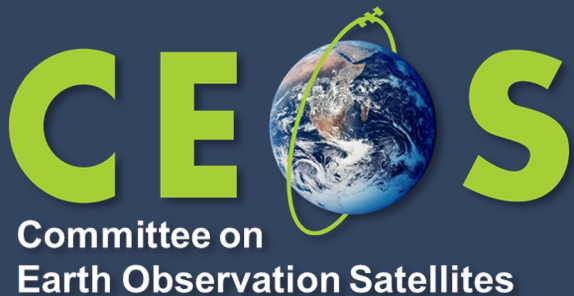


WGCV-52

Terrain Mapping Subgroup (TMSG) & DEMIX Report



Peter Strobl, EC-JRC

Agenda Item 2.4

WGCV-52, ESA/ESRIN, Italy

5th - 9th June 2023

Proceedings of the Terrain Mapping SubGroup (TMSG)

- Re-activated early 2020
- as of May 31st 2023:
 - 64 subscriptions (+1)
 - 15 countries
 - ~50% with CEOS background
 - ~30% Geomorphometry.org
 - ~35 expressed interest in the intercomparison exercise DEMIX (incl. industry!)
- main (only) activity so far **still** is DEMIX
- (hybrid) DEMIX workshop & TMSG plenary scheduled for 12/13 July 2023, supported by ESA

Minor update!

Subscription page: https://ec.europa.eu/eusurvey/runner/WGCV-TMSG_membership

Findings of the JRC DEM benchmarking workshop (Jan 2019):

Situation in 2019

- ❖ **new data sets** are coming up (“Copernicus DEM“), which might change the DEM ‘landscape’
- ❖ EO platforms and ‘data cubes’ make data increasingly available also at **continental to global scales**
- ❖ literature is rich in **DEM validation and comparisons** of (almost) everything with everything else in many different places
- ❖ methodologies vary and results are not always **representative or comparable** between studies and locations
- **a coordinated approach is desirable!**
- **bring CEOS TMSG and the International Society for Geomorphometry (ISG) together!**

CEOS WGCV mandate for DEMIX:

- perform a state-of-the-art comparison of the major global (free&open) DEMs
- provide recommendations on best available DEM options depending on domain and area to allow informed choices

decision in 2020

Expected Outcomes

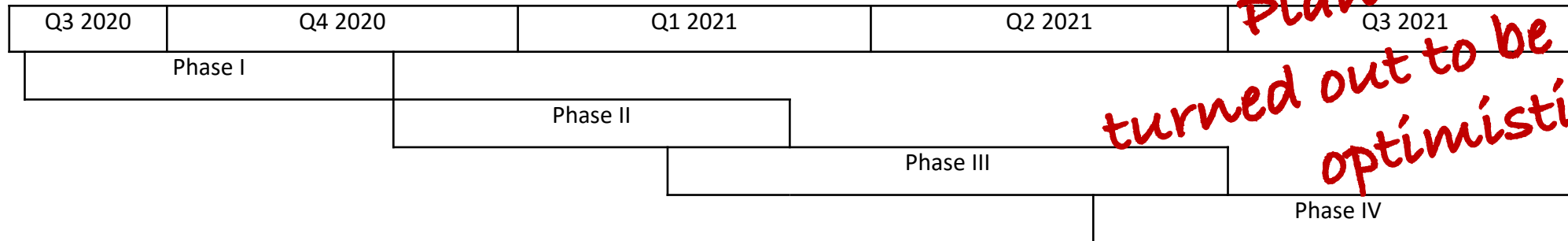
- ❖ Consistent and comprehensive DEM definitions and terminology (t)
- ❖ Base (t) and extended (g) set of benchmarking metrics and respective algorithms (t) and open source tools (g)
- ❖ Detailed comparison results on test areas (t) and aggregated wall to wall benchmarking results (g)
- ❖ Recommendations regarding reference DEMs (t) and consistent orthoimage (g)
- ❖ Final report (t) and peer-reviewed publication (g)

(t) threshold; (g) goal

DEMIX is performed in 4 phases

- I. General agreement among main contributors (data owners) on approach & scope; Call for expression of interest to further partners (incl. industry); selection of base (Δx , Δy , Δz) & extended (slope, aspect, morphology) testing methods and algorithms; Identification of suitable test areas (at least 1 per continent);
- II. Cross-comparison of all participating data sets on test areas. If available and where applicable cross-comparison to suitable orthorectified (reference?) imagery (Sentinel-2?); Workshop to exchange experiences from the test areas and agree on details of an eventual global roll-out;
- III. Feasibility testing & potential global roll out of at least base tests & determination of suitable aggregation scale for reporting;
- IV. Calculation of agreed comparison metrics for all candidates and publication of results.

Timeline



*Plan in 2020
turned out to be slightly
optimistic!*

after

- 3 years,
- 3 plenaries,
- a Teams groups
- 3 subgroups, each with 5-15 active members,
- 130+ subgroup meetings, each with at least 4 participants
- a [conference paper](#) and [video](#),
- 2+ peer-reviewed publications,
- a new '[DEMIX tiling](#)' system,
- a processing platform, ...

we are almost there...



Committee on Earth Observation Satellites

DEMIX Sub-group 1: Terminology



What is a DEM? ... and what not?



Unambiguous and shared terminology is a prerequisite of any joint endeavor (since Babylonian times)

- ❖ Definition: DEM (digital *elevation** model): general term for a digital representation of a *topographic surface* in form of a *georectified area-based grid*, composed of *elevations* on the Earth.

Note: DEMs should use raster file storage formats. Alternative structures for digital topography, like triangulated irregular networks (*TINs*), *contours*, and *point clouds* are not DEMs because they are not *grids*.

*these *terms* all have their own definitions!

The concept of 'spheres'



Many 'topographic surfaces' are imaginable on Earth and require **boundary layers** (what is above and what below) to be defined between **spheres**:

Atmosphere:

the layer of gases, commonly known as air, including suspended liquid and solid particles known as aerosols (incl. dust, clouds, snow and ice)

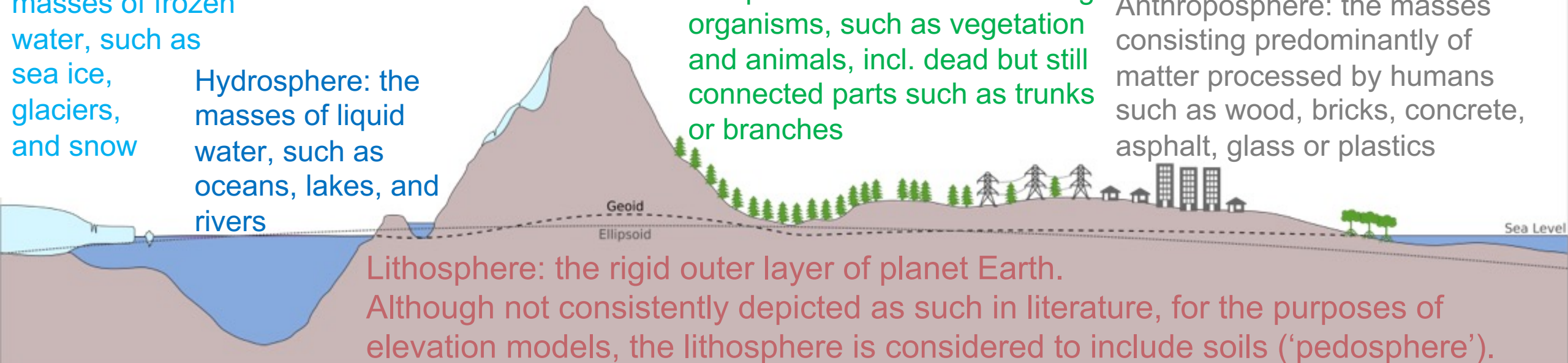
Cryosphere: the masses of frozen water, such as sea ice, glaciers, and snow

Hydrosphere: the masses of liquid water, such as oceans, lakes, and rivers

Biosphere: the masses of living organisms, such as vegetation and animals, incl. dead but still connected parts such as trunks or branches

Anthroposphere: the masses consisting predominantly of matter processed by humans such as wood, bricks, concrete, asphalt, glass or plastics

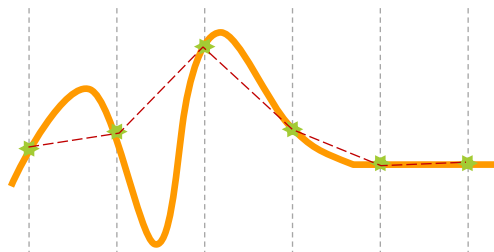
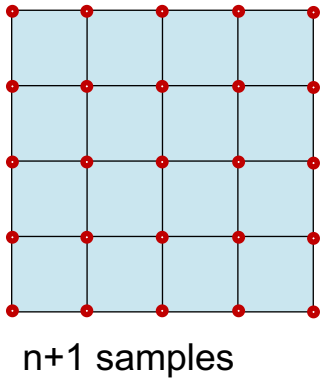
Lithosphere: the rigid outer layer of planet Earth. Although not consistently depicted as such in literature, for the purposes of elevation models, the lithosphere is considered to include soils ('pedosphere').



