

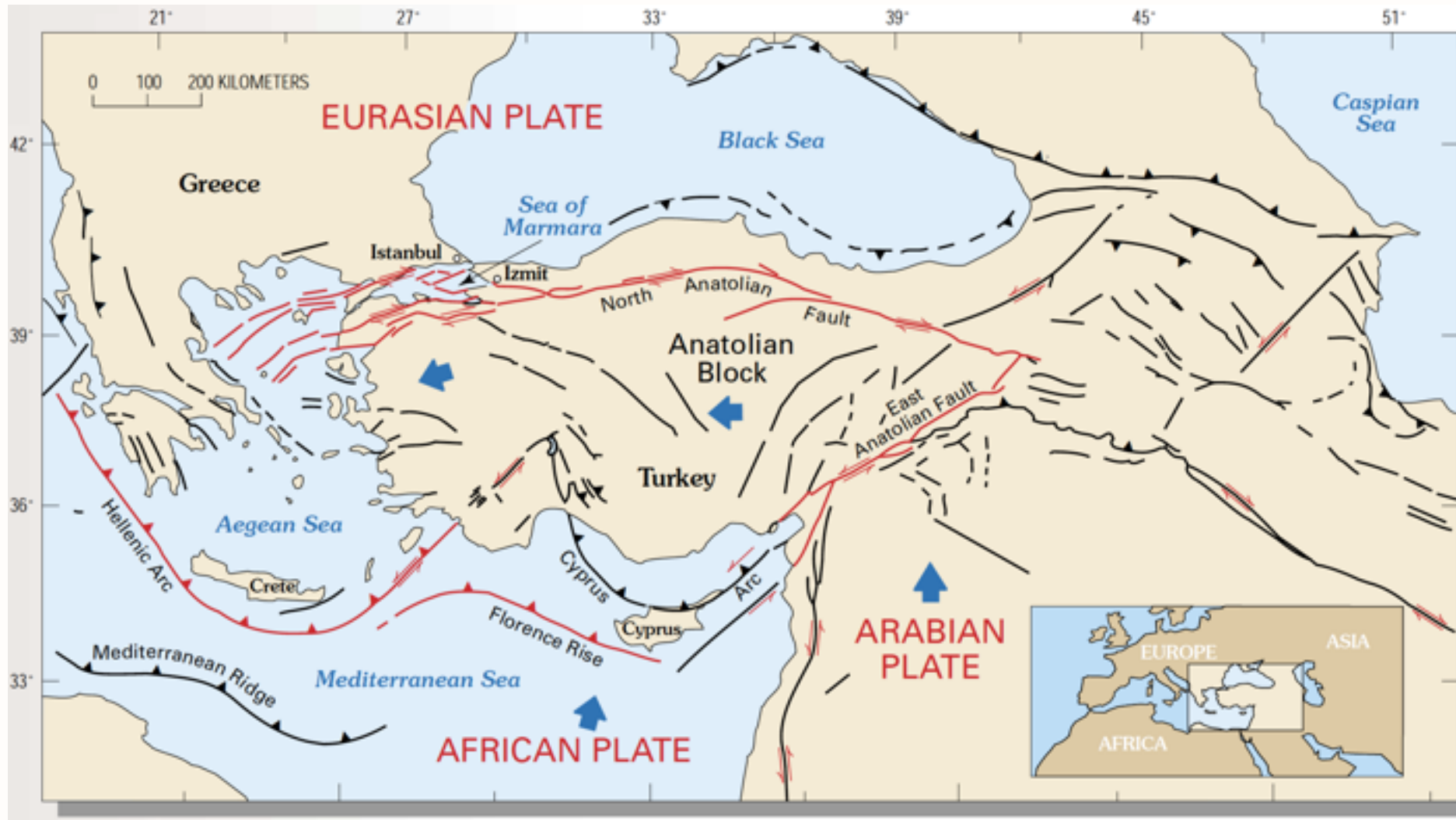
Strain rates in the Anatolia-Caucasus region from Sentinel-I InSAR and GNSS, and comparison with earthquake catalogues



Chris Rollins - Tim Wright - Yasser Maghsoudi Mehrani - Milan Lazecky - Qi Ou - Jonathan Weiss - Hua Wang - many others

FRINGE 2023 - University of Leeds - 14 September 2023

Arabia-Eurasia collision - Anatolia motion - Caucasus orogeny



USGS [2000]

February 2023 $M_w=7.8$ and $M_w=7.5$ earthquakes: East Anatolian and adjacent faults

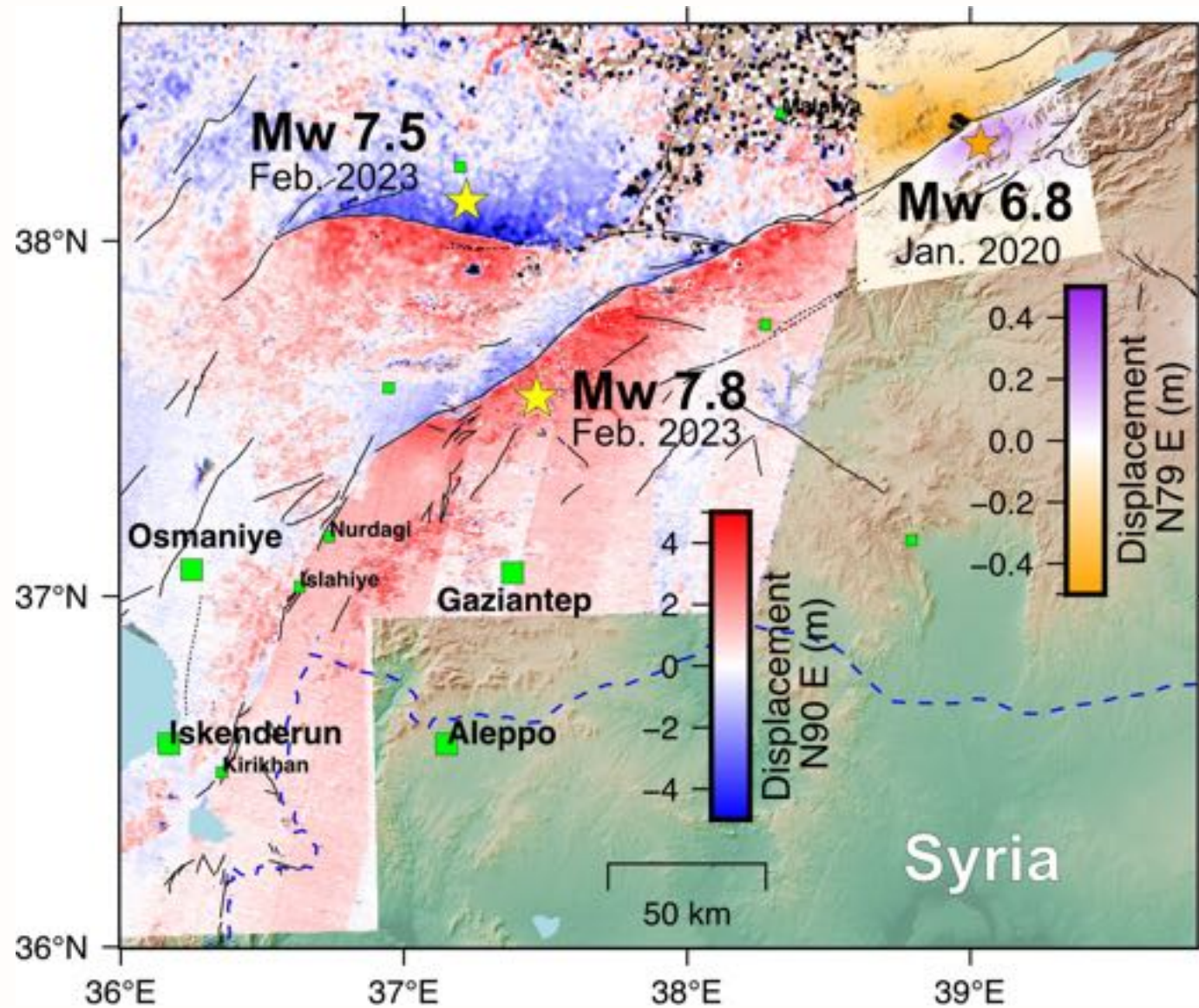


Figure from Chris Milliner

20th-century earthquake sequence on the North Anatolian Fault

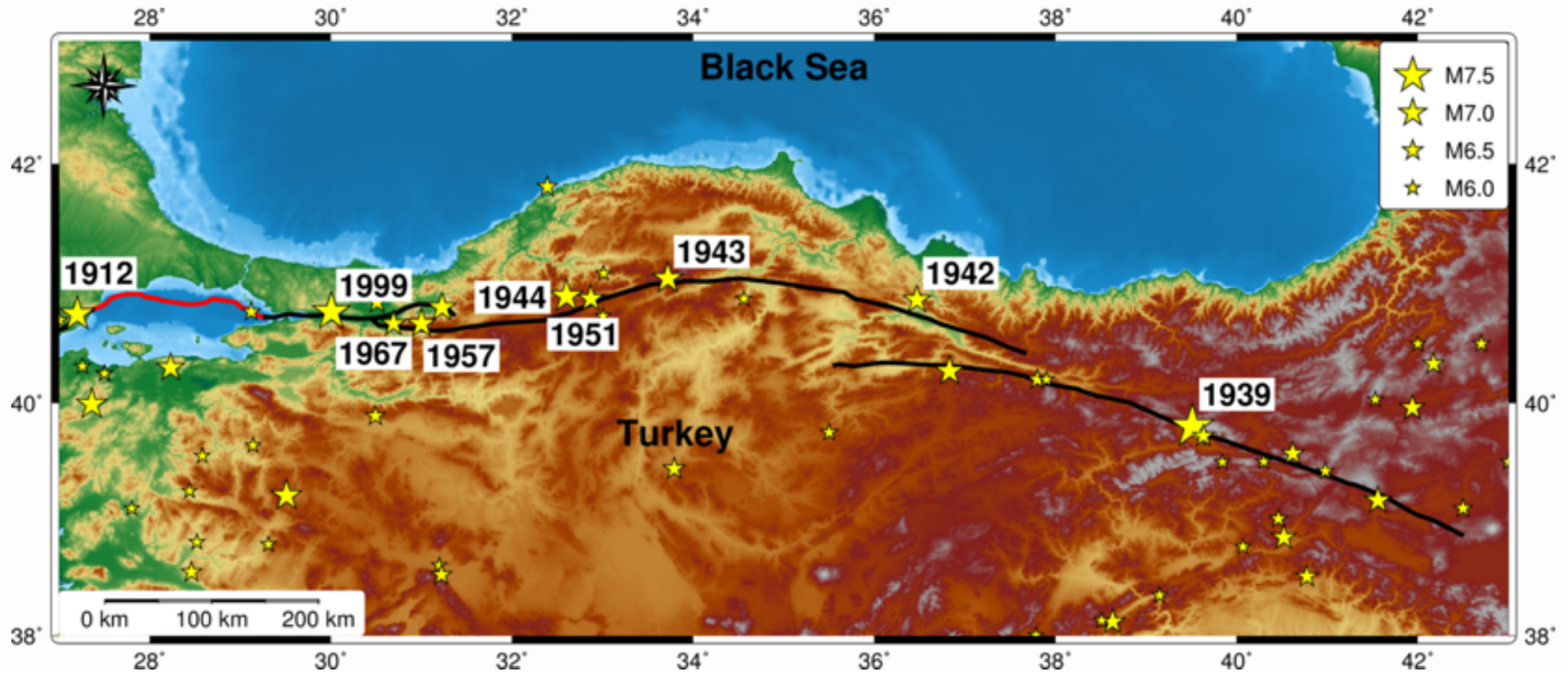
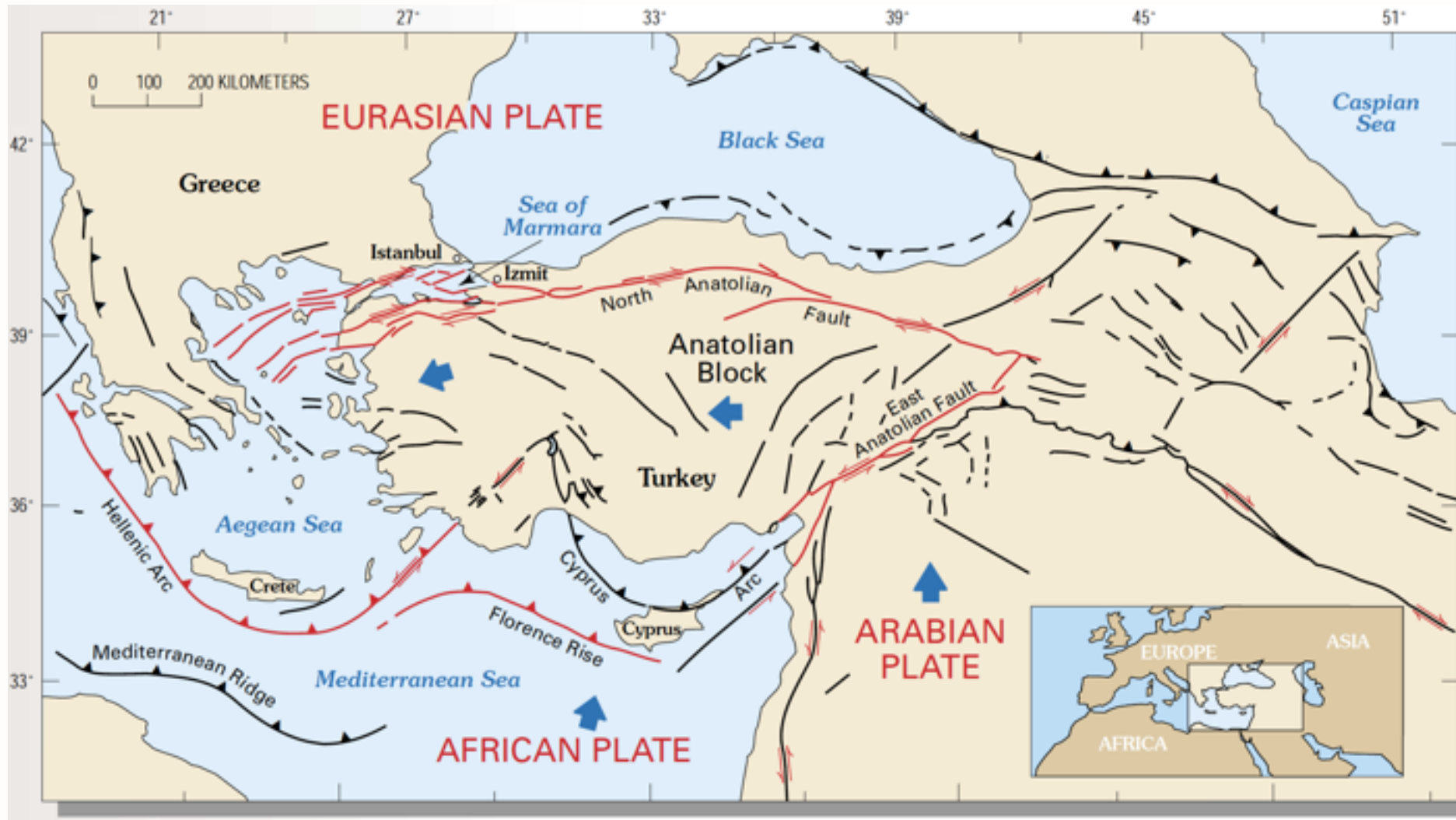


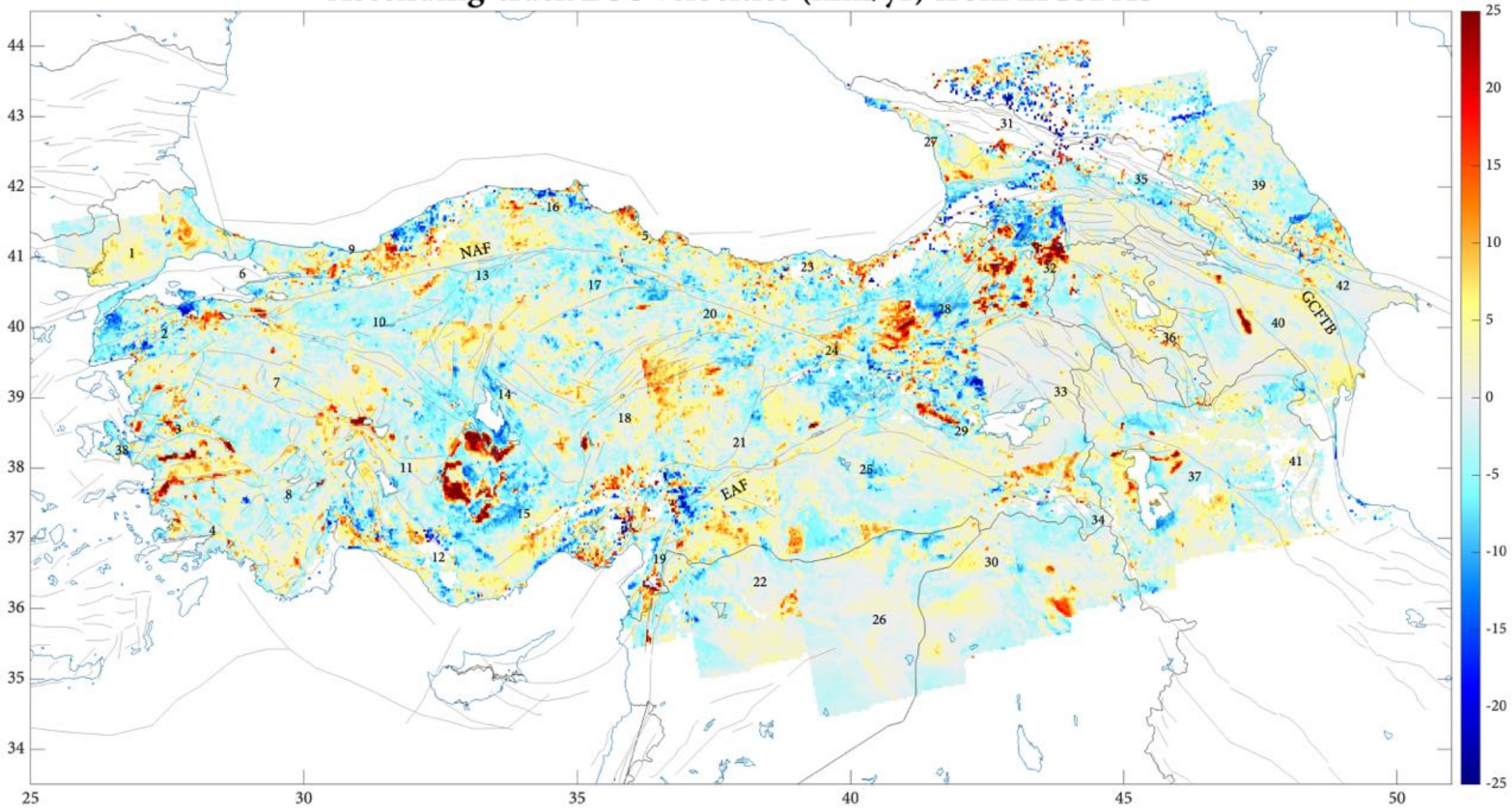
Image from GONAF

What is going on year by year, km by km? Can we see from space?

