# SENTINEL 2-A IN-FLIGHT MTF MEASUREMENTS DURING IOT PHASE

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# OUTLINE

- Sentinel-2 mission and instrument overview
- Weighted Least Squares method
- MTF determination on bridge images
- Results & future work

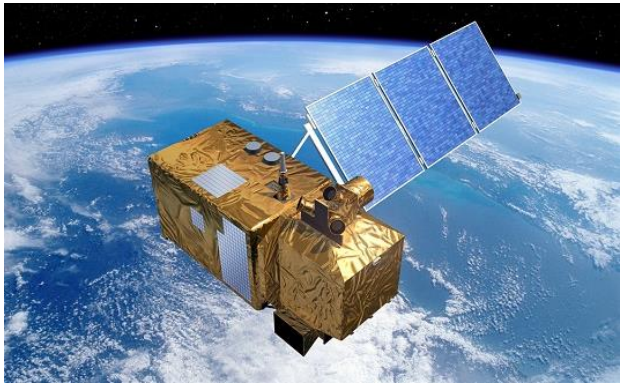
# SENTINEL-2: MISSION & INSTRUMENT OVERVIEW

## Main features

- 13 spectral bands : VNIR to SWIR (443nm – 2190nm)
- Spatial resolutions :10m (VNIR), 20m (red-edge & SWIR), 60m (atm)
- With 2 satellites: 5-day revisit (same viewing conditions)
- Global coverage of land surfaces (56°S to 84°N)
- Lifetime : 7 years (propellant sized for 12 years)
- Launch : S2-A June 23, 2015
  : S2-B 2016

## Orbit & geometry

- Near polar sun synchronous orbit
- Repeat cycle : 10 days
- Inclination : 98.5 deg
- Cycle : 14.3 orbits/day
- Equator cross. Time : 10.30 AM
- Altitude : 786km
- Swath : 290 km
- Nadir-pointing during mission



## Instrument (MSI)

- Telescope: TMA (Tri Mirror Anastigmat)
- Push-broom imager
- Pupil : 150 mm
- Focal length : 0.598 m
- FOV : 20.6 deg
- Focal plane array:
  - Si CMOS VNIR detectors
  - HgCdTe SWIR detectors (passively cooled)
  - 12 detectors to cover the total swath
- Radiometric resolution: 12 bits
- Very limited in-flight refocus capacity

# MTF DETERMINATION WITH WLS METHOD

## Principle: comparison with a reference image

- Search for instrument parameters allowing to simulate the target image from the reference image
- Iterative estimation of the parameters through least squares method
- Integration of all parameters in a state vector changing at each iteration
- End the loop when residues are stable

## Assumptions

- Target and reference in same geometry
- Resolution ratio is an integer

## State vector

- Target parameters: FTM in X and Y of the filter to be applied to the reference image
- Secondary parameters:
  - Radiometric setting
  - Residual geometric shift
  - Other filter parameters

# MTF DETERMINATION WITH WLS METHOD

## Selection of reference images

- PLEIADES images Sensor XS
  - Limitation to S2 « equivalent » spectral bands : B2, B3, B4, B8
- Low incidence angle (< 10 deg)
- Close acquisition date (1 day to 1 month)
- Toulouse, Albuquerque, Las Vegas, Los Angeles, Dallas