The role of sampling (and grids)

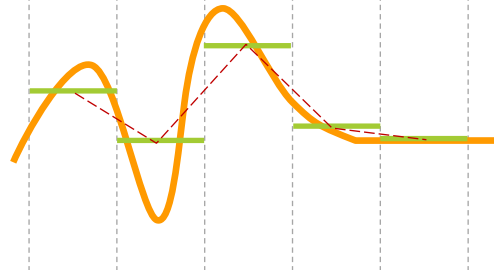
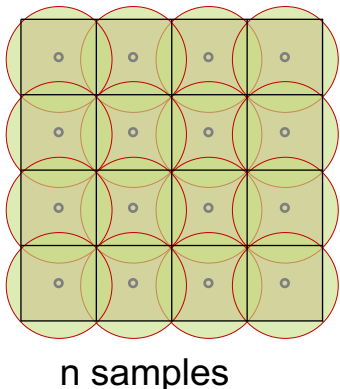


Pixel is Point:



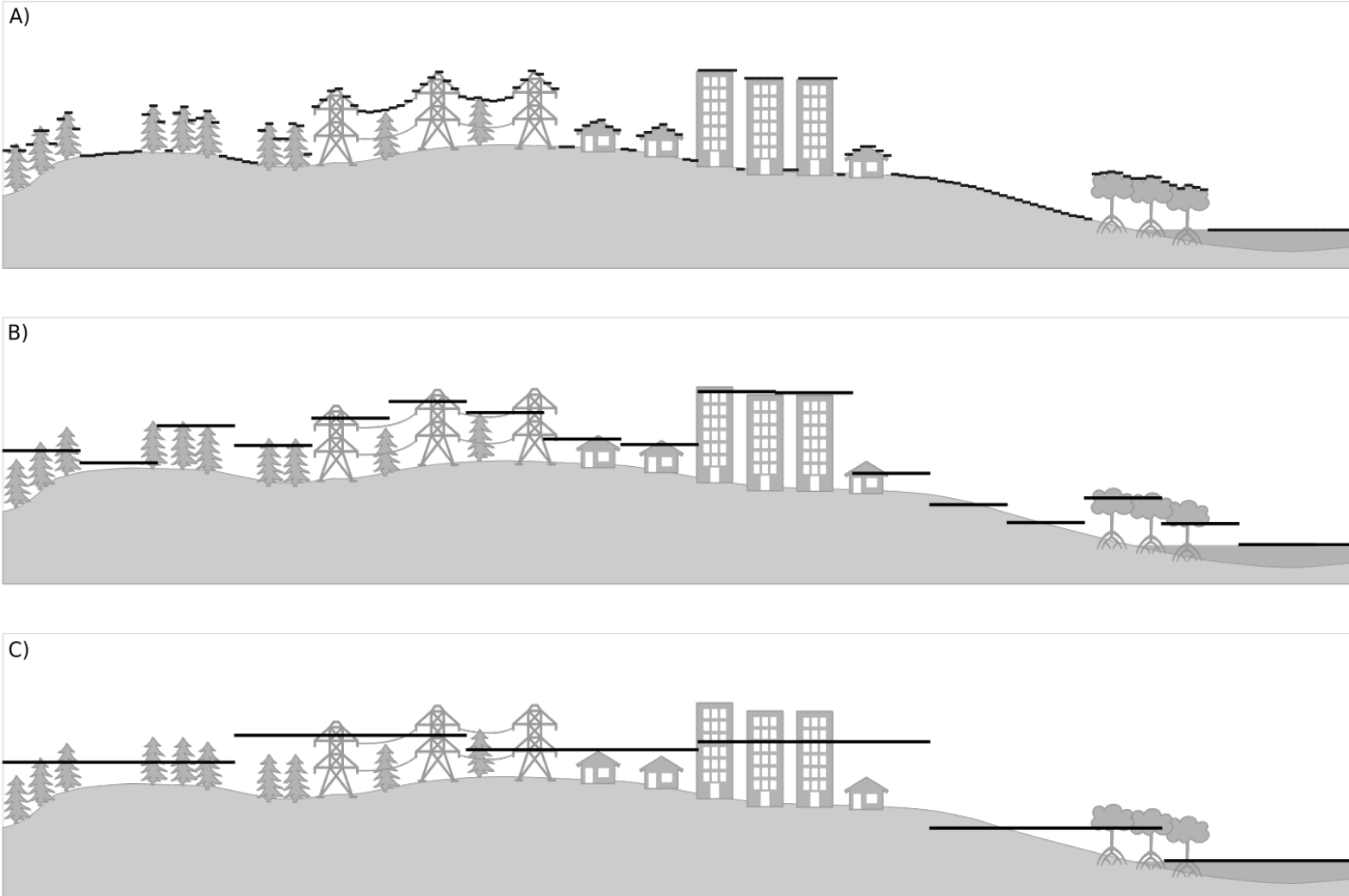
- Sample extent is small wrt. to sampling distance
- Only a small fraction of the feature is actually measured (at the grid nodes)
- Values between samples need to be interpolated (if feasible)
- Risk of aliasing
- Often used in field surveys

Pixel is Area:



- Sample extent is equal (or slightly larger) wrt. to sampling distance
- The whole feature is covered by measurements (which are represented by the grid cells)
- No risk of aliasing
- Usual method for imaging devices

The effect of 'scale' or 'resolution'



Graphics courtesy of C. Grohman

- ❖ Because of the 'area based' nature of DEMs the elevation at a given point might (and often will) depend on the sampling interval (often synonymous for 'scale' or 'resolution')
- ❖ The elevation value for a given cell is representative (weighted average) for the whole cell, but not necessarily accurate for most of the points within a cell

