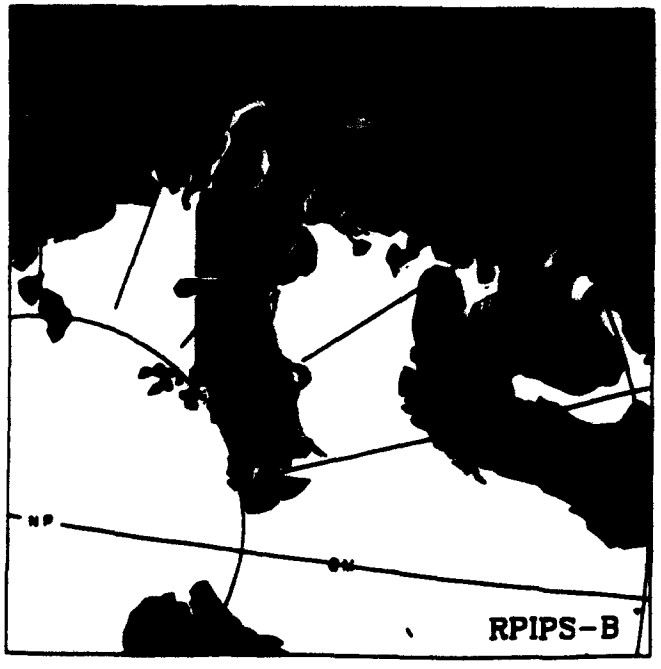

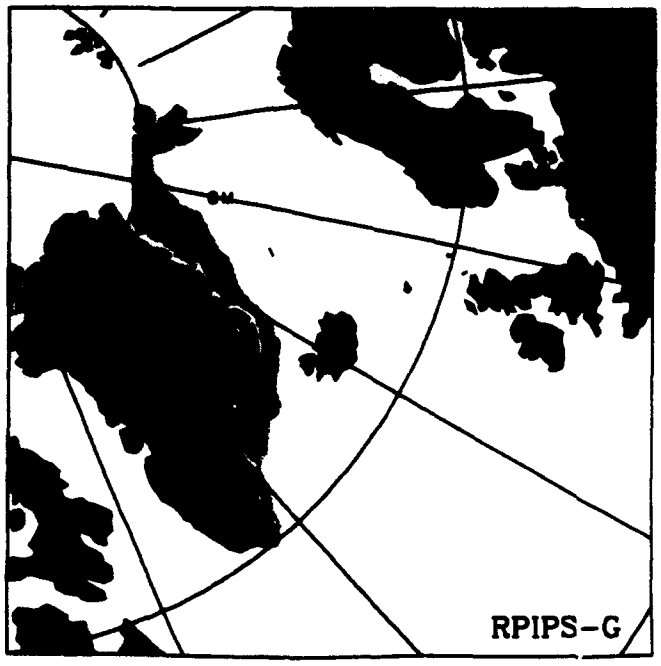

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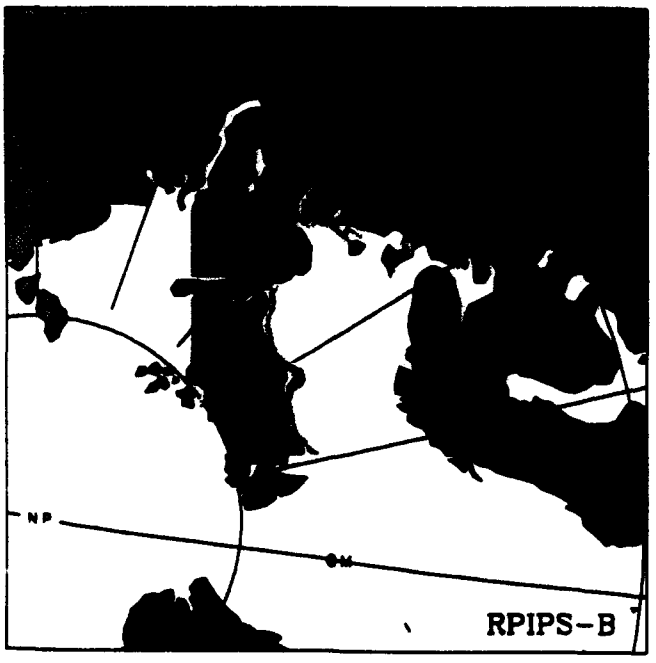

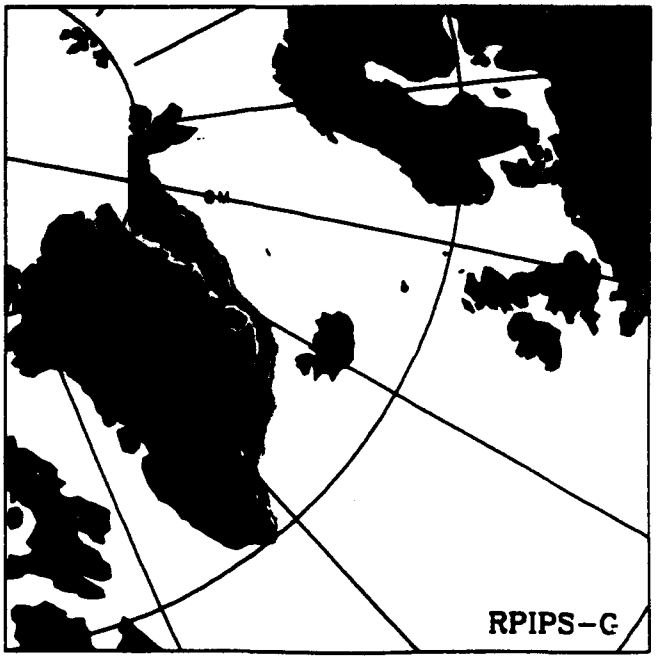

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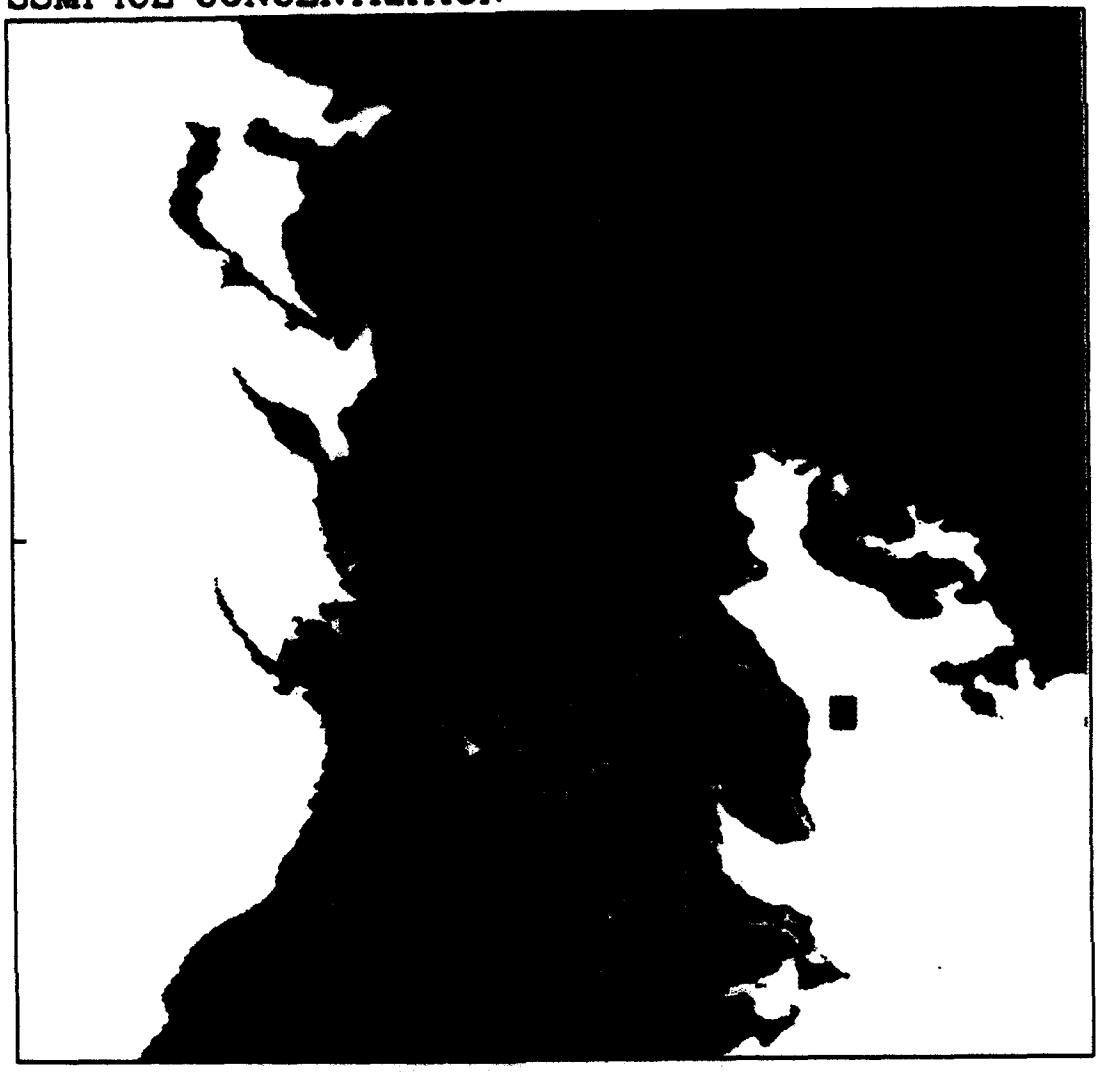

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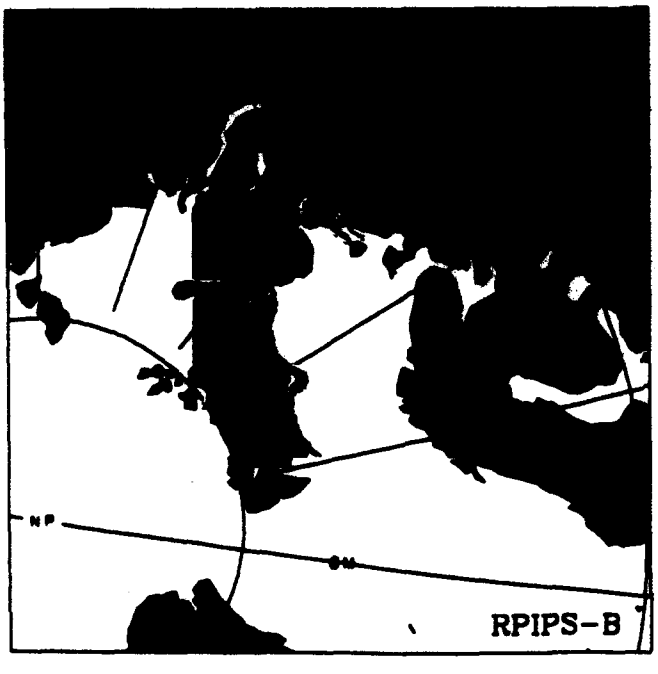

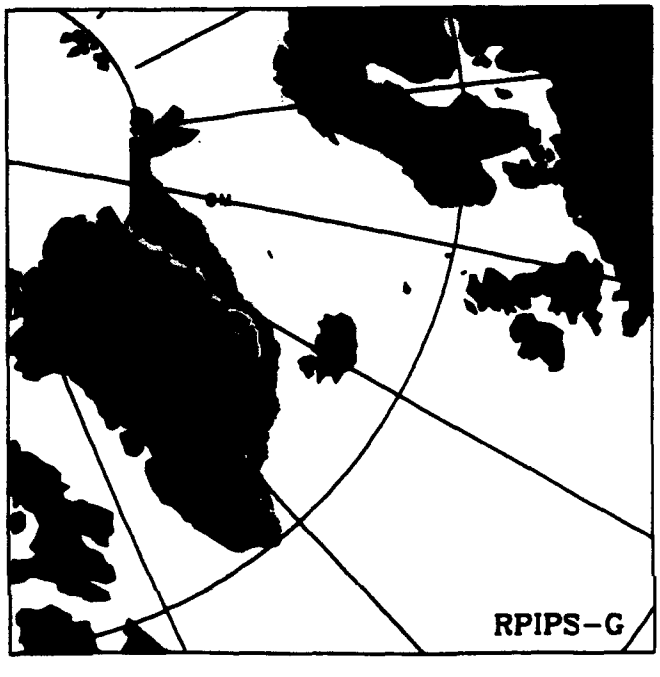

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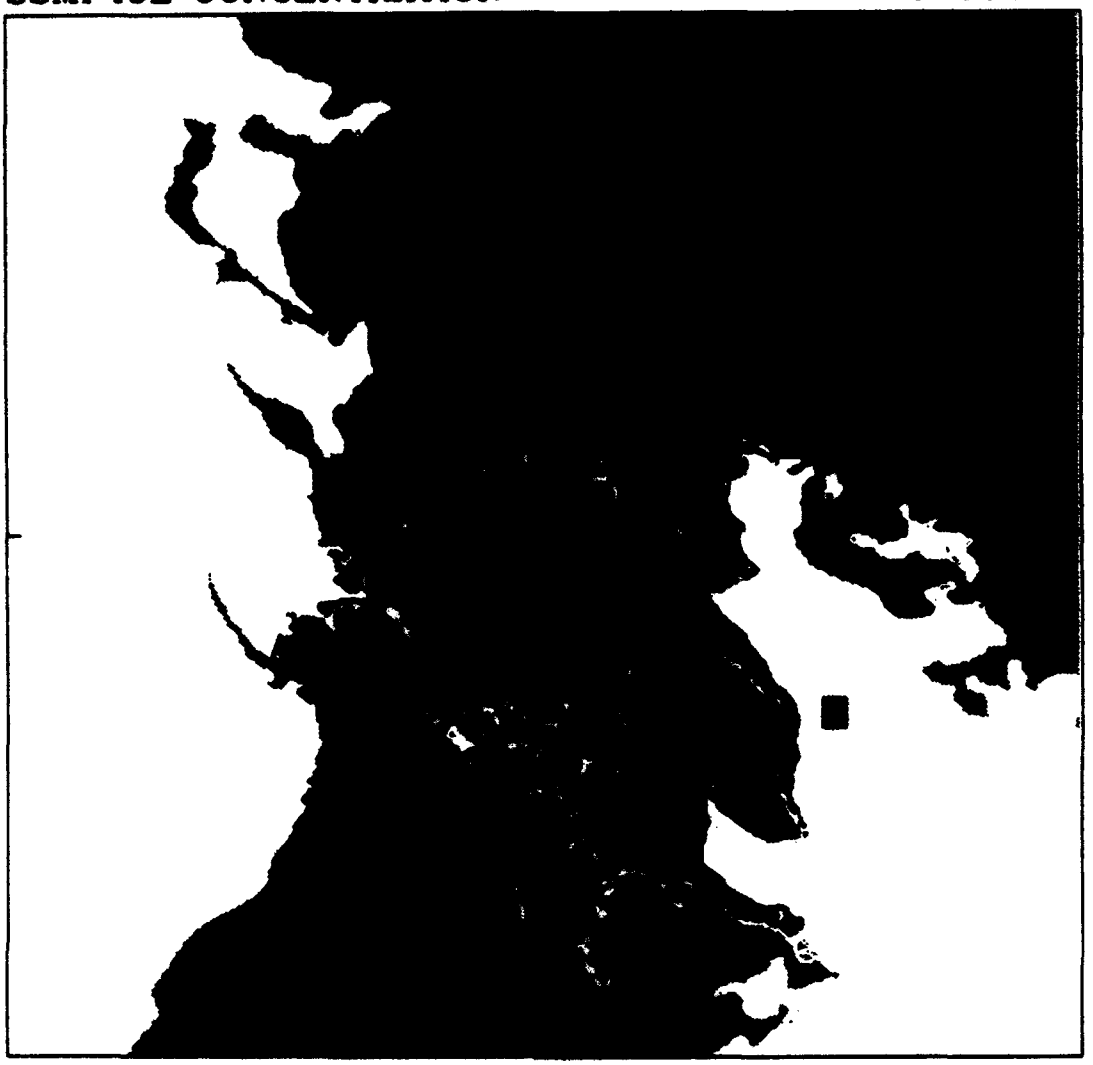

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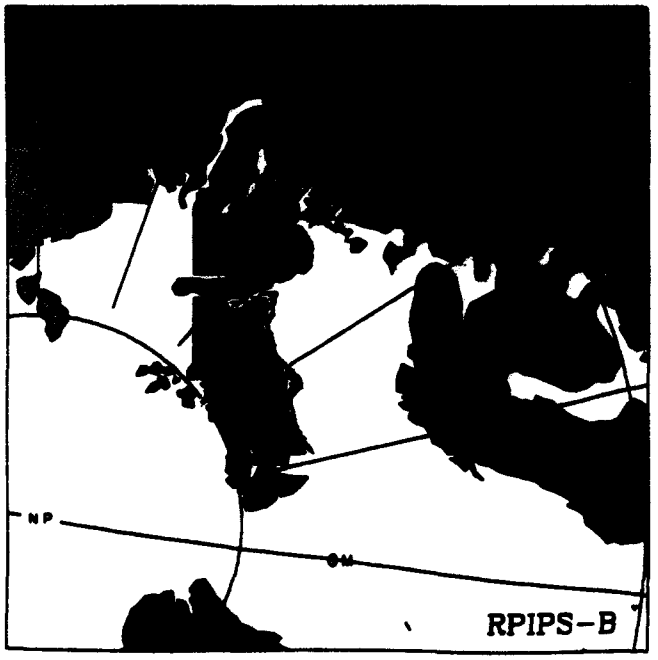

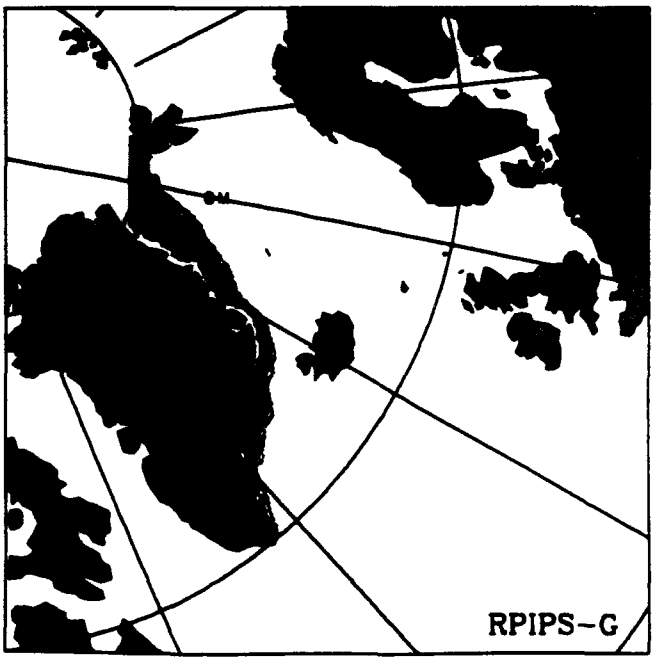

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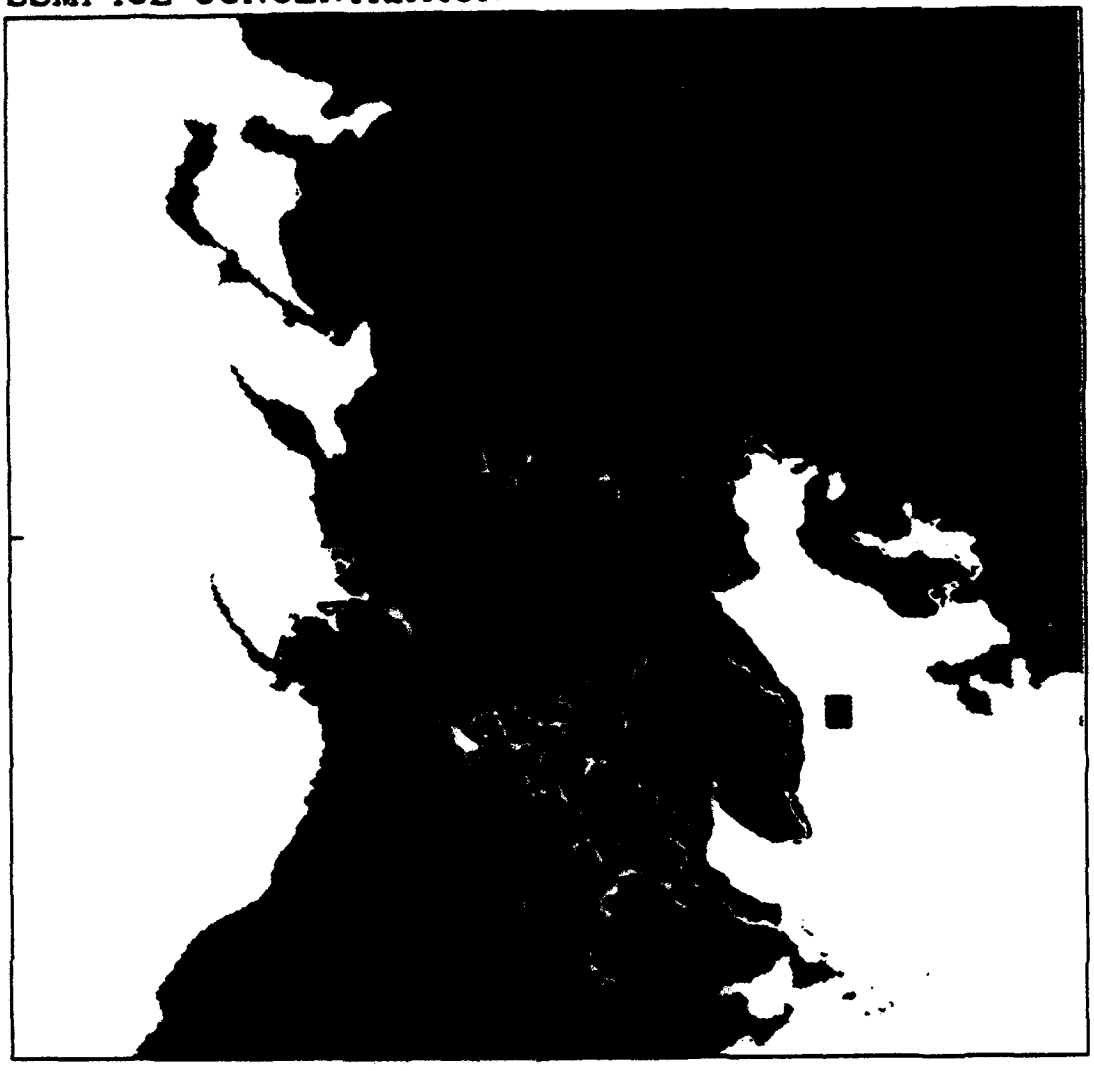

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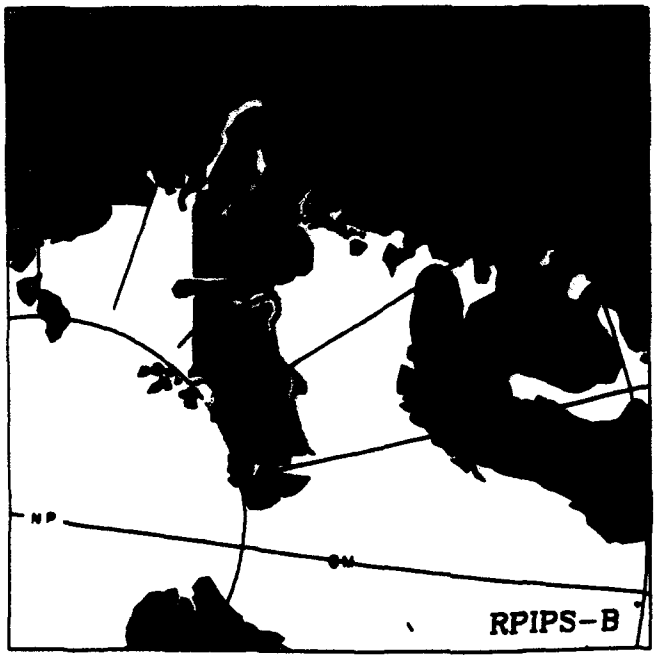

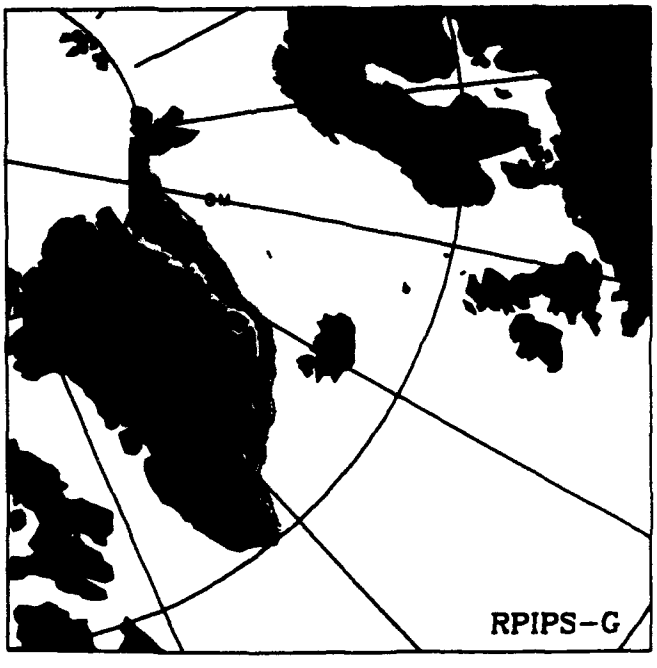

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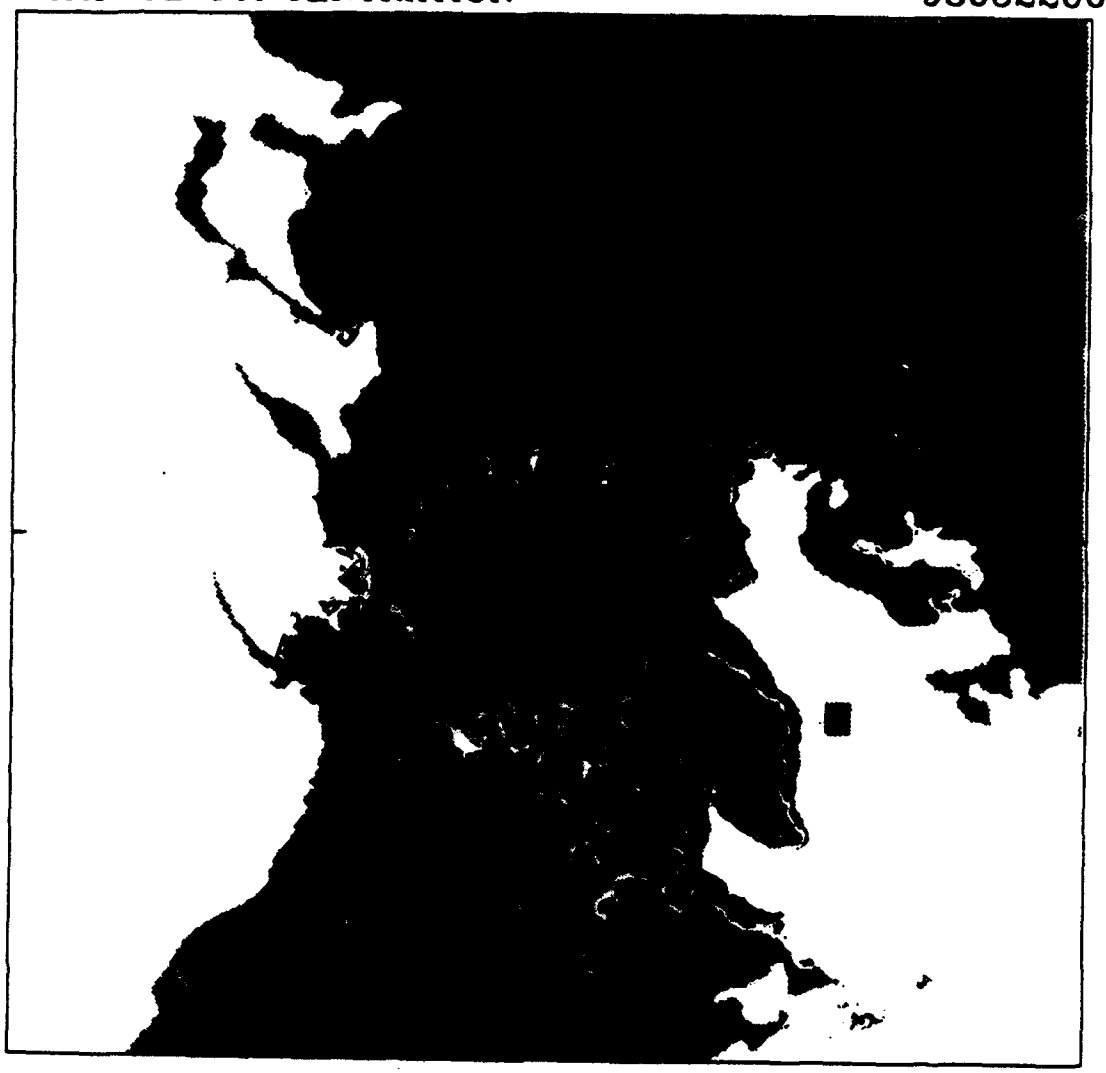

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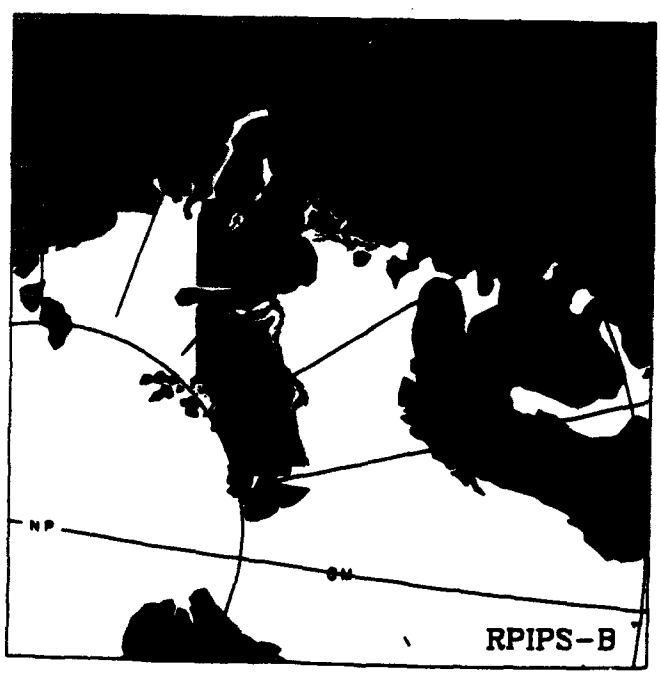

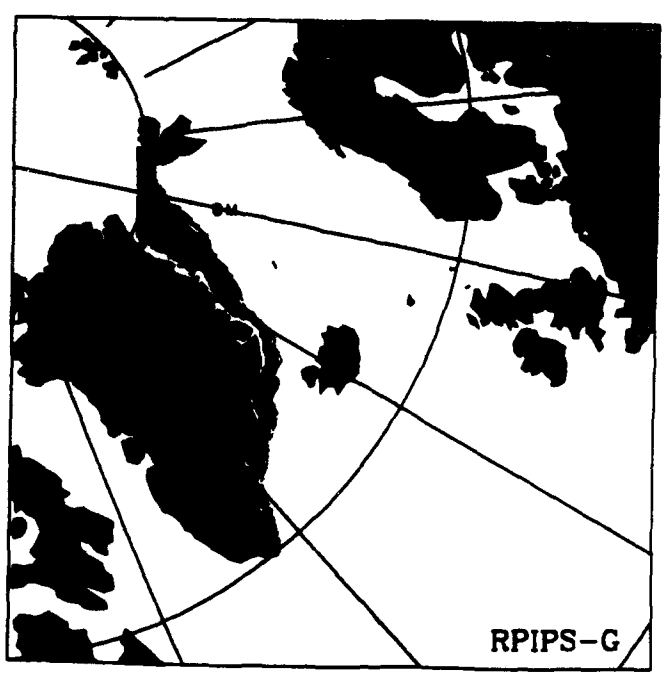

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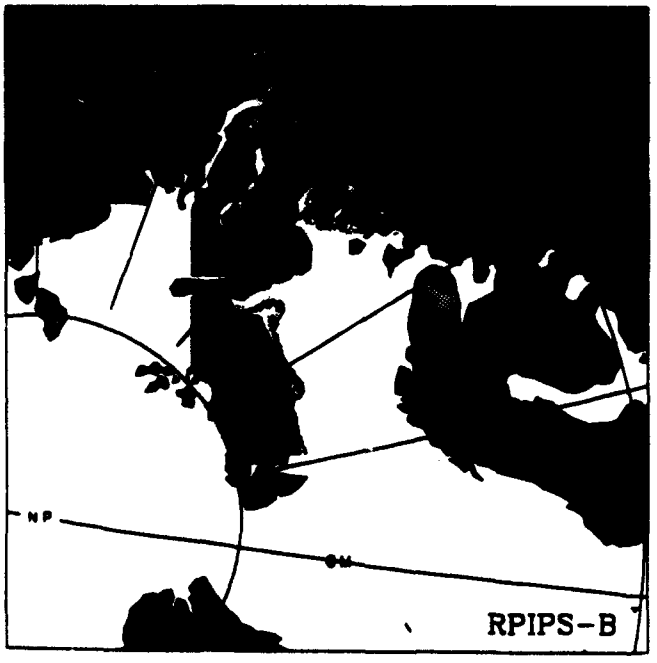

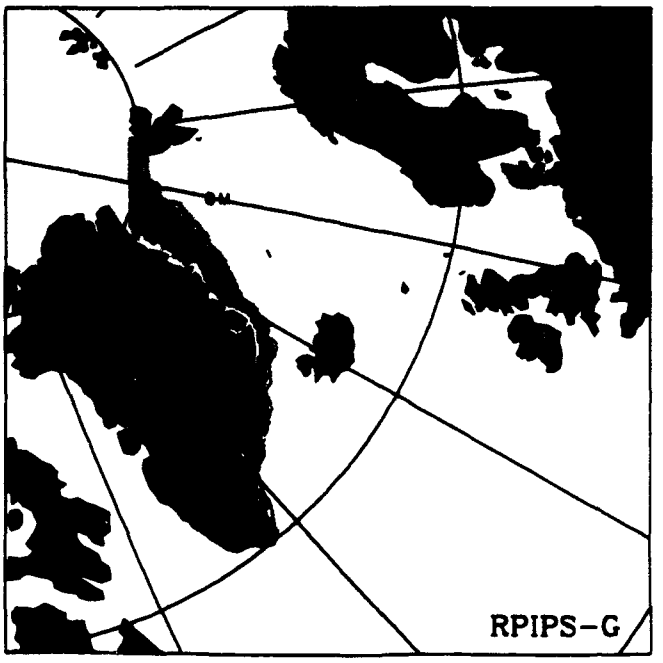

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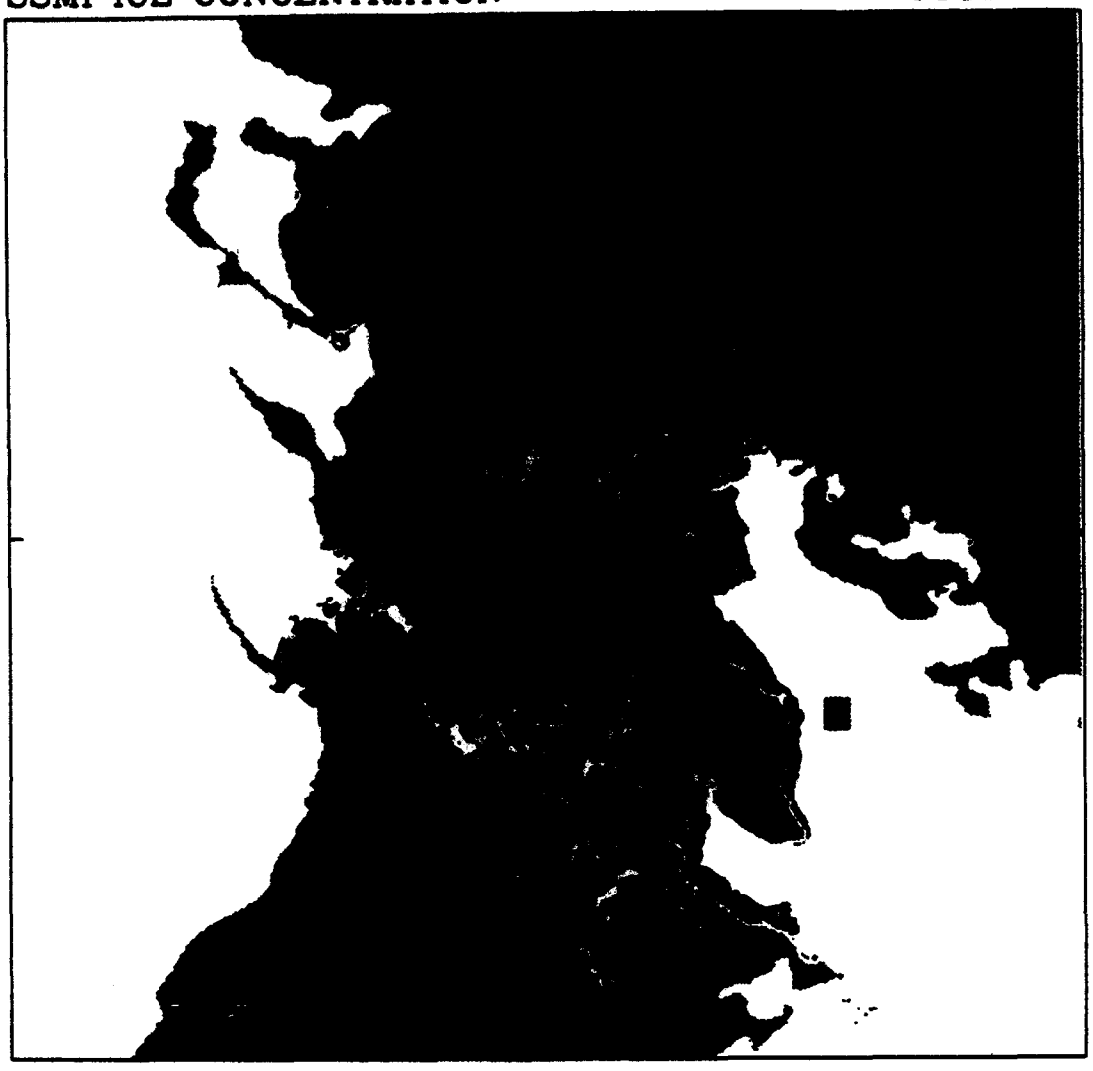

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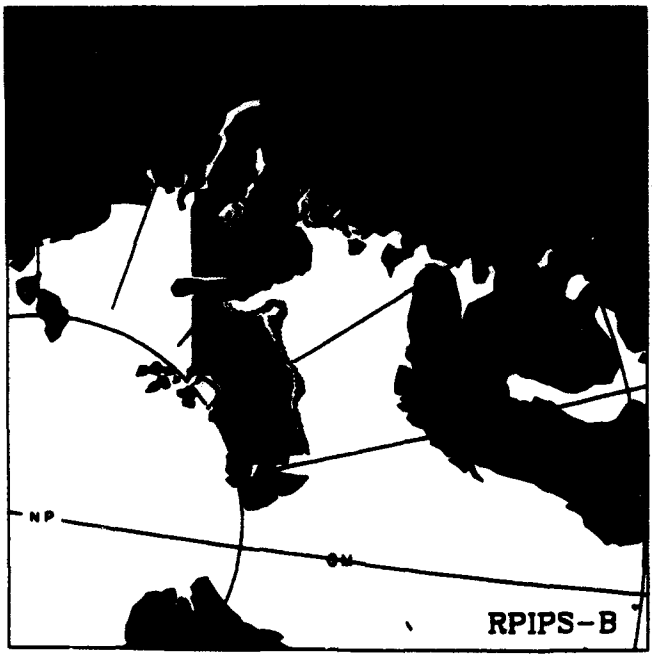

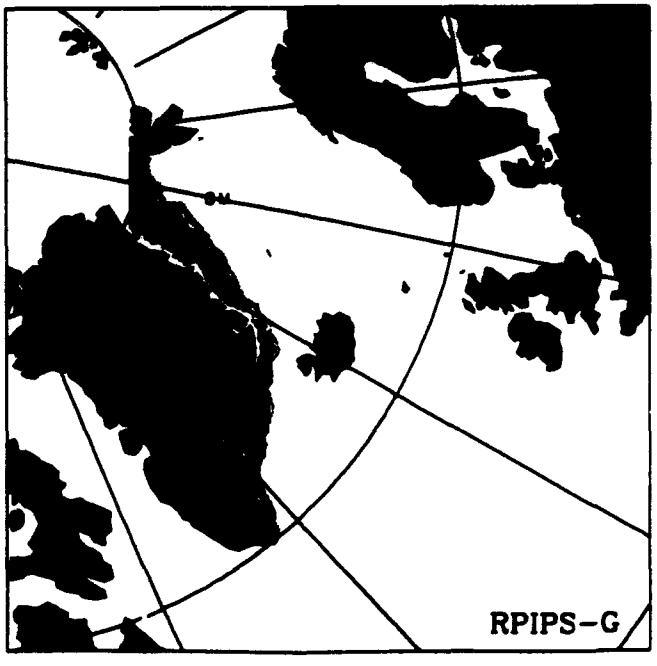

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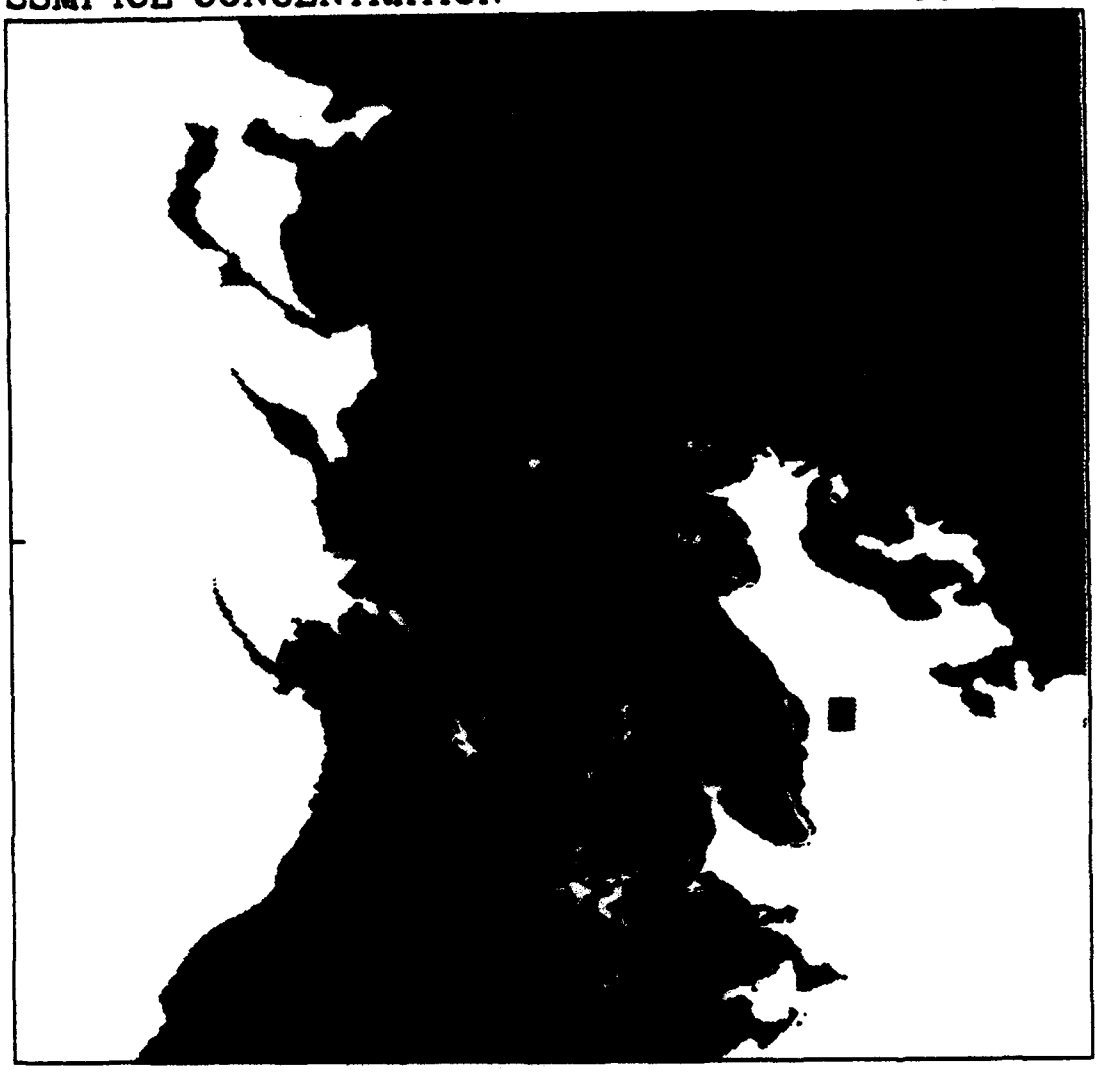

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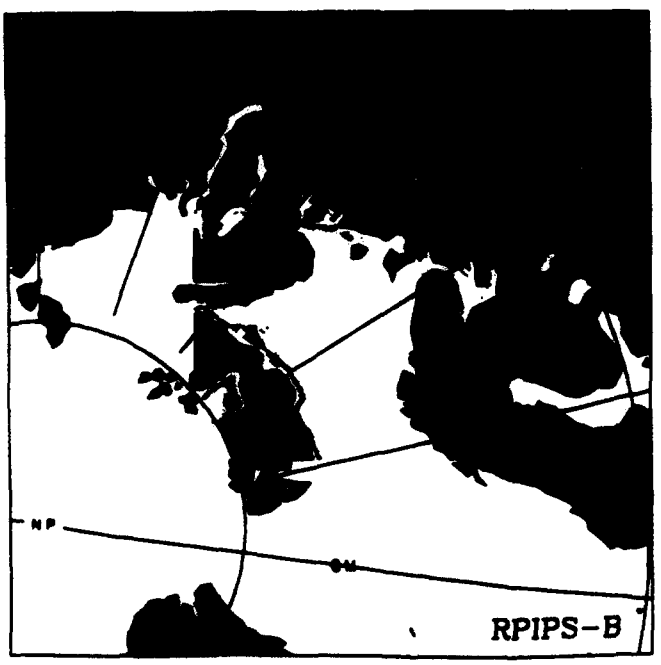

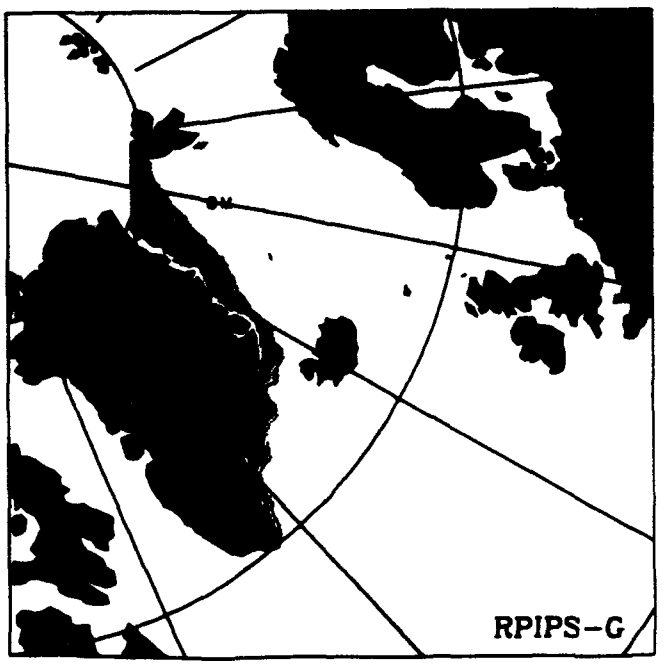

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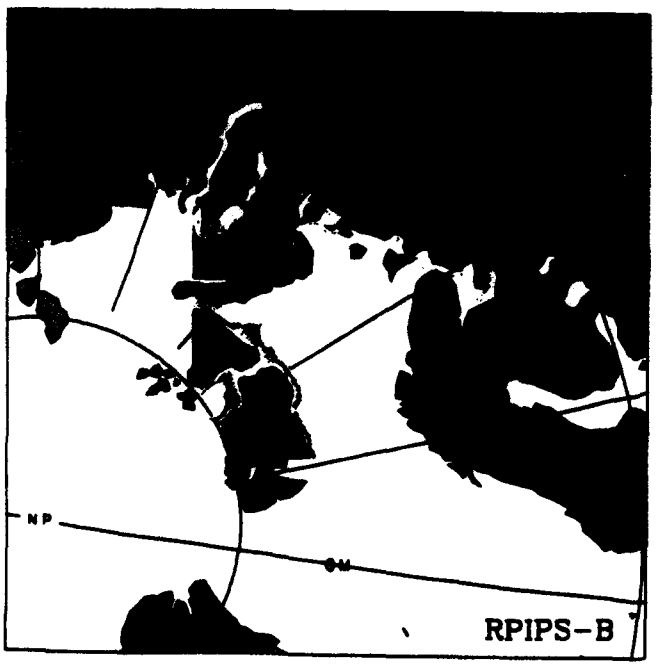

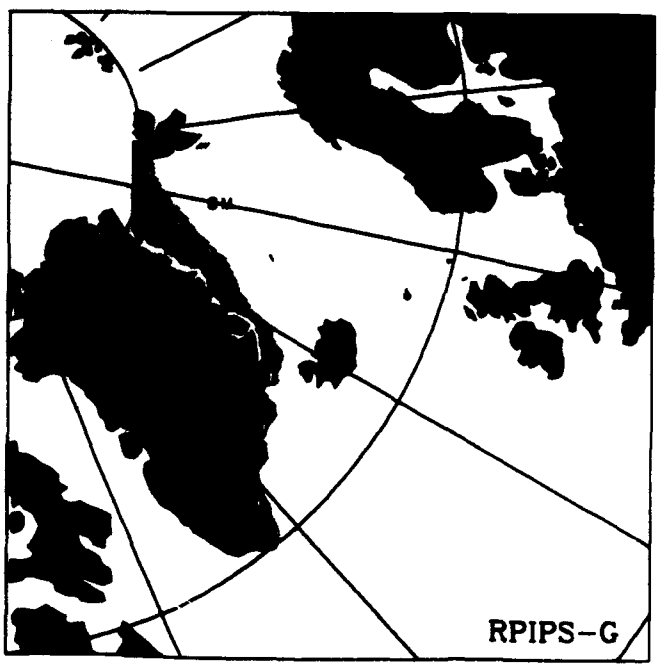

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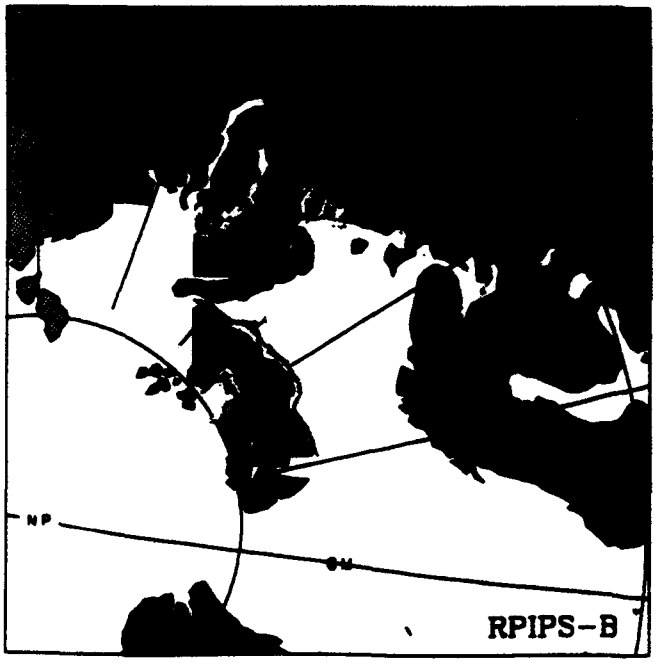

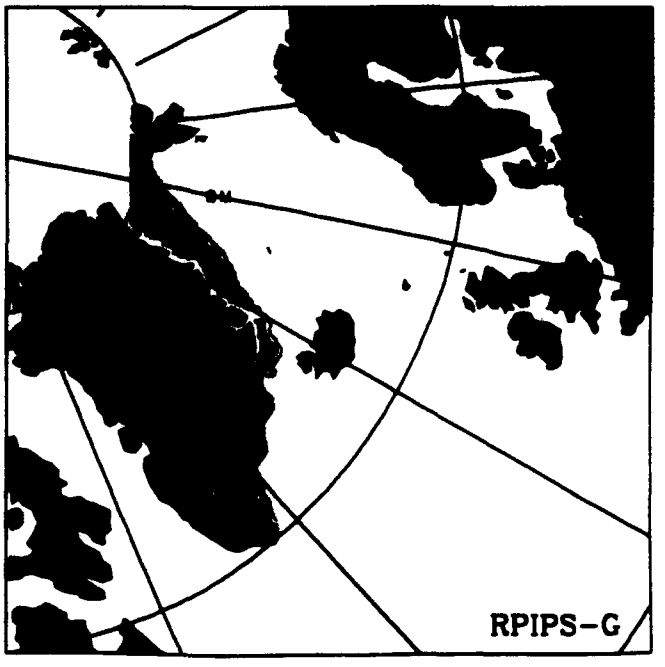

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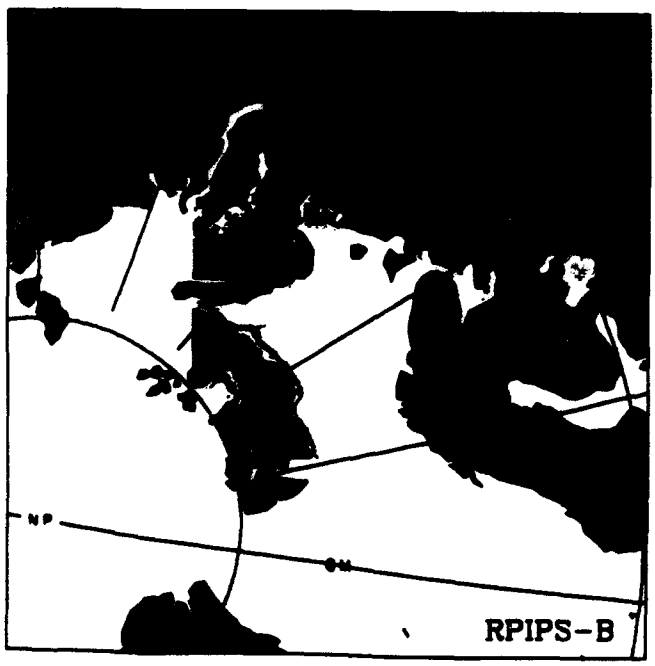

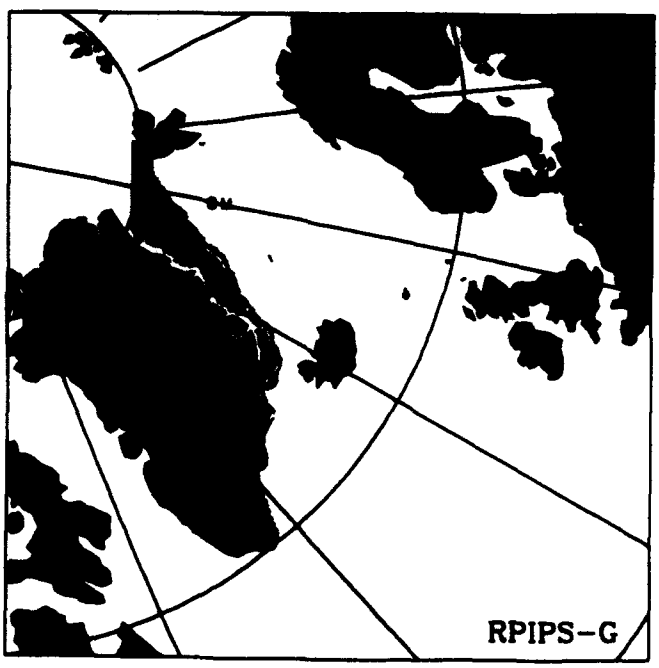

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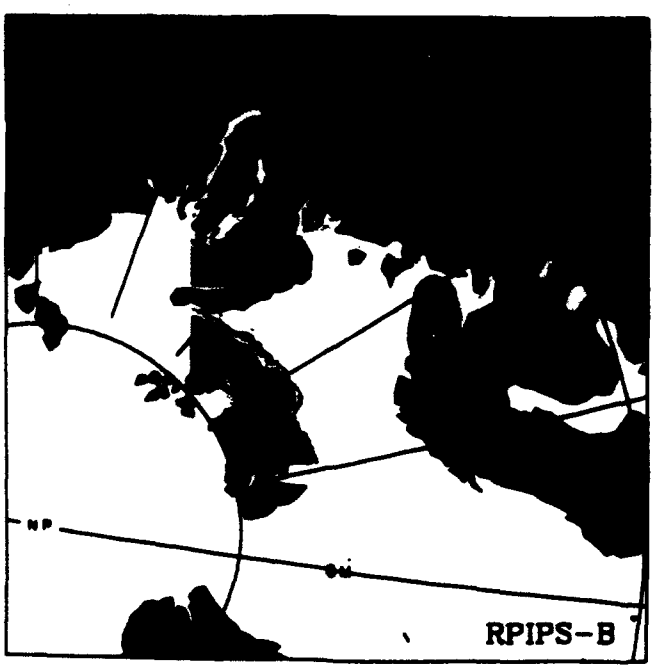

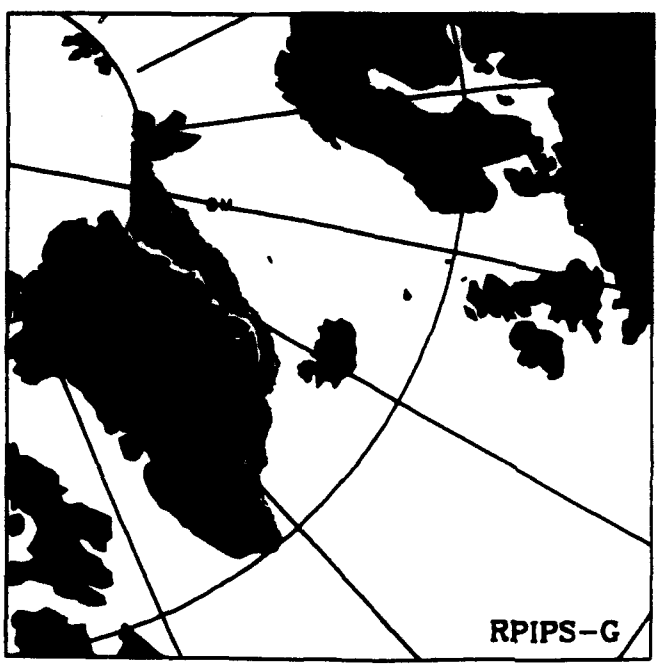

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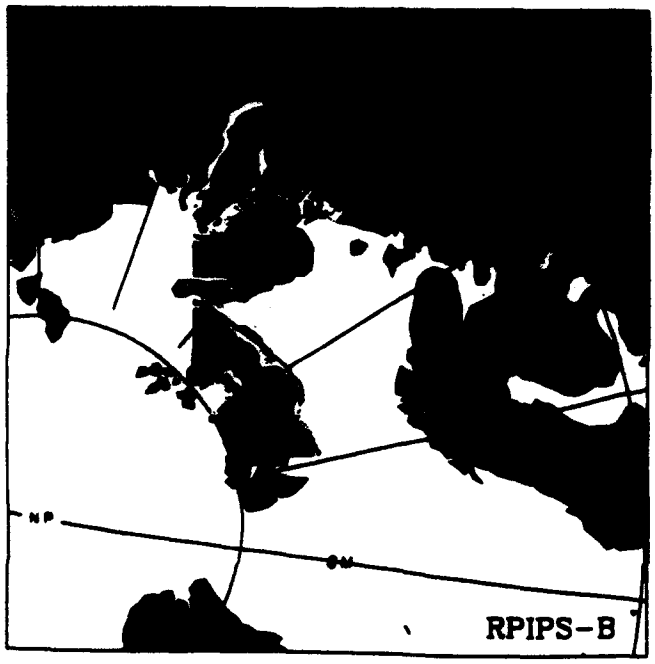

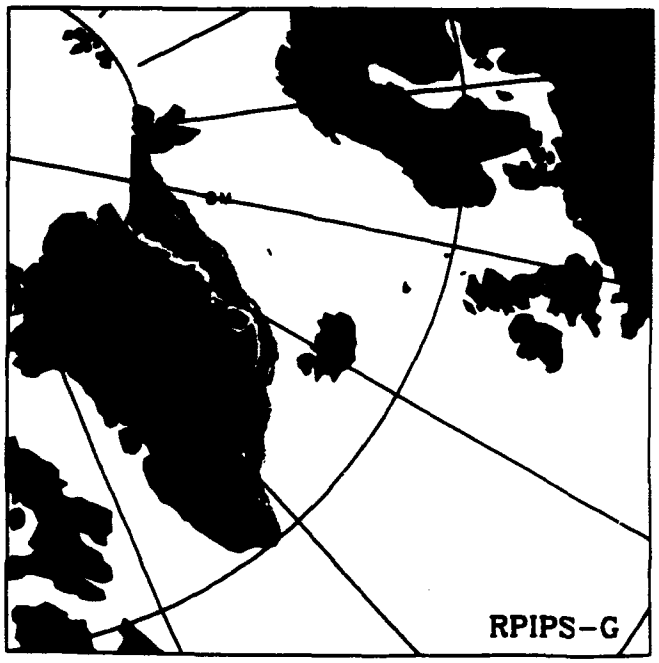

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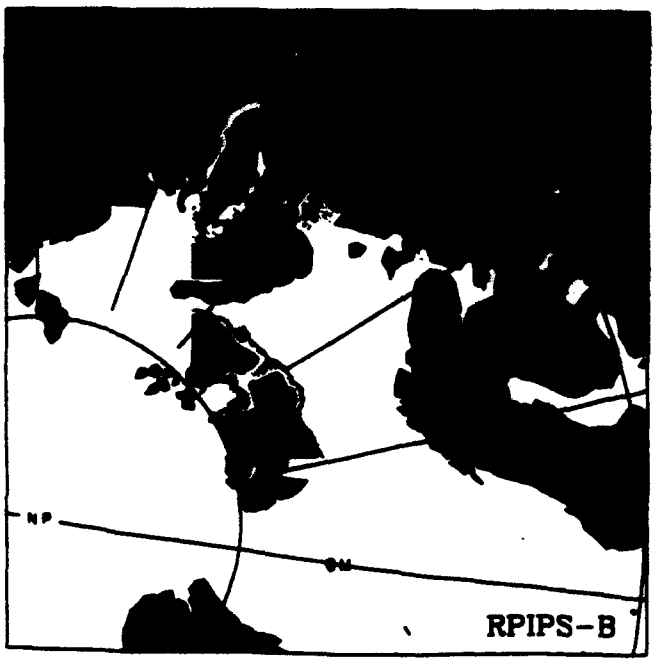

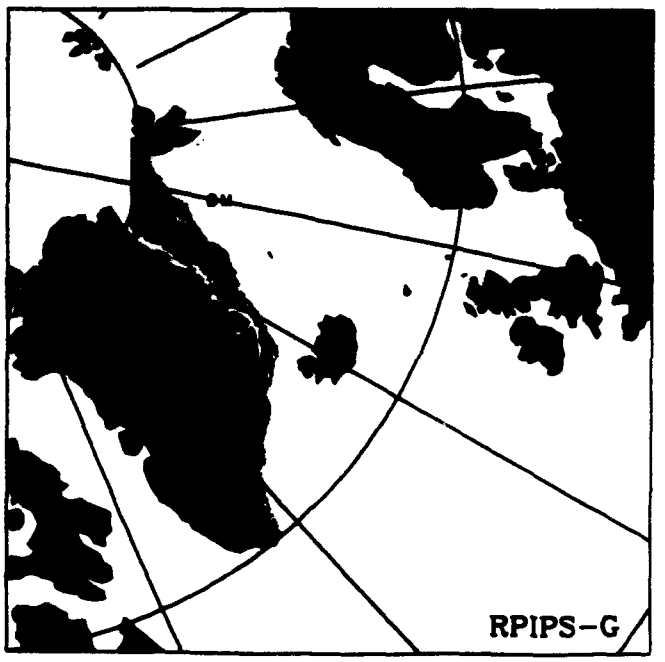

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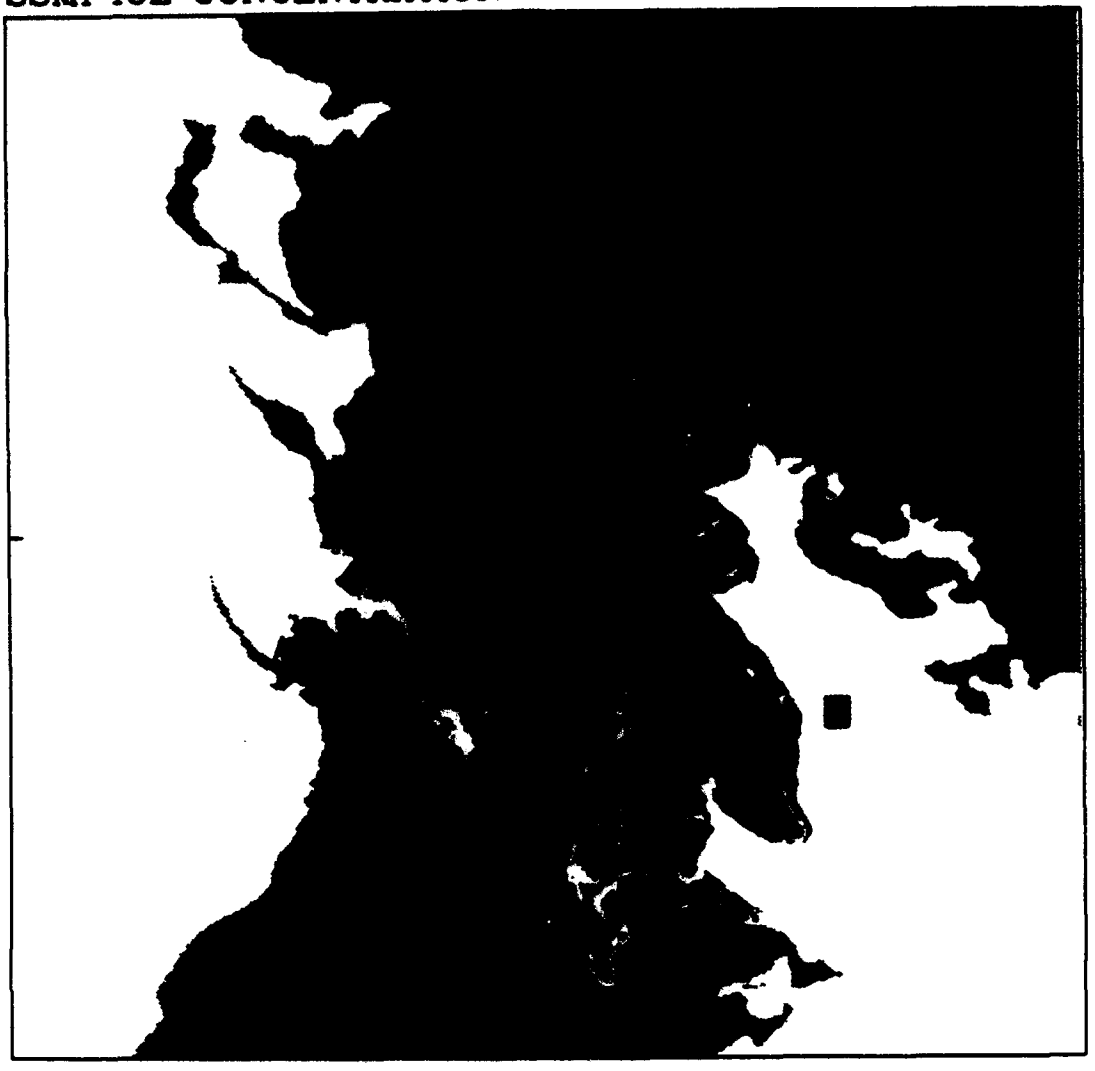

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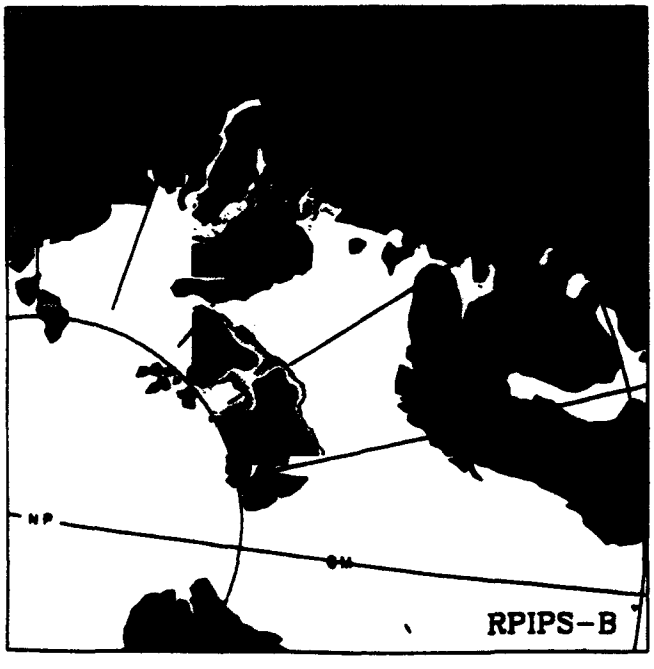

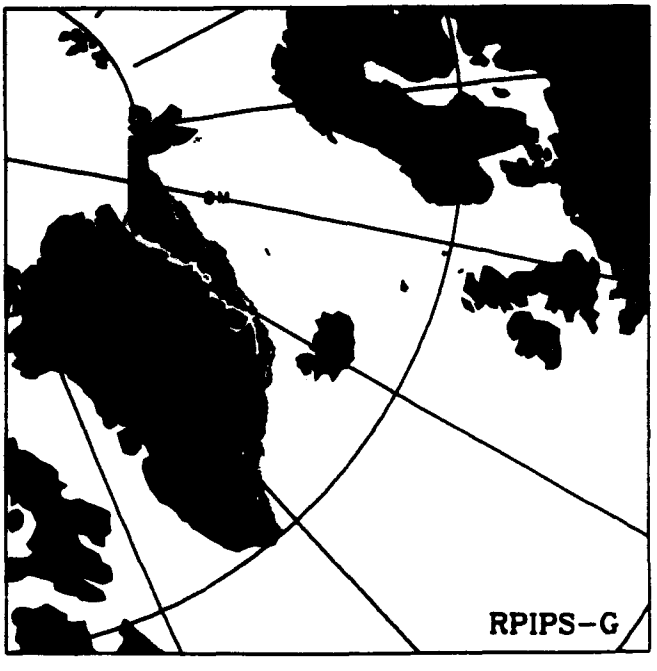

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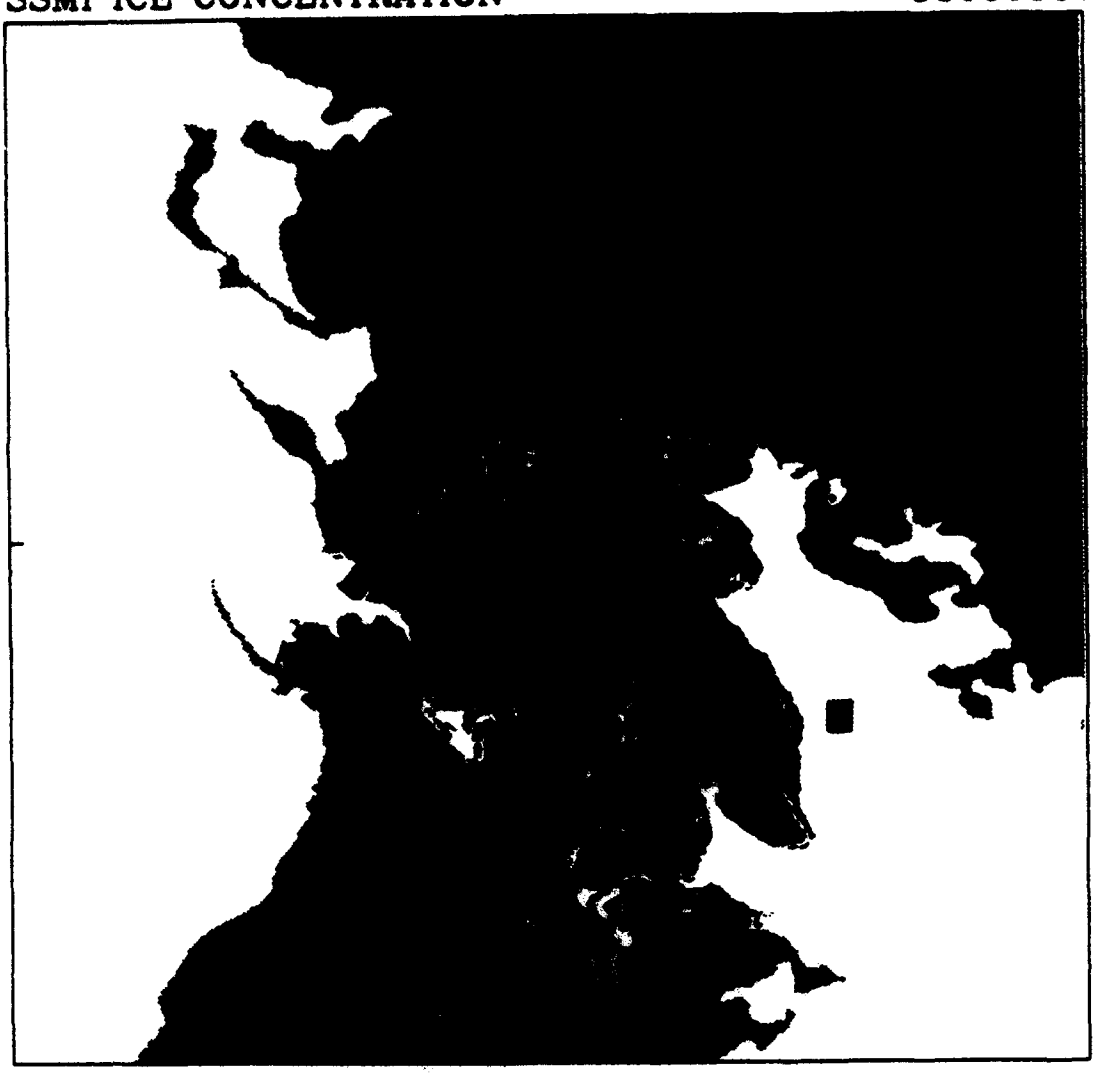

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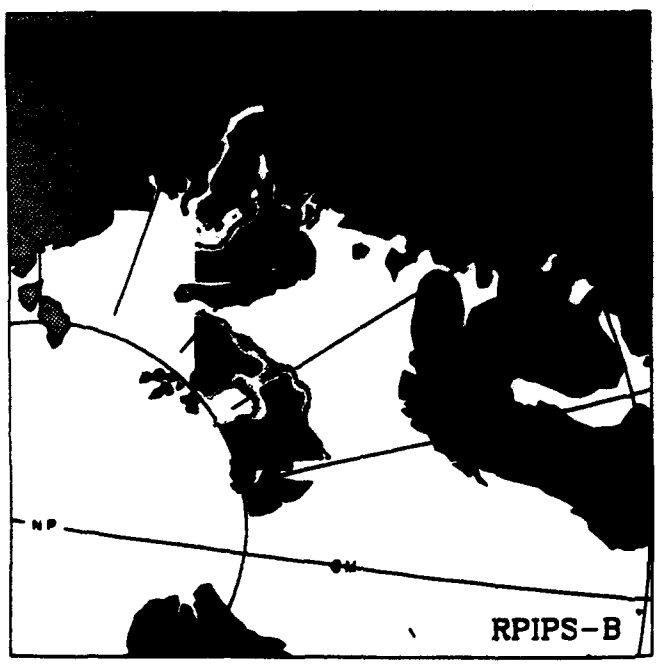

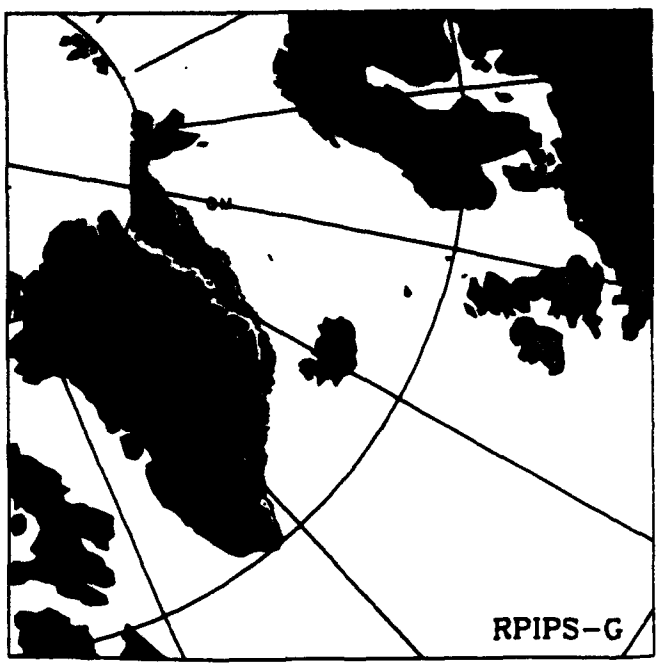

SSMI ICE CONCENTRATION 93061100

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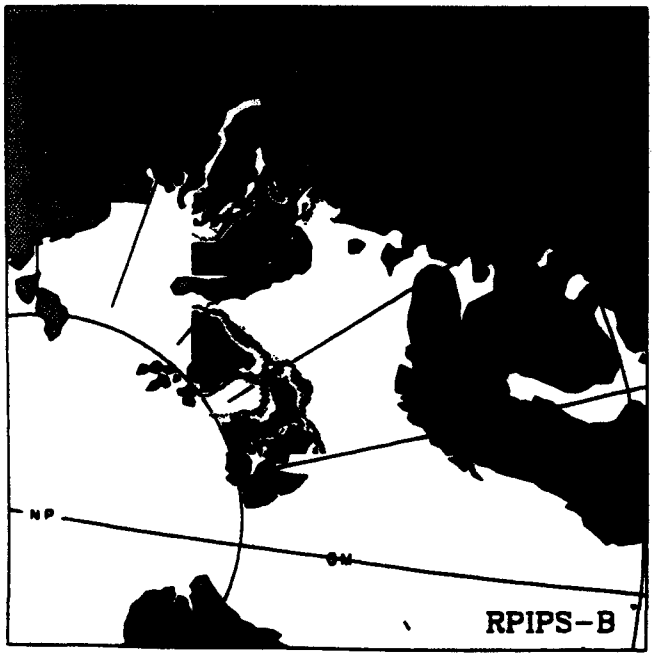
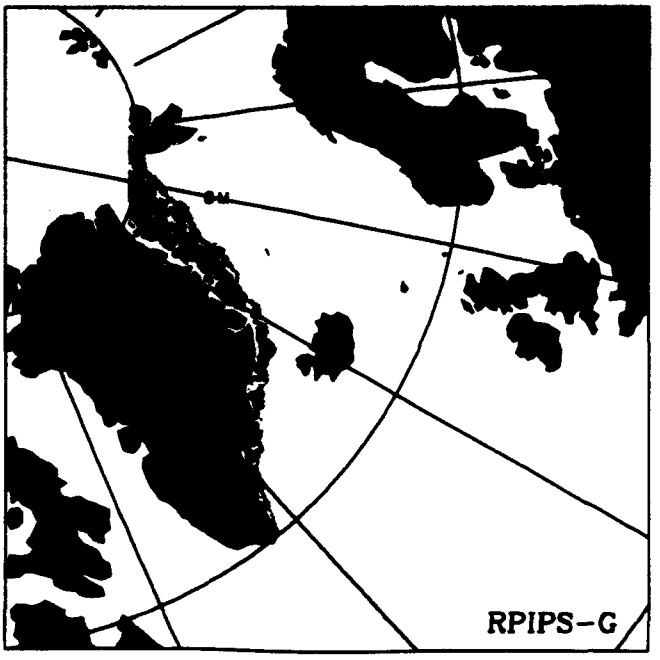
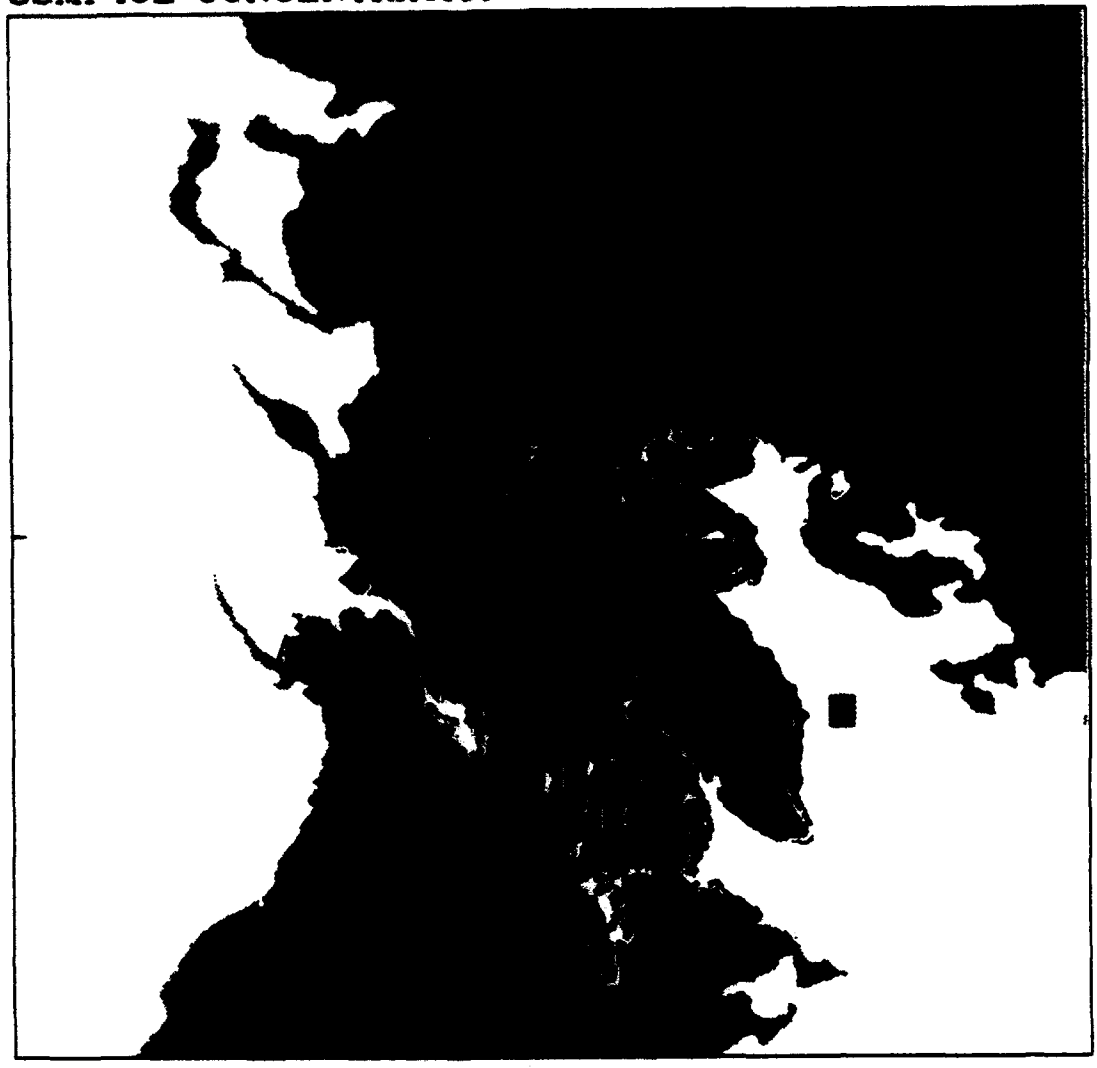




SSMI ICE CONCENTRATION 93061200



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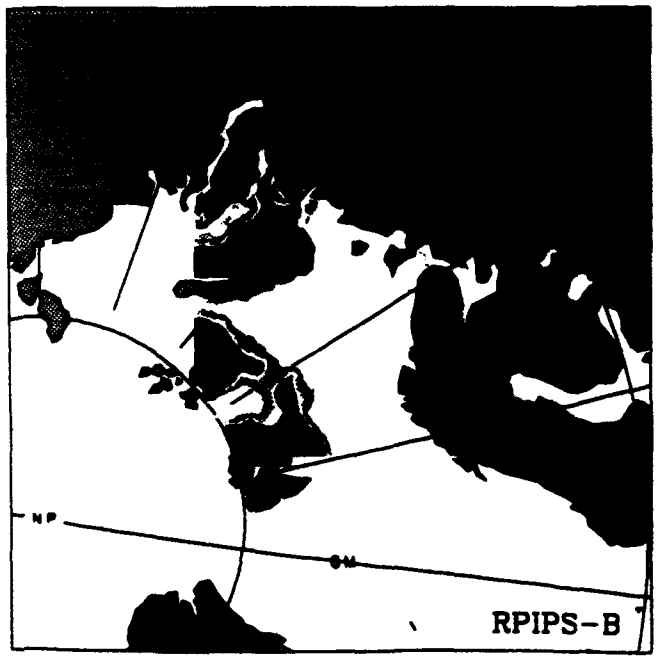

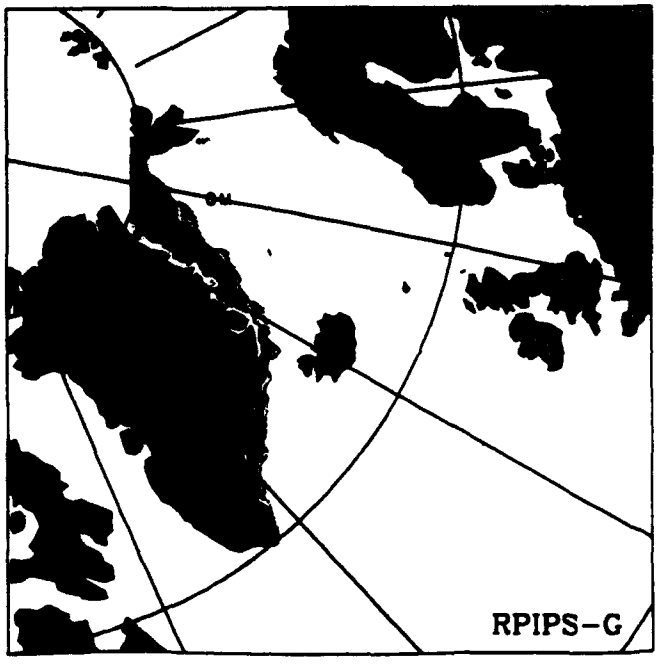

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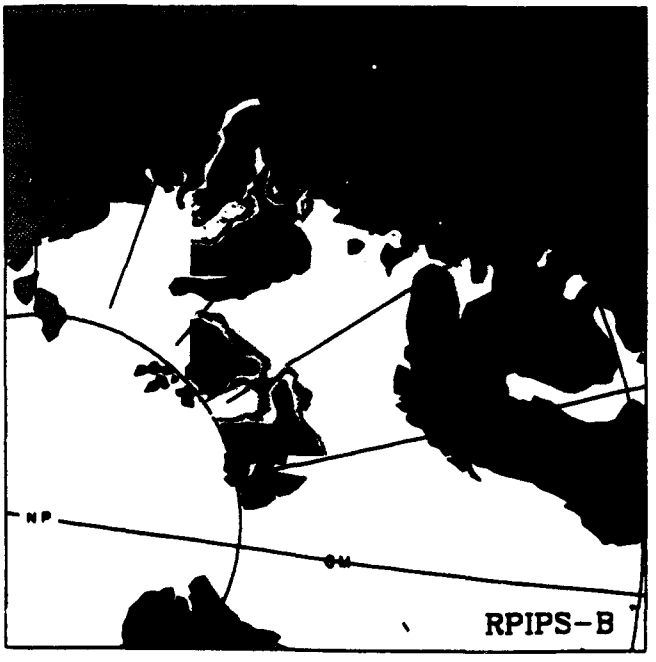

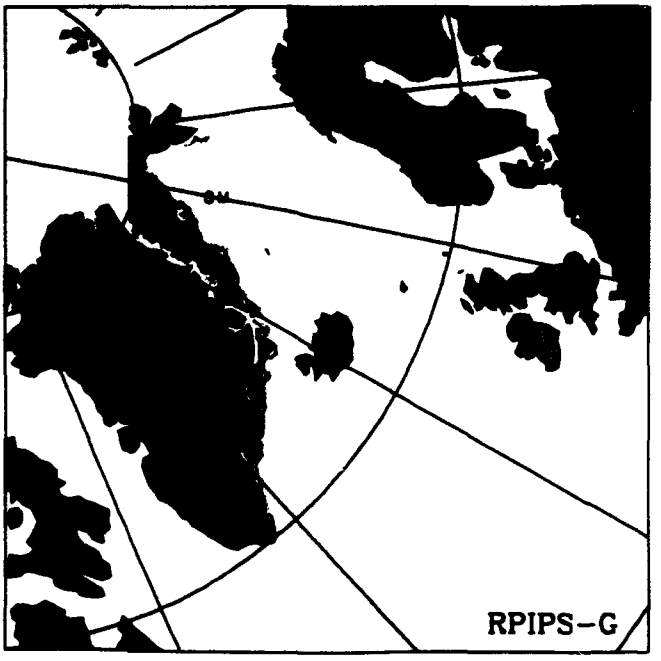

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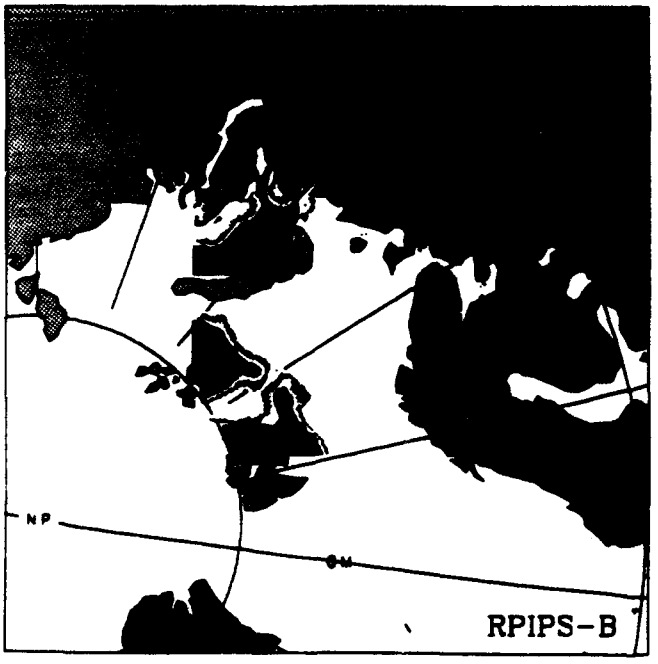

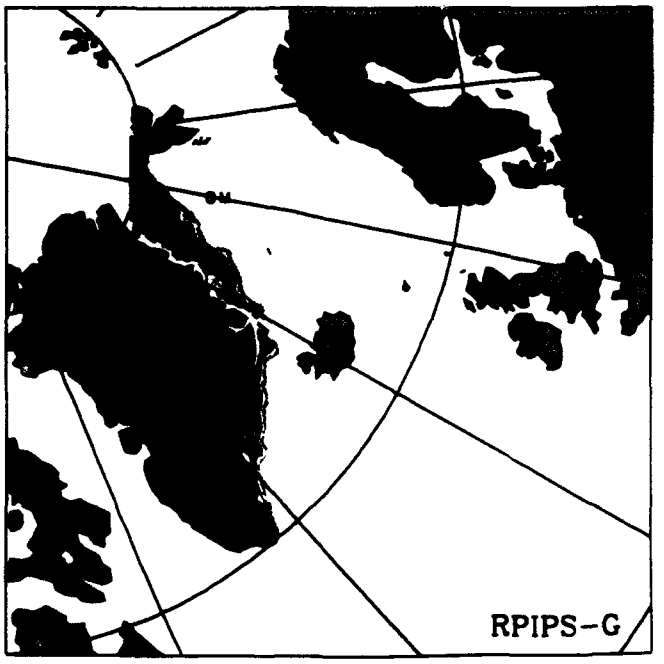

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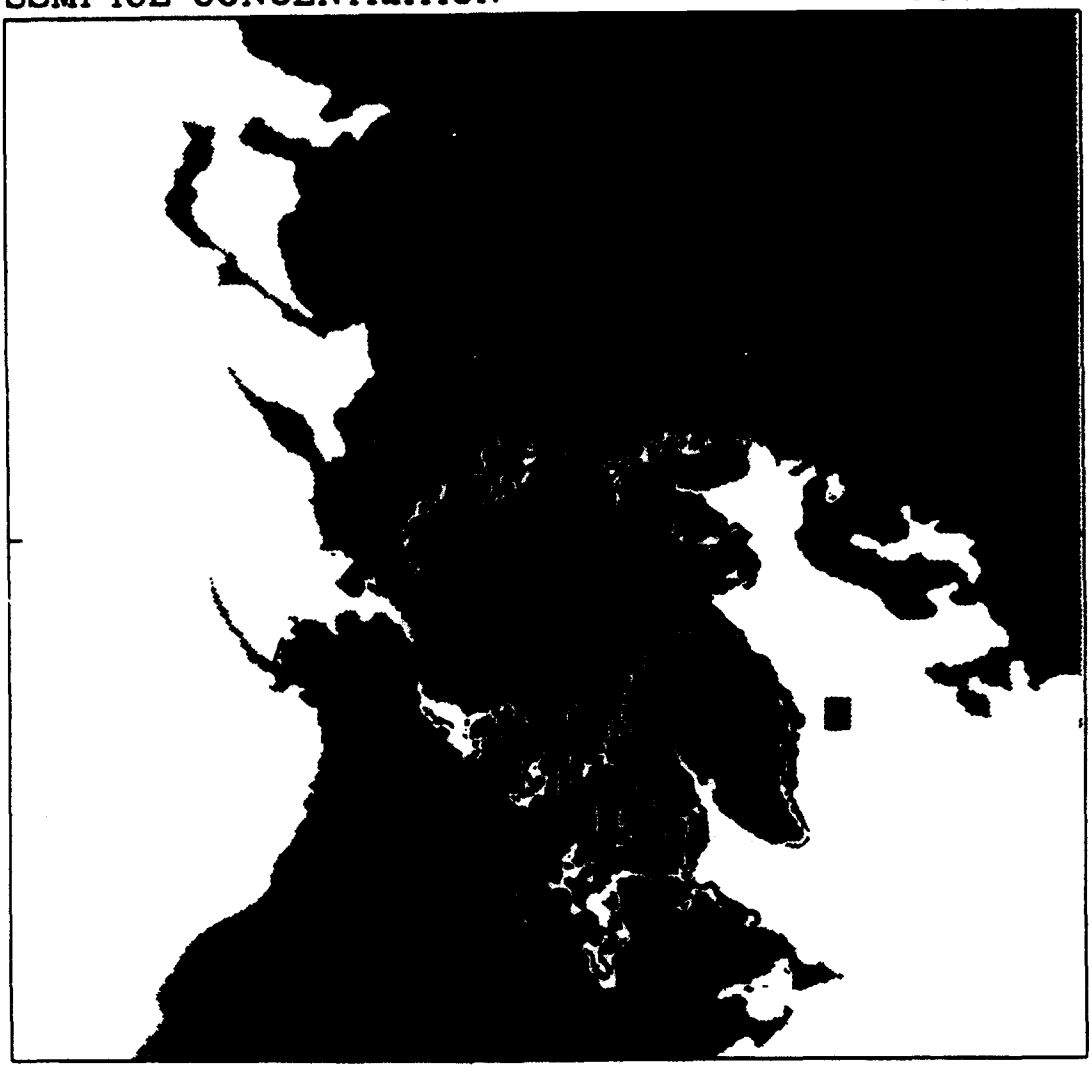

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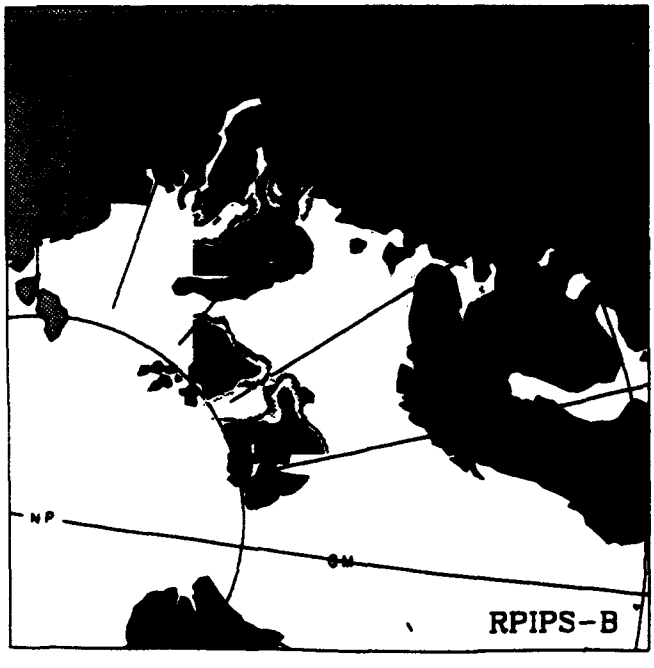

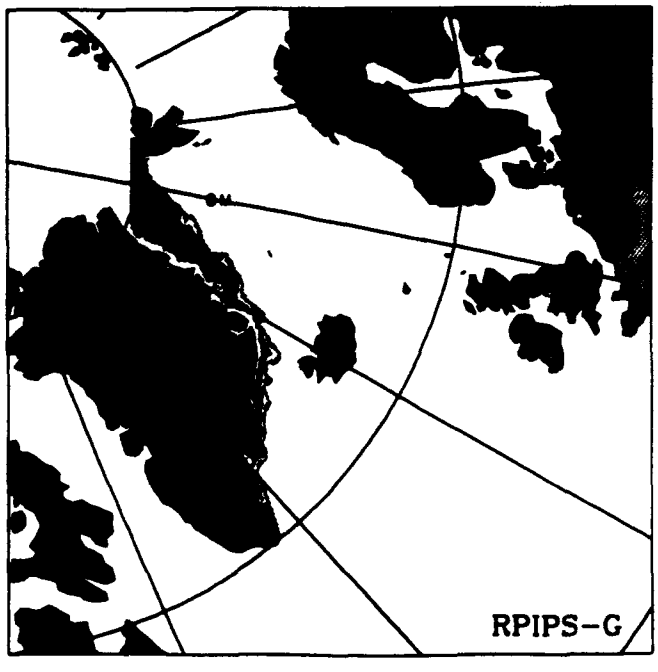

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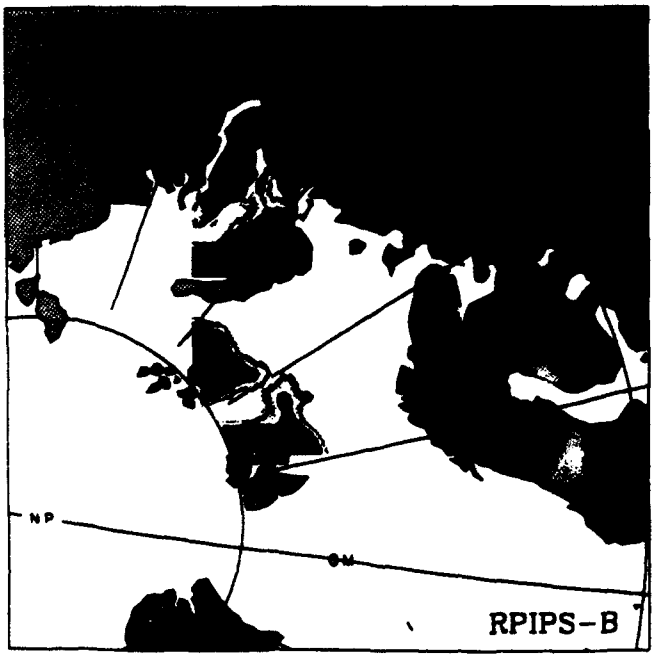

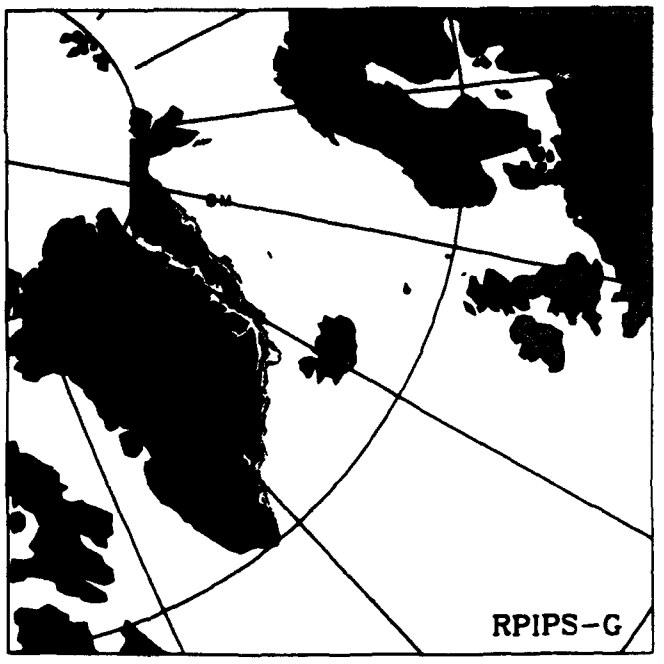

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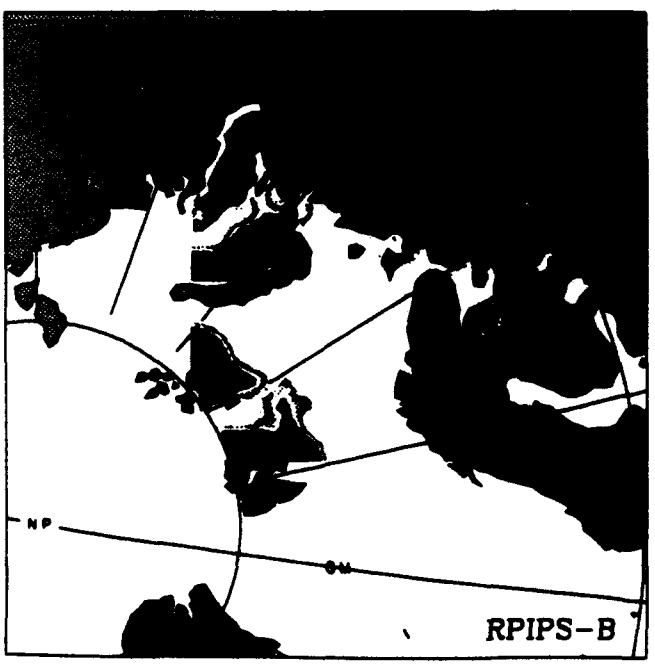

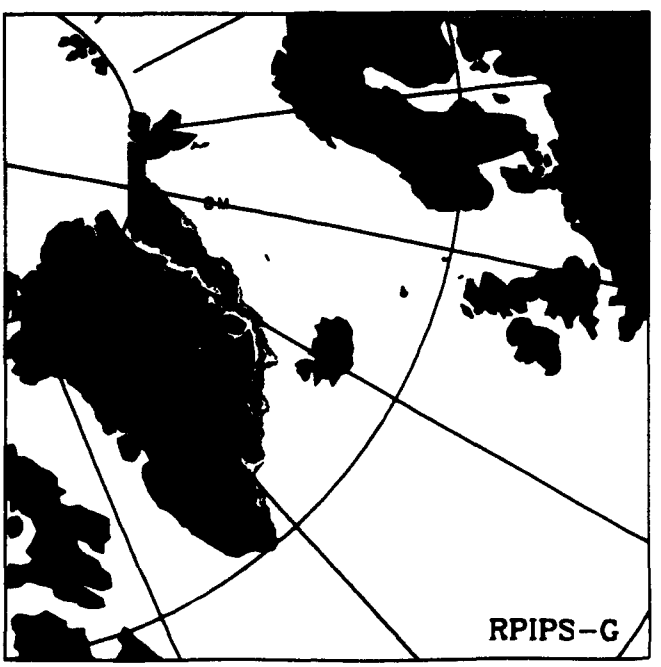

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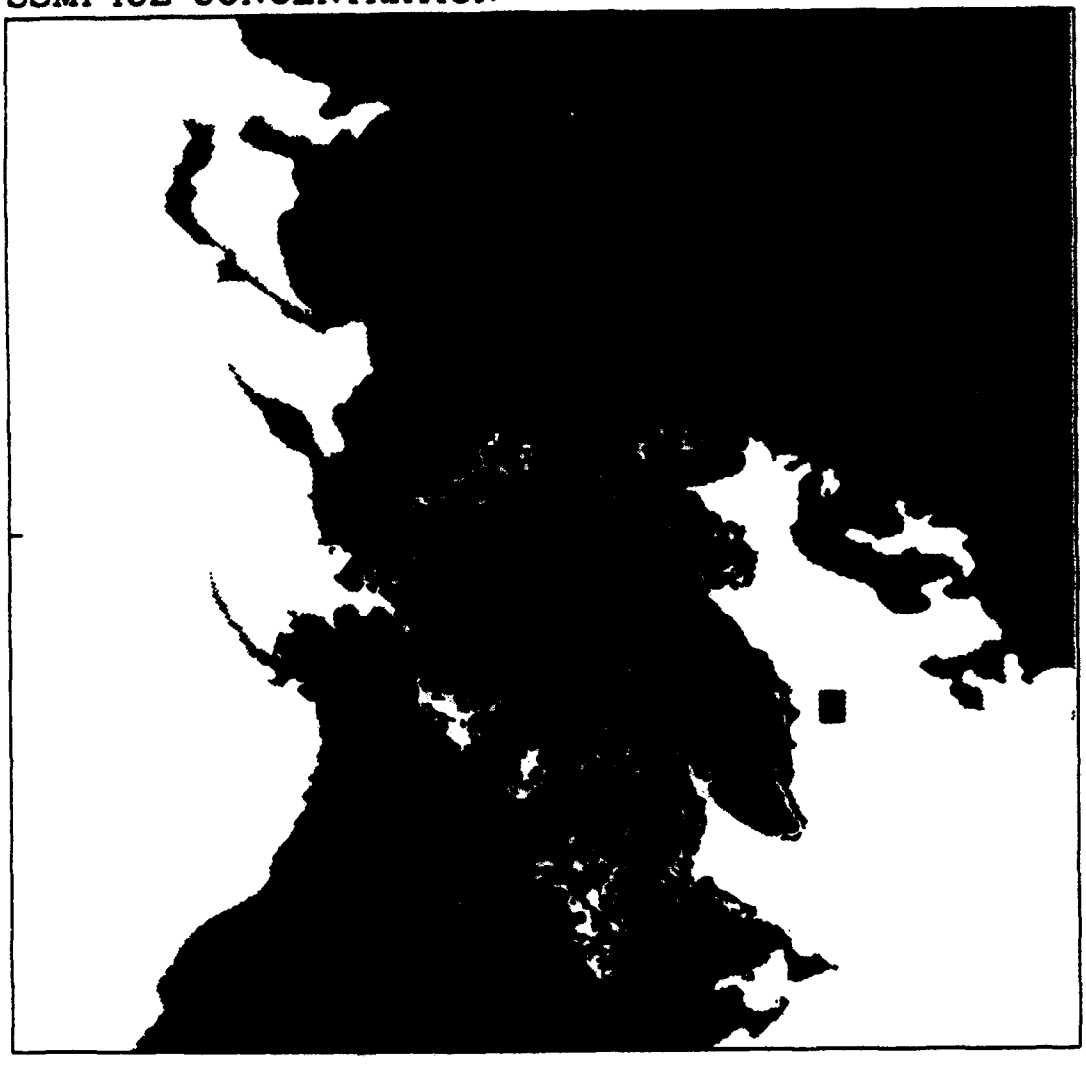

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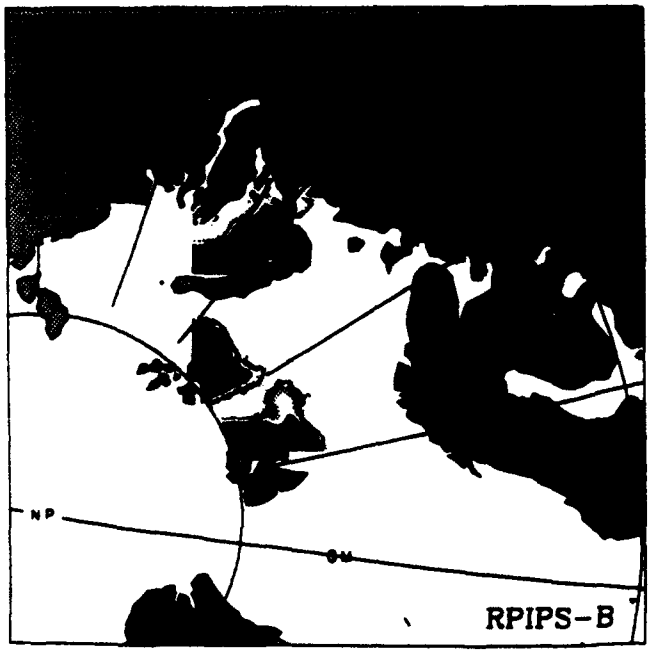

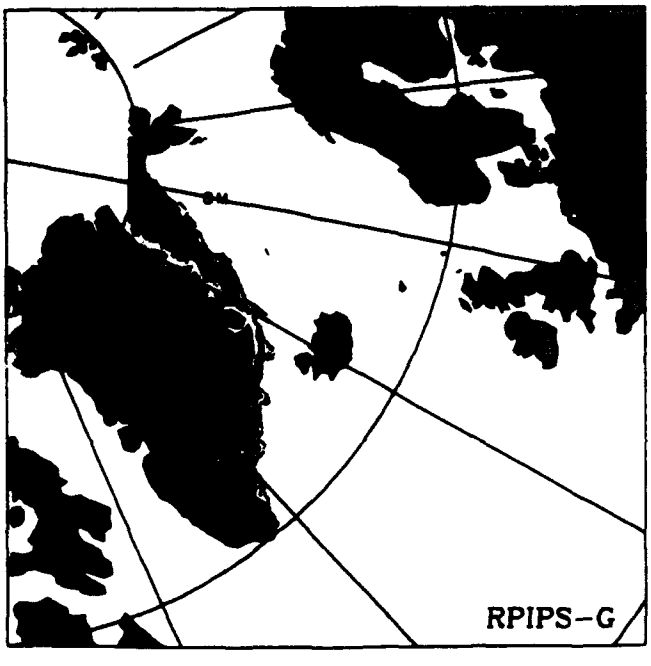

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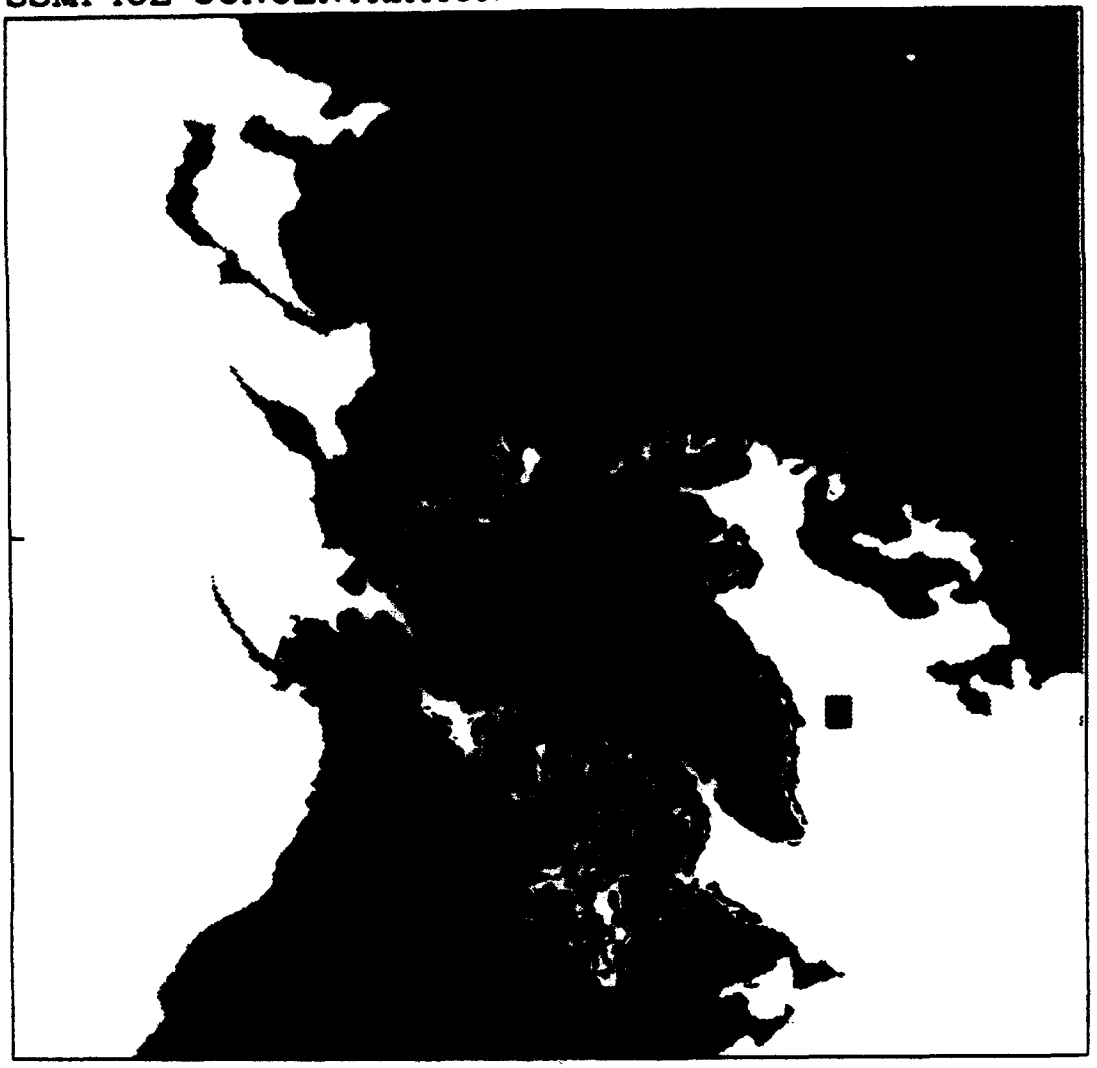

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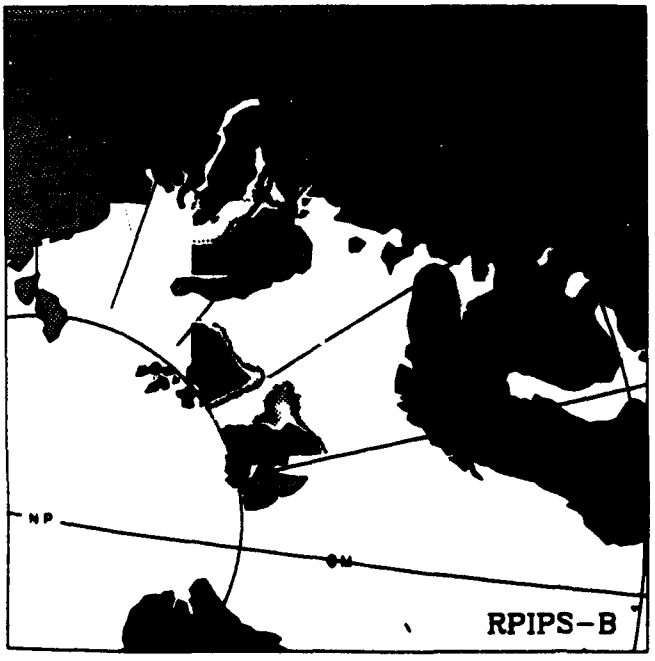

