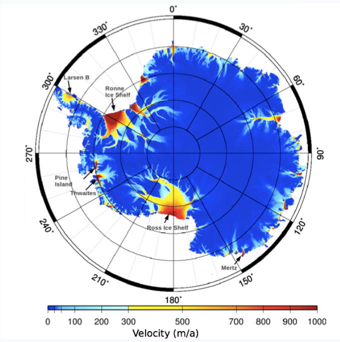
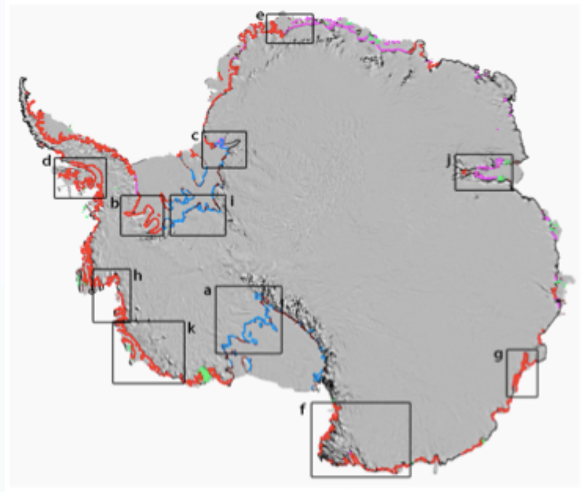
* On the continental ice – ocean interface in Antarctica : Grounding Lines (GL) *

Key issue in ice science: numerical models at the GL

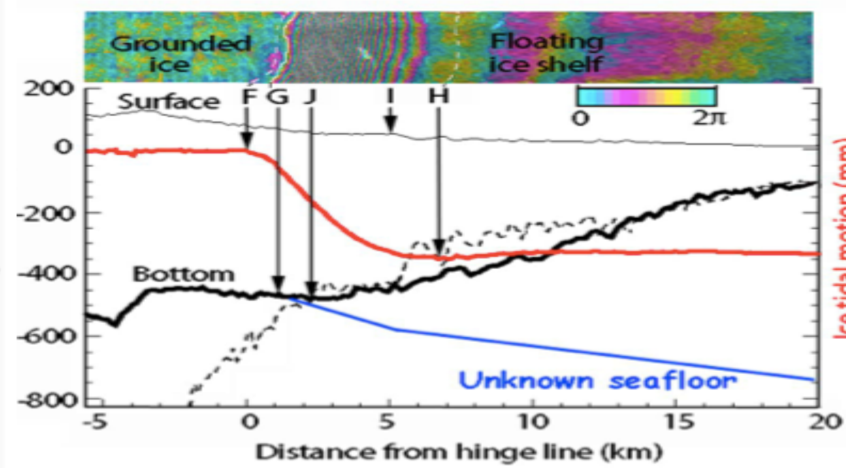
Surface velocities InSar-derived.
Images from [Rignot et al.' 11]



GL locations



GL detection method using DInSar (eg. Sentinel 1)



Modeling open problems remain at the Grounding Line ("dynamic contact point")

- Force balance computations at fine scale not reliable yet (contact point)
- Reliable unsteady numerical model not available yet
- Stability analysis are partial only

Few softwares available at GL: ISSM JPL-UCI, Elmer LGGE etc

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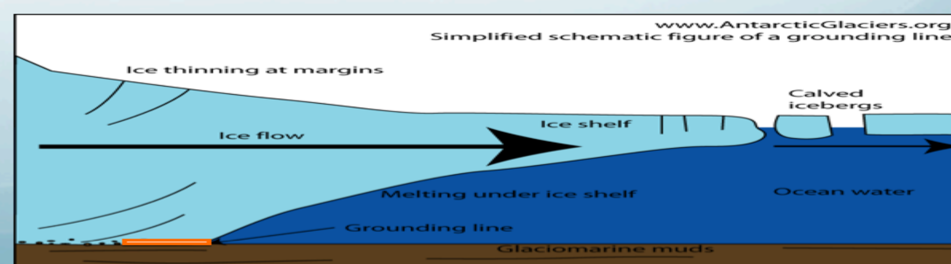
Under the hydrostatic assumption at GL, preliminary **coupling with ocean dynamics** in progress.