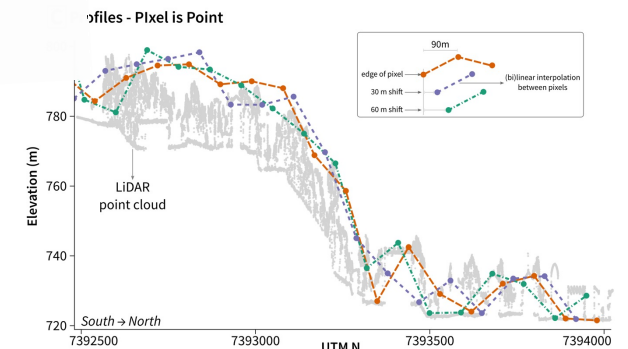
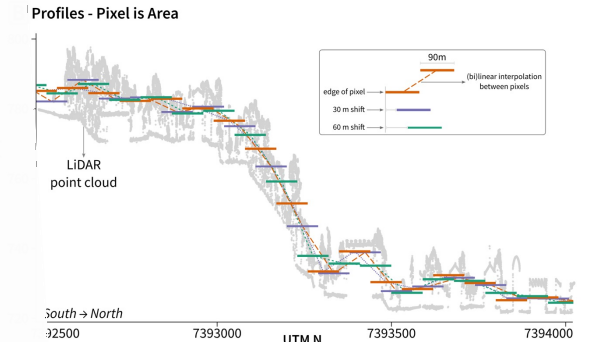
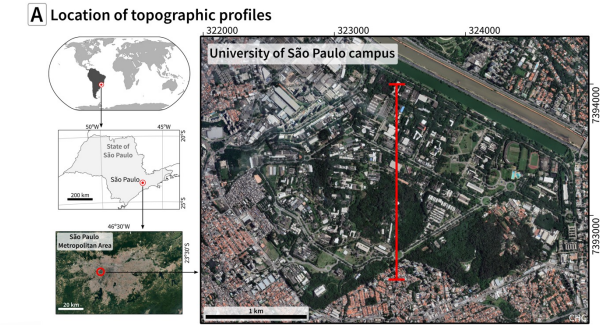
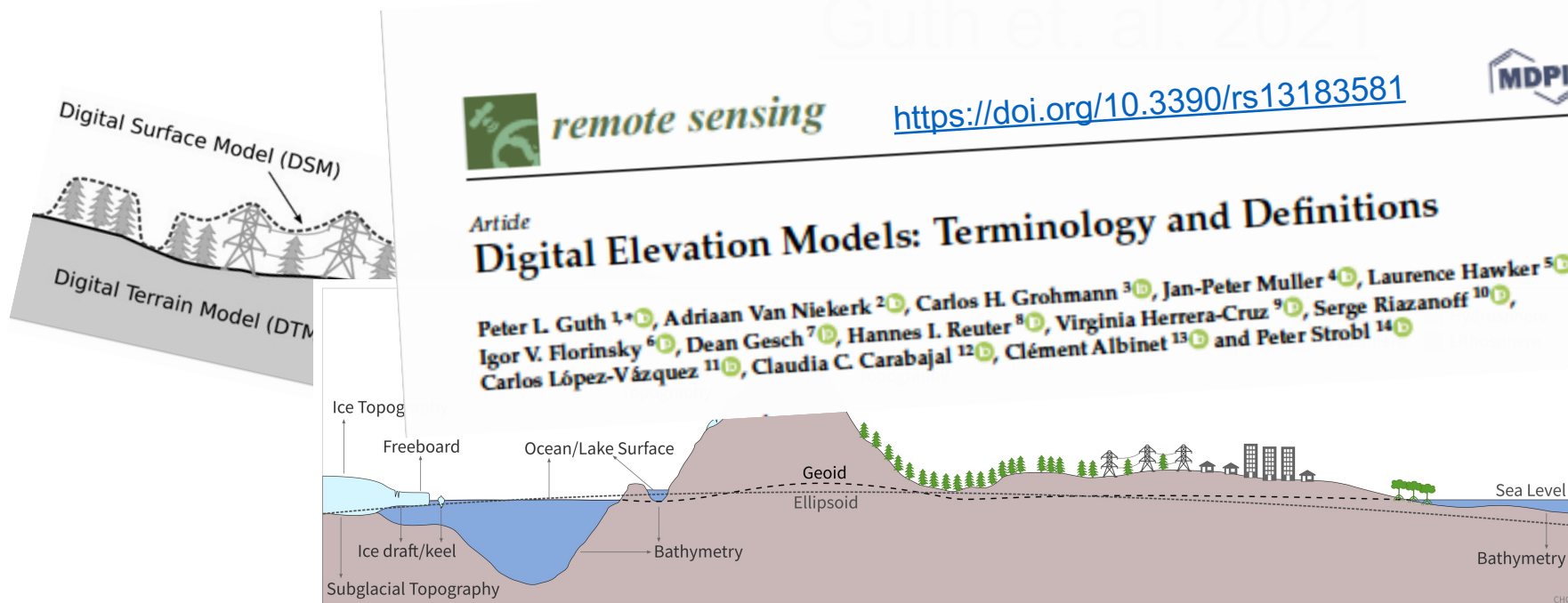
- nDSM: normalized DSM, the difference between a DSM and a DTM. This surface represents the heights of objects on the Earth's surface such as buildings and vegetation.
- CHM: Canopy Height Model, the height of the vegetation above the ground. Except for features like power lines, it is the difference between the DSM and the NVS.
- Water depth: difference between the DSM over water bodies (hydrosphere) and the bathymetric surface (lithosphere)
- Ice thickness: difference between the DSM over ice bodies (cryosphere) and the subglacial topography (lithosphere)
- plus Geomorphometric surfaces: slope, aspect, curvature and many more

These layers do not represent elevations and thus are not DEMs!

Subgroup 1



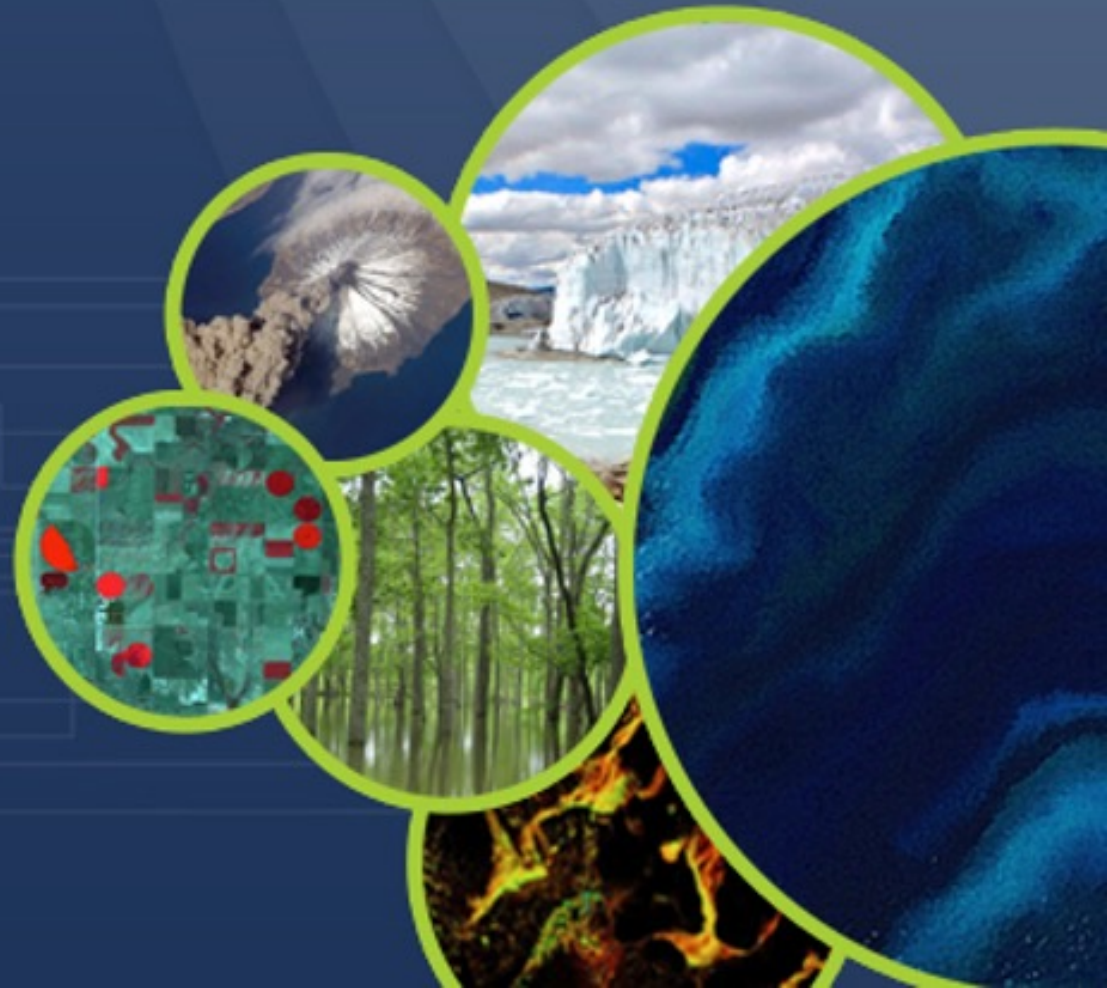
Job done! - currently retired
Revised terminology and comprehensive definitions (glossary) finished
Peer reviewed paper published:





Committee on Earth Observation Satellites

DEMIX Sub-group 2: Algorithms and Software



Characteristics of a DEM



Before talking about quality we must define **criteria and metrics** which characterize a DEM and which can be used to compare them

Three main groups were identified:

1. Linear difference (or error) measures such as **RMSE, LE90, CE90, Median** and normalized median absolute difference (NMAD), separately for **horizontal displacement** and **(vertical) elevation difference**, distinguished by e.g. slope, land cover, and not generalized spatially over more than 10^6 - 10^7 values
2. Morphological descriptors, e.g. **slope, aspect, roughness**. **Complex morphological metrics** like **number of peaks and pits, length of ridges and troughs, number of outliers (spikes), consistency of stream networks**
3. Other: Autocorrelation length, SNR
 - ❖ plus non-quantitative:
Completeness, availability and reliability of Metadata, visual appearance ...

