



→ PROBA-V SUPER-RESOLUTION

Artificial Intelligence for Remote Sensing

Marcus Märtens

AI in space: a game-changer



Robotics

Rovers, underwater robotics, path planning and scheduling, automated reasoning, etc.



Spacecraft Design

Preliminary phases, multi-disciplinary design optimization, concurrent design



Knowledge management

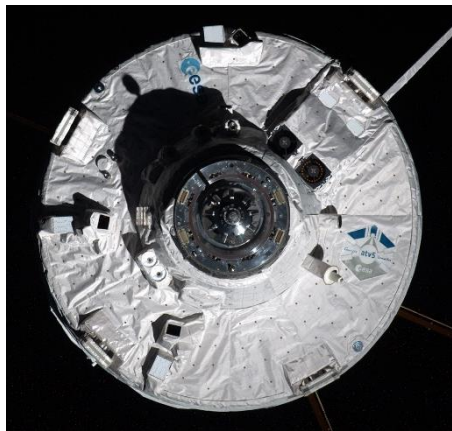
Ontologies, semantics, document classification, document rating, search, etc.



AI in space: a game-changer

Guidance, Navigation and Control

Landing, docking, interplanetary transfers, hovering, Pose estimation, docking, etc.



Payload data processing

Earth Observation, Space Situational Awareness, Space environment



Ground operations

Health monitoring, Telemetry, Collision Avoidance, Monitoring and tracking of space debris



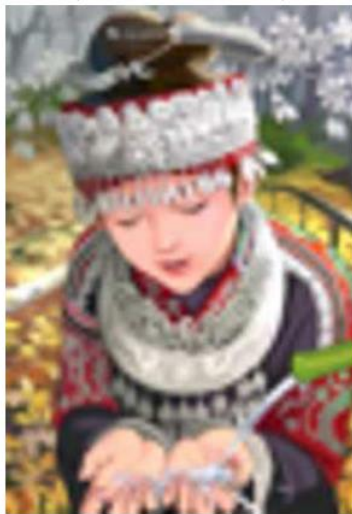
What is Super-resolution?

- ~~Optical Super-resolution: improving an optical system "beyond" their diffraction limit~~
- **Geometrical Super-resolution:** Increasing resolution by image processing

SISR (Single Image Super-resolution)

- Inverting image degradation
- Ill-posed problem

bicubic
(21.59dB/0.6423)



SRGAN
(21.15dB/0.6868)



original



Ledig, Christian, et al. "Photo-Realistic Single Image Super-Resolution Using a Generative Adversarial Network." *CVPR*. Vol. 2. No. 3. 2017.

What is Super-resolution?

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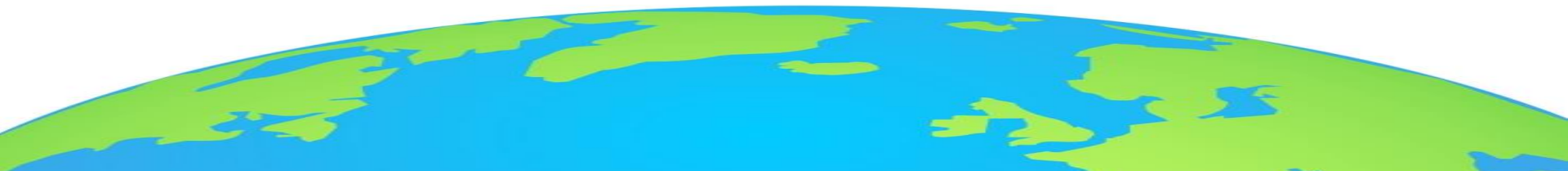
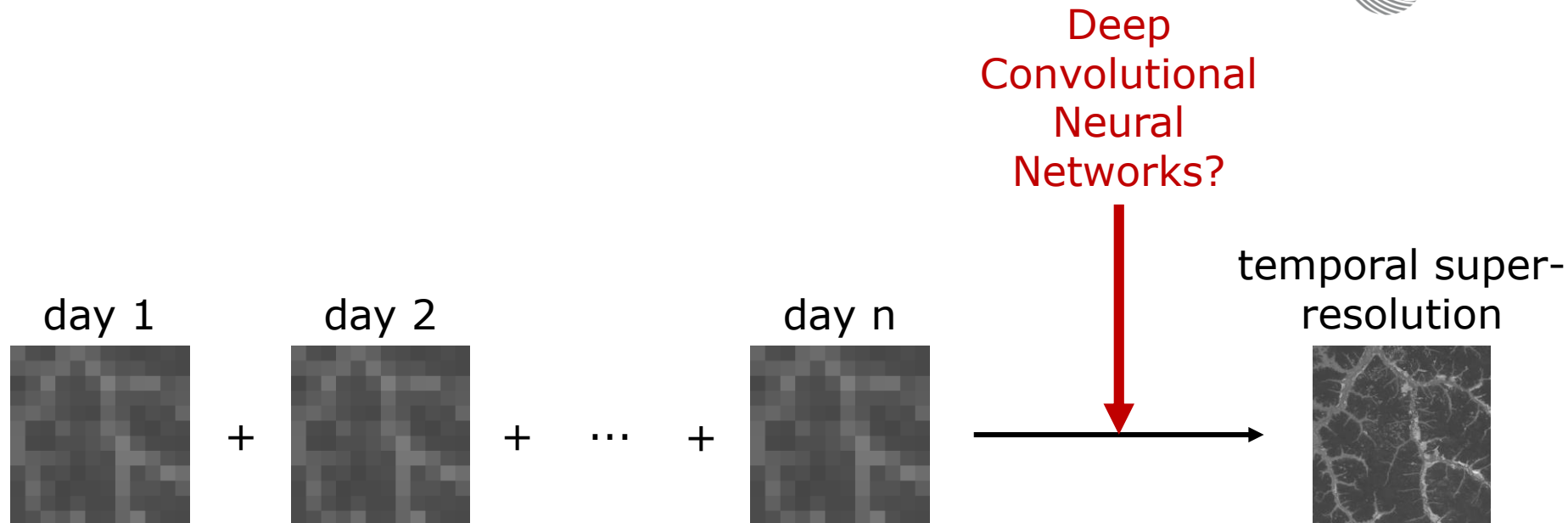
MISR (Multi Image Super-resolution)

- Video enhancements by fusing close frames
- From multiple low to single high resolution
- De-blurring / De-noising

Sunkavalli, Kalyan, et al. "Video snapshots: Creating high-quality images from video clips." *IEEE transactions on visualization and computer graphics* 18.11 (2012): 1868-1879.