e.g. H. Seroussi et al. ISSM software JPL



Currently,
no funds on this point in SWOT projects

Université Fédérale Toulouse Midi-Pyrénées

Contribution of SWOT to the understanding of polar ice sheet dynamics & fully integrated data assimilation system (SWOT-IceCap-DA)

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Tosca CNES Project (2016-xx)

by J. Monnier (INSA & Math Institute of Toulouse, FR)

with H. Gudmundsson (BAS Cambridge, UK), F. Malgouyres (IMT, Toulouse, FR), and P.-A. Garambois (ICUBE, FR)

Also in collaboration with H. Seroussi (JPL, USA), M. Morlighem (UC Irvine, USA)

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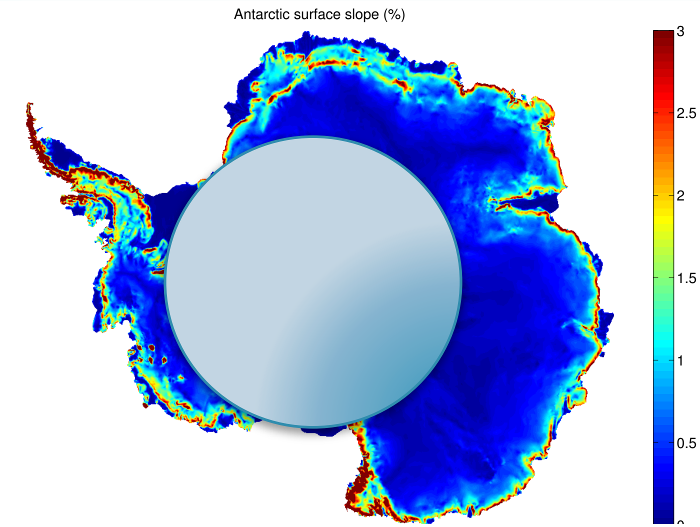
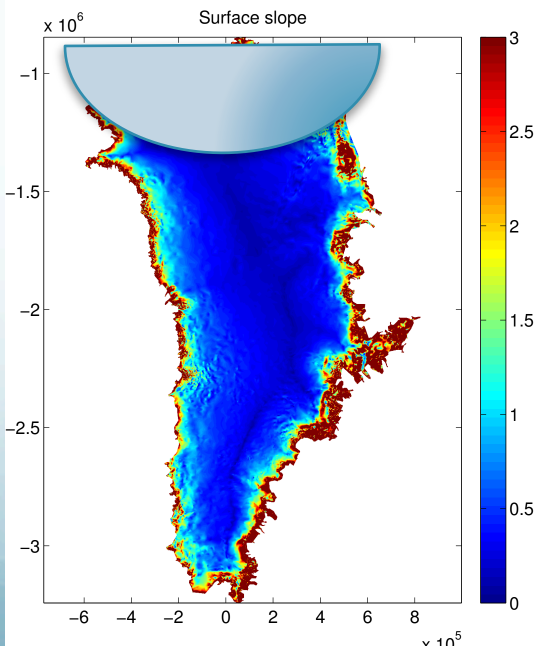
Satellite altimetry

	Sentinel-3	ICESat 2	SWOT
Launch	2016	2017	2020
Footprint	300 m Nadir over SeaIce	10 m footprint (4 lasers)	120 km swath
Repeat	27 days with (up to) 10 repeats at high latitude	30/90 days	22 days with (up to) 10 repeats at high latitude
Accuracy	? (SSH: 3-5cm)	15 cm	10-50 cm
Limitations	Snow/ice penetration ?	3 km space tracks Cloud coverage	Snow/ice penetration ?



