Planetary Terrain Analysis for Robotic Missions

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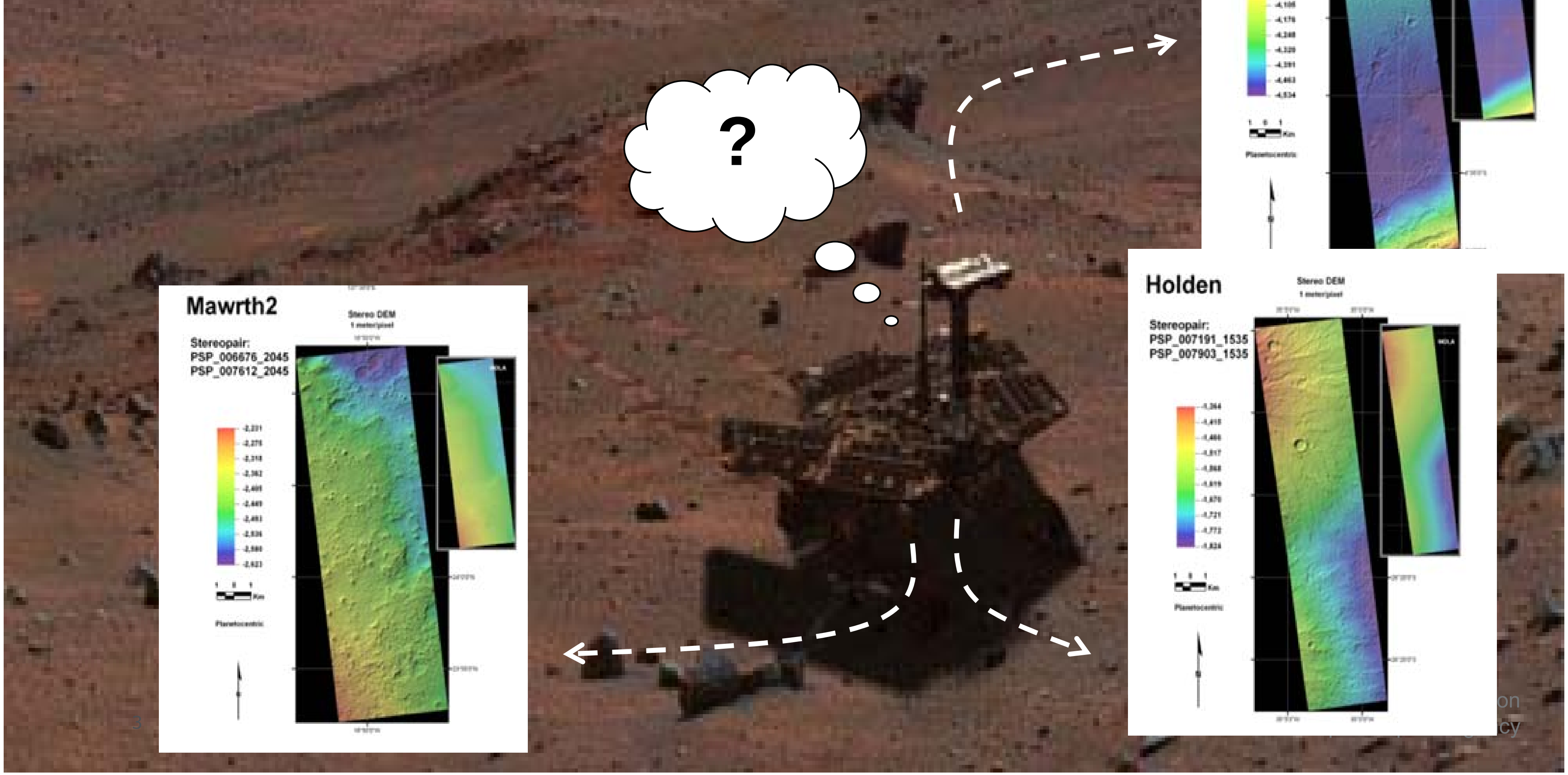
Why terrain analysis

- From early studies to actual design of a planetary rover mission the knowledge of the type of terrain is crucial:
  - engineering constraints for EDL are deeply related to terrain morphology,
  - rover missions need a reference terrain for design and verification of surface mobility (e.g. Navigation, distance travelled per sol).
  - Rover and landing system capabilities are both constraining the landing site selection.

Why terrain analysis

In general knowledge *a priori* of the terrain is not possible.



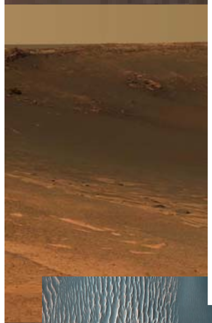
Why terrain analysis

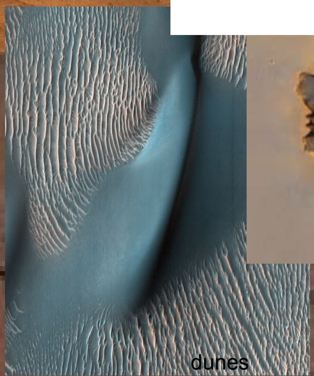
Mars presents a huge diversity of features and hazards

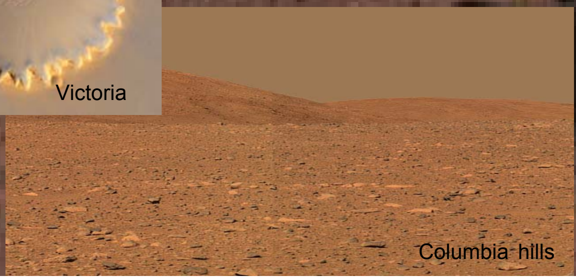
??

