# THE SEPARATION OF SEA-ICE TYPES IN RADAR IMAGERY

## (Abstract)

by

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ABSTRACT

The ability to distinquish the several major types of sea ice with active radar instruments has been well studied in recent years. The separation of sea-ice types by radar results principally from variations in radar back-scatter due to characteristic differences of these ice types in surface morphology and brine content. When sea ice is viewed with an active radar at angles greater than about 20° from nadir, undeformed ice reflects radar waves and results in a low return, while ridges, hummocks, and small-scale surface features scatter the radar waves and produce a high return. The presence of salt increases the dielectric constant of ice; penetration by radar into the ice is then negligible, and the return is essentially determined by surface morphology. The absence of salt reduces the dielectric properties of ice; radar waves can then penetrate the ice to some depth and are scattered by air bubbles and brine-drainage channels (called volume scattering), thereby enhancing the return even for roughened surfaces. All these properties vary significantly with radar frequency and polarization as well as seasonally. For example, higher radar frequencies respond to smaller-scale surface features, while lower radar frequencies penetrate further into the ice with resulting volume scattering.

The high-resolution imagery from synthetic aperture radars (SAR), mounted on aircraft, shuttle, or satellite platforms, is very effective for many sea-ice studies, including the separation of ice types. An aircraft-mounted X-band (9 GHz) SAR, for example, can discriminate smooth first-year ice, rough first-year ice, multi-year ice, and open water by the intensity (tone) of the radar returns and floe geometry. The preferred SARs to date for satellites and shuttle platforms have been L-band (1–2 GHz) systems. SAR imagery of sea ice was extensively acquired by Seasat in 1978 over the Beaufort Sea, with limited quantities obtained by the Shuttle Imaging Radar (SIR-B) over the Weddell Sea in 1984. While L-band SAR can discriminate rough and smooth ice along with roughened open water based on image intensity and floe geometry, the returns from thick first-year ice and multi-year ice are not clearly distinguishable. The fact that there is volume scattering from multi-year ice suggests that there may be textural or spatial frequency variations that could be used to separate these two major ice types in radar imagery. In order to investigate the separation of sea-ice types in the large amount of L-band SAR imagery available, image-analysis techniques including filtering and classification programs have been utilized, pointing towards an automatic classification algorithm for use in future SAR sea-ice data sets, especially from space.

An important characteristic of all SAR imagery is the presence of image speckle, a coherent form of noise caused by the random variability of scatterers across even a uniform surface. Most SAR processors reduce this effect by averaging multiple independent samples but this is done at the cost of reducing resolution. Speckle reduction can also be accomplished by filtering. Several filters have been tested including median, box, and adaptive edge filters. Each filter has different characteristics in terms of smoothing speckle and in the response to sharp gradients or edges, such as ridge or lead openings, as well as computational requirements. Optimization of each filter's parameters has been determined by the quality of classification of each ice type.

The classification programs that have been tested are based on tone and texture image characteristics. The programs are supervised; that is, a small training area for each class is pre-selected for statistical analysis. From these statistics, the remainder of the imagery is subjected to the particular classification algorithm. The tone program separates classes based on the mean, standard deviation, and number of standard deviations of each class, and includes a Bayesian maximum-likelihood classifier for ambiguous elements. The texture program determines the statistical homogeneity of each class and the optimal segmentation of each small area into the various classes.

# CARTOGRAPHIC REMOTE-SENSING MONITORING OF GLACIOLOGICAL SYSTEMS (EXAMPLE, MOUNT EL'BRUS, U.S.S.R.)

## (Abstract)

by

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ABSTRACT

Remote-sensing methods in monitoring the glacierization of Mount El'brus are used to produce base and dynamic maps, and to obtain quantitative information (dynamic indices) about the rate, intensity, and variations of the process. The monitoring system is divided, according to scope and territory covered, into small-scale for total glacierization and the periglacial zone, medium-scale for separate glaciers, and large-scale (detailed) for part of the glaciers or sectors of the adjoining slopes. The approximate relationship of even scales is 1 : 4.

Small-scale monitoring remote-sensing systems are important for making maps showing the complex characteristics of the glaciological system. A series of maps was produced including geographical, those of high-altitude zones, slope and exposure angles, geological, glaciomorphological, climatic (temperature, precipitation, and winds), distribution of direct solar radiation, hydrological (source of streams), seats of avalanches, and landslides. All these data serve as a cartographical basis in monitoring the glacierization of Mount El'brus. They are compiled from remotely sensed and Earth-based data.