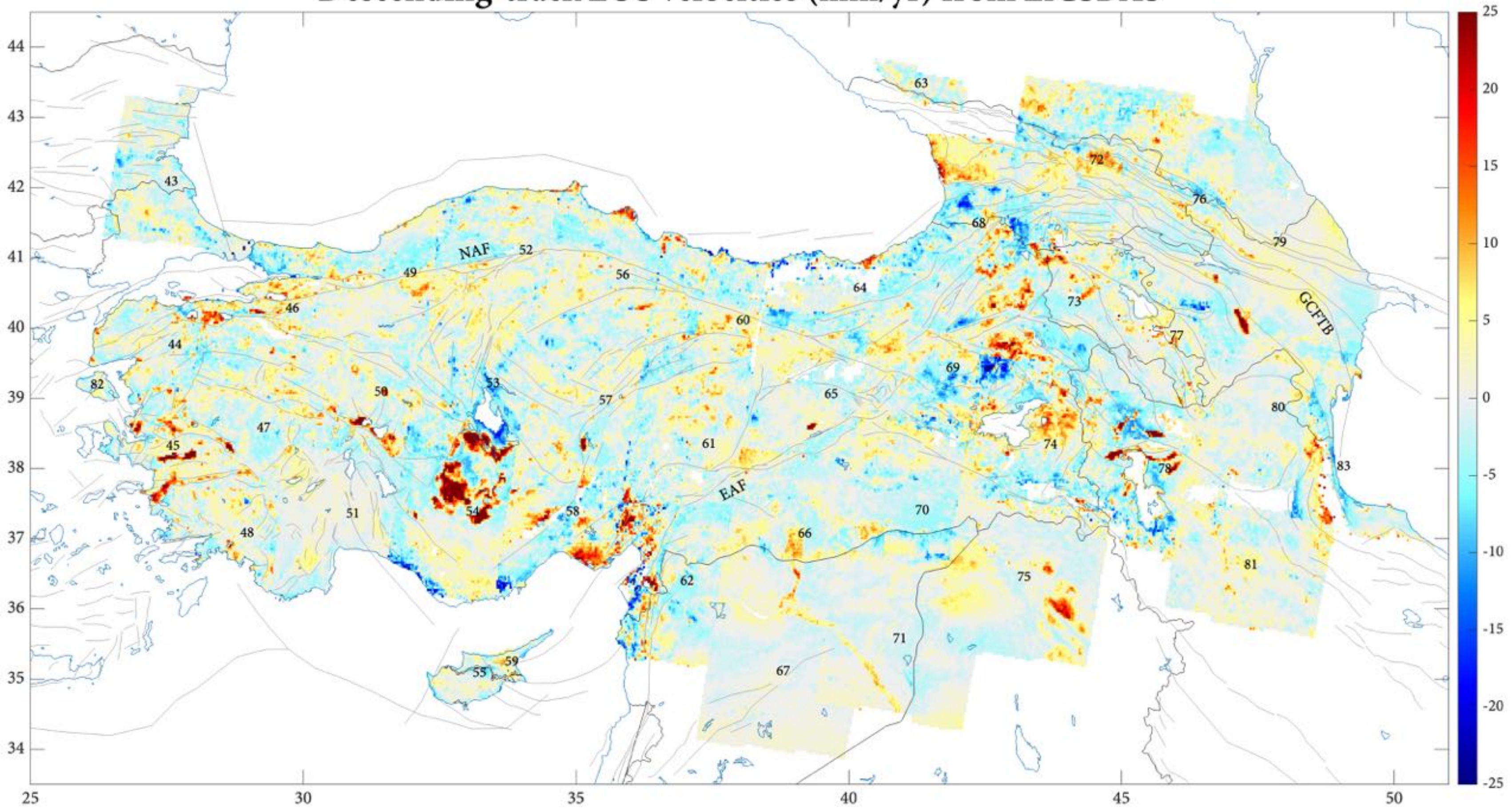


What might it imply for earthquake hazard?

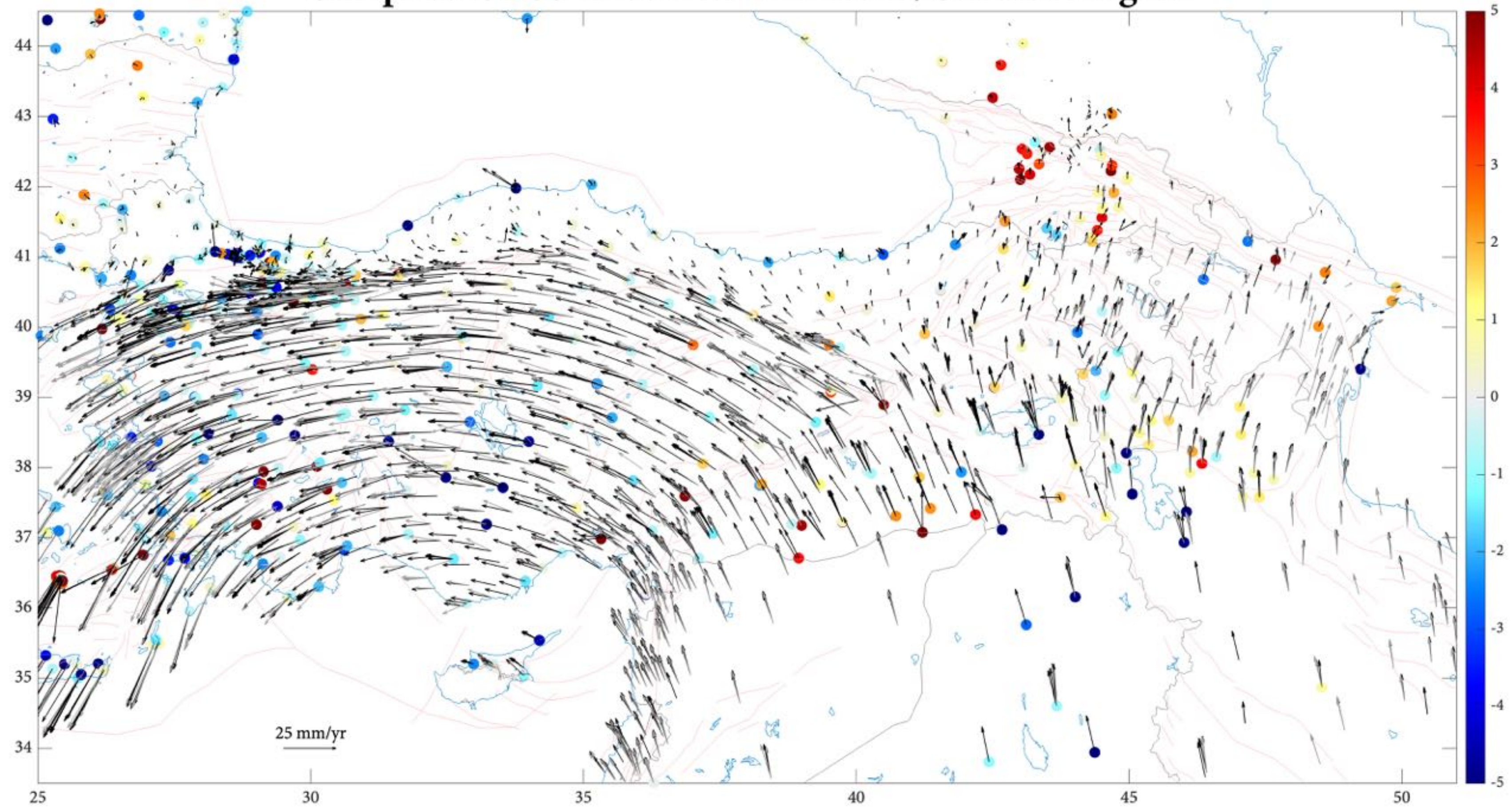
Ascending-track LOS velocities (mm/yr) from LiCSBAS



Descending-track LOS velocities (mm/yr) from LiCSBAS

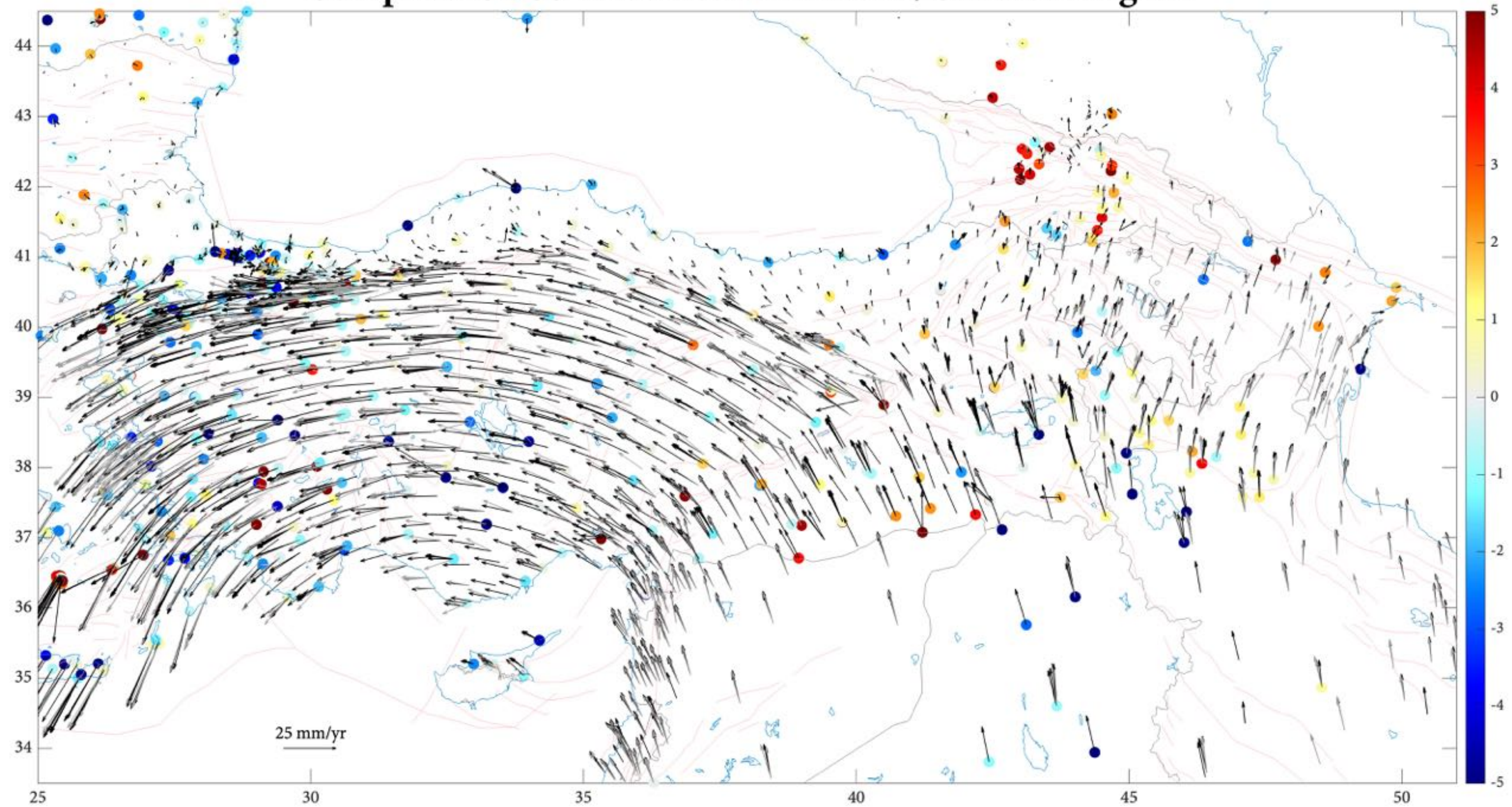


Compiled GNSS velocities in Anatolia/Caucasus region

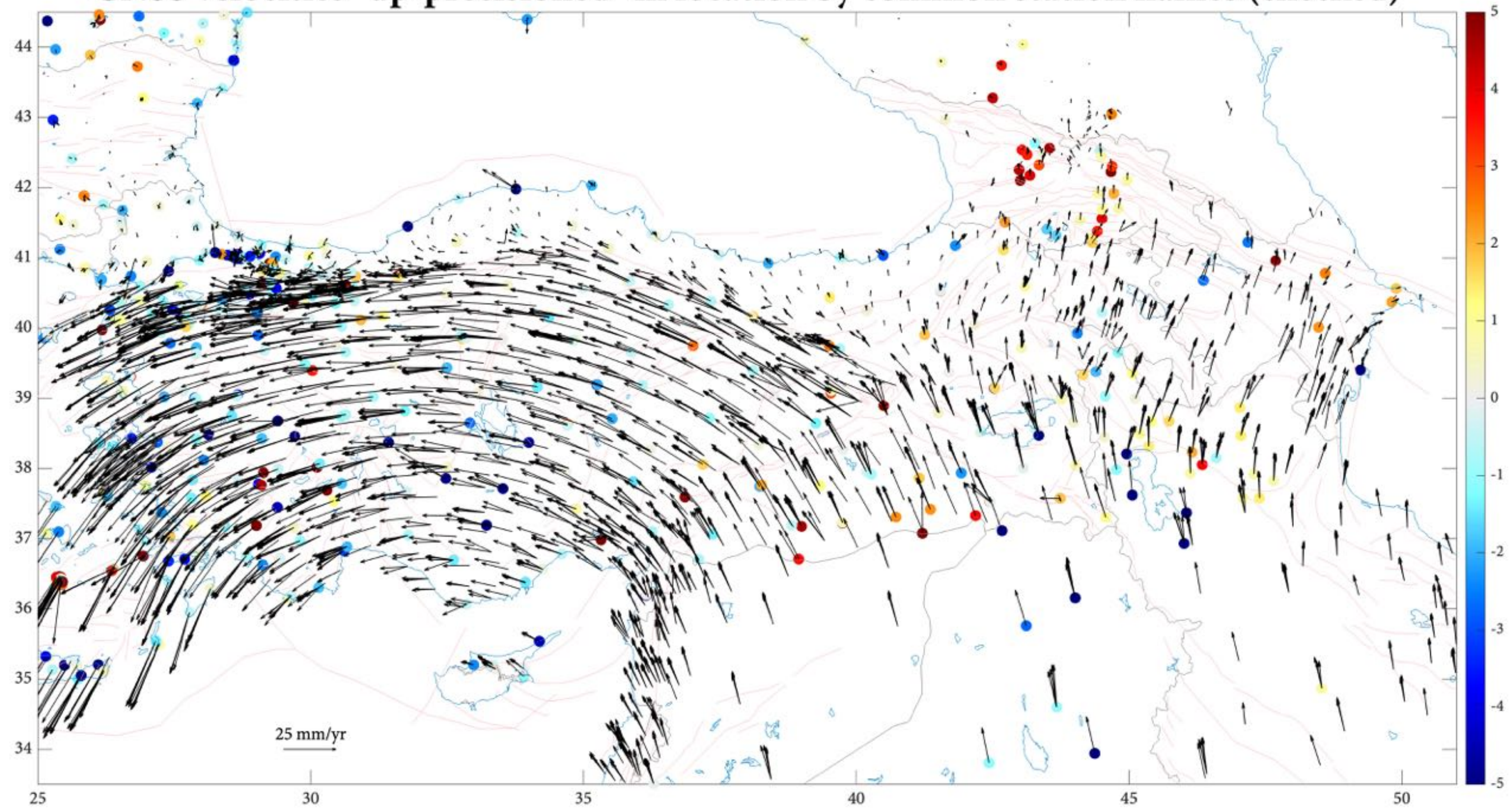



```
43 studies = {...
44     'atanasova14',...
45     'briole21',...
46     'dagostino20',...
47     'ergintav14',...
48     'ergintav23',...
49     'floyd23',...
50     'jolivets23',...
51     'kadirov14',...
52     'khalkhali21',...
53     'khorrami19',...
54     'kreemer14',...
55     'kurt22',...
56     'masson15',...
57     'measures',...
58     'midas',...|
59     'milyukov15a',...
60     'milyukov15b',...
61     'milyukov22',...
62     'mironov22',...
63     'ozdemir19',...
64     'palano18',...
65     'pietrantonio16',...
66     'saleh15',...
67     'sokhadze18',...
68     'viltres22',...
69     };
```

