Defining an optimised inter-calibration strategy based on matchup correlation

Javier Gorroño and Nigel Fox

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  Orbit modelling, temporal delay, TOA error modelling and TOA error dispersion

Traceable inter-calibration: TRUTHS proposed as an ESA Earth Watch mission

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- TRUTHS provides a continuously calibrated hyperspectral dataset of **solar and lunar irradiance** and **Top of Atmosphere Earth-reflected radiance** in the Visible/NIR/SWIR waveband as well as **surface reflectance**.
- Payload design is driven by the radiometric demands of the **climate application**
- Mission orbit allows optimal sampling to quantify the climate and facilitate match-ups for **cross-calibration** with other sensors and **FRM sites**.

Main features:

- 5-8yr mission S/M platform [P/L Mass ~ 150 kg, Power ~ 280 W, Data ~ 4500 Gb per day]
- Hyperspectral imaging spectrometer payload, measuring the Earth, Moon & Sun.
- On-orbit & on-board SI-traceable calibration that provides 10x improved accuracy compared to current sensors (0.3% spectral radiance.
- 90deg precessing orbit to provide true diurnal cycle sampling & optimised cross-cal match-ups

Defining an inter-calibration strategy

Different areas that complement each other and help defining an optimum inter-calibration strategy that supports the development of TRUTHS mission and maximises the return of investment

1. Match criteria

   Selection of best areas (e.g. PICS), temporal constrains and acquisition conditions (e.g. agile platform) that minimise the intercalibration uncertainty..

2. Ground processing correction

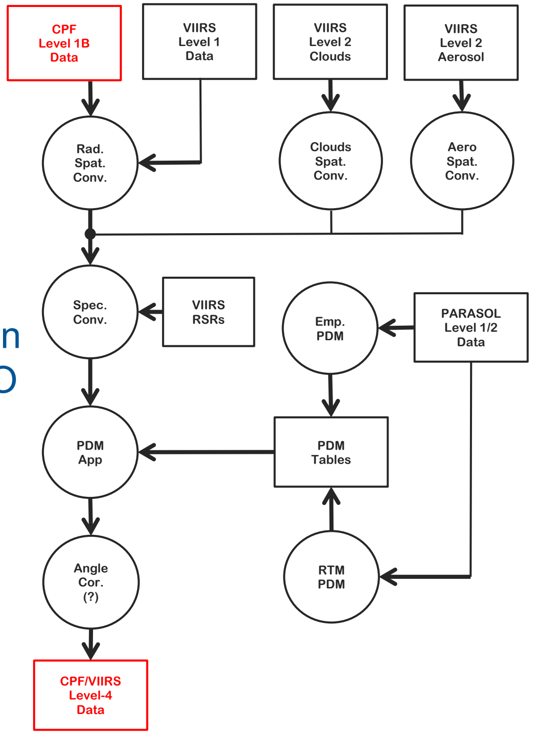
   The correction of systematic errors through a dedicated ground processing (e.g. CPF/VIIRS or CERES L4 products)

3. Match-up Correlation

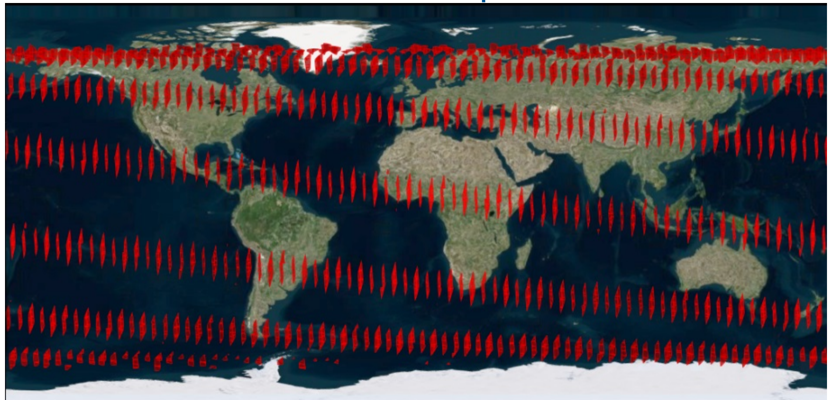
   Correlation between uncertainty sources through multiple matchups and crossing boundaries.

The concept for Phase A: implement mechanisms that help us take a case-by-case and optimum decision based on an end-to-end global scenario.

Example of CPF/VIIRS L4 product processing chain [from CLARREO Pathfinder, GSICS presentation, March 2019]



Example of S2A and TRUTHS orbit match for 30 min difference and 6 month period



A global inter-cal simulation. Why this?

