CLOUDMAP2: Quantitative assessment of outlier detection methods with MISR-stereo height measurements of ground topography

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Objectives

- Assess whether **M4** and **PGotcha** stereo matching methods using a simple and fast height retrieval technique provide for clear-sky scenes over rugged terrain
  - -more accurate and reliable results than MISR **2TC**.
  - -results similar to height measurements of ground topography.
- Assess whether blunder detection techniques can improve the stereo-matched heights

Datasets

- Selected cloud-free scenes over mountain ranges with heights up to 9km, with both East-West (Himalayas) and North-South (Rockies) orientation.
- Areas selected were those with good quality NIMA DTED-0 data including maximum heights at 30" derived from 3" DTED-1 data

Methods

- MISR **2TC** Stereo-Height produced for AnAf camera pair on a 1.1km grid include "correction of wind advection effects", irrespective of whether clouds are present.
- Applied **M4** & **PGotcha** to 275m grid MISR 2TC L1B2 ellipsoid radiance for AnAf camera pair. PGotcha results given at sub-pixel level accuracy.
- Use simple equation (no wind correction) to retrieve Stereo-Heights:

$$H = \left|\frac{disp_{along\text{-}track}}{\tan\theta_f - \tan\theta_a}\right| \quad \text{with } \theta_a = 0° \text{ and } \theta_f = 26.1°$$

Results

- Blockiness in **2TC** due to wind correction. No blockiness when using the **Tan** equation for the height retrieval.
- **M4** provides the best coverage but has more blunders especially in low regions (effects due to thin clouds?)
- **PGotcha** provides the smoothest results.
- Histograms show that **2TC** has a wider Stereo-heights dispersion for both low and high altitude regions.
- **M4** and **2TC(Tan)** show similar results.
- Scatterplots show that **PGotcha** has less blunders than the other matchers. Sub-pixel accuracy could explain the differences between **PGotcha** and the other matchers.
- The **Tan** function is a simple and fast alternative for 2TC Stereo-Height retrieval than for clear-sky scenes.

Methods

- Improve the Stereo-Heights retrieved for clear-sky scenes by the matchers **M4**, **PGotcha** and **2TC(Tan)**
- Apply blunder detection strategies initially developed for map contour grid-point interpolated Digital Elevation Models

Results

- Blunder detection techniques improved the Stereo-matched Heights by reducing the number of blunders. However, they did not remove all of them and some good points were deleted.
- M4 not affected by the interpolation due to its good coverage and both blunder detection techniques work better for it
- Less blunders for PGotcha – probably due to the sub-pixel accuracy
- Felicisimo shows better results for our scenes than Lopez (lower error values & less false alarms)
- Standard deviation & other parameters reduced but at the cost of an increase in bias

References cited

*Felicisimo, A.M., 1994. Parametric statistical method for error detection in digital elevation models, *ISPRS Journal of Photogrammetry and Remote Sensing*, 49(4), pp. 29-33

**Lopez, C., 2000, On the improving of elevation accuracy of Digital Elevation Models: a comparison of some error detection procedures, *Transactions in GIS*, 4(1), pp.43-64

§Muller, J-P., A. Mandanayake, C. Moroney, R. Davies, D. J. Diner, S. Paradise, 2002. MISR stereoscopic image matchers: techniques and results, *IEEE Transactions on Geoscience and Remote Sensing*, 40(7), pp.1547-1559

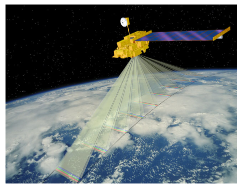
§§Muller, J-P., M-A. Denis, R. D. Dundas, K. L. Mitchell, H. Mannstein, 2003(submitted). Stereo cloud-top heights and motion retrieval from ATSR2, *International Journal of Remote Sensing CLOUDMAP special issue.*