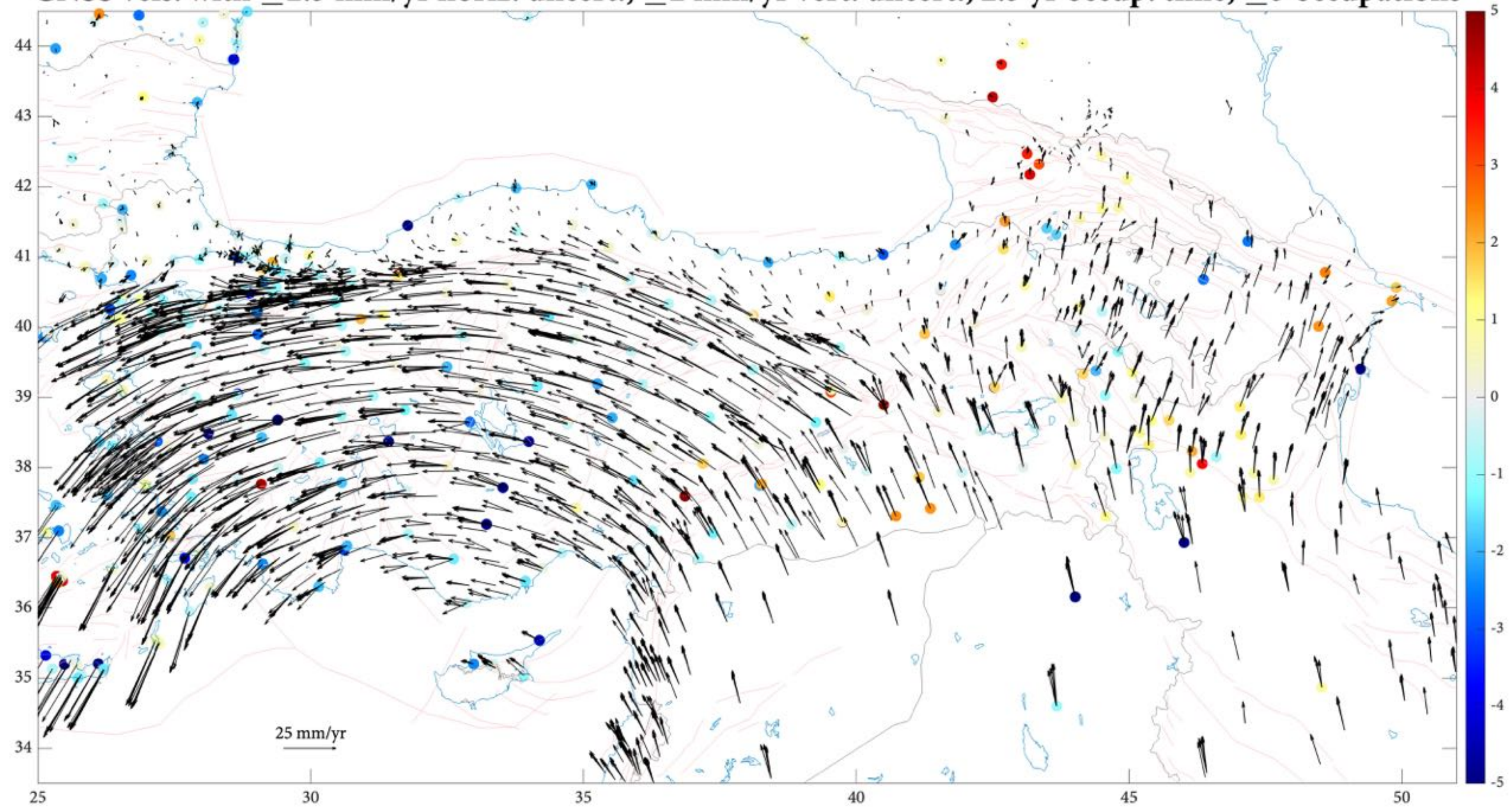
Compiled GNSS velocities in Anatolia/Caucasus region



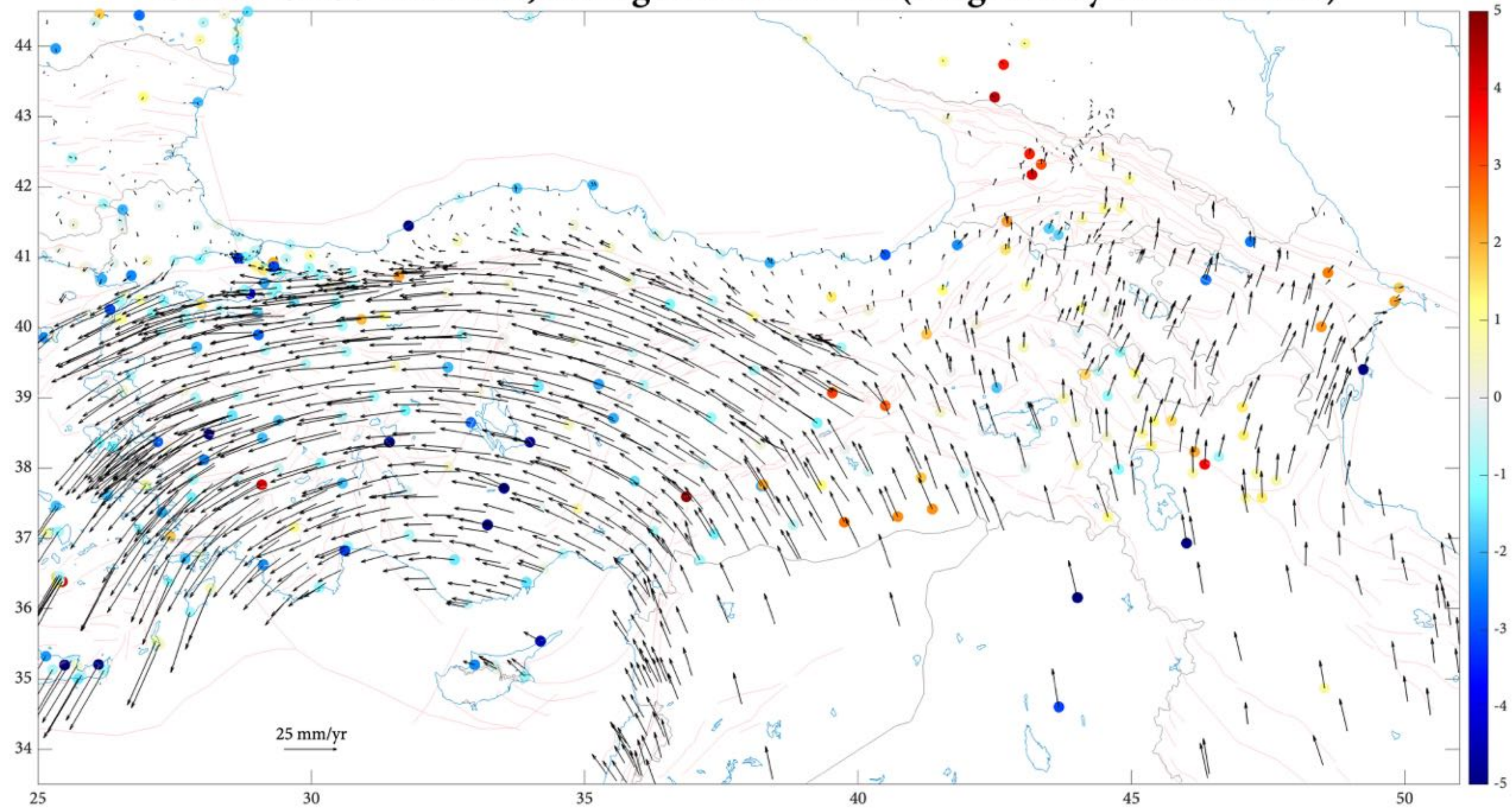
GNSS velocities "up-precisioned" in location by common station names (checked)



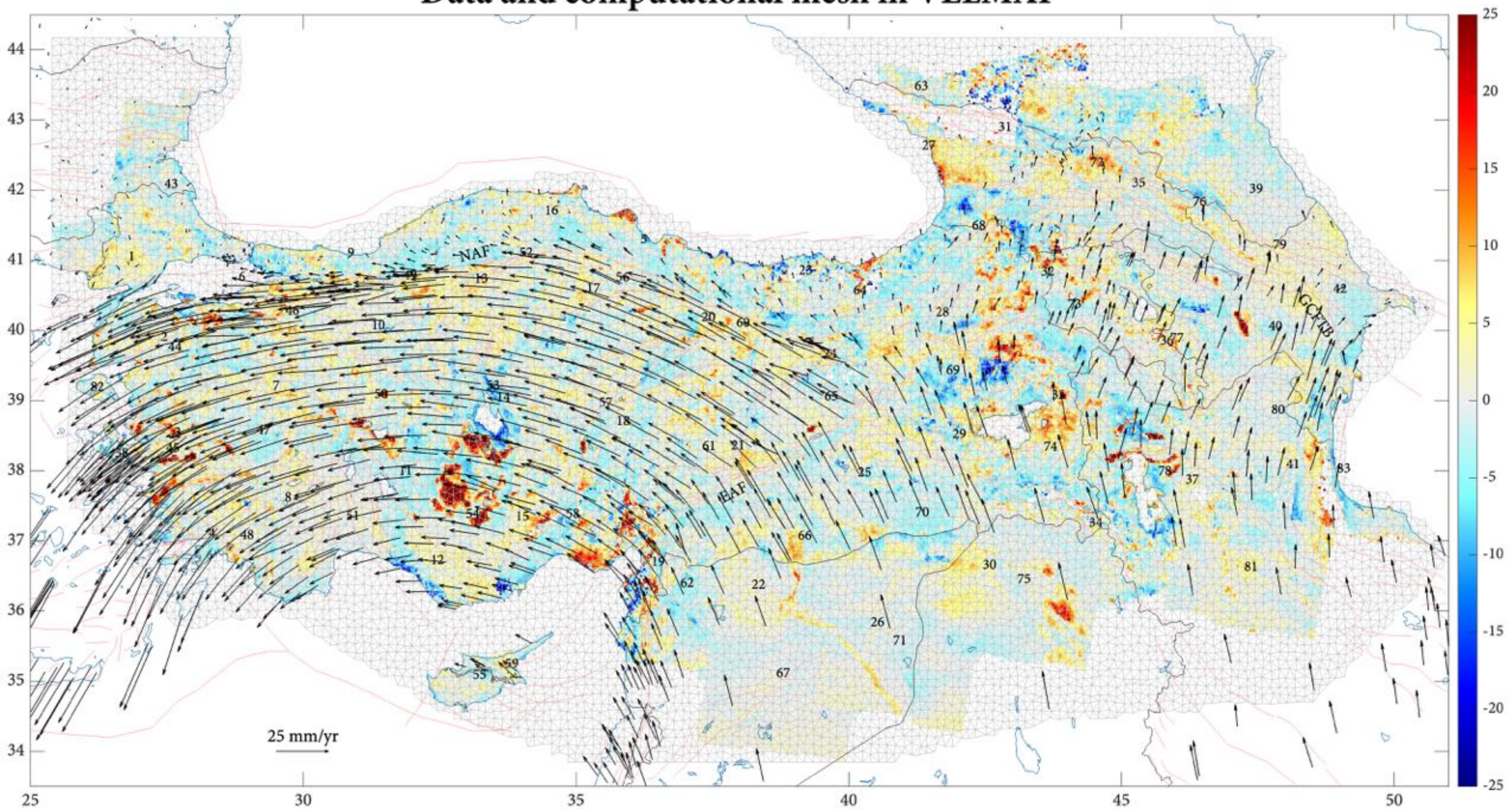
GNSS vels. with ≤ 2.5 mm/yr horiz. uncert., ≤ 2 mm/yr vert. uncert., 2.5 yr occup. time, ≥ 3 occupations



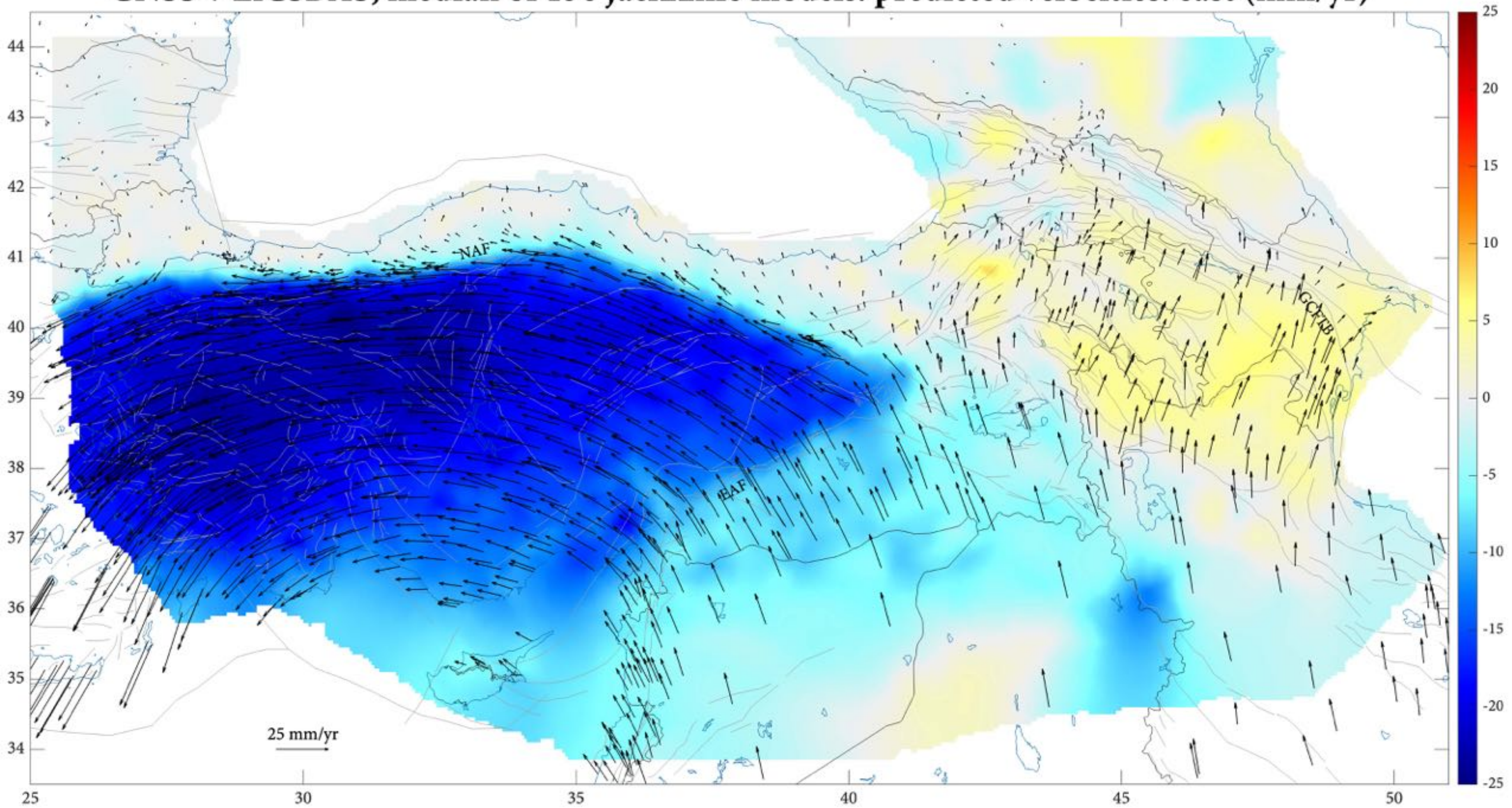
Culled GNSS velocities, averaged within 3 km (weighted by uncertainties)



