A Brief Summary of the GLIMS Project and Databasing Issues at the University of Alberta

Introduction

The GLIMS (Global Land Ice Monitoring from Space) project is an international effort to map the present extent of the world's permanent land ice (except for the interior regions of Greenland and Antarctica). Previous projects, most notably the World Glacier Monitoring Service at the University of Zurich, have also created (partial) catalogues of the world's glaciers which contain single variables for each glacier such as centre location, name, length, snowline elevation and orientation. GLIMS will expand on these previous efforts by providing detailed vector data on the scale of individual glaciers. The primary product will be closed polygonal outlines representing the outline of each glacier, together with surface topography, velocity fields, and glacier facies where the data is available. It is also planned that a line approximating the median flow line will be produced for each glacier. In addition, the database will have the ability to store point and raster information (e.g., debris thickness, ice temperatures, ice depths, accumulation-area ratio, land-based photos), as well as to store associated information such as references to journal articles. The ultimate aim is that the GLIMS database will provide the first global picture of the distribution and characteristics of glaciers, and that the database will serve as the basis against which past and future fluctuations of glaciers will be determined.

Regional Centres

To achieve the mammoth task of collecting information for every ice mass, a network of approximately 40 regional centres (RCs) has been established at universities throughout the world. In addition, a network of 'Stewards' will provide information to the RCs for localised areas with which they are familiar. Using universally defined protocols, each RC will be responsible for the analysis of the glaciers in their region of interest; the University of Alberta is the RC for the Canadian Arctic. Each RC will report their findings to the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado, which will house the central GLIMS database and be responsible for distributing information to users via a web interface. There is currently no central funding available for the RCs: each is responsible for developing its own funding sources. A current list of collaborators and regional centre responsibilities is available at http://wwwflag.wr.usgs.gov/GLIMS/collaborators.html

Source Imagery

The initial aim of GLIMS was to base virtually all glacier identification and analysis on imagery from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instrument on the TERRA satellite. After a delay from its planned launch date, TERRA reached orbit on December 18, 1999, and is currently producing imagery. TERRA is a joint NASA/Japanese Space Agency project, and RCs receive free access to ASTER data for the purpose of creating the GLIMS database. So far, I have found approximately 40 useful images from the year 2000 for the Queen Elizabeth Islands (QEI), out of a total of ~160. These are all Level 1A data (unprocessed, uncorrected), as no Level 1B data (geometrically and radiometrically corrected) is currently available for this area. We have made a request to the USGS in Flagstaff to manually process our best Level 1A image to Level 1B specifications for the purposes of testing; this image covers a heavily glaciated area of northern Ellesmere Island. Each ASTER image covers a ground area of 60 x 60 km, and can be downloaded for free from the USGS EOS data center.

Due to the relatively small coverage and high cloud cover provided by the currently available ASTER imagery, it presently makes sense to use Landsat 7 imagery as the basis for most of our glacier identification work in the QEI. We currently have Landsat 7 imagery from summer 1999 and 2000 for every major ice mass there. All of the Landsat scenes are of excellent quality and are almost entirely cloud free. They also have a ground resolution of ~15 m in the panchromatic band, which is more than sufficient for our needs. Each Landsat 7 image covers a relatively large area (183 x 170 km), which makes it easier to track large glaciers which commonly cross scene boundaries in ASTER imagery. In addition, there are no restrictions on the use, reprocessing or redistribution of Landsat 7 data. This is important, as it is hoped that an image of each glacier from the source imagery will be included in the final database. This will facilitate easier identification of glaciers for end-users, and will enable rapid estimates of temporal changes in glacier extent and surface features. If future ASTER images are of better quality than at present, and are widely available in Level 1B form, then these may be used in addition to the Landsat imagery. The stereo capabilities of ASTER may also be very useful in producing present-day DEMs of ice masses in the QEI, although this product does not yet seem to be available.

Ultimately, the GLIMS database can handle glacier outlines from any source, including aerial photography. Consequently, we could also include glacier polygons derived from 1950s/60s aerial photography in the GLIMS database if time allows. When compared with new satellite imagery, this would provide a comprehensive record of glacier changes in the QEI.

