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Sea Ice Motions in the Central Arctic Pack Ice as Inferred from AVHRR Imagery

Final Progress Report

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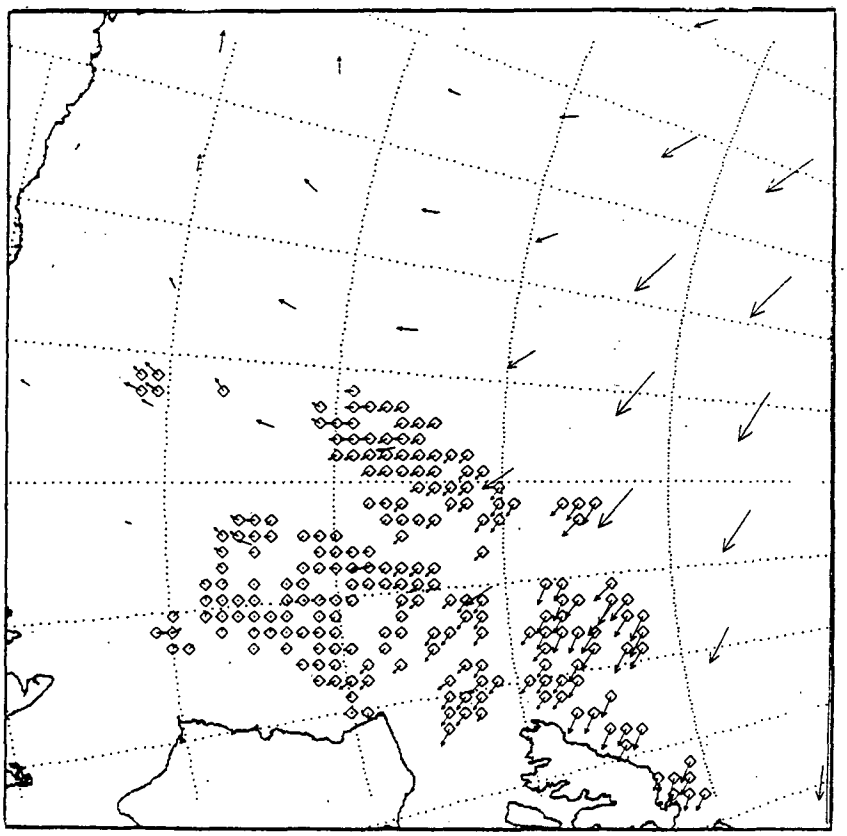
William Emery, James Maslanik, Charles Fowler

Colorado Center for Astrodynamics Research
University of Colorado
Boulder, Colorado 8030
emery@orbit.colorado.edu (William Emery)
jimm@northwind.colorado.edu (James Maslanik)



5 cm/sec 10 cm/sec

◇ –AVHRR VECTORS

MODEL VECTORS (arrows only)

(NASA-CR-198835) SEA ICE MOTIONS IN THE CENTRAL ARCTIC PACK ICE AS INFERRED FROM AVHRR IMAGERY Final Progress Report (Colorado Univ.) 26 p

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1.0 Rationale and Objectives

Synoptic observations of ice motion in the Arctic Basin are currently limited to those acquired by drifting buoys and, more recently, radar data from ERS-1. Buoys are not uniformly distributed throughout the Arctic, and SAR coverage is currently limited regionally and temporally due to the data volume, swath width, processing requirements, and power needs of the SAR. Additional ice-motion observations that can map ice responses simultaneously over large portions of the Arctic on daily to weekly time intervals are thus needed to augment the SAR and buoy data and to provide an intermediate-scale measure of ice drift suitable for climatological analyses and ice modeling.

Principal objectives of this project were to: 1) demonstrate whether sufficient ice features and ice motion existed within the consolidated ice pack to permit motion tracking using AVHRR imagery; 2) determine the limits imposed on AVHRR mapping by cloud cover; and 3) test the applicability of AVHRR-derived motions in studies of ice-atmosphere interactions. Each of these main objectives was addressed. We conclude that AVHRR data, particularly when blended with other available observations, provides a valuable data set for studying sea ice processes. In a follow-on project, we are now extending this work to cover larger areas and to address science questions in more detail.

2.0 Research Highlights

This section provides a quick overview of some of the most significant results.

- Daily ice motion fields were generated for the Beaufort Sea for July 1992 - June 1993 using AVHRR 1 km imagery and a combination of optimally-interpolated AVHRR and drifting buoy observations. The products have been archived at NSIDC;

- While cloud cover is extensive in the Beaufort, cloudiness did not preclude the retrieval of useful ice motion data from AVHRR;

- Mean ice-drift patterns were determined for summer and winter, and for high-pressure and low-pressure atmospheric regimes;

- The spatial and temporal correlations of motions were estimated for different time periods and synoptic conditions. The motion fields exhibit a pronounced directional component of drift that appears de-coupled from the NMC geostrophic winds. Either (1) the ice conditions exert a strong non-isotropic control on drift speed as a function of direction (either at the micro scale, or on a macro scale [such as due to pre-existing lead patterns]). (2) the coupling of wind stress with the surface differs substantially with synoptic conditions. or (3) the NMC winds have large errors;

- Summaries of remotely-sensed motions over different time intervals suggest that substantial errors in estimates of open-water production are possible if the data are sampled at the seven-day time interval proposed for operational production within the RADARSAT Geophysical Processing System (GPS);

- Comparisons of AVHRR-derived motions to buoys and SAR motions showed good agreement - sufficient to conclude that the AVHRR provides useful ice motion data. Uncertainties in precise location due to the AVHRR field of view and geolocation accuracy introduce errors that are significant for calculating ice divergences. However, these errors are random and thus should not affect mean fields. A source of bias in the AVHRR-derived motions exists since motions are observed only for thin-cloud or clear-sky conditions, and thus reflect motions during synoptic conditions that favor thin cloud or reduced cloud fraction;

- The remotely-sensed motion fields provide a valuable comparison set for investigating ice model performance. In general, the ice models used capture the basic aspects of the motion pattern, but some large differences were noted (mostly related to the directional differences between winds and ice motion noted above). Intercomparisons of Special Sensor Microwave/Imager (SSM/I)-derived and model-estimated changes in ice concentration with the AVHRR-derived motion fields show some correlation in space and time. However, magnitudes of open-water production differ substantially among the different data sets. In particular, the comparison suggests that the ice model as used may need to be modified to include open-water production due to shear;

- A version of our 2-dimensional dynamic-thermodynamic sea ice model was developed to test the use of the observed ice motions directly within the model. Twelve-month simulations were performed using the AVHRR-derived motion fields in a simple data assimilation experiment;

- This project supported the Ph.D. research of Charles Fowler, who will complete his thesis defense this summer. His Ph.D. dissertation is titled "Ice Motion Derived from Satellite Remote Sensing with Application to Ice Studies in the Beaufort Sea."

Publications:

Maslanik, J.A., C. Fowler, J. Heinrichs, R.G. Barry, and W.J. Emery, 1995. Remotely-sensed and simulated variability of Arctic sea-ice concentrations in response to atmospheric synoptic systems. *Int. J. Remote Sensing*. (in press)

Emery, W.J., C. Fowler, and J.A. Maslanik, 1994. Arctic sea ice concentrations from SSM/I and AVHRR satellite data, *J. Geophys. Res,* 99, C9, 18,329-18-342.

Maslanik, J.A. and H. Maybee, 1994. Assimilating remotely-sensed data into a dynamic-thermodynamic sea ice model. IGARSS '94, Pasadena, CA, 1306-1308.

Fowler, C.A., J.A. Maslanik, and W. Emery, 1994a. Observed and simulated ice motion for an annual cycle in the Beaufort Sea. IGARSS '94, Pasadena, CA

Maslanik, J.A., C. Fowler, W.J. Emery, J. Heinrichs, and R.G. Barry, 1994. Ice-atmosphere interactions in the central Arctic: Remotely-sensed and simulated ice concentration and motion. Proc. Second ERS-1 Symposium, ESA SP-361, Hamburg, 373-378.

Fowler, C., J.A. Maslanik, and W.J. Emery, 1994b. Observed and simulated responses of a high-concentration ice cover to synoptic weather systems. Submitted to J. Geophys. Res., (previously submitted, rejected, and now being revised for resubmission).

Additional publications based on this work are planned.

3.0 Summary of Methods and Results

This section provides more detail on the methodology and results.

3.1 Motion Retrieval Methodology

Our efforts to generate and apply AVHRR-derived motion data build upon earlier work on algorithm development. In this project, we have extended the AVHRR ice-motion product generation to address applications of motion data to the study of ice-atmosphere interactions through observations and modeling (e.g., Fowler et al., 1994a, 1994b; Maslanik and Maybee, 1994; Maslanik et al., 1994, 1995; Emery et al., 1994). Efforts during this project centered on the production and use of a one-year sequence of daily AVHRR data for a 1000 km x 1000 km region covering the Beaufort Sea (Fowler et al., 1994a). As part of this effort, ice motion fields were calculated from AVHRR data for Oct. 1991 and June 1992 - June 1993 for a 1000 km x 1000 km region in the Beaufort Sea. For the June 1992-June 1993 period, AVHRR motions were combined with buoy motions using optimal interpolation to provide daily motions on a uniform 12 km grid. Ice motions and ice conditions were intercompared using AVHRR, SAR, SSM/I, drifting buoys, and sea ice model output. Simulations were performed in which the daily ice velocities from the interpolated AVHRR and buoy observations were assimilated directly into a 2-dimensional ice model

The basic AVHRR processing steps include geolocation, calibration, and product generation. Ice-motion mapping requires precise geolocation (Fowler et al., 1994a). We have devised an automated procedure (the Polar Region Ice Motion System or PRIMS) to implement this scheme (Figure 1). In turn, PRIMS is a component of a larger software scheme (Figure 2), which includes production of other polar data from AVHRR such as the CASPR or SATR retrievals developed by J. Key for the POLES effort. The advantage of combining PRIMS with other elements of AVHRR processing is that since most of the data processing effort is used by the initial step of retrieving, downloading, and navigating the AVHRR imagery, the additional PRIMS and CASPR processing add only modest extra cost.