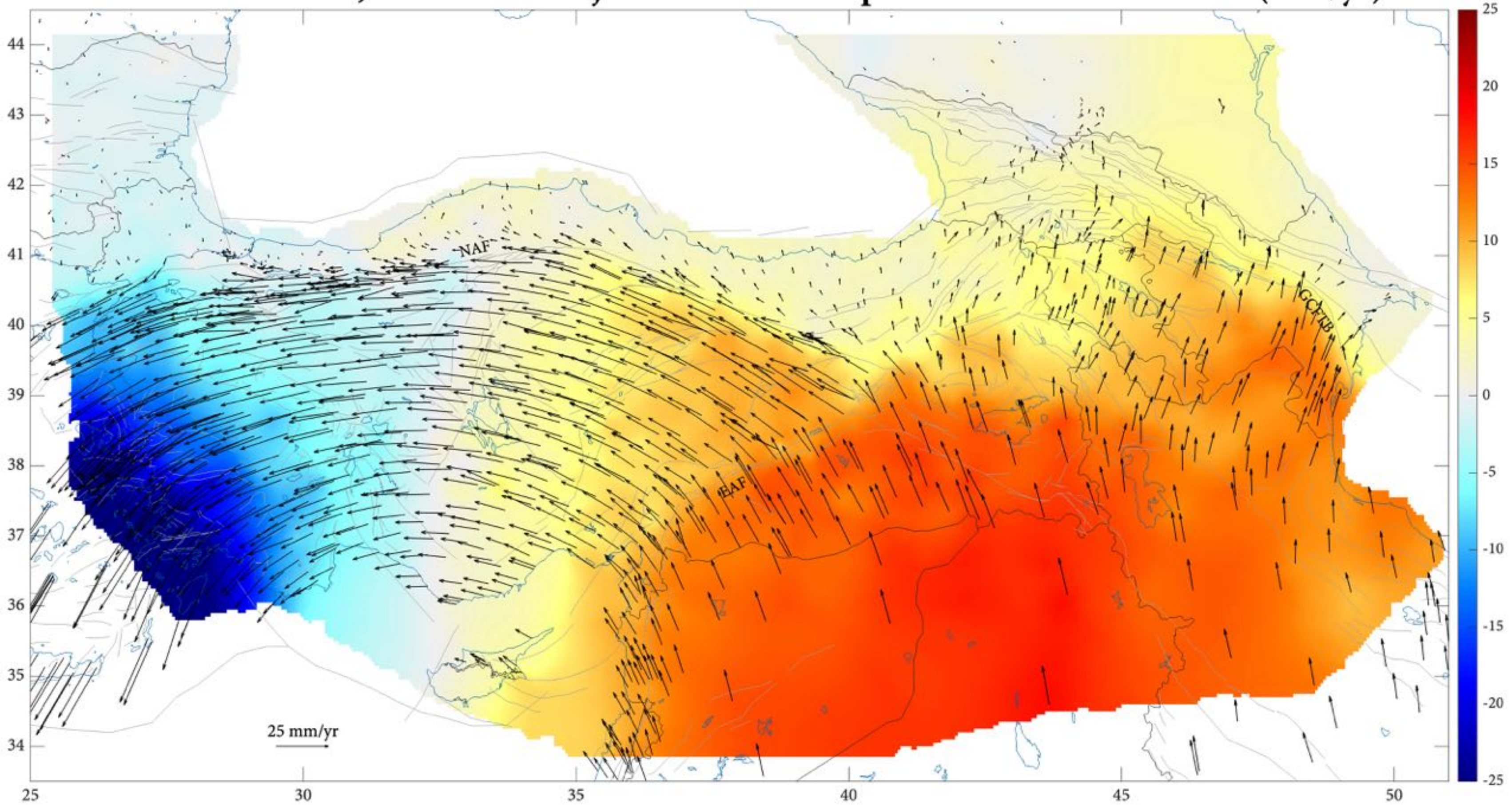
Data and computational mesh in VELMAP



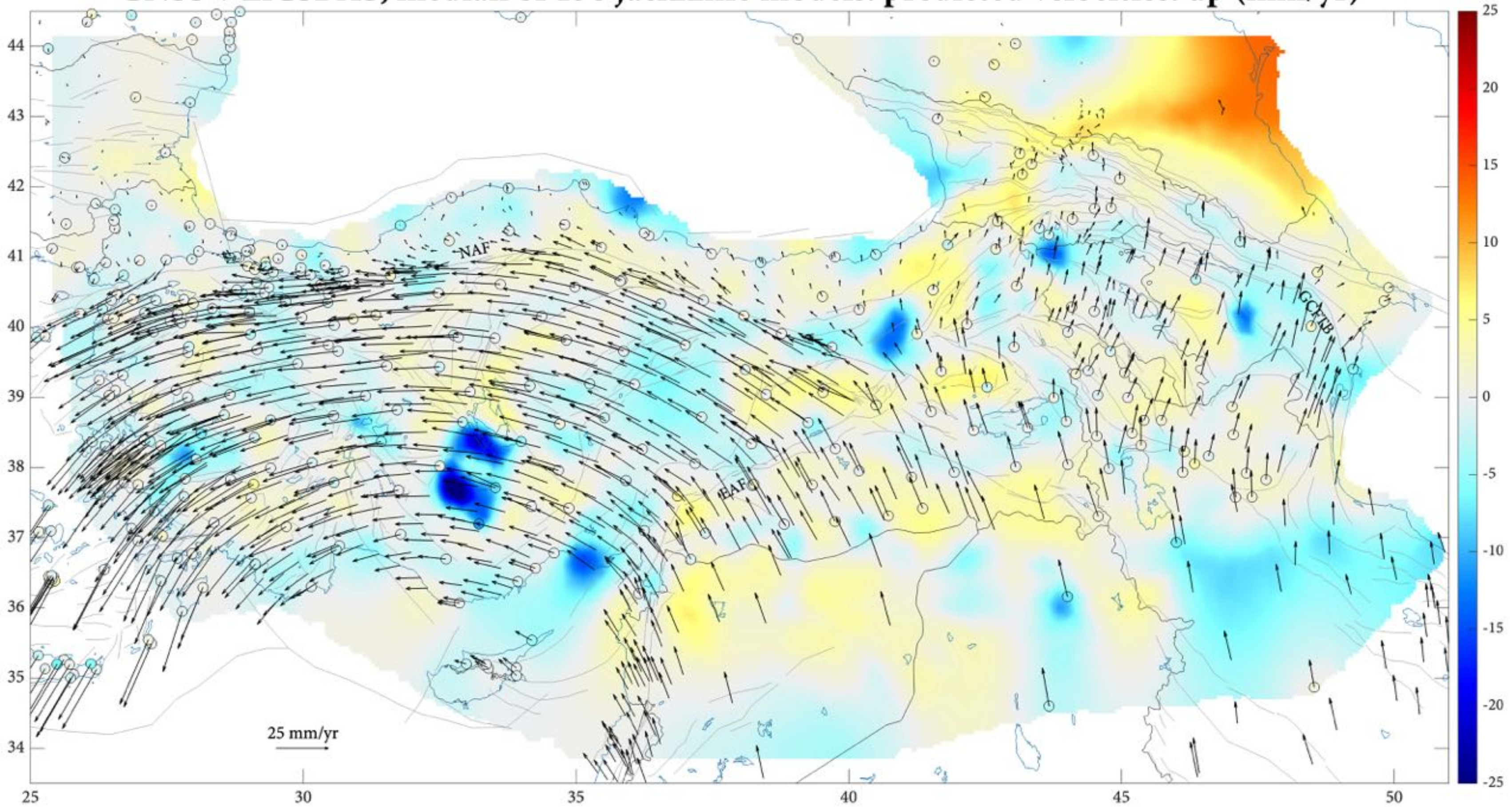
GNSS + LiCSBAS, median of 150 jackknife models: predicted velocities: east (mm/yr)



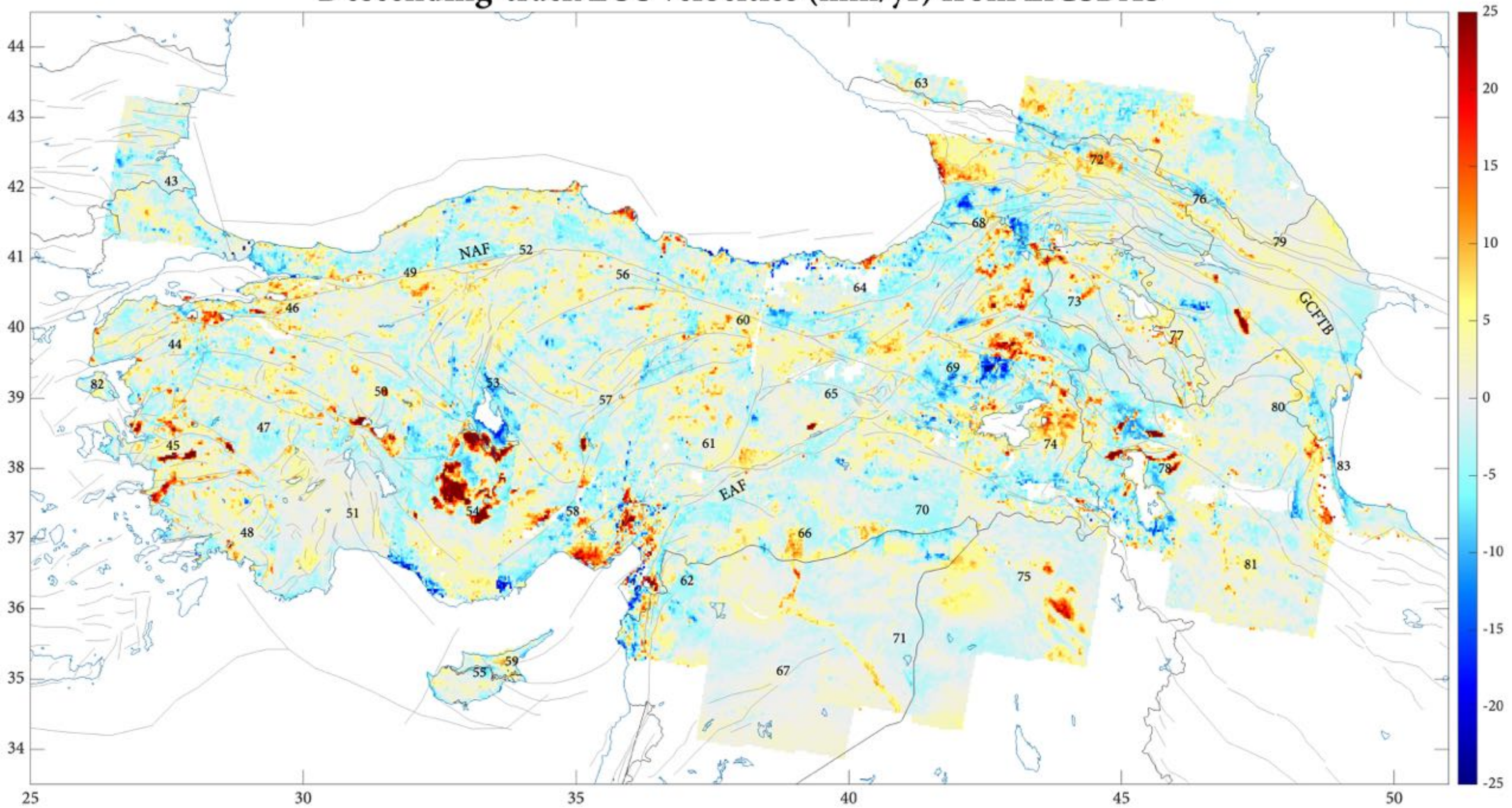
GNSS + LiCSBAS, median of 150 jackknife models: predicted velocities: north (mm/yr)



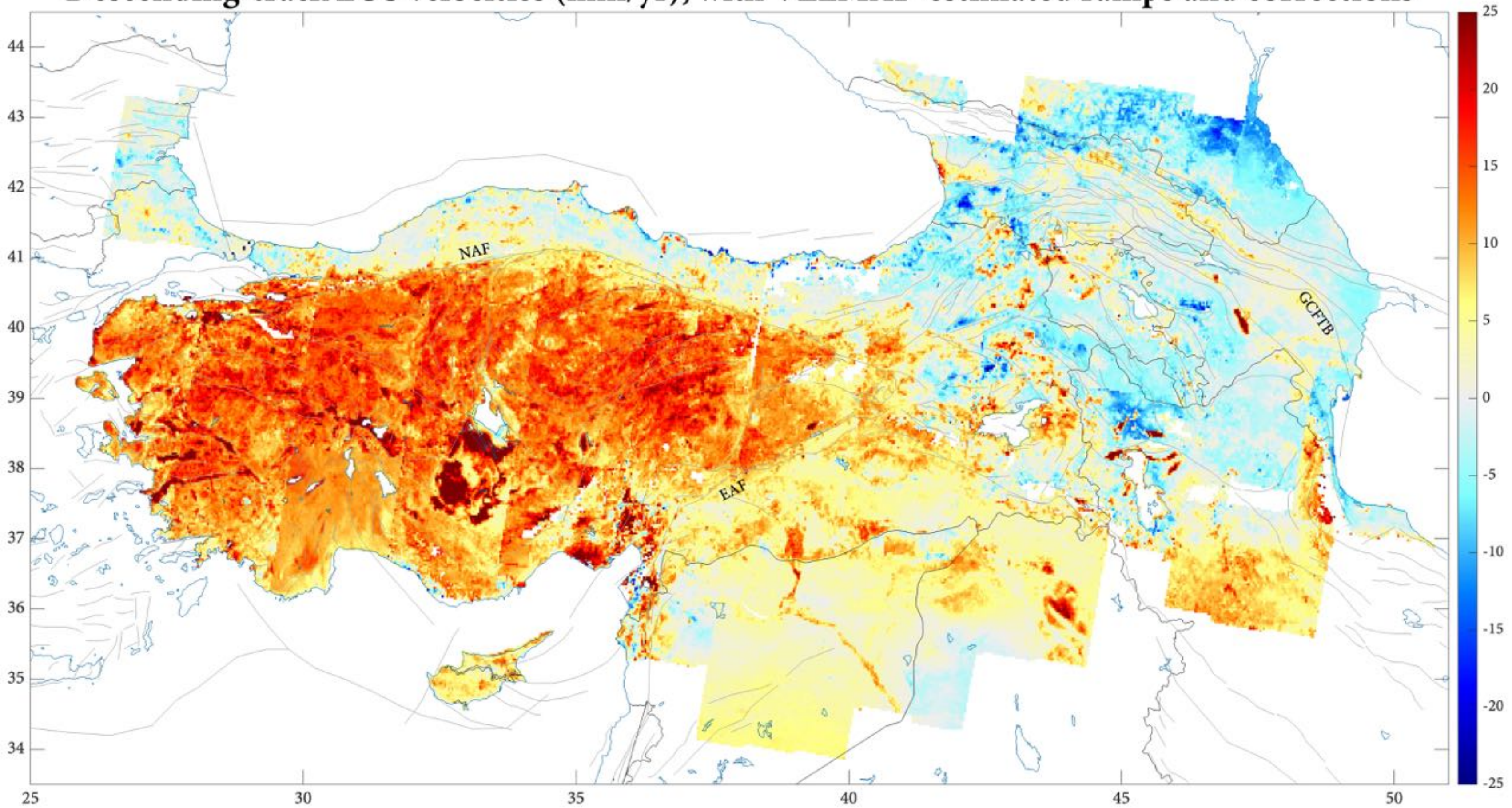
GNSS + LiCSBAS, median of 150 jackknife models: predicted velocities: up (mm/yr)