- Intercomparison is only useful for (non-expert) users if they in the end get a **ranking**:

Are there significant differences and if so which options are better and which are worse?

- Not every user might want to apply the same criteria and even the same criteria could result in different rankings depending e.g. on location

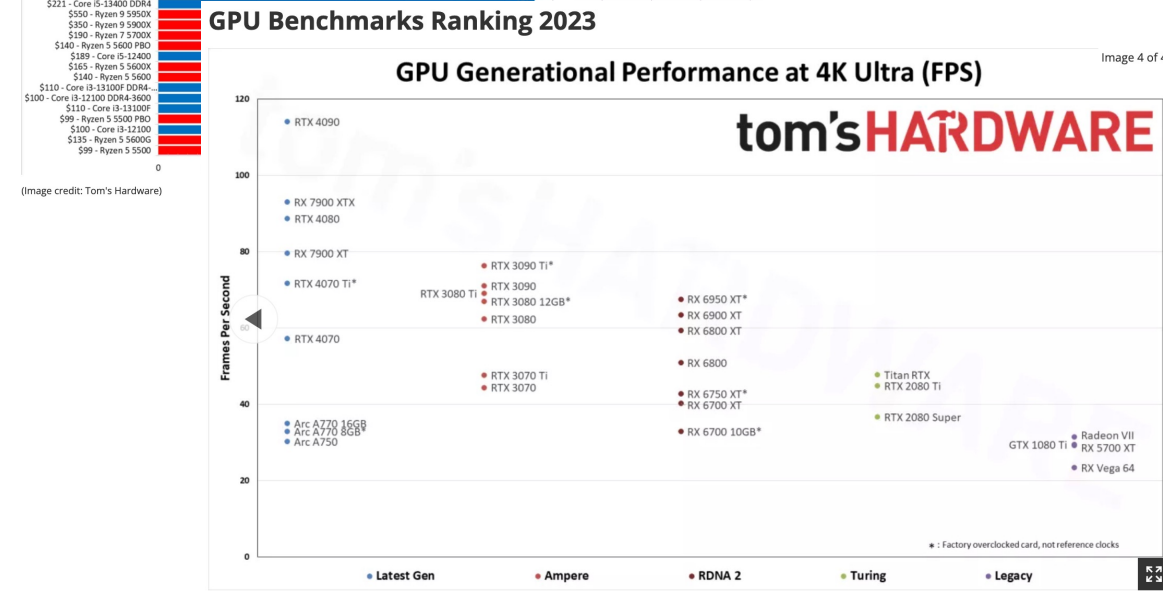
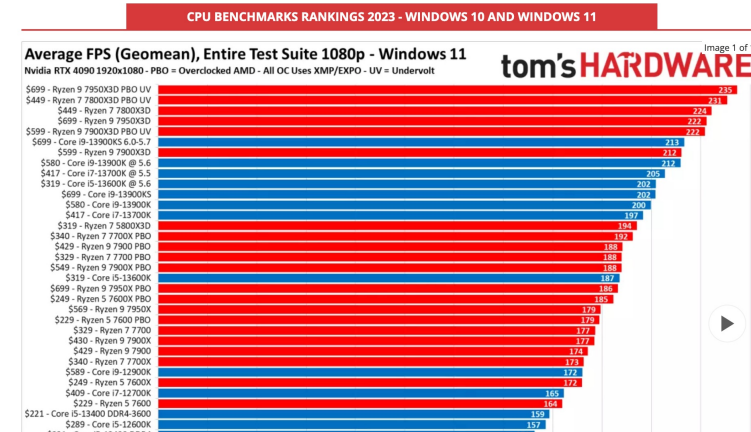
We are less interested in an ‘overall winner’, but the best solution in a given context!

- **We need a configurable, re-usable and expandible test environment!**

Why a ranking tool?



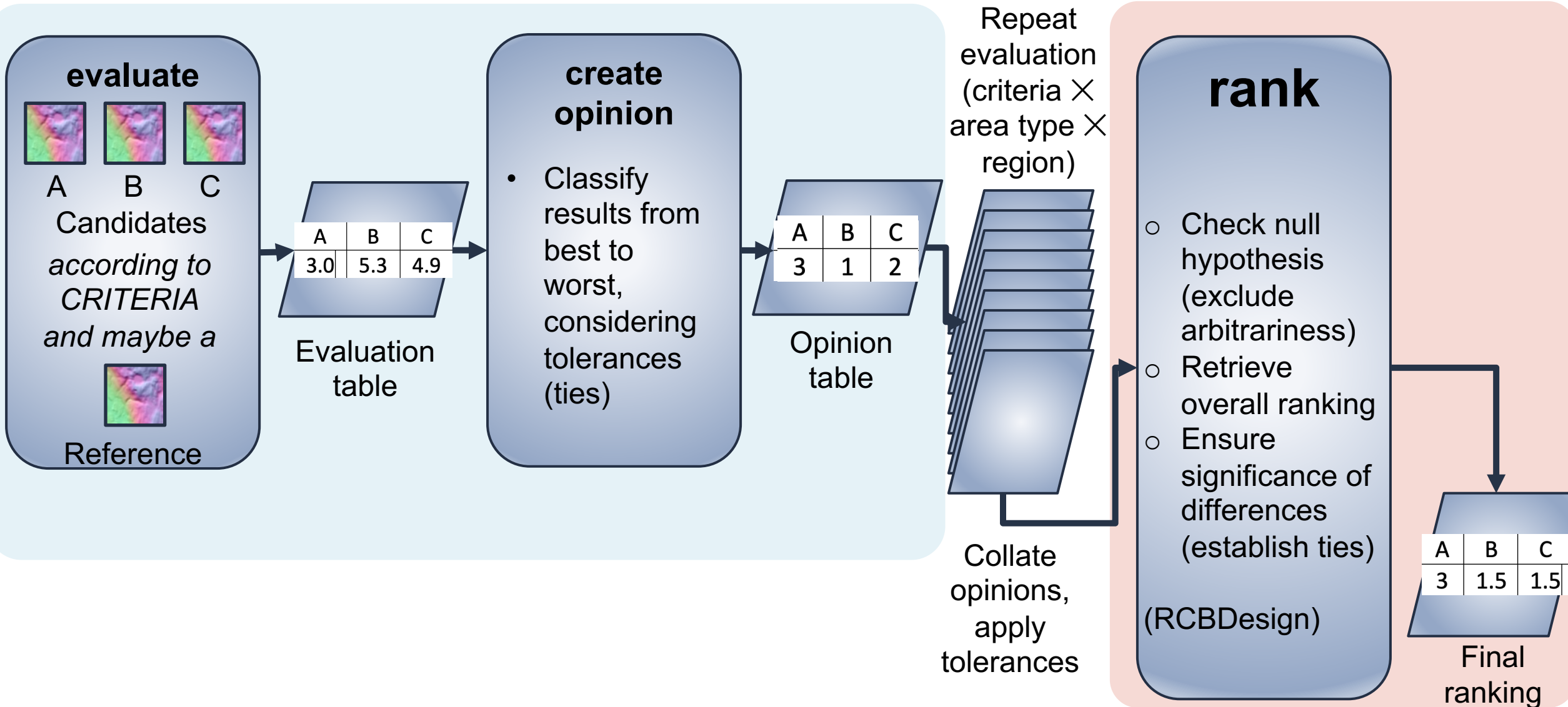
- Ranking products is not new, but it helps consumers choose
- You don't need to be an expert to make an informed choice
- Not everyone is happy with final rankings
- Criteria can be chosen based on user's purpose
- Rankings will be continuously updated as new products and criterion are developed



