Exercise sheet : Remote Sensing of the Cryosphere 2

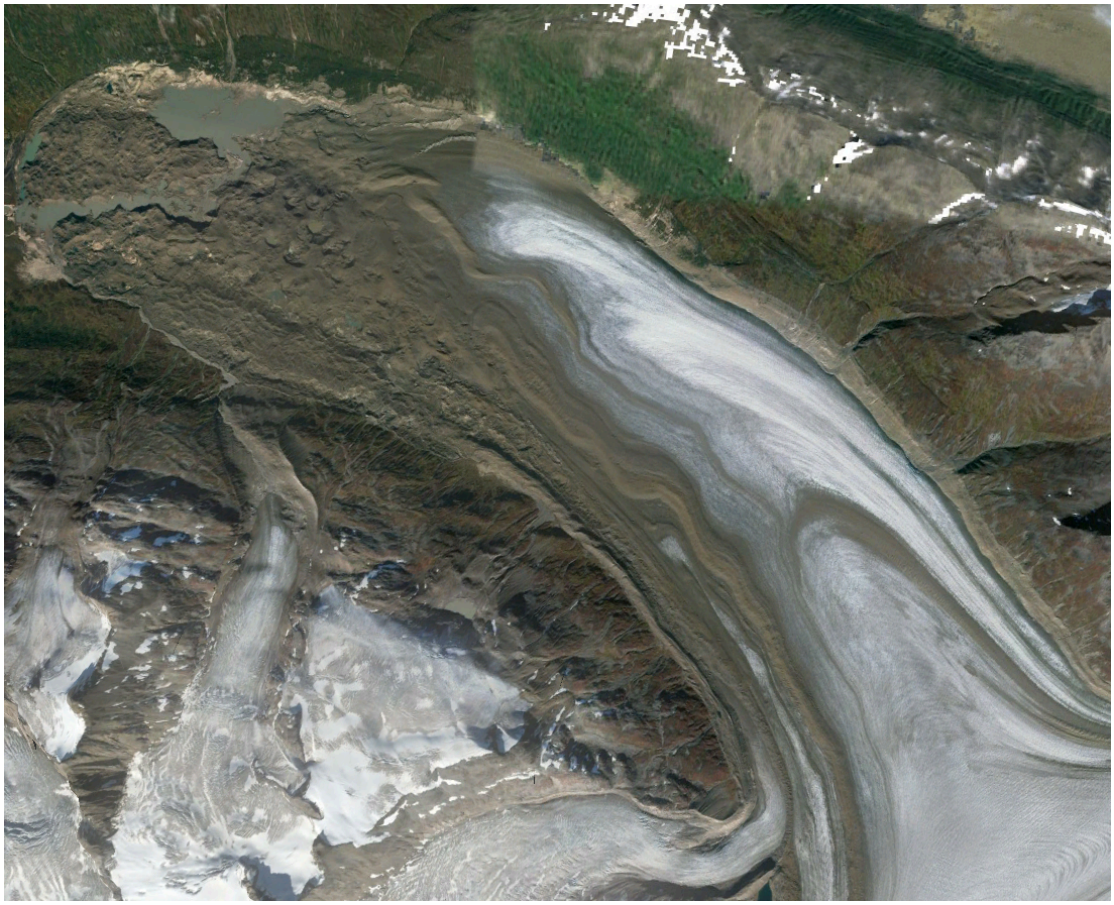
1. Glacier outlines / extent

In isolation (do not confer with other students), mark on the following images where you would consider the glacier outline to be:

a)

b)

c)



Now, compare your outlines with others. How do they differ? Where do they differ? What do you think are the reasons for those differences? What additional information might you use to improve the accuracy of your area estimates? How might you devise an experimental approach to quantifying the uncertainty in a glacier area estimate?

a) should all be similar
b) differences due to snow cover and shadowing
c) differences due to debris cover

Additional information: *in situ* measurements, DEM for surface slopes, multispectral band composite image (e.g. Landsat 543), velocity map to show which debris-covered parts are actually flowing

2. Glacier volume change and uncertainty

You have been given two datasets: (i) a set of air photos from late summer 1990 with a corresponding photogrammetrically-processed digital elevation model (DEM); and (ii) an airborne laser altimetry profile collected from a survey flight up the glacier forefield and centreline in spring 2010. Both datasets cover a mountain glacier which has been surveyed in the field for mass balance purposes since 1995.

a) What information could you use to determine an appropriate density for converting a calculated glacier volume change to a mass change?

Winter mass balance density measurements from snow pits
Amount of snow cover present in the 1990 aerial photograph images

b) Thinking about the steps necessary to calculate geodetic mass balance from these two datasets, what sources of error will contribute to the total uncertainty of your mass balance estimate?