Surface slopes. Courtesy H. Seroussi, E. Larour et al. JPL



SWOT:
Most ice-streams covered with high accuracy/frequency
➔ Precious for the glaciology community

State of the art from a numerical modeling point of view

- Flow models with inversion tools are now available
- Inferences from the surface observations (elevation altimetry-derived, InSAR-velocities) + airbone radars

Challenges

From descriptive models (calibrated steady-state)
to predictive models (sea level rise problem, IPPC)

I) Research directions of the SWOT-IceCap-DA TOSCA project

1) A complimentary method to infer the bed topography

Method based on new derivations of shallow ice flow equations

2) Towards a fully integrated image data assimilation chain

II) Continental ice – ocean interface in Antarctica : Grounding Lines (GL)

Bed properties inference: state of the art (1/2)

Difficulties

- Infer how things are beneath the surface!

- Ice-caps flows are *multi-regimes:*
from fully sheared (very slow ~m/y, divides)
to pure slip (fast ~km/y, ice-streams)

- Error propagation in the inversions

Few inversion methods exist

a) Inversion of a nonlinear transport problem
+ regularization [Michel-Picasso et al]'13

Method highly sensitive to the surface noise

Model validity: fully sheared flows (no-slip at bottom)

Extremely slow flows and alpine glaciers only

See also [Heining-Sellier'16]

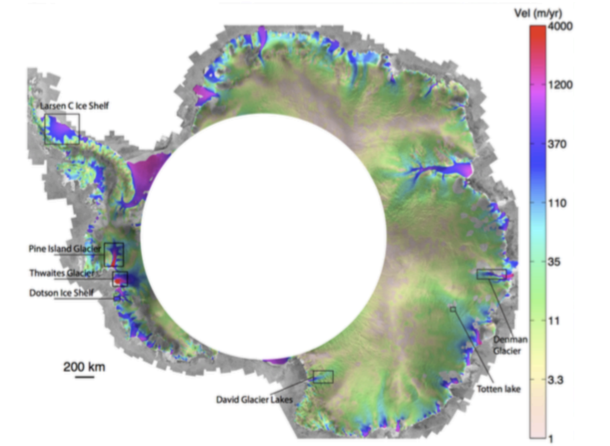
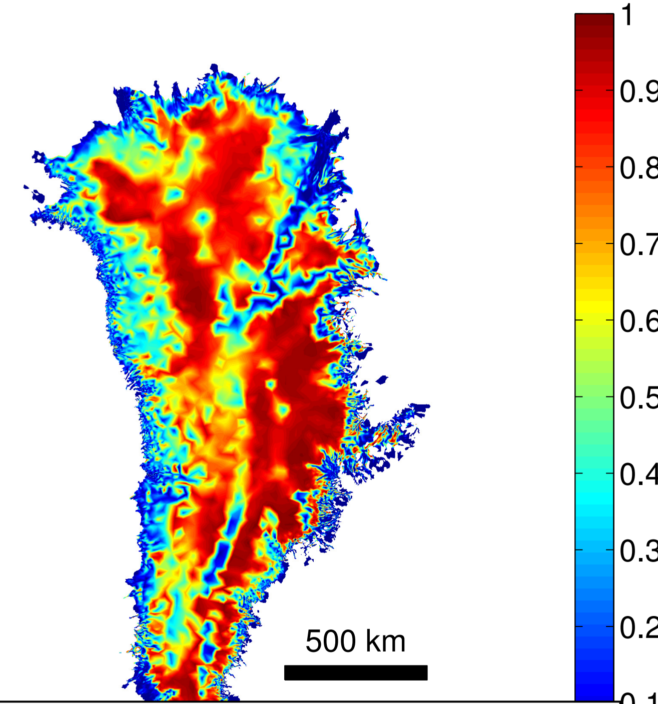


Figure 4. Examples of potential targets for the Antarctic ice Sheet. Background is observed surface ice velocity (Rignot et al. 2011a) overlaid on a MODIS mosaic.