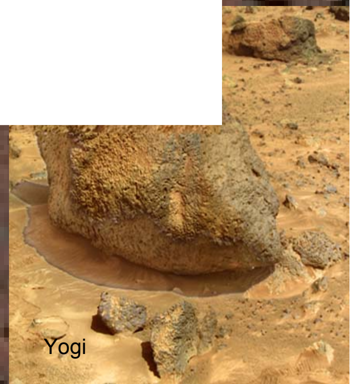
➡ Computer simulations to support rover design

Advantages: repeteability, speed, low-cost and flexibility in the definition of parameters and costraints.









Reference terrain

- Usually a reference terrain is given to help mission design, knowing that the actual Martian terrain will be different.

- The primary parameters which describe surfaces of a terrain given its DEMs are:
  - slopes,
  - aspects,
  - rocks.

→ Analysis of real terrain to deduce requirements for the reference terrain.

Outline

- Definition of the slopes computation algorithm **Adirectional Slope Method**

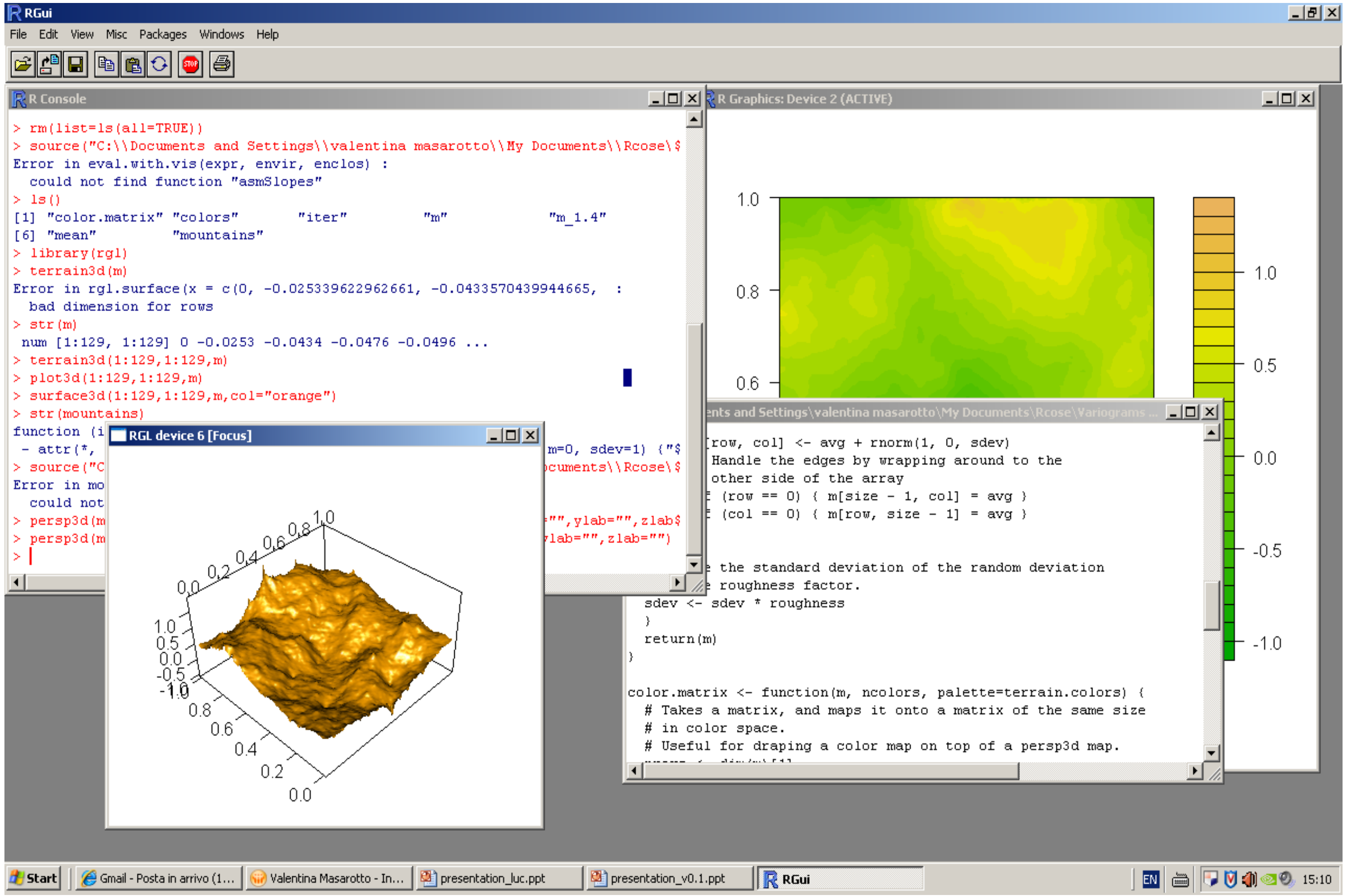
  + Slopes distribution for the reference terrain.

- Brief recall on rocks distribution.

- Examples of terrain generation methods.

Tools

- All simulations have been run in the statistical environment **R.**
- Analysis of the DEMs has been done importing the geo reference files in the geographical information system **GRASS.**



Both are free and open source

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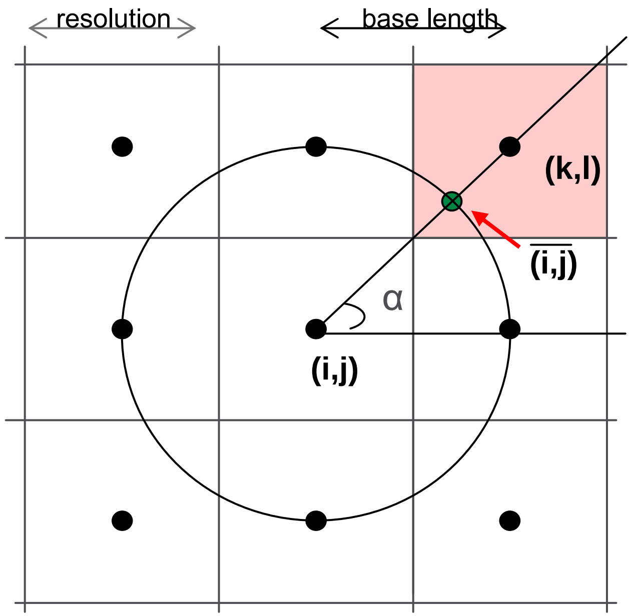
ASM + terrain requirements

