

Differential coordinate changes (velocities) vs. coordinate differences (epoch coordinates) for realising the time dependency of the ITRF

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- The International Terrestrial Reference Frame (ITRF) provides epoch coordinates and constant velocities for interpolating or extrapolating the station coordinates to an arbitrary epoch, e.g. for satellite tracking, terrestrial positioning, precise navigation ...
- The basic reason for this procedure was that crustal movements were assumed to be mainly caused by tectonic motions, which are constant over long time intervals.

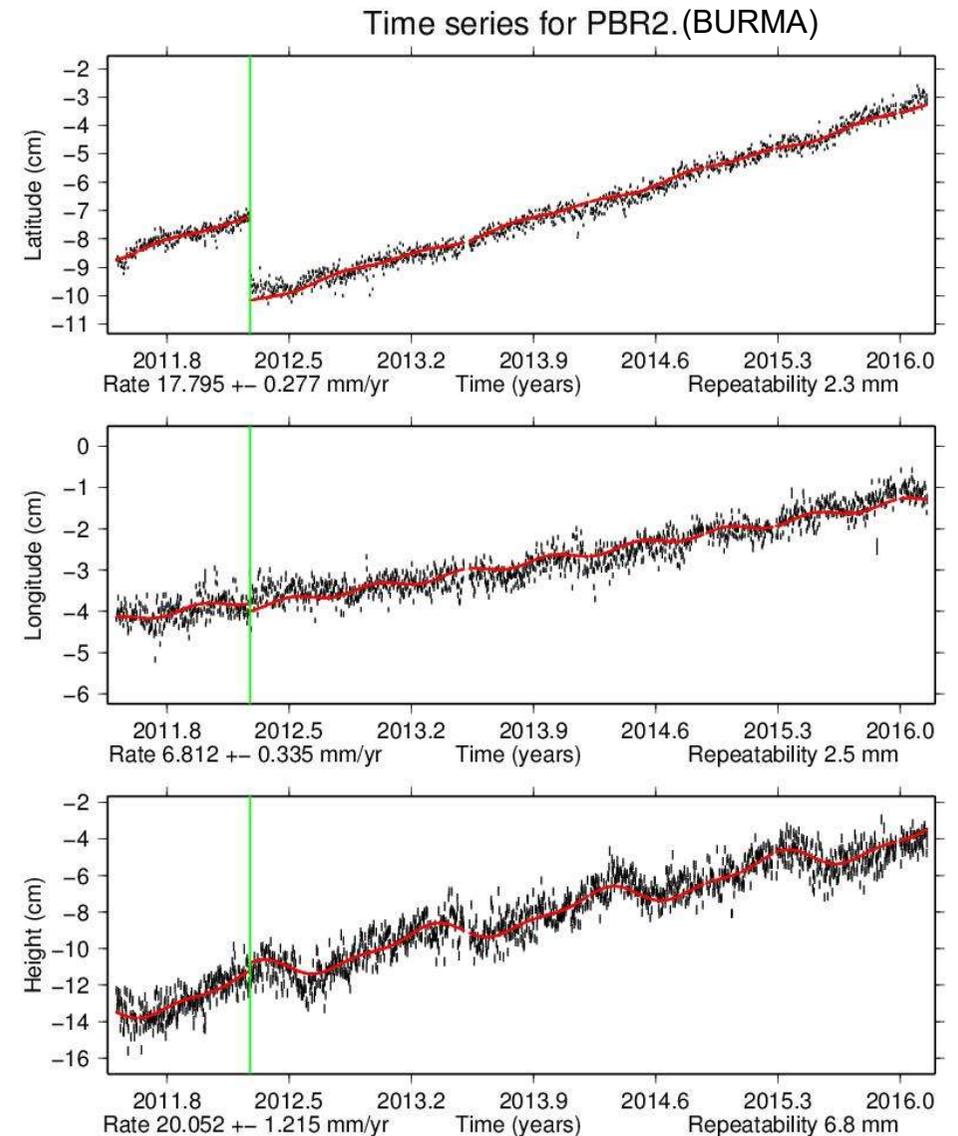
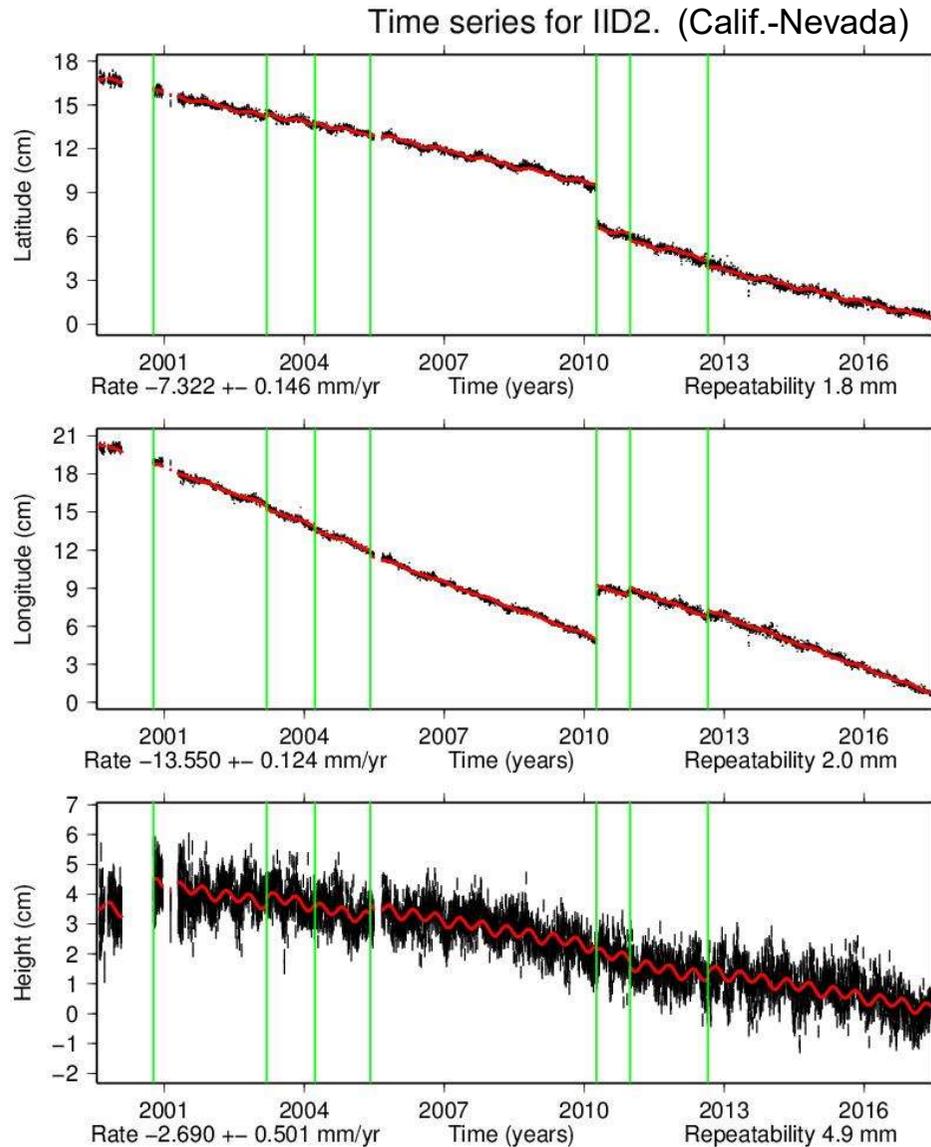
[At the beginning of the ITRF-series (1989) velocities were taken from the geophysical plate model AM0-2 (Minster and Jordan 1978)].