Surface velocities from Rignot et al

Slip ratio ($1-|v_b|/|v_s|$)



Slip ratio map from ISSM computations.
Courtesy H. Seroussi et al. JPL

Bed properties inference: state of the art (2/2)

Ice Bridge (NASA)
2015 campain

Existing inversion methods:

b) The depth-averaged (shallow) mass equation
+ Variational DA of the data cocktails by M. Morlighem et al. (UCI)

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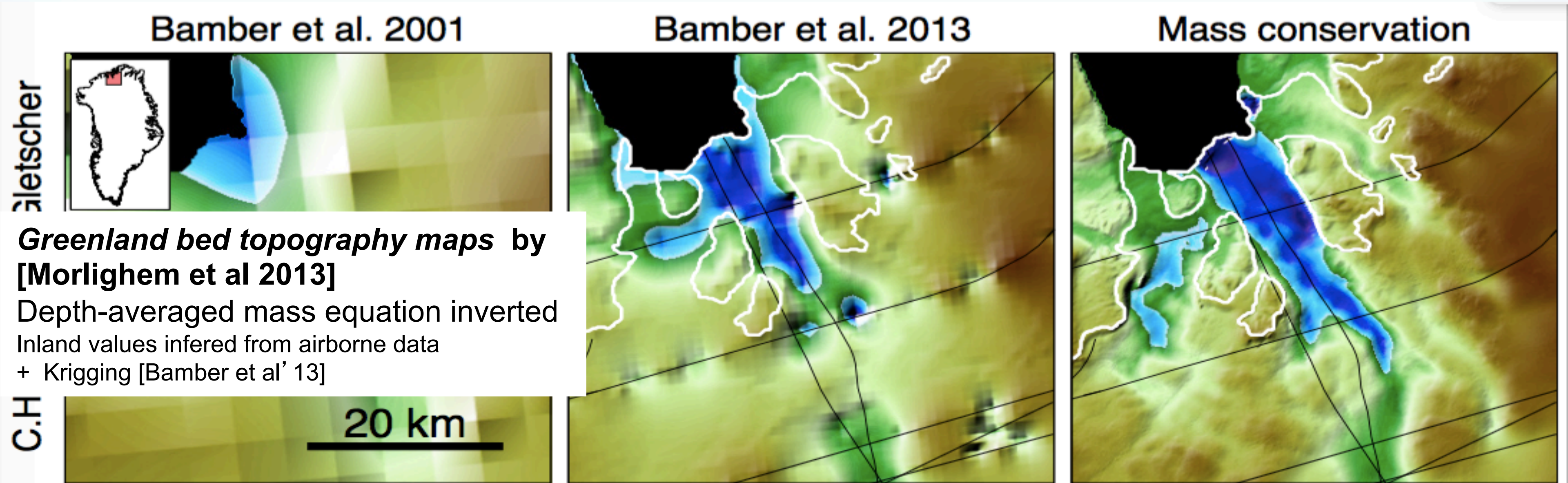
Adv: efficient since VDA and the mass is conserved
Dis: a hyperbolic eqn + regularization
=> the depth at upstream is required and errors are propagated

➔ **Useful in coastal areas where dense flight tracks are available**



Greenland bed topography maps **by [Morlighem et al 2013]**
Depth-averaged mass equation inverted
Inland values infered from airborne data
+ Krigging [Bamber et al' 13]

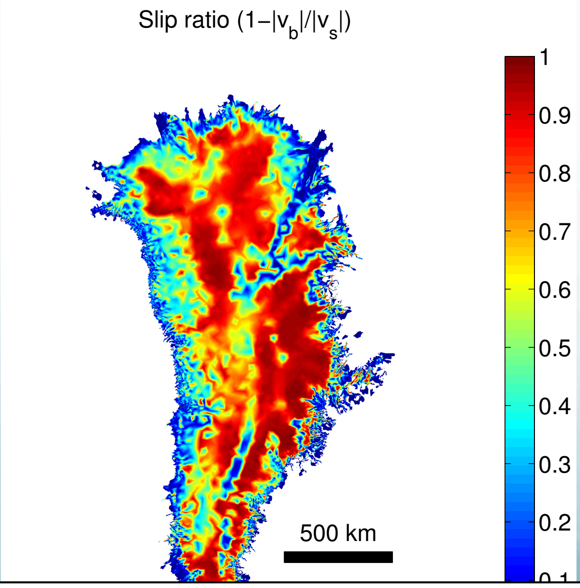
Bed properties inference: SWOT-IceCap-DA towards a complementary method to infer the (topography, friction) pair. On-going researches

Ingredients: New extended xSIA model with a mix of explicit calculations (asymptotics) & VDA computations.

