Image Processing for Earth Observation

Midterm Exam

Glacier retreat in the Himalayas and implications for local populations

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Context

Our project concerns the rapid glacier retreat in the Himalayas and the implications on local populations. More specifically, we will be studying the south-eastern Tibetian Plateau region, located in China, and the growth of glacier-fed lakes in this basin. In fact, glacier-fed lakes are often dammed by unstable moraines which can collapse and lead devastating glacial lake outbursts floods (GLOFs). These lakes have been increasing in size and quantity due to global warming and are becoming an increasing threat to the local populations. Our project will therefore study the increasing amount and size of these lakes in this basin, but also the corresponding glacier retreat and try to establish a correlation between both of these. The exact hydrological basin has not been chosen yet, but will either be in Upper Mekong, Salween, Qaidam, Hexi Corridor, Yellow or Yangtze basin, as defined by [1].

1 Question 1

In your project, imagine that you would have enough resources/budget to make a/several drone image acquisition campaign(s).

1.a What campaign(s) would you plan (frequency, coverage, spatial/spectral resolution)

If a drone image acquisition campaign was within the budget of this study, then it would first and foremost be used to complement the data that is already available. Most existing studies that have already characterised the Tibetan Plateau use satellite resolutions of 30m or worse [1, 2, 3]. As such, a drone campaign would be useful as it could greatly increase the resolution of the data acquired. However, due to the very large surface areas covered, this might not exactly be realistic or economically viable. To reduce the cost, the drones could fly at higher altitude, reducing resolution, but still providing imagery at a resolution near to 10cm for a flight at 50m altitude [4]. The acquisition frequency would be comparable to the previous studies, obtaining data once every ten years. It is likely that the data would be collected every ten years or so over a summer, where seasonal snow would have mostly melted. The bands to be used would be the ones that are used to calculate the NDWI index (see question 2), so mostly NIR, SWIR and green bands.

1.b How would that data fit within your project (complementing or replacing current data, which processing steps involved, etc.) ?

The drone data would complement the low resolution 30m data that is freely available online. To reduce the large costs of flying a drone over thousands over square kilometres, free data would first be used to determine zones with high glacial lake content. Since the detection of lake is limited to the resolution of a few pixels (lakes are typically restricted to an area of 4 pixels minimum), many glacial lakes cannot be properly detected with this data. As such, a drone flying over the areas with a large lake density would better detect the smaller lakes and also lead to a smaller error when it comes to the estimation of the lake areas.

Additionally, two problems arise when looking at satellite imagery for glaciers and lakes. The first is that glaciers that have been covered by rock can be very hard to distinguish from simply rock itself. Drone footage might provide higher resolution imagery that would allow for covered glaciers to be better identified. Also, glacial lakes have a very similar spectral signature to mountain shadows. This can be somewhat corrected with digital elevation models (DEM), but drones can potentially have less shadows in their images since a campaign can better chose the time of day at which to perform fly-bys.

1.c What budget should you assume roughly for that/those campaign(s)? Explain how you derive it.

Overall, the drone campaign would likely cost upwards of \$100,000. In fact, the main limiting factor when using drones for remote sensing is the covered area. In this case, even after identifying regions with a large glacial lake concentration as suggested above, a study area of at least $10km^2$ is to be studied, but most likely closer to $50km^2$. This figure was derived from the lake areas given for the South-eastern Tibetan Plateau in [1] and is the minimum area the drones would need to cover. The lecture slides given in class [4] give an order of magnitude of around \$10,000/km^2, leading to the minimum price of \$100,000 given above. Unfortunately, drone operations don't experience much economy of scale and scanning a larger area leads to a proportionally larger bill. It is also very likely that the rough terrain and climate present in the Himalayas would provide for an additional challenge that would certainly increase the above figure.

1.d Assume that the campaign(s) have to be replaced by VHR satellite data.

1.d.1 Estimate the budget difference this would make:

Replacing the drone acquisition campaign by VHR satellite data would make much more sense, both on an economical and logistical point of view. VHR data can be of high enough resolution to allow for detection of smaller lakes and reducing area estimation error, while being coarse enough to not be overpaying for resolution that is not necessary. According to once again the slides given in class [4], data obtained with a 1m resolution, which is likely enough for our case, would cost around $\$8/km^2$, much lower than the price for drone campaigns. There indeed seems to be a minimum price for a campaign, but a coverage area of around $50km^2$ should cost a few thousand dollars. If a resolution comparable to drones is desired to further reduce error, then 30cm imagery can be obtained for the modest price of $\$30/km^2$, which would still lead to a fairly low price tag for the kind of surface area to be monitored.

1.d.2 Would it make sense to replace the drone campaigns by VHR satellite data? In both case explain why and what is the main reason for choosing one or the other in your project.