- Time series of station coordinates demonstrate many non-constant velocities due to various reasons:
 - abrupt co-seismic dislocations (at the time of an earthquake);
 - abnormal post-seismic velocities (after an earthquake);
 - non-linear environmental effects (at any time);
 - instrumental (antenna) changes.

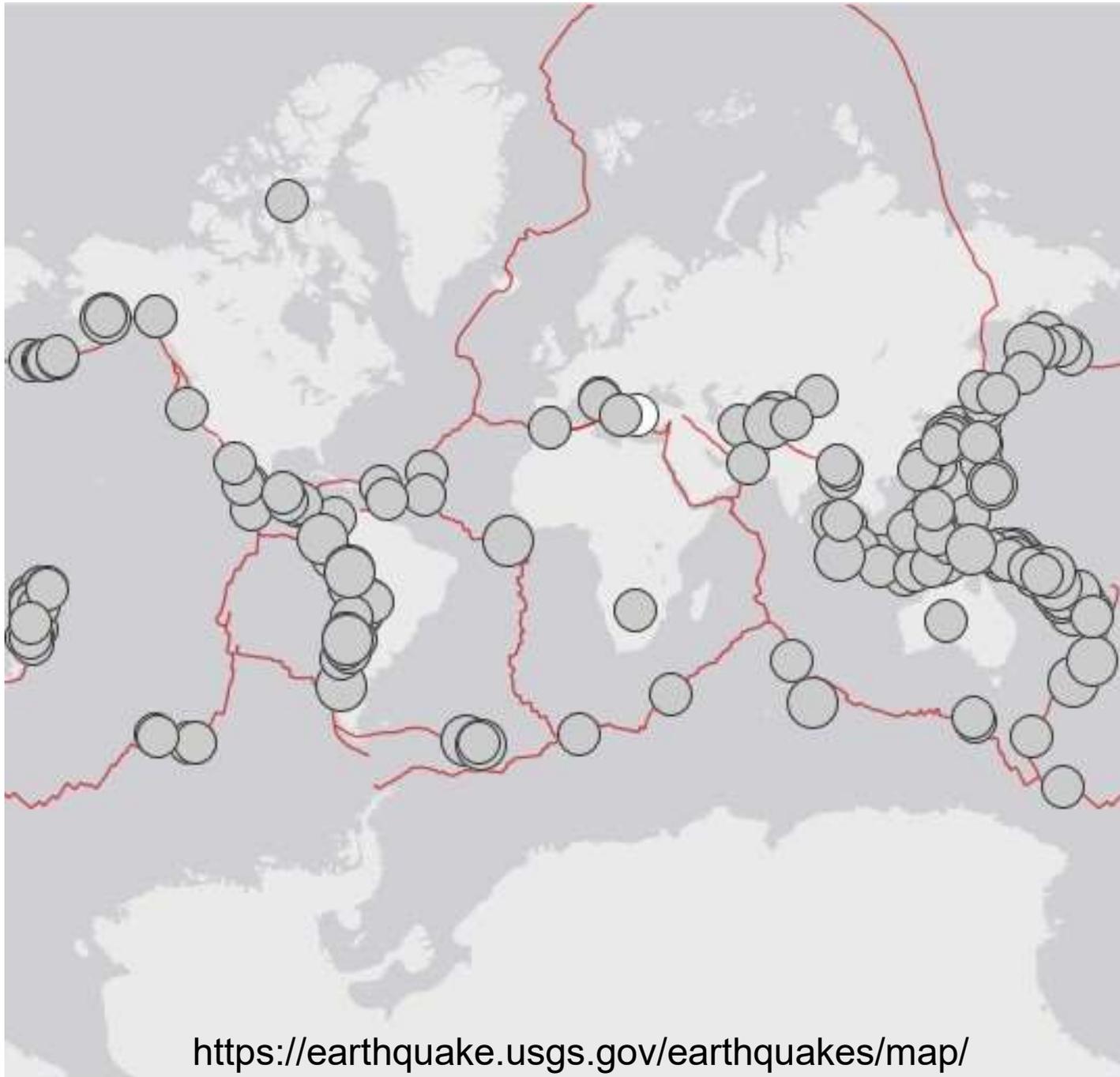
Examples of dislocations in station position time series