GLIMS Database

It is planned that the GLIMS database will hold information on a number of variables for each glacier. This can be broadly categorised into static information (e.g., location, name), dynamic information that is tied to a particular analysis/date (e.g., glacier outline, area, ELA), and background information such as a description of the source imagery, instrument specifications, and name and contact information of the processing institution. Based on information from the GLIMS website, the present database will contain up to 9 tables for each glacier:

Table No.	Table Name	Description
1	Static	Time -independent glacier information, such as its name, general location, etc.
2	Dynamic	Time -dependent glacier information, such as its boundaries, area, equilibrium line altitude
4	Image Tiepoint Region Information	Information about non-glacierized regions near a glacier suitable for finding inter-image tiepoints
5	Image Cube	Information about a source image, including instrument, time/date, location, cloud severity
6	Instrument	Complete information about remote sensing instruments
7	Instrument bands/modes	Information about instrument bands, such as spatial and radiometric resolution
8	Displacement vector information	Vectors of ice displacement, as derived by comparison of multitemporal images of the same glacier
10	Source Snow Regions	Information (e.g. boundaries) about snow regions from which glaciers derive
11	GCPs/Reference Points	Information about control and reference points, such as latitude/ longitude/elevation and their uncertainties, image chip of point

A full description of the contents of each table is provided in Appendix 1. Some tables (e.g., displacement vector information) will not be used for all glaciers, while some tables will remain the same for many different glaciers (e.g., image cube, instrument).

Databasing Issues

1. Coordinate system

As described fully in Appendix 2, current GLIMS policy calls for three separate coordinate systems to be used in the database:

(i) Line/sample (L/S): this is the global coordinate system used to locate the satellite imagery.

(ii) Northing/Easting (N/E): this is a local coordinate system in metres from a ground reference point (e.g., mountain peak) which is identifiable in the imagery. The plan is to use this coordinate system to store the location of virtually all variables (e.g., glacier boundary polygons) in the database. A new reference point, and therefore a new local coordinate system, will be defined for most glaciers.

(iii) Latitude/Longitude (L/L): this system will be used to provide the coordinates of points to end-users after converting from the local N/E system

It is argued that the advantages to using a local coordinate system as the primary data storage method is that (a) it will make the difference between relative and absolute uncertainties explicit, and (b) it will facilitate easy and rapid updating of spatial information as improved knowledge of the location of reference points becomes available. Information on how to transform between L/S and N/E, and N/E and L/L, will be stored in the database.

For our work at the University of Alberta, we must decide whether to adopt the use of these three coordinate systems for GLIMS data storage. There are several issues to consider:

(a) There is not an easy way to connect different N/E coordinate systems with different reference points across scenes. This could be a major limitation when using imagery with a small footprint (e.g., ASTER, aerial photography), as large glaciers which cross scene boundaries will have points located in two or more independent coordinate systems.

(b) It is currently assumed that an improvement in geolocation information will be used to update the data associated with a reference point by shifting all data a constant northing and easting. This is problematic, however, as georeferencing of an image across many ground control points results in spatially variable warping of the image.

(c) It will be difficult to compare spatial information from the same area collected from different sources at different times, and it will be hard to plot maps of glacier information over large areas – the N/E coordinates of every glacier would have to be processed separately to convert them into L/L.

Based on these arguments, I feel that our analysis will be greatly simplified by using only the L/L coordinate system. This will simplify the referencing of our results by future researchers, and will reduce the level of the complexity in the database. Of course, the downsides are that error estimates will not be explicit, and the spatial information for an entire scene will have to be updated if improved geolocation information is found. Bruce Raup (NSIDC) states that the database is designed to handle either L/L or N/E coordinates: the decision of which to use is a GLIMS policy issue (which has not yet been finally decided upon).

2. Glacier definition

One of the biggest concerns for our analysis is the actual definition of a glacier. The GLIMS project defines a glacier as the fundamental unit in the database, and states that each branch of an ice mass should be treated as an individual glacier. In particular, a glacier is defined as being in only one hydrological basin, which means that an ice divide is always considered a glacier boundary. Consequently, the closed polygonal outlines of glaciers to be stored in the GLIMS database will frequently contain ice divides as their upper boundaries. If we are to define divides, then we must have detailed topographic information for all the glaciers that we will be analysing, and calculate the surface drainage patterns for these. Getting access to the topographic data is not a problem as we currently have 1:250,000 digital elevation (CDED) data for every map sheet that includes significant ice masses in the QEI. In addition, ASTER should soon provide high resolution stereo imagery that could be used to produce topographic information.