Yes, VHR satellite data makes more economical and logistic sense to use than drones. Not only are drones significantly more expensive than VHR, performing a drone image acquisition campaign present various challenges due to the remote nature of the locations and the difficult meteorological conditions. In this sense VHR does not have these problems, as images from the region can easily be ordered from a private company and had within a relatively short time. VHR would also provide the resolution required to improve lake identification and reduce area estimation error. However, VHR still suffers the issue of cloud coverage which is quite high in these regions. Drones on the other hand, would fly below the clouds and don't have this issue. VHR also does not solve the issue of mountain shadows as drones could, however there are other ways to compensate for this such as using DEMs. Nonetheless, VHR would still provide for the best compromise between cost and increase in information quality.

2 Question 2

2.a Do you plan to extract band indices from your data in your project?

If yes, which one(s), what bands are involved and why?
If no, motivate why did you discard indices?

Yes, band indices extraction is planned. First, the NDWI (Normalized Difference Water Index) or MNDWI (Modified Normalized Difference Water Index) could be extracted from our project data. Theses indices allow water detection, in our case this is how lakes would be detected [2, 5, 3]. MNDWI could be better on open water. Besides, the NDSI (Normalized Difference Snow Index) is also planned to be extracted in order to detect glacier areas. For this purpose, the data must be taken in late Summer period or Autumn to avoid the high cloud coverage during the monsoon season and ensure minimal seasonal snow coverage. In fact, the aim is to detect as accurate as possible lake and glacier areas and cloud or snow coverage could distort results. Cloud coverage of under 10% is desirable and this can be quite difficult to obtain in this region of the world. Hence, data might have to be taken from nearby years.

NDWI is related to NIR and SWIR bands, some examples of bands are Landsat 8 bands 5 and 6. MNDWI is related to Green and SWIR, as water absorbs much more light in the NIR band than in the visible band. Moreover, snow and ice have generally high reflection in the green bands, whereas it is low in the shortwave infrared (SWIR), consequently Green band and SWIR band could be used to derive NDSI [5].

2.b What index could you create that would be related to your project topic?

Our project topic is related to the study of the change in area of glacial lake and of glacier, and also the relations between as well as the consequences. Then we could create an index to highlight lake area change, and another index highlighting glacier area change. Theses indices would use temporal data. In our case the indices can be deduced by comparing data from 2010 and data from 2020. Then it will form a quantification basis for an upcoming interpretation of phenomenons.

3 Question 3

Does your project require some "domain adaptation" (in other word, is there the need to either preprocess the data in a manner to standardize it or to adapt a model between different datasets)?
If yes, describes what adaptation is needed and how you can perform it.
If no, consider the situation where your project would be taken further by other students next semester and describe cases where they could be facing "domain adaptation" in relation to your topic.

Yes, our project require some "domaine adaptation" or a need to preprocess the data in a manner to standardize it. In fact, several normalized differences indices have to be derived from raw data : NDWI or MNDWI, and NDSI. Raw data will be from different bands, such as NIR, SWIR or Green. Another preprocessing step needed is to derive the slope terrain. This can be done from DEMs (Digital Elevation Models). Slope terrain is needed to classify a zone as a lake or not. In fact, from satellite imagery shadow often occurs on steep slopes, and they have spectral characteristics similar to those of glacial lake water, resulting in a similar NDWI. Because of this, mountain shadows could be confused with lake. Thus, to differentiate glacial lake from shadows of steep slopes, another variable is studied in addition of the NDWI value, which is the slope, and it should be below a certain threshold, frequent values of threshold are $<5°$ or $<10°$ [2, 3]. This process could consist to overlay a map with NDWI values and a slope map derived from DEM.

4 Question 4

Does pansharpening is involved in your project?
If yes, explain where it is involved and what positive and negative impacts it can have?
If no, can you still imagine a possibility for pansharpening the type of data involved in your project? Check and report relevant literature if existing.

Yes pansharpening could be useful in our project. It would allows to detect smaller lakes and also to reduce error for lake measurement. As mentioned earlier, the area estimation of the glacial lakes is directly correlated with the resolution, as measurements are only accurate up to ± 0.5 pixels. Pansharpening and increased resolution would therefore significantly reduce the error in the estimation of the glacial lakes area. Then there is a need of information with higher resolution. It can be achieved with drone campaign as discuss before, or with VHR satellite data. The positive impact is that higher resolutions lead to higher precision in our study. Negative impacts are linked to acquisition technologies. A drone campaign appears quite costly and with complicated logistics, while it is not the case with VHR satellite but there is some drawbacks with cloud coverage or mountains shadows, as mentionned in question 1.

5 Question 5

5.a Does it make sense to use morphology in your project?

If yes, explain why, how you will apply it and what morphology operations you plan to use? Could several operations or chaining of operations be useful in your case?
If no, explain why and provide examples of other applications where it could make sense with the same type of data than in your project.