Using software developed at the Colorado Center for Astrodynamics Research (CCAR) at the Univ. of Colorado, AVHRR swaths are geocoded using orbital ephemeris combined with corrections for pitch, roll, and yaw of the platform (Figure 2). The resulting images were then typically examined visually and shifted using control points to achieve the maximum geolocation accuracy. (Fully-automated registration that removes this step have been tested successfully).

While the determination of ice motion does not require calibrated data, we calibrated our AVHRR sets to allow for retrievals of other parameters such as surface albedo, temperature, and cloud properties. Typical calibration procedure includes calibration coefficients for the reflected-wavelength channels (channels 1 and 2) determined by the AVHRR Land Pathfinder project using post-launch comparisons to ground targets. Thermal channels (Channels 3, 4, and 5) are calibrated according to the on-board calibration readings in the AVHRR data stream using non-linear corrections. The geolocated and calibrated imagery were mapped to a polar stereographic projection. As part of the pre-processing stage, a spectral clustering routine is used to detect three basic cloud classes. Cloud- covered areas are then masked out prior to calculating ice motions, and can be saved as a separate product.

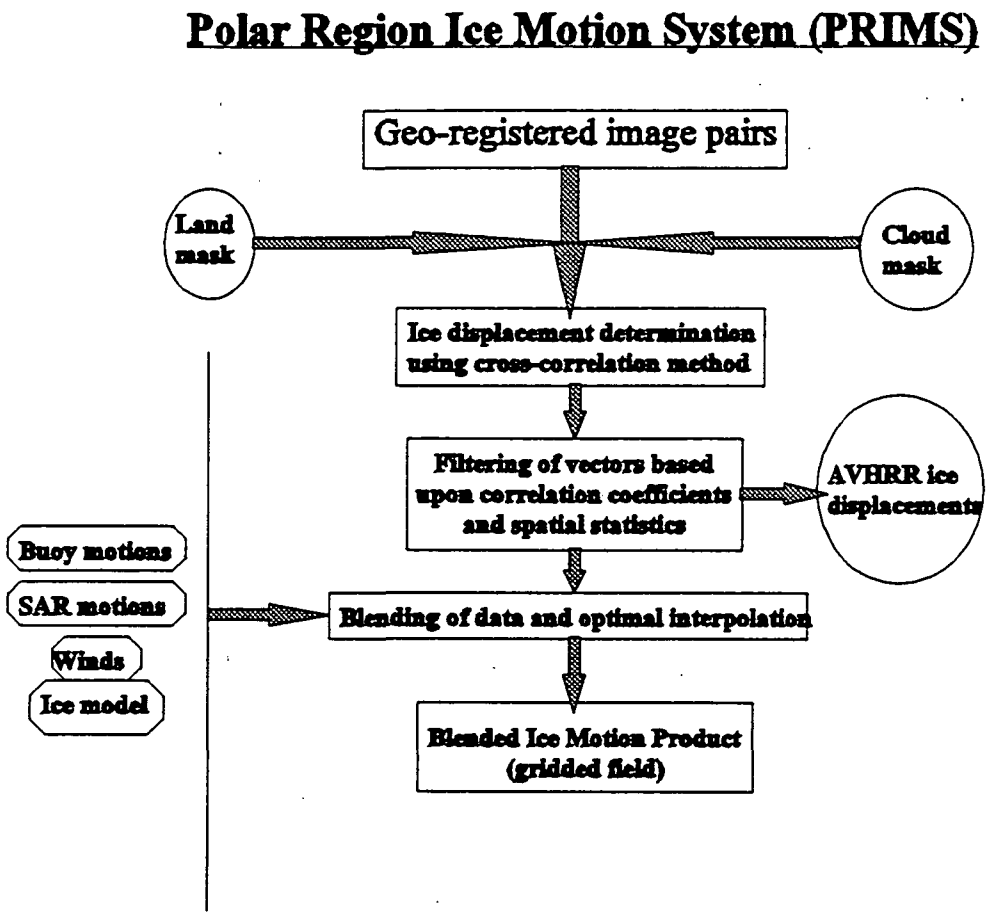


Figure 1. Basic steps in the generation of AVHRR-derived ice motion products.

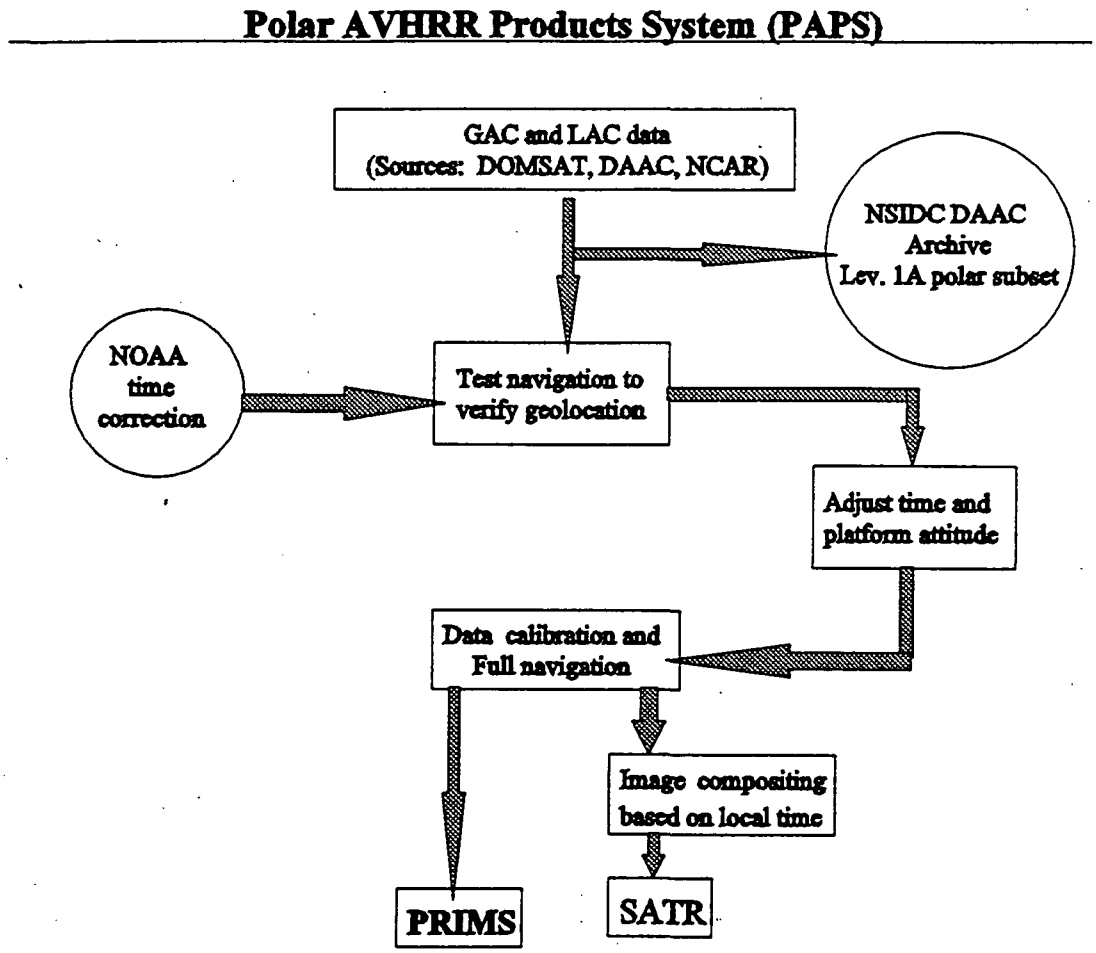


Figure 2. Pre-processing steps for AVHRR navigation and calibration.

3.2 Results

The techniques described above have been developed and tested to determine ice motion from AVHRR imagery. These methods produce ice velocity vectors in quantities up to 3 orders of magnitude, depending upon cloud cover, greater than the numbers of vectors using buoy information. During the summer, the visible channel is used, while the infrared channel is used during the winter.

For a pair of images with little or no cloud cover, a vector field can be generated such as that given in Figure 3. This vector field was determined from a pair of images on July 6 and 7, 1992. The vectors clearly show a strong clockwise rotation of the ice in the Beaufort Sea. The ice has retreated along the coastlines where no vectors are present. In the lower right, near the Sverdrup Islands, there is fast ice with no motion. Also in these data, two fairly large regions with little ice motion in the center of the study area appear to move south-southeast in a coherent way from July 5 to July 17 (July 17 map not shown). These regions may relate to the "slabs" of ice that have been detected in SAR data (H. Stern, pers. comm., 1994). Other, smaller regions with apparent coherent motions can be seen in these and other examples. Such details of ice movement are not available from motion data derived from the existing buoy record due to limited spatial coverage (four to five buoys mainly in the periphery of the study region), and in ERS-1 SAR data due to the narrow swath width of the SAR.