The major question, however, is the scale at which we should define individual glaciers. If we take John Evans Glacier as an example, it is technically an ice cap with approximately 20 different outlets around its margins. Should we therefore call each outlet a separate glacier and calculate the associated variables (e.g., ELA, AAR) separately? Alternately, we could follow the classifications assigned by the WGMS, but these only cover parts of Axel Heiberg and Ellesmere Islands, and are not consistent. Unfortunately there is no simple solution, although we should define a consistent policy for our work. Hugh Kieffer (GLIMS team lead at USGS-Flagstaff) stated in a recent email that ultimately the decision of the scale of analysis will depend on local conditions and the knowledge of the regional centre undertaking the work. Ultimately, the goal must be to ensure that we have accurately accounted for all of the ice in our region of interest.

3. Other potential issues

There are also several other issues that we should consider:

(a) Should we include DEMs for each glacier in the database? Copyright issues if we use CDED data? Can we process stereo ASTER imagery?

(b) Should we include satellite imagery of every glacier in the database? If so, then at what resolution, in which format, from which sensor, etc.? Should we include copies of aerial photography as well? Again, there are questions about copyright, etc.

(c) How should we orthorectify our imagery? By reference to features on map sheets? But then how accurate are the map sheets?

(d) Are there any priority areas that should be analysed first?

(e) What's the best software to perform the analysis?

I am certain that there are many other questions that need to be answered – please let me know what they are!

Luke Copland (luke.copland@ualberta.ca), March 9, 2001

Reference material

Kieffer, H. et al. 2000. New eyes in the sky measure glaciers and ice sheets. *EOS, Transactions, American Geophysical Union,* **81**(24), 265 & 270-271.

Raup, B.H., et al. 2001. The GLIMS database: scientific considerations in the design of a global glacier data archive. *To be published in the Annals of Glaciology.*

Main GLIMS website: http://www.glims.org

Protected website for RCs: http://wwwflag.wr.usgs.gov/GLIMS/usgsdist/main.html
(user id = glimsguest, password = ber1ng789)

World Glacier Monitoring Service: http://www.geo.unizh.ch/wgms

TERRA home page: http://terra.nasa.gov/

ASTER home page: http://asterweb.jpl.nasa.gov/

EOS Data Gateway (to search for ASTER imagery):
http://edcimswww.cr.usgs.gov/pub/imswelcome

Landsat 7 home page: http://landsat7.usgs.gov/

USGS Earth Explorer (to search for Landsat imagery):
http://edcsns17.cr.usgs.gov/EarthExplorer/

Toporama (high resolution maps of Canada): http://toporama.cits.rncan.gc.ca/

Canadian Centre for Topographic Information (DEMs of Canada):
http://www.cits.rncan.gc.ca/

Appendix 1 – Detailed description of database contents

(from http://wwwflag.wr.usgs.gov/GLIMS/db_design.html)

The following is a description of the tables in the relational database designed to store GLIMS-produced glacier data. Each table is associated with a number, which appears next to the name in parentheses. Dependent tables have the same number as their parents', with a letter appended.

Under each table name is a list of fields expected to be stored.

Static (1) - table of static glaciological parameters
ID: unique Glacier ID number.
Glacier name, if there is one.
World Glacier Monitoring Service (WGMS) ID, if assigned
Pointer to info on previous ground studies and notes
Pntr to literature reference database (?) # added 6/30/97
Number of drainage basins
Glacier type (flags for surging, temperate, ice stream, etc)
Offset (northing) bet. glacierID pt & ref pt
Offset (easting) bet. glacierID pt & ref pt
Current default ground reference point # added 6/30/97
List of images containing this ref pt
Pointer to high-resolution Digital Elevation Model (DEM)
Typical radiance at time of EOS-AM1 fly-over, at summer solstice(?)
Source snowfield Information
ID of tiepoint region for this glacier

Image List (1b) [dependent]
ID of image that contains this glacier
Best image flag

Center Line (1c) [dependent]
Northing of Center Line
Easting of Center Line

Dynamic (2) - table of changing glaciological parameters
ID: unique Glacier ID number.
Dynamic information ID
ID of image that is basis of these measurements
Time stamp for this information
Mean width of glacier
Total length of glacier
Total area of glacier as measured from imagery
Uncertainty in computed glacier area
Ablation area of glacier as measured from imagery
Area of ablation zone

Outline Polygon (2b) [dependent]
Sequence number
Northing of Polygon
Easting of Polygon
Polygon Uncertainty, northing
Polygon Uncertainty, easting
Terminus location flag

Image Tiepoint Region Information (4)
ID of tiepoint region
ID of image(s) that is basis for this G-Ring
Reference point for G-Ring
List of GCPs within this region

Tiepoint Region G-Ring (4b) [dependent]
Sequence number
Northing of G-Ring
Easting of G-Ring