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1. TRUTHS inter-calibration products can attach a reliable estimate.

   Previous studies address each individual error separately…but what is its combined effect in the inter-calibration coefficient? (end-to-end bias, uncertainty and correlation)

   TRUTHS inter-calibration product uncertainty will be dependent on 1) matching criteria and 2) sensor characteristics.

2. Inter-calibration scenarios/trade-off can be better studied,

   Matching criteria defines the performance of the inter-calibration. Some questions:

   - What is the impact of the orbit type?
   - How long do we need to reach a certain uncertainty level?
   - Does a relaxation of viewing and temporal conditions increase the uncertainty or only its uncorrelated component (i.e. convergence time)?

3. Matchup uncertainty is crucial as a constrain of calibration inversion processes.

   Harmonisation requires that the uncertainty associated with the matching is assessed. [...]Similarly, harmonisation requires information about the expected difference in radiances measured by the two sensors […] and their associated uncertainty, […] the assumption that the errors in measurements of the direct observables are independent is not always justified (Giering et al. 2019).

A global inter-cal simulation. Flow diagram

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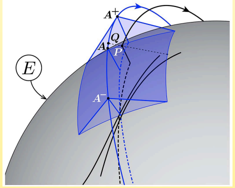
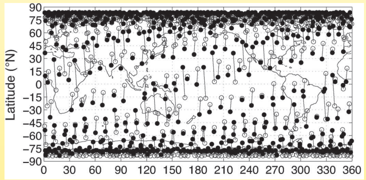
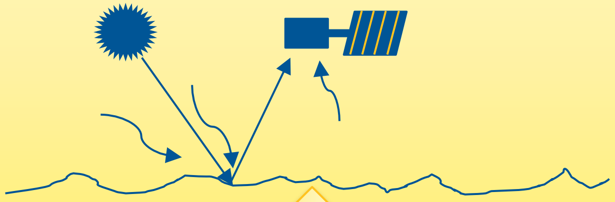
Orbit library configured on: Δt, $\Delta\theta_{view}$,$\Delta\varphi_{view}$, lat/lon bounds





Matchup list: lat,lon,t_1,t_2, θ_{view1},φ_{view1}, θ_{view2},φ_{view2}

1. Cloud/cloud shadow check
2. $\rho_{TOA}(RTC_1,\lambda,t,\text{lat},\text{lon},\theta_{view},\varphi_{view})$
3. $\rho_{TOA}(RTC_2,\lambda,t,\text{lat},\text{lon},\theta_{view},\varphi_{view})$
4. Consistency check



Orbit matchup generator → Matchup products selection → TOA model generator

Matchup products database

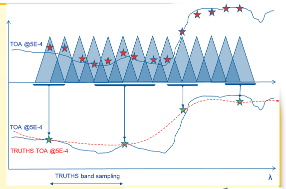
DEM
Altitude, slope and aspect

Atmosphere
Total AOD + type
N2O, O3, CO2…
DPM(degree of polarisation model)

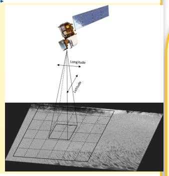
Cloud
Cloud fraction
Cloud shadow
(threshold use)

Surface
BRDF products
or
default land cover

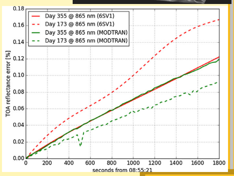
Error matchup generator



Spectral
Spectral accuracy, sampling, knowledge (Gorroño,2017)



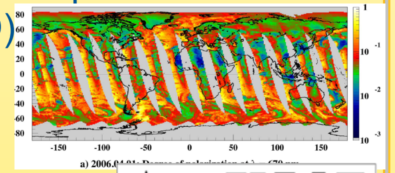
Spatial
Regression curve as in (Gorroño,2017)



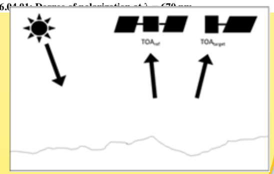
Temporal: sun angle
TOA model + time (Gorroño,2017)

Temporal: scene variation
Not considered in small delays
~>10min create scenarios (TBD)

Temporal: adjacency
Mismatch conditions of adjacency or straylight. Model potential scenarios (TBD)



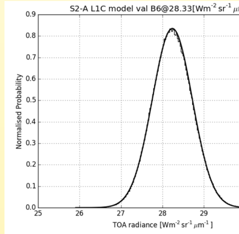
Polarisation
DPM *
pol. sensitivity
(Lukashin, 2013)



