Super-resolution and 3D reconstruction

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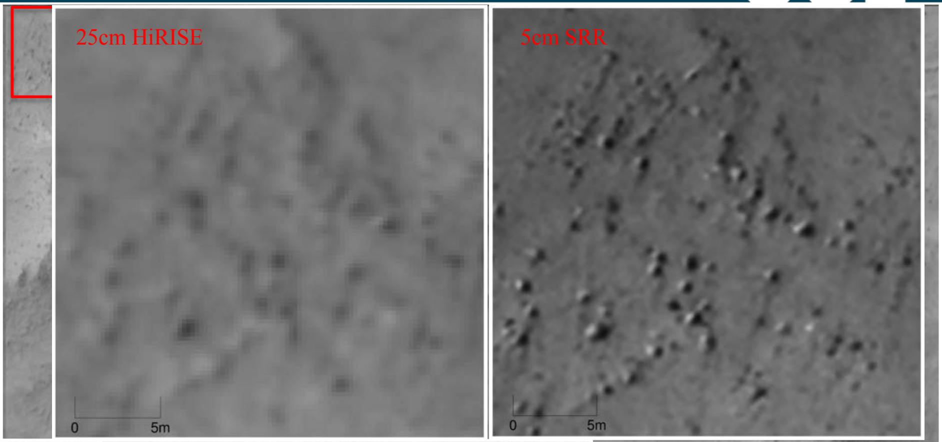
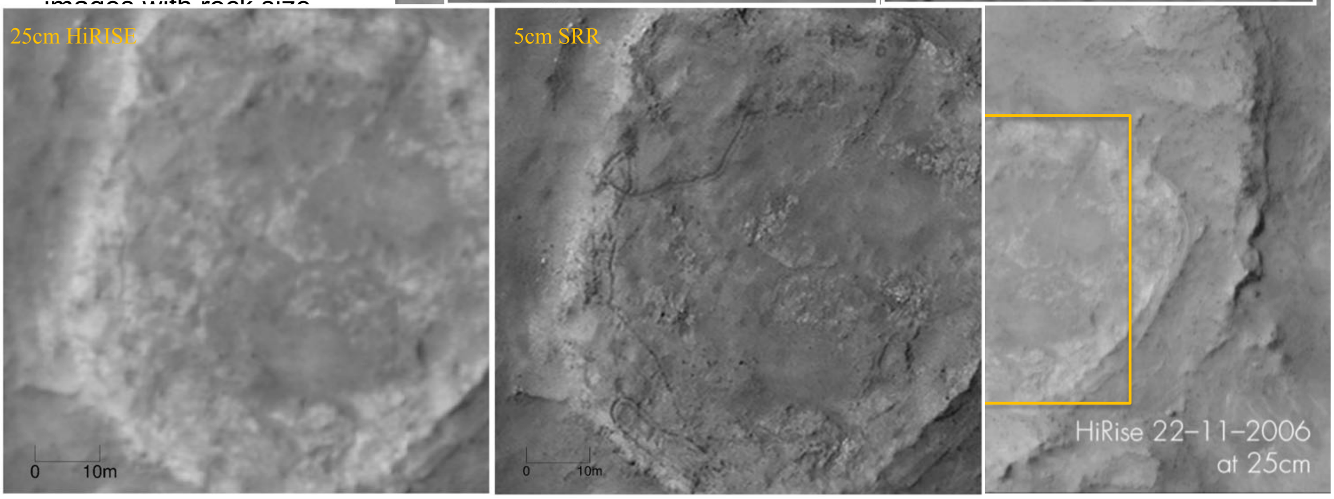
Overview

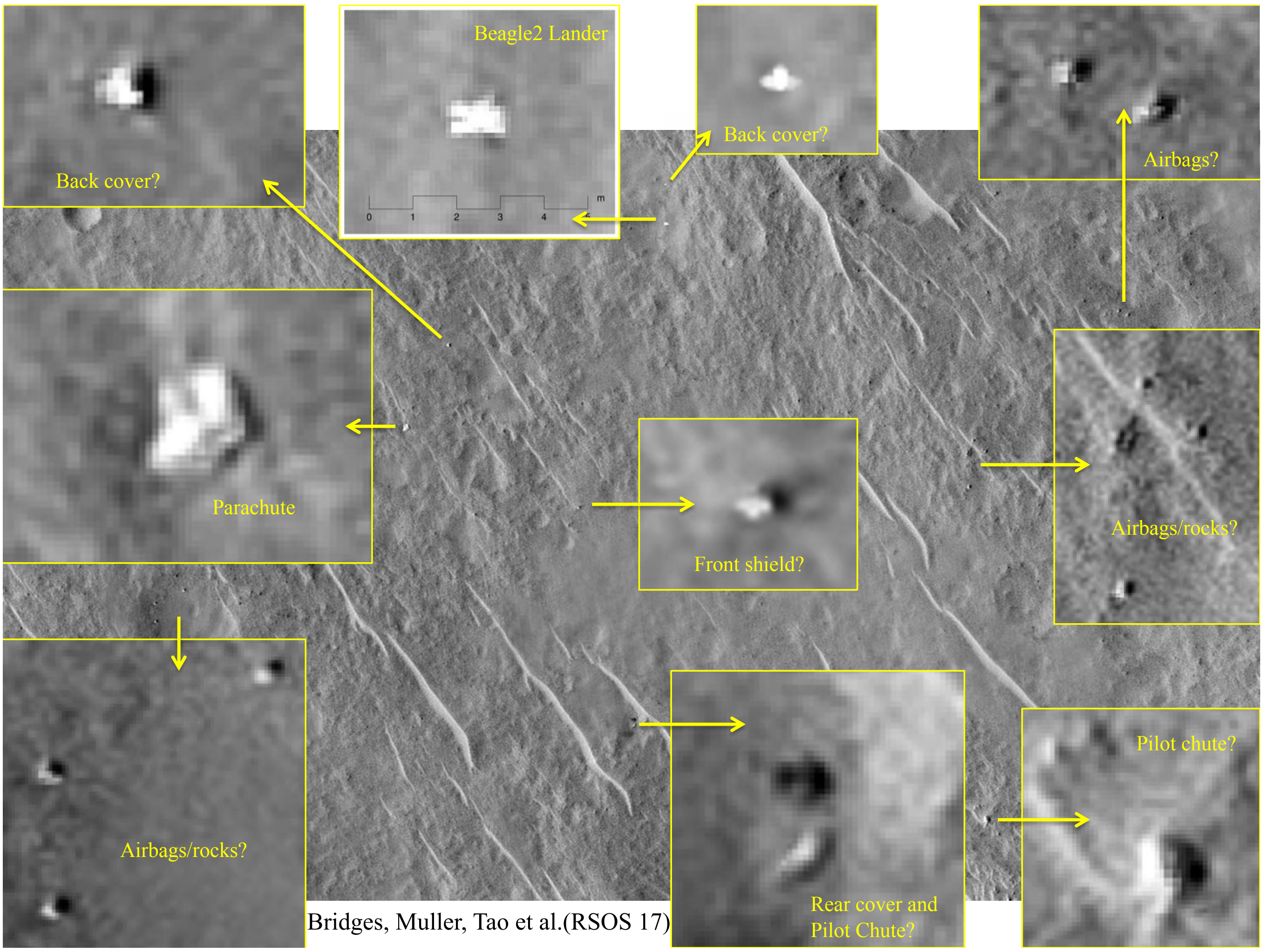
- Introduction to Super-Resolution Restoration (SRR) for Mars imaging of rovers & crash-landed spacecraft
- The UCL MAGiGAN method
- GPU implementation of the UCL MAGiGAN system
- Test and training datasets for GAN refinement
- MISR, Deimos-2 & Carbonite-2 SRR results
- OverPASS 3D reconstruction using CASP-GO
- Predicted impacts of new technologies