Error in DEM 1 (results of photogrammetric bundle adjustment, quality of ground control points, image scale 1:10,000 higher resolution that 1:50,000, image texture [much snow?], results of stereo matching algorithm, quality of any manual editing); Error in lidar data (steep slopes, processing problems); Error in area delineation of glacier; Profile-to-glacier error when extrapolating 2010 centreline data to entire glacier. Uncertain density-depth profile and resultant assumptions.

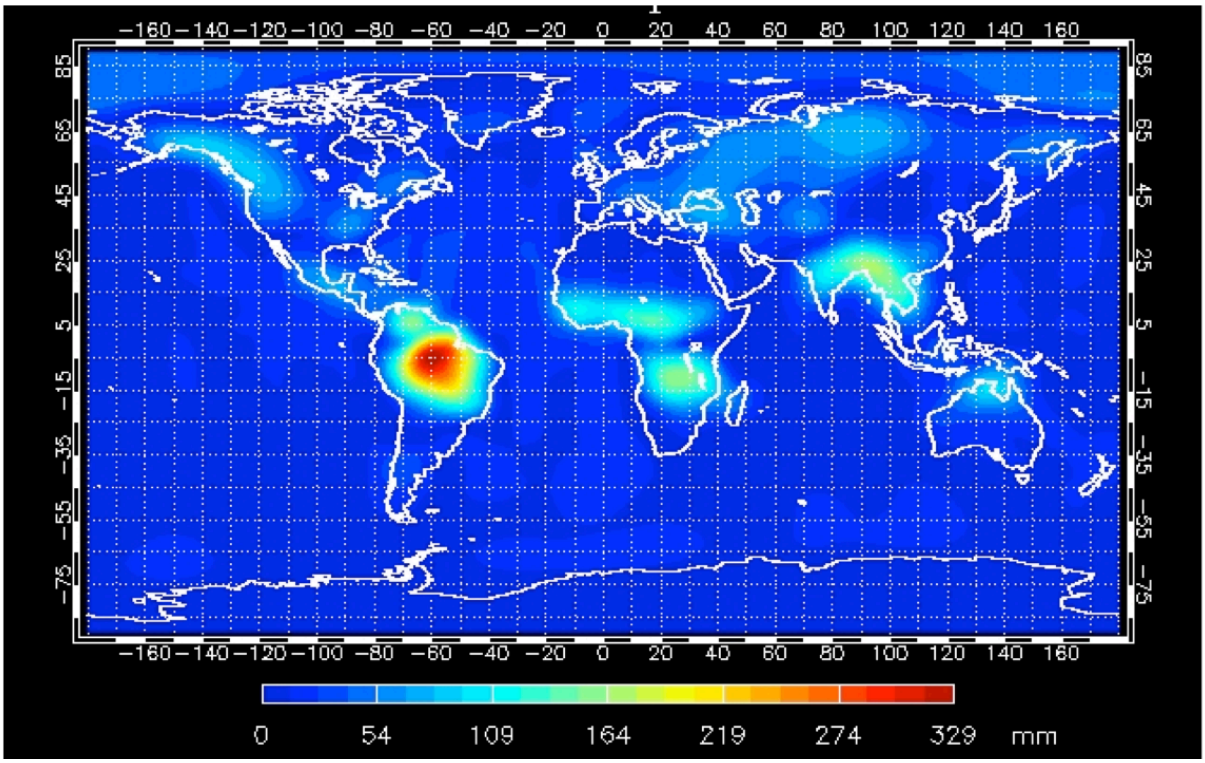
c) How might you go about estimating the horizontal and vertical elevation accuracy of your geodetic datasets?

Comparison of 3D DEM coordinates with points of a known, higher accuracy (reference datums), comparison of lidar and photo elevations over ice-free, stable terrain.