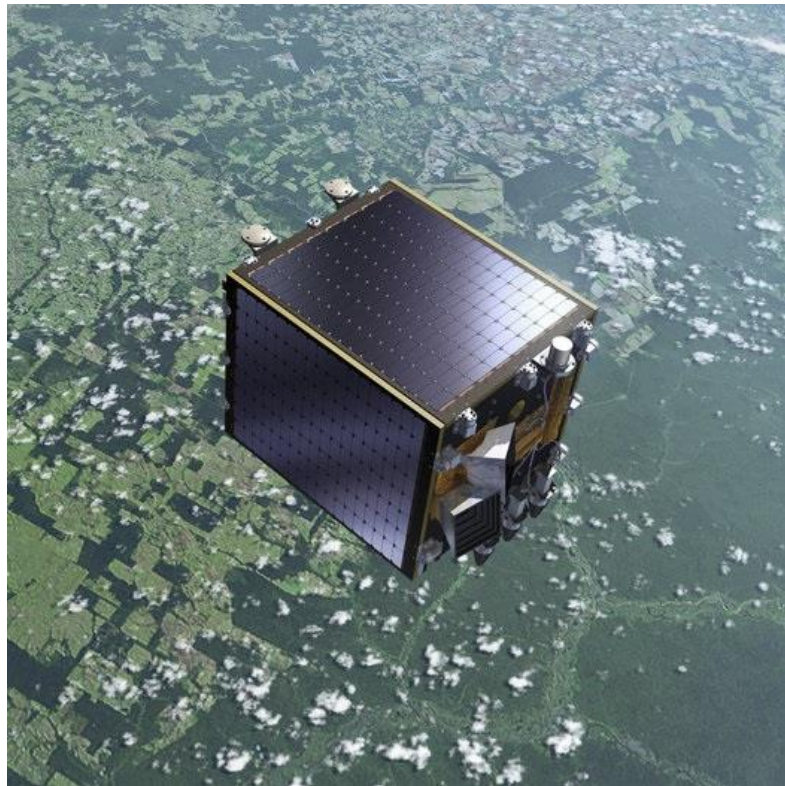
The Vision



About PROBA-V

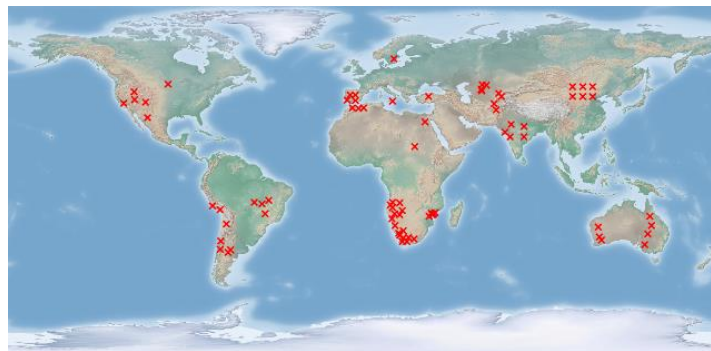
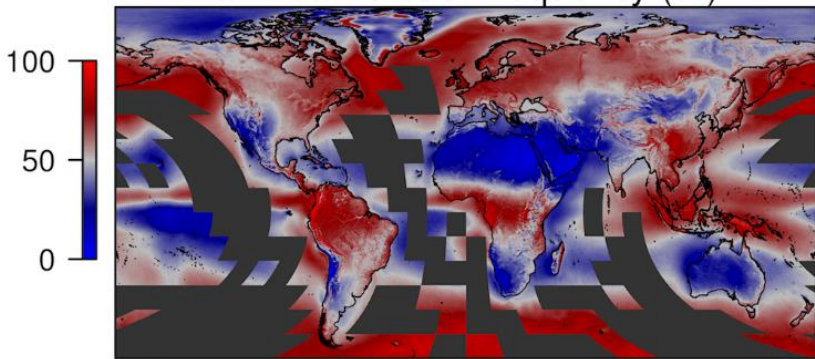
PROBA-V:

- Launched 6th May 2013
- Provides Space-borne monitoring of **vegetation**
- Products:
 - 300m resolution
 - Near global (90%) coverage daily
 - 100m resolution
 - Global coverage ~5 days
- Geolocation mean accuracy: ~61m (± 50 m)
- FOV / Swath: 102,6° / 2250 km
- Spectral bands: NIR, RED, BLUE and SWIR
- Pixel quality maps for clouds, shadows, ice, etc.



Gathering Data for the competition

a. Mean Cloud Frequency (%)



1. Global cloud coverage maps

Remotely Sensed High-Resolution Global Cloud Dynamics for Predicting Ecosystem and Biodiversity Distributions. PLOS Biology, 2016, 14(3): 1–20, doi:10.1371/journal.pbio.1002415

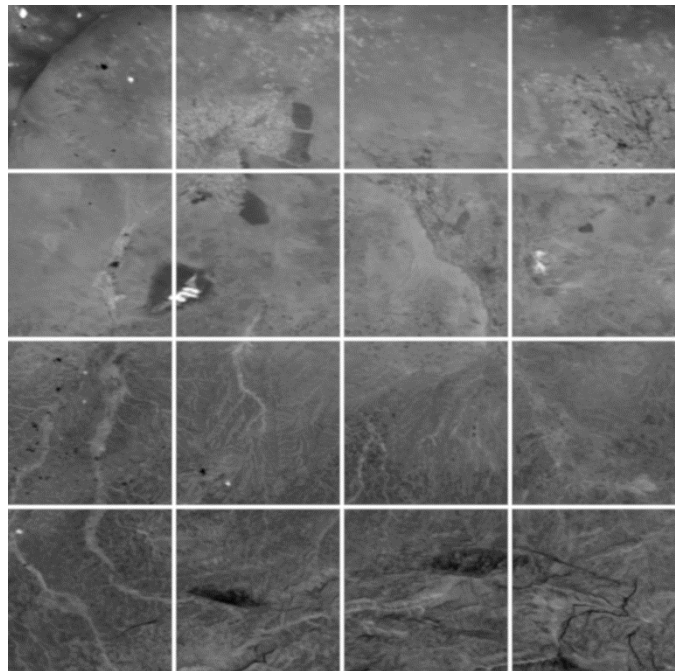
2. Identification of Regions of Interest (ROI)

- Selecting land-regions with interesting geographical features and diversity
- Downloading data from the month with least expected cloud occurrence

