ACES MWL data analysis center at SYRTE

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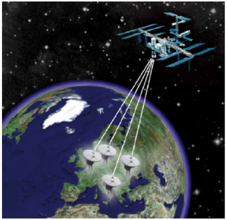
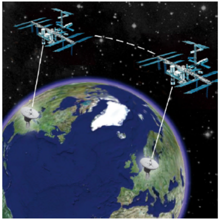
SYRTE (Observatoire de Paris, LNE, UPMC, CNRS)

The ACES-Pharao mission

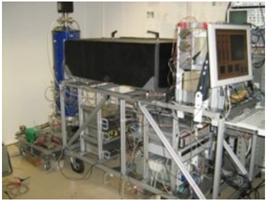
Goals

- Realize the best time scale in orbit to date
- Allow time and frequency comparison between this timescale and the best ground clocks worldwide
- Use this data to perform fundamental phsics tests
- Demonstrate possible applications in chronometric geodesy, inter-continental optical clocks comparisons, etc. . .

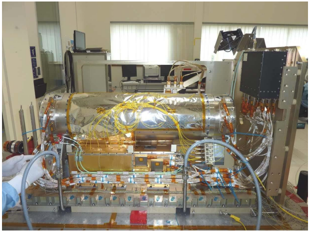




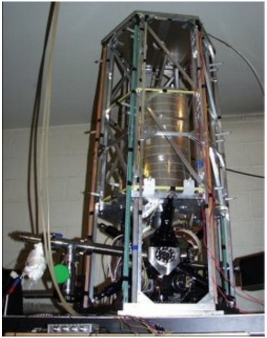
A cold-atom clock in space



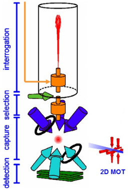
FOM, fontaine mobile Cs (SYRTE)



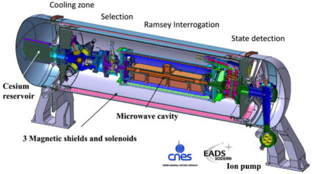
Pharao, Cs jet (CNES, SODERN, SYRTE)



FO2, fontaine Rb/Cs (SYRTE)