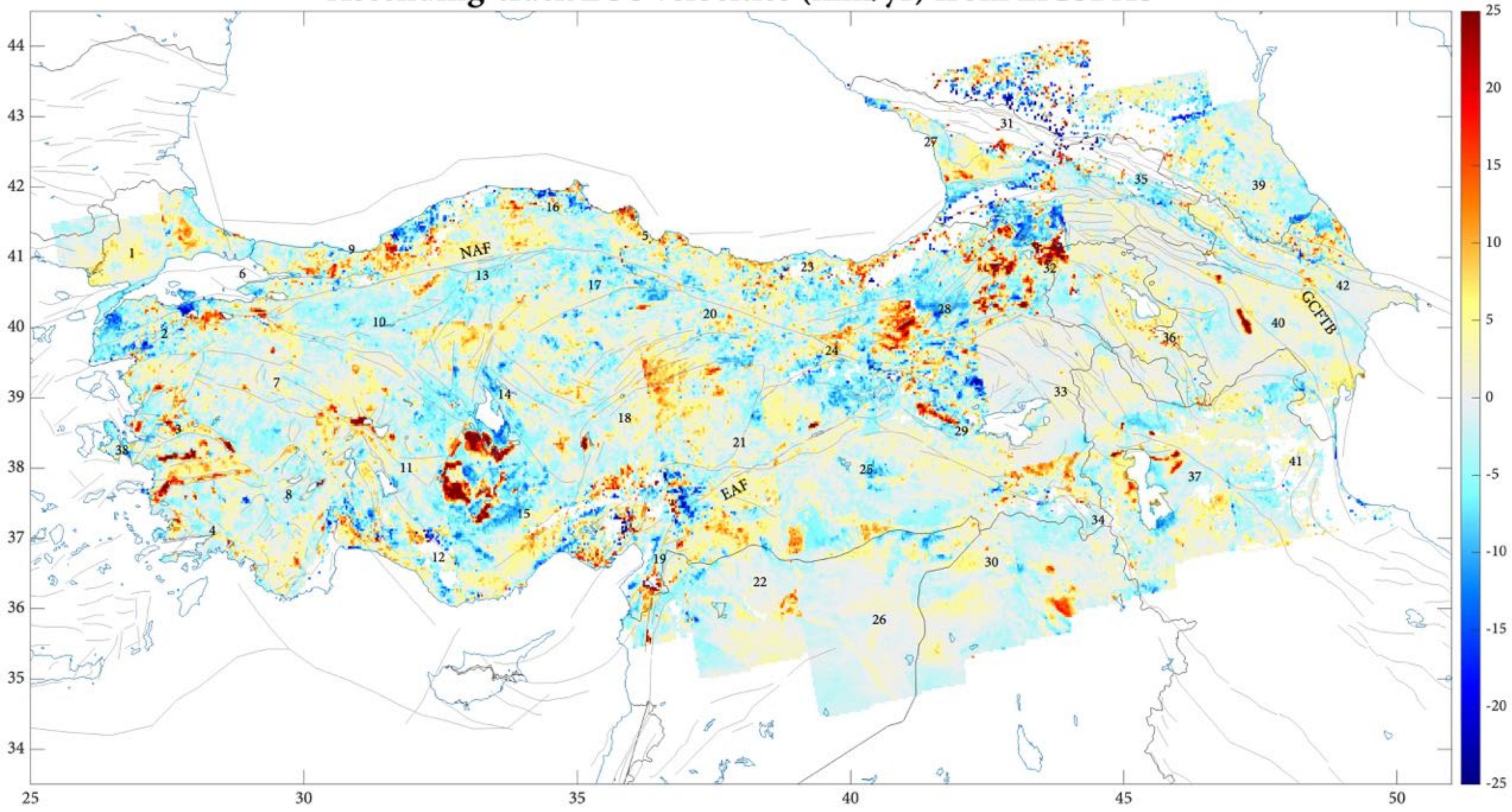
Descending-track LOS velocities (mm/yr) from LiCSBAS



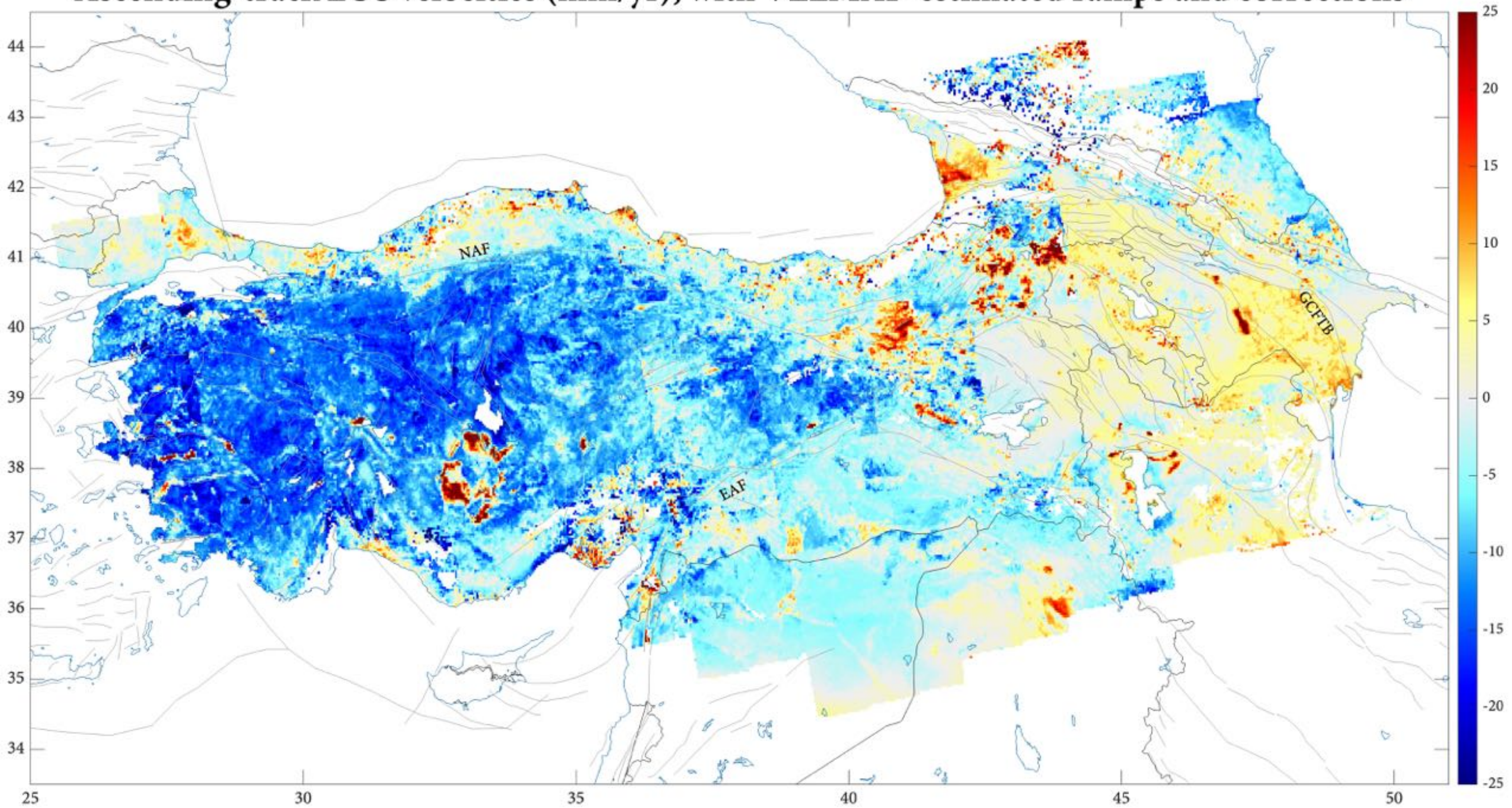
Descending-track LOS velocities (mm/yr), with VELMAP-estimated ramps and corrections



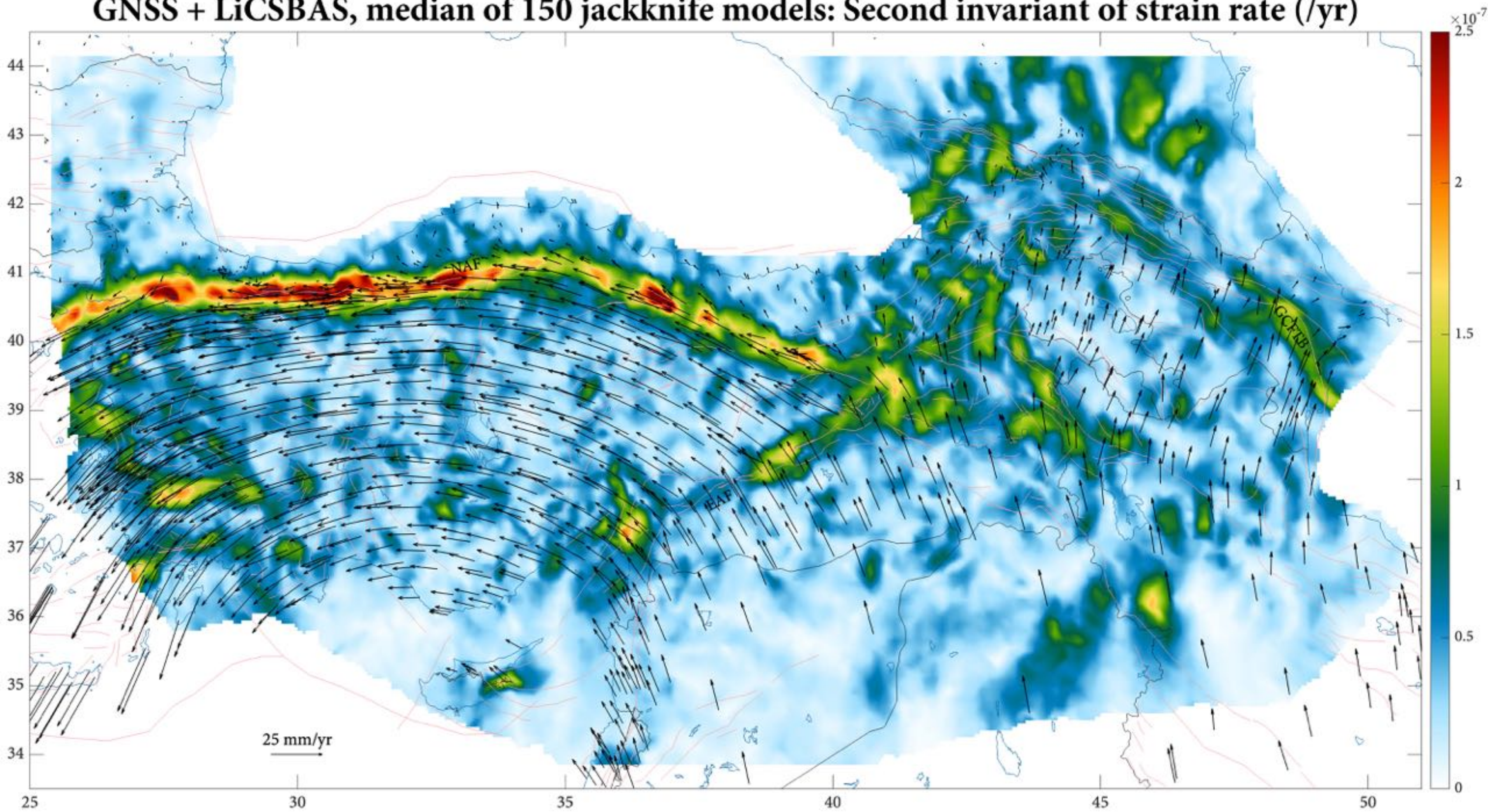
Ascending-track LOS velocities (mm/yr) from LiCSBAS



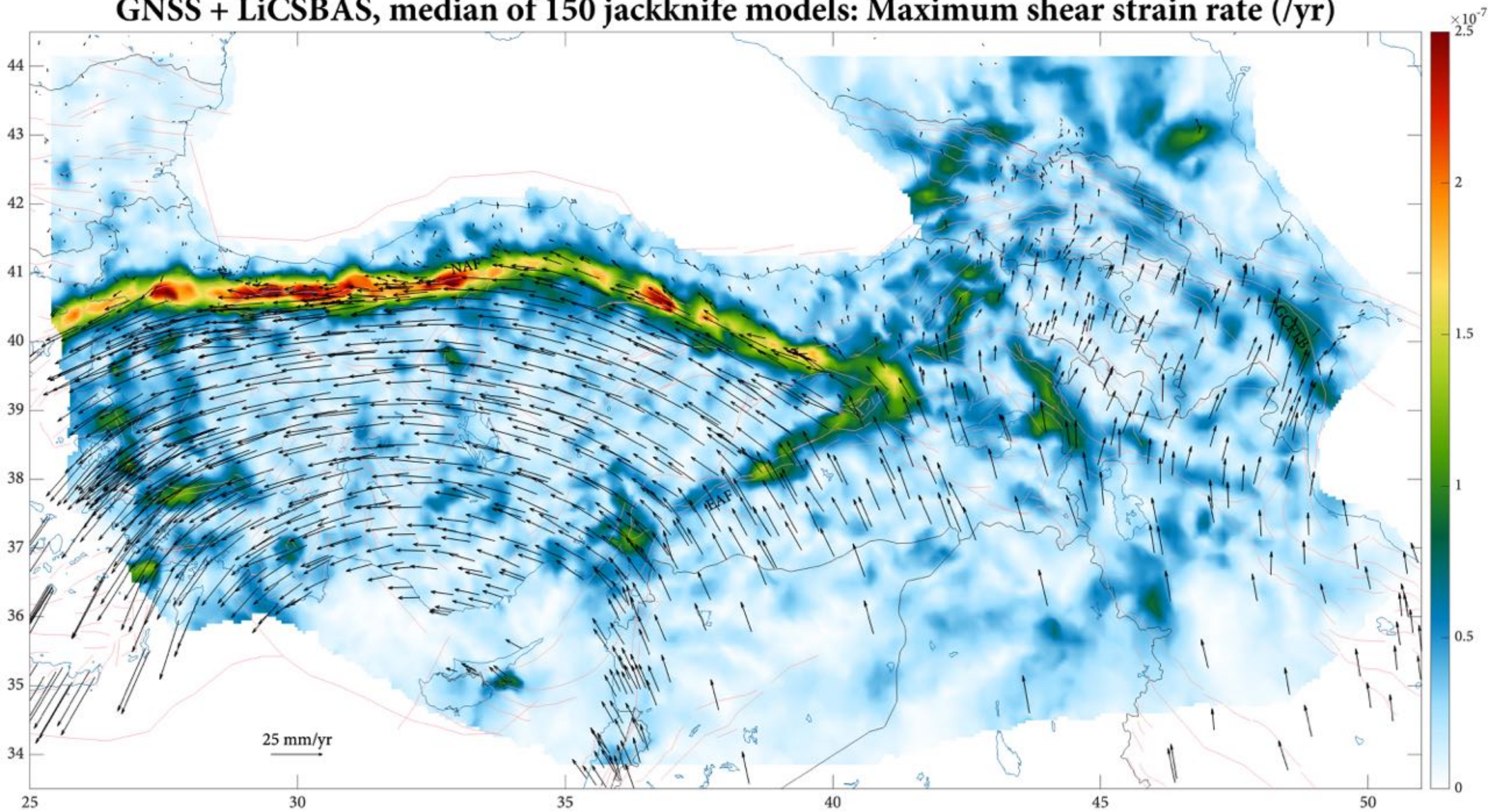
Ascending-track LOS velocities (mm/yr), with VELMAP-estimated ramps and corrections



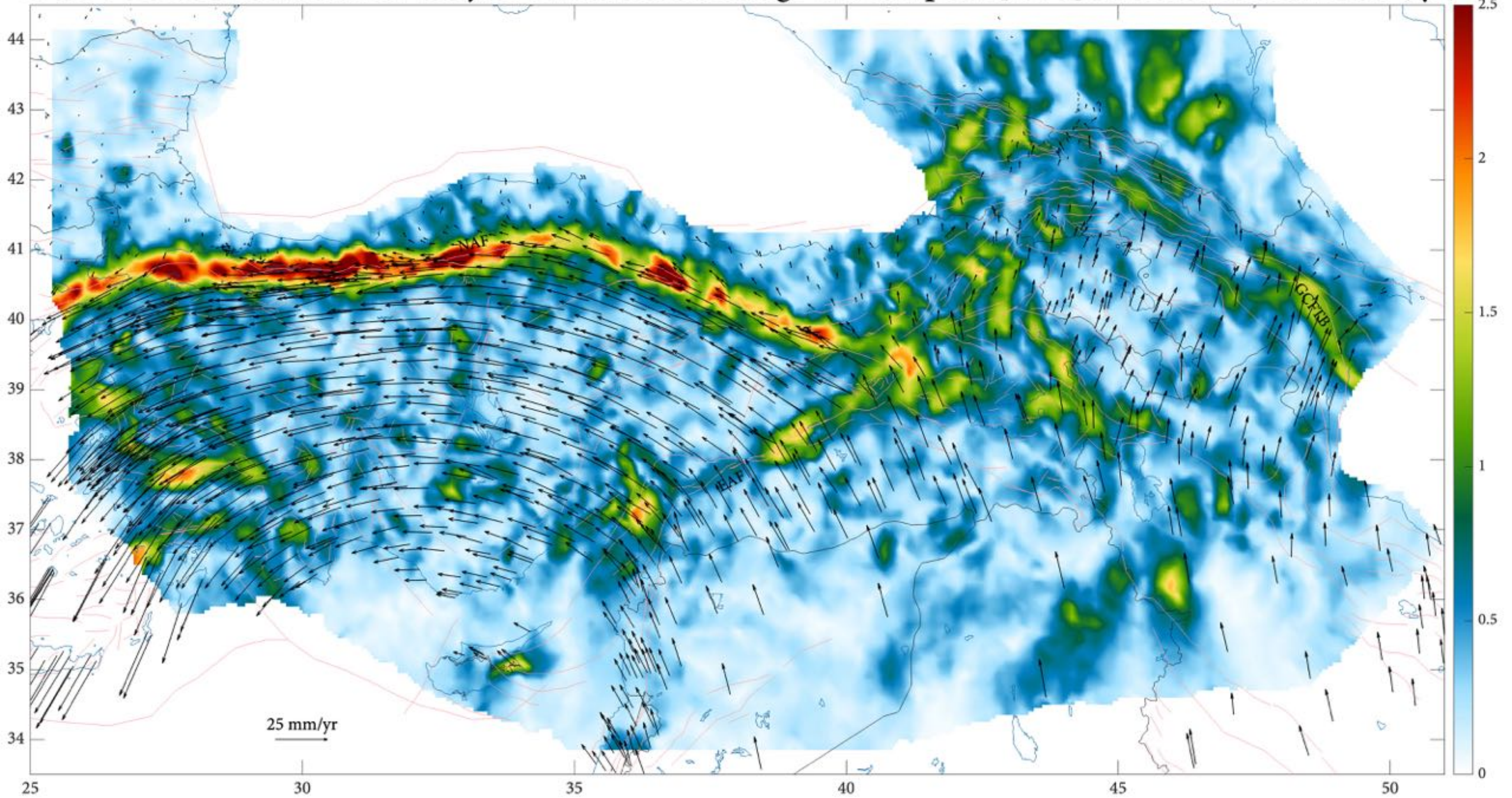
GNSS + LiCSBAS, median of 150 jackknife models: Second invariant of strain rate (/yr)