Latest generation AMD, Intel, and Nvidia GPUs on the left, progressively older cards to the right. (Image credit: Tom's Hardware)

- A major challenge is how to combine different criteria and metrics to arrive at an overall ranking (if any?) of different tested DEMs
- Proposal is to use the ‘**wine contest**’ method in which k different wines (candidate DEMs) are assessed according to C different criteria (metrics) by N different judges (test sites)
- allows
 - establishing of an overall ranking
 - testing the significance of the differences
 - flexibility in adding, removing, and filtering metrics and test sites

The 'wine contest' framework



Advantages of the 'wine contest'

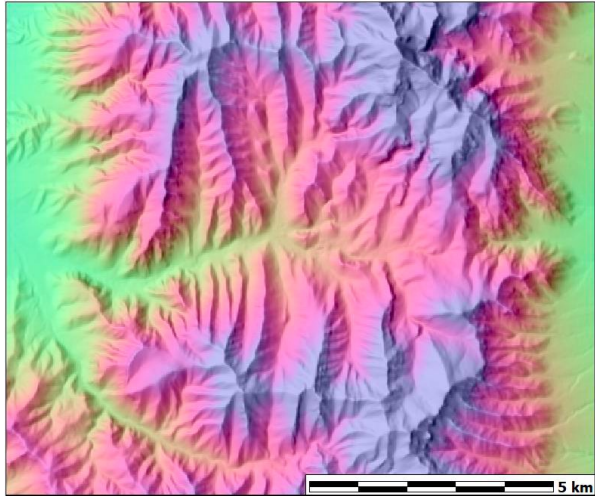


- the procedure can accommodate any number of DEMs, test sites and criteria
- accepts objective (quantitative) as well as subjective (qualitative) criteria (and combinations)
- allows ties, both as input or as output.
- has a sound statistical basis
- provides a confidence level for the final ranking
- can be stratified, like:
 - only hilly terrain for the test sites
 - only objective criteria

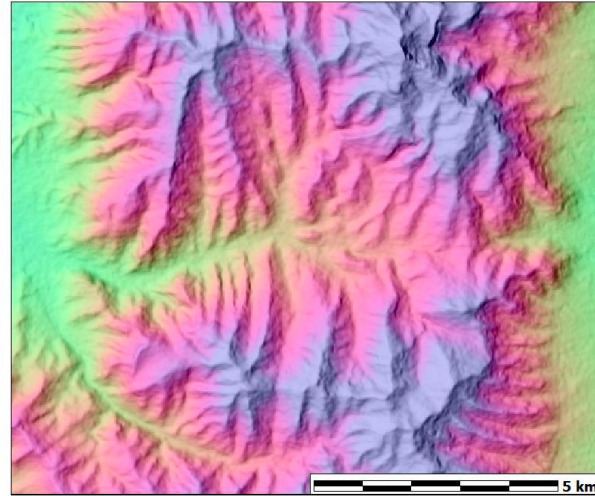
Scope and Products to be included: All datasets which have an at least continental coverage and are available under a free & open data policy, including:

- **SRTM** (v3 NASA/CGIAR, the de-facto reference for more than a decade)
- **NASADEM** (NASA, JPL, most recent reprocessing of the SRTM product line)
- **ASTER-GDEM v3**, (METI, NASA, from ASTER stereo imagery)
- **ALOS World 3D 'AW3D30'** (JAXA, based on the PRISM stereo scanner)
- **Copernicus DEM GLO30 'COPDEM'** (EC/ESA, f&o version of WorldDEM™ procured by Airbus, the commercial version of DLR's TanDEM-X mission)
- **FABDEM**, (L. Hawker et al., UoB), DTM based on COPDEM

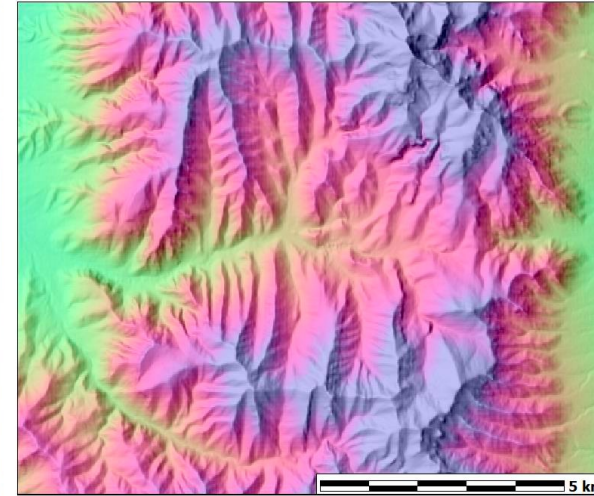
Which DEM?