## Geometric transformation

- Re-sampling PHR Perfect Sensor → S2 L1B
- Resolution ratio = 5

## Tuning of the WLS algorithm

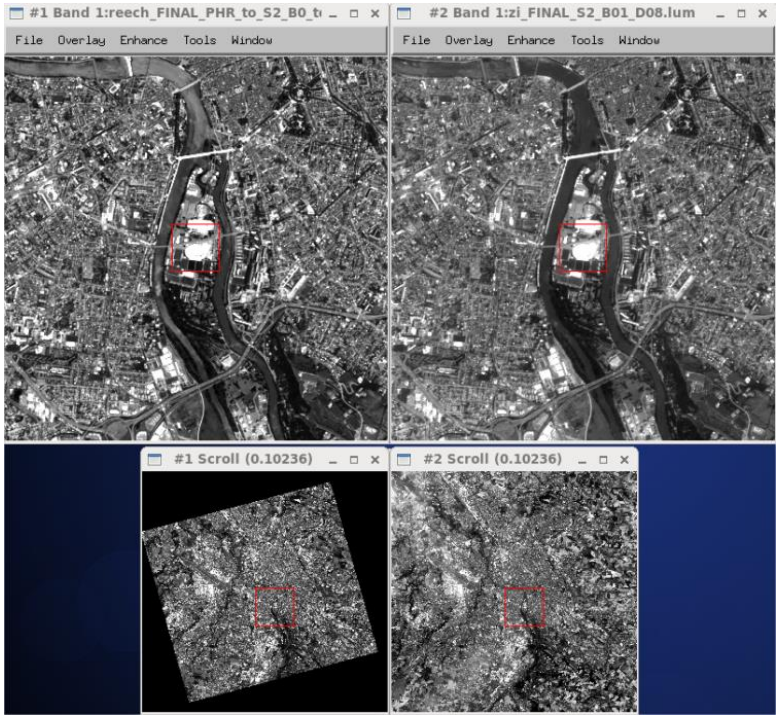
- PHR MTF taken into account
- Images size (before unzoom): 1000x1000 (→ 50 images per PHR scene)
- Filtering of results: 50% best results in terms of residues
- Average of the results

# MTF DETERMINATION WITH WLS METHOD

## Used acquisitions and associated dates

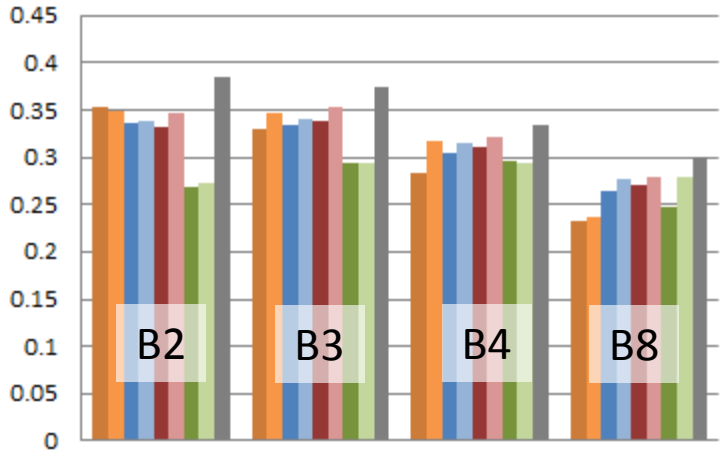
| Site | Sentinel 2 L1B (target) | PHR XS (reference) | S2 Detector |
|---|---|---|---|
| Toulouse (1) | 06/07/2015 | 23/06/2015 | D8 |
| Toulouse (2) | 06/07/2015 | 04/06/2015 | D8 |
| Albuquerque | 18/08/2015 | 17/08/2015 | D1 |
| Las Vegas (1) | 10/08/2015 | 13/08/2015 | D5 |
| Las Vegas (2) | 20/08/2015 | 13/08/2015 | D5 |
| Los Angeles (1) | 23/08/2015 | 24/08/2015 | D5 |
| Los Angeles (2) | 02/09/2015 | 31/08/2015 | D5 |
| Dallas | 06/08/2015 | 03/08/2015 | D2 |