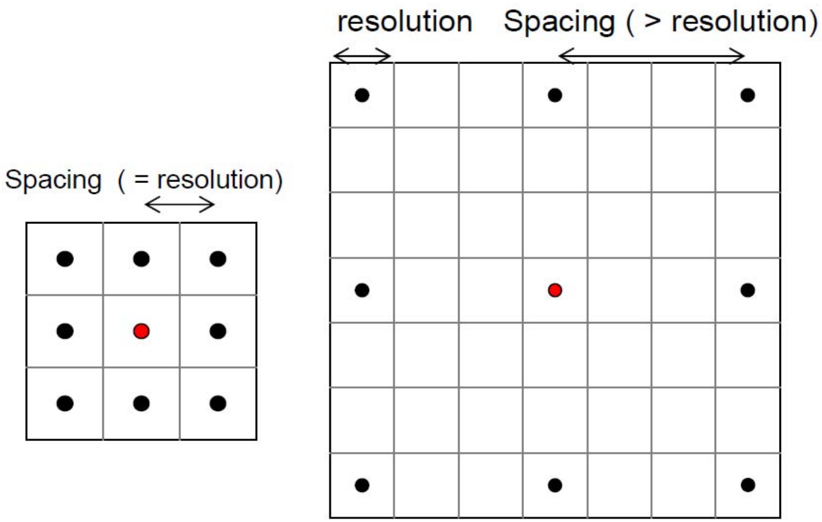
Def: *The **adirectional slope** in a point is given by the absolute value of the maximum slope computed around the point, measured at a specific length scale.*

Adirectional Slope Method:

- Set a base length L and an angle α.
- Consider a circle of radius L around $P_{(i,j)}$.
- α identifies $P_{\overline{(i,j)}}$ on the circle.
- Pick $P_{(k,l)}$ as the closest DEM point to $P_{\overline{(i,j)}}$.
- Compute the slope between $P_{(k,l)}$ and $P_{(i,j)}$.
- Repeat for increments of α.
- The slope in $P_{(i,j)}$ is the maximum value.



A similar method



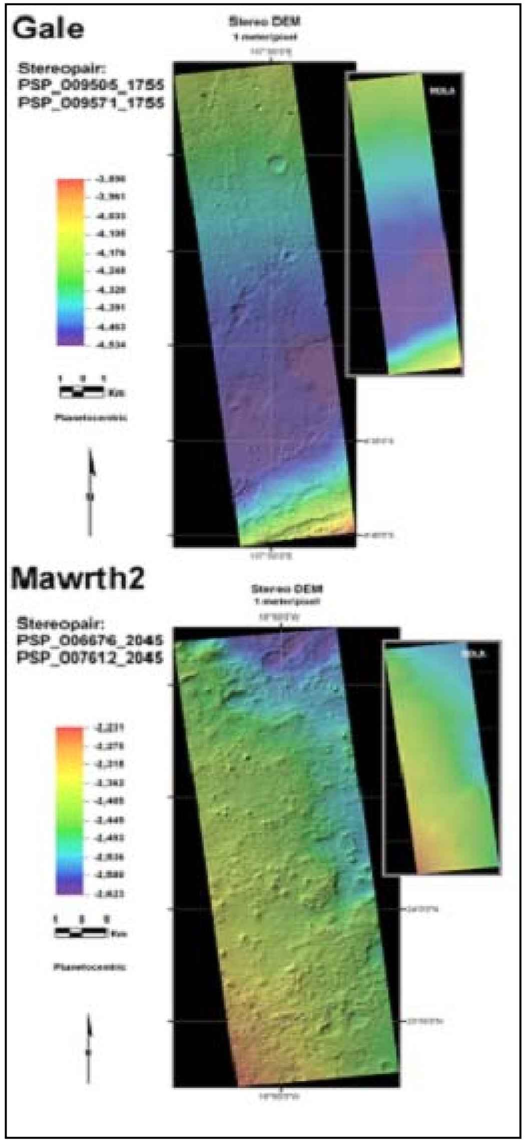
Steepest neighbour:

- Pick the steepest of the 8 adjacent neighbours, considering the real distance on the grid.

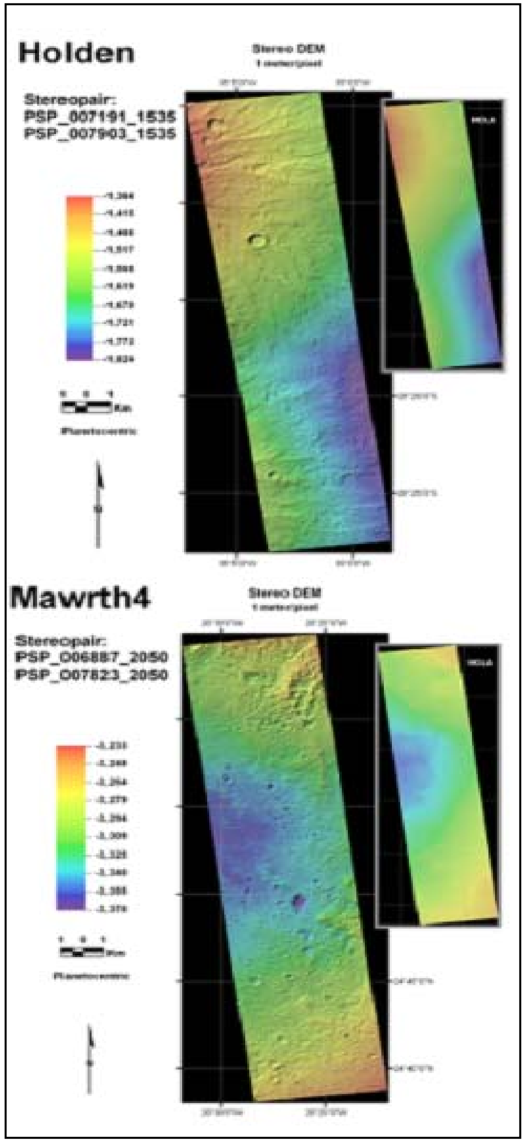
- Equal to ASM when L=res, but limits the computation to 8 points only when L > res.