Model valid from highly to mildly sheared flows, hence also valid inland where there very few or no in-situ measurements

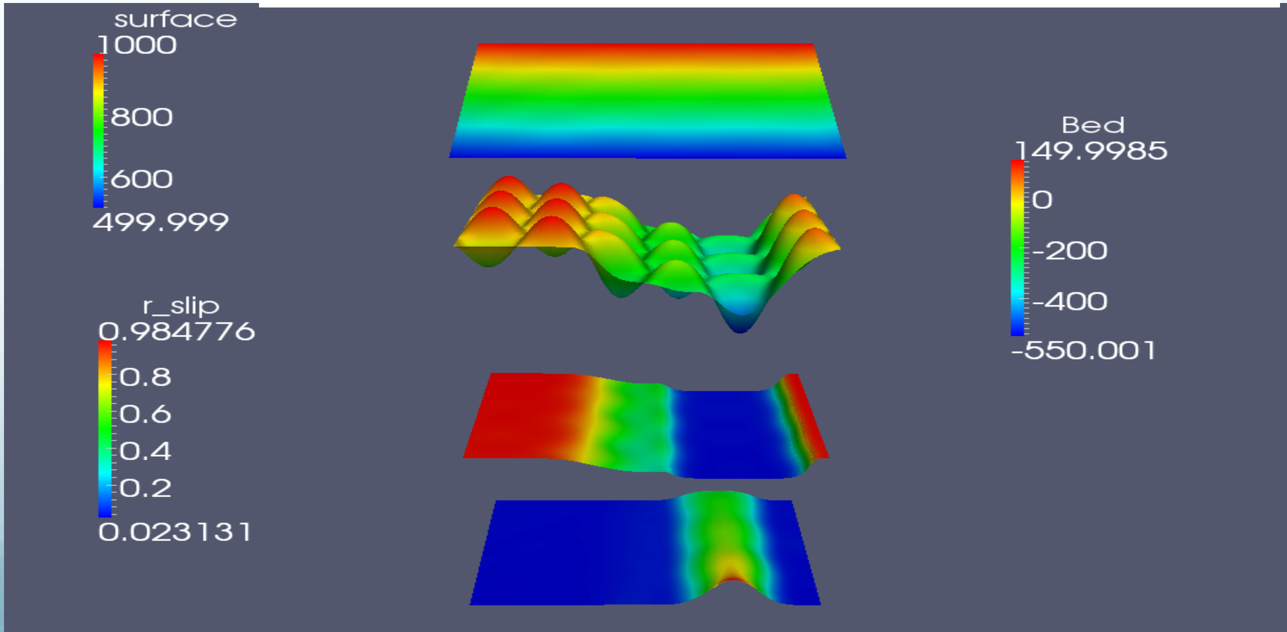
Adv:

- mass + momentum taken into account
- does not require dense flight tracks
- diffusive model hence errors are damped
- no upstream data required



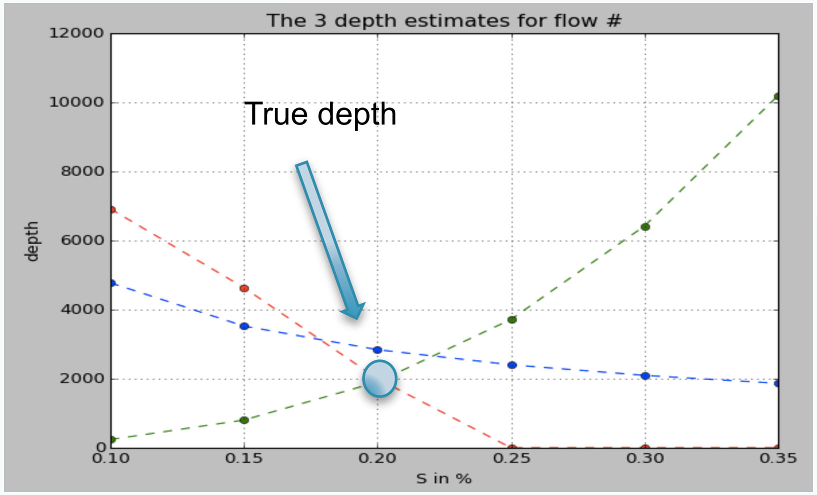
Slip ratio map from ISSM computations.