For the one year data set over the Beaufort Sea, the percentage of vectors produced on a daily basis at any one location ranges from 5 to 35 percent of the time (Figure 4). Thus, even though clouds are common, a substantial sampling of vectors is still possible. Percent sampled in coastal areas is less because ice is not present throughout the year, and some areas were sampled less frequently at the edges of the study region. For the entire area, 17 percent of the area will have vectors. The sampling shown in Figure 4 is not evenly distributed over time - a region may have vectors available for a number of days running, and then no AVHRR-derived vectors available for several days due to persistent cloud cover.

The sampling interval in space and time of the AVHRR data complement the other currently available data sets. For example, Figure 5 shows a comparison between the different available ice motion vectors from different remote sensing instruments. The small triangles show the limited number of buoy vectors at any particular time, usually 5 to 10 in the Beaufort Sea. The AVHRR derived vectors can number anywhere from none to several thousand on a 10 km grid. Ice velocity from the European and Japanese SAR satellites can produce a very dense ice velocity grid, but is confined to narrow strips and only on approximately three day intervals. The spatial coverage will improve with RADARSAT, but the anticipated ice velocities will be seven day averages.

We therefore conclude that overall, the AVHRR-derived vectors can substantially augment, but not replace, the existing buoy network. Also, persistence of clear-sky patches occasionally occur that allow the detailed study of daily ice motions for case studies. Combinations of motion fields and imagery (e.g., Figure 5) also provide an additional tool for studying ice

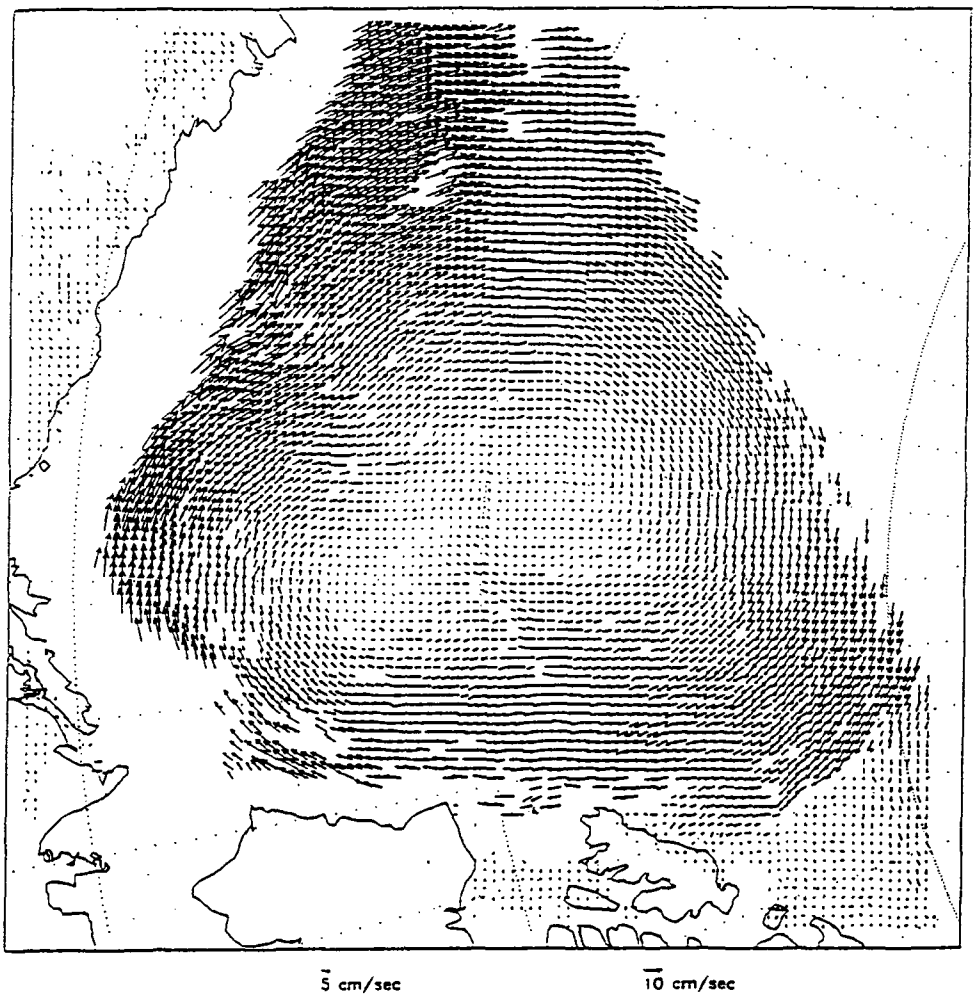


Figure 3 Ice motion from AVHRR (July 6 -7, 1992) showing the detailed coverage possible during extensive (and rare) clear-sky or thin-cloud conditions. Other examples are available that show detailed regional coverages.

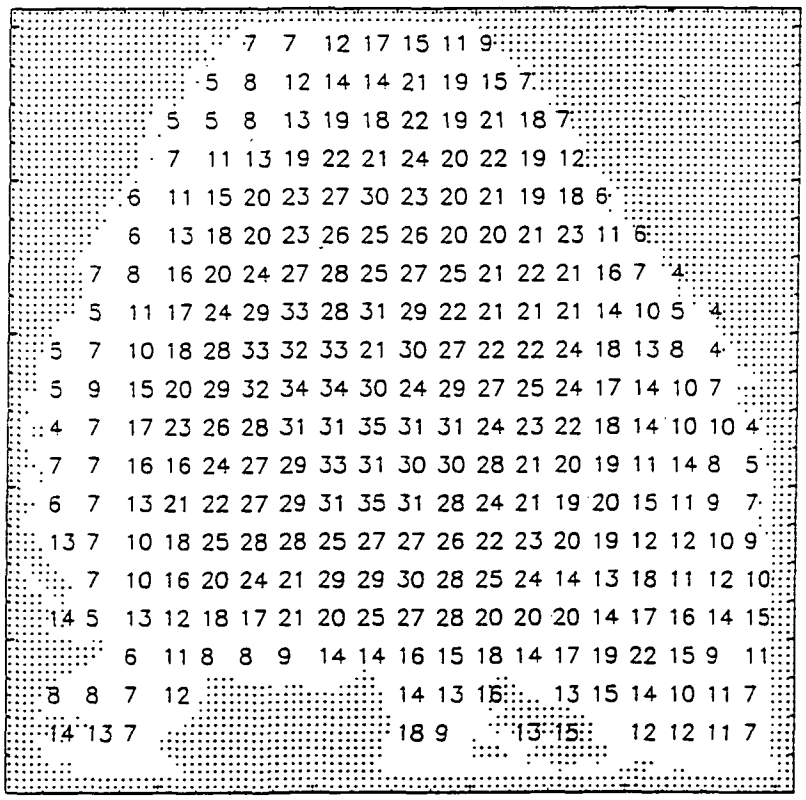
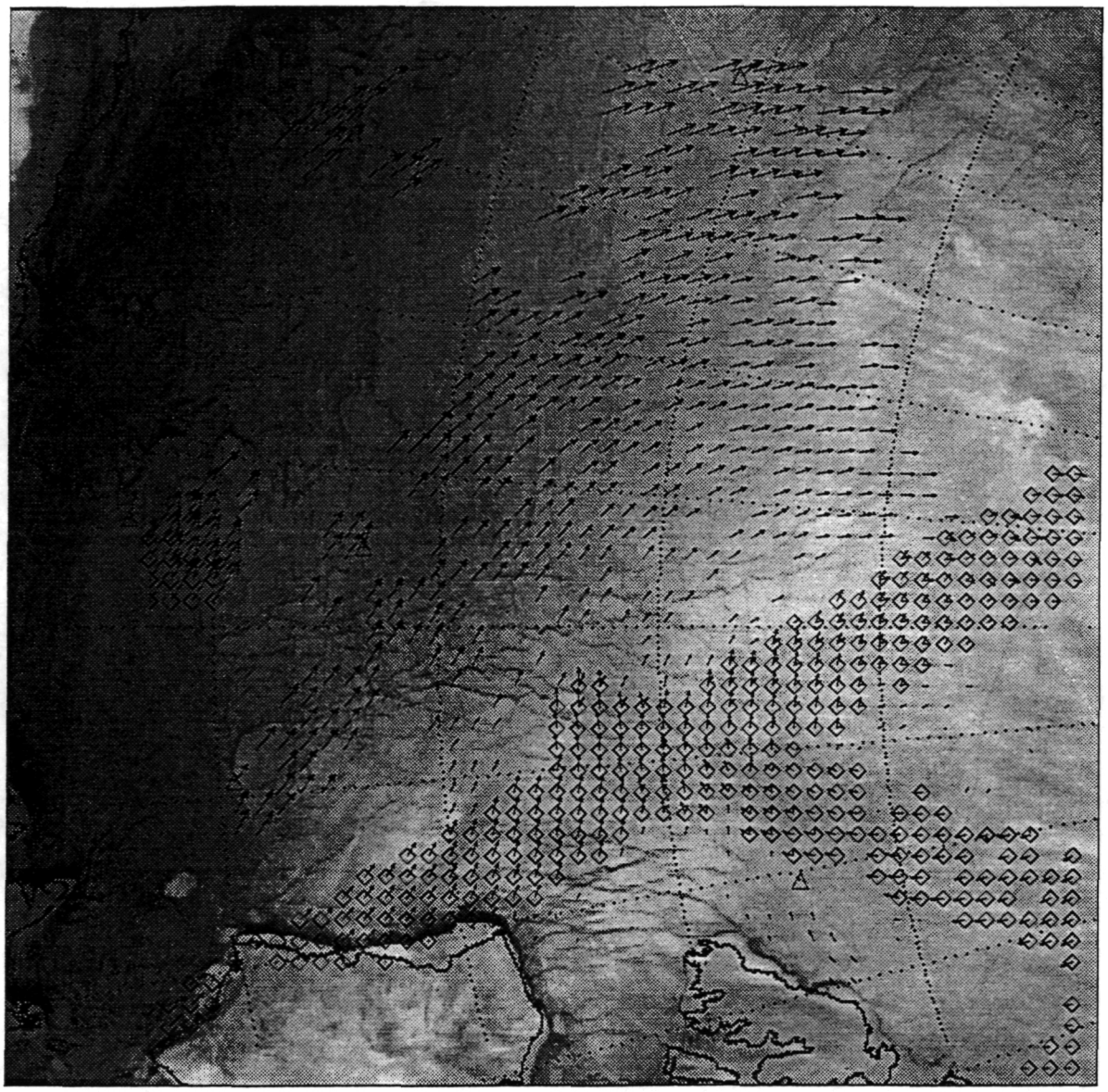