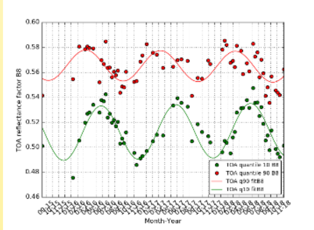
Viewing angle
TOA model + angles
Possible correction (Yang,2016)

Uncertainty assessment

Error Distribution



Curve fitting



Minimisation

$\mathcal{J}(\propto, \mathcal{M}, \mathcal{S}(\mathcal{M}))$

or other sensor characterisation e.g. uniformity

Error matchup generator: inter-cal errors (1/2)

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Spectral

- **Resolution/sampling** Defined by the hyperspectral ability to defined the TOA signal
- **Spectral wavelength knowledge** Defined by the target and reference mission SRF uncertainty

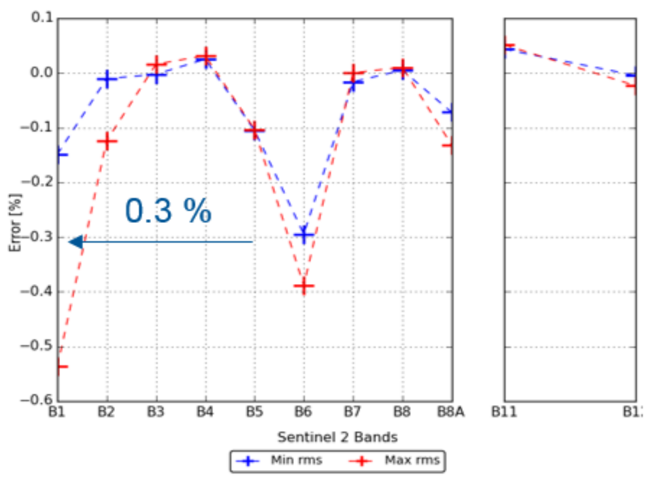
Spatial

- Based on a regression of std error wrt to geolocation area

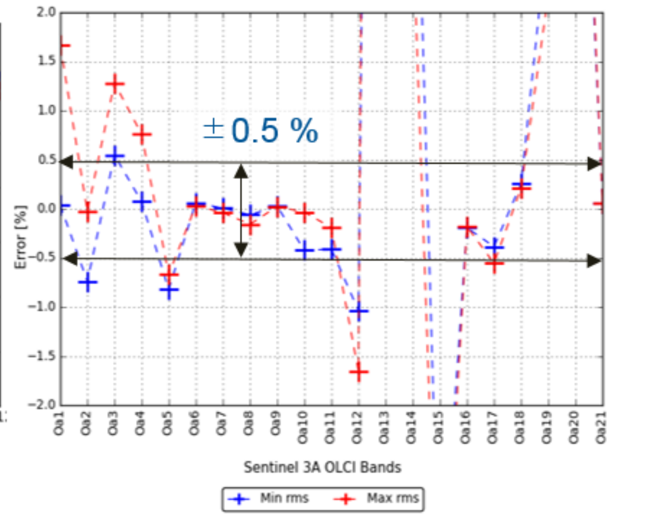
Temporal: sun angle

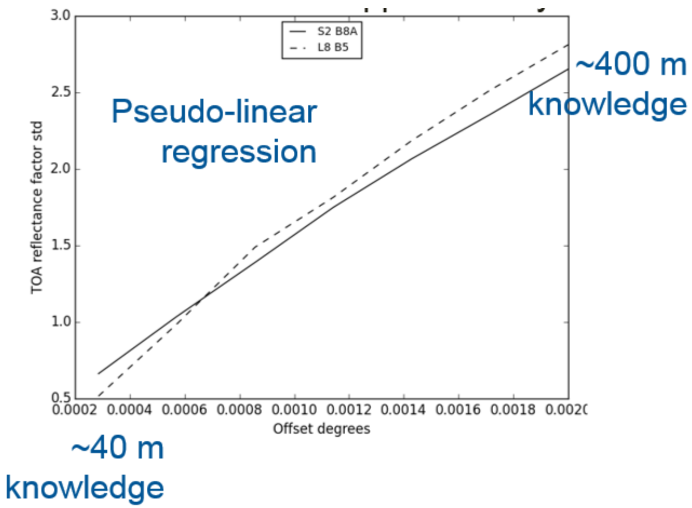
- Time delay minimisation (<10min)
- Greater delay (<30min) by modelling the sun angle impact over selected areas (e.g. PICS)

