ACCOUNTING FOR UNCERTAIN FAULT GEOMETRY IN EARTHQUAKE SOURCE INVERSIONS

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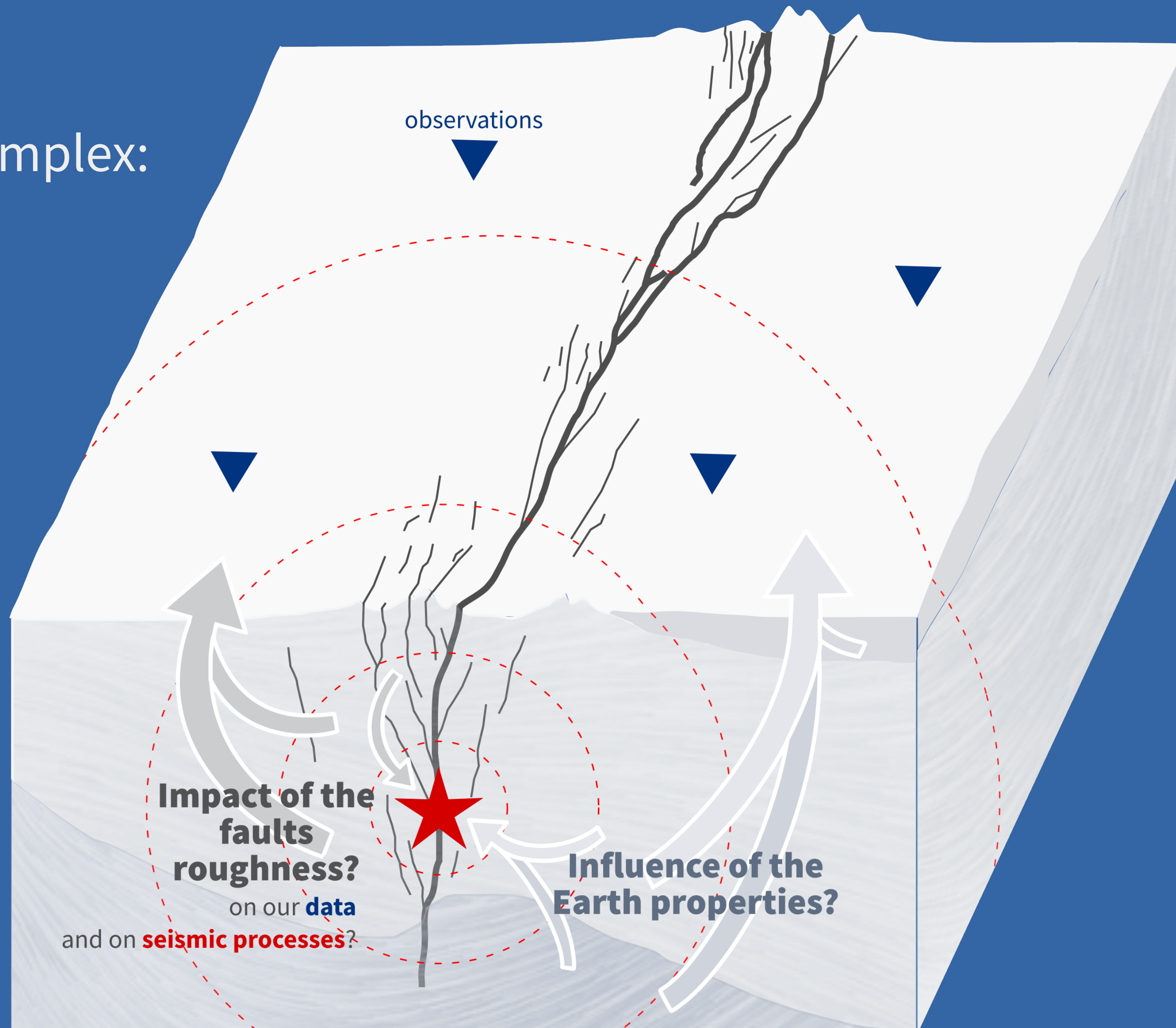
The Earth is complex:



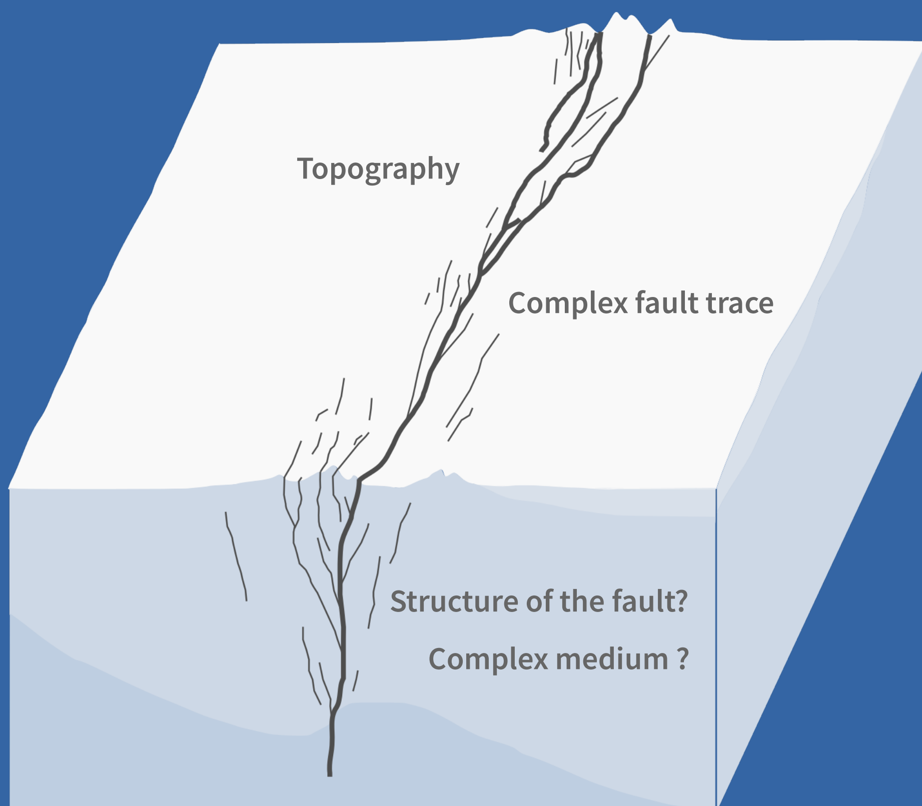
What is the impact of this complexity on our models?

$$\mathbf{d} = \mathbf{G} \cdot \mathbf{m}$$

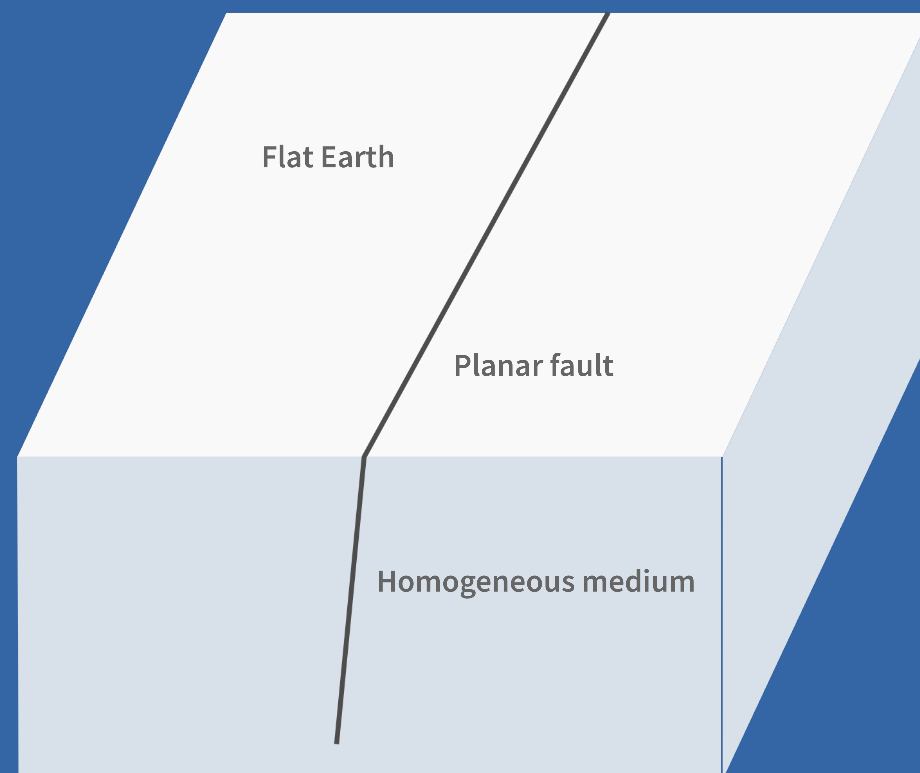
Yet the Earth is also poorly known...

And thus often simplified to an uncertain approximation

Reality?