## Sample images (Toulouse)

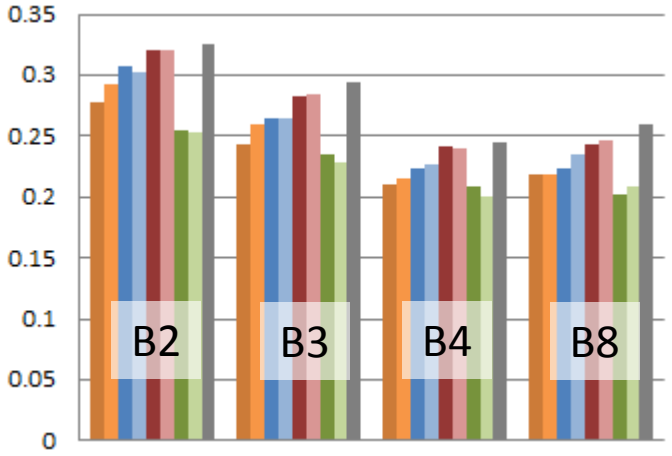


# WLS METHOD: RESULTS

## MTF (fe/2) in row (X – ALT)




## MTF (fe/2) in column (Y – ACT)




## Acquisition & S2 detector

| | |
|---|---|
| Albuquerque | D1 |
| Dallas | D2 |
| Las Vegas (1) | D5 |
| LasVegas (2) | D5 |
| Los Angeles (1) | D5 |
| Los Angeles (2) | D5 |
| Toulouse (1) | D8 |
| Toulouse (2) | D8 |
| ADS Ground Measures | |

Results standard deviation : 0.01-0.03

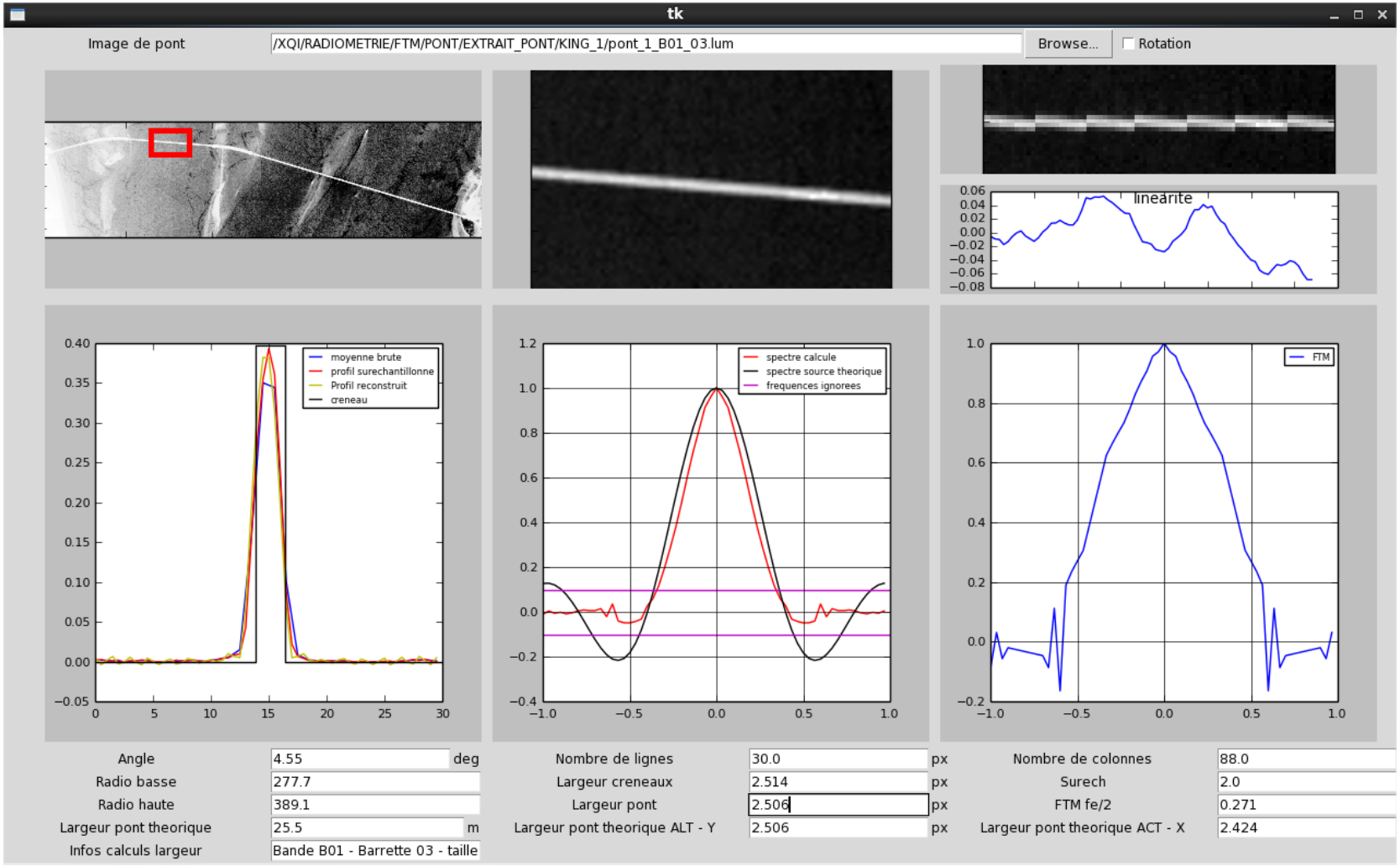
S2 scenes not acquired on same S2 detector
→ can explain part of the observed descrepancies