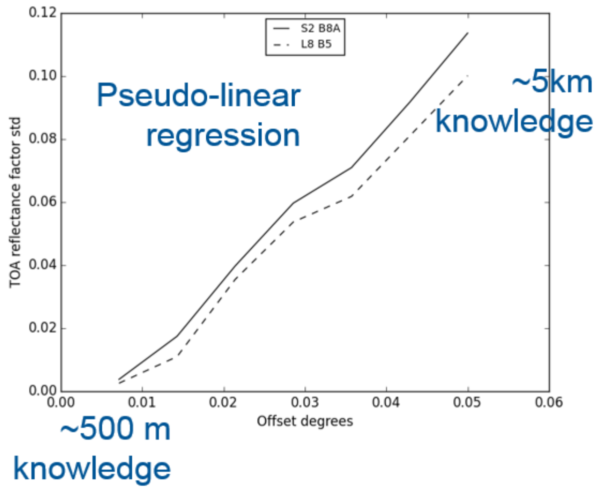
S2 MSI



S3 OLCI







Images extracted from (Gorroño et al. 2017)

Uncertainty budget for TRUTHS – satellite comparisons

(single overpass – reduces for multiple overpasses)

Uncertainty	Best S2 bands	Worst S2 bands
Spectral resolution TRUTHS	0.1 %	0.6 %
Spectral accuracy TRUTHS	0.1 %	0.2 %
Spatial co-alignment mismatch	0.1 % (Libya) 0.12 % (La Crau)	0.1 % (Libya) 0.5 % (La Crau)
30 minute time difference (atmospheric effects)	0.1 % (if corrected) 0.3 % (if atmosphere not known)	0.1 % (if corrected) 2 % (if atmosphere not known)
30 minute time difference (surface BRF)	0.2 %	0.4 %
Combined with reasonable corrections	**0.4 % - 0.5 %**	**0.7 %**

Error matchup generator : inter-cal errors (2/2)

Temporal: scene variation

- Based on change of scene. TBD.

Temporal: adjacency

- Change of adjacency conditions (mostly cloud movements) and straylight of sensor.

Polarisation

- <0.1% if DoP and sensitivity are low
- Possibility to account for polarisation correction models as in (Lukashin et al. 2013)

Viewing angle

- Minimised for PICS areas and/or gimbal optimisation
- Potential correction using radiative modelling. PCRTM model considered for CPF mission (Q. Yang et al. 2016).

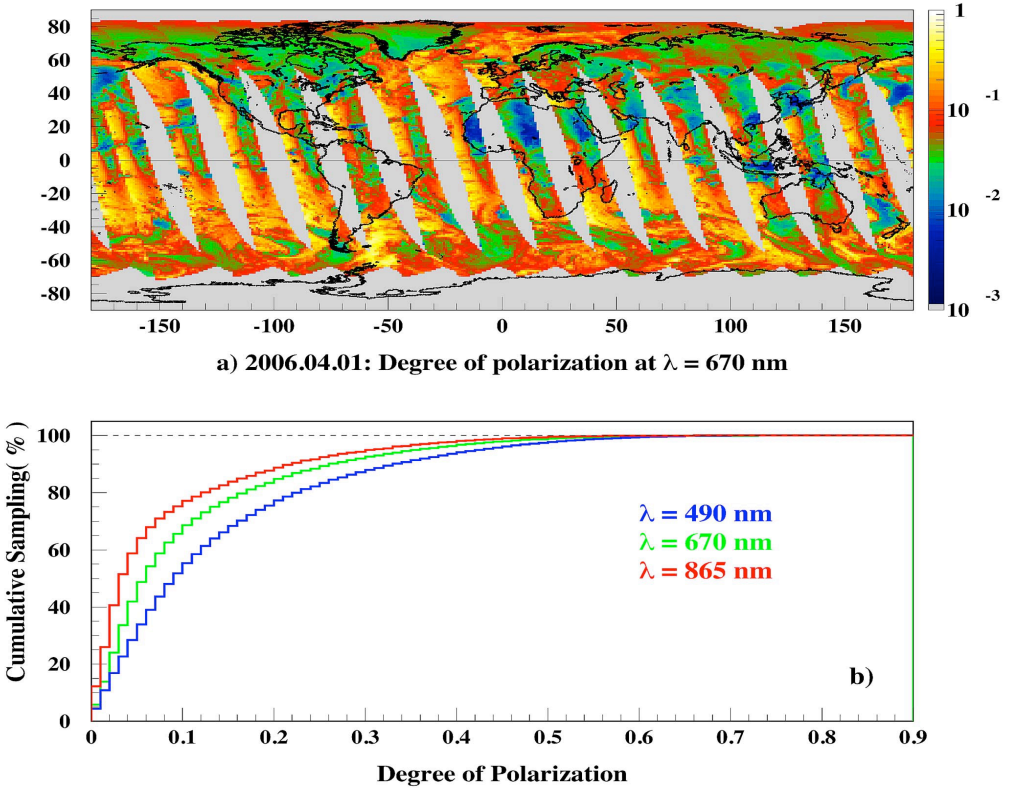


Image extracted from (Lukashin et al. 2013)