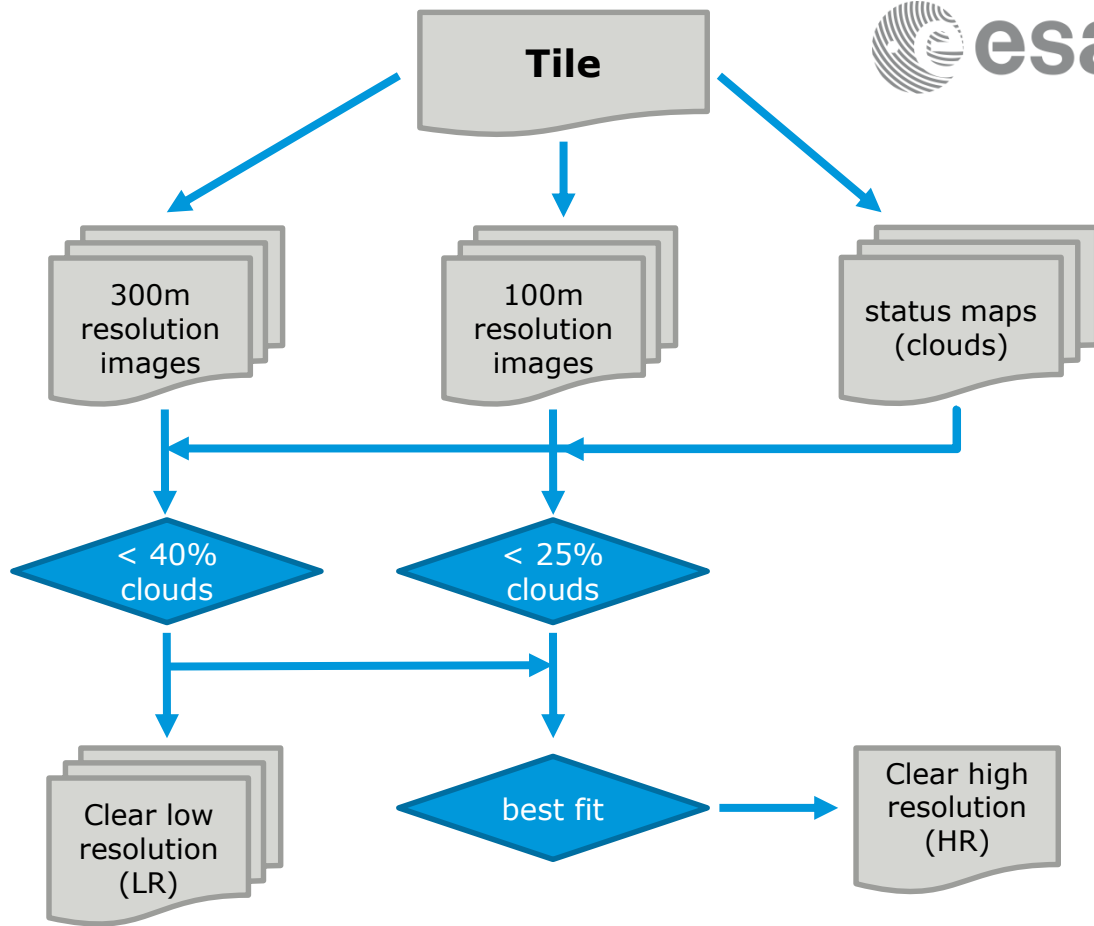
3. Tiling

- Divide each ROI into 4x4 tiles
- 1 tile corresponds to roughly a patch of land with 1475km²

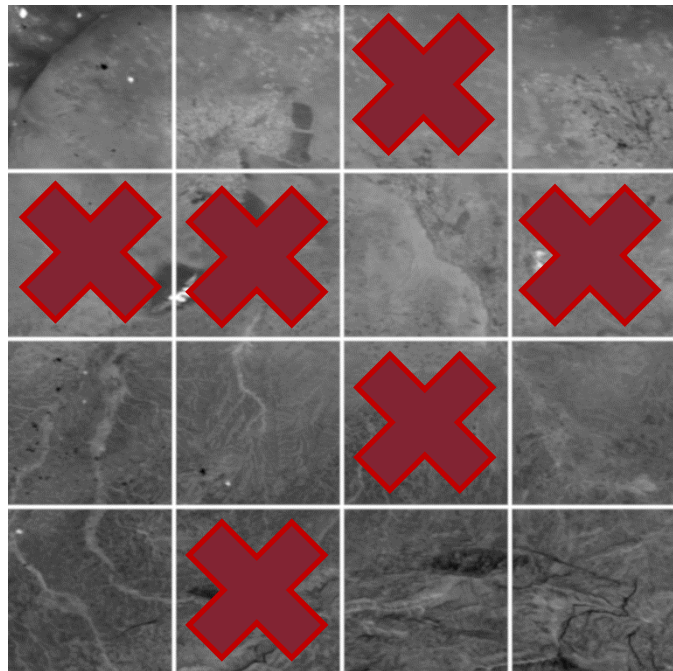
Example Tiling of a ROI



4x4 NIR image tiling, 300m resolution
36°19'19.2"N 65°36'39.6"E, North Afghanistan

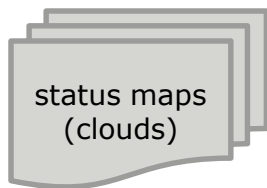


Quality Ensurance



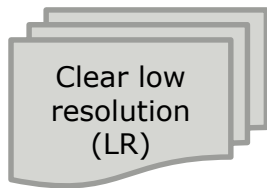
4x4 NIR image tiling, 300m resolution
36°19'19.2"N 65°36'39.6"E, North Afghanistan

1 datapoint



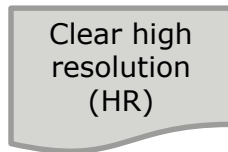
status maps
(clouds)

- One map for each LR and HR image
- Binary: pixel valid or not valid



Clear low
resolution
(LR)

- Less than 40% cloud coverage
- **At least** 9 images
- 128x128 grey-scale 16bit



Clear high
resolution
(HR)

- Less than 25% cloud coverage
- **exactly** 1 image
- 384x384 grey-scale 16bit

39% of all tiles are discarded because of clouds!