1. Abrupt co-seismic dislocations (caused by large earthquakes)

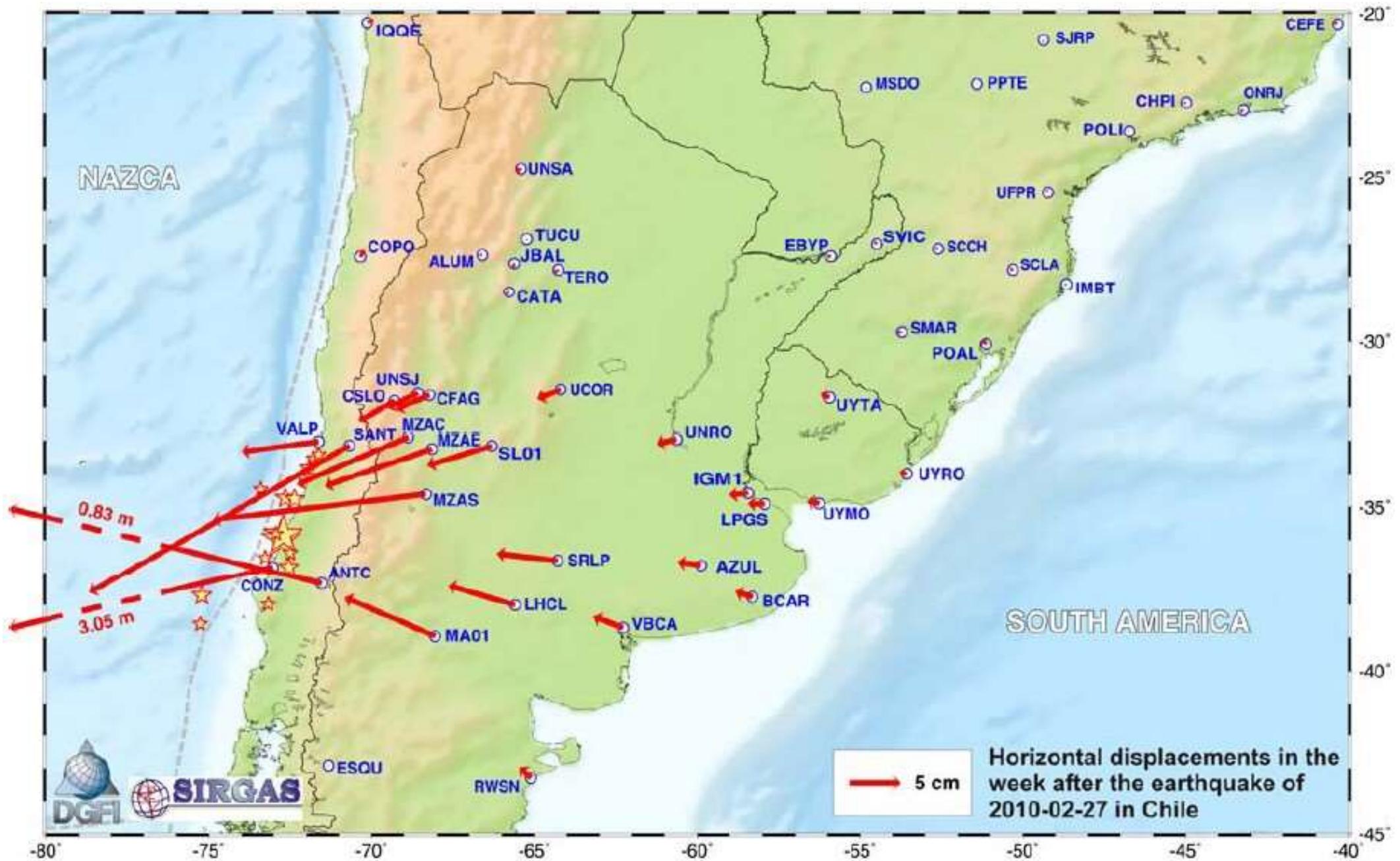


Earthquakes $M > 6$ over two years time interval



From 2015-07-01 until 2017-06-30 we had **265** earthquakes $M > 6.0$ causing significant deformations of the Earth's crust; not only close to the epicentre, but **extended over very large regions.**