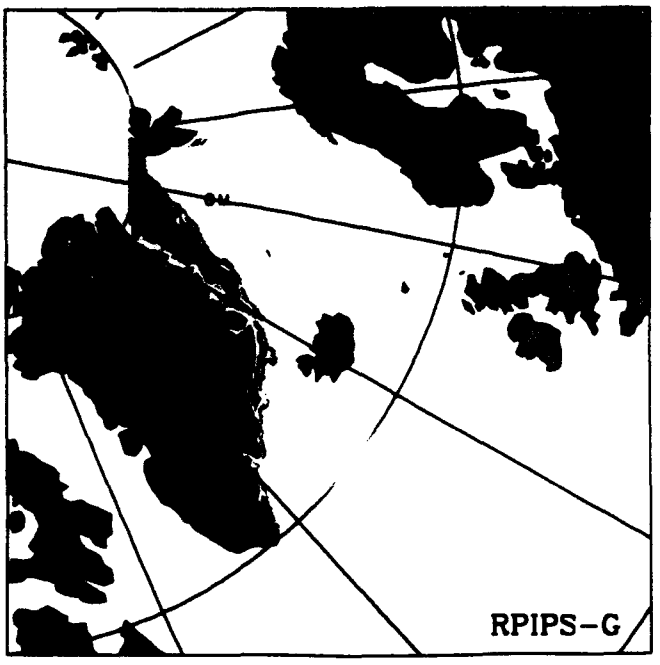

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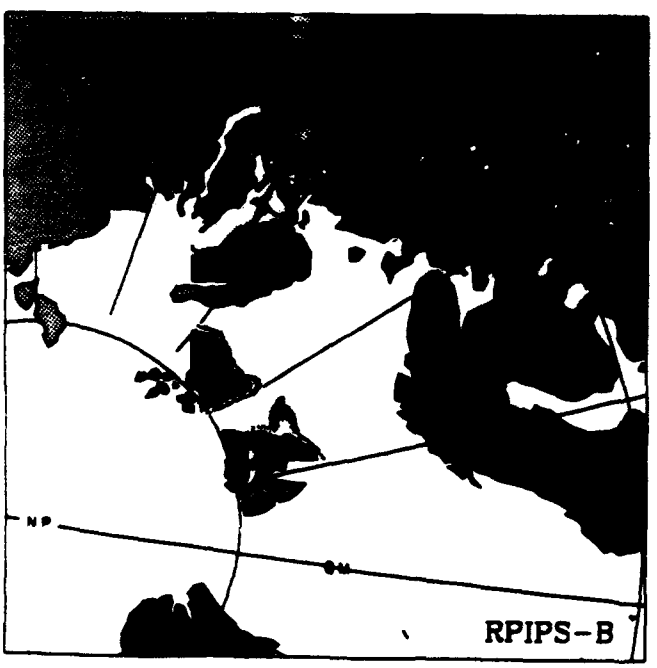

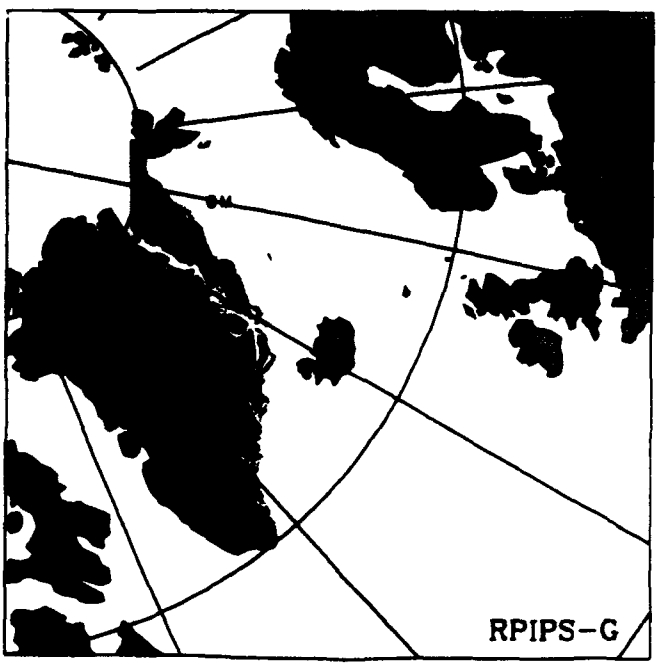

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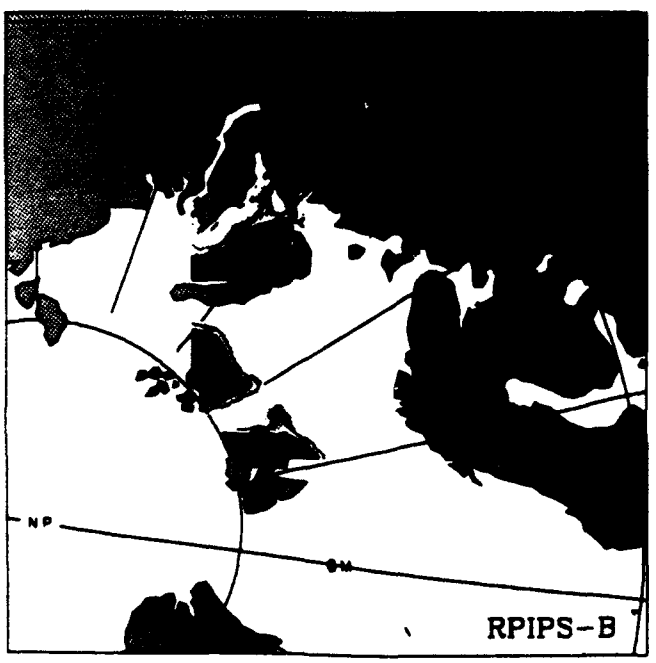

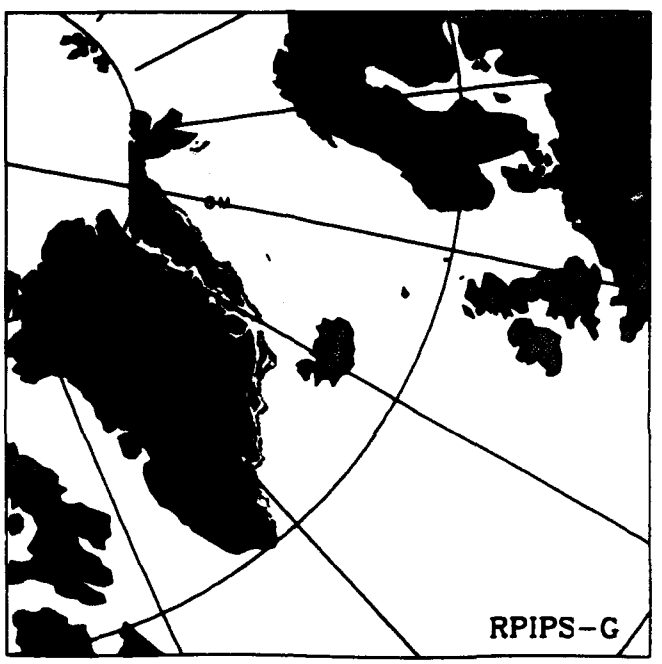

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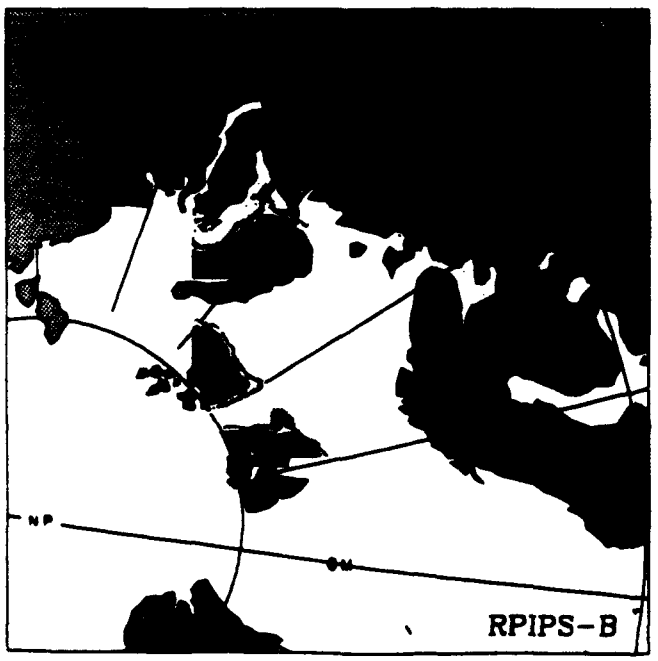

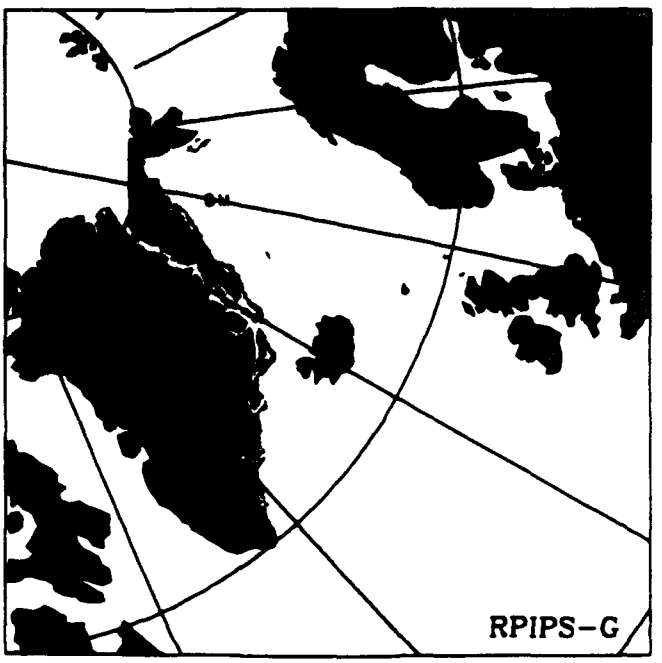

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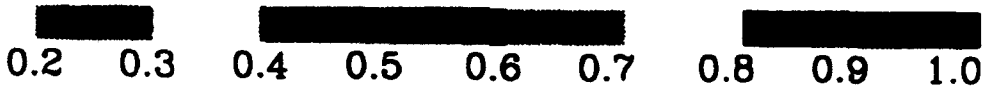

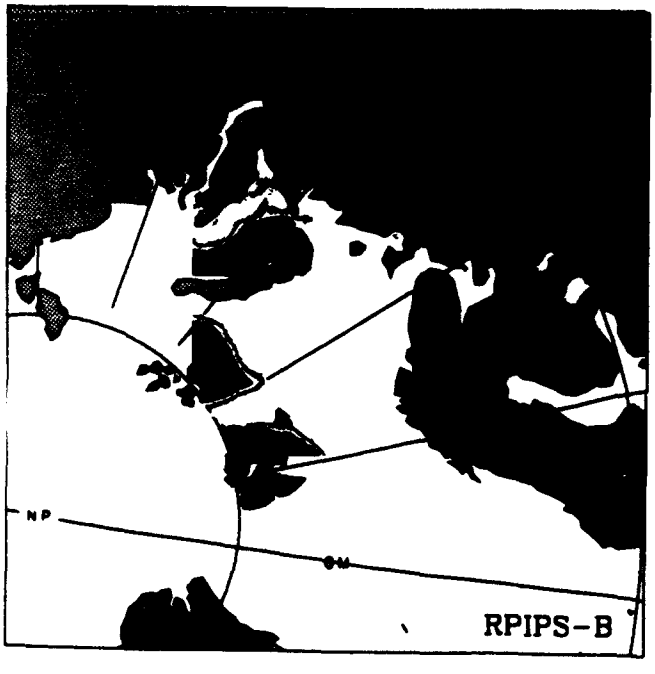

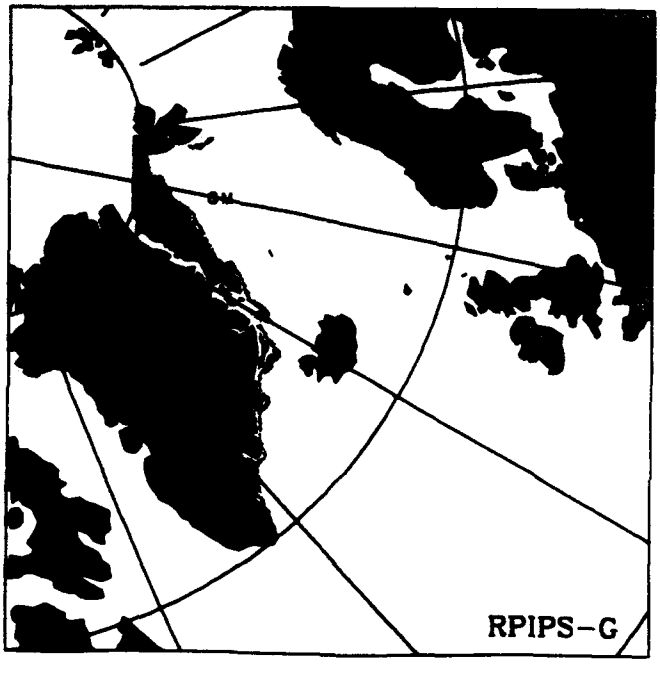

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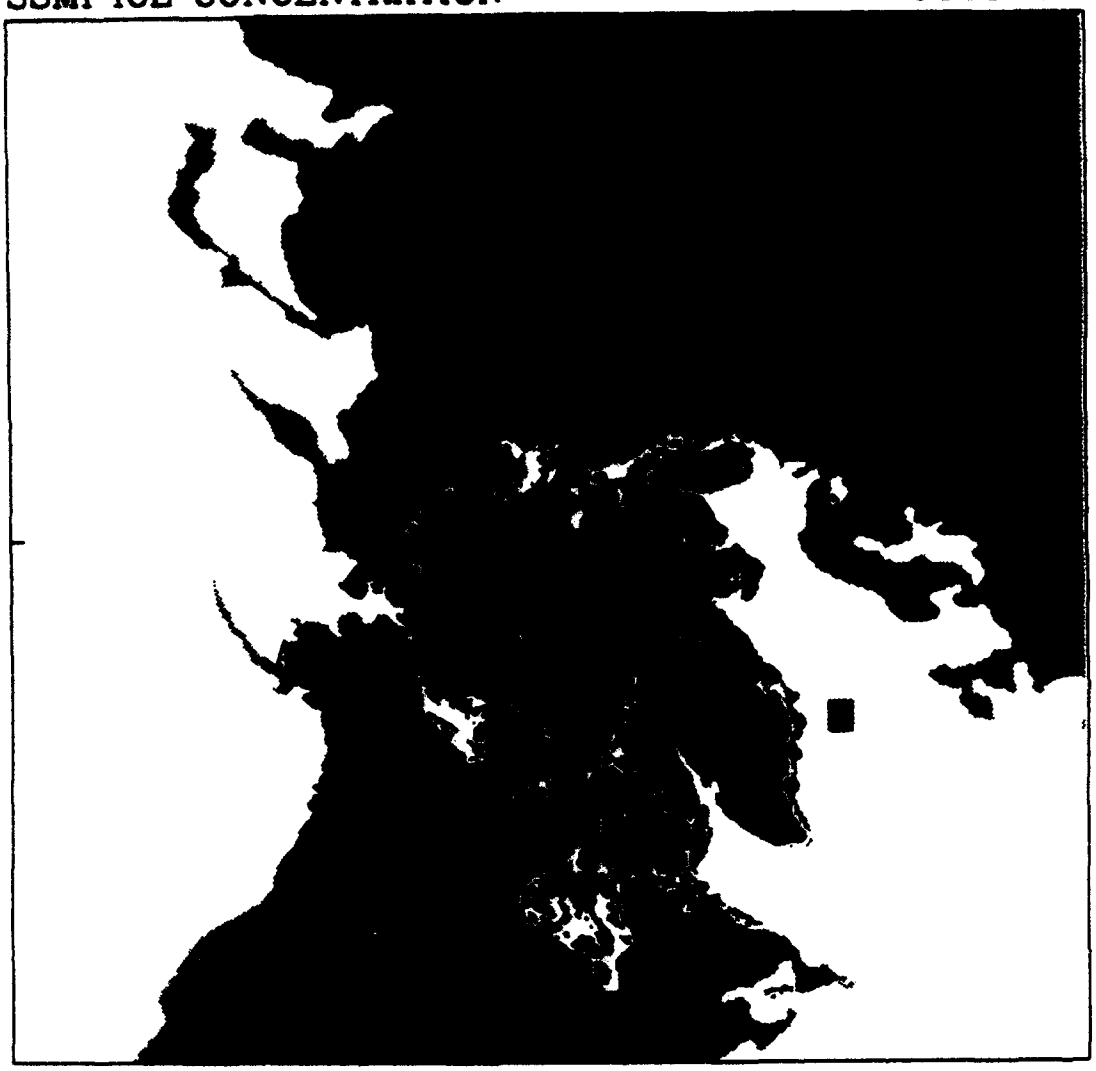

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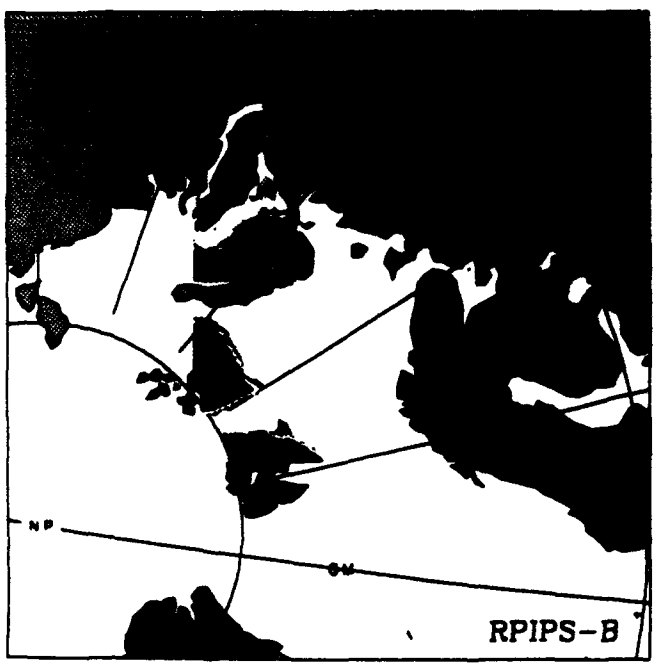

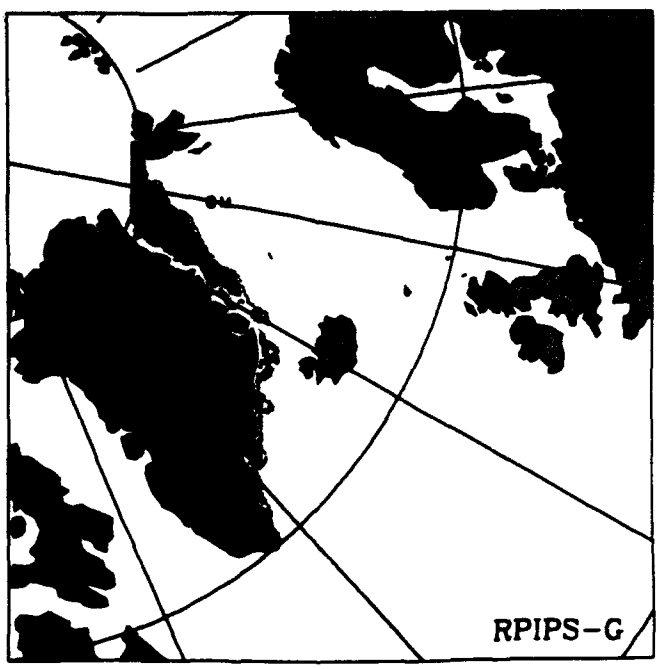

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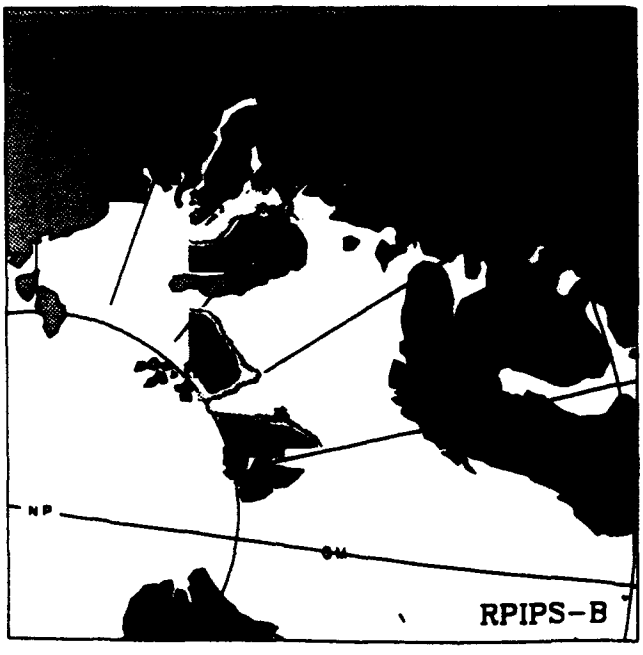

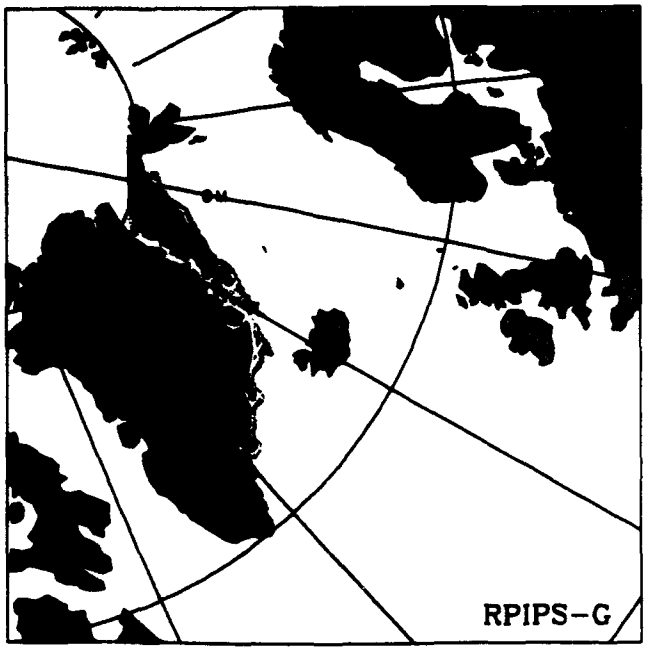

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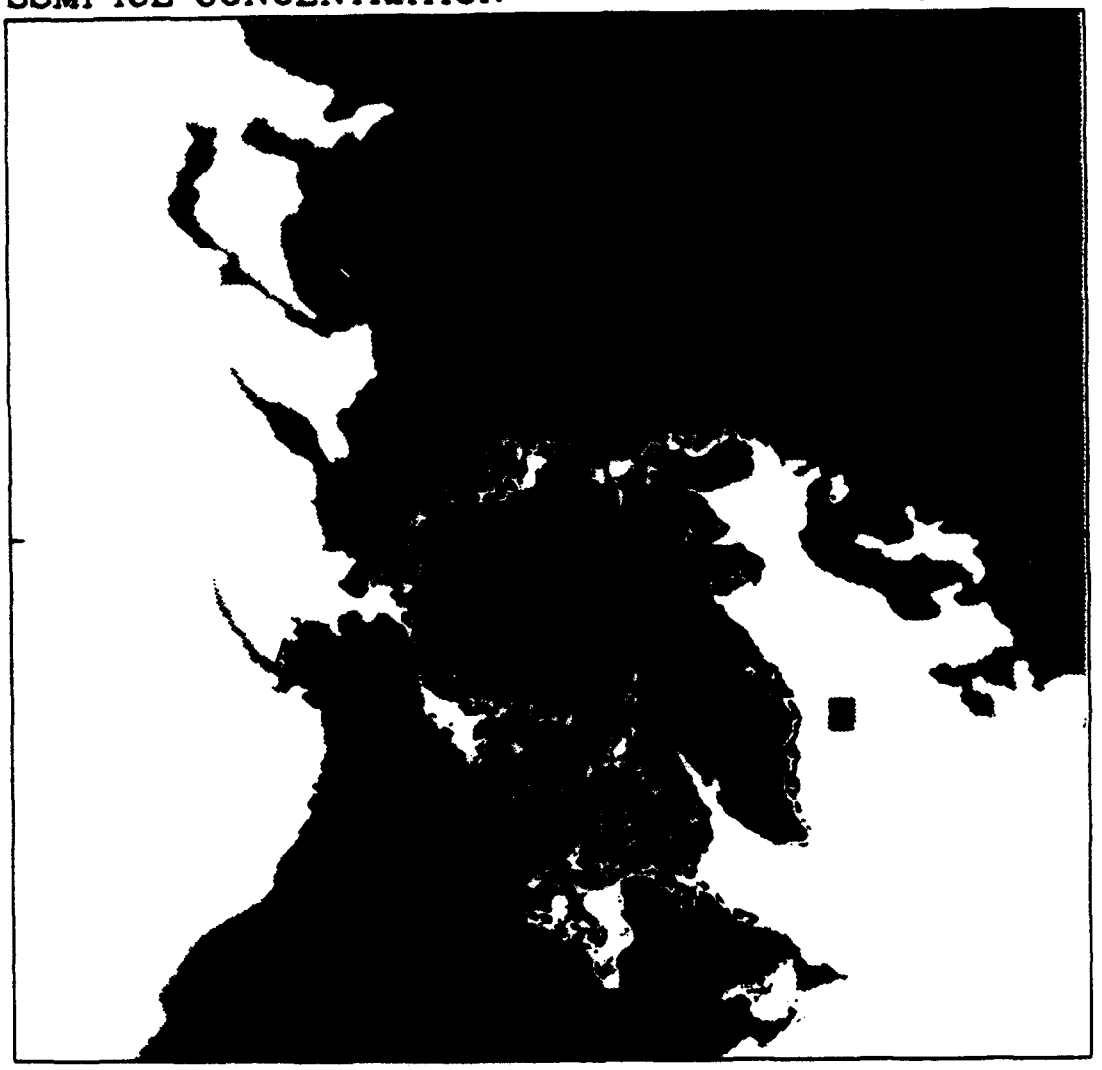

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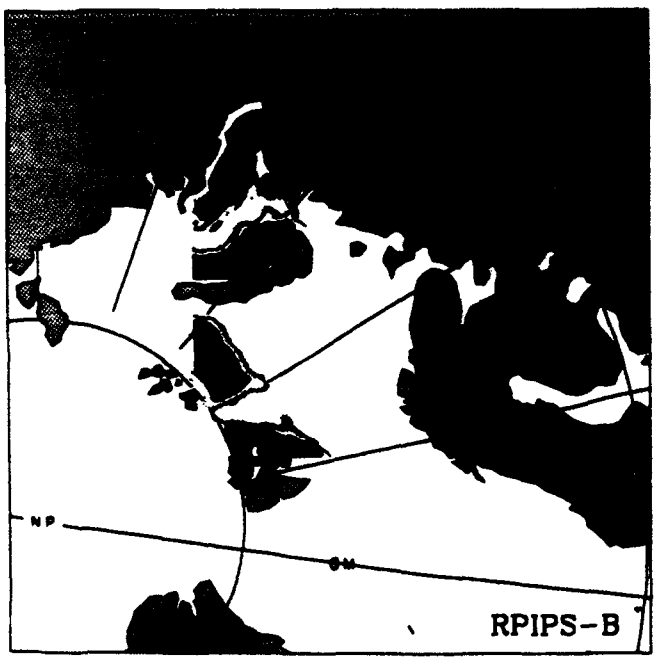

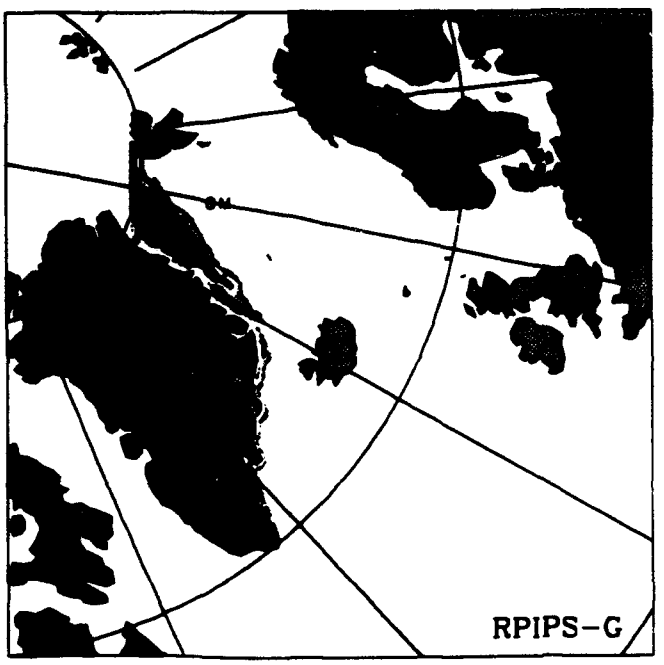

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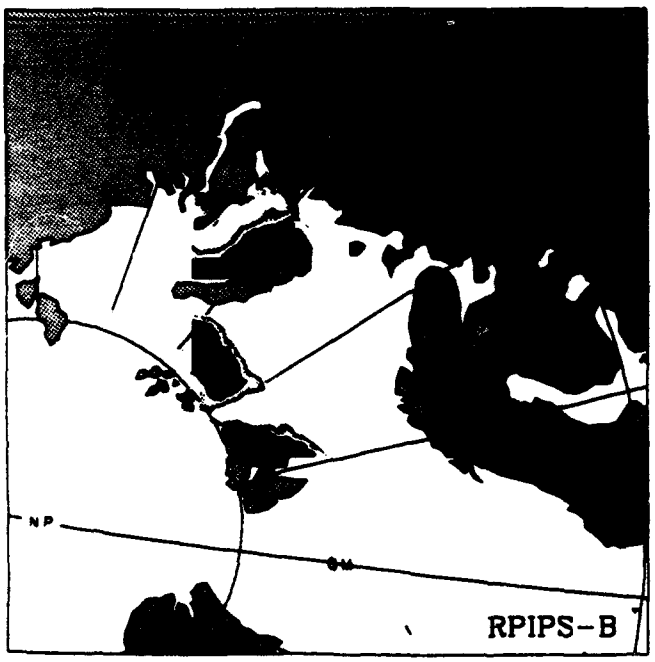

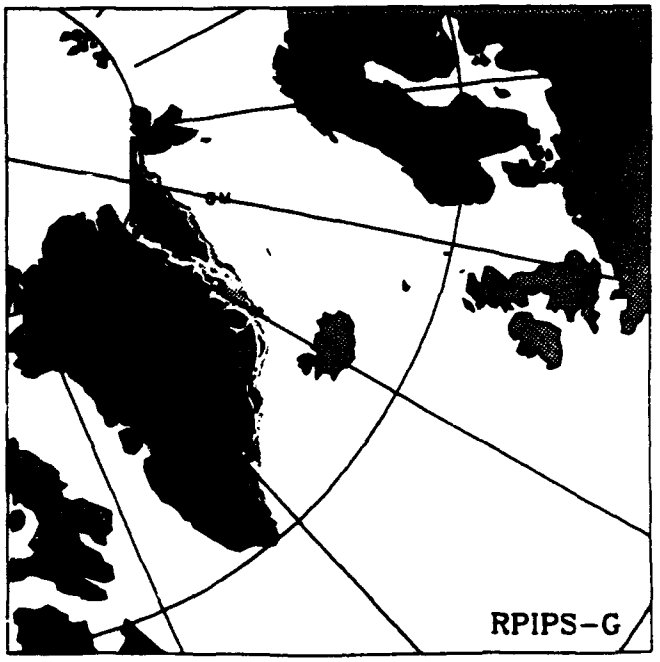

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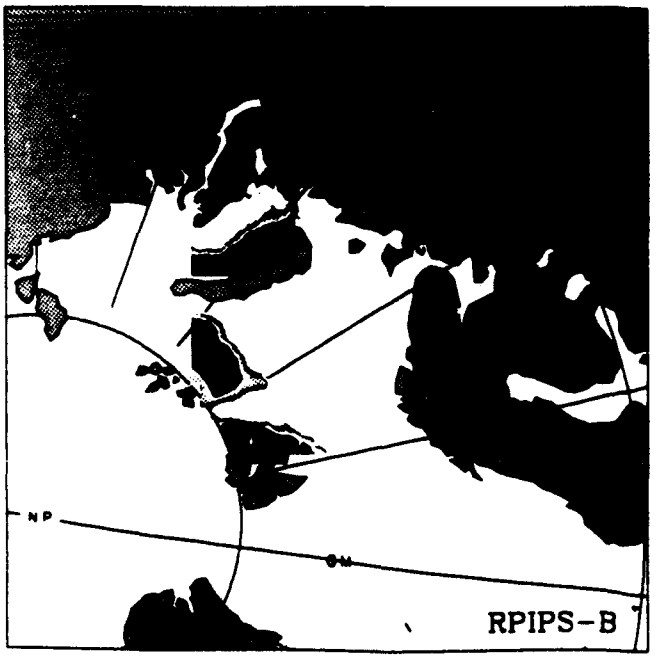

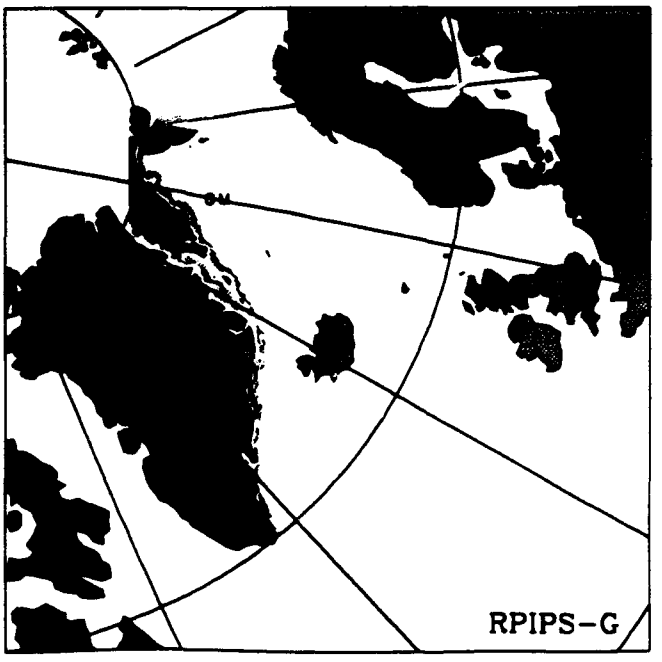

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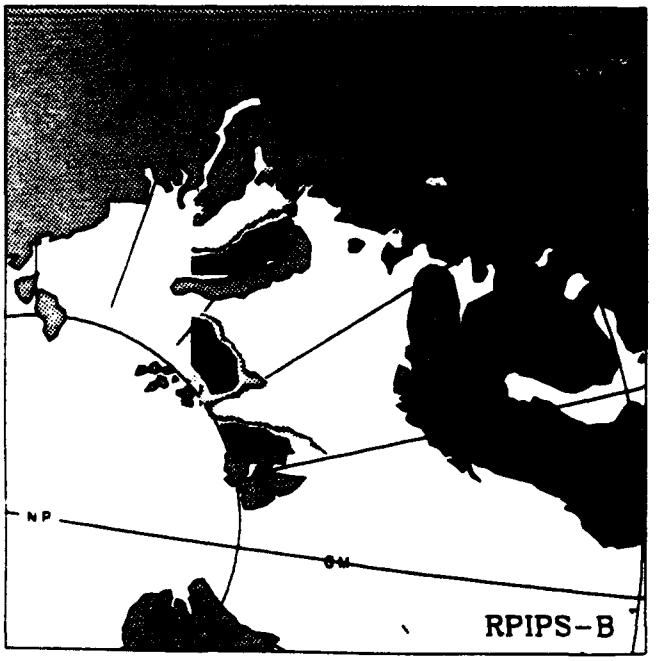

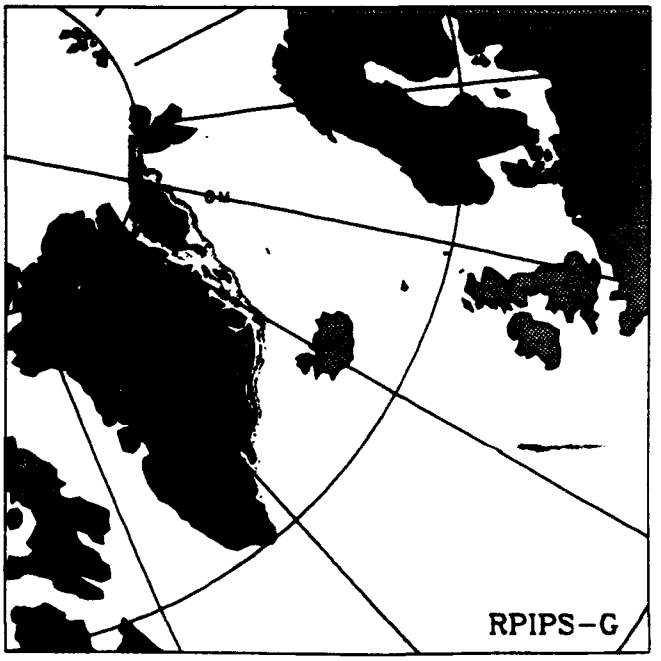

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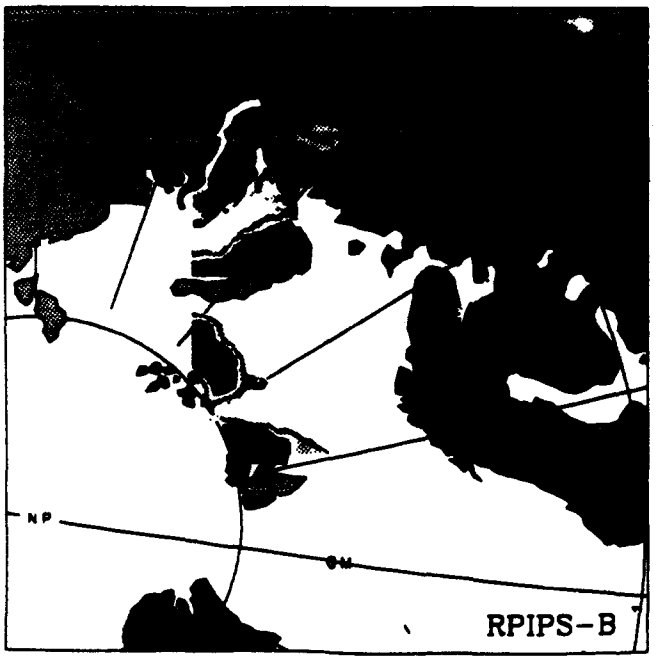

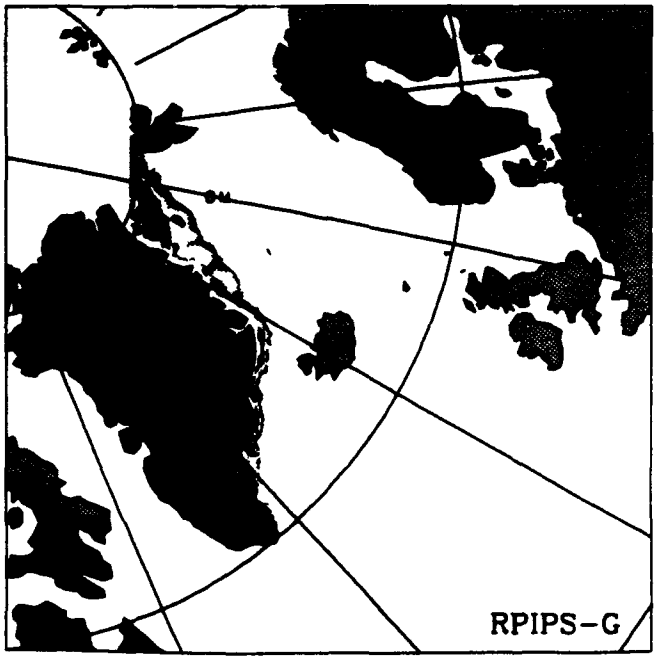

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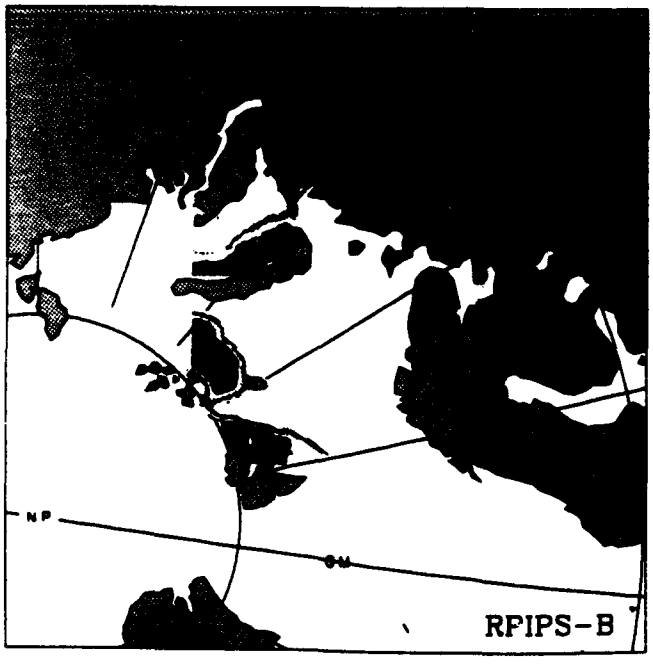

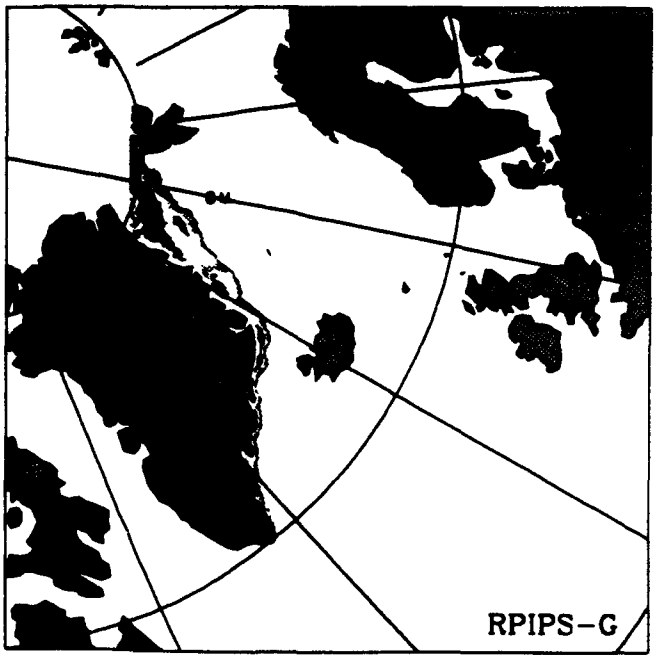

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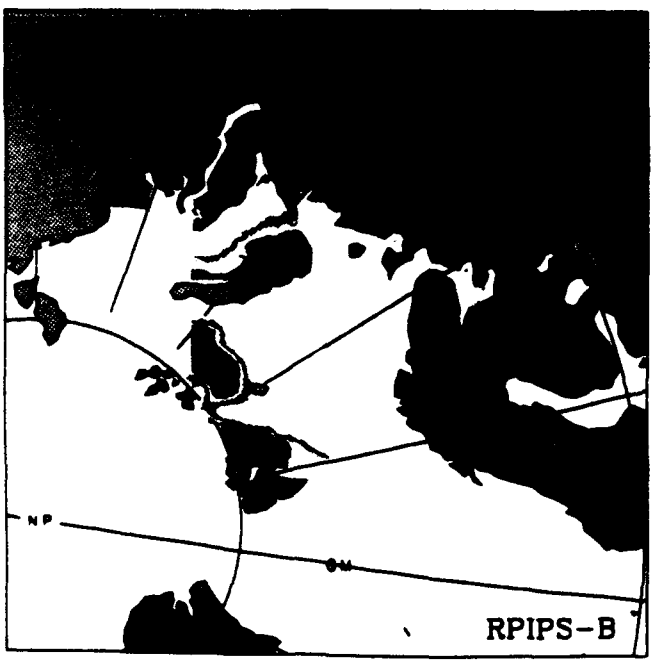

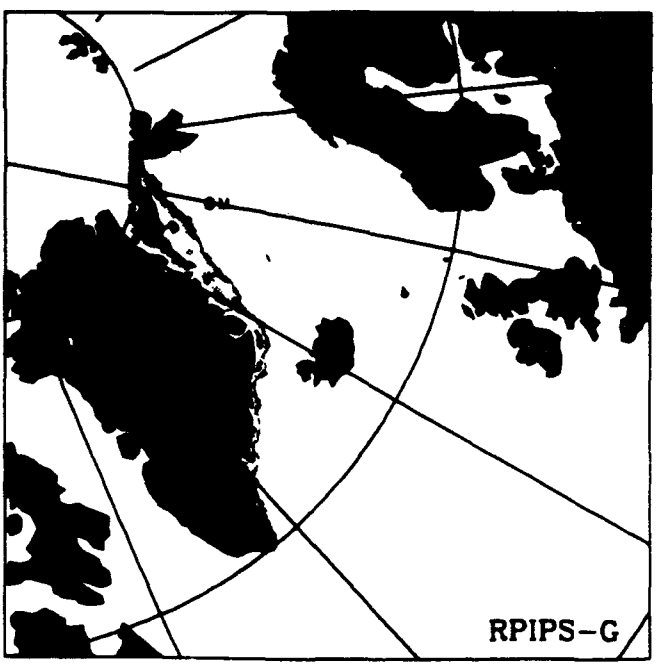

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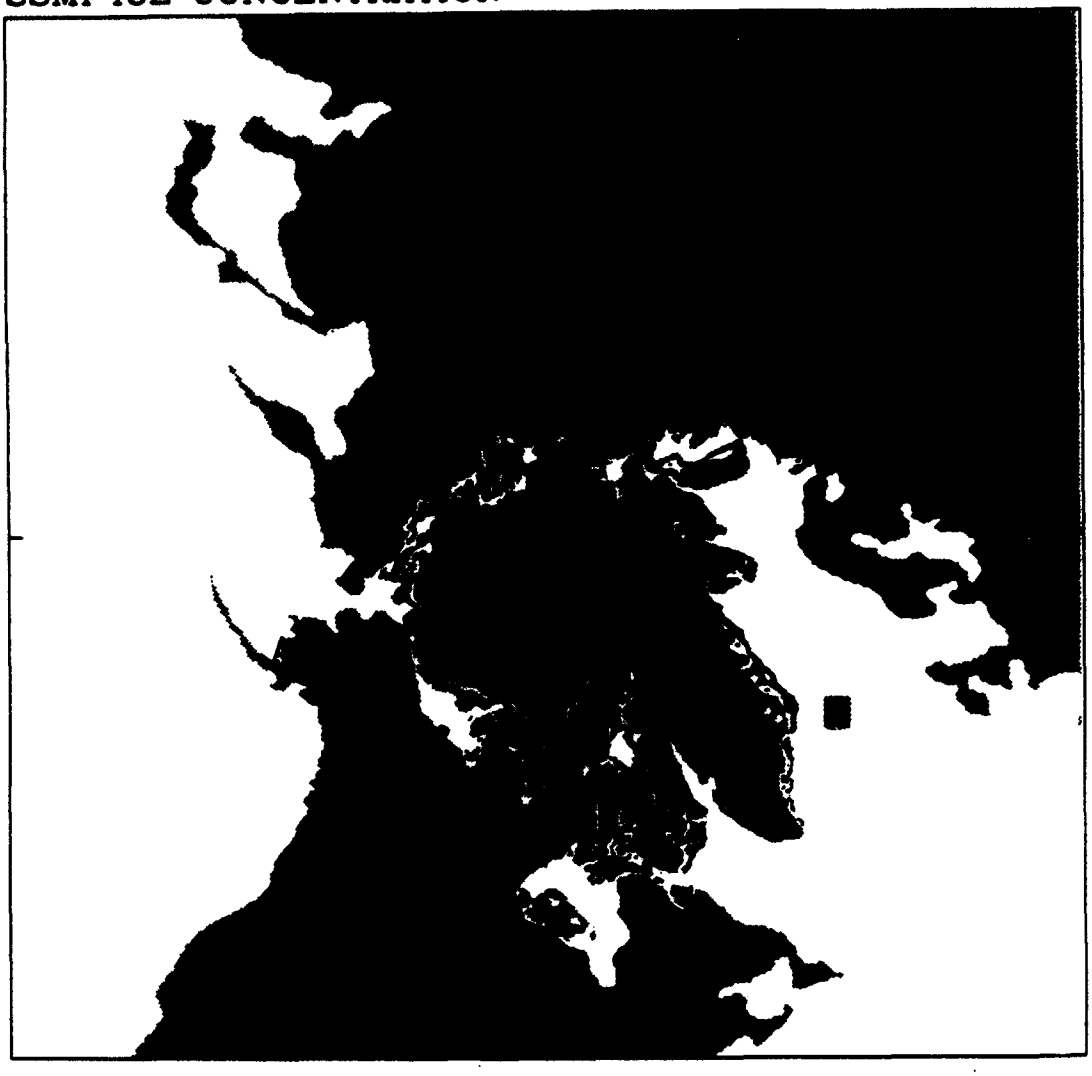

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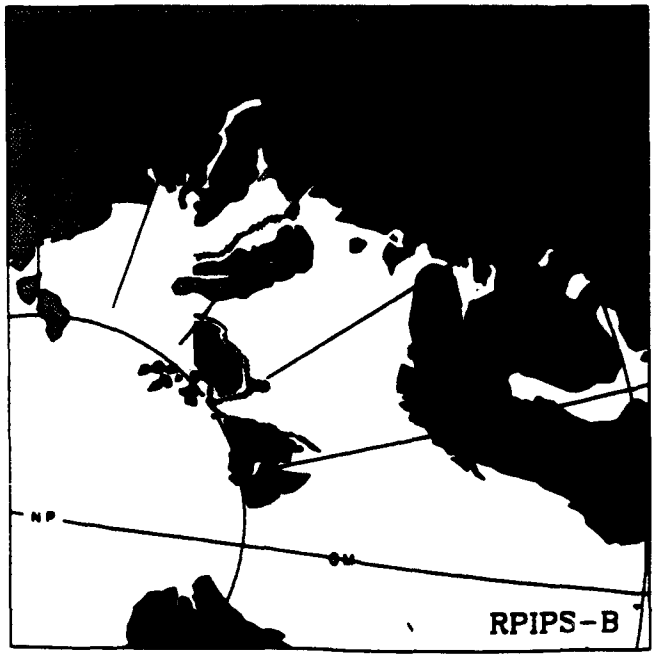

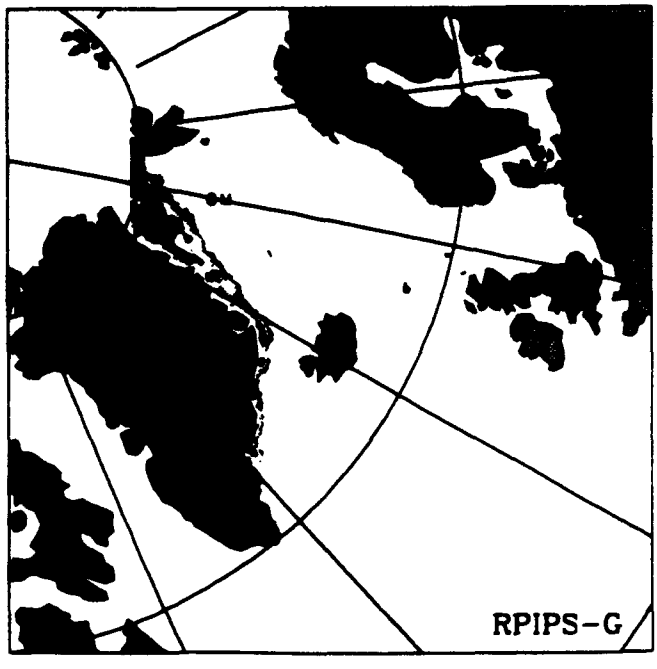

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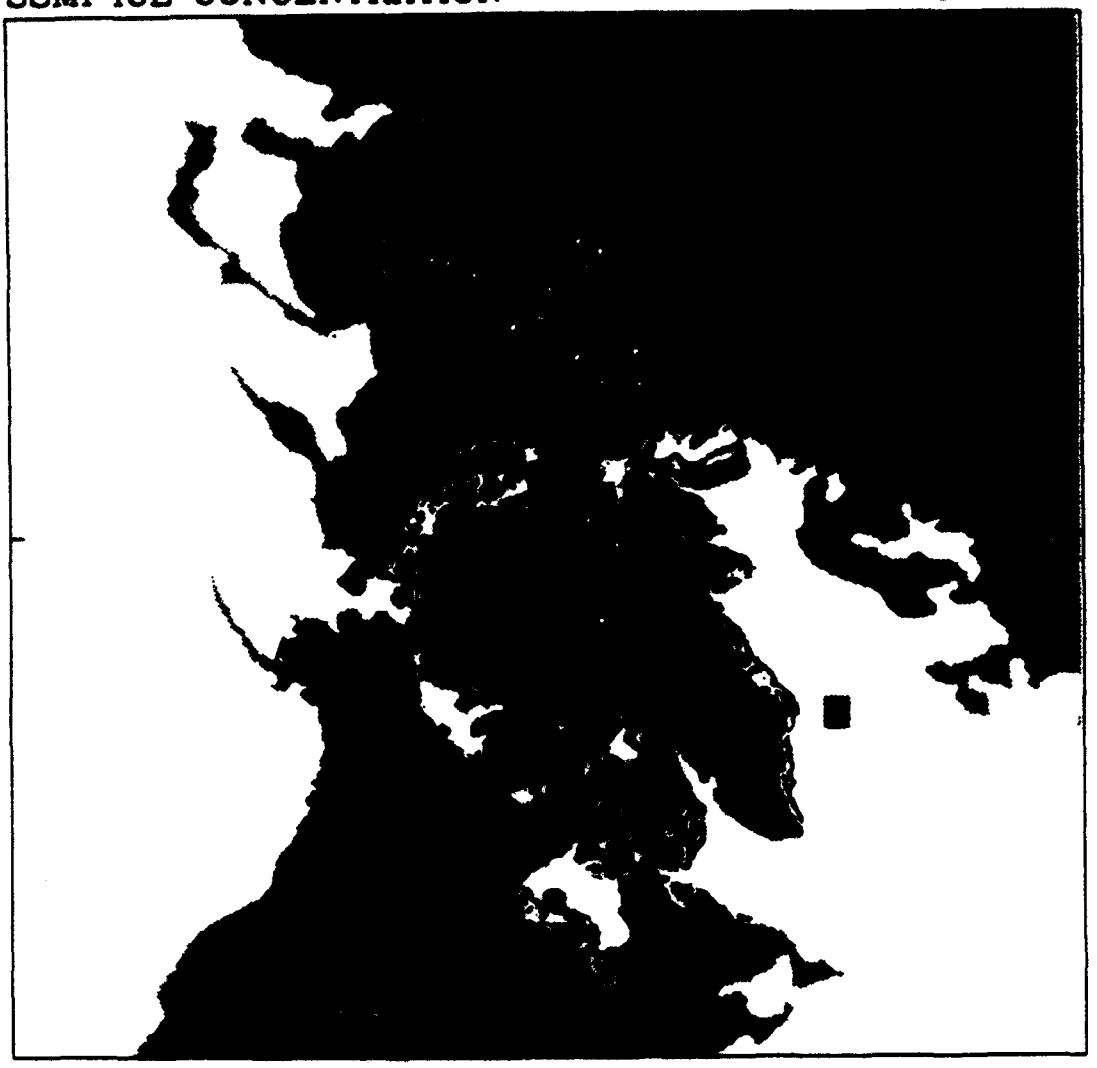

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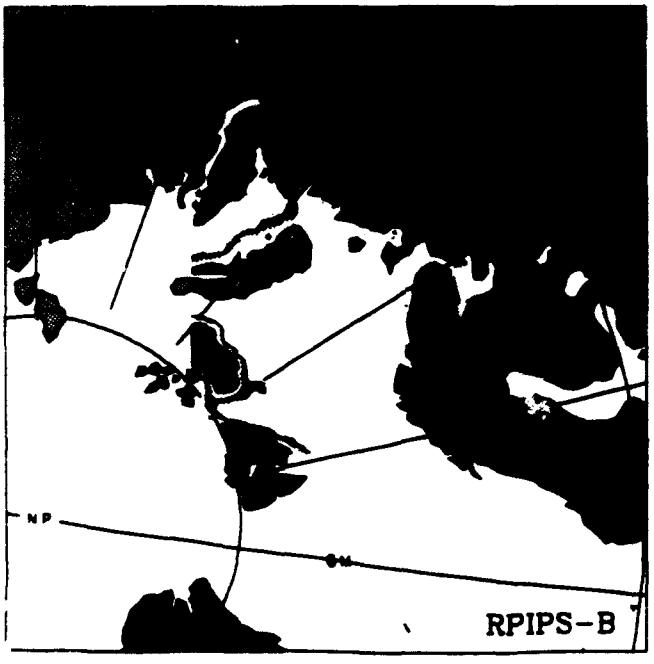

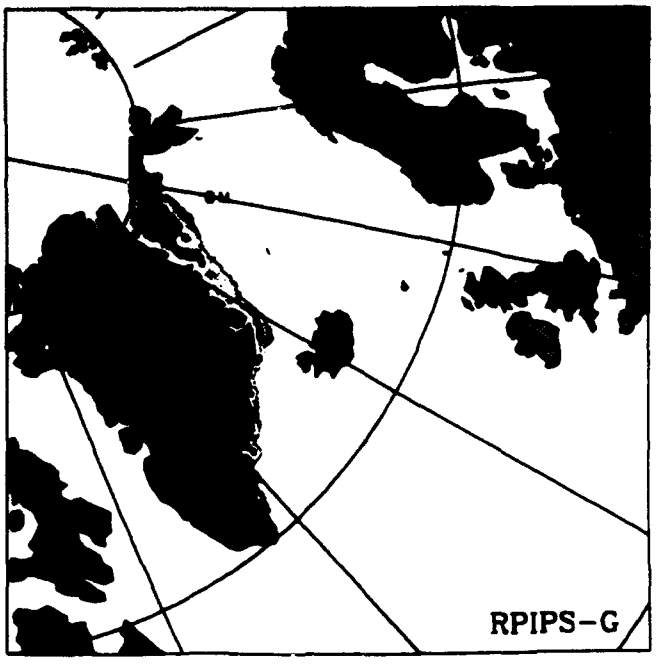

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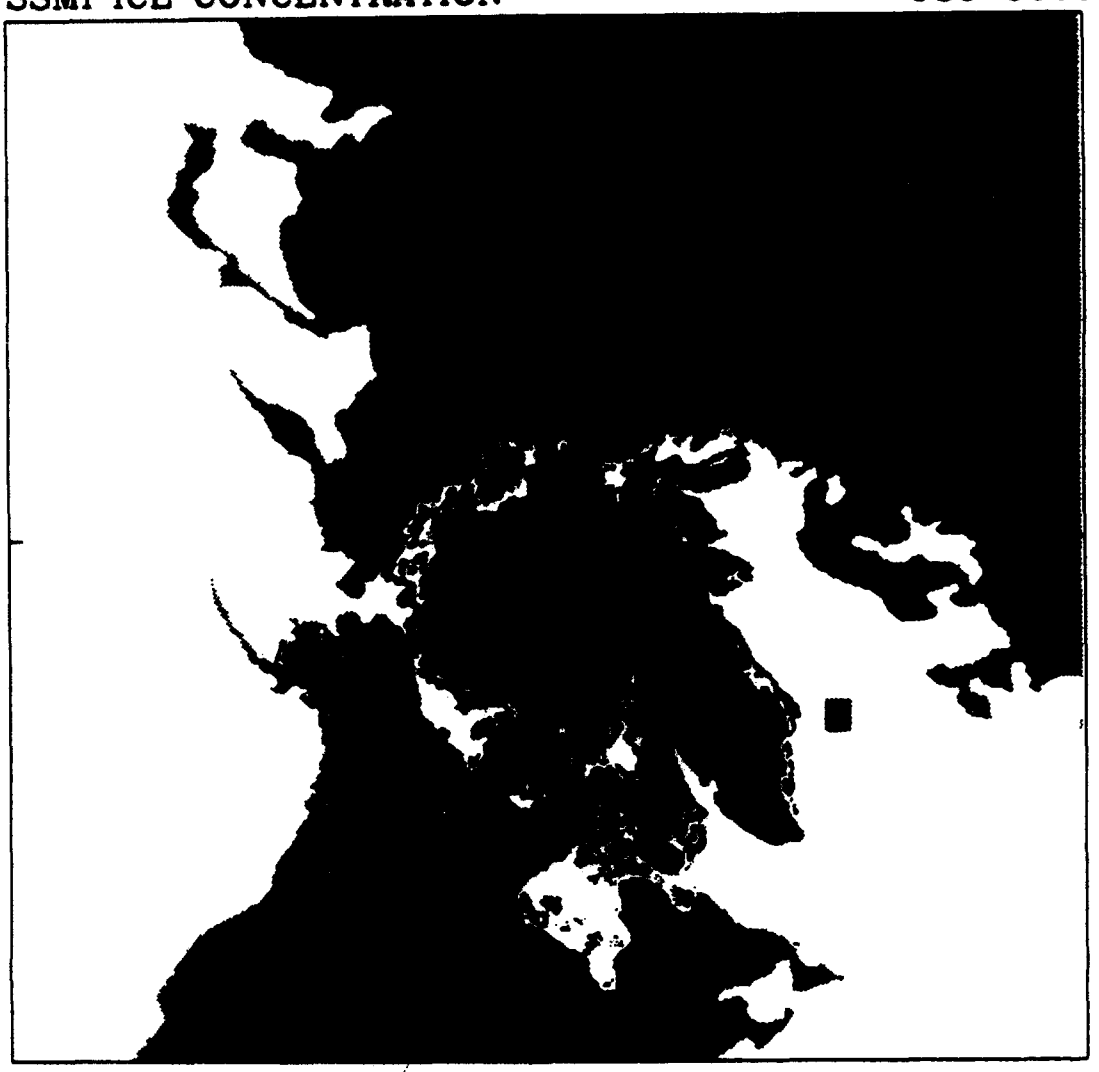

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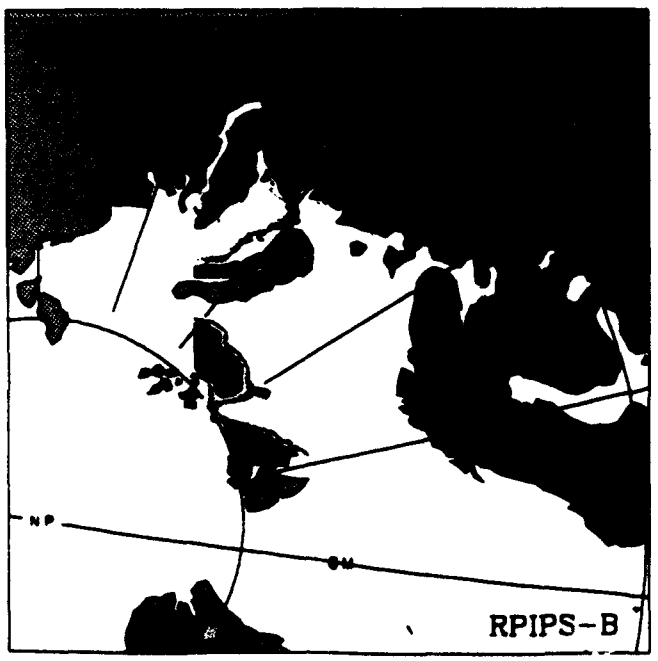

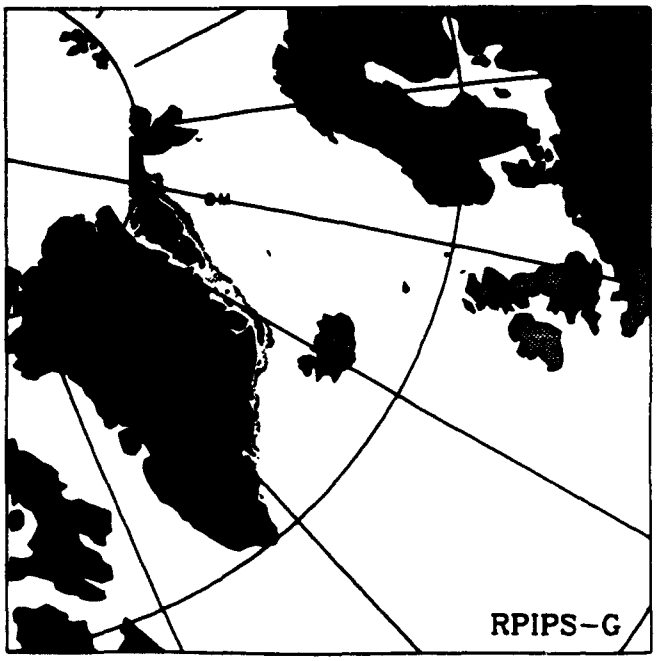

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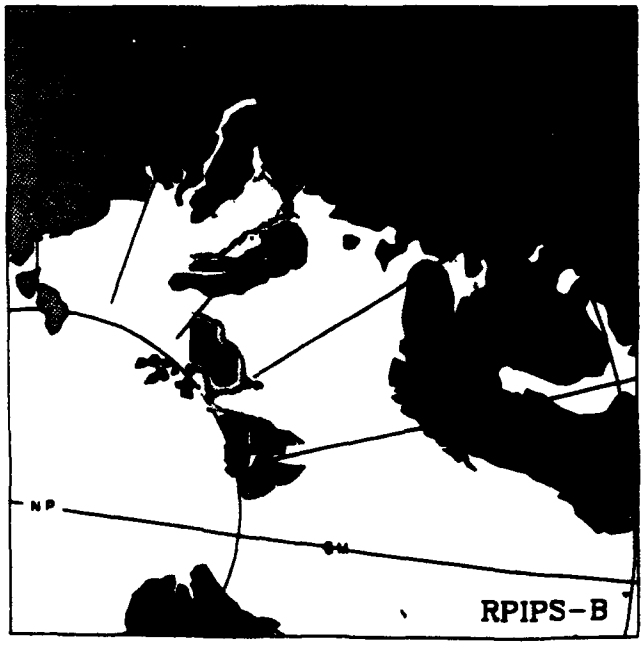

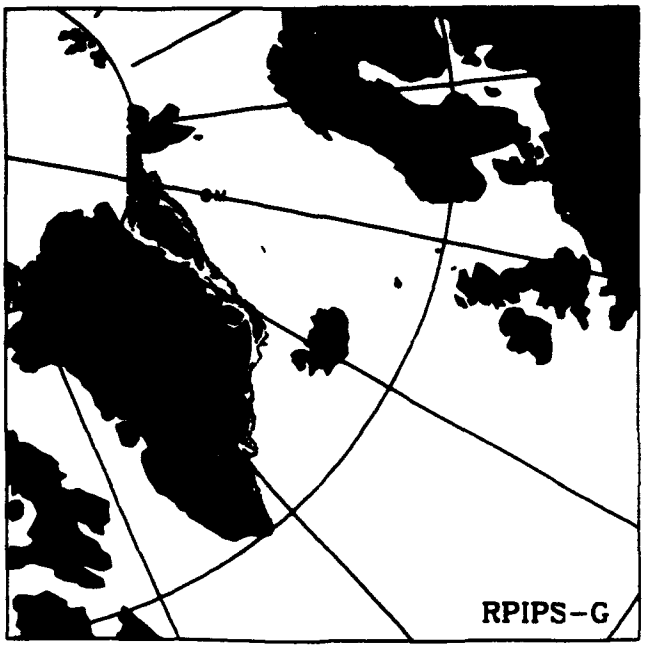

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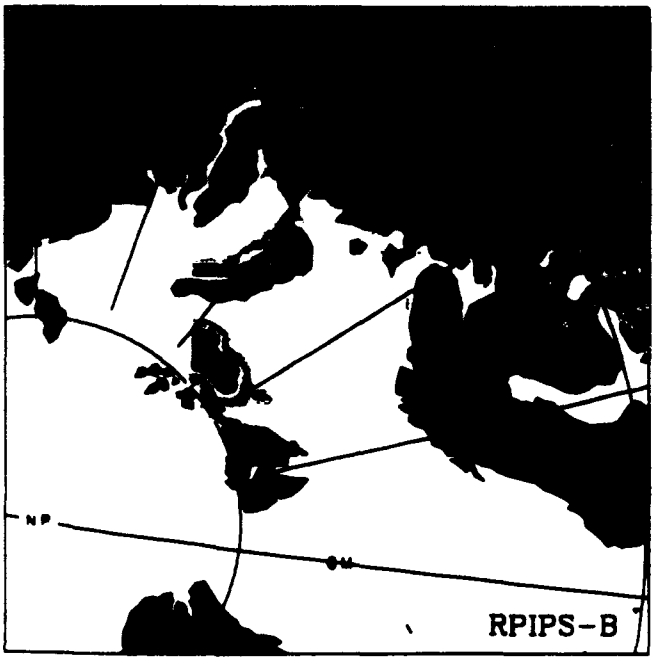

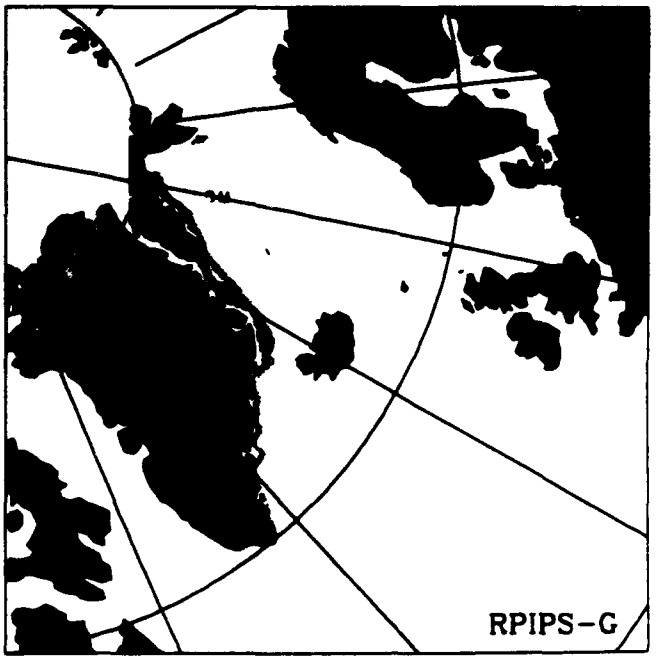

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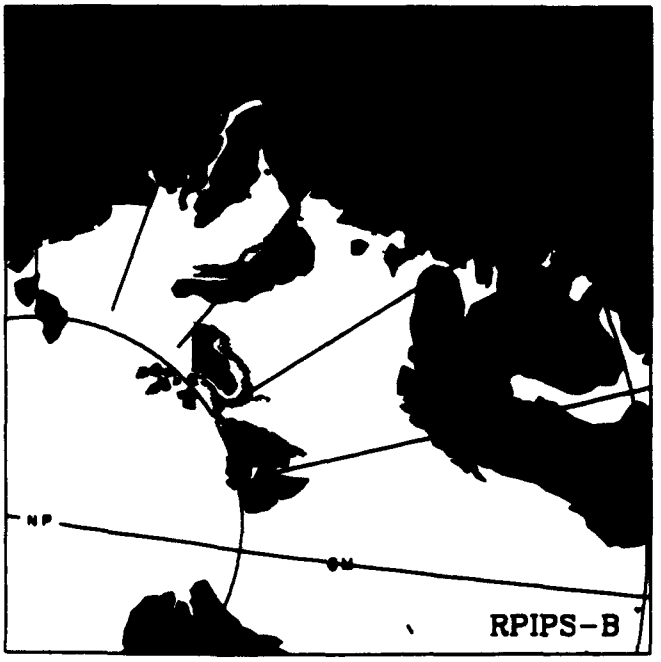

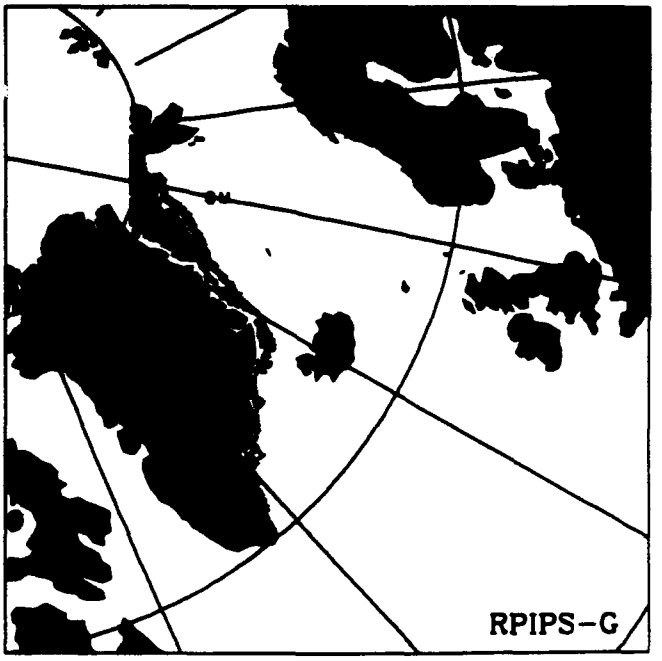

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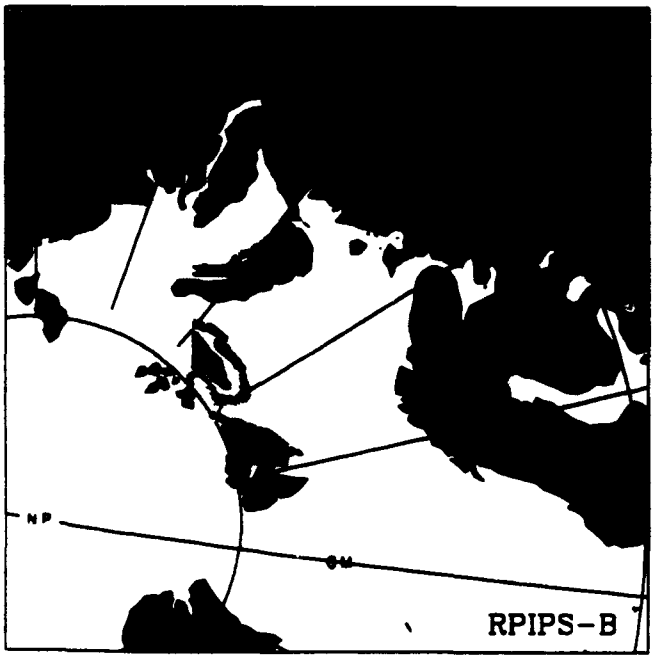

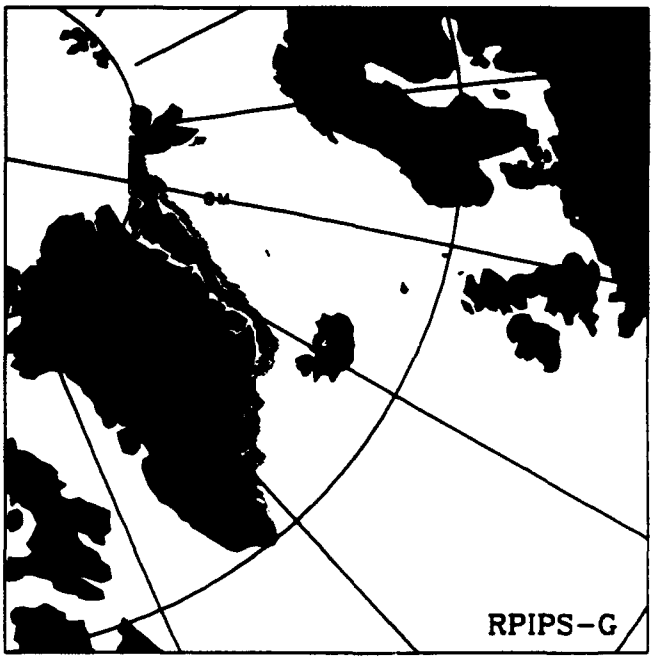

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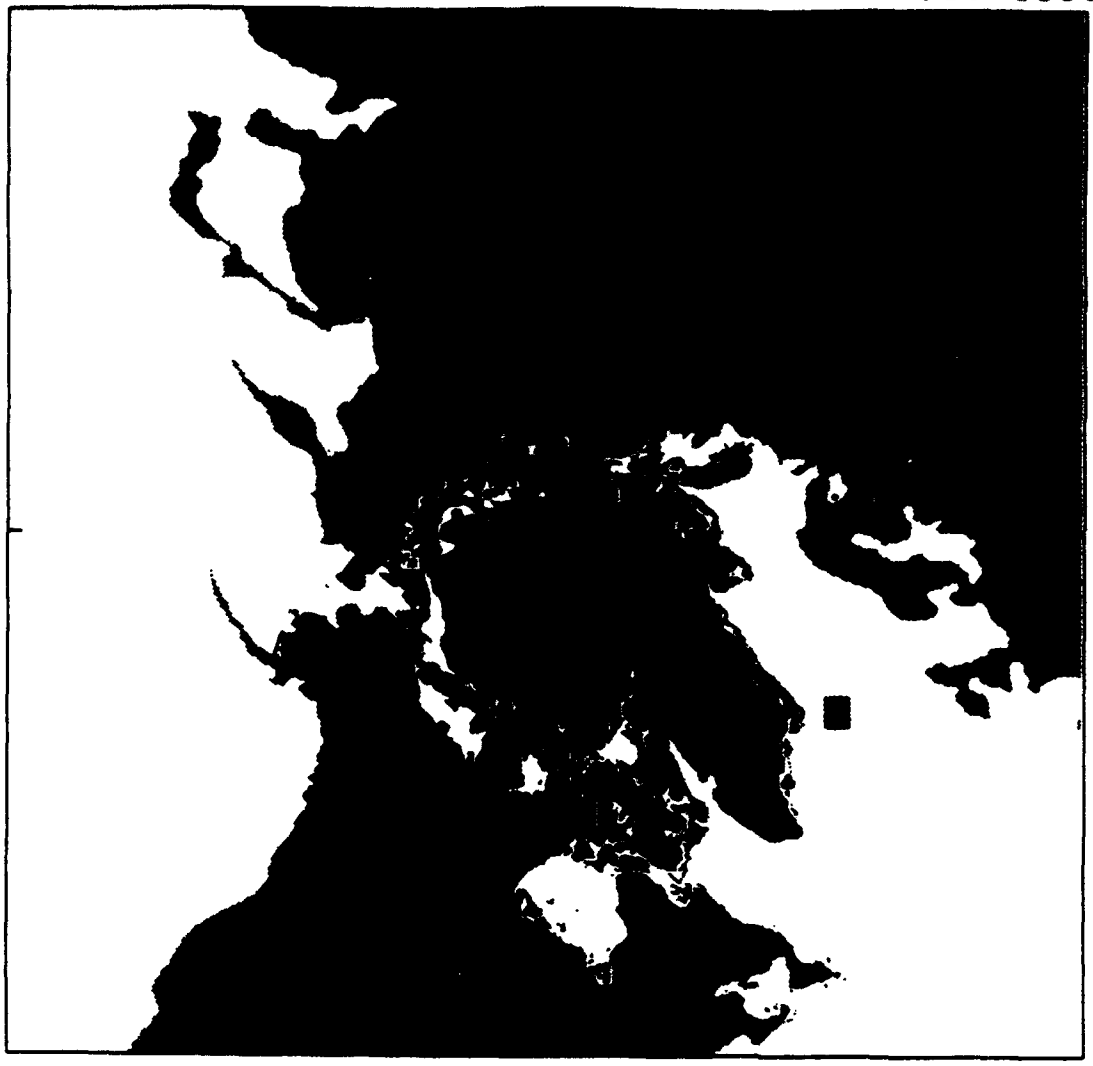

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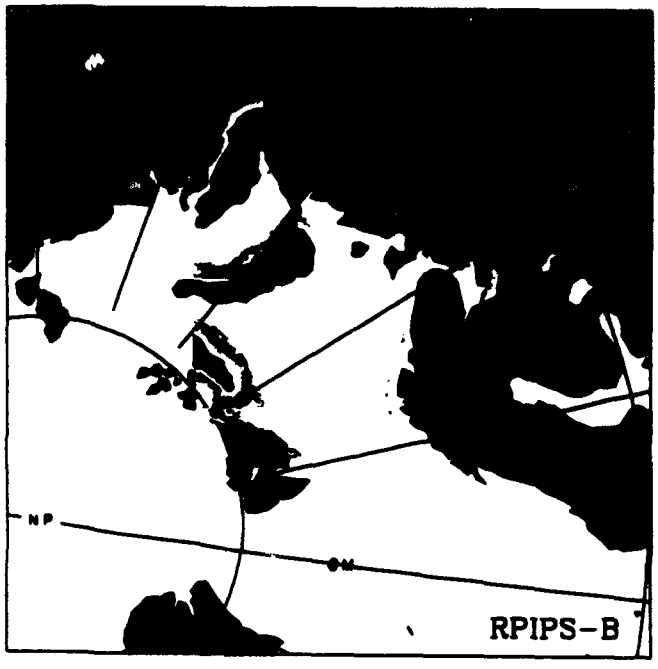

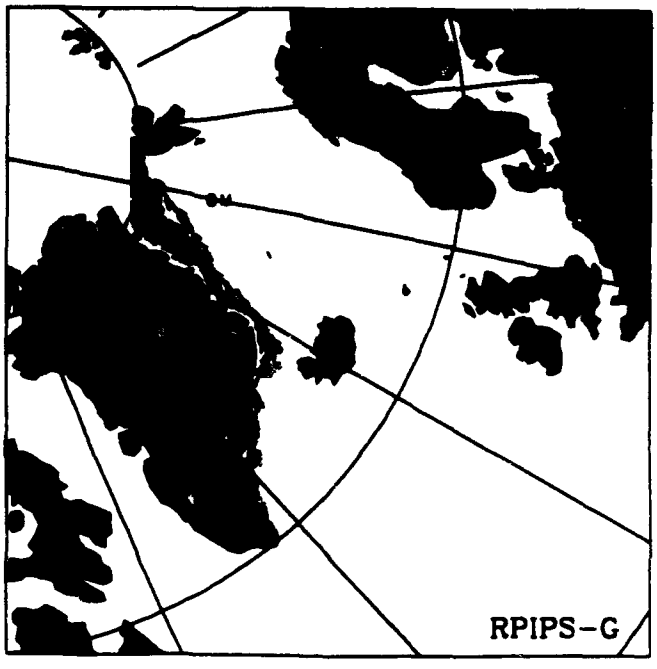

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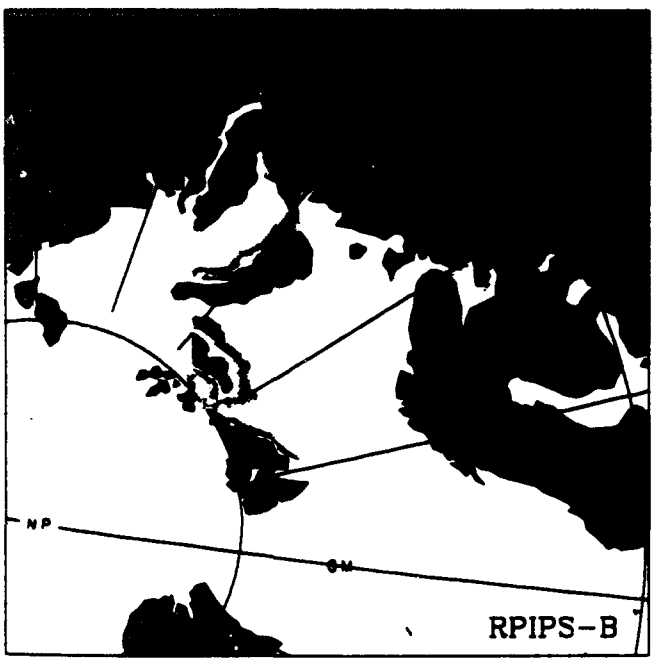

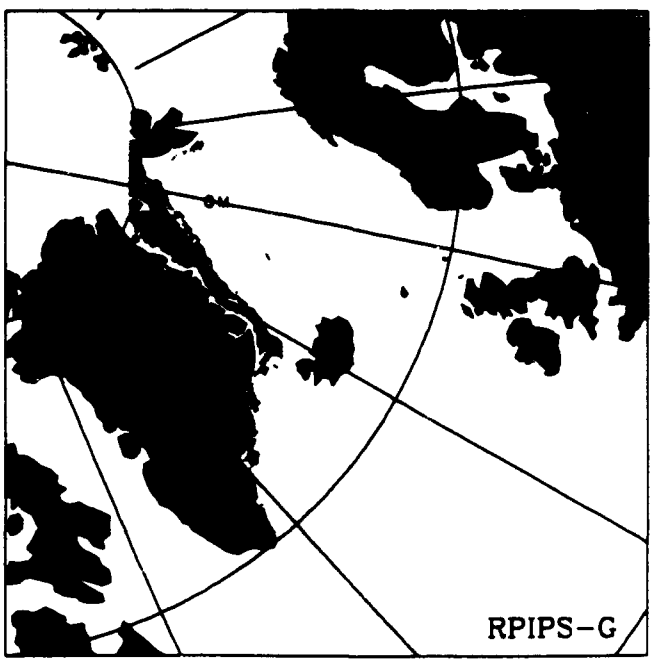

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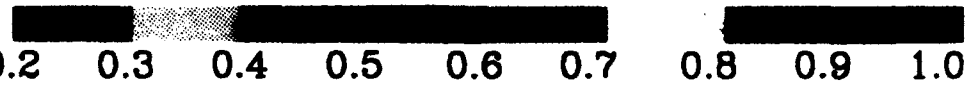

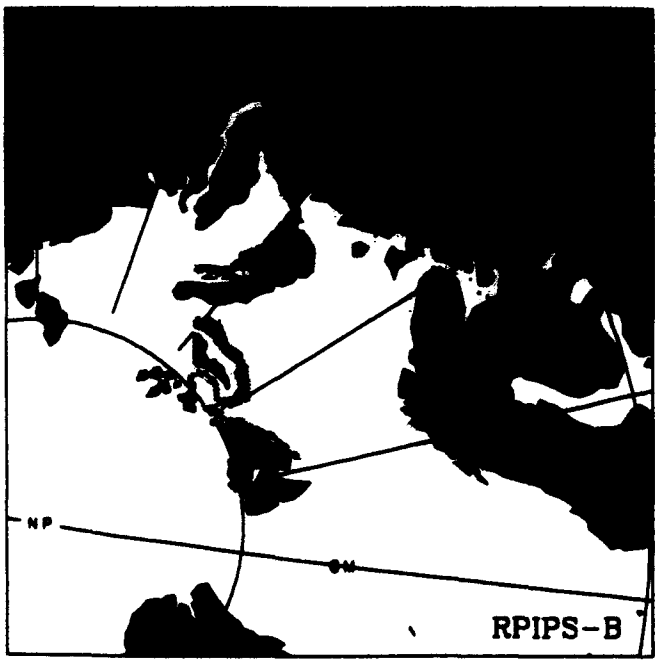

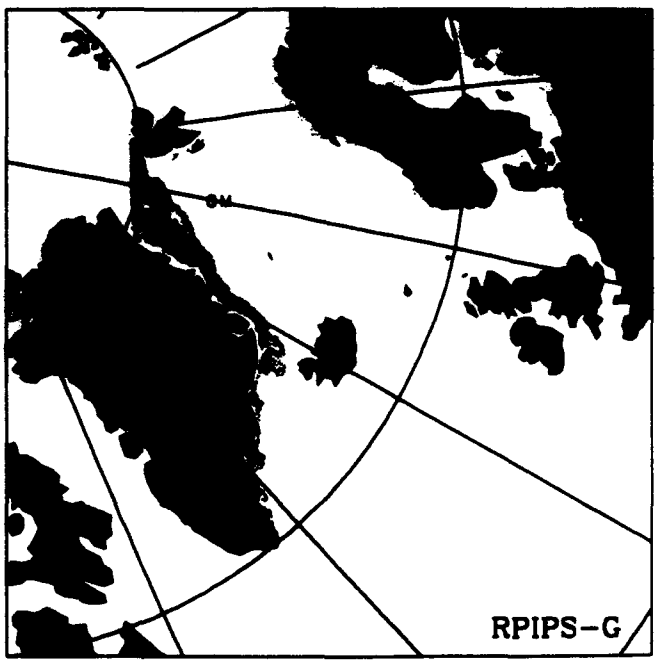

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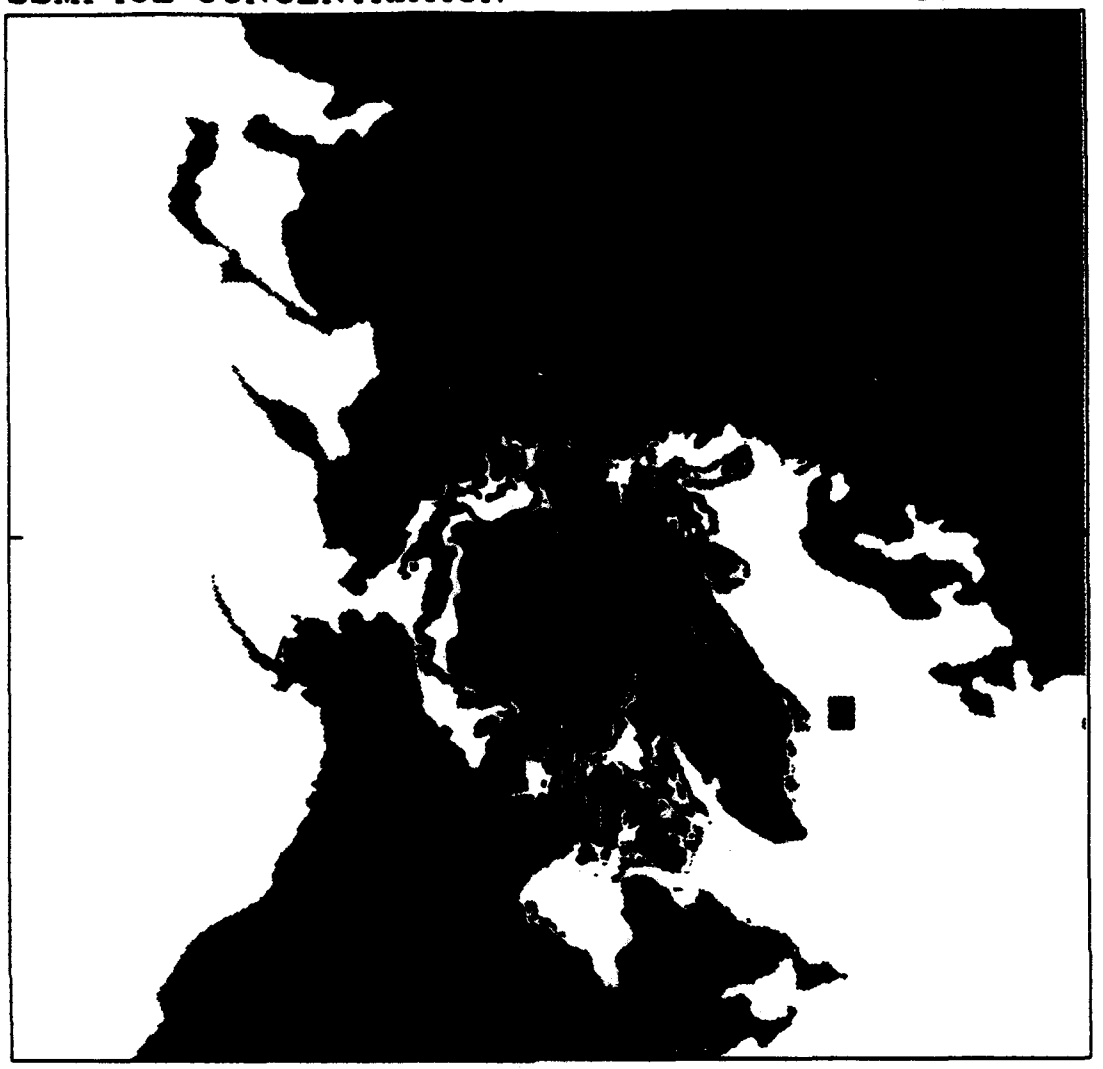

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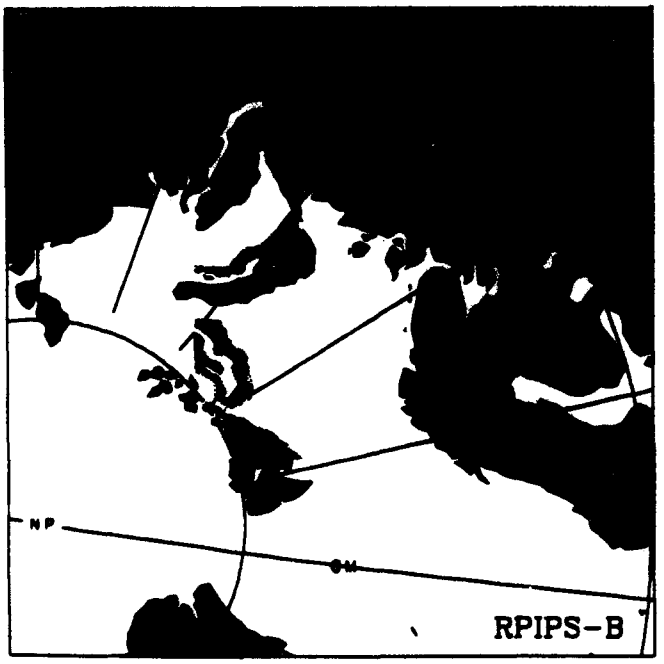

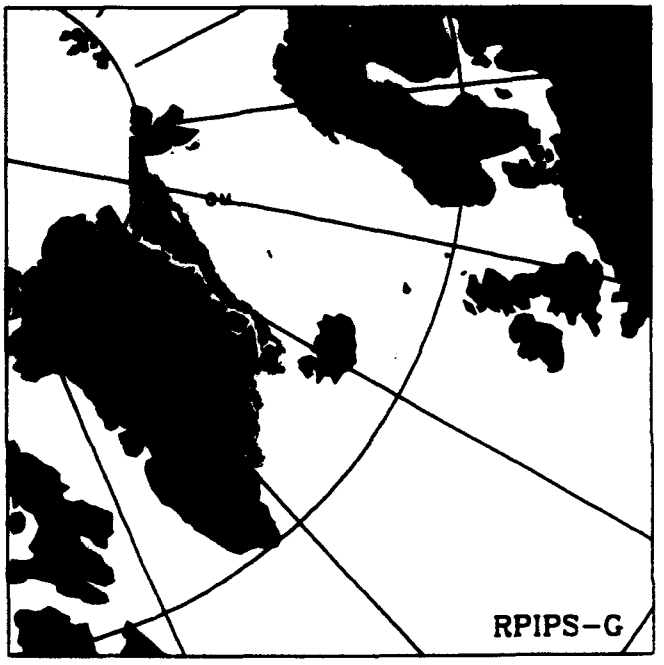

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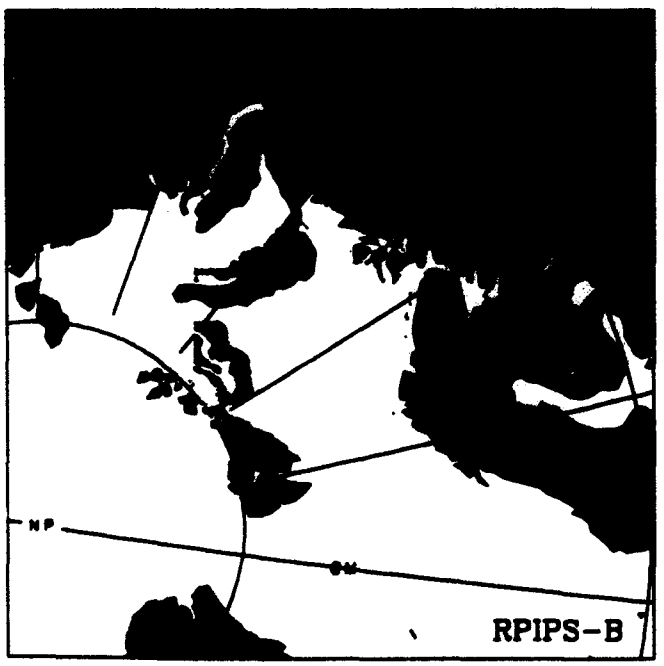

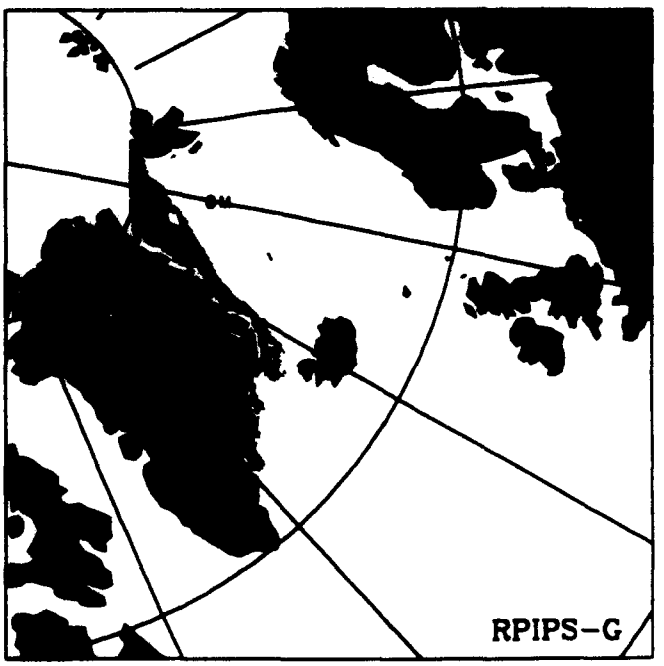

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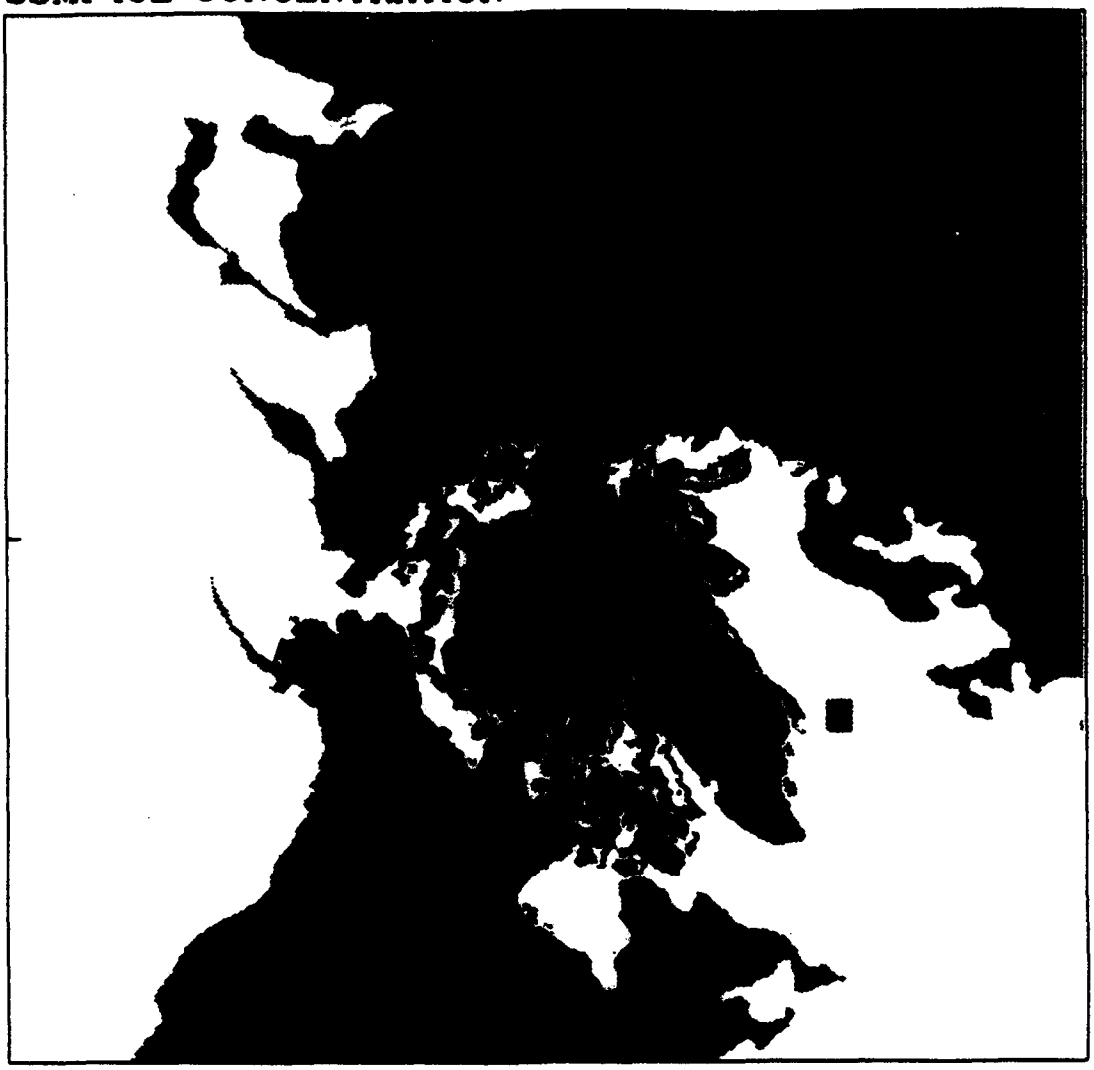

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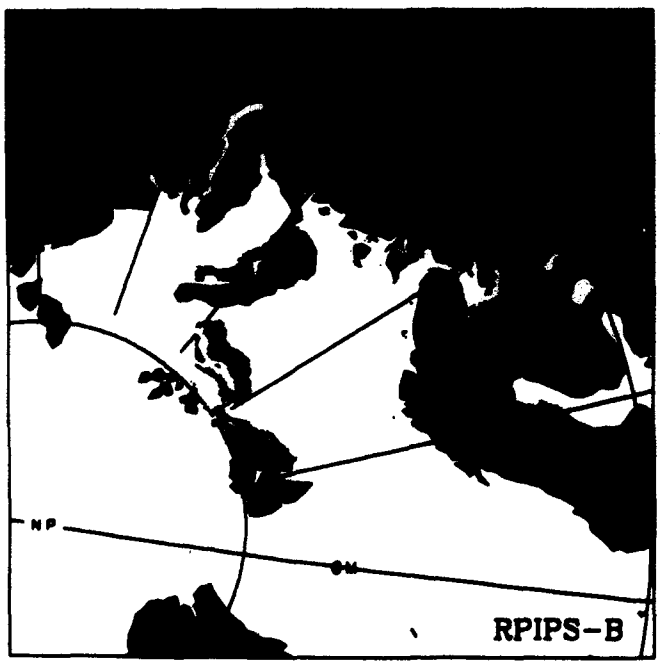

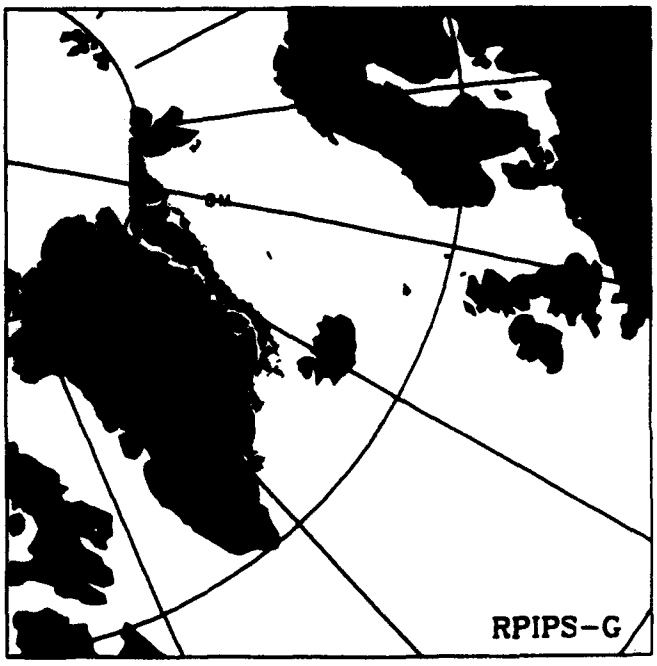

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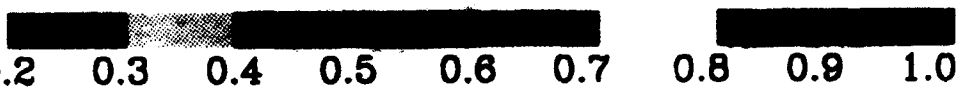

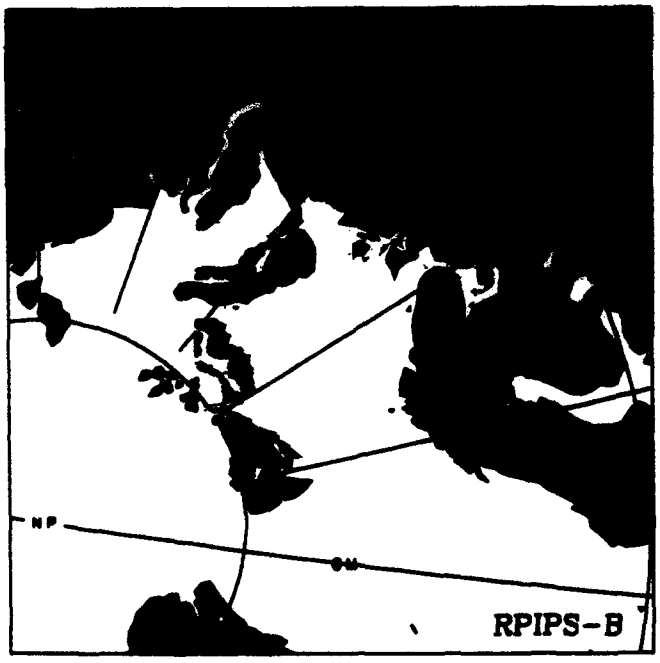

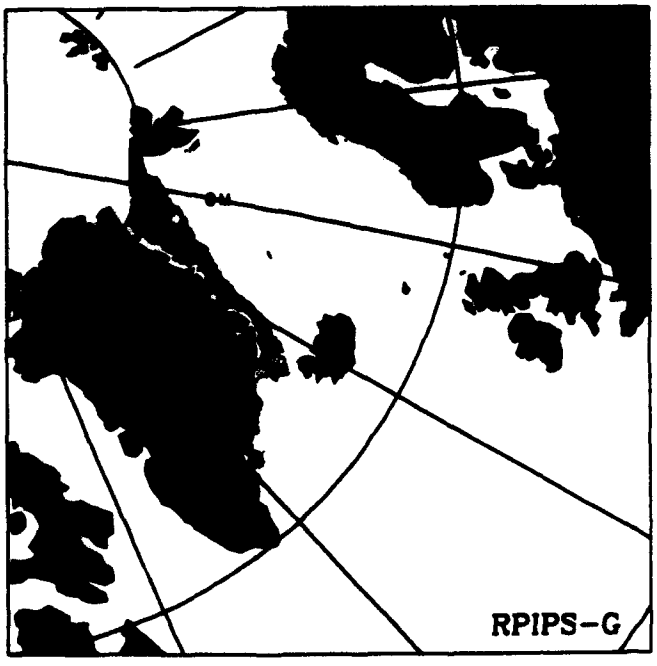

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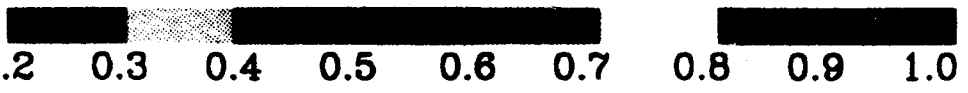

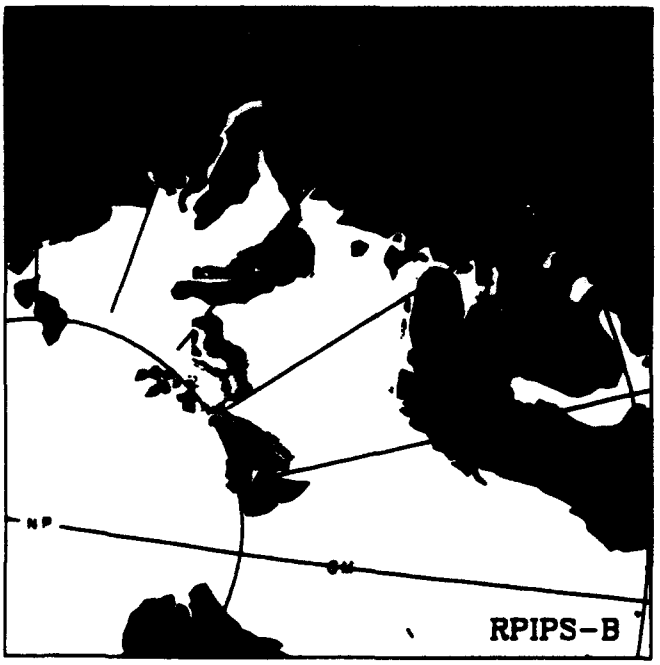

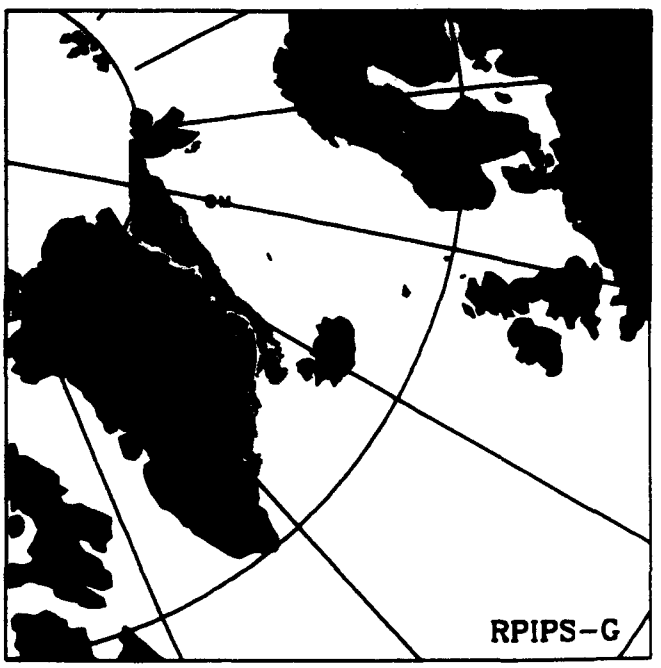

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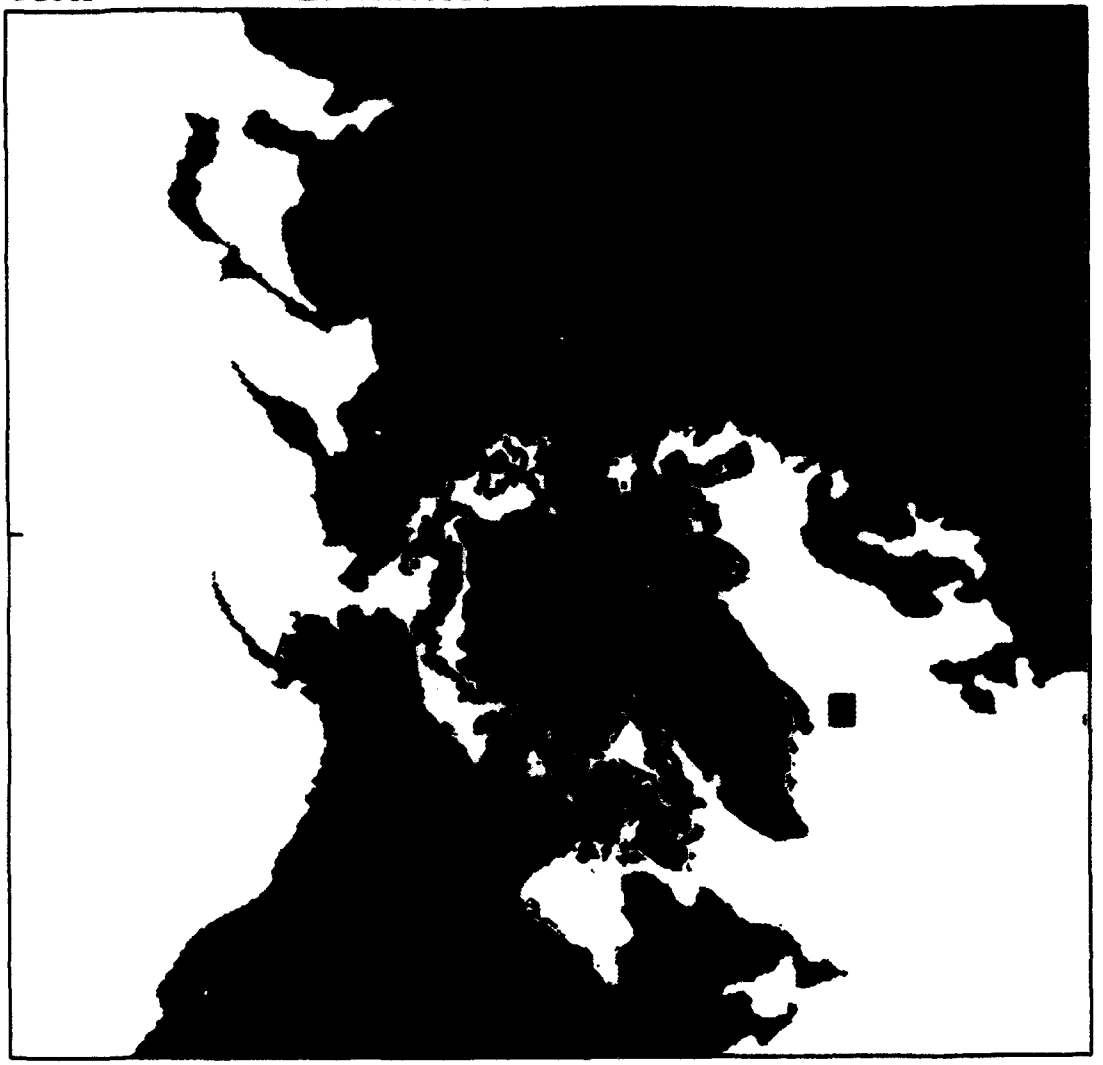

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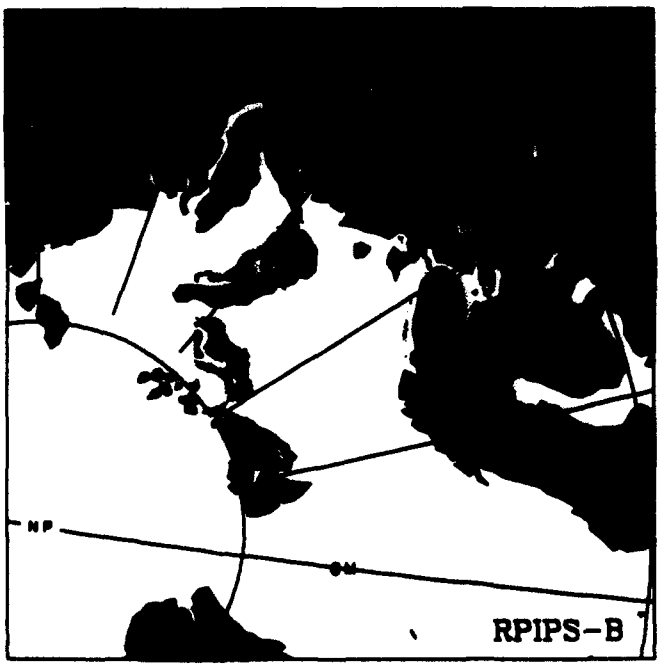