What we assume:



$$\mathbf{d} = \mathbf{G} \cdot \mathbf{m}$$

Uncertain

For large earthquakes (Mw>8):

Uncertainties in the forward model **>** **10^3 to 10^6** x **observational errors**

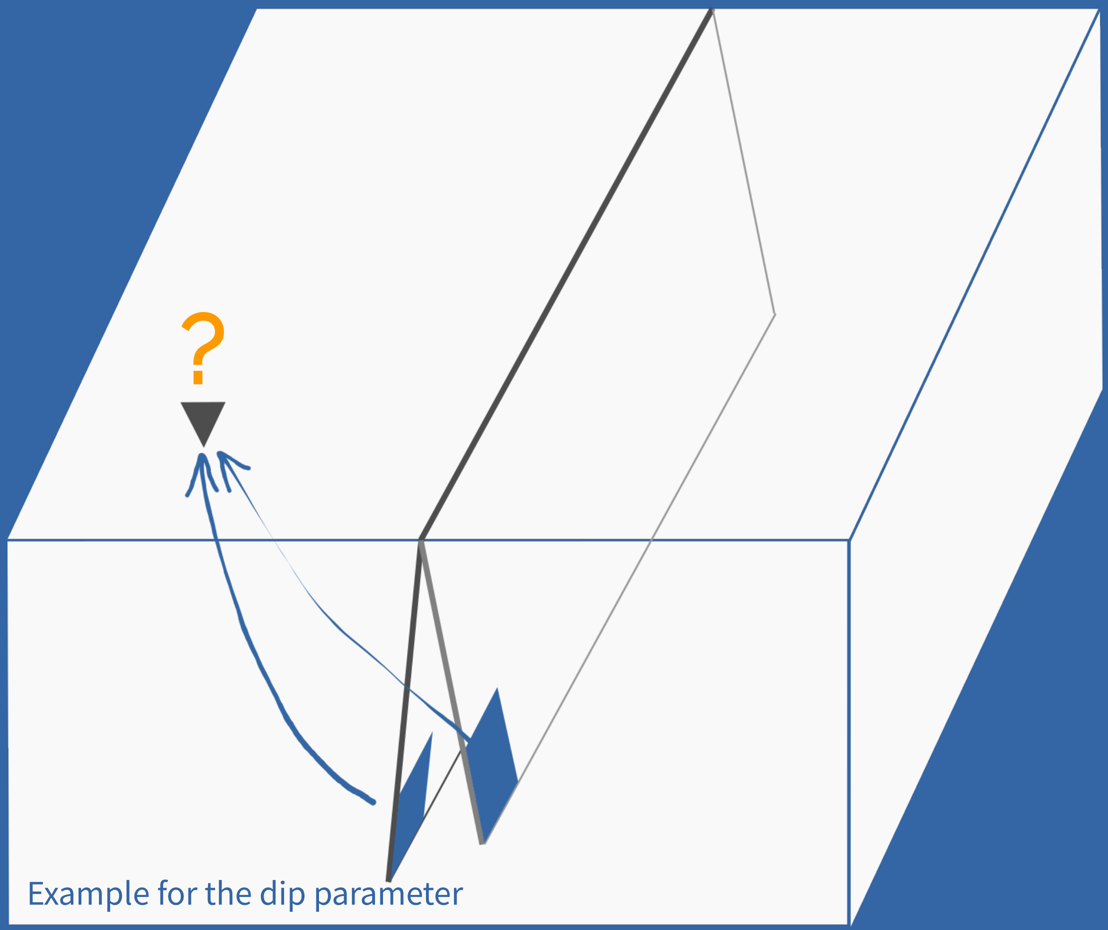
Up to 1m

σ^2~10^{-3} to 10^{-6}m

Ragon et al. 2018

Yet only observational errors are usually accounted for

Account for uncertainties in the fault geometry through a **sensibility analysis**



What is the impact of a small variation of the geometry on static measurements?

after *Duputel et al. 2014*
Ragon et al. 2018

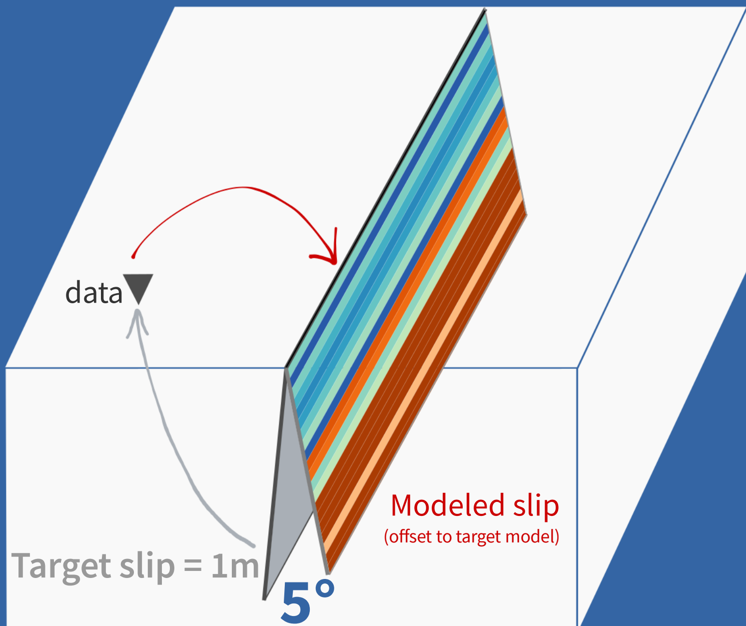
$$\mathbf{K}_{\mathrm{dip}} = \frac{\partial\, G_d}{\partial\, d}$$

$$\mathbf{C}_{\mathrm{p}} = \mathbf{K}_{\mathrm{dip}} \cdot \mathbf{C}_{\mathrm{dip}} \cdot \mathbf{K}_{\mathrm{dip}}^{T}$$

$$\mathbf{C}_{\mathrm{d}} \rightarrow \mathbf{C}_{\mathrm{d}} + \mathbf{C}_{\mathrm{p}}$$

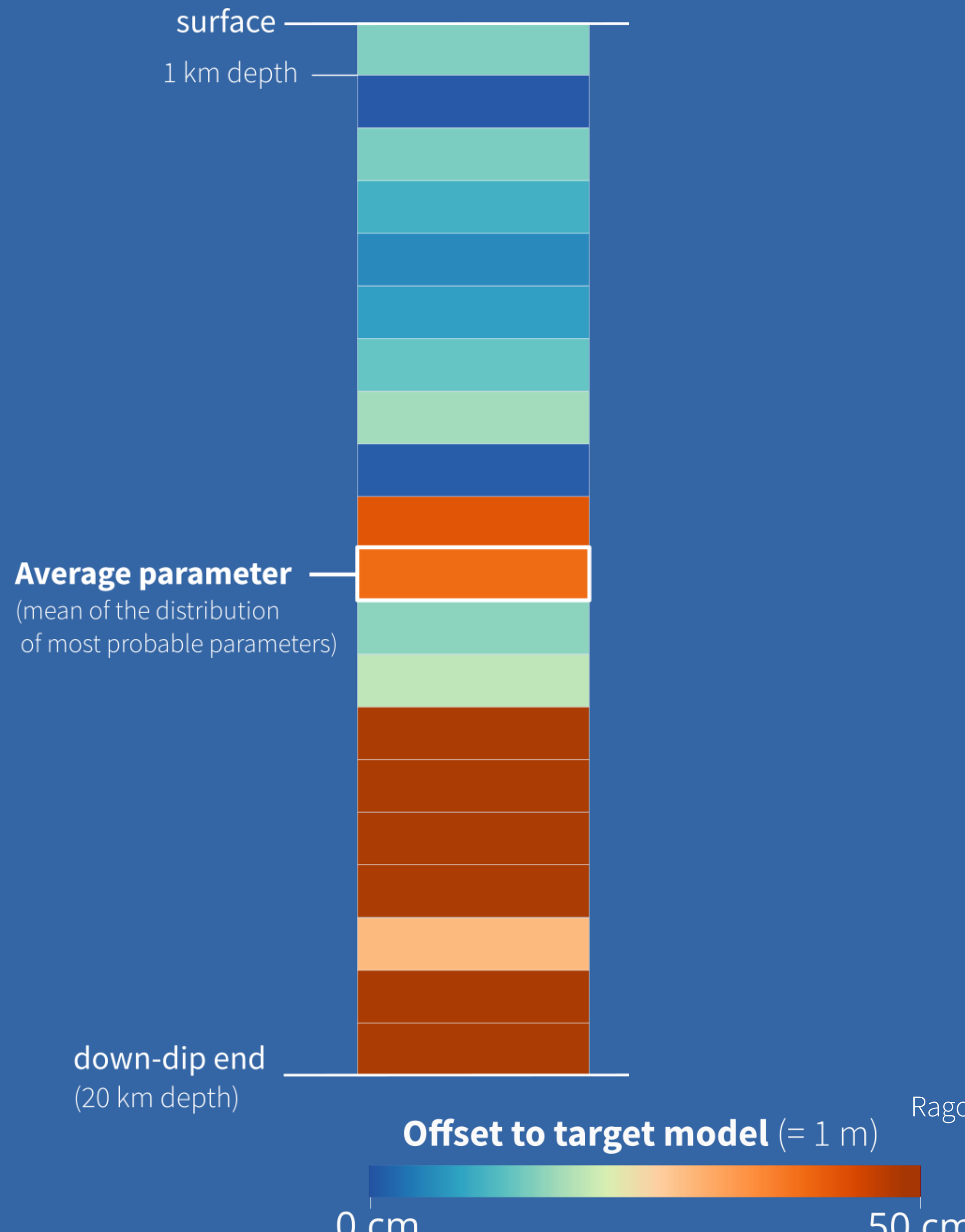
Updated misfit covariance matrix
→ **can be used in any inversion method**