misses higher slopes

Terrains analysis



- ASM applied to four potential landing sites for MSL to study their slopes distribution.
- DEMs from HiRISE stereo camera.
- Analysis of the DEMs is done importing the geo reference files in GRASS and then running ASM in R.



Terrain analysis

- **Goal:** define one known probability density function at specific base length that describes the slopes distribution of the four candidate landing sites.

⇛ **requirements for the reference terrain**

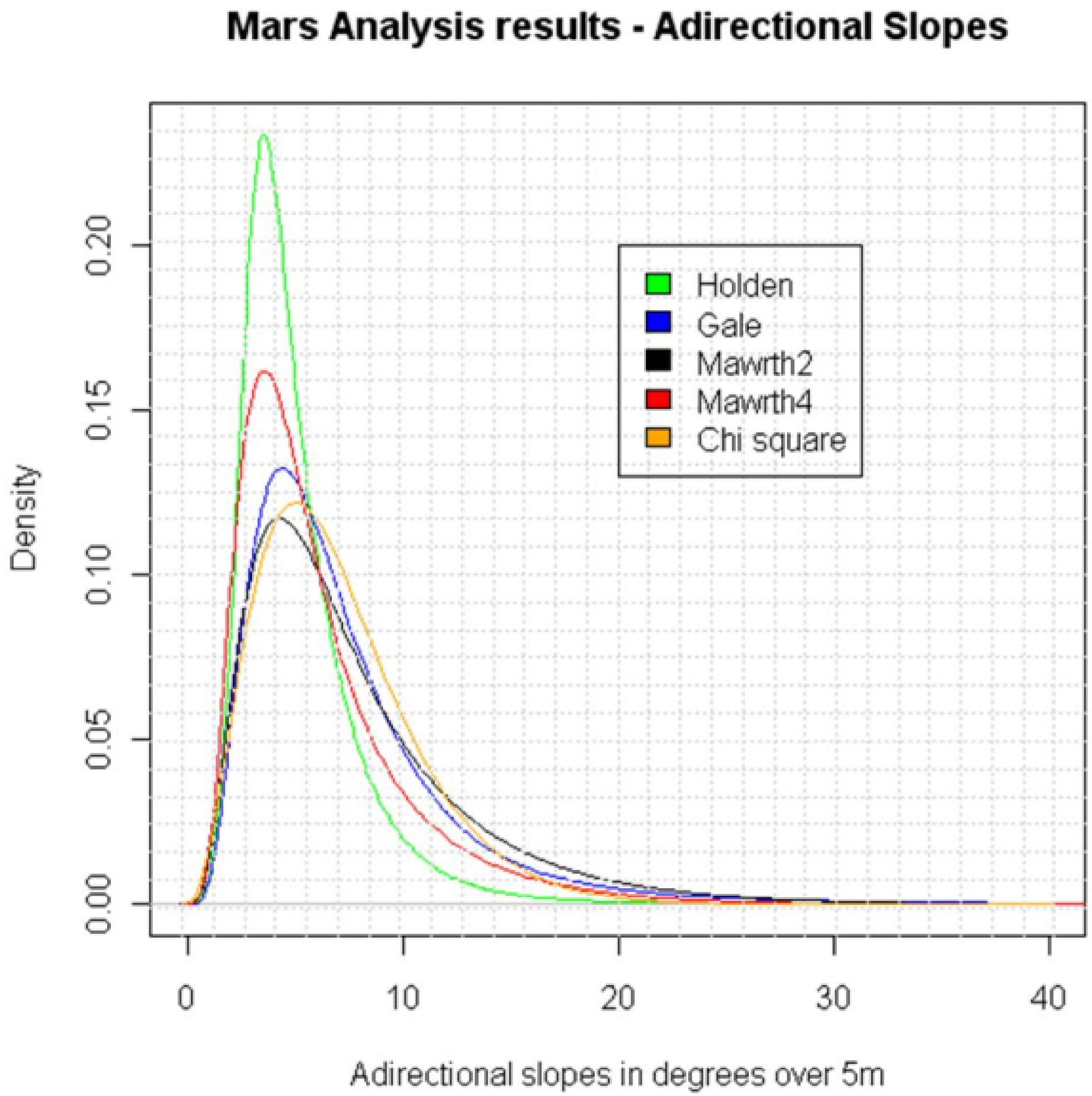
- ESA focused on slopes computed over 5m and 100m distance.

- Assumption: over 5m the surface is flat (but inclined !)