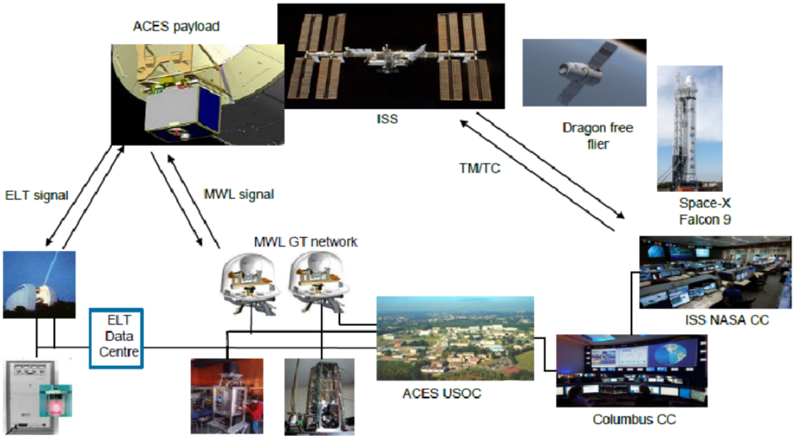


Atomic fountain principle



Pharao schema

ACES Mission components

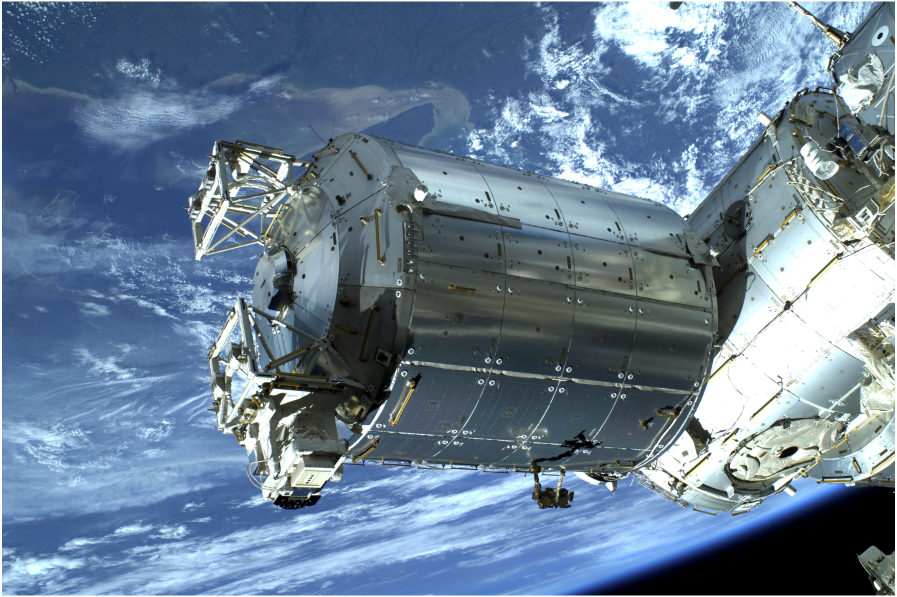


Expected launch date : 2018 (SpaceX)

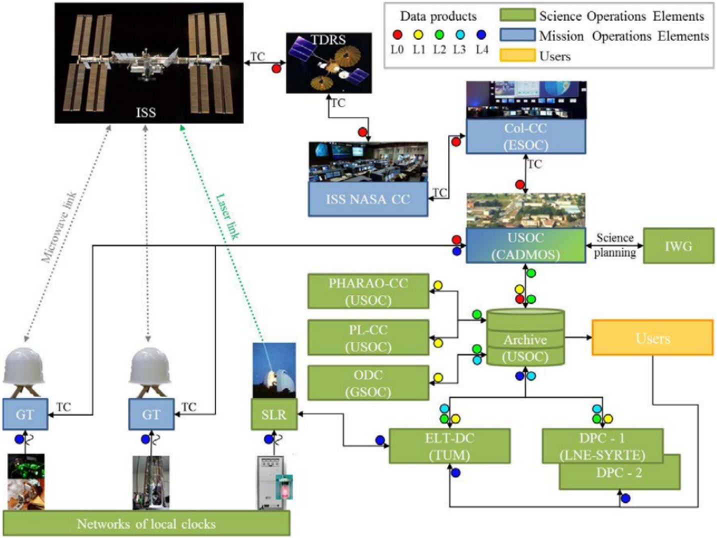
Falcon9 Launcher

Dragon module

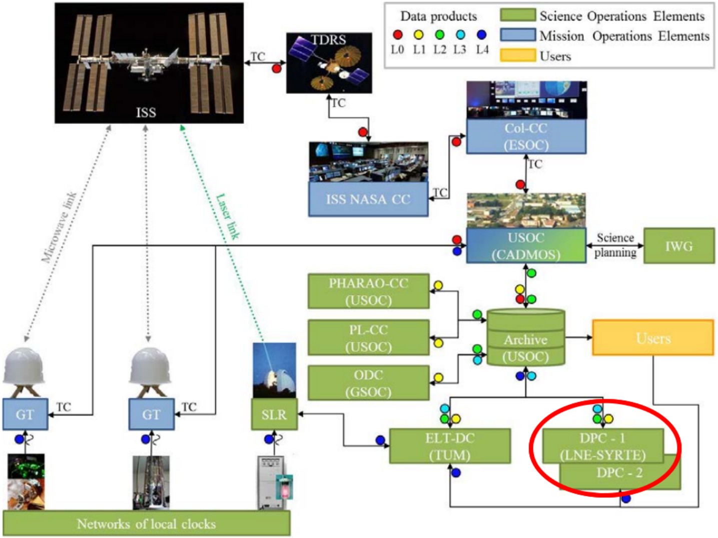
Colombus module, attached to the ISS



ACES Ground segment



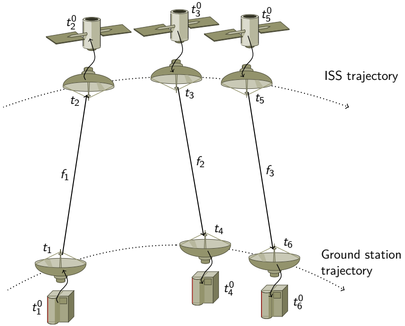
ACES Ground segment



ACES microwave link setup

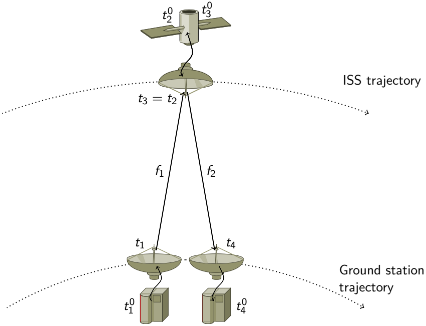
Ku-band uplink : 13.475 GHz, Ku-band downlink : 14.703 GHz, carrying code at 100 MHz + S-band downlink : 2.24 GHz (ionospheric delay determination).