Application to a toy model



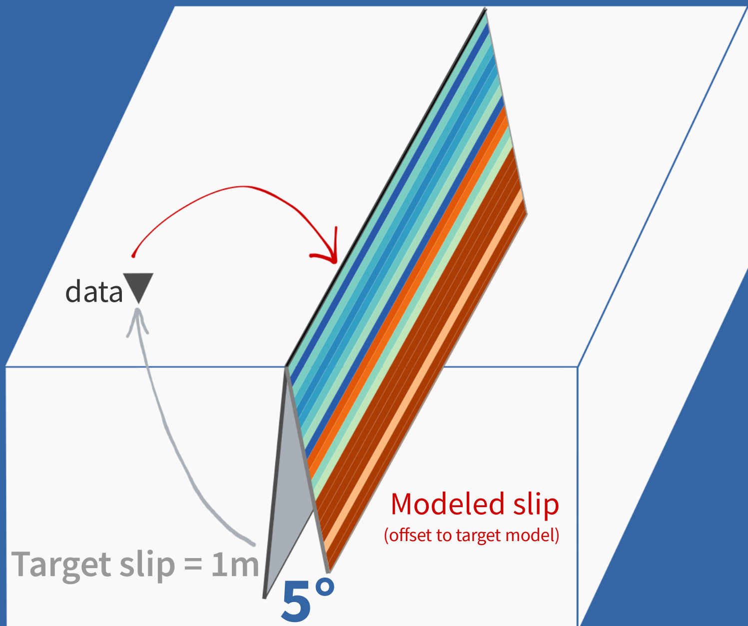
Can we infer **the target slip if assuming a wrong fault geometry?**

Red = no **Blue = yes**



Ragon et al. 2018

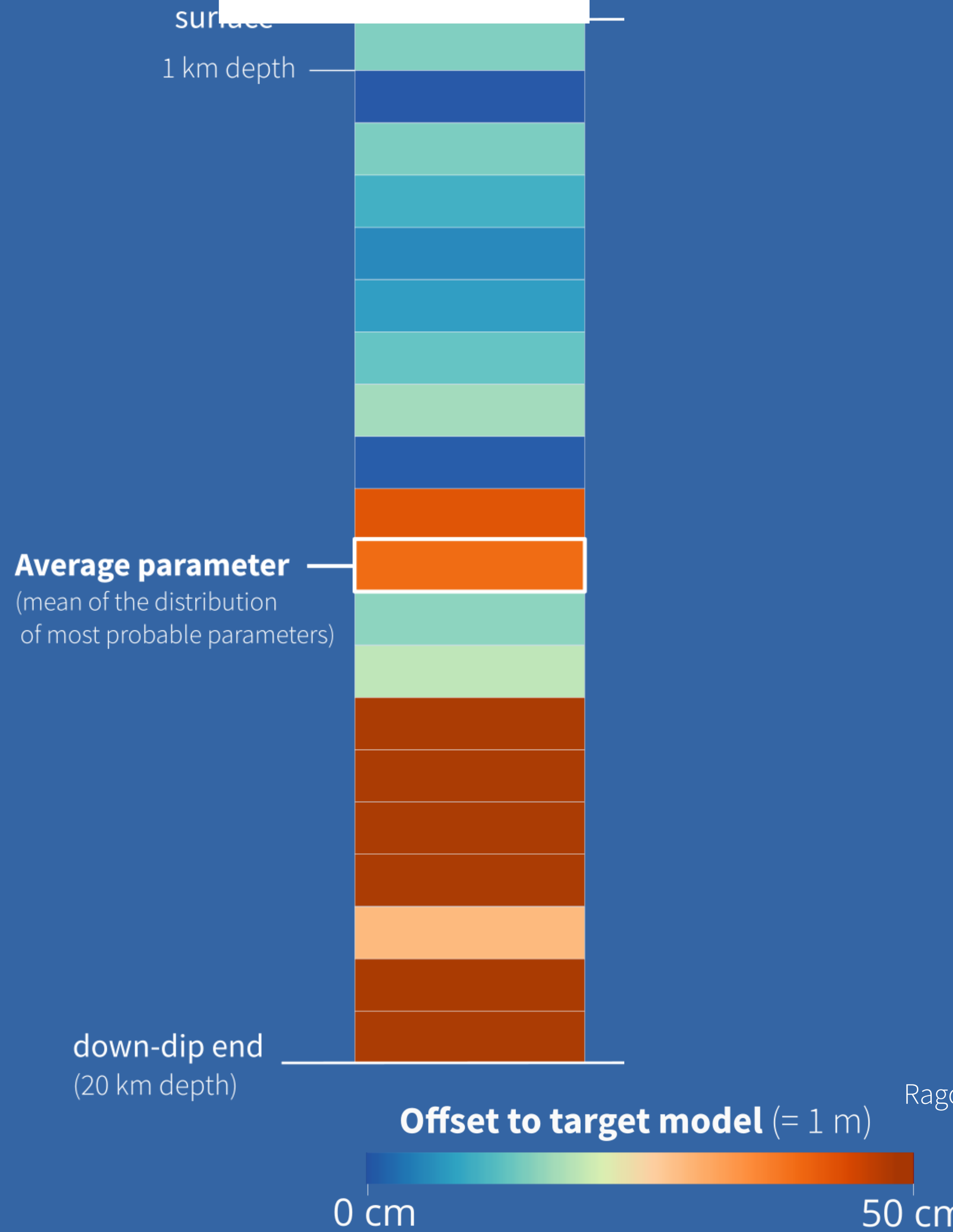
Application to a toy model



Can we infer **the target slip if assuming a wrong fault geometry?**

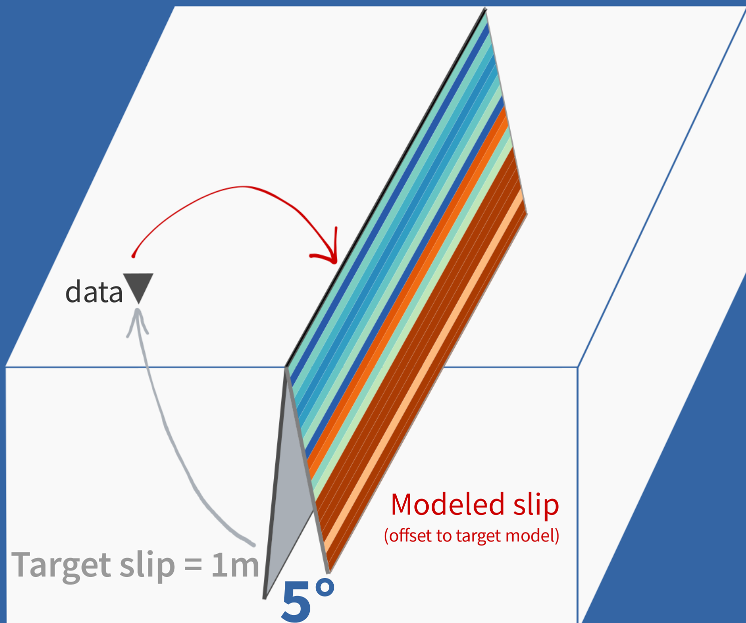
Red = no **Blue = yes**

If we assume that **our fault geometry is certain**



Ragon et al. 2018

Application to a toy model



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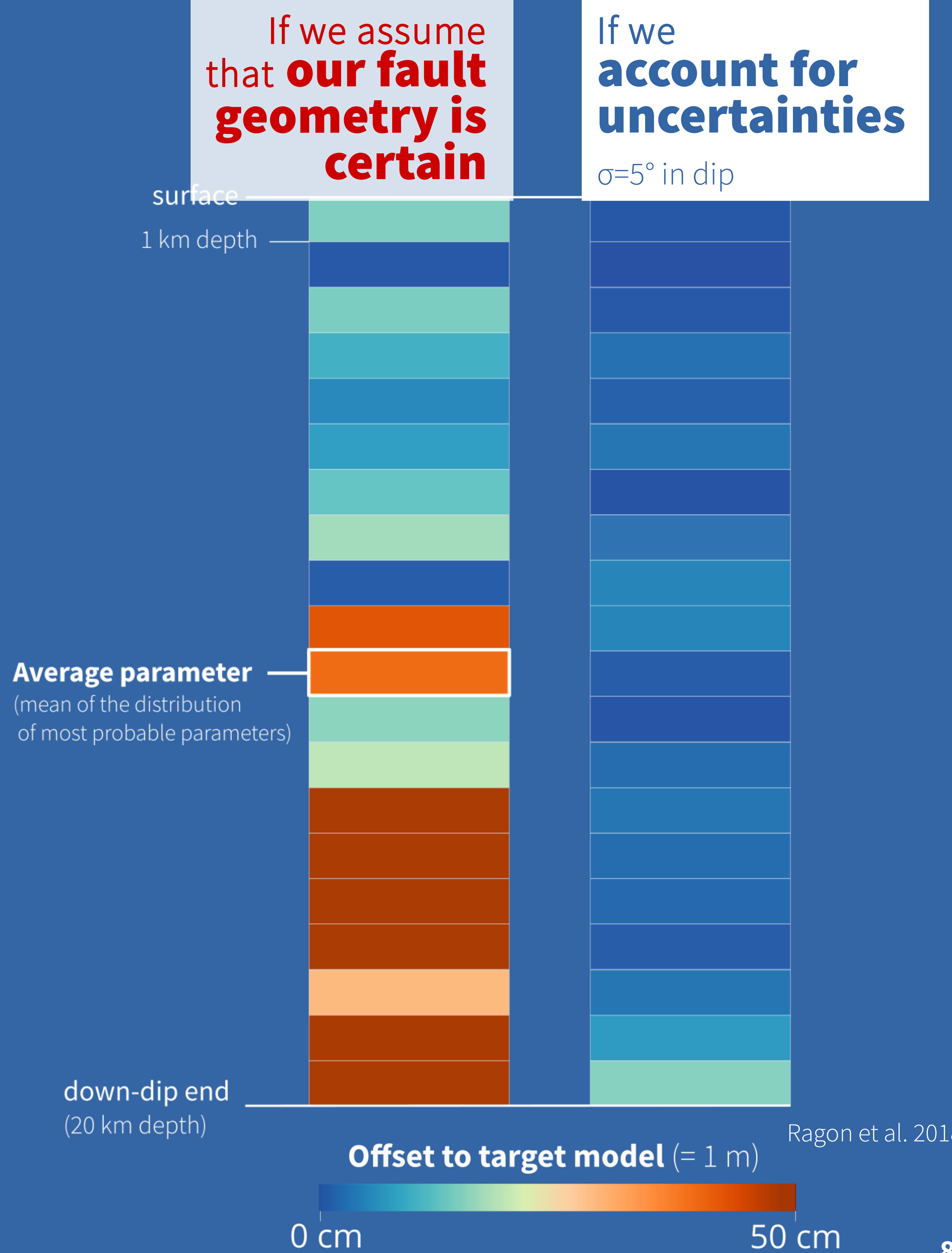