Preliminary study: orbit modelling

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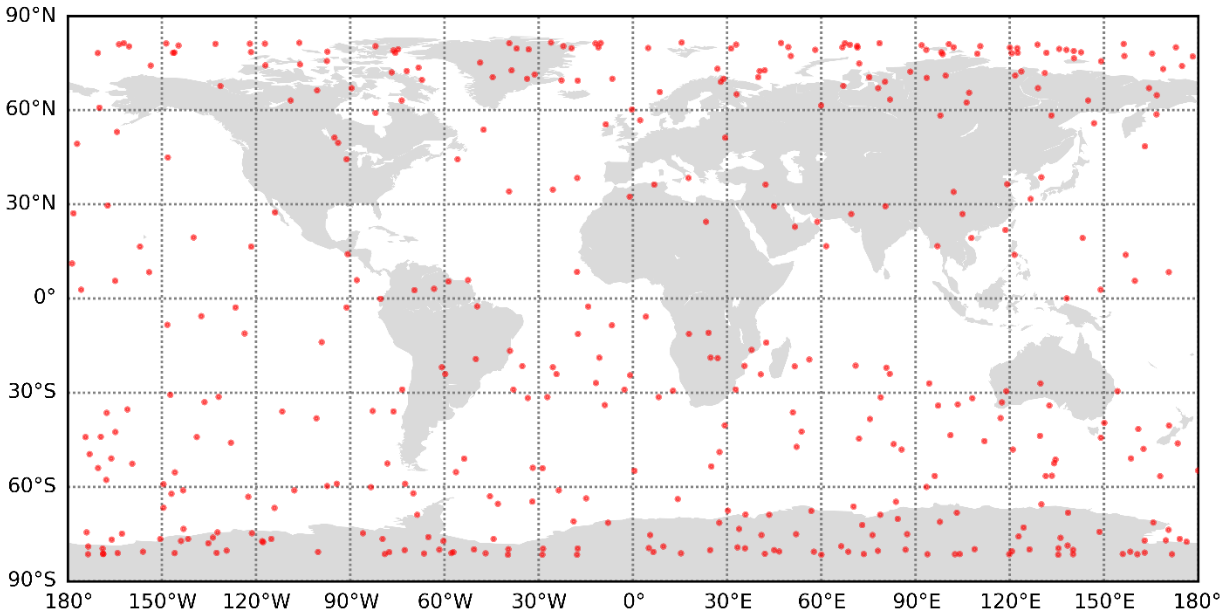
A first attempt to show the usefulness of an end-to-end study and matchup error correlation in an inter-calibration strategy. Orbit crossings nadir→ temporal delay distribution→ TOA reflectance distribution

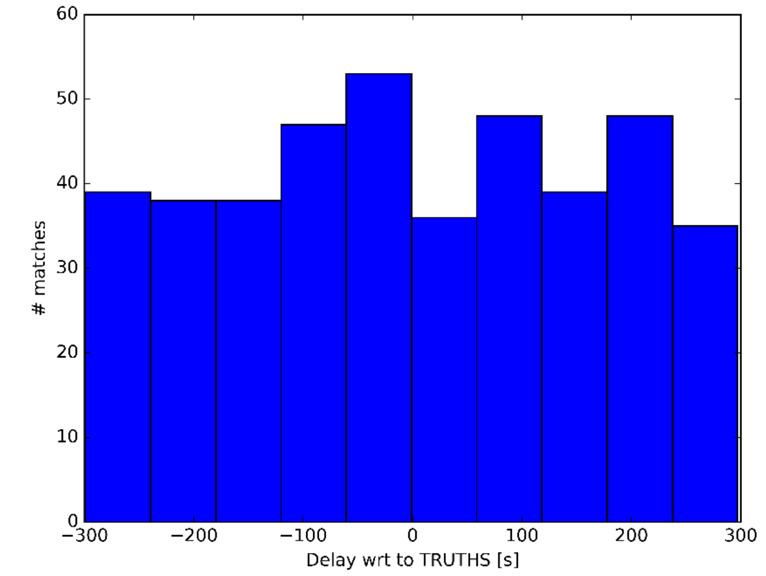
- Orekit library to model a TRUTHS and S2-like orbits (see parameters below)
- Considered eclipse conditions
- Crossings in ±5 minutes from TRUTHS overpass
- Crossings more abundant in poles with clear seasonality (similar to Roithmayr et al. 2014)




```
# from ROITHMAYR et al.: CLARREO APPROACH FOR REFERENCE INTERCALIBRATION OF REFLECTED SOLAR SENSORS
# The orbit is technically 609km but really will have a small oscillation (imperfection)
truthsdict['ra'] = 610 * 1000  # Apogee!
truthsdict['rp'] = 608 * 1000  # Perigee!
truthsdict['i'] = math.radians(90)  # inclination
truthsdict['omega'] = math.radians(90.0)  # perigee argument
truthsdict['raan'] = math.radians(0)  # right ascension of ascending node
# eccentricity is almost zero, mean anomaly and true anomaly are almost the same (there is a correct way to convert)
truthsdict['lv'] = math.radians(0)  # True anomaly

truthsdict['initialDate'] = AbsoluteDate(2012, 1, 26, 16, 0, 00.000, utc)
```