Figure 4 Percentage of available vectors from AVHRR over a 1 year period.



5 cm/sec 10 cm/sec

◇ –SAR VECTORS
△ –BUOY VECTORS
AVHRR VECTORS (arrows only)

Figure 5. Ice motion vectors from various sources, superimposed on an AVHRR thermal-channel image; ERS-1 SAR (diamond symbols), drifting buoys (triangles), and AVHRR data (arrows only). SAR vectors are displacements between Julian days 300 and 303, 1991. AVHRR and buoy data are for displacements between days 298 and 302, 1991.

dynamics. For example, note that in Figure 5, motions tend to be roughly perpendicular to the orientation of open or thin-ice leads, as has been suggested by other case studies. The generation of ice motion vectors in these quantities allows new information to be obtained regarding the movement of the sea ice, and the spatial and temporal coverage is suitable for comparison to ice models. Taking an average of all the vectors at each location, Ice motion in the Beaufort Sea is in a clockwise direction for both summer and winter periods, with stronger velocities during the summer; similar to drift patterns shown in summaries of drifting-buoy velocities. In addition, details of the mean ice motion emerge (Figure 6) that have not been obtainable previously. Rapid movement is apparent in the ice cover moving northwest away from the Alaska coast. Mean ice transport near the coasts show little movement, consistent with the nature of the ice pack in this region. Figure 7 depicts the principal components of the variability of the annual ice motion. These AVHRR-only motions provide a sufficient statistical sample to identify a relationship between the direction of mean motion and the direction of the maximum variability. This relationship is more apparent in a plot of the angle difference between the mean motion and the first principal component versus the magnitude of the mean motion (figure 8). The mean of the difference is 38 degrees at the velocity of 2 cm/sec and drops to 17 degrees at 5 cm/sec. The anisotropic nature of this and other relationships suggests that isotropic models of the ice cover (the typical implementation of the viscous plastic and cavitating fluid rheologies) may need to be supplemented by additional constraints under certain conditions such as flow adjacent to "boundaries" such as the Alaskan coastal fast-ice zone.

While the information gained from the AVHRR-derived vectors alone are informative, many applications require a gridded ice motion field uniform in time and space. As noted above, cloud cover necessitates that the AVHRR coverages typically supply patches of motion vectors rather complete coverages. Methods have been studied to merge AVHRR ice velocity vectors and vectors from other sources in an optimal interpolation scheme. We used buoy data as representative of these other sources. Figure 9 shows one attempt to produce a gridded field. A difference can be seen between this figure and Figure 6, most notably along the coastlines. Figure 10 is an improved estimation of the ice motion by using the annual mean and variability fields to "normalize" the buoy and AVHRR vectors before interpolation. The mean ice motion more closely resembles the mean motion in Figure 6. We have therefore developed a methodology that works well for blending vector data from different sources.

In addition to applying the motion data for characterizing the mean and variability fields for the region, we have also used the motion data to test the performance of sea ice models (Maslanik et al. 1994; 1995). As an example, for the same time period as Figure 3, NMC wind vectors and model-derived ice motion (forced by the NMC winds) are shown in figures 11a and 11b. Comparing the model output with the observed vectors in Figure 3, it can be seen that the model tends to overestimate the ice motion in the higher concentration areas such as those along the Canadian Islands of Banks and the Sverdrup Islands. The actual center of rotation appears elongated and is not reproduced in the model output. Another example (Figure 12) shows another example where the model tends to get the drift directions nearly correct, but overestimates drift speed.

Direct comparison of the remotely-sensed motions with buoy motions and modeled motions using a viscous plastic or cavitating fluid rheology also points out some underlying relationships among the data sets. Observed and modeled motions are significantly

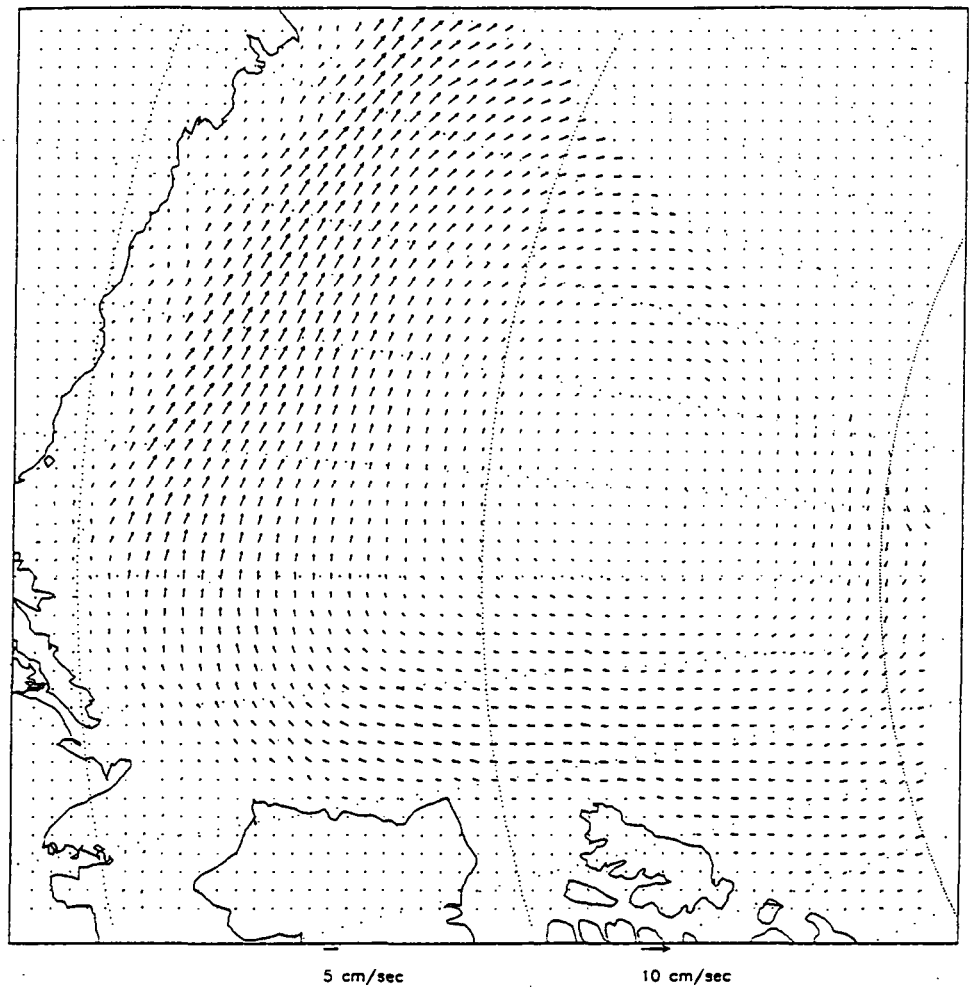


Figure 6 Annual mean ice motion for Beaufort Sea (June 1992 - June 1993) estimated from AVHRR data only.

