Mapping error due to image geometric correction

A small speech to ask some questions and food for thought…

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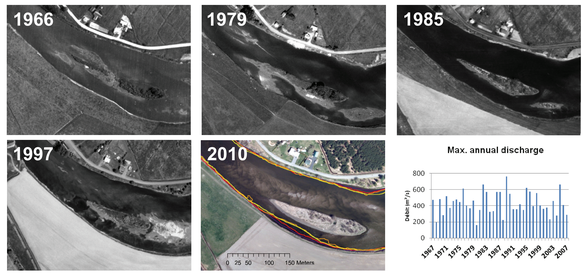
Introduction

Here is an example of the Nicolet River in Quebec. We work over a period of forty-four years and we want to put the bank erosion rate in relation to changes in discharges or the landuse.

We have a series of five images between 66 and 2010. These images were selected because they was token for comparable discharges. This zone is located in the Lowlands south of the St. Lawrence, with a very low relief in the Arthabaska county. A this place, the Nicolet River has a width of 75 meters and a catchment of 1125 km ².



The images have been geo-referenced with polynomials equations in a commercial software and the top of the bank was digitized.

Displacement between 1,5 and 9,5 meters by decade are observed. By different methods, one could calculate an erosion rate **but what about the precision of these observed displacement** ?

Year	Duration (y)	Mean retreat (m)	Rate (m/y)	VP error (m)	Signifiance
1966 - 1979	13	1,5	**0,11**	3	NO
1979 - 1985	6	9,5	**1,58**	2,5	YES
1985 - 1997	12	4,5	**0,37**	2,5	YES
1997 - 2010	13	3,5	**0,27**	2	YES
1966 - 2010	***44***	***19***	***0,43***	***3***	***YES***

VP error : Error estimated by variance propagation method due to referencing

Can we say that they are significant?

If we ignore the errors of interpretation and digitizing, **what about referencing images, maps or aerial photographs by a system of polynomial equations**? Currently, tools for image processing or GIS are becoming more accessible to many

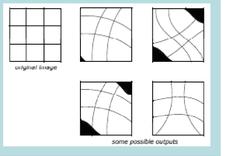
In most cases, there is no use of photogrammetric processes : in other word, no orthorectification or no parallax effects elimination

And, it is clear that most of studies are based on these kinds of simplistic uses.

Second order polynomial (Leica ©, PCI©)

$$X' = a.X^2 + b.Y^2 + c.X.Y + d.X + e.Y + f$$
$$Y' = g.X^2 + h.Y^2 + i.X.Y + j.X + k.Y + l$$

12 coefficients -> Usable with a minimum of 6 GCP's



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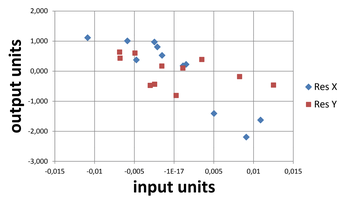
Consider the case of resampling a source image of 1997 using a reference orthophoto of 2010. Eleven checkpoints are used. The software give us residues and **RMS for each X and Y and a total RMS but given in the input unit** (based on image size and resolution in pixels per inch, because of scanned images).

How express RMS in cartographic unit ?

Use a proportional rule ?

- Need the scale of the input document.
- Need the image resolution (dpi).
- But in case of second order or higher polynomial, there is **no linear relation between input residues and output residues**



Retrieve the used model ?

- Least square adjustement : **Ax – v + W = 0** (obs. eq.)
- X and Y error for each GCP and **Total RMS in output unit**
- A total RMS about **1 meter** for this example

#GCP	X input	Y input	X Ref	Y Ref	Res X ref	Res Y	RMS	RMS total
1	16.739	13.121	402608.005	5095155.144	0.228	-0.433	0.489	1.082
2	12.481	5.784	401751.343	5094009.972	-2.191	0.106	2.194	
3	1.892	12.207	400137.126	5095300.177	0.528	0.638	0.828	
4	19.932	7.724	403044.958	5094184.324	0.809	0.605	1.010	
5	17.145	21.388	402828.491	5096499.010	1.116	0.392	1.183	
6	9.265	15.221	401412.240	5095650.697	0.181	0.173	0.250	

Expressed in output unit

Is the total RMS significant and what about the other points of the image ?

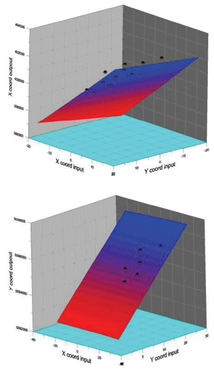
Bootstrap GCP's validation ?

- Recompute n models with n-1 observations
- Compare each bootstrapped GCP to obtain a independent validation of the model
- A total RMS about **3 meters** for this example !!!