$$74 \times 2 \times (4 \times 4) = 2368$$

Regions
Of
Interest

Spectral
bands

Tiling

Datapoints unfiltered

1450

Datapoints filtered

1160

Training set



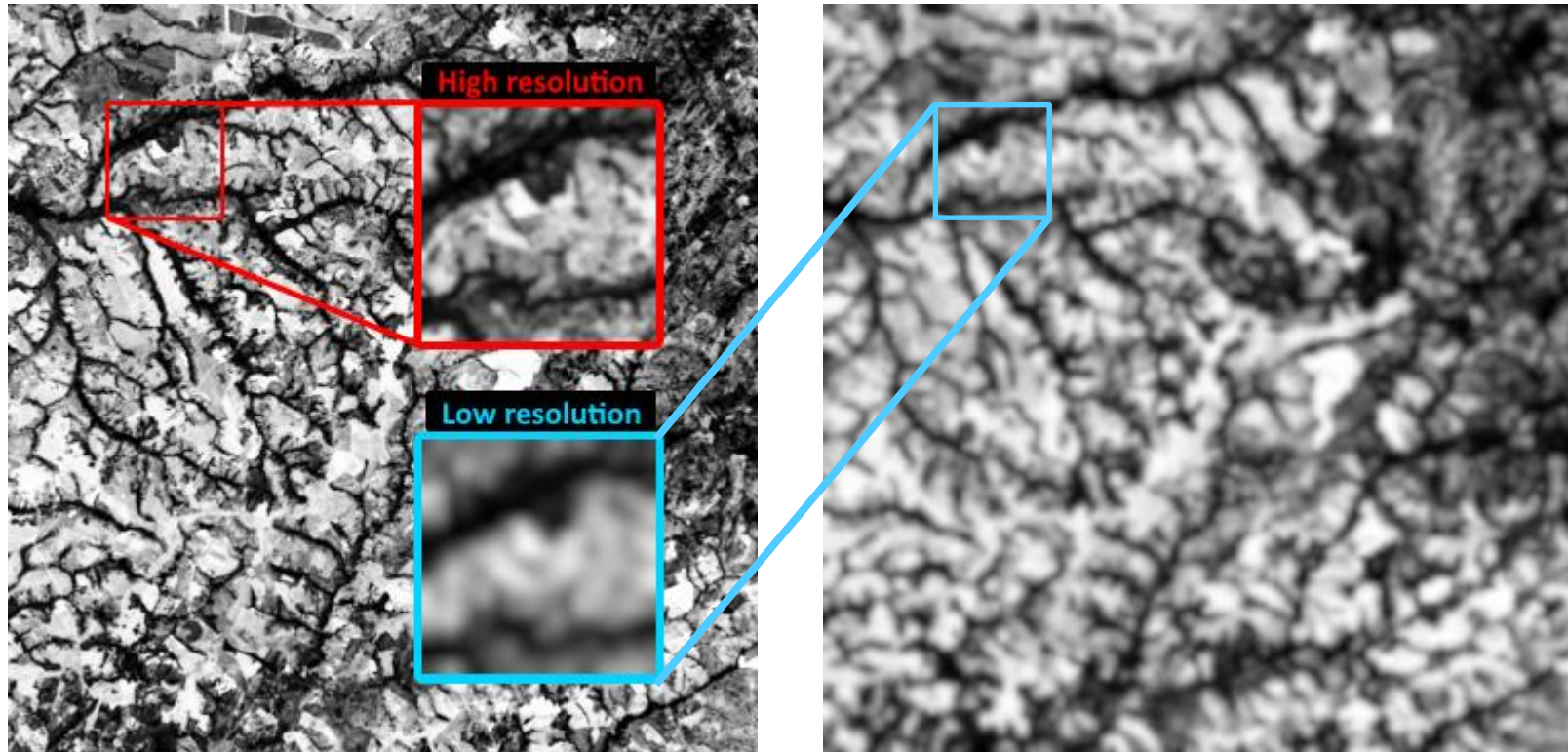
290

Test set

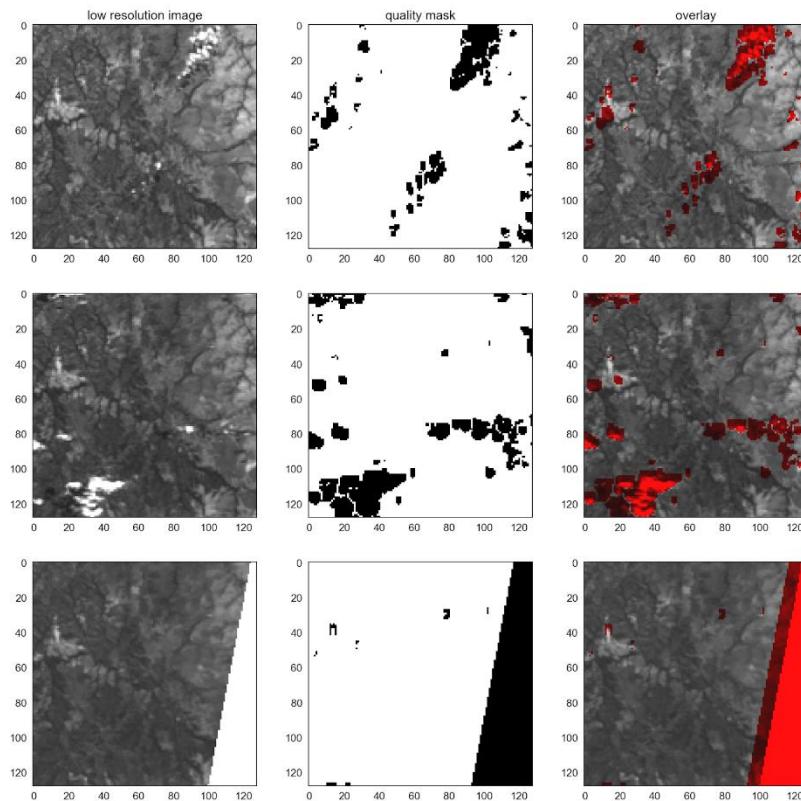


The HR for the test set was
kept secret during competition

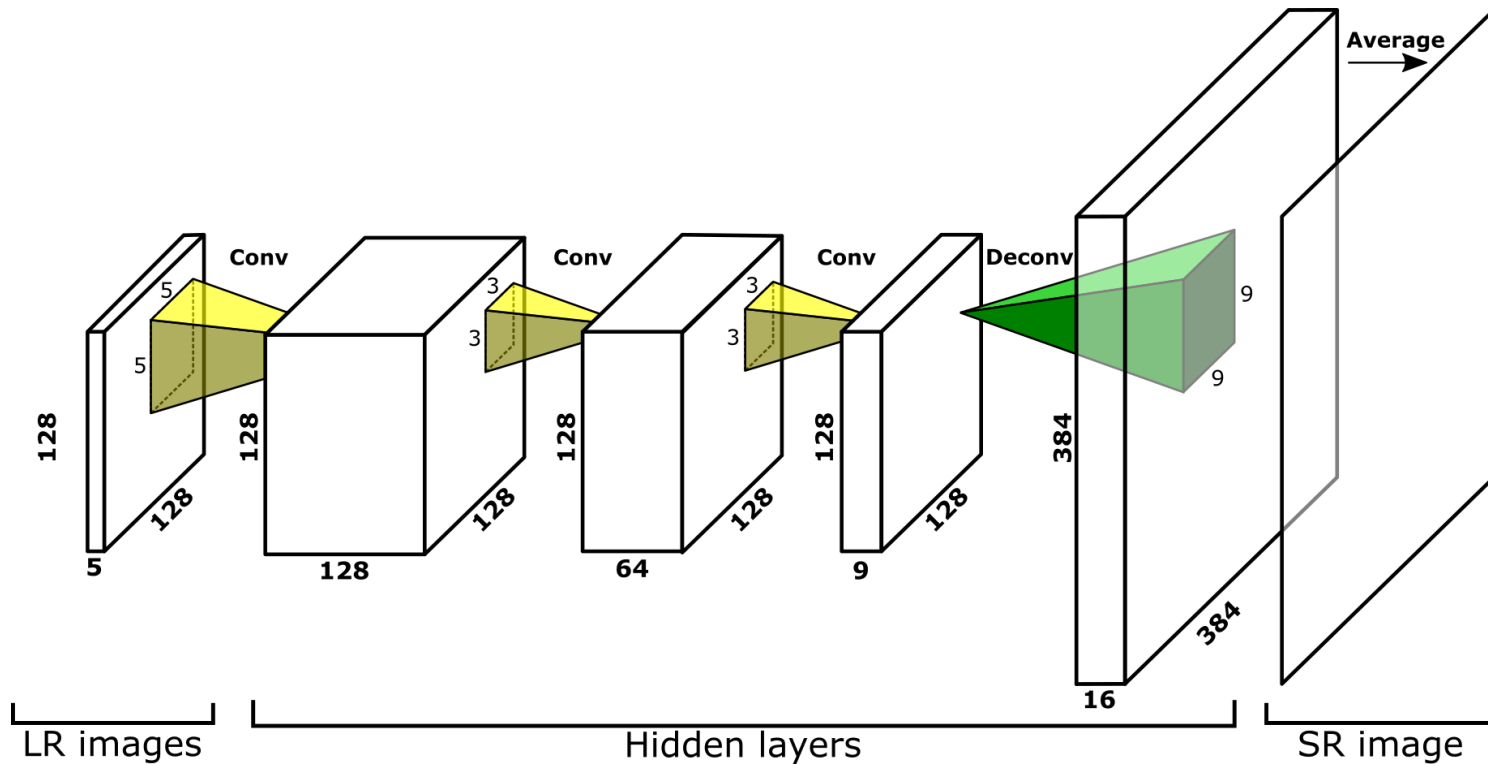