It makes sense to use morphology in our project, because it would allow to better distinguish the elements of glacial lake and those of glacier from the others. To do this, a Opening Top Hat (also called a White Top Hat) with a threshold could be apply as in our project there is a need to respect the border of objects as well as to keep the geometrical information. Morphology use would allow a easier detection of elements of interest. However, we should be careful about the effect applied in order to not neglect the small lakes. In fact, a too aggressive morphology operation might remove lakes that are smaller than the filtering size used.

5.b Do you consider using convolution filters or co-occurrence indices?

If yes, explain which filters or indices you think about and why these ones. Which pre-processing is needed when using these filters?
If no, explain why and provide examples of other applications where it could make sense with the same type of data than in your project.

Yes, convolution can be used, a high pass filter could be used in order to enhance high contrasted areas. For example an contour reinforcement would lead to enhance edges without loosing information in the objects. Afterwards the detection of glacial lake or glacier would be facilitated. These filters could be applied directly on the images obtained from Landsat data, or on the indexed images. Indeed, using a filter on these indexed images might be a good method to further increase the contrast provided by these indexes. Once again, effects of filter should be mastered to keep small lakes workable.

6 Question 6

You will have to assess the performances of your project outputs based on some validation data. You want that these performances tell about your outputs accuracies and the generalization and robustness of your approach.

6.a Explain how you will setup your training and validation data (e.g. how to split, rough amounts, etc.)

To train and validate the model, some of the data will have to be labelled manually. To do so, a series of scenes will be taken from the hydrological basin of interest and the regions on the scenes will be given a label according to the information that can be seen on the bands or on the indices discussed earlier. The data will be labelled into a few different categories. These will be glaciers, clouds, glacial lakes, mountain shadows, other and potentially rock-covered glacier. The latter might be difficult to identify on satellite imagery and as such might not be included. Both glacial lakes and mountain shadows will be a possible label so that the model can be trained to properly identify these. The same can be said for glaciers and clouds, which might be confused for one another in the classification. Scenes of sufficient size with enough points of each label will have to be chosen, although the exact size has not been determined yet. It is likely that 50 or so regions of each category will be required, which will likely lead to tens of thousands of pixels with each label to train and validate the model.

Once this is done, then the labelled data set should be split in perhaps 4 or 5 folds and a k-folds will be done over this data set. By doing so, the model is automatically validated on the labelled data and is not over fitted to part of the data if the data set is split in a training and validation data set. The accuracy and f1-score of the model should be used to evaluate a model, although alternatively the Kappa measure can be used as well. If enough labelled data is present, more folds, up to around 10, can be made, at the expense of increased computational cost for training the models. Once the model is trained on the labelled training data set, it can be applied on unlabelled data and verified manually on a small subset of the unlabelled data.

6.b Complete the confusion table row and column names with your foreseen output classes (remove/add necessary columns/rows)

Table 6.1: Confusion matrix for the labelling of the data

		Ground truth					
		Glaciers	Clouds glaciers	Rock-covered lakes	Glacial shadows	Mountain	Other
Prediction	Glaciers						
	Clouds						
	Rock-covered glaciers						
	Glacial lakes						
	Mountain Shadows						
	Other						

7 Question 7

7.a Based on the data characteristics for your project which of the main families of supervised classifiers would best apply to it?

For the data that is to be analysed, a non-parametric method is likely better as it makes no assumptions about the distribution of classes and is therefore less strict. Due to the low number of features used to classify the data (namely a few bands and a few indices) and the low amount of data (HR imagery), methods like Random Forest or Artificial Neural Networks are not suitable. This leaves the three other non-parametric methods seen in class which are minimum distance, K-NN and SVM. K-NN might prove to take a large amount of memory depending on the number of labelled pixels and as such is likely not the best candidate. This leaves minimum distance and SVM. Minimum distance is a very simple method that would not be complex to implement and supposedly performs rather well. However, it lacks some of the complexities of SVM which might make the latter a better candidate. In the end, minimum distance will likely be tried first due to its very easy implementation and if its results are not good enough, then SVM will be used.

7.b Are you planning to use unsupervised classification?

If yes, explain why and how you will use these outputs.
If no, explain what you could gain in using it to complement a supervised approach.
No, we are likely not planning on using unsupervised classification. The reason for this is that the data we want analyse should be fairly easy to manually label and the classes we are looking for are fairly well understood. However, unsupervised classification methods might be useful to determine if there are other important classes that were not included or thought of previously. In fact, there might be further distinguishing features that further classify glaciers or glacial lakes in subclasses. For example, some articles further categorize lakes into supra-glacial lakes, pro-glacial lakes and lakes disconnected from glaciers. It is therefore possible that unsupervised classification might help bring these other subclasses forward and help in identifying them, as well as perhaps finding new unknown subclasses.

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