Two-way measurement cancels range + tropospheric delay at 1st order



General case

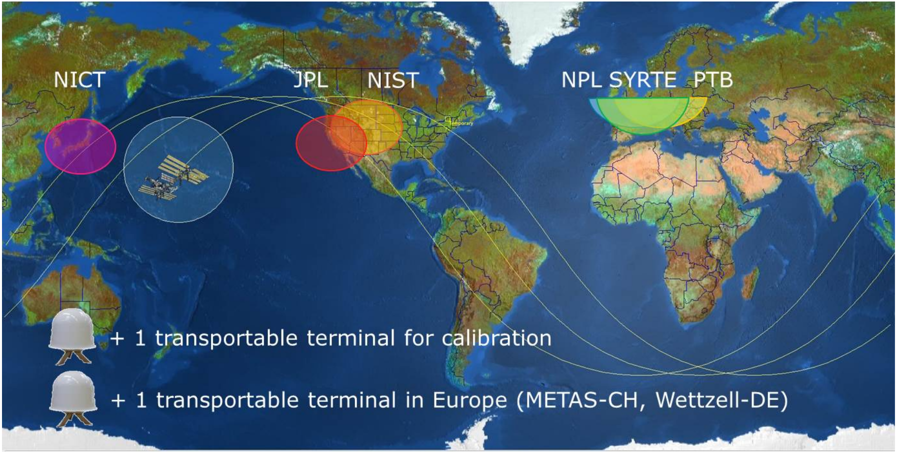
one measurement each 80 ms on ground and in space



Λ configuration (interpolated)

minimizes effects due to orbit determination and troposphere model errors

Ground terminals location



The continuing story of ACES data processing

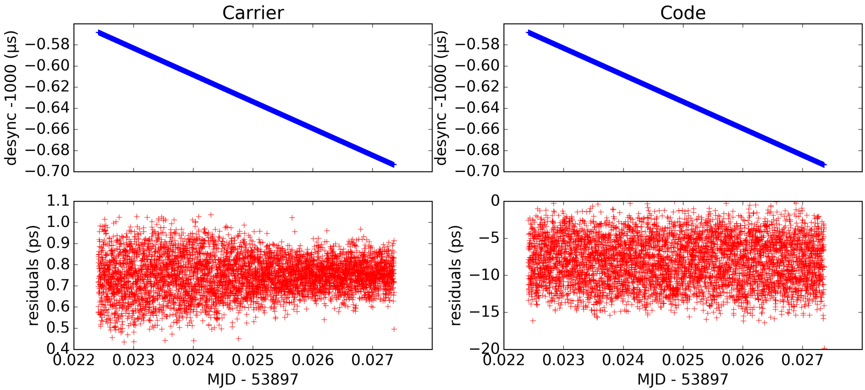
Processing software

- Early developments $\simeq$ 10 years ago
- First lines of this code written in 2011
- Now $\simeq$ 6300 lines of Python
- Takes raw data as input and returns desynchronisation (+ TEC, pseudo-range. . .) between ground terminal and flight segment.

