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Snow Depth Mapping in Mongolia

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ABSTRACT

The Great Lakes Environmental Research Laboratory (GLERL) has a cooperative program with Mongolian scientists to produce snow depth maps for that country. Snow depth data has been provided to GLERL. A raster data set was compiled from these data and preliminary maps produced. Since all stations are currently located inside the country in valleys, the snow depths are not correctly projected across the country's borders or over mountains. This progress report presents the preliminary maps and outlines the future course of the project. Information on locale, climate, people, customs, and problems with the study is also included.

INTRODUCTION

Animal husbandry is the primary agricultural focus in Mongolia and produces most of the country's food as well as many of the raw materials used in manufacturing. Because of the increasing demands of Mongolia's expanding population, the Mongolian government is identifying ways in which animal husbandry may be promoted.

The region is arid, and herdsmen travel considerable distances each year in search of suitable forage and water. The winter-spring transition period is the most critical time of year for obtaining forage. Early spring forage is usually insufficient to fulfill animal fodder needs due to its spatial and temporal variability. The herdsmens' quandary is that they do not know in advance which northern path they should follow to take advantage of the best developing forage.

The thin and unevenly distributed snowcover is the most important parameter during this period since it controls spring soil moisture. Mongolian officials have identified snow depth mapping as a first step toward providing the herdsmen information on spring forage.

Although Mongolia has a satellite down link, NOAA AVHRR data cannot produce the snow maps desired by itself (Badarch 1990). Mongolia does have a network of snow depth stations which report on a ten day interval. The satellite data would be useful if combined with the snow depth data such as in establishing the southern snowcover boundary.

Snow depth measurements are now being provided to GLERL as part of a cooperative program (see acknowledgements). Mongolian scientists are working with GLERL scientists to produce snow depth maps from station data. The program's goal is to enable the Mongolian government to map snow depth and ultimately provide spring forage forecasts on a weekly time step for the herdsmen.

Background Information

Mongolia is roughly the size of Western Europe at 1,565,000 km^2 (Akiner 1991). Its size is illustrated by overplotting it on North America at its correct latitude (Figure 1). Mongolia has almost 2,200,000 people and 27,000,000 animals (Fed. Res. Div. 1990). Mongolia's population is growing about twice as rapidly as the rest of the world. This growth rate is producing a population markedly skewed toward younger people. About 42% of the population is under age 15, and about 75% is under age 35. Averaging less than 1.4 persons per km^2, the population is unevenly distributed throughout the country. About 25% (500,000) of the population lives

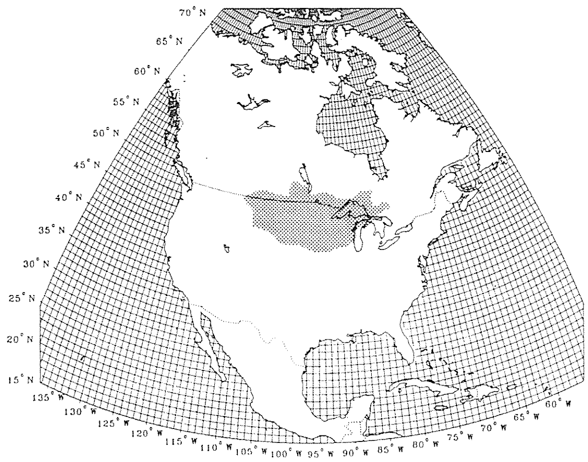

Figure 1. Mongolia over-plotted on North America at its correct latitude.

in the capital, Ulaanbaatar. There are approximately 1,500 settlements; about two thirds of these have less than 500 inhabitants. Approximately 60% of the rural population live in nomadic settlements. Two thirds of these settlements are of the suur' type, a co-operative farm engaged mainly in free-range livestock breeding. There currently are about 35,000 suur' composed of from one to several households (The Acad. Sci. MPR 1990). Both permanent and nomadic settlements use ger dwellings (the ger, also known as a yurt, is a round, collapsible, wood-framed structure covered with layers of felt).