High and Low Resolution in Comparison



Status Maps



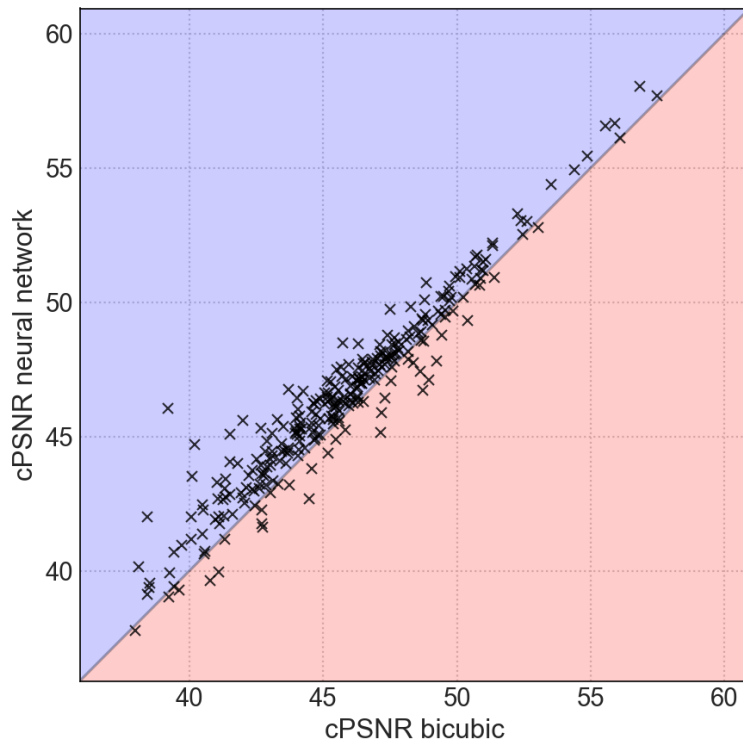
Proof of Concept: SRCNN



Results from the SRCNN (1)

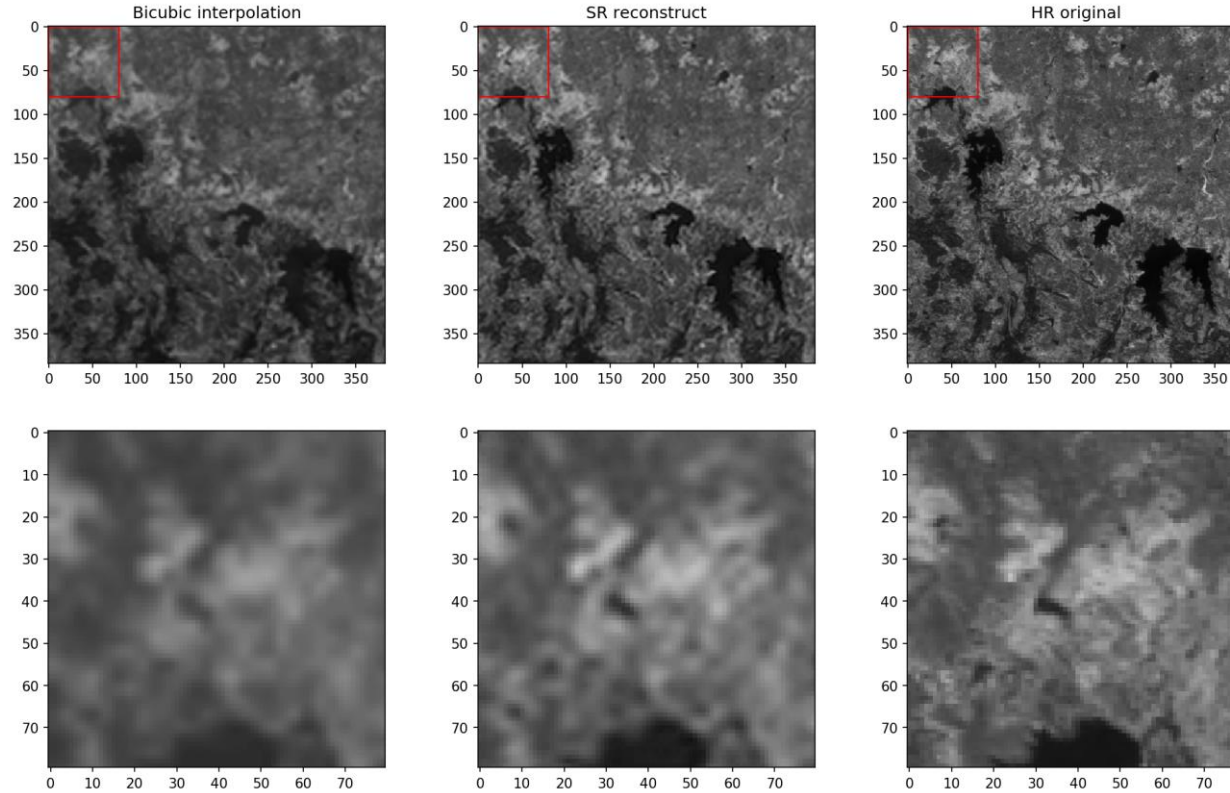
- Baseline: **bicubic interpolation**
- Quality metric: **cPSNR**
 - PSNR modified for
 - registration
 - bias in pixel intensity
 - clouds