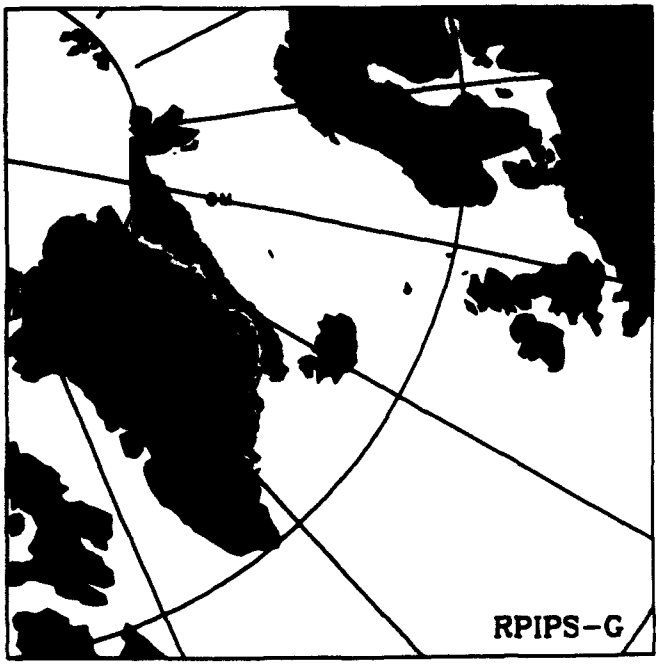

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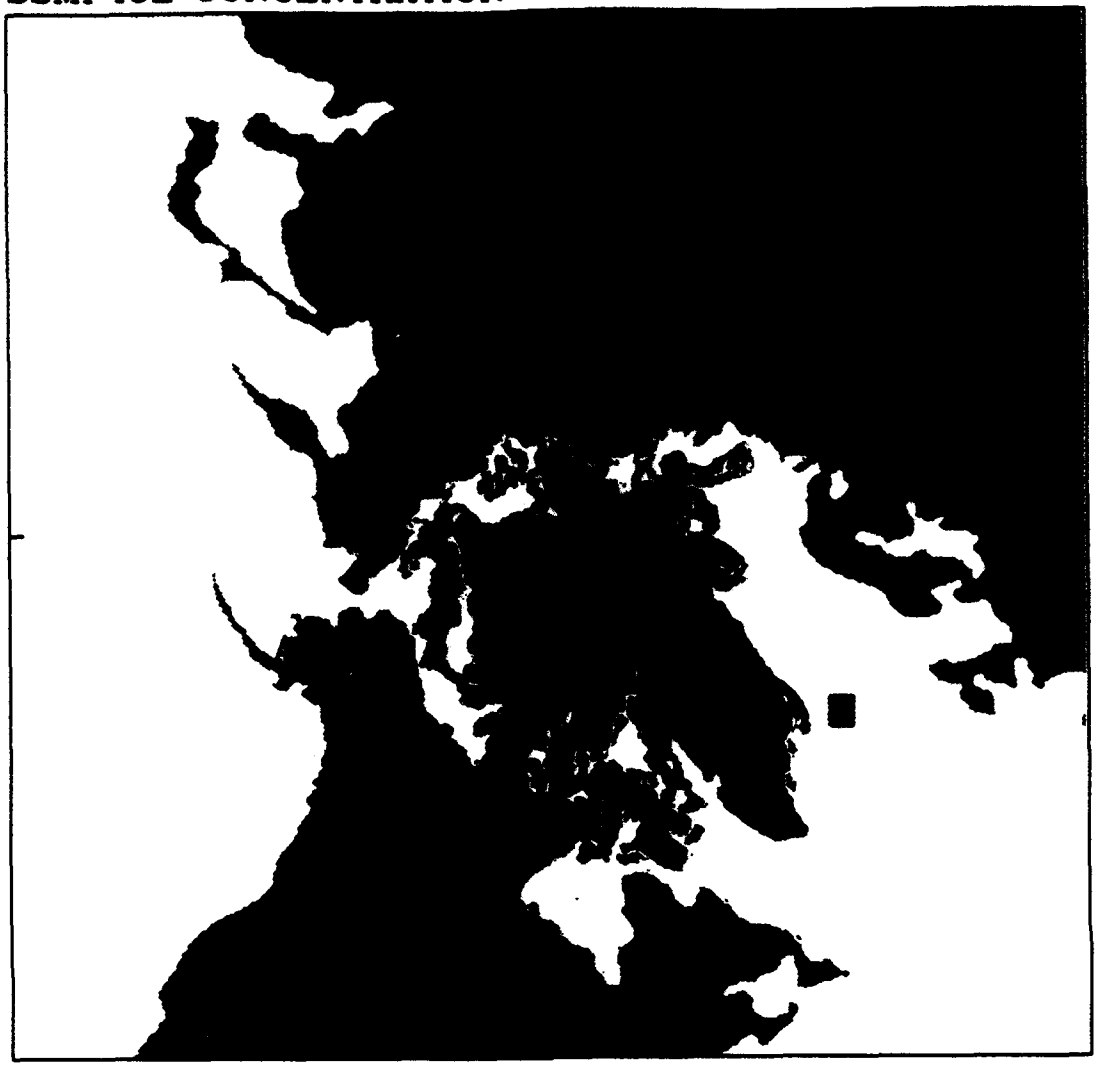

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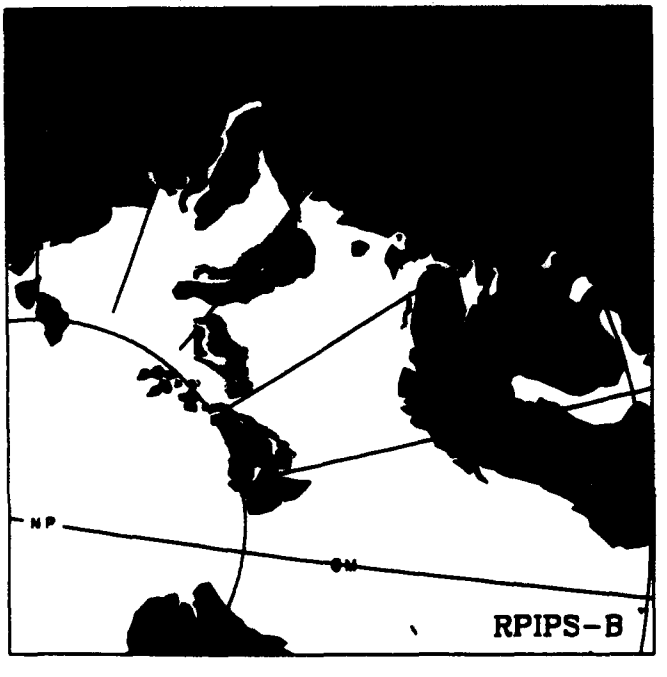

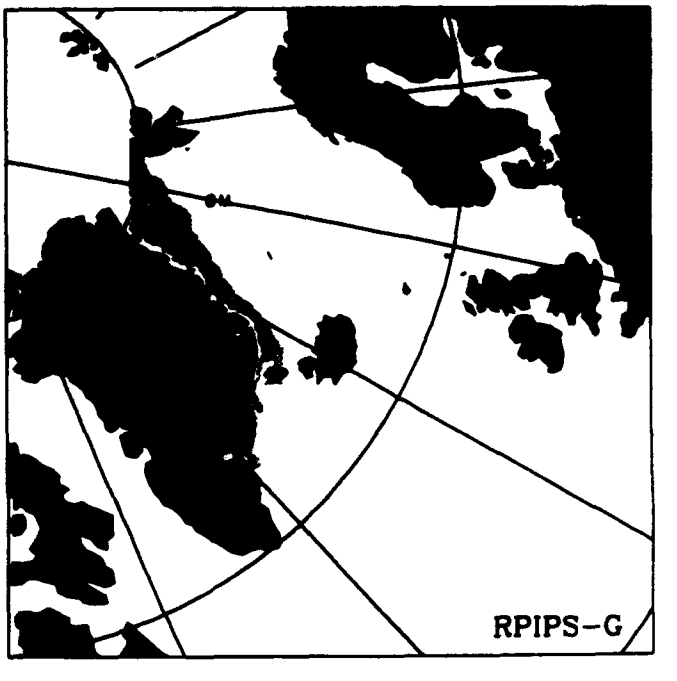

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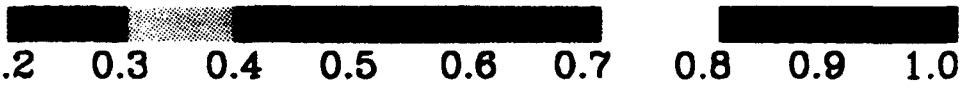
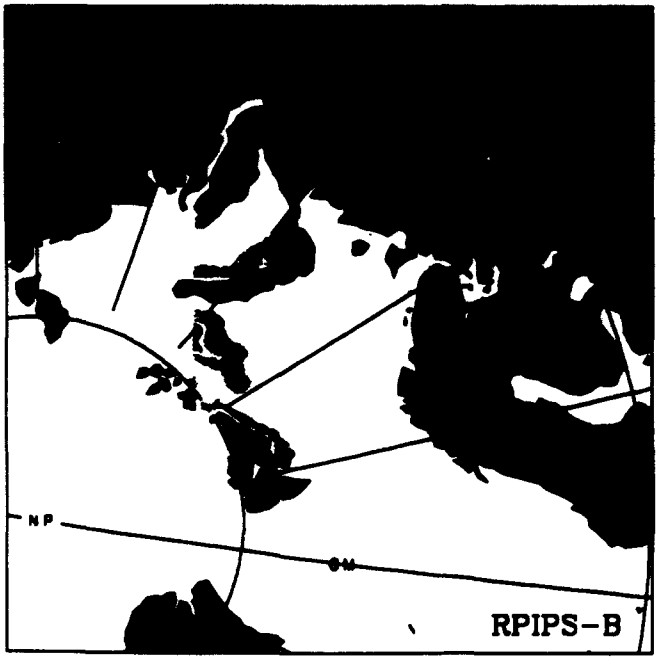
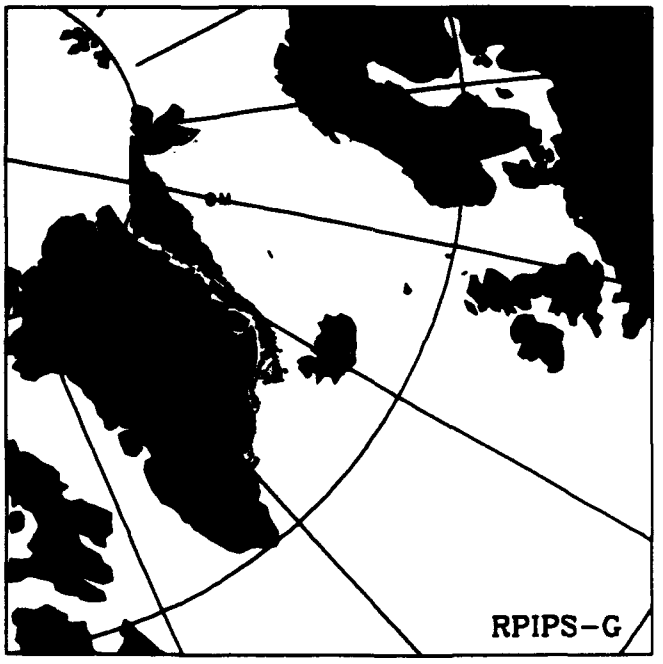
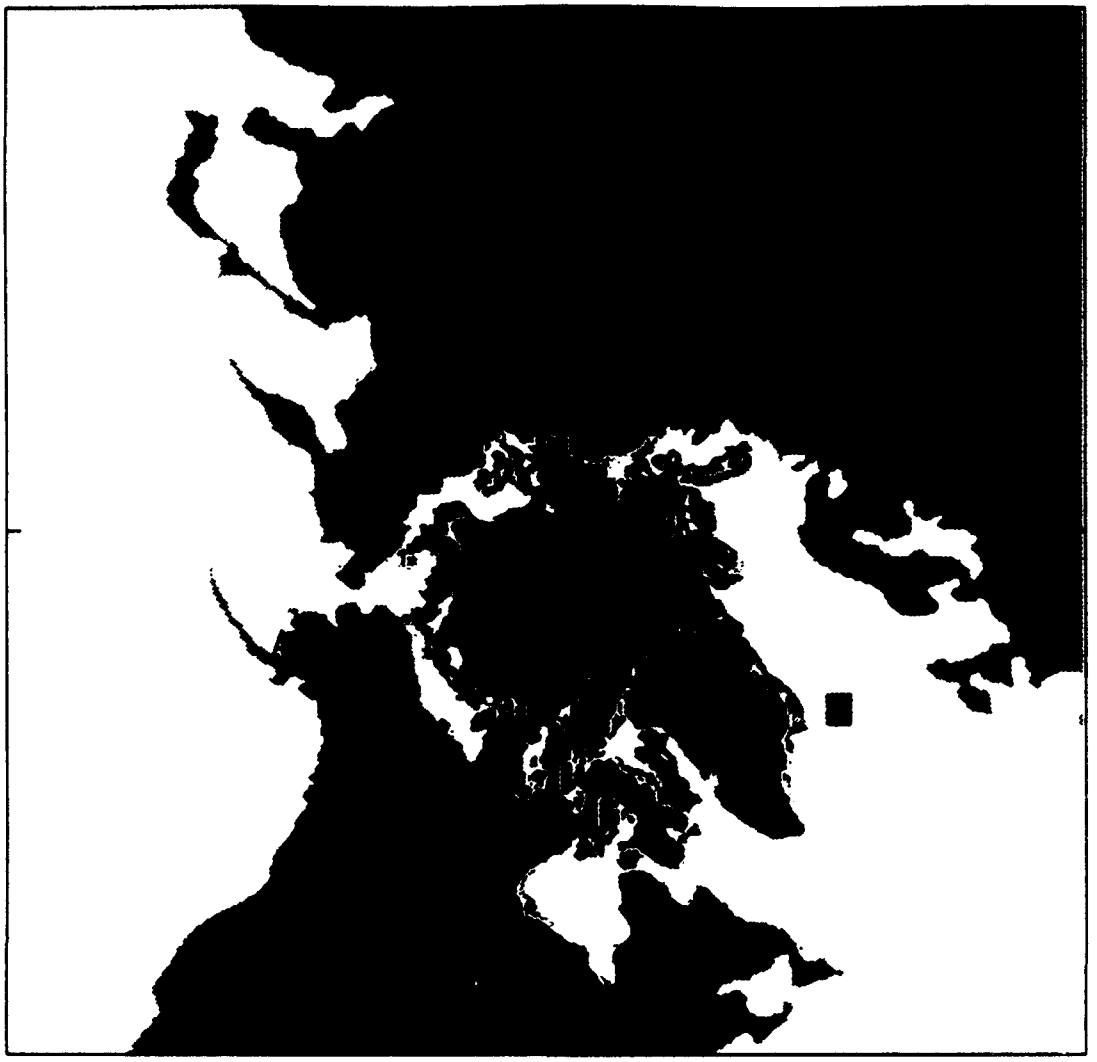
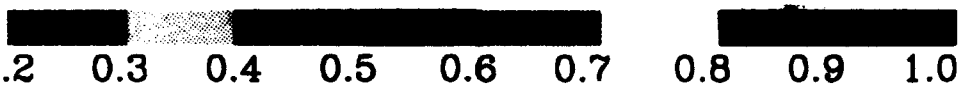


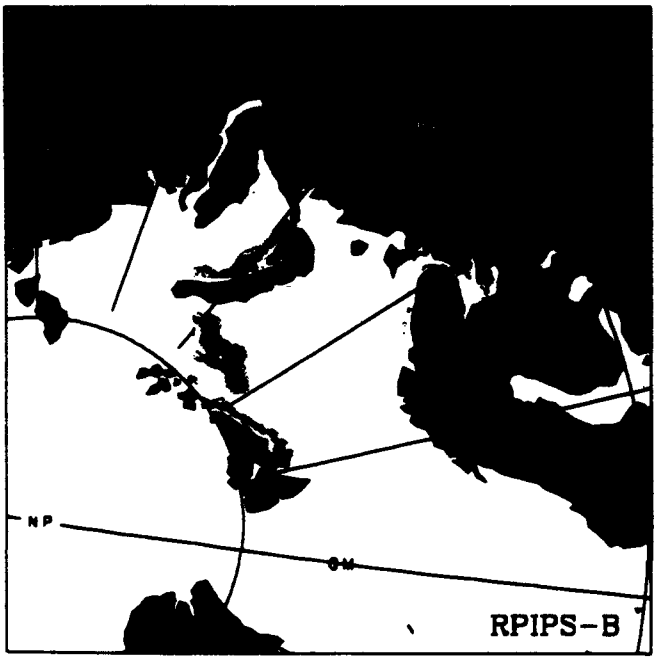


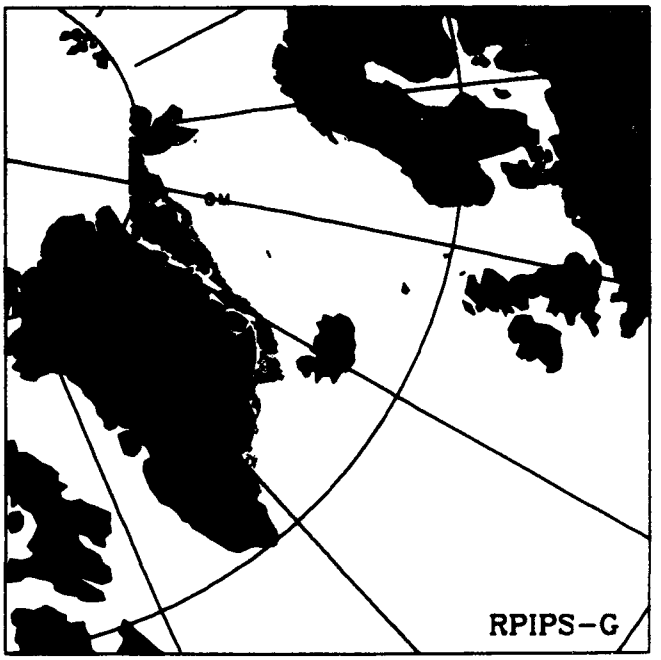


SSMI ICE CONCENTRATION 93072300









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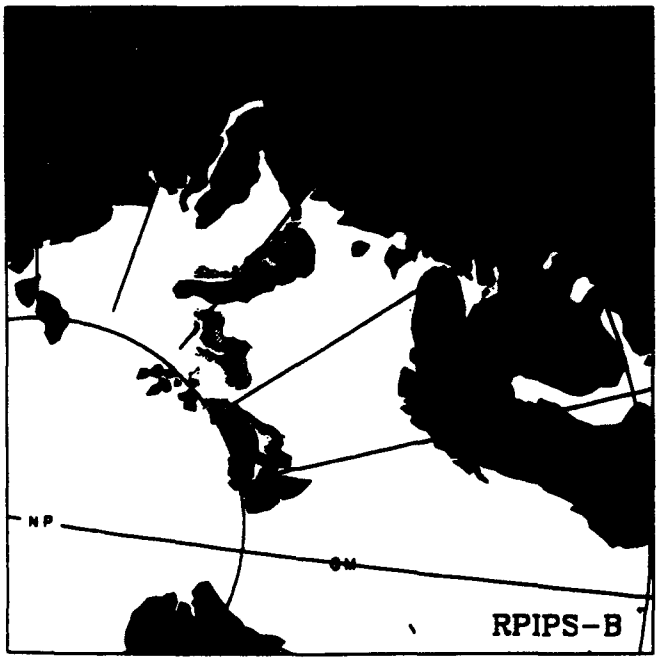

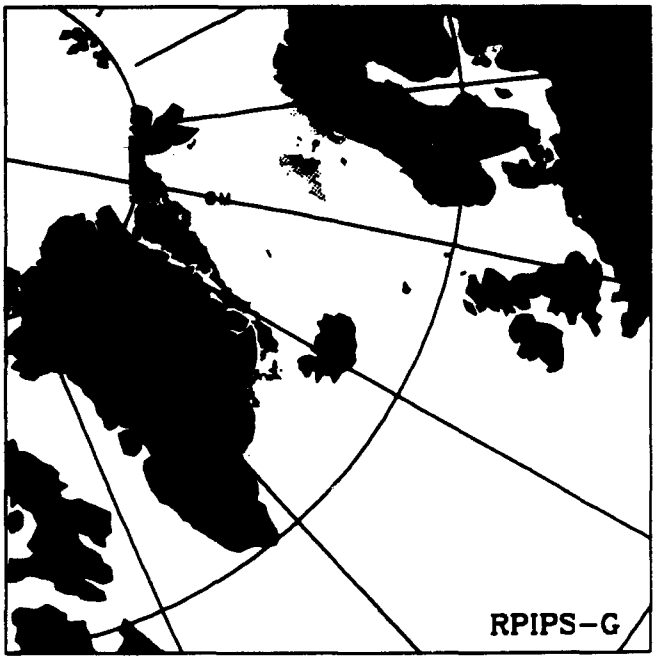

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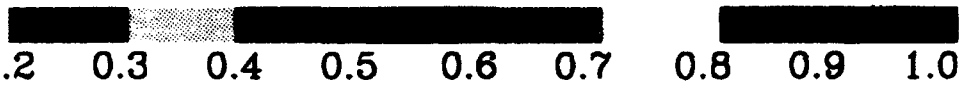

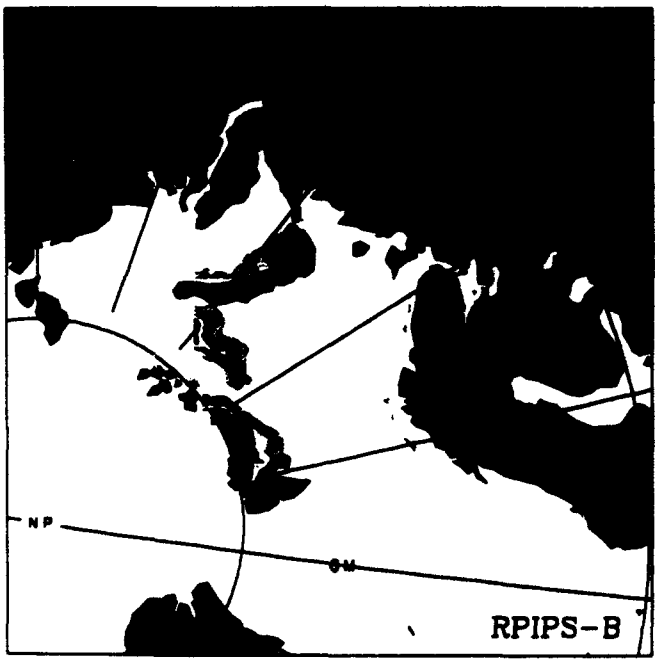

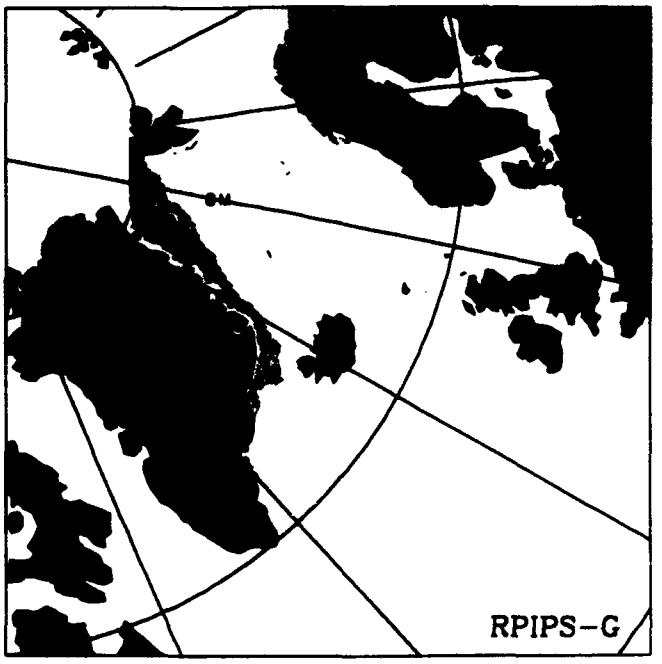

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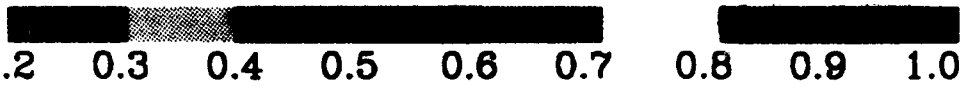

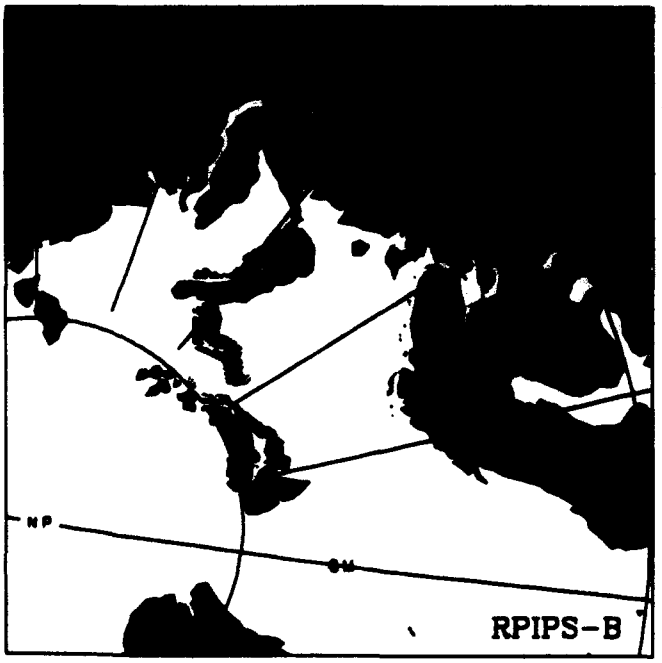

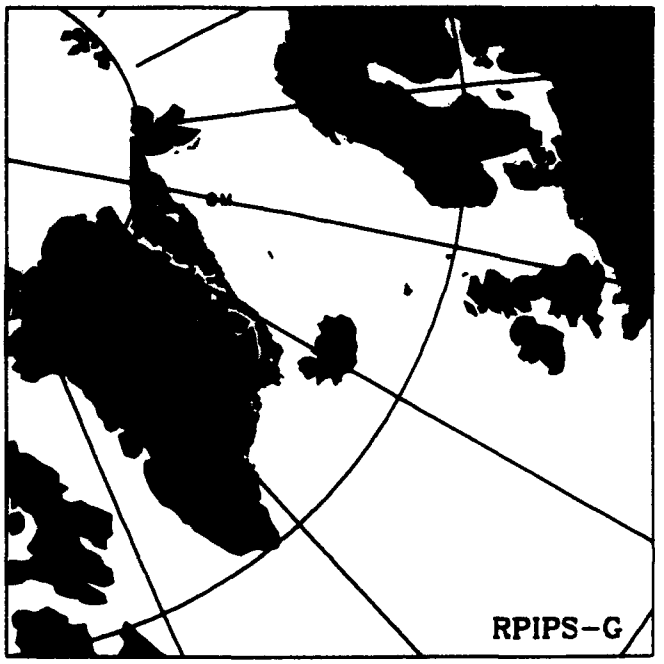

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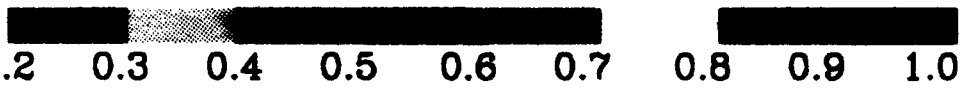

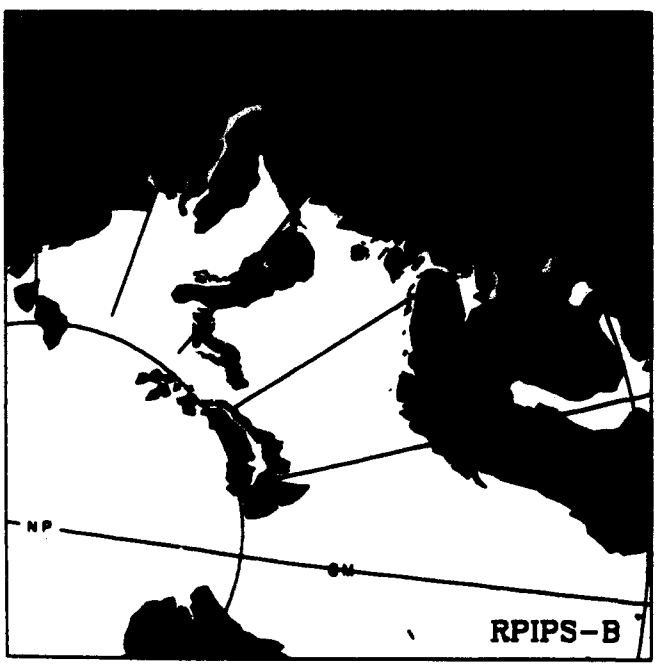

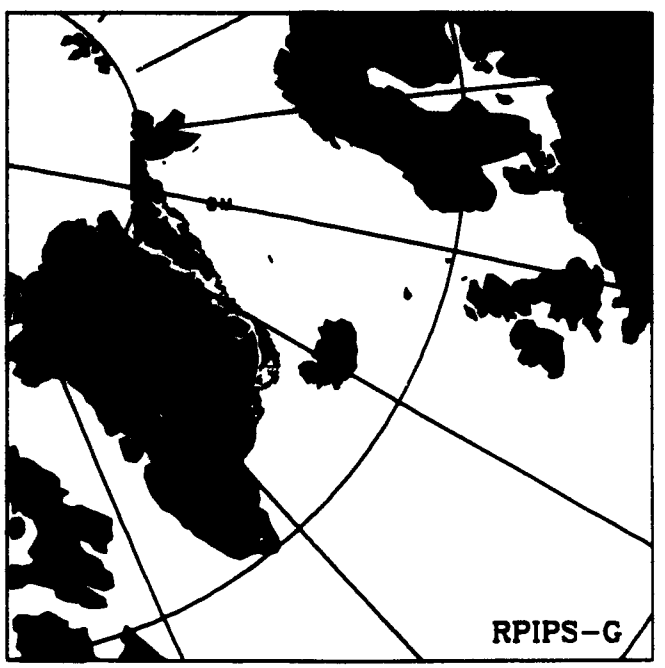

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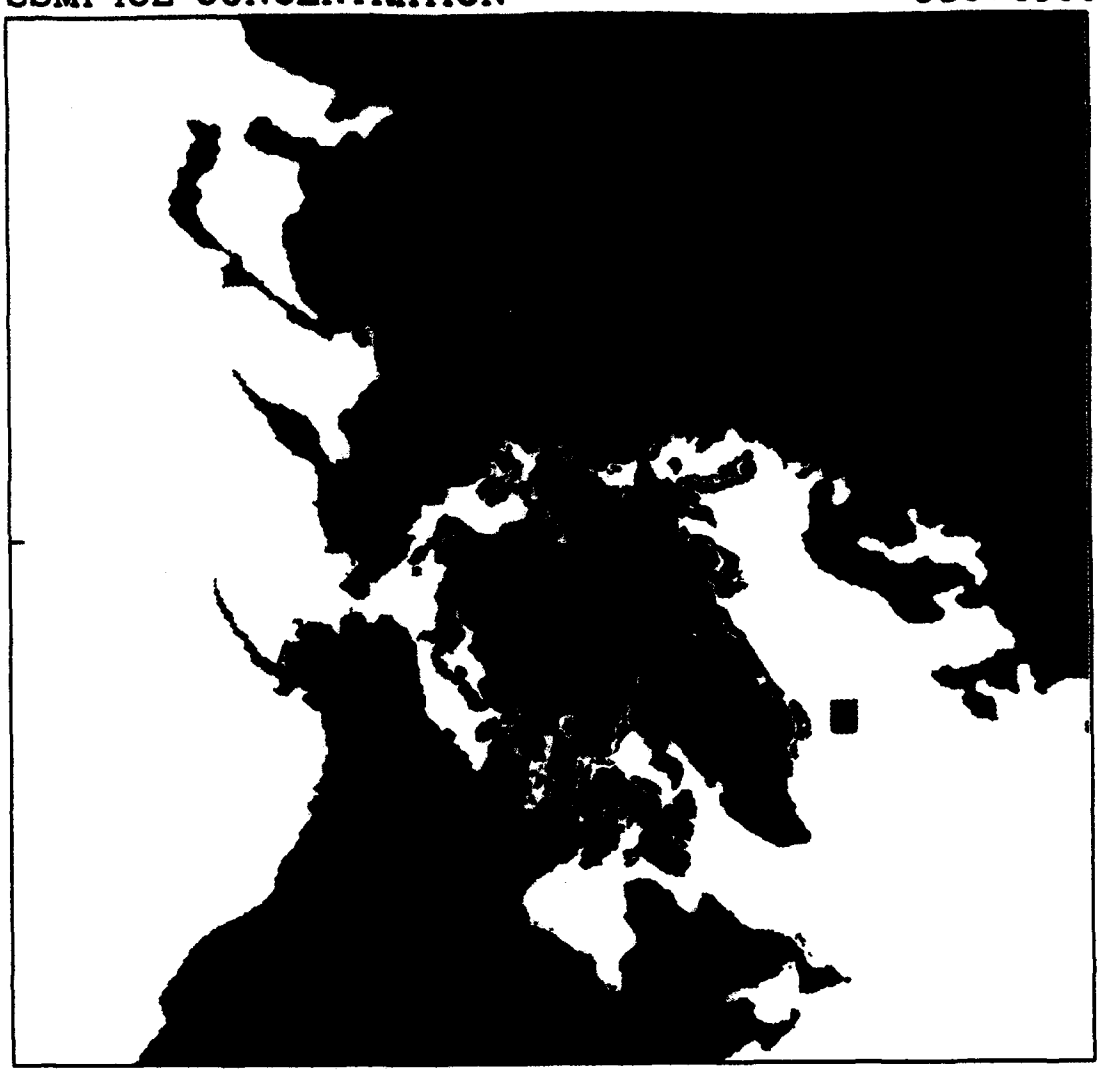

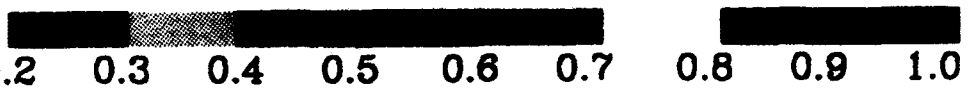

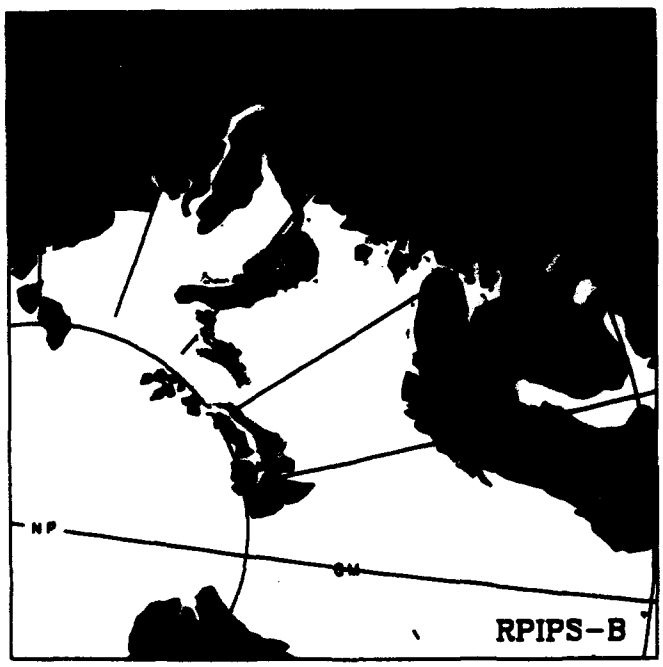

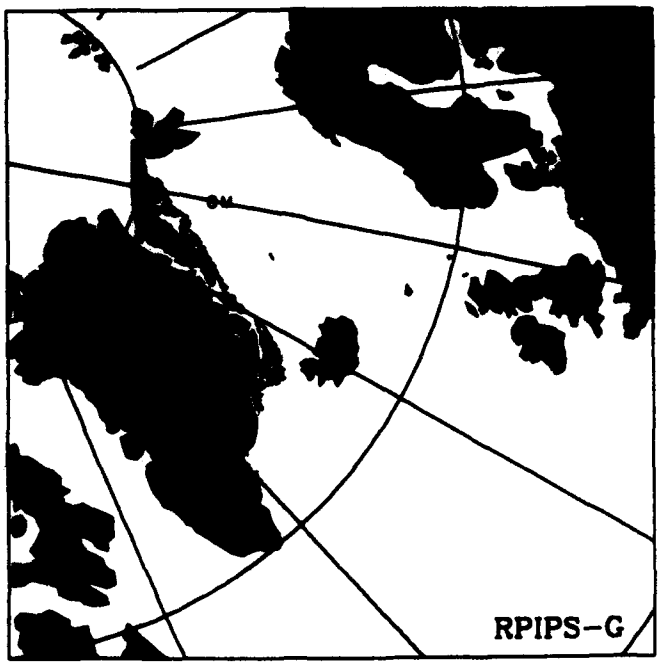

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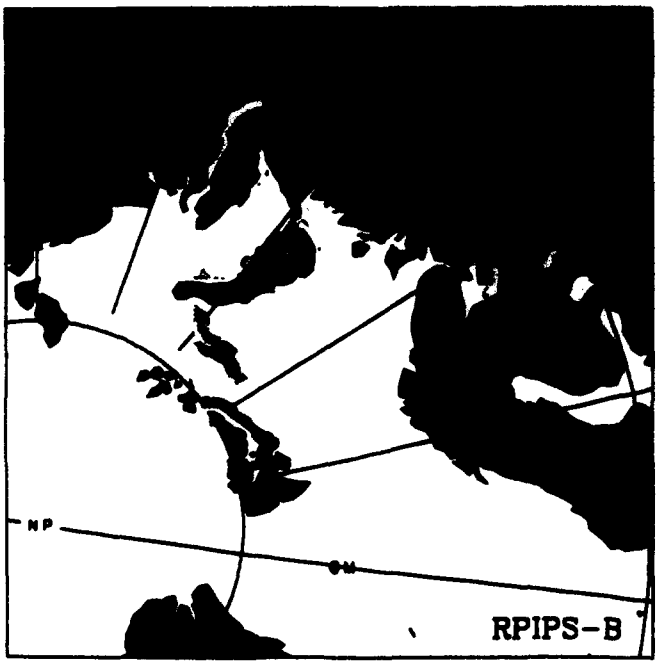

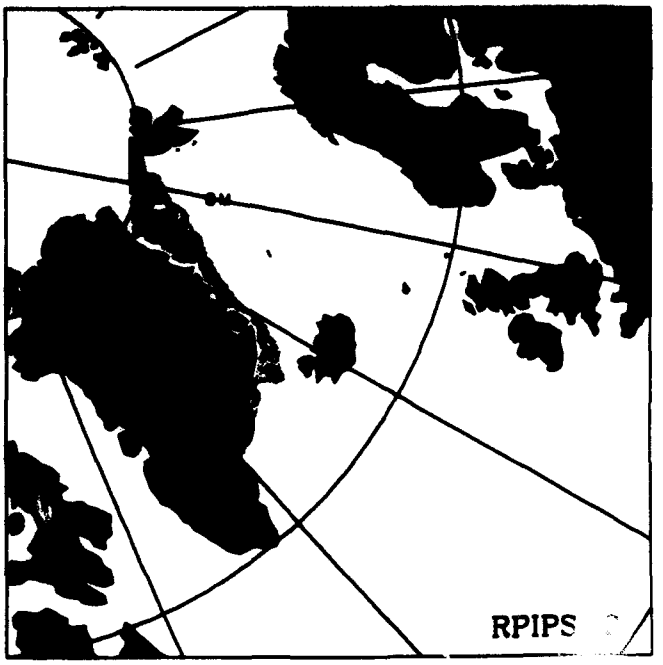

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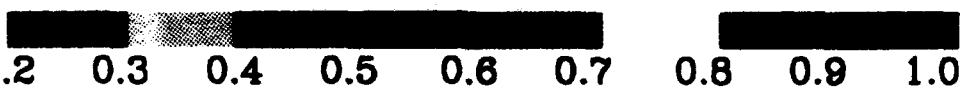

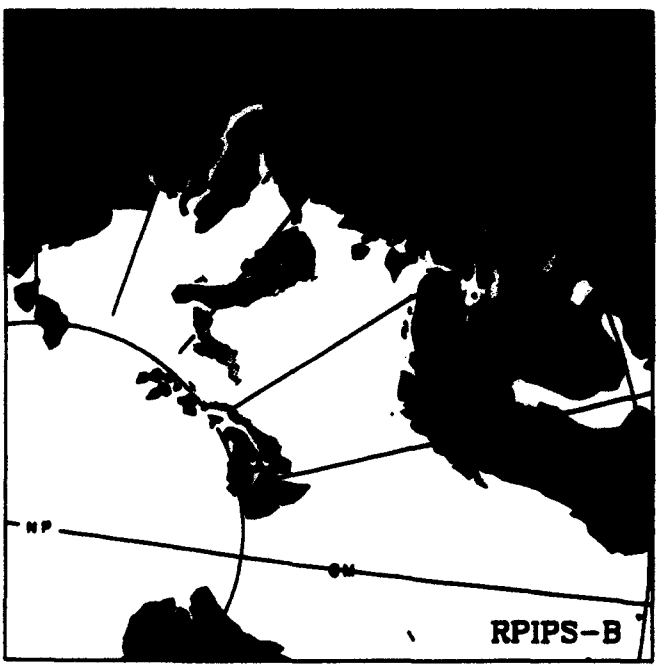

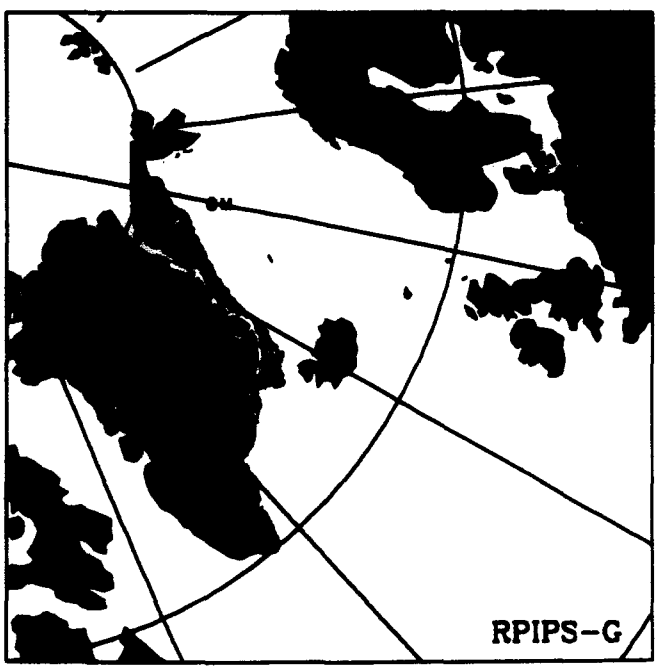

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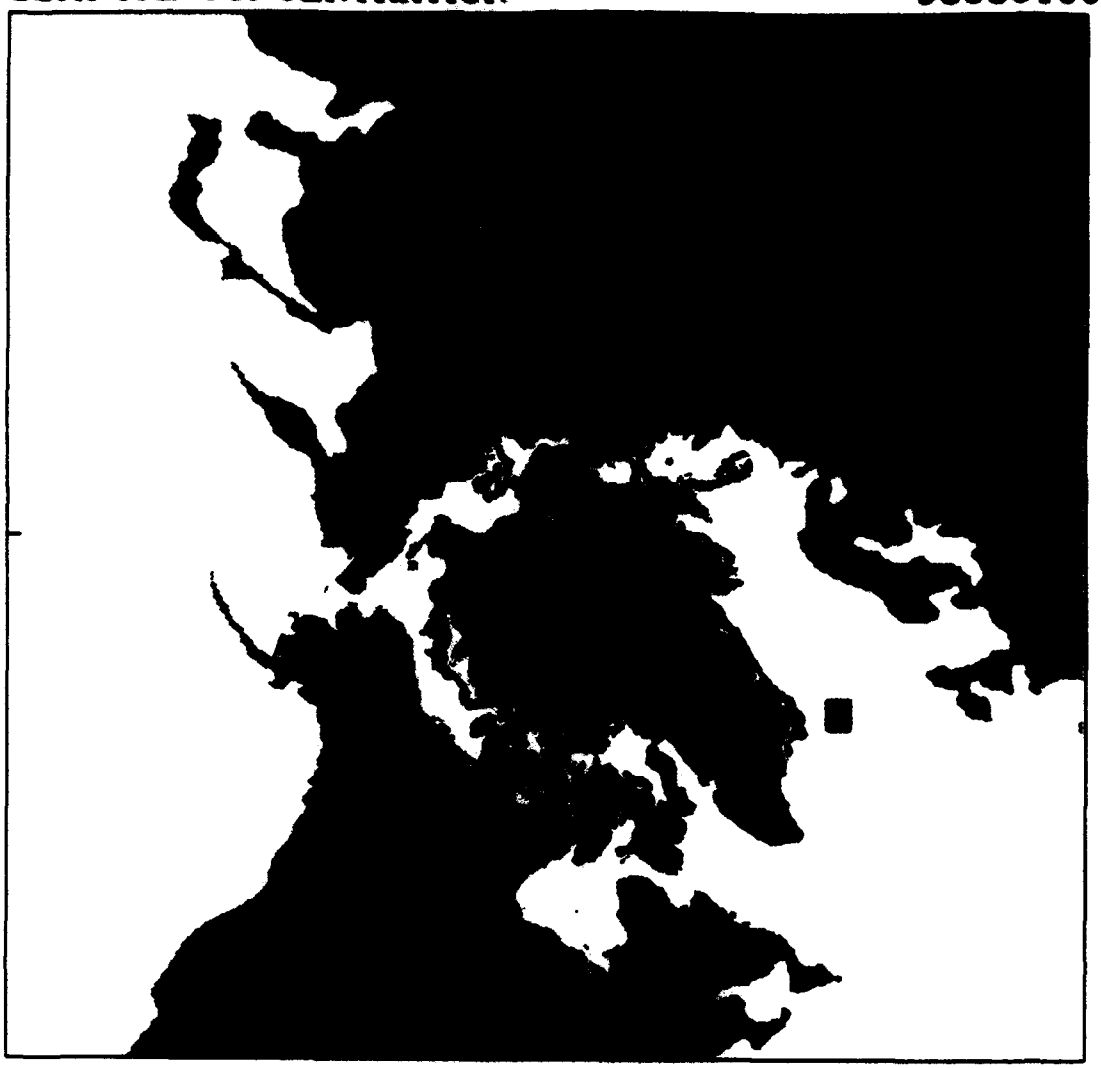

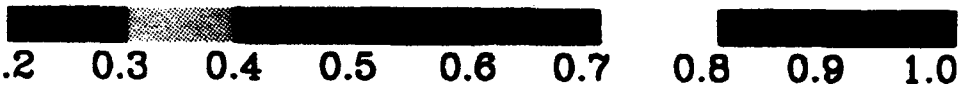

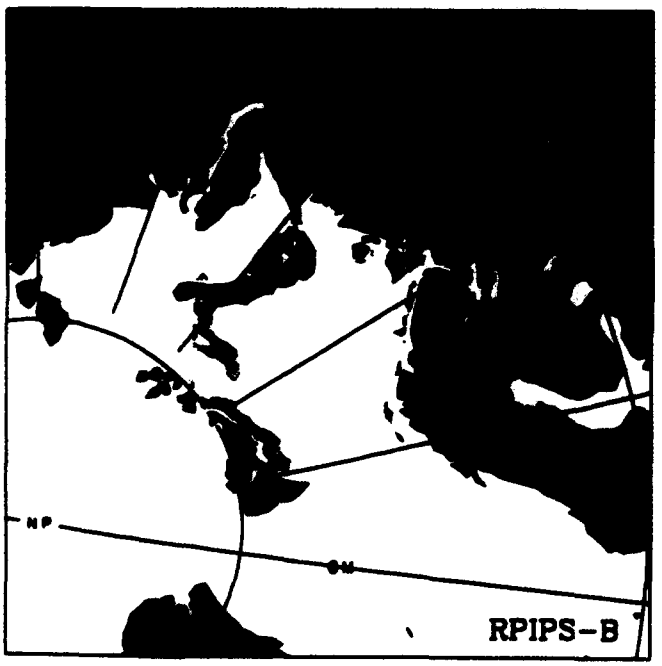

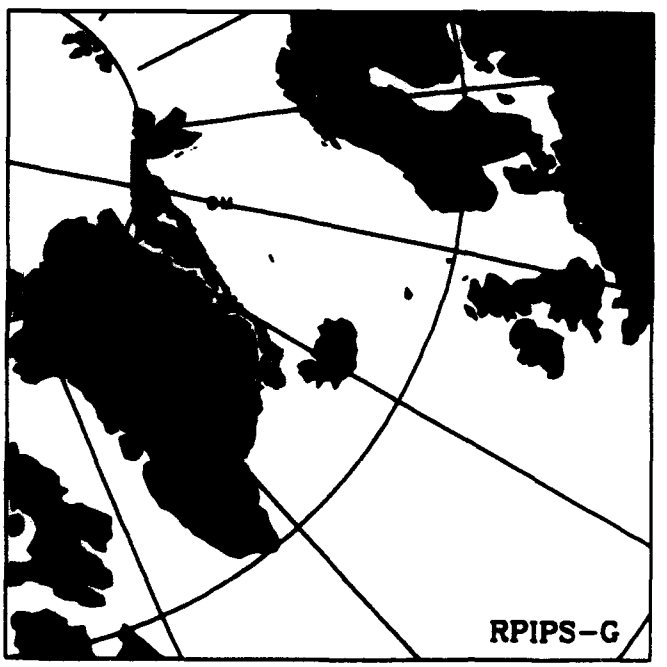

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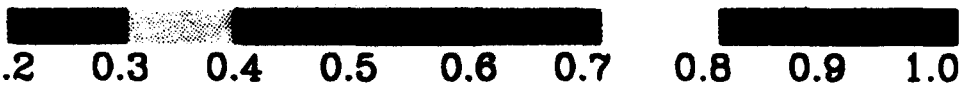

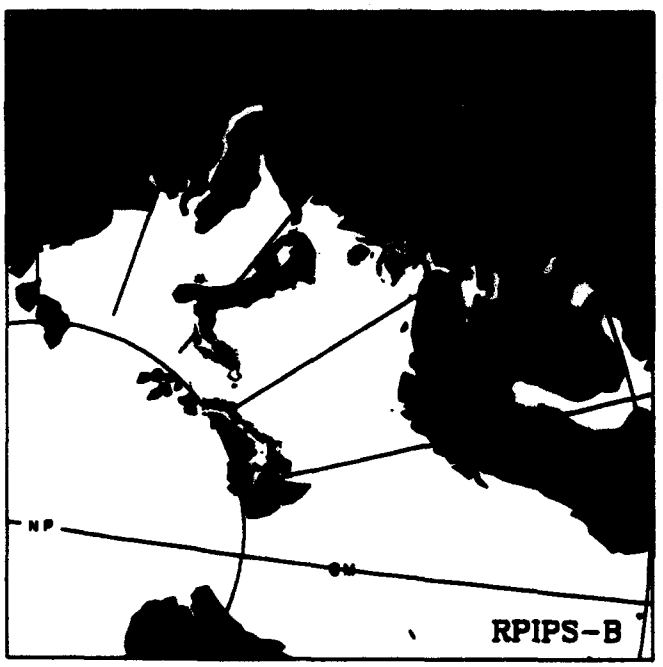

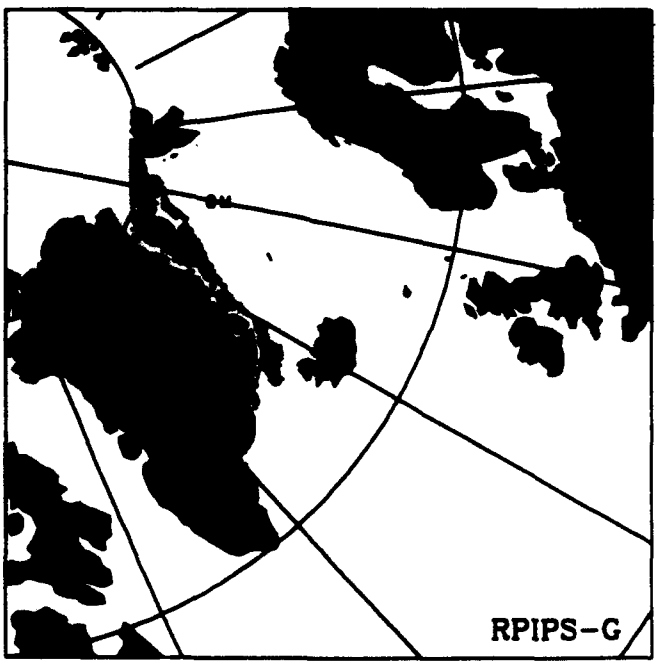

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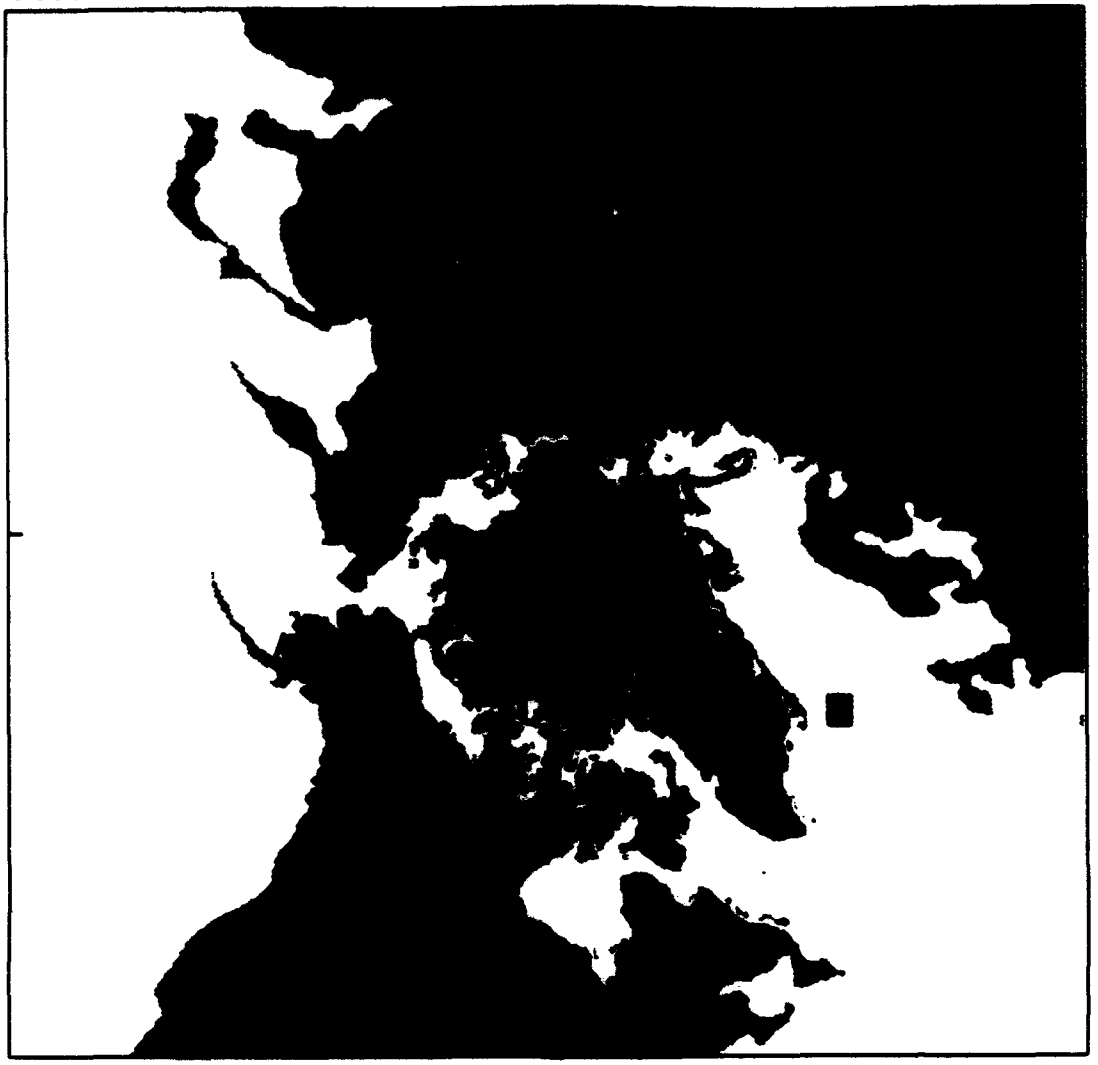

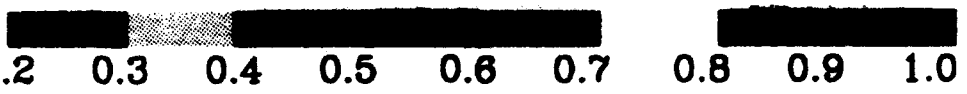

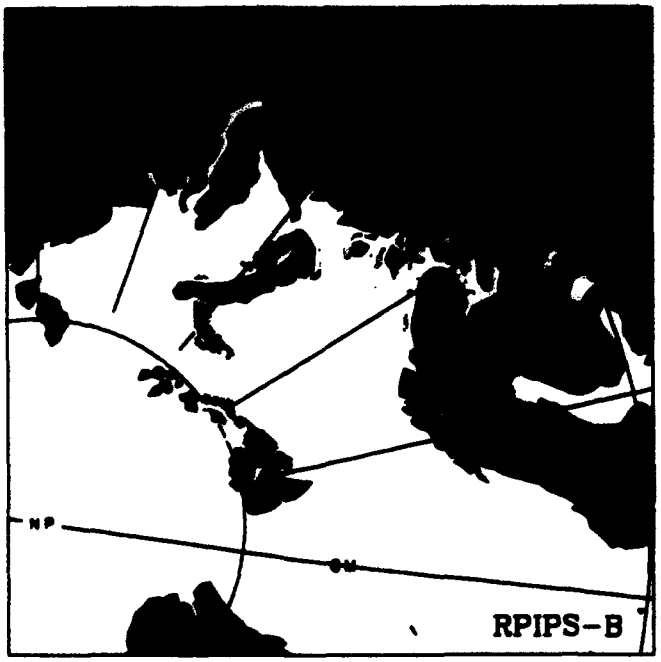

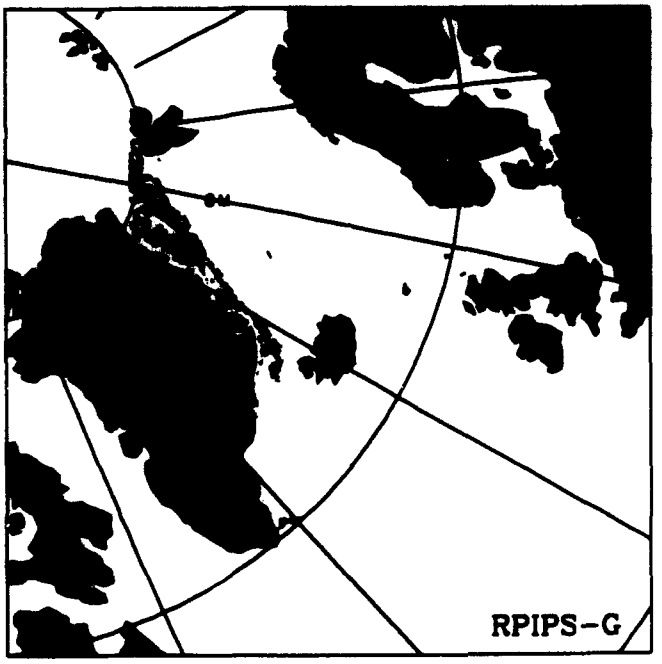

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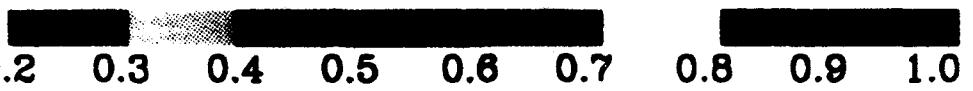

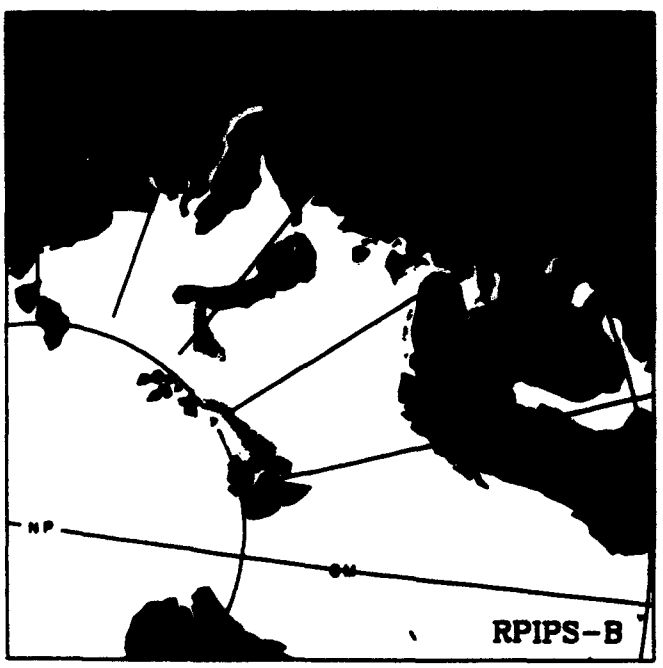

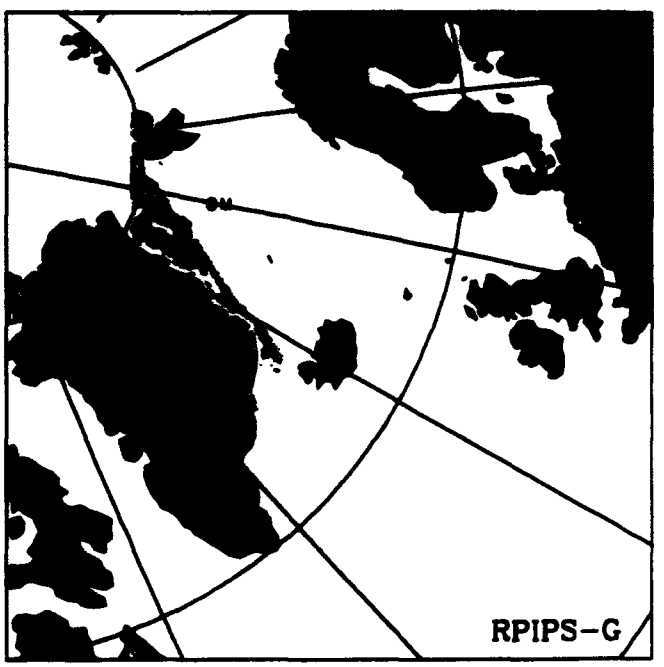

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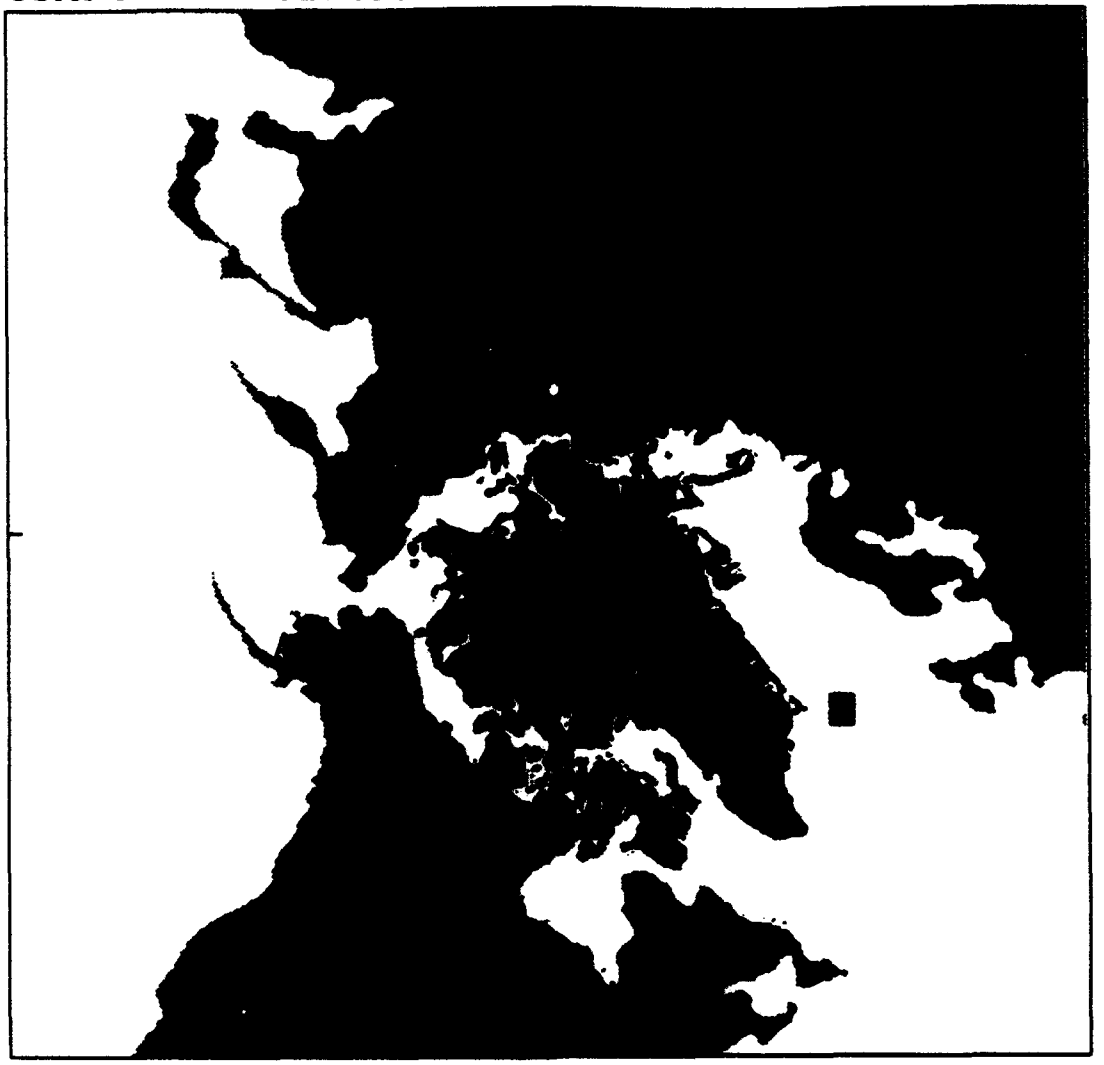

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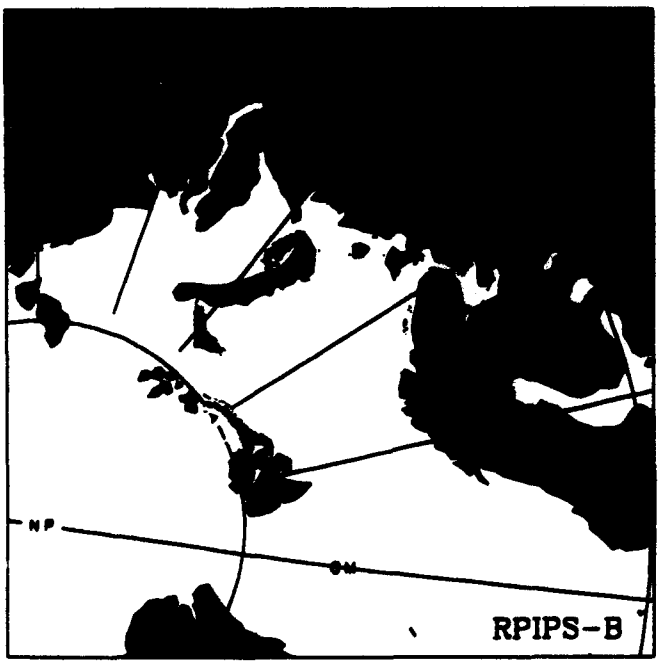

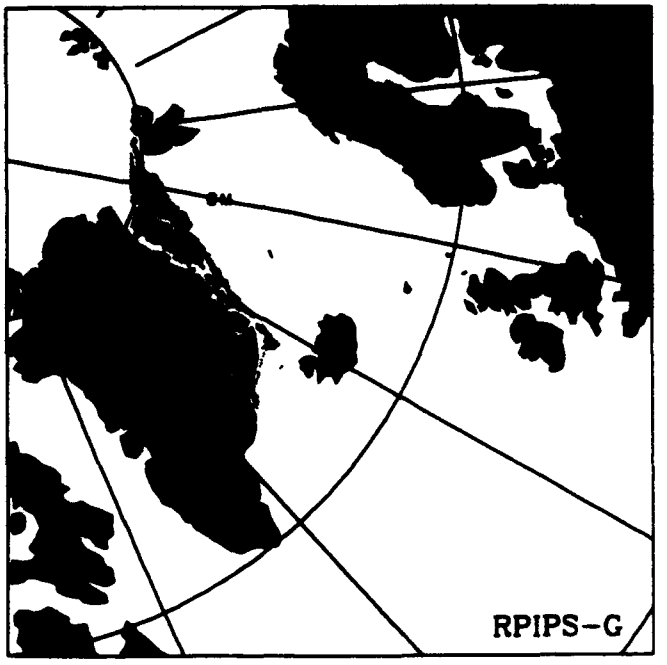

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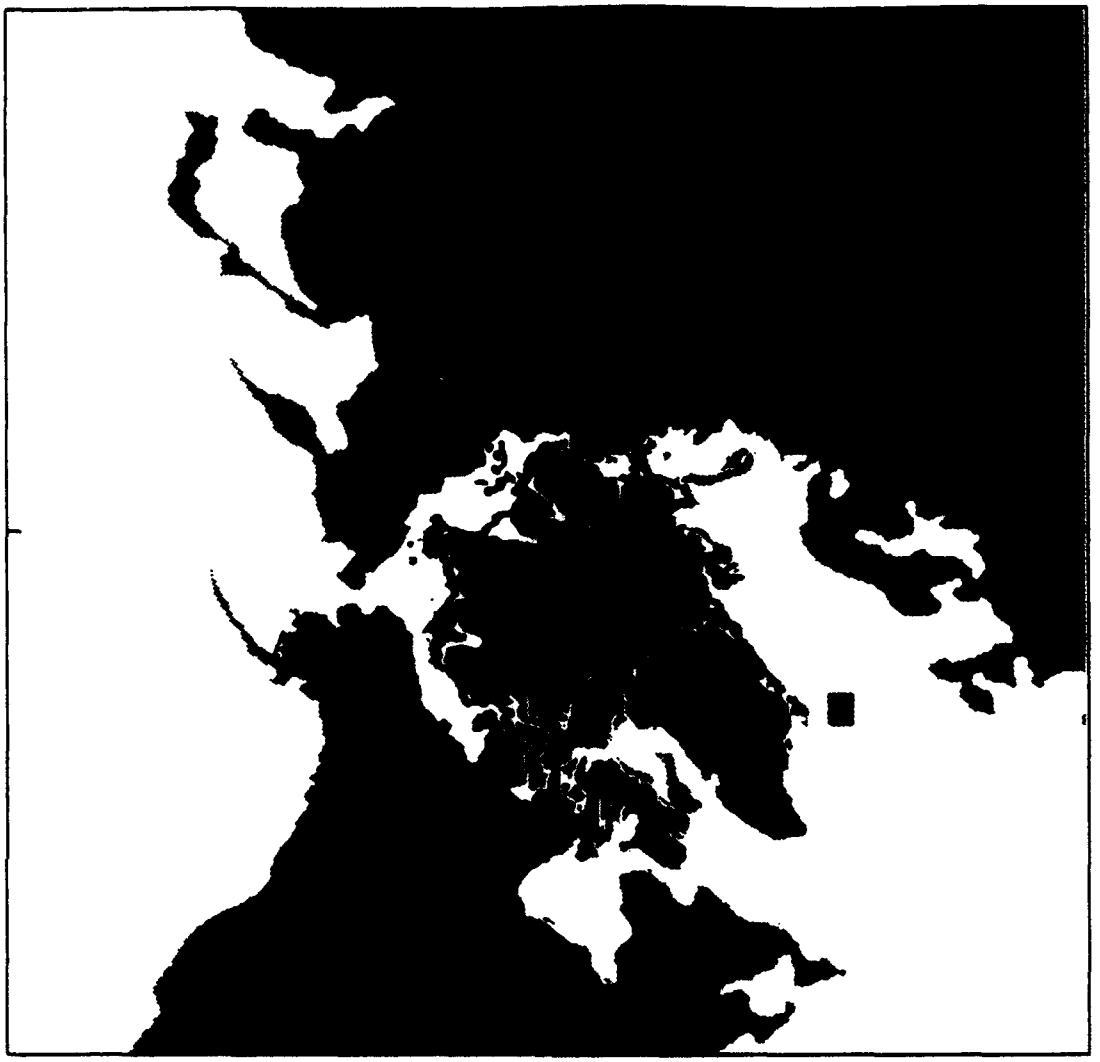

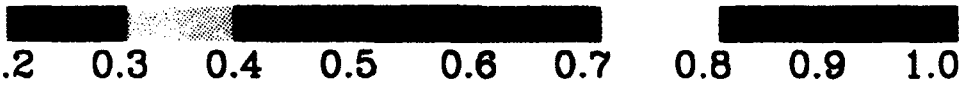

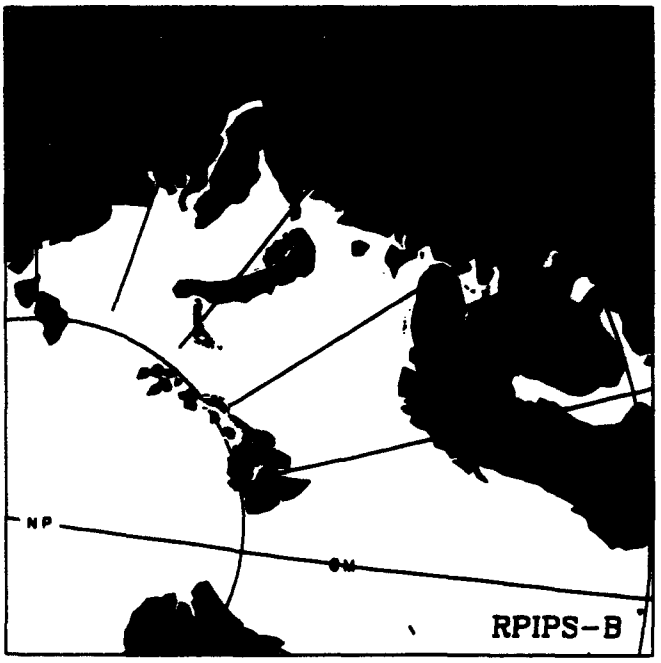

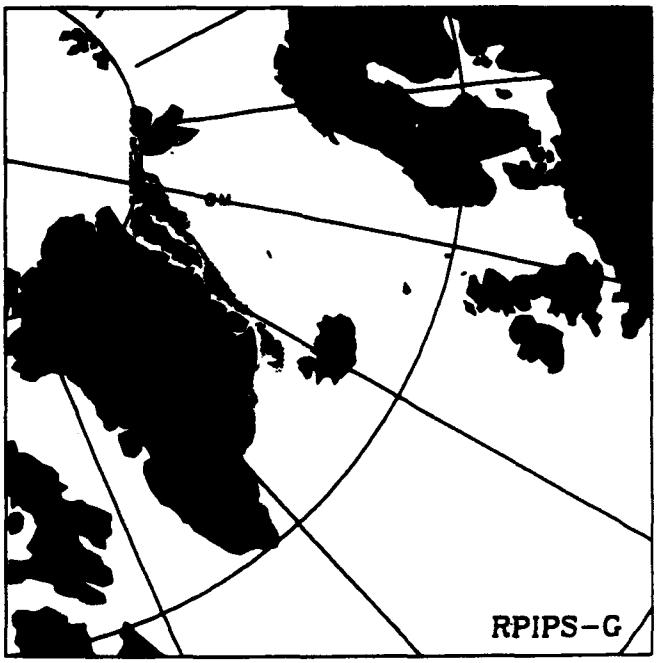

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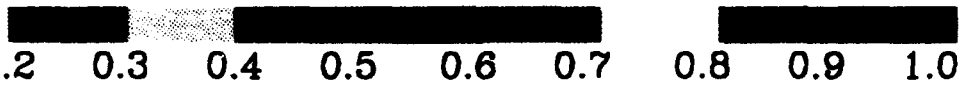

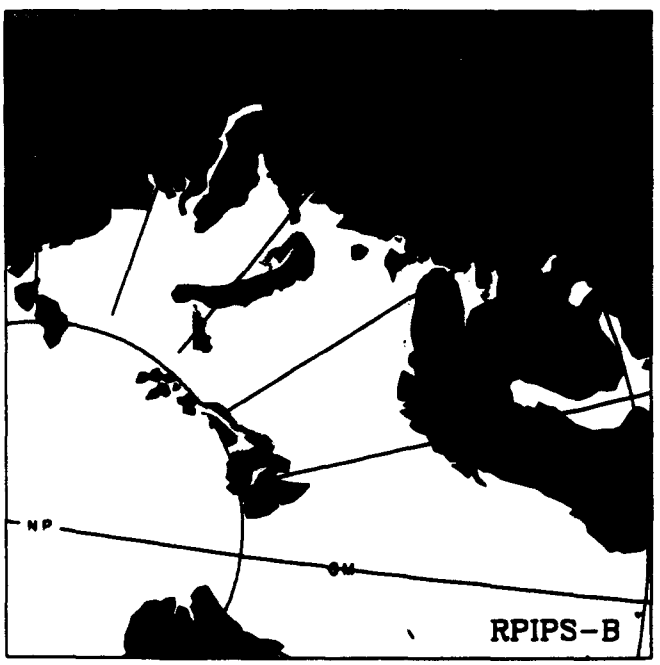

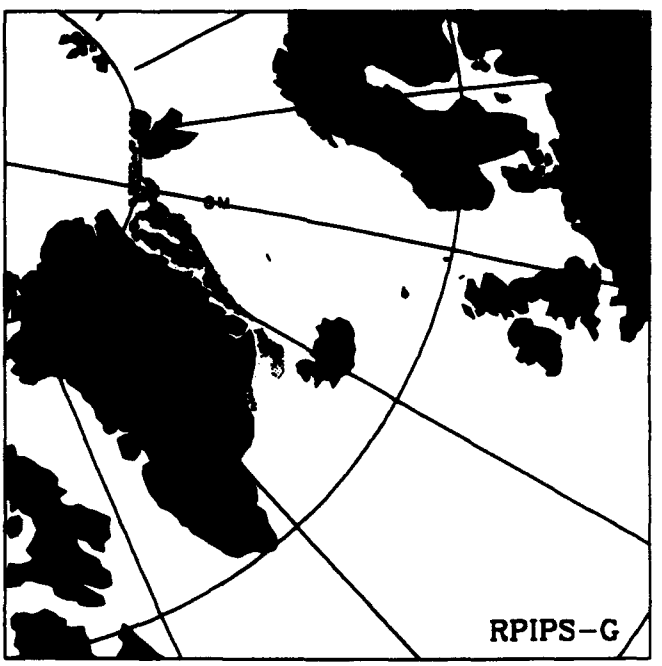

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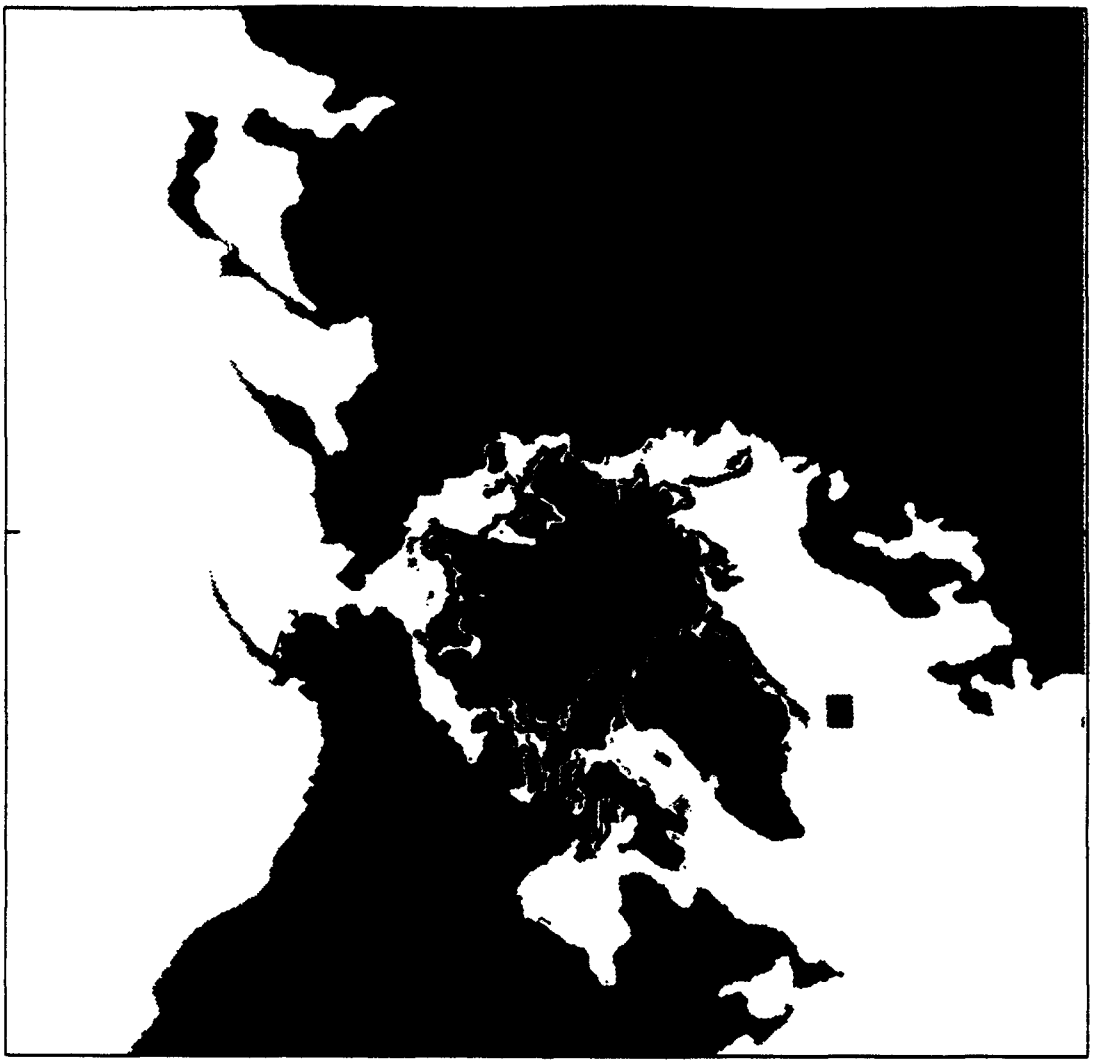

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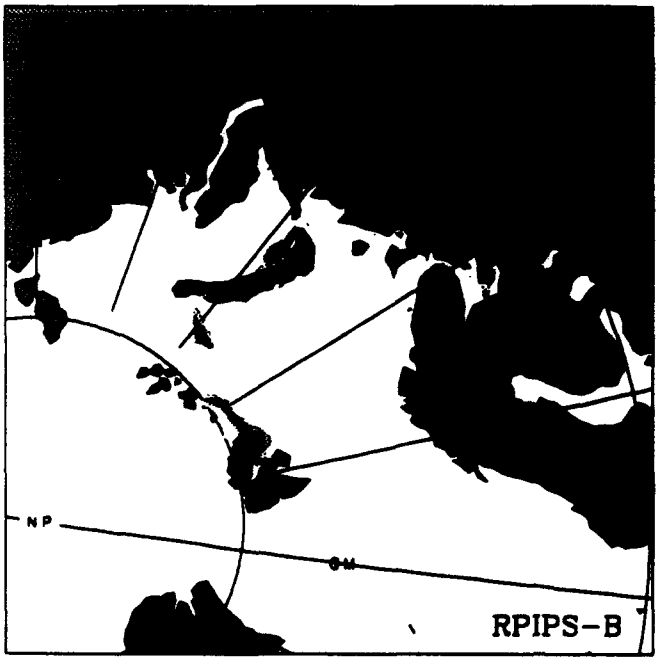

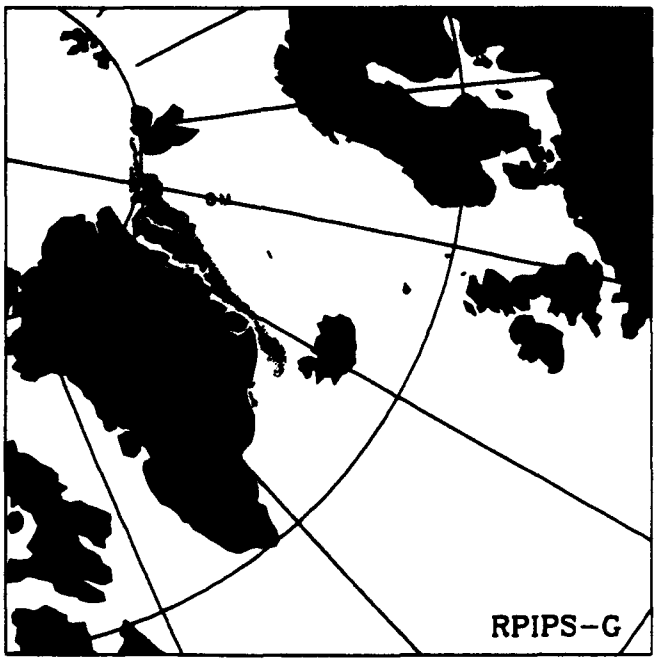

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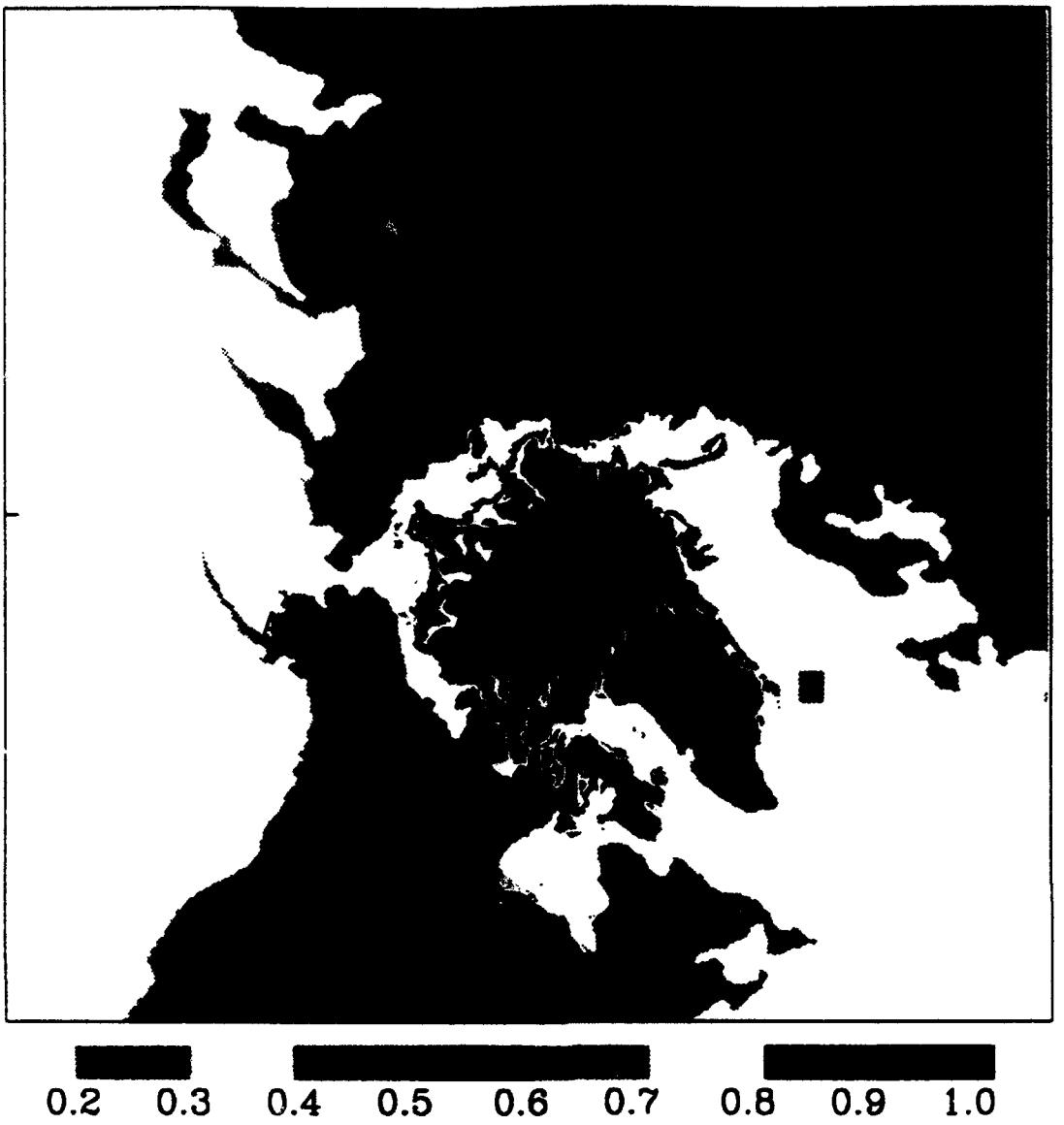
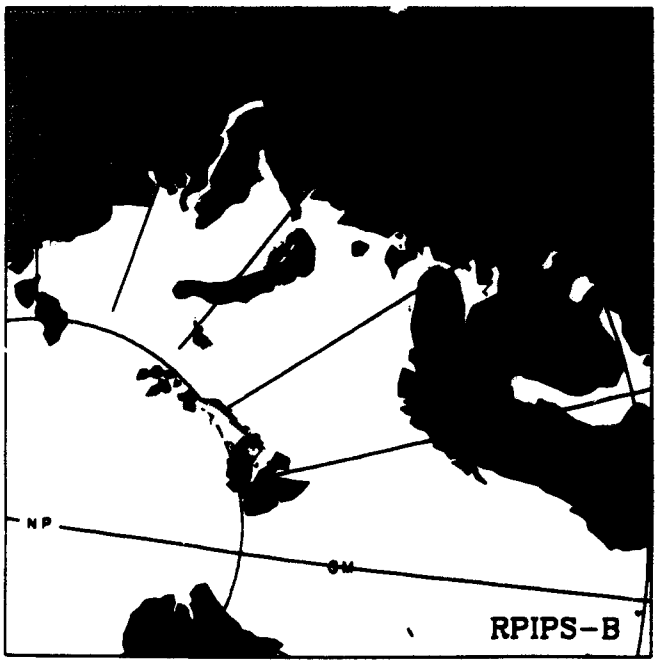
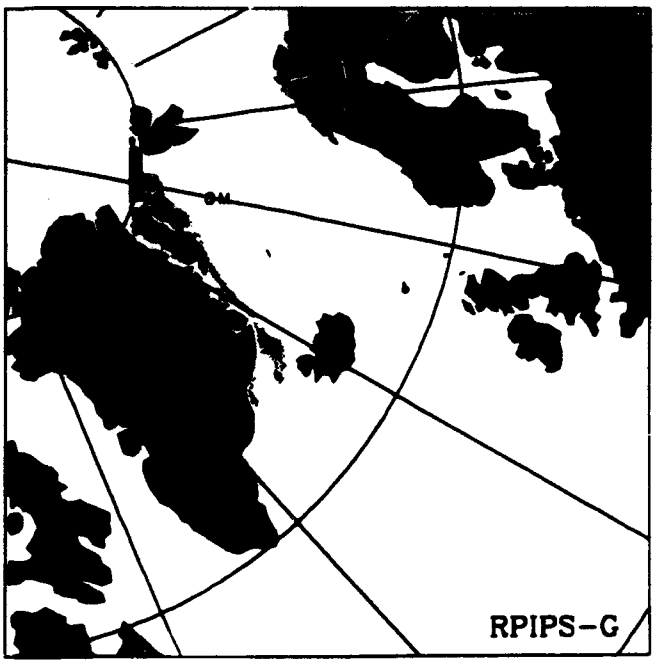
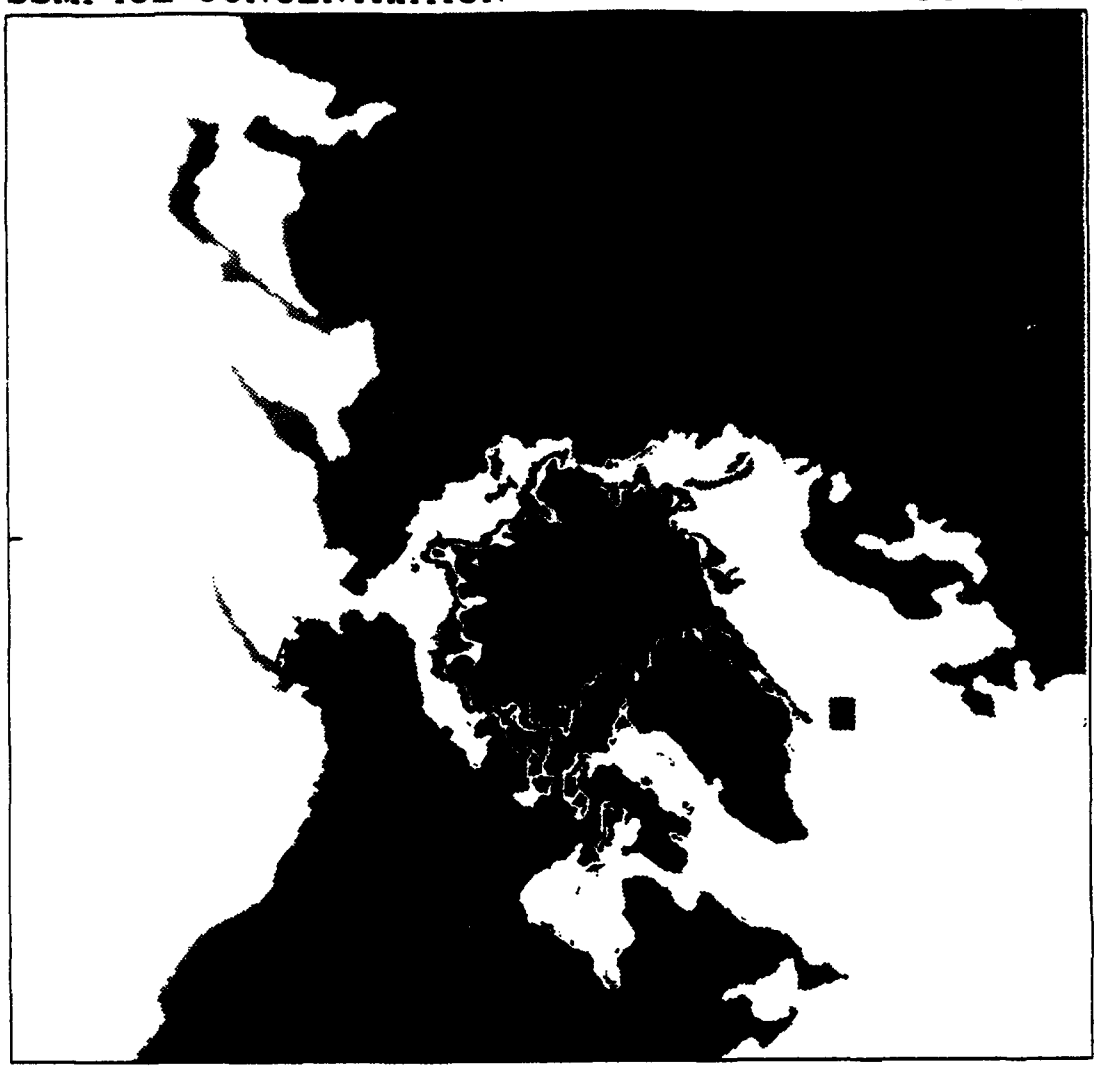






SSMI ICE CONCENTRATION 93081000



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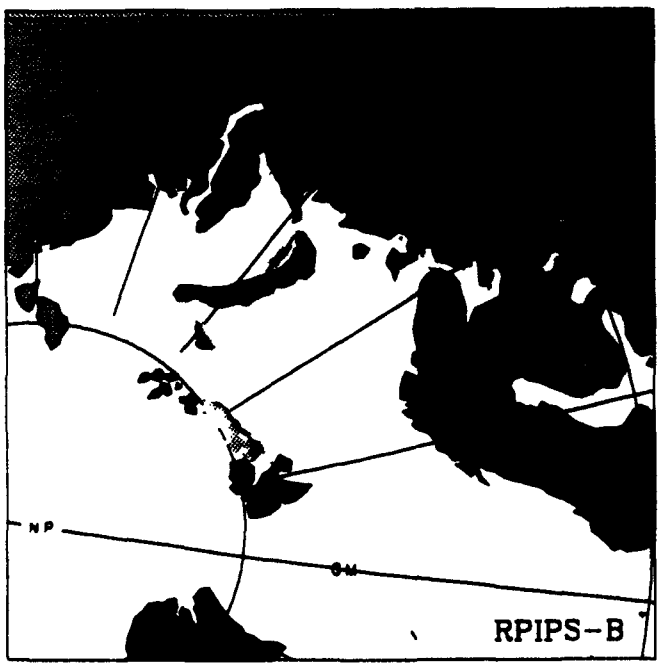

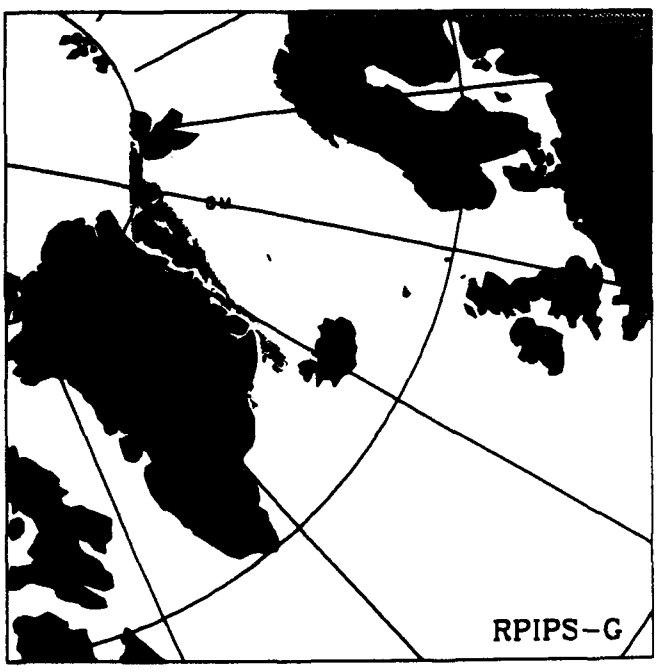

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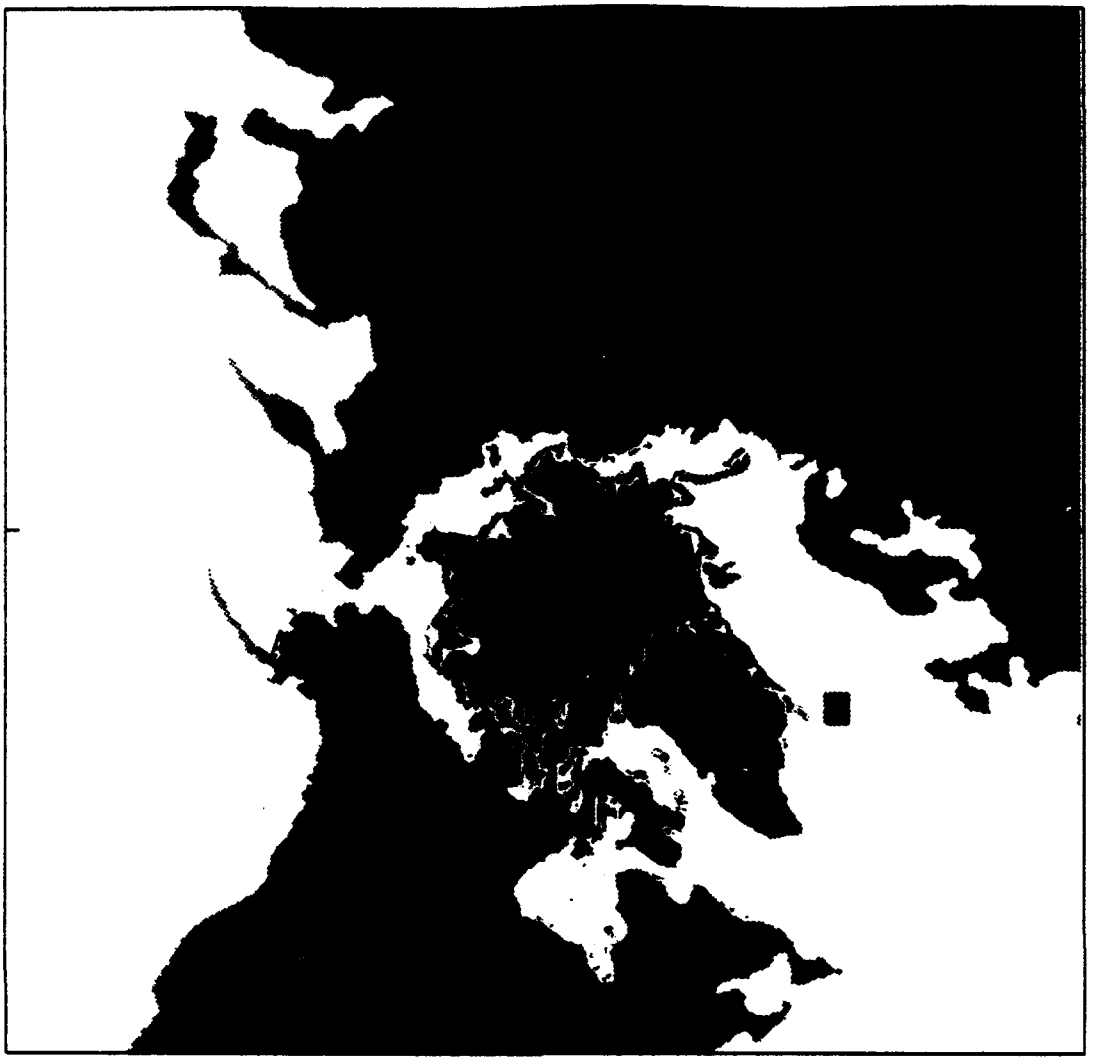

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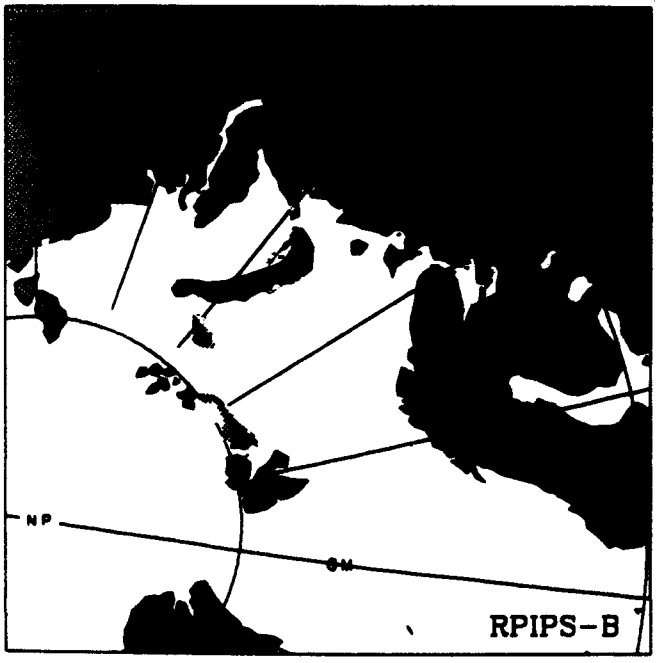

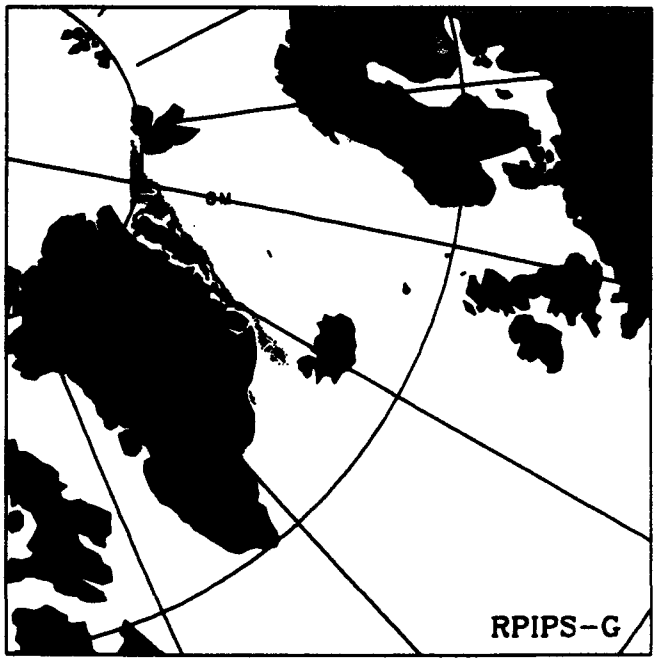

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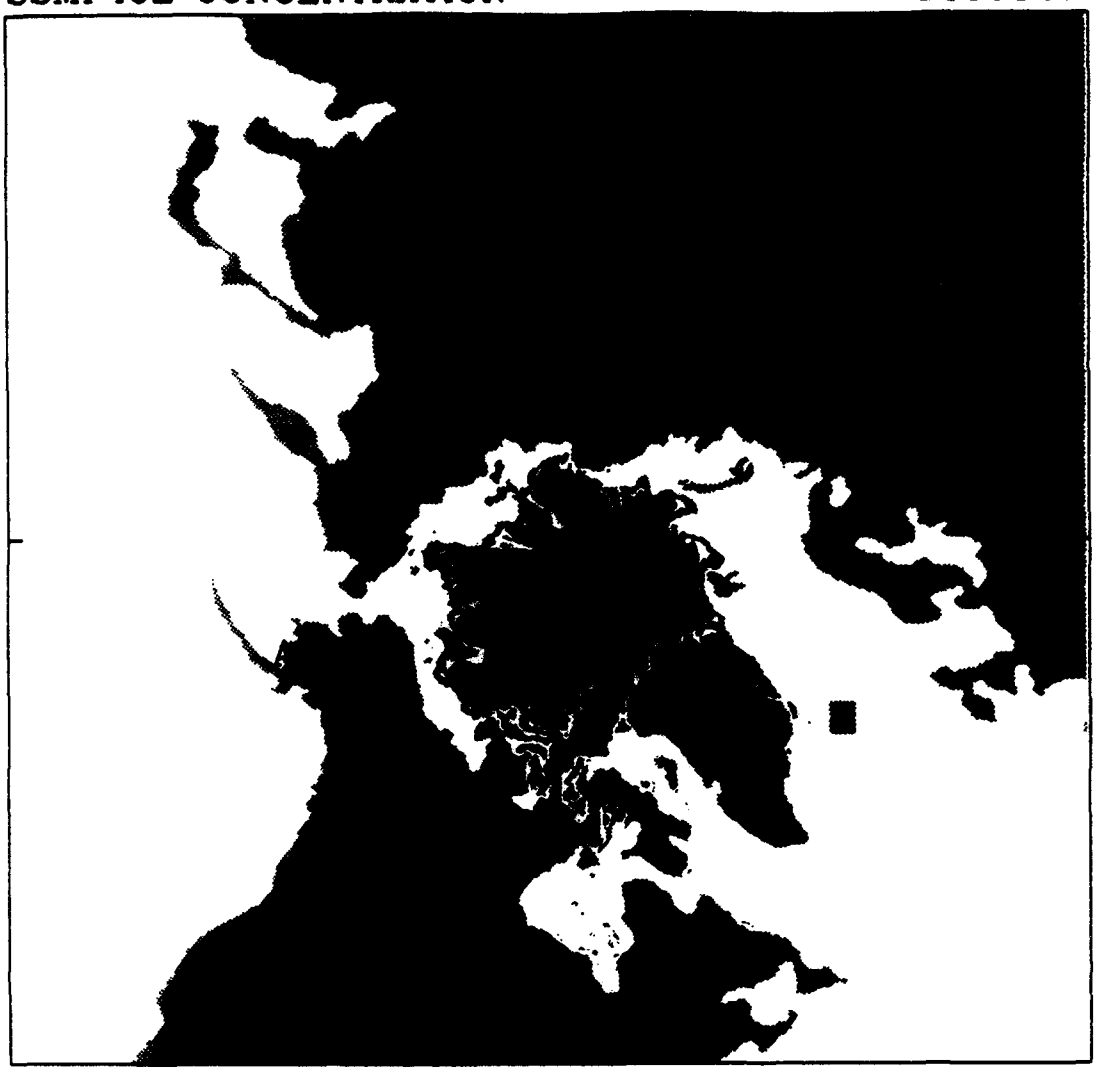

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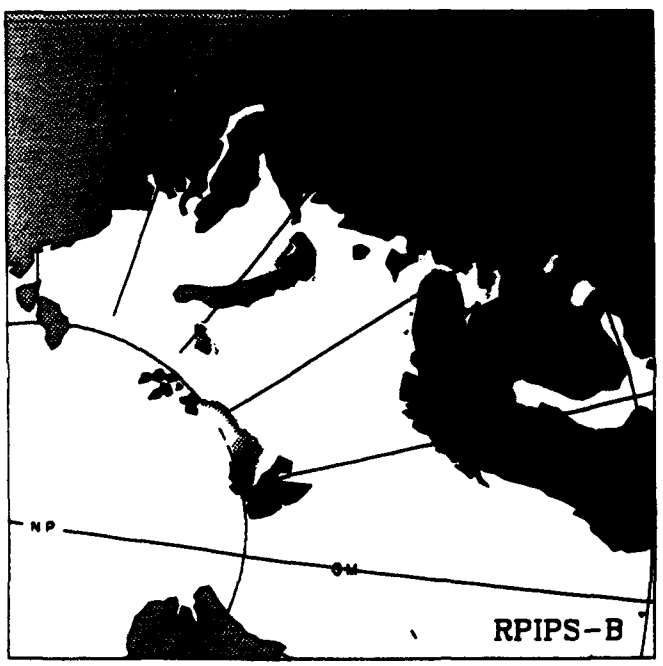

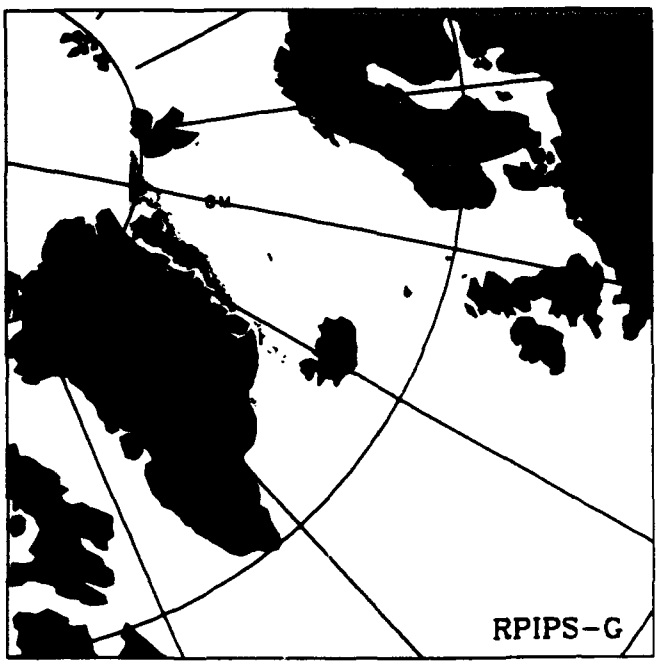

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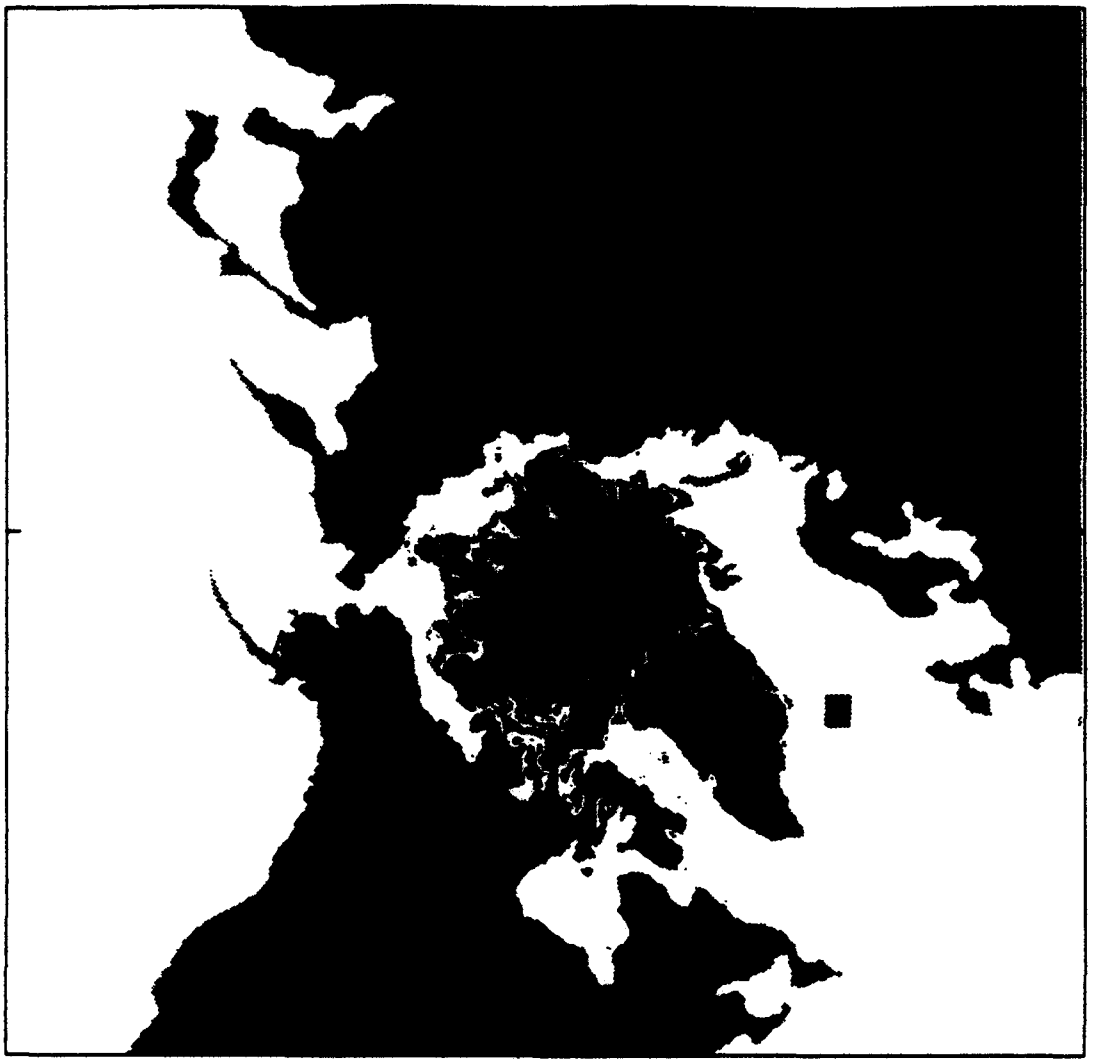

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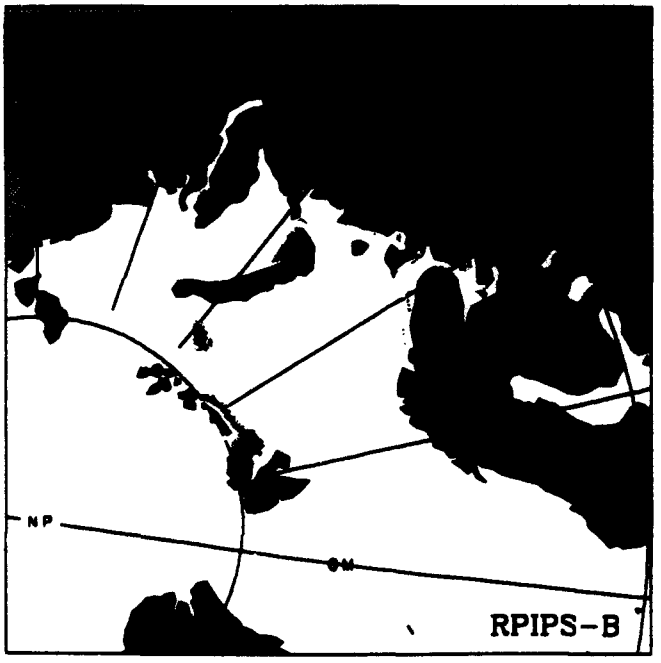

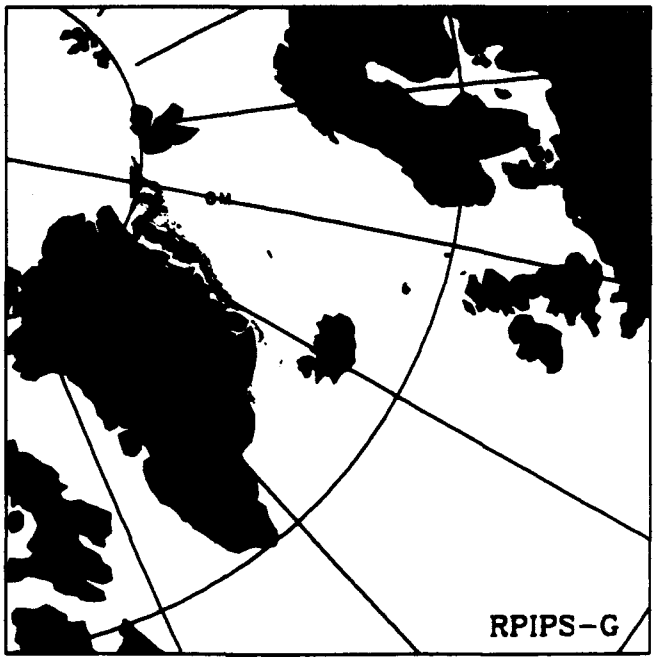

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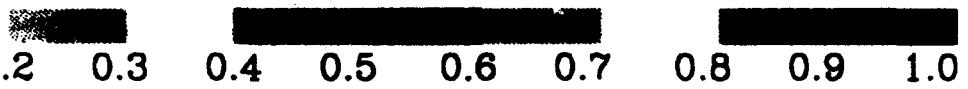