CLOUDMAP2: The project

- Develop the technology, including semi-operational processing systems, to extract cloud parameters from existing and soon-to-be-launched European EO sensors in near real-time (≤3 hours) and ground-based remote sensing instruments in real-time.
- Create, based on this technology , a distributed database of cloud measurements
- Validate satellite cloud and WV products using ground-based remote sensing instruments and through satellite-satellite intercomparison
- Assess, qualitatively and quantitatively, how this cloud database can be used to improve the accuracy and/or validation of Numerical Weather Prediction and Climate General Circulation Models, specifically by providing statistical information

MISR multi-angle sensors for stereo cloud-top height and motion retrieval

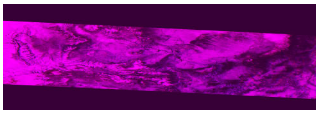
- 9 pushbroom cameras
- 4 spectral bands
- 275m constant off-nadir,
- 250m nadir IFoV
- Swath≈380km
- Repeat time ≈9 days
- 7 minutes between foremost and aftmost cameras



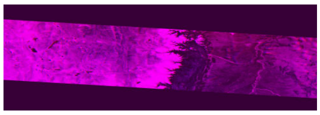
Datasets

Rockies: P037 O5525 B58-63

Anaglyph shows a few thin clouds on the bottom right corner as well as a missing data line on the left-hand side.



Himalayas: P140 O11837 B65-71



Anaglyph shows a clear-sky scene except for a few small Cu clouds in the top right corner.

Area-based stereo-matching techniques

2TC

- Operational MISR matcher uses M2/M3 (Muller et al., 2002)§
- M2 (mean of normalised differences) uses a stripped-down version of an Adaptive Least Squares Correlator ("Gotcha"):
  - Normalise grey-levels within corresponding patch in search window by subtracting mean
  - Calculate mismatch difference between normalised pixel between left image patch and corresponding patch in right search area
  - Comparison to a threshold
- M3 variant uses median rather than mean

M4

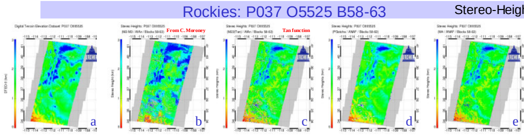
- Derived from M2 and developed at UCL/DLR as part of the EU CLOUDMAP project (1997-2000). Muller et al. (2003)§§
- Addresses the deficiencies of 2TC by providing a single matcher which does:
  - Not require disparity range-setting,
  - Is very fast,
  - Provides a good coverage.
  - Pixel-level accuracy.
- Nevertheless, setting the search window for M4 improves the time processing:
  - 6h for 6 MISR blocks on Linux 5 PE cluster array

PGotcha

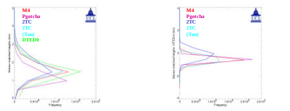
- Highly-configurable derivative of Gotcha (Grüen-Otto-Chau Adaptive Least squares correlation algorithm developed in the Alvey project in the 1980s):
  - Adaptive least squares correlation which leads to sub-pixel accuracy.
  - Requires disparity range-setting.
  - Region-growing algorithm
  - Pyramidal technique (random seed points)
- Time processing:
  - 2 days for 6 MISR blocks on SGI

Stereo-Heights retrieval assessment

Rockies: P037 O5525 B58-63



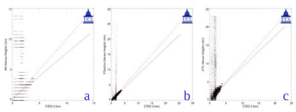
DTED-0 (a) and Stereo-Heights retrieved using: M2-M3 (b), M2-M3 and Tan function (c) PGotcha (d), M4 (e).