251 out of 290 images reconstructed by SRCNN have a higher cPSNR than the bicubic interpolation.

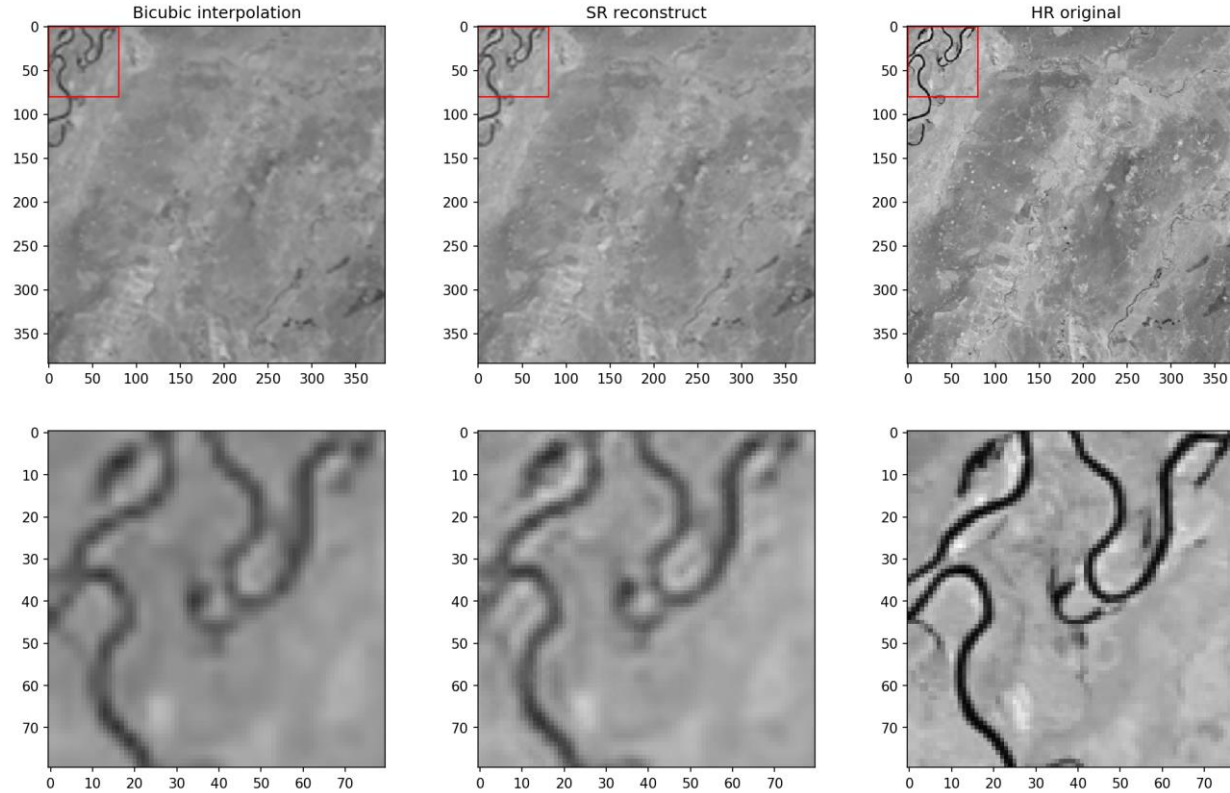


Märtens, M., Izzo, D., Krzic A., Cox, D.: „**Super-resolution of PROBA-V images using convolutional neural networks**”, in *Astrodynamics*, 2019. <https://doi.org/10.1007/s42064-019-0059-8>