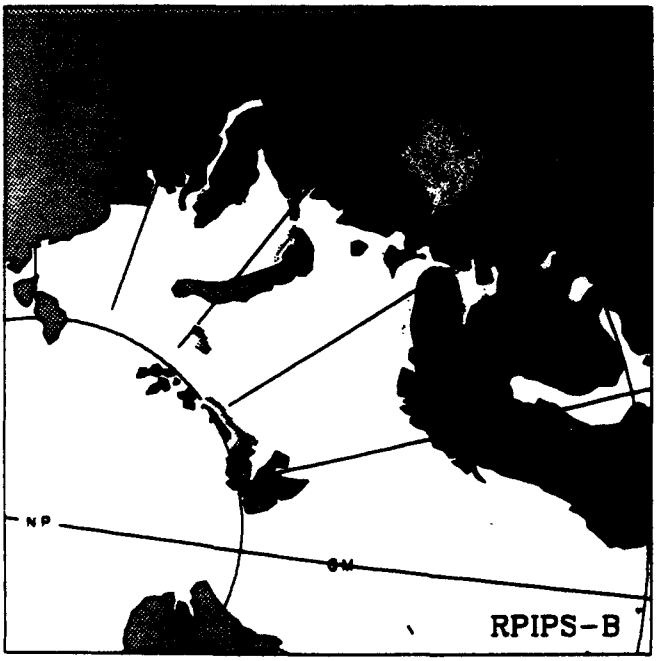

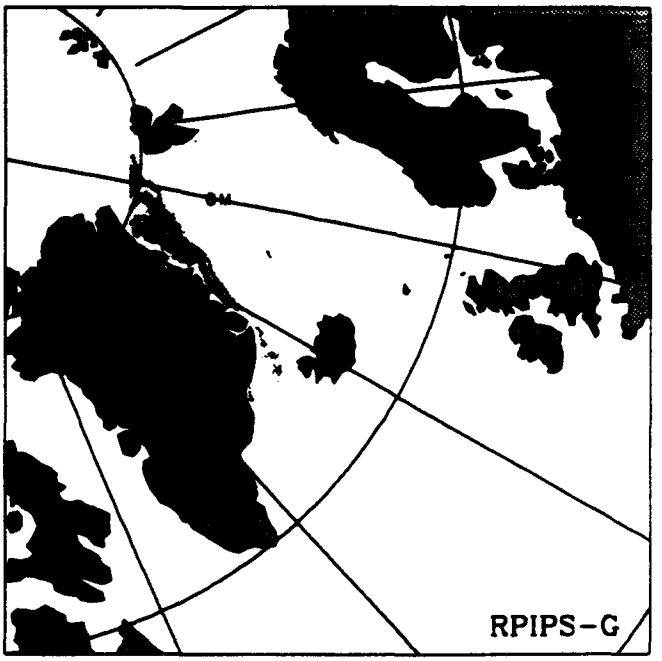

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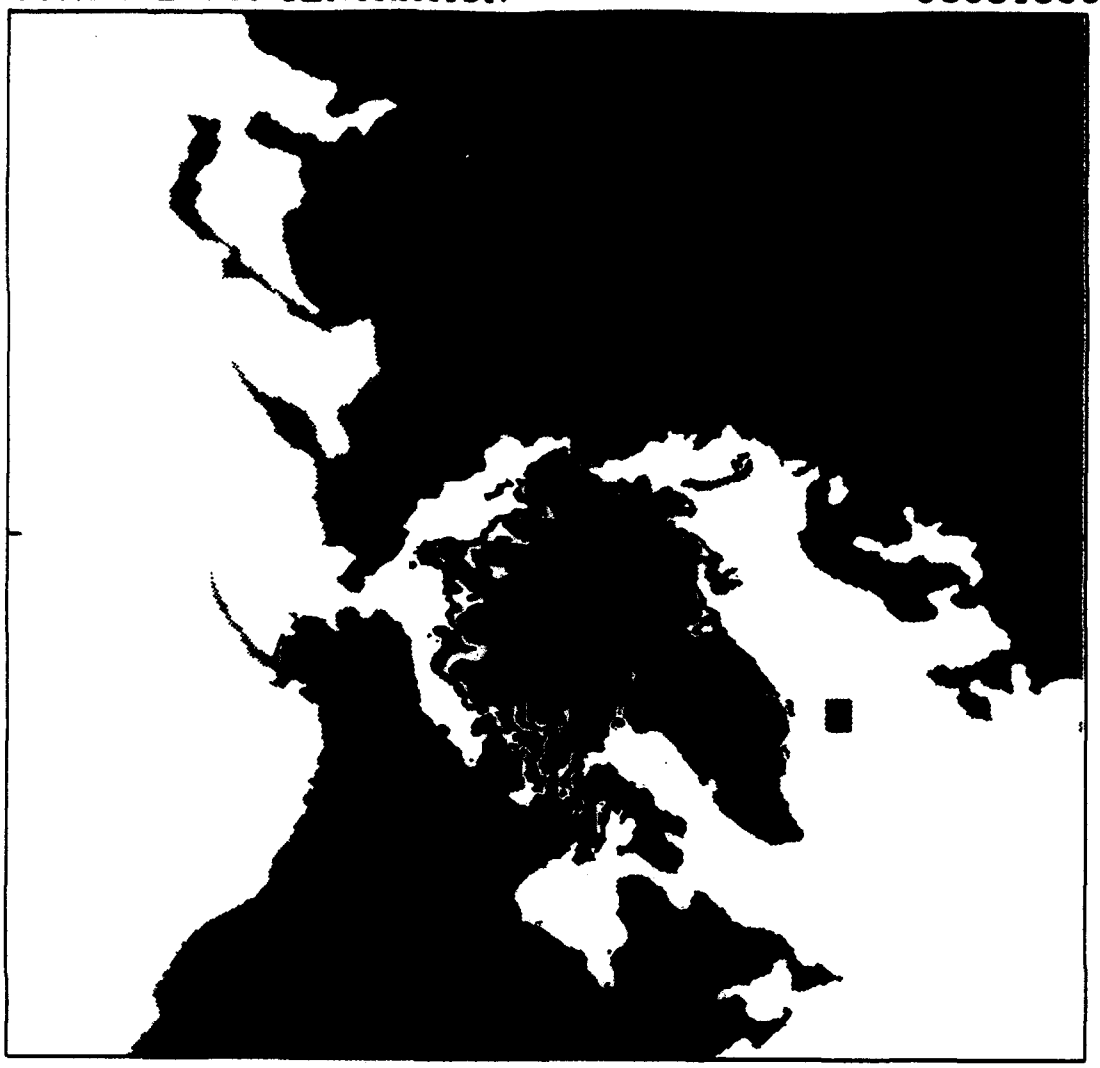

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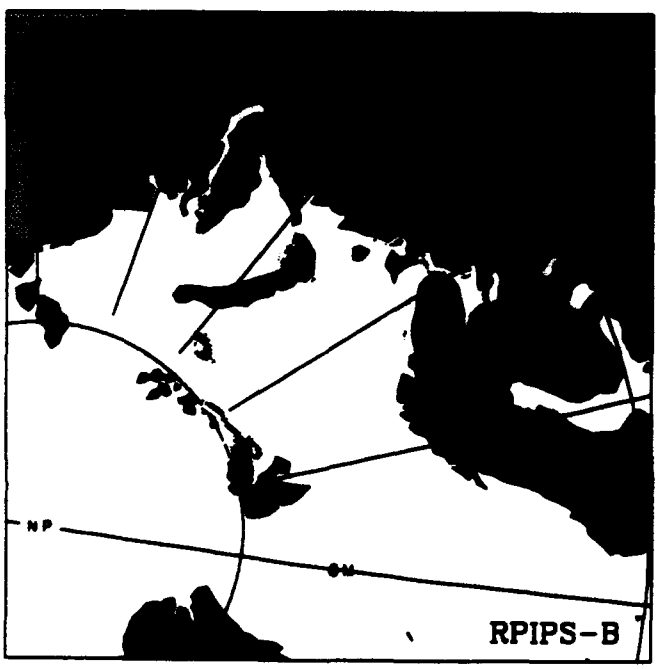

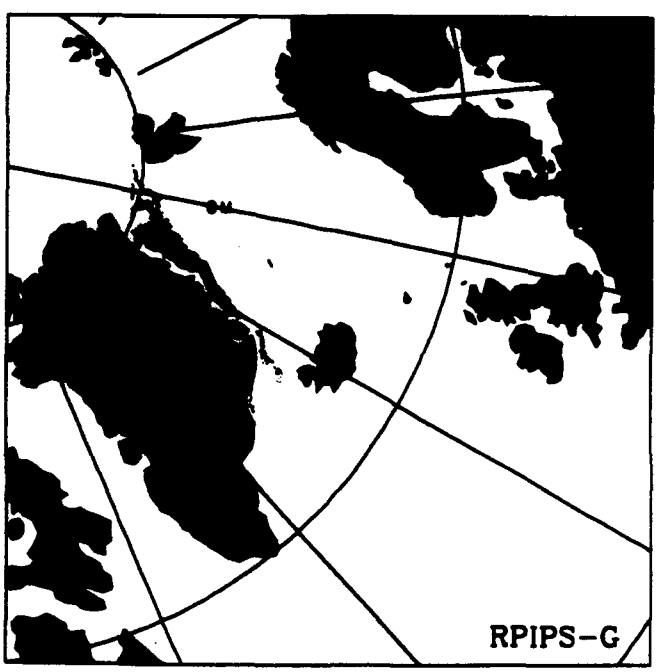

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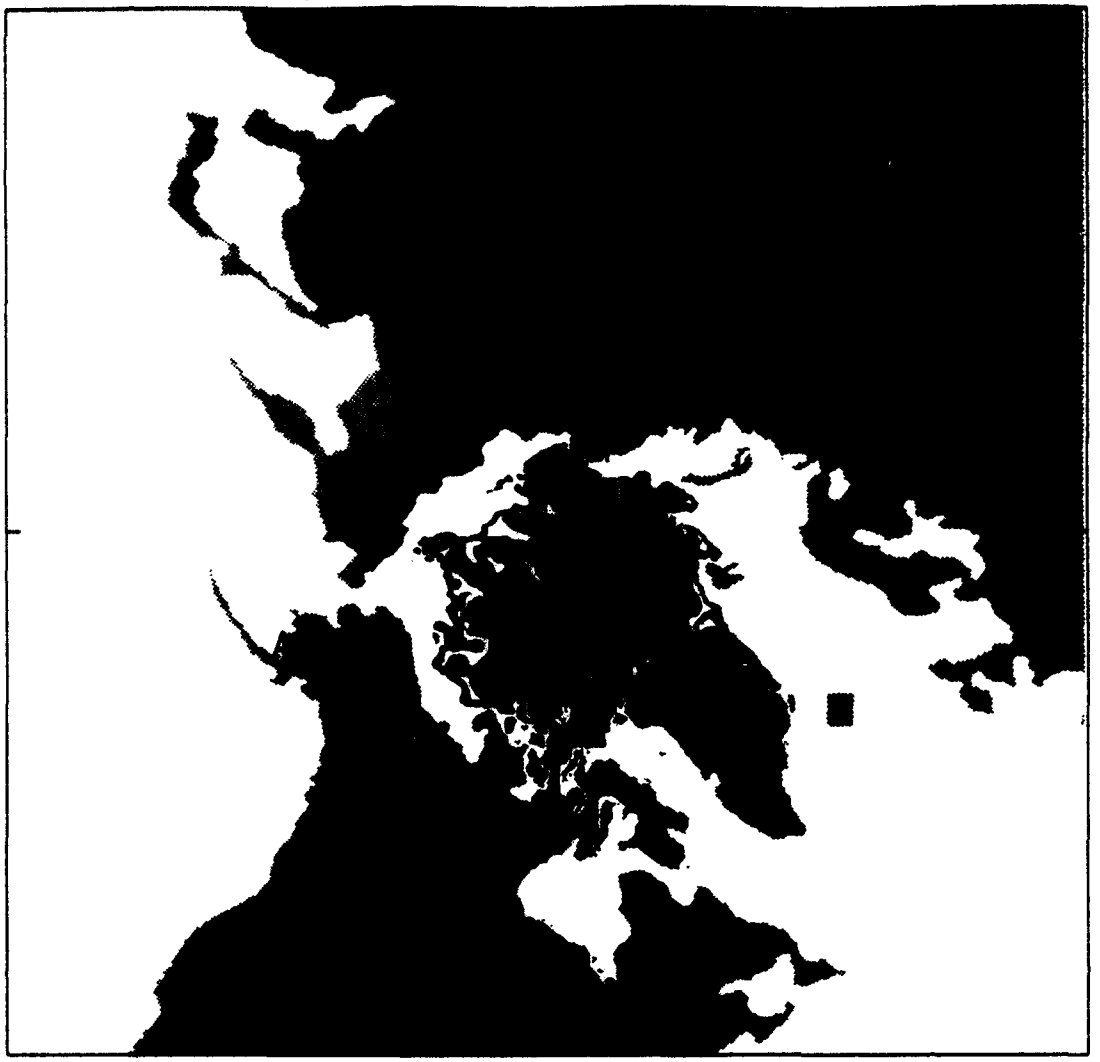

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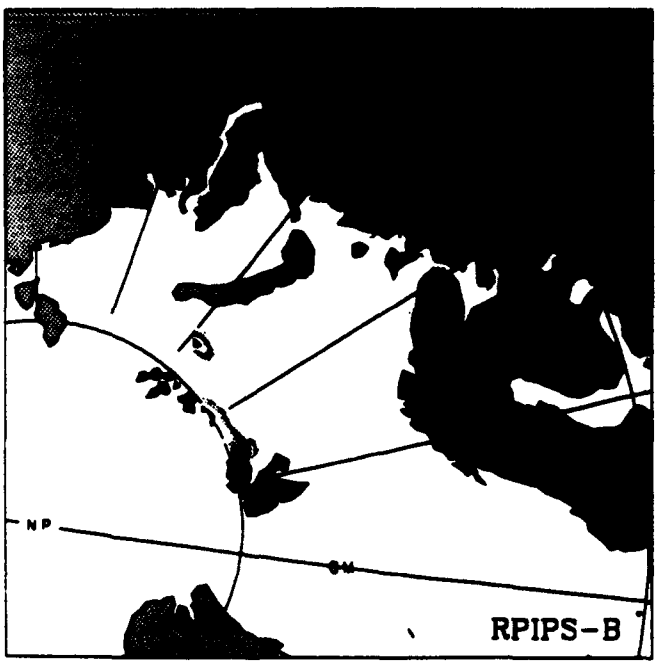

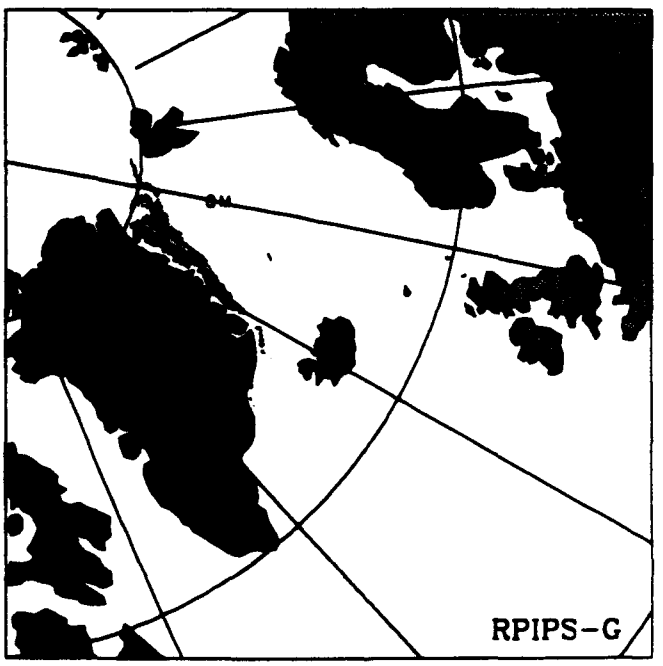

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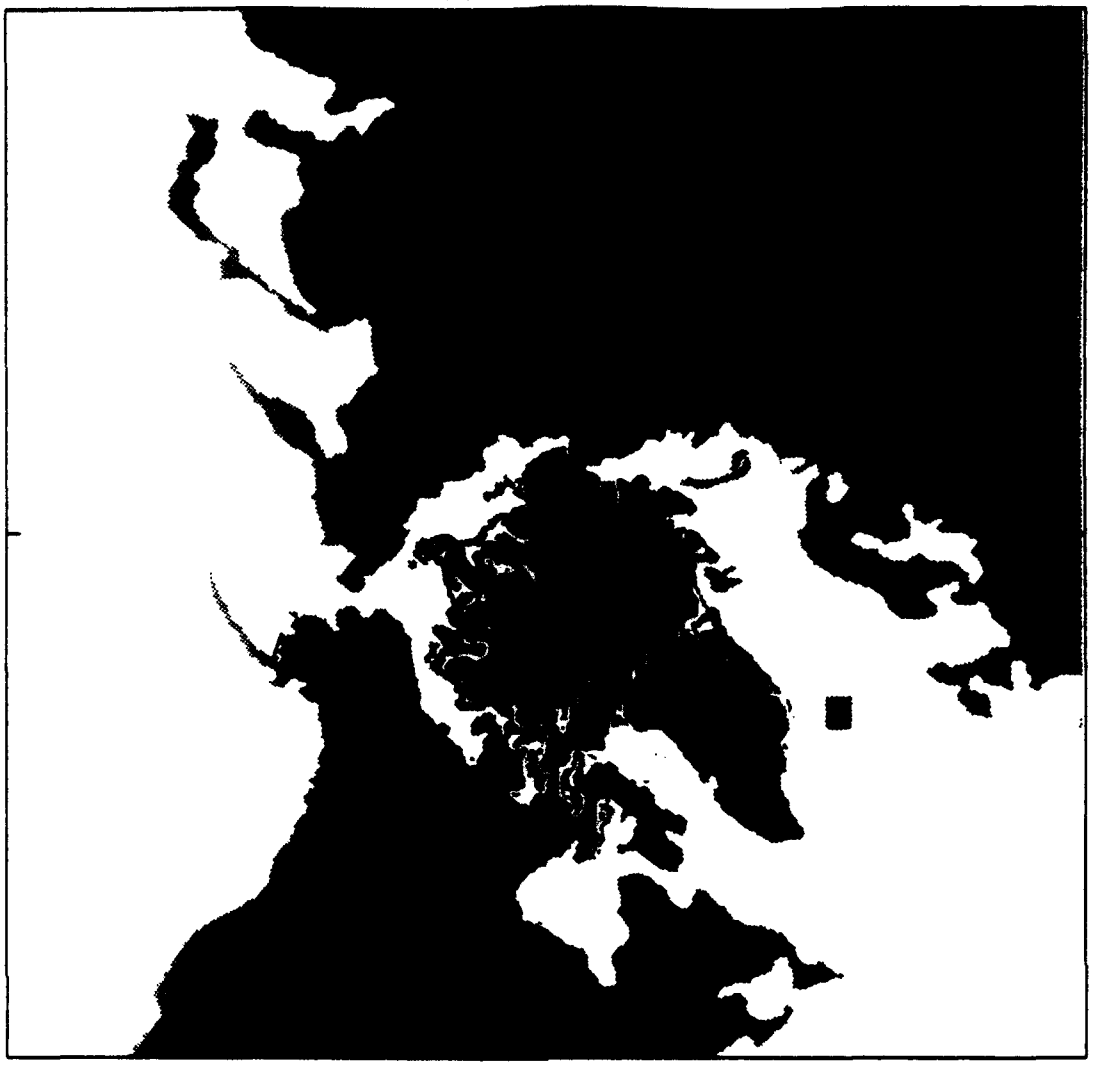

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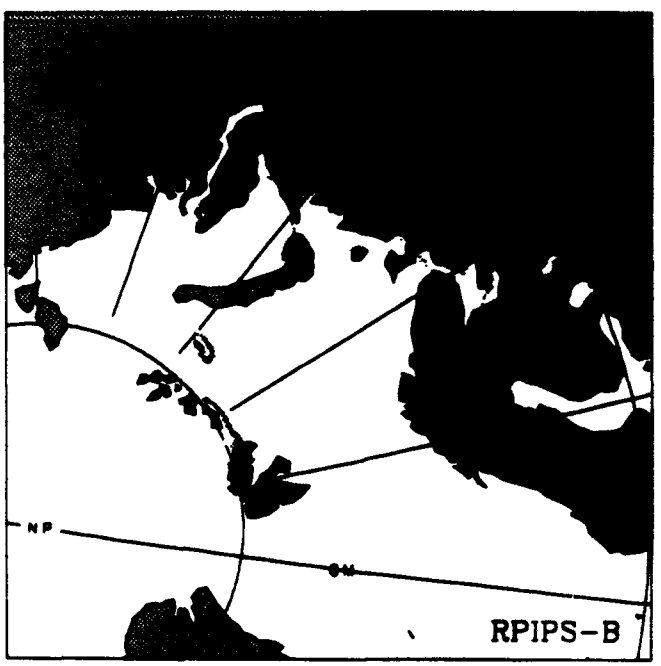

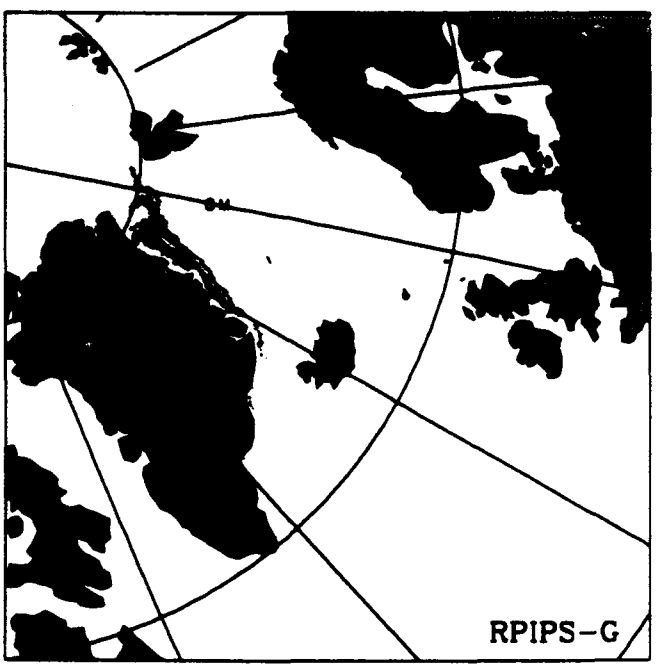

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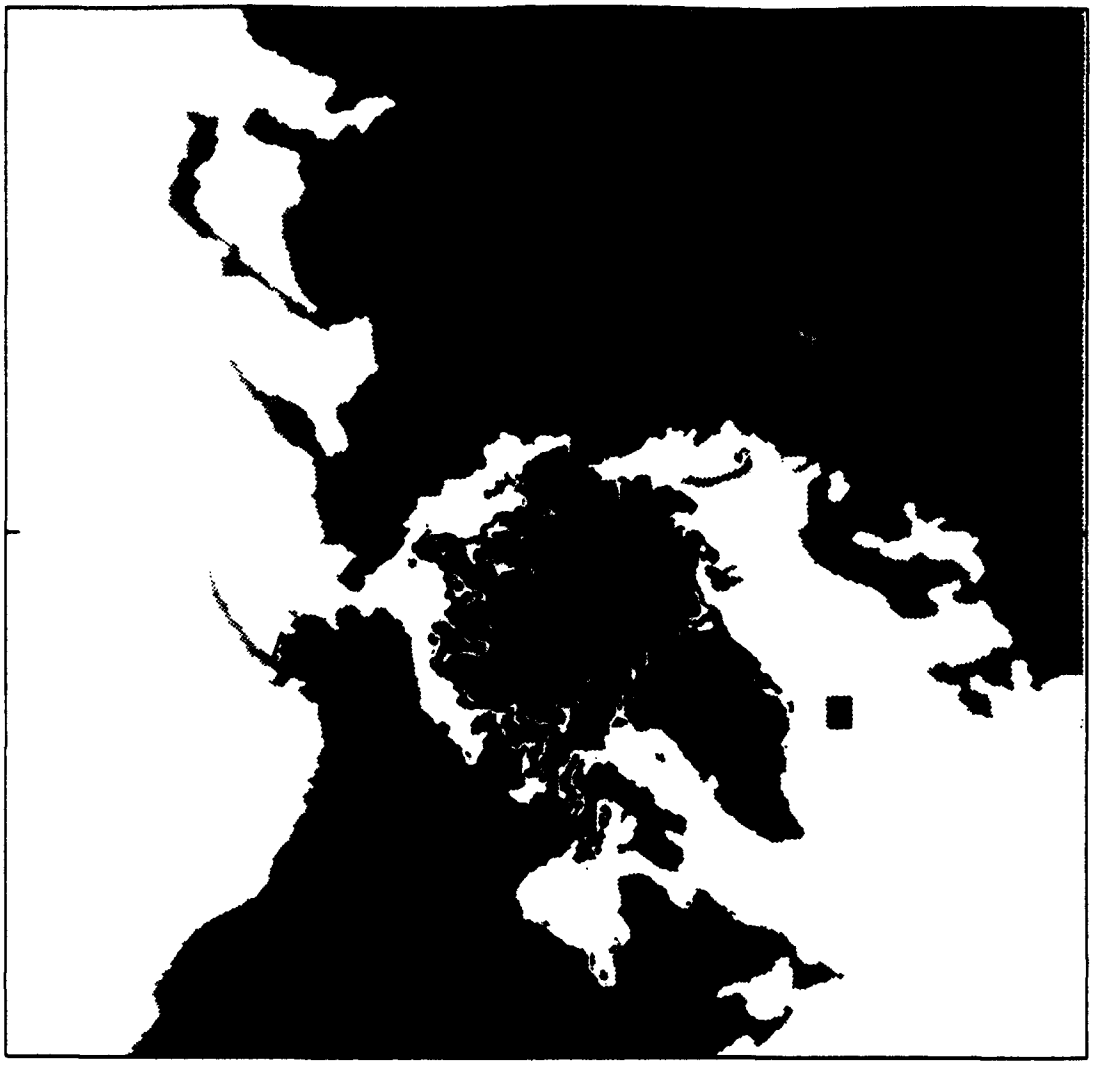

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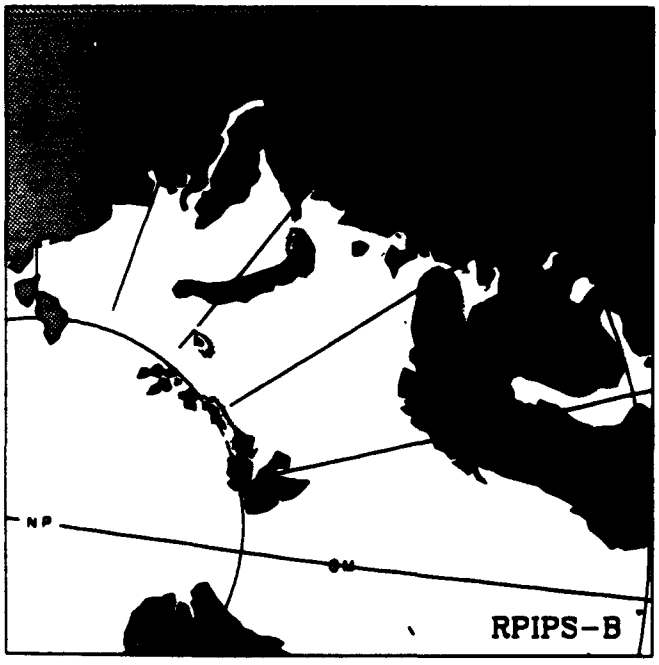

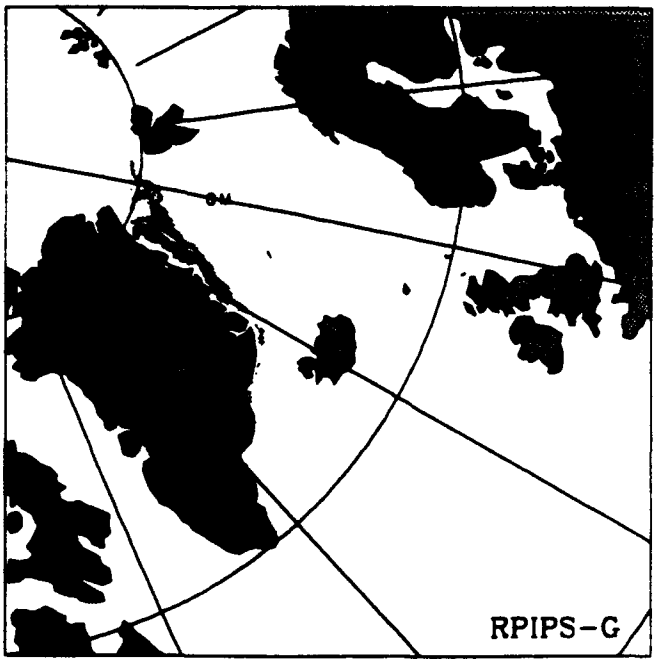

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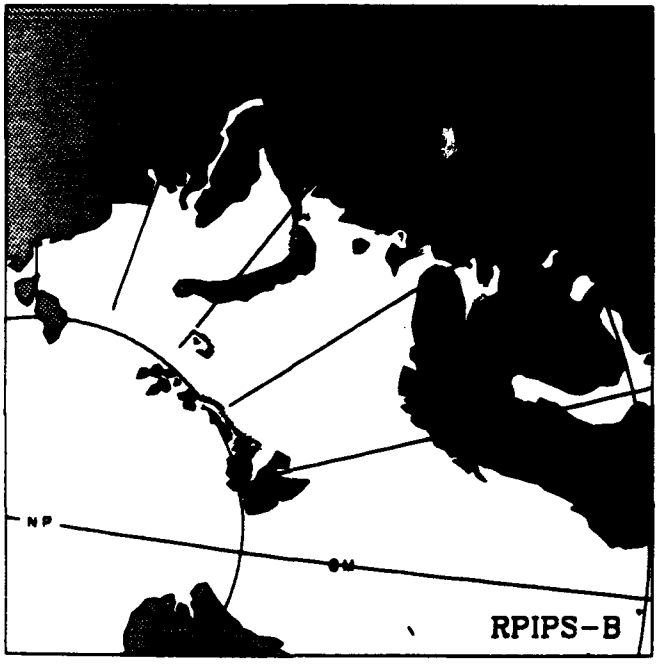

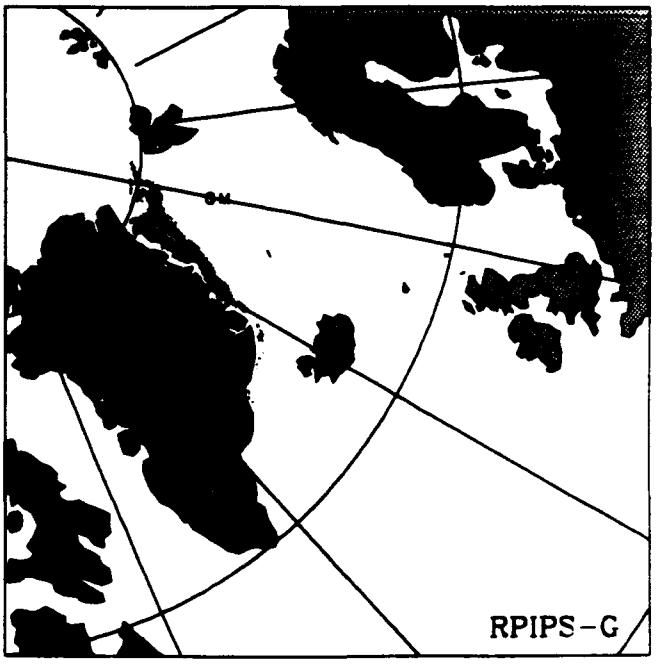

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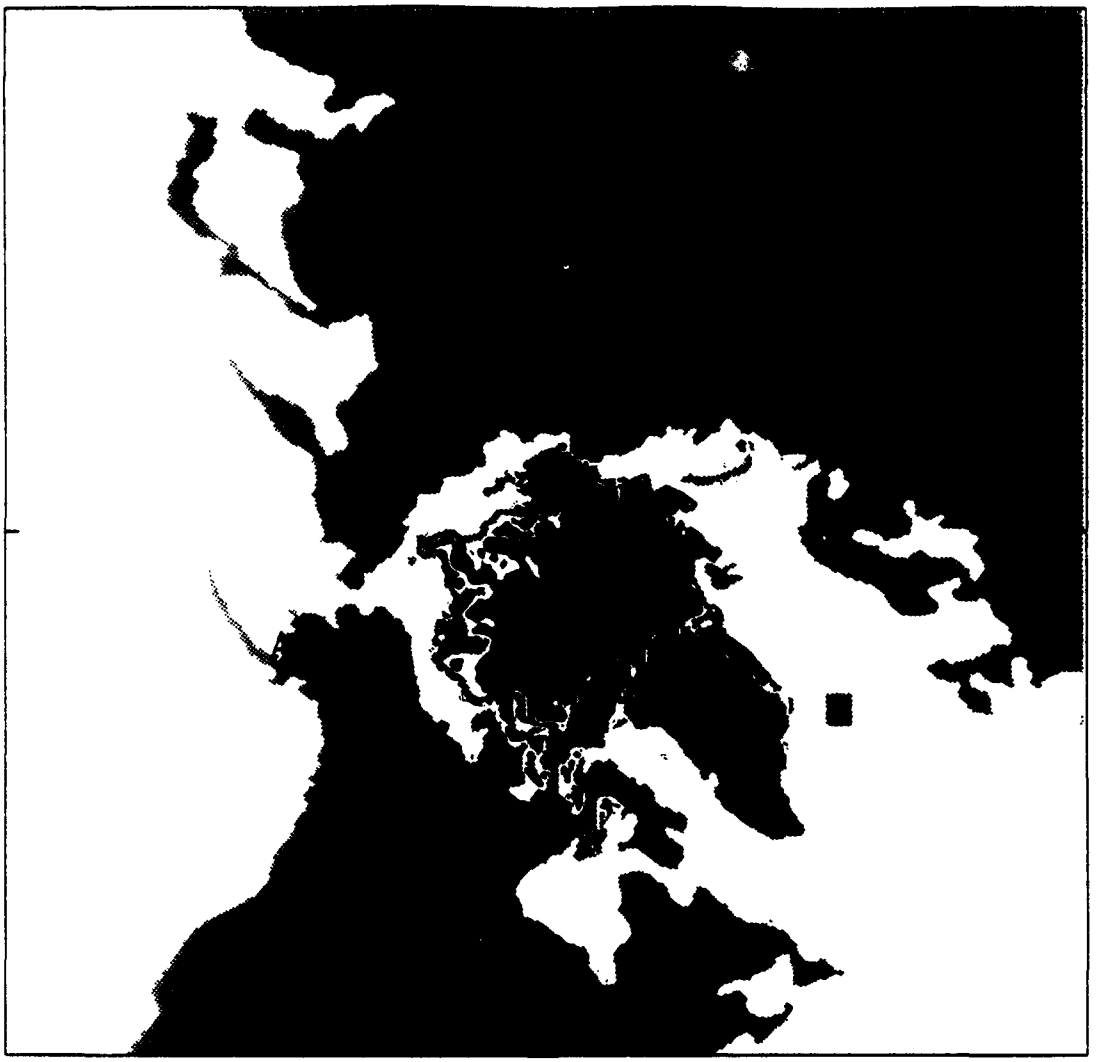

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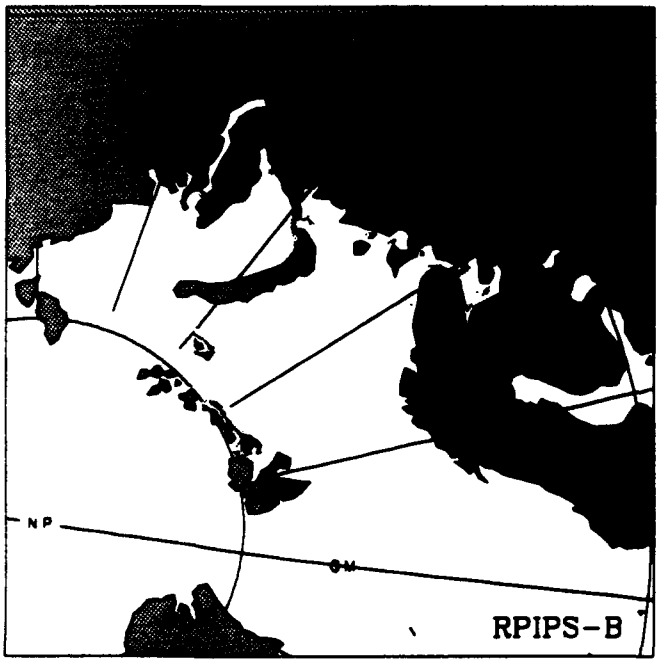

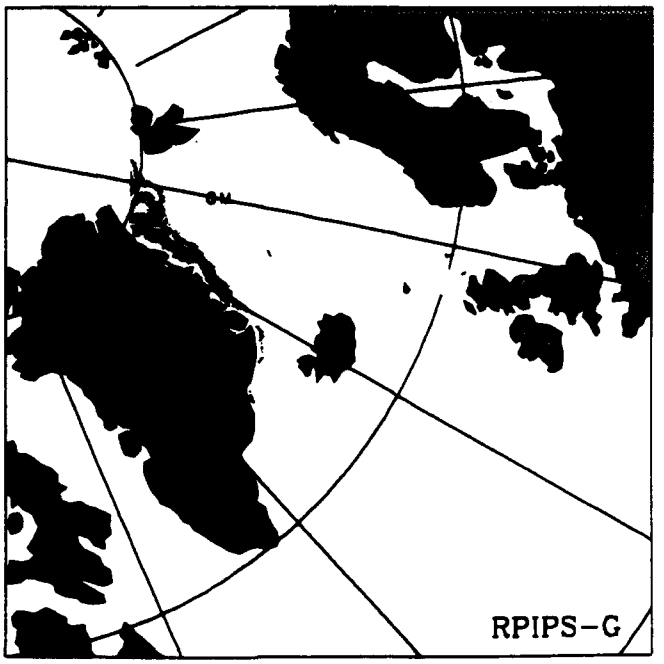

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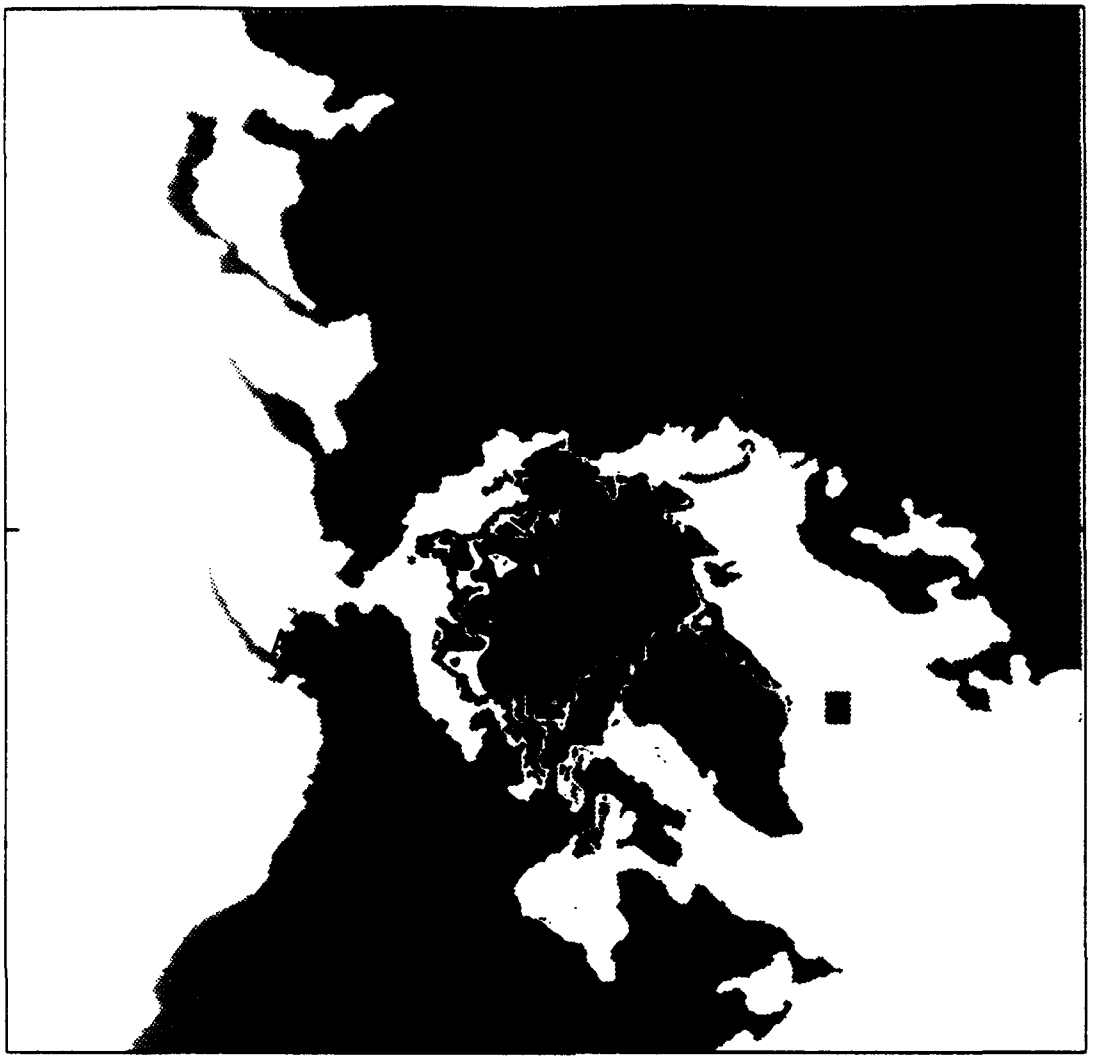

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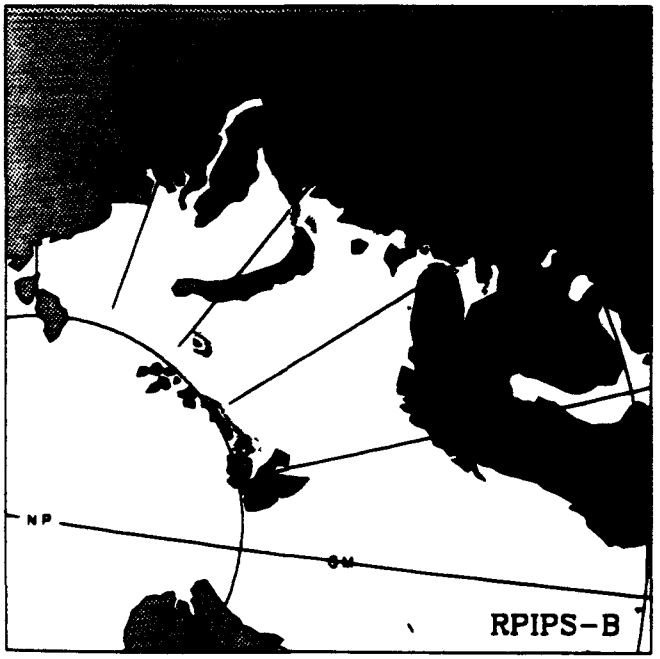

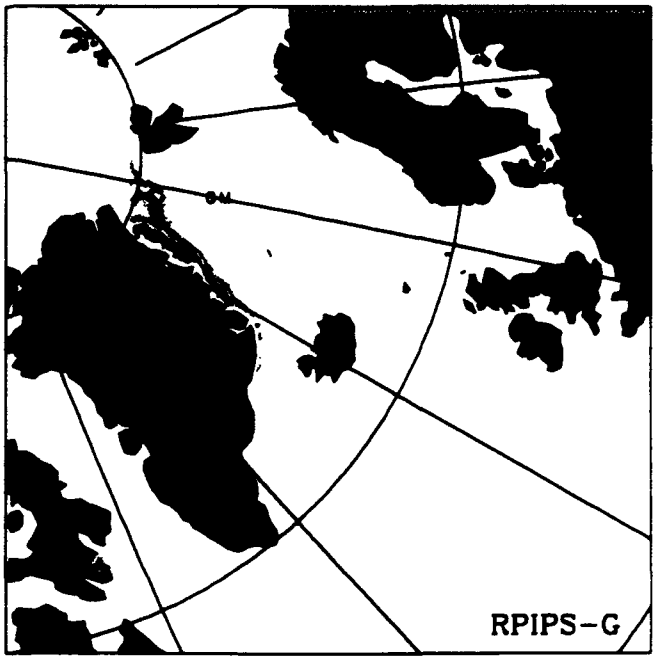

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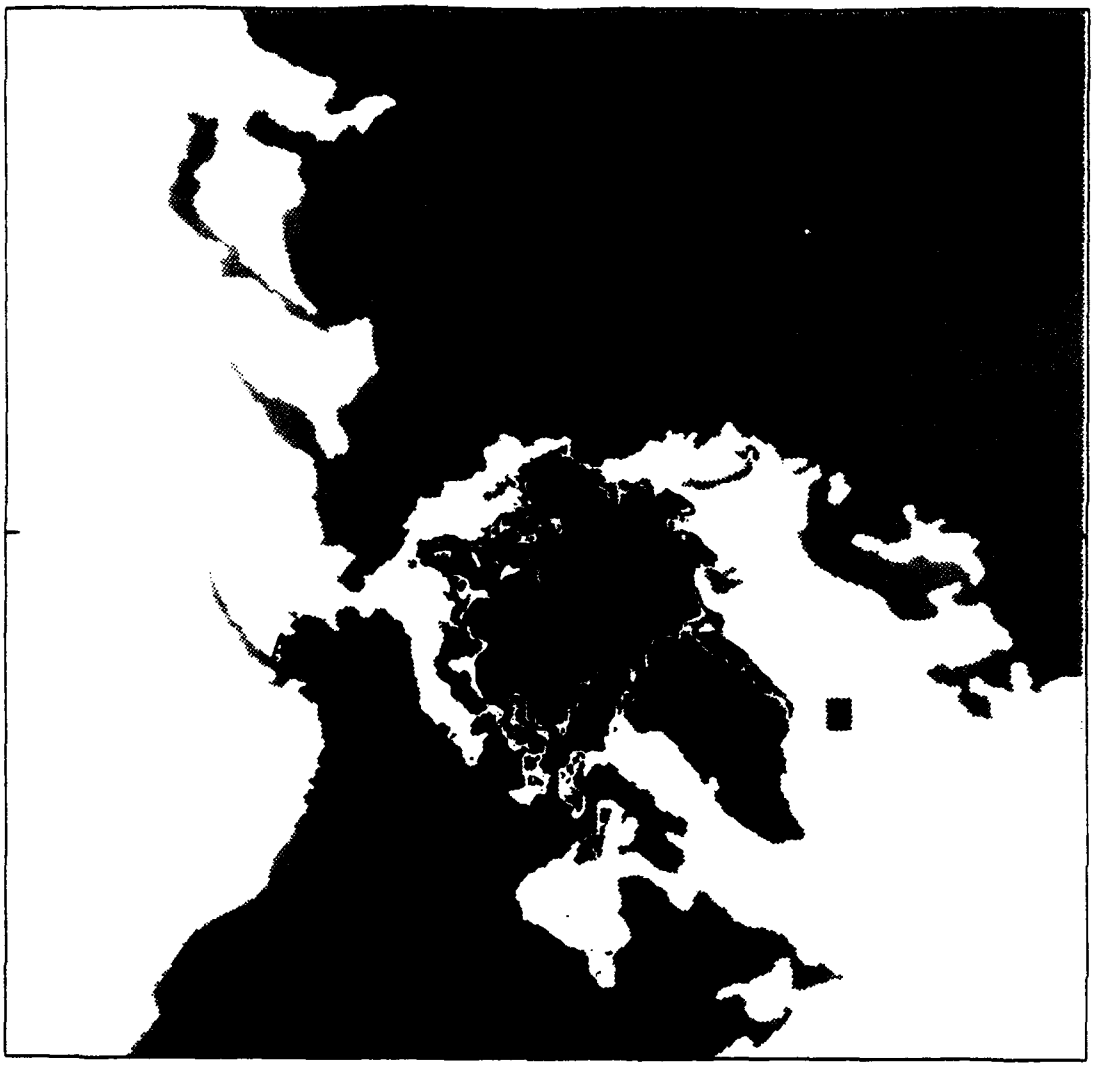

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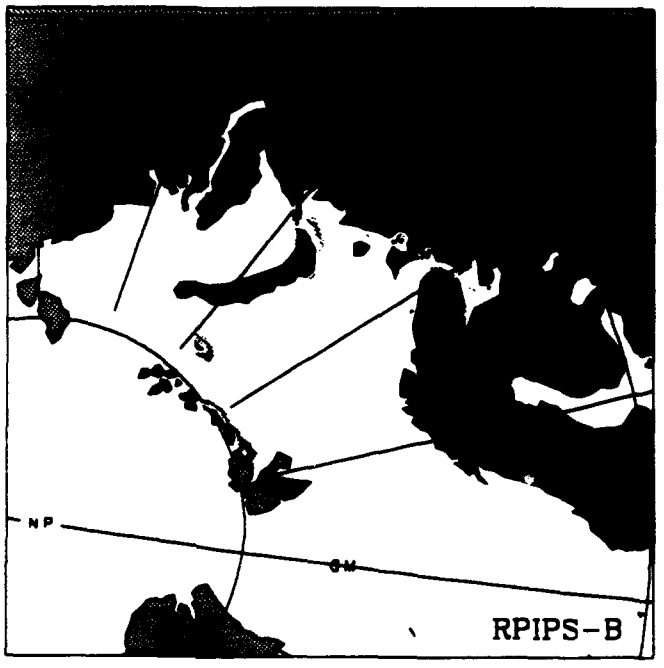

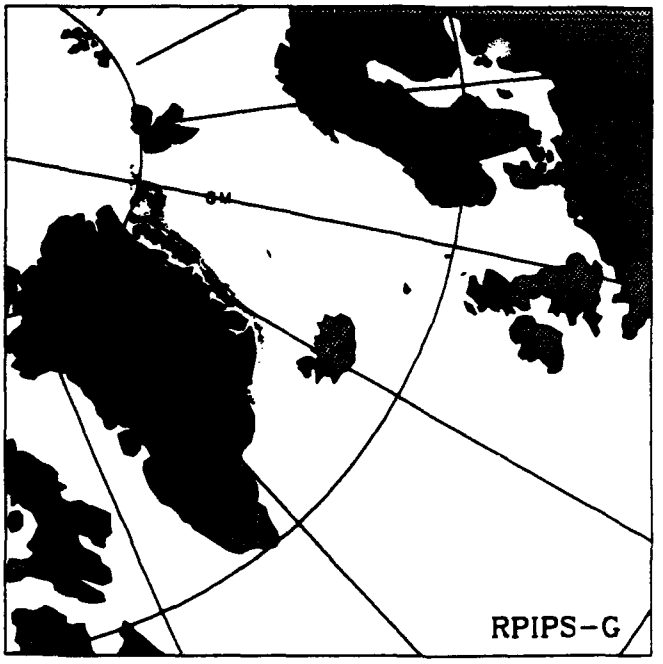

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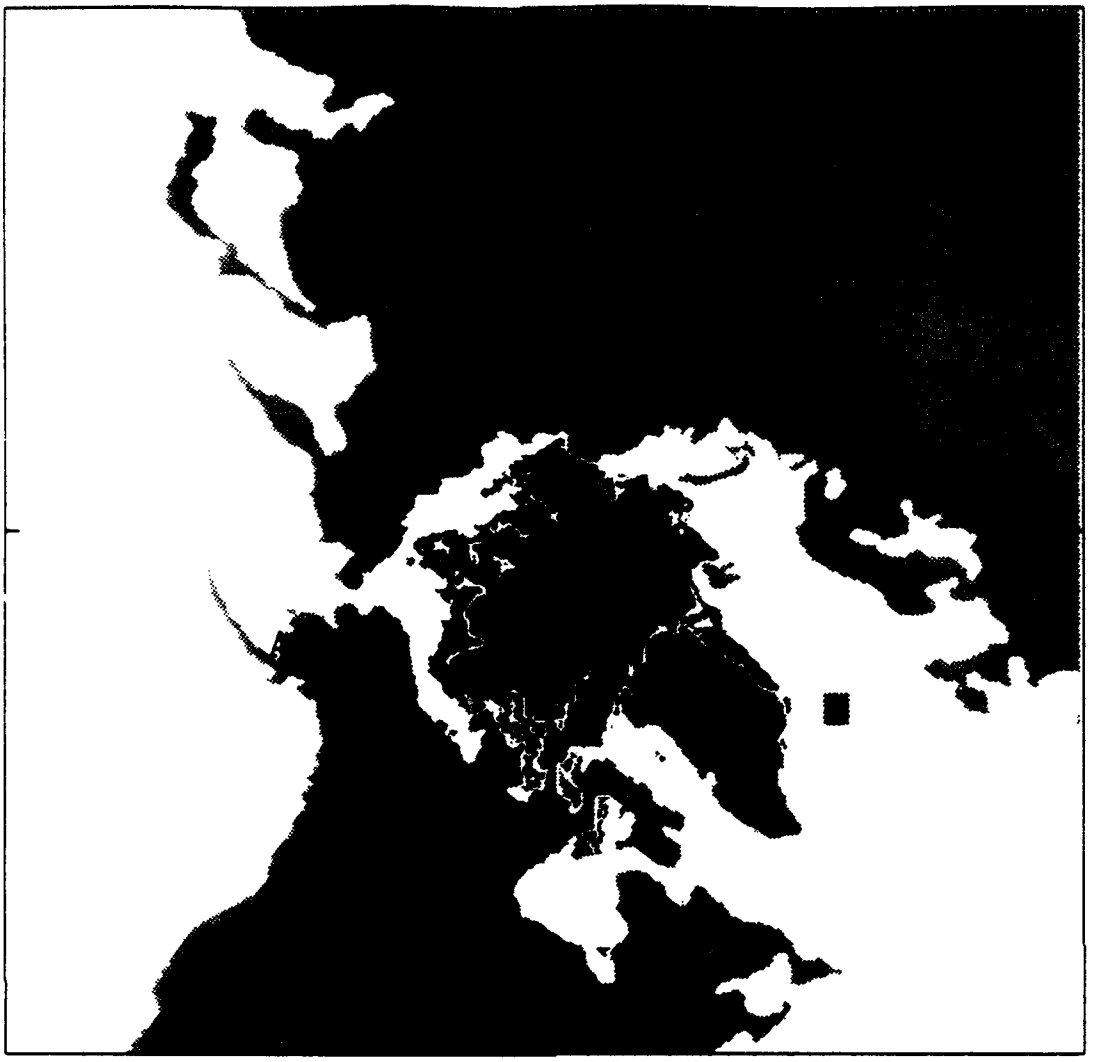

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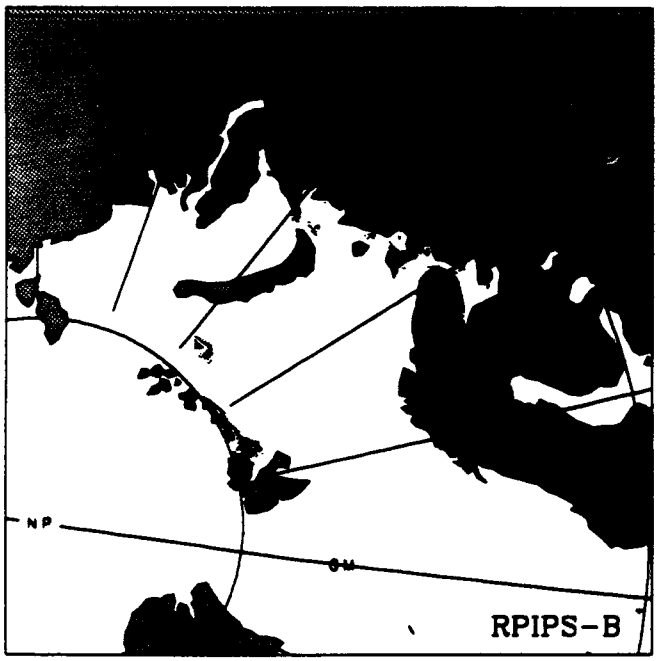

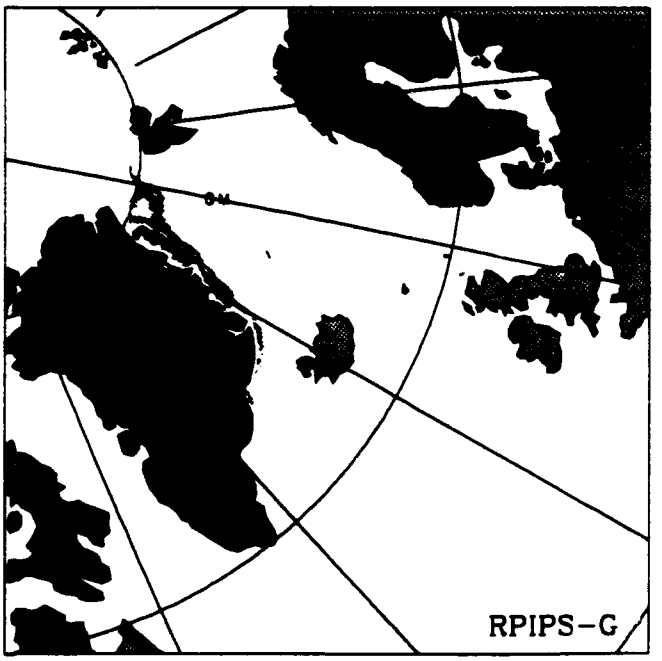

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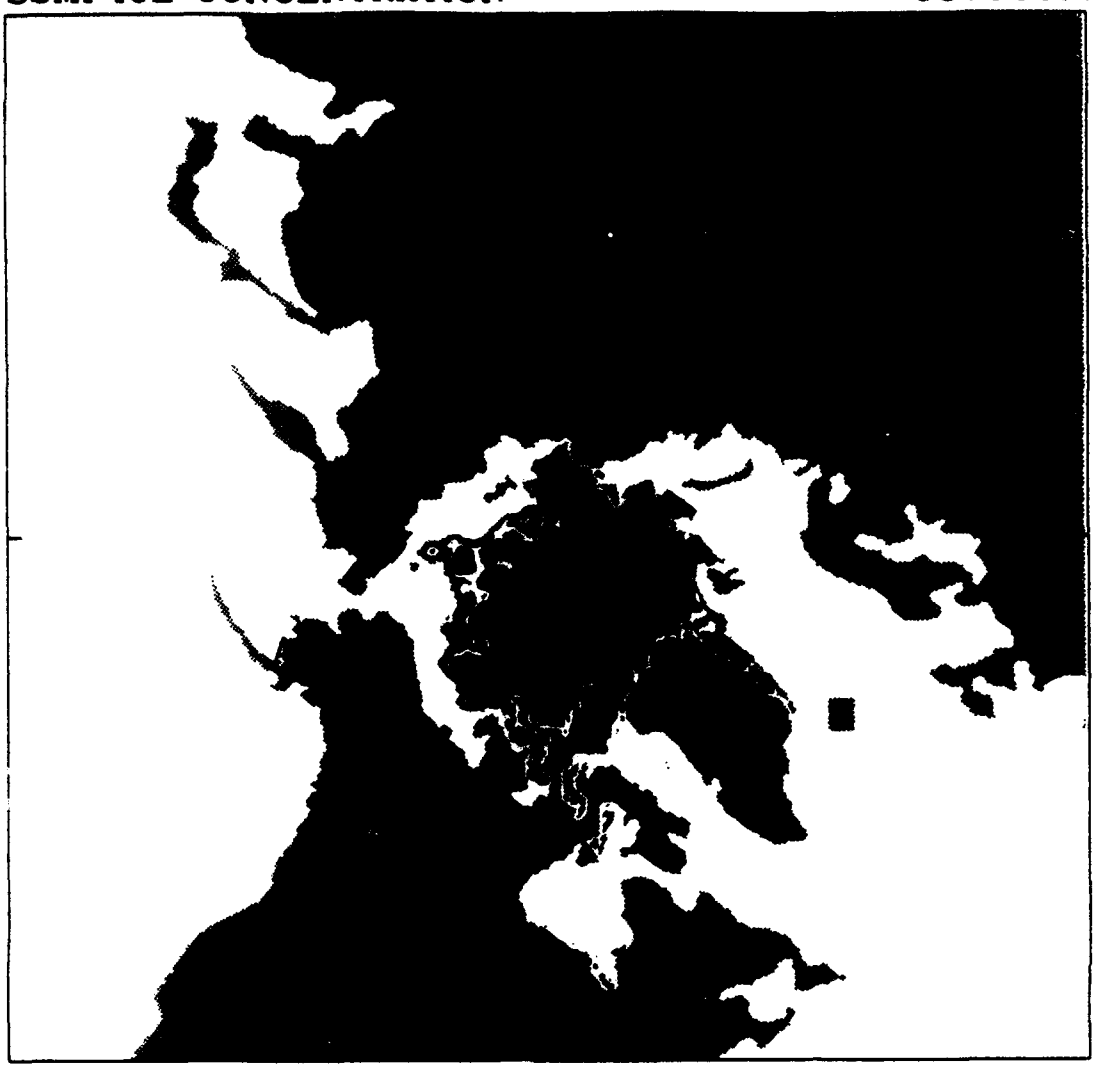

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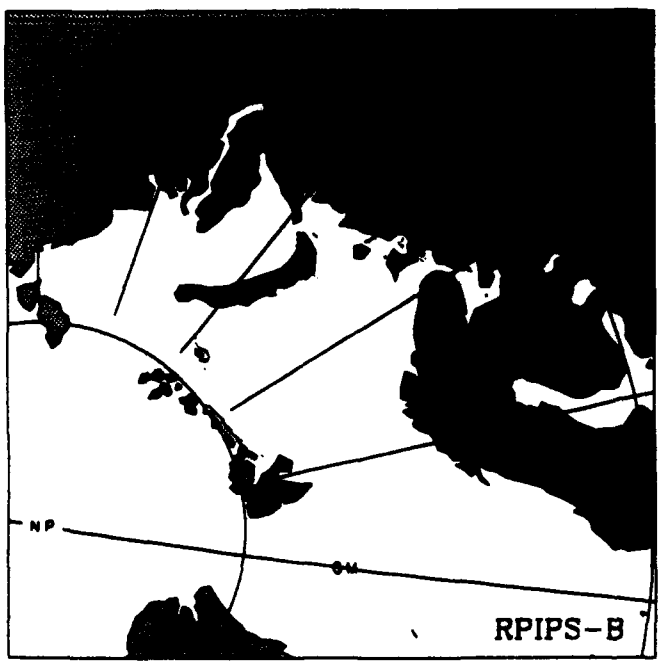

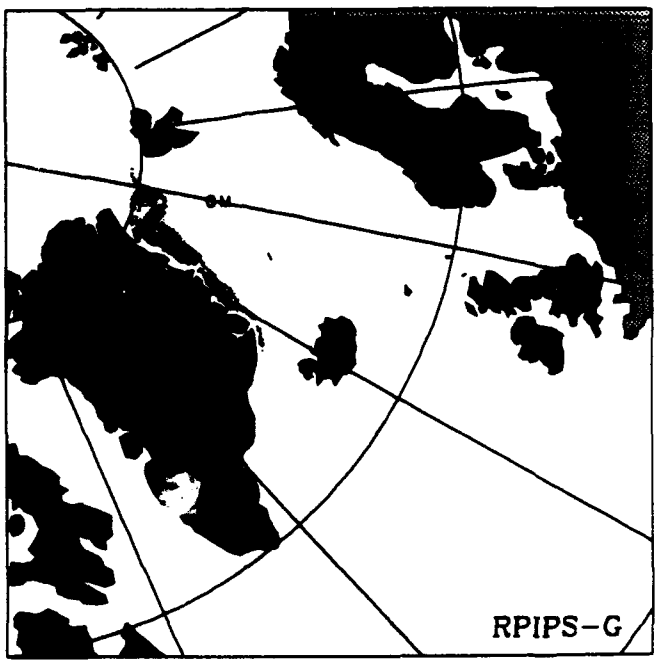

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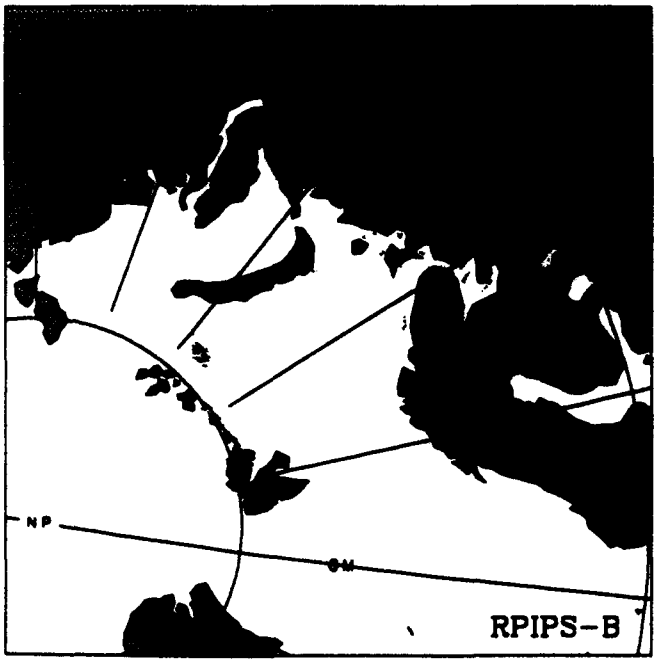

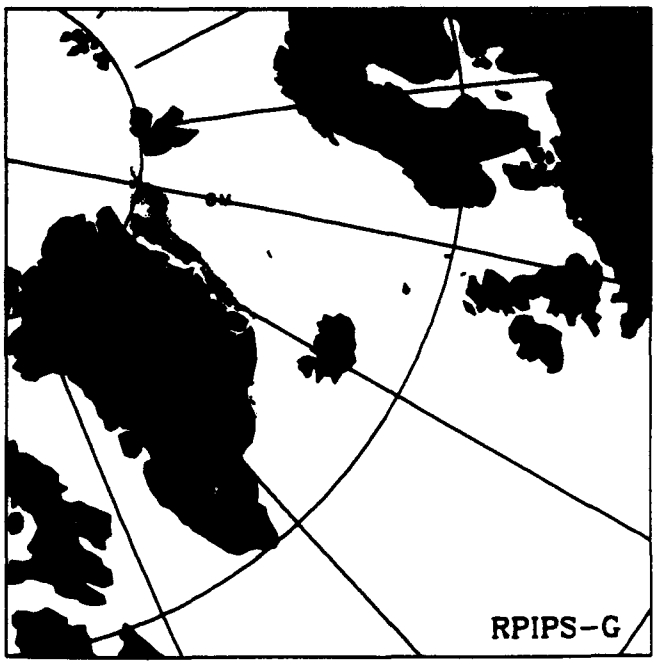

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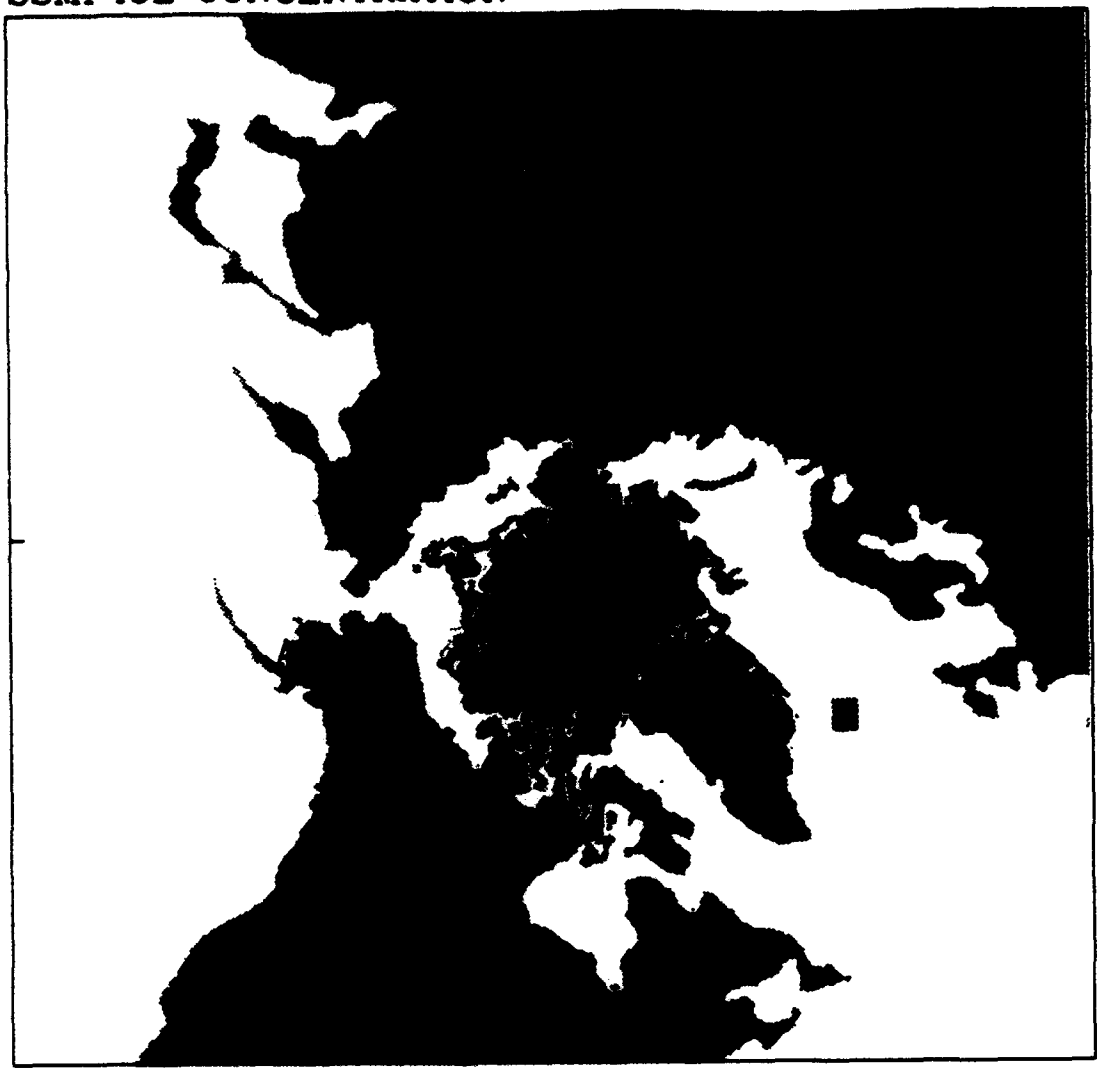

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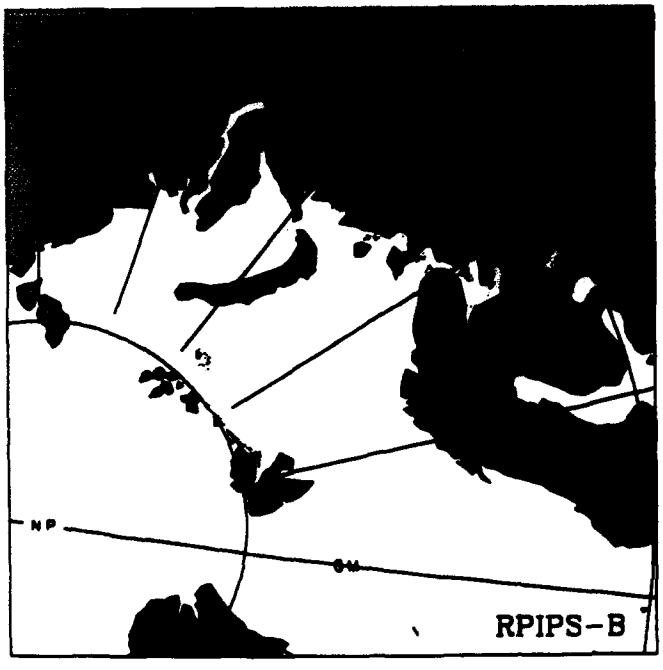

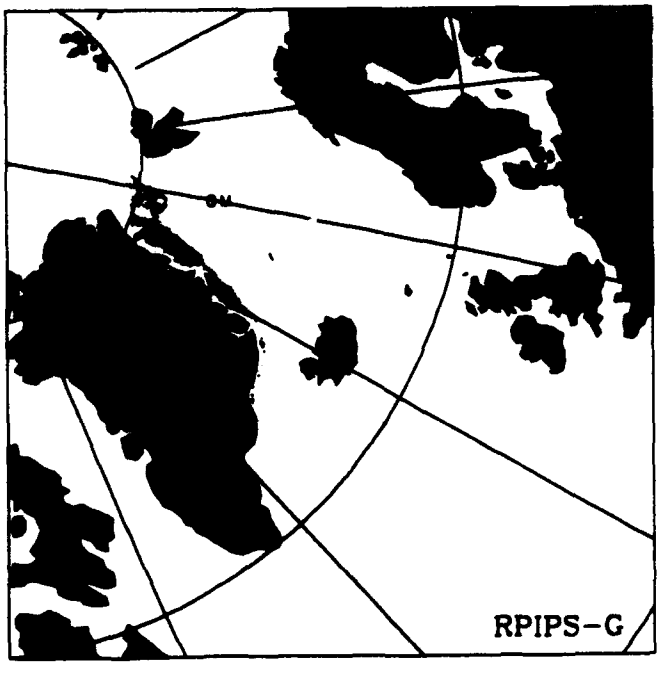

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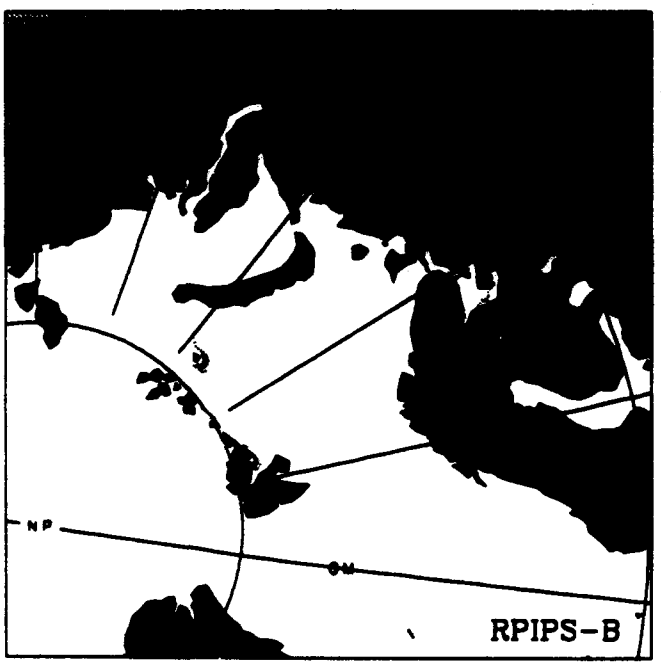

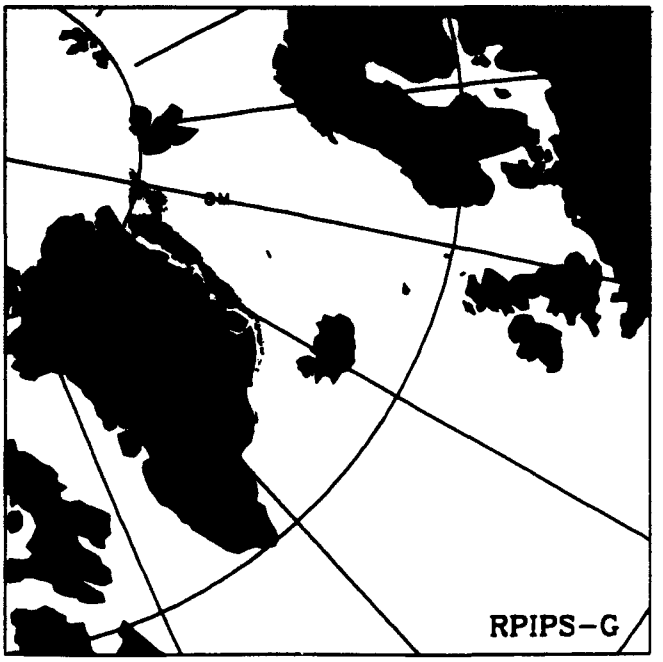

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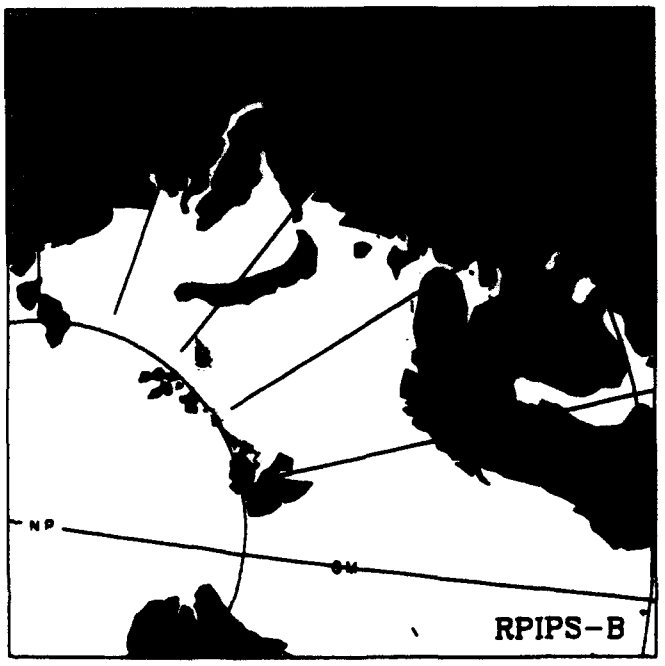

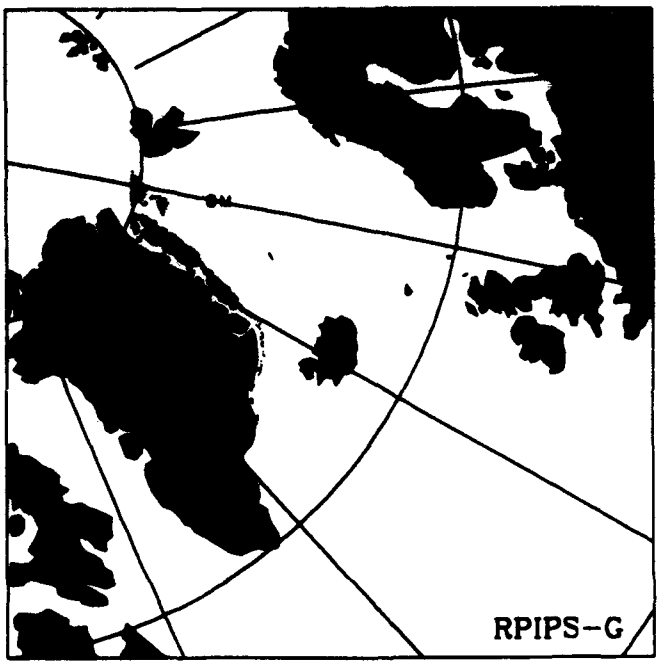

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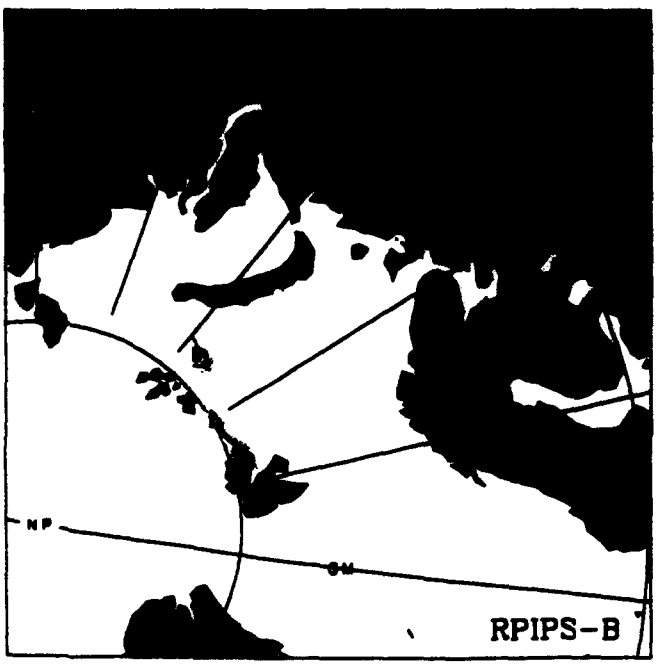

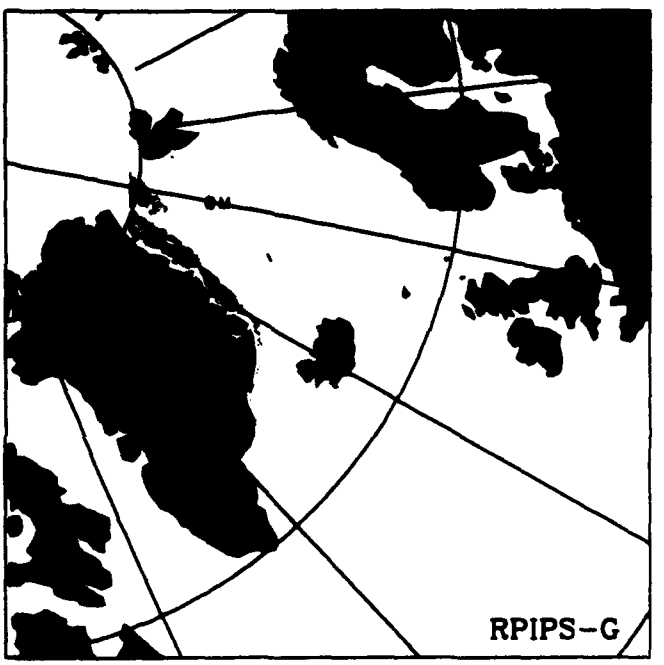

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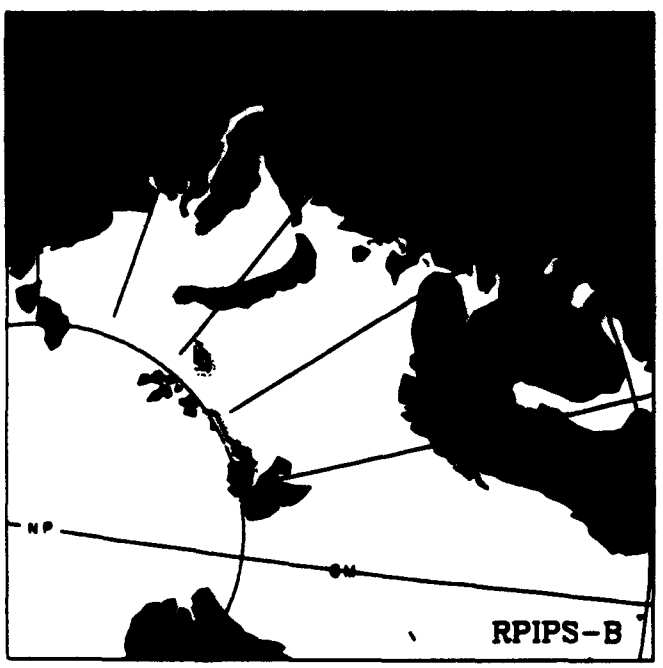

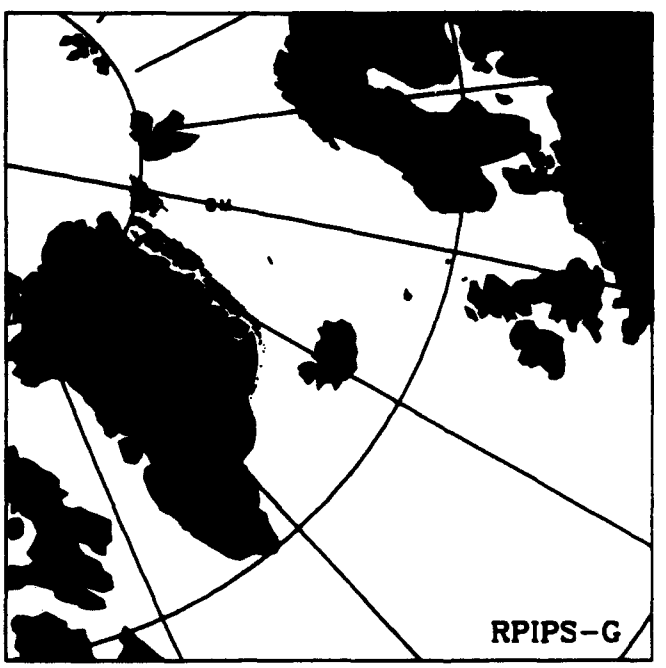

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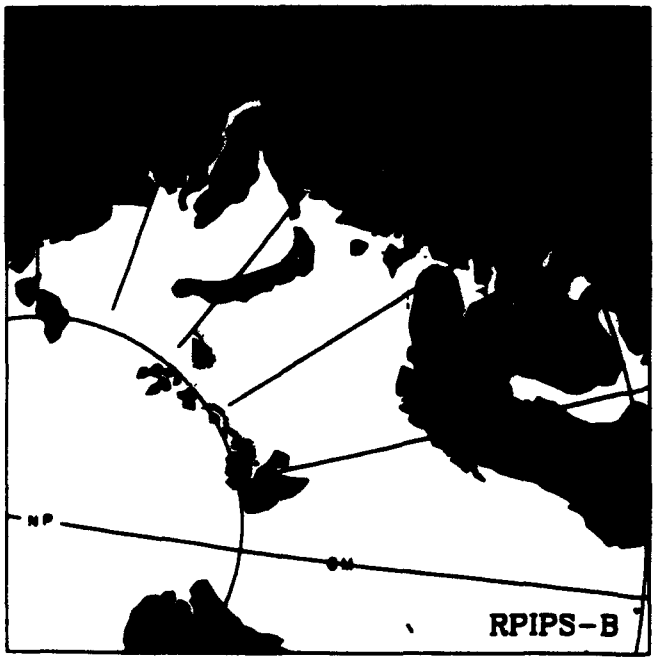

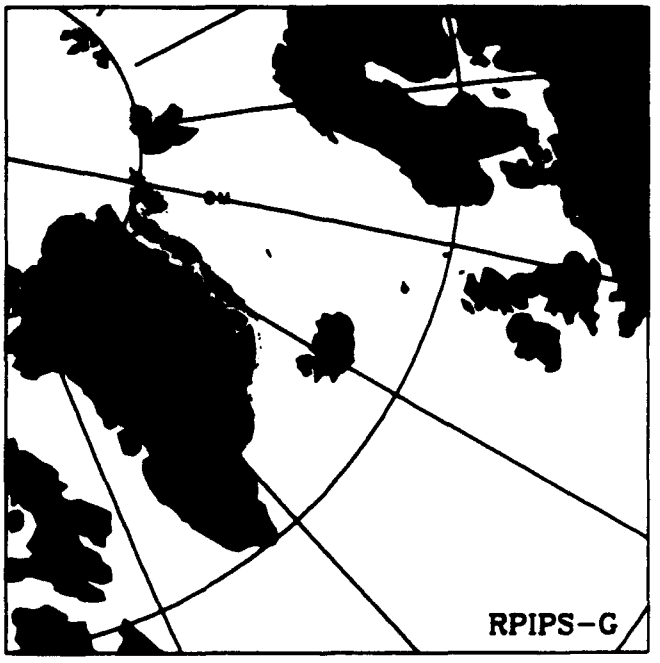

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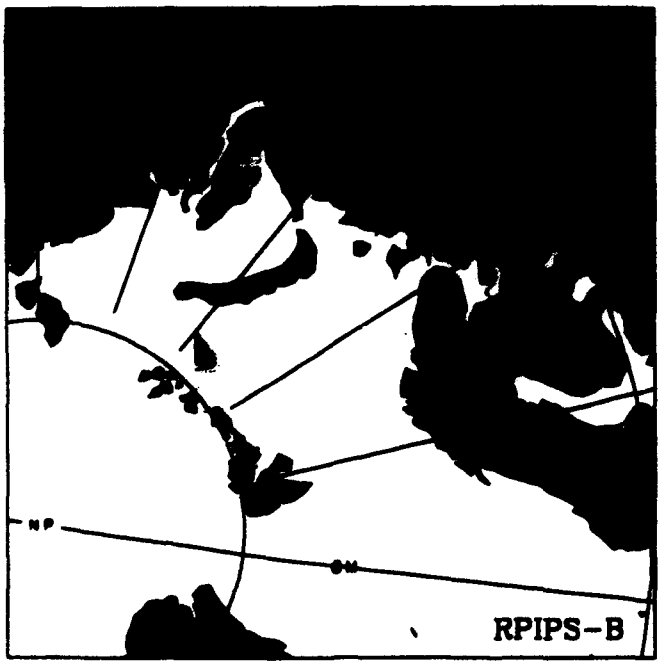

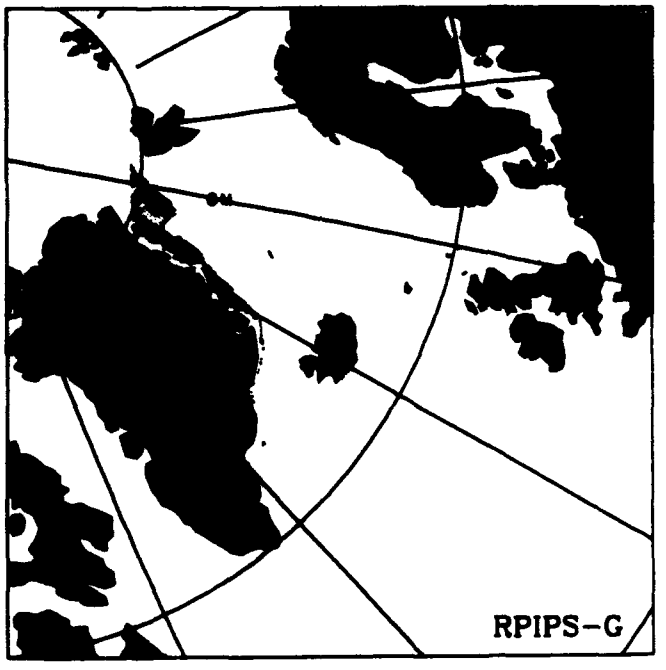

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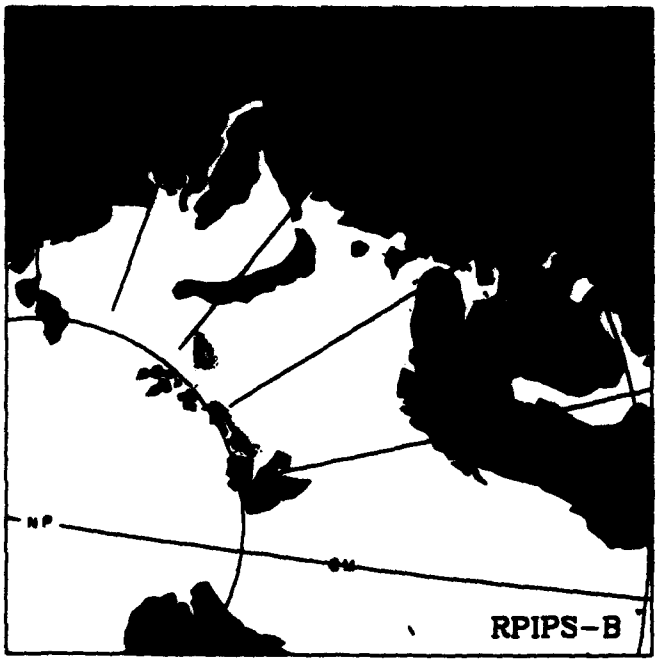

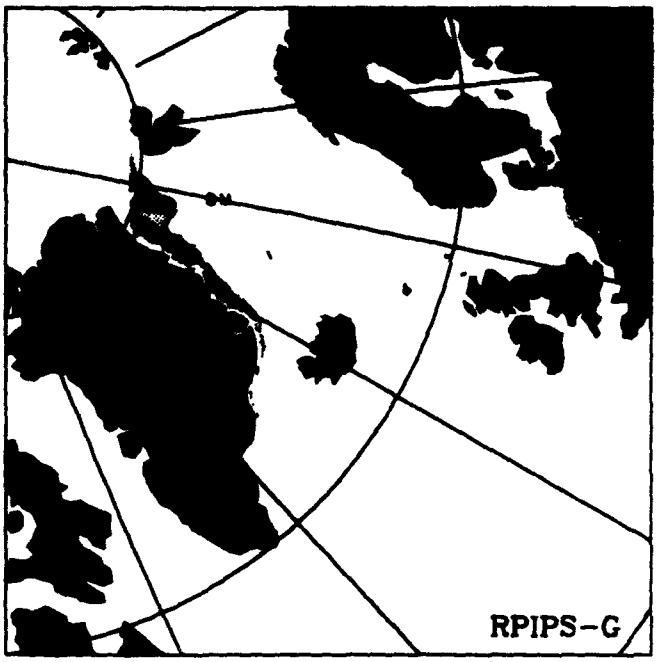

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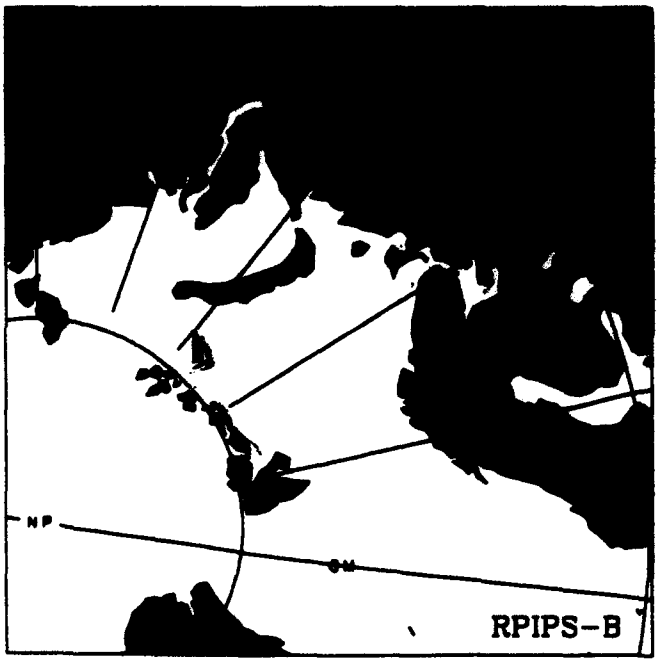
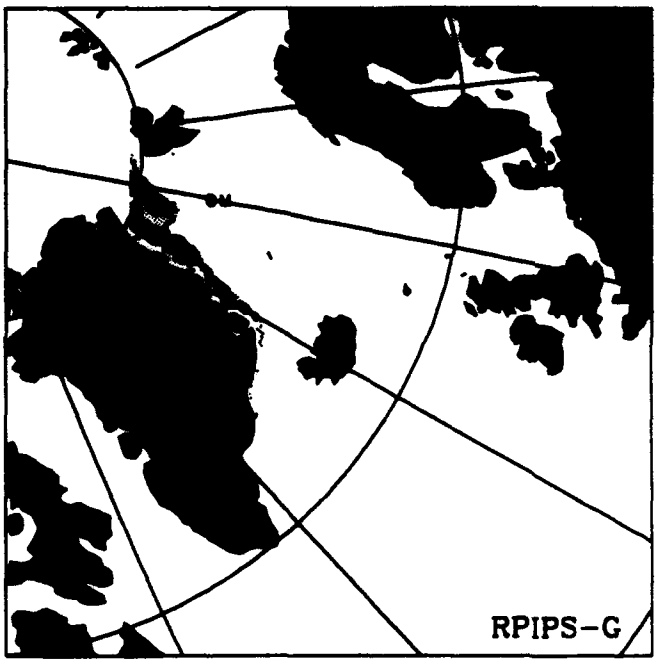
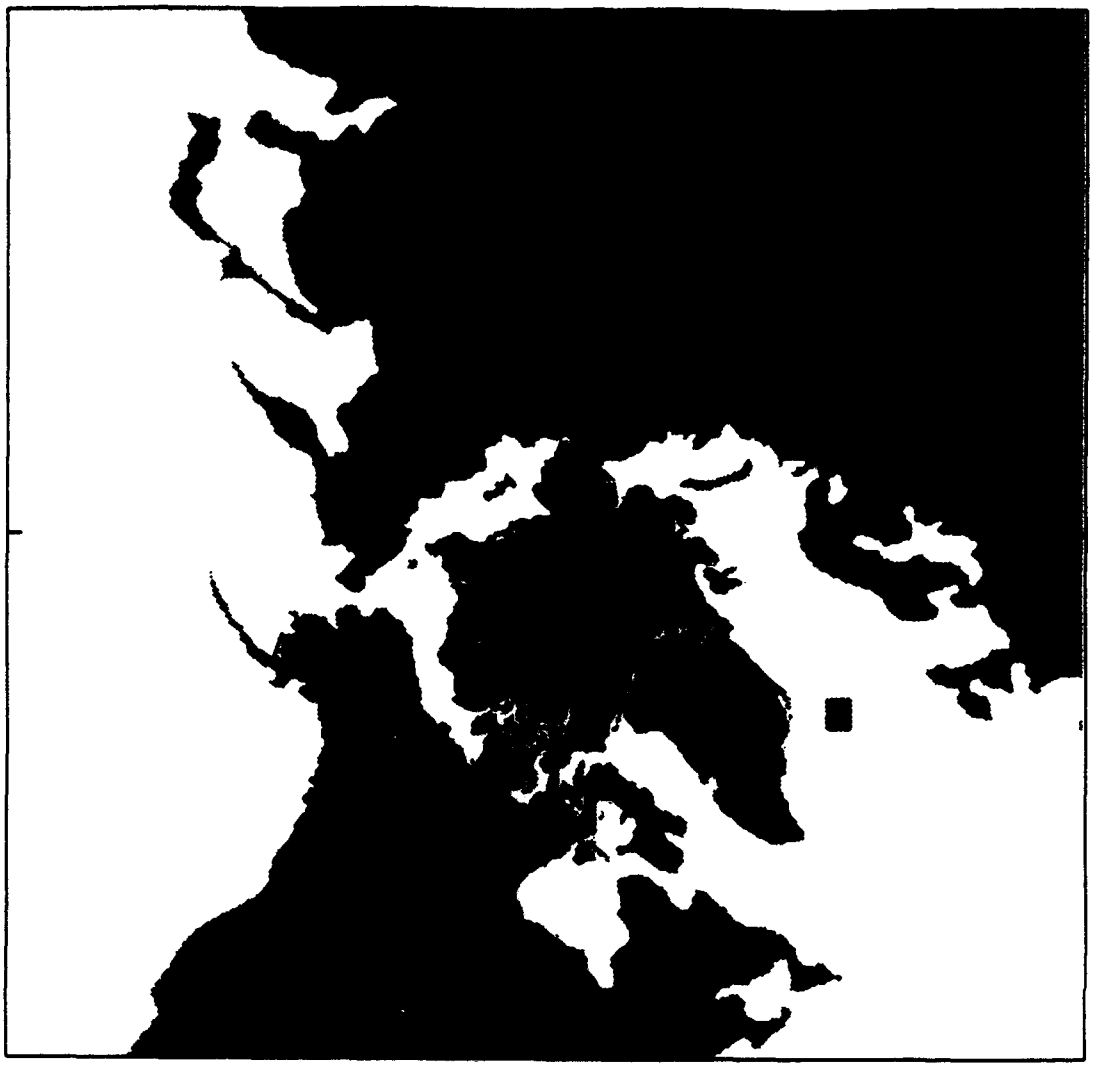




SSMI ICE CONCENTRATION 93090500



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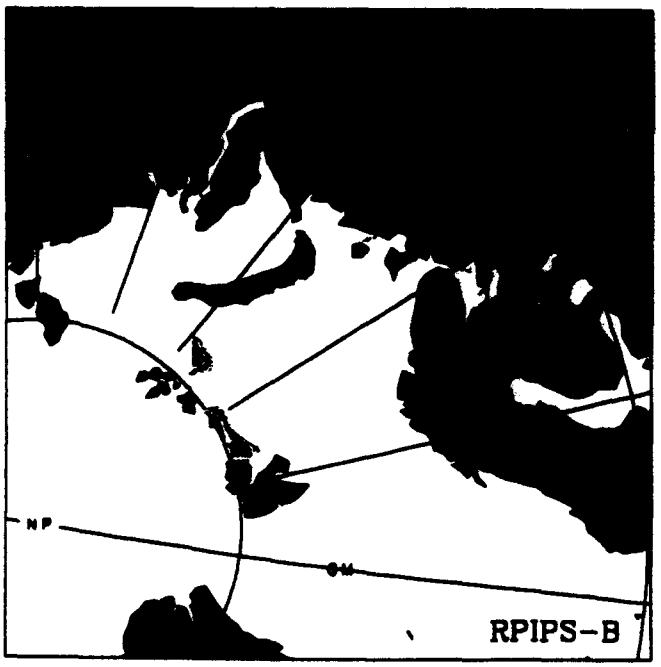

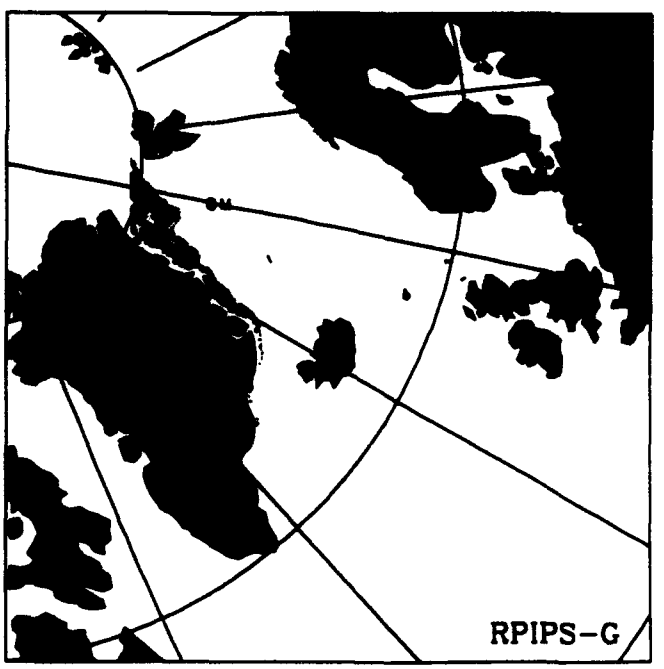

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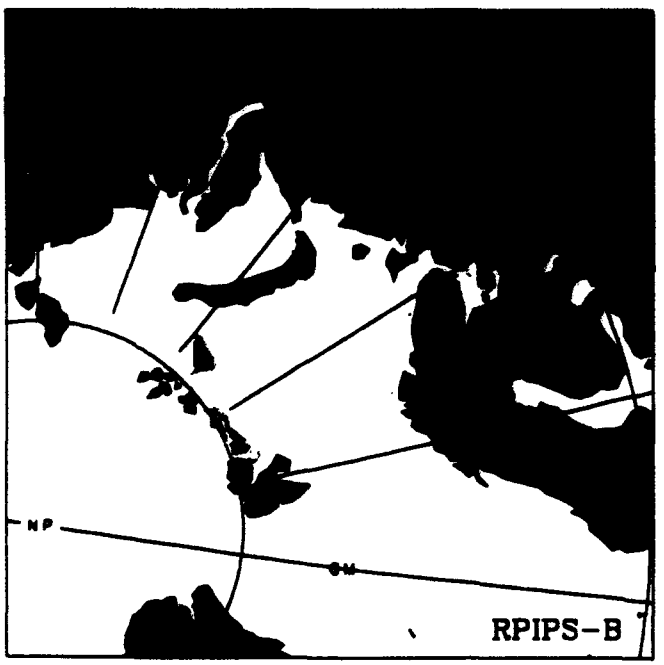

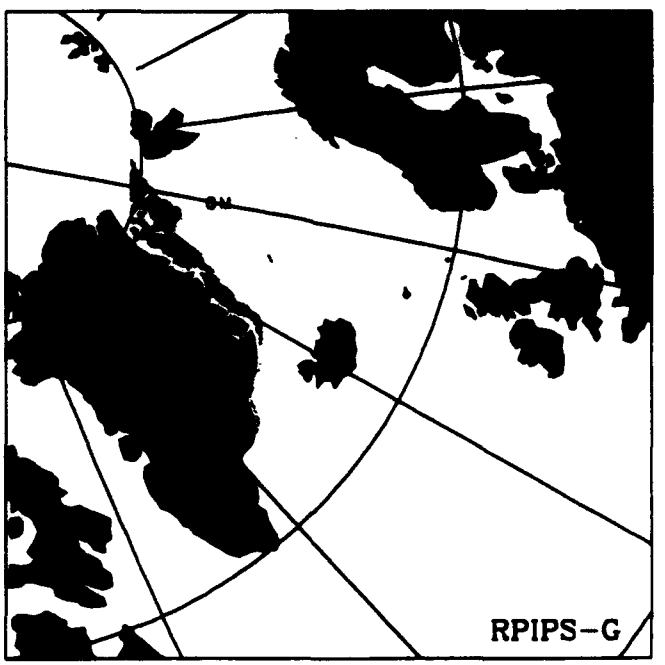

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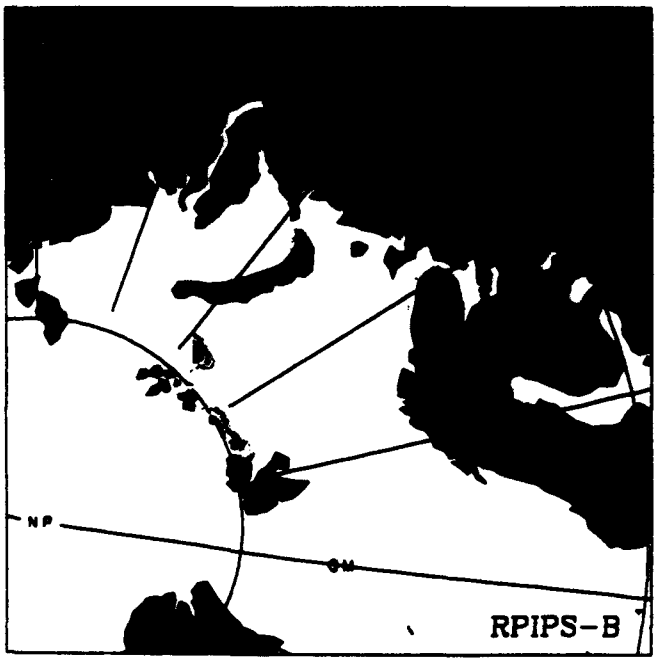

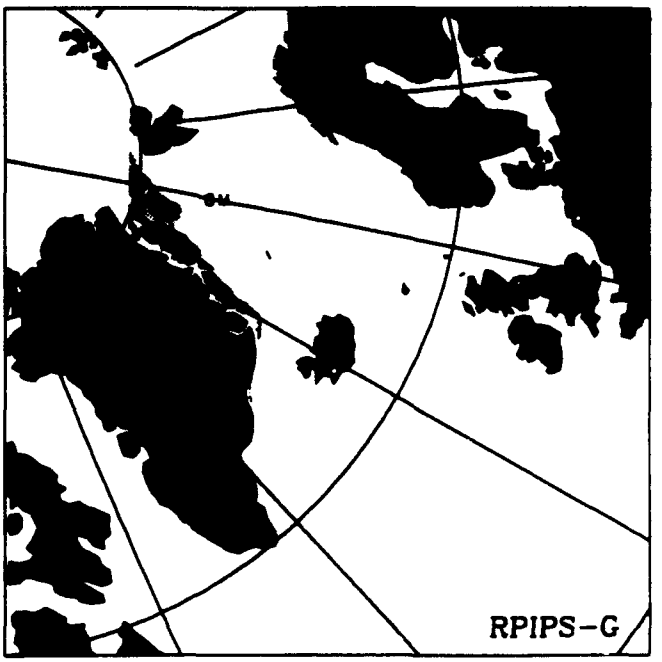

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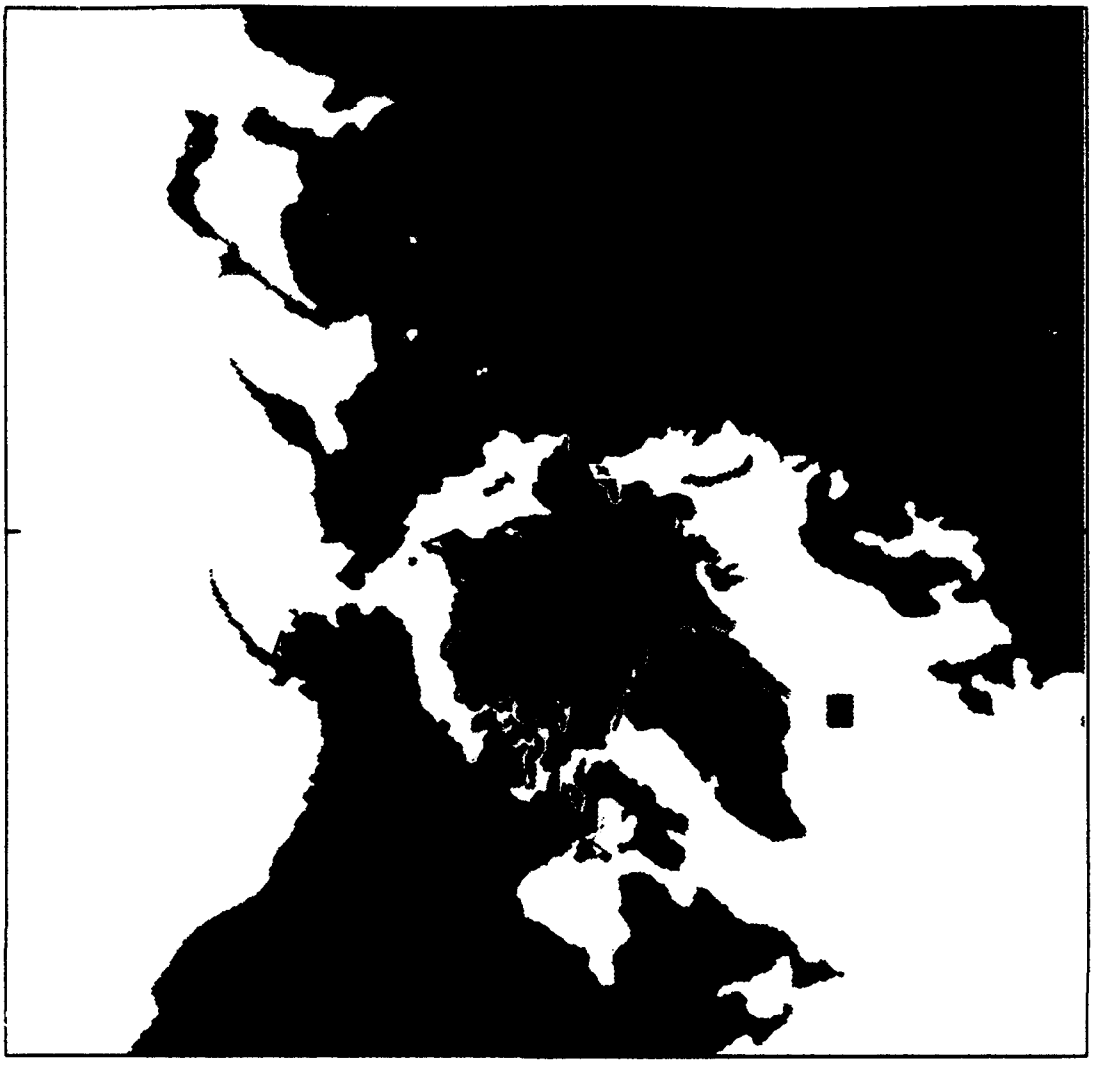

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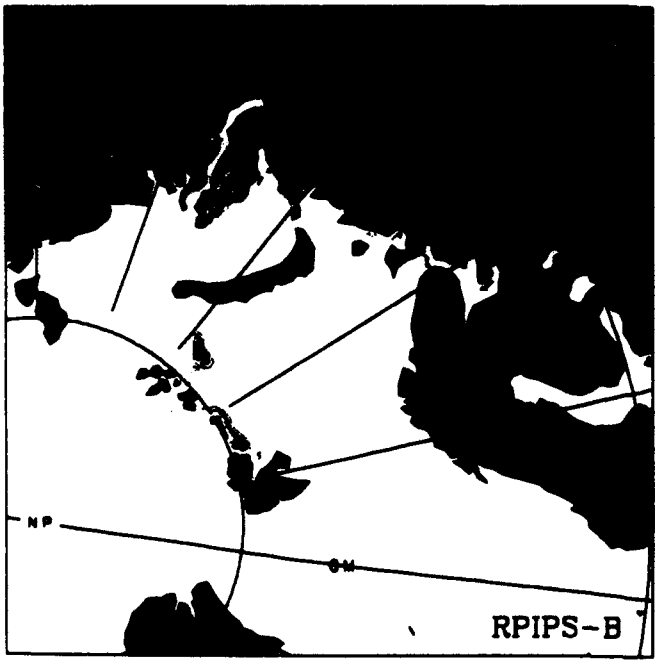

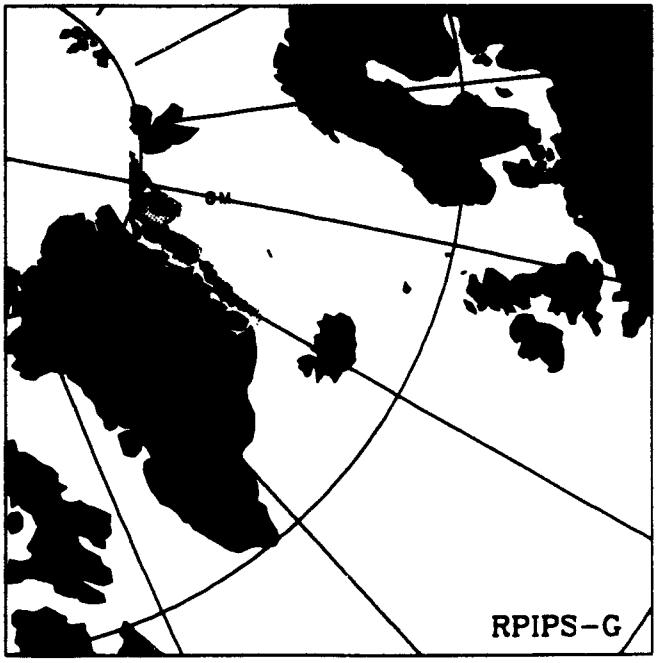

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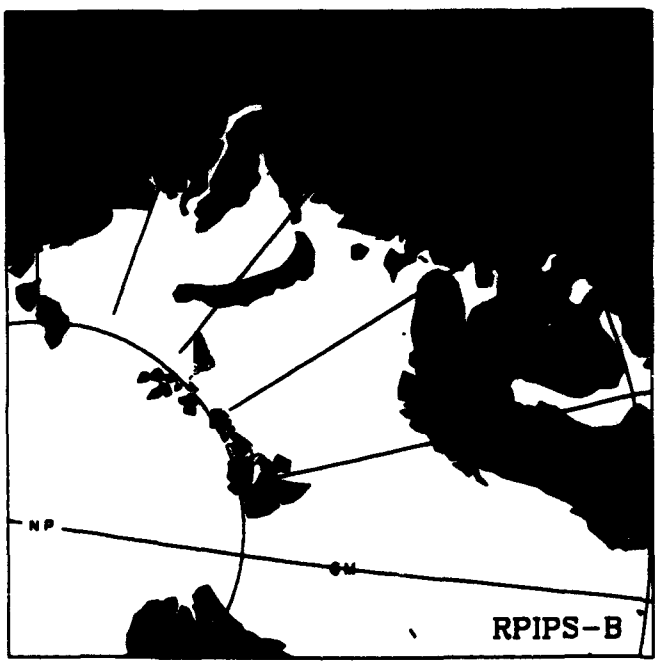

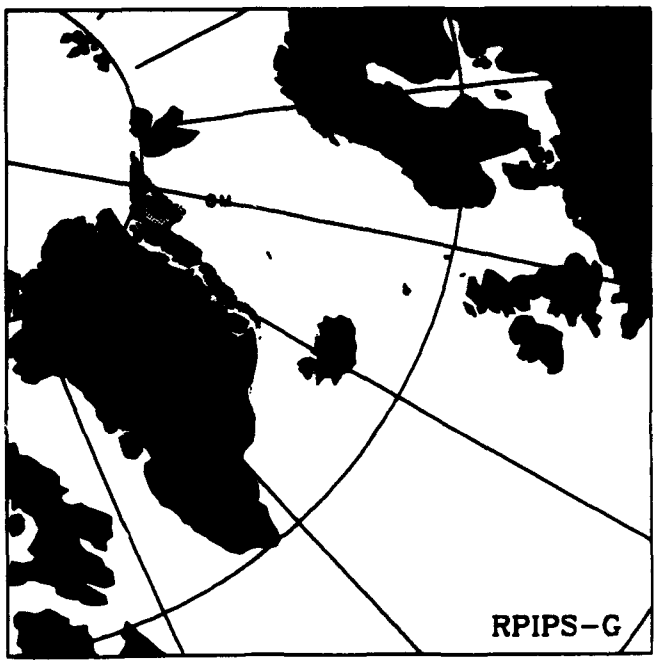

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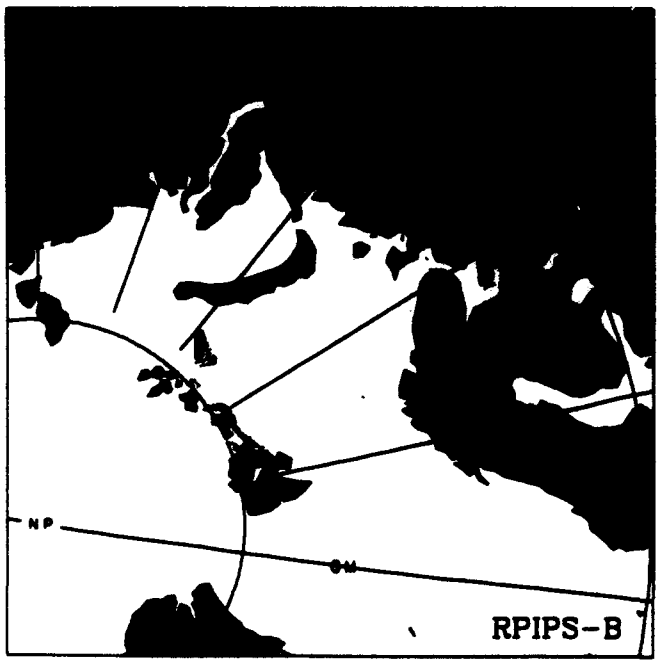