GNSS + LiCSBAS, median of 150 jackknife models: Maximum shear strain rate (/yr)



GNSS + LiCSBAS, median of 150 jackknife models: Savage and Simpson [1997] function of strain rate (/yr) $\times 10^{-7}$



Assembling a combined earthquake catalogue for the region

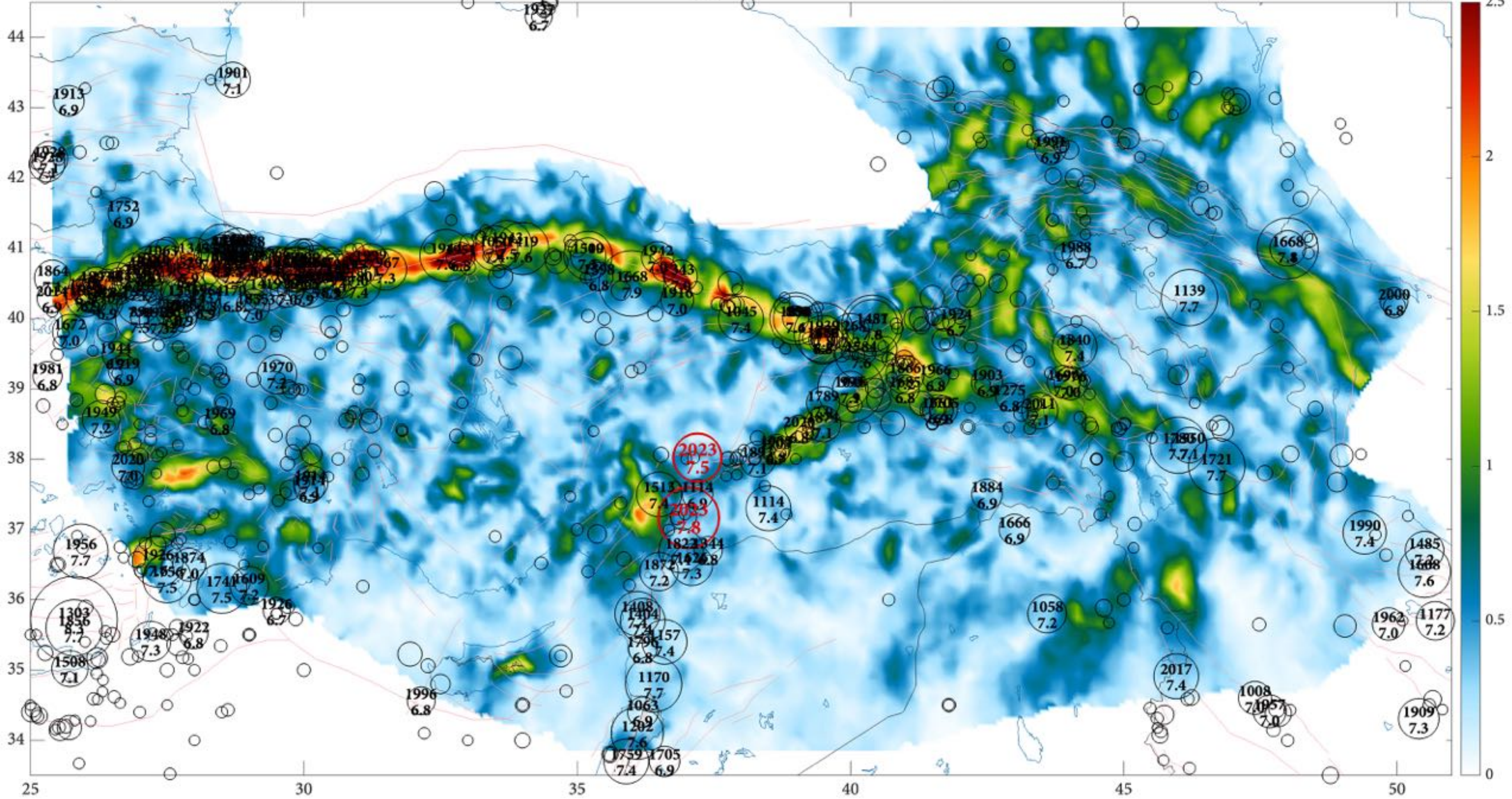
Source	Period	Parameters
Kadirioğlu et al. [2018] (full catalogue)	1900-2012	Event dates, locations, depths, magnitudes
ISC-EHB catalogue	1964-2018	Depths, a few M_w magnitudes
Global CMT catalogue	1976-2020	Depths, M_w magnitudes
ISC-GEM catalogue	1900-2018	Depths, M_w magnitudes
USGS catalogue	1973-2020	Depths, M_w magnitudes
GEM Global Historical EQ Catalogue	1000-1903	Dates, locations, depths, magnitudes
Bohnhoff et al. [2016] NAF catalogue	342 BC-2014	Dates, locations, magnitudes

(Region: 30-47° N, 19-51° E)

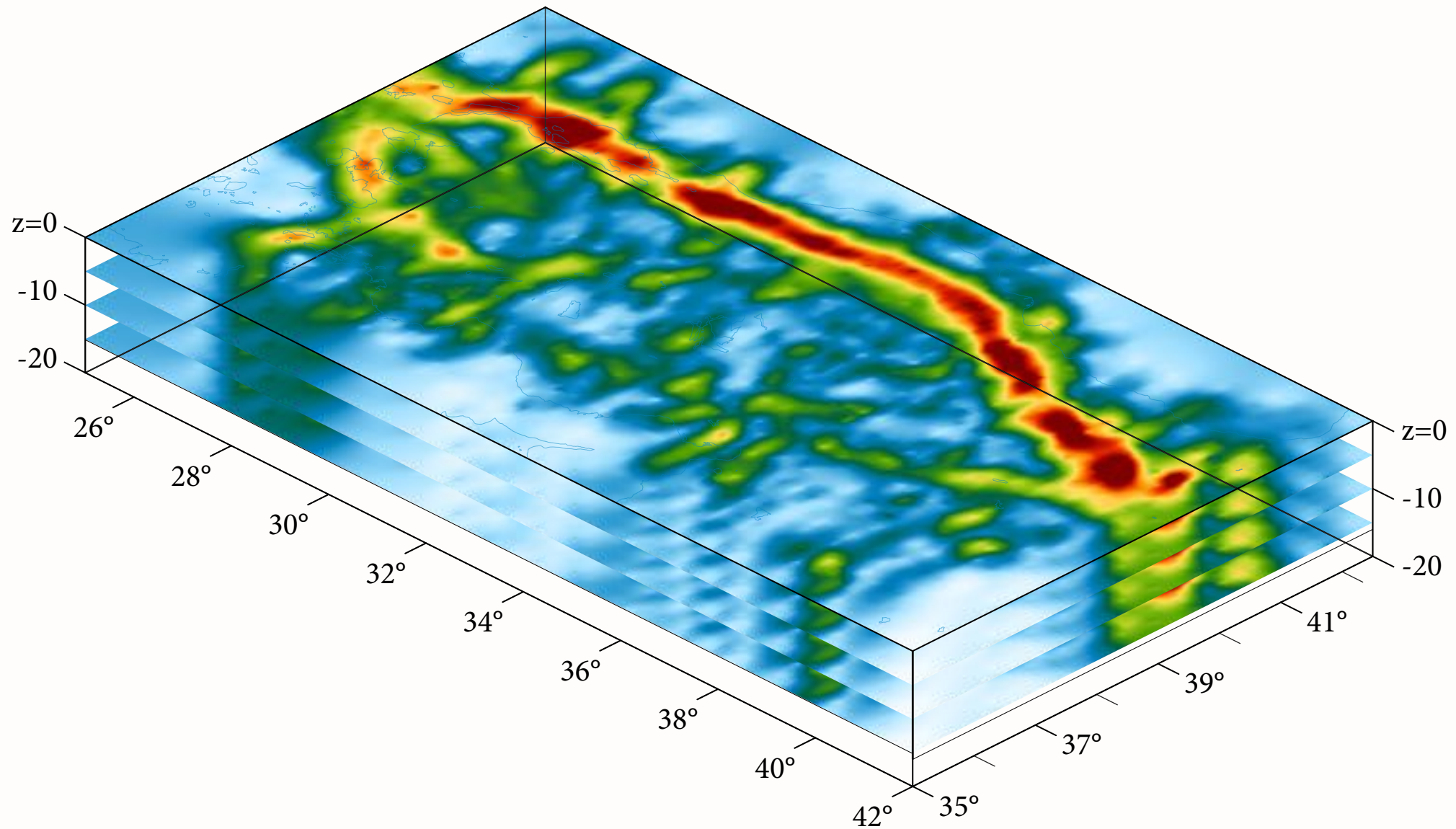
In the process of adding: Tan [2021], Rojo Limon et al. [2021]

More soon!

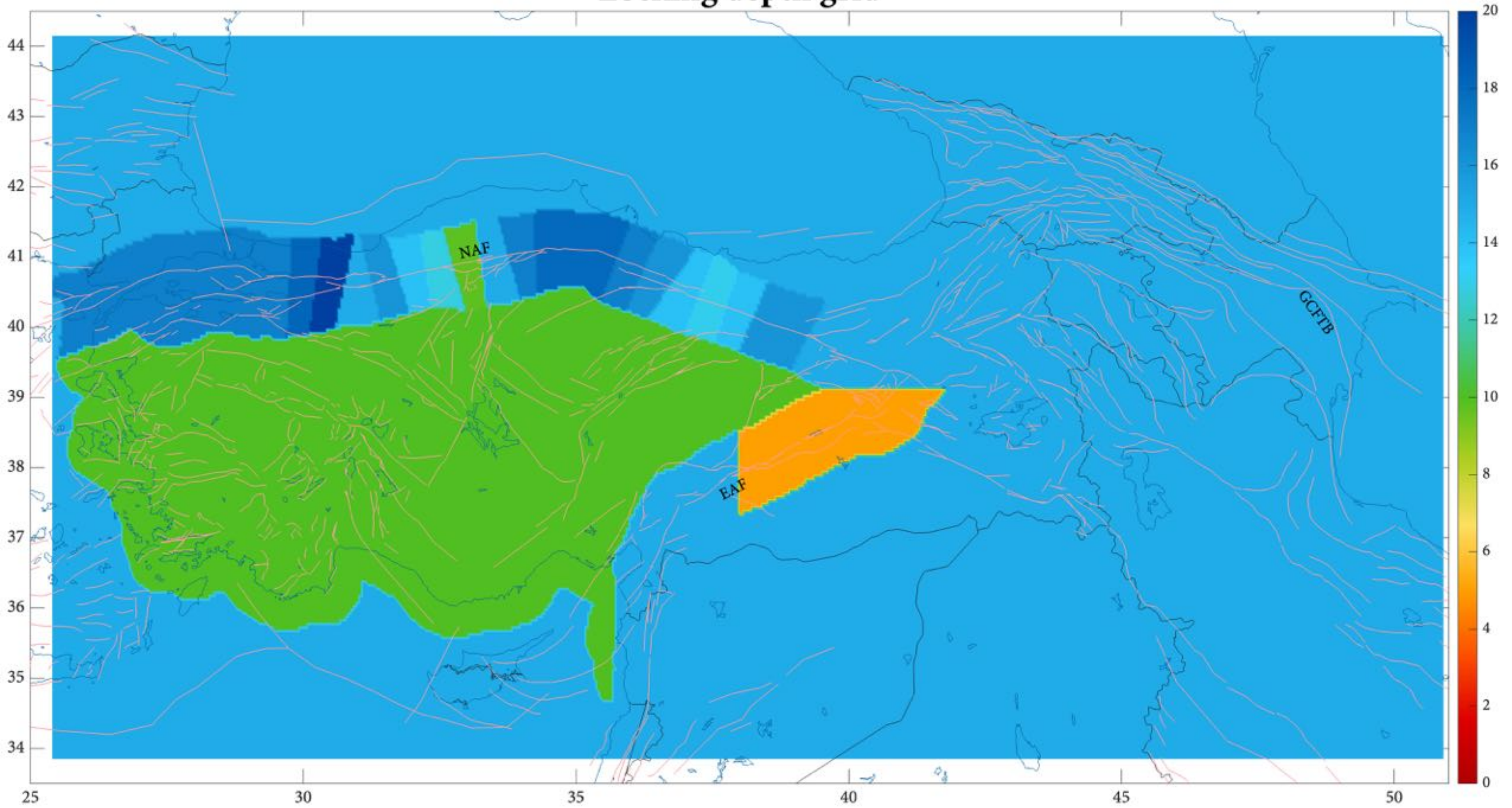
Savage and Simpson function of strain rate (/yr) + shallow $M \geq 5.5$ earthquakes ($M > 6.7$ labeled)



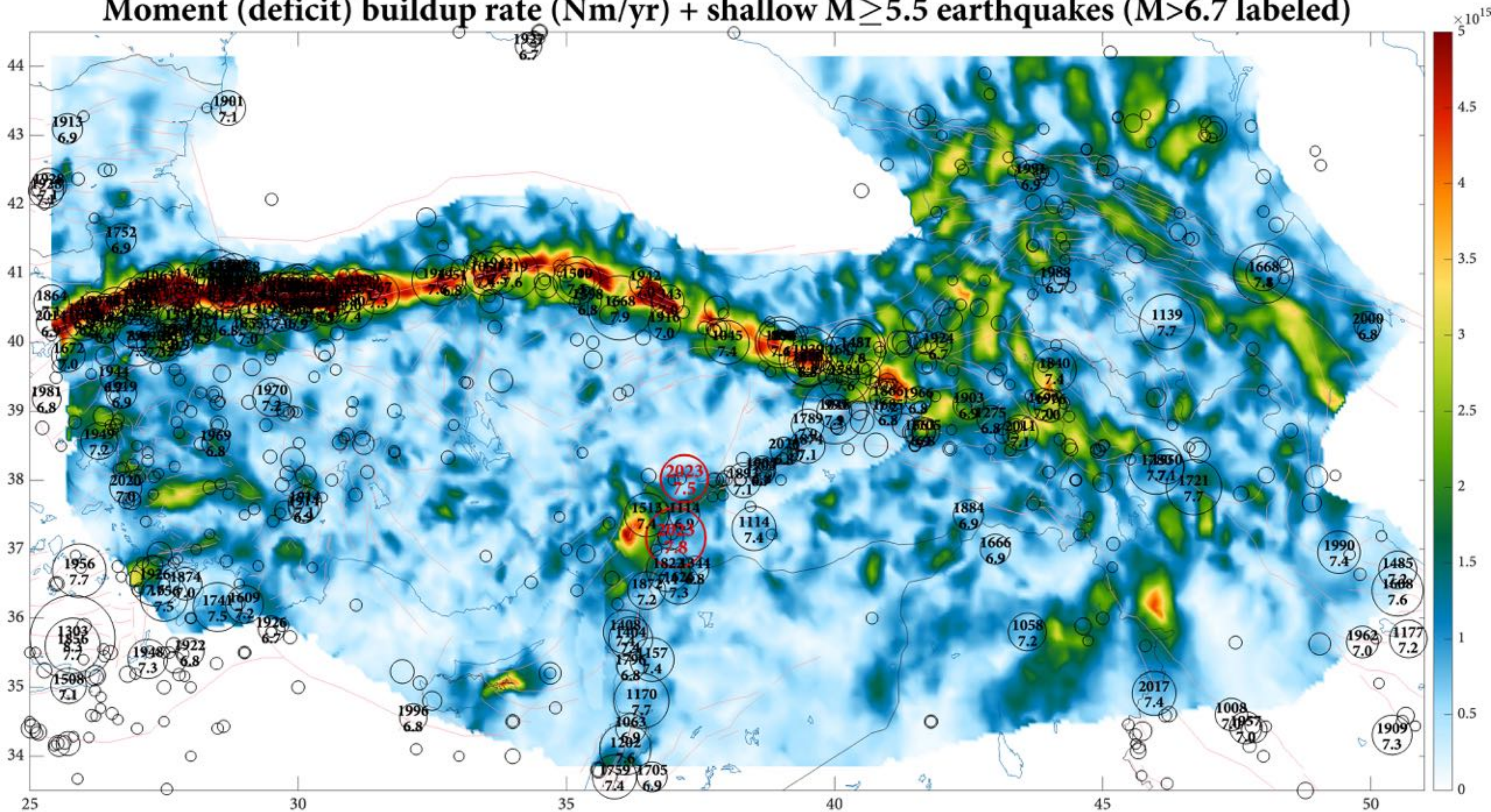
Assume surface strain rates continue down to ~ 15 km depth and that $\mu = 32$ GPa
→ can estimate **moment (deficit) buildup rate** and compare to moment release in EQs