Introduction

- A multi-angle Super-Resolution Restoration (SRR) algorithm was developed previously for application to Mars images.
- SRR has been applied to HiRISE (25cm) repeat-pass images to yield resolution enhancements of between 2-5 times (SRR=5-12.5cm)
- These results have been validated using rover







Bridges, Muller, Tao et al.(RSOS 17)

UKSA VM-RSL: Automated RSL feature detection and tracking

- Due to the static nature of the SRR technique, we are able to restore matched (unchanged) features and meanwhile automatically track the unmatched (dynamic) pixels to characterise and measure any "change".
- Preliminary results show linear "hydrological like" features that are extracted from the "unmatched mask" in GPT-SRR processing.
- Experiments used 17 HiRISE images at Nectaris Montes (-1.746, 304.573) at Valles Marineris crossing 3 MYs.

HiRISE ID	Date	MY
ESP_025441_1650	30/12/2011	31
ESP_027973_1650	15/07/2012	31
ESP_029318_1650	27/10/2012	31
ESP_029674_1650	24/11/2012	31
ESP_030452_1650	24/01/2013	31
ESP_031019_1650	09/03/2013	31
ESP_031876_1650	15/05/2013	31
ESP_032298_1650	17/06/2013	31
ESP_032865_1650	31/07/2013	31
ESP_033366_1650	08/09/2013	32
ESP_034711_1650	22/12/2013	32
ESP_036267_1650	22/04/2014	32
ESP_038311_1650	28/09/2014	32
ESP_039208_1650	07/12/2014	32
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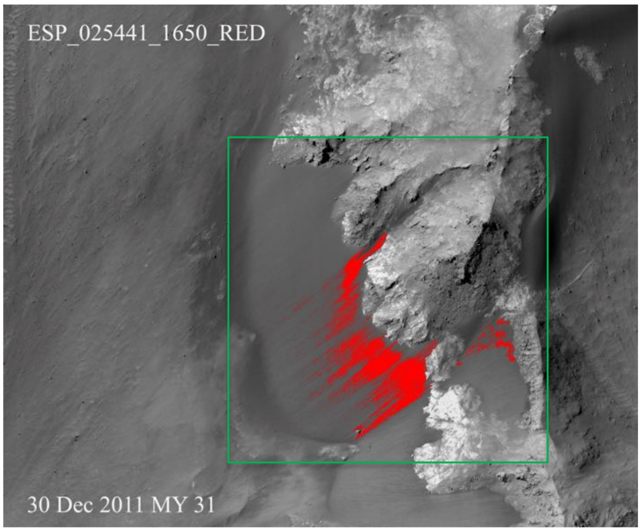
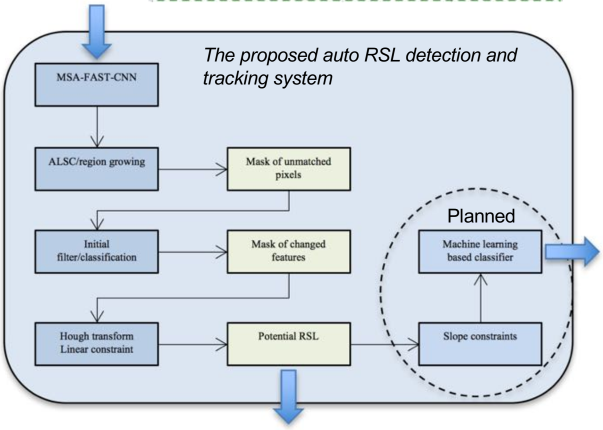
ESP_041898_1650	05/07/2015	33