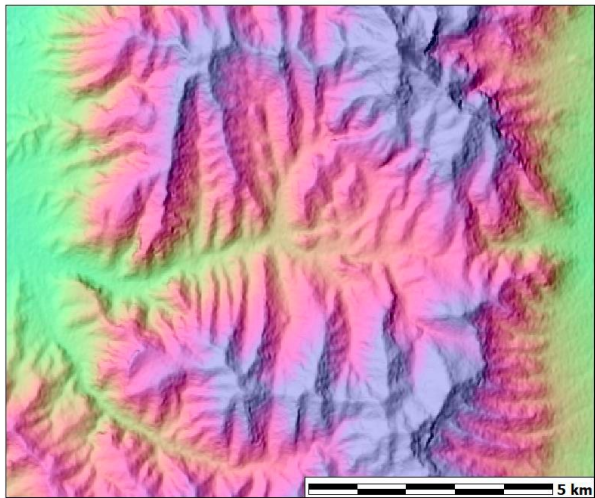
COP



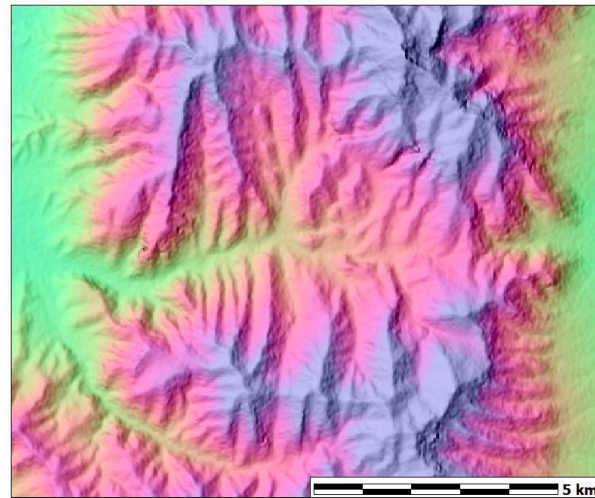
ASTER



ALOS



SRTM



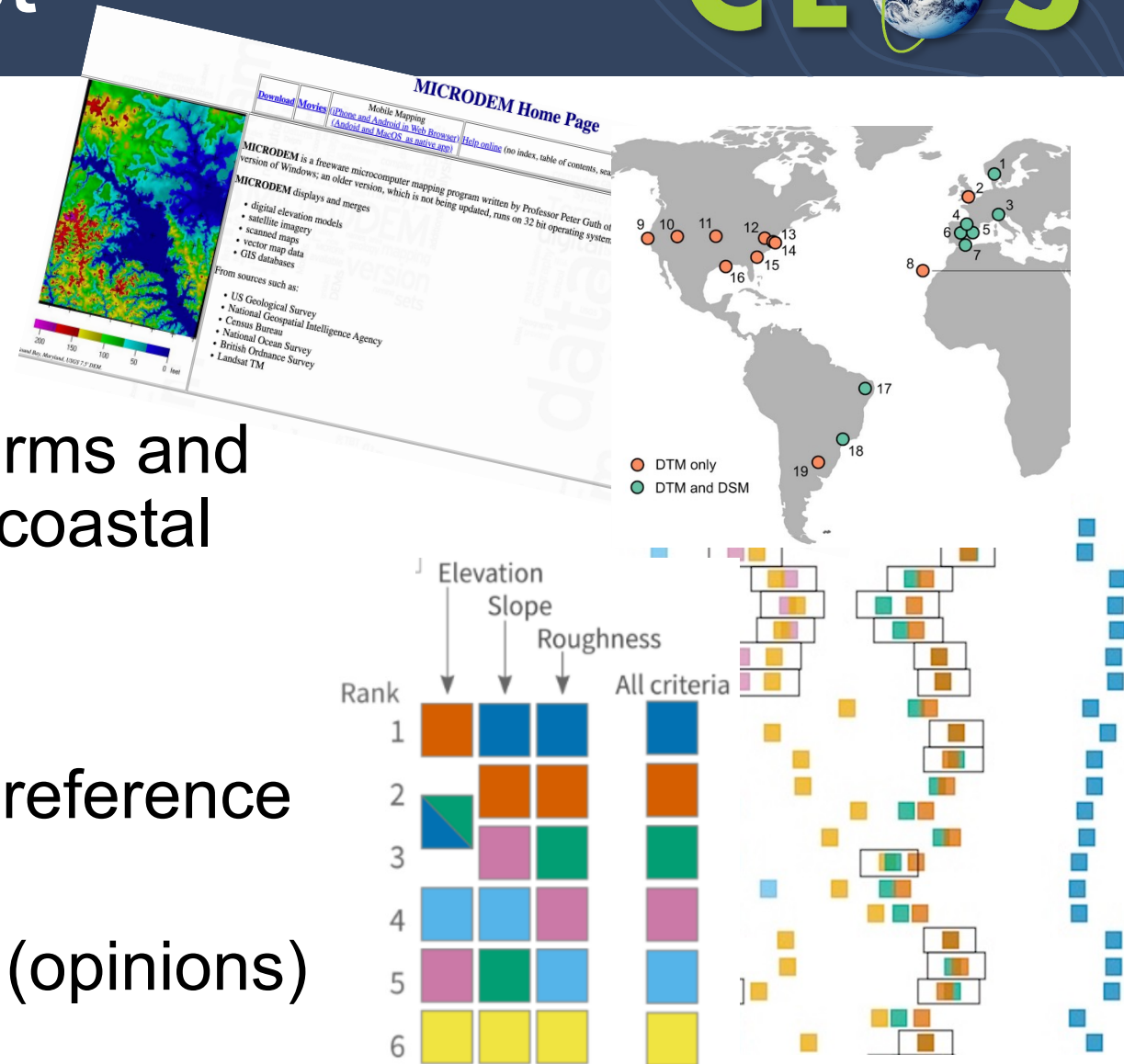
NASA

Graphics courtesy of P. Guth

The DEMIX wine contest



- ❖ 133 DEMIX tiles on three different continents with reference data
- ❖ Reference data preparation tool
- ❖ All major geomorphological landforms and landcover types represented incl. coastal areas (partial water)
- ❖ 15 different criteria in 3 classes
- ❖ Pixel by pixel comparison against reference data
- ❖ Just under 20.000 individual tests (opinions)



The ranking tool



- Idea is to have a simple to use interface allowing users to filter for
 - Criteria type (elevation, slope, ...)
 - Spatial characteristics (geomorphology, landcor, ...)
 - Reference (DTM or DSM)
- Ranking is recomputed according to user's purpose
- Python notebook as base (portable and cloud compatible)

```
DEMIX_wineContest_SIMPLE.ipynb
File Edit View Insert Runtime Tools Help Changes will not be saved
+ Code + Text Copy to Drive
SIMPLE version of the DEMIX notebook
Carlos H Grohmann version 2022-08-11
Instructions
This is a simple version of the notebook where we only need to run 3 cells (to run, click in the cell and press shift-enter)
The first cell will download auxiliary data, functions and CSV files from GitHub, import python libraries, install the qgrid module and load a selected CSV and create the ranked dataframe.
This cell produces a lot of text output. It's safe to clear the output after it's finished
[ ]
[ ] # get external files - Friedman tables, custom DEMIX functions and CSV files used for the analysis
!gdwn 1vptCe1Rj2LUYuYP9JEBnppy34CsMdc # Friedmans_tables.zip
!unzip Friedmans_tables.zip
!gdwn 1nP7bUJ7d6YPeVU0X2e7fBdg4LY4f1HJ5 # demix_wine_functions.py
!gdwn 1boywbglFuDpnQe4cnL61QtVdkru9JGc5 # demix_wine_contest_matrix_18aug2022.csv
!gdwn 1iGMXaxTQ7roZmRCgIgu9_f71fQ6fuoIq # hillshade_criterion.csv
!gdwn 1Pr7aLbmHxETY3by1OC1cQtVRNrebMqWn # demix_wine_contest_matrix_simple_example.csv
# install qgrid, a version that works with Colab
!pip install git+https://github.com/lukewys/qgrid.git
# imports
import sys,os
import pandas as pd
```