Current monitoring on a small scale includes observations of the conditions which determine the existence of the glacial system – this includes data on winter snowfall and



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the period of snow cover. These observations were obtained from meteorological and resource satellites, and from scanner data of medium and high resolution. Also important are observations of changes in the outline of glaciers, times of snowfall and character of the distribution of snow, and its redistribution due to avalanches and snowstorms. High-resolution space photographs, small-scale aerial photographs, and aerovisual observations provide the data for these observations. It has been determined that the area of the glaciers of Mount El'brus has been reduced by 1% in the last 25 years, i.e. the rate of its deglacierization dropped sharply as compared to preceding decades.

The role of quantitative information gains importance in the medium-scale level of monitoring. Topographical maps of separate glaciers compiled from aerial photographs or data from ground stereo-photogrammetric surveys constitute the base maps at this level. The main methods used in monitoring were large-scale surveys from aircraft, perspective surveys from helicopters, and phototheodolite surveys. Multi-date surveys of the glaciers provide data about the changes in their outlines and height, the character of their relief, their moraines, the amount of snow accumulation and ablation in separate years, the surface rates of ice flow and their fluctuations. The techniques by which quantitative information is obtained about changes in the glaciers are derived from processing the data of multi-date surveys. The organization and techniques of phototheodolite surveys have been improved. A theory evolved for determining the surface-ice movement by stereo-photogrammetric means and the technique for it has also improved; algorithms and programs for machine processing of the data of multi-date surveys (ground and from aircraft) have been produced.

At this level of monitoring, it has been found that the retreat rate of most glaciers has slowed down and several glaciers are now in equilibrium. Several glaciers became active at the beginning of the 1970s and 1980s; this was accompanied by an increase in their height and forward movement. For example, activation of Kyukyurtlyu Glacier has been recorded (higher surface and increasing flow rate) which has caused the glacier to move forward 100 m. Surveys at an interval of 2 years recorded the beginning of the process of retreat of this glacier.

Detailed monitoring is used to detect the mechanism of the dynamic processes and to study it on local representative sectors. On a glacier it may take the form of annual surveys of its tongue, which makes it possible to observe the processes of formation of moraines and glacio-fluvial relief. Studies may also be made of the mechanism of the movement of avalanches and landslides, deducing their quantitative characteristics and appraising the results of avalanches and landslides. Multi-date surveys of sectors of the slopes provide information about processes in the periglacial zone. At this level, regularly repeated ground stereo-photogrammetric surveys are the main means of observation.

Glaciological remote-sensing monitoring provides a wealth of data for theoretical development in the field of glaciology. It makes it possible to forecast and produce warnings about hazardous processes and phenomena.

# METHODS OF CALCULATION AND REMOTE-SENSING MEASUREMENTS FOR THE SPATIAL DISTRIBUTION OF GLACIER ANNUAL MASS BALANCES

## (Abstract)

by

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ABSTRACT

The areal distribution of glacier annual mass balance $b(z)$ is an important characteristic of the existence of glacierization and its evolution. At present the measured value of annual mass balance at different elevations is only available for a limited number of mountain glaciers of the globe, because of the great amount of labour required for such measurements.

The analysis of long-term mass-balance measurements made at Abramova Glacier, Limmerngletscher, White Glacier, Hintereisferner, and Peyto Glacier has revealed that for each year the spatial distribution of annual mass balance is well described by quadratic equations. The main variable in these equations is altitude ($z$). The various parameters of these formulae are estimated by the author for mean weighted height of the ablation and accumulation areas, and for the glaciers as a whole. It is found that the parameters of annual mass balance for each glacier can be calculated from formulae which include combinations of the following variables: annual balance at one of the three weighted altitudes, maximum annual snow-line elevation, annual and seasonal amounts of precipitation, and air temperatures at nearby meteorological stations.

Therefore, in order to calculate the distribution of annual mass balance as a function of absolute altitude, it is sufficient to obtain a value for mass balance measured only at a single point on a glacier, and common meteorological observational data. A comparison of actual and calculated values of mass balance has shown good agreement between them.

Considering the successful use of aerial remote-sensing for the measurement of snow depth in mountains by means of special stakes, it is satisfactory to accept this method for the assessment of annual mass balance at the mean weighted altitude of the ablation zone. It is possible to use aerial photo-surveys or stereophotogrammetry to resolve this problem. Then annual mass balance for the whole area of a glacier is calculated by using data from one point together with data from a nearby meteorological station.



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