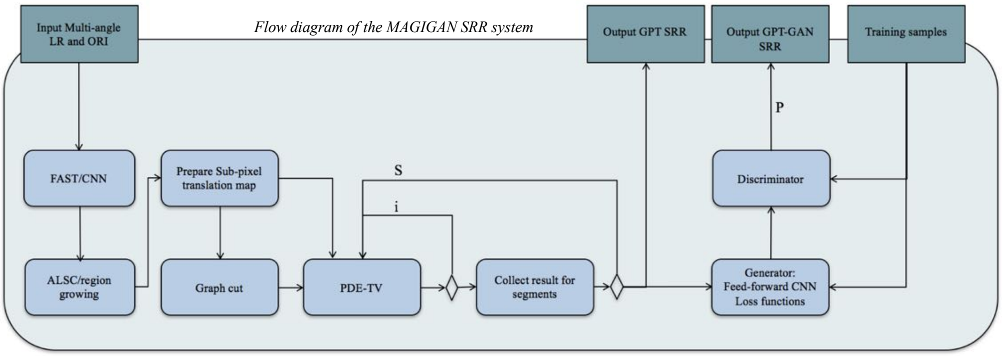




The UCL MAGiGAN method: GPT and GAN

Steps:

1) Image segmentation and shadow labelling;
2) Initial feature matching and subpixel refinement;
3) Subpixel feature densification;
4) Estimation of the image degradation model;
5) GAN network training + SRR refinement (prediction).



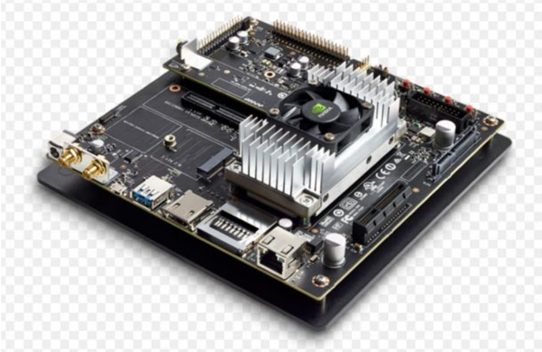
Algorithms:

- Sub-pixel motion vectors (down to 0.01 pixel) use Mutual Shape Adapted Features (***Tao & Muller, Icarus, 2016***) from Accelerated Segment Test (MSA-FAST) with Convolutional Neural Network descriptors.
- Adaptive Least Squares Correlation (ALSC) and region growing (Gotcha) (***Shin & Muller, Pattern Recognition, 2012***).
- Partial Differential Equation (PDE) based Total Variation (TV) in segmented tiles for image degradation modelling (***Tao & Muller, Planetary and Space Science, 2016***).
- The **GPT**-SRR technique is optimal for orbital imagery because it not only uses marginal information from pixel shifting (limited to 1.75x enhancement) but also restores distorted features onto an ortho-rectified grid from comparatively large viewing angles (***Tao & Muller, ISPRS, 2016***).

- **GPT** with Generative Adversarial Network (**GAN)** restores high frequency texture information (***Tao & Muller, Remote Sensing, 2018***).
- **GAN** can be applied to single images after suitable training but risks **errors** without GPT input

GPU implementation

- The MAGiGAN SRR system has been ported (except Gotcha) onto the NVIDIA® Jetson® TX-2 GPU board within the CEOI SuperRes-EO project.
- The GPU implementation is based on Tensorflow and OpenCV's CUDA interface.
- The GPU version has a speedup of 8x for PDE-TV and 20x for GAN prediction.



NVIDIA® Jetson® TX-2 (Space qualified by ESA)

Example of 8 LR inputs: 2048*2048 -> 8192*8192

	MFCNN	Gotcha	PDE-TV
CPU (16 cores) PC	20 - 30 min	~ 1 day	~ 1 day
Jetson TX-2	10-30 sec	> 2 day	2-4 hours

Example of 8 LR inputs: 256*256 -> 1024*1024; LR training 256*256; HR training 1024*1024

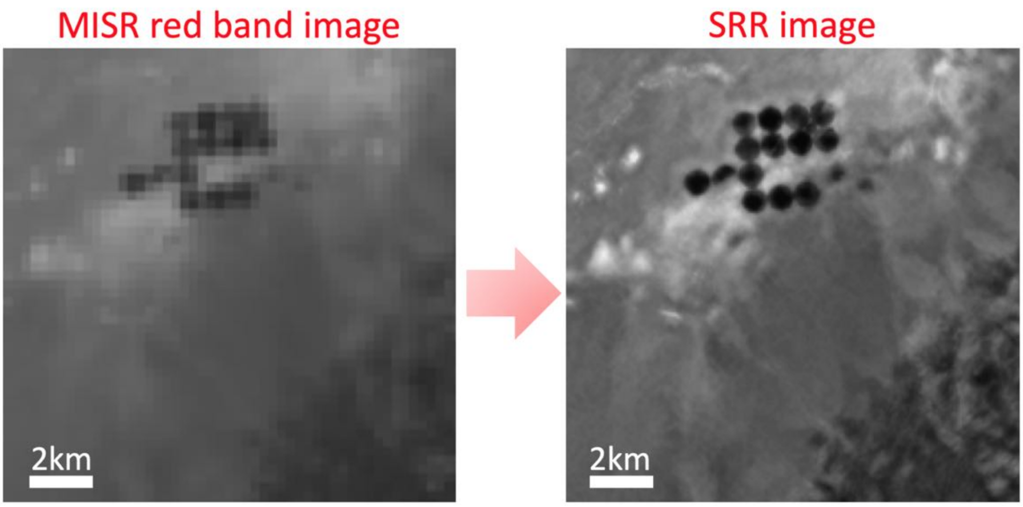
	GAN training (less than 500 samples)	GAN	GAN training (37k samples)
CPU (16 cores) PC	4 - 6 hours	20-40min	n/a
Jetson TX-2	1 – 2 hours	1 – 2min	~ 3 days