⇛ **rocks added on a second stage,**

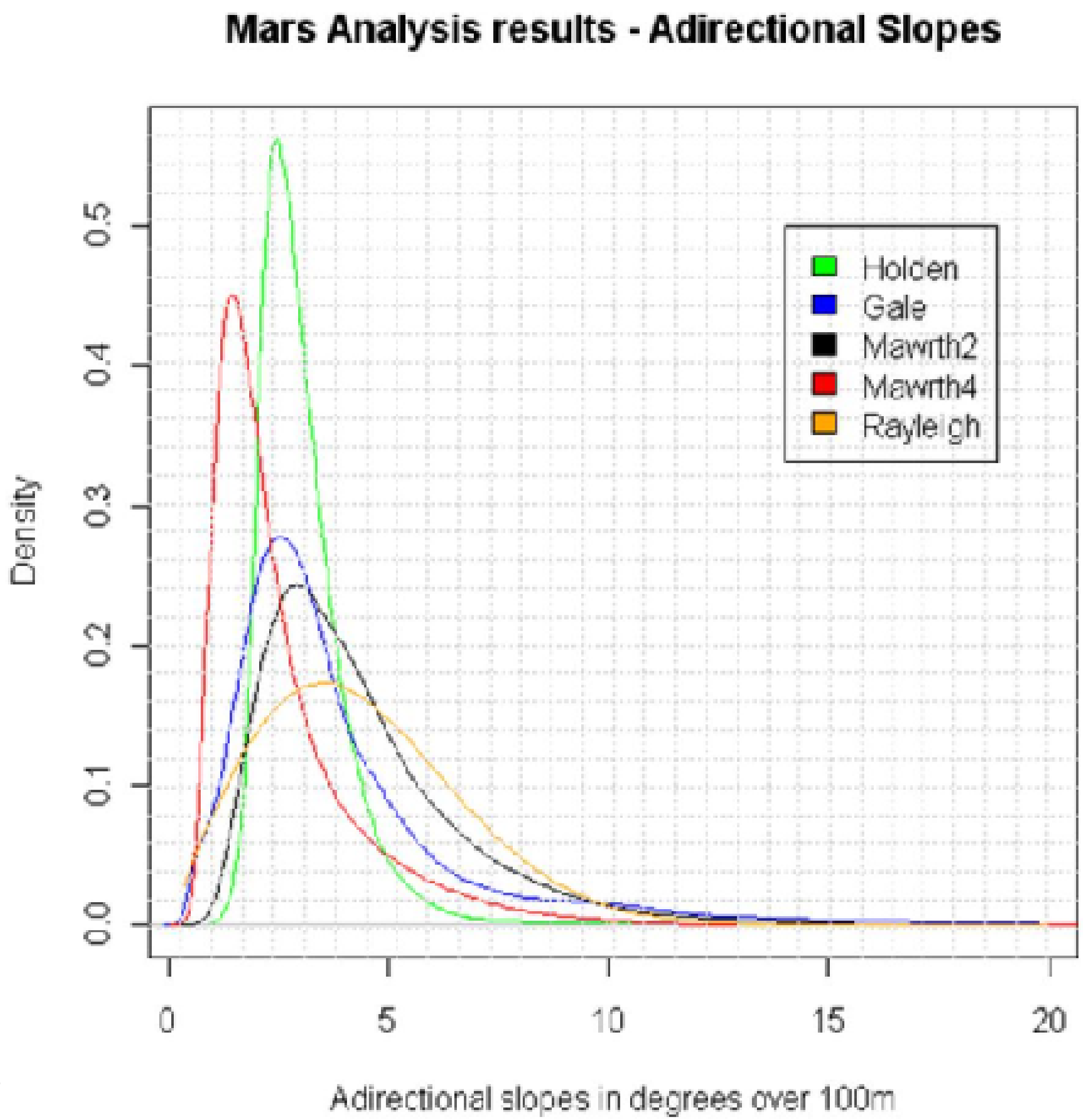
craters not considered (avoided by rover)

Slope distribution over 5m



Chi square!

Slopes distribution over 100m



Rayleigh!

Summary

Requirements for the reference terrain	
5m base length:	maximum slope (99.7th percentile): 21.5° Chi-square distribution
100m base length:	maximum slope (99.7th percentile): 12° Rayleigh distribution

On top: ROCKS

Rocks

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Few remarks over rocks distribution

- Golombek et Rapp ⇒ the size-frequency distribution of rocks could be fit with exponential functions.

- Cumulative fractional area covered by rocks of diameter greater than a given D:

$$F(D) = k \exp(-q(k) * D)$$

with

$$q(k) = 1.79 + 0.152/k;$$

$$k = 0.069 \text{ (ExoMars).}$$

- Cumulative number of rocks:

$$N(D) = \int_D \frac{F}{\text{area}}$$

Few remarks over rocks distribution

- N(D) is known given F and k (deterministic model). But we need a probabilistic one.

- Golombek *et all.* → the probability of having n rocks over a surface of area S is an **homogeneous 2-dimensional Poisson spatial process** of mean N*S, i.e.

$$p_{S,N}(n) = \frac{N^n S^n}{n!} \exp(-NS)$$

- How to generate it?

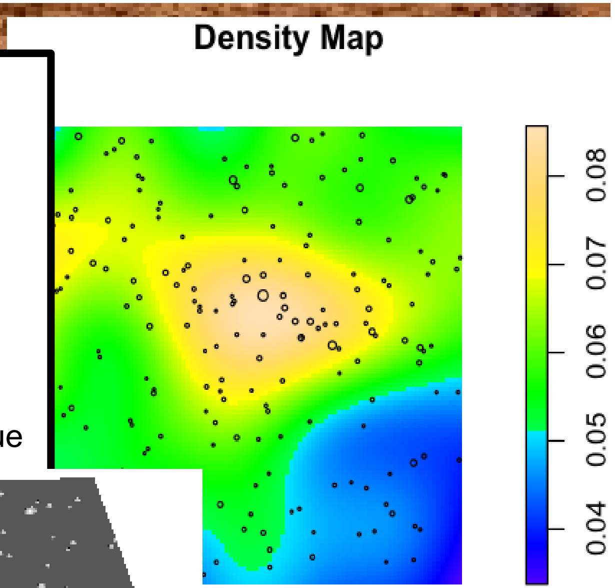
  Compute $p_{S,N}(n)$ and scatter the points uniformly over S.