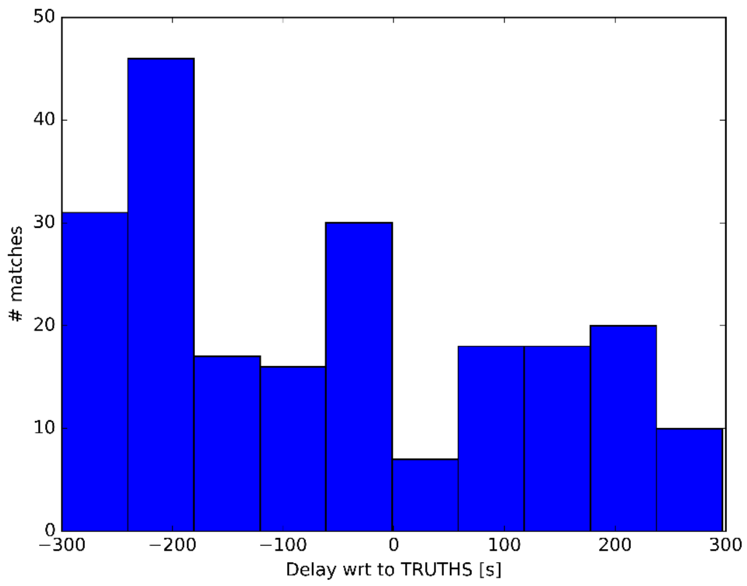
```
# S2A orbit from here https://www.n2yo.com/satellite/?s=40697 and https://heavens-above.com/orbit.aspx?satid=40697
targetdict['ra'] = 796.9 * 1000  # Apogee!
targetdict['rp'] = 795.3 * 1000  # Perigee!
targetdict['i'] = math.radians(98.6)  # inclination
targetdict['omega'] = math.radians(91.7561)  # perigee argument
targetdict['raan'] = math.radians(315.3112)  # right ascension of ascending node
# eccentricity is almost zero, mean anomaly and true anomaly are almost the same (there is a correct way to convert)
targetdict['lv'] = math.radians(268.3738)  # True anomaly

targetdict['initialDate'] = AbsoluteDate(2013, 6, 23, 16, 0, 00.000, utc)
```