	Jetson TX2
GPU	NVIDIA Pascal™, 256 CUDA cores
CPU	HMP Dual Denver 2/2 MB L2 + Quad ARM® A57/2 MB L2
Video	4K x 2K 60 Hz Encode (HEVC) 4K x 2K 60 Hz Decode (12-Bit Support)
Memory	8 GB 128 bit LPDDR4 59.7 GB/s
Display	2x DSI, 2x DP 1.2 / HDMI 2.0 / eDP 1.4
CSI	Up to 6 Cameras (2 Lane) CSI2 D-PHY 1.2 (2.5 Gbps/Lane)
PCIE	Gen 2 | 1x4 + 1x1 OR 2x1 + 1x2
Data Storage	32 GB eMMC, SDIO, SATA
Other	CAN, UART, SPI, I2C, I2S, GPIOs

N.B. Core speed of ARM processor on Jetson is only 1.1GHz and RAM is only 8GB

EO Test Datasets: MISR, Deimos-2 & Carbonite-2

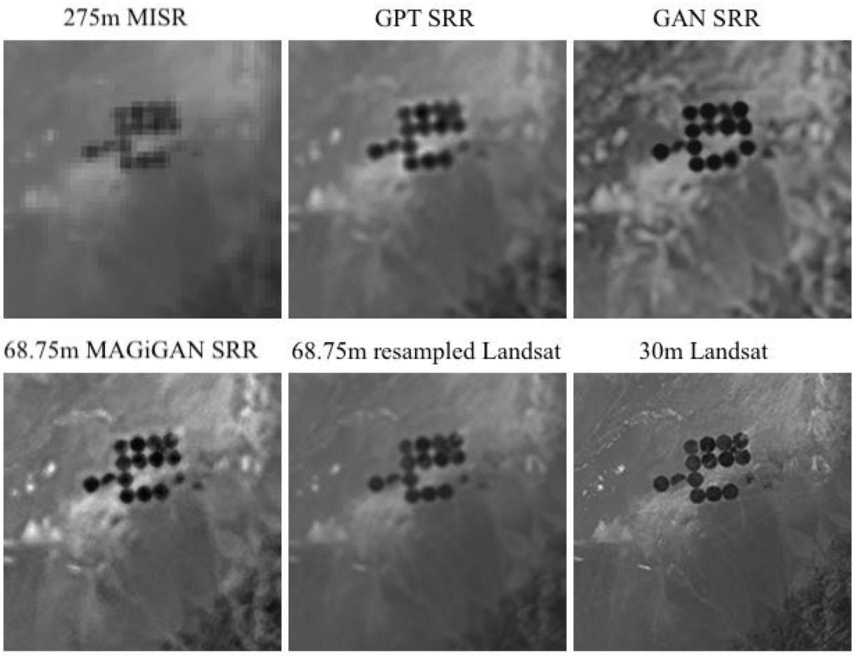
- **MAGiGAN** applied to 275m Multi-angle Imaging Spectro-Radiometer (**MISR**) Level 1B1 red band images to produce SRR enhancement of 3.5x - 4x.
- **MAGiGAN** applied to stacks of 4m UrtheCast **Deimos-2** multi-angle repeat-pass images over several experimental sites to produce SRR results with up to 3.75x resolution increase.
- **Carbonite-2** SRR results had a resolution enhancement of 2x - 2.5x due to limitations on viewing angle range.



- MISR Dataset ideal for MAGiGAN SRR processing:
  - A wide range of multi-angle views (9 angles up to ±70º);
  - Input images have small time delay (<7min) resulting in less surface changes;
  - Have global coverage of different targets for deep learning network training.
- Training datasets used:
  - MISR (275m): 225,282 LR and 225,282 HR
  - Deimos-2 (4m): 18,782 LR and 18,782 HR
  - Carbonite-2 (1m): 1,648 LR and 1,648 HR

MISR – lessons learnt

- **GPT SRR** is able to restore the structural information of the central pivot irrigation (CPI) targets but is not able to restore high frequency texture details, whereas the **GAN SRR** result shows more texture details than the **GPT SRR** result.
- The **GAN SRR** result shows sharper edges of the CPI targets compared to the **GPT SRR** result, but textures and edges are not consistent with the Landsat truth image.
- **N.B.** lower right corner of the **GAN SRR** misidentifies one of the dark spots as a CPI spot. This is clearly wrong cf Landsat
- The **MAGiGAN SRR** result is visually the most similar to the 68.75m down-sampled Landsat truth image.
- The **MAGiGAN SRR** result shows that using **GAN** as a refinement process for the intermediate HR image, generated the best overall structural and texture restoration quality and reduced unreliable synthesis (artefacts) arising from pure deep learning based methods.



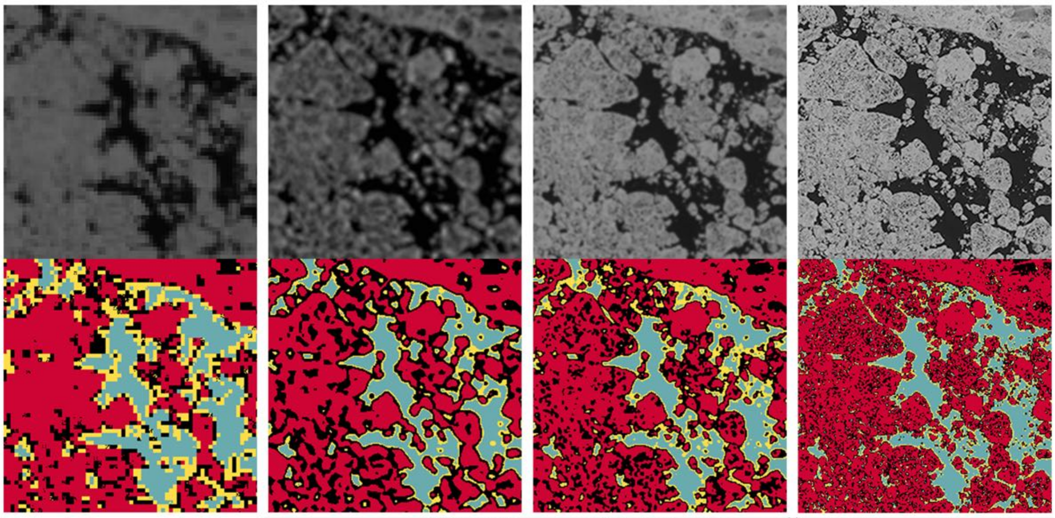
Tao, Y.; Muller, J.-P. Super-Resolution Restoration of MISR Images using the UCL MAGiGAN System, Remote Sensing, vol. 11 doi: 10.3390/rs11010052 http://www.mdpi.com/2072-4292/11/1/52/pdf