Simulation software

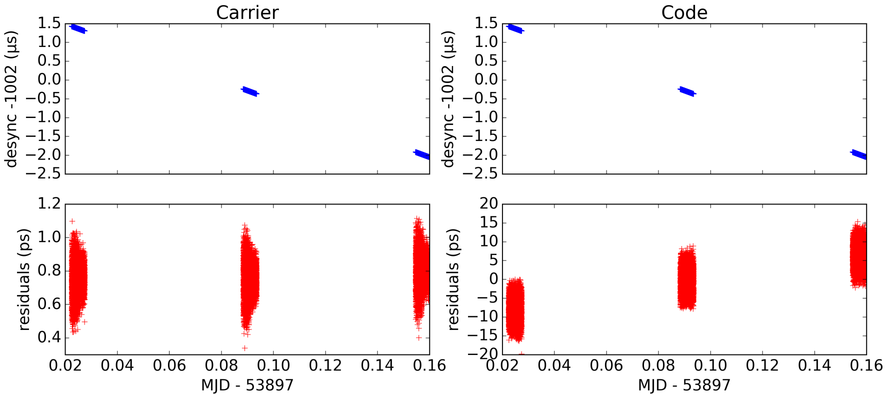
- Parallel development (different developer, different language)
- $\simeq$ 1500 lines of Matlab
- Highly flexible
- Mimics what is expected to be L1 data (best guess sometimes !)

A typical pass



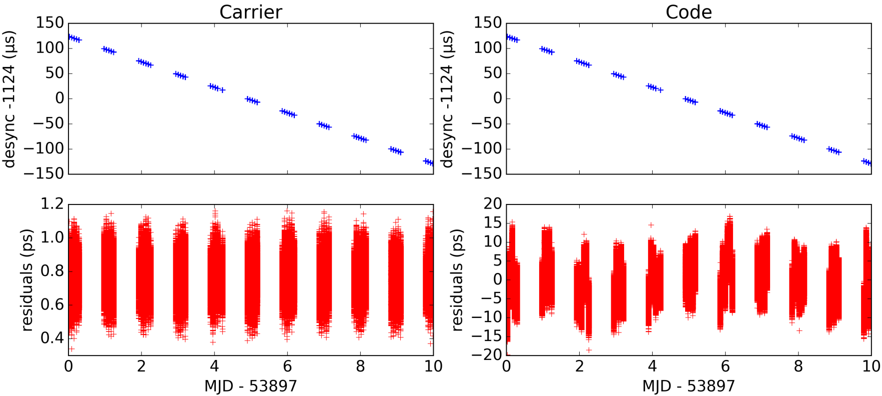
- Top : input desynchronisation (drift = GR)
- Bottom : residuals (theoretical - calculated desynchronisation)
- Noise = counter quantization (= noise floor)

Major recent milestone : Carrier disambiguation



Simulated passes with desynchronisation (1 ms offset + RG drift), code residuals mean values change within ± 10 ps as expected, but carrier residuals mean values stay stable at the sub-ps level.

Major recent milestone : Carrier disambiguation



10 days ($\simeq$ 50 passes) during a "quiet" period (no ISS boosts).
Simulation uses real ISS orbit data

Using the software for interesting things (before having actual data)

Produce test data for Ground Segment developers

- General Debugging
- Special cases scenarios
- Validation data

Prepare for future data analysis

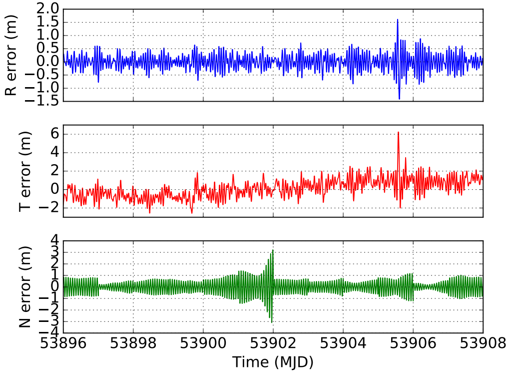
- Check sensitivity to GR deviations
- Get ready to deal with expected perturbations

Experiment !

- influence of the uncertainty on ISS position
- ...

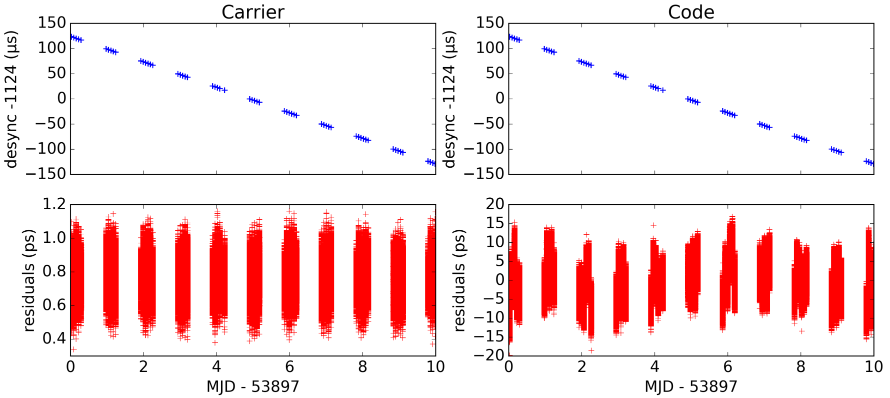
Simulation of ISS orbitography uncertainty