Accounting for epistemic uncertainties

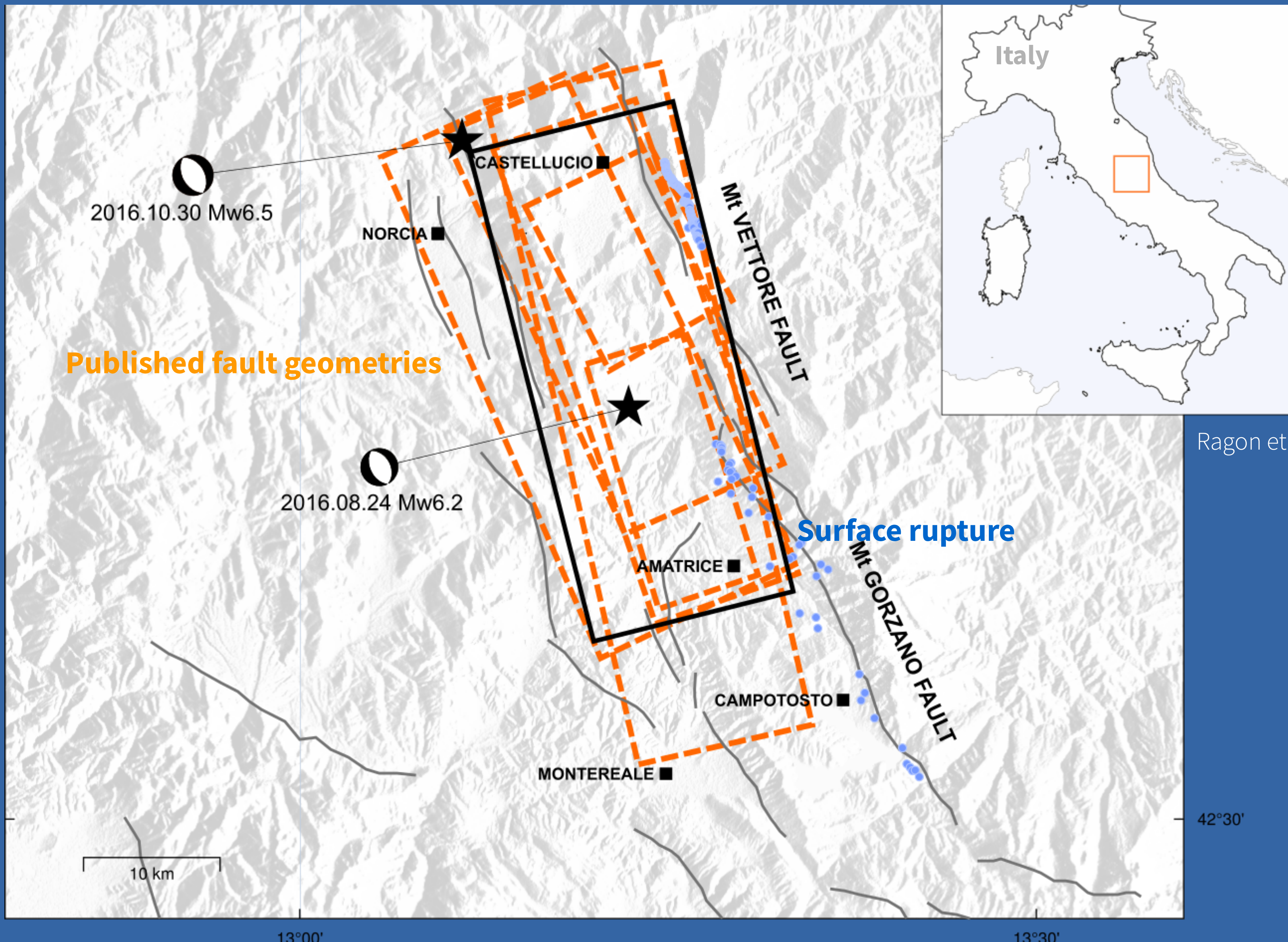
=

Allow for a **larger misfit between observations and predictions**

=

Predictions are not **over-confident in a wrong forward model**

Application to the Mw6.2 Amatrice earthquake, 2016, Central Italy

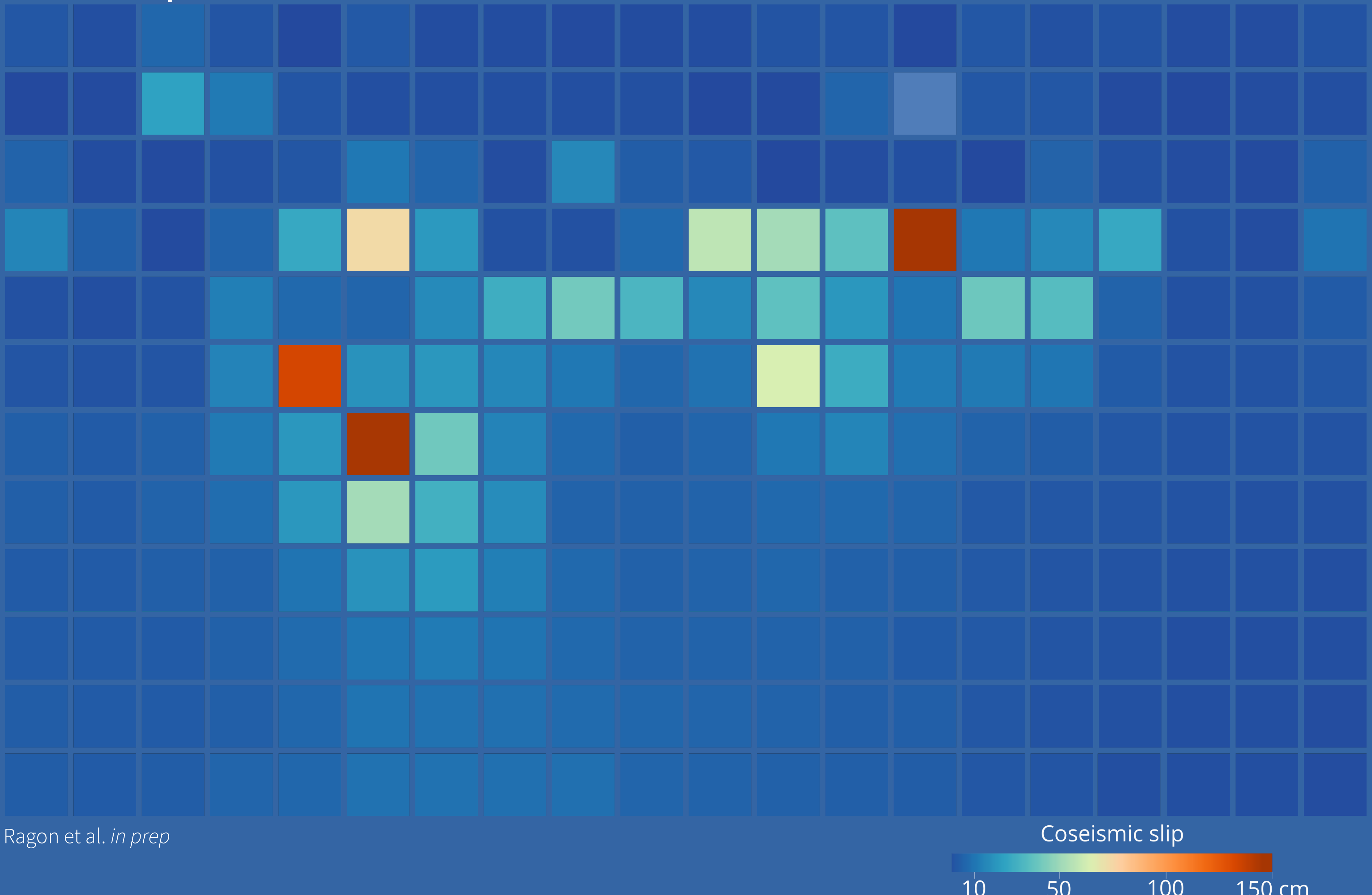


Ragon et al. *In prep*

Variability of fault geometries assumed for the Amatrice earthquake, from Lavecchia et al. 2016; Tinti et al. 2016; Huang et al. 2017; Liu et al. 2017; Chiaraluce et al. 2017; Cheloni et al. 2017.