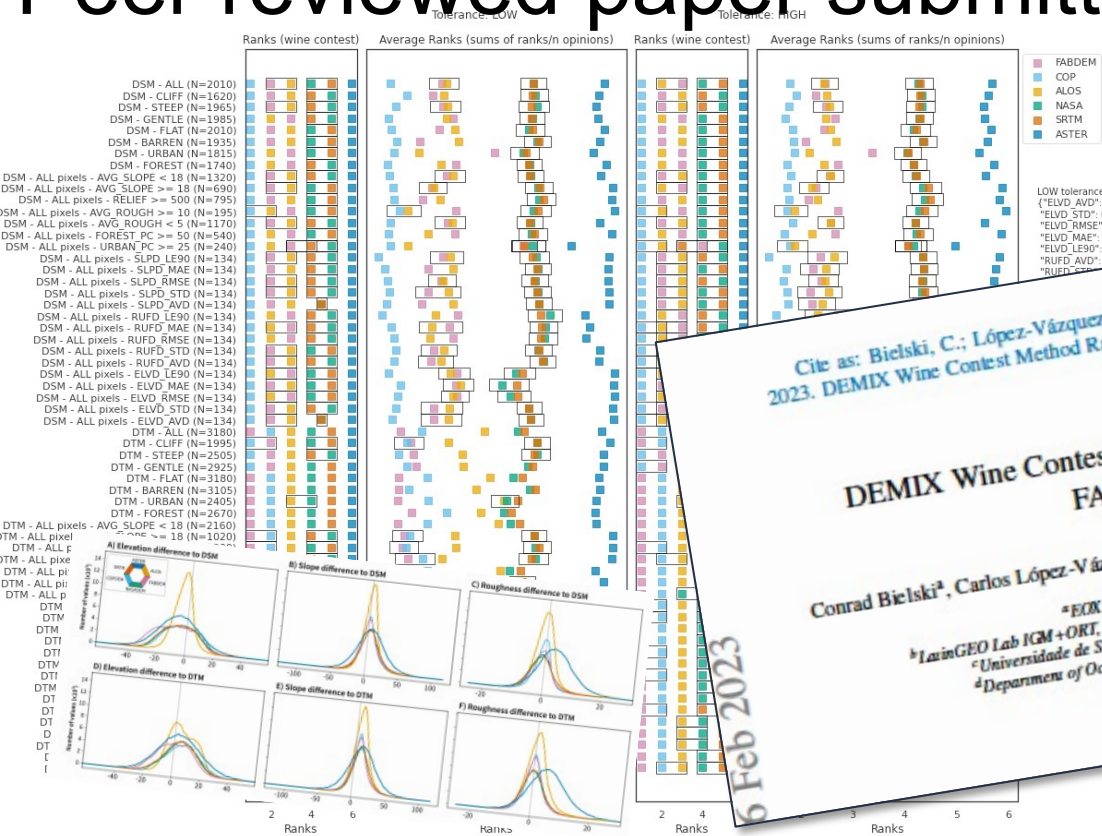

Subgroup 2 outcome



Wine contest implemented and comprehensive intercomparison undertaken

Peer reviewed paper submitted: Bielski et al 2023

<https://arxiv.org/abs/2302.08425>



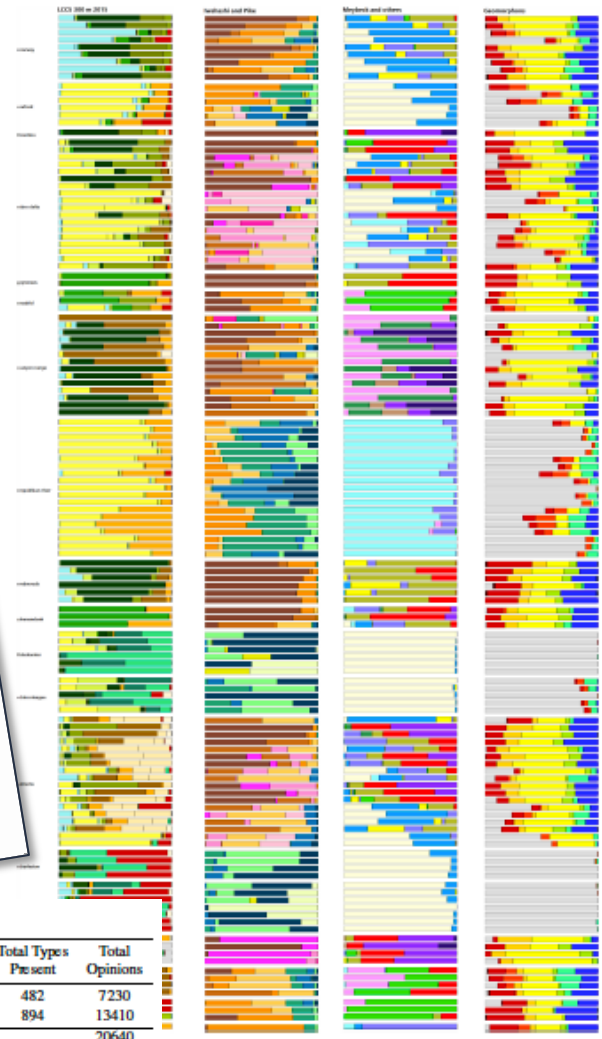
Cite as: Bielski, C.; López-Vázquez, C.; Guth, P.L.; Grohmann, C.H. and the TMSG DEMIX Working Group, 2023. DEMIX Wine Contest Method Ranks ALOS AW3D30, COPDEM, and FABDEM as Top 1" Global DEMs.

DEMIX Wine Contest Method Ranks ALOS AW3D30, COPDEM, and FABDEM as Top 1" Global DEMs

Conrad Bielski^a, Carlos López-Vázquez^b, Carlos H. Grohmann^{c*}, Peter L. Guth^d, TMSG DEMIX Working Group^e

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^dDepartment of Ocean and Atmospheric Sciences, US Naval Academy, Annapolis, 21402, MD, USA
^eCEOS WGCV Terrain Mapping Subgroup

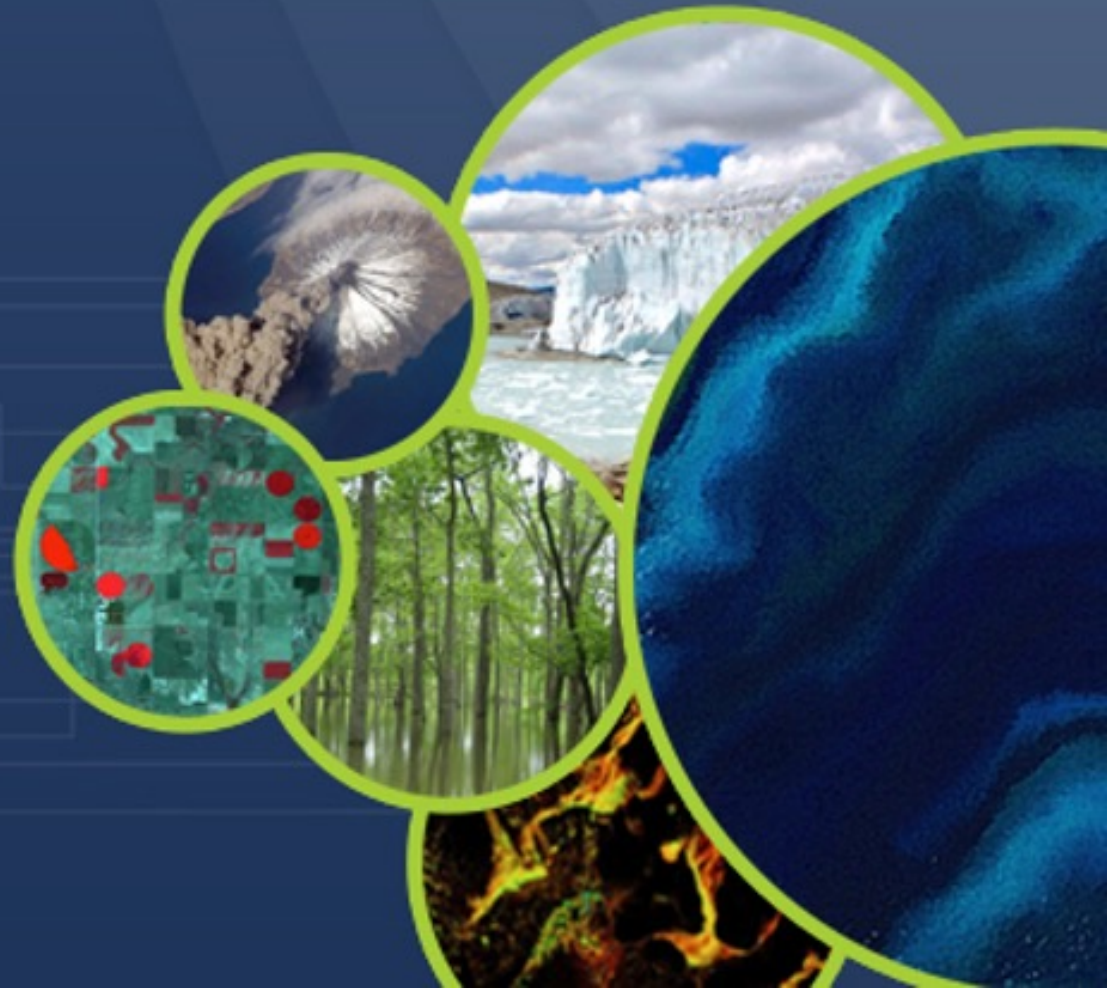
6 Feb 2023





Committee on Earth Observation Satellites

DEMIX Sub-group 3: Platforms



Why a common platform?



Main reasons for establishing a common platform:

- Collect all data in a single (cloud based) environment accessible to all participants
- The involved data sets are of significant size (tens of TeraByte)
- Results and methods are of wider interest within CEOS and beyond
- All data and tools are intended to be released free&open

Two options for platforms are currently investigated:

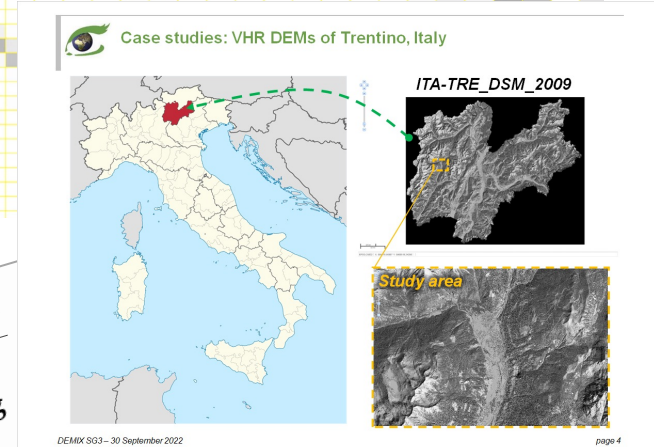
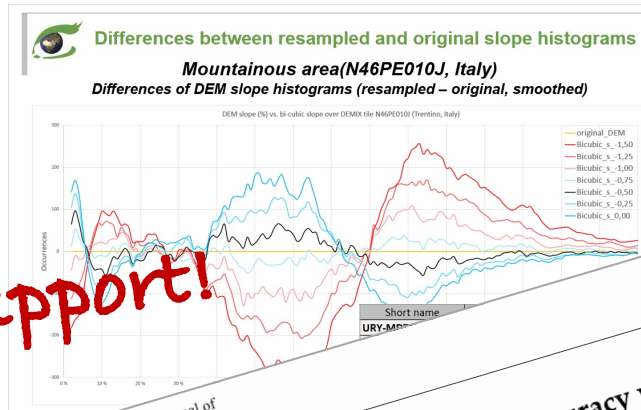
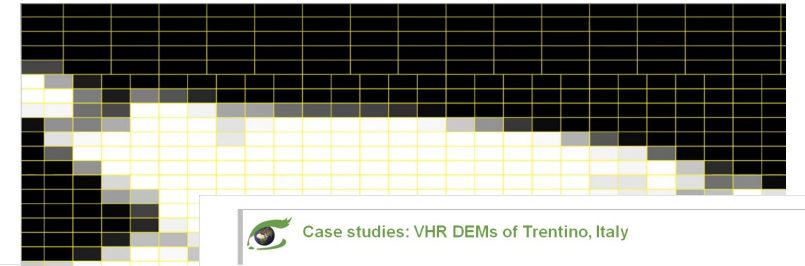
- [VtWeb](#) by [Visioterra](#) (sponsored by ESA)
- CEOS Earth Analytics Interoperability Lab (*EAIL*)