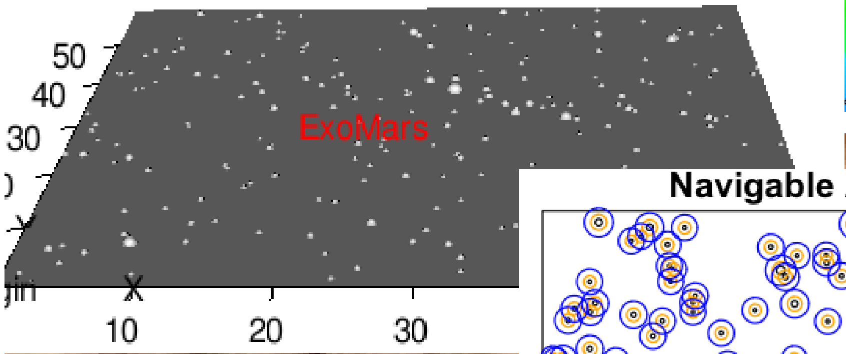
→ R can do it!

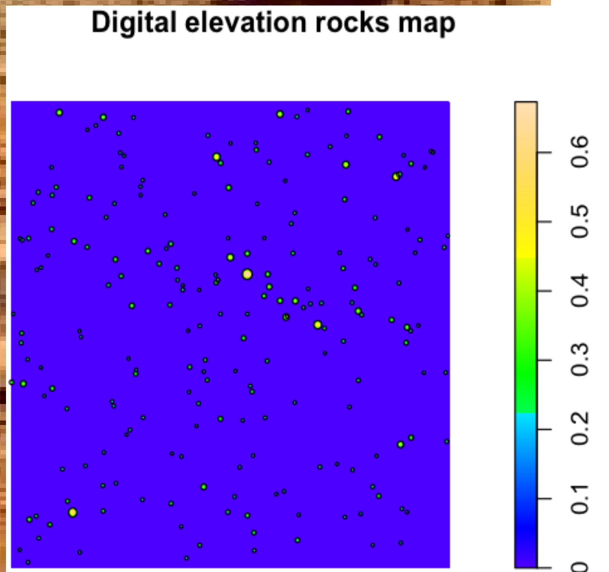
On a 60x60m terrain

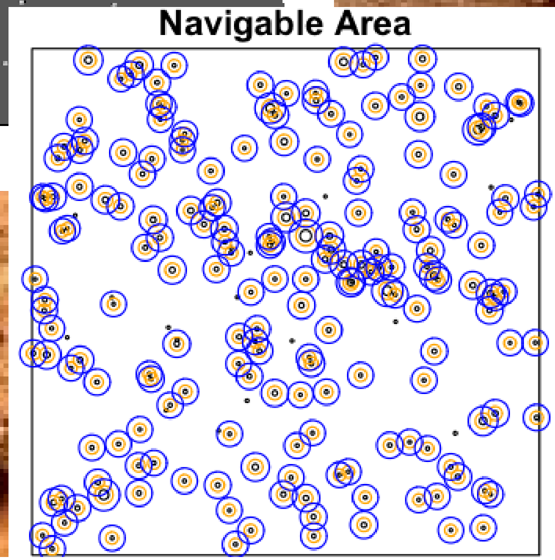
```
############# Input # General Variables ############
k=0.069 #Percentage of area cover by rocks
dimin = 0.4 #Minimal diameter [in meters]
dimax = 2 #Maximum diameter [in meters]
ratio = 0.5 #Ratio between heigth and diameter
areaLength = 60 #Side of square area to generate [in meters]
terrainResolution = 0.1 #Resolution for the DEM [in meters]

#Variables for the Navigable Path Image
navThreshold = 0.4 #rocks diameter threshold
#The Navigation Map will be create to rock > (strict) to the navThreshold diameter value
roverRadius = 0.8 [in meters]
```