Dislocations after the Maule (Chile) earthquake 2010

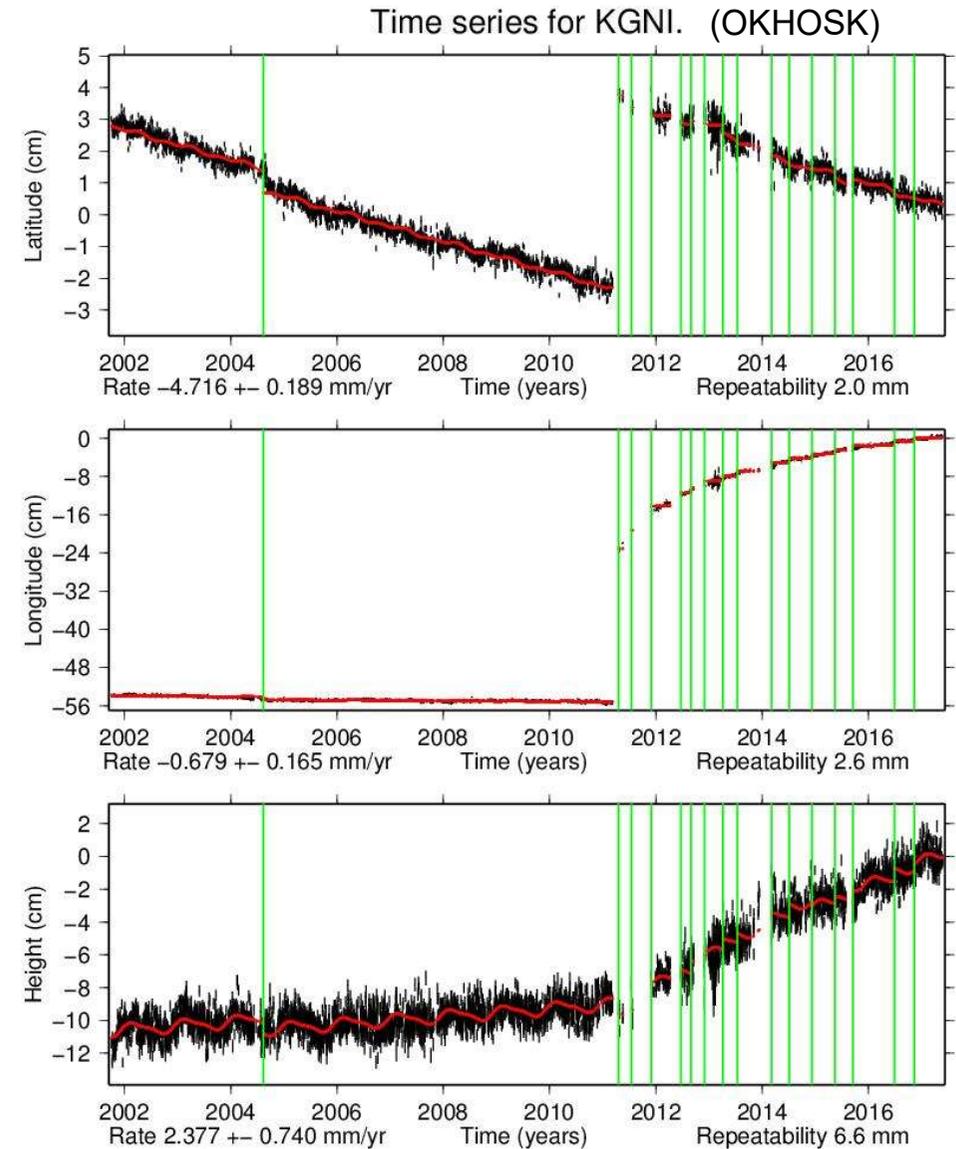
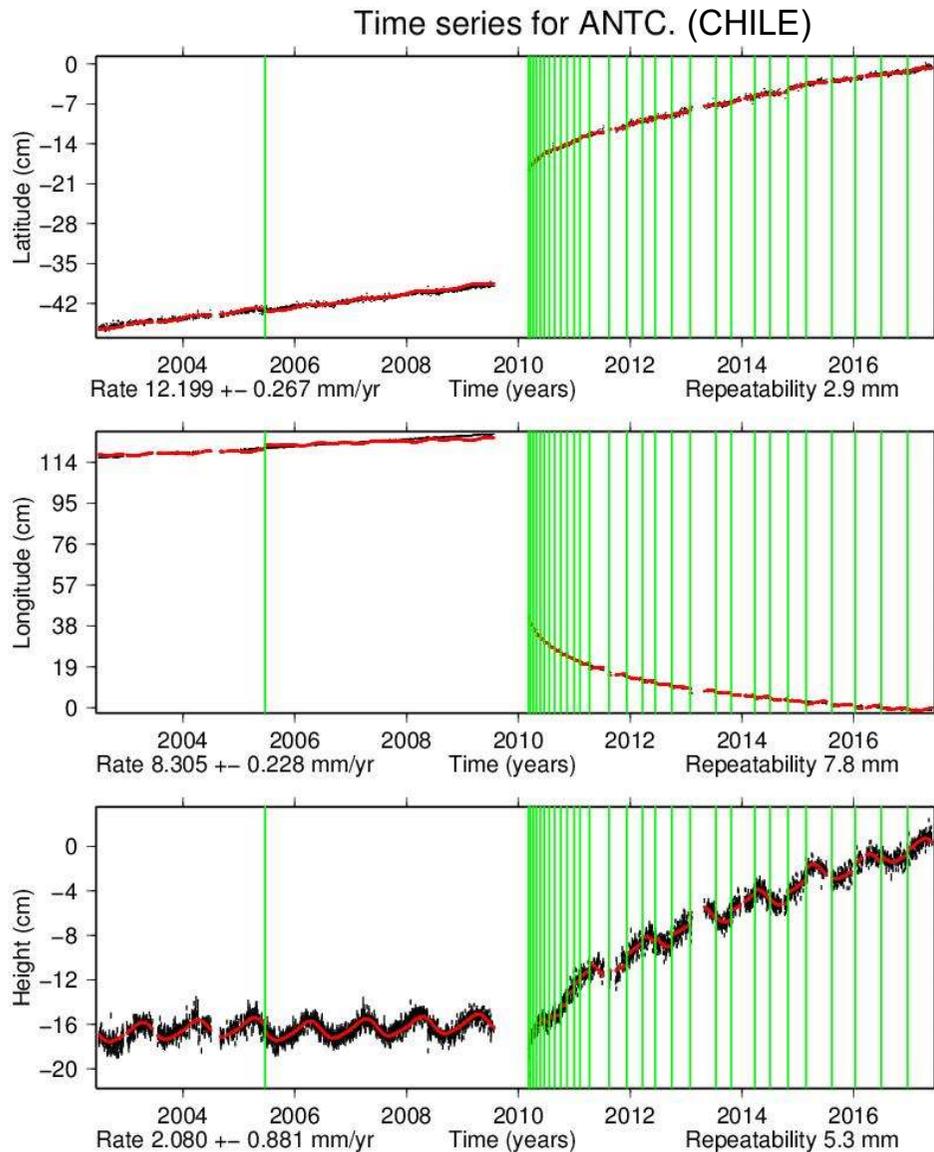