Static estimation of co-seismic slip from **4 interferograms and 28 GPS stations**

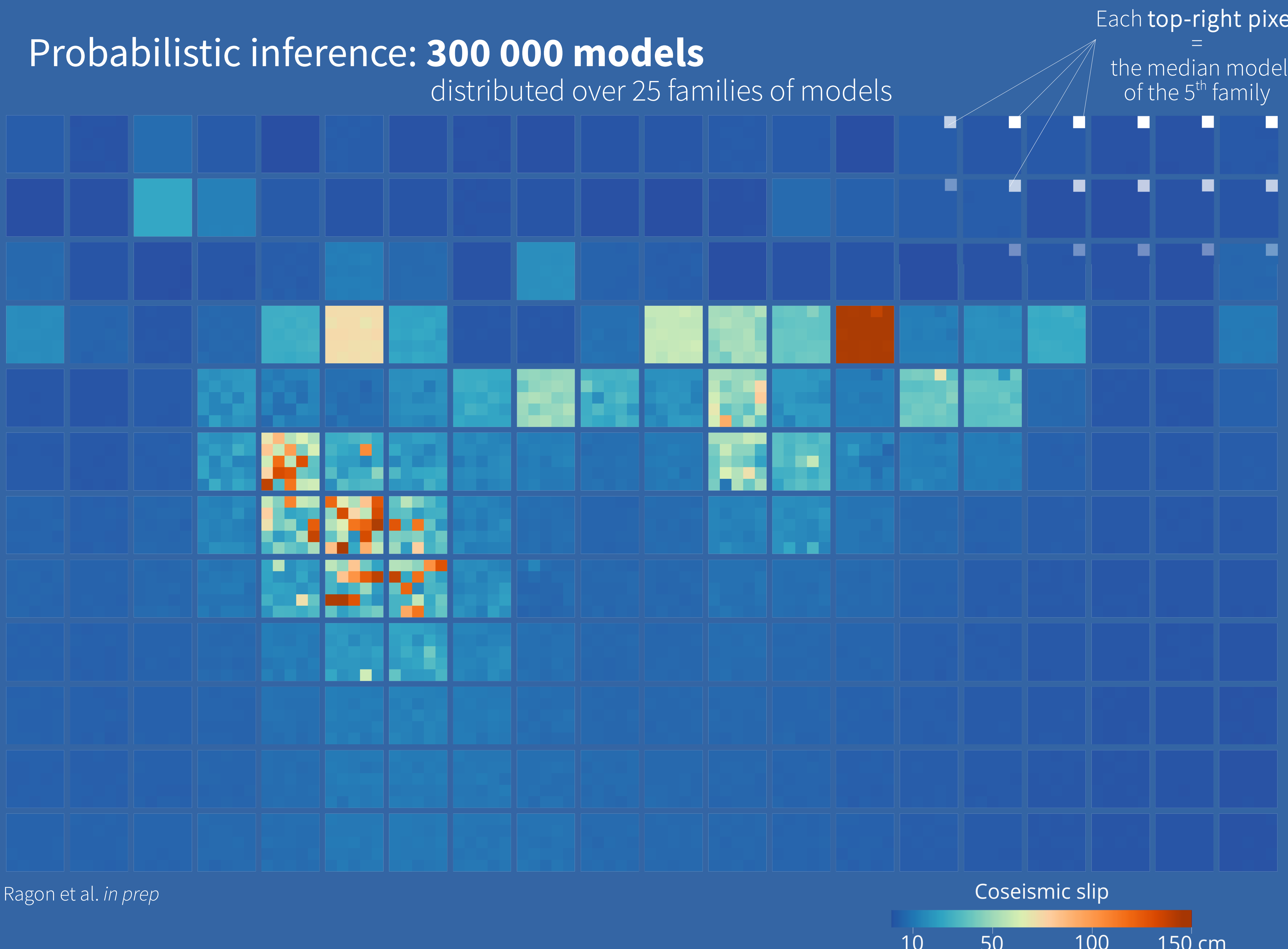
Usual optimization: **1 model**



Ragon et al. *in prep*

Probabilistic inference: **300 000 models**

distributed over 25 families of models



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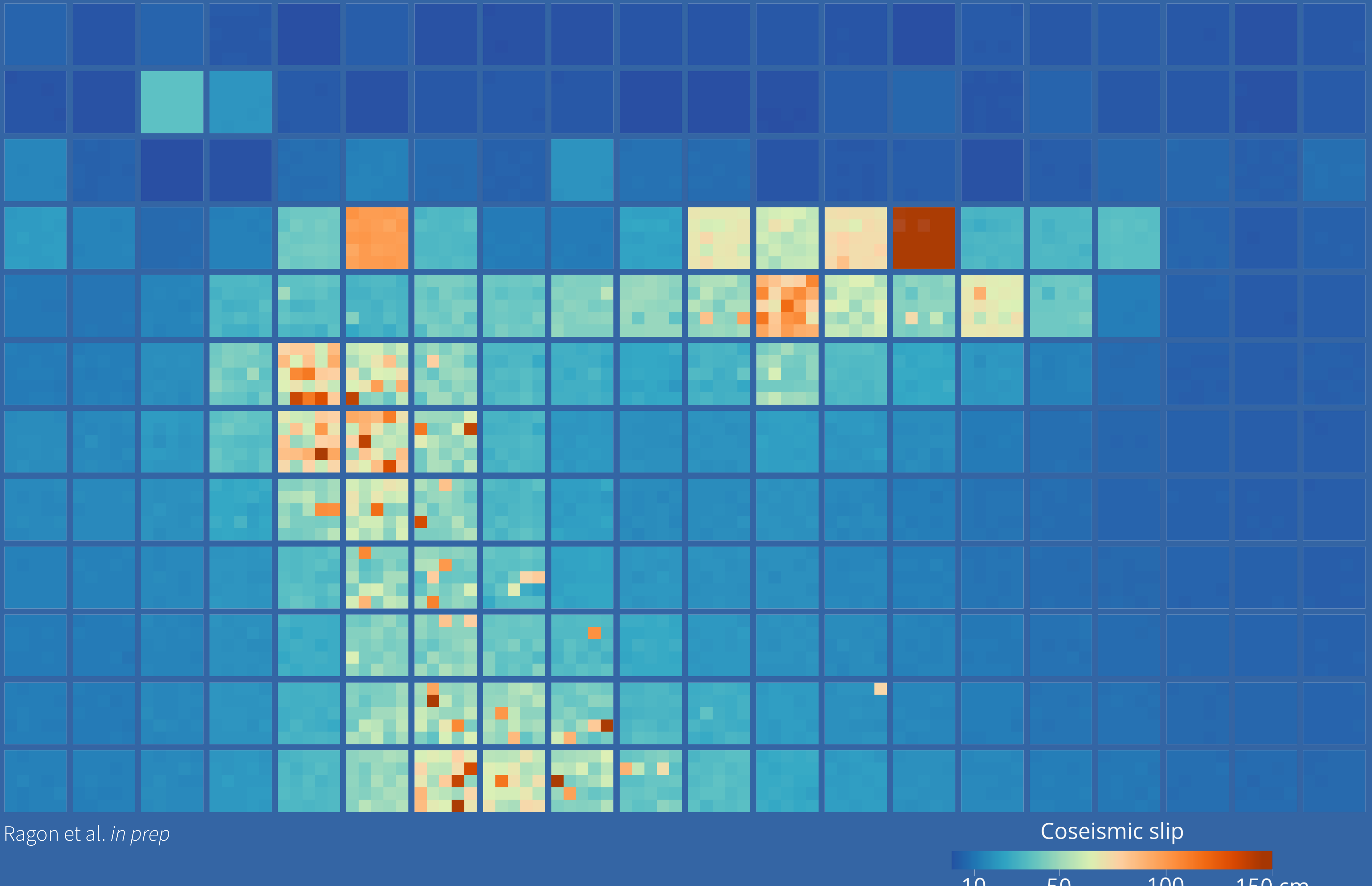
ACCOUNTING FOR UNCERTAINTIES

σ=5° in dip, 2km in position



Ragon et al. *in prep*

Uncertainty in fault geometry impacts earthquake slip estimates

And may bias

shallow slip estimates
tsunami hazard assessment

Particularly for events well observed in near field

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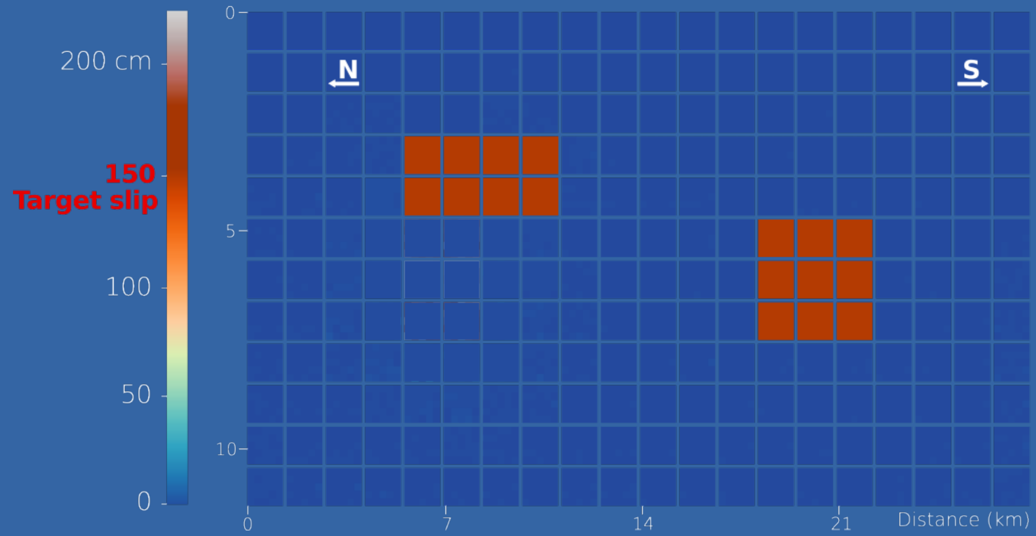
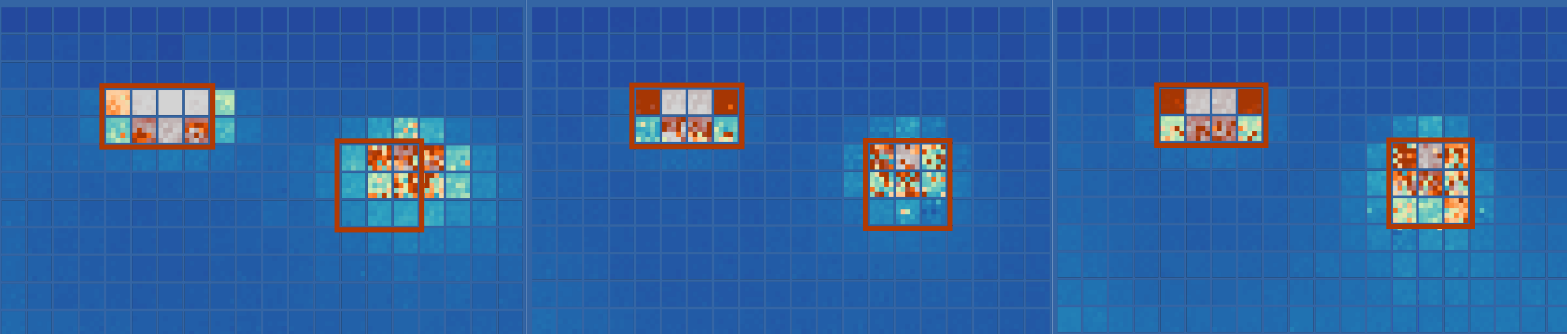
Synthetic tests: wrong Earth properties and Fault geometry