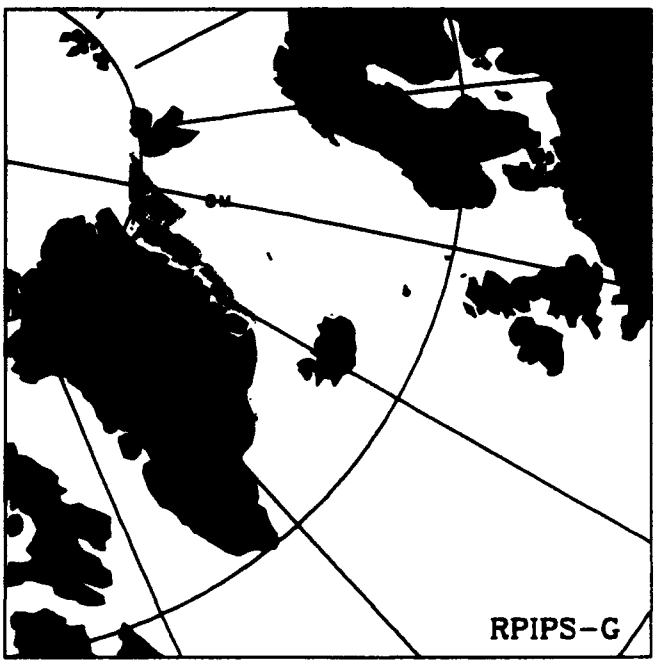

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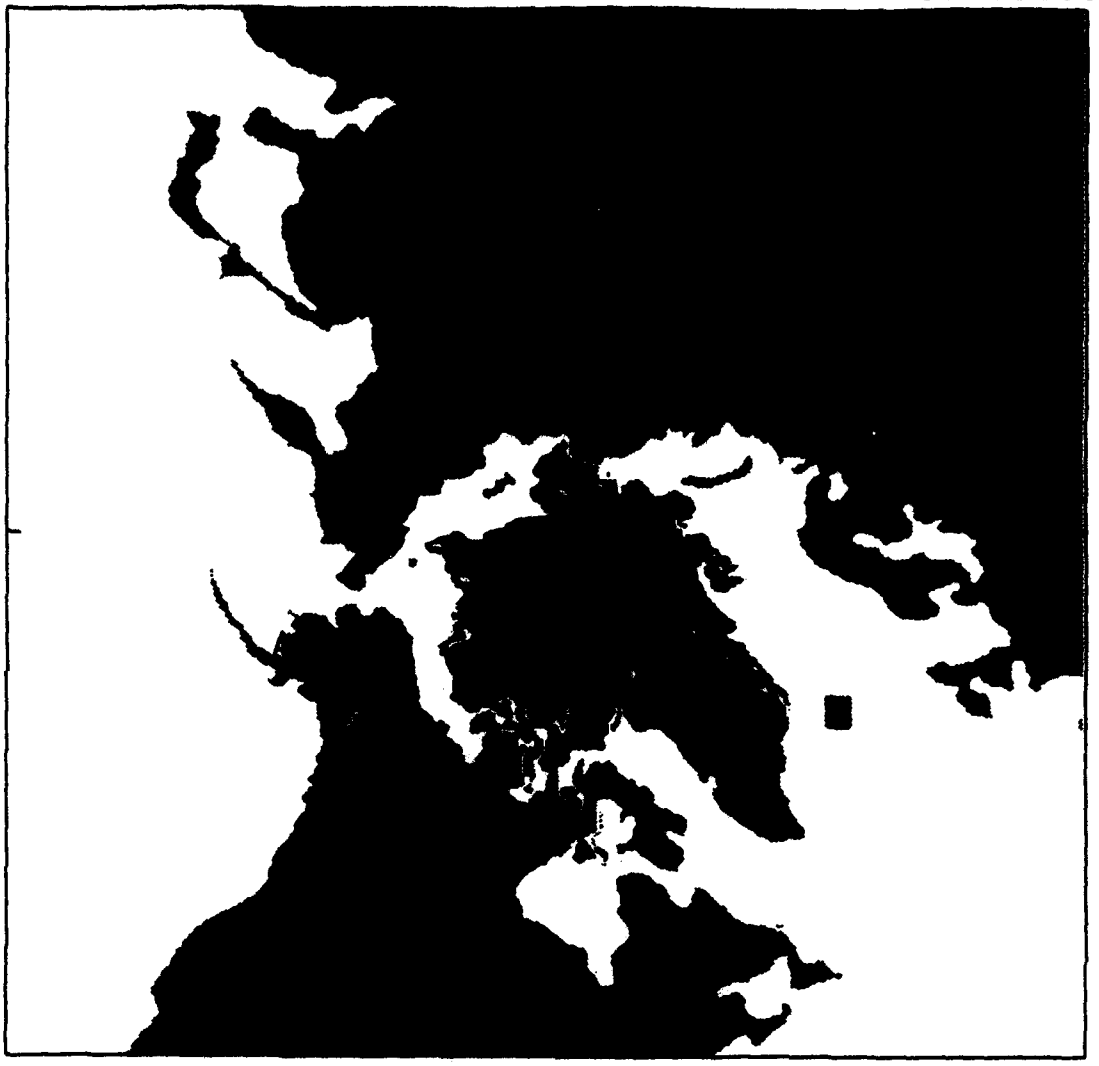
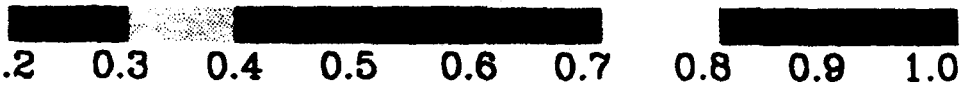
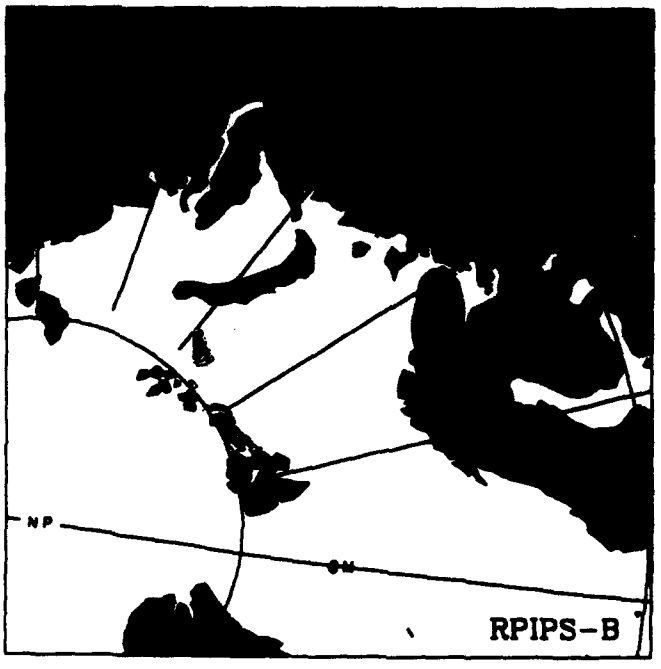
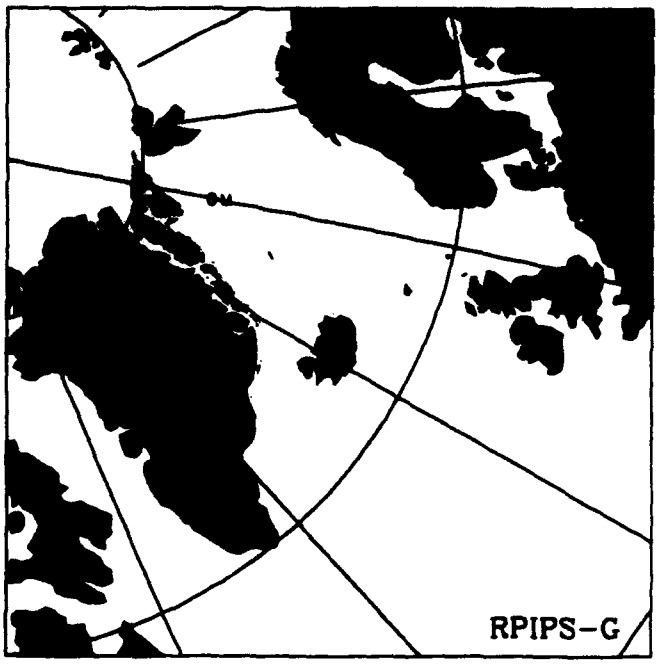
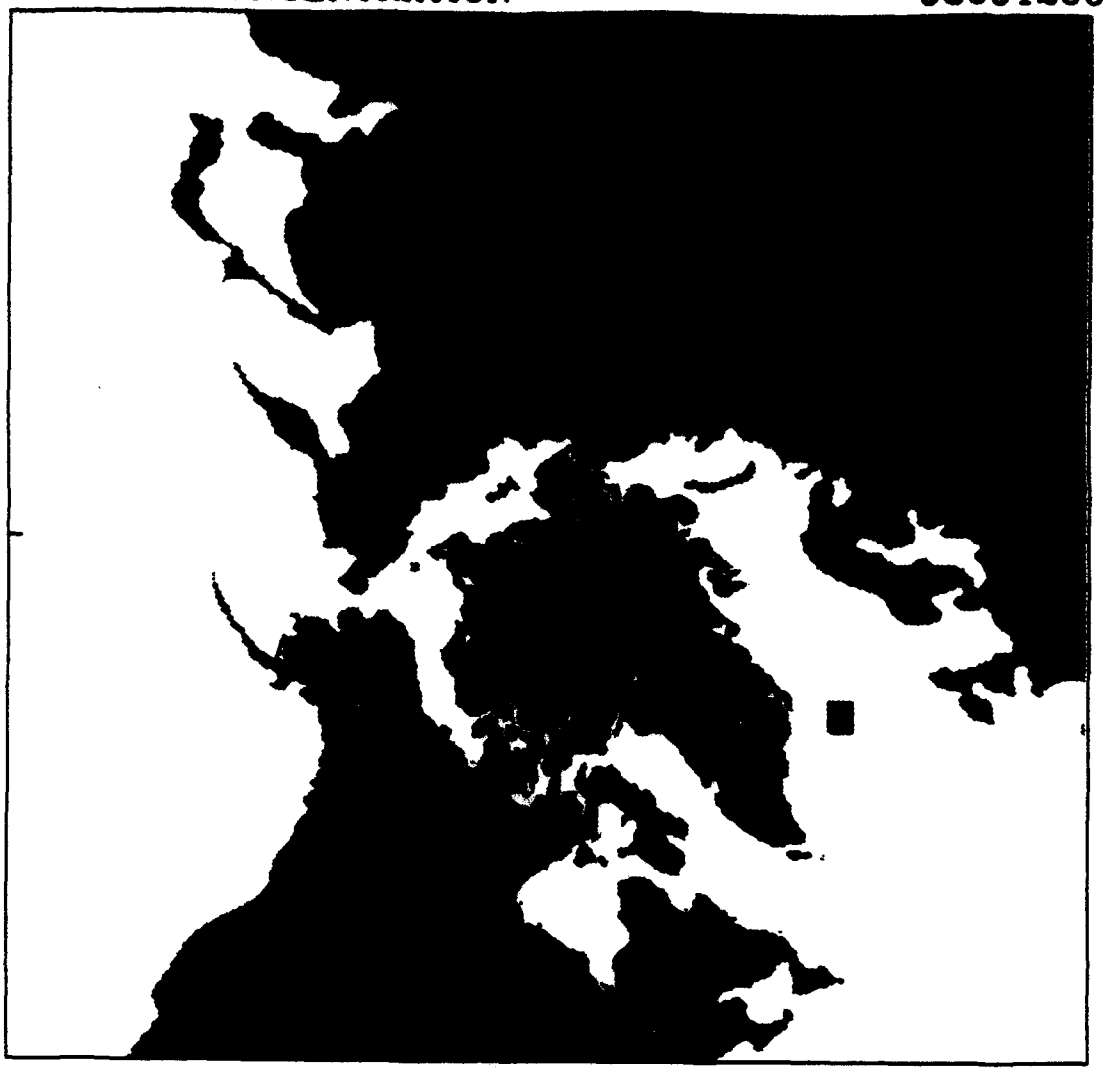








SSMI ICE CONCENTRATION 93091200



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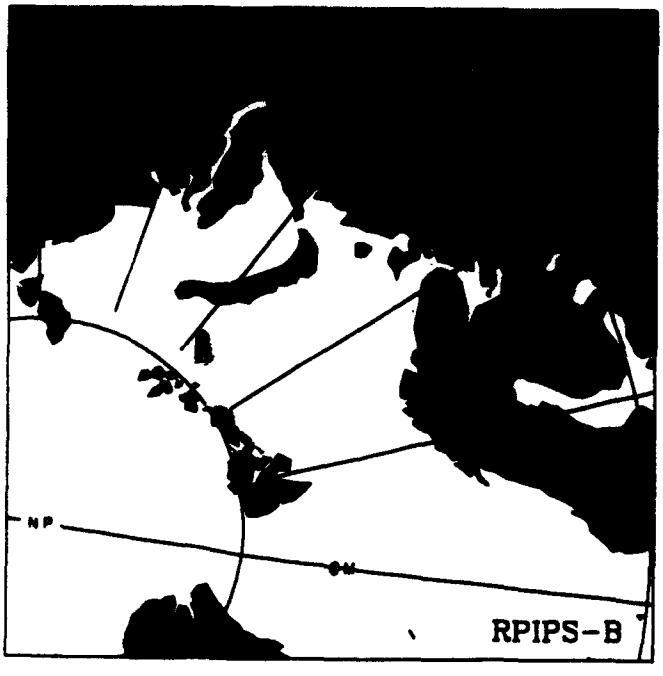

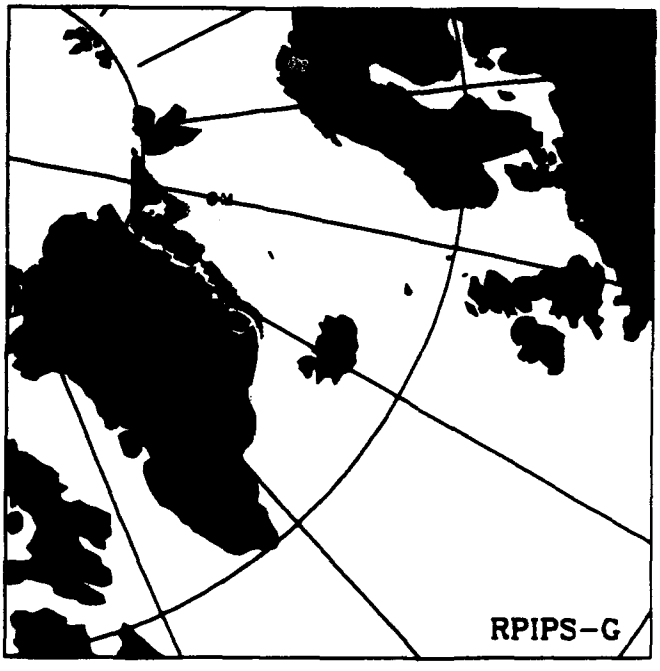

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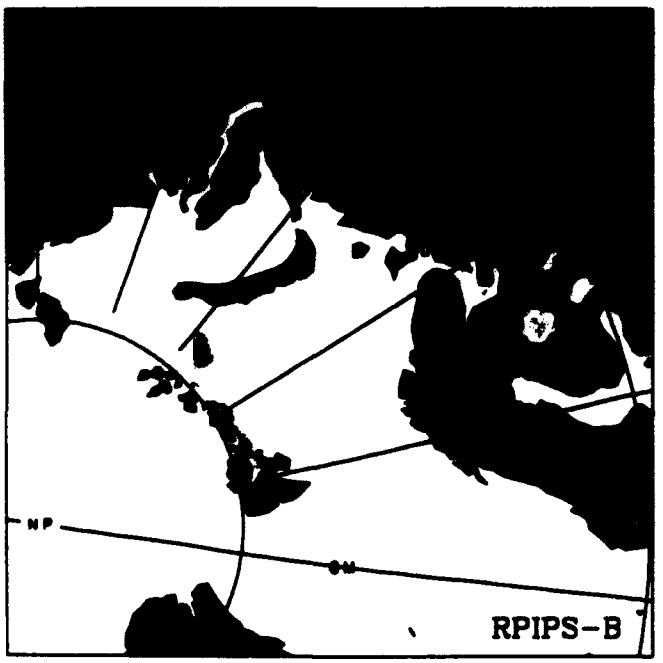

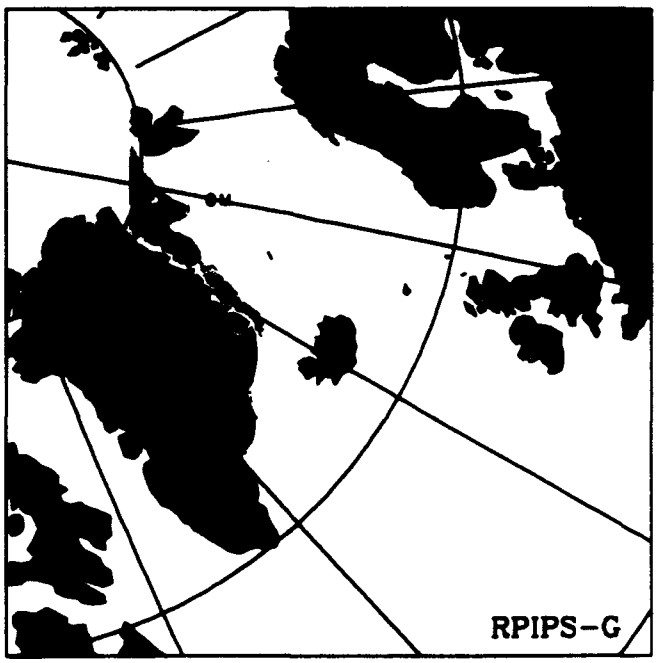

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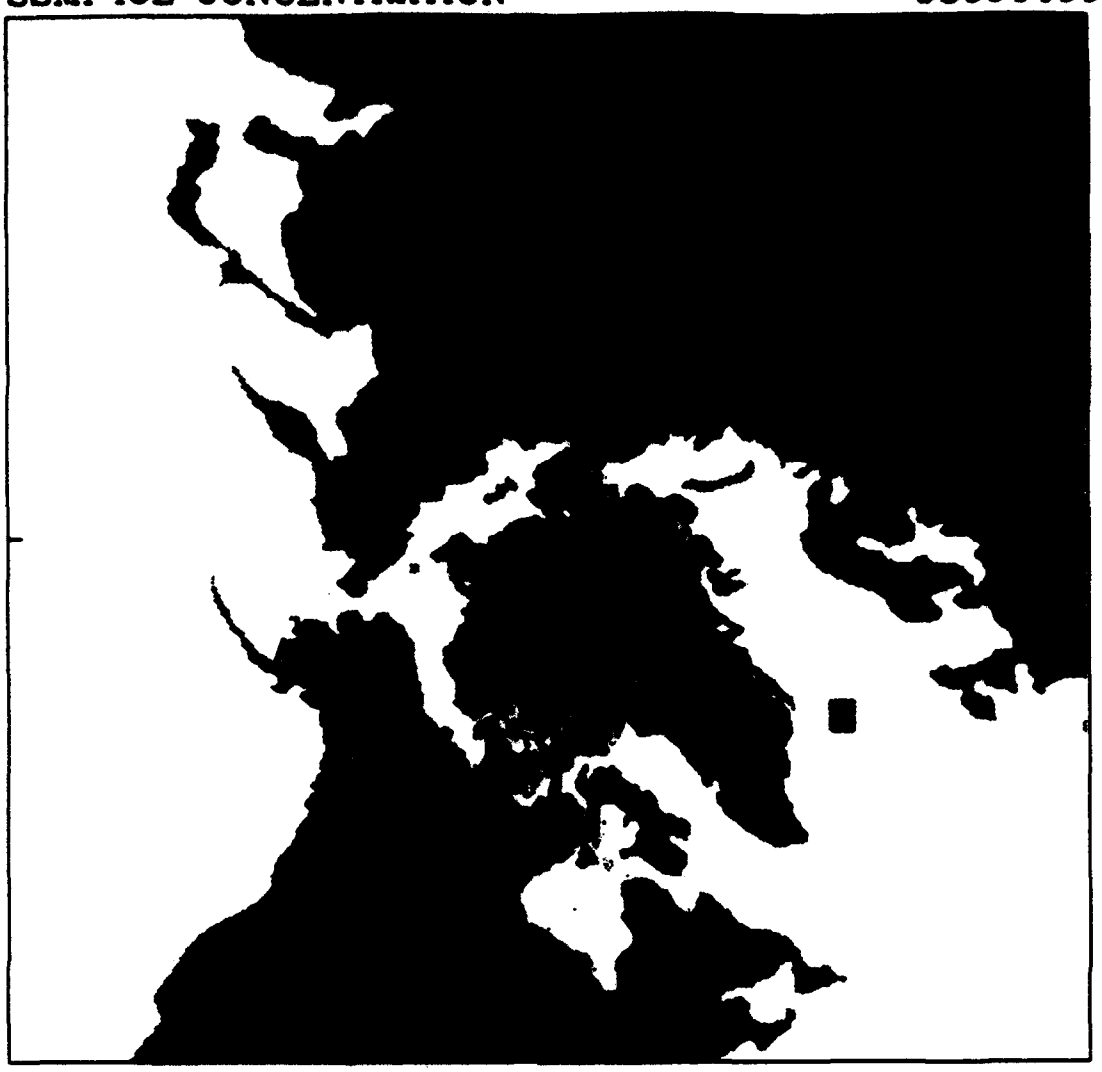

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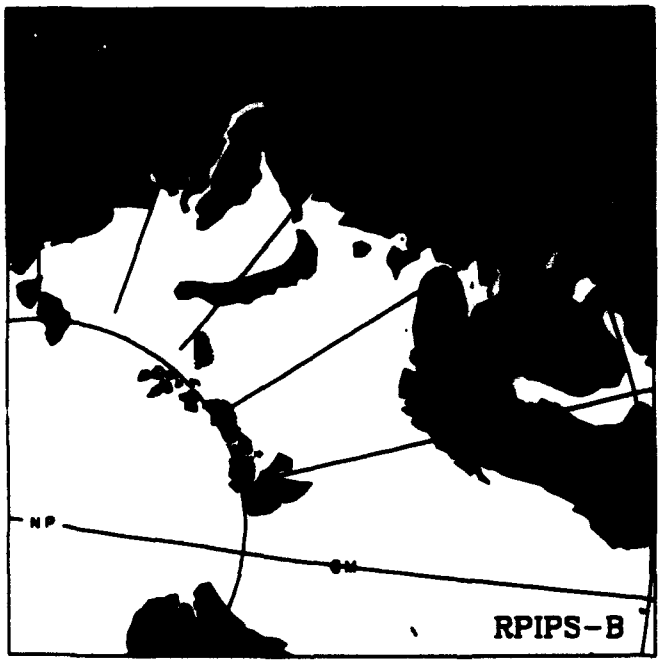

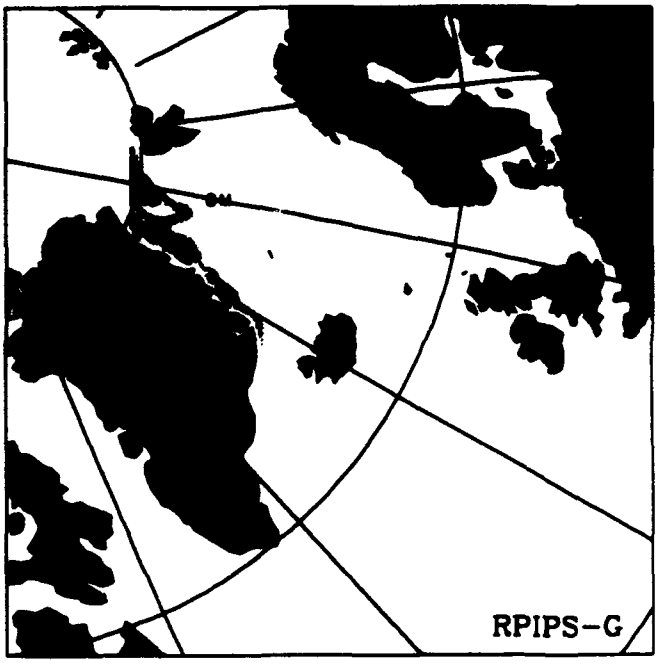

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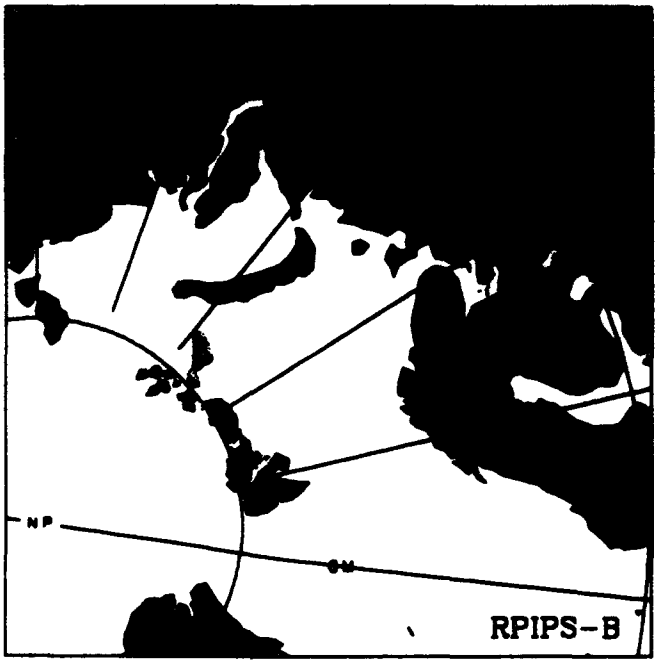

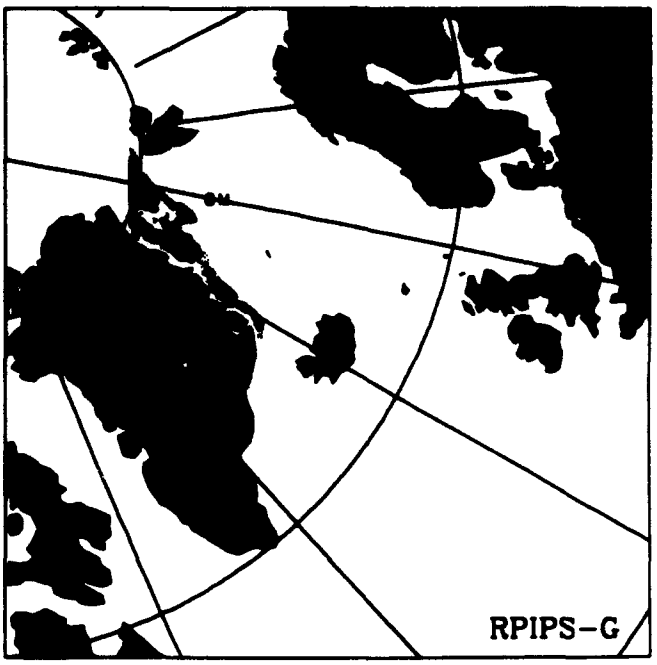

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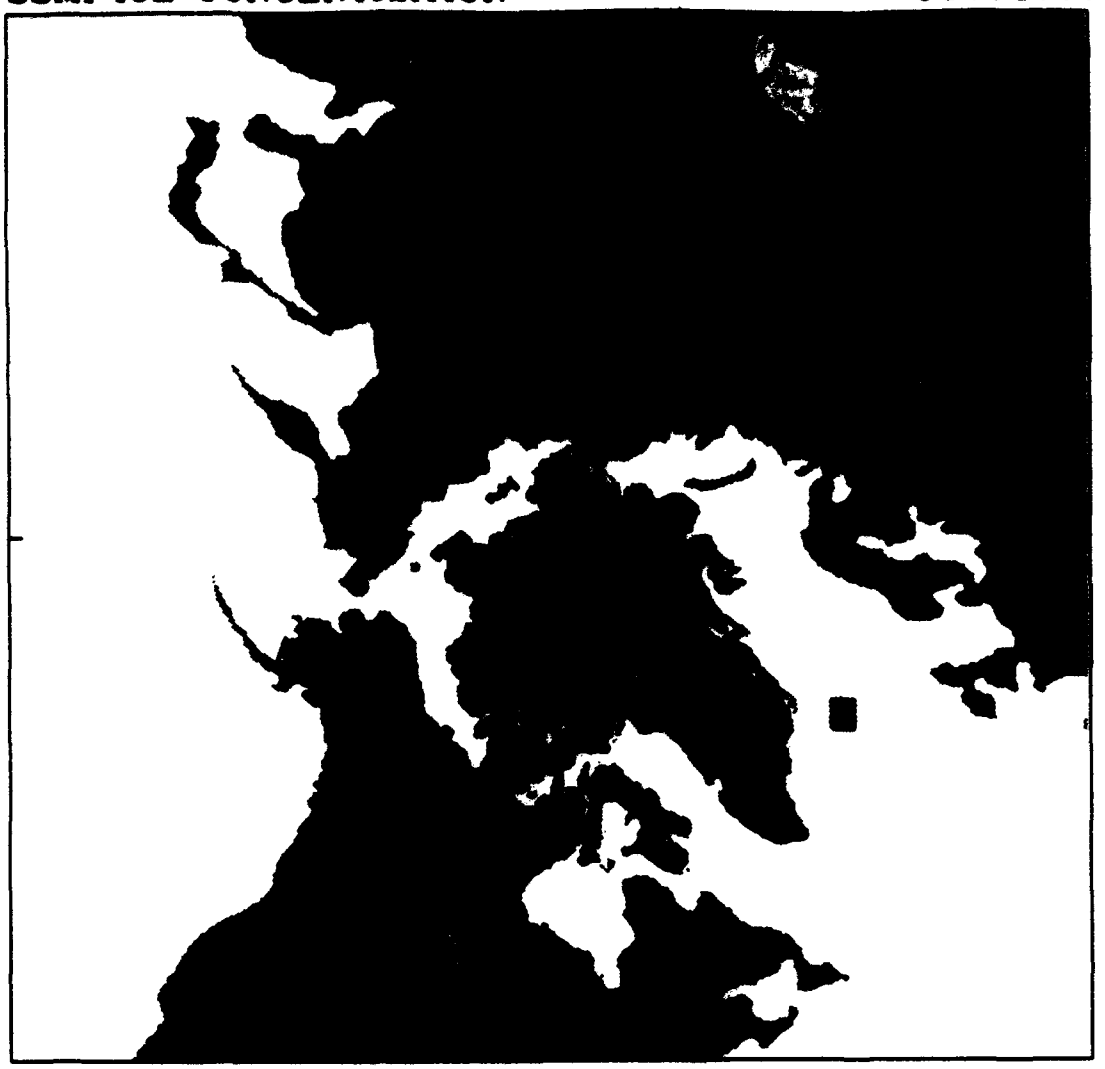

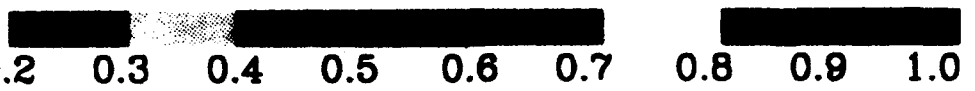

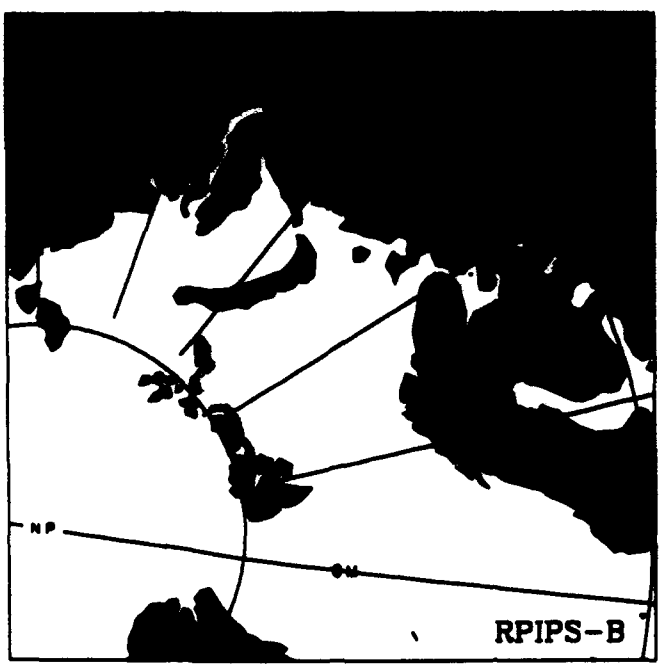

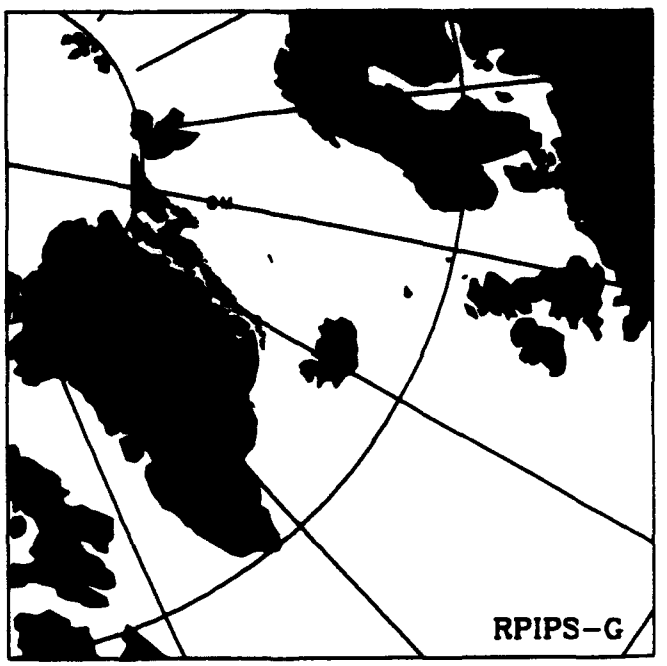

SSMI ICE CONCENTRATION 93091700

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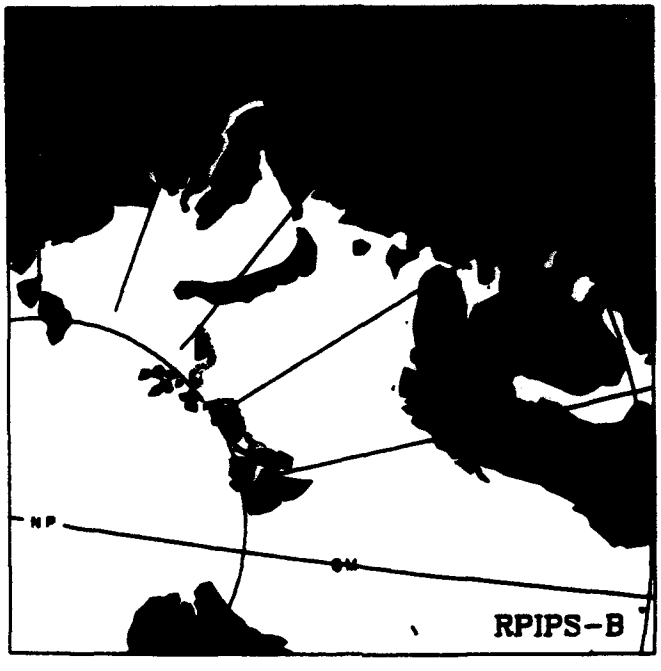

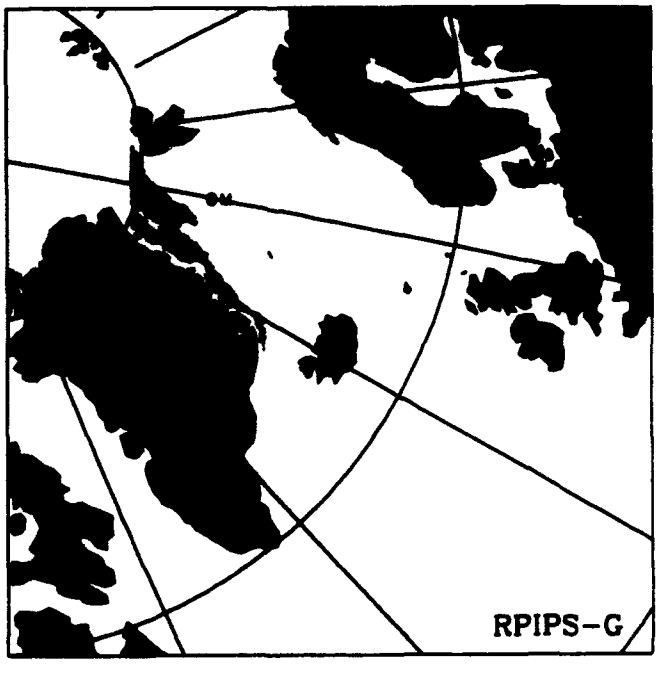

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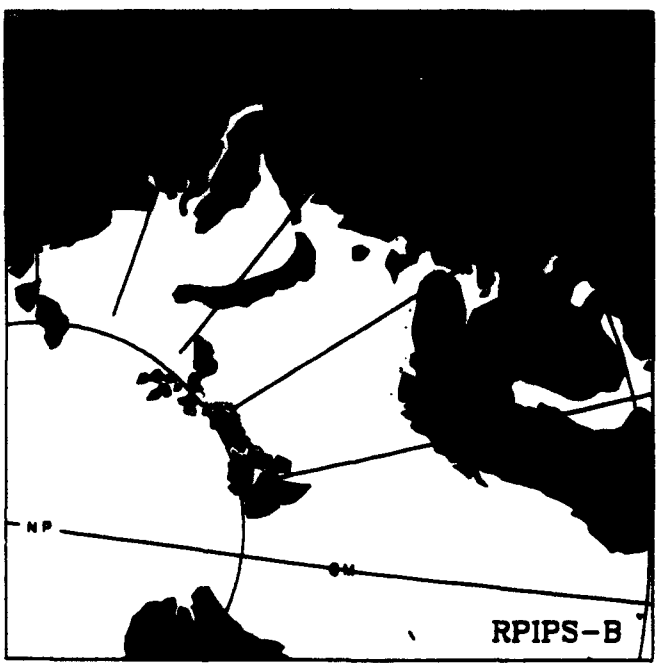

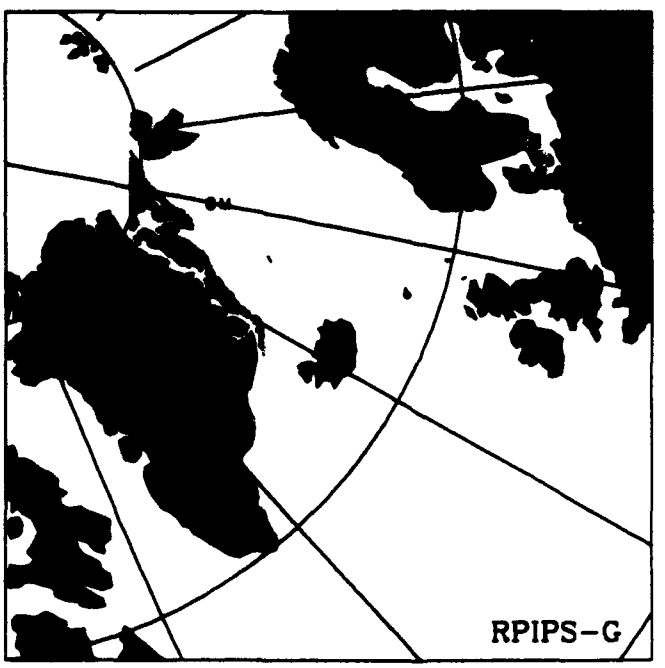

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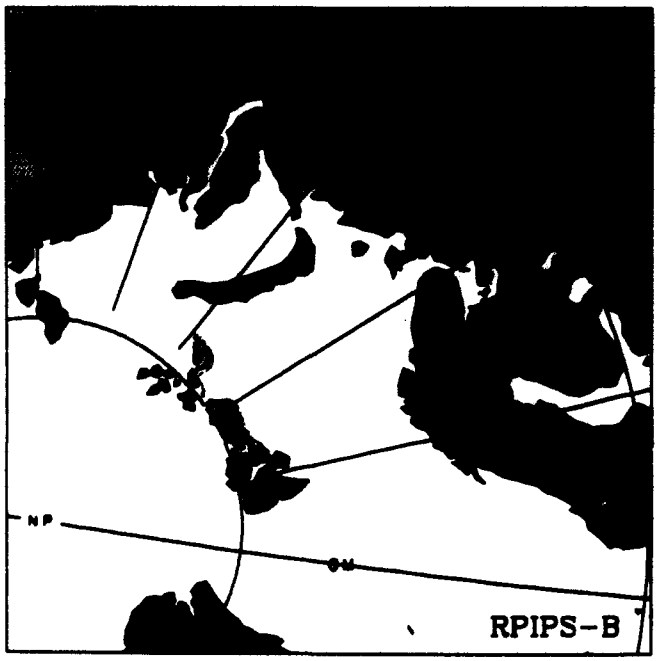

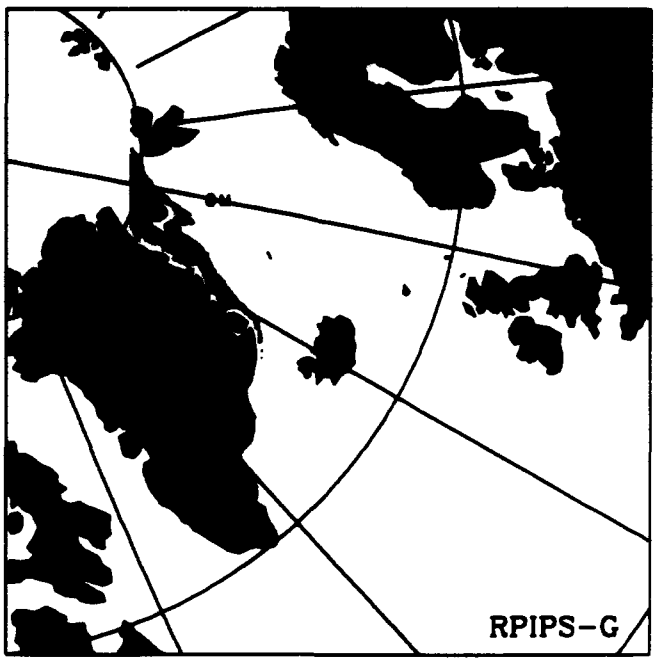

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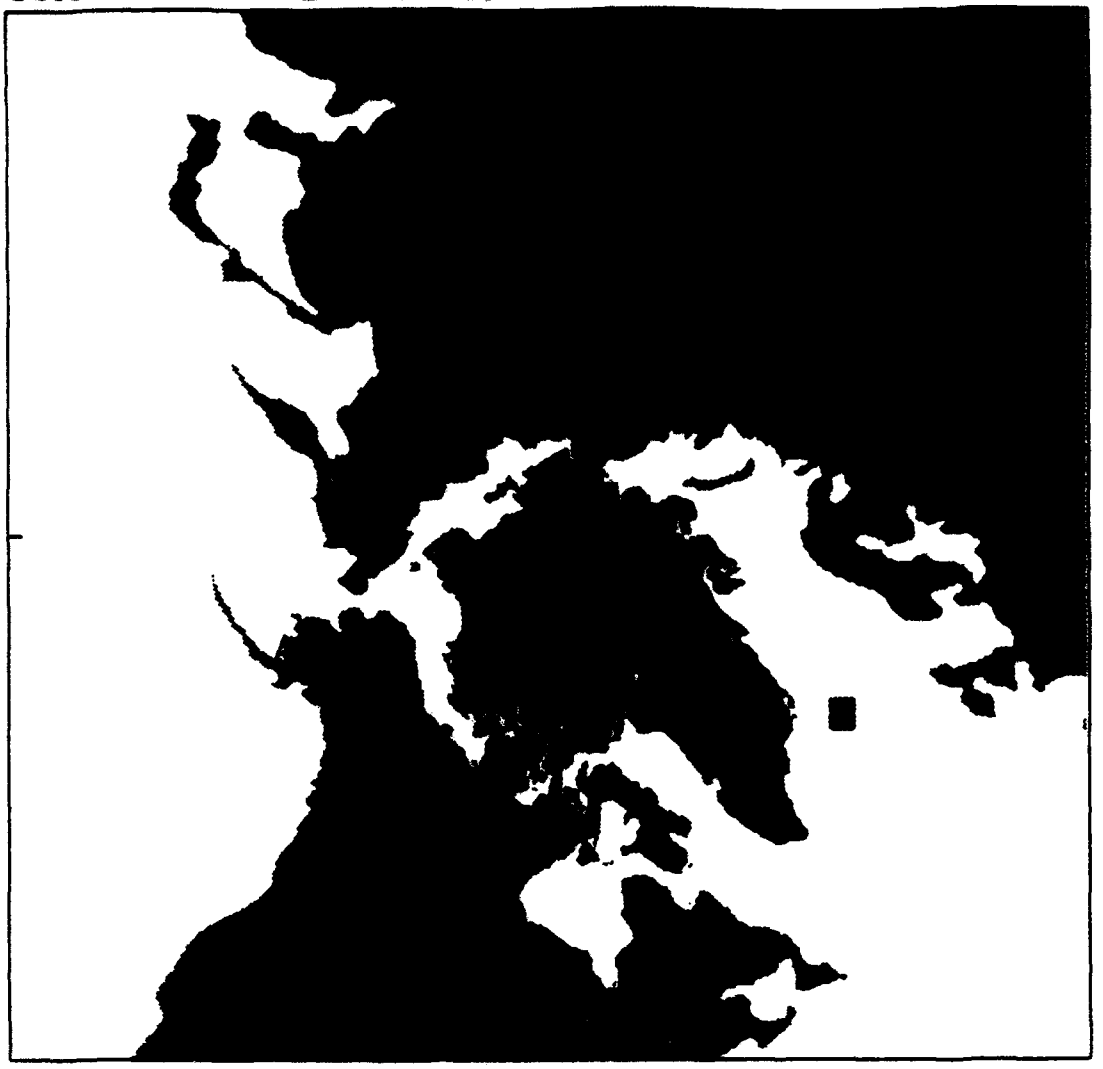

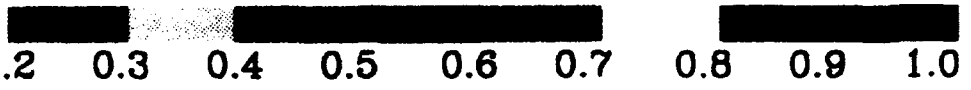

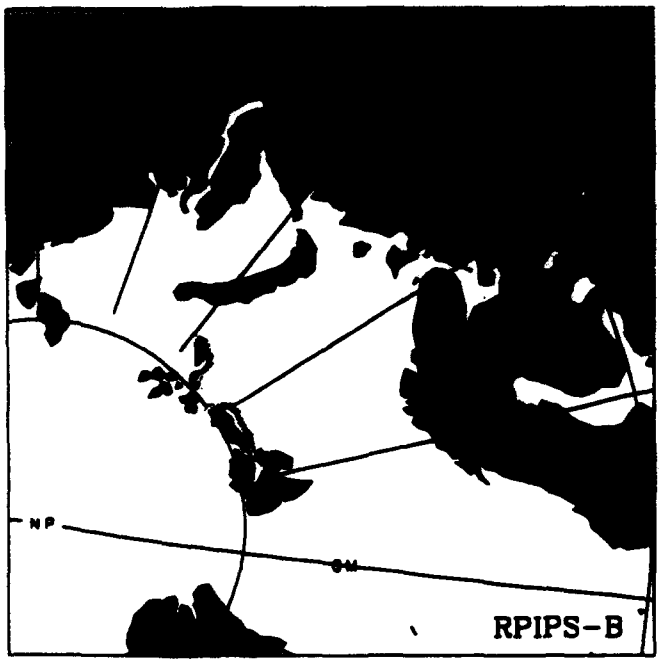

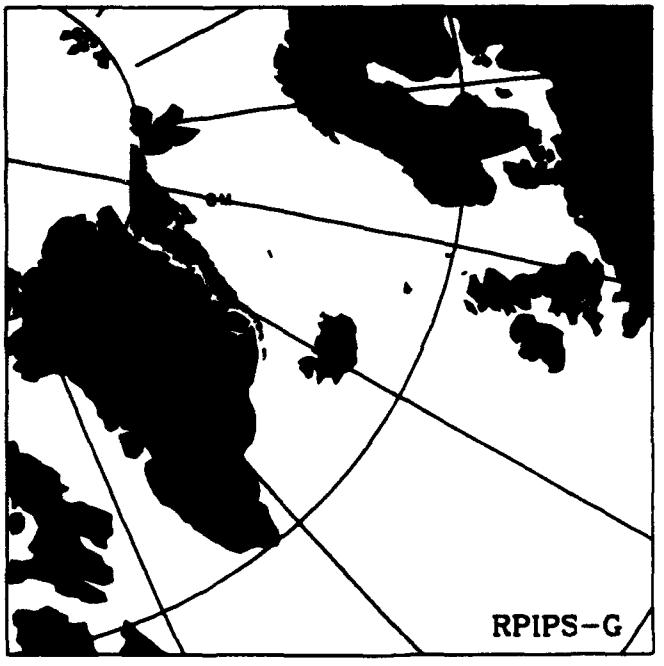

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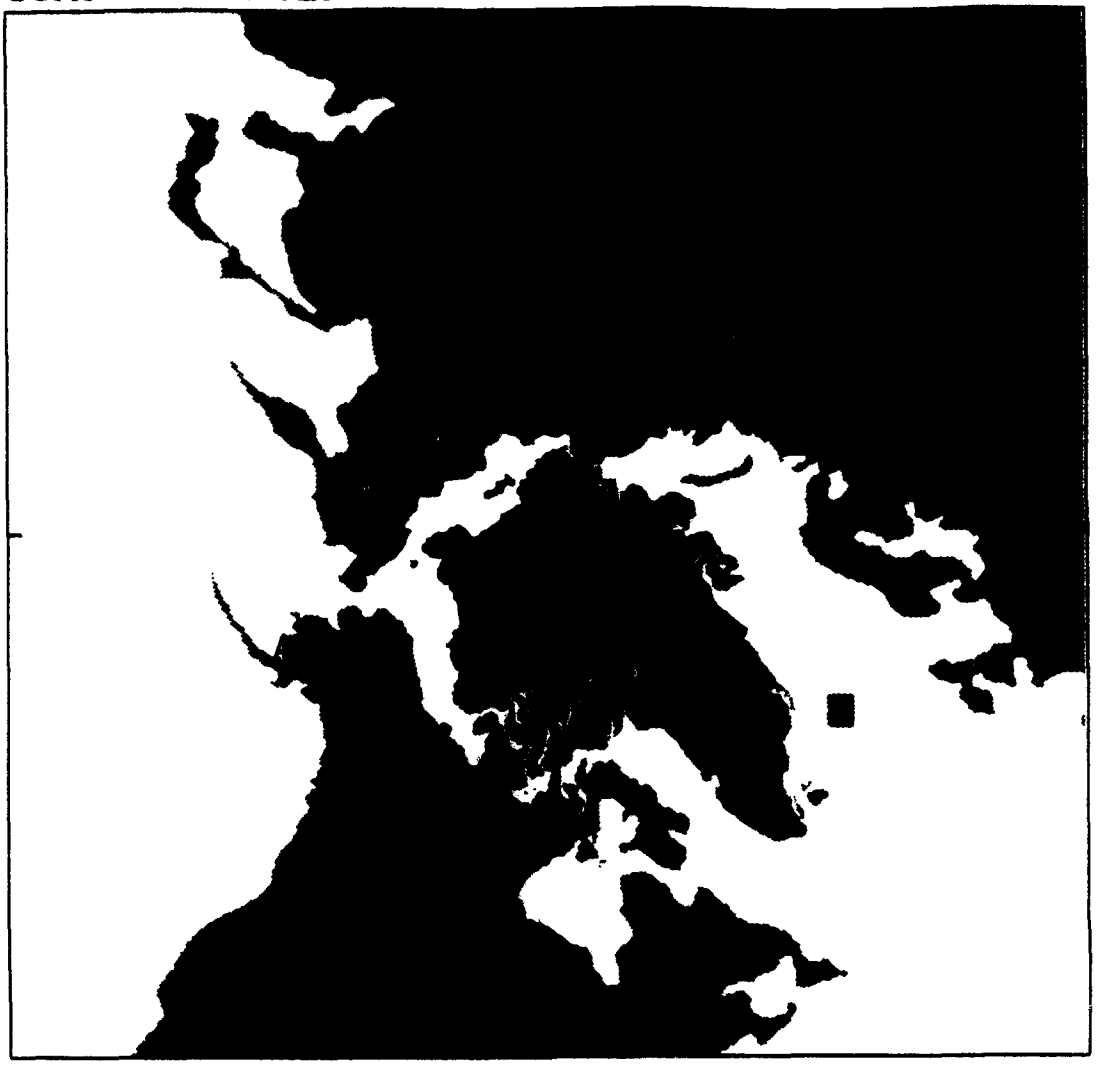

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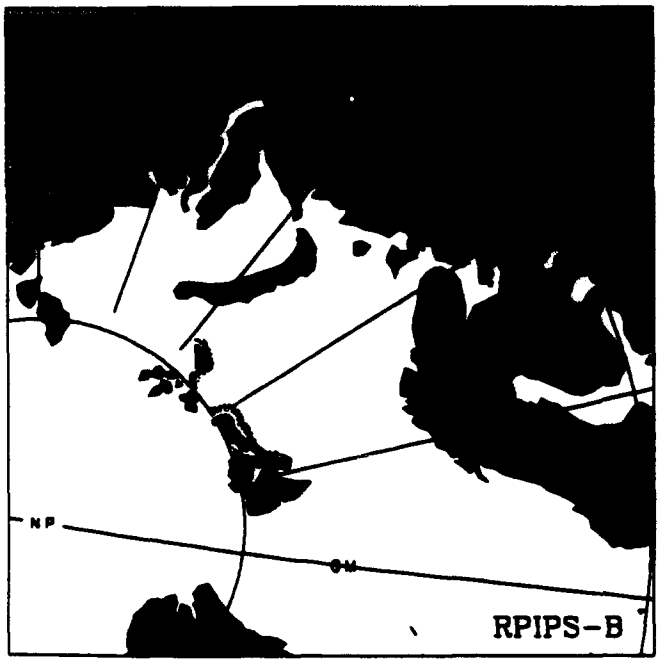

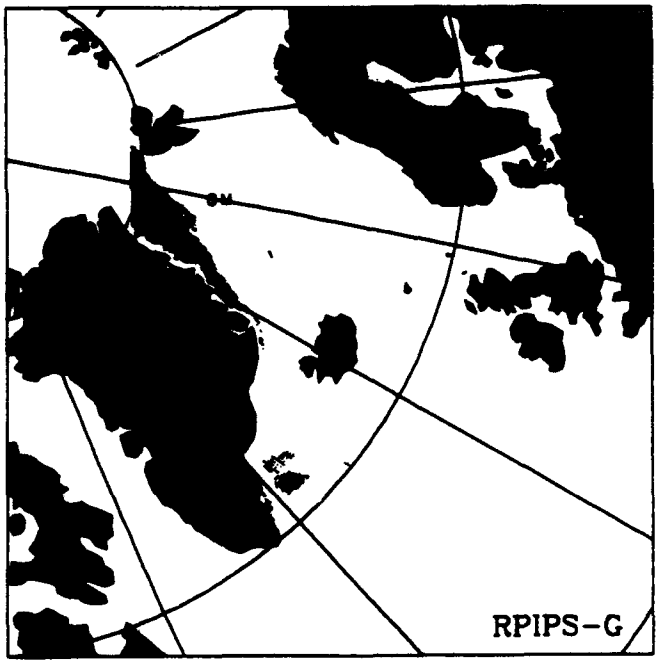

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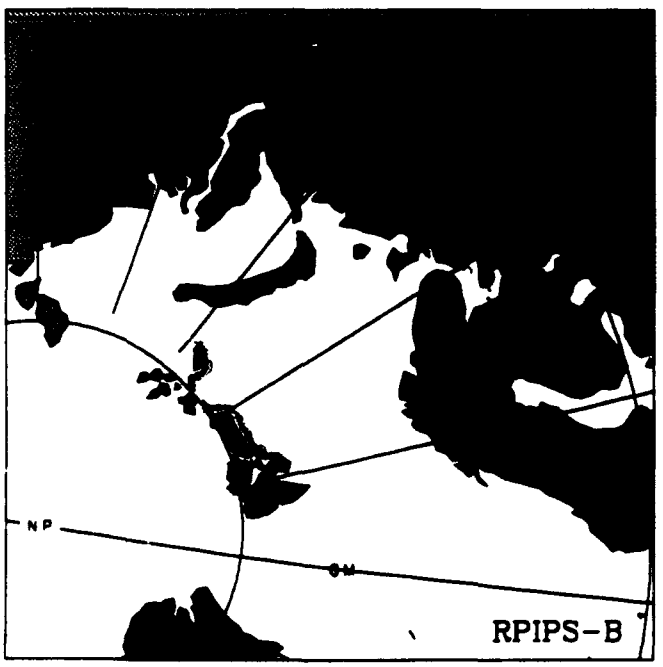

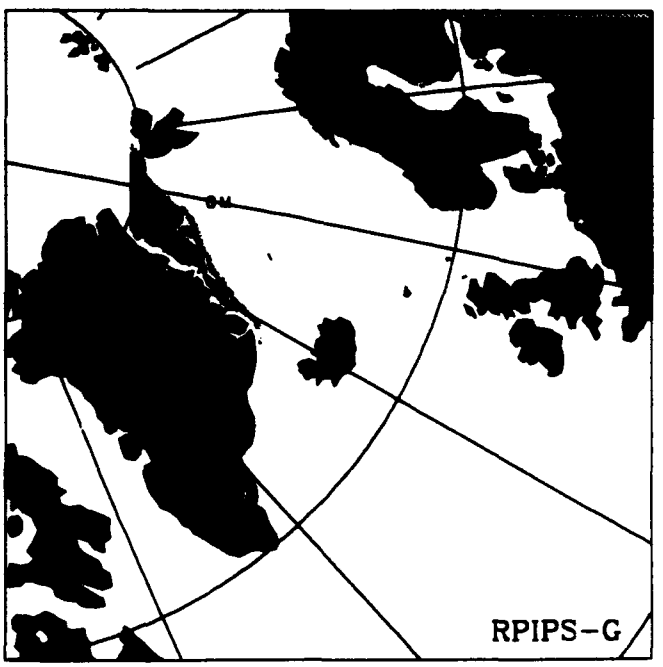

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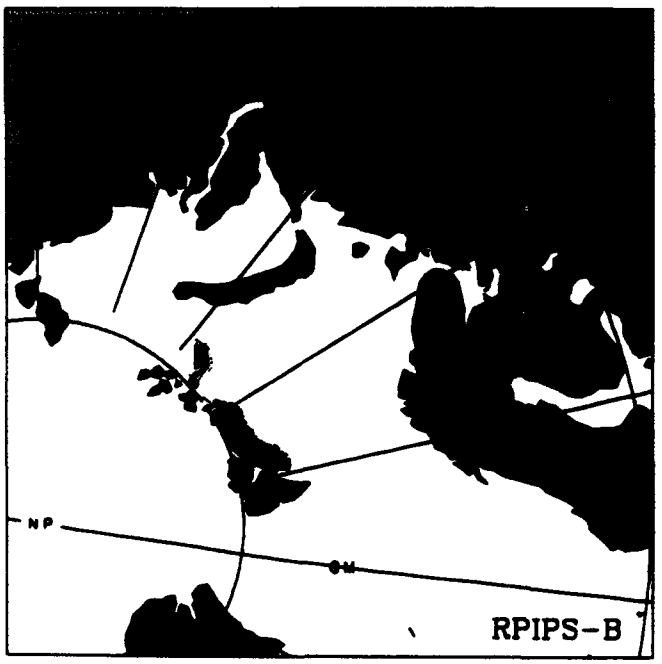

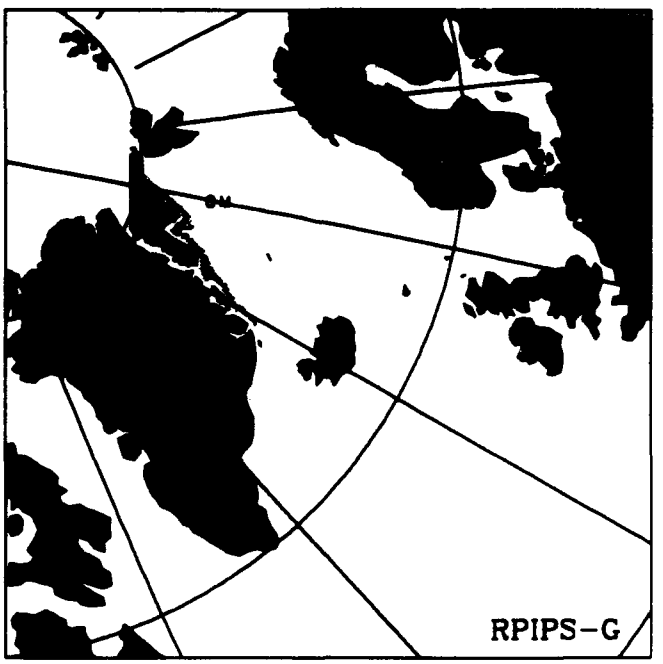

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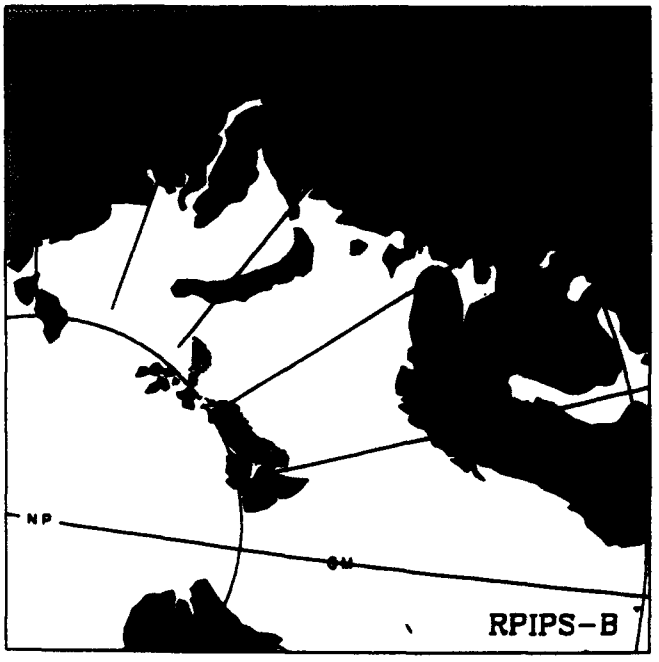

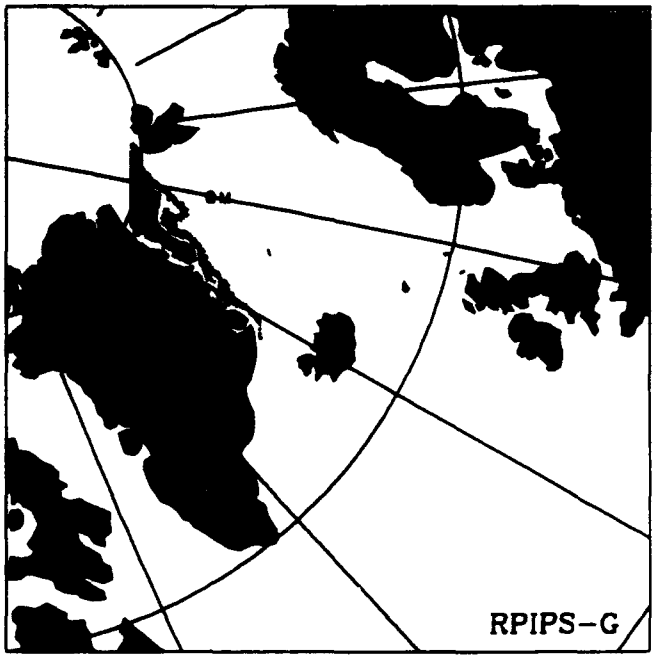

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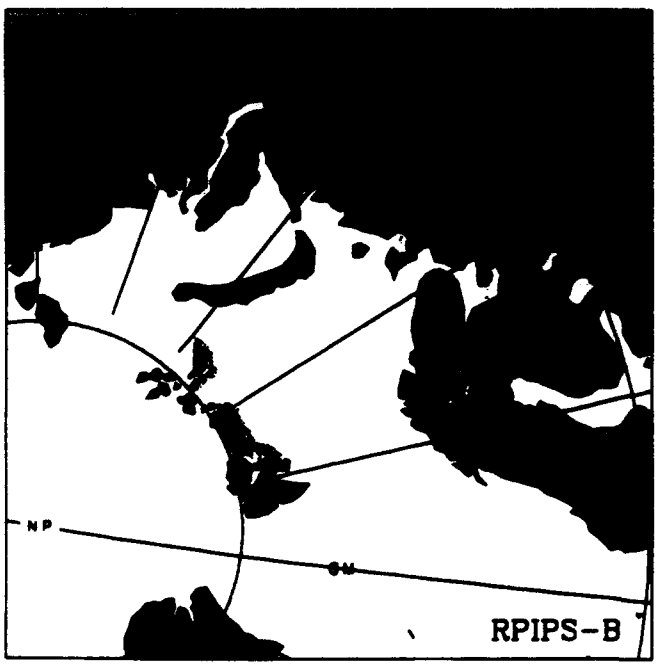

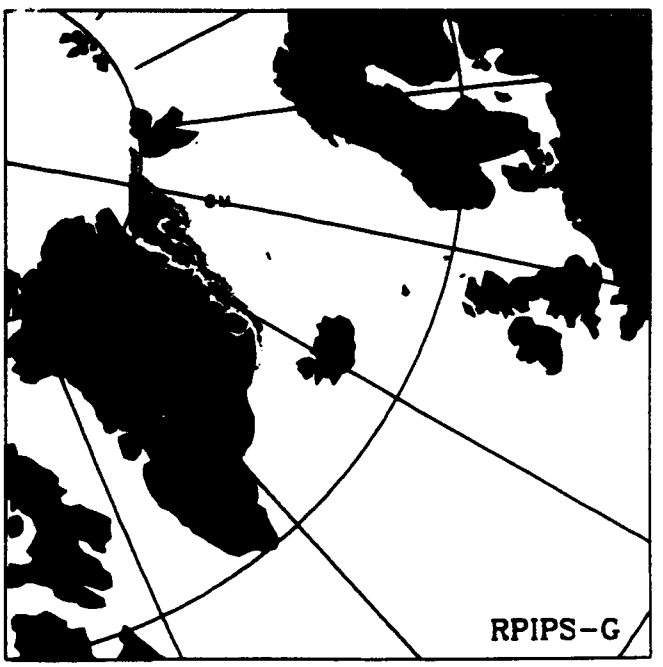

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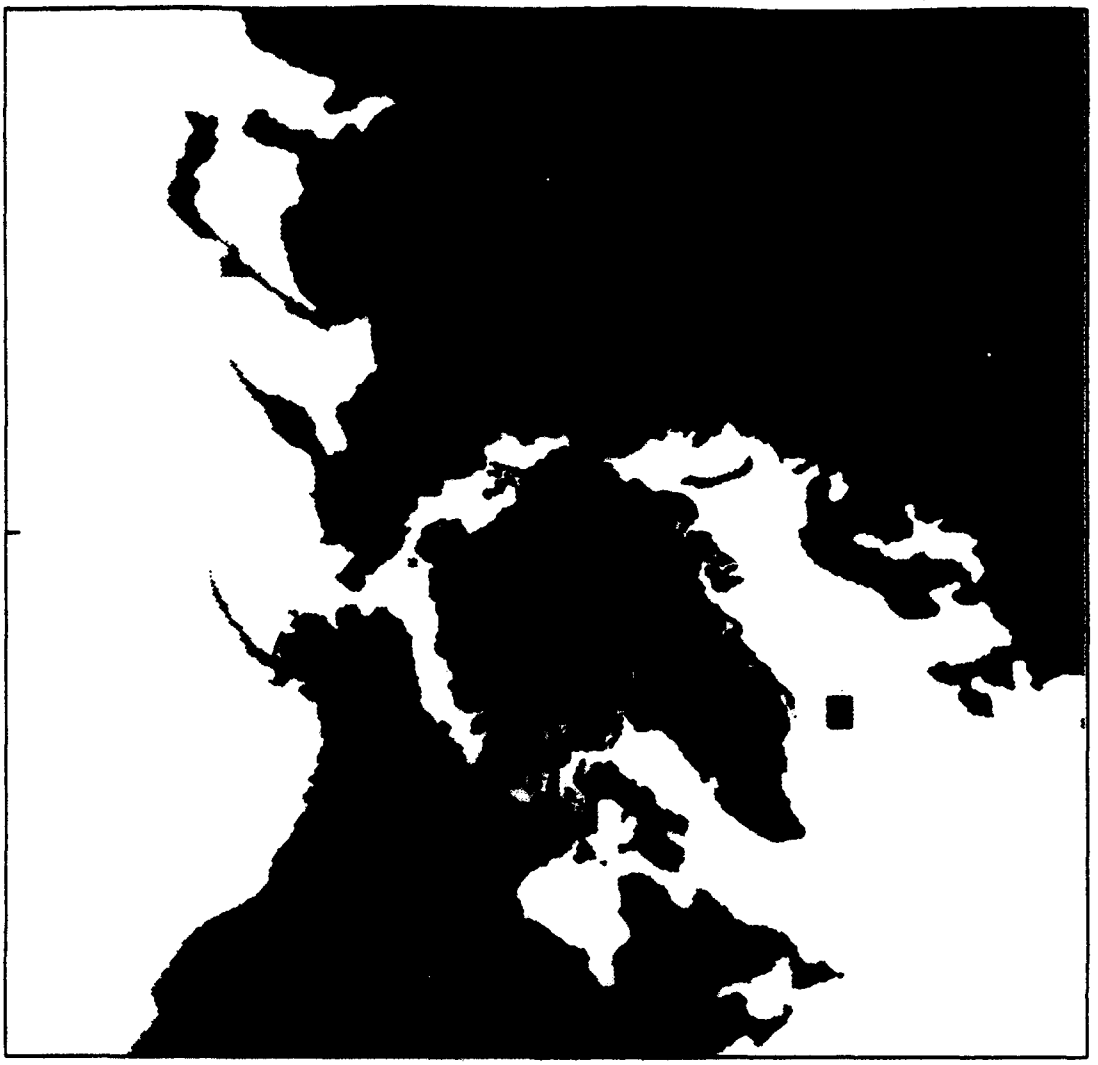

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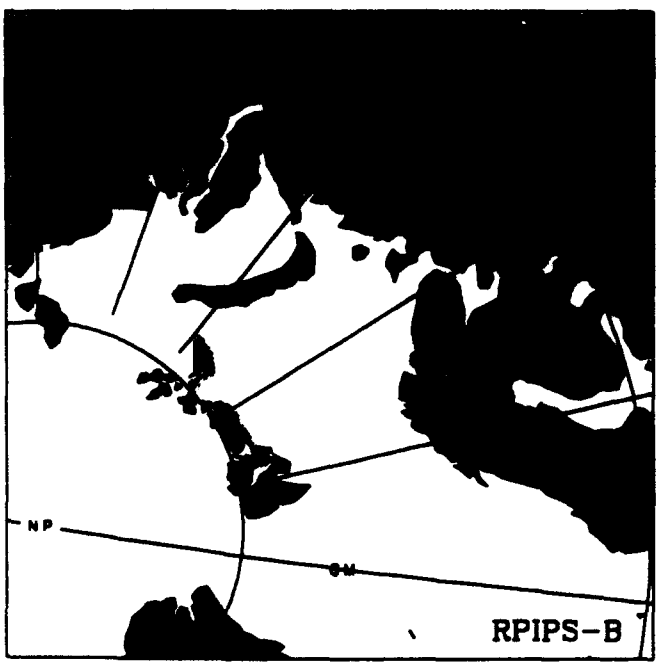

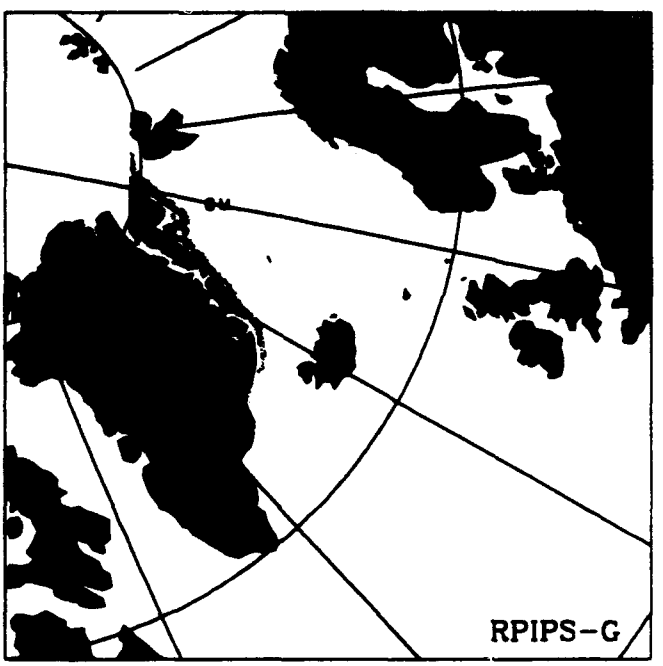

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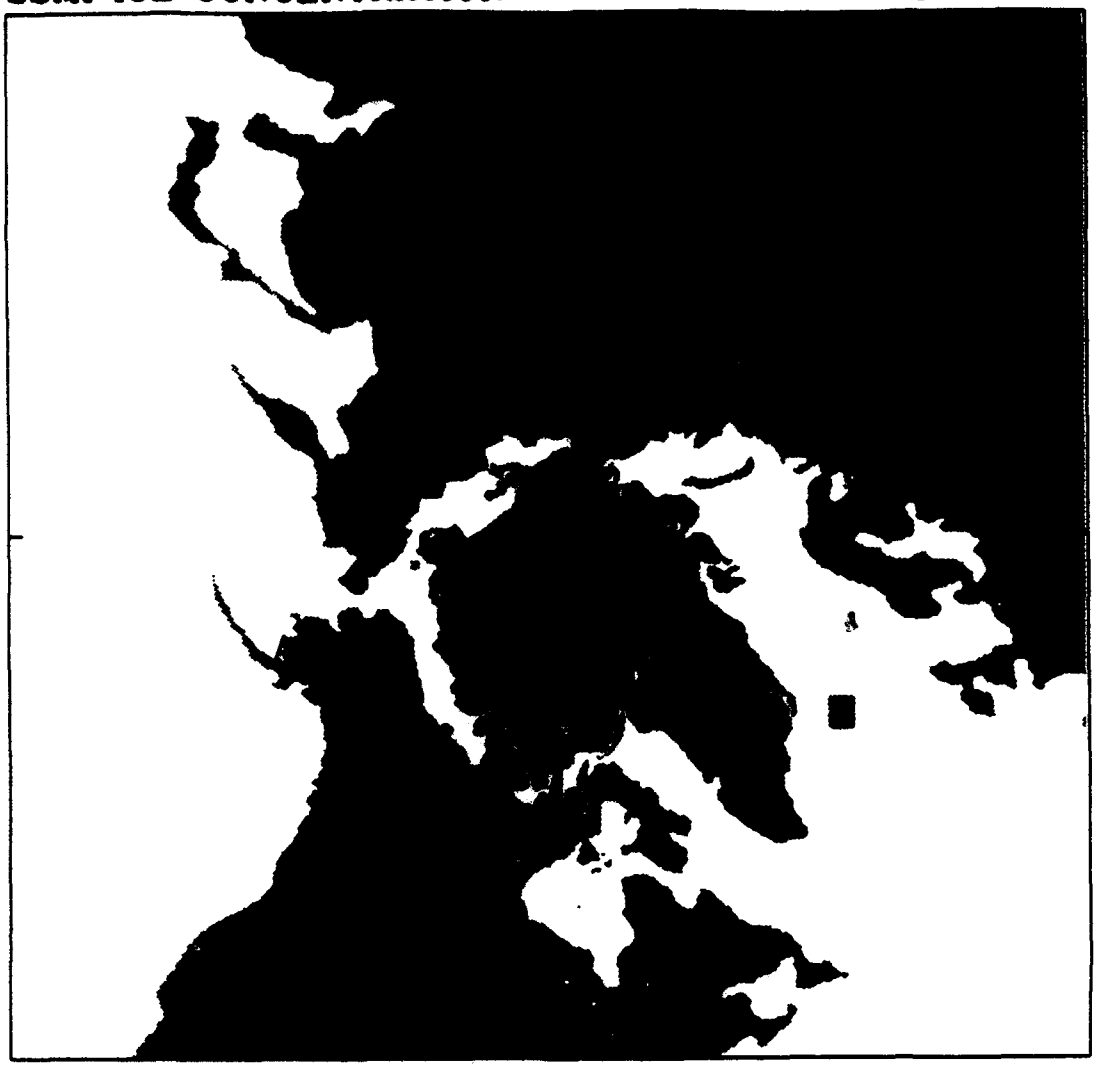

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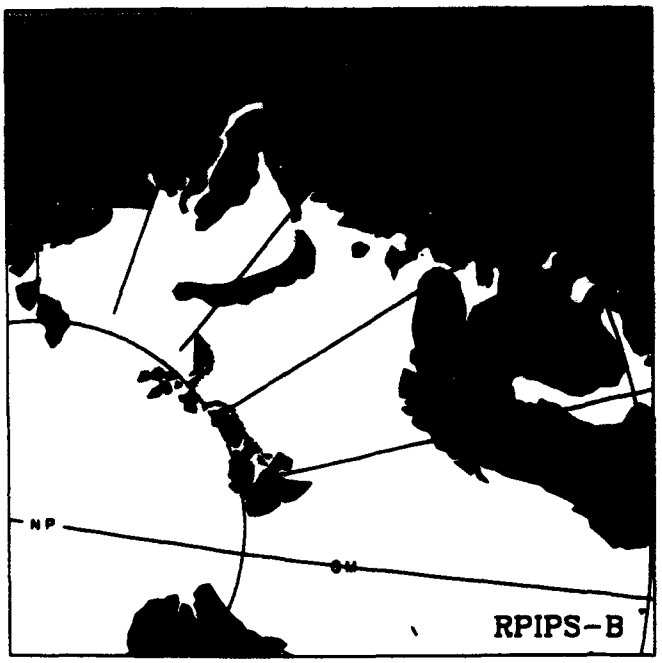

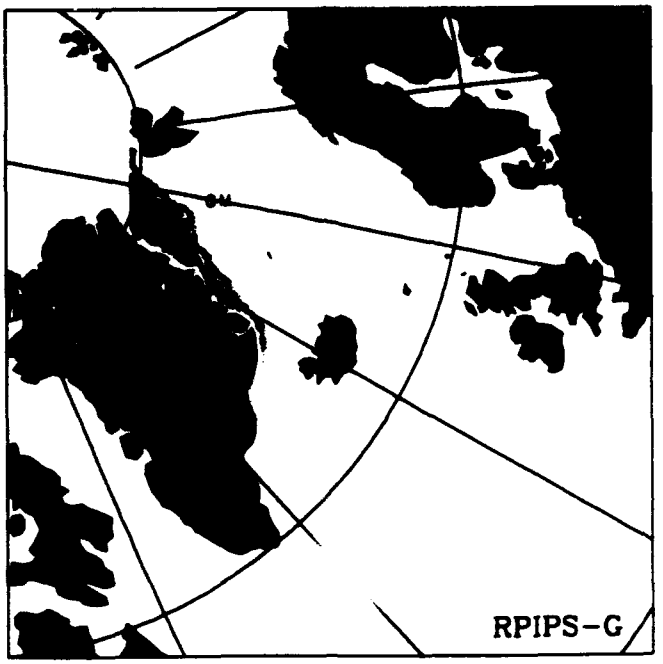

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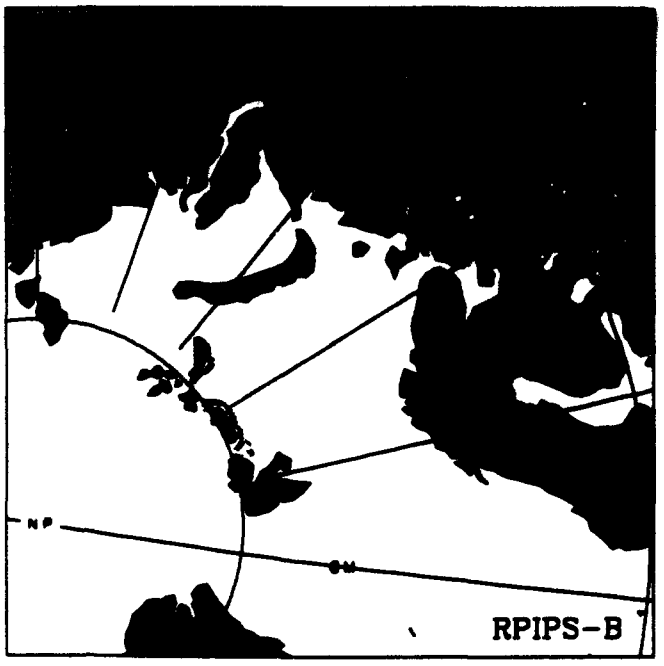

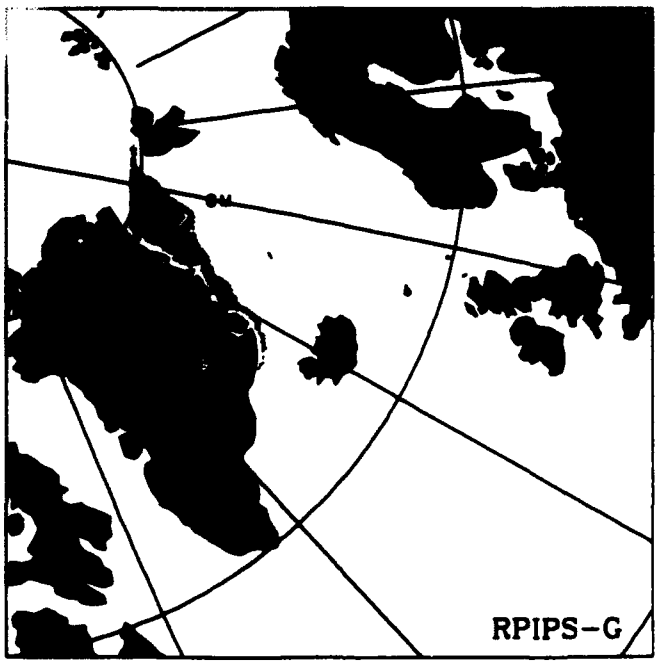

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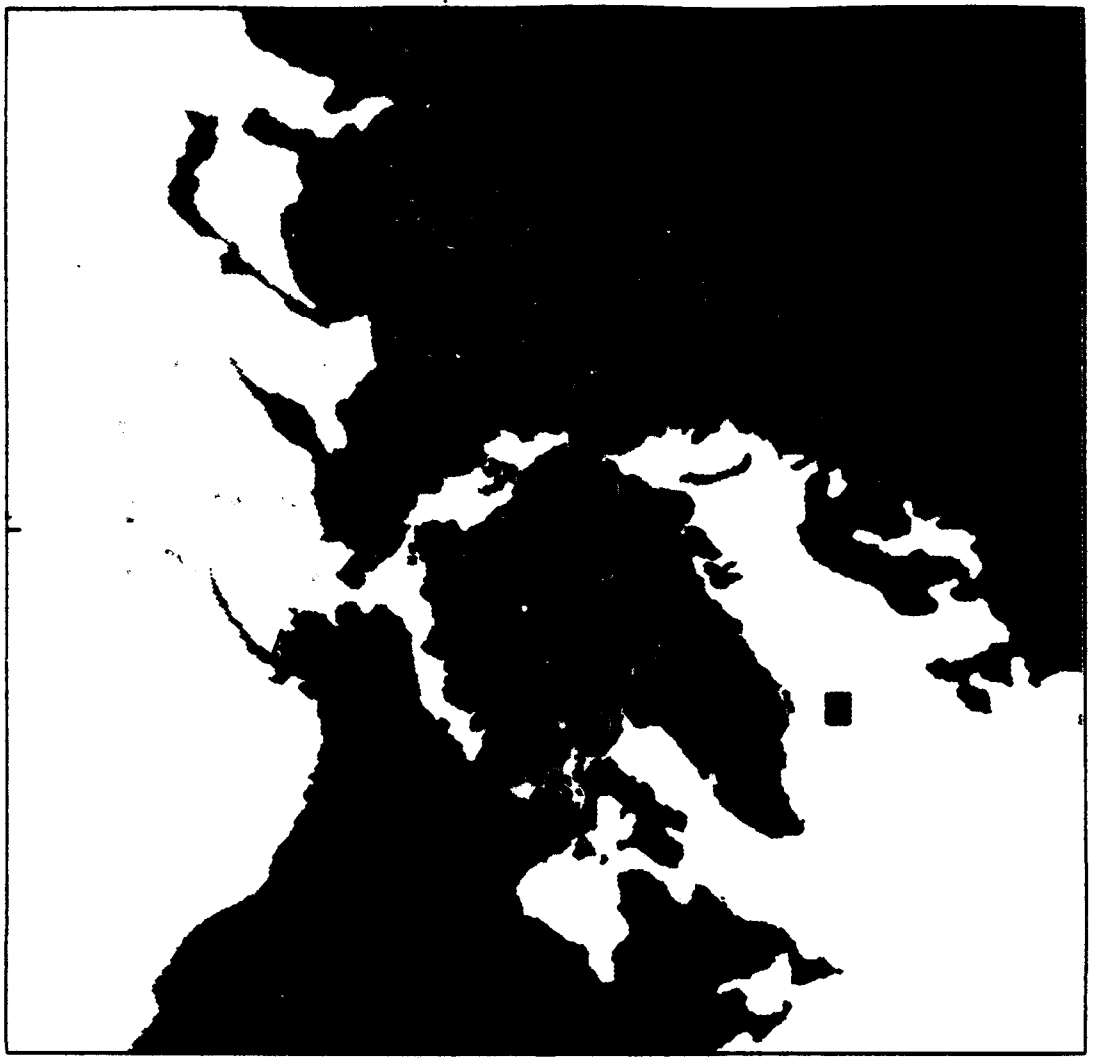

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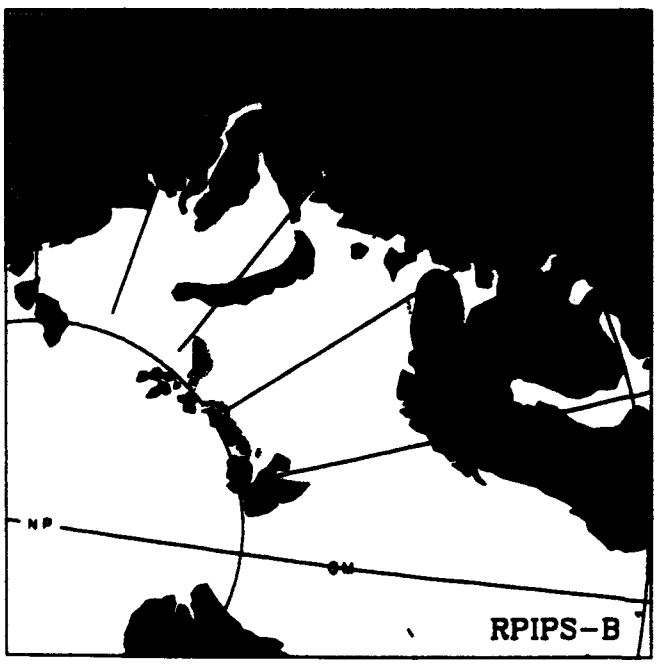

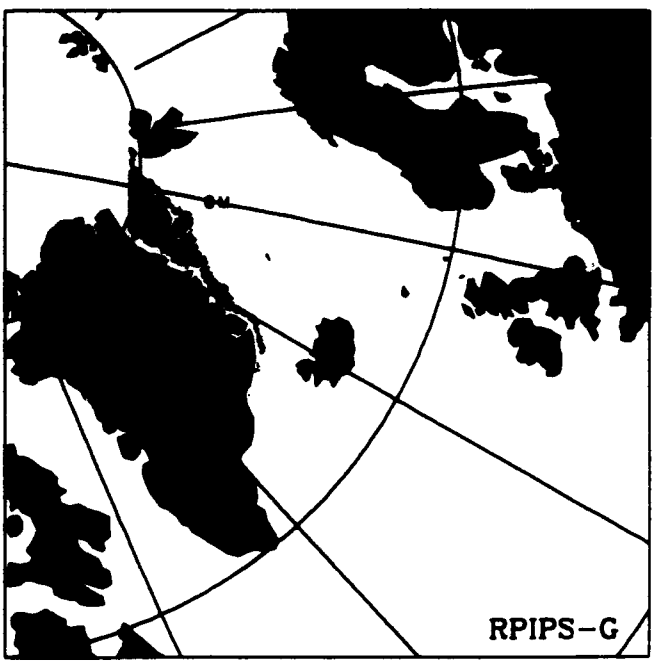

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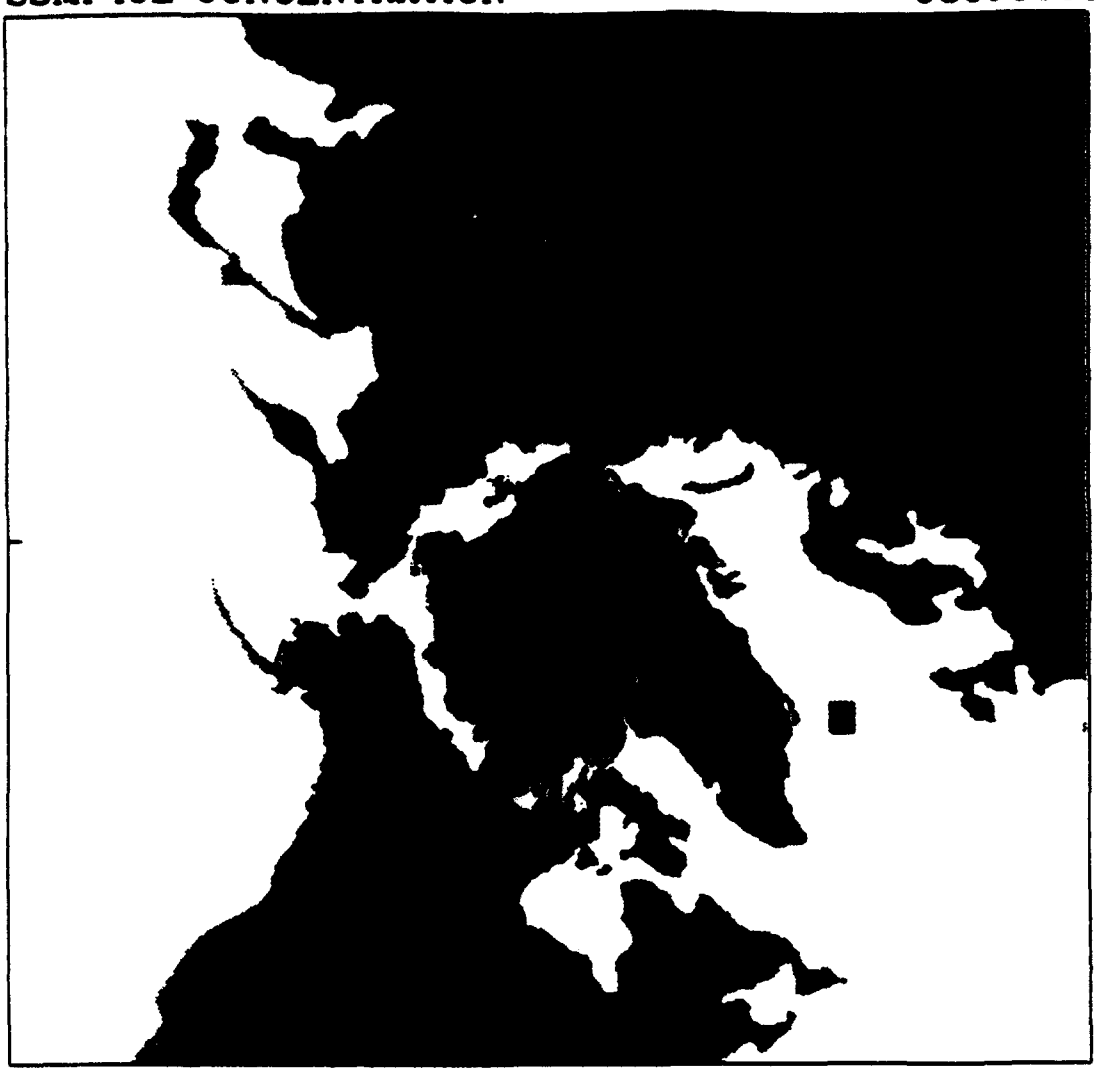

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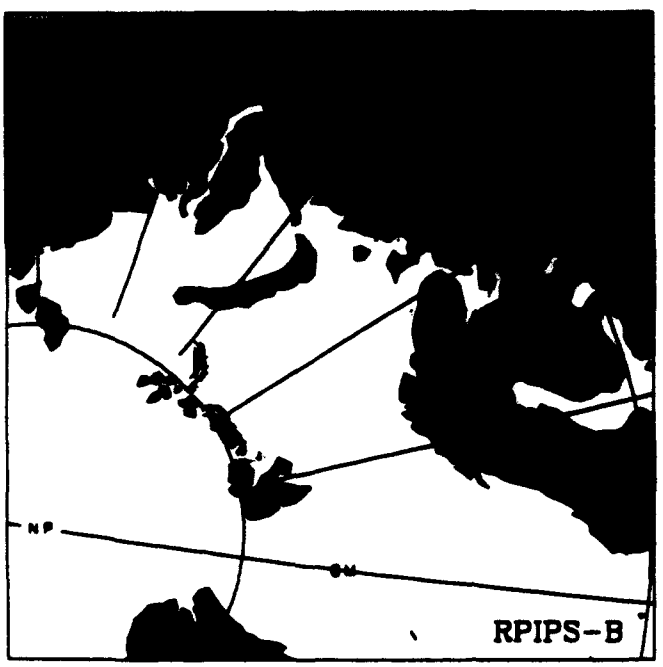

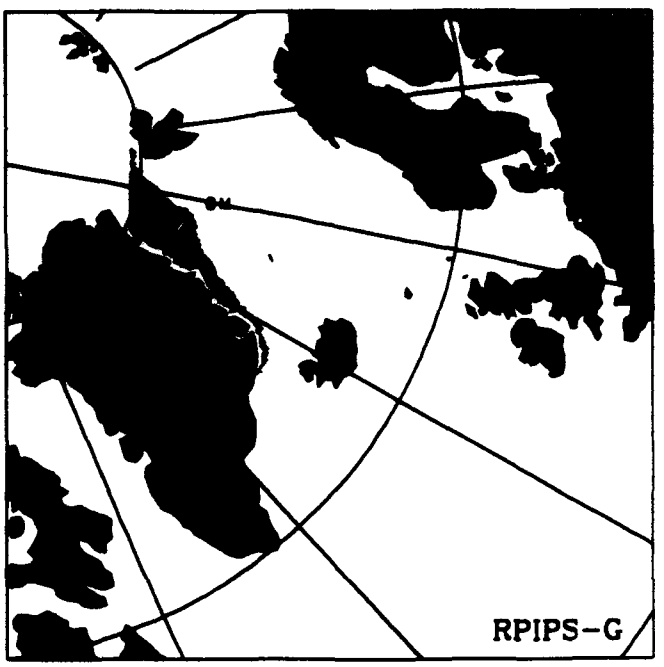

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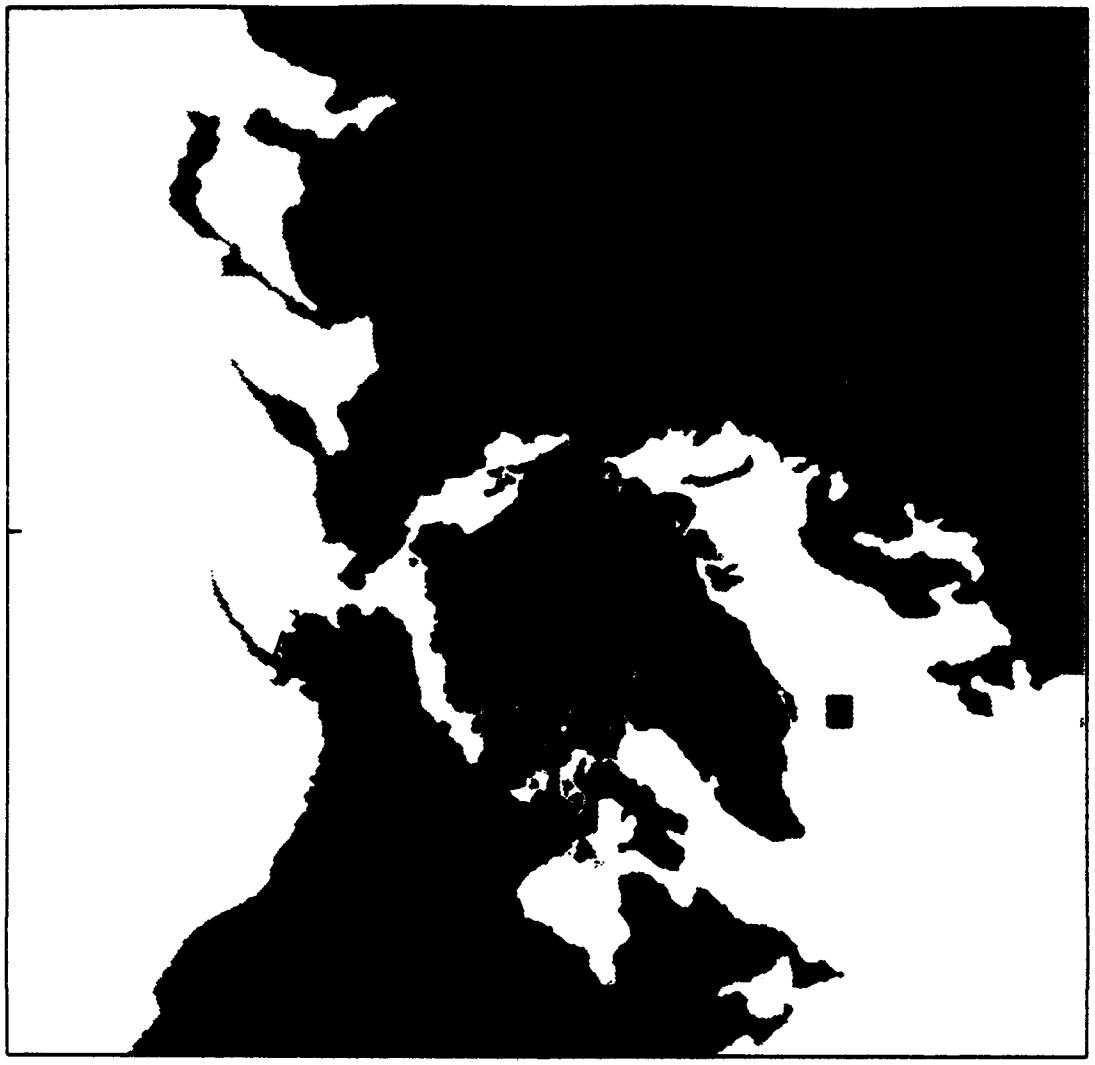

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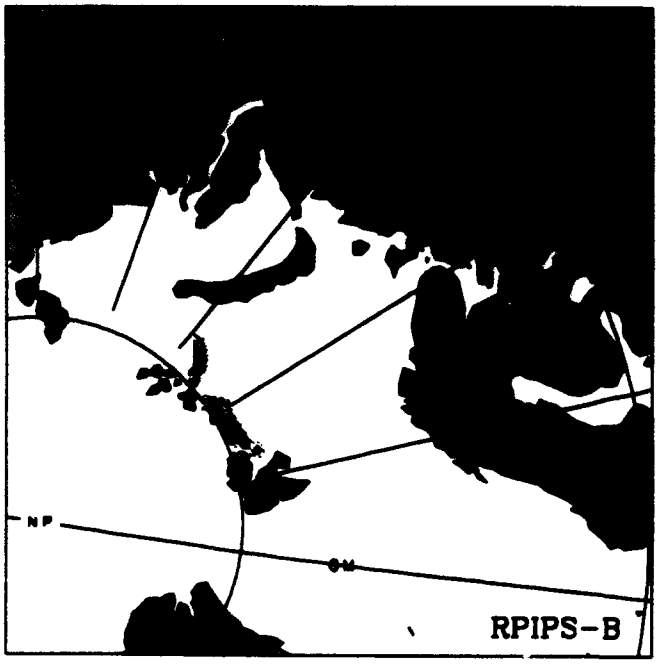

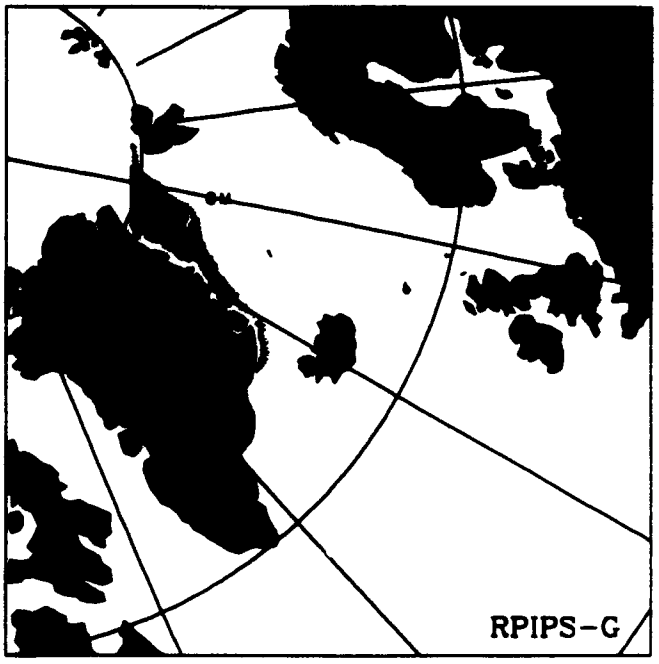

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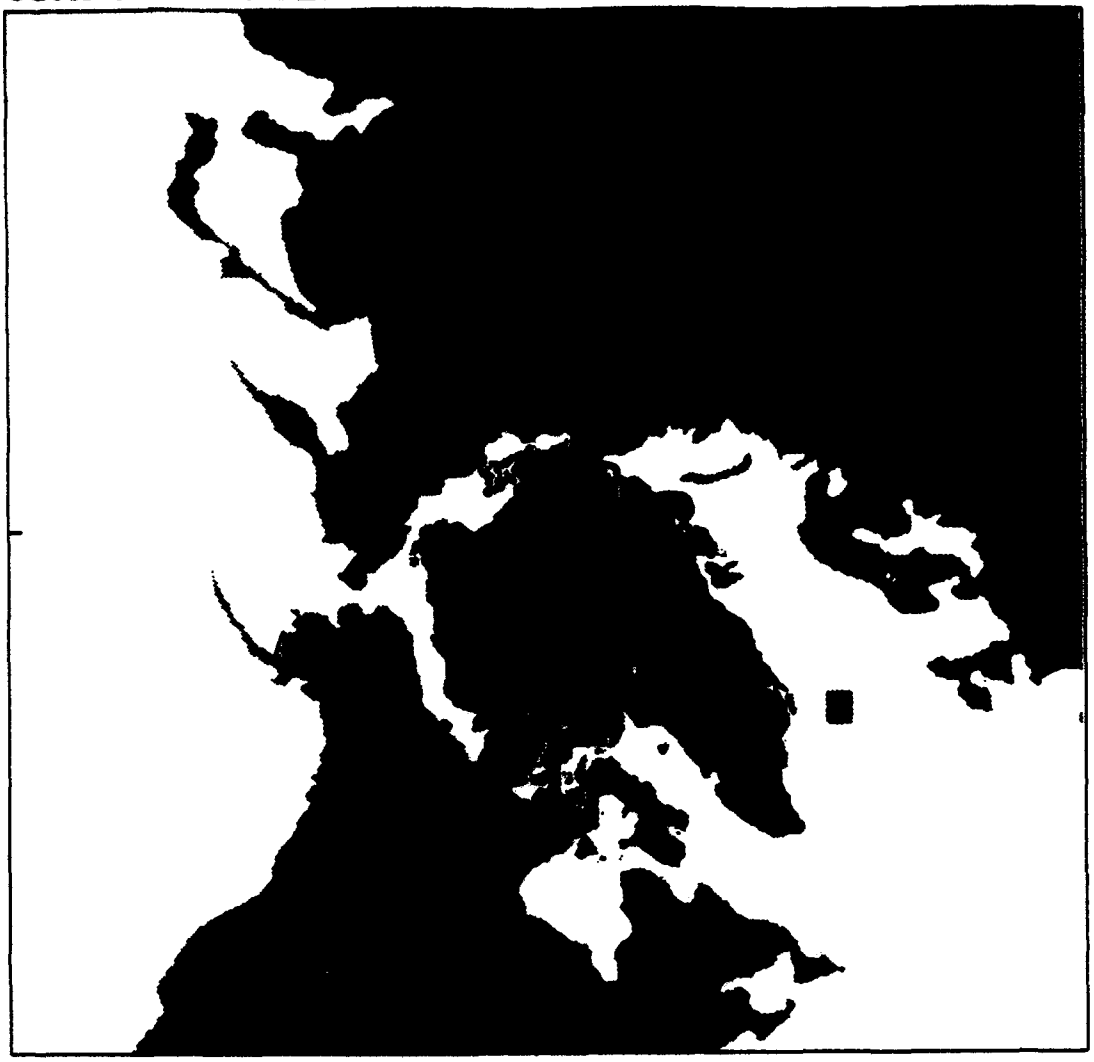

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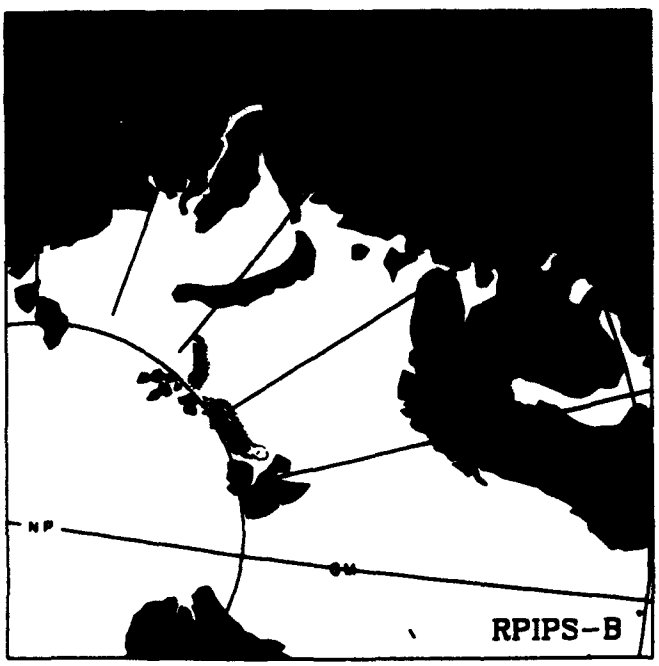

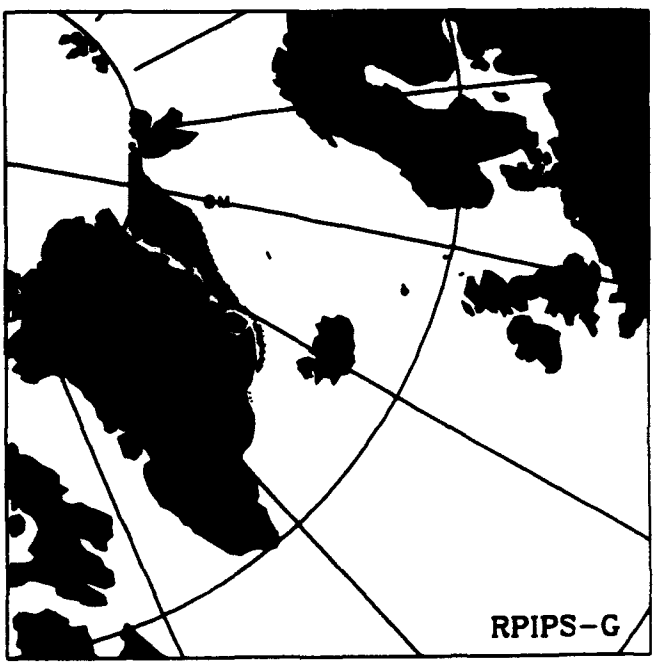

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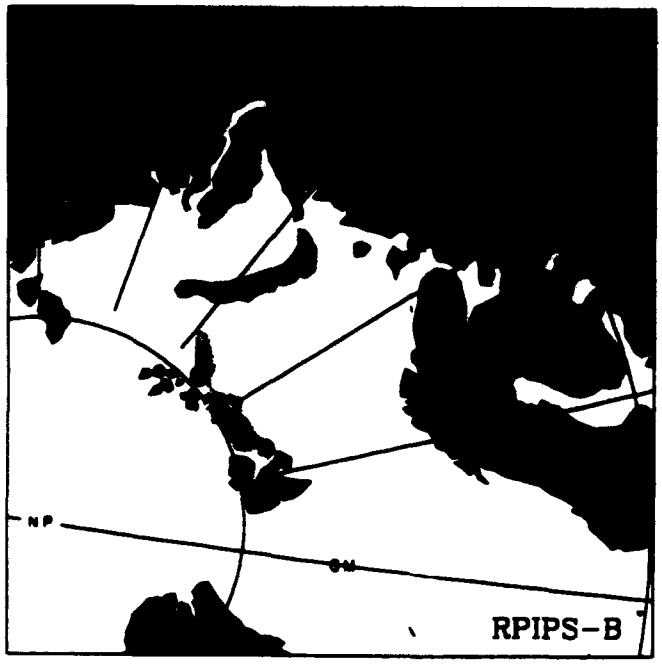

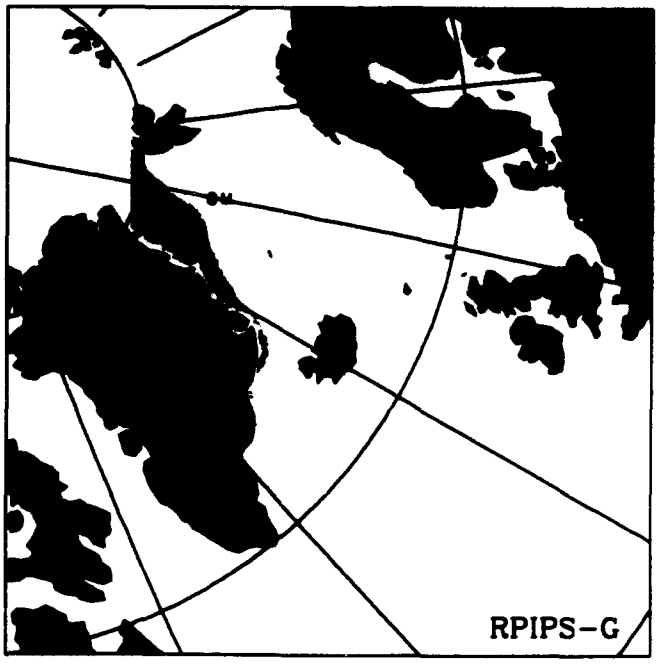

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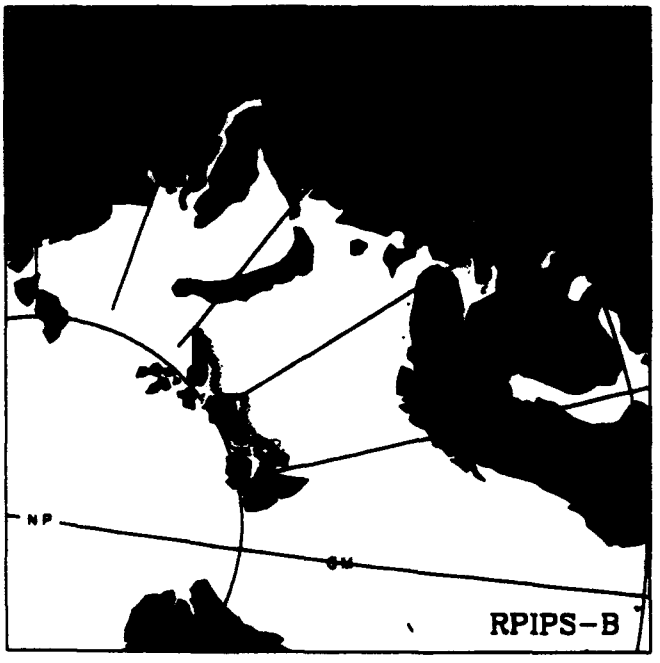

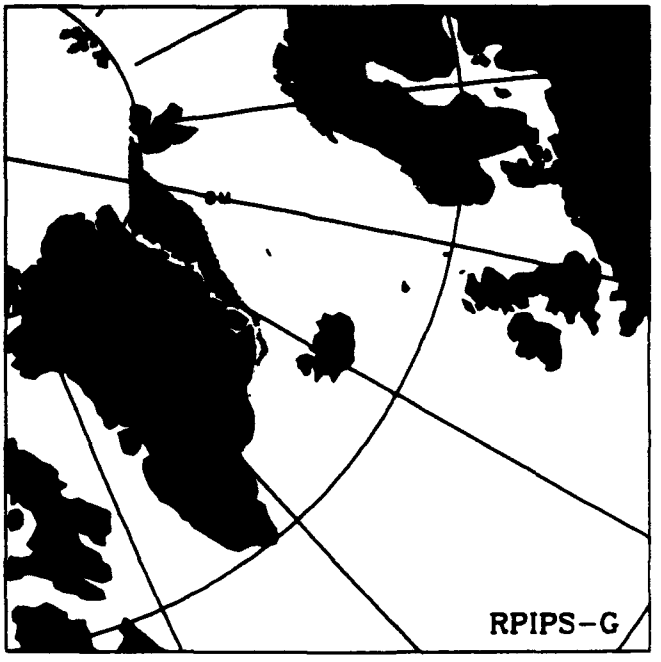

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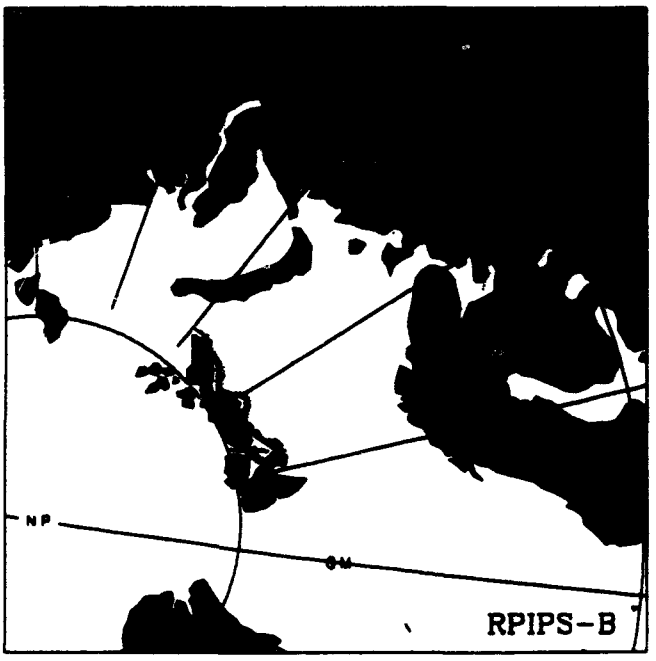