Scientific and Commercial Applications: Sea ice leads & melt pond classification with SRR images

- During the Arctic summer time, a large portion of the sea ice area contains melt ponds. The melt ponds can absorb and store more heat, which gradually lead to more sea ice melting.
- Effective monitoring of sea ice leads and melt ponds are essential to calculating the radiative budget of the ocean, ice, and atmosphere system.
- Their distribution, particularly in the Spring, has been shown to accurately predict the summer sea ice extent which is drastically reducing since 2000
- We demonstrate ability of applying the MAGiGAN SRR system to better classify sea ice leads and melt pond studies.
- MISR L1B1 images are processed over two test sites of sea ice fields into 68.75m SRR images
  – (76.9º, -142.6º; **P080_O039735**; 7 June 2007)
  – (75.8º, -123.7º; **P068_O098625**; 3 July 2018) with simultaneous ASTER
- Initial SVM segmentation results of sea ice leads and melt ponds are demonstrated using MISR and SRR images in comparison with the 15m ASTER image.

Classification results of sea ice leads and melt ponds

Ice | Open Water | Melt Pond | Lead | Exposed Land



Top: 275 m MISR red bicubic, 68.75 m MAGiGAN SRR, 68.75 m down sampled ASTER and 15m ASTER
Middle: Pixel-based SVM classification for single band (left to right)
Lower: difference between MISR and SRR classification, illustrating updated pixels and corresponding class (left); surface type proportions by image, in preference to confusion matrices for ease of preliminary comparison across four resolutions (right)
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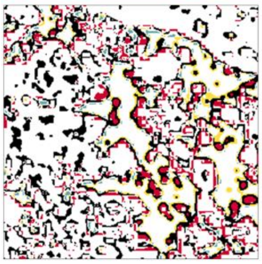

Scene m0n0	275m MISR red bicubic %	68.75m MAGiGAN SRR %	68.75m ASTER downsampled %	15m ASTER (compressed) %
Ice	48.17	47.39	46.65	53.16
Open Water	18.69	14.57	14.09	17.15
Melt Pond	17.49	29.99	28.45	22.30
Lead	15.65	8.05	10.81	7.39
Exposed Land	-	-	-	-

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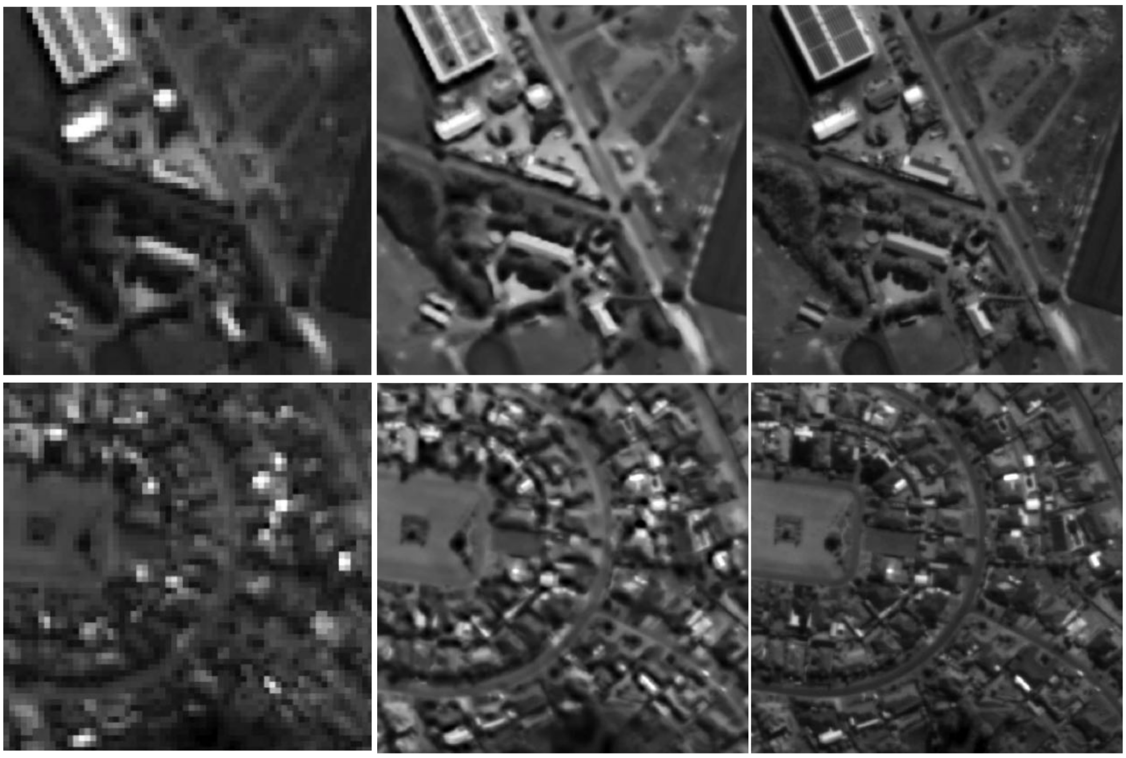
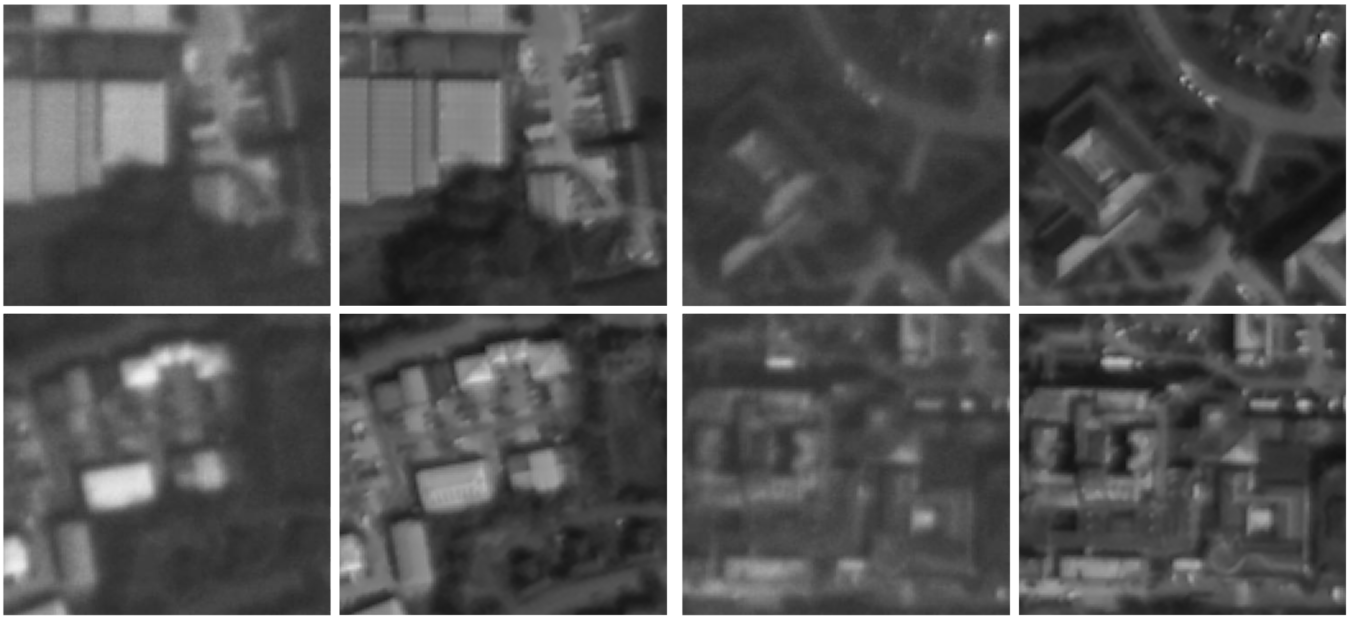
MAGiGAN applied to Deimos-2 (3.75x)