Ragon et al. *in prep*

Accounting for uncertainties **in fault geometry**

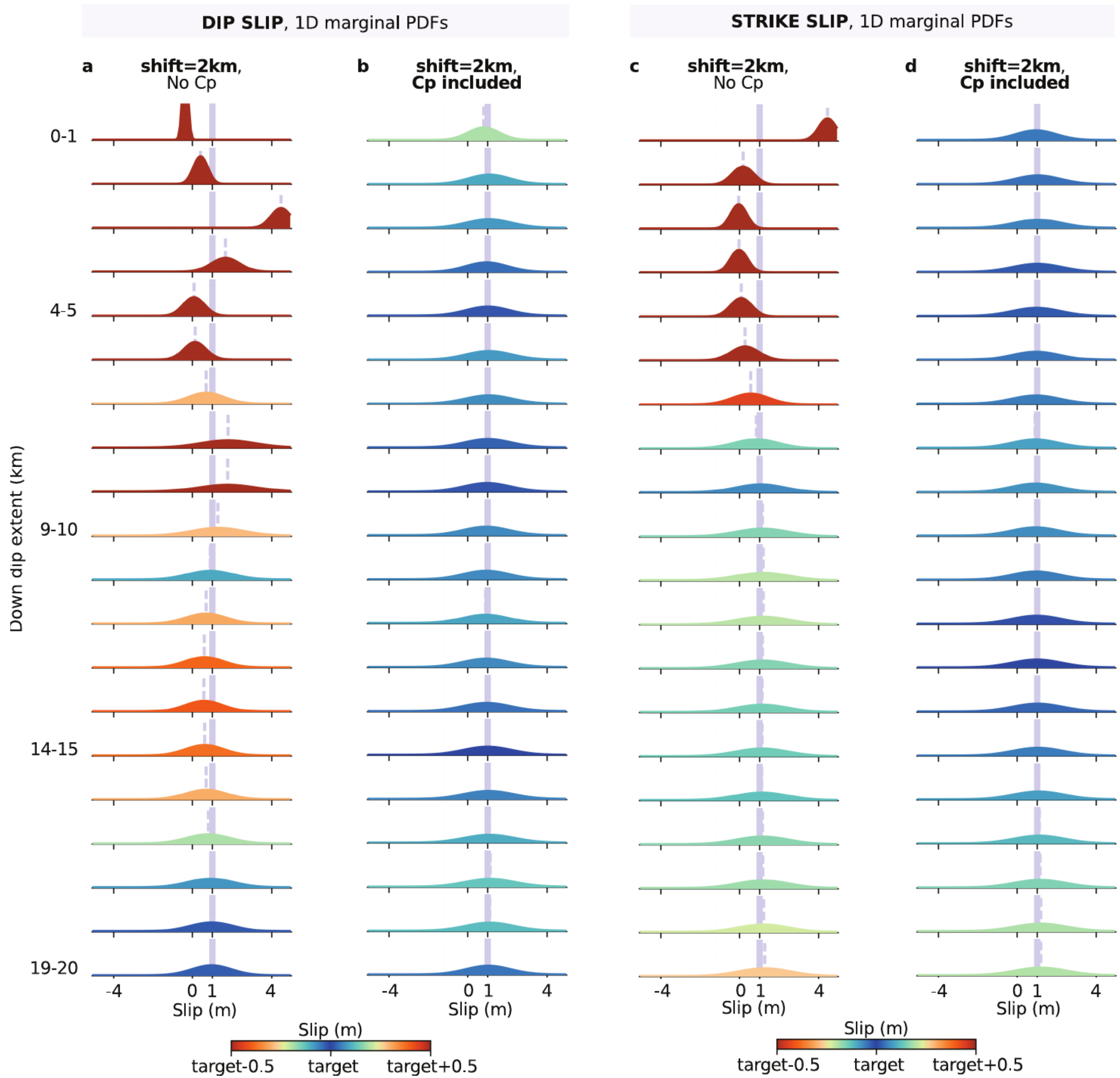
Accounting for uncertainties **in fault geometry** and **Earth properties**

Uncertainty ~~in fault geometry~~ **in the forward model impacts earthquake slip estimates**

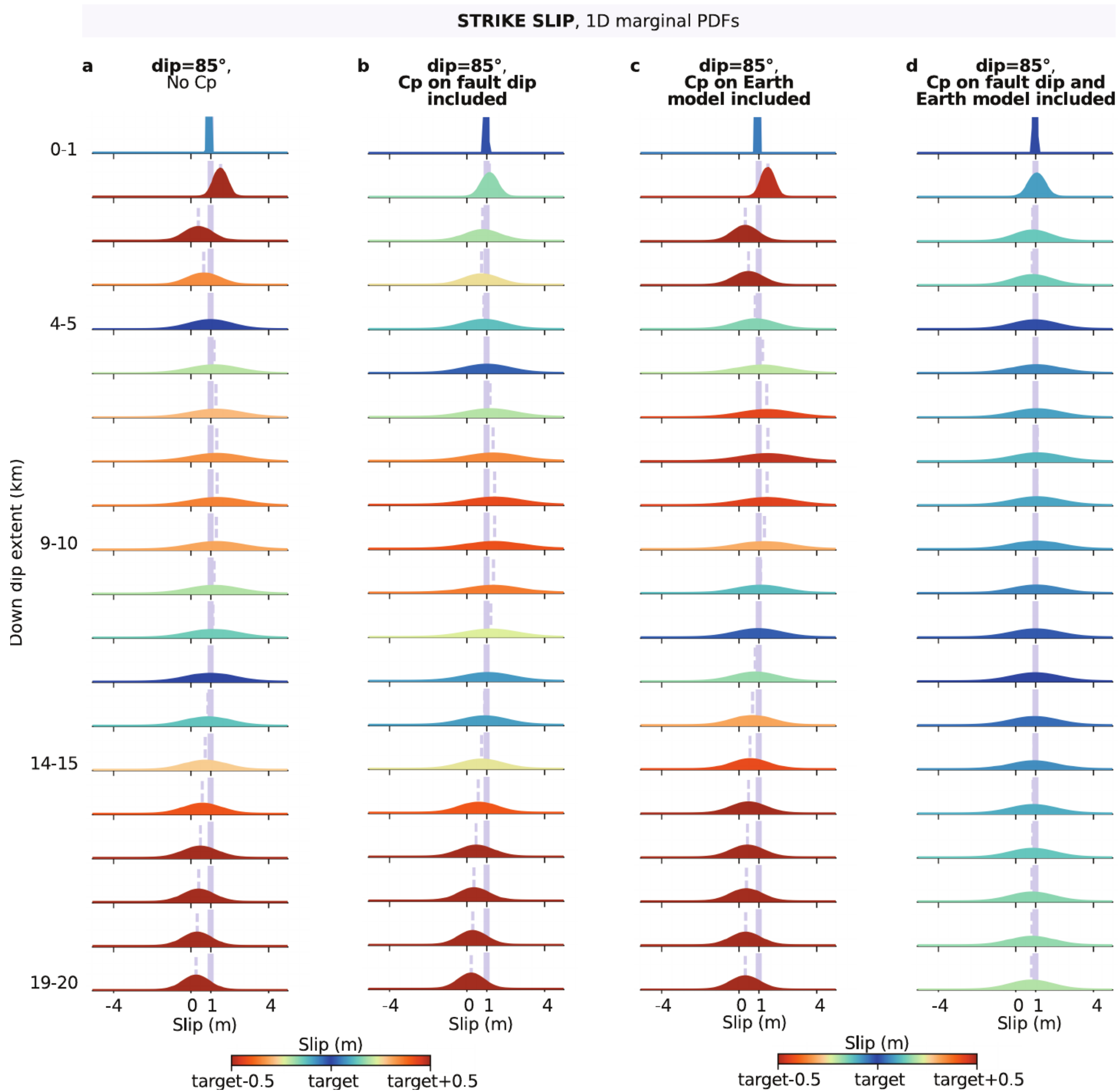
And we should account for it!