Starting point : difference between SIGI orbitography and more precise GNSS orbitography, data provided by O. Montenbruck from 2006 ISS orbitography archive



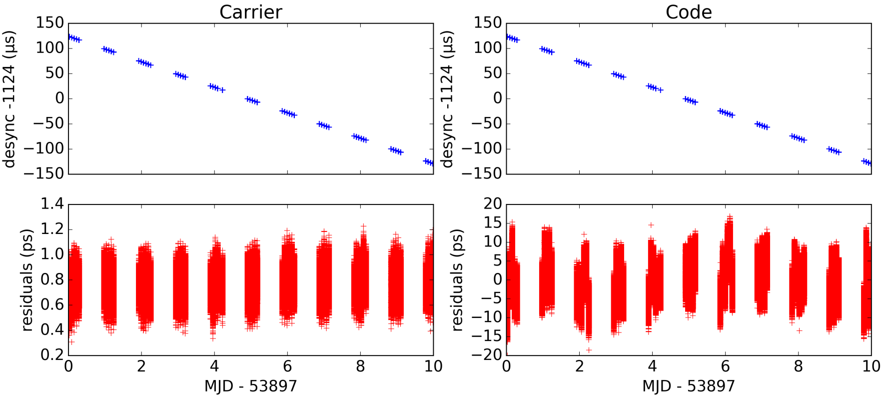
- Difference vector is projected on Radial, Transverse and Normal unitary vectors
- Order of magnitude : a few meters (smaller on R)
- We chose a quiet period (no ISS boost)
- Simulation is generated using precise orbitography (POD data)
- Then we generate « fake » orbitography as input for data processing (base data + k × error)

Evolution of desync. recovery as a function of ISS orbitography uncertainty



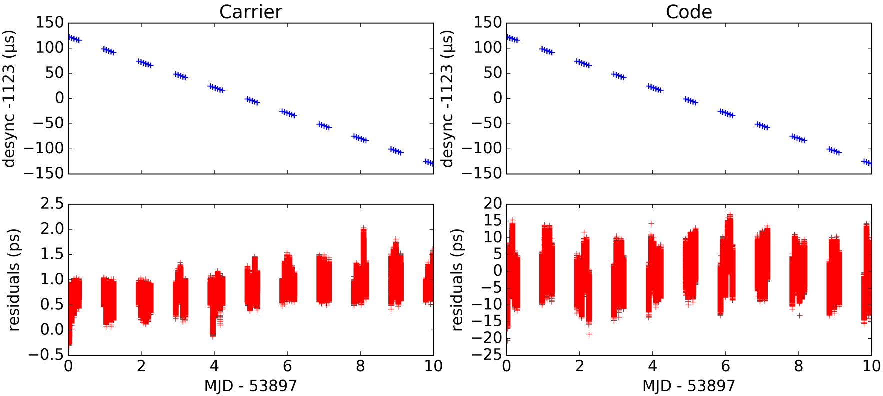
10 days, 57 passes with exact knowledge of ISS position

Evolution of desync. recovery as a function of ISS orbitography uncertainty



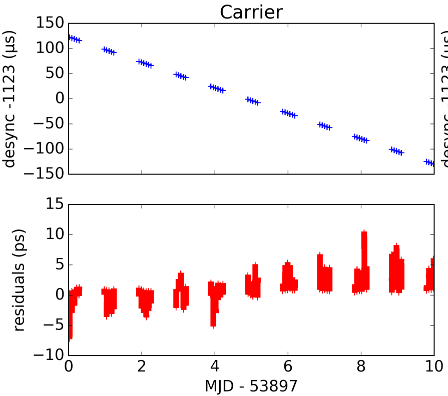
10 days, 57 passes with expected error on knowledge of ISS position (few m)