4m Deimos-2 MS green band | 1m SRR from MAGiGAN | 0.75m Deimos-2 PAN band

MAGiGAN applied to Carbonite-2



1m Carbonite-2 green band images | Carbonite-2 SRR results | 1m Carbonite-2 green band images | Carbonite-2 SRR results

Conclusions - SRR

- Demonstrated the MAGiGAN SRR system based on the GPT multi-angle SRR system and deep learning algorithms provide a resolution enhancement factor up to 3.75x.
- The MAGiGAN system not only retrieves subpixel information from multi-angle distorted features, but also uses the GAN network to retrieve high-frequency texture details.
- The MAGiGAN system was integrated onto a space-qualified NVIDIA® Jetson TX-2 GPU board to speed-up processing. Achieved ≈20x cf 16-core Linux for GAN.
- Experimental results shown of time sequence of UrtheCast Deimos-2, 7-minute MISR sequences, SSTL Carbonite-2 video point-and-stare.
- New CEOI project OverPASS with Earth-I, SSTL & Cortexica to GPUize real-time 3D clouds and SRR

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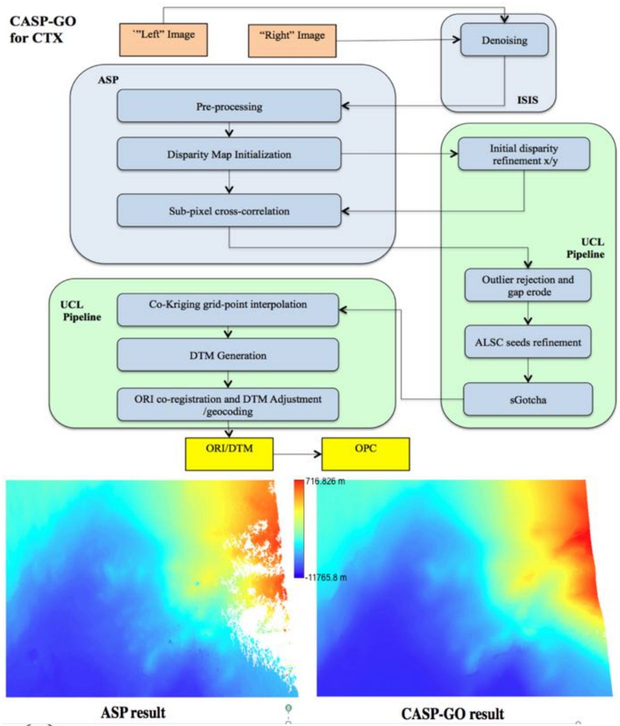
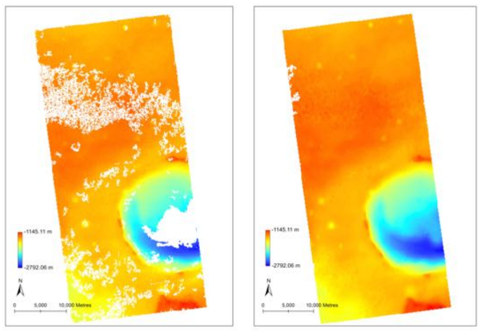
OverPASS: 3D Reconstruction

- 3D modelling is essential to improving our understanding of the formation process of the Martian surface.
- Within the completed EU FP-7 iMars project, a fully automated multi-resolution DTM processing chain has been developed, called **CASP-GO** (Co-registration ASP-Gotcha Optimised (CASP-GO)) see Tao et al., PSS, 2018
- CASP-GO is based on the open source NASA Ames Stereo Pipeline (ASP) [Moratto, 2010; Broxton, 2008], tie-point based multi-resolution image co-registration [Tao & Muller, ICARUS, 2016], and **Gotcha** [Shin & Muller, 2012] sub-pixel refinement method.
- The CASP-GO processing chain was applied to generate ~5,300 NASA MRO CTX stereo-derived 3D imaging products using the MSSL-Imaging processing cluster and the Microsoft Azure® cloud computing platform.
- These DTMs cover ~18% of the Martian surface at 18m/pixel grid-spacing compared to the current HRSC DTM coverage of around 50% with grid-spacing from 50-150m grids.