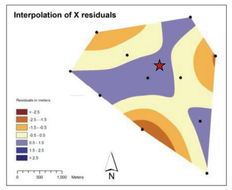
#GCP	X input	Y input	X ref	Y ref	Res X ref	Res Y ref	RMS	Res X boot	Res Y boot	RMS boot
1	16.738797	13.121412	402608.005	5095155.14	0.228	-0.433	0.489	0.321	-0.609	0.689
2	12.481279	5.783563	401751.343	5094009.97	-2.191	0.106	2.194	-4.847	0.234	4.852
3	1.892166	12.20735	400137.126	5095300.18	0.528	0.638	0.828	1.992	2.409	3.126
4	19.932475	7.723926	403044.958	5094184.32	0.809	0.605	1.010	1.338	0.999	1.670
5	17.14526	21.387829	402828.491	5096499.01	1.116	0.392	1.183	7.342	2.579	7.782
6	9.2654	15.221065	401412.24	5095650.7	0.181	0.173	0.250	0.180	0.174	0.250
7	21.069791	16.529864	403388.884	5095630.98	-1.624	-0.472	1.691	-4.511	-1.310	4.697
8	4.757203	17.828275	400728.274	5096161.48	-1.406	-0.460	1.479	-4.375	-1.432	4.604
9	6.30154	9.511008	400803.285	5094763.86	1.010	-0.806	1.292	1.659	-1.324	2.123
10	21.516841	1.203392	403196.37	5093028.96	0.376	-0.179	0.417	3.147	-1.493	3.483
11	12.373101	12.559333	401872.29	5095150.63	0.973	0.435	1.066	1.377	0.615	1.508
						RMS total	1.082		RMS total	3.162
						σ^2	0.337		σ^2	4.938

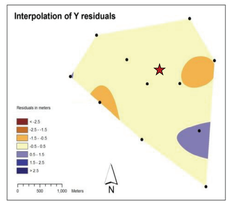
Interpolate GCP's error in each points of the image?

- Requires a very strong **assumption that the error is continuous between the GCP's**…
- Need to test the spatial continuity of the error vector (direction and magnitude)
- Construction of a semi-variogram (but very few points) before try an interpolation to assess whether it makes sense (random variation or spatial autocorrelation of errors)



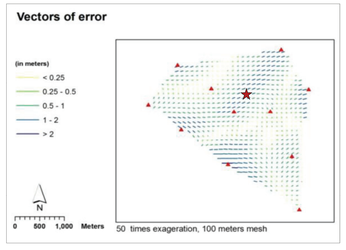
Suppose that yes…





★ *study area*

- We can interpolate two images from the X and Y residuals between GCP's
- Generate mesh of vectors illustrating the direction and the magnitude of the error in each point (about **3 meters** for the study area)



Explore another way ? Variance propagation ?

LSA adjustment manage the precision during all process by using a stochastic model in addition of the mathematical model during the transformation. This gives us variance on parameters of the transformation. Knowing the precision of all elements and variance/covariance matrix on transformation parameters, we apply variance propagation on the model.

- Precision on inputs points coordinates
- Precision on calculated parameters

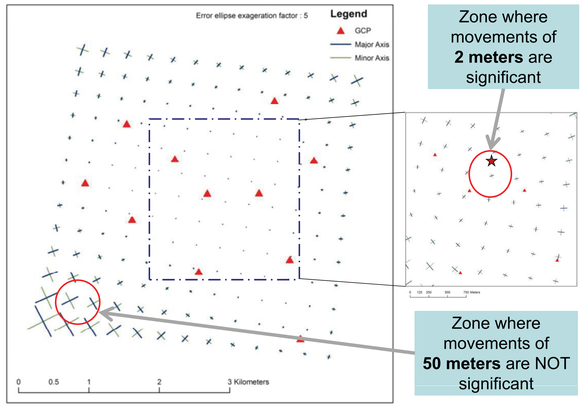
Variance propagation on model :

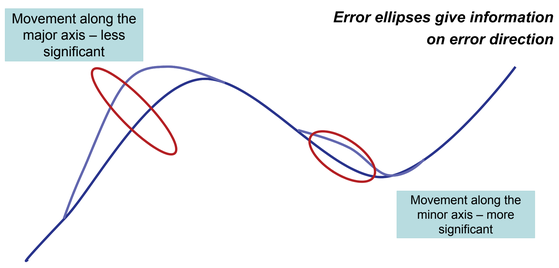
$$\sigma_z = \pm\sqrt{\left(\frac{\partial Z}{\partial x_1}\sigma_{x_1}\right)^2 + \left(\frac{\partial Z}{\partial x_2}\sigma_{x_2}\right)^2 + \ldots + \left(\frac{\partial Z}{\partial x_n}\sigma_{x_n}\right)^2}$$

- *Considering precision on our input point : 1 pixel*
- *Considering precision on 12 factors : obtained from LSA*

As an output, we obtain for **all the points in the image:**

1. VAR/COVAR matrix on transformed points
2. **Confidence ellipses** on points at 95%
3. Statistical test on supposed movement – significant or not.





Discussion

- In this case, movements between 1 to 3 meters are not significant according to the different methods used. The variance propagation method gives us an error of about **2 meters**. **The erosion rate for the decade 1997-2010 seems to be significant.**
- Complex problem and no quick fix, even there is best solution to correct and reference aerial pictures (**photogrammetry**), these questions fully remain for old maps or another historic cartographic documents
- Interesting example of using a well-known topographic methods to solve image processing problems
- The work must go on !

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