Image cube (5)
ID of image
InstrumentID
Time of image exposure
Lat location of center of image
Lon location of center of image
Uncertainty of image georeferencing - lat
Uncertainty of image georeferencing - lon
Orientation of image with respect to north, deg
Cloud severity (0 to 100%, 100% being worthless)
Sun azimuth
Sun elevation
Whether image is processed or not
Number of glaciers in this image
Size of header
Image format
S/L location for first and last line of image

Image Band List (5b) [dependent]
Band in this image
Number of lines
Number of samples

Image Glacier List (5c)[dependent]
ID of glacier in this image

Image GCP List (5d) [dependent]
GCP in this image

Instrument (6)
ID of instrument
Name of instrument
Abbreviation
Average orbit altitude
Orbit inclination
Number of bands
List of names of bands/modes

Instrument Bands/Modes (7)
ID of instrument
Band/Mode name (or number) # or band number

Scan type
Sample interval X (radians) # nominal, or include nom. alt.
Sample interval Y (meters) # At nominal center of image
Low edge of passband
High edge of passband
Number of bits per DN
Number of lines per nominal scene
Number of samples
Polarization (for radar)

Displacement Vector Information (8)
ID: unique Glacier ID number.
ID of velocity information set
ID of first image of pair
ID of second image of pair
Number of displacement vectors
Representative speed as measured from imagery (km/a)

Vector Sets (9) [dependent]
x-location of feature in first image, in km, N/E coord system
Uncertainty
y-location of feature in first image, in km, N/E coord system
Uncertainty
x-location of feature in second image, in km, N/E coord system
Uncertainty
y-location of feature in second image, in km, N/E coord system
Uncertainty

Source snowfields/regions (10)
Source region ID (same method as glaciers)
ID of image that is basis for this G-Ring
Source-region name, if any.
Reference point ID

Source Region G-Ring (10b) [dependent]
Sequence number
Northing of G-Ring
Easting of G-Ring
G-Ring Uncertainty, northing
G-Ring Uncertainty, easting

Source Region Glacier List (10c) [dependent]
ID of glacier in this source region

GCPs (Ground Control Points)/ Reference Points (11)
(same ID method as glaciers and snowfields)
Name of ground reference point, if there is one
Text for how location determined (~50 characters)
Latitude of GCP
Uncertainty in Latitude
Longitude of GCP
Uncertainty in Longitude

Elevation of GCP
Uncertainty in Elevation
Image chip (32 x 32 image cube)
ID of source image for chip
Number of bands in image chip
Bands in image chip # a fixed list of band numbers
Line in source image of first line of chip
Sample in source image of first column of chip
Line location of GCP within chip (floating pt number)
Sample location of GCP within chip (floating pt number)
Pointer to source of more detailed information

Appendix 2 – Geographic control

(from http://wwwflag.wr.usgs.gov/GLIMS/db_control.html)

The locations of all geographic entities in the GLIMS database, such as glacier boundary polygons, are stored as northing/easting coordinates (offsets) from a reference point which is identifiable in imagery. Reference points will typically be mountain peaks, sharp bends in rivers or lake boundaries, or other stable and easily identifiable features. These coordinates are related to the line/sample and latitude/longitude coordinate systems via standard transformations. In scenes that do not contain any appropriate immobile features, such as within ice sheets away from all rock, an artificial reference point will be used.

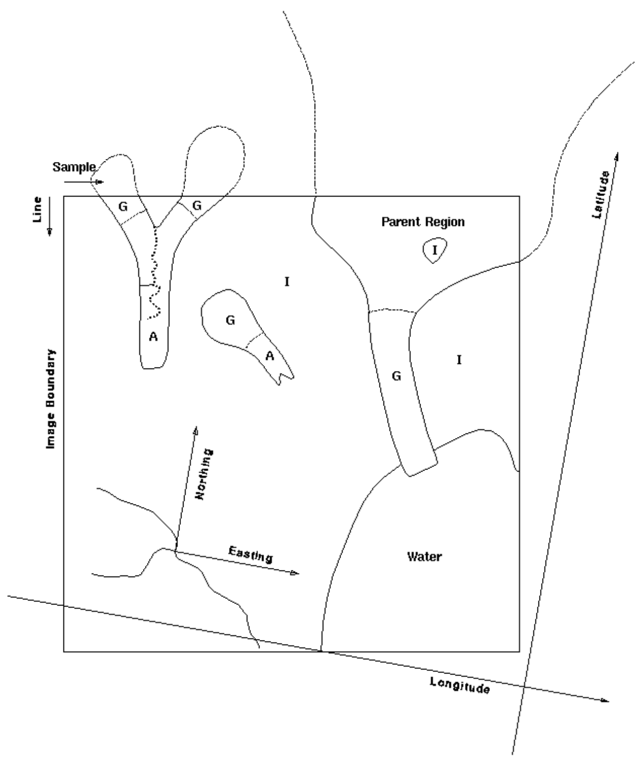

Figure 1: Relation between difference coordinate systems. G: glacier; A: ablation zone; I: immobile region.