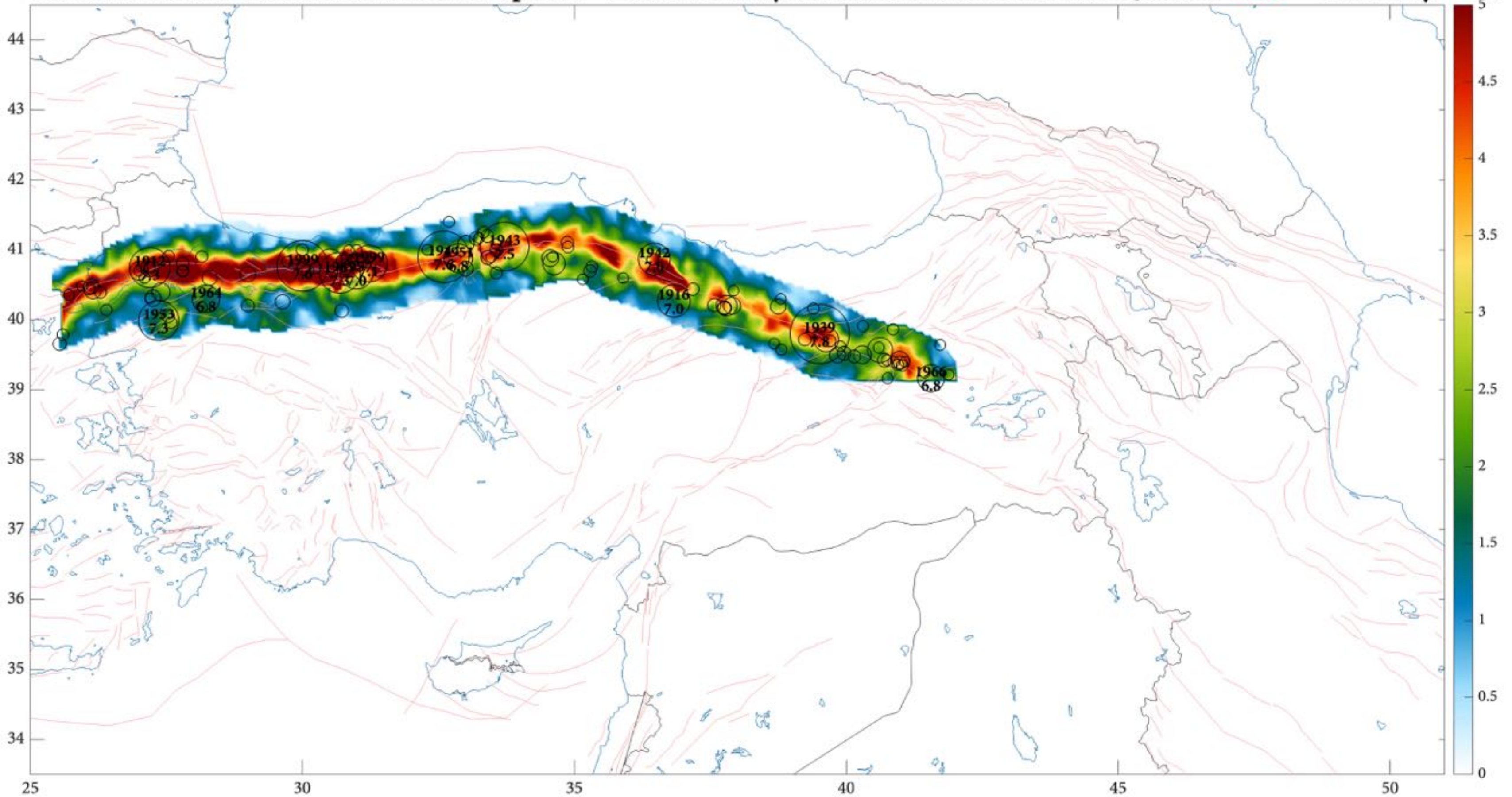
Locking depth grid



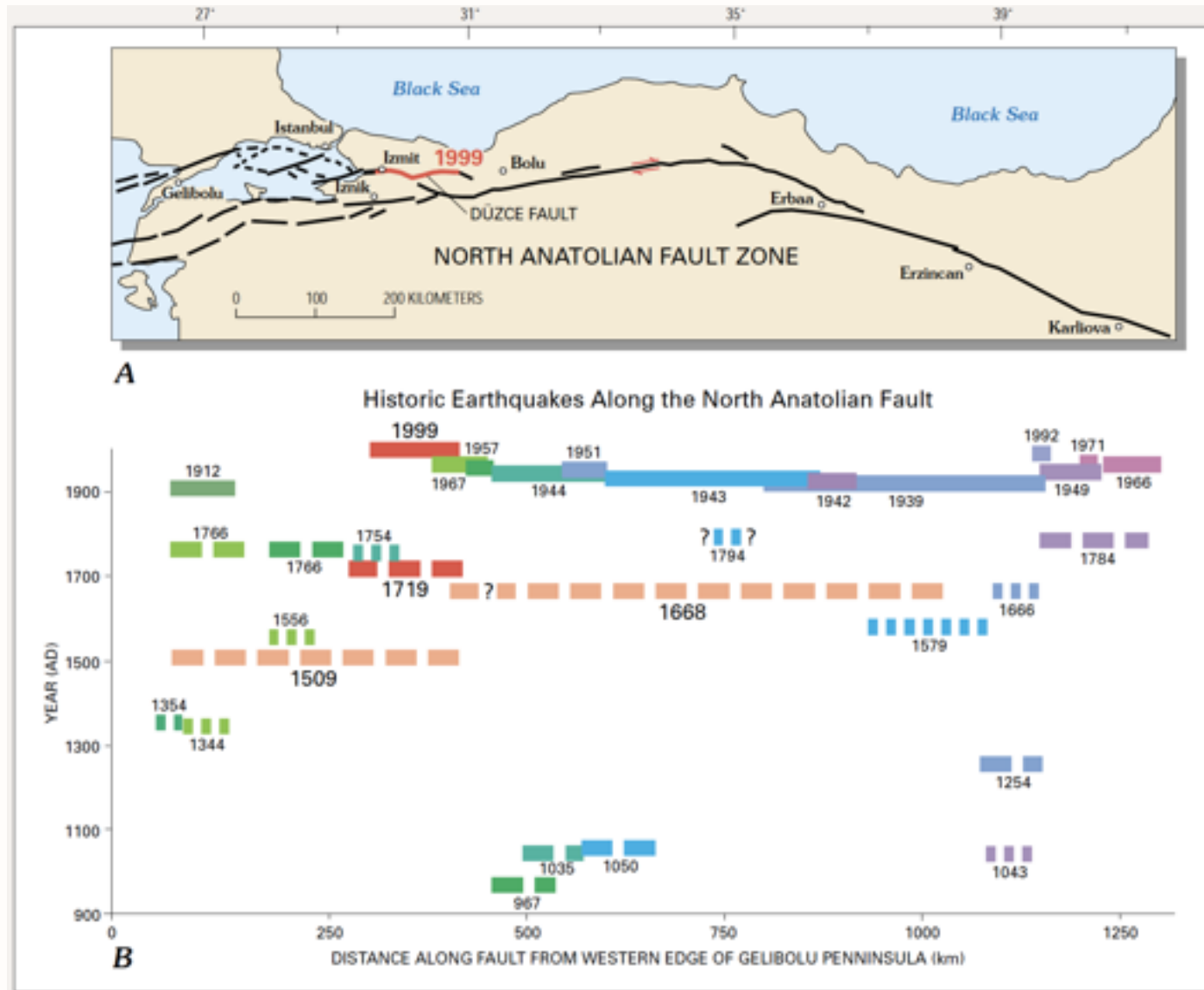
Moment (deficit) buildup rate (Nm/yr) + shallow $M \geq 5.5$ earthquakes ($M > 6.7$ labeled)



North Anatolian Fault: moment buildup rate = 2.0×10^{19} Nm/yr; moment release rate in EQs since 1900 = 1.7×10^{19} Nm/yr

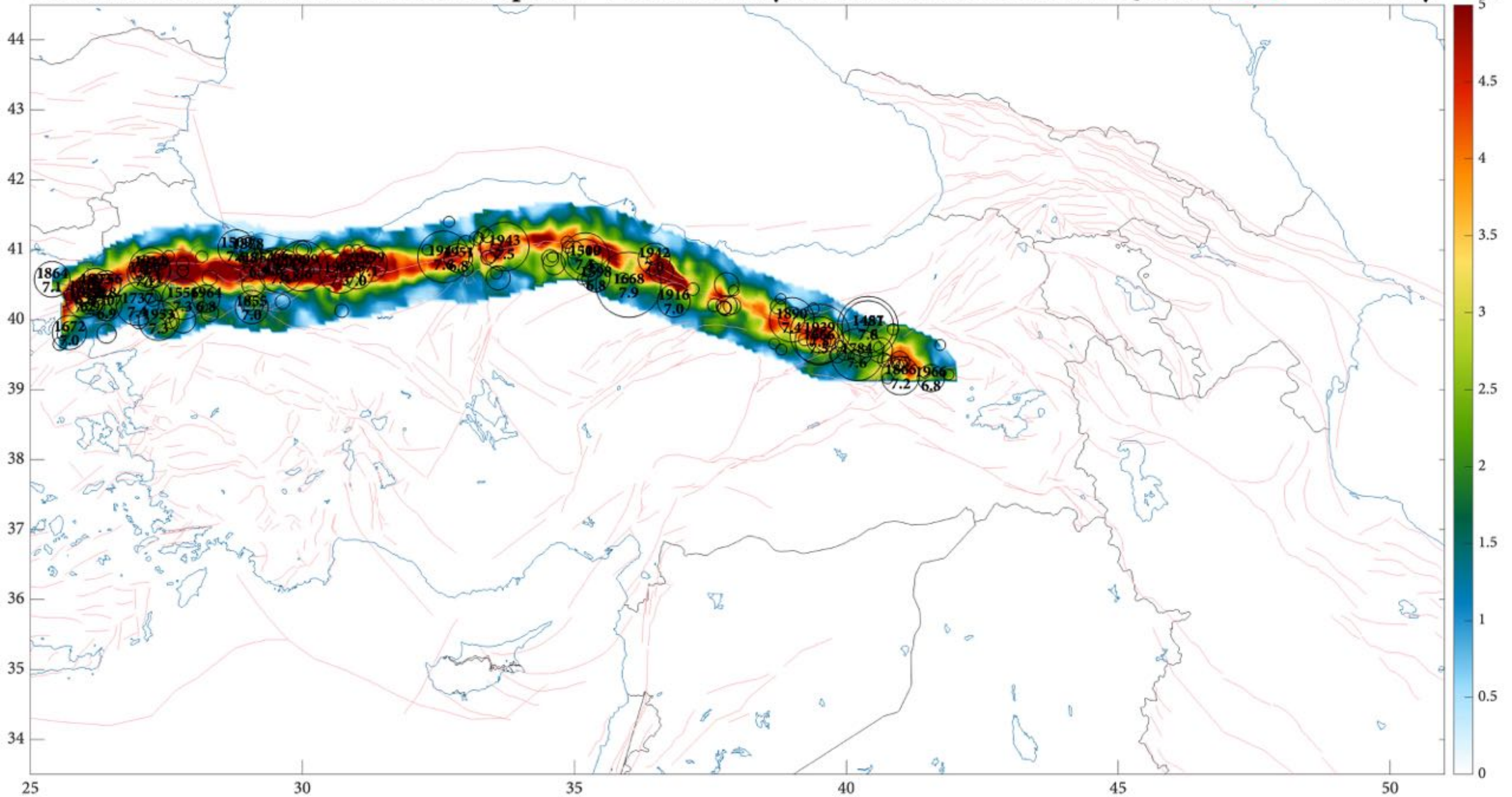


But the last 120 years may not be a full earthquake cycle on the NAF

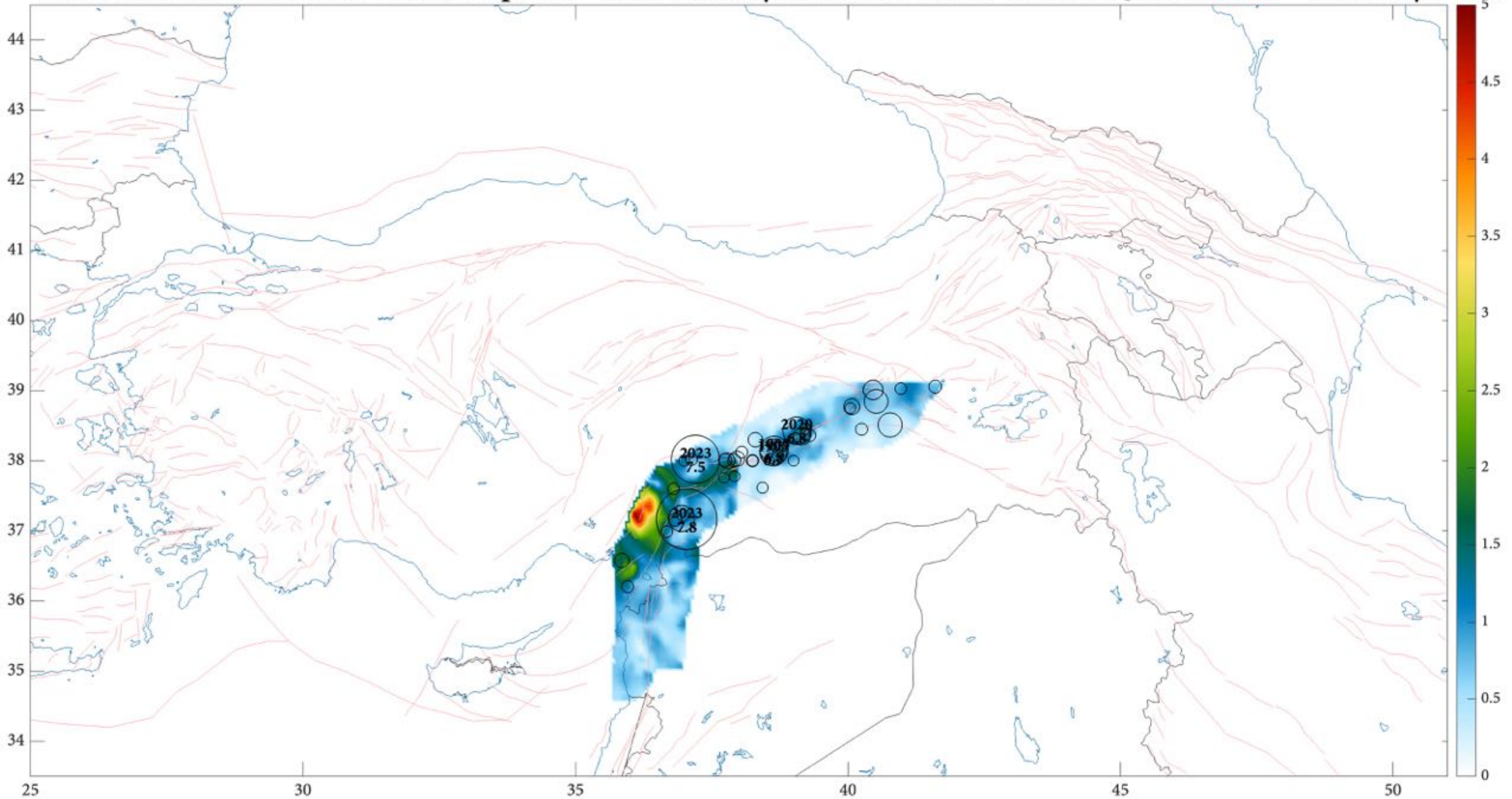


USGS [2000]