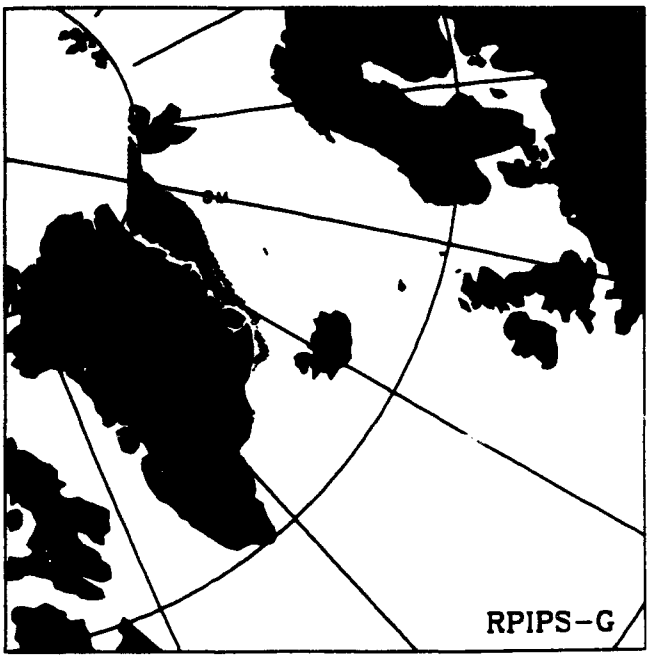

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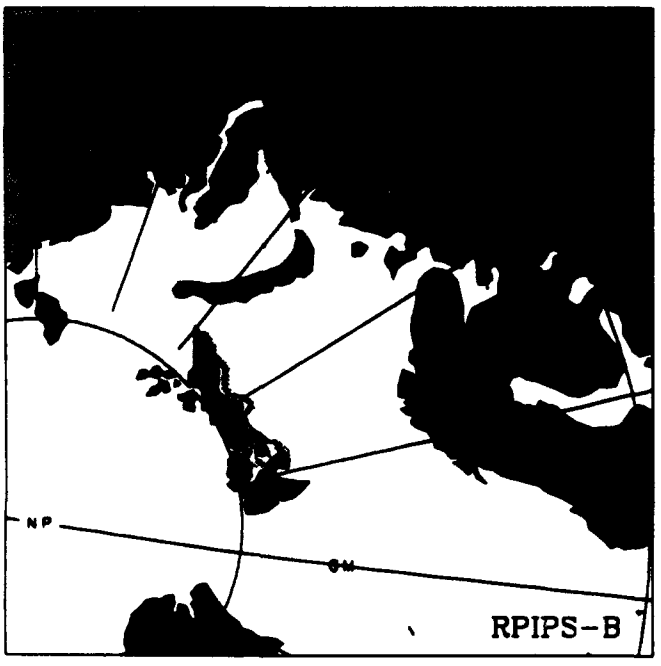

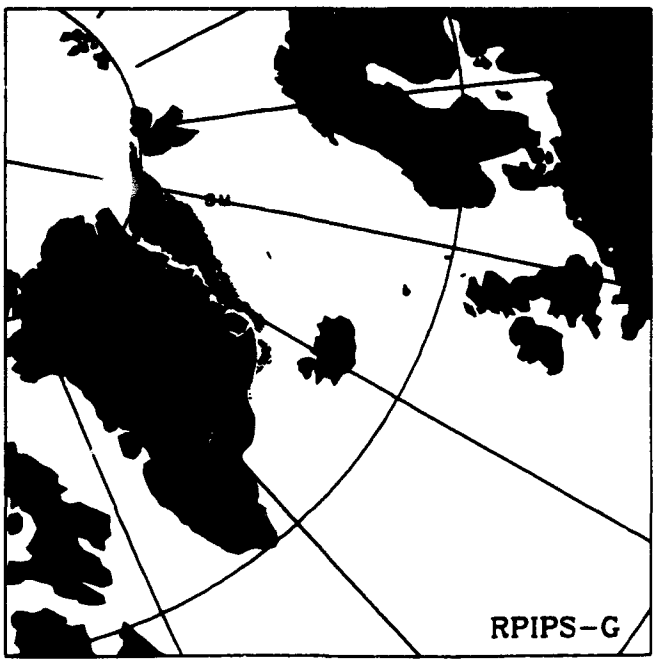

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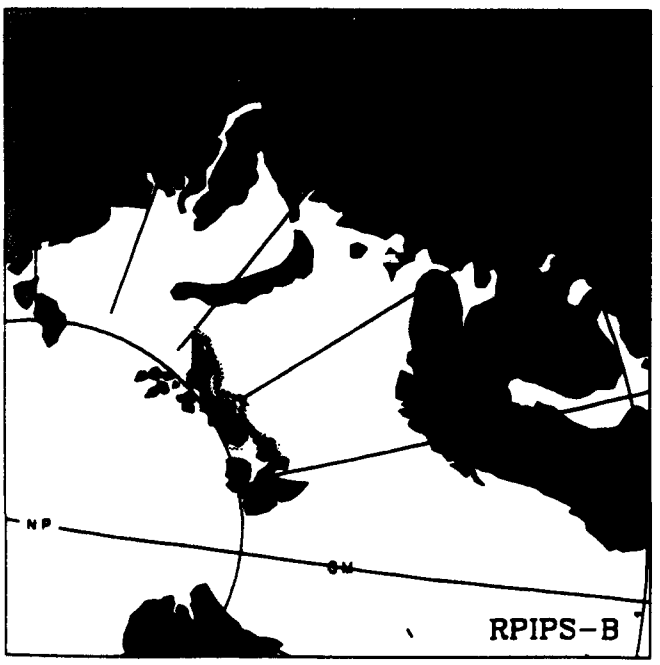

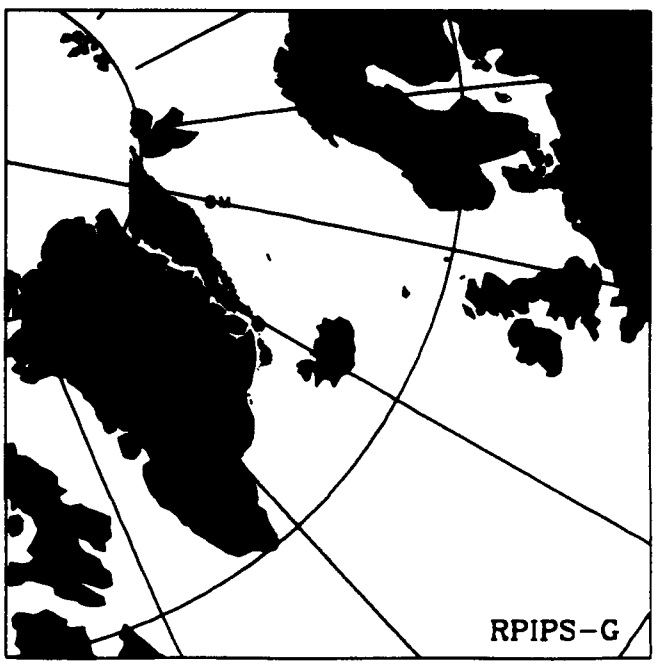

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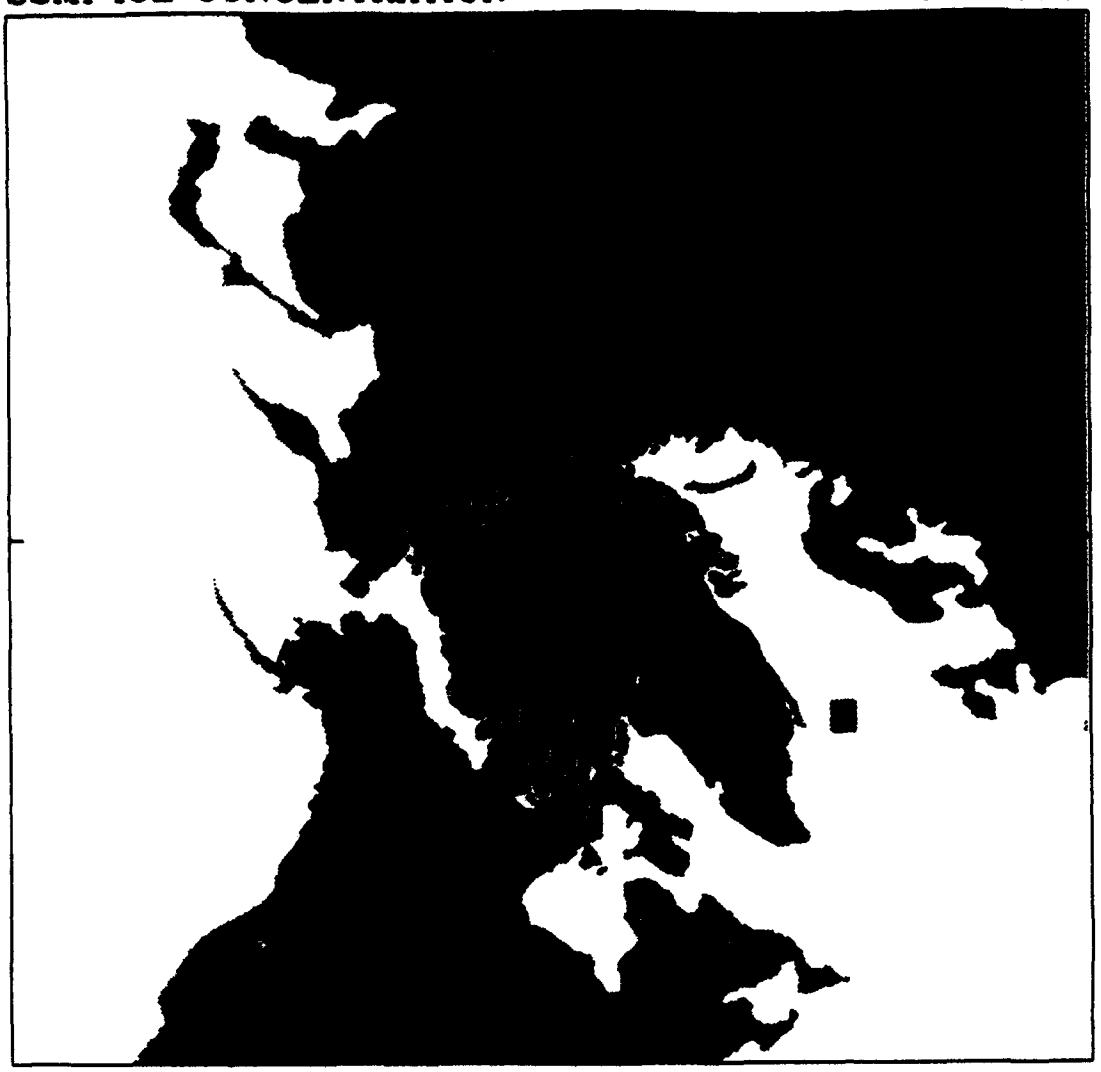

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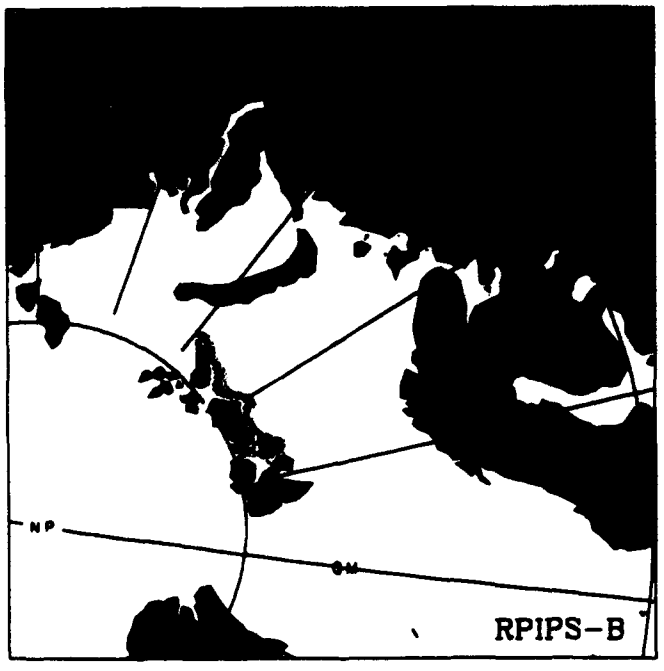

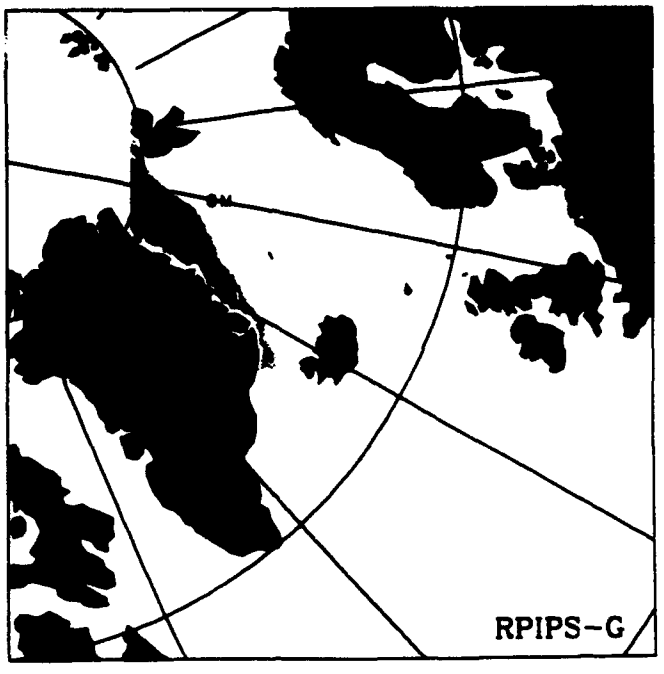

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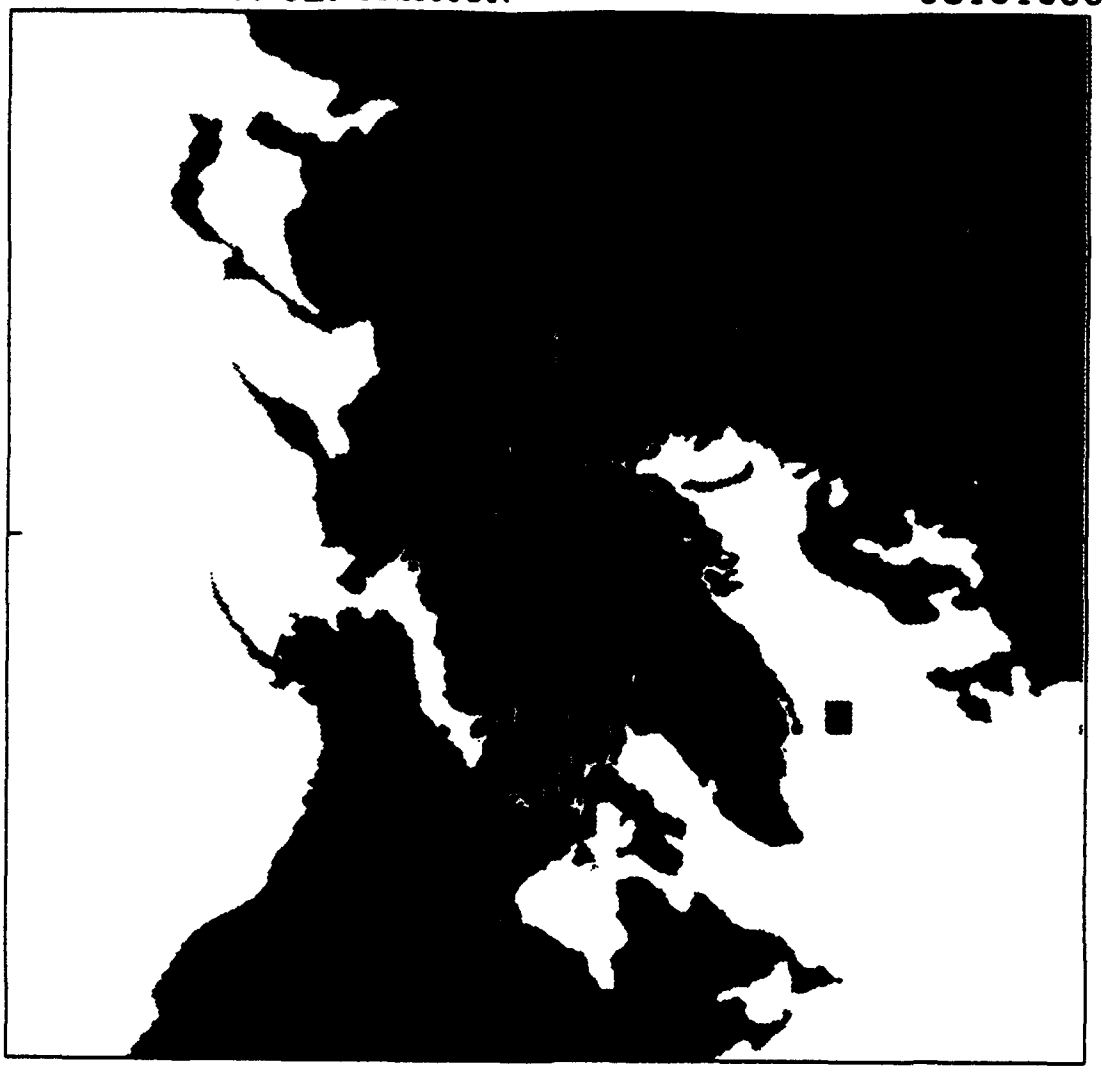

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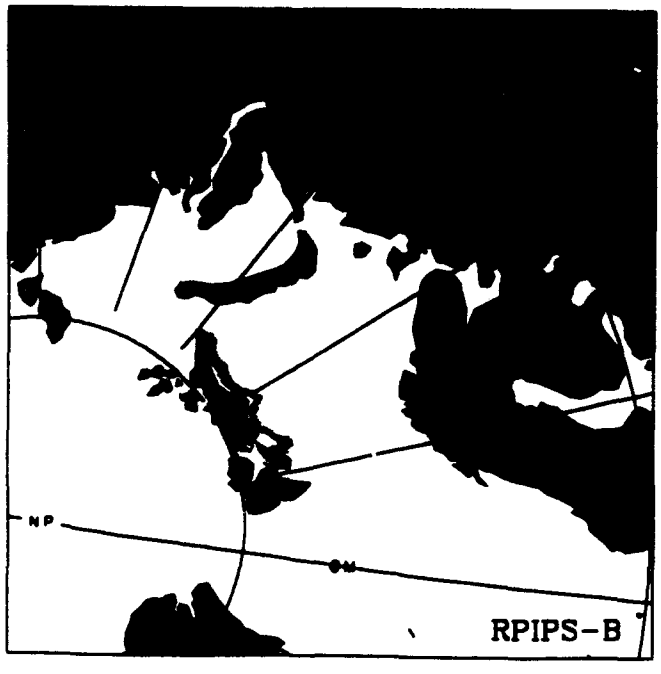

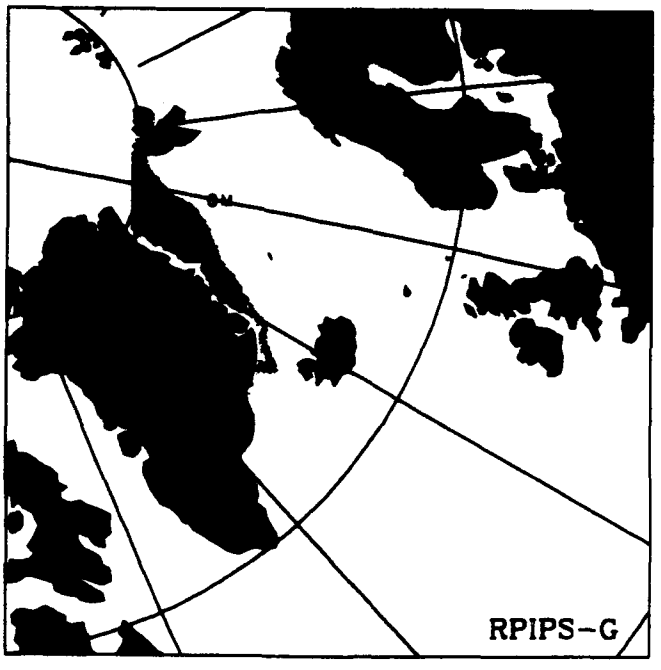

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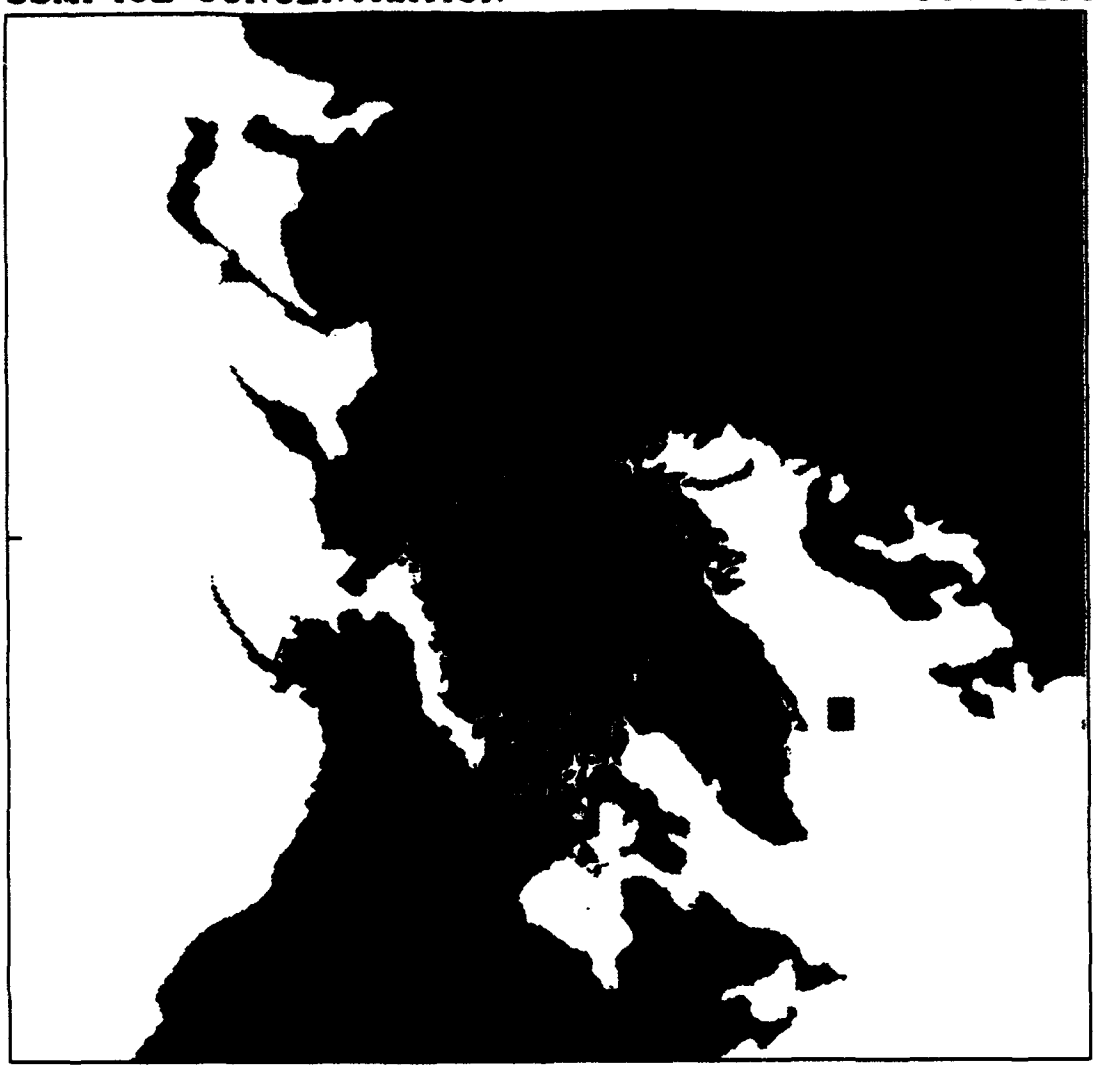

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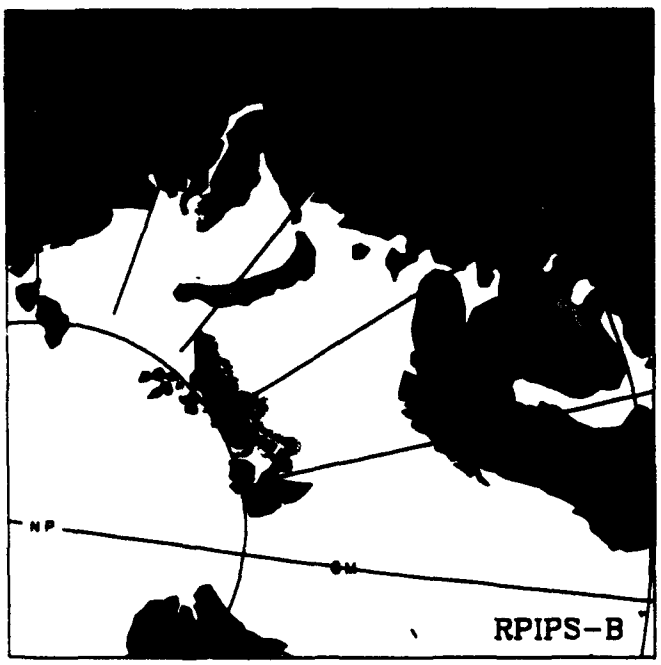

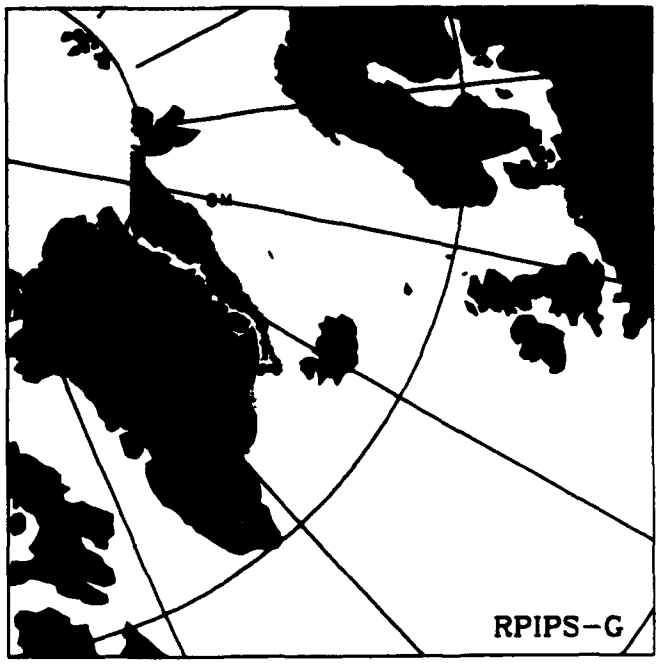

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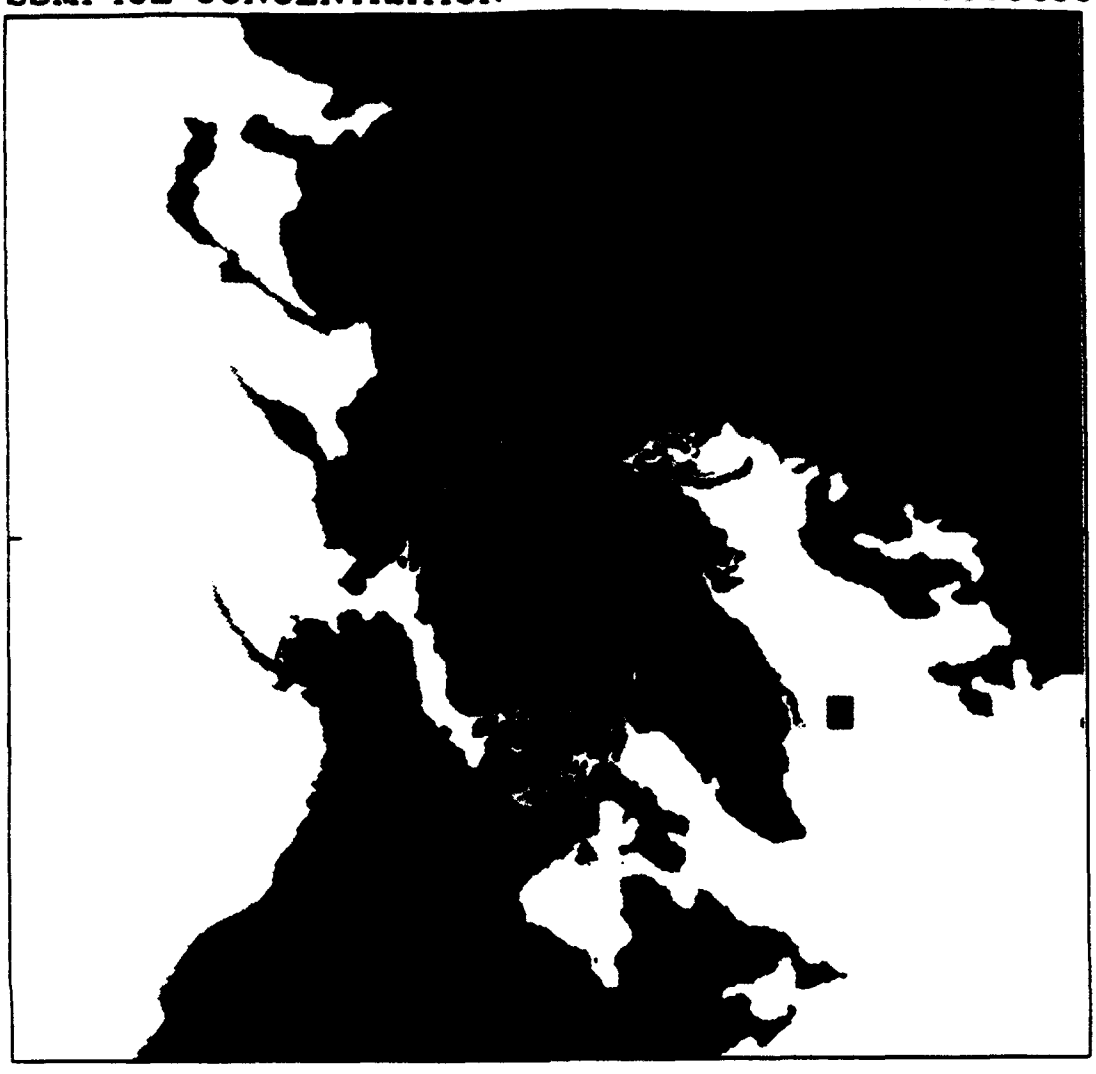

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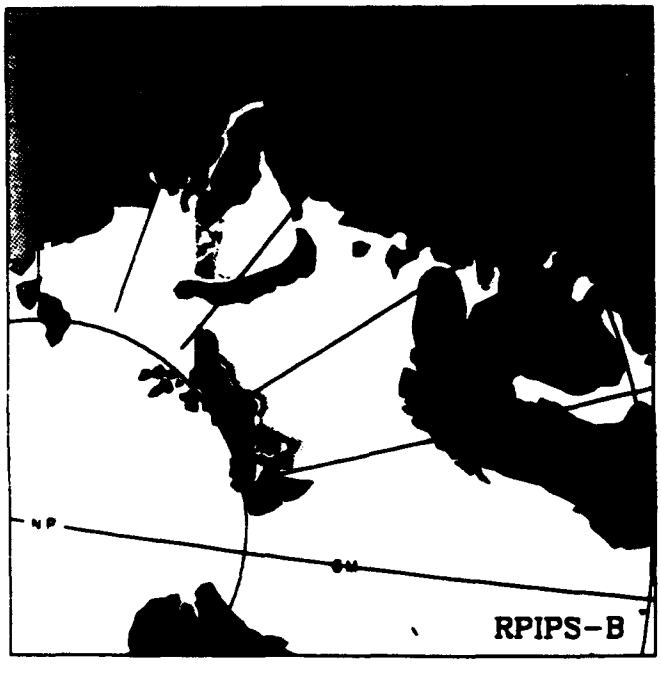

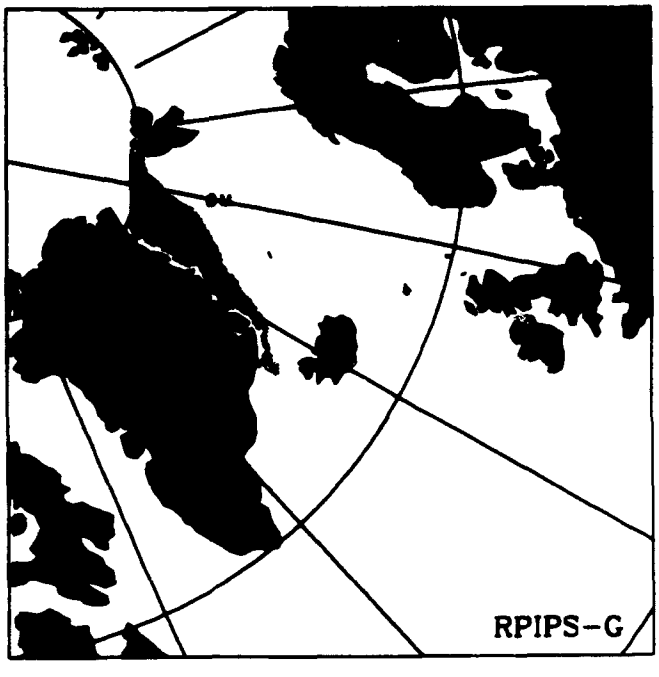

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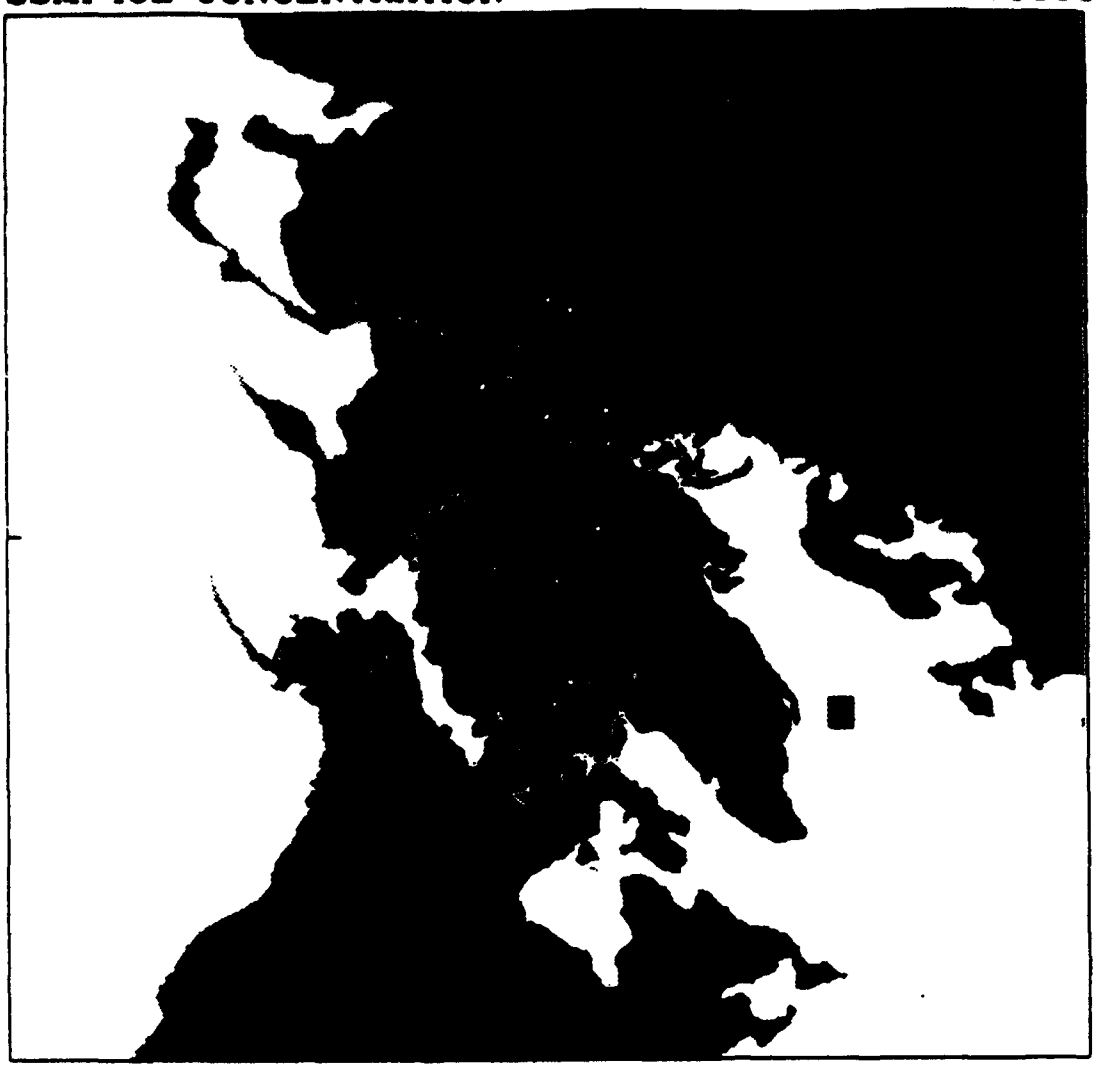

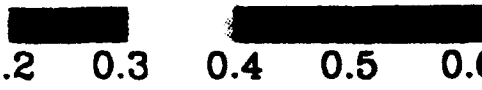

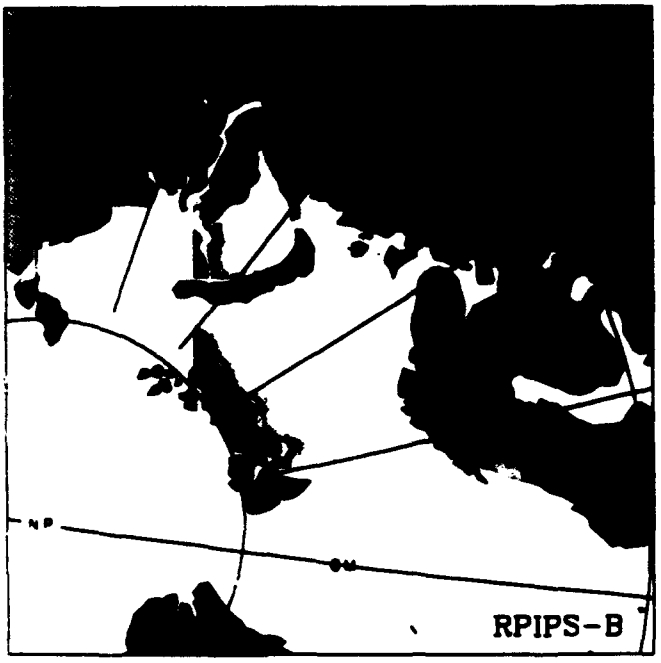

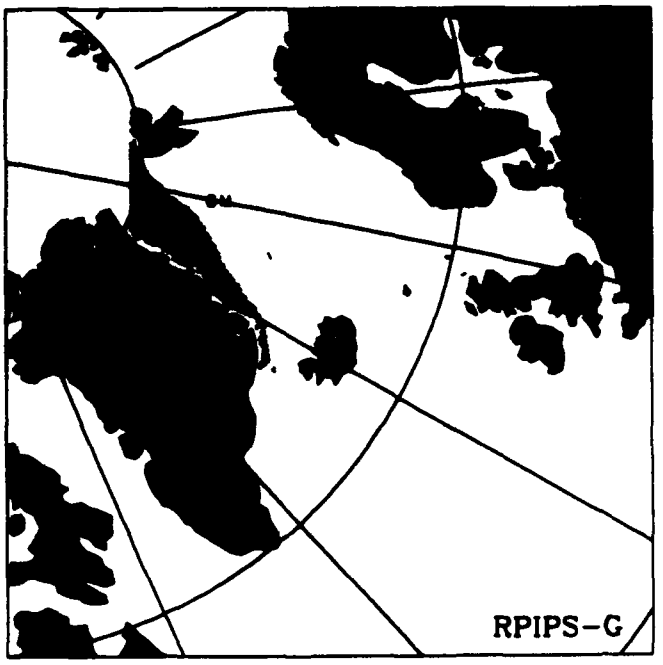

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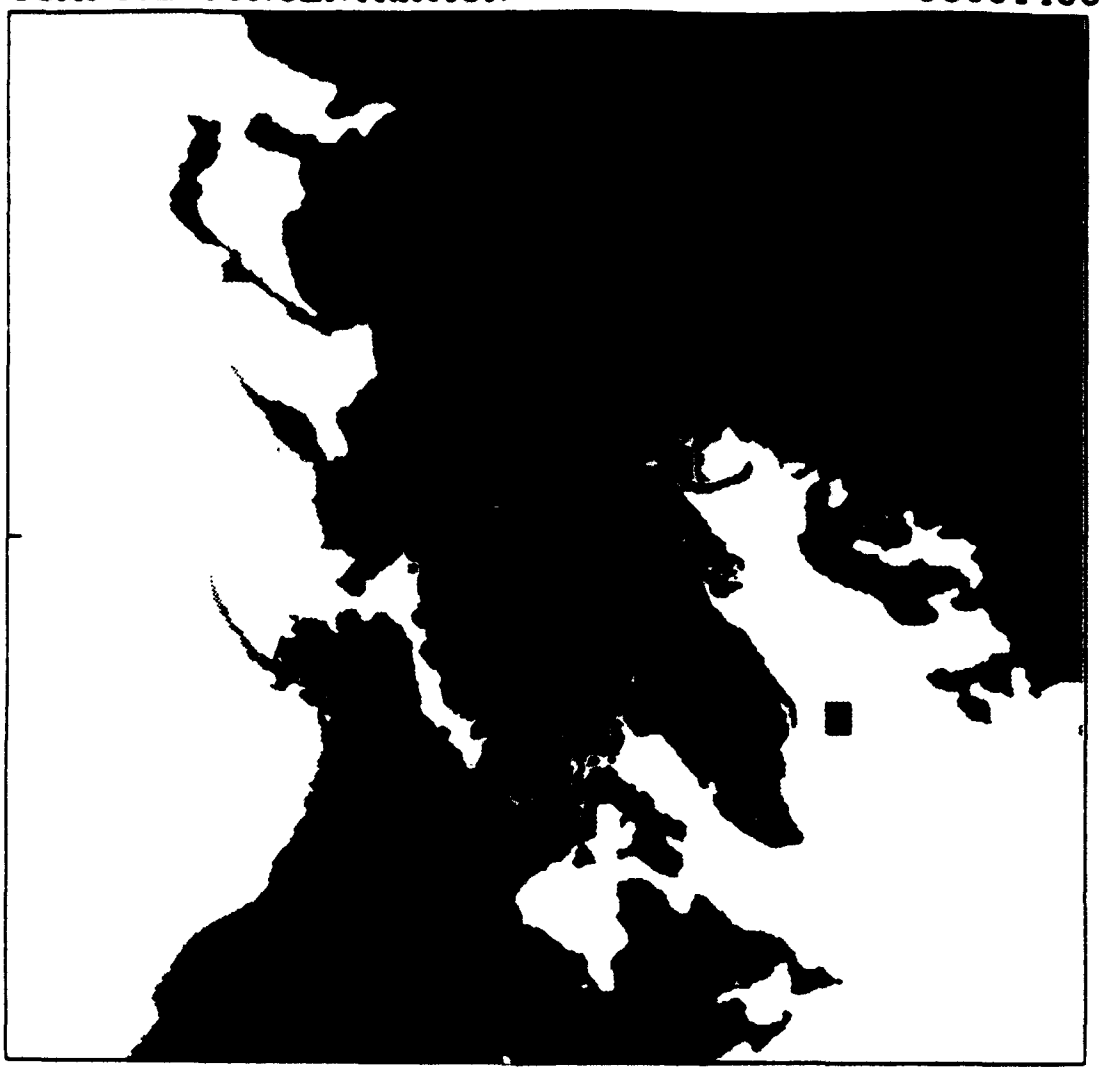

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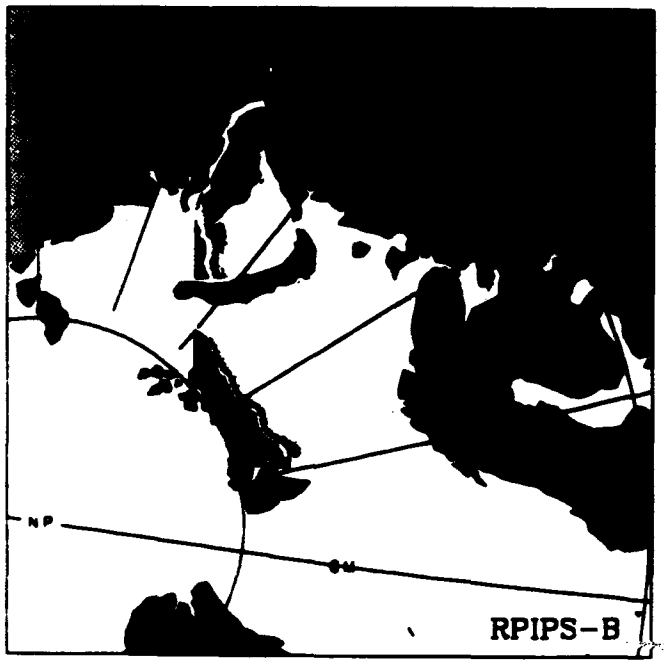

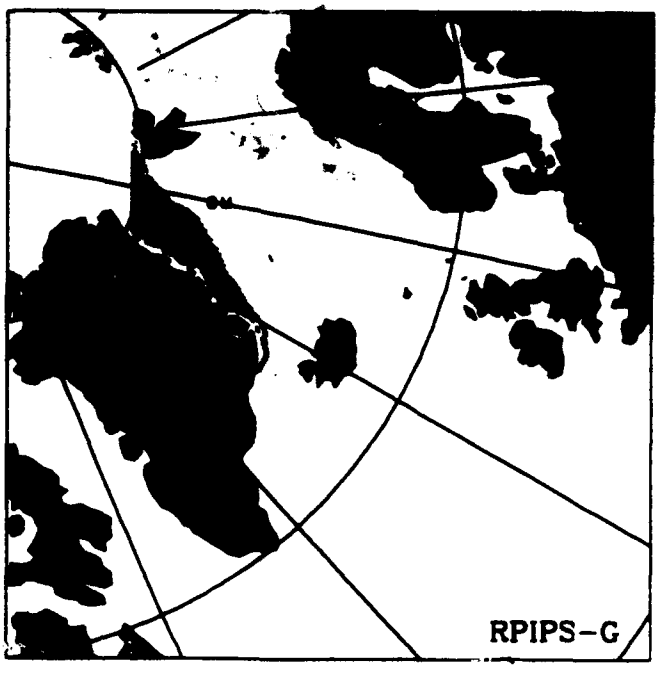

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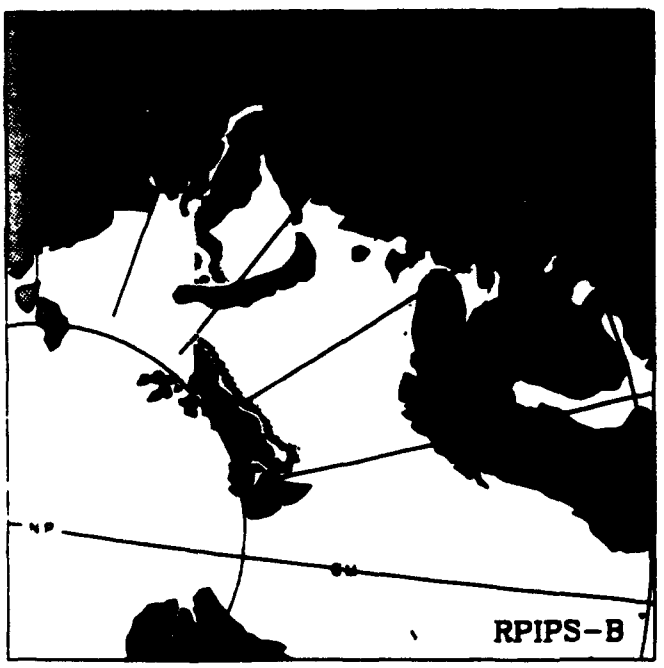

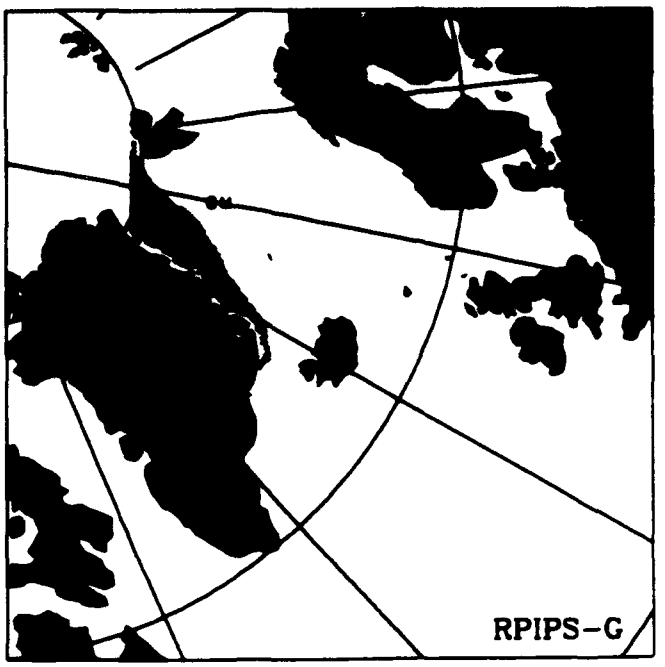

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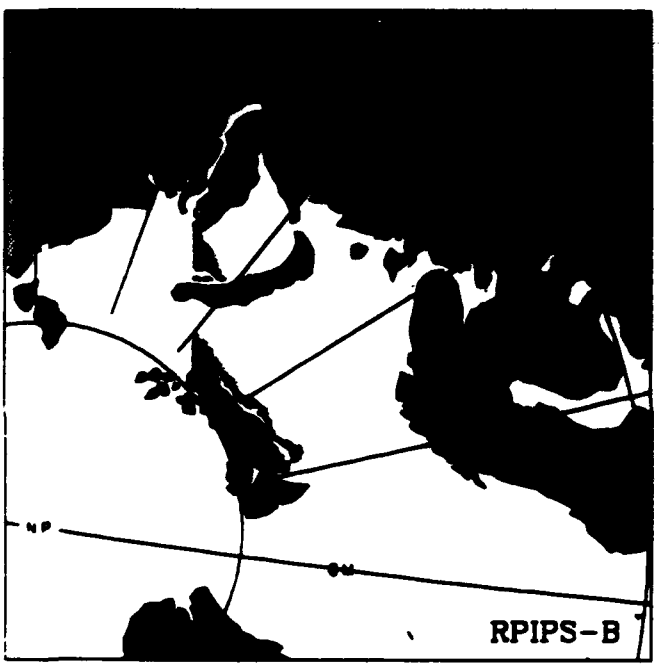

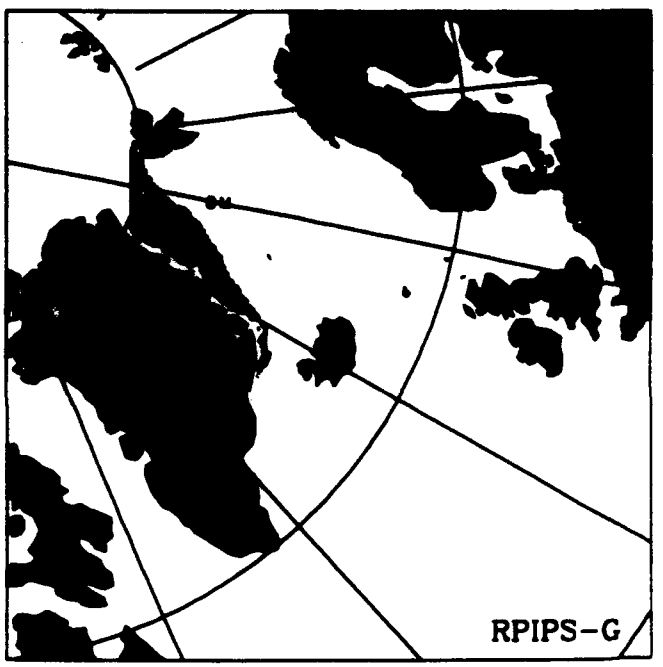

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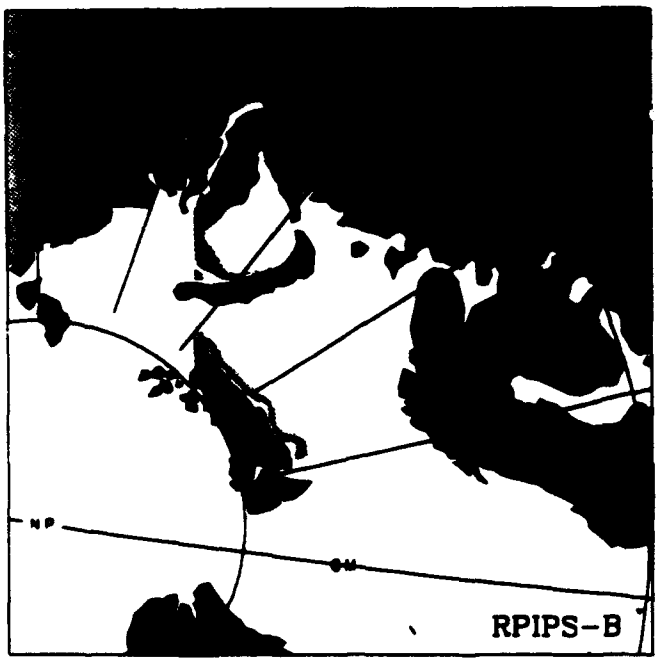

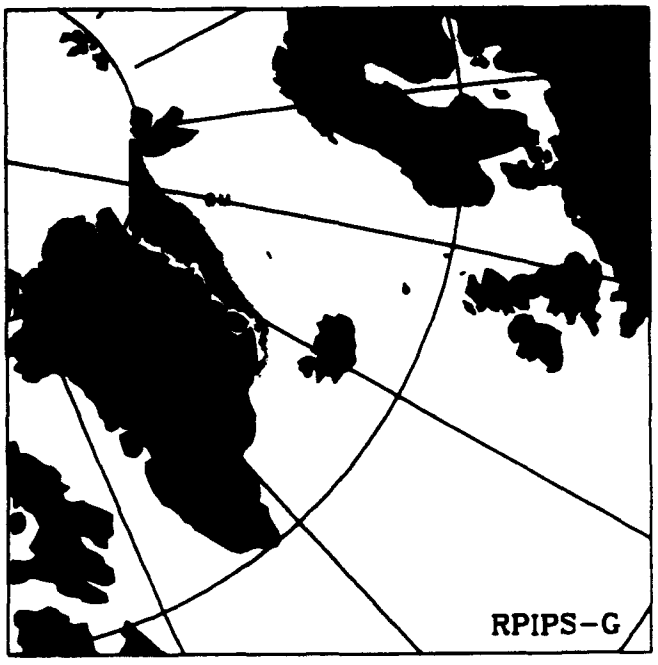

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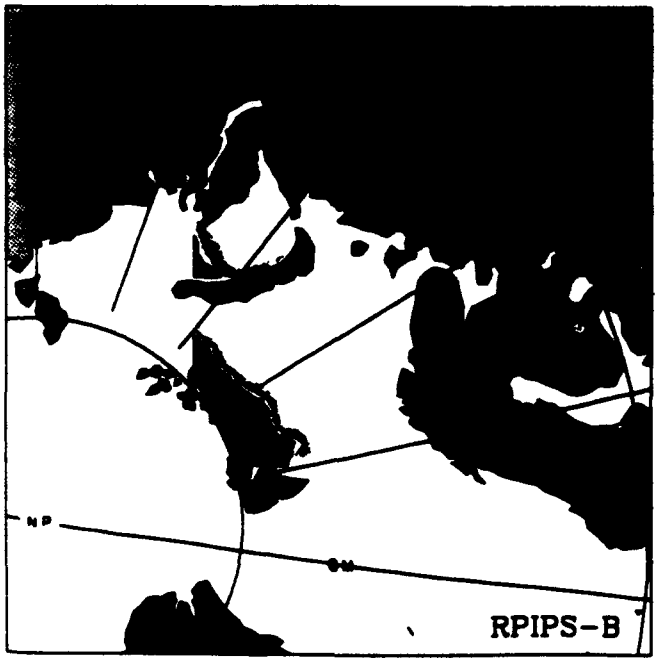

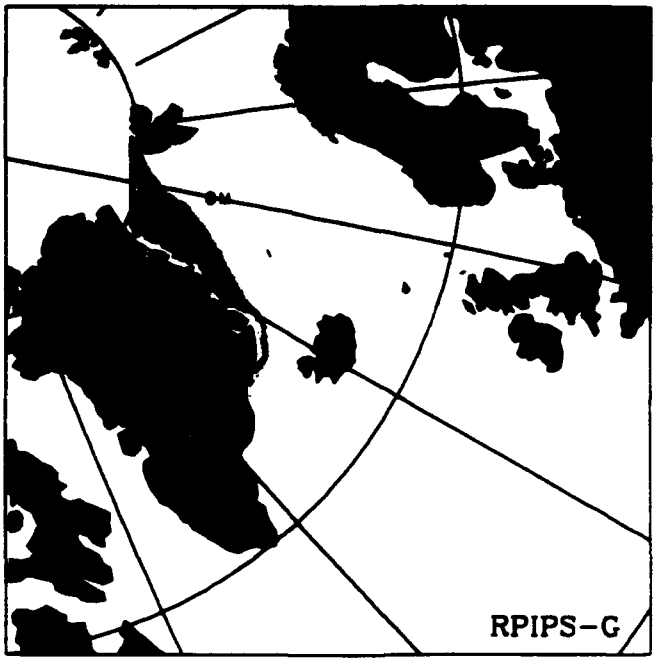

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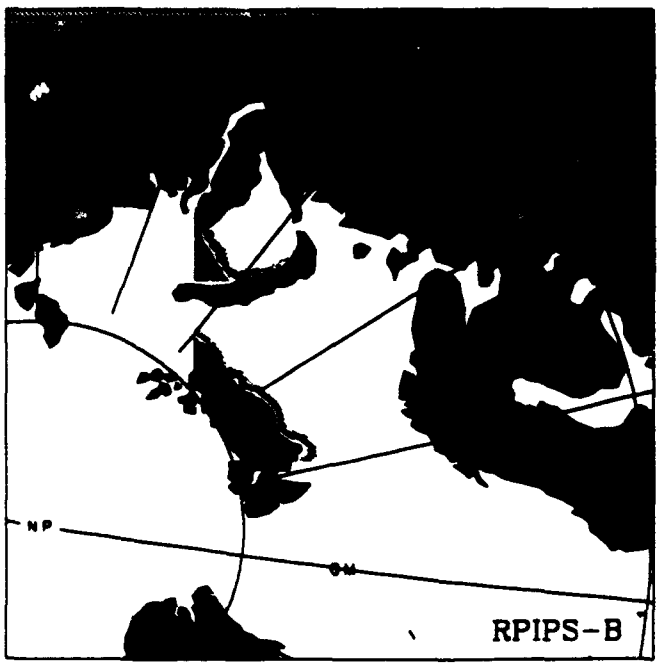

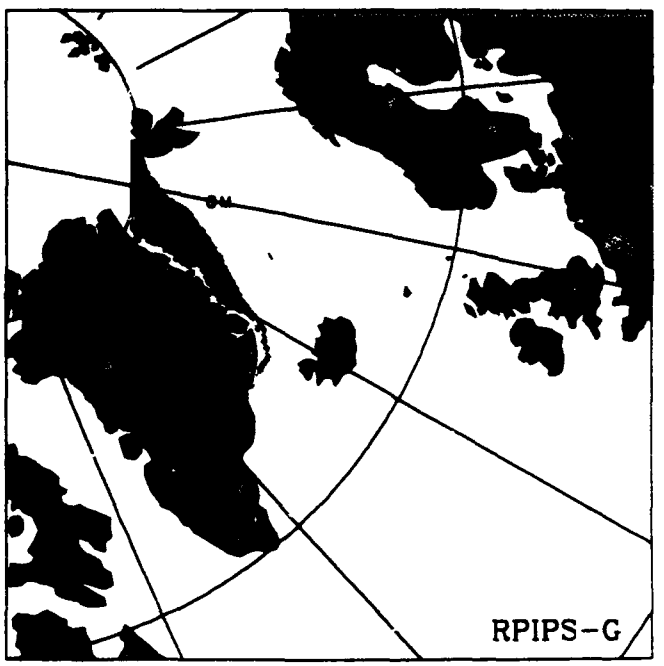

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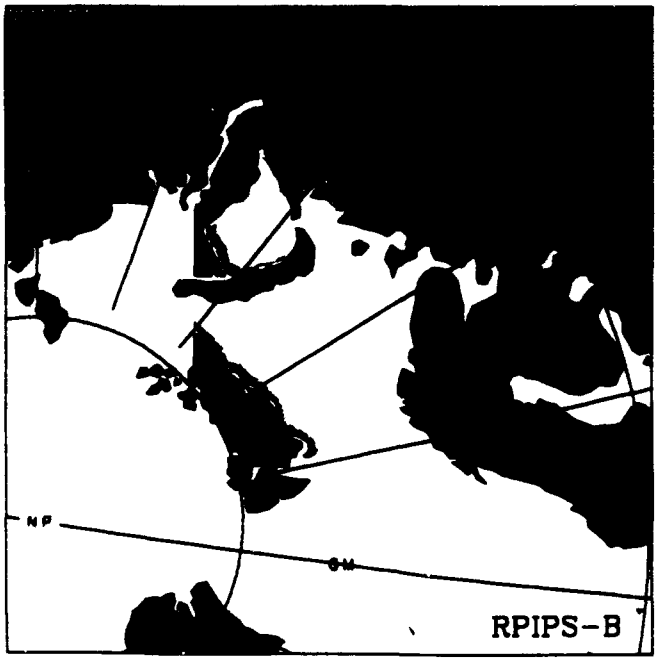

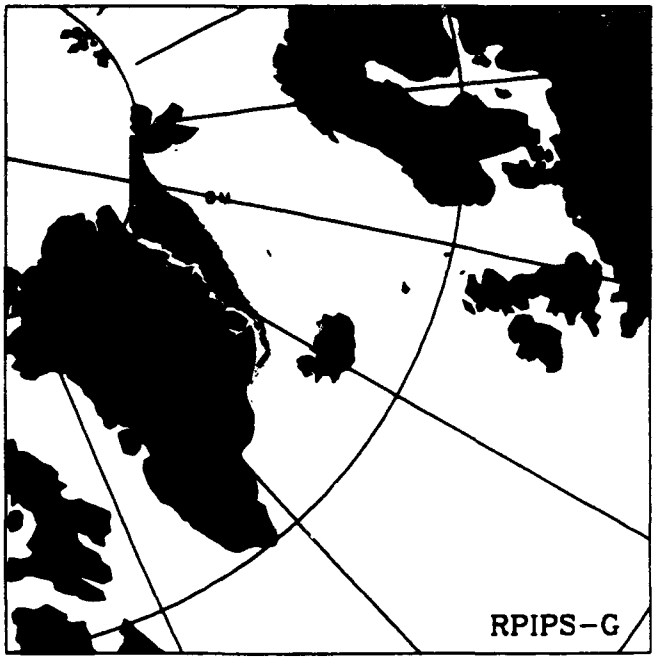

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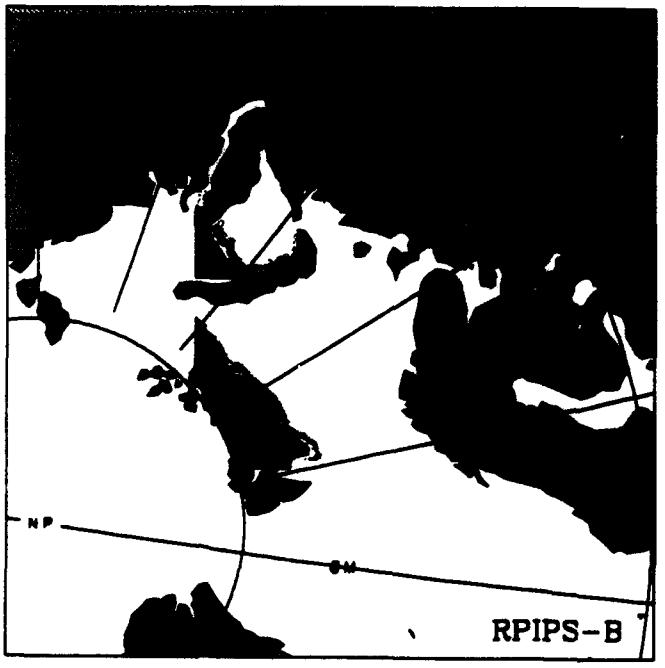

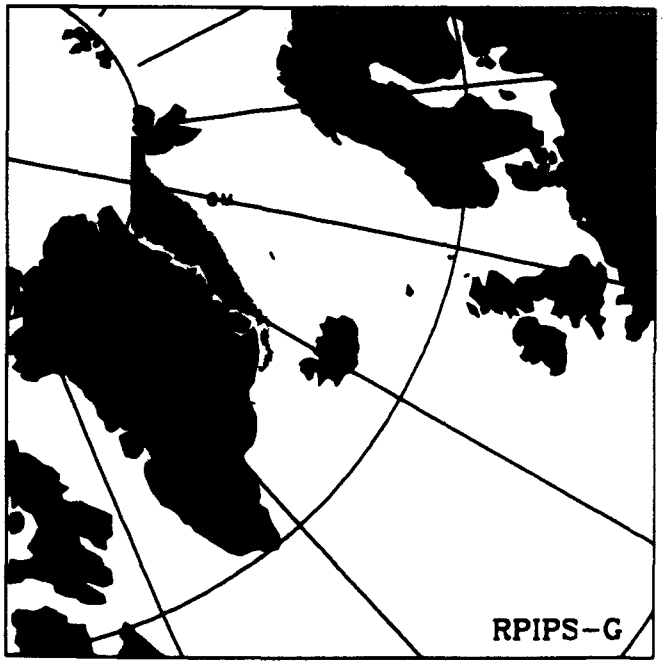

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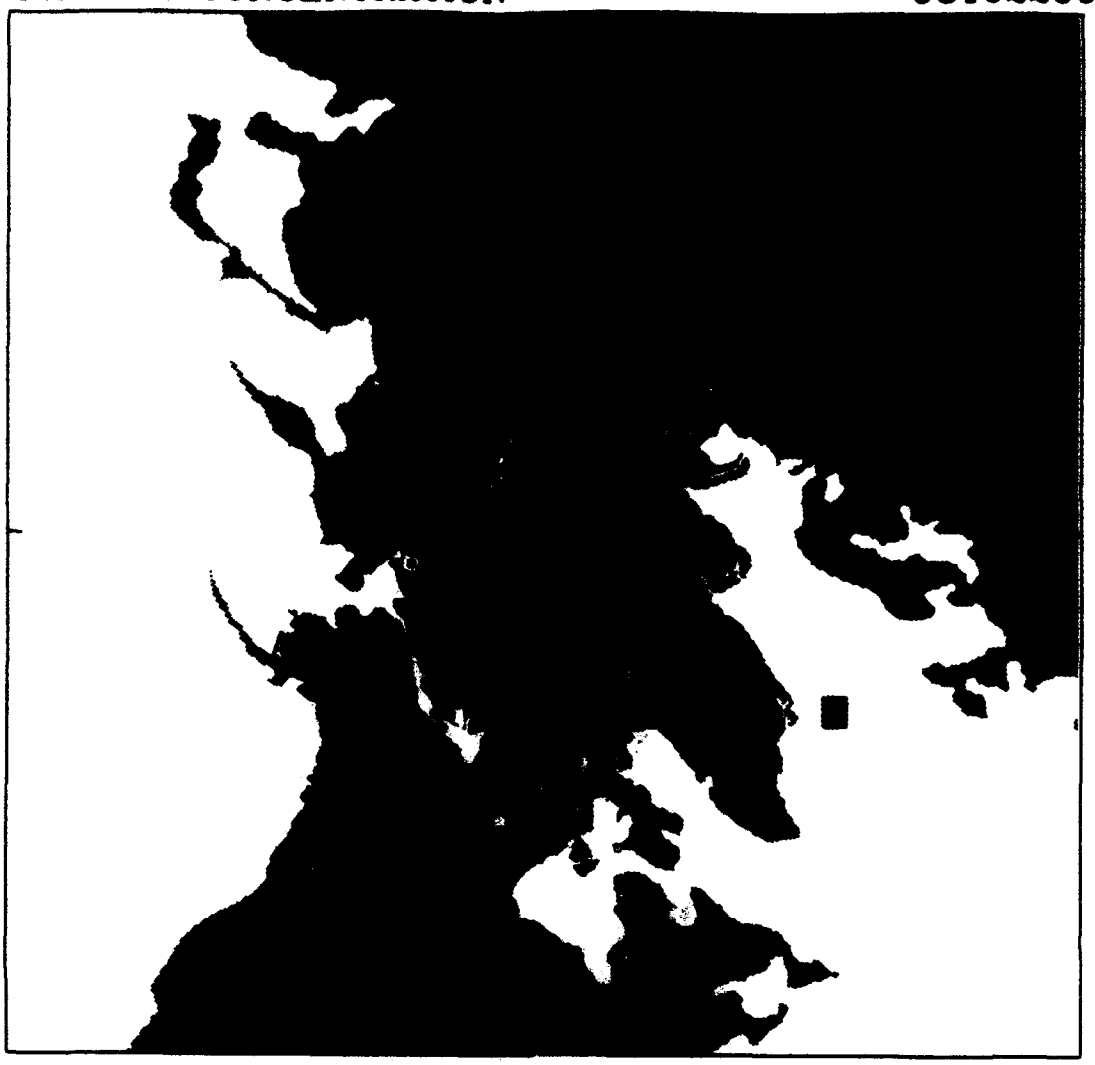

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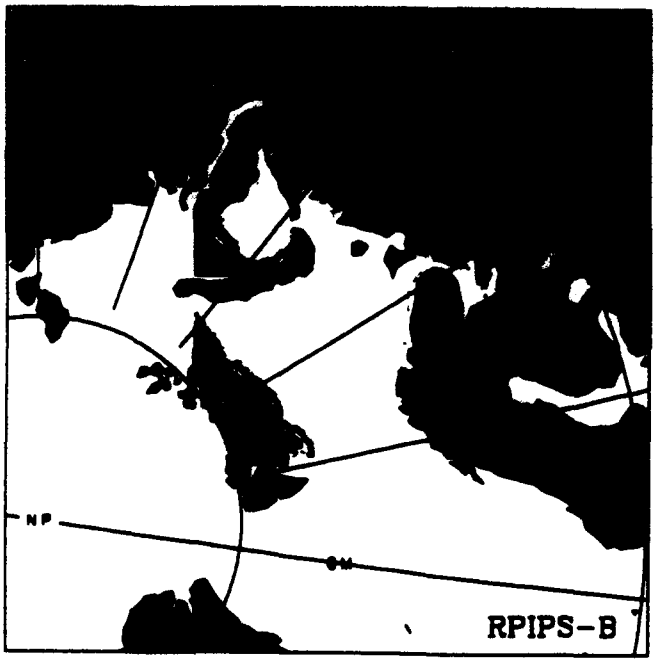

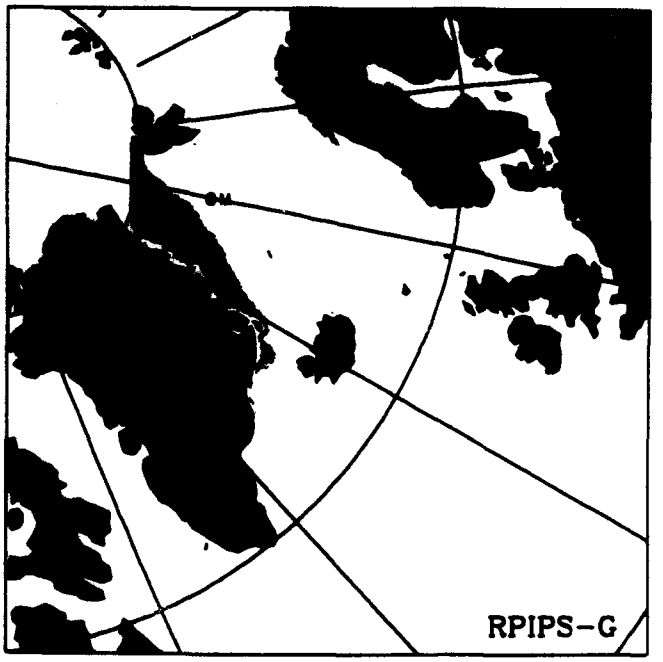

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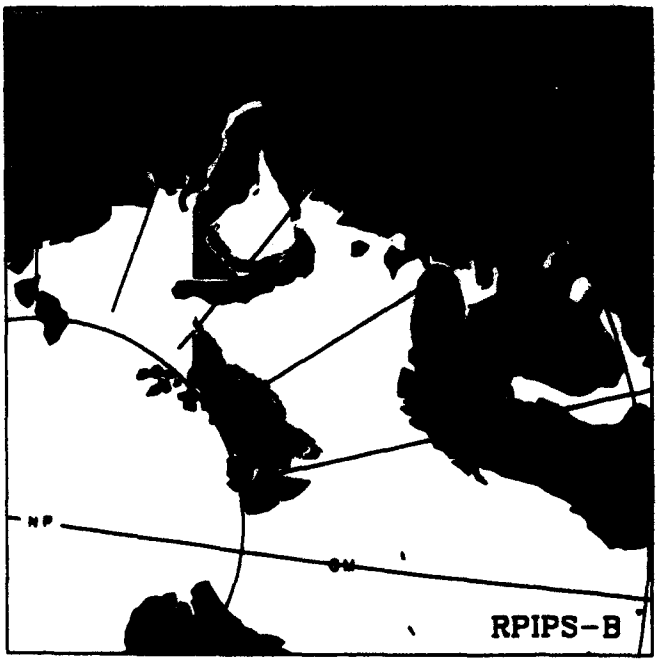

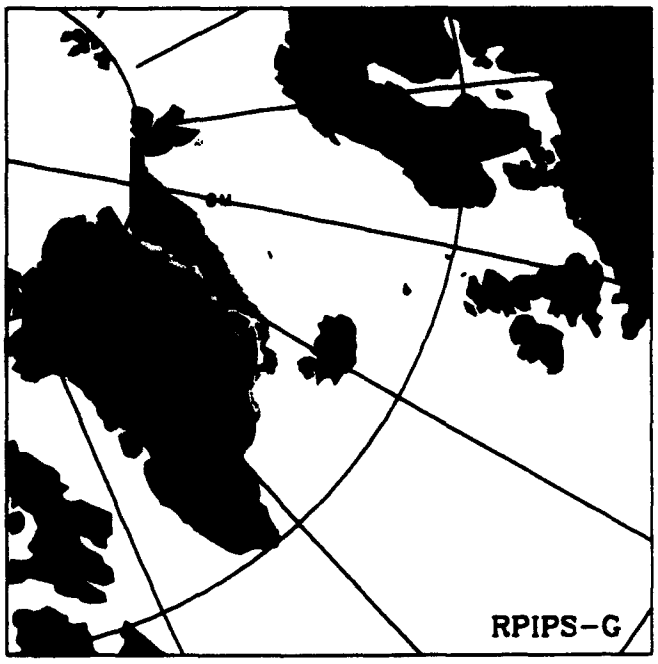

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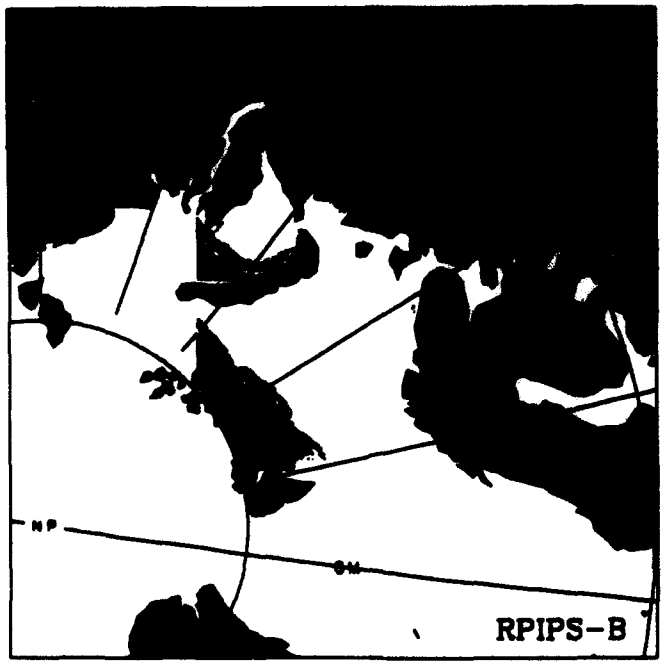

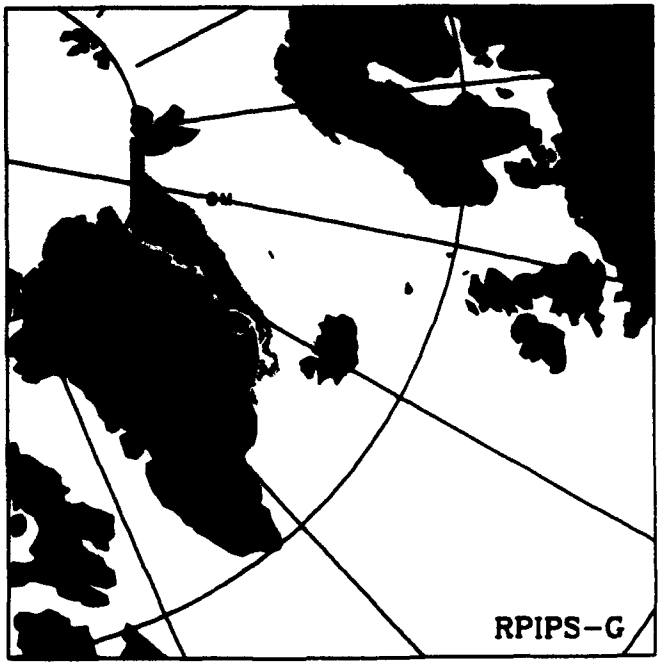

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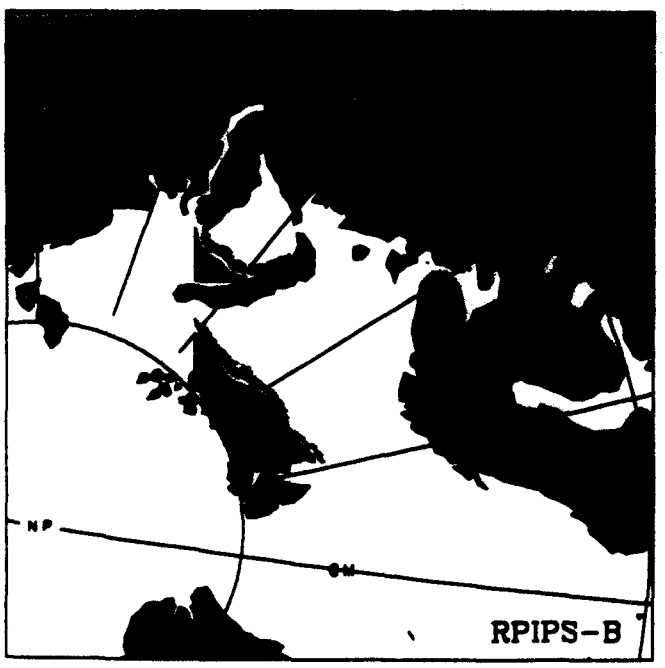

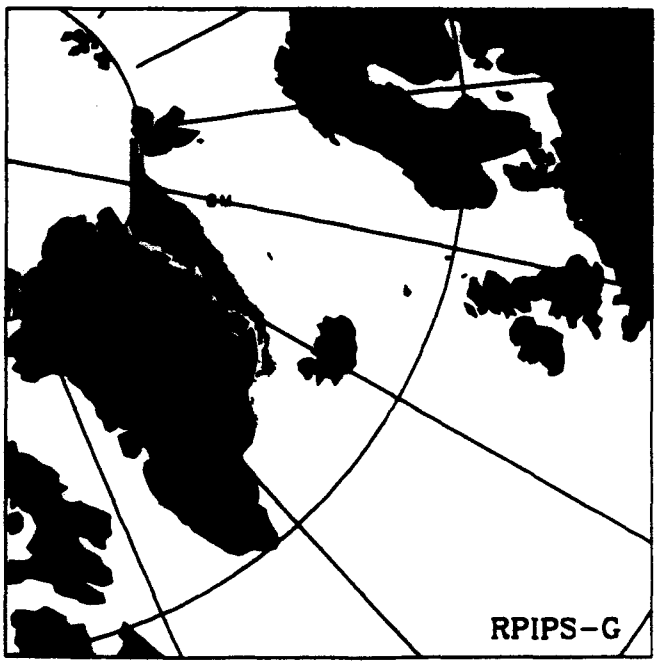

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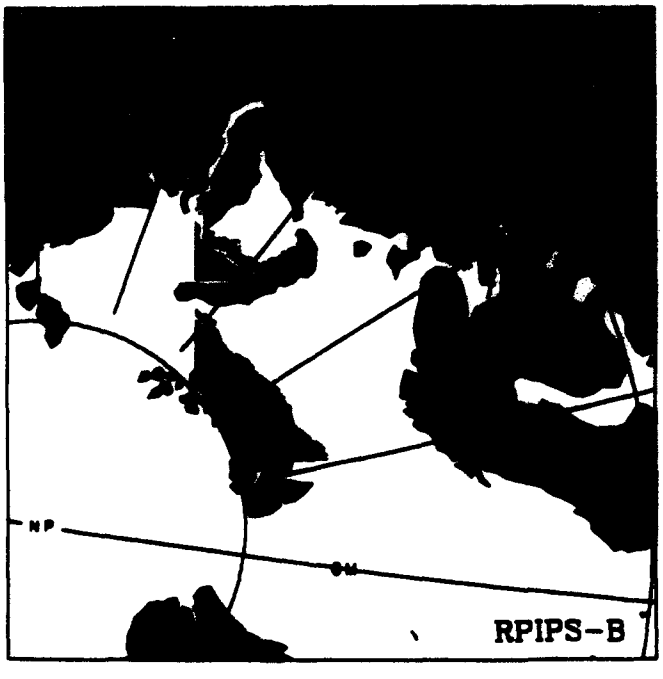

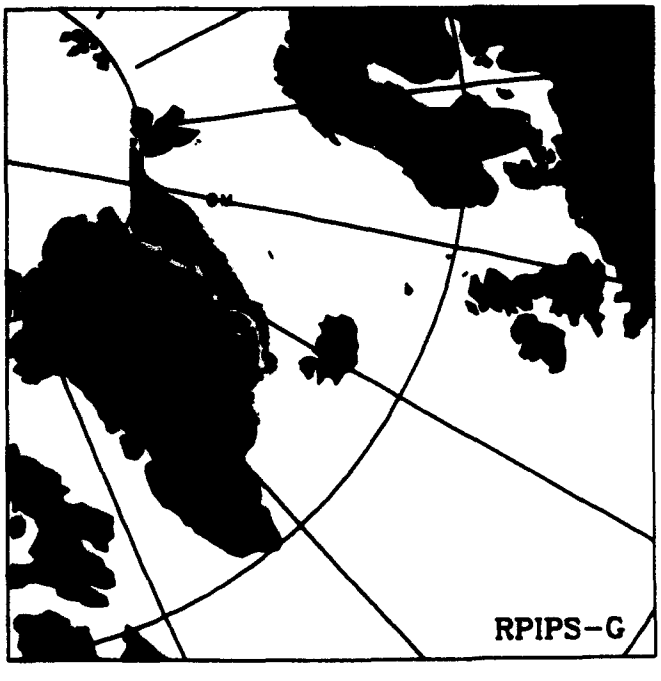

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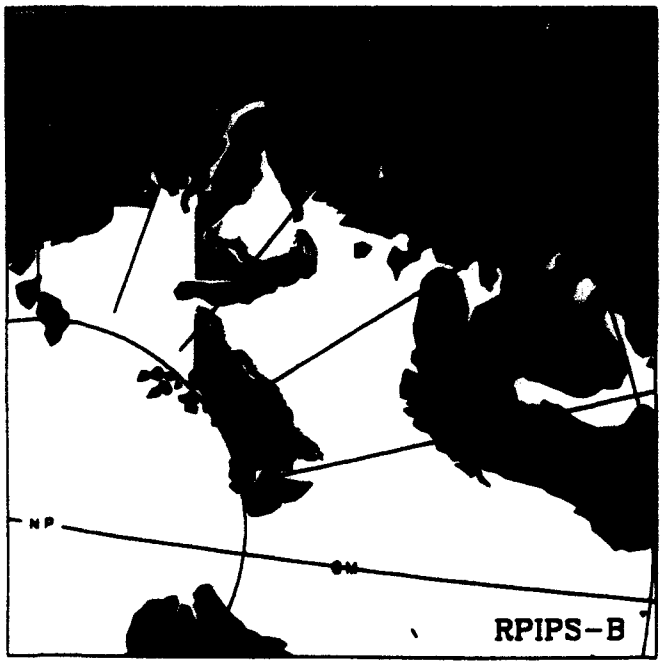

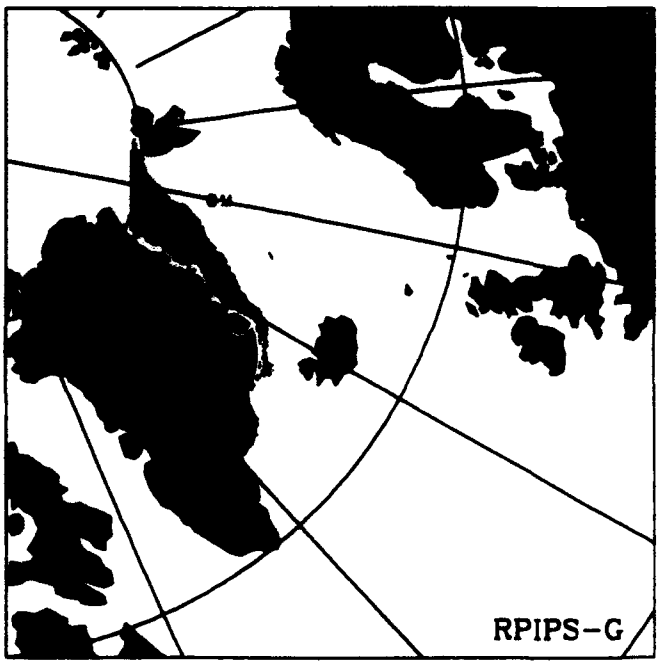

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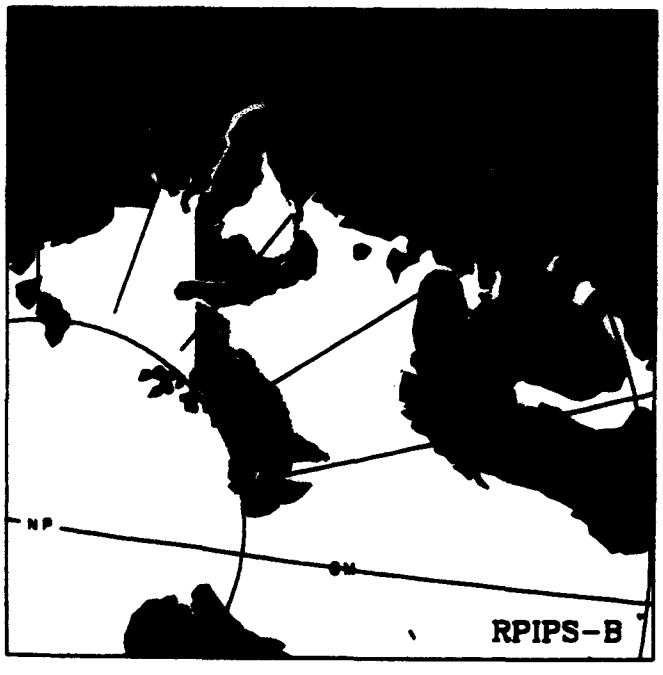

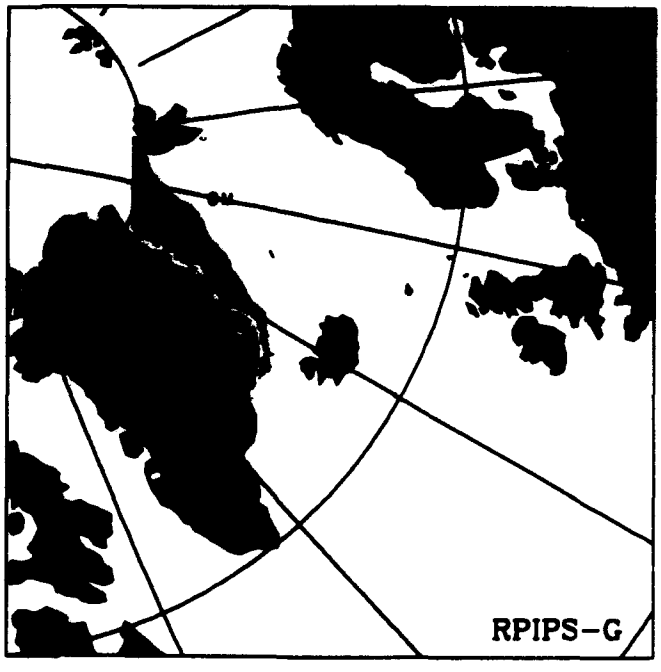

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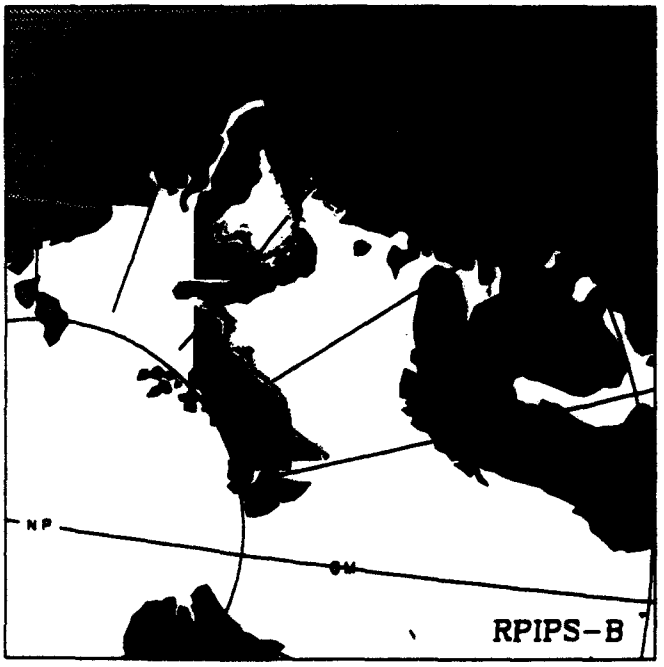

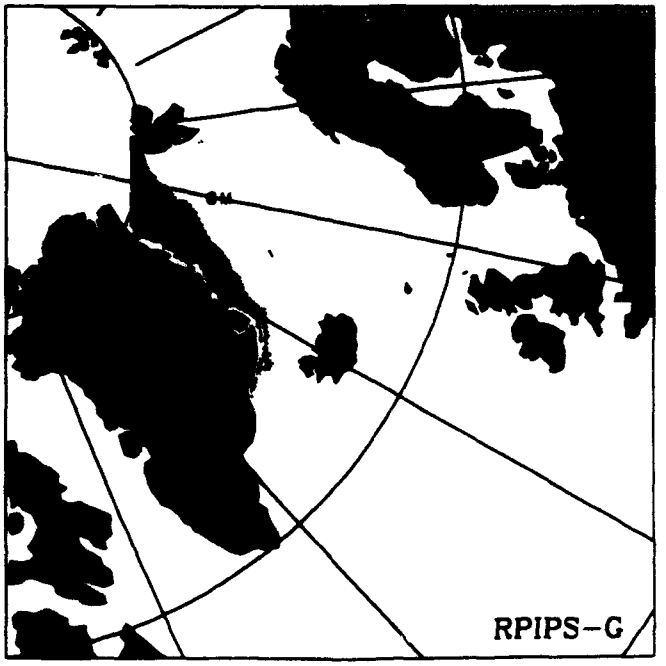

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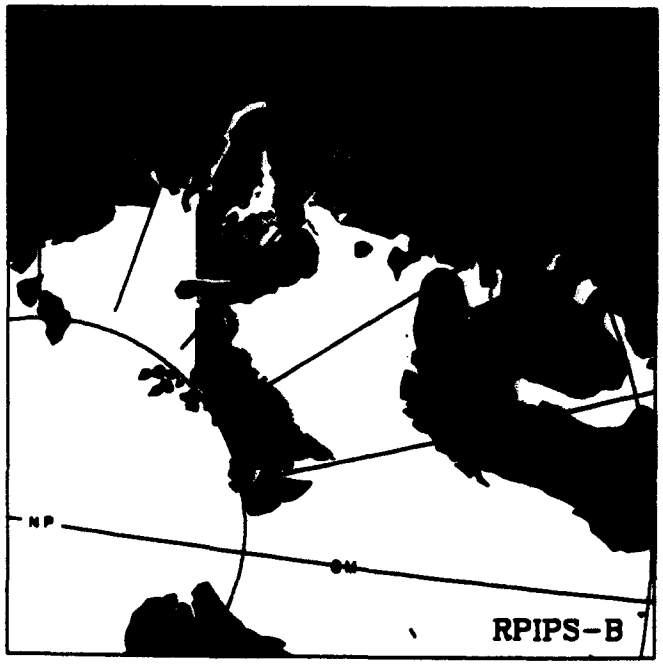

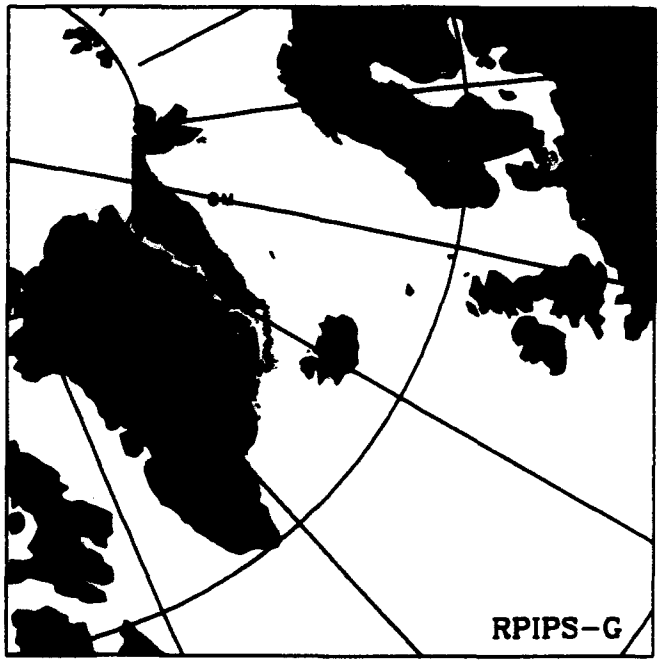

SSMI ICE CONCENTRATION 93103100

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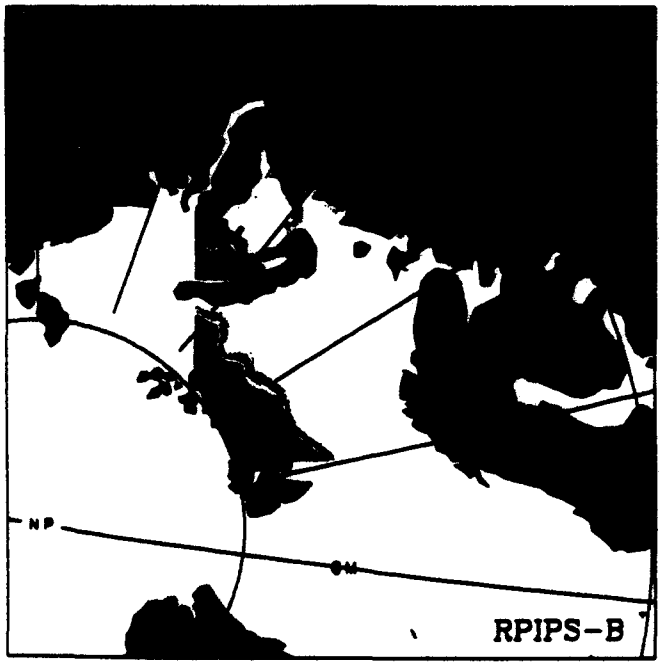

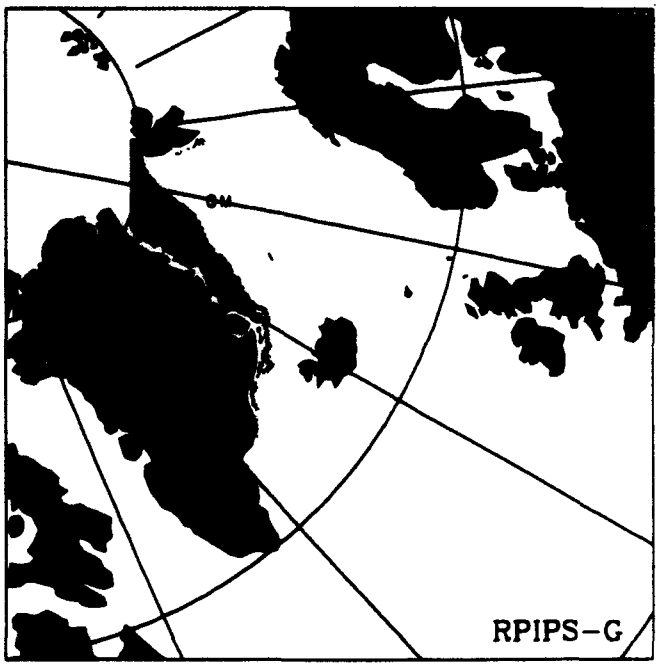

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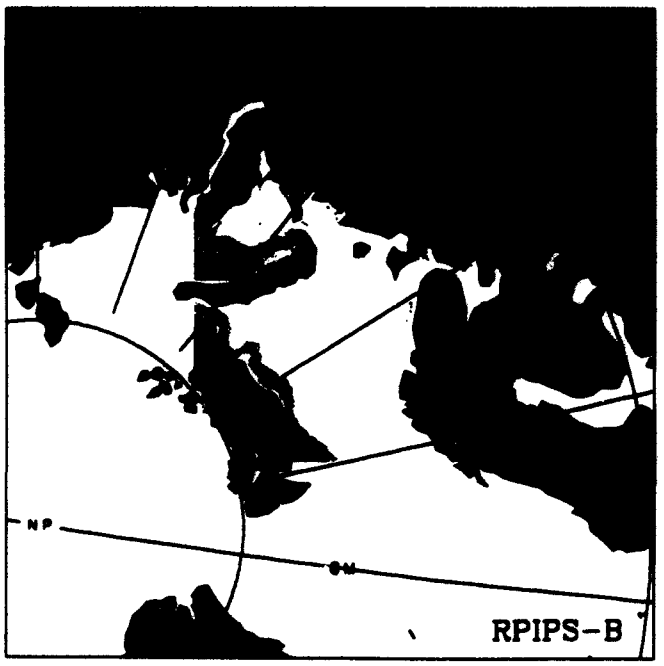

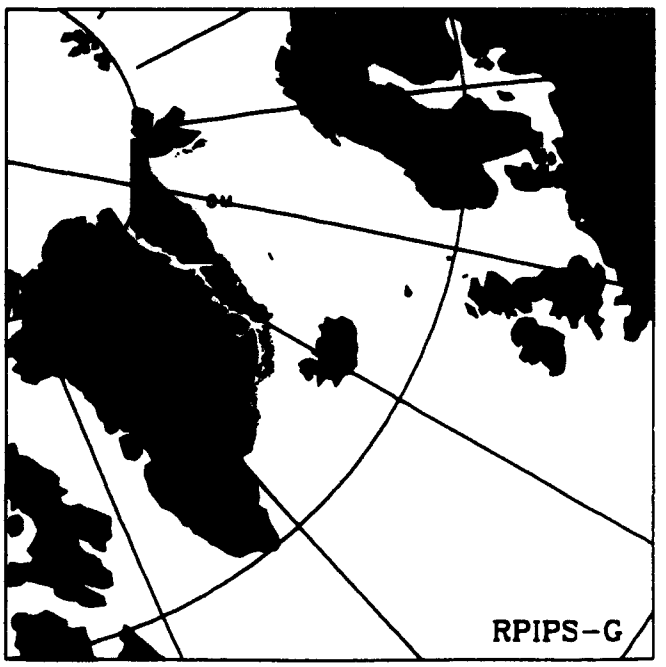

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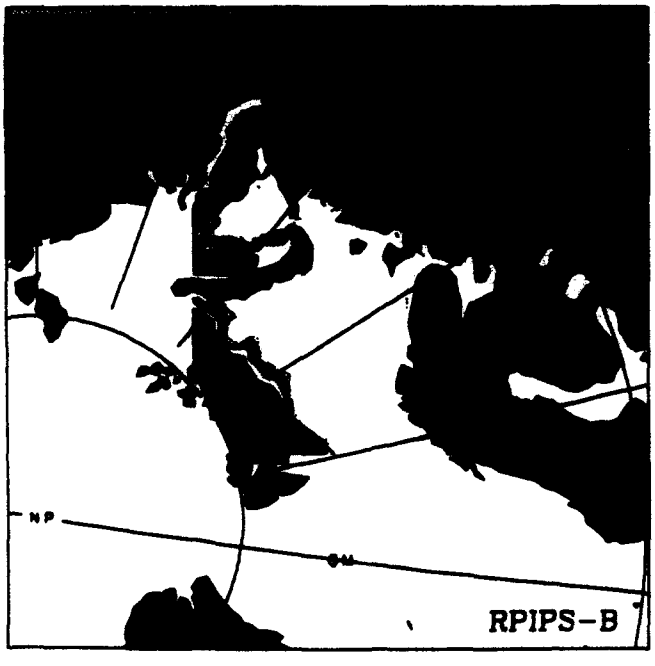

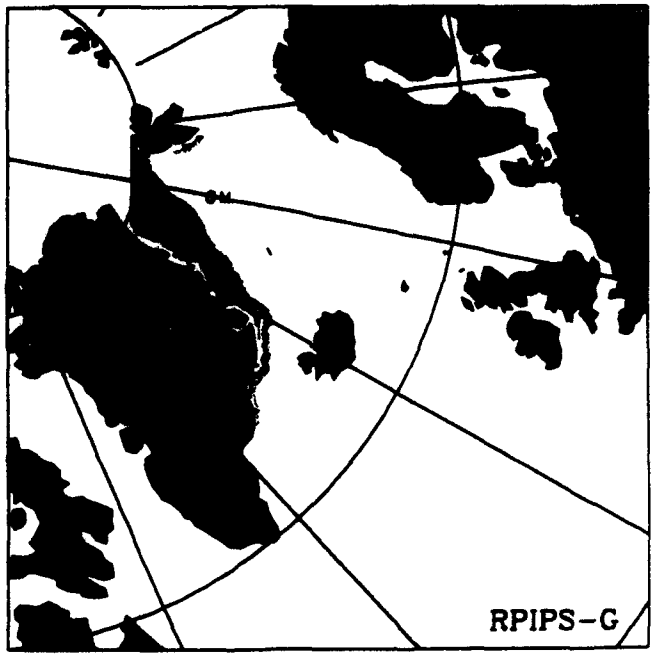

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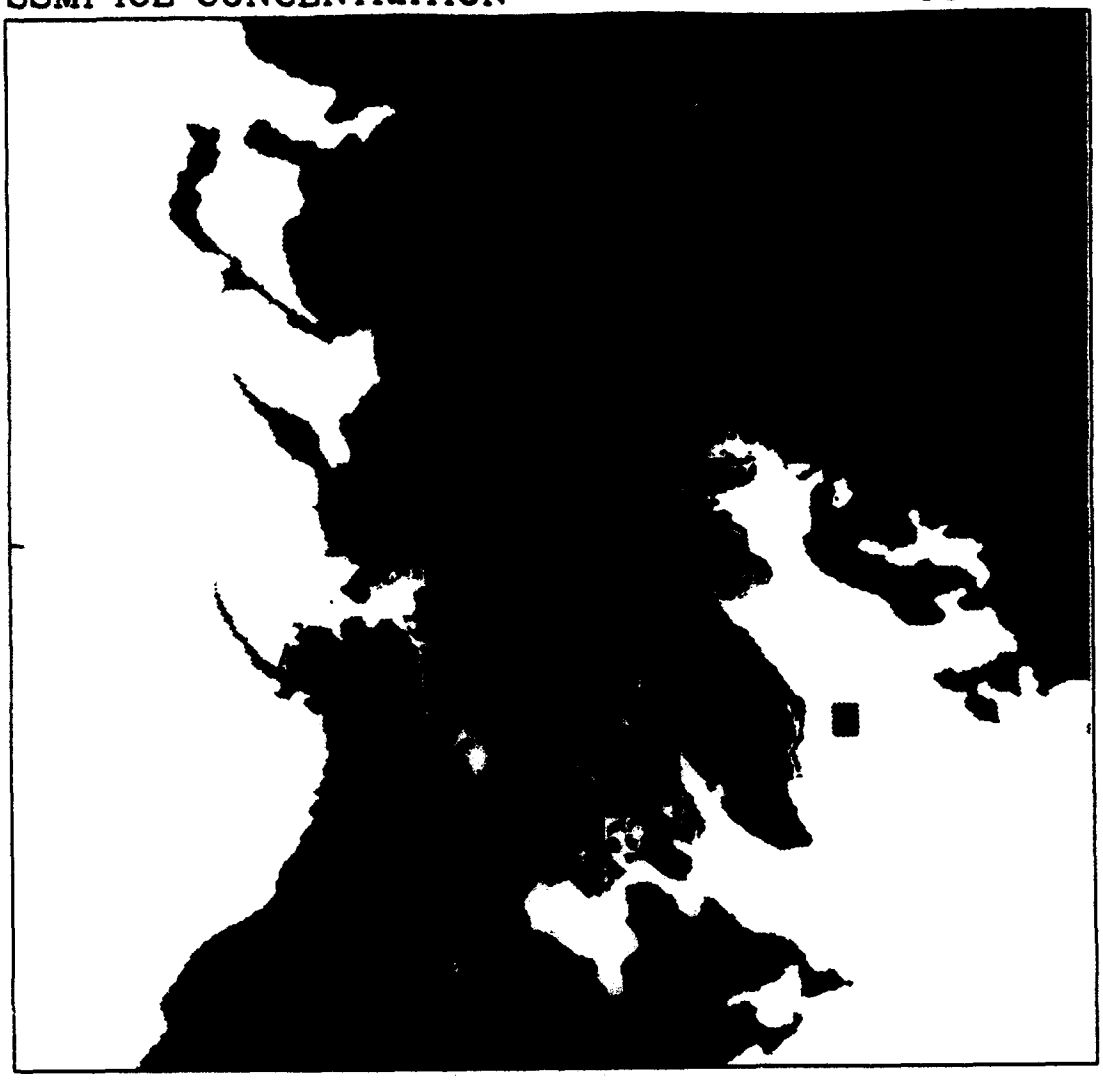

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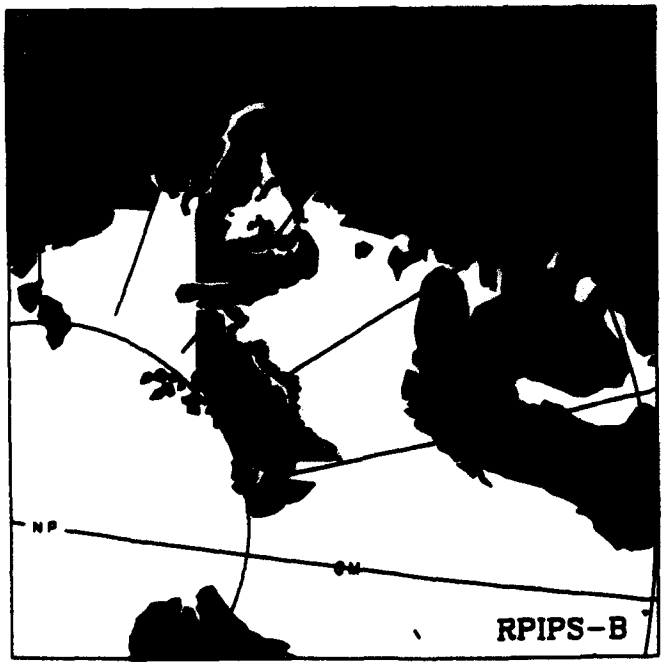

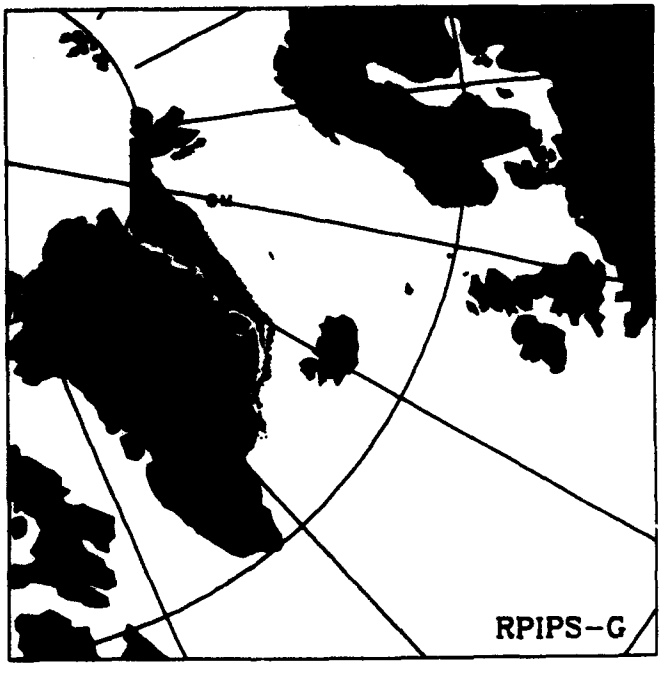

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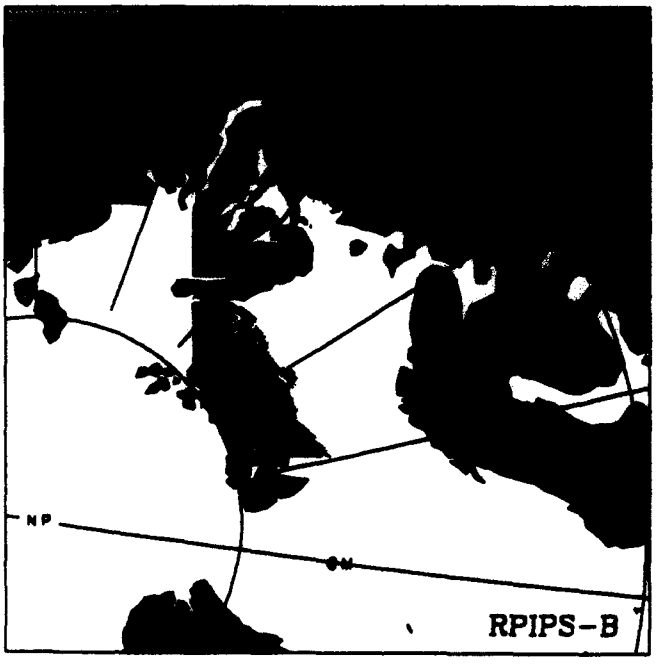

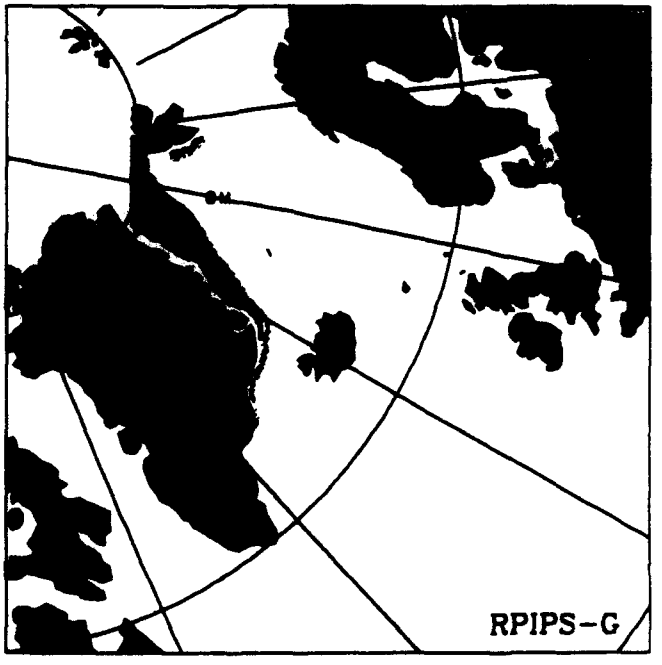

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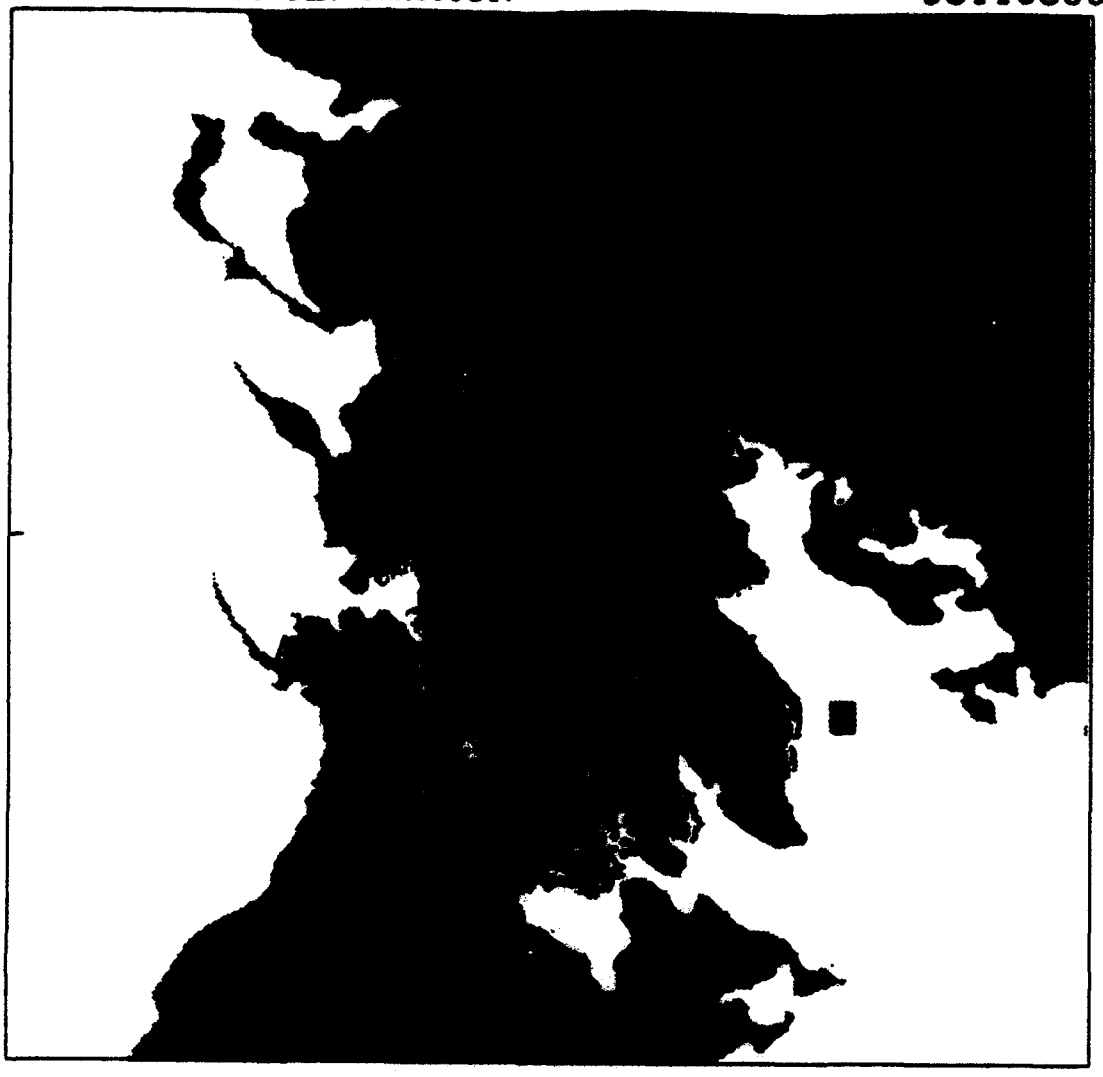

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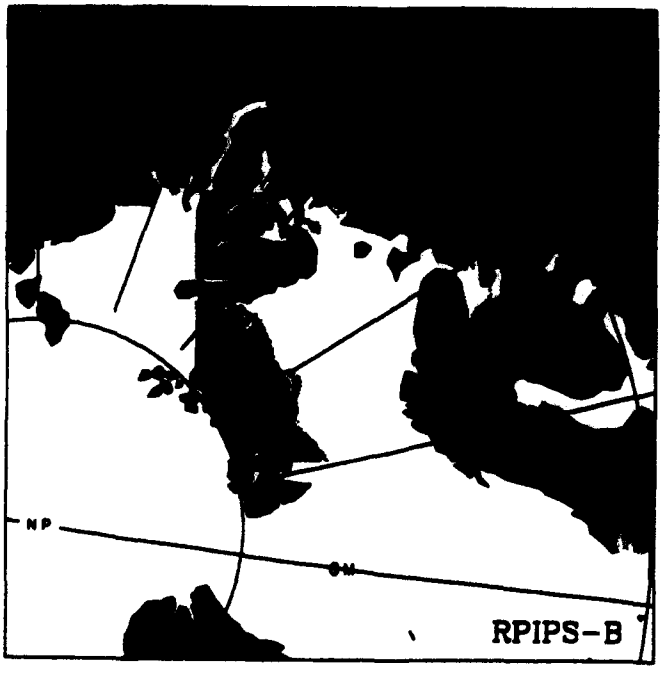