Currently test are rolled out on VtWeb, while possibilities on EAIL are under investigation.

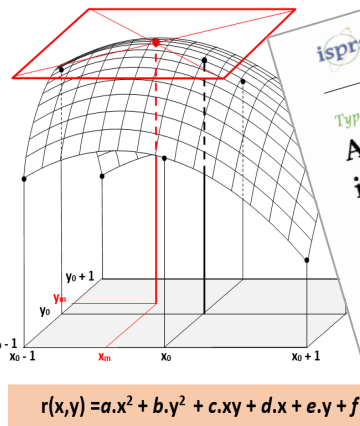
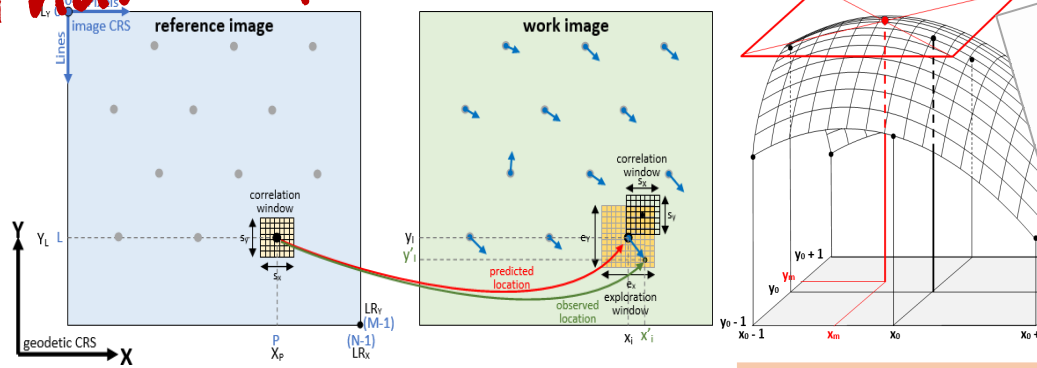
Subgroup 3



- ❖ Global master grid ('DEMIX-tiles') implemented
- ❖ Extensive study on influence of resampling on planimetric misregistration
- ❖ Reference DEM repository and DEMIX test tile preparation facility



Thanks for vtvweb & ESA support!



International Journal of Geo-Information
 Type of the Paper (Article, Review, Communication, etc.)
A new method to achieve a sub-pixel accuracy while matching images by disparity analysis. Application to planimetric misregistration assessment between DEMs. Seeking for the best Bi-Cubic (BBC).
 Serge Riazanoff^{1*}, Axel Corseaux¹, Kévin Gross¹ and Clément Albinet²
 1 VisioTerra, 14 rue Albert Einstein, 77420 Champs-sur-Marne, France; info@visioterra.fr
 2 ESA/ESRIN, Largo Galileo Galilei 1, 00044 Frascati (Roma) Italy; clement.albinet@esa.int
 * serge.riazanoff@visioterra.fr; tel.: +33 9 6130 6628



Abstract: XXX A single paragraph of about 200 words maximum. For research articles, abstracts should give a pertinent overview of the work. We strongly encourage authors to use the following

NOR_DTM_2007	Tinitaly DEM		
NOR_DTM_2007	Norway National DTM		
NOR_DSM_2007	Norway National DSM		
4	30 m	DSM	v2.1 (date not found)
5	depend on tile	DTM	Not found
5	0.5 m	DTM	Not found
5	0.5 m	DSM	Not found
6	1.5 m	DTM	2021
6	1.5 m	DSM	2021
6	2 m	DSM	(26.04.2021)
6	2 m	DTM	(26.04.2021)
7	0.5 m (in GeoTIFF)	DSM	(26.05.2021)
8	1 m	DSM	Not found
9	1 m	DTM	Not found
9	-	-	(2002)
10	1 m (type 1), 2 m (type 2, 3)	DSM	Not found
10	1 m (type 1), 2 m (type 2, 3)	DTM	Not found
11	1 m	DSM	Not found
11	1 m	DTM	Not found
11	0.5 m	DBM (DTM + Buildings)	Not found
11	0.5 m	DSM	Not found
11	0.5 m	DSM	Not found
11	0.5 m	DTM	Not found
11	1 m	DSM	(17.02.2015)
11	1 m	DSM	(17.02.2015)
11	1 m	DTM	(2020)
11	1 m	DSM	(2020)
11	1 m	DSM	(2020)
11	1 m	DSM	(2020)
11	10 m	DSM ?	(2007)
11	1 m	DTM	25.09.2022
11	1 m	DSM	24.09.2022



Committee on Earth Observation Satellites

DEMIX Outlook



What's next?



- Finalisation of SG2 paper
 - Is 'wine contest' appropriate? Should we fight for it?
- Consolidation of VTWeb platform for reference DEM access
 - Make all transformations bullet-proof!
 - How can we get more reference data? Volunteers?
- **FINALLY** Wrap up DEMIX !!!
- Time for the DEMIX Workshop and TMSG plenary!
... and maybe a new chair or at least a co-chair 😄



- ❖ Wednesday 12 July: DEMIX workshop
- ❖ Thursday 13 July: TMSG plenary

Join TMSG/DEMIX, come to Geomorphometry23 and participate in the discussion!

Geomorphometry23 web page: <https://geomorphometry.org/geomorphometry-2023/>
DEMIX WS / TMSG plenary registration: https://ec.europa.eu/eusurvey/runner/DEMIX-WS_TMSG-PL_IASI-2023_registration
TMSG Subscription page: https://ec.europa.eu/eusurvey/runner/WGCV-TMSG_membership

- Lessons learned from DEMIX?
 - ❑ Clarifying terminology and concepts is worth the time, but we have just begun!
 - ❑ Outside-CEOS partners are indispensable, as are sponsors!
 - ❑ Careless use of grid conventions, metadata, and vertical datums are a real nightmare!

Diversity (often) kills interoperability!

- ‘Wine contest’ for everyone?
 - (Inter-)Comparisons are academic without ranking!
 - Ranking is only sound if based on proper statistics!

- Geolocation is a pre-requisite for spatial data interoperability
- DEMs are a key input for geolocating any non-nadir remote observation
- Co-registration (precision) is more important than absolute accuracy
- Consistency requires global references, in x, y, and z

- Ideas for future activities:
 - DEMIX reloaded: more criteria, more reference tiles, fully in the cloud
 - GCPIX: intercomparison of GCP libraries
 - GDMIX: spatial matching and comparison of global GCPs with (shaded) DEMs

Thank you!

Big thanks to all active volunteers!
In particular the sub-group leaders:
Peter Guth, Carlos Grohman,
Conrad Bielski, Serge Riazanoff,
and Carlos López-Vázquez, the wine contest mastermind!

as well as ESA (**Clement Albinet**)
and USGS (**Dean Gesch**)
for their support!