Evolution of desync. recovery as a function of ISS orbitography uncertainty



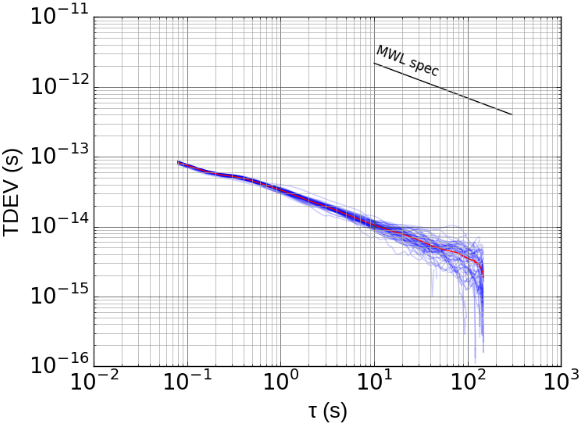
10 days, 57 passes with ×10 worse error on knowledge of ISS position (≃100 m)

Evolution of desync. recovery as a function of ISS orbitography uncertainty



10 days, 57 passes with $\times$100 times worse error on knowledge of ISS position ($\simeq$1 km)

Evolution of TDEVs as a function of ISS orbitography uncertainty



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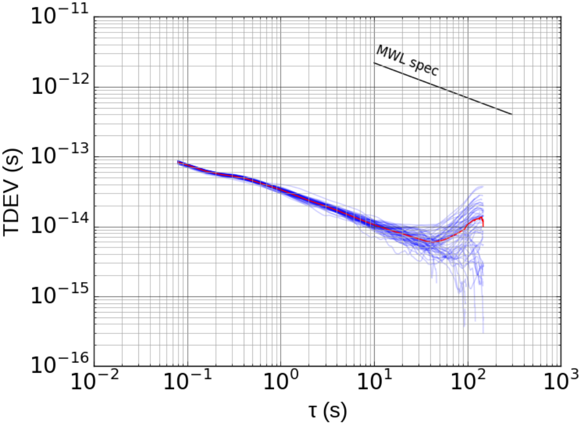

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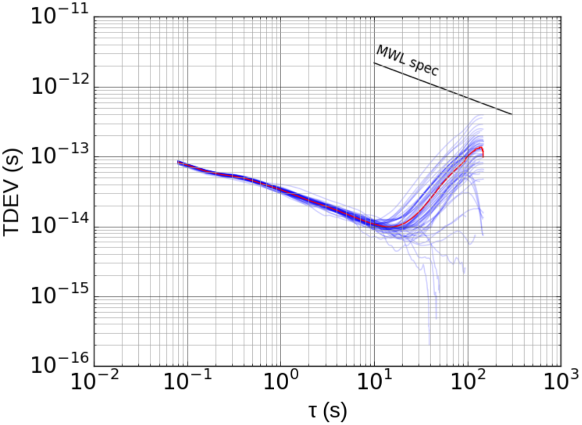

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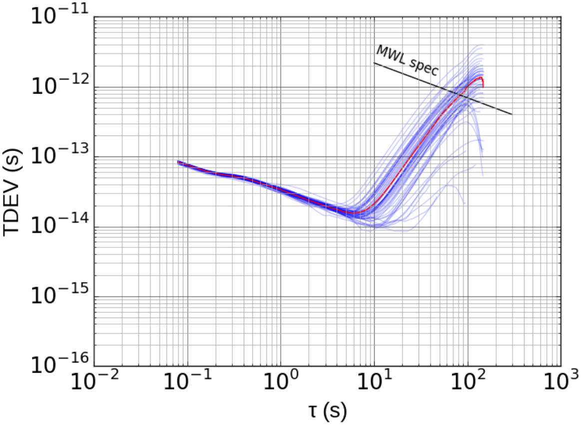

10 days, 57 passes with $\times 100$ worse error on knowledge of ISS position ($\simeq$1 km)

Conclusions

On ISS position uncertainty impact

Should be well within specifications as far as per-pass desynchronisation is concerned.
Next step : more thorough study on impact on integrated gravity potential modelisation.

On Data Analysis Center readiness

Our software is already able to process large chunks of data (parallelisation) in a semi-automated way.
Definition of the interface with the CADMOS Data Center is ongoing.
We accumulate experience on data handling, visualisation and validation.
Eagerly waiting for real data !