Significant displacements over more than 1300 km (Sánchez et al. 2013)

Examples of abnormal velocities in station time series

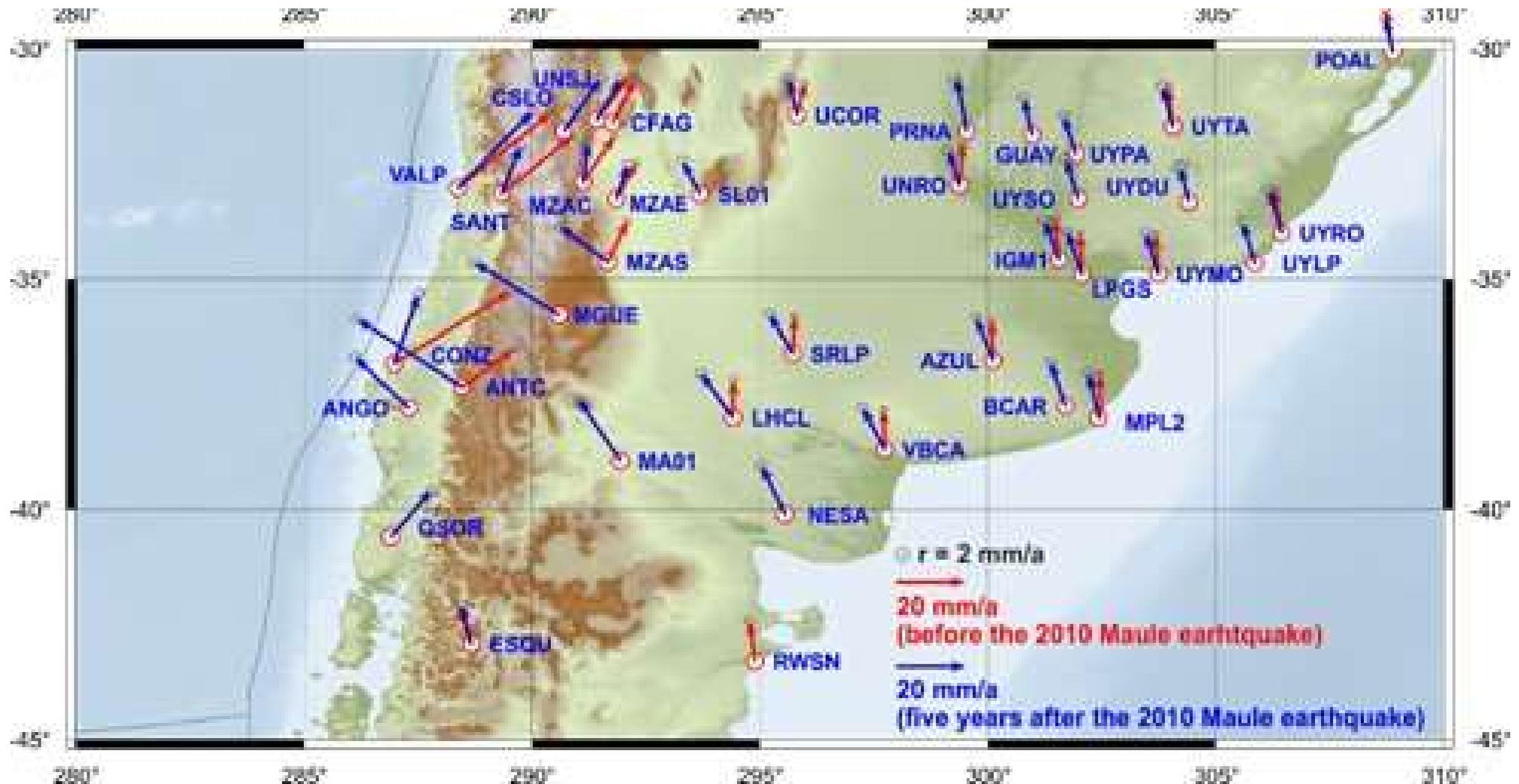


2. Abnormal velocities after earthquakes



Velocity changes after the Maule (Chile) earthquake 2010