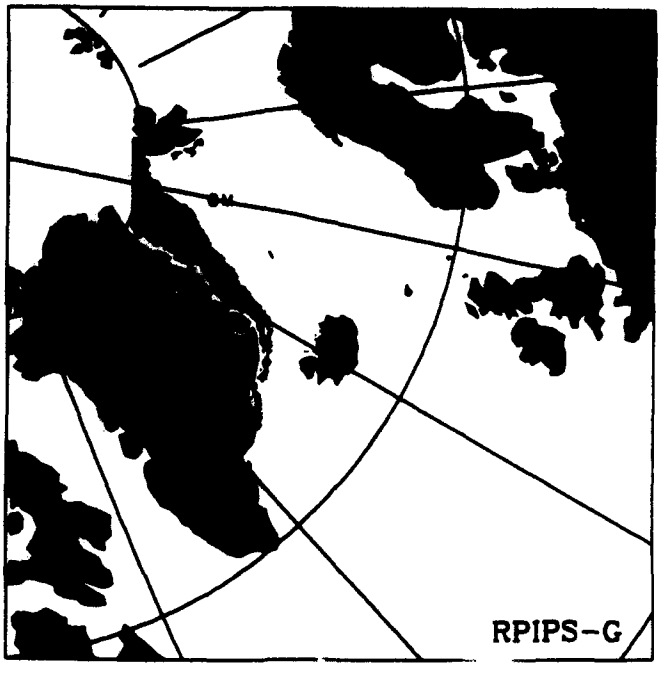

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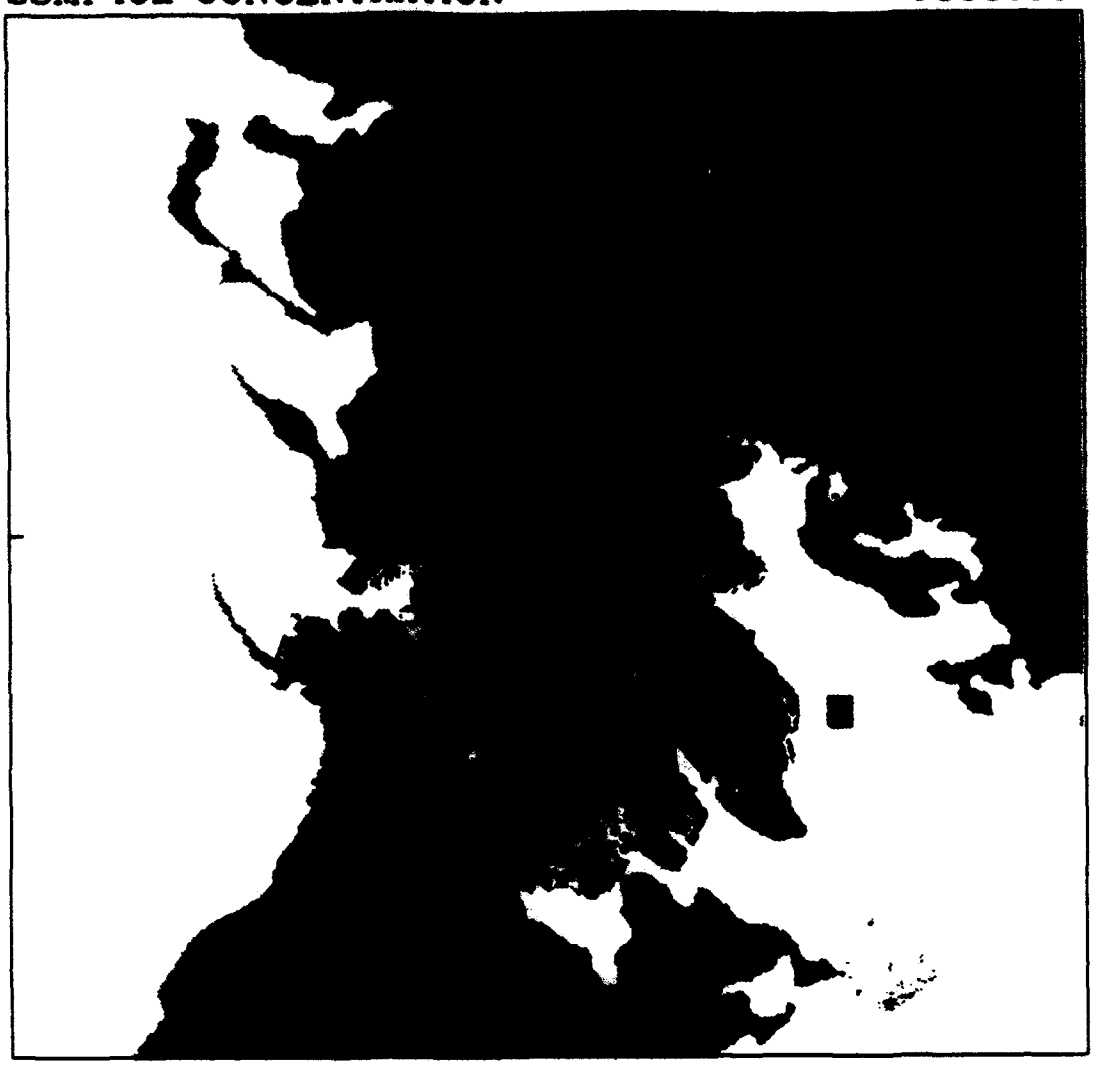

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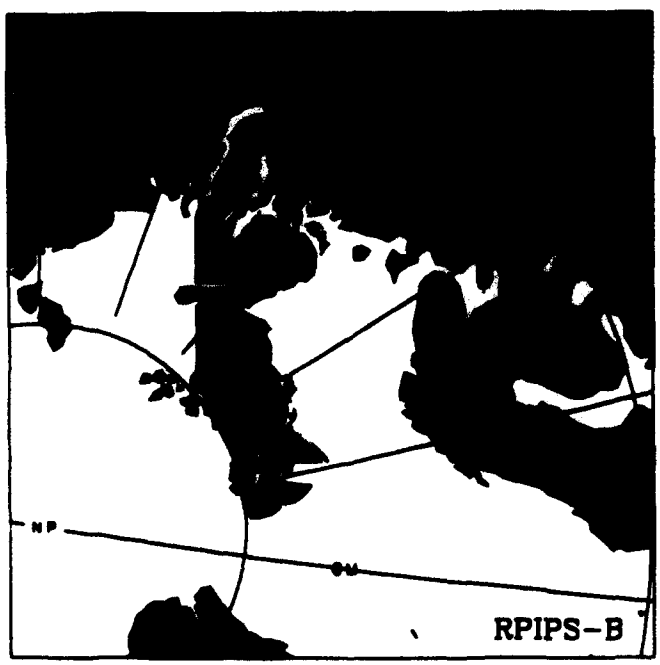

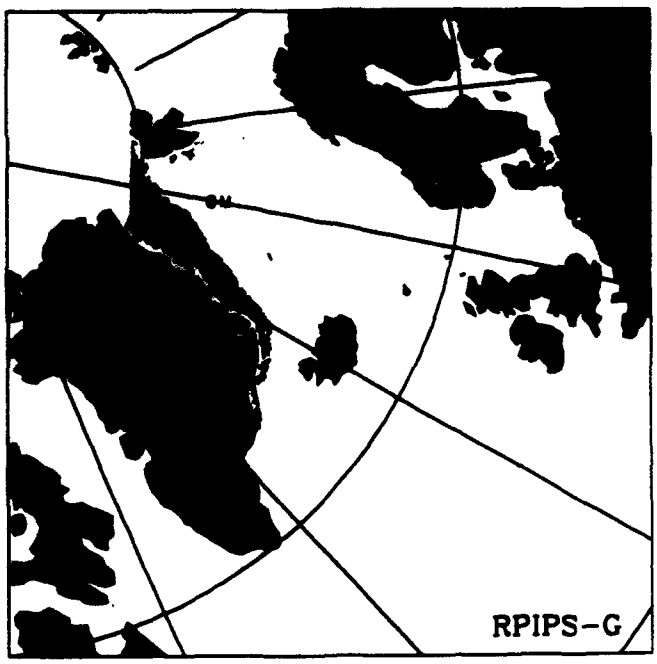

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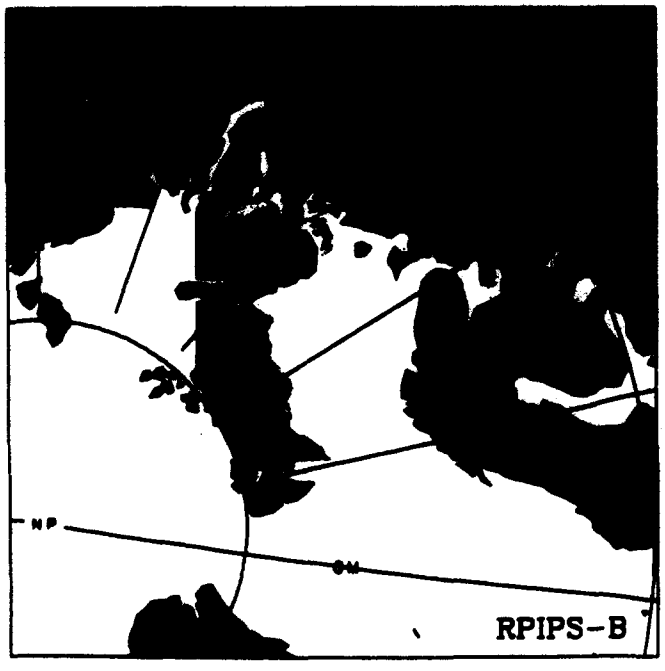

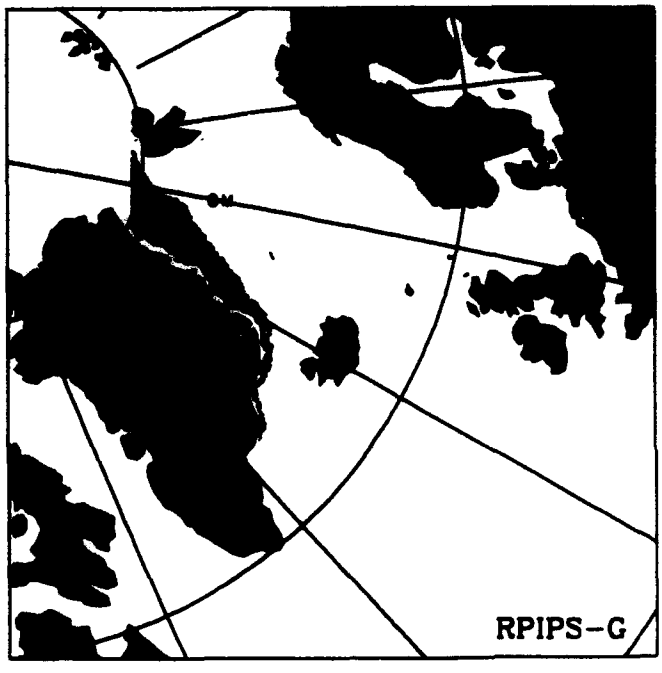

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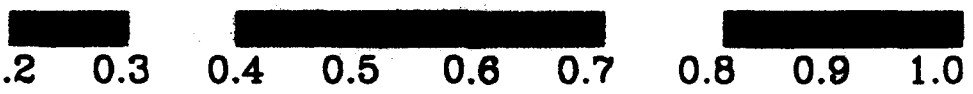

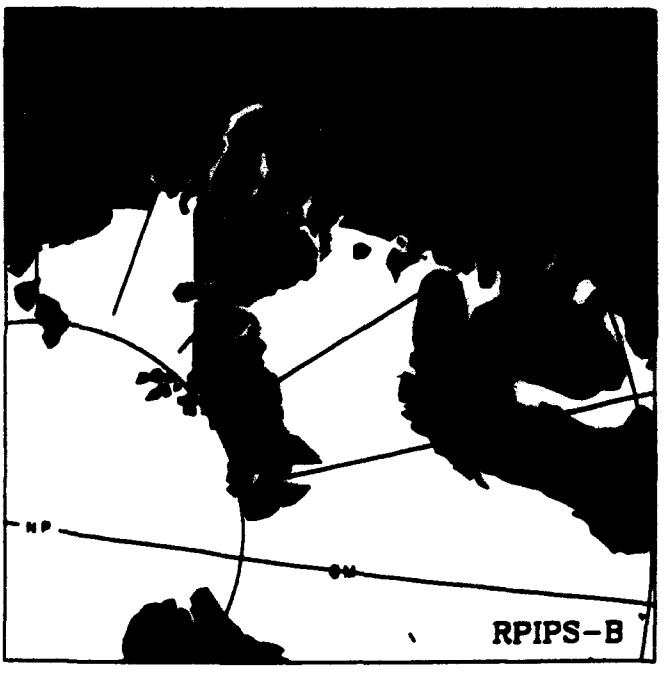

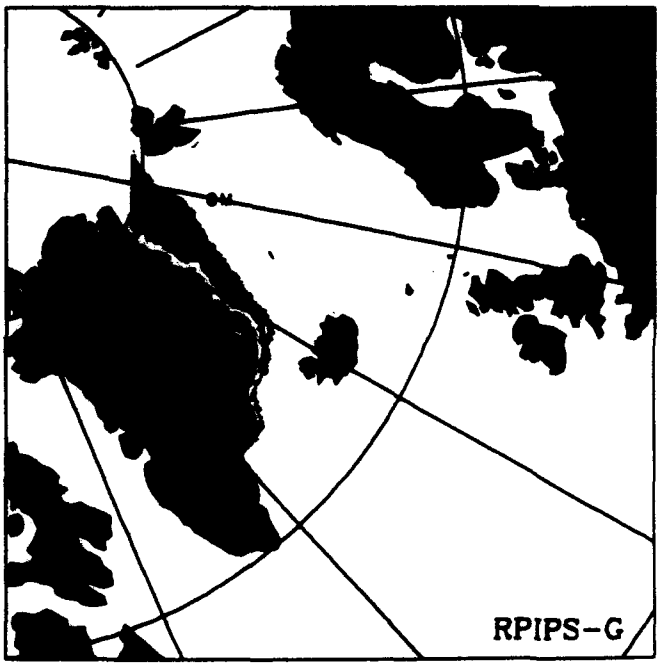

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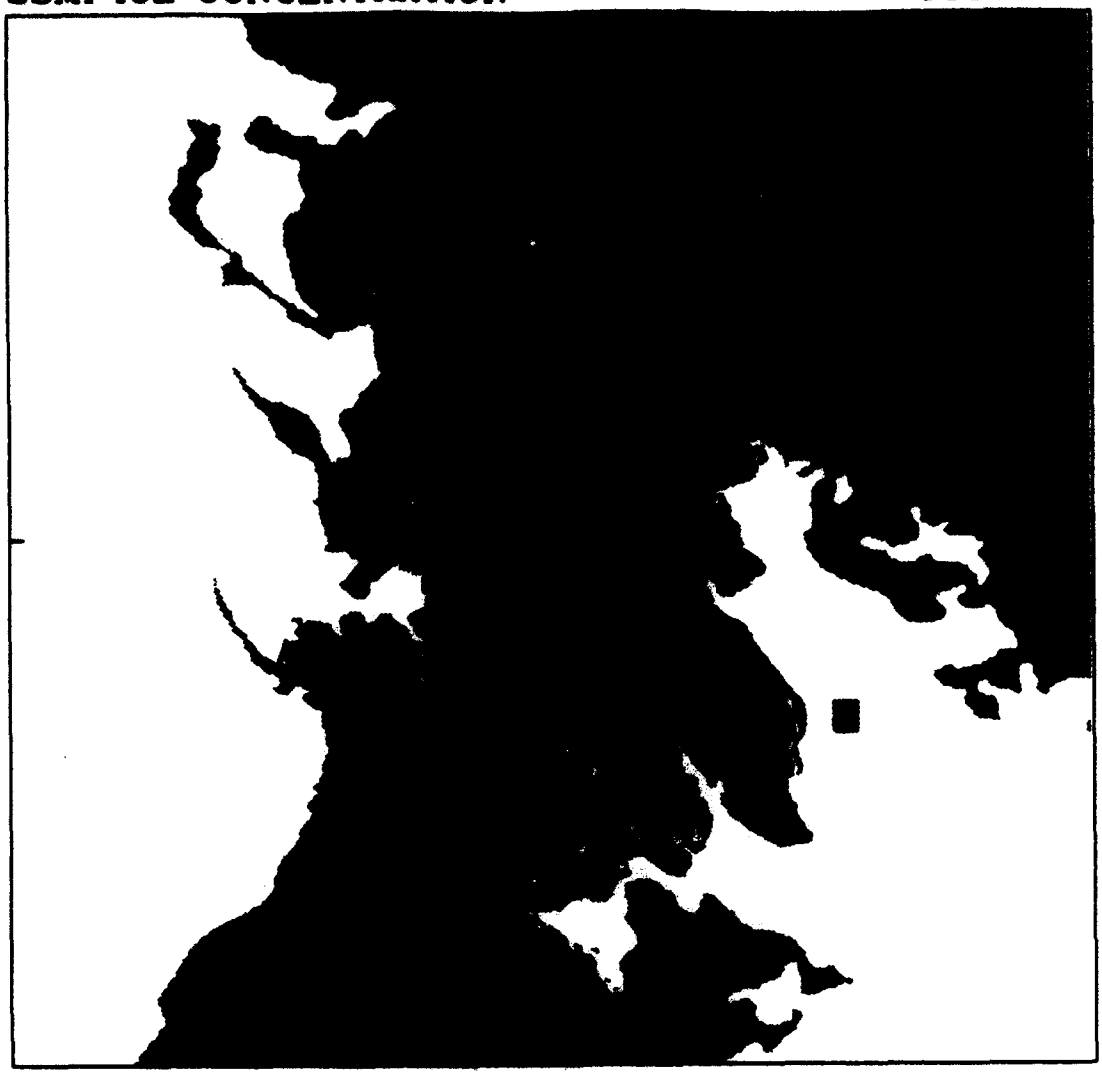
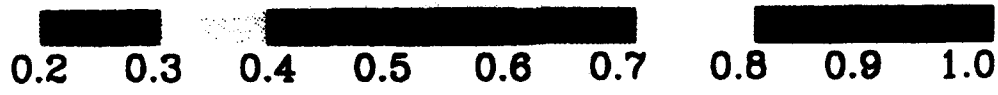
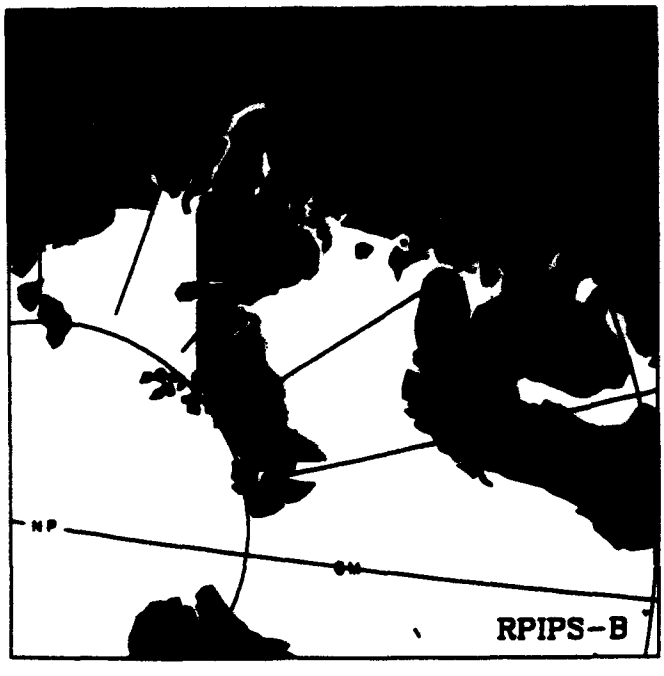
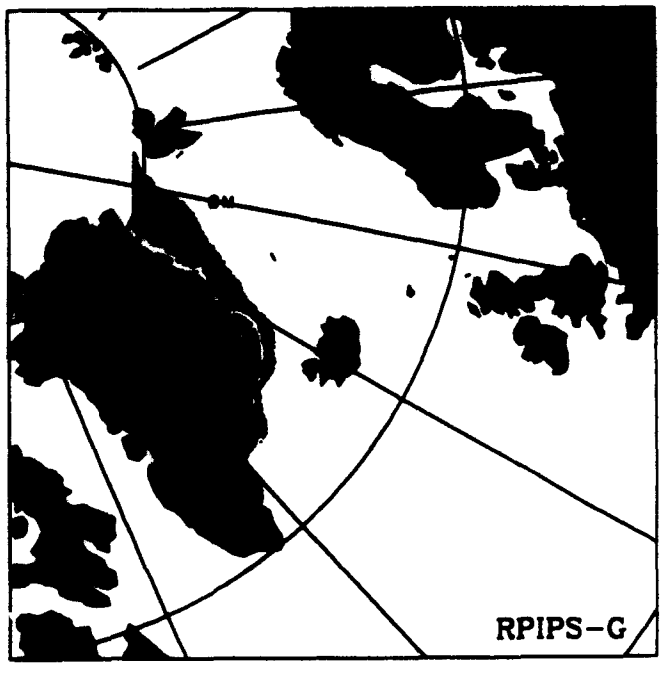
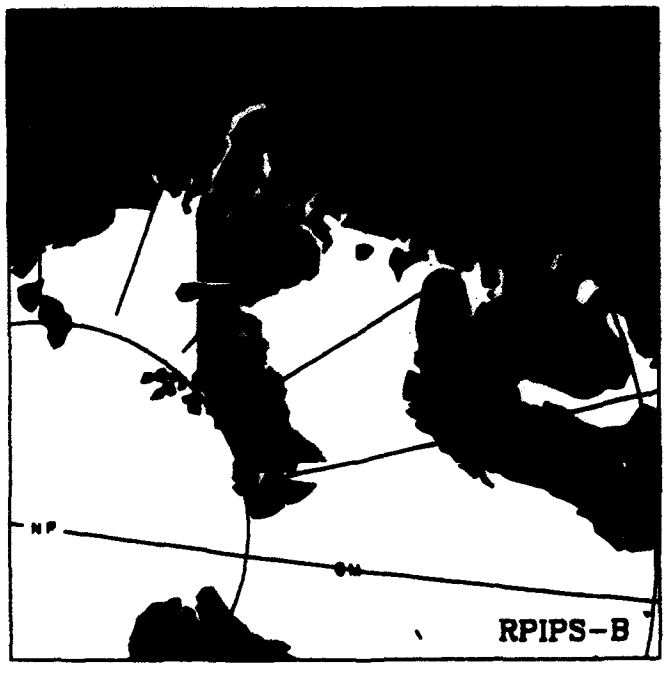


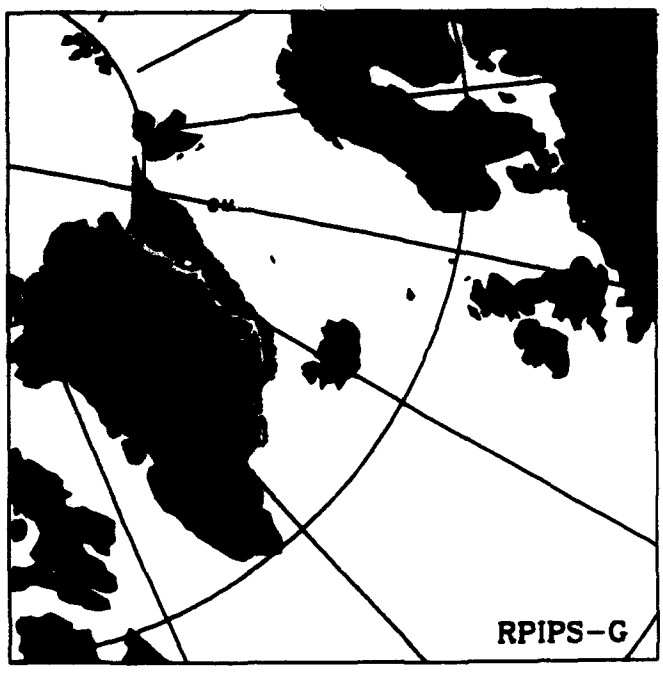






SSMI ICE CONCENTRATION 93111000





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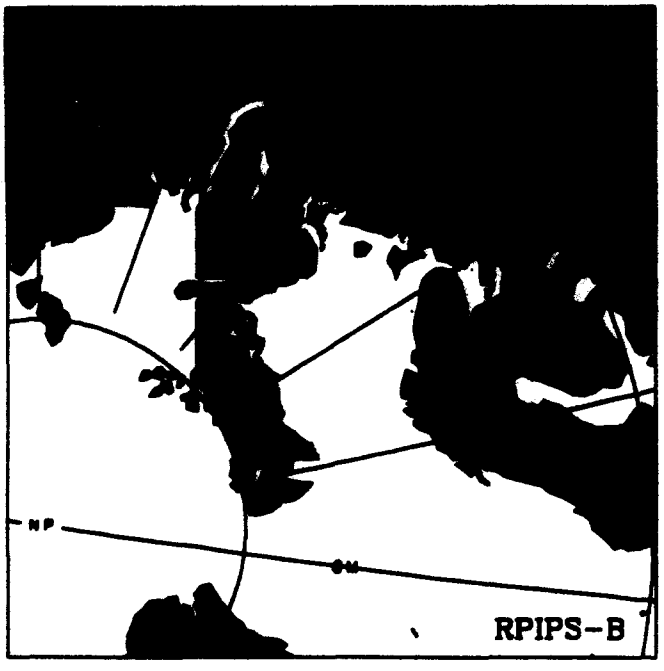

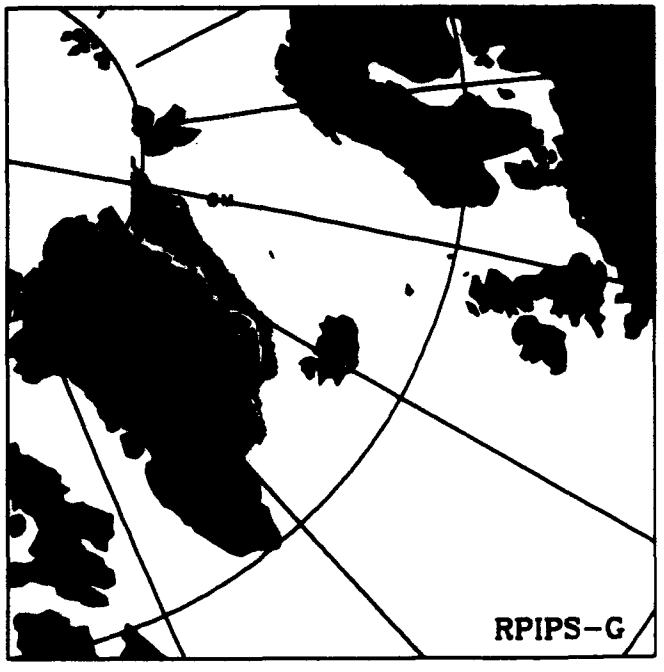

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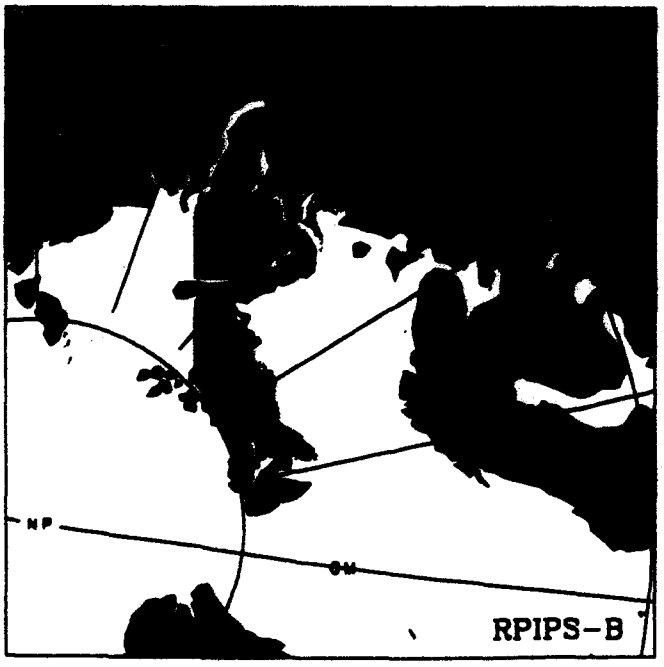

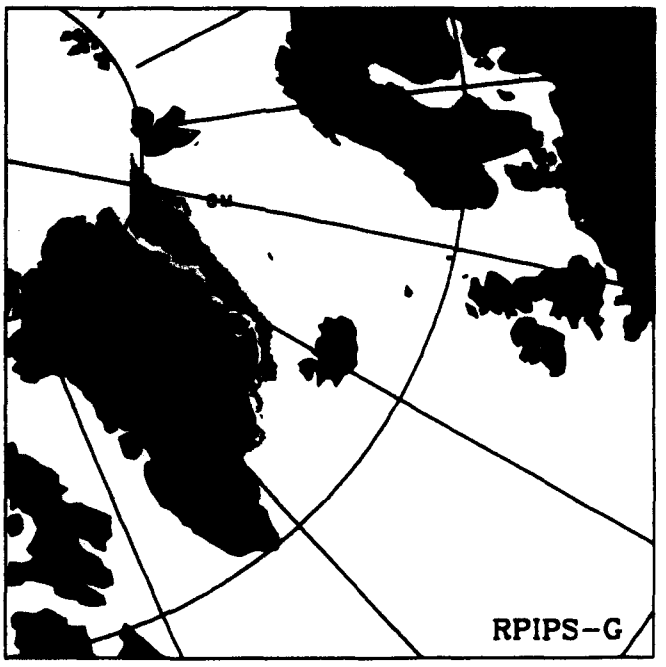

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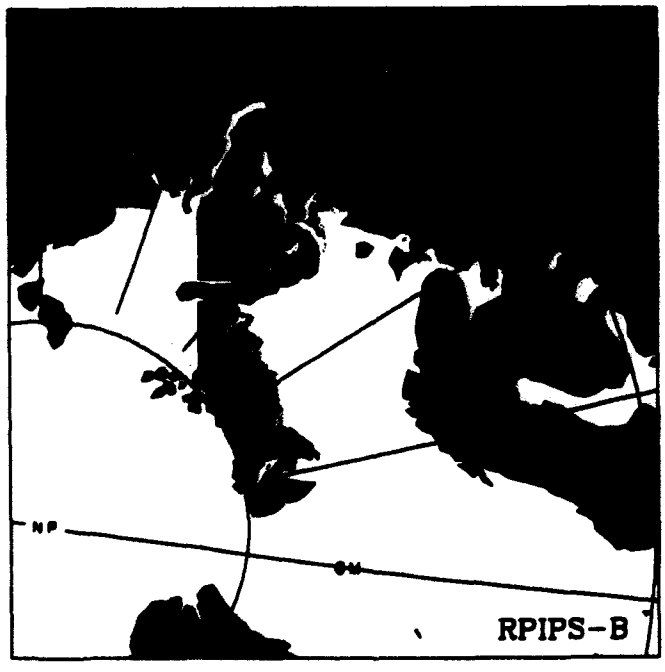

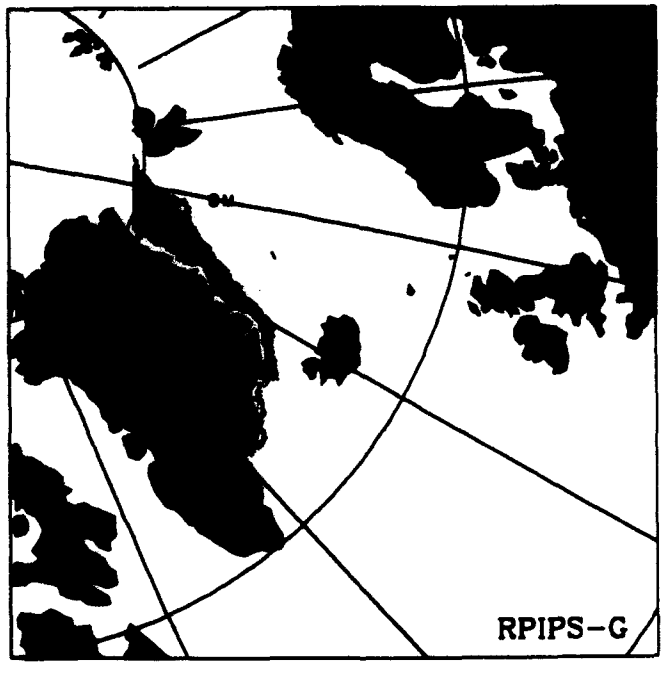

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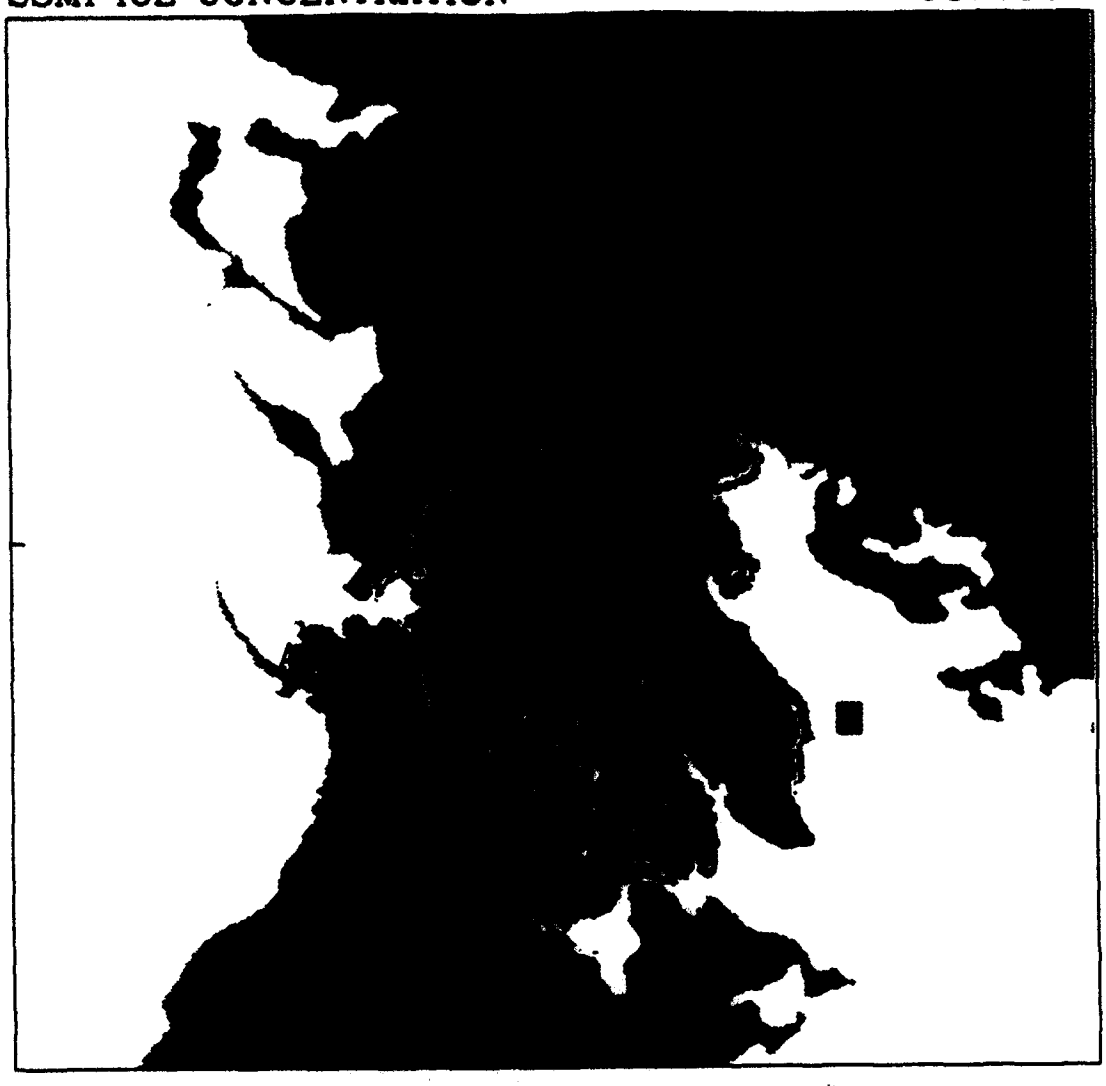

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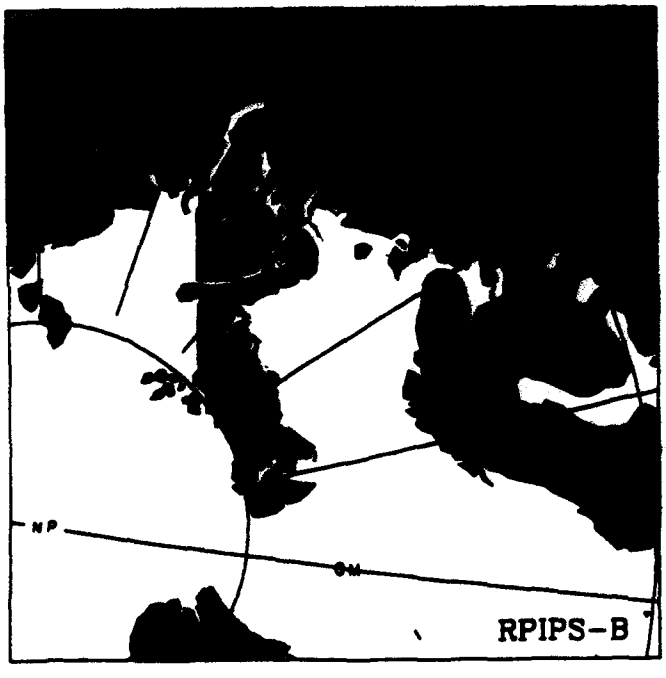

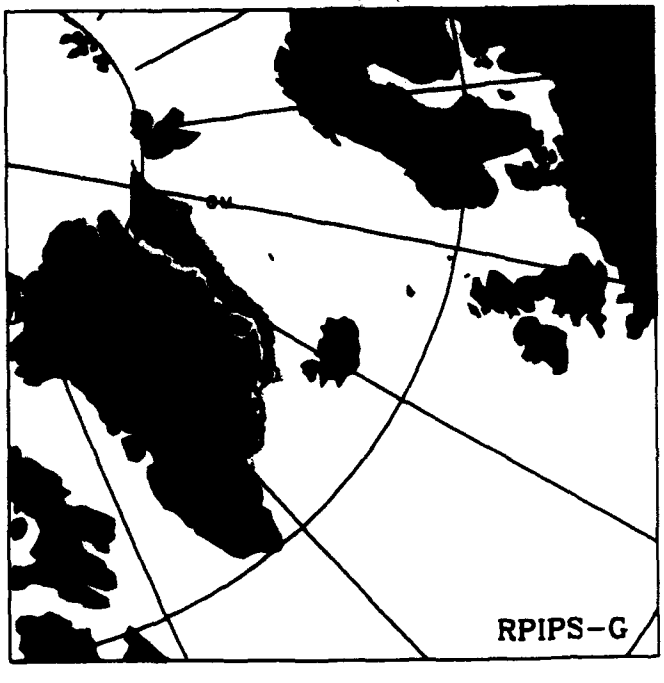

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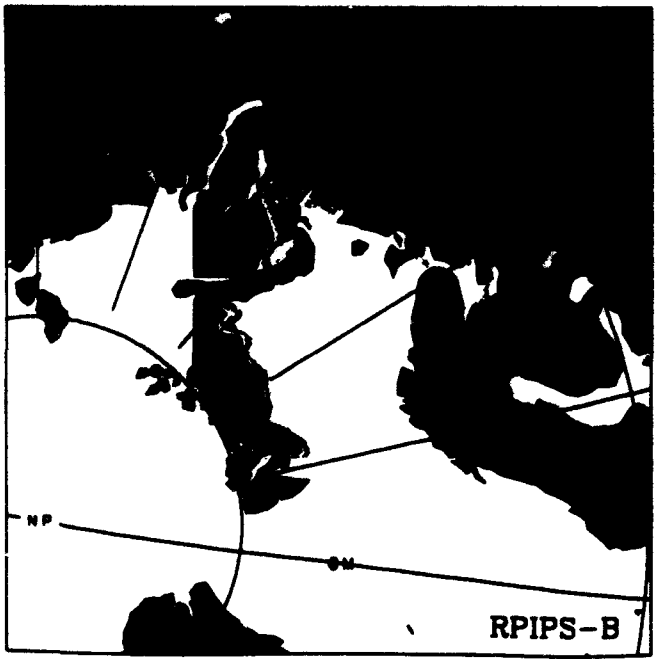

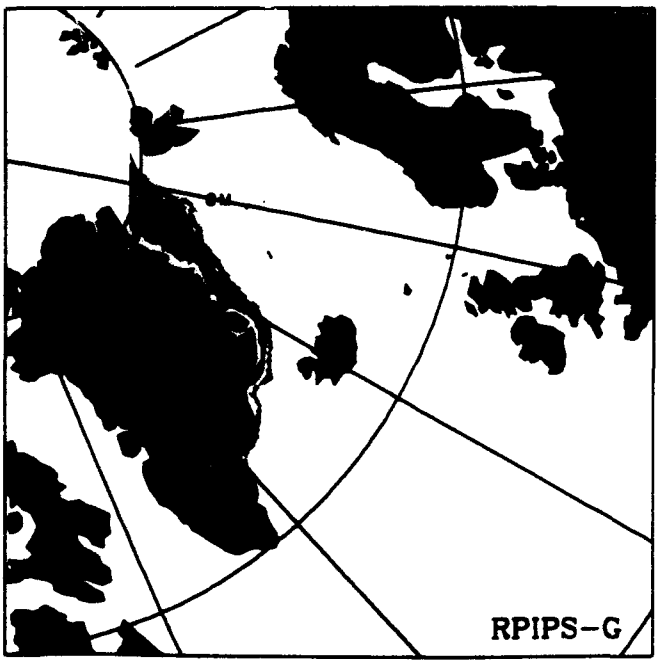

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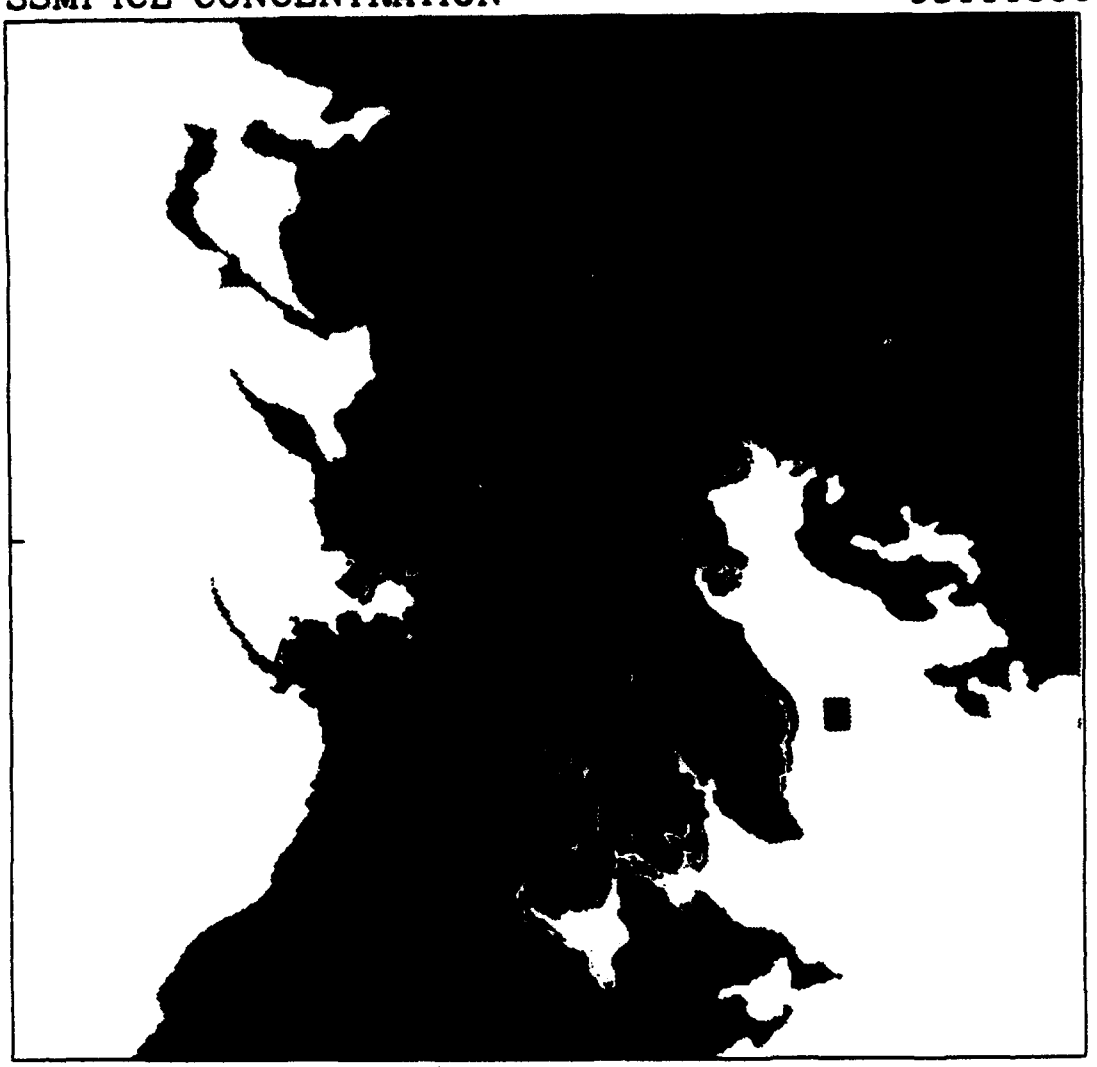

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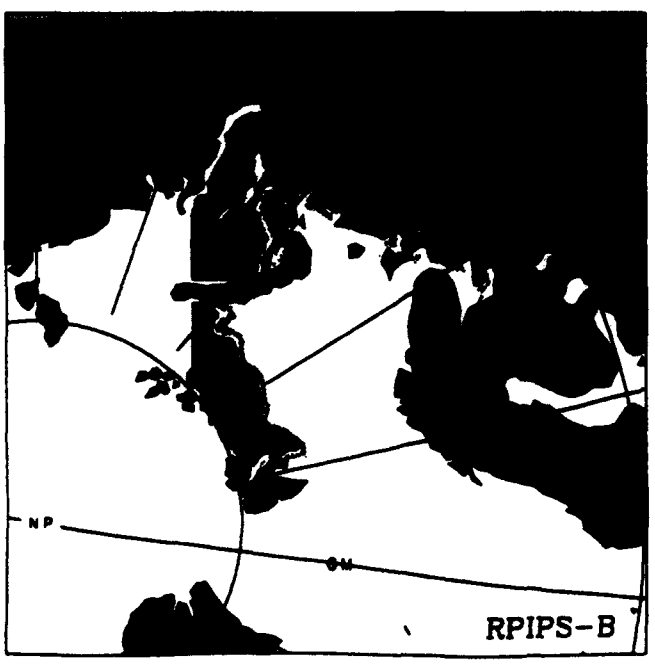

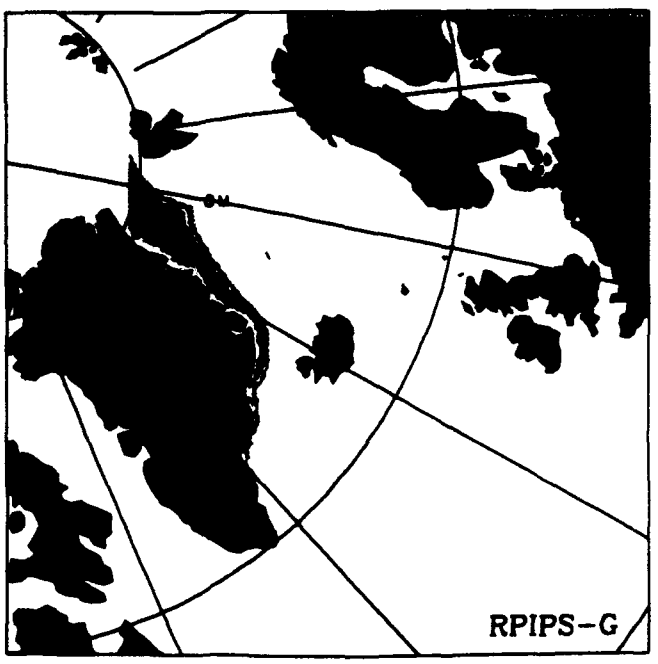

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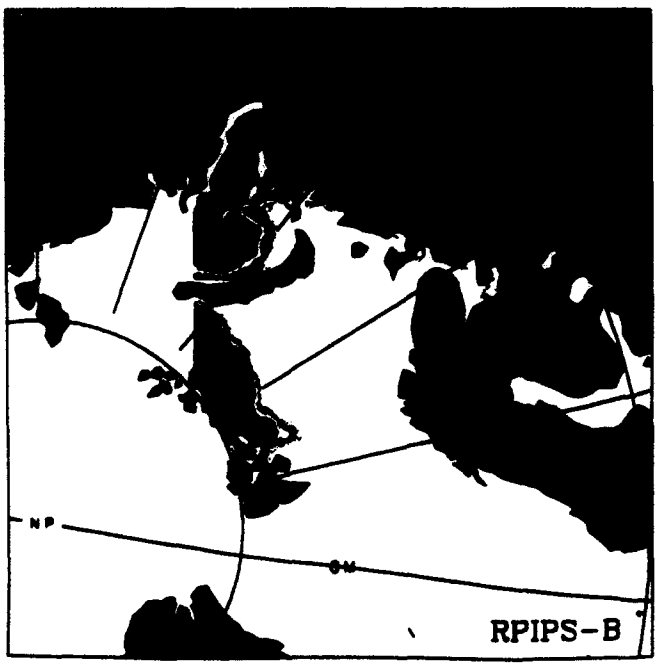

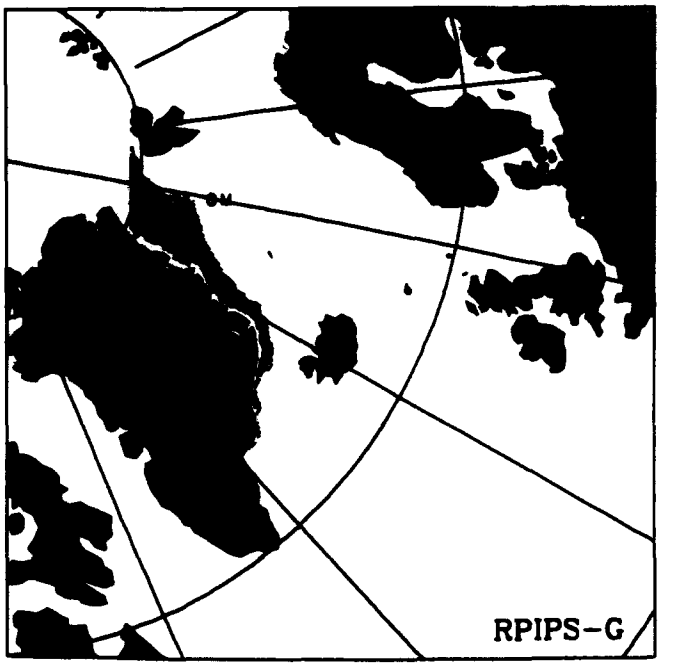

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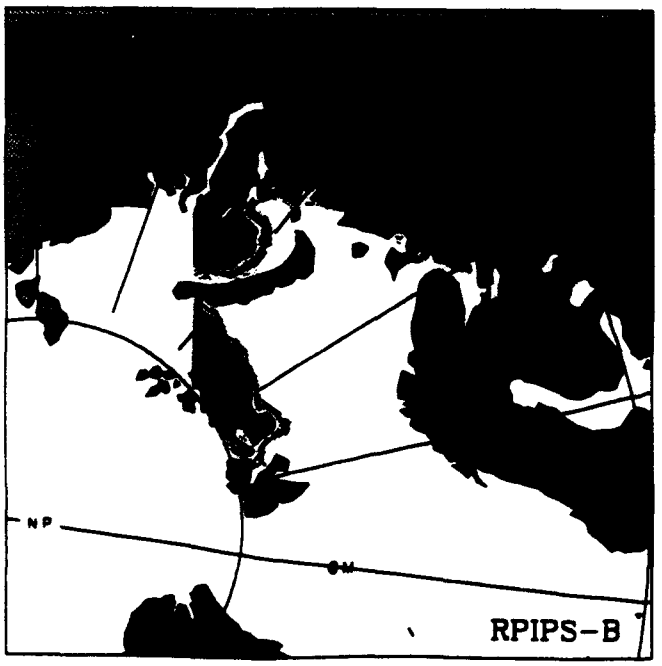

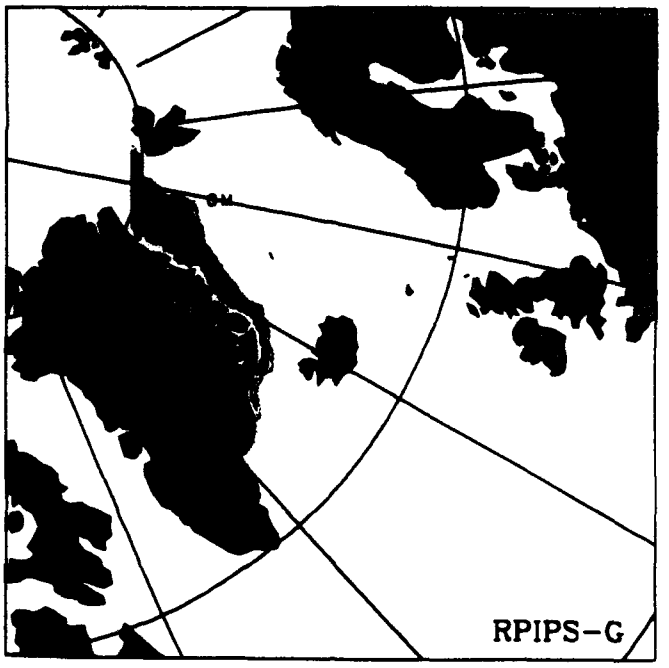

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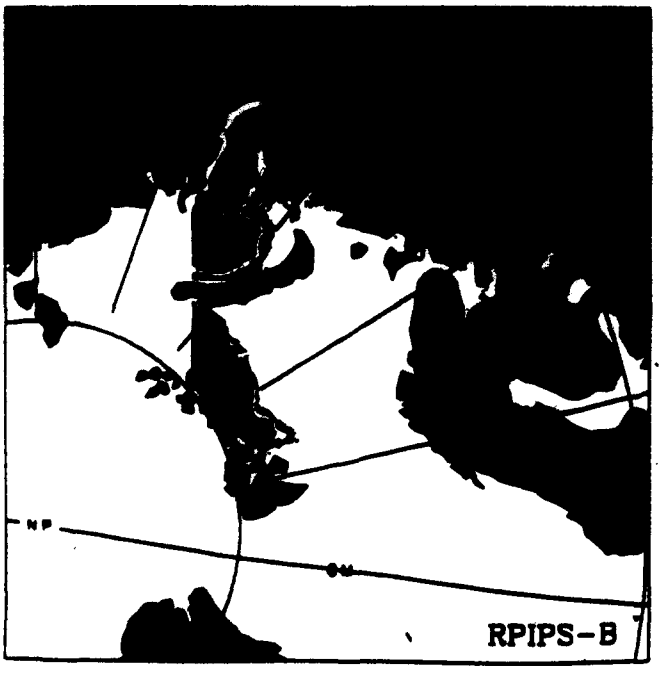

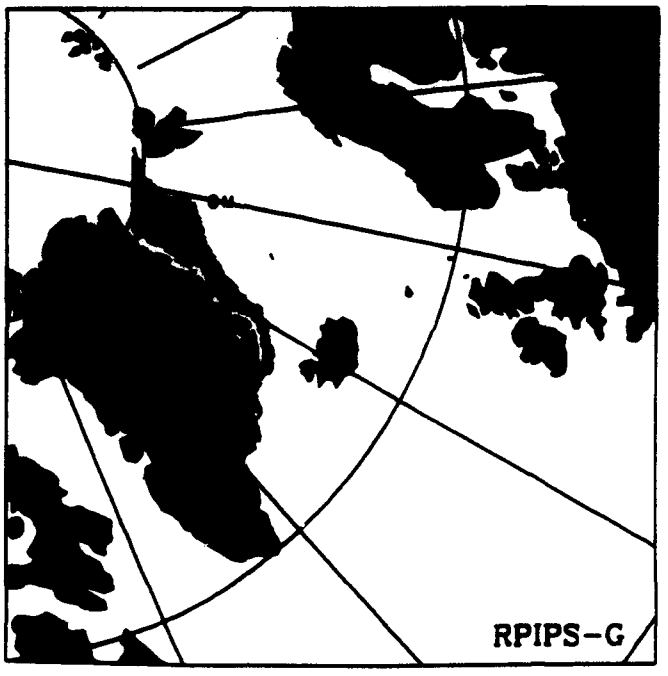

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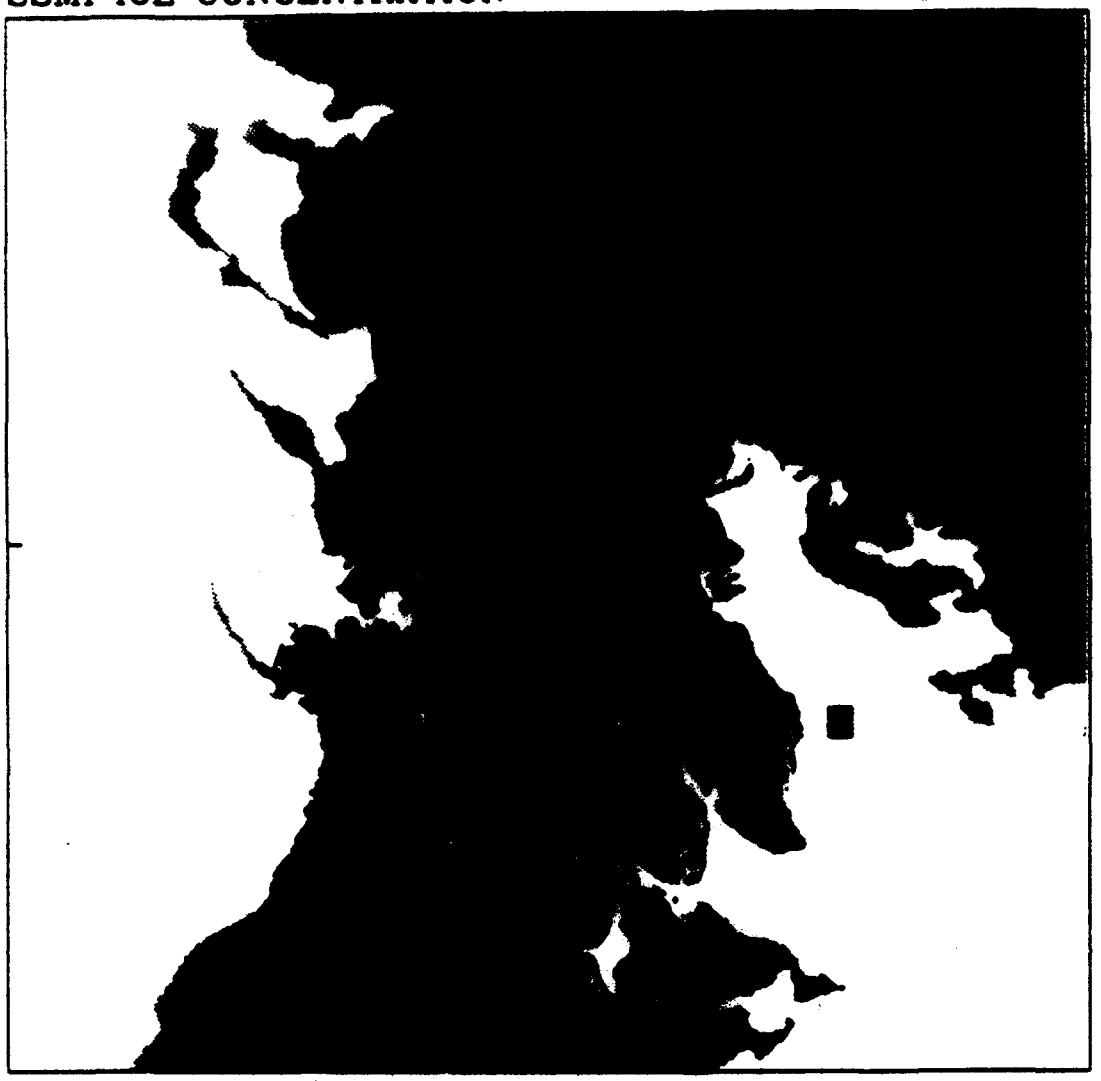

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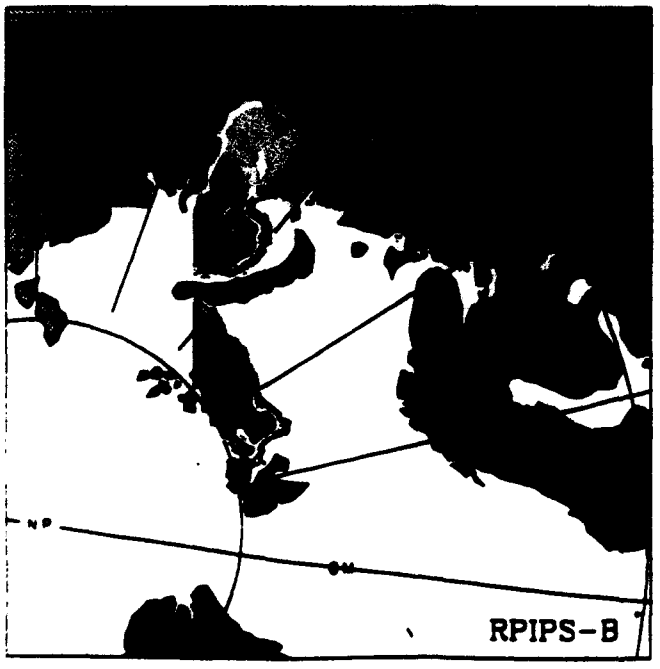

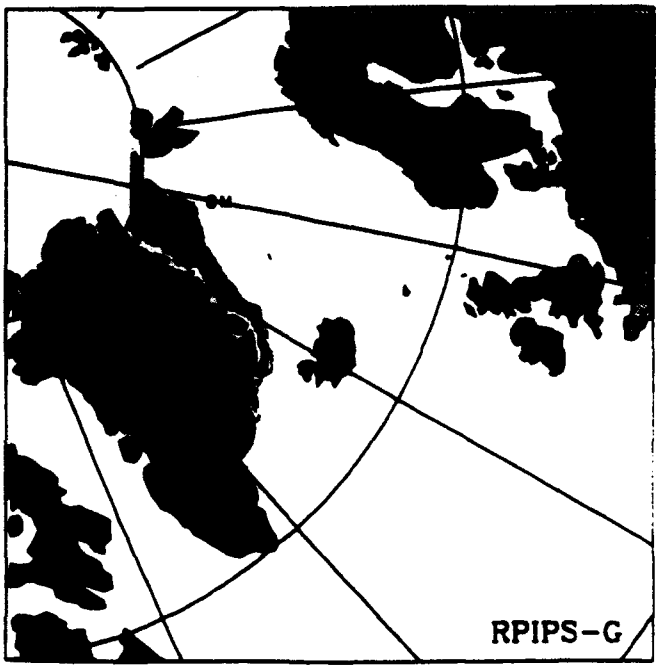

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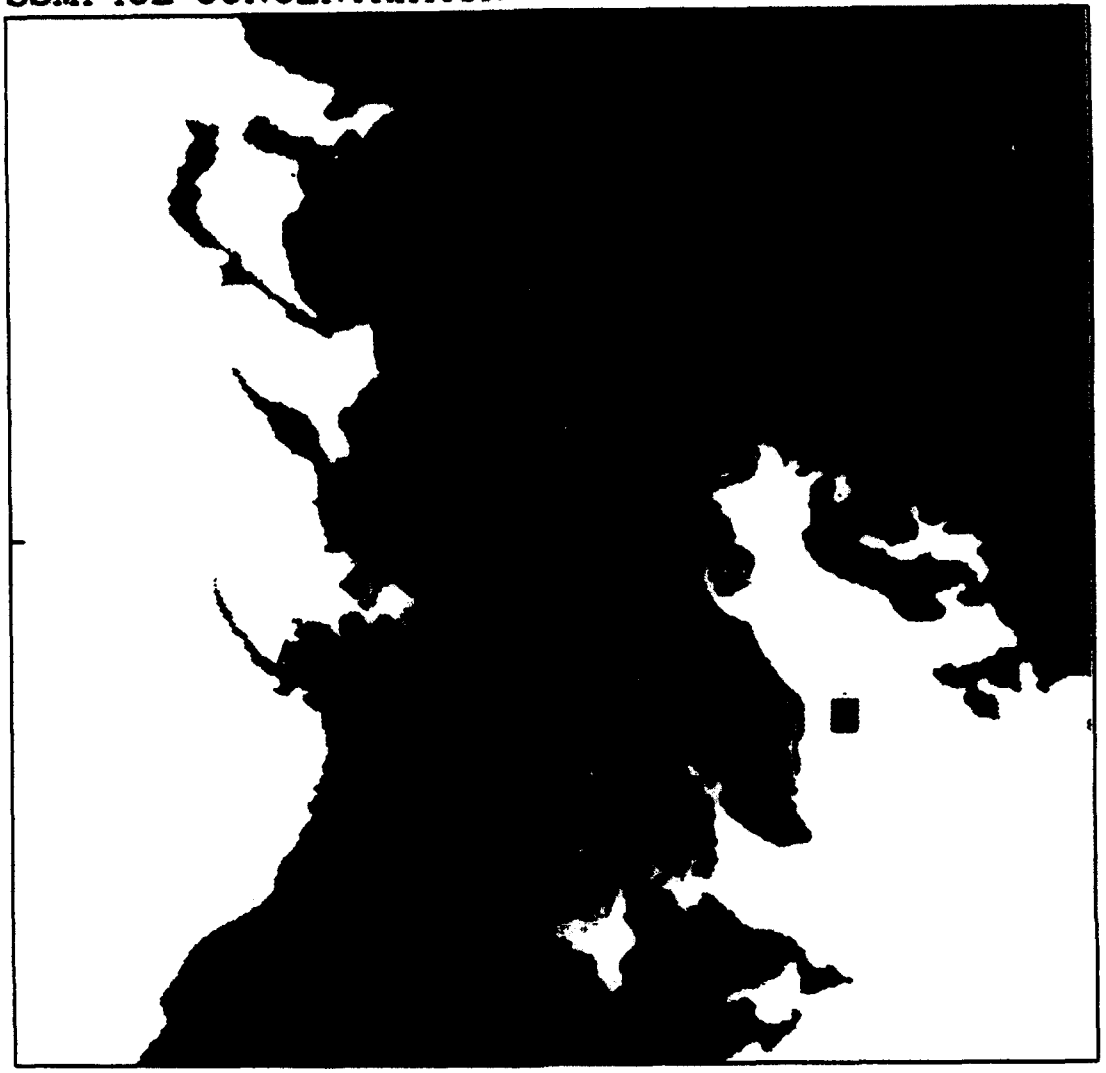

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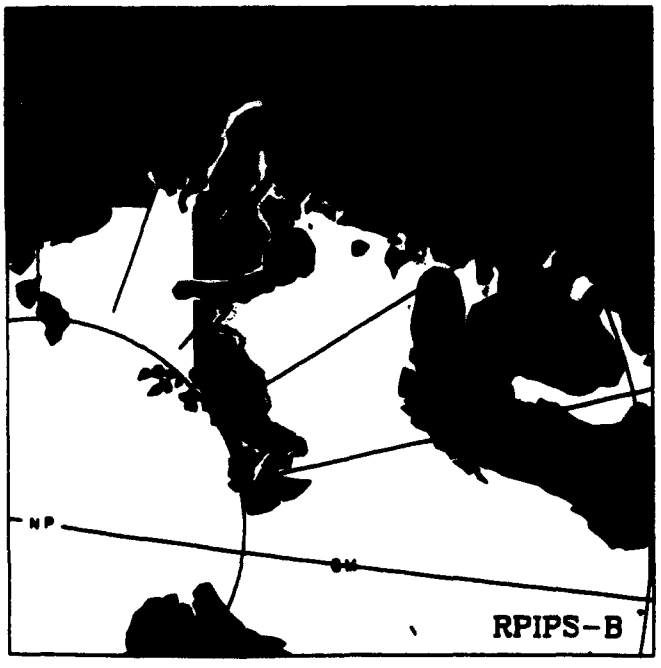
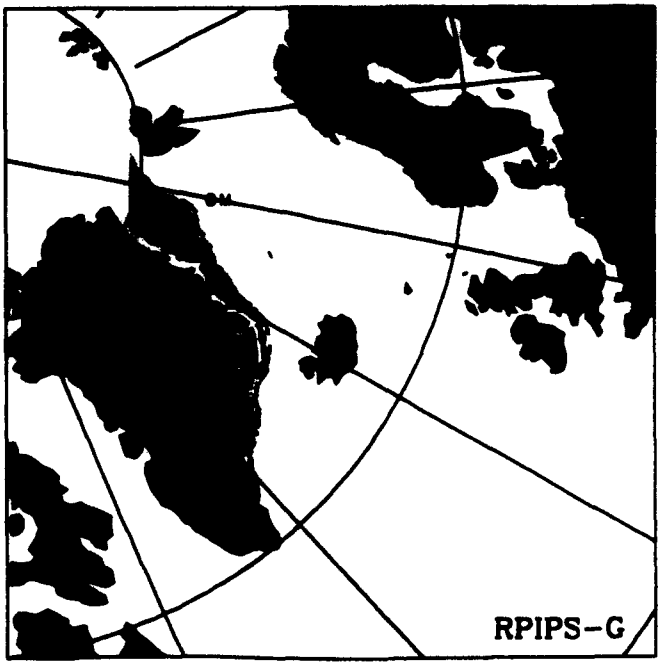
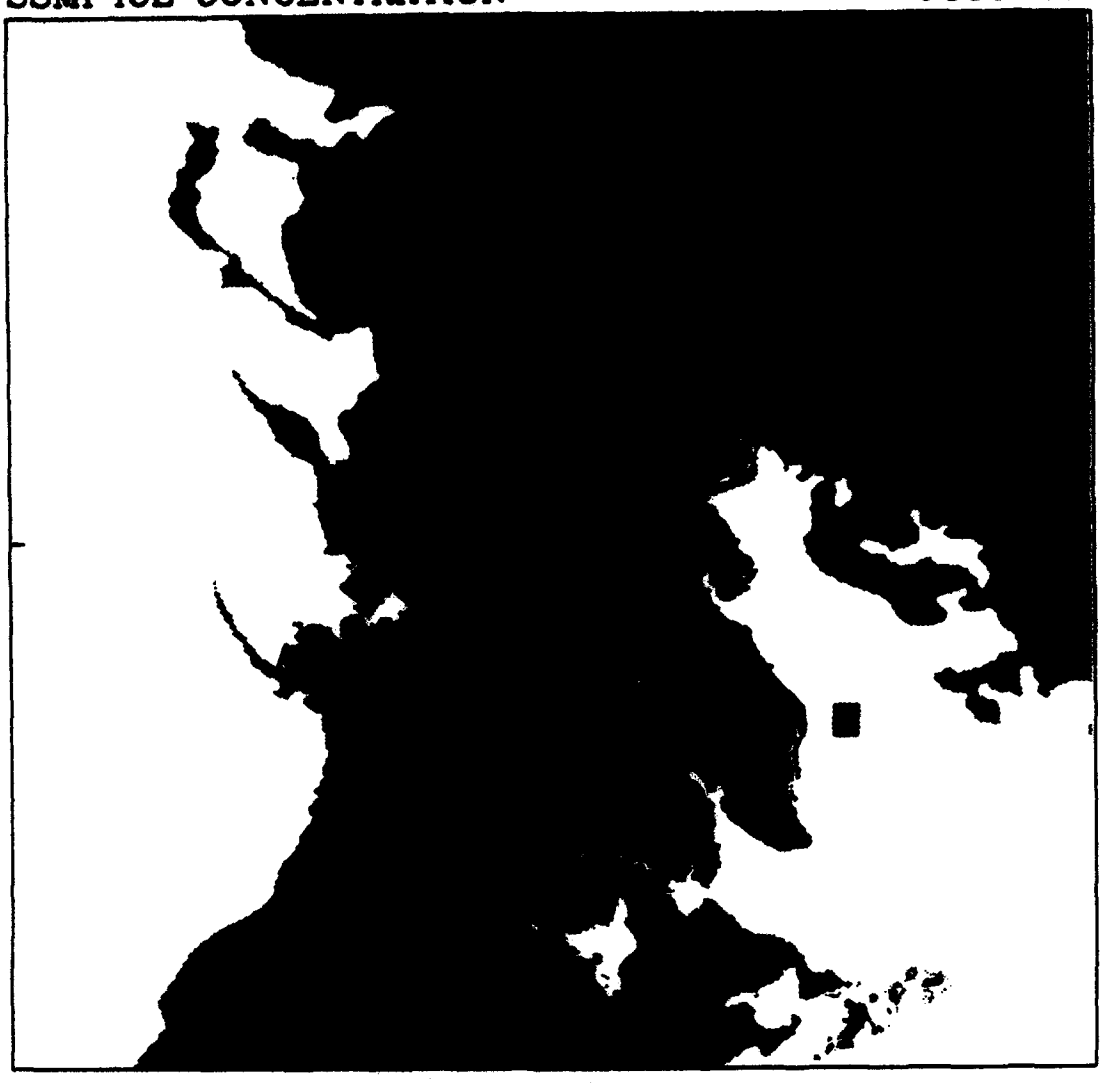




SSMI ICE CONCENTRATION 93111800



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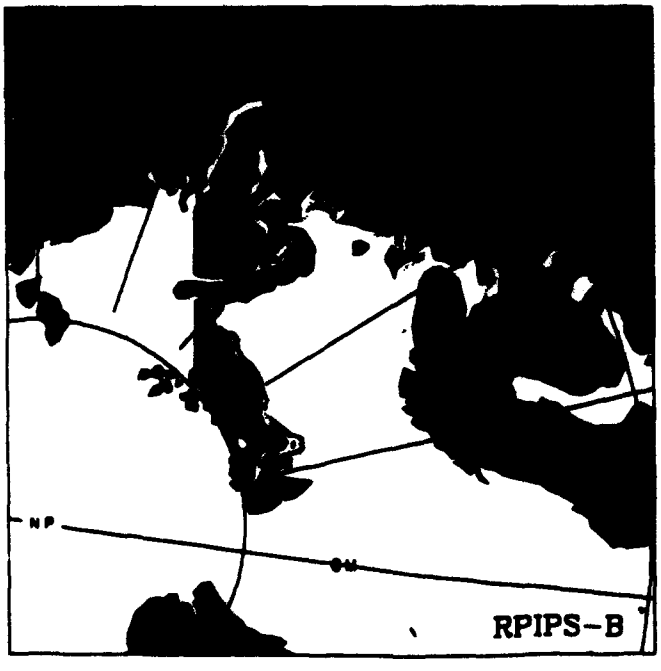

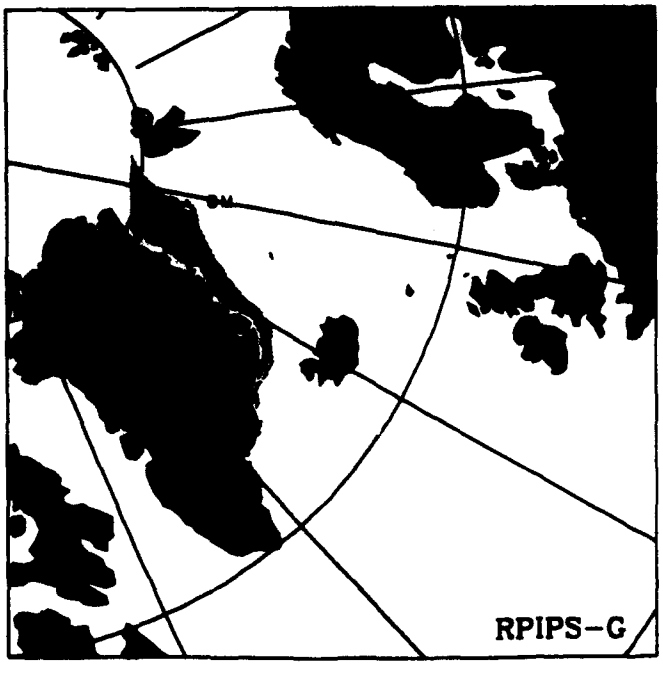

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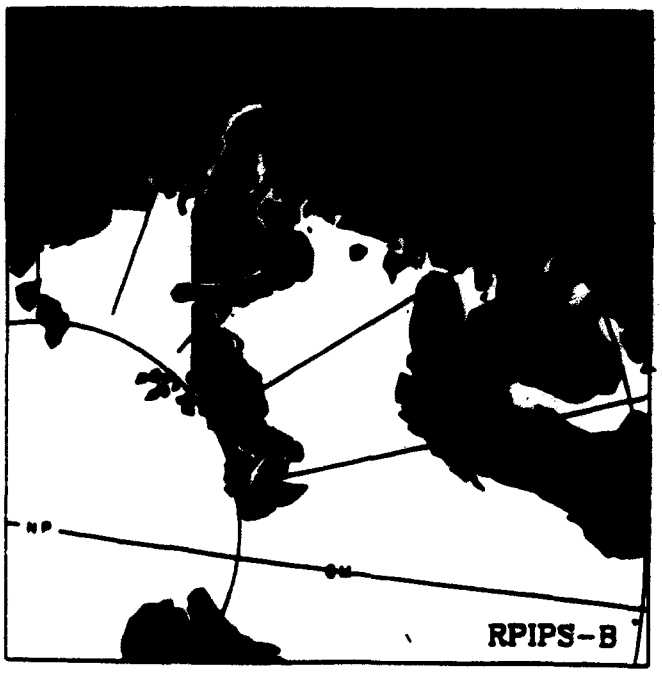

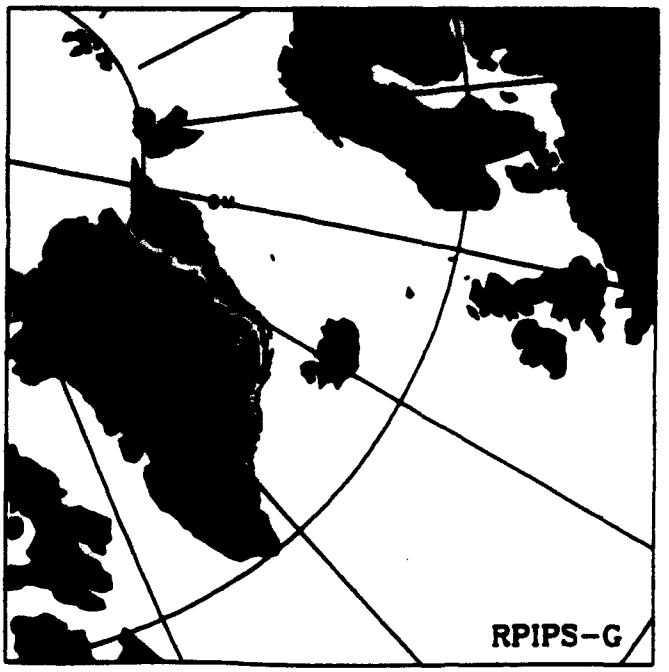

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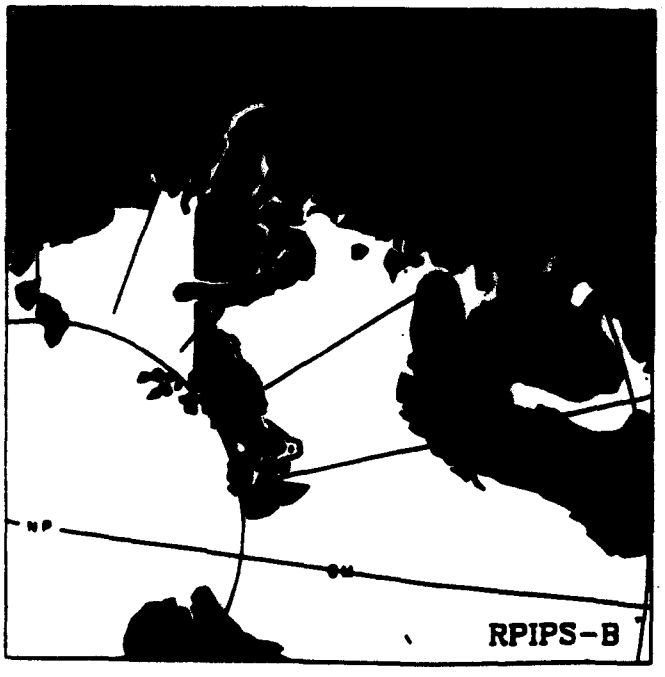

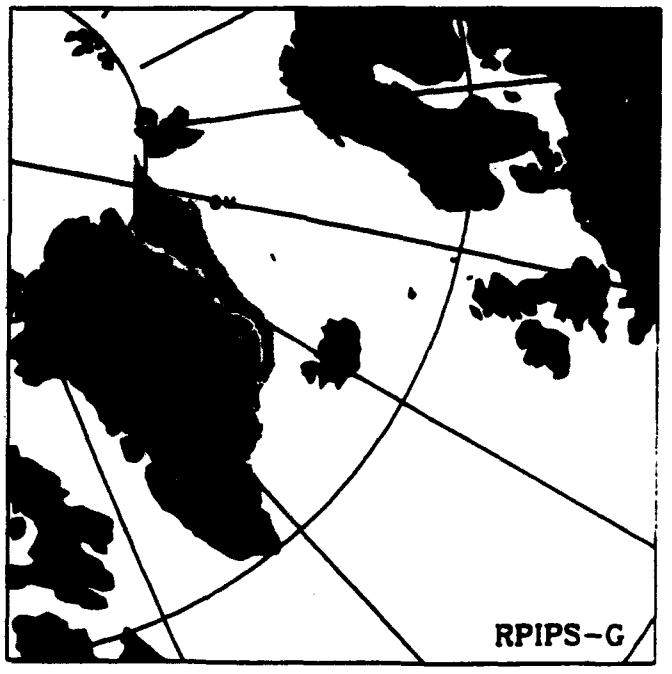

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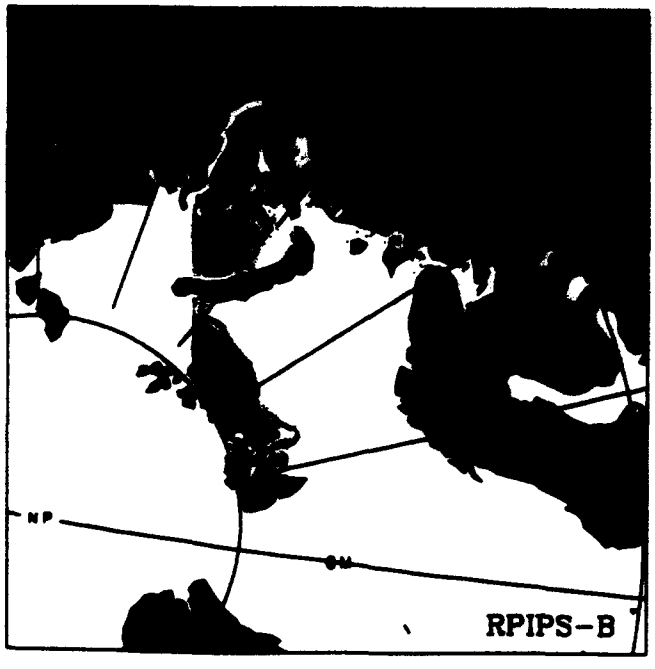

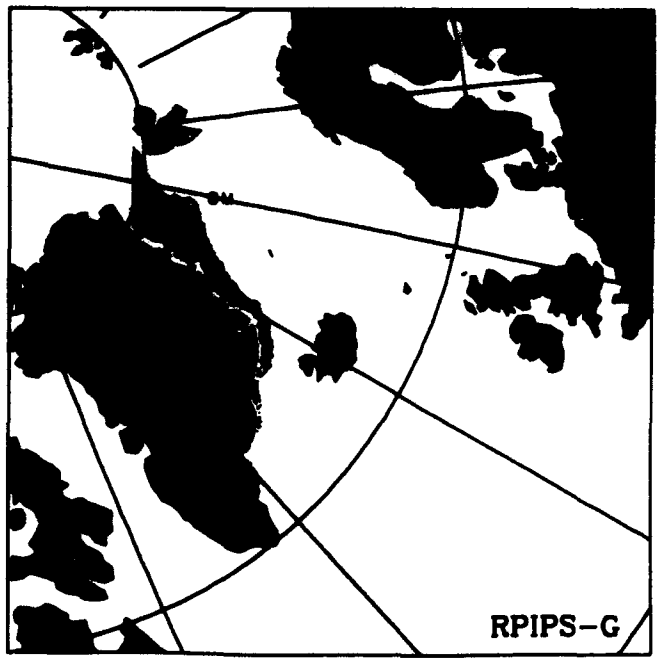

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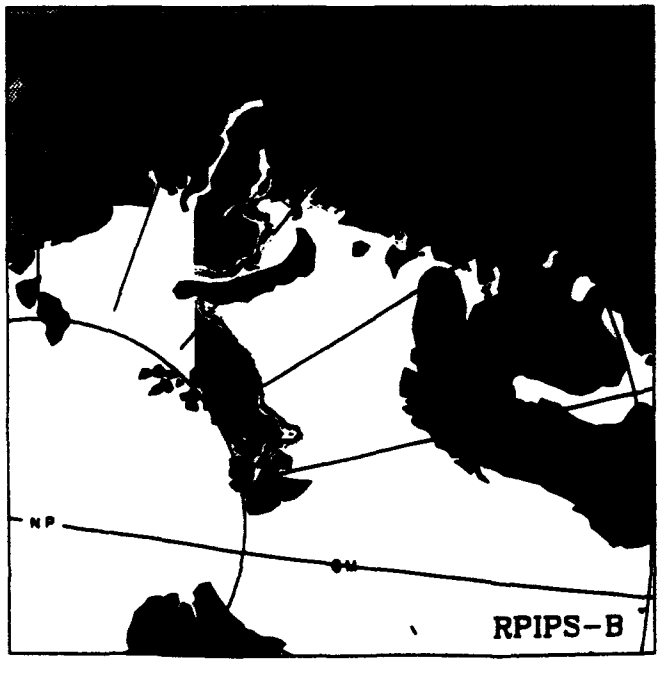

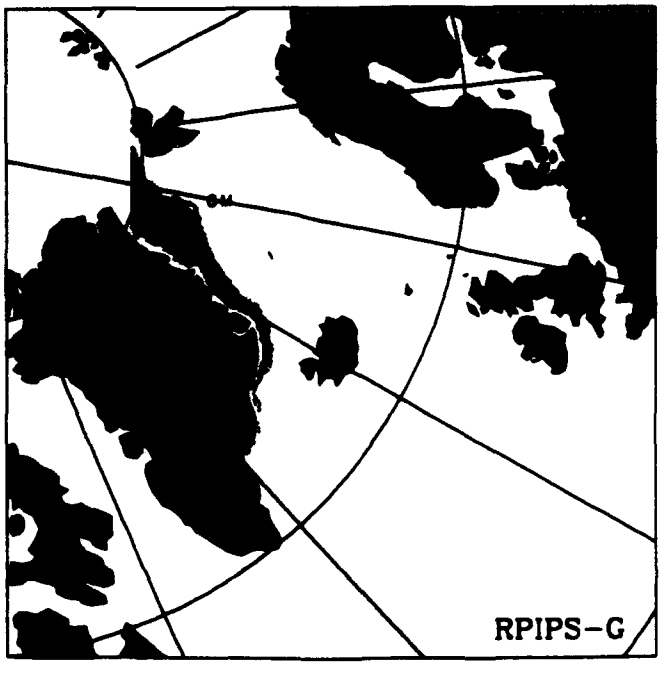

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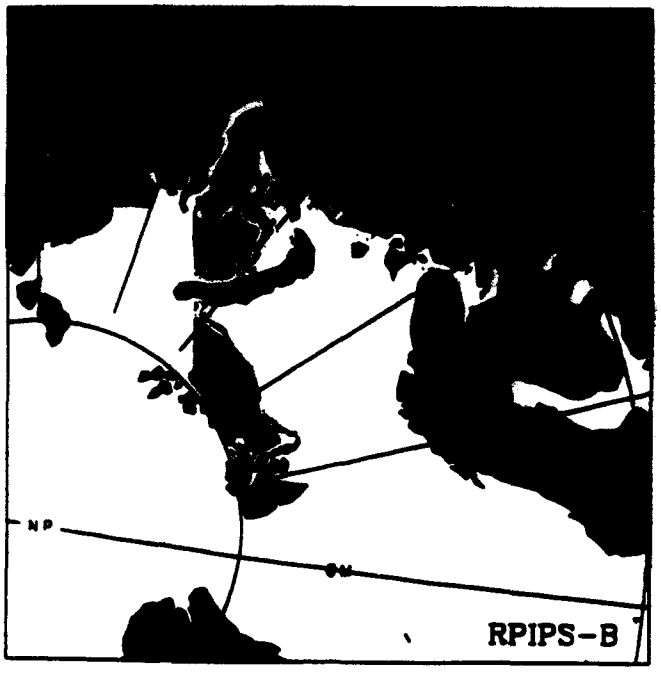

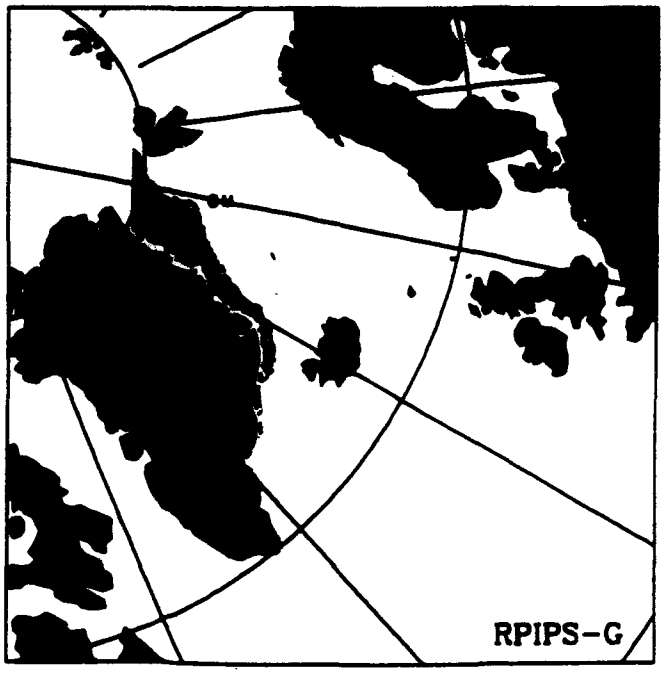

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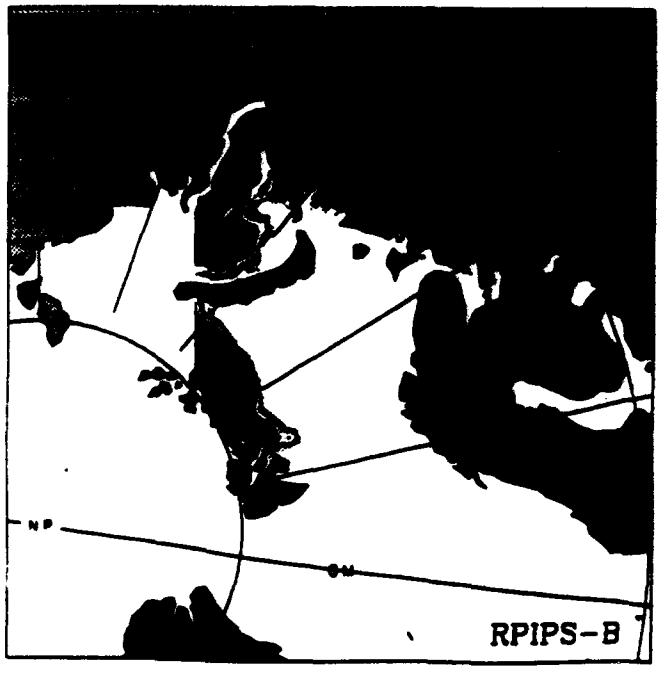

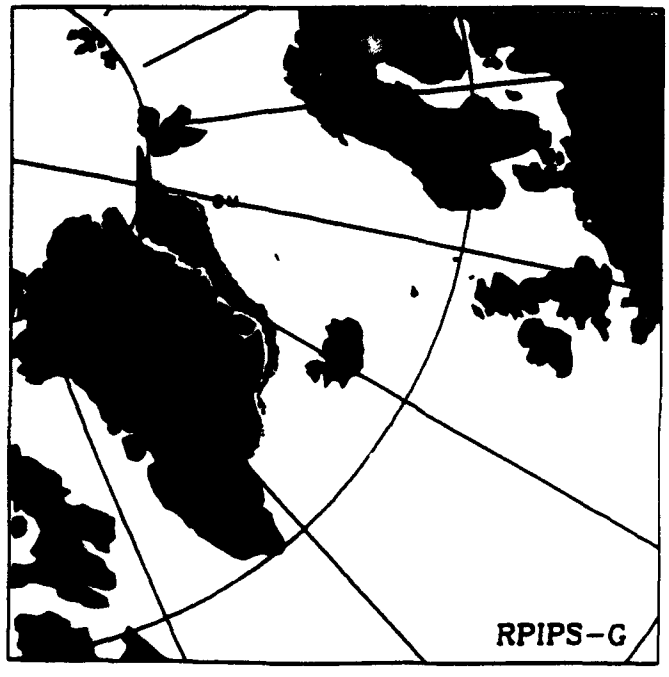

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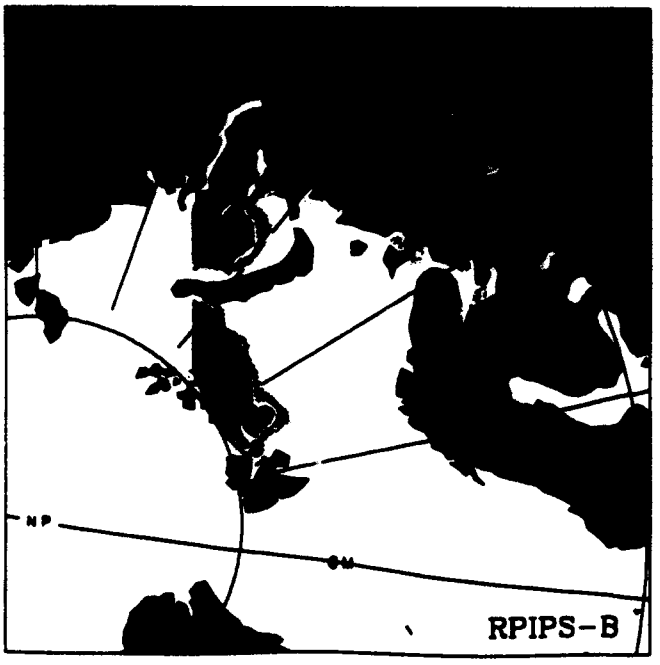

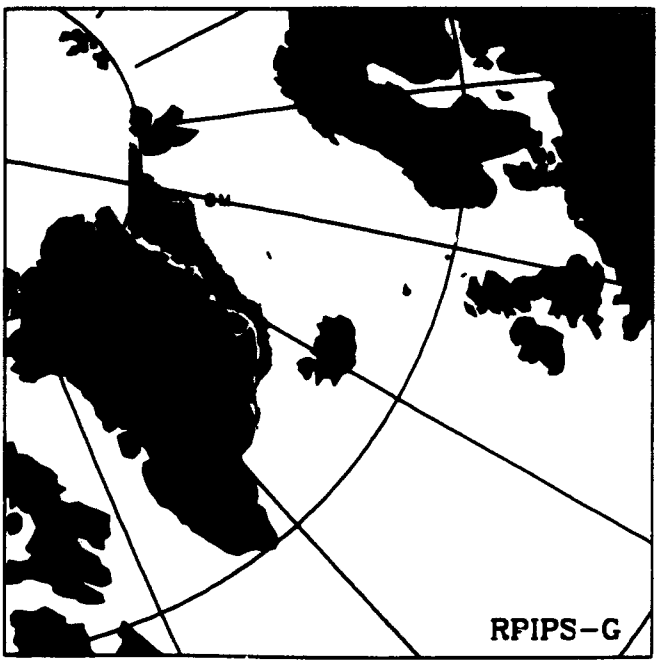

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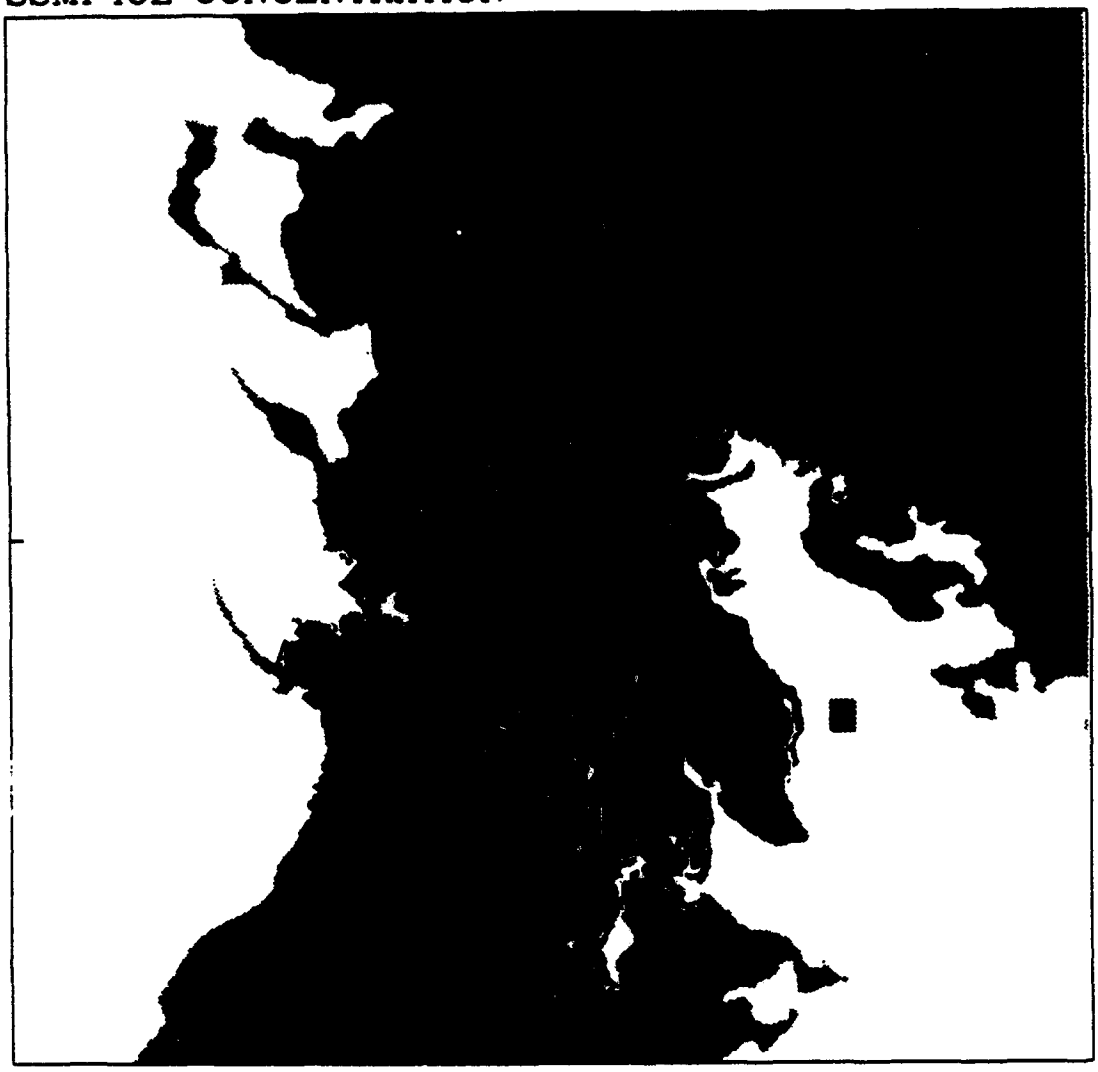

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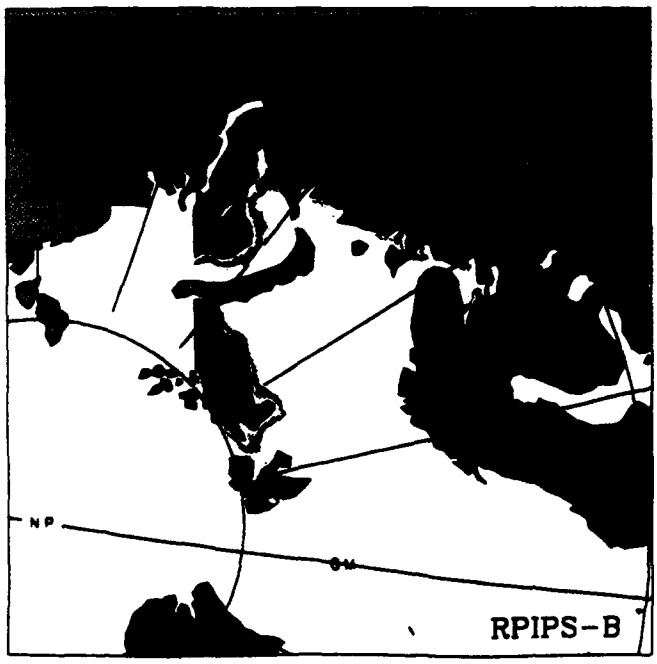

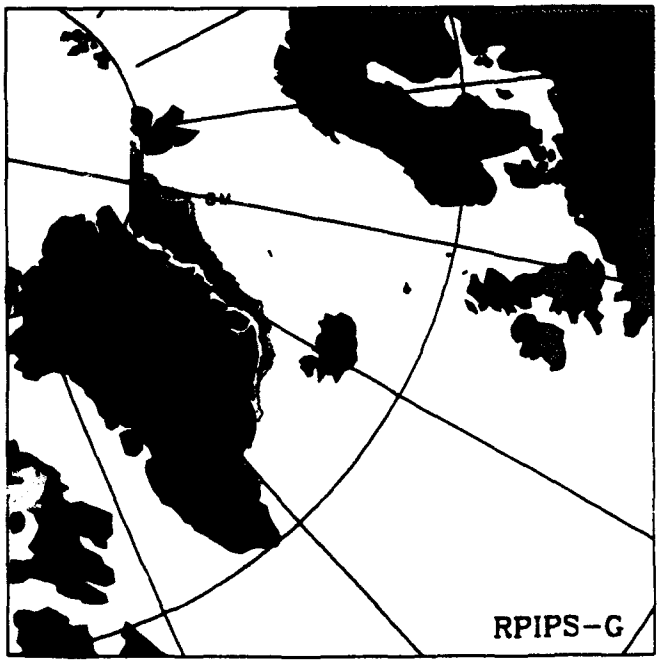

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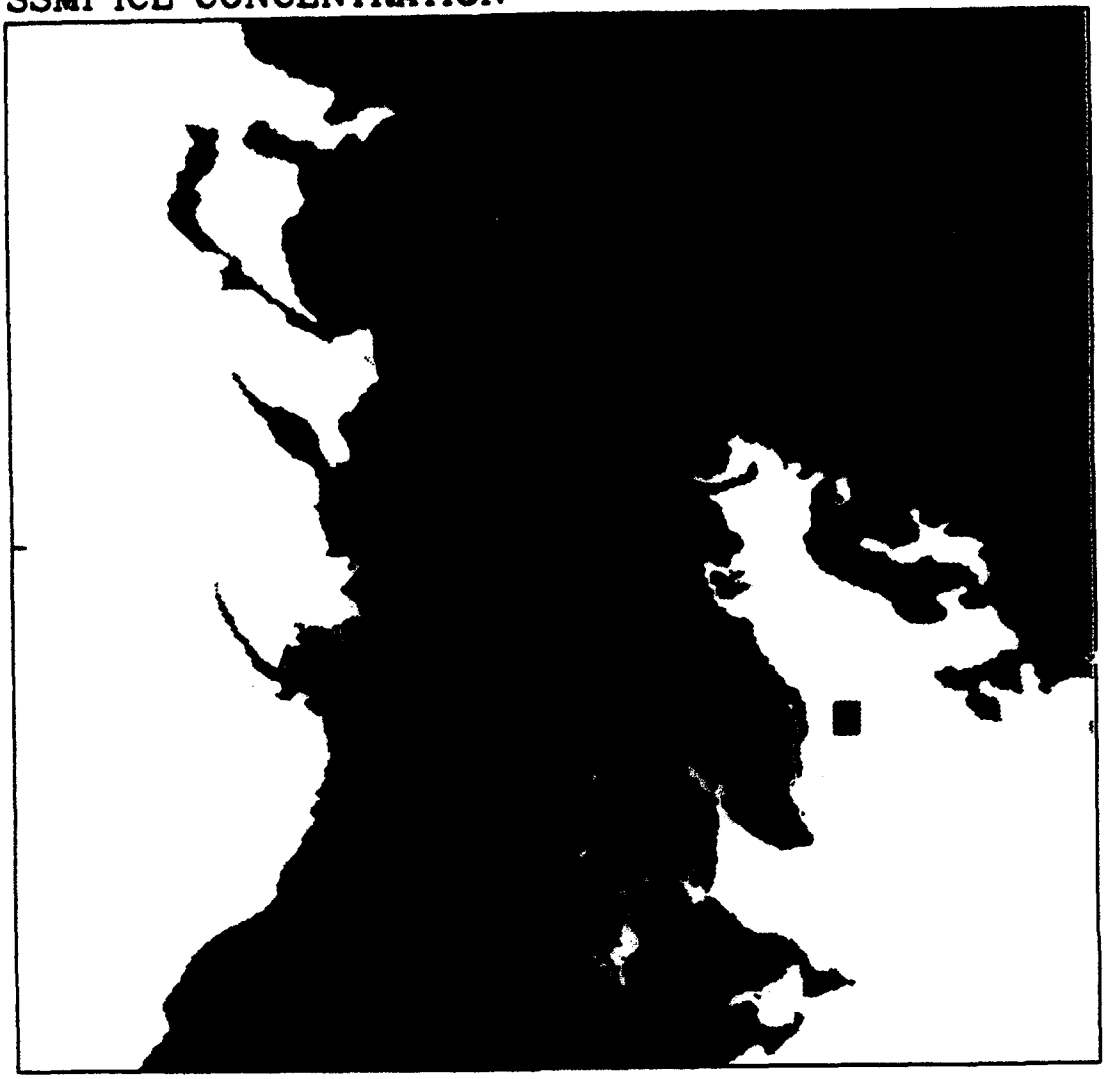

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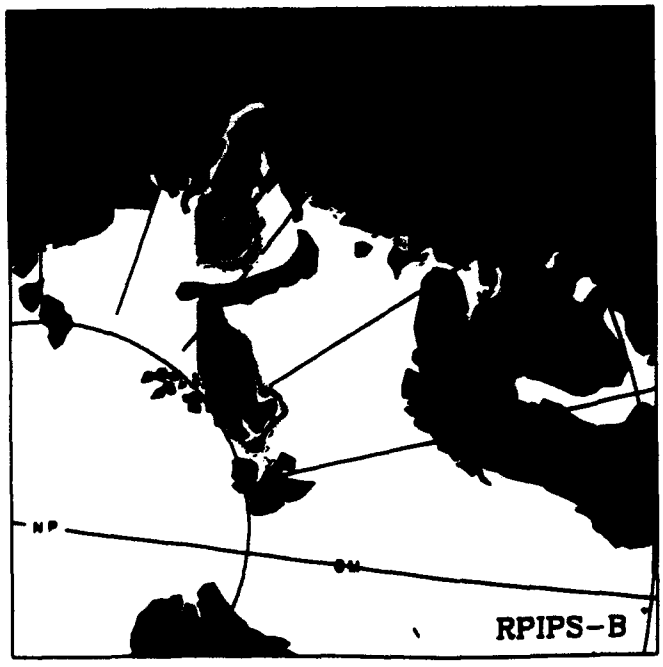

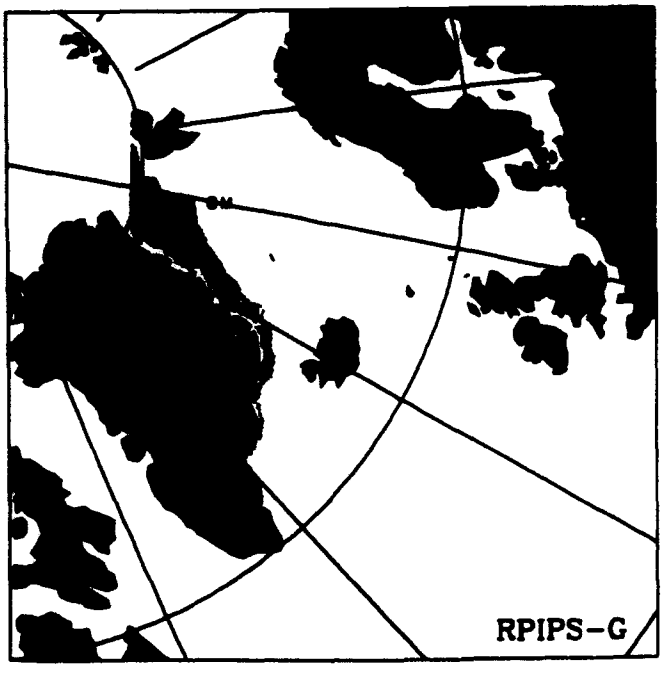

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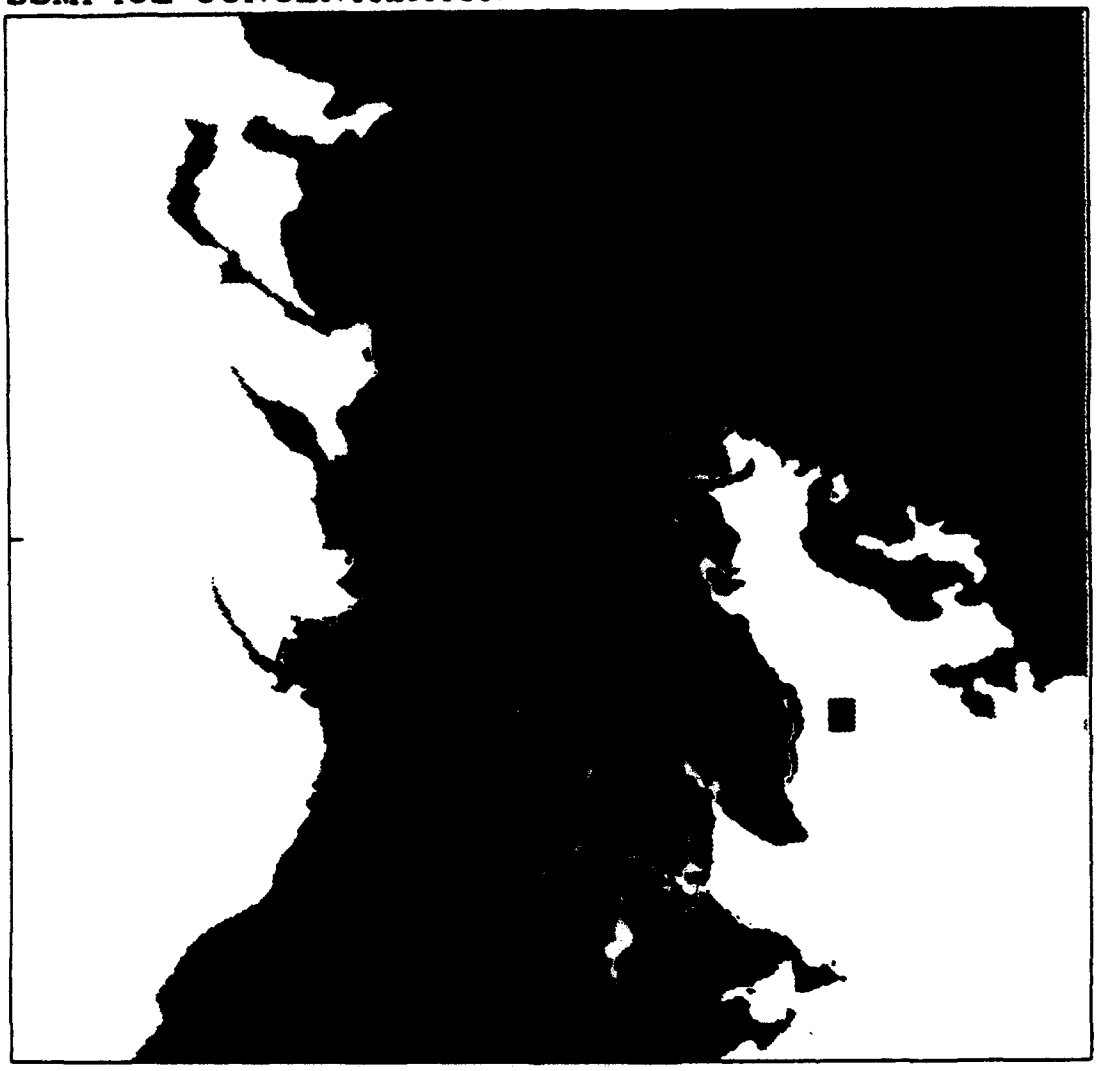

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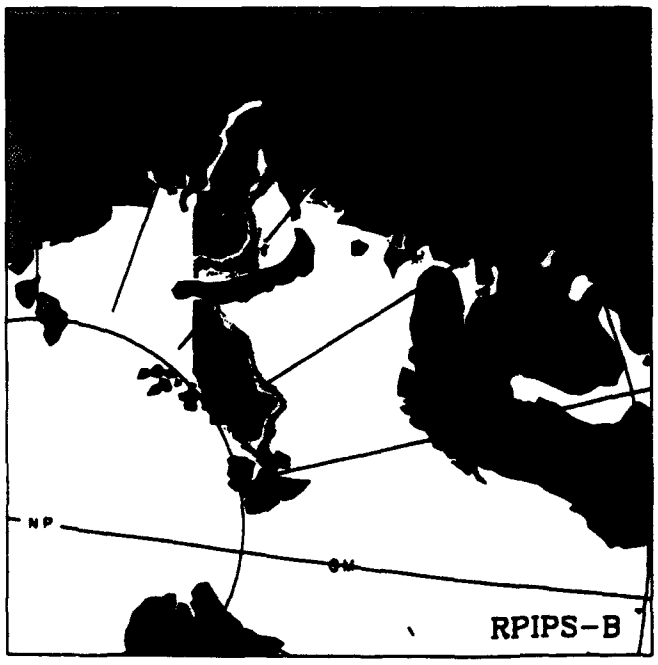