Preliminary study: temporal delay

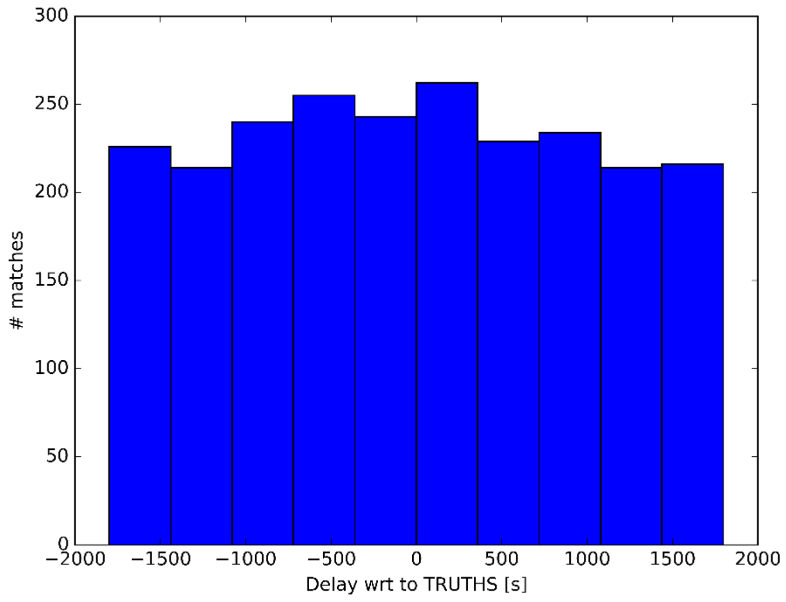


Distribution of delays TRUTHS-S2 like orbit in ±5 minutes

Distribution of delays S3-S2 like orbit in ±5 minutes

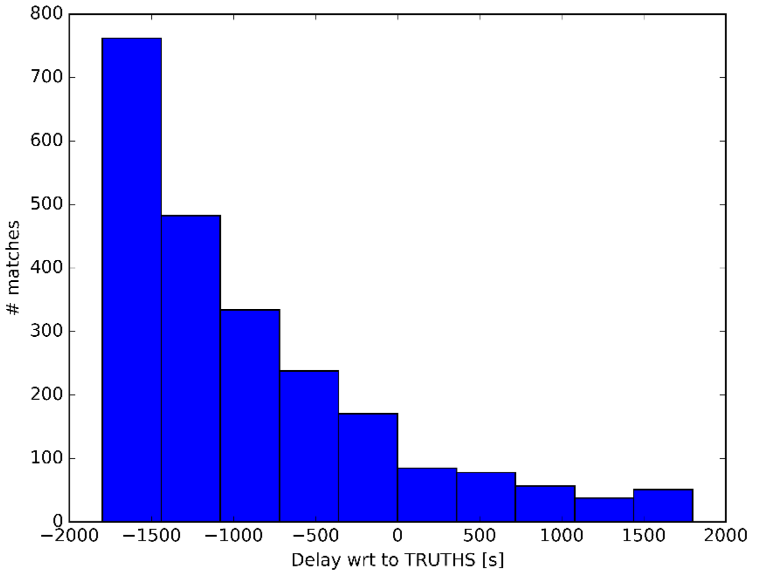


- Distribution of delays TRUTHS-S2 like orbit is almost uniform whereas S3-S2 tends to be exponential
- TRUTHS orbit shows that the temporal delay error is an unbiased distribution compared to SSO.
- For example…if we use a window of e.g. 30min, can we get the same uncertainty levels as in 5 min?
- is the natural variability an issue? How much longer time is needed?...



Distribution of delays TRUTHS-S2 like orbit in ±30 minutes

Distribution of delays S3-S2 like orbit in ±30 minutes



Preliminary study: TOA error modelling

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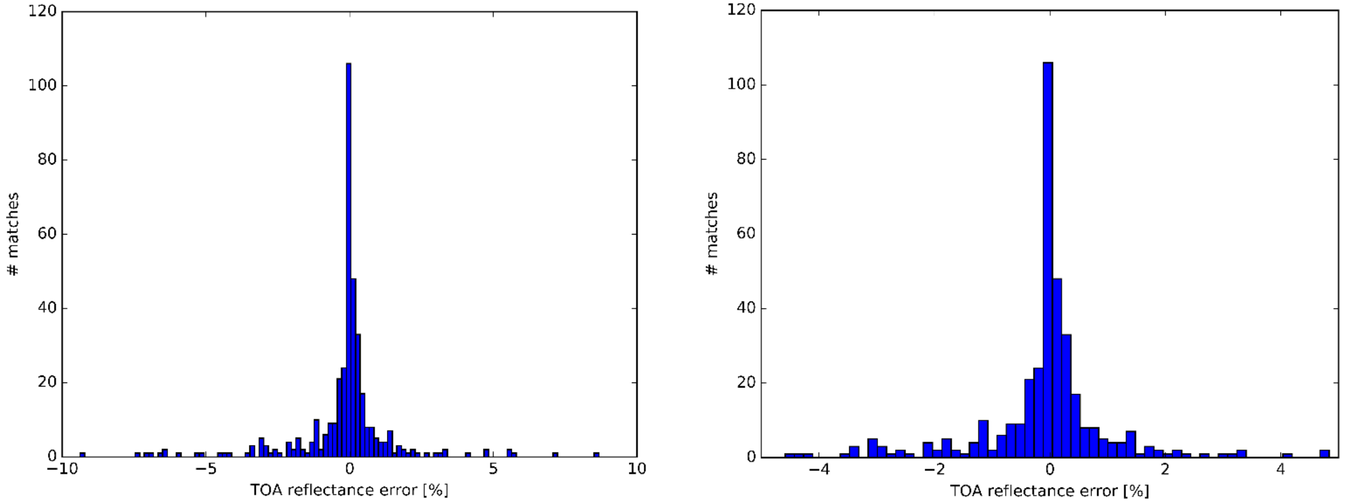
- A simple test in 6SV1 propagates the temporal delays of TRUTHS and target mission in 5 min.
- Surface can be characterised by using BRDF products or as a backup a land classification
  - This first test uses ESA Land Cover CCI v2 LC2015. with a query using a .csv file of lat/lon.
  - Then associates a predefined (GreenVegetation, Sand, ClearWater) homogenous Lambertian spectrum.
- Aeronet and/or satellite products can provide reliable estimates of aerosol estimates
  - This first test uses a fix AOT@550m with a aerosol profile dependent on the land cover type (maritime, desert, continental)
- For test purposes we have set a mid-latitude summer atmosphere and 100m altitude.
- The sun angle is obtained from the matchup locations and: timestamp for TRUTHS, timestamp+delay for target sensor.
- The viewing is set to nadir.
- The error is calculated as 100*(target_toa-truths_toa)/truths_toa