The CASP-GO automated DTM production system





The CASP-GO system has improved performance compared to the original NASA Ames Stereo Pipeline system:

(a) Co-registered geo-spatial coordinates w.r.t HRSC (and MOLA) data;

(b) Improved DTM completeness for unmatched areas;

(c) Reduced DTM artefacts;

(d) Improved DTM accuracy;

(e) Fully documented uncertainty value for all interpolated area.

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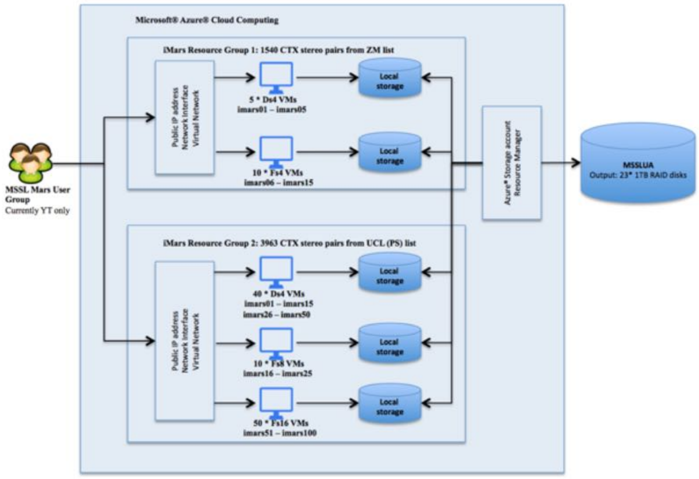
Batch CTX processing on Microsoft® Azure® cloud VMs

- In mid 2016, Microsoft Research offered a year of sponsorship to access Microsoft Azure's High Performance Computing (HPC) resource.
- In iMars, we configured 70 "Fs" type (Intel® Xeon® E5v3 processor, with 8 cores & 112GB RAM) and 90 "Ds" type (Intel Xeon® E5-2673 processor with 4 cores & 56GB RAM) VMs running RHEL v7.2 Linux.



- A total of 5,503 CTX stereo pairs were processed using the Azure cloud VMs using a similar batch processing set-up as on 14-blade MSSL Imaging cluster.
- The input data was directly downloaded to the VMs from the PDS nodes at NASA JPL. Processing results were temporarily stored on the cloud storage space and downloaded back to MSSL later.