# MTF ESTIMATION ON BRIDGE IMAGES

## Principle

- The method is inherited from MTF estimation methods on edge images
  - » Use of a regular and uniform bridge, slightly inclined w.r.t. the axes
- inclination of the bridge → 1-D over-sampled profile
- The bridge is modeled as a radiometric rectangular function
  - → 3 parameters to estimate from the 1-D profile
  - » Width : the profile FT shall oscillate at the same frequency than the rectangular function (cardinal sine function) → the width is deduced from the position of the first zero
  - » Low level : mean radiometry in the dark area surrounding the bridge
  - » High level : deduced from width and low level knowing that the mean value in the image is independent from MTF value
- Ratio of the FT of the over-sampled profile and of the model

# MTF ESTIMATION ON BRIDGE IMAGES



# MTF ESTIMATION ON BRIDGE IMAGES


King Fahd bridge

*Saudi Arabia to Bahrein*

Aerial view (top left), google Earth satellite view and S2-A image (bottom)

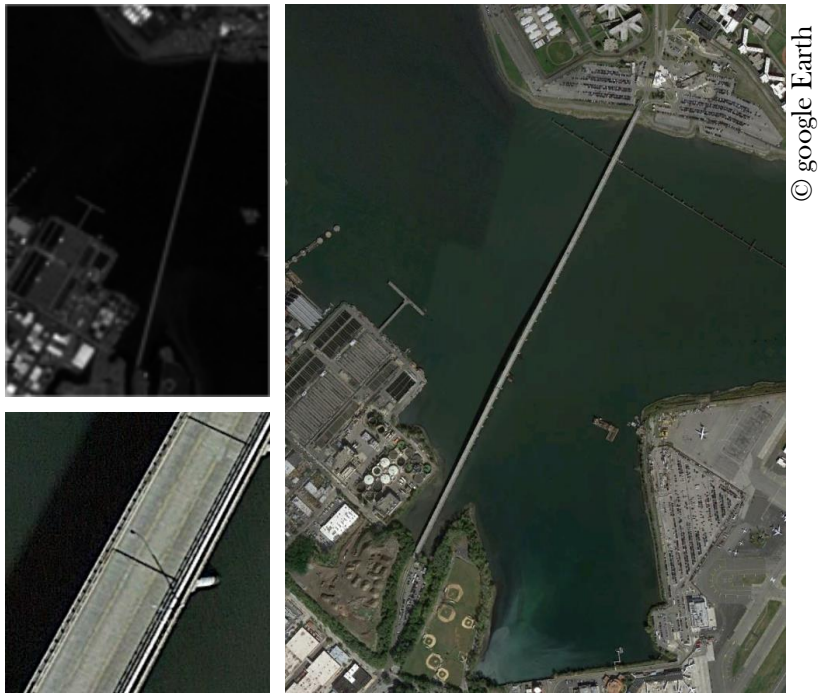
# MTF ESTIMATION ON BRIDGE IMAGES


## Albermarle bay bridges

*North Carolina, US*

West bridge (left), and East bridge (right) (© google Earth)

# MTF ESTIMATION ON BRIDGE IMAGES




Rikers island bridge

*New York, US*

S2-A image (top left), close (bottom left) and global view (© google Earth)