Difficulties

Communication between GLERL and Mongolia has not been simple. Telephone communication is difficult, and mail is often routed through the former Soviet Union, taking months or sometimes years for delivery. GLERL has utilized the U.S. Embassy in Beijing, China and the U.S. Embassy in Ulaanbaatar, Mongolia to overcome some of these difficulties. Mongolian scientists frequently use visiting scientists to transport material outside their country and then to mail it. Although a number of Mongolians read and speak some English, the lack of fluency in the languages often poses a problem for researchers on both sides.

MONGOLIAN AGRICULTURE

Mongolia is a mountainous country. Mountains (1,500-3,000 m) occupy more than 40% of the country, hummocks (1,000-1,500 m) cover about 40%, and plains cover 15% (The Acad. Sci. MPR 1990). Less than 1% of the country is arable, and 8-10% is forested. Excluding the mountains, the remainder ranges from sub-alpine pasture to desert (Fed. Res. Div. 1990). Very few vegetables are grown with the primary foods being red meat and milk products. Mutton is the staple meat of the Mongols. Animal husbandry dominates Mongolian agriculture. Animal wool, hair, skins, and hides are important agribusiness products. There are over 20 million head of livestock under the suur'. The heards contain sheep (60%), goats (15%), cattle (8%), and yak, pigs, horses, and camels make up the remaining 17%. These herds graze on about 125 million hectares of free-range (The Acad. Sci. MPR 1990).

In the north there are alpine-tundra soils changing to extra-arid soils in the south. Northern surface soil moisture does not exceed 60-70% of capacity even in the wettest years (The Acad. Sci. MPR 1990). The winter-spring transiton represents the greatest seasonal change in surface soil moisture during the year due to strong winds, low humidity, little rain, and clear skies. Mongolian herds do not usually find sufficient grazing fodder in the spring. Dust storms occur in the spring (Fed. Res. Div. 1990).

MONGOLIAN CLIMATE

Mongolia is centrally located on the Asian continent (Figure 2). This location places it at a greater distance from an ocean than any other country in the world. Thus, it exhibits the strongest "continental climate" of any nation in the world. Temperatures can range from -50°C during winter in northern basins to +40°C during summer in the southern desert (The Acad. Sci. MPR 1990) with bare ground temperatures of 65-70°C (Bespalov 1964). There are great diurnal temperature ranges, sharp seasonal variations, and little precipitation. With an average elevation of 1,560 m, the country can be characterized as having a cold and dry climate. Annual precipitation is highest in the north, which receives 20-35 cm, and lowest in the south, which averages 10-20 cm. In the Gobi Desert in the extreme south, some regions receive no precipitation in most years (Fed. Res. Div. 1990). Precipitation is not uniformly distributed throughout the year with 65-75% of the total falling in the summer over 80-90% of the country. Although meager (8-10%), winter's accumulated moisture is very important for drinking water and spring forage (The Acad. Sci. MPR 1990). The maximum relative humidity (70-80%) occurs during the winter due to the extreme cold, and the minimum (30-40%) occurs in May and October (The Acad. Sci. MPR 1990). Thus, spring soil moisture is rapidly evaporated.

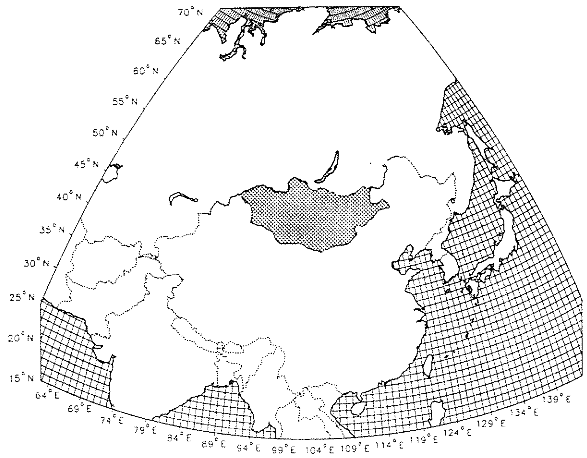

Figure 2. Mongolia's location in central Asia.