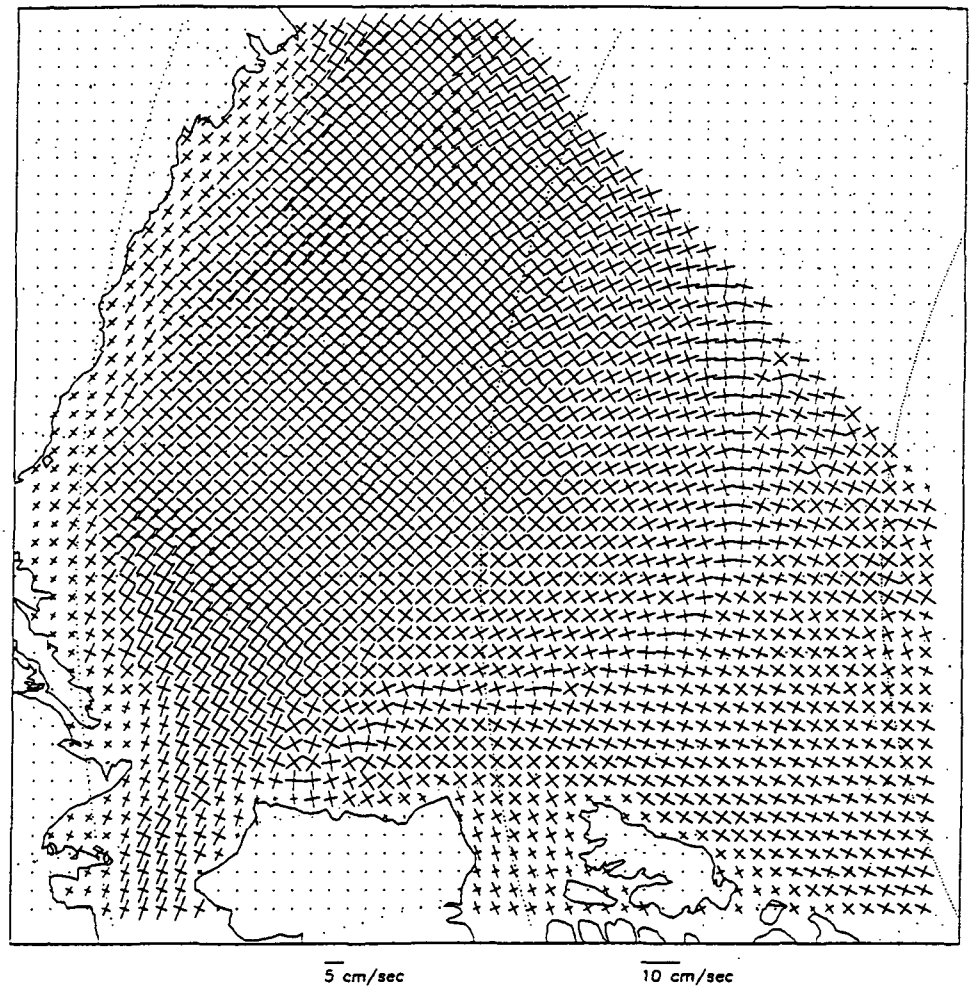


Figure 7 Principal components of annual ice motion variability for Beaufort Sea (June 1992 - June 1993).

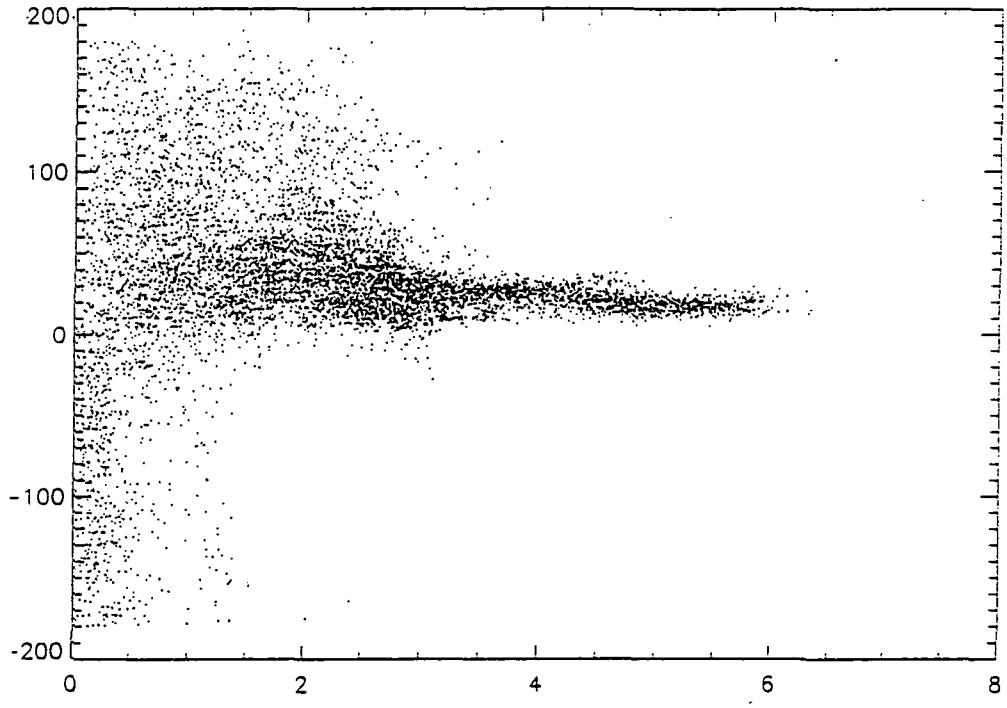


Figure 8 Mean ice velocity vs. difference between direction of mean ice motion minus direction of maximum ice variability.

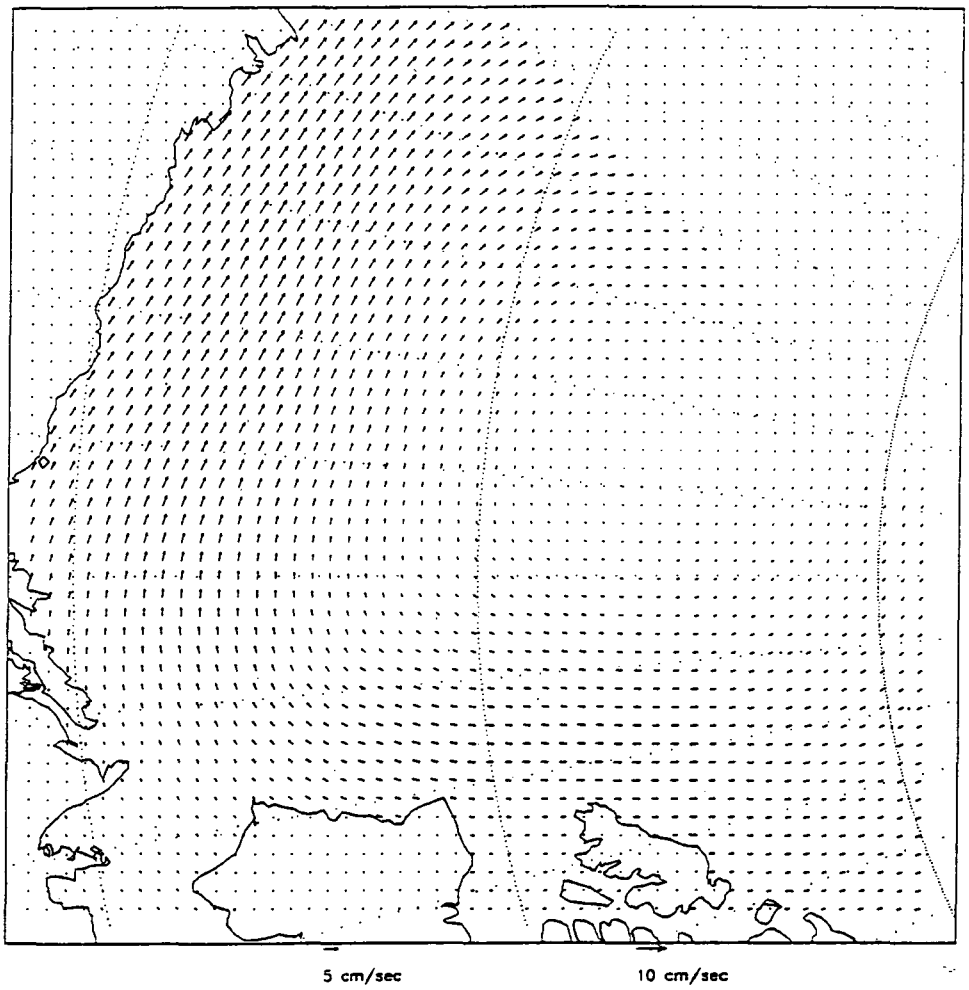


Figure 9 Annual mean ice motion from interpolated ice motions.