# MTF ESTIMATION ON BRIDGE IMAGES

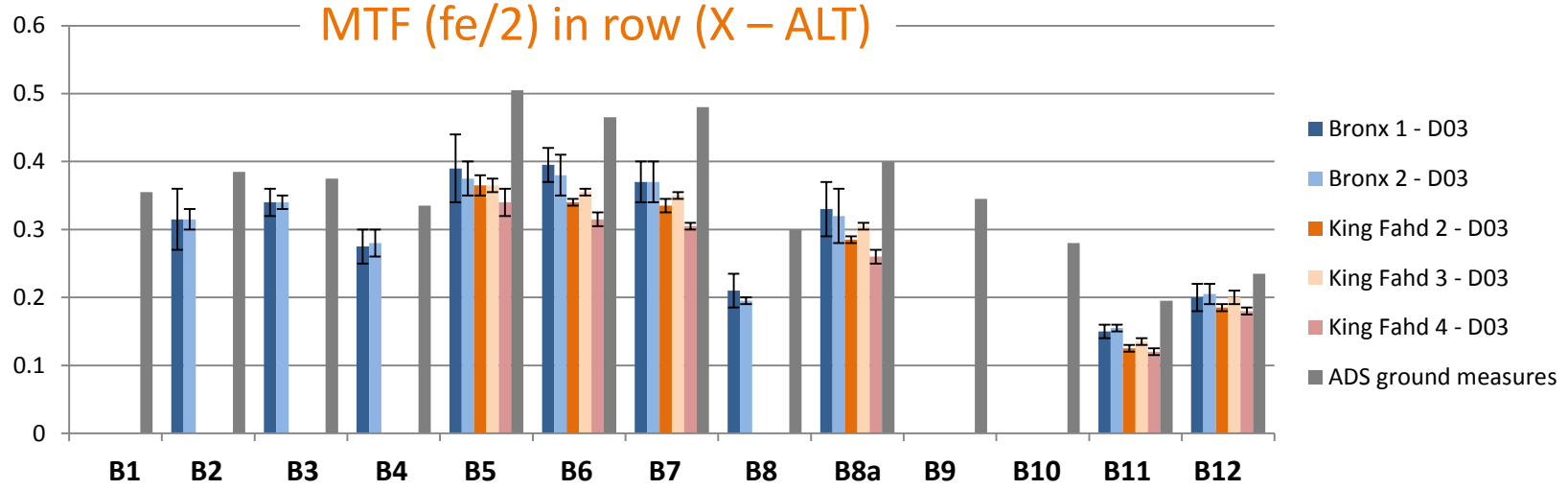
## Tuning

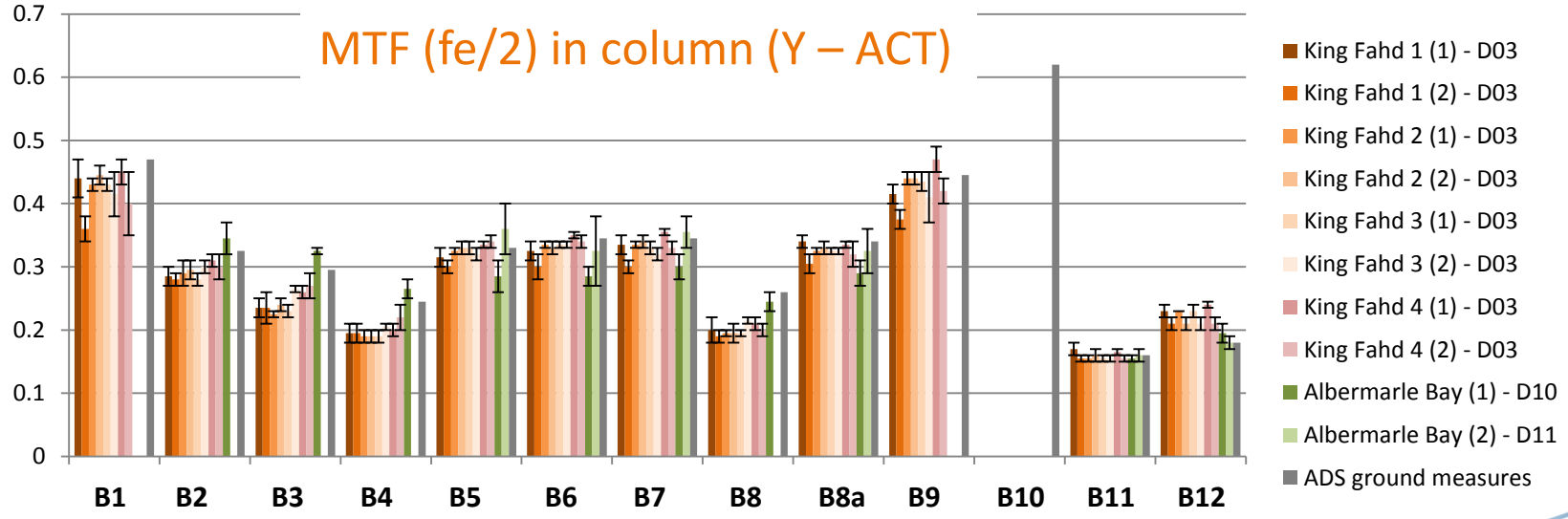
- Method used for all S2 bands
  - → various resolutions:10, 20 and 60 m
- Bridge width
  - » Very sensitive parameter (sensitivity depends on resolution)
  - » Width difficult to estimate from image
    - → use of external info