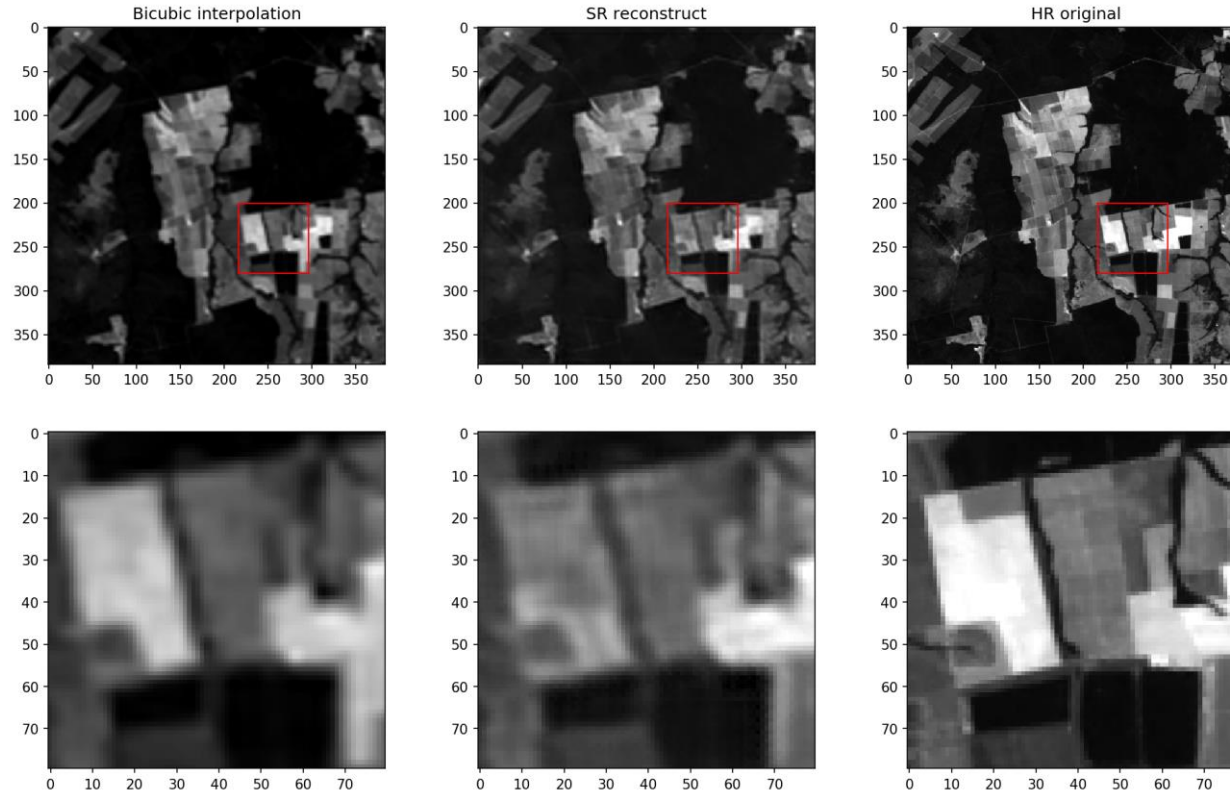
Results from the SRCNN (2)



Results from the SRCNN (3)



Results from the SRCNN (4)



→ PROBA-V Super Resolution

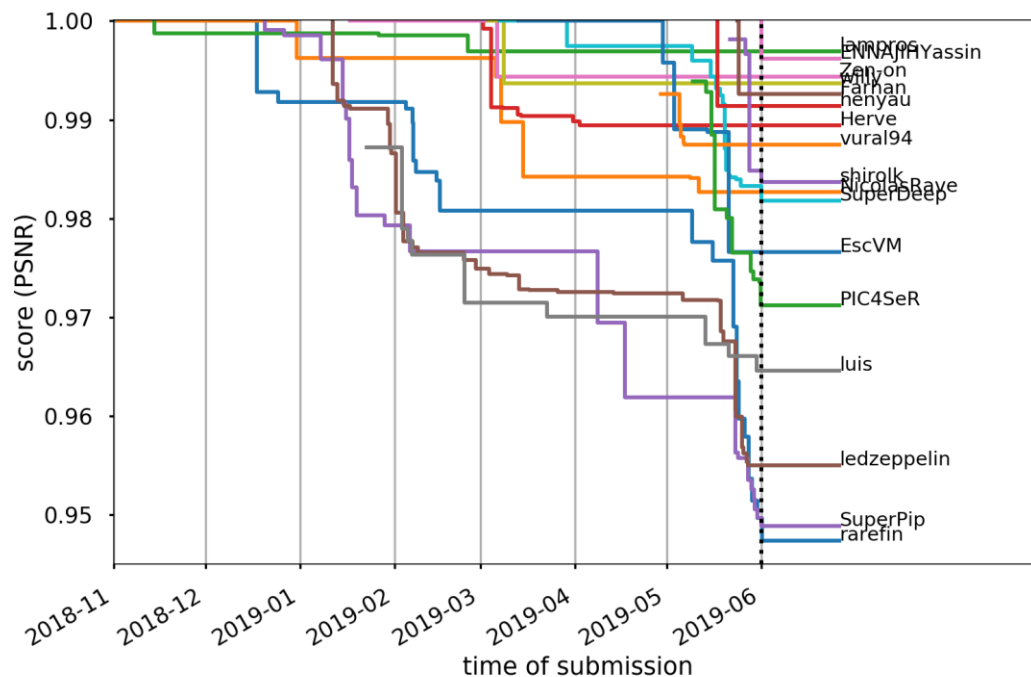
Enhance the vegetation payload performances

 Take Part

<https://kelvins.esa.int>

The Competition

- **Time span: 6 month**
- **Total submissions: 412**
- **Teams**
 - Registered: 70
 - Leaderboard 25
 - Below Baseline 17
- **Online Meet-up: 08.03.2019**
- **Kelvins day: 11.09.2019**