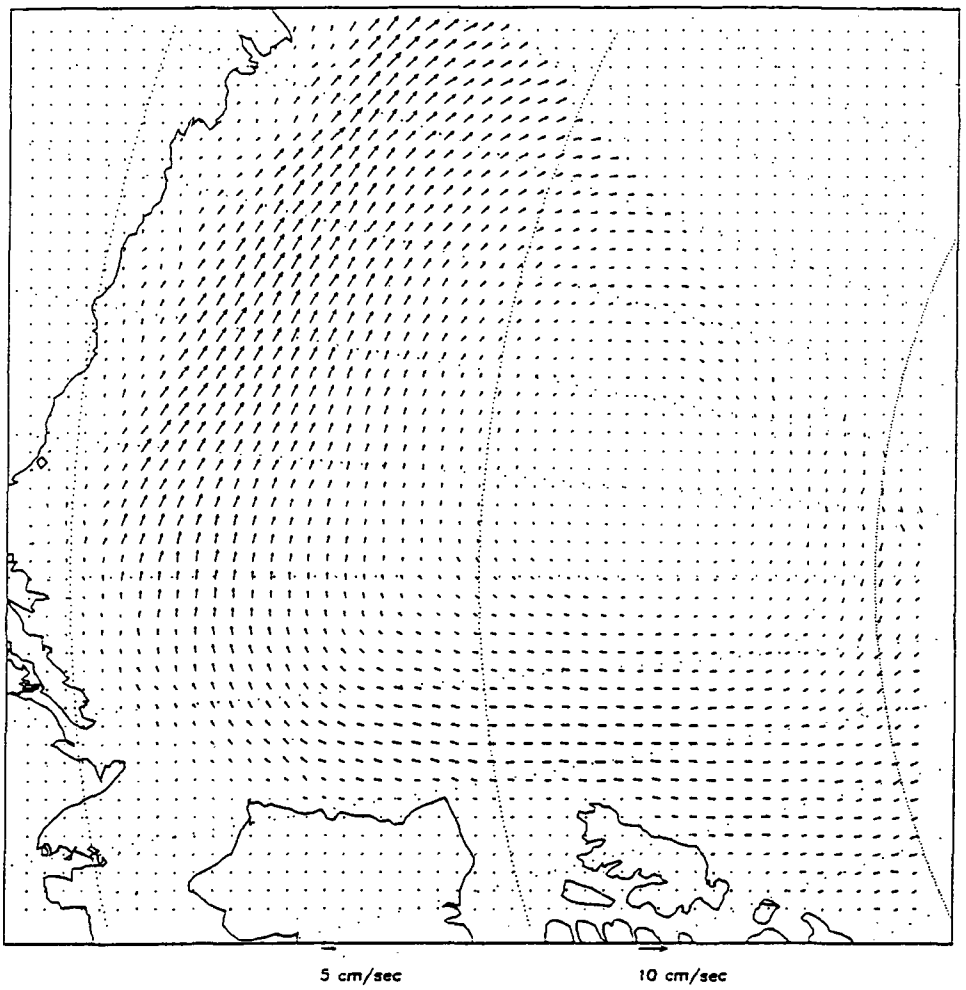


Figure 10 Annual mean ice motion from interpolated ice motions. This interpolation makes use of knowledge of annual mean and variability from the AVHRR ice motion vectors.

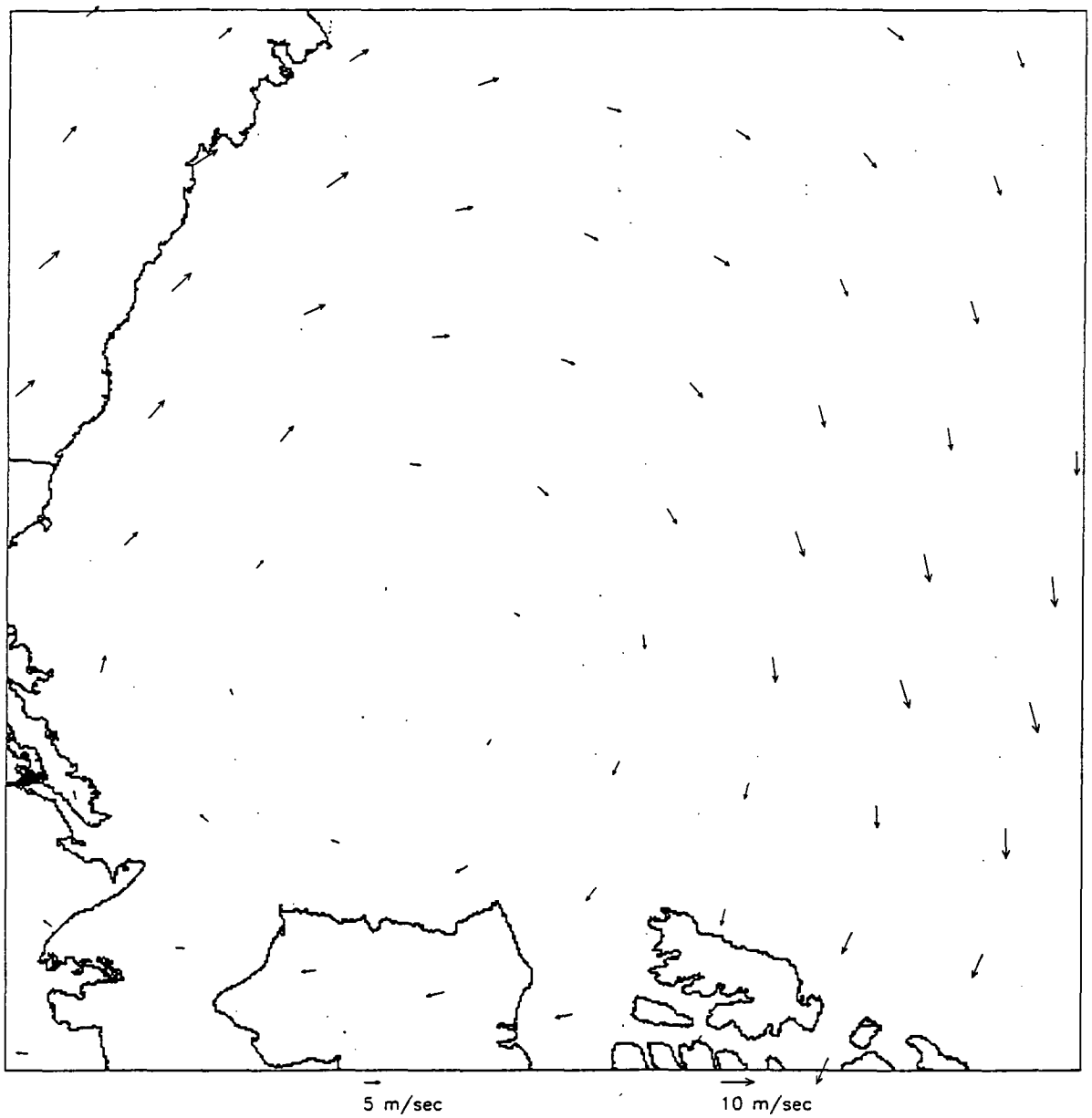


Figure 11. Figures showing wind velocity (a) and model derived ice motion (b) at same time period as figure 3.

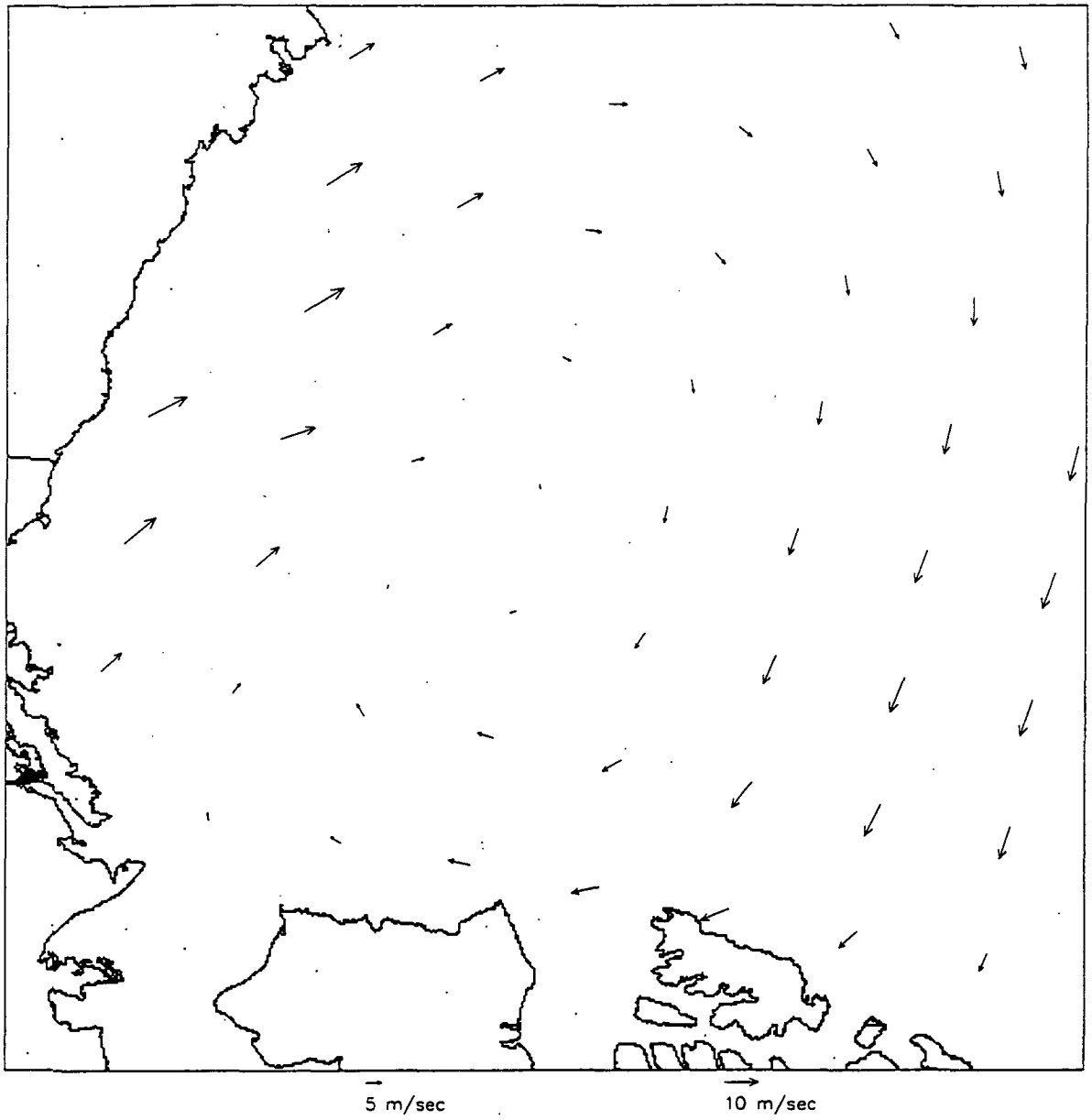


Figure 11(b).