Stereo-Heights histograms   Stereo-Heights - DTED0 histograms

	M4-DTED0	PG-DTED0	2TC-DTED0
Mean	-0.19	-0.21	0.22
σ	0.75	0.48	1.30
Max	13.7	23.8	22.4
Min	-3.0	-2.0	-2.5

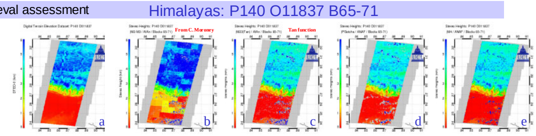
Stereo-Heights – DTED0 statistics



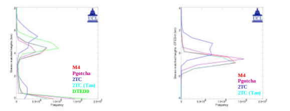
Stereo-Heights vs. DTED-0: M4 (a), PGotcha (b) and 2TC(Tan) (c).

Histograms show that **PGotcha** has lower Stereo-Heights than **M4**.

Himalayas: P140 O11837 B65-71



DTED-0 (a) and Stereo-Heights retrieved using: M2-M3 (b), M2-M3 and Tan function (c) PGotcha (d), M4 (e).

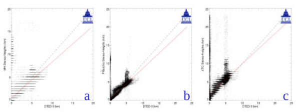


Stereo-Heights histograms   Stereo-Heights - DTED0 histograms

	M4-DTED0	PG-DTED0	2TC-DTED0
Mean	-0.14	-0.24	1.04
σ	1.52	1.03	2.09
Max	17.9	23.5	23.3
Min	-5.8	-5.6	-6.6

Stereo-Heights – DTED0 statistics

No Stereo-heights were retrieved for the Cu clouds using **2TC**. Retrieval of Stereo-Heights for the Cu clouds using the **Tan** equation and the other matchers.
Lower Stereo-Heights for **M4** (7km) vs.**PGotcha** (9km) over the Himalayas plateau (lake, clouds?)
Histograms show that **2TC** has consistently higher Stereo-Heights.



Stereo-Heights vs. DTED-0: M4 (a), PGotcha (b) and 2TC(Tan) (c).

Blunder detection techniques

Felicisimo(1994)*

- Based on statistical criteria
- Allows the estimation of the error probability at each pixel
- Assumption: outliers weakly spatially correlated and follow a random gaussian distribution
- Analysis of the difference between the altitude value and the value obtained by a bi-linear interpolation from the four closest neighbours by means of a standard Student t-test

Implementation

- Assume that errors in our datasets are not so weakly spatially correlated than in Felicisimo
- Replace the bi-linear interpolation by a mean filter with a non-fixed kernel size
- Application of the method to Stereo-matched Heights retrieved from M4, PGotcha and M23 (Tan function) matchers

Lopez(2000)**

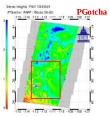
- Based on Principal Component Analysis
- Dataset is subdivided into elongated strips (w<<n)
- Blunder candidates found by analysing the cloud points in Rw space
- Technique applied to row-wise and column-wise strips
- Common candidates are the first ones to be considered as blunders
- Multi-resolution implementation in order to take into account very space-correlated errors

Implementation

- More complex than Felicisimo's approach for MISR
- Currently it can't handle large arrays and missing values (due to missing data and matcher failure)
  - Selected a maximum of 3 blocks over the highest terrain
  - Selected window-subset (cut the missing values at the edges)
  - Replaced the remaining missing values by their interpolated values using different neighbourhood sizes (weighted mean filters).

Blunder detection assessment

Rockies: P037 O5525 B58-63



Subset-window area

		Pixels	Bias	σ	COV	Skewness	Kurtosis	RMS
2TC(Tan)–DTED0	Raw	106310	-0.279	0.23	0.8	5.7	246	0.36
	Interpolated	110512	-0.259	0.30	1.2	6.1	118	0.40
PGotcha–DTED0	Raw	109380	-0.247	0.13	0.5	0.1	2	0.28
	Interpolated	110592	-0.246	0.13	0.5	0.1	2	0.28
M4-DTED0	raw	110565	-0.280	0.22	0.8	0.5	4	0.35
	Interpolated	110592	-0.280	0.22	0.8	0.5	4	0.35

Stereo-Heights – DTED0 statistics using Felicisimo's technique with raw & interpolated data