Bed topography inference:
acadamic test cases representing the whole regime range

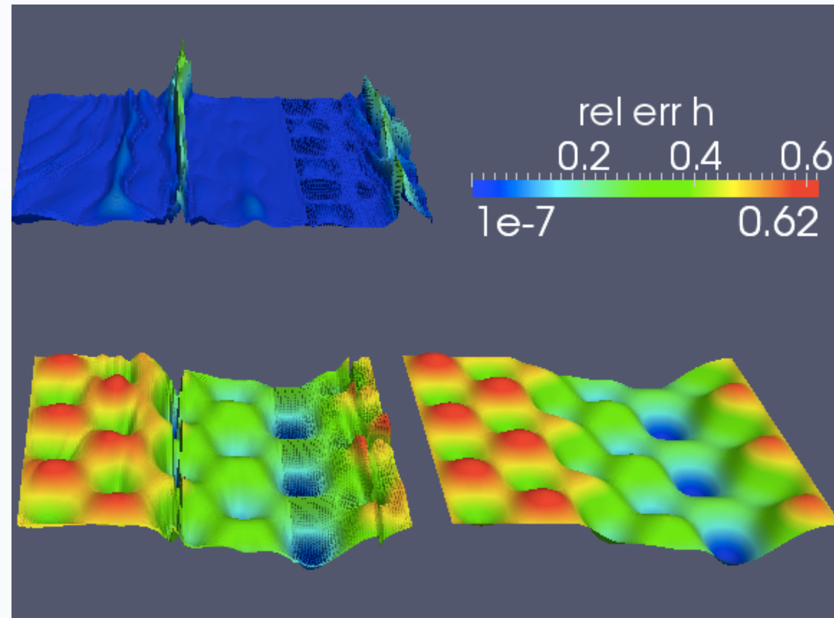


SWOT-IceCap-DA bed properties inference. On-going researches

Dis: highly sensitive to the slope scale definition…
but a math analysis may give the correct value:



Depth values infered from 3 estimations vs slope values
Solution = the intersection point.
Fig: 1D uniform case with 10% noise on Us



Multi-regime flow: Bed topography infered from 1 single pt measurment
(U) error on the depth h
(L) Bed infered (R) Bed true

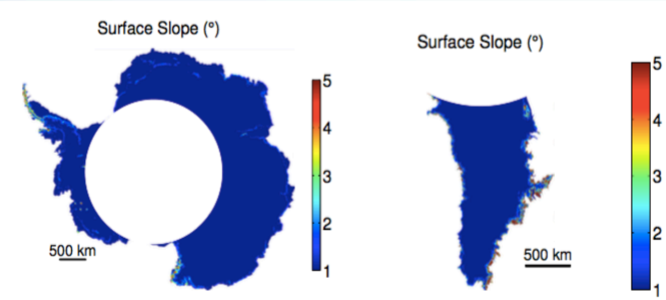


Figure 1. Estimated coverage of SWOT over Antarctica (left) and Greenland (right): surface slopes (in °) and radar coverage. The white zones correspond to areas not covered by the radar

Surface slopes of the main ice caps.
Courtesy H. Seroussi, E. Larour et al. JPL

Ref. Multiregime shallow models [Boutounet-Monnier-Vila 2015]
Inferences on academic test cases: [Monnier] in preparation.

Next step: Method assessement on real data and benchmarks….