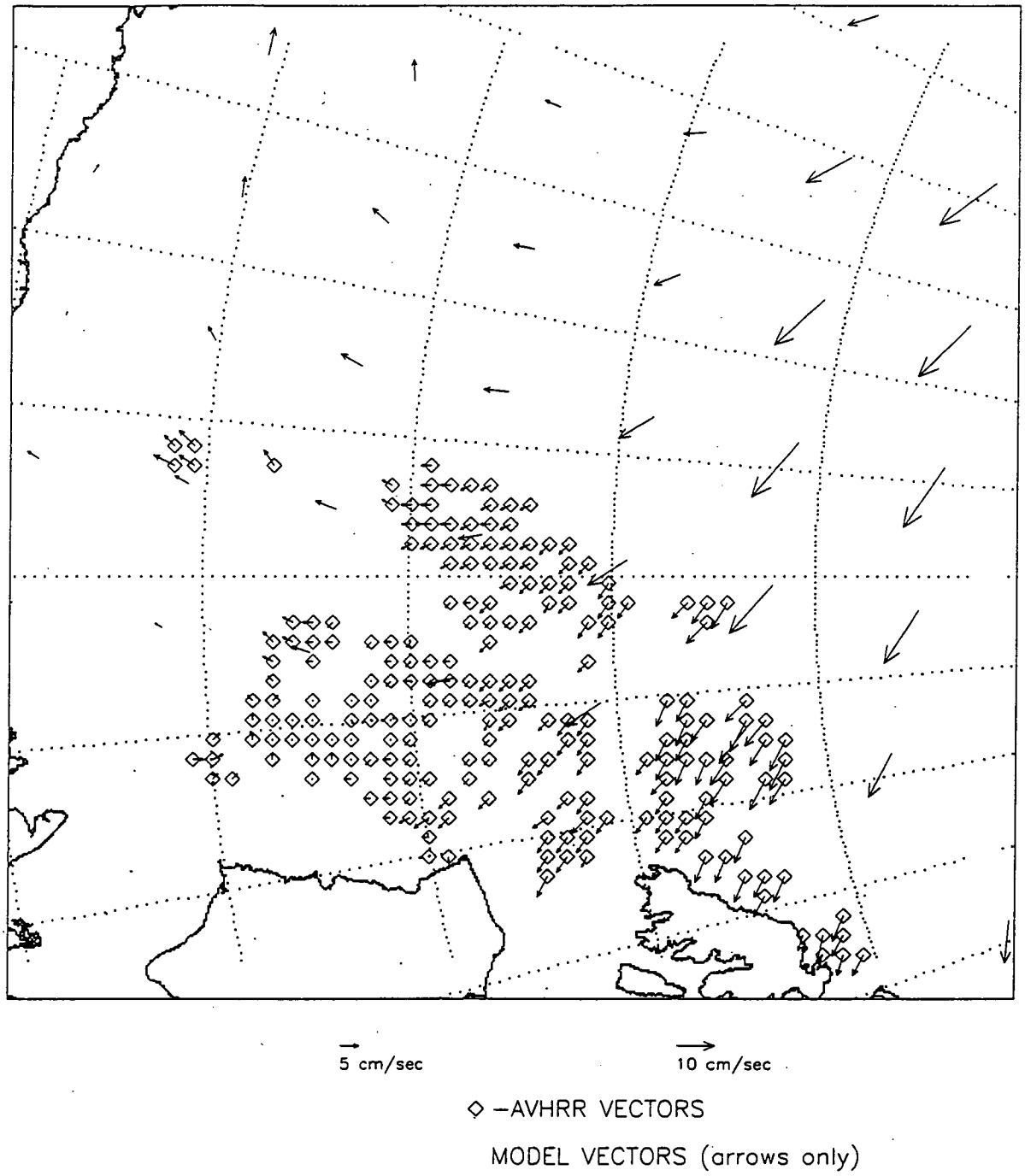


Figure 12. Another example comparing simulated and observed motions for Julian days 297 to 298, 1991. Observed motions are the displacement between these 2 days; simulated motions are the averages for the 2 days.

correlated, but the differences are a function of drift speed, with these differences varying depending on rheology used. For example, in one test case, the cavitating fluid rheology (without inclusion of a now-available shear strength approximation) overestimated mean drift speed by about 20%, whereas the difference between observed and viscous-plastic motions was 0%. From this case, a preliminary relationship between observed and simulated motions (an exponential function of drift speed) was derived that could be used to adjust simulations to bring the modeled ice velocities more closely in line with the observations (Figure 13). In this case, the simulations tend to overestimate drift speed at observed speeds below 8 cm/sec, but underestimate drift at higher speeds. Further work is needed to best choose how to apply such relationships in ways that are consistent with the ice-model rheology.

4.0 Conclusions

This section summarizes the main conclusions from our work.

- Under clear-sky conditions or when cloud cover is sufficiently thin so that surface features are visible, accurate and detailed ice motions can be estimated from AVHRR HRPT, LAC and GAC data for the consolidated ice pack, based on comparisons with SAR and buoy-derived ice-motions, and geostrophic winds. Comparisons with buoy-derived ice motions showed excellent agreement in both speed and direction, with mean differences of less than 0.1 cm/sec and standard deviations about 2.0 cm/sec. These deviations are within the registration error of the buoy and AVHRR vectors themselves.

- AVHRR data alone can provide ice-motion coverage suitable for case studies but only under relatively cloud-free conditions. Combination with other data types is needed to provide daily, large-area coverage of ice motions. Cloud cover was the only significant limiting factor for determining ice motion to within the spatial resolution limits of the AVHRR data. It was found that on average, vectors could be determined 17% of the time over this entire region sampled at daily intervals. At any particular location, the percentage varied from 5% along the coasts to 35% in other areas. Cloud cover precludes long-term continuous monitoring of specific locations at least at the highest spatial resolution.

- The scale of AVHRR-derived motions is well-suited to regional studies and complements the higher-resolution SAR motions and low-resolution buoy coverage. Ice motion derived from AVHRR demonstrates that ice motion can vary dramatically on a daily basis. Superimposed on the broad patterns are details that ought to be of some value for ice process studies. The detail shown in the AVHRR coverages suggest that valuable information will be gleaned from RADARSAT gridded motion fields, even with a seven-day repeat scheme.

- Optimally-interpolated motion fields that combine AVHRR, SAR, and buoy observations can yield realistic, daily motion fields for large areas. Optimal interpolation of AVHRR and buoy data yields results generally consistent with gridded wind fields. The buoys contribute enough information to permit useful interpolation of fields during cloudy periods, but the spatial coverage was such that the combined AVHRR and buoy fields

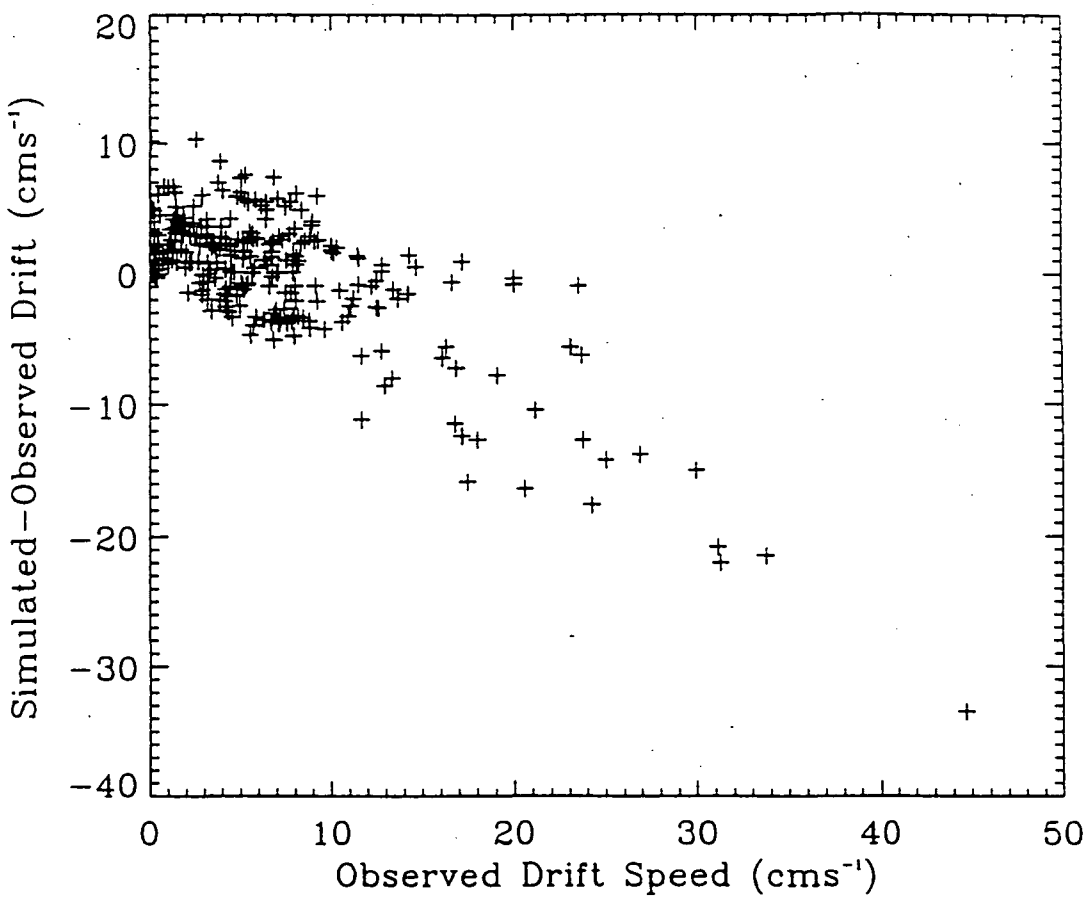


Figure 13. Comparison of observed and simulated (viscous-plastic) motions for a case study.

were not simply a reproduction of the buoy motions. As with the case-study examples, the additional spatial coverage of the AVHRR motion vectors, when summarized into mean seasonal fields, adds information not apparent in the buoy data alone. For example, details such as faster movement away from the Canadian and Alaskan coasts with slower movement closer to the center of the Beaufort can be seen. Motions during winter show the distinction between the pack ice and the fast-ice regime, with little or no average ice movement near the coasts over the shelf areas. Regional differences are also apparent in the direction of variability of motions.