- Zero crossing can be too close to Nyquist
  - → unstable MTF ratio

→ Many measurements had to be performed

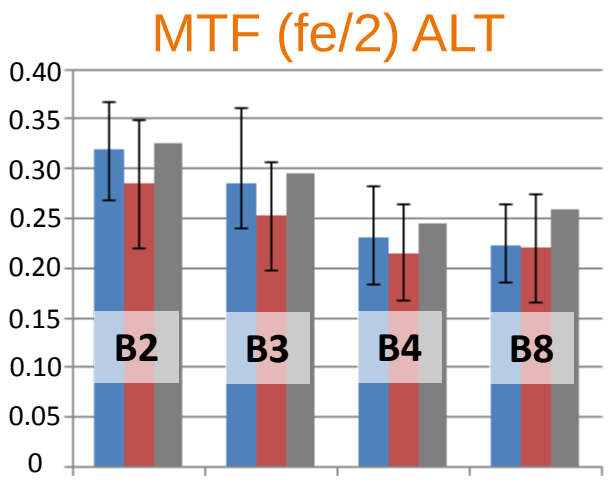
# BRIDGE METHOD: RESULTS

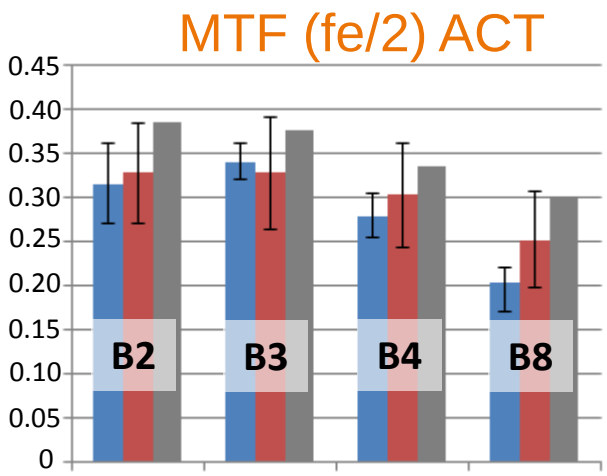


# COMPARISON OF MTF METHODS

Global average of measurements (all measurements, all scenes, all detectors)




Bridges
Weighted Least Squares
ADS Ground Estimation

*Error bars: min/max (bridges) or 3-sigma (WLS)*

# COMPARISON OF MTF METHODS

## Conclusions

Good accordance between the 2 in-flight methods used, however:

- In-flight MTF lower than ground predictions: defocus ?
- In-flight MTF estimation in the whole swath remains to be done
- Additional info on MTF could be obtained using interdetector areas / multi-spectral information (delta-defocus between detectors / between bands)