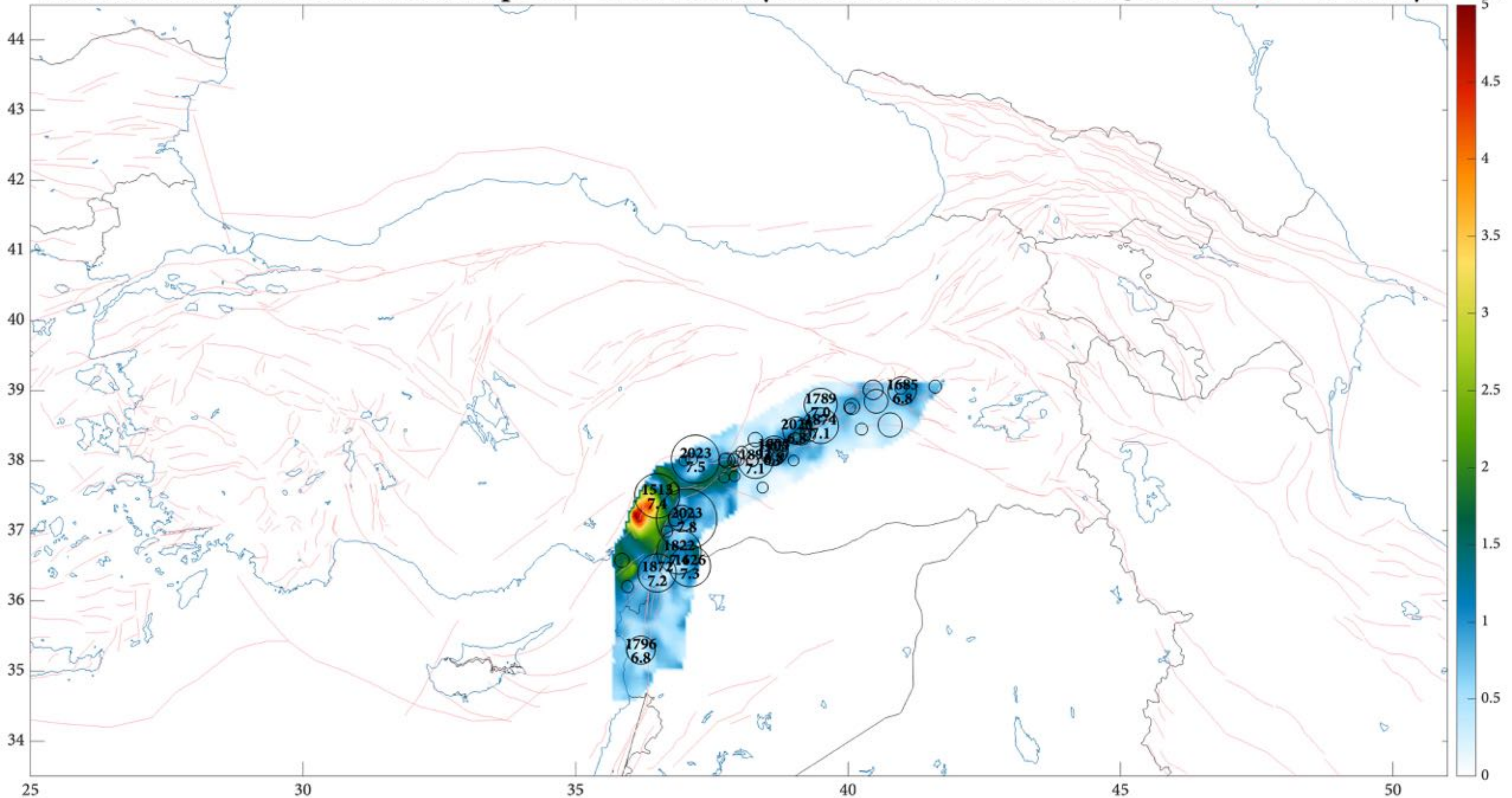
North Anatolian Fault: moment buildup rate = 2.0×10^{19} Nm/yr; moment release rate in EQs since 1450 = 1.1×10^{19} /yr



East Anatolian Fault: moment buildup rate = 3.1×10^{18} Nm/yr; moment release rate in EQs since 1900 = 8.1×10^{18} Nm/yr



East Anatolian Fault: moment buildup rate = 3.1×10^{18} Nm/yr; moment release rate in EQs since 1450 = 2.9×10^{18} Nm/yr

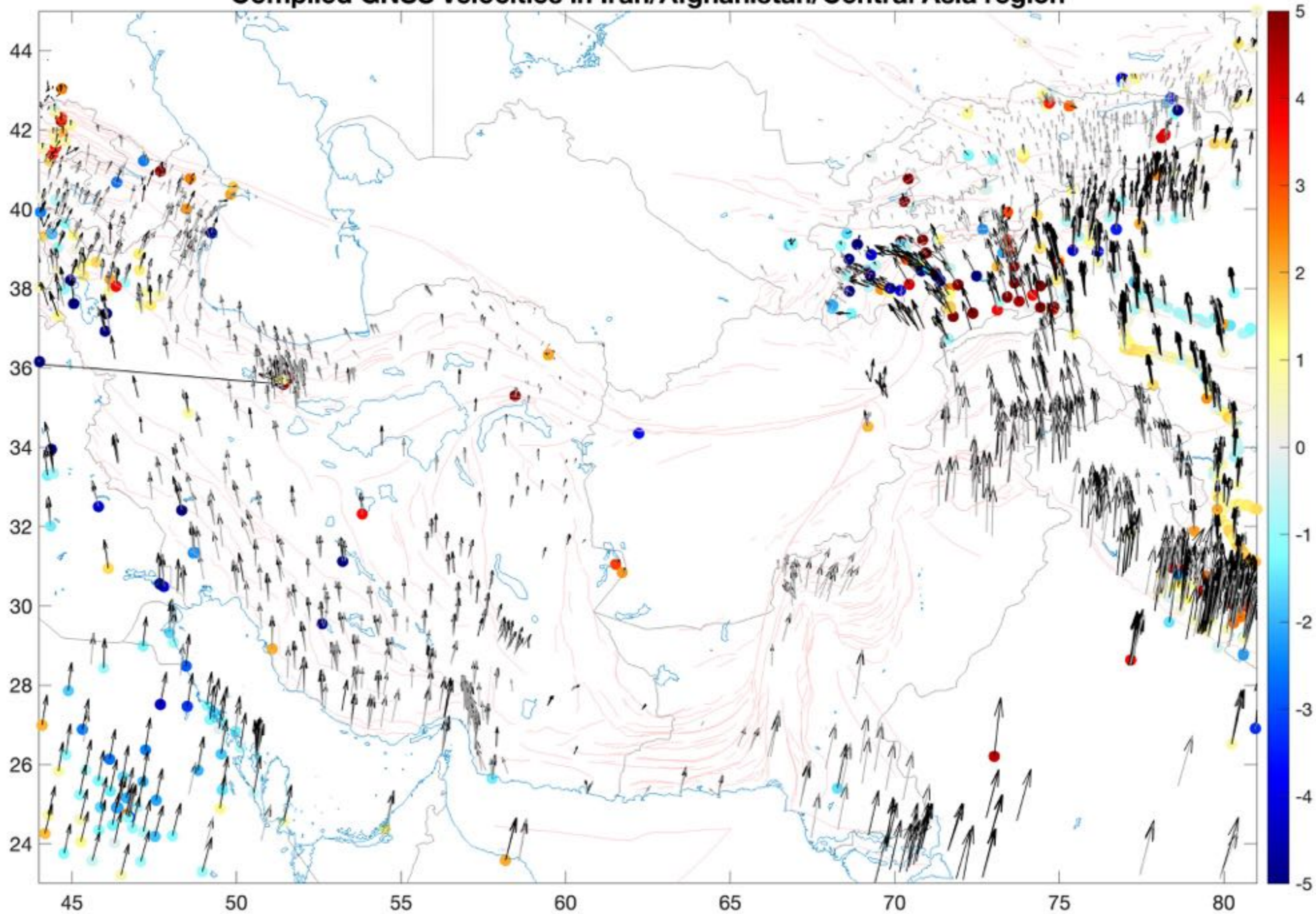


Caveats on comparing moment buildup and release

	Difference if corrected, on NAF/EAF (guesses)
1. We are aliasing aseismic creep as seismic strain buildup	Buildup rate ↓10-30%?
2. Aliasing nontectonic deformation as strain buildup	Buildup rate ↓10-30%?
3. The way strain is computed may amplify noise	Buildup rate ↓ ?
4. We aren't accounting for postseismic deformation	Release rate ↑10-30%?
5. Not accounting for moment release in smaller EQs	Release rate ↑10-30%?
6. Incompleteness in EQ catalogue (especially pre-1900)	Release rate ↑ ?

- Note: away from the NAF and EAF, effects #2, #3, #5 and #6 may skyrocket

Compiled GNSS velocities in Iran/Afghanistan/Central Asia region



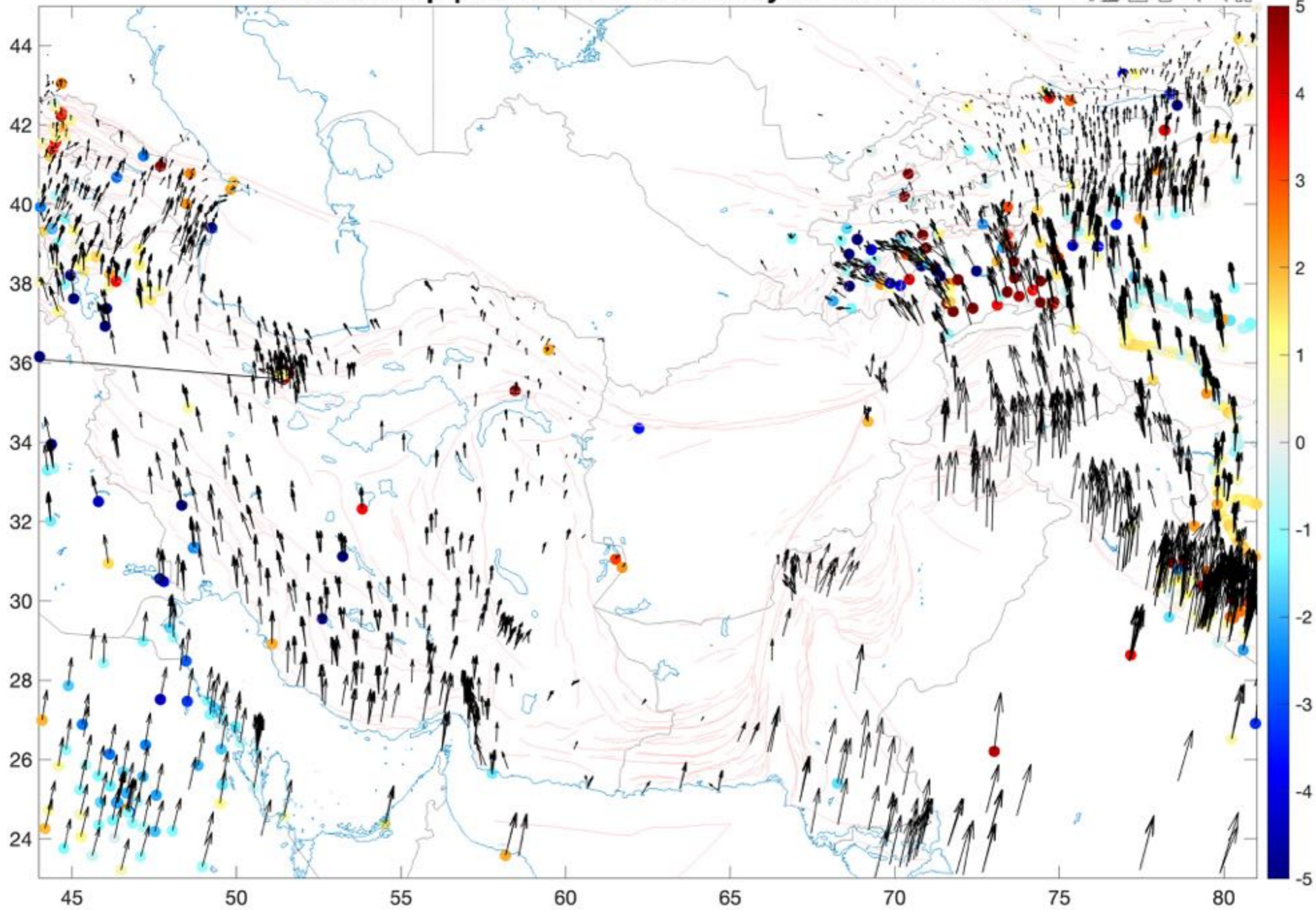
```
43 studies = {...
44     'bisht20',...
45     'dumka14',...
46     'dzwang20',...
47     'ergintav23',...
48     'frohling16',...
49     'gahalaut19',...
50     'gautam17',...
51     'ge15',...
52     'hao19',...
53     'jade11',...
54     'jade14',...
55     'jade17',...
56     'jade20',...
57     'jouanne14',...
58     'jouanne17',...
59     'kadirov14',...
60     'khalkhali21',...
61     'khorrami19',...
62     'kreemer14',...
63     'kufner21',...
64     'kundu14',...
65     'kurt22',...
66     'li22',...
67     'masson15',...
68     'metzger20',...
69     'measures',...
70     'midas',...
71     'milyukov15a',...
72     'milyukov15b',...
73     'milyukov22',...
74     'mironov22',...
75     'ozdemir19',...
```

```
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
```

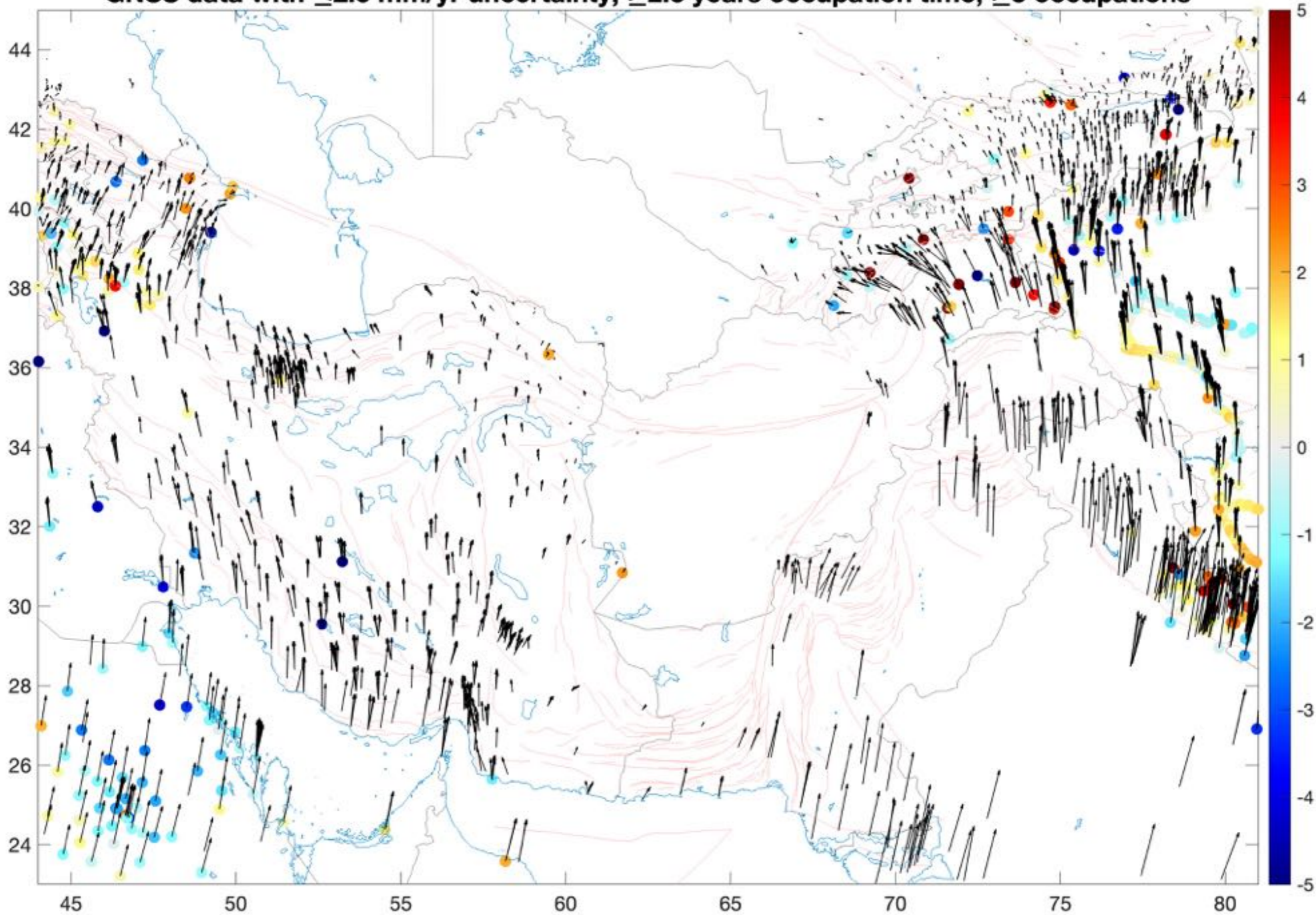
```
'ozkan23',...
'palano18',...
'pan16_vert',...
'pan18',...
'pan19',...
'pan20',...
'pan21_vert',...
'pan22_vert',...
'perry19',...
'pietrantonio16',...
'rui19',...
'saleh15',...
'sharma20',...
'sokhadze18',...
'vernant14',...
'viltres22',...
'wang17',...
'wangshen20',...
'wu22_vert',...
'xiong21',...
'yadav19',...
'yadav20',...
'zhao15',...
'zhao23_vert',...
'zheng17',...
'zhou16',...
};

for studyindex = 1:length(studies)
    gpslocal = load([studies{studyindex} '/' s
    gps.names = [gps.names; gpslocal.(studies{
    for staindex = 1:length(gpslocal.(studies{
        gps.studynames = [gps.studynames; stud
```

GNSS data up-precisioned in location by same station name



GNSS data with ≤ 2.5 mm/yr uncertainty, ≥ 2.5 years occupation time, ≥ 3 occupations



Culled GNSS velocities: weighted averages within 1 km