Although there is a decrease in cloudiness from north to south, the country averages 257 cloudless days a year (Fed. Res. Div. 1990). Annual sunshine varies from 2,600 hours in the north to 3,200 hours in the south. Thus, Mongolia receives from 200 to 500 hours more sunshine per year than most other places in the northern hemisphere at the same latitude (The Acad. Sci. MPR 1990). This amount of irradiance combined with the spring increase in atmospheric transparency (i.e. haze reduction), lowest seasonal precipitation and humidity, strong winds, and spatially variable soil moisture brings about rapid (irradiance) but frequently short-lived (soil moisure) spring floral blooms in the north. In the south, there are no flowers or leaves on trees until the latter half of May.

The winds are predominantly from the northwest and are often of high velocity. These Siberian winds sweep across the Mongolian highlands onto the warmer plains of the Gobi and into the northern provinces of China.

In the south, the desert area of the Gobi has been expanding, threatening fragile pastures. During 44 recent spring-summer periods there was a 6-year drought in the north and a 14-year drought in the south (The Acad. Sci. MPR 1990). These droughts combined with the expanding population are placing ever greater demands on agriculture.

In winter there is a pronounced Asiatic high-pressure region centered in northwestern Mongolia. Winds are often neglible near the center of this anti-cyclone. The air is strongly chilled by the weak air movement and sparse cloud cover at night. Cloud cover is at an annual minimum during the winter season. This subjects the ground surface to deep freezing (3-5 m) since it is poorly protected from heat loss by only a thin snowcover. Permafrost underlies about 63% of the country. Most of the approximately 200 glaciers are in regression. In the eastern part of the country, the barometric gradient increases, and winds become stronger. Winter winds are primarily (85%) from the northwest. Most snow and rain falls on the northern slopes, and most of the rivers flow away from the interior of the country (The Acad. Sci. MPR 1990).

SNOW MAPPING

Snowcover maps are made from station data obtained by ruler measurement. There are currently 47 stations in the network (Figure 3), and measurements are taken on the 10th, 20th, and 30th day of the month. GLERL has obtained some historical data from that network. Many of the stations were established in the early 1940's. Measurements taken at these stations have sometimes been very infrequent, with years often passing between observations. Snow density was often measured concurrently with the depth measurements. Visual inspection of the hard-copy data obtained indicates a density range of .04-.50 g/cm^3 with a median value in the .20-.25 g/cm^3 range. The stations are located in populated areas in valleys, where snowcover conditions differ from those in the adjoining areas of higher elevation. No snow surveys have been made in the mountains (Badarch 1990).

Based on 30 years of station data, the northern valleys have snowcover from mid-November into early April, 130-140 days, decreasing to 40-60 days in the southern plains. Based on 1966-1976 satellite data, snowcover over the low mountains averages 170 days and in the higher mountains from 200-280 days (Badarch 1990). Southern snowfalls of 2-5 cm normally melt/sublimate before the next snowfall occurs. The annual maximum snowcover occurs in February and averages 90% coverage of the entire country. Maximum snowcover of 96% has occurred in both January and February, leaving only portions of the Gobi uncovered. The December-March average snowcover is 69% (Badarch 1990).

Computer software was generated at GLERL to produce snow depth maps. The techniques used were similar to those described in Norton and Bolsenga (1993). The station data were converted to raster form using a grid of 12 minutes longitude by 12 minutes latitude to form a grid of 39,600 cells. Although 30 arc second grids are desireable in alpine models, the alpine basins are relatively small and well instrumented. The Mongolian stations are 100 km or more apart (Figure 3), segregated in the valleys, and there is little additional meteorological data available.