Virtual terrain

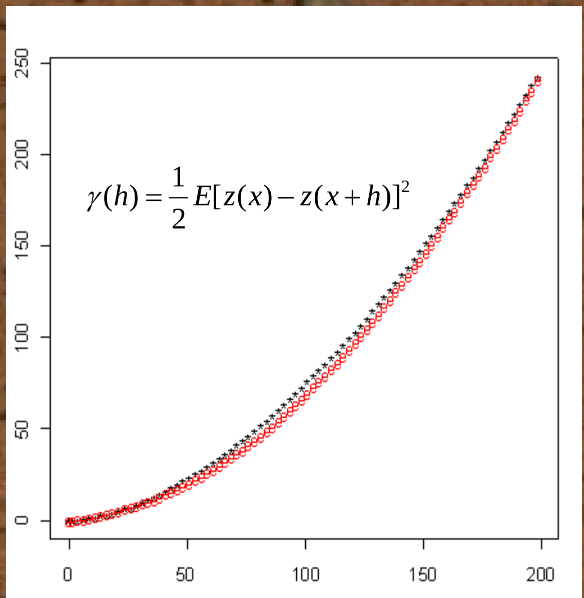
Terrain generations

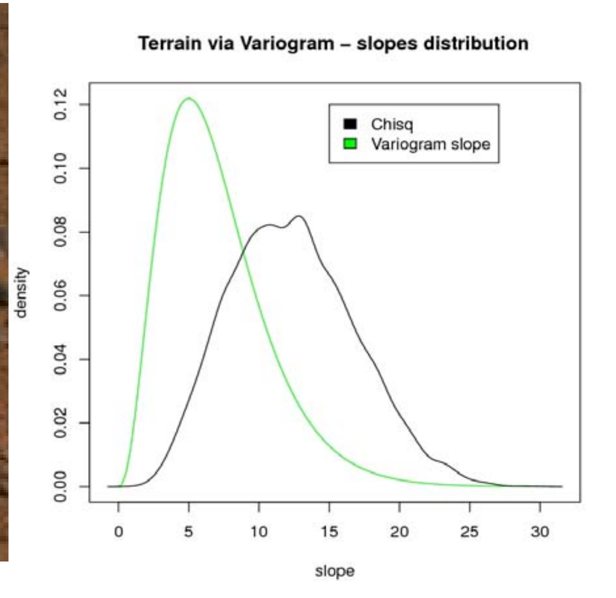
Variogram

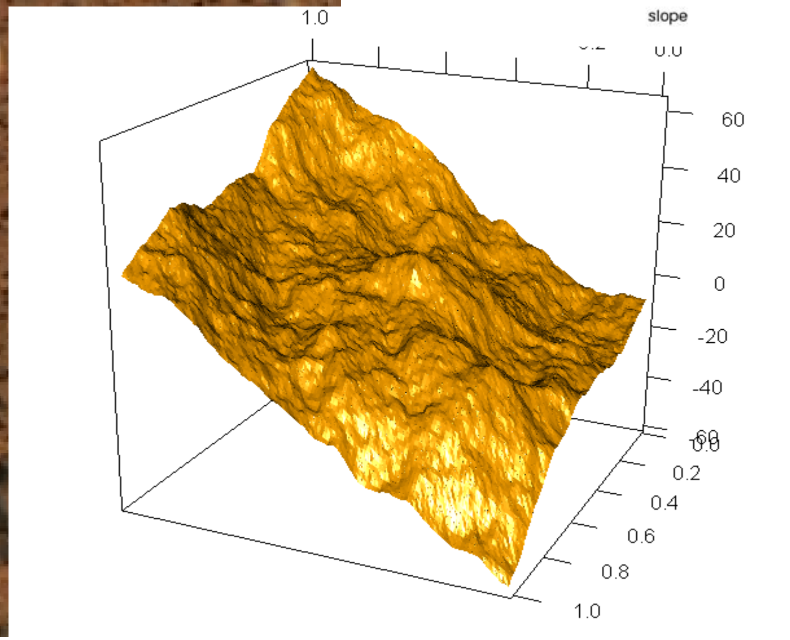
R on real terrain

(Mawrth2 here)