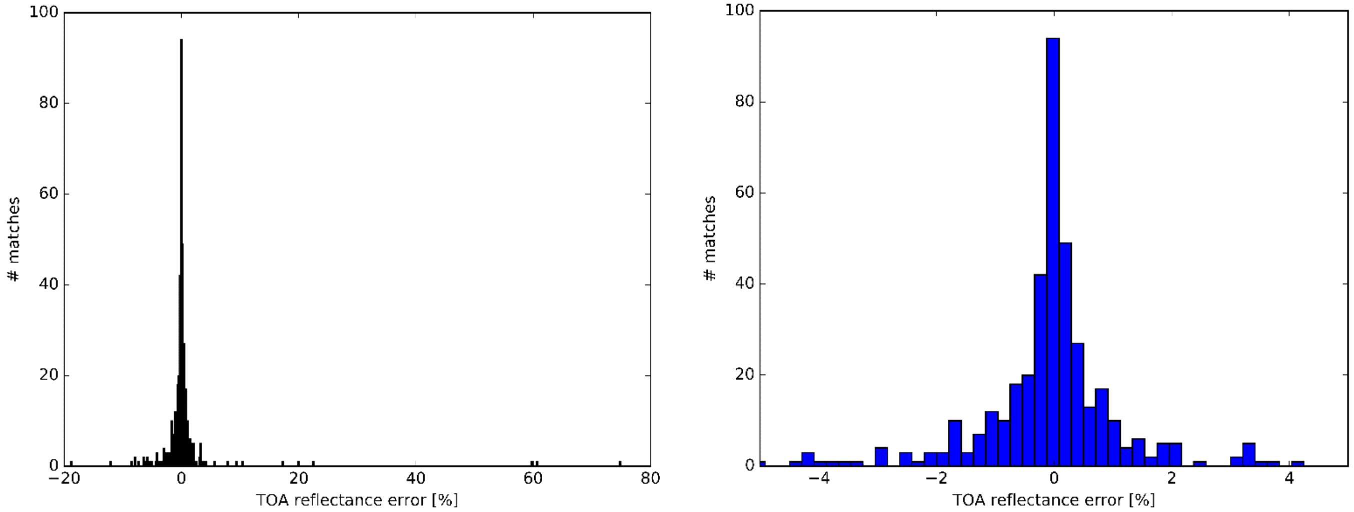
Preliminary study: TOA error dispersion

- The temporal delay of TRUTHS vs. a target sensor in a year results in a symmetric distribution largely unbiased→ errors converge with time.
- Longer delay does not necessarily mean worse accuracy but just longer convergence time
- Will the sun temporal error converge for two SSO orbits?
- We can now test dependence with location, SZA… This is just a first test…

TOA error @490nm due to temporal sun angle (mean=-0.08%)



TOA error @865nm due to temporal sun angle (mean=0.38%)



Conclusions

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- TRUTHS mission unprecedented uncertainty will provide a benchmark for mission inter-calibration. The inter-calibration strategy of the mission must be based on a **case-by-case** and optimum decision based on an **end-to-end global** scenario.
- An initial global simulation tool has been presented. It considers a flexible and end-to-end approach (Orbit matchup→ Matchup products database→ TOA model→ Error matchup → Uncertainty assessment)
- A simple first example has demonstrated the utility of this approach.

  Distribution of delays TRUTHS-S2 like orbit is almost uniform whereas S3-S2 tends to be exponential

  The temporal delay of TRUTHS vs. a target sensor in a year results in a symmetric distribution largely unbiased→ errors converge with time.
- The work is on-going and expected to expand from the first example to include: matchup products, better orbit modelling, more study cases…

Thanks! Questions?

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