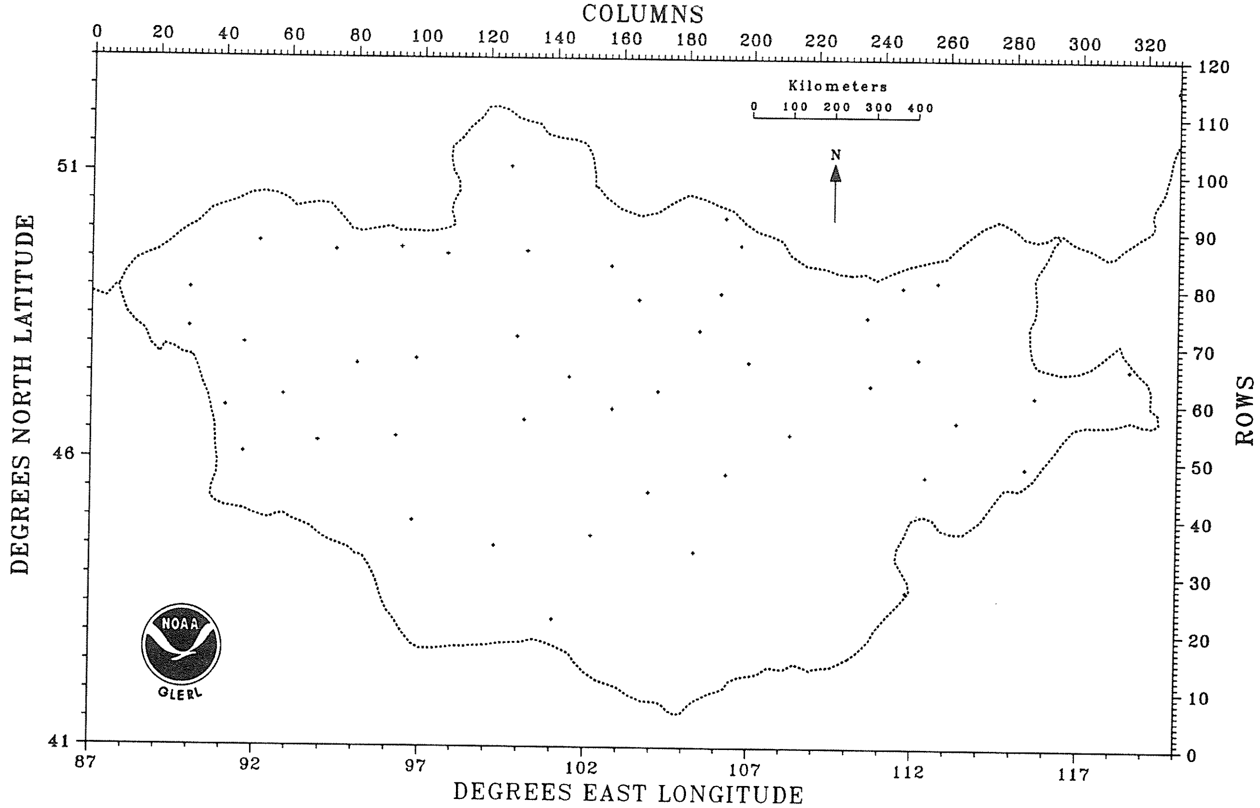

Figure 3. Mongolian snow depth stations.

The 1/5 th degree grid chosen met forecasting resolution requirements, i.e. site-specific locations to which herdsmen could be directed, and was sufficiently dense to reasonably represent elevation changes. A grid keyed to latitude and longtiude was employed since it was the simplest method to extract data from maps of various scales and projections.

The inverse of distance squared weighting function was used to translate the station data to cellular data. The cells were then averaged over two columns and two rows. Since the cells are rectangular in the cylindrical map projection used, every row is displayed with every other column to produce the rather uniform shading. The cell values are individually scaled in this representation.

The accuracy level attainable in future forecasting is unknown. The snow depth amounts used in this study are at the noise level for most alpine studies, while the size of the region to be forecast is orders of magnitude greater. Some validation may be possible by hindcasting past winters and evaluating corresponding spring agricultural data.

According to the station data thus far received and represented by the preliminary maps, the annual permanent snowcover begins in the north in late September or early October and is well established by November (Figure 4). The snowcover reaches its maximum extent in February (Figure 5). Even during the maxima, this snowcover is normally less than 10 cm over the lower elevations. When blizzards occur, they can cover the grasses with enough snow and ice that grazing is impossible, killing off tens of thousands of animals (Fed. Res. Div. 1990). Also, transport to bring in relief food can be very difficult. The March snowcover is the least of the winter season (Figure 6). The snowmelt evident through the center of the country coincides with an area of lower elevation than that to the east or west of it (Figure 7).

The snow maps are classified as preliminary since they do not take the mountains (Figure 7) into account (all the stations are located in the valleys). Computer mapping using enhancing algorithms will be required to more accurately estimate snowcover at higher elevations.