- Limited comparison of the observed motions to simulations from a dynamic-thermodynamic ice model indicate good overall agreement in mean speed and direction. The simulations underestimate velocities during periods of rapid drift, as is expected since the continuous fields and lower resolution of the model do not represent local conditions. For the same reason, the simulations overestimate drift at low drift speeds. If the relationships between drift speed and open-water production are linear, then the net effect is minimal. However, the interactions between open-water production and turbulent fluxes are not linear, so the overall effects of underestimating rapid-drift events may be significant. The use of a viscous-plastic versus cavitating fluid ice rheology has little effect on drift direction, but the cavitating fluid rheology appears to further overestimate drift speed under conditions of rapid motion.

- The AVHRR motions and interpolated fields were documented and staged at an ftp site at NSIDC for members of the RGPS working group (Appendix I describes this archived data set). Also included were SAR and buoy motions, and the un-interpolated AVHRR motions. The daily motion fields were successfully used by other investigators. One application was to test a Lagrangian scheme for estimating ice production from SAR imagery (e.g., the proposed Lagrangian tracker for the Radarsat Geophysical Processing System [RGPS]). The interpolated AVHRR and buoy product produced realistic patterns of ice transport in the RGPS tracker, but the imprecision within the AVHRR field-of-view could yield potentially large errors in estimates in open-water production in comparison to the accuracy expected from RADARSAT SAR. Based on this application, a full-Arctic AVHRR-derived field has been recommended as a needed product for development of the RGPS.

- The AVHRR time series was calibrated and subsequently used to generate a corresponding time series of cloud properties, radiative fluxes, surface temperature, and albedo for June 1992-July 1993.

In conclusion, the principal objectives of this project were to: 1) demonstrate whether sufficient ice features and ice motion existed within the consolidated ice pack to permit motion tracking using AVHRR imagery; 2) determine the limits imposed on AVHRR mapping by cloud cover; and 3) test the applicability of AVHRR-derived motions in studies of ice-atmosphere interactions. We met the first objective by developing and analyzing AVHRR-derived motions and comparing these data to other observations. The second objective was met by documenting the frequency with which daily ice motions could be detected over the study area for an 11-month period. The third objective was addressed by comparing the motion products to winds under different synoptic conditions, and by studying the relationships between modeled and observed ice motion and concentration under high and

low pressure systems. We believe that the methods and experiments completed as part of this project demonstrate that AVHRR data can be used to provide valuable sea ice information, and can augment other existing data such as drifting buoys and SAR imagery, and will complement the data to be provided by the RADARSAT program.

APPENDIX 1: DOCUMENTATION FOR AVHRR-DERIVED MOTION PRODUCTS ARCHIVED AS PART OF THE NSIDC DISTRIBUTED ACTIVE ARCHIVE CENTER

From:

C. FOWLER, J.A. MASLANIK, W. EMERY
Colorado Center For Astrodynamics Research
Campus Box 431
University of Colorado
Boulder, CO 80309

EMail:
cfowler@samwise.colorado.edu
jimm@northwind.colorado.edu
emery@frodo.colorado.edu

Chuck Fowler
T:303.492.1308 F:303.492.2825

GENERAL INFORMATION

Ice motin vectors for the Beaufort Sea have been put online at NSIDC on a trial basis for testing, comments, etc.

The area studied during the period from June 1992 through August 1993 was a region of about 1200 by 1200 kilometers that covered the Beaufort Sea. All the vector are oriented to a polar stereographic map grid the same as the map grid used by NSIDC for SSM/I Arctic data with longitude 45W running vertically.

ftp to:
ftp sidads.colorado.edu (128.138.135.20)
user: icemove
passwd: *****

There are 5 directories. One is a directory called animation. This directory contains compressed binary files of the various vector files, and an IDL (PV-WAVE) routine for animation.

For more information, see the separate readme.animation file in the ftp directory. All directories total about 200 megabytes. The other 4 directories are labelled sar, avhrr, buoy, and interp. Each of these contains files containing vector data. To save space, and reduce time for transferring over the internet, only latitude, longitude, u, and v are included.

The avhrr and buoy directories contain the vectors used for the interpolated vectors in the interp directory.

The interp directory contains vectors interpolated to about a 12 kilometer spacing. A 5 kilometer grid was attempted, but each file was over 1 meg of data. Even at 12 km spacing, each file is about 340000 bytes.

The sar directory contains ice vectors extracted from data from the Alaska Sar Facility. In this directory are composites of all the vectors on the same day. These vectors were not used in the interpolated vector fields.

We are still trying to determine the best method of incorporating these 3-day average ice velocities into the 1-day motions. Possibly, users will only need 3-day velocities. The SAR have been included for any users that may want to blend with the avhrr, buoy, or interpolated vectors. (Ron Kwok has a method for splitting the 3-day average vectors into 3 1-day average vector fields.)

All u and v values are in cm/sec.

MORE SPECIFIC INFO ON EACH DATA SET

AVHRR DATA

AVHRR data was purchased from the Atmospheric Environment Service (AES) in Edmonton, Canada. One pass per day for over a year was archived at approximately 2300 GMT from the NOAA-11 satellite. These passes were processed and projected onto the map grid described above. To compensate for attitude (roll, pitch, and yaw) errors and errors in the imbedded times of the raw data stream, manual nudging of coastline features to a reference map was done. A cross-correlation technique was used to generate ice velocities from 1 day apart image pairs using both AVHRR channels 1 and 4. The resulting vector grid points are 10 km apart. The vectors were generated on a 10-pixel (~12 km) grid.

Cloud cover is a major problem in producing ice motion vectors. No cloud filtering was done before the vectors were generated. However, 3 levels of filtering was done on the ice vectors. First, a cutoff value was assigned to the correlation coefficients. Since ice appears to move locally in a coherent manner, a second filter compares a vector the immediately adjacent vectors. This vector is retained if it matches at least 3 neighboring vectors within a 2 pixel displacement in any direction. With these two filters, most spurious vectors are removed. However, a few isolated vectors can remain. A third filter was then used. The criteria was that there be at least 5 vectors within 100 kilometers such that their differences lay within

a certain range based on the distance from the vector being checked. The combination of these 3 filters, while being quite conservative in that some "good" vectors may be thrown out, worked for all days for the entire range of data.

The only AVHRR files included are those with vectors. Some days are missing because coverage was lost. Other days are missing because of total cloud cover and no vectors could be generated.

BUOY DATA

Drifting buoy observations from the Arctic Ocean Buoy Program consisted of buoy positions at 12-hourly intervals. To best match the ice velocities obtained from the AVHRR data, buoy locations at 0000 GMT were used to compute the ice velocity from 1 day displacements. About 5 to 9 buoys were usually available within the study area.

SAR DATA

Ice velocity data derived from SAR imagery was obtained from the Geophysical Processing System of the Alaska SAR Facility (Kwok, et.al.). These ice velocities are 3-day average velocities due to the repeat cycle of the ERS-1 satellite. (For more specific information of these vector products, see Kwok, R. and G. Cunningham, Alaska SAR Facility-Geophysical Processor System- Data Users Handbook, Version 1.1, Feb 1993, JPL, JPL D-9526,pp1-70) Again, only the lat/lon and u and v values are provided.

INTERPOLATED FIELDS

Simple spatial auto-correlation statistics for the u and v velocity components were computed from this set of year long vectors. Spatial correlations can be done by decomposing the u and v components into parallel and perpendicular components as described by Thorndike in "The Geophysics of Sea Ice". Another possible method is described in Journal of Atmospheric and Oceanic Technology (June 1993), which results in a single spatial correlation value.

The interpolation was done with the simple kriging method of optimal interpolation using the buoy and AVHRR derived velocities together with the u and v spatial correlation statistics mentioned first above. The interpolations were done only using spatial statistics, and not with any temporal information. We are working with interpolation techniques using different statistics, both temporally and spatially.

One thing to remember is that the values in areas where there were no input vectors, the interpolated results may not be correct. This is especially true along coastlines. Seldom, if ever, is there any buoy information. Therefore, the interpolated vectors will only be close to be "correct" when there are AVHRR dirived vectors.