Ragon, Sladen, Simons – *GJI*
Accounting for uncertain fault geometry in earthquake source inversions – 1 (2018)
Accounting for uncertain fault geometry in earthquake source inversions – 2 (to be submitted September 2018)

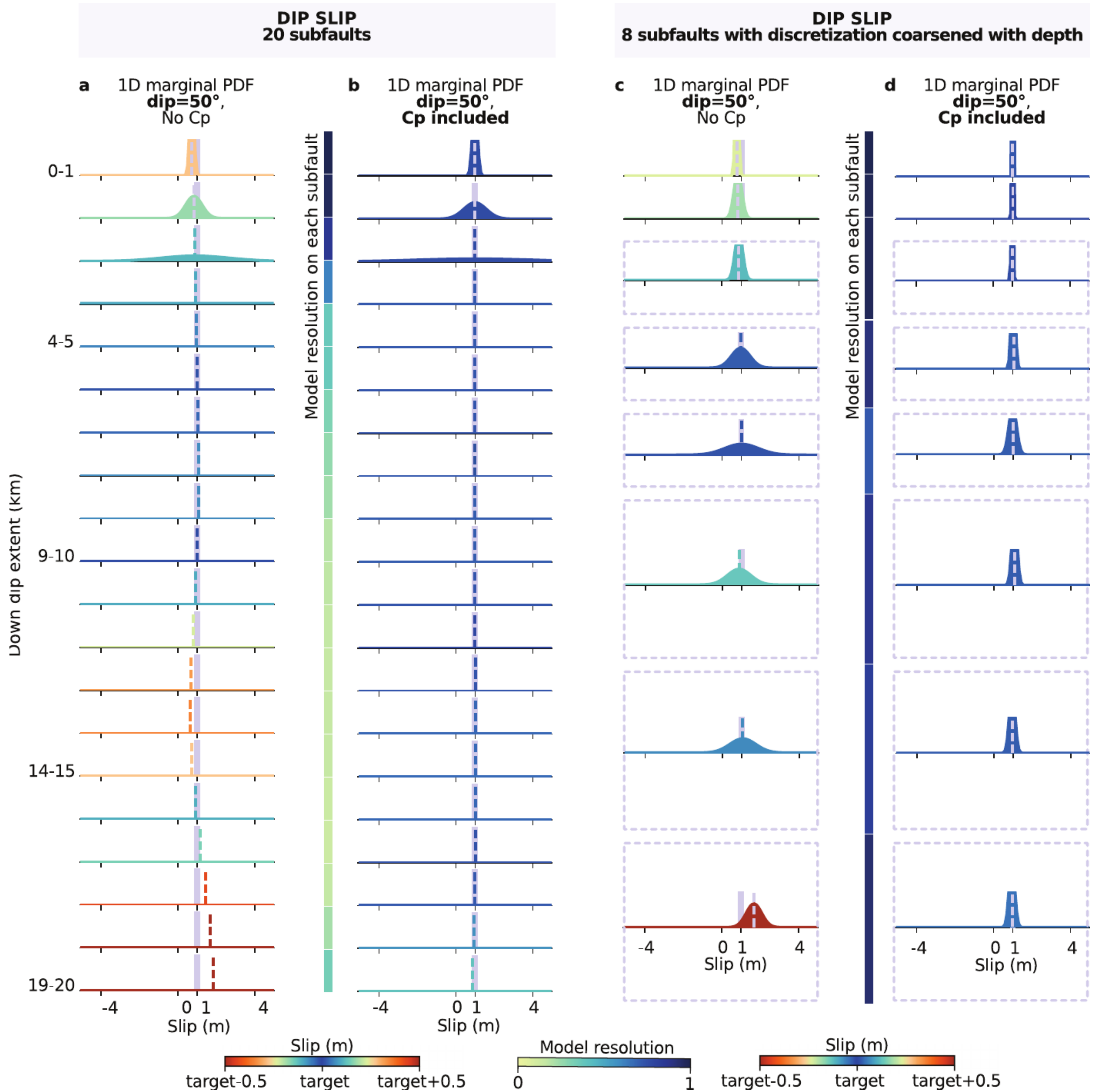
Contact ragon@geoazur.unice.fr
You can find the slides at ragonthea.wordpress.com



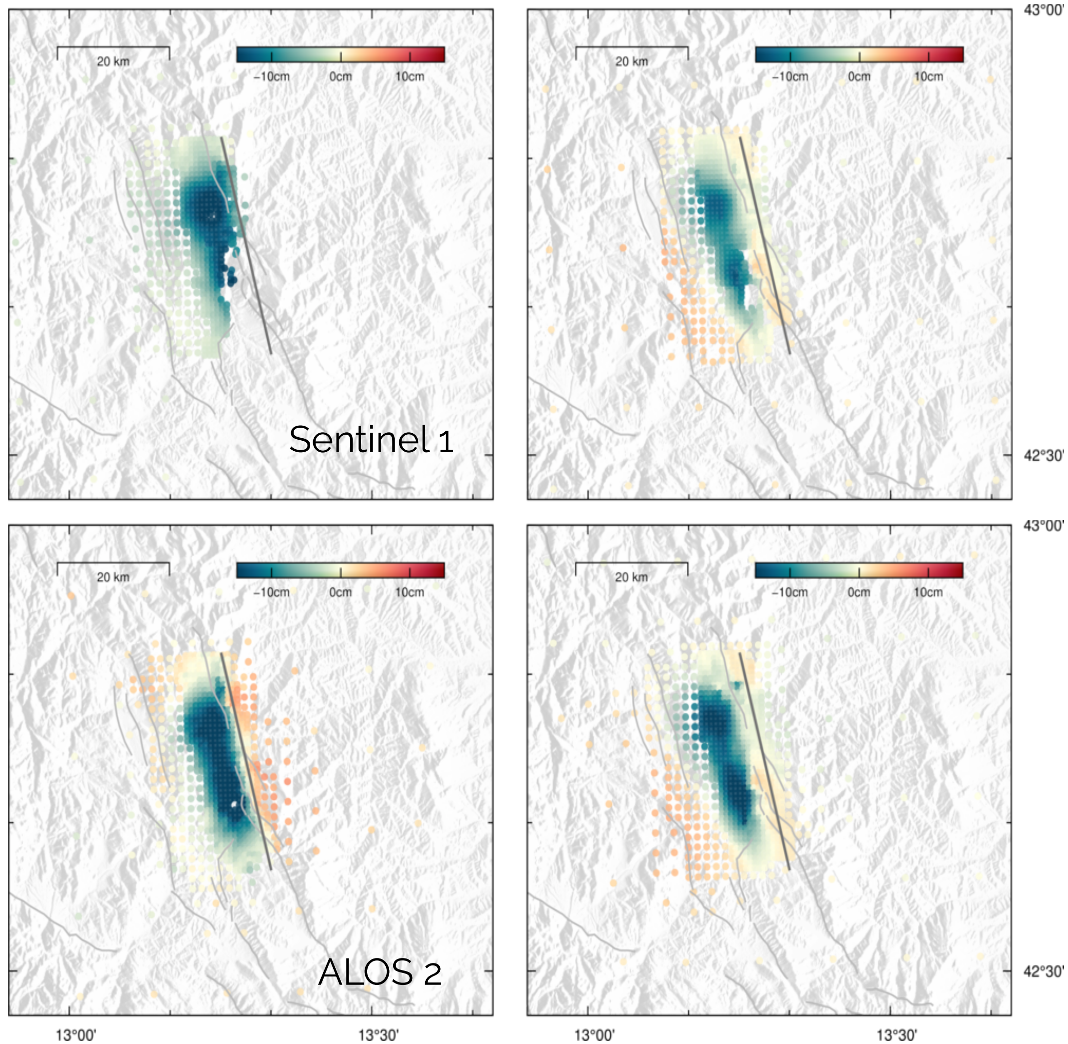
DIP SLIP, 1D marginal PDFs
STRIKE SLIP, 1D marginal PDFs
a
shift=2km,
No Cp
b
shift=2km,
Cp included
c
shift=2km,
No Cp
d
shift=2km,
Cp included
0-1
4-5
9-10
14-15
19-20
Down dip extent (km)
-4
0
1
4
Slip (m)
target-0.5
target
target+0.5