FUTURE DIRECTIONS

When funding permits, elevation data will be used to extend the range of the available snow depth data. A first pass will compute snow depth between stations in the valleys using a weighting function. These cellular values would then be used on a second pass to estimate snow depth across the higher elevations. This will be a categorical system in which

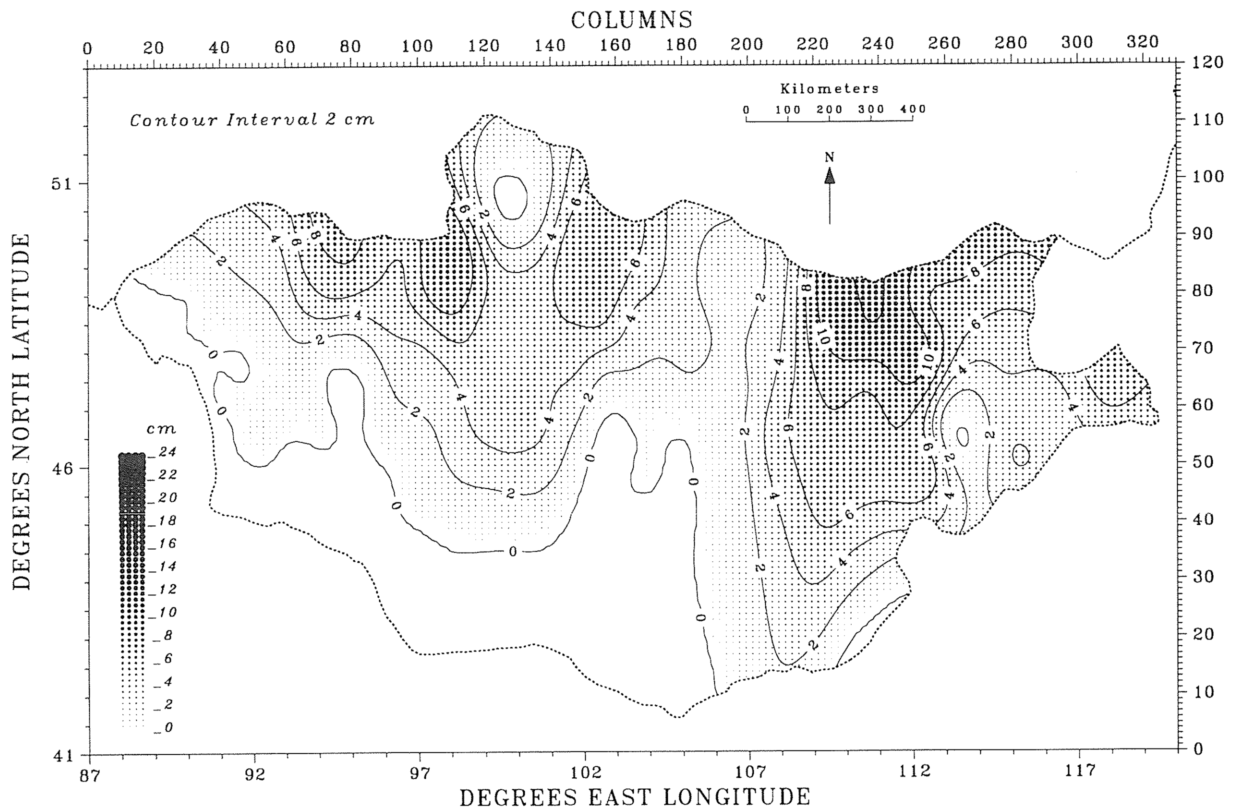

Figure 4. Mongolian snow depth for November 10, 1990 based on station data.