There will be three basic coordinate system types used in this processing and in the database:

1.Local image coordinate system (abbreviated L/S). Units are line/sample, and are referenced to a corner of the image.

2.Local ground coordinate system (abbreviated N/E). Units are meters north and meters east of some reference point on the ground that is probably, but not necessarily, contained in the image. Typically, there will be one reference point per glacier, although a single reference point can be shared by many glaciers.
3.Global coordinate system (abbreviated L/L). Units are geographic longitude and latitude (degrees).

The Figure 1 above depicts the three interrelated coordinate systems.

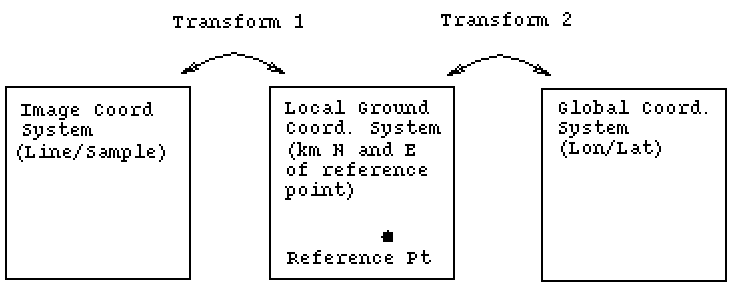

Figure 2: Coordinate Transformations

Polygons, vectors, and the like will be stored in the database expressed in the local ground coordinate system (N/E). Also stored will be the transformations to go between L/S and N/E (Transform 1 in Figure 2), and between N/E and L/L (Transform 2 in Figure 2). We will not know the precise geolocation of most images, thus all location information should be stored in a relative sense. As new information is obtained relating the N/E reference point to L/L, only that latitude/longitude coordinate need be updated, rather than having to update every location associated with that reference point, as would be the case if we stored everything in L/L to start with. In this scheme, L/L coordinates are computed every time they are desired, making it easy to update geographic coordinates for image-derived data. This flexibility represents little computational burden for modern computers, for which the time to read L/L coordinates from a disk is longer than required to do a N/E to L/L calculation. Note that the reference point for the N/E coordinate system is simply the origin for that coordinate system. It is not to be confused with tie-points used to co-register two images, or ground control points (GCP's) used to refine absolute locations.

The alignment between the image coordinate system and the true L/L grid is determined by the angle the orbit track makes with the meridian lines (a known function) and the yaw of the spacecraft, typically known to better than 10 arc-seconds (48 microradians). This amounts to 3 m over the 60 km width of an ASTER image, and should thus not be a problem. The angular relation between the N/E system and the L/L grid varies slightly over a spacecraft scene and depends upon the cartographic projection used. Any well-defined cartographic projection may be used; GLIMS will probably use Transverse Mercator with a local central meridian for individual scenes, and UTM for mosaics.

Each glacier will be assigned an ID automatically the first time it is entered into the GLIMS system. This ID will be a combination of a representative longitude and latitude for the glacier, rounded to the nearest 0.001 degree, which corresponds to 111 m at the equator. Because the uncertainty of dead-reckoned positions (based upon engineering information alone) in current spacecraft imagery systems is typically about 200 m (e.g., RADARSAT; expected to be 185 m for ASTER), even where no ground control, ID assignments should rarely, if ever, need to be modified.

Transform 1 can consist of a rotation, translation, magnification, the location of the reference point (L/S) in the image, topographic correction, and any geometric distortion internal to an imaging system. It does not depend upon absolute geodetic locations. Transform 2 simply consists of the longitude and latitude, together with their uncertainties, of the ground reference point, together with standard mapping transforms for converting northings and eastings to L/L. Thus, it does not depend upon the imaging system, only upon the geodetic control.

A given image will have associated with it as many ``Transform 1''s as there are reference points associated with it. Pointers to ``Transform 2''s will be stored with the glacier information (pointers because several glaciers might share the same reference point, and the information about the reference points should be stored only once).

Since glacier IDs will contain location information in the L/L coordinate system, searching for glaciers based on latitude and longitude will be straight forward.