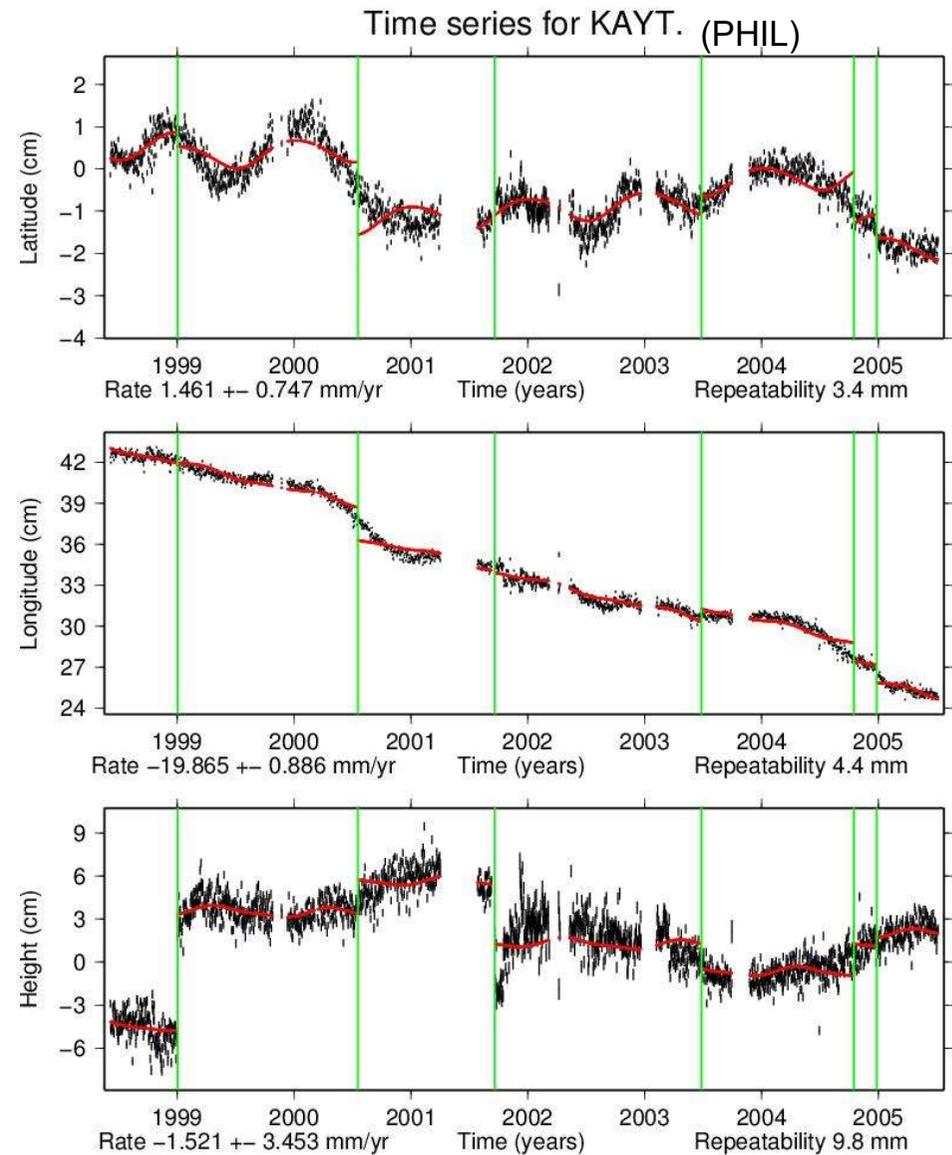
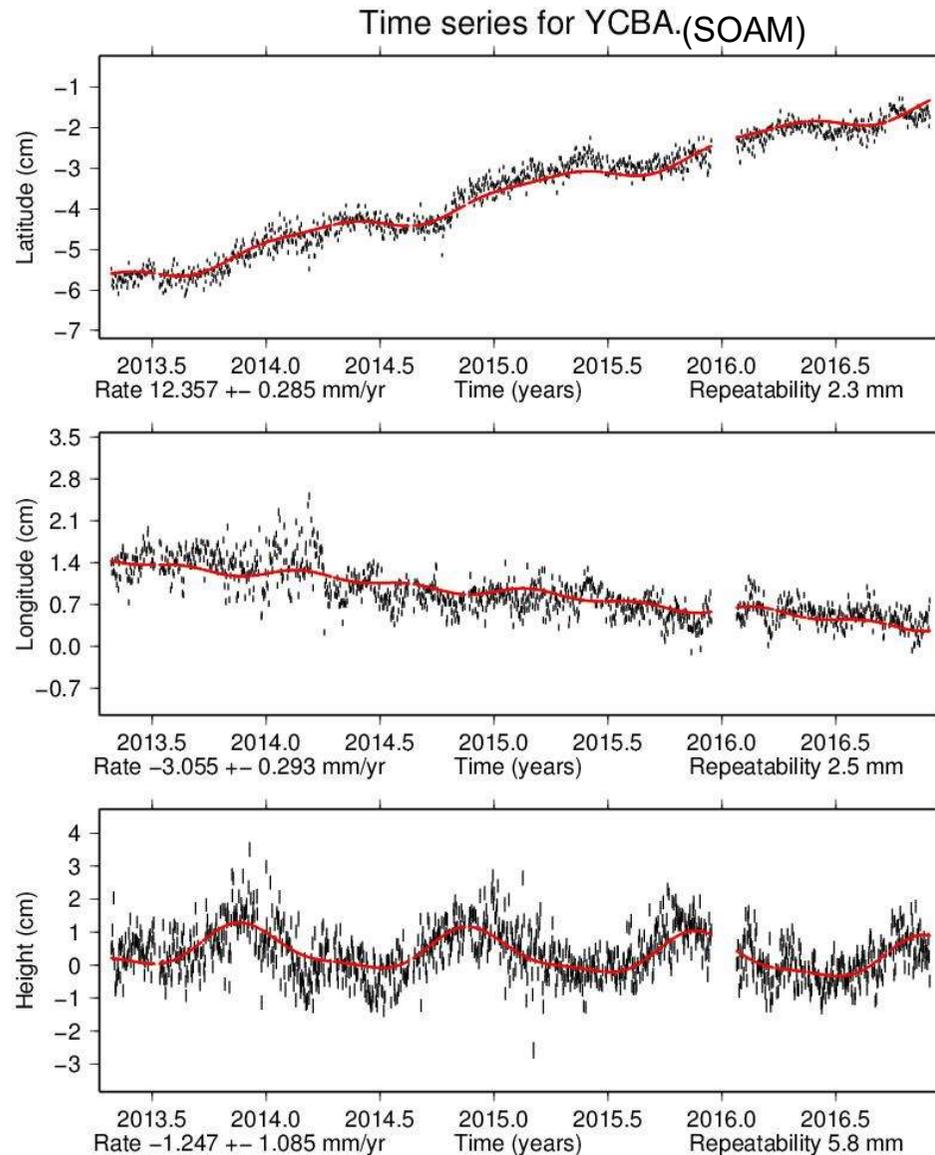
The velocity change extends between latitude -30° and -40° over the entire continent from the Pacific to the Atlantic coast (Sánchez and Drewes 2016)



Environmental effects on position time series