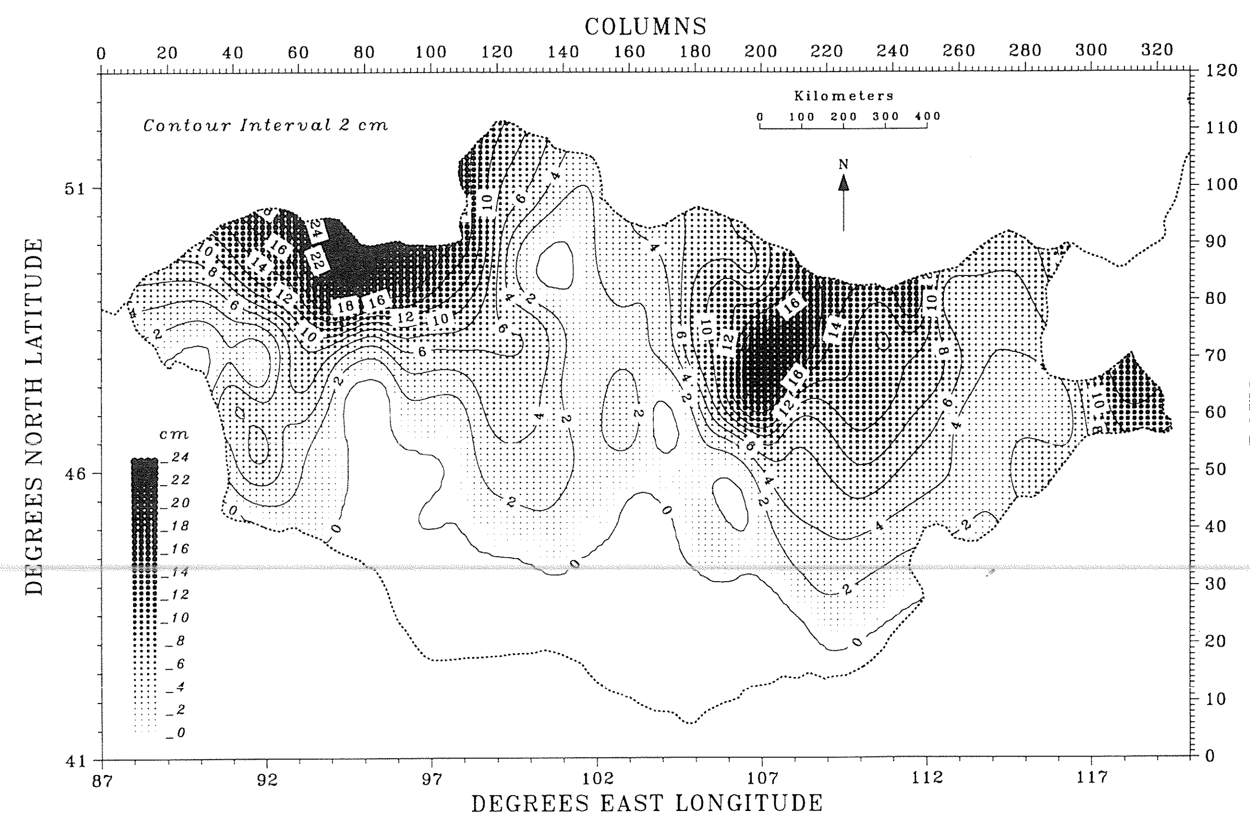

Figure 5. Mongolian snow depth for February 28, 1991 based on station data.