		Bias	σ	COV	Skewness	Kurtosis	RMS	False Alarm %
2TC(Tan)-DTED0		**-0.244**	**0.72**	**3.0**	**18.1**	**379**	**0.76**	
	Felicisimo	-0.259	0.3	1.2	6.1	118	0.40	42
	López	-0.264	0.48	1.8	21.3	610	0.55	71
PGotcha-DTED0		**-0.247**	**0.14**	**0.6**	**0.6**	**11**	**0.28**	
	Felicisimo	-0.246	0.13	0.5	0.1	2	0.28	80
	López	-0.247	0.13	0.5	0.3	4	0.28	91
M4-DTED0		**-0.276**	**0.28**	**1.0**	**4.8**	**126**	**0.39**	
	Felicisimo	-0.280	0.22	0.8	0.5	4	0.35	19
	López	-0.278	0.25	0.9	2.2	37	0.37	66

Stereo-Heights – DTED0 statistics using both blunder detection methods with the interpolated data

Red (increase) / Blue (reduction).

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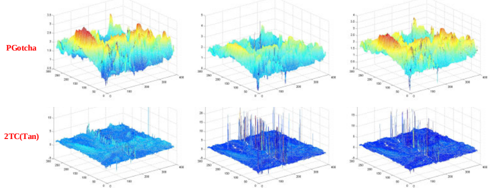
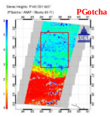
Less blunders detected for **PGotcha**: ~0.5% vs. 1% for the other matchers



Corrected heights using Felicisimo   Raw heights   Corrected heights using López

Himalayas: P140 O11837 B65-71



Subset-window area

		Pixels	Bias	σ	COV	Skewness	Kurtosis	RMS
2TC(Tan)–DTED0	Raw	120191	-0.543	0.45	0.8	4.0	40	0.71
	Interpolated	122812	-0.529	0.48	0.9	3.7	33	0.71
PGotcha–DTED0	Raw	117893	-0.565	0.36	0.6	2.5	18	0.67
	Interpolated	122880	-0.552	0.38	0.7	2.0	12	0.67
M4-DTED0	raw	122875	-0.582	0.37	0.6	1.6	12	0.69
	Interpolated	122880	-0.582	0.37	0.6	1.6	12	0.69

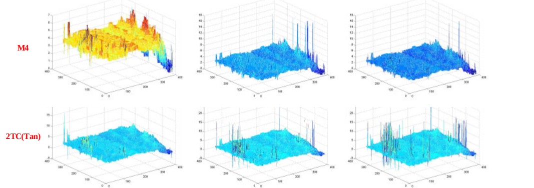
Stereo-Heights – DTED0 statistics using Felicisimo's technique with raw & interpolated data

		Bias	σ	COV	Skewness	Kurtosis	RMS	False Alarm %
2TC(Tan)-DTED0		**-0.516**	**0.72**	**1.4**	**11.1**	**191**	**0.89**	
	Felicisimo	-0.529	0.48	0.9	3.7	33	0.71	28
	López	-0.537	0.55	1.0	9.7	204	0.77	57
PGotcha-DTED0		**-0.551**	**0.40**	**0.7**	**3.1**	**21**	**0.68**	
	Felicisimo	-0.552	0.38	0.7	2.0	12	0.67	55
	López	-0.557	0.39	0.7	3.0	22	0.68	74
M4-DTED0		**-0.573**	**0.44**	**0.8**	**5.2**	**128**	**0.72**	
	Felicisimo	-0.582	0.37	0.6	1.6	12	0.69	28
	López	-0.579	0.39	0.7	2.6	53	0.70	57

Stereo-Heights – DTED0 statistics using both blunder detection methods with the interpolated data

Red (increase) / Blue (reduction).

Less blunders detected for **PGotcha:** ~1% vs. 1.5-2% for the other matchers



Corrected heights using Felicisimo   Raw heights   Corrected heights using López