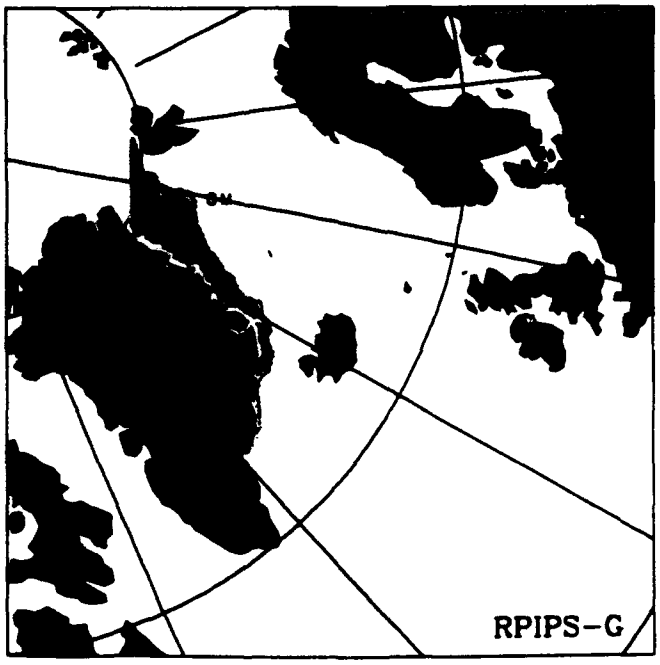

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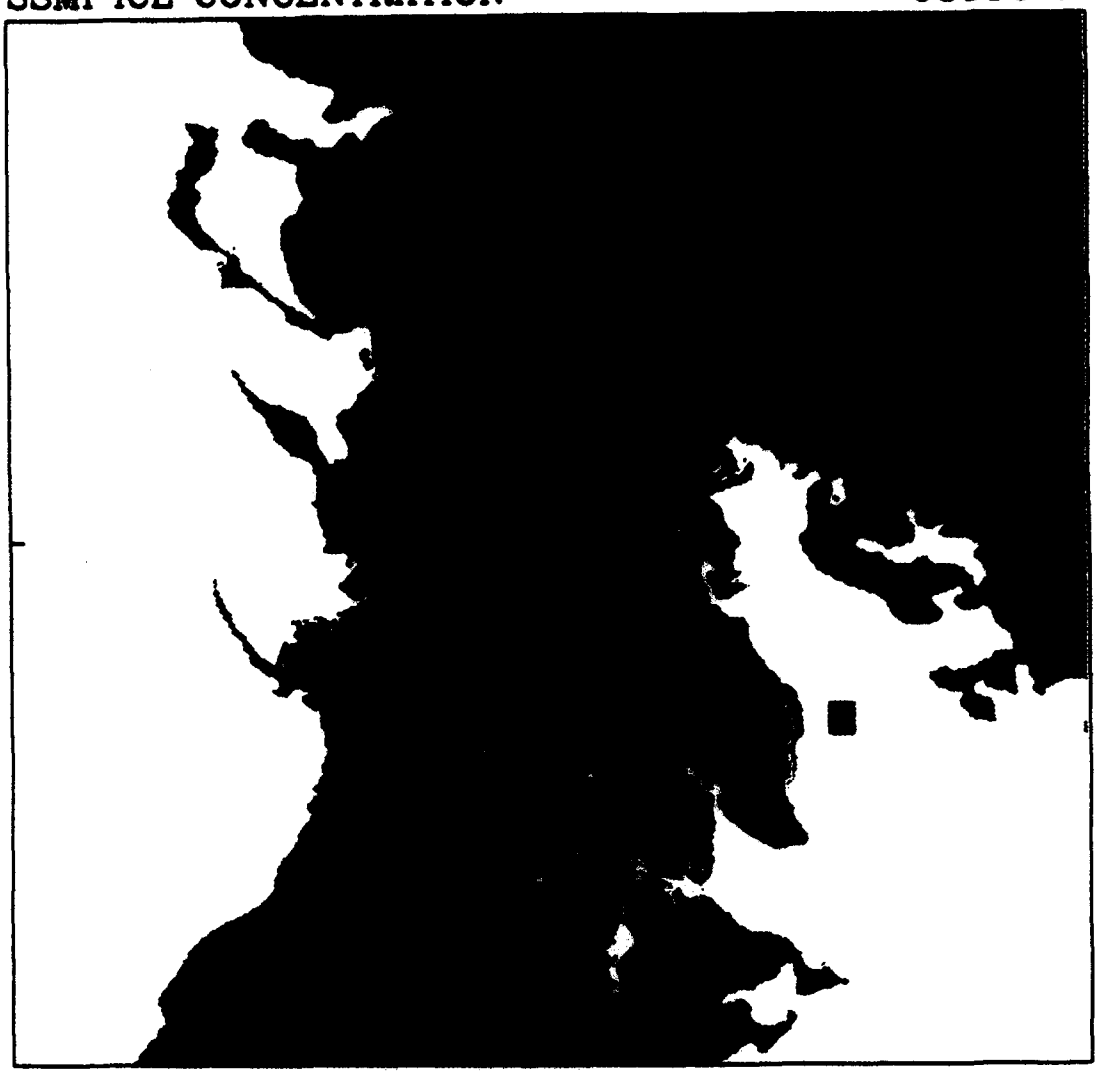

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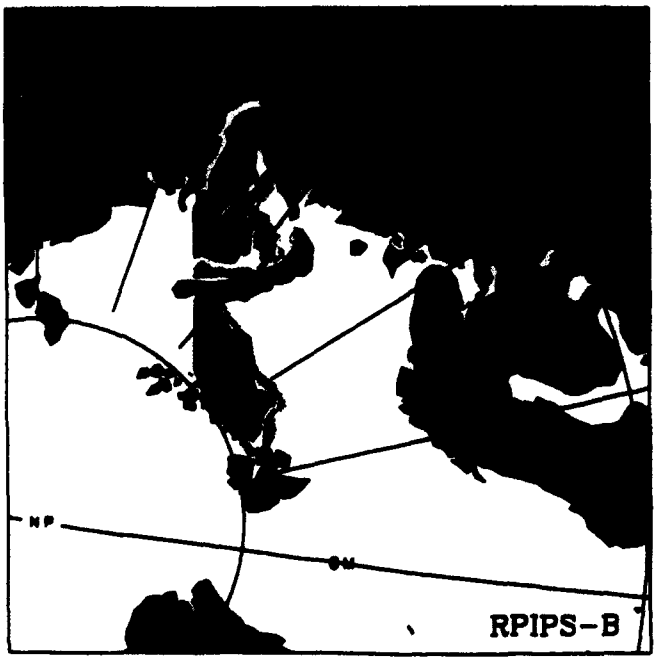

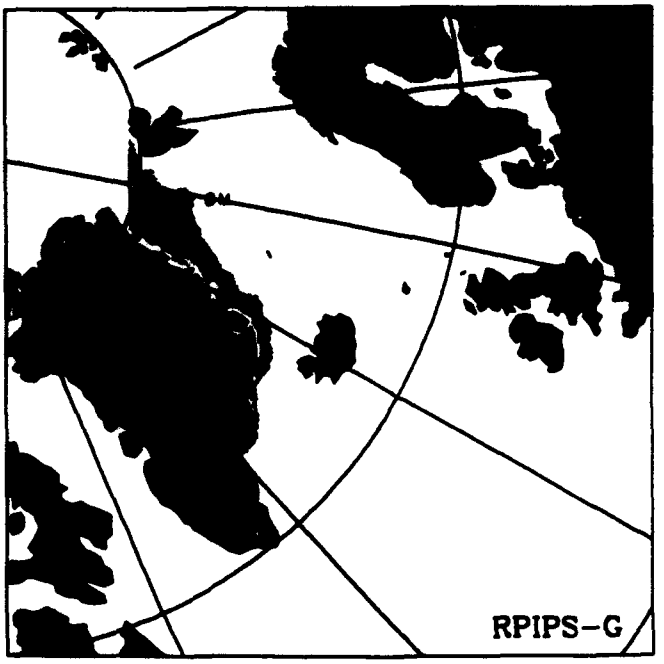

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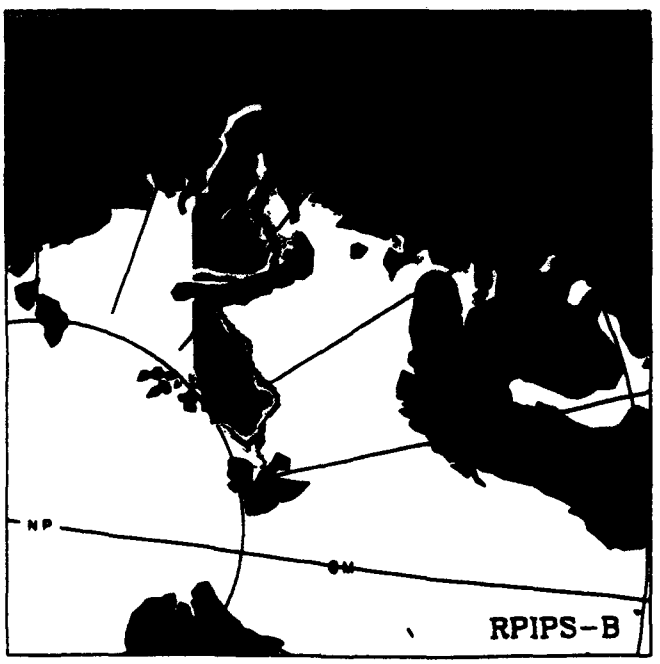

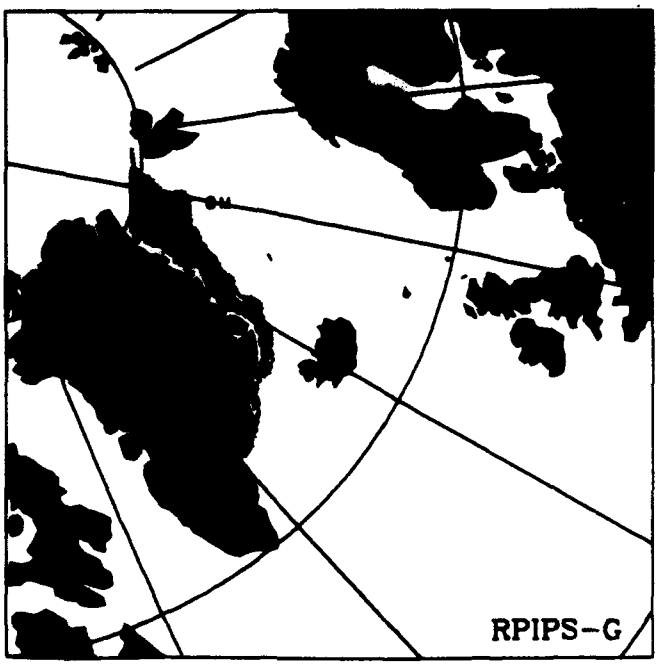

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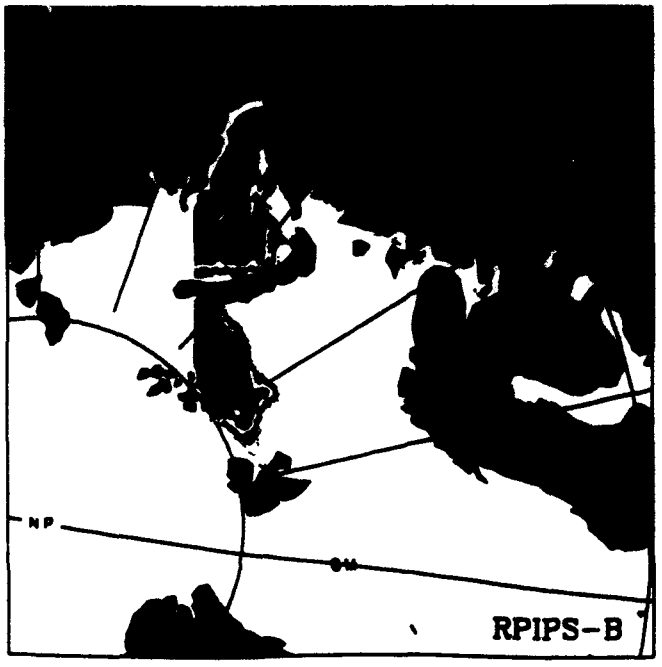

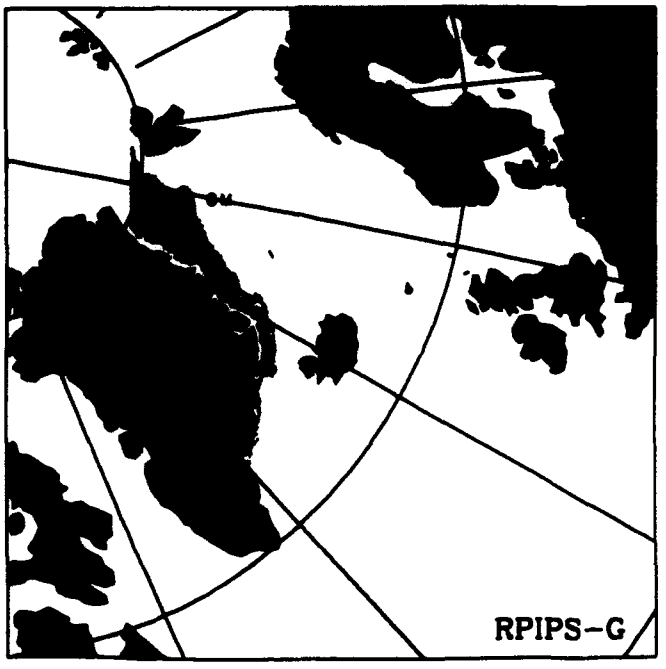

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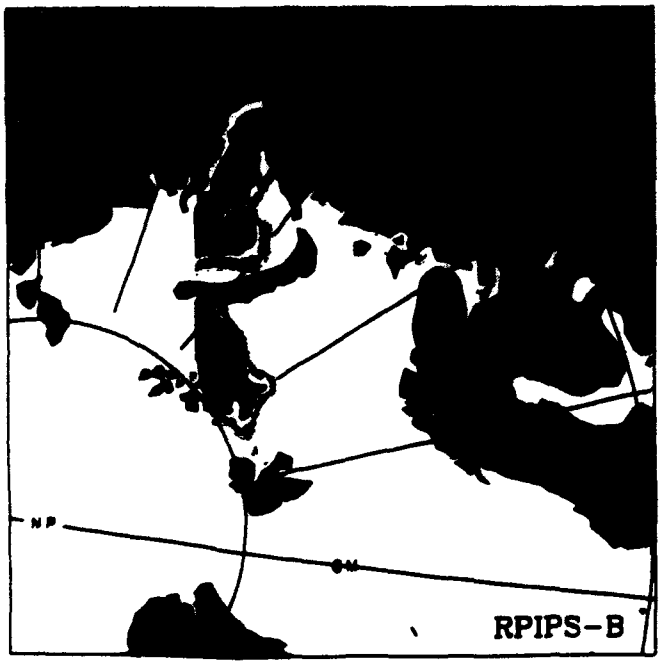

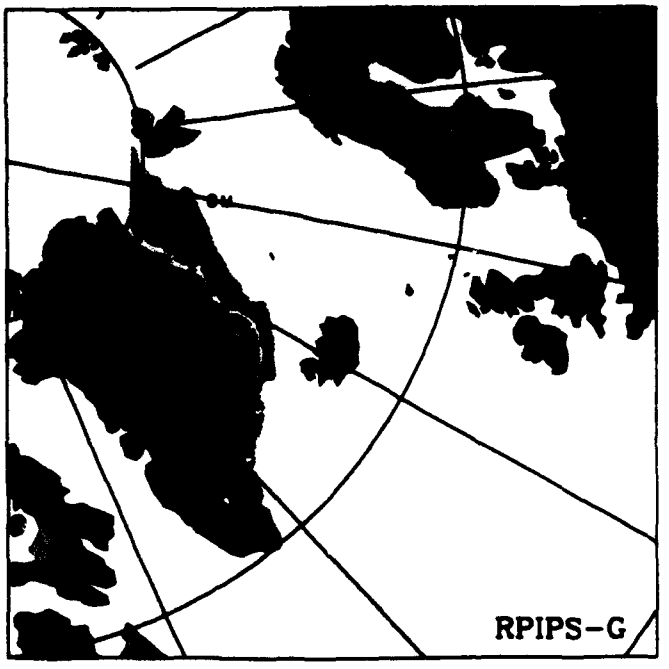

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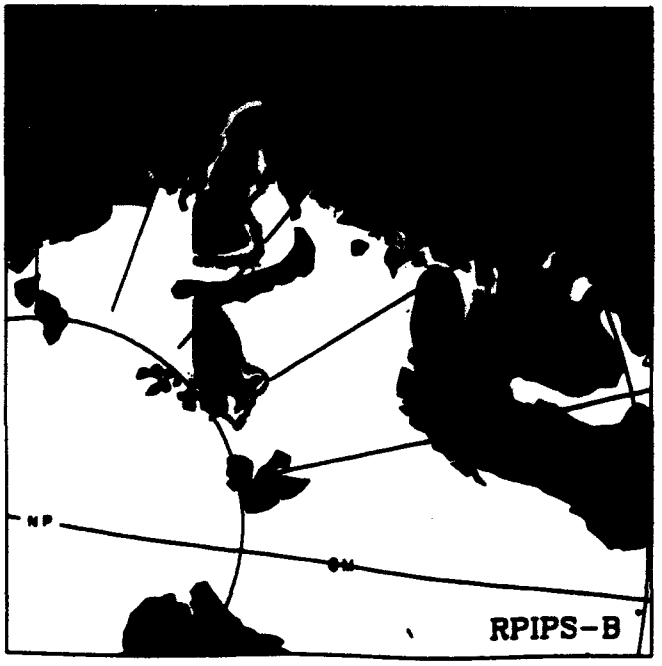

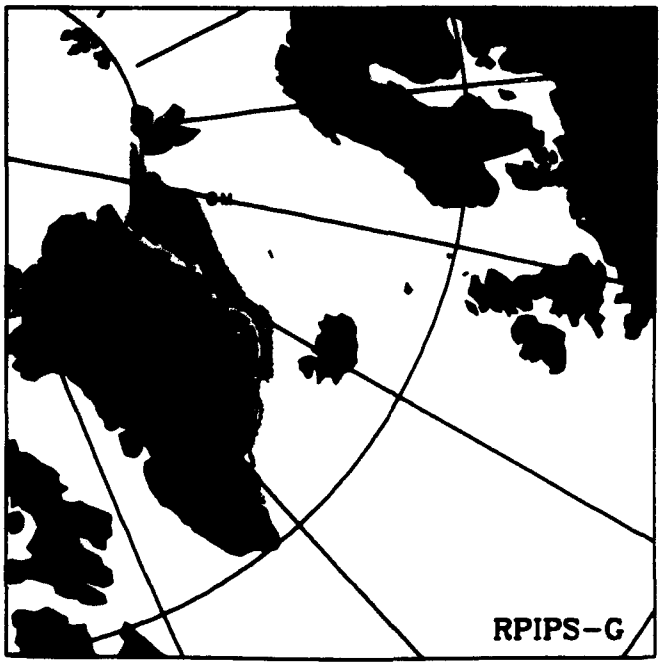

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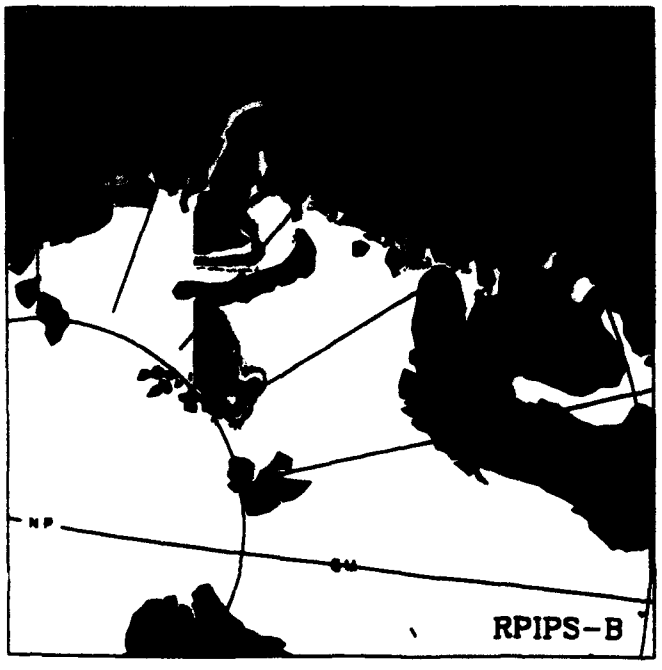

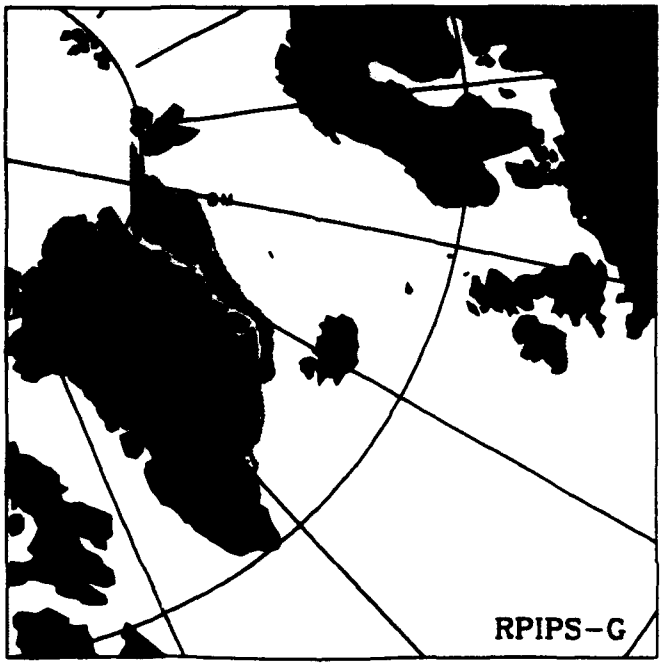

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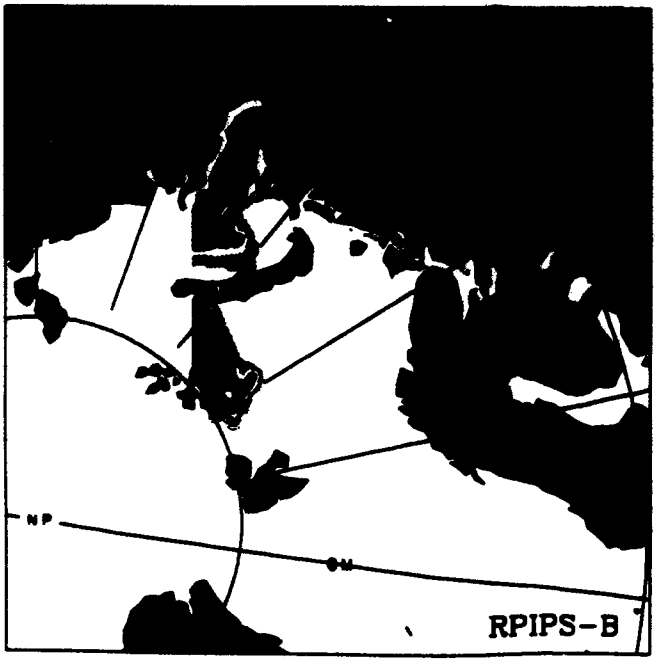

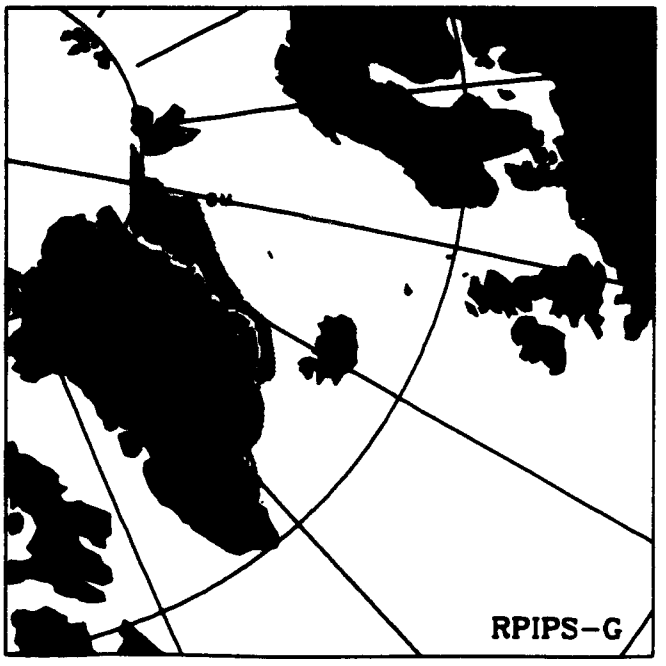

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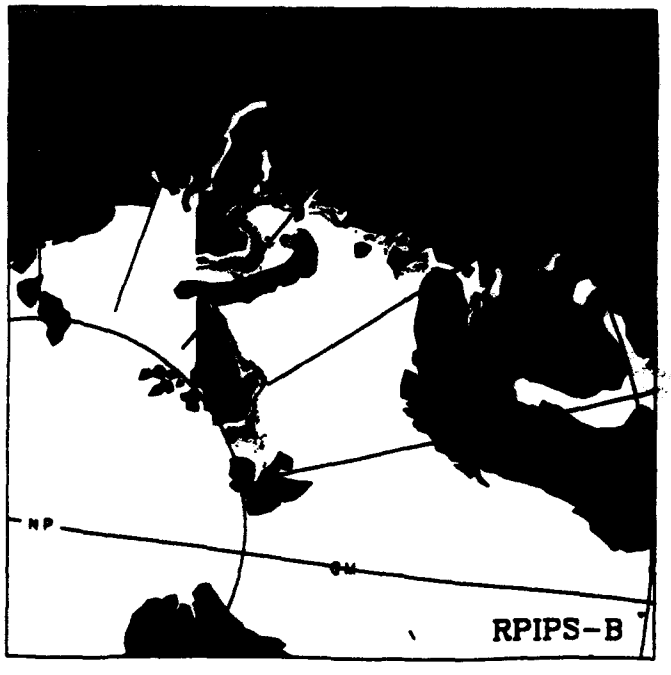

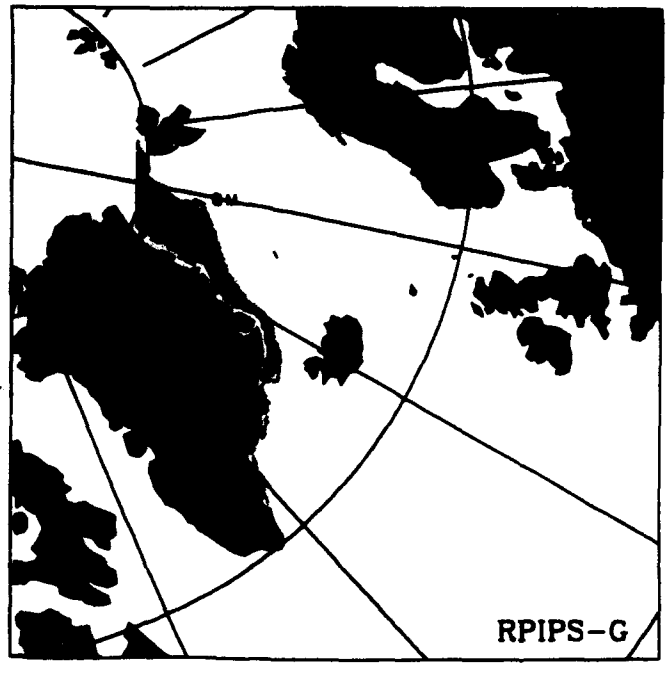

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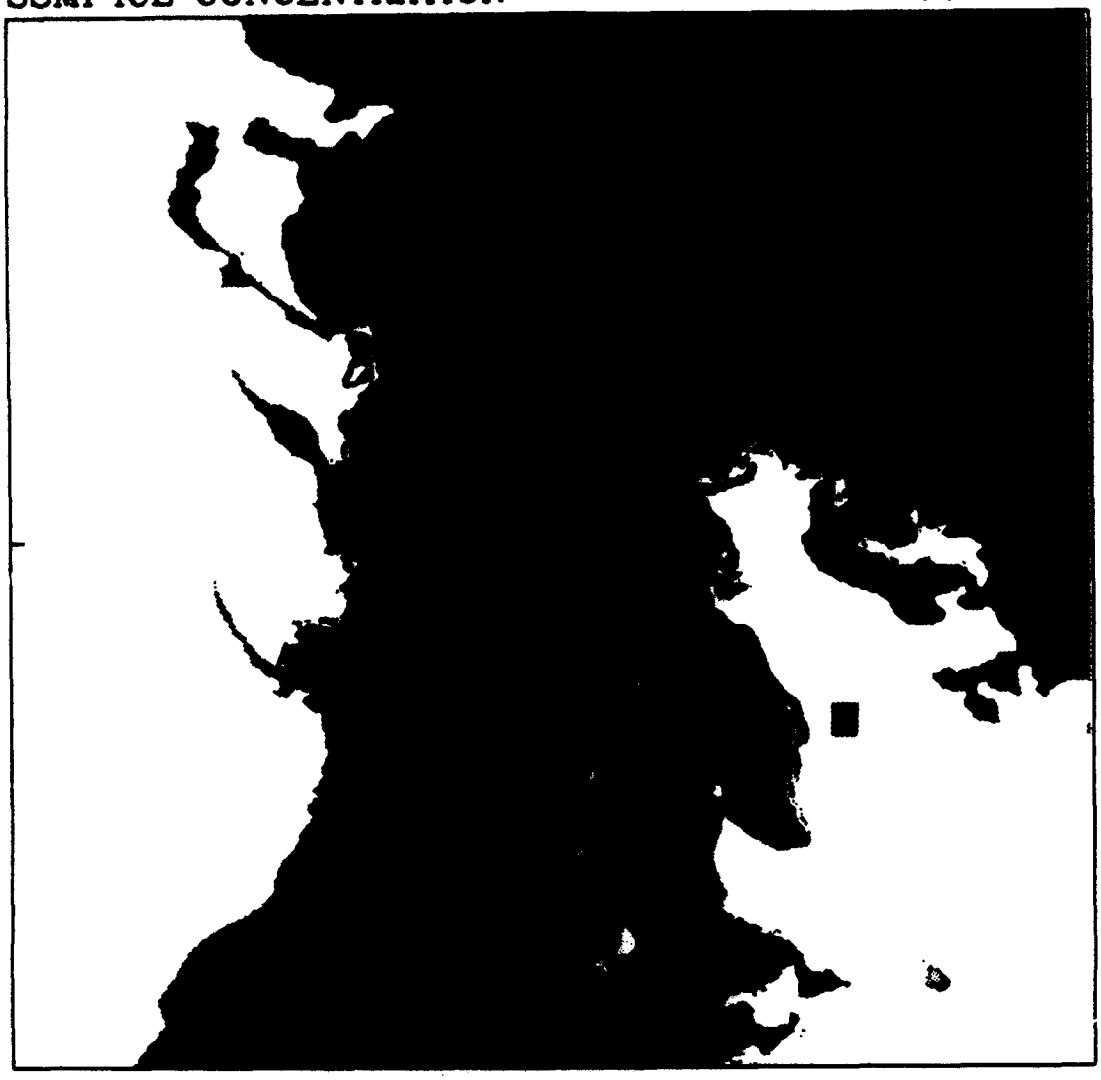

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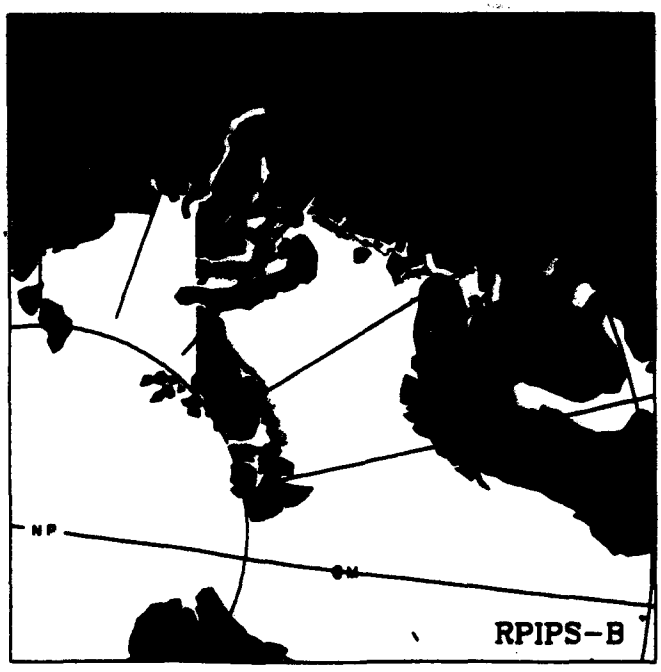

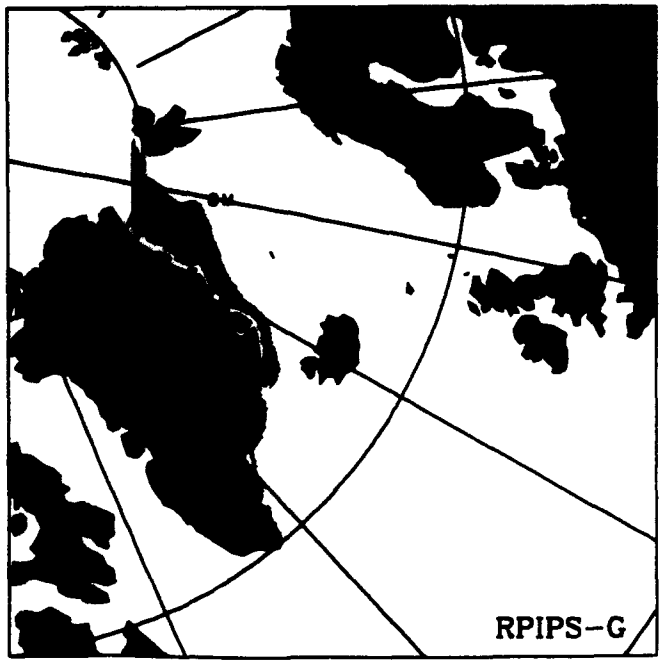

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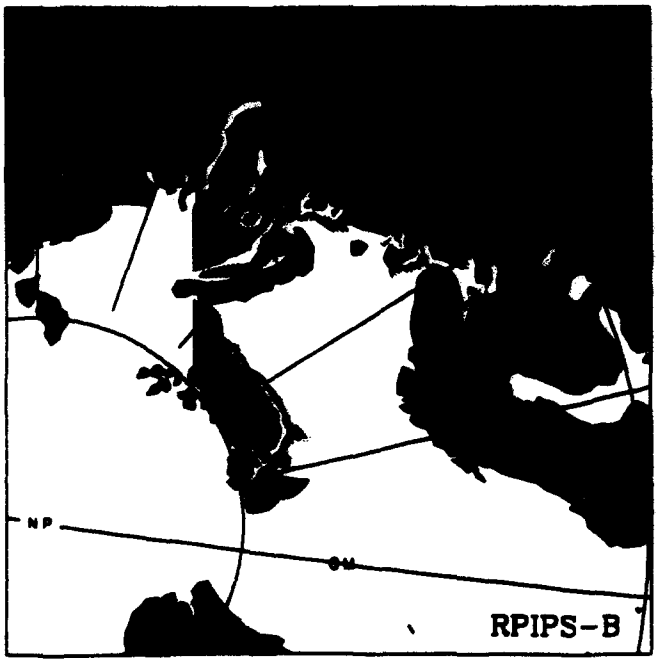

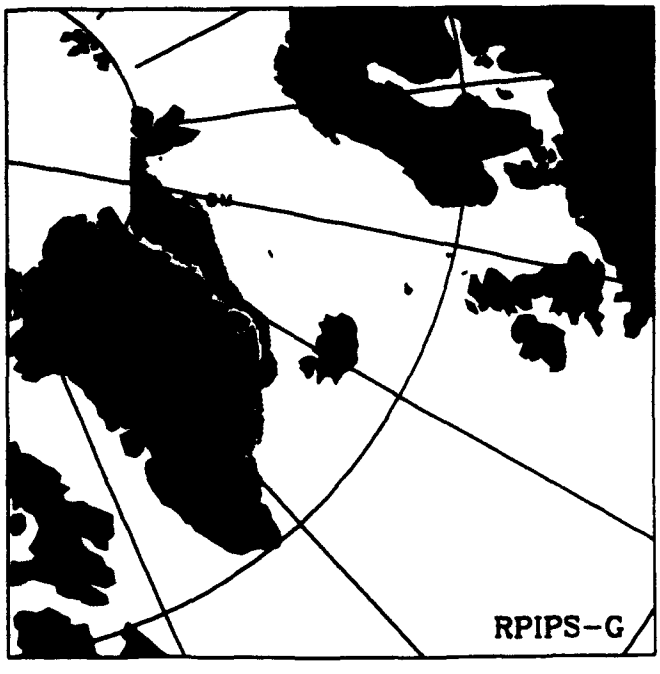

SSMI ICE CONCENTRATION 93121100

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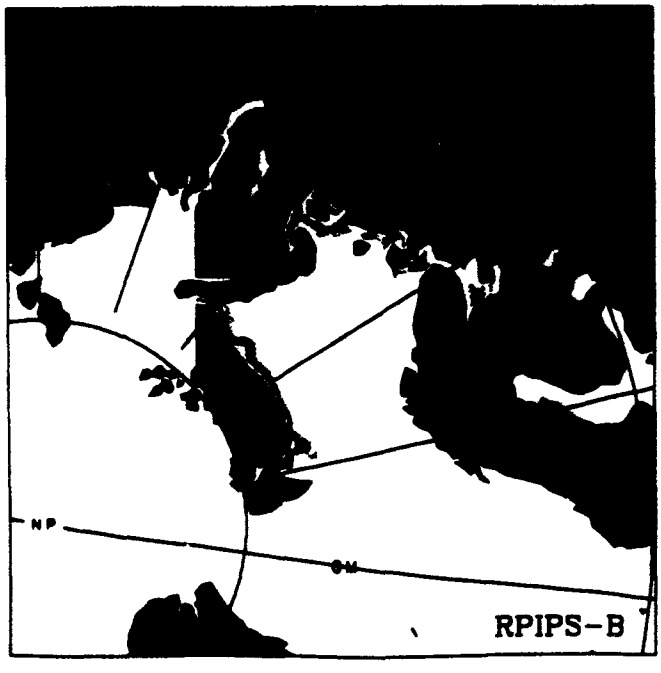

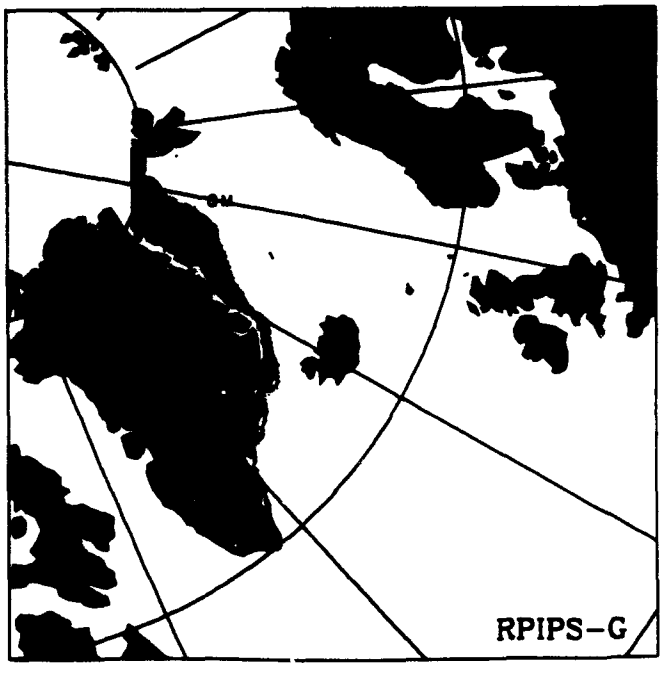

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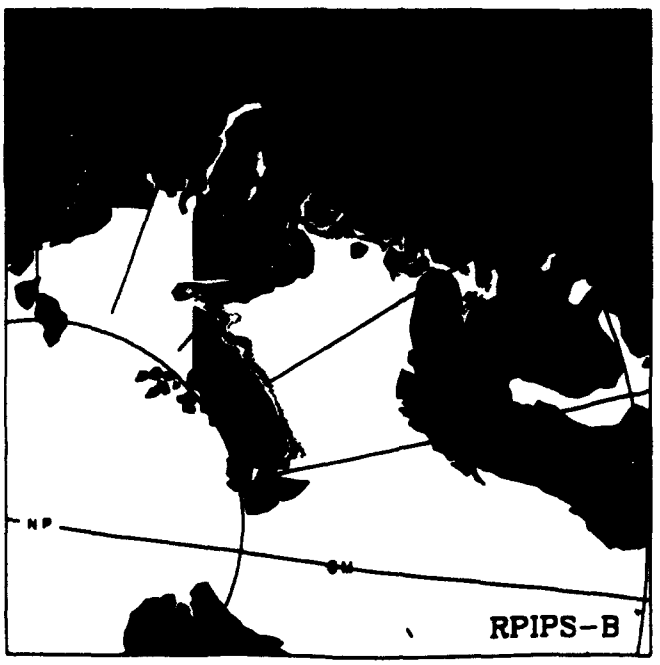

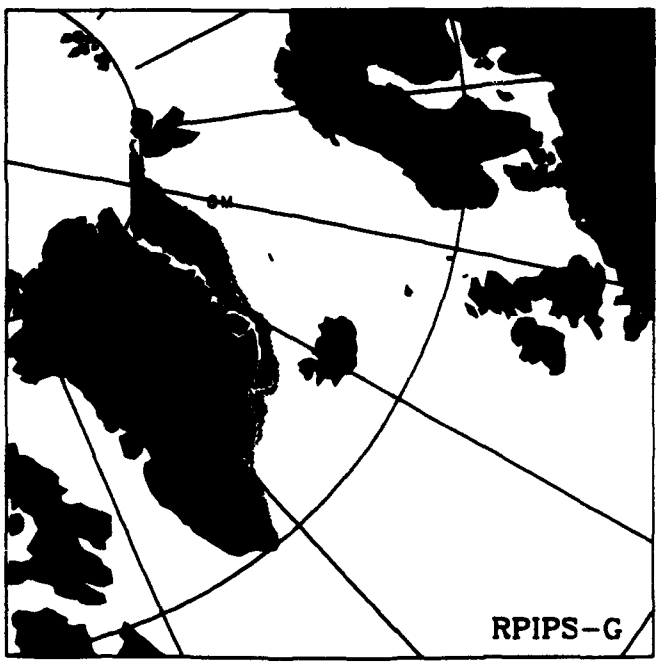

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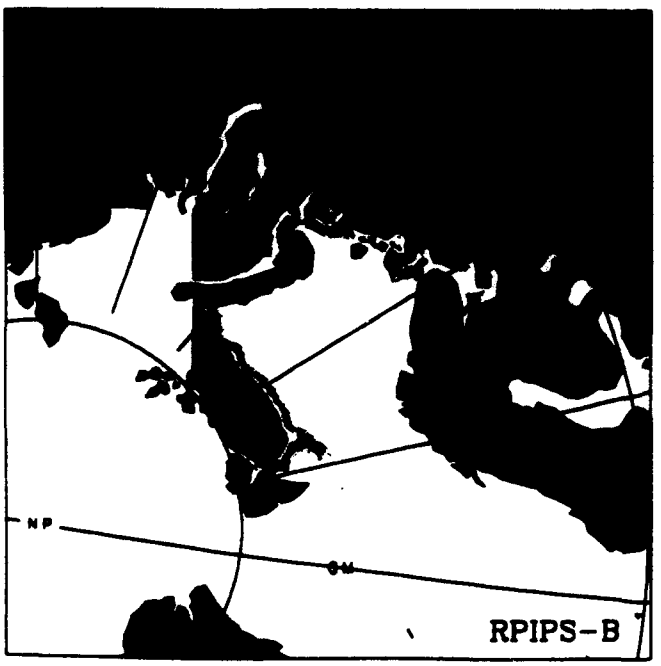

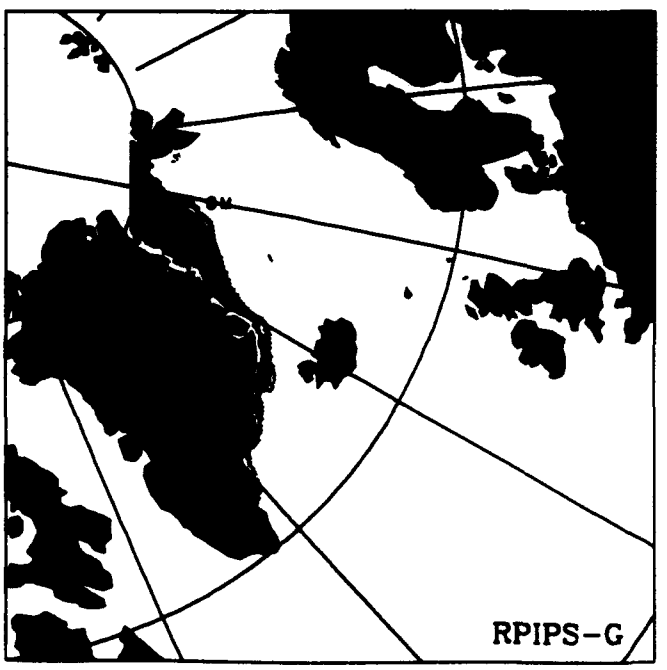

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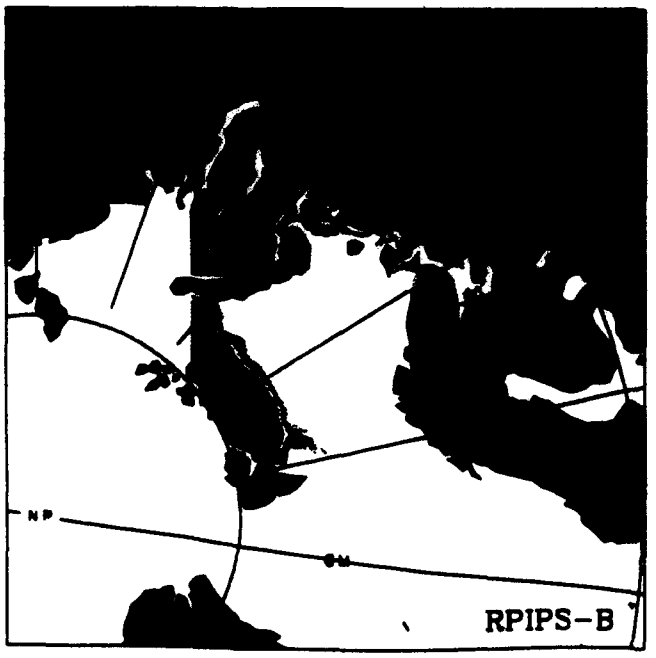

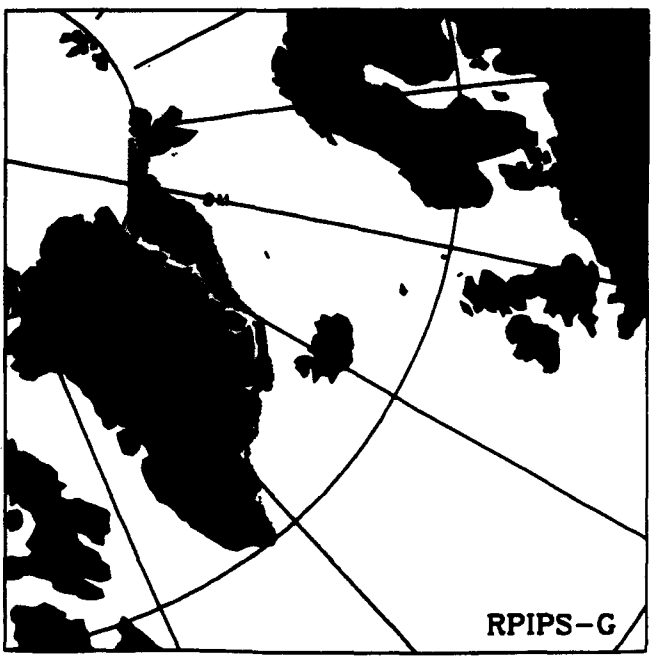

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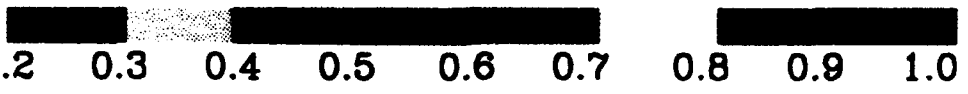

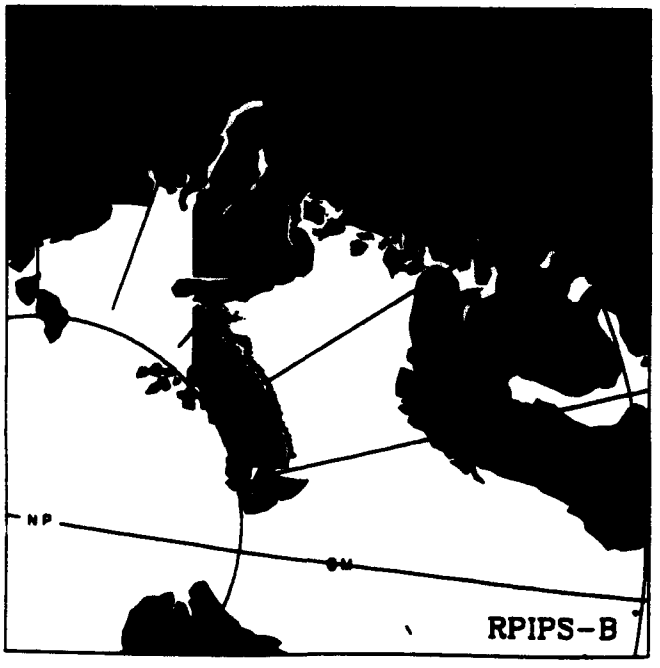

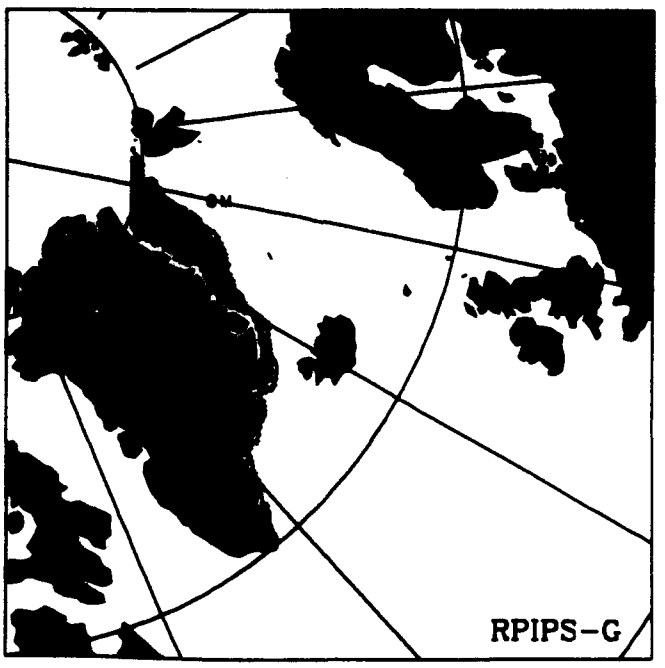

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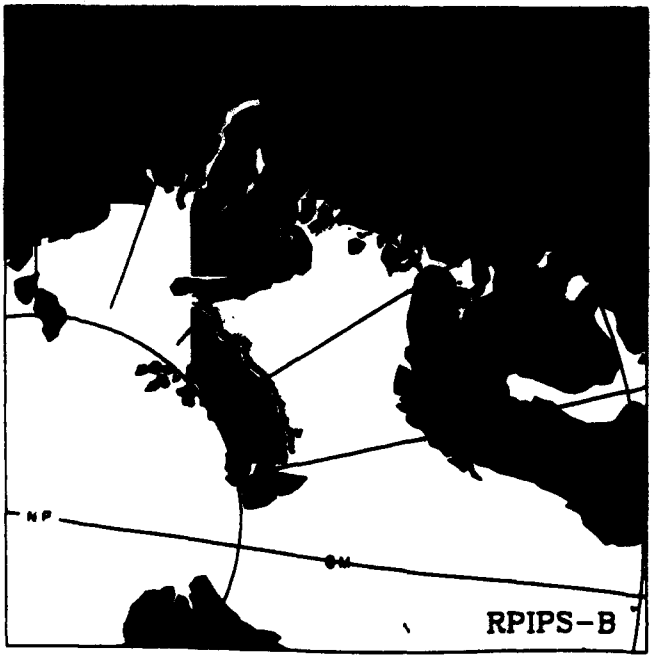

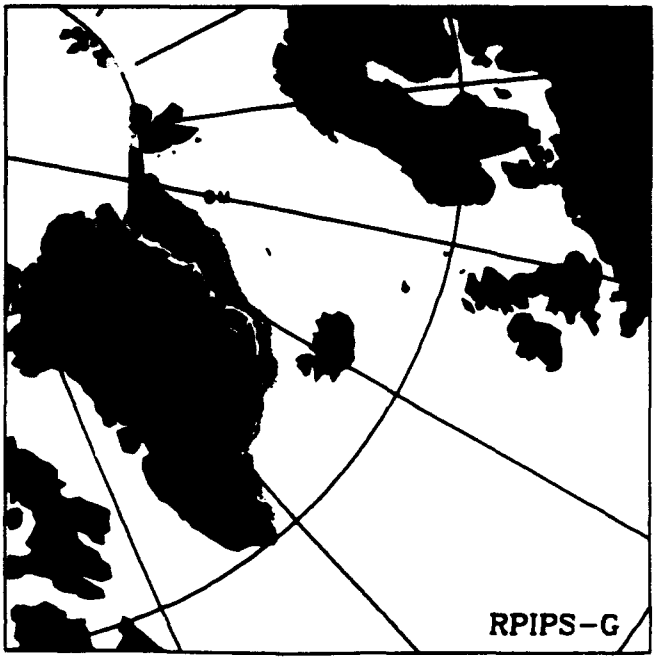

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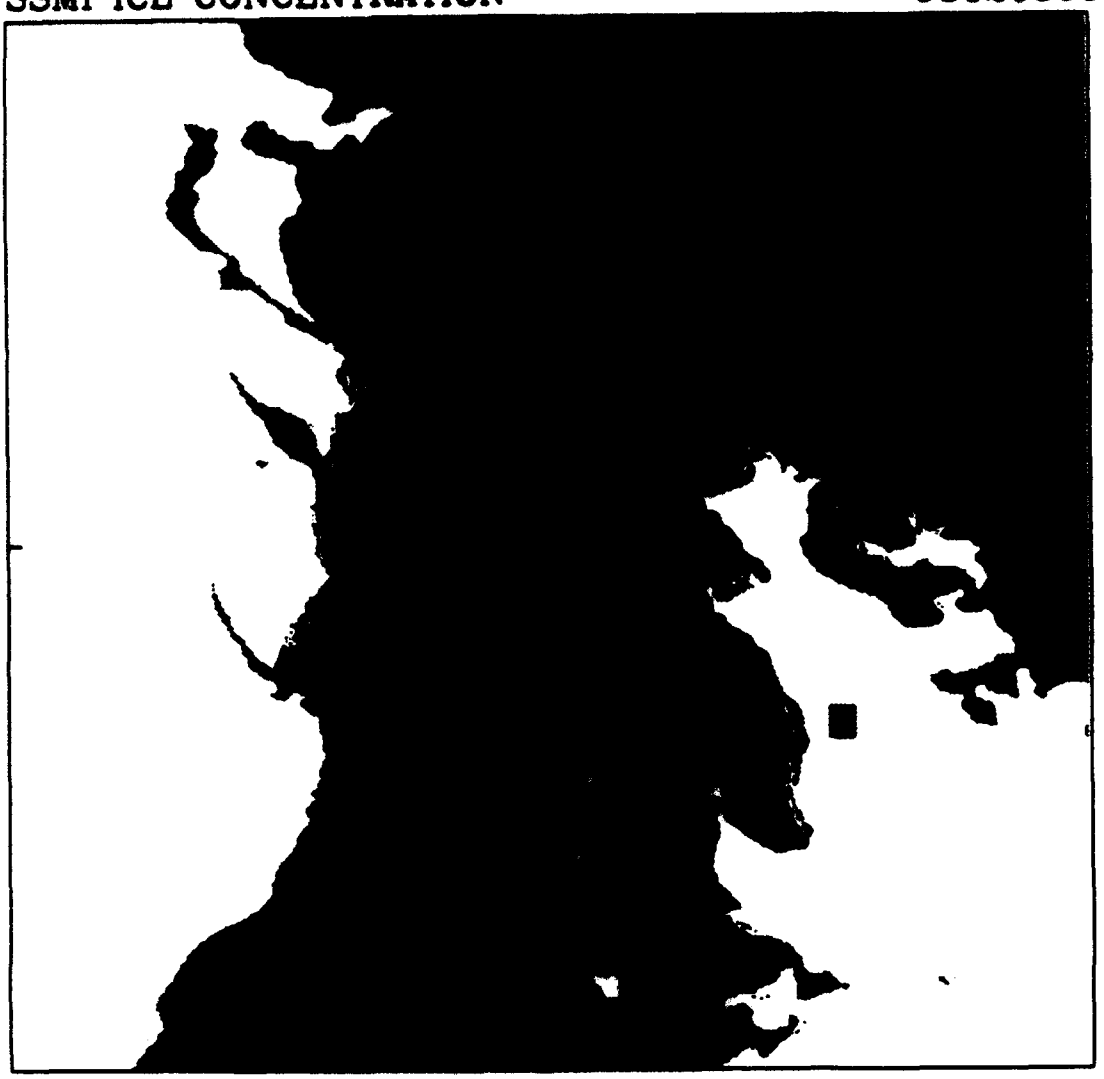

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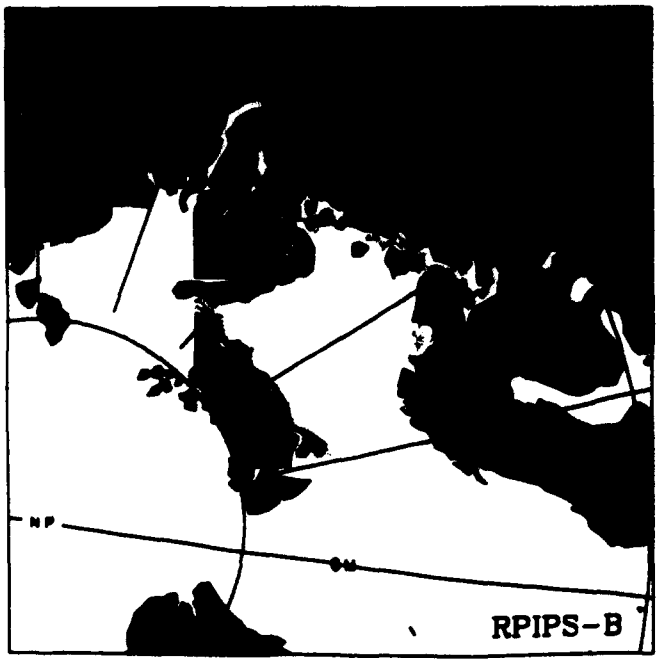

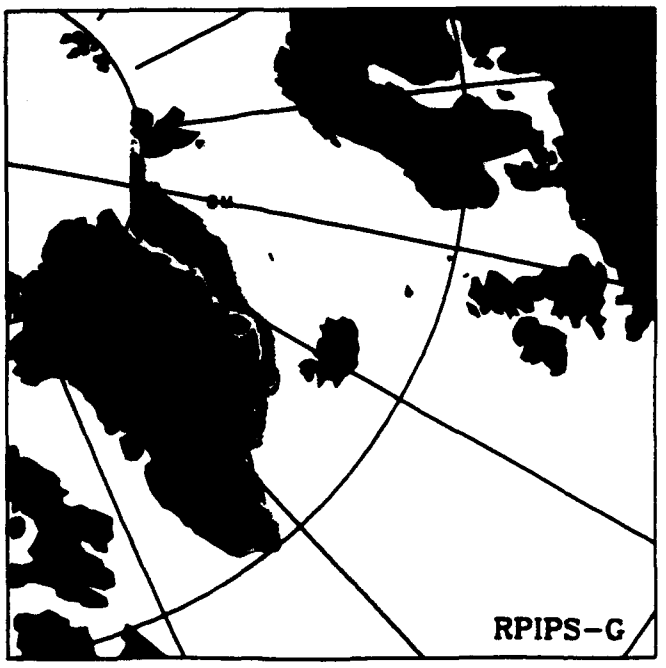

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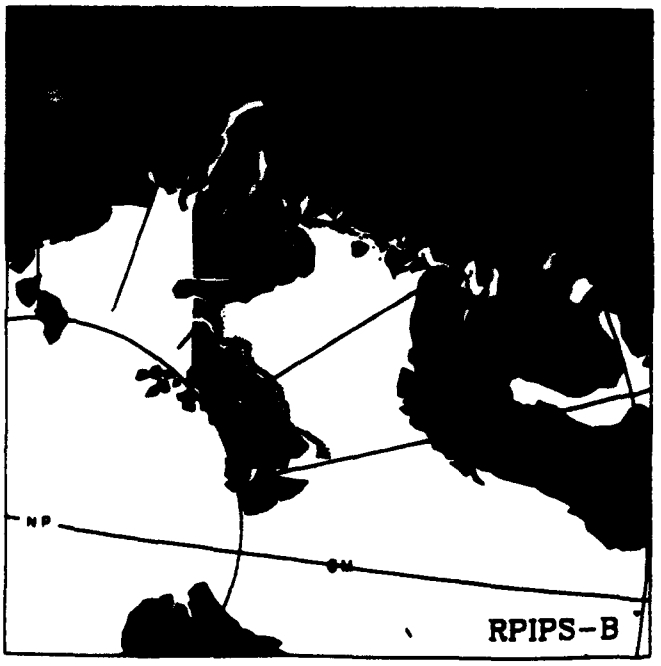

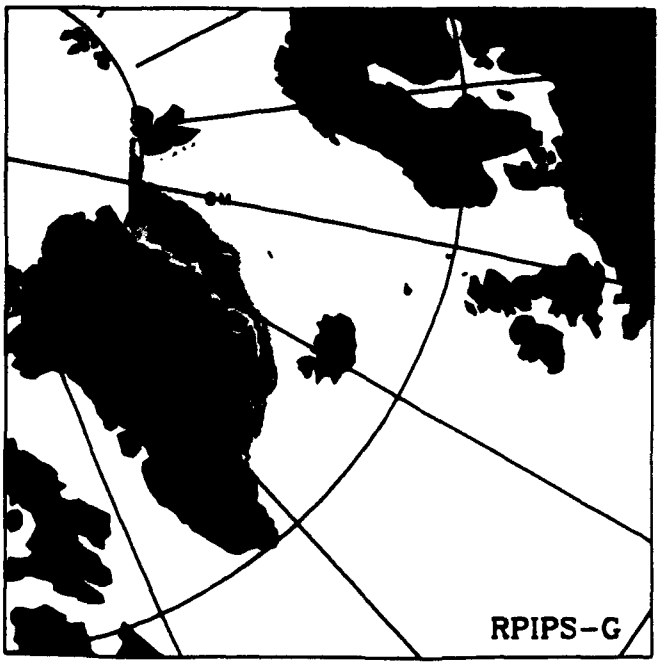

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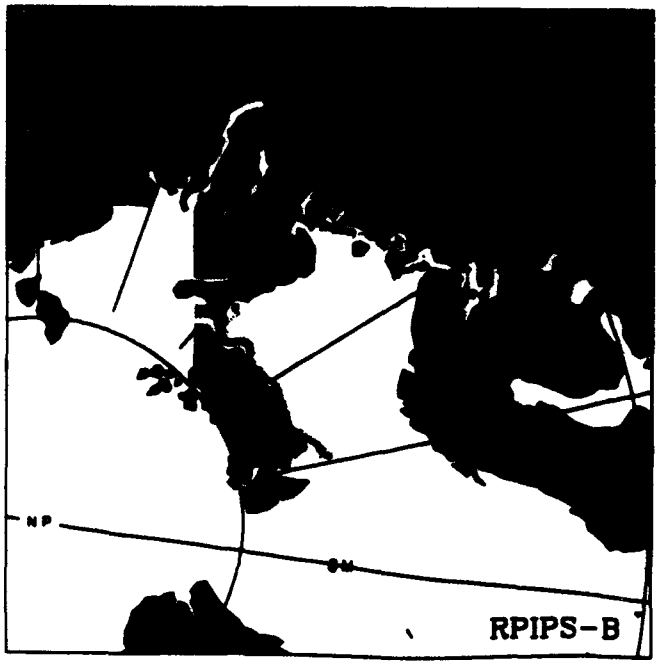

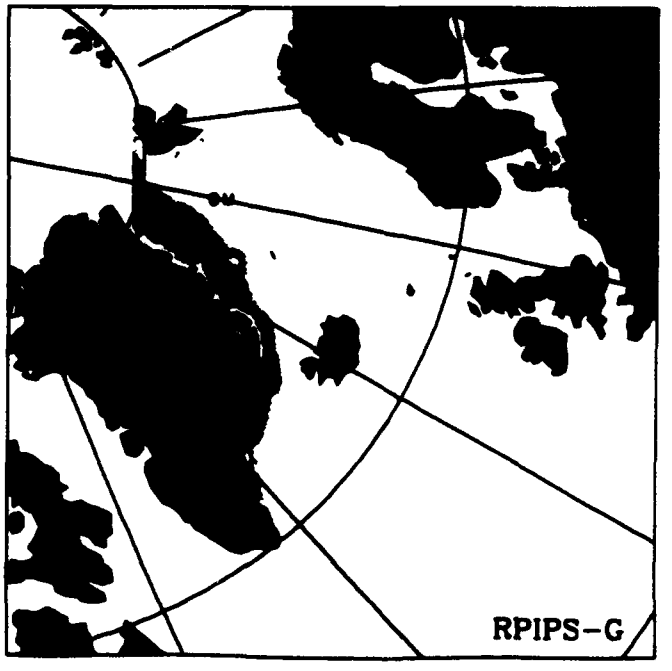

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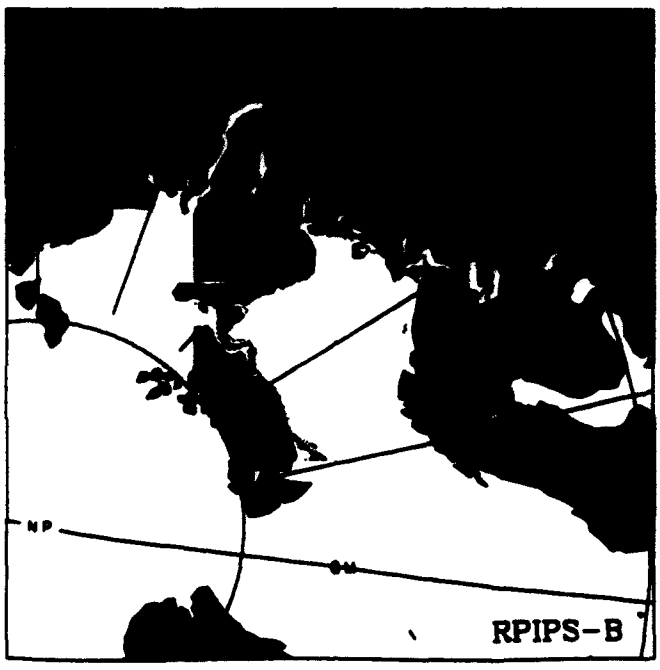

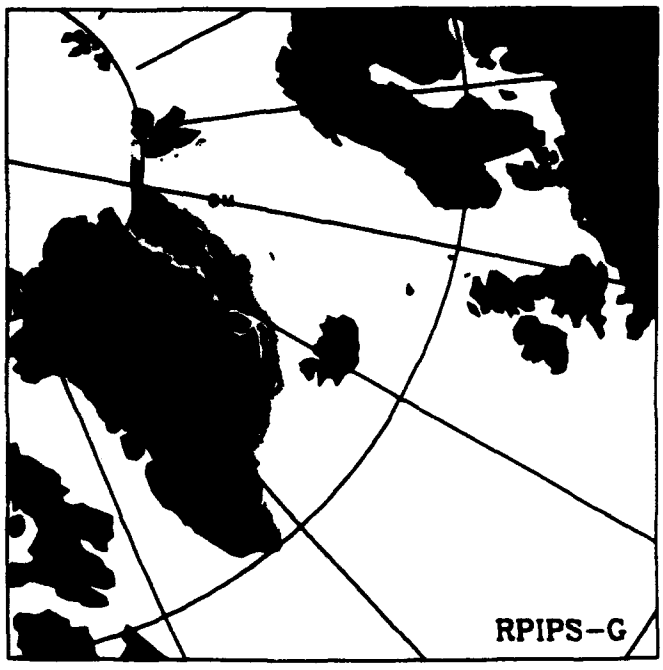

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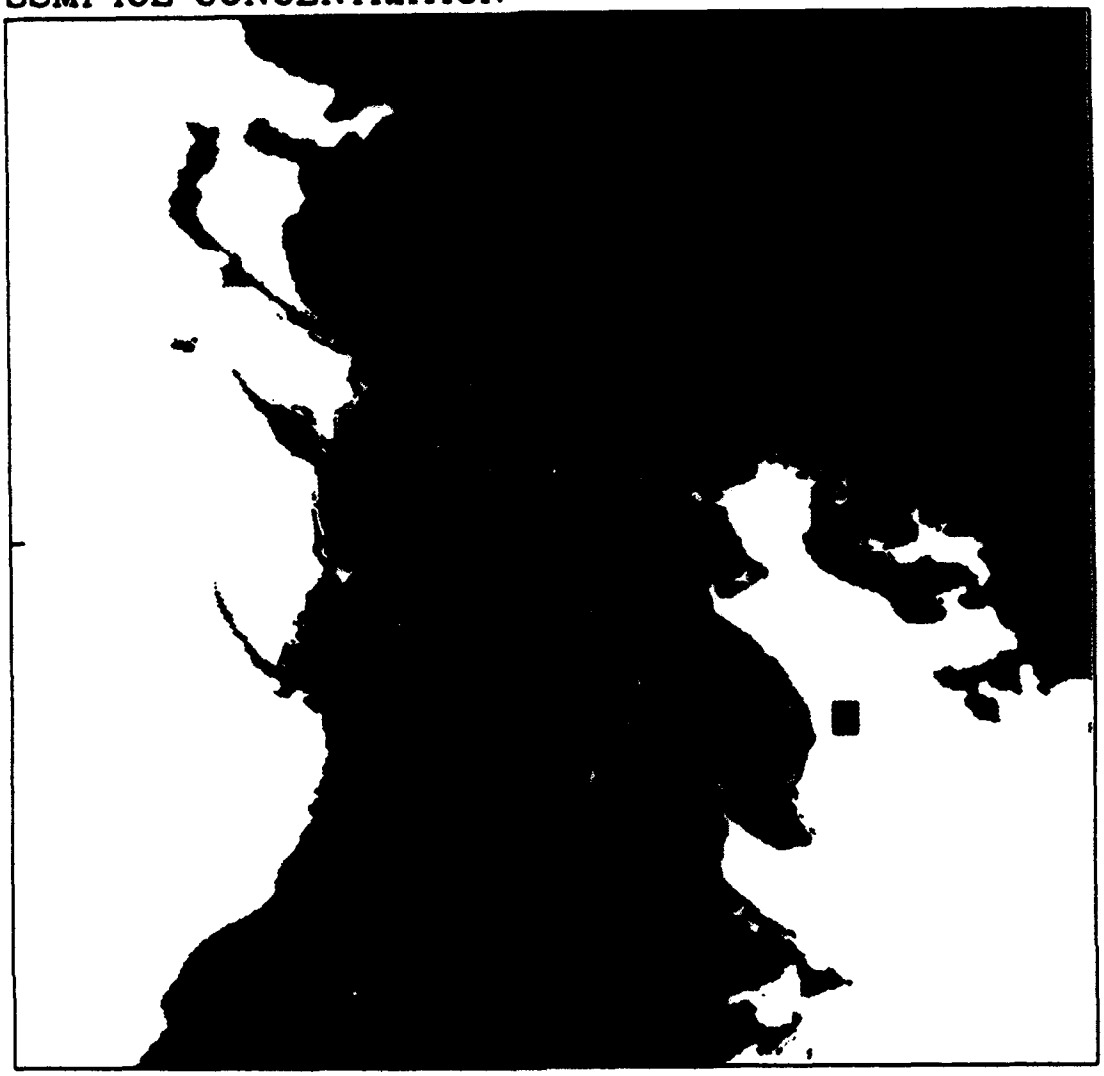

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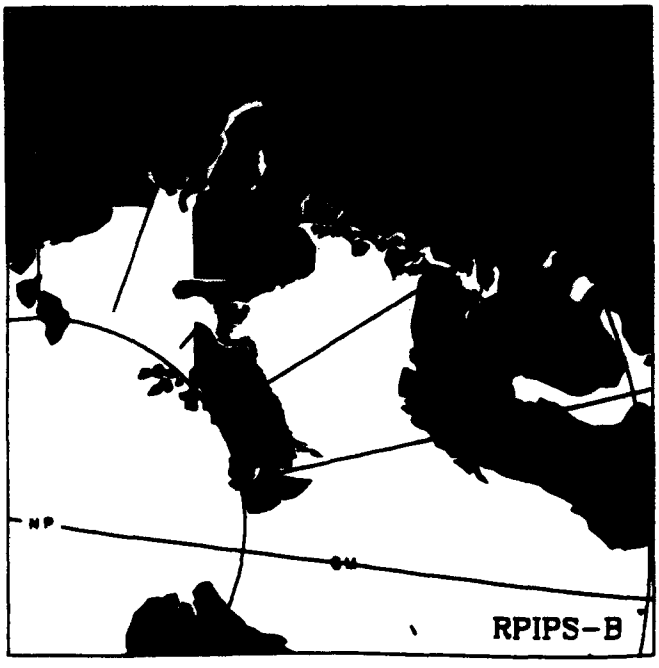

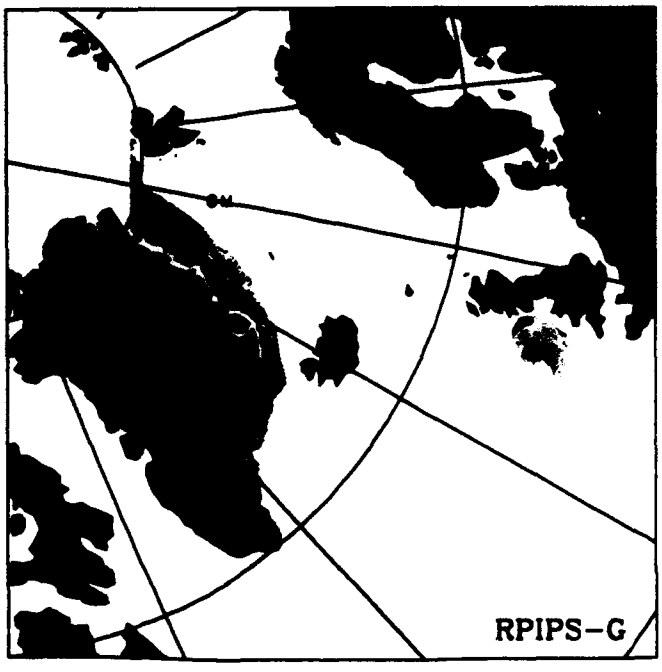

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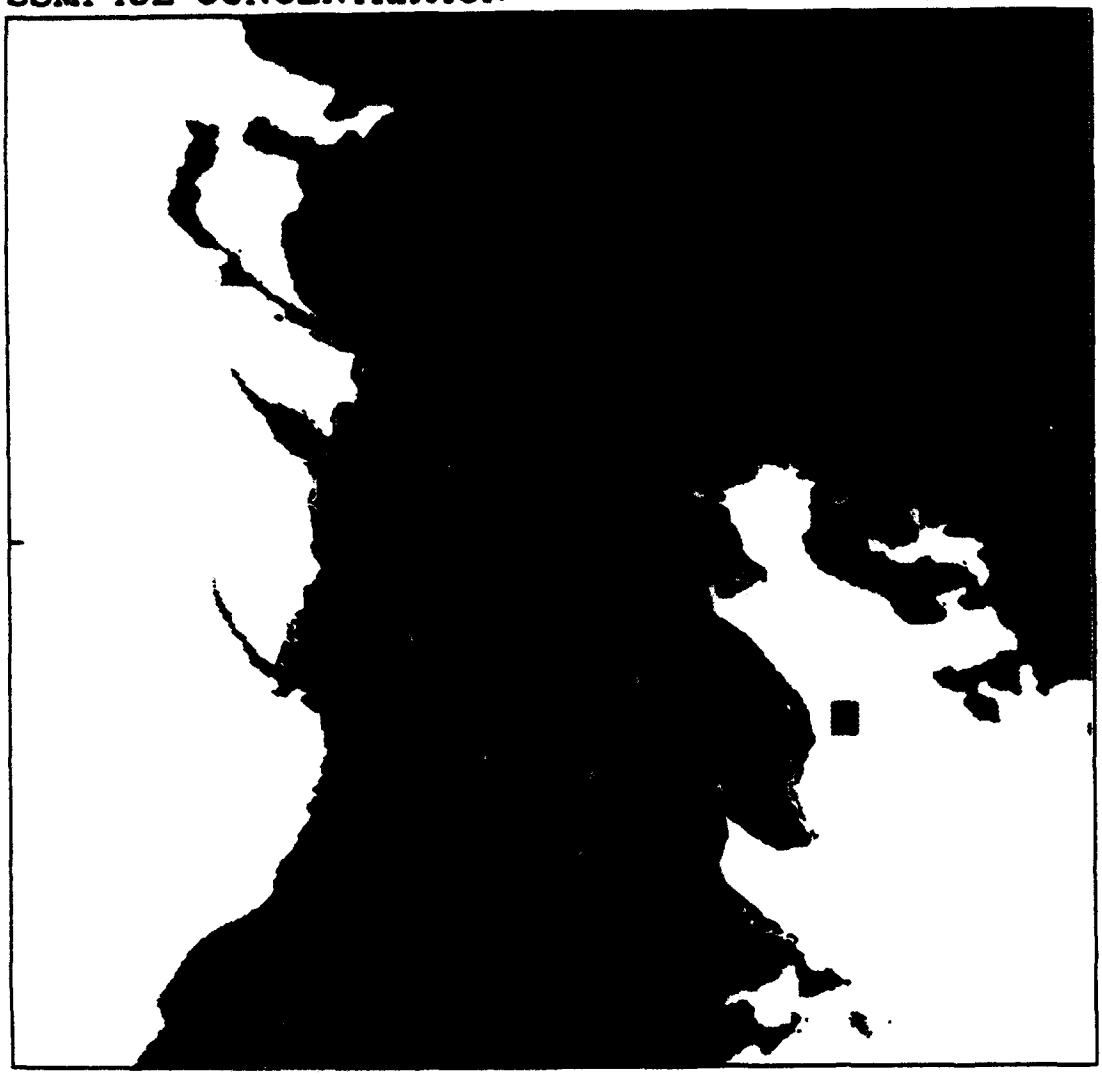

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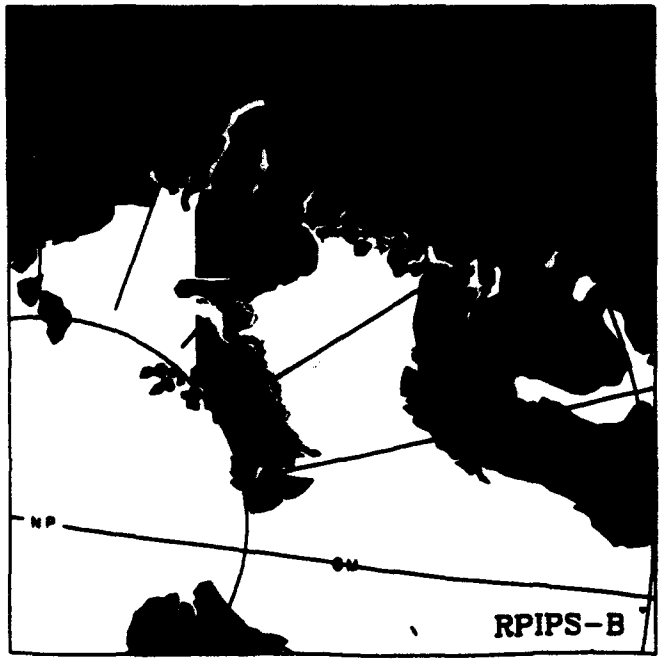

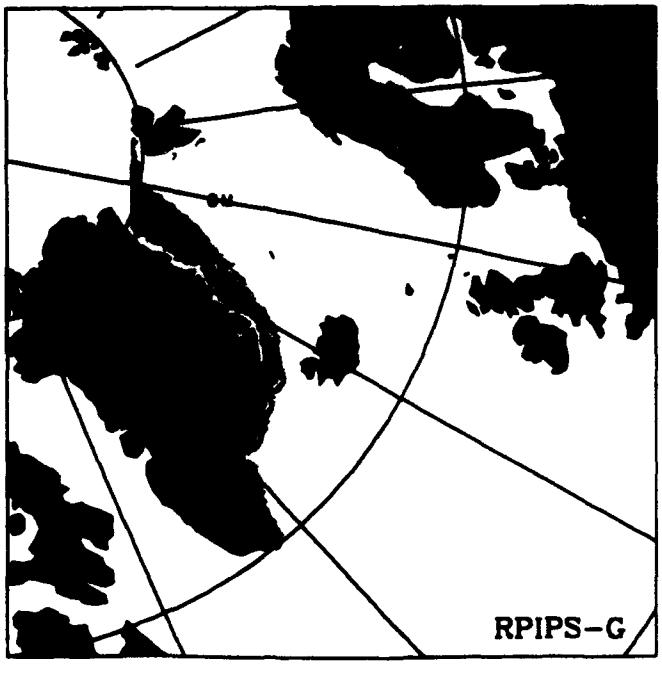

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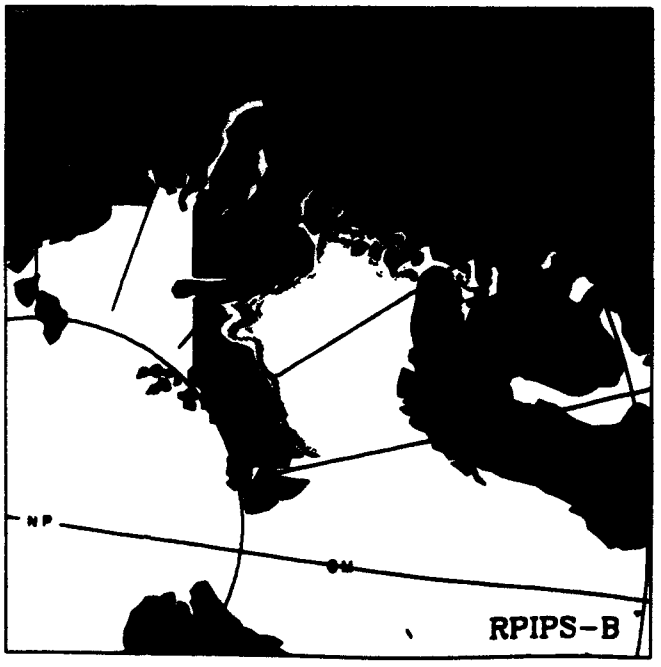

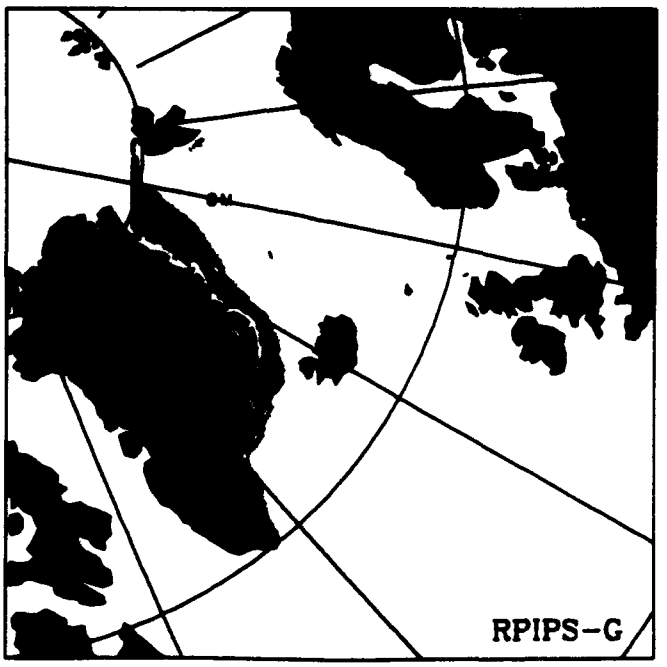

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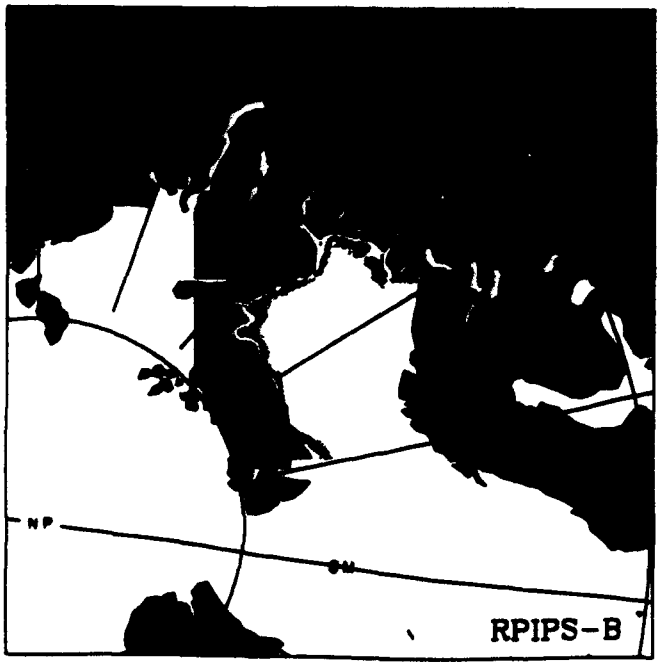

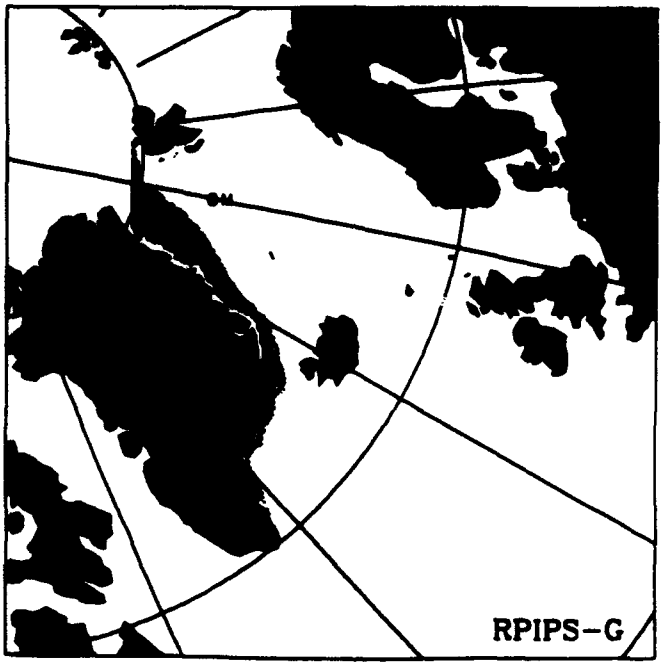

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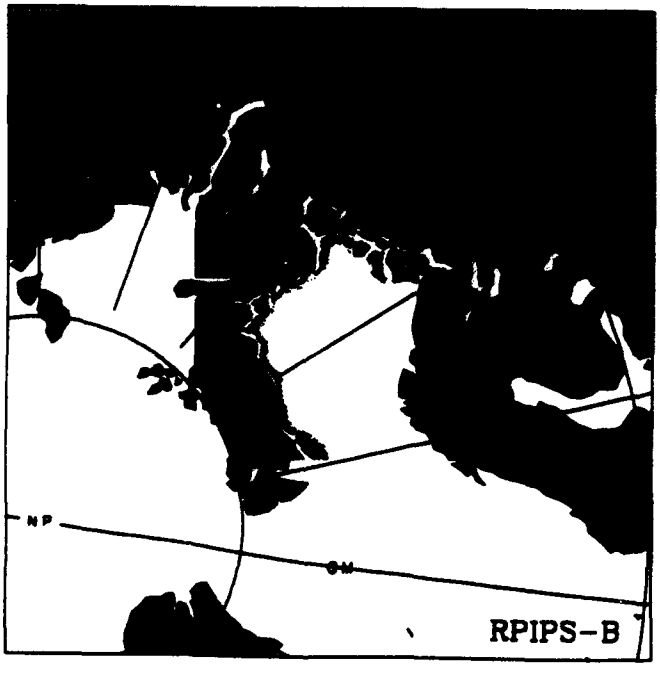

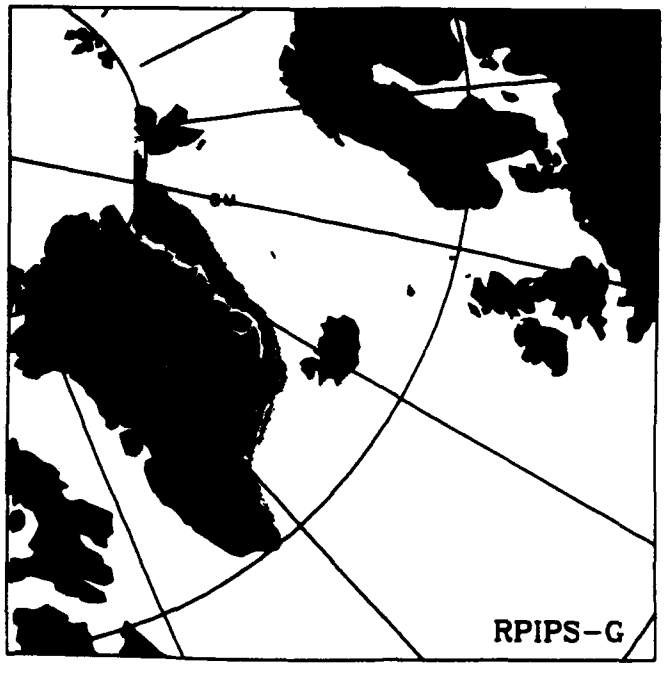

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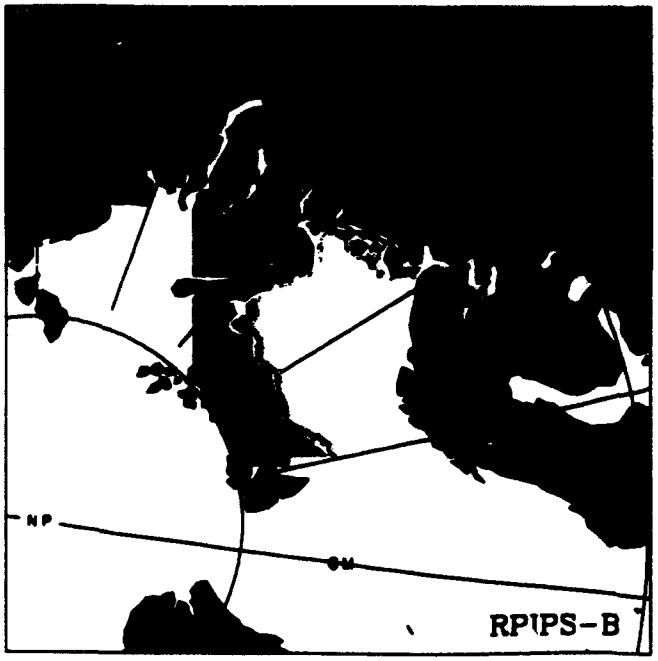

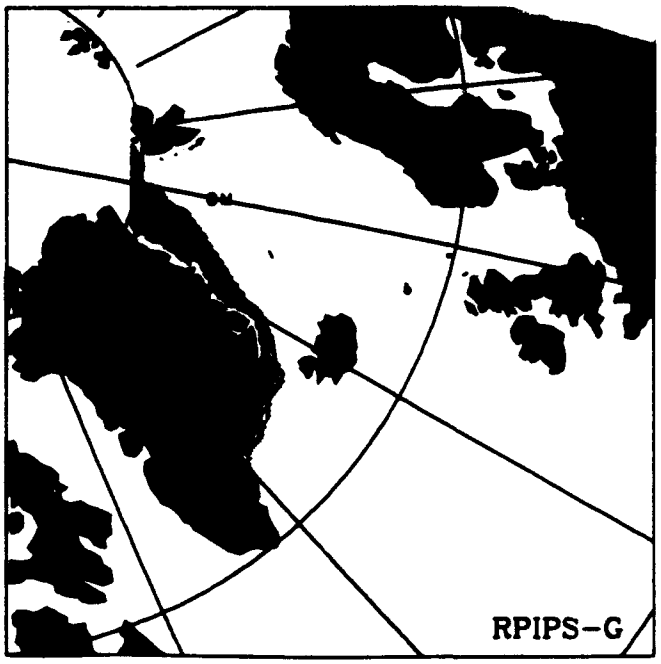

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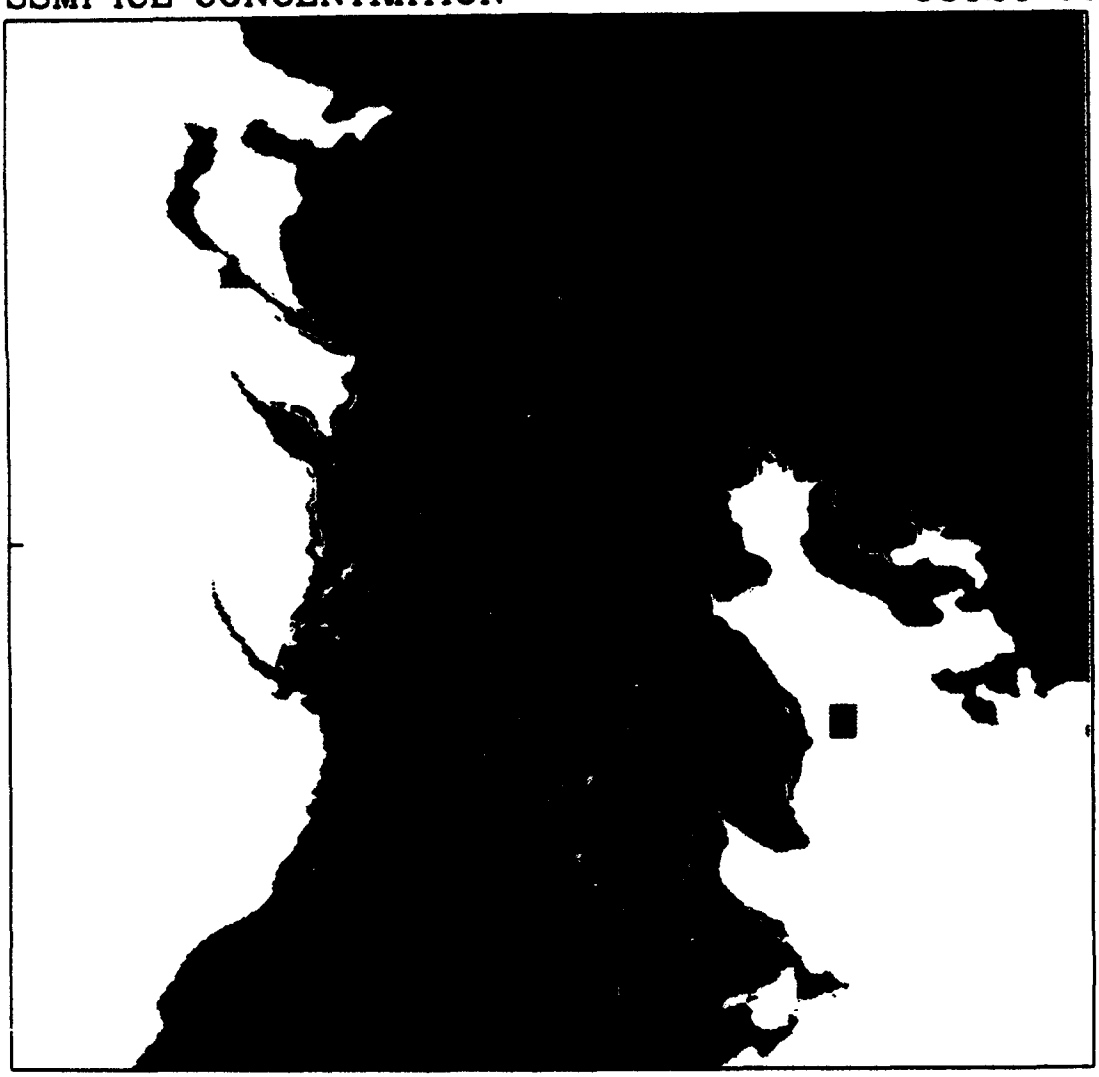

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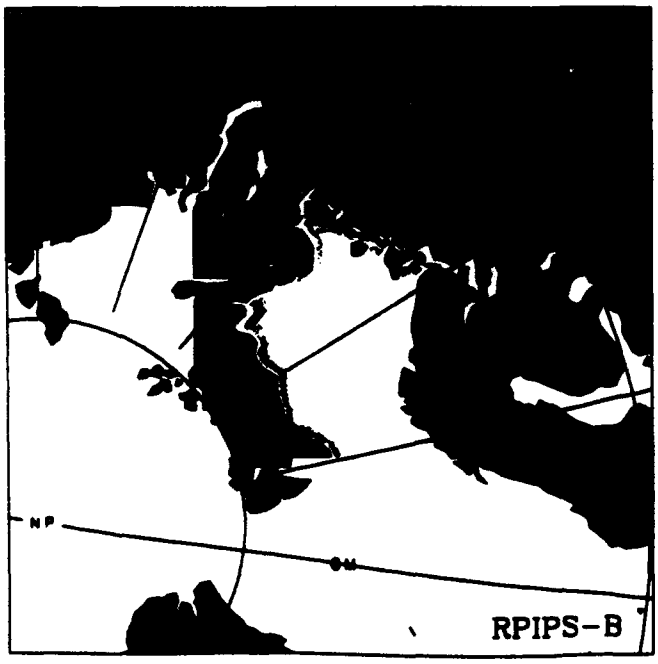

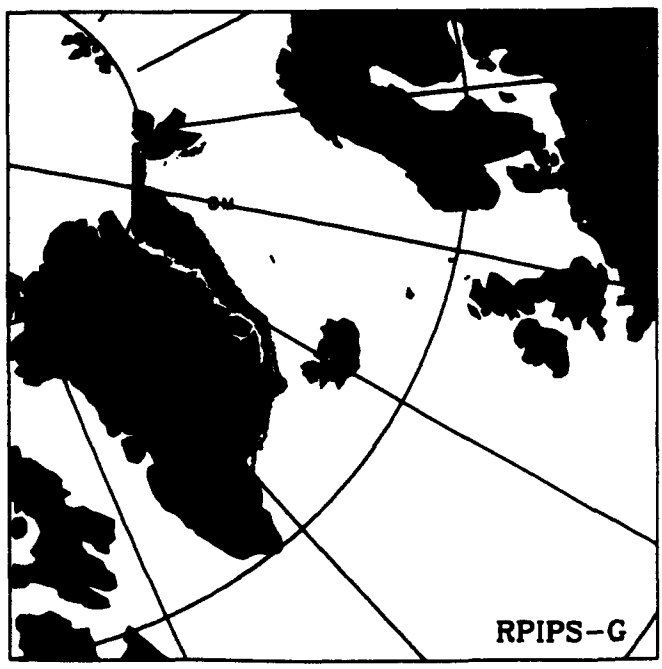

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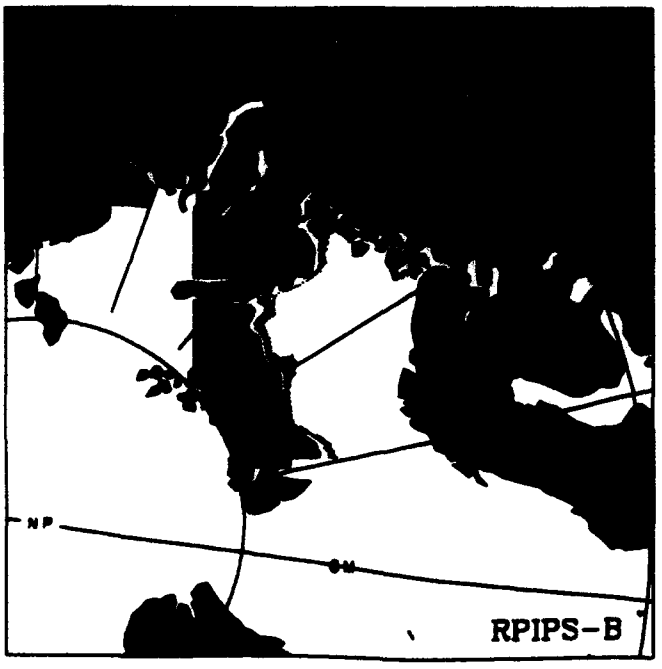

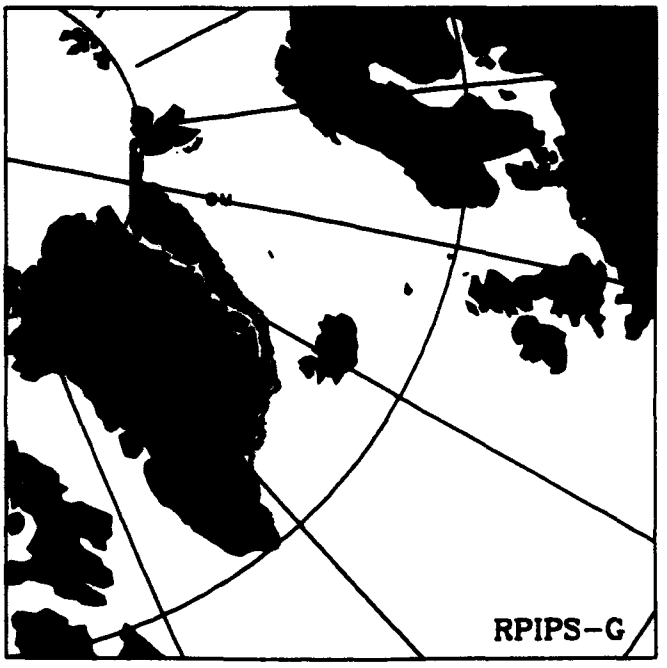

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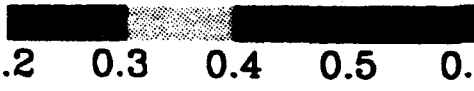

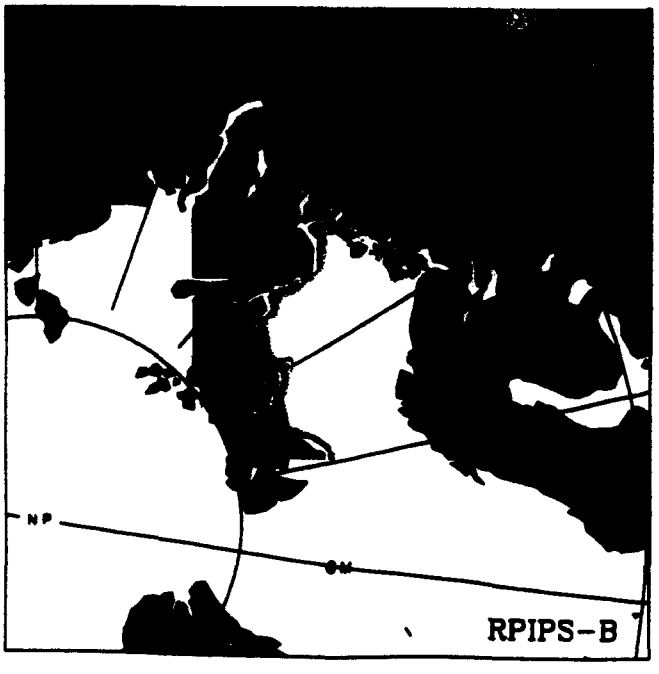

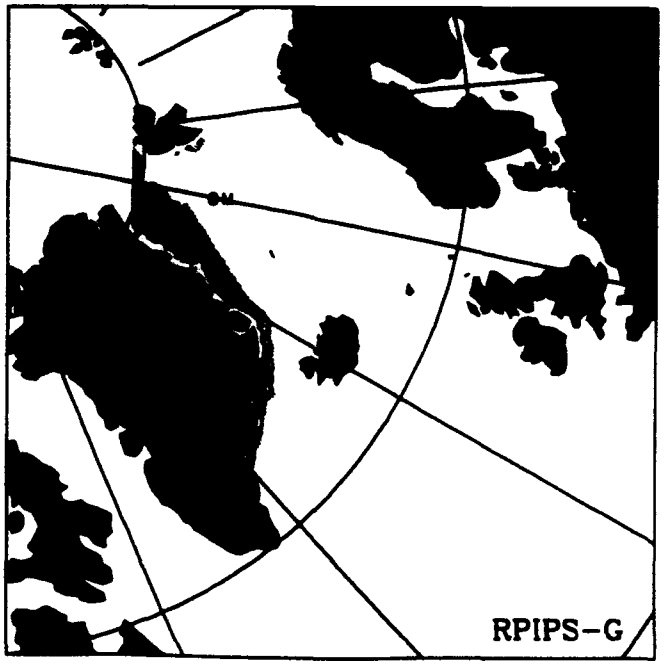

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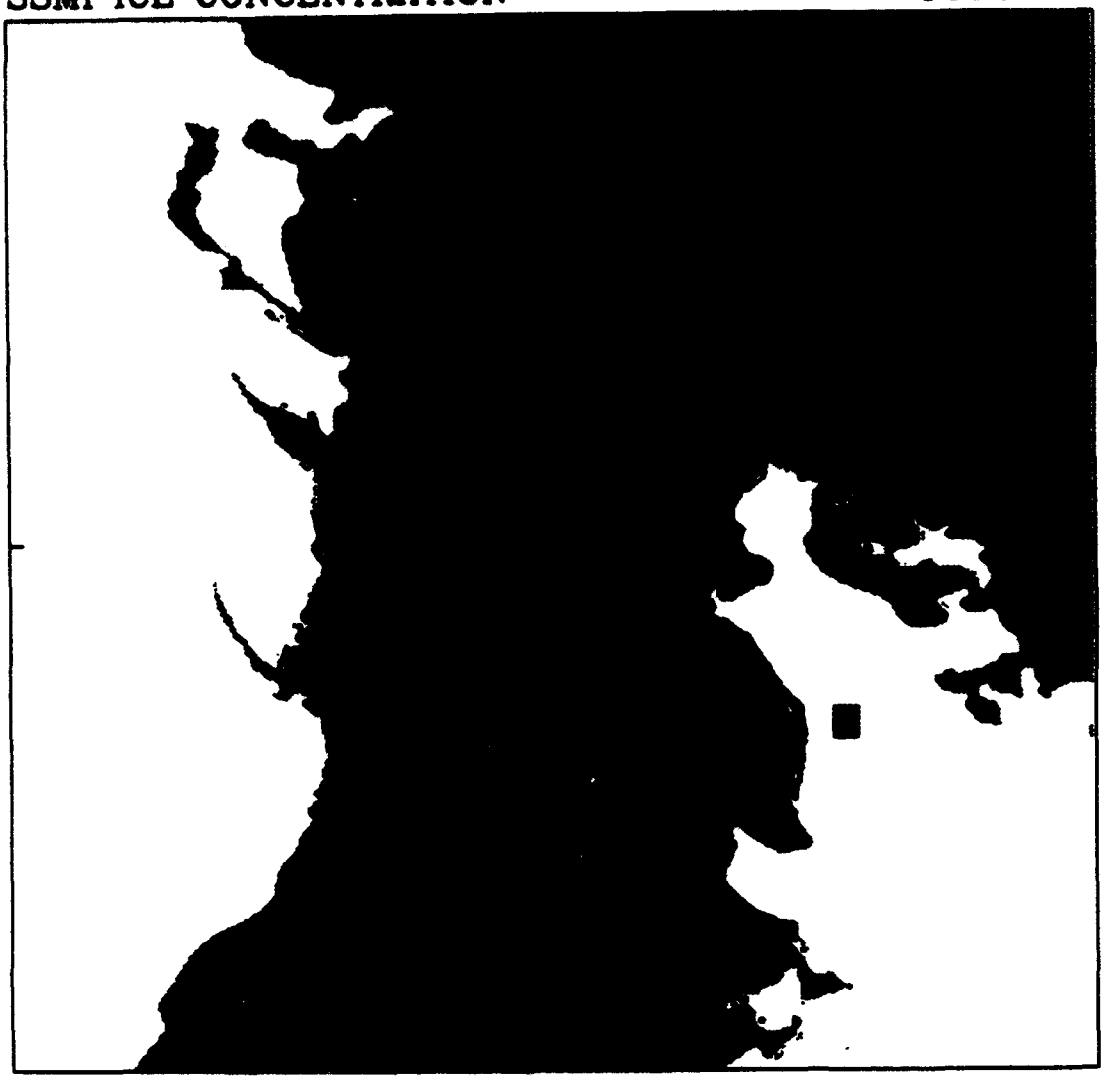

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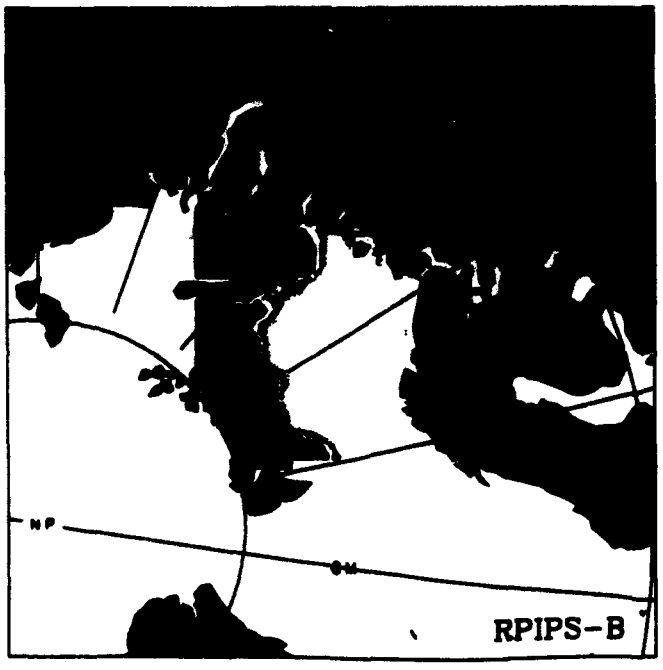

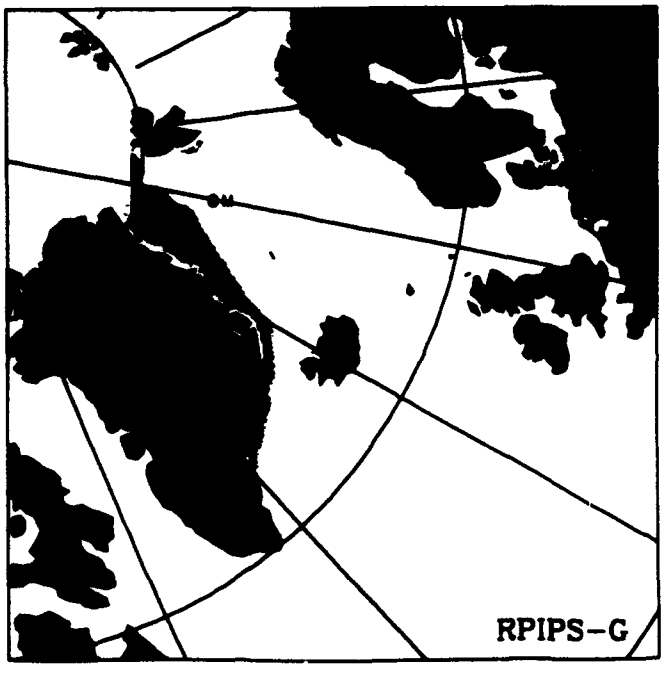

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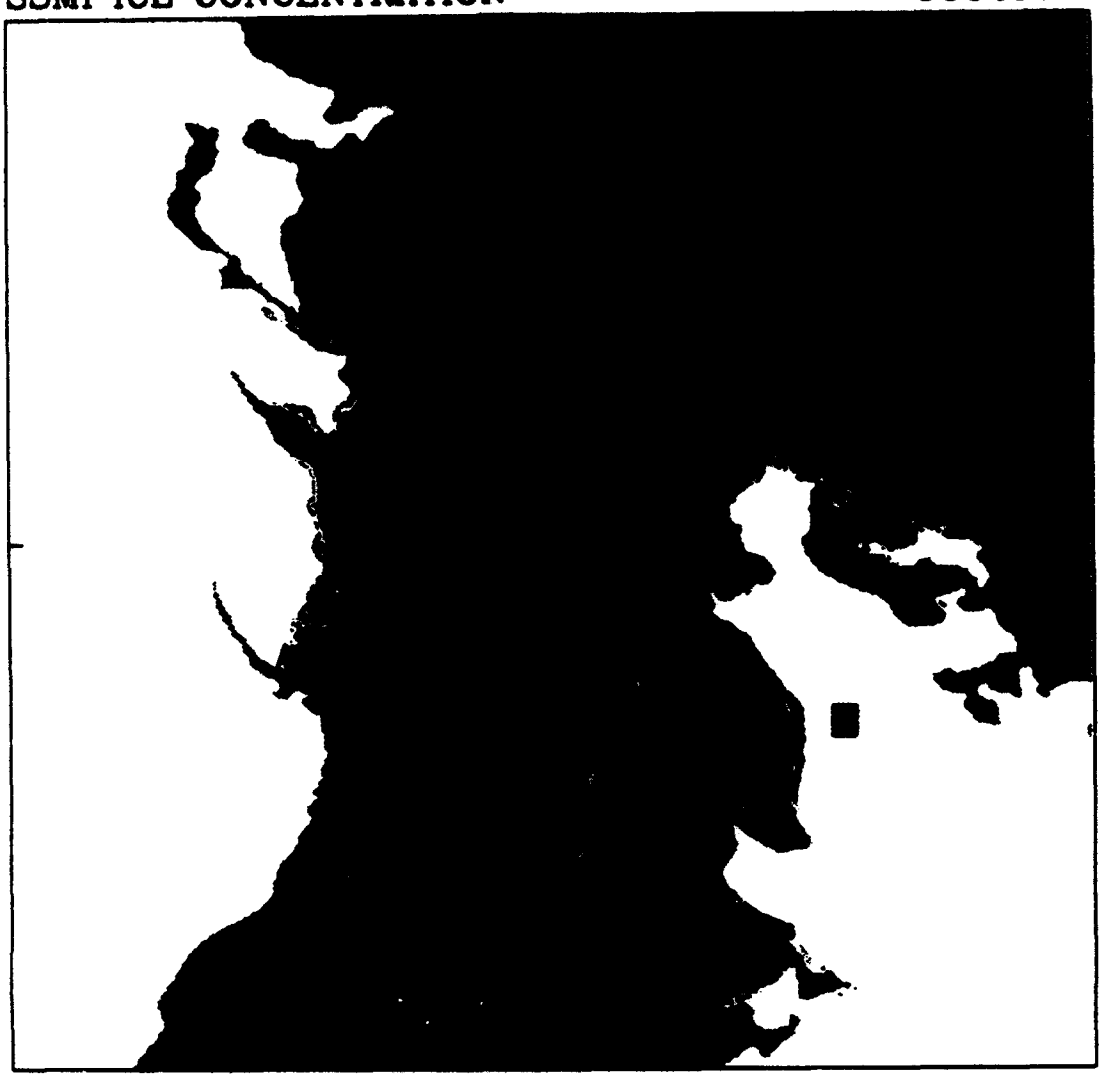
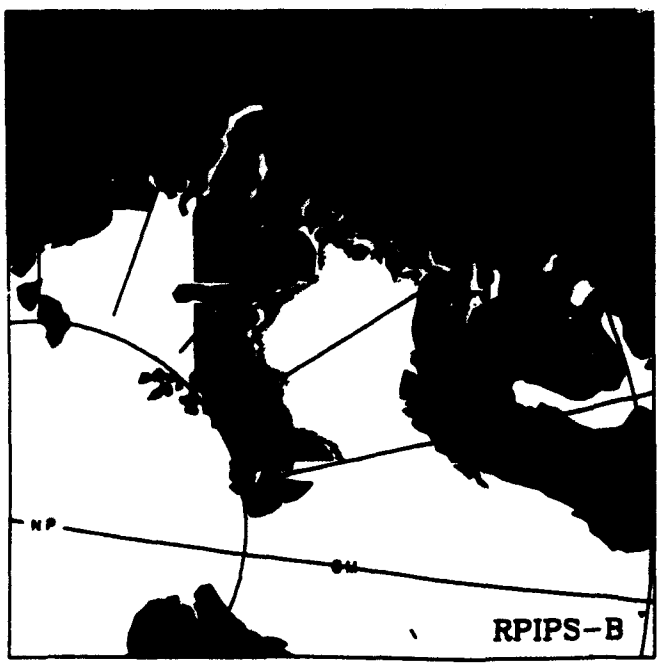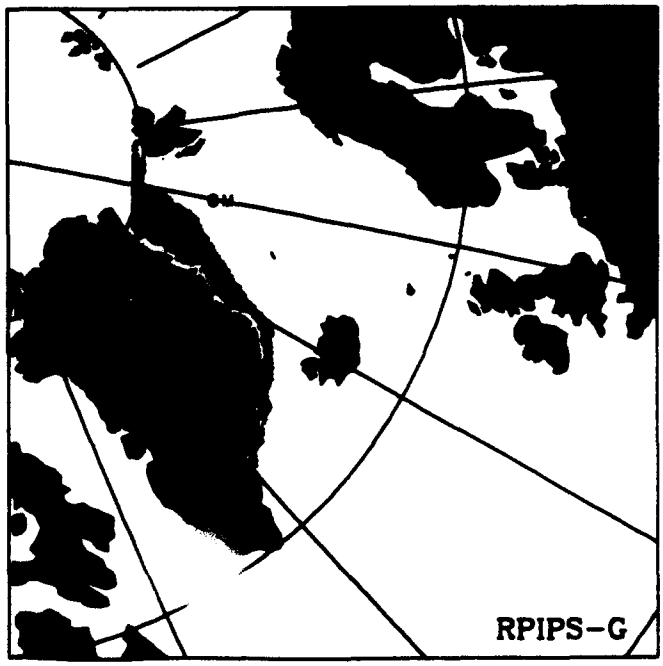
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0