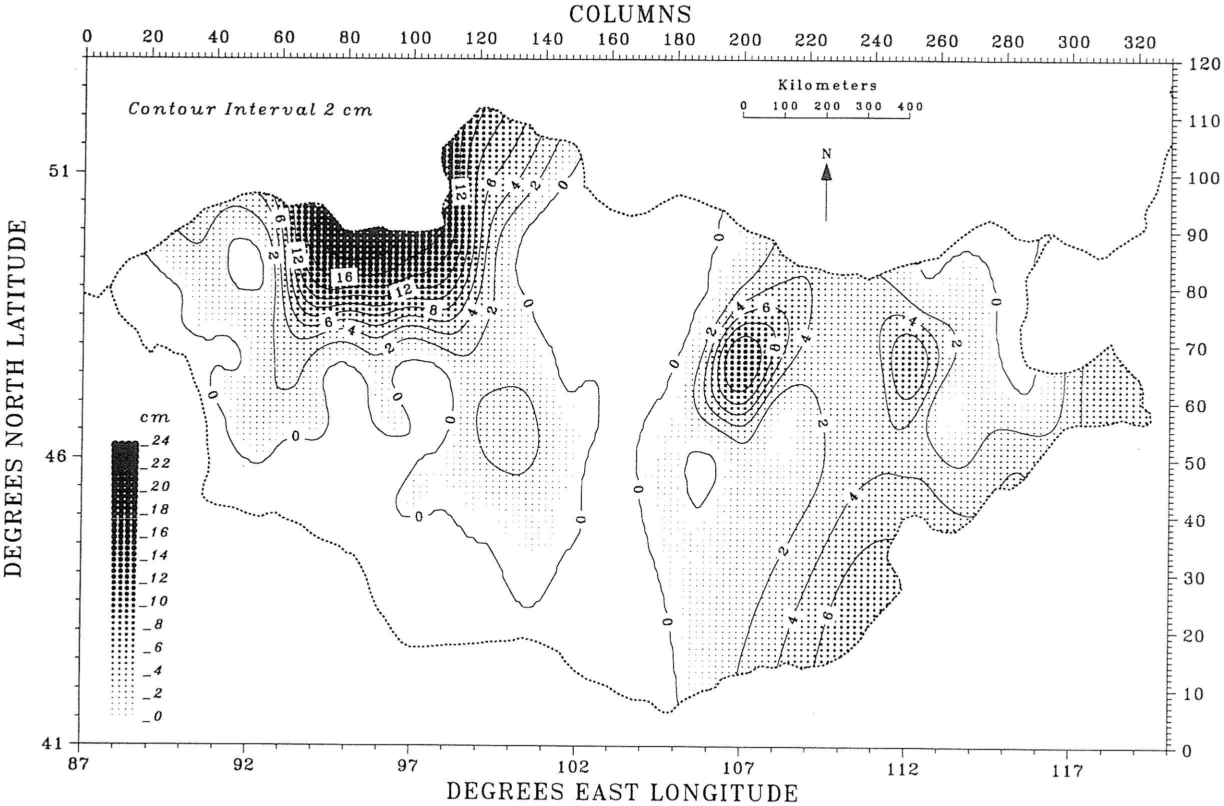

Figure 6. Mongolian snow depth for March 30, 1991 based on station data.