Final Ranking

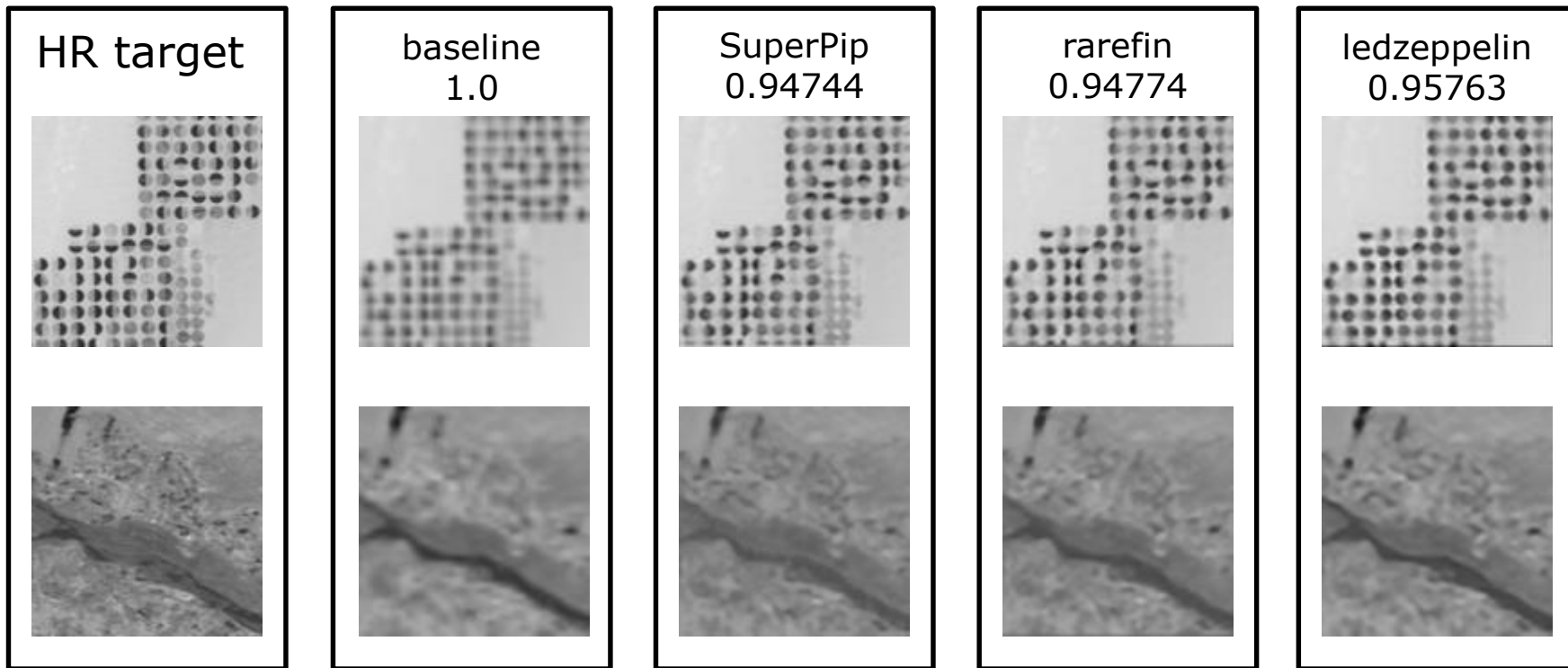


- **1st place: SuperPip**
Image Processing and Learning Group @ Politecnico di Torino
- **2nd place: rarefin**
joint team: MILA @ Quebec and Elementai @ London
AI for Good
[blogpost](#)
- **3rd place: ledzeppelin**
Matteo Taccola, Instrument Engineer @ ESTEC/ESA

Results

Name	Submissions	Last Submission	Best Submission	Final Score
SuperPip	43	May 31, 2019, 9:39 p.m.	May 31, 2019, 9:39 p.m.	0.9474466476281652
rarefin	46	May 31, 2019, 11:34 p.m.	May 31, 2019, 11:34 p.m.	0.9477450367529225
ledzeppelin	86	May 31, 2019, 4:58 p.m.	May 27, 2019, 12:25 p.m.	0.9576339586408439
luis	9	May 30, 2019, 7:44 a.m.	May 30, 2019, 7:44 a.m.	0.9626599626701344
PIC4SeR	15	May 31, 2019, 4:59 p.m.	May 31, 2019, 4:59 p.m.	0.9721971077481462
EscVM	20	May 31, 2019, 4:31 p.m.	May 21, 2019, 6:05 a.m.	0.9785367146826757

Results from the Participants (1)



Open Source Code Sharing During Competition



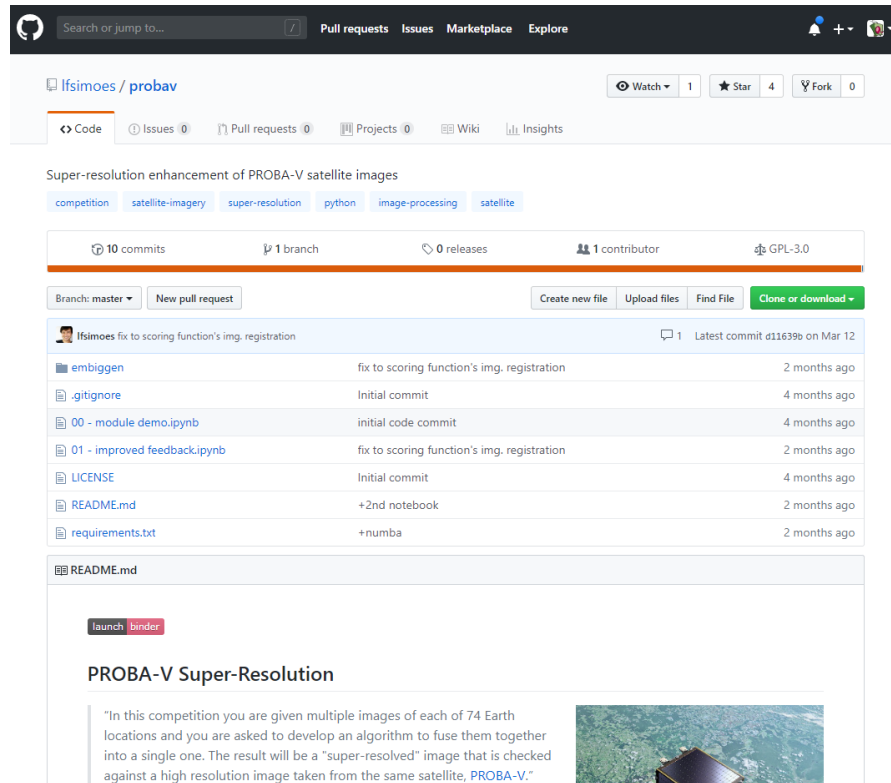
Embiggen module

By Luís F. Simões

- Simplifies loading data
- Generating submissions
- Preliminary data analysis

Everything online and for free

<https://github.com/lfsimoes/probav>



Scientific Publications:

- Märtens, M., Izzo, D., Krzic A., Cox, D.: „**Super-resolution of PROBA-V images using convolutional neural networks**”, in *Astrodynamics*, 2019. <https://doi.org/10.1007/s42064-019-0059-8>
- Molini, A.B., Valsesia, D., Fracastoro, G. and Magli, E., 2019.: “**DeepSUM: Deep neural network for Super-resolution of Unregistered Multitemporal images**”. *arXiv preprint arXiv:1907.06490*.

Open Source Code:

- **Team Rarefin:** HighRes-net: Multi Frame Super-Resolution by Recursive Fusion
(<https://github.com/ElementAI/HighRes-net>)
- **Team SuperPip:** DeepSUM: Deep neural network for Super-resolution of Unregistered Multitemporal images
(<https://github.com/diegovalsesia/deepsum>)

Proba-V Postmortem:

<https://kelvins.esa.int/proba-v-super-resolution-post-mortem>

Follow-ups on Super-resolution

- Multispectral super-resolution
- Merge Pan-sharpening with super-resolution (comparison)
- Deconvolution with point spread function
- Data augmentation

Follow-ups on CNNs for EO

- Correction of microvibrations with CNN
- Transfer learning and domain adaptation for hyperspectral satellite images

**Thanks for your attention!
... Questions?**



Working on this project

- Marcus Märtens
- Dario Izzo
- Andrej Krzic
- Daniel Cox

Links to the project:

- <https://esa.int/act>
- <http://www.esa.int/gsp/ACT/projects/proba-u.html>
- <https://kelvins.esa.int>
- <https://kelvins.esa.int/proba-u-super-resolution>

Backup Slides



proba-v