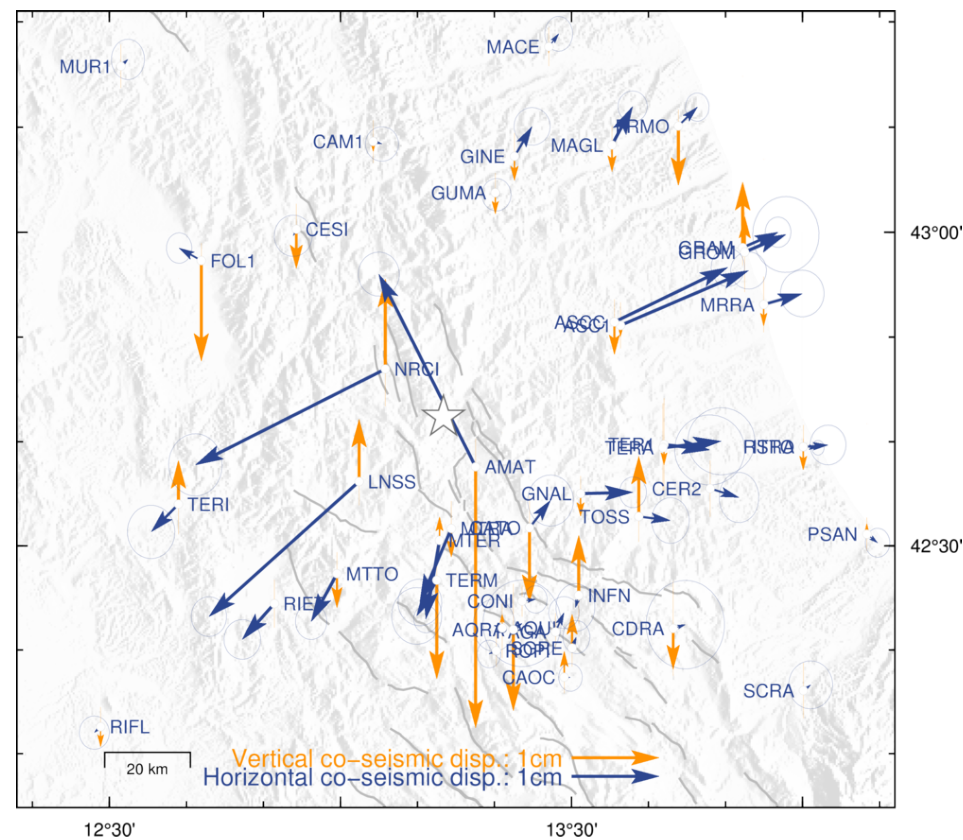


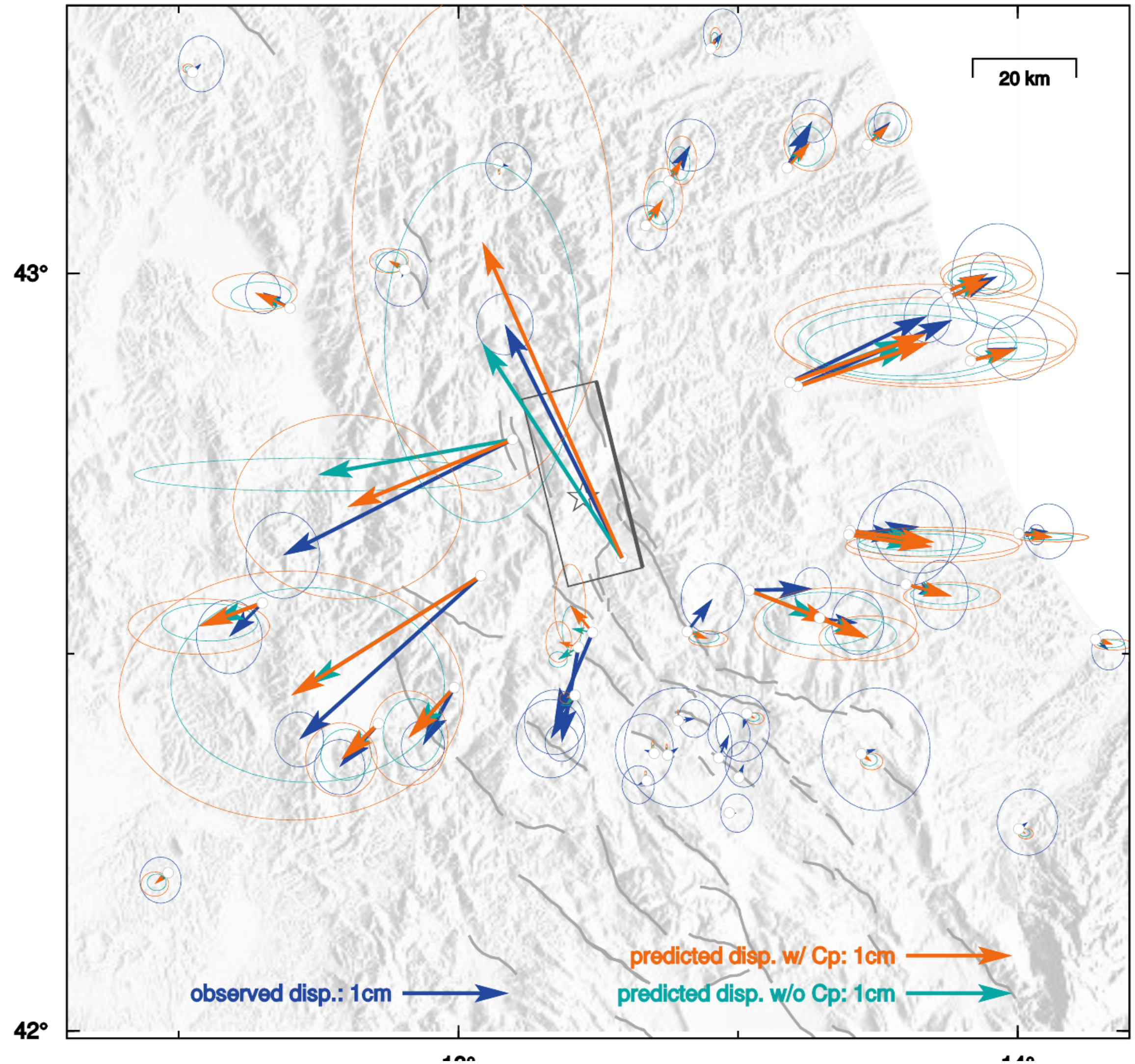
STRIKE SLIP, 1D marginal PDFs
a
dip=85°,
No Cp
b
dip=85°,
Cp on fault dip
included
c
dip=85°,
Cp on Earth
model included
d
dip=85°,
Cp on fault dip and
Earth model included
Down dip extent (km)
0-1
4-5
9-10
14-15
19-20
-4
0 1
4
Slip (m)
Slip (m)
target-0.5
target
target+0.5



DIP SLIP
20 subfaults
DIP SLIP
8 subfaults with discretization coarsened with depth
a 1D marginal PDF dip=50°, No Cp
b 1D marginal PDF dip=50°, Cp included
c 1D marginal PDF dip=50°, No Cp
d 1D marginal PDF dip=50°, Cp included
Down dip extent (km)
0-1
4-5
9-10
14-15
19-20
Model resolution on each subfault
-4
0 1
4
Slip (m)
Slip (m)
target-0.5
target
target+0.5
Model resolution
0
1


20 km
−10cm
0cm
10cm
Sentinel 1
ALOS 2
43°00'
42°30'
13°00'
13°30'


MACE
MUR1
CAM1
GINE
MAGL
ARMO
GUMA
CESI
FOL1
GRAM
GROM
MRRA
ASCC
ASC1
NRCI
AMAT
TERI
LNSS
TERA
RSTO
GNAL
CER2
TOSS
PSAN
MTER
MTTO
RIET
TERM
CONI
INFN
AQRA
CDRA
ROPI
SCRA
CAOC
RIFL
20 km
Vertical co−seismic disp.: 1cm
Horizontal co−seismic disp.: 1cm
43°00'
42°30'
12°30'
13°30'



	Fault geometry A, no C_p	Fault geometry B, no C_p	Fault geometry B, C_p
GPS	0.318	0.279	0.376
ALOS ascending	2.67	1.73	1.91
ALOS descending	3.48	2.62	3.33
Sentinel ascending	5.02	4.16	5.54
Sentinel descending	2.30	2.99	4.13

TABLE S2 – Residuals between observations and predictions of inferred models for fault geometries A and B, accounting or not for $\mathbf{C}_\mathrm{p}$.

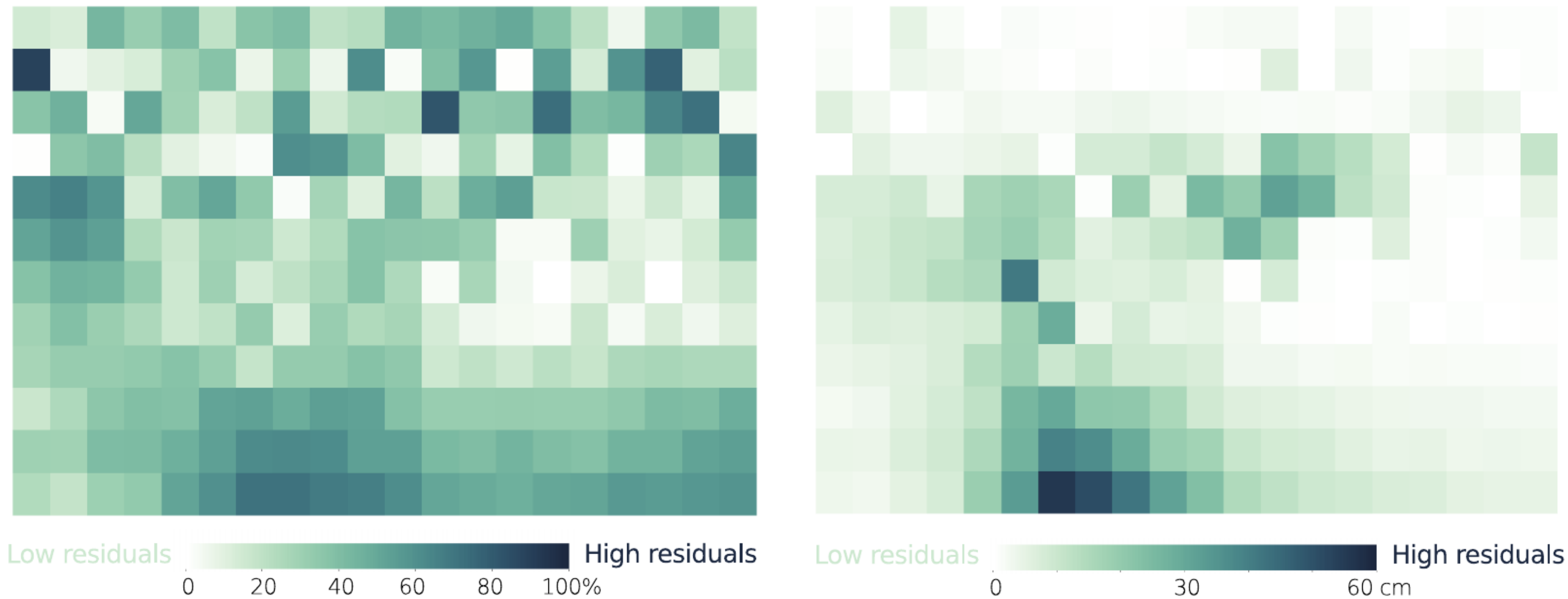


FIGURE S10 – Comparison of the residuals between inversion accounting or not for $\mathbf{C}_\mathrm{p}$ and with fault geometry B as reference. The residuals corresponding to dip-slip amplitudes of average models are presented in terms of percentage of slip (left) or as absolute values (right).