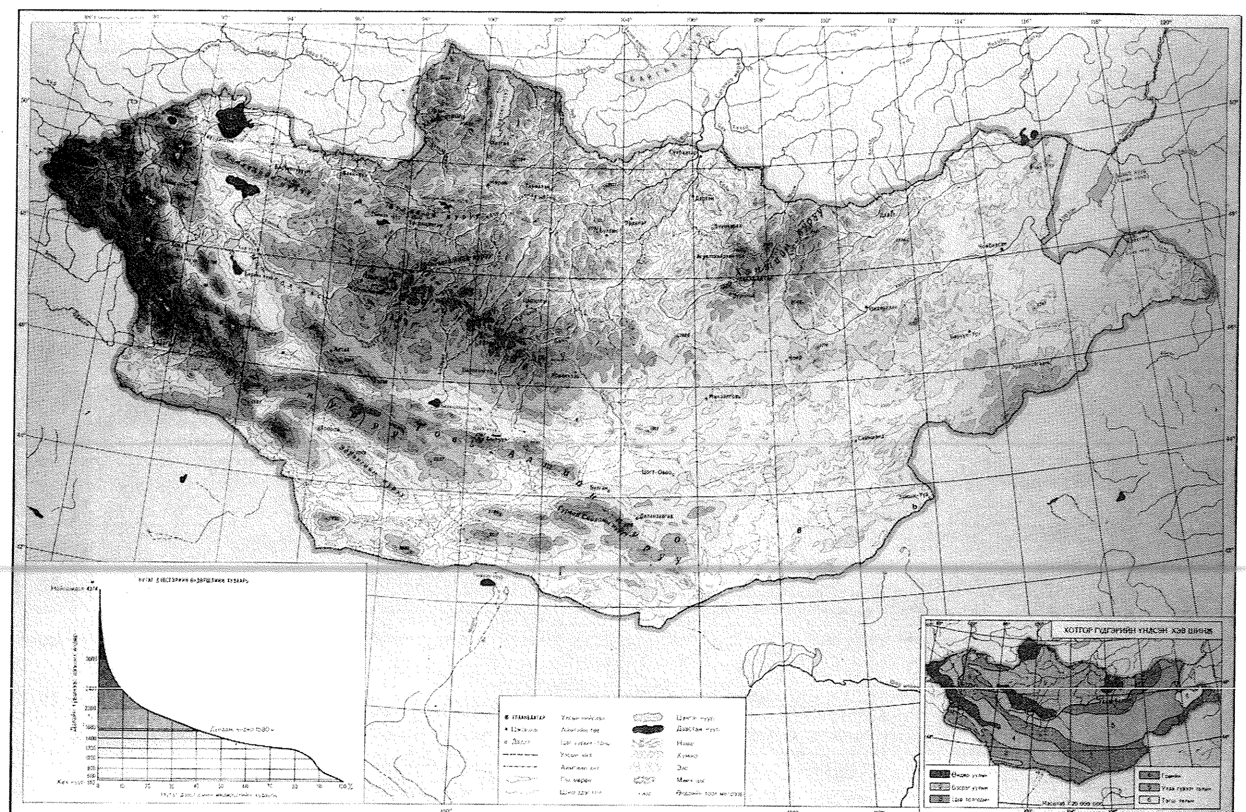

Figure 7. Mongolian topography and drainage (from Gloscomgidromet USSR and GUGMS of Mongolia, 1985).

each cell is assigned an increment constant based on the elevation change between it and the adjacent cells. This constant will be subjectively tuned for prevailing winds, i.e. windward or leeward, at GLERL. Mongolian scientists will subjectively define an adjusting grid to grossly compensate for other parameters (i.e. slope, aspect, flora composition, soil, etc.). A third pass will use this grid to produce a final snow depth map. GLERL staff will assemble the software framework to generate and adjust these cellular maps. Since GLERL staff have no first hand observations of snow depths in the region, the final tuning of the software will be accomplished by Mongolian scientists.

Elevations at 12 arc minute intervals have been assembled from topographic maps in Mongolia and provided to GLERL. At this writing, these elevation data have not yet been processed. Since snow depth data is not readily available outside the country, "imaginary stations" will be subjectively defined outside Mongolia to adjust estimates along the nation's borders. These stations will be assigned values derived from the closest Mongolia stations. These derivations will initially be an average of the closest stations, and then subjectively tuned through trial and error adjustments of weightings and location. Imaginary stations will also be defined in the Gobi to limit snow depth there. Without the control provided by such stations, inaccurate projections of data will sometimes occur as indicated in the southeast portion of Figures 4 and 6.

A future direction for study might be to develop a vegetation forecasting plan for spring when good pastures are critical for livestock. The system could use temperature lapse rate with elevation to adjust the cellular snow depth data between stations. These data could be converted to water equivalent and weekly changes monitored. The strong, dry spring winds are capable of removing substantial amounts of water vapor from the snow pack. A variable, evaporative losses grid will ultimately be required. Slope and aspect would probably not be used since higher resolution elevation data would be required than is available at this time. A generalized parameter for slope and aspect may be included in the algorithm as a first enhancement. The water equivalent data could be combined with soil type to derive surface soil moisture. This moisture could then be used with flora and elevation (i.e. temperature) to forecast pasture quality. Since the snow depth station data are telemetered to Ulaanbaatar, the project's goal would be to make and distribute a weekly pasture forecast to the herdsmen from the National Remote Sensing Centre in Ulaanbaatar.

Acknowledgements

Since much of NOAA's research is global in nature, access to data, technology, and foreign scientists is necessary. The Office of Oceanic and Atmospheric Research's International Activities (IA) Office in NOAA assists its environmental research laboratories towards participation in international scientific programs. IA serves as a liaison between the laboratories, the Department of State, and U.S. and foreign embassies. This role involves exploring opportunities for cooperation, establishing contacts, facilitating communication, and placing these opportunities in the context of constantly changing foreign and domestic policies.

With the recent independence of Mongolia, contact has been made possible with that nation. IA provided leadership in establishing potential science and technology programs. The Mongolian government identified snow depth mapping and forecasting as an area in which they had significant interest. In order to facilitate such a program, IA established communication between GLERL and Mongolian scientists. IA's assistance is gratefully acknowledged. This is GLERL Contribution No. 839.

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