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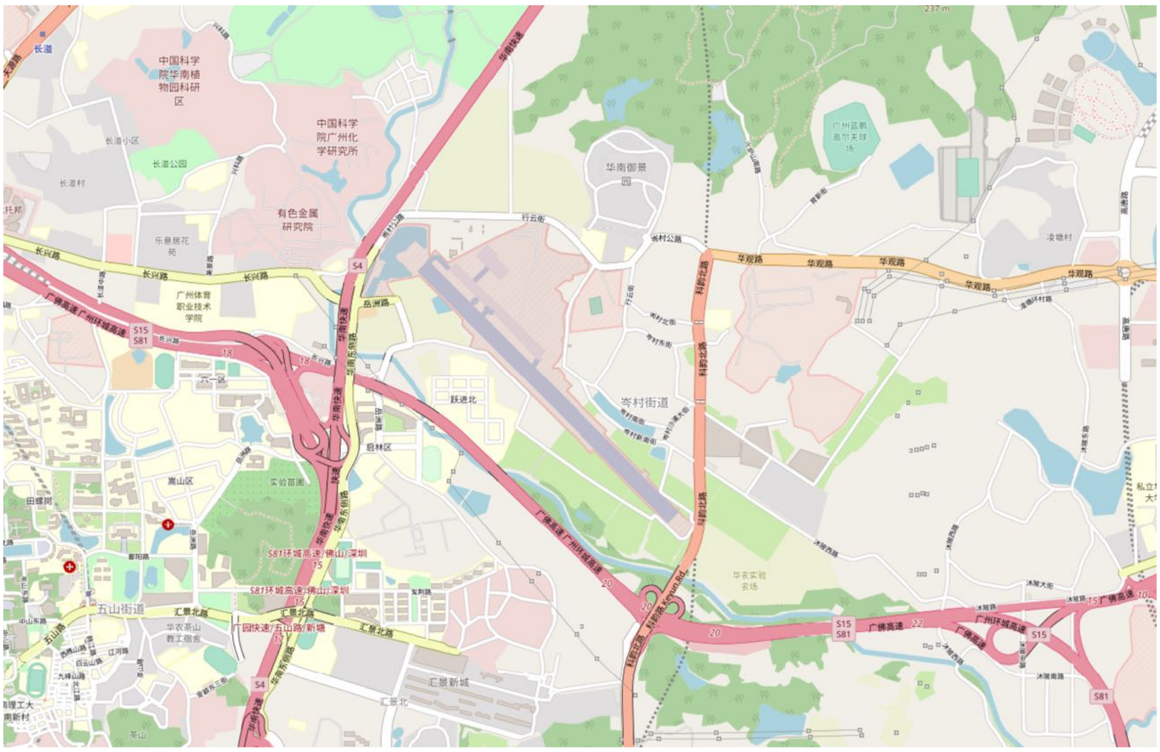
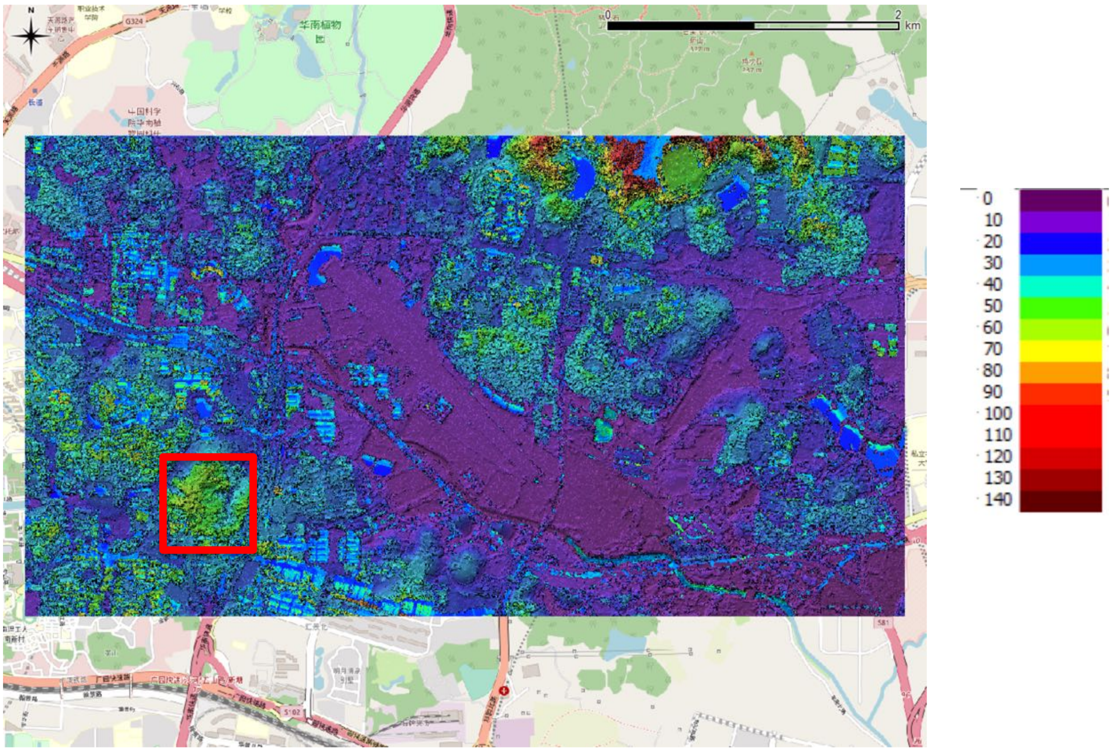
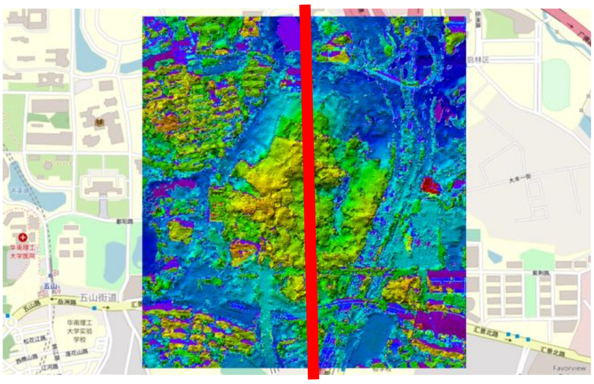
Location of Sample WorldView-2 stereo, Guangzhou China

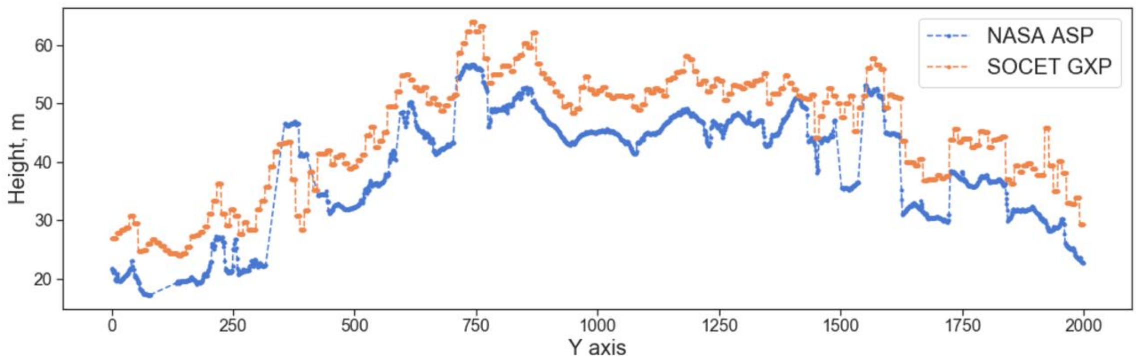


NASA ASP system applied to WorldView-2



WV-2 DEM profiles: NASA ASP cf. SOCET-GXP





Aim: apply this to Planet SkySat and Carbonite-2 “video from space” to achieve sub-pixel 3D point clouds

Predicted impacts of new SRR + 3D technologies

- MAGiGAN SRR system has potential as a game-changer for building cheaper and lighter space hardware and use either onboard or on ground
- MAGiGAN could be offered as a bureau service for export markets or bundled on the appropriate GPU hardware, such as Jetson or MyraidX
- In addition to EO (video) imaging, MAGiGAN could also be applied to hyperspectral and spectroscopic data
- New mission concepts involving swarms of CubeSats with multi-angle capabilities which could be employed. These Cubesats could be launched from the new UK Lockheed Sutherland space port.
- SRR offers the possibility of improved science returns from Sentinel missions as well as from multi-angle missions such as CHRIS-PROBA, MISR and PARASOL
- SRR + 3D will provide commercial traction to open up new markets, develop new downstream services and eventually new commercial missions

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