3. Ice mass change from GRACE

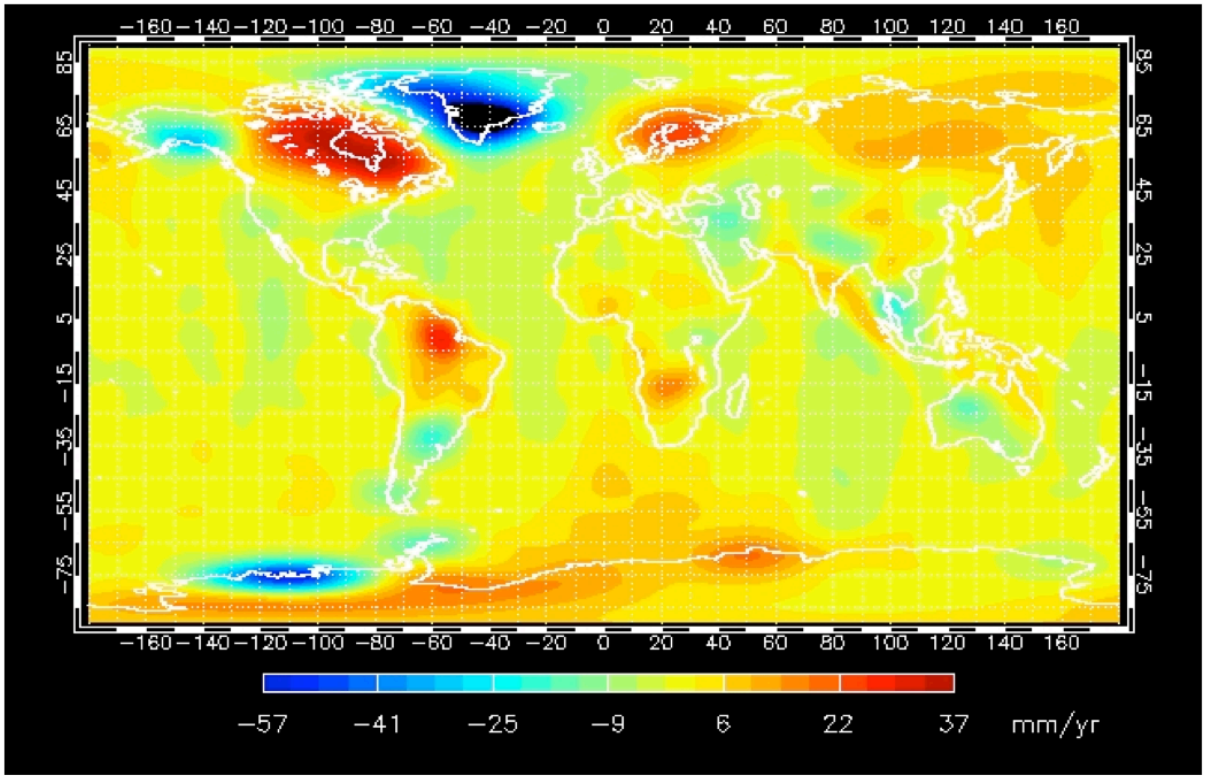
Below are two spatial maps produced from time-series of filtered GRACE level 2 data (gravity field in mm w.e.). For each map, describe which geophysical parameter is being plotted (phase, amplitude, trend, or frequency). List at least 2 regional geophysical signals that can be identified in each figure (ideally as many as you can).

(a)



Parameter: Annual amplitude of mass change
Regional geophysical signature: Amazon basin water storage, snowmelt from Gulf of Alaska, Indian Monsoon

(b)



Parameter: Trend in mass change
Regional geophysical signals: Glacier mass loss from Gulf of Alaska, Greenland, Patagonia, Antarctic Peninsula, Amundsen Sea Sector of WAIS, Glacio-isostatic adjustment in Canada and Scandinavia.

4. Ice mass change from GRACE

Unlike other instruments, GRACE is able to directly measure regional changes in mass. This means that GRACE is not sensitive to changes in the density profile and, because GRACE has complete global coverage, mass change estimates do not require extrapolation of point observations. That said, GRACE is not able to directly separate changes in glacier mass from other mass change signals. To separate out other sources requires the use of land surface, climate reanalysis, and GIA models and/or well-constrained regional observations.

a. Do you think it is easier to separate glacier mass changes from other mass change signals for (a) continuous glacier systems, or (b) highly dendritic glacier systems, and why? Give real-world examples of each.

   It is easier to separate glacier mass change signals for continuous glacier systems when the GIA is well constrained because the relative magnitude of other hydrological signals (soil moisture, groundwater content, seasonal snow) are relatively small compared to the glacier signal. Examples include Greenland, the Canadian Arctic, and Alaska. When the GIA is poorly constrained, this is no longer true (Antarctica).

b. Why do GRACE-derived glacier mass anomalies have much smaller uncertainty bounds for Greenland than for Antarctica? Hint: think about what the ground is doing? How can the large Antarctic mass change uncertainties be reduced?

   The rate of mass transfer under the Antarctic ice sheet is very poorly constrained. There is little exposed bedrock to mount high accuracy GPS systems for the measurement of uplift rates and modelling is limited by the poorly known mass history of the ice sheet. This generates the large uncertainties in mass change estimates of the Antarctic ice sheet.

   In Greenland there is a higher density of uplift measurements, a smaller total area, and a better history of changes in the mass of the ice sheet. These all lead to lower uncertainties of the estimated mass change resulting from GIA, and therefore lower uncertainties for estimates of the mass change of the ice sheet.