R

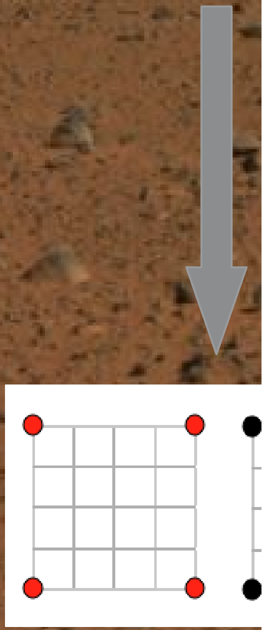




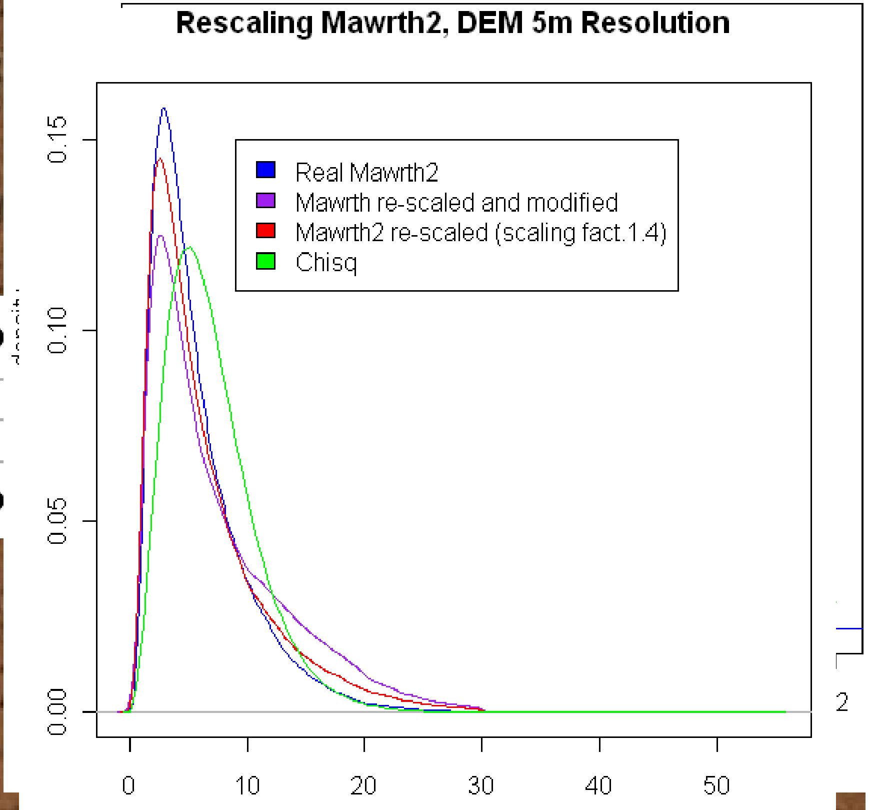


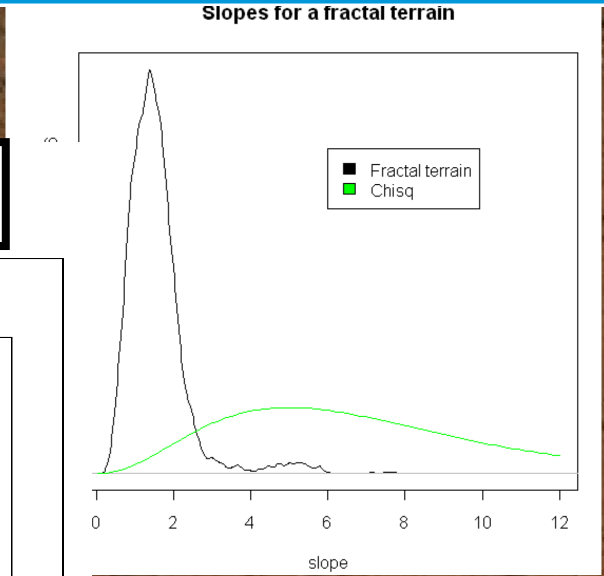
Terrain generations

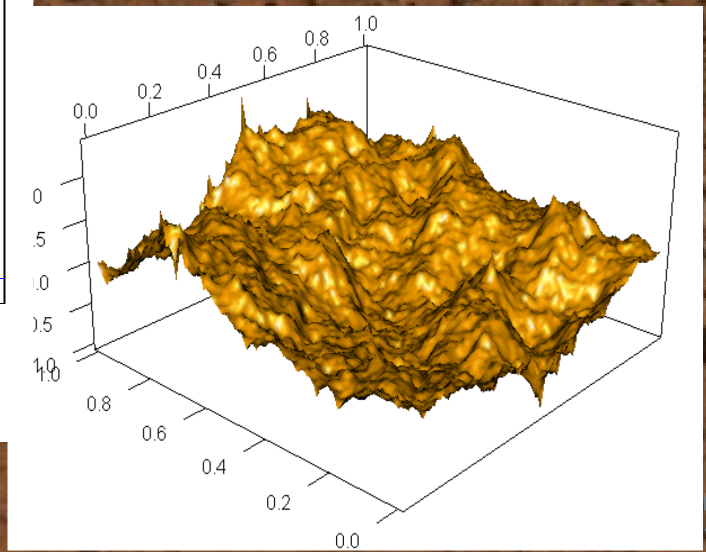
Fractals



Manual rescaling



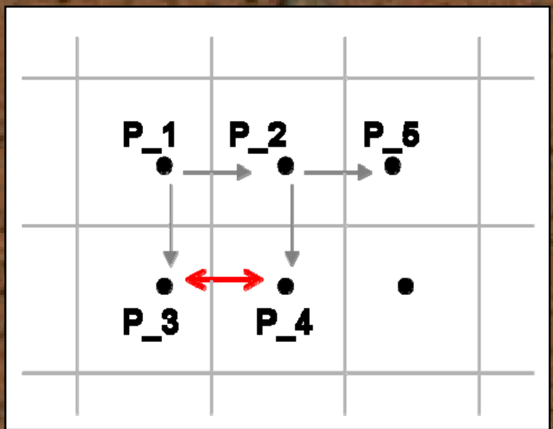




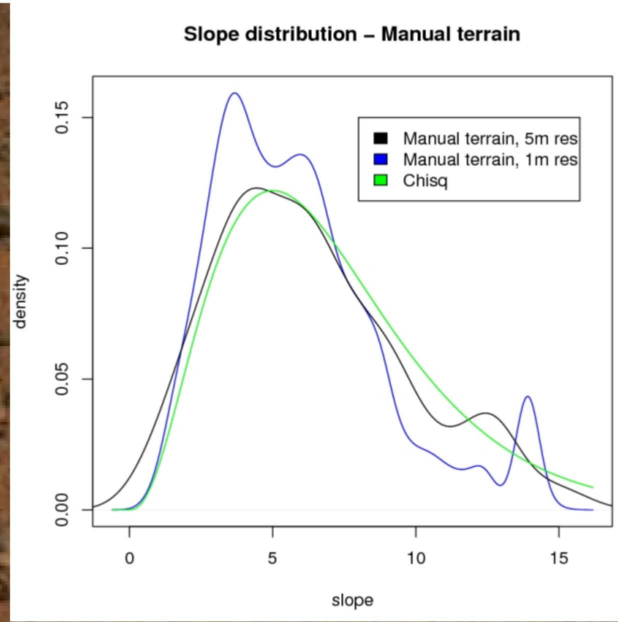
Terrain generations

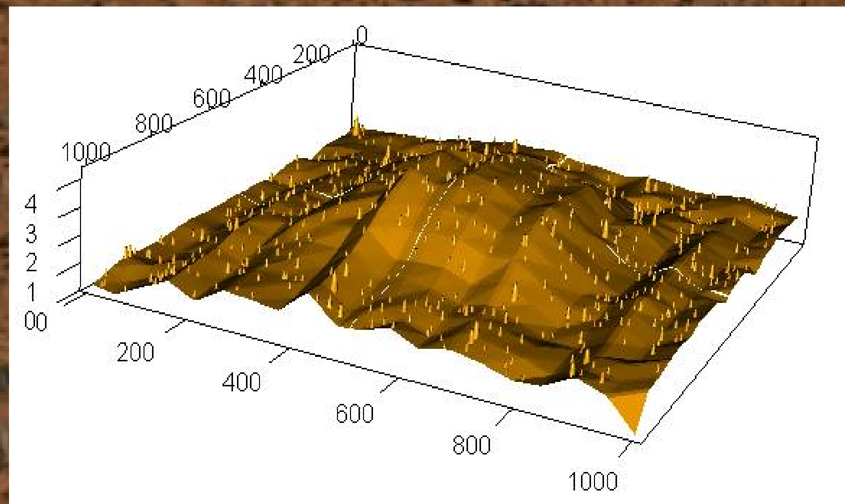
Manual terrain

R



R





Conclusion and future work

- Introduction of ASM and its role for terrain assessment/generation.
- Extremely flexible, free, open-source softwares.

- Match between 5m and 100m requirements.

- Improve appearance of the manual terrain/ manual rescaling.

- Other generation techniques?

- Implementation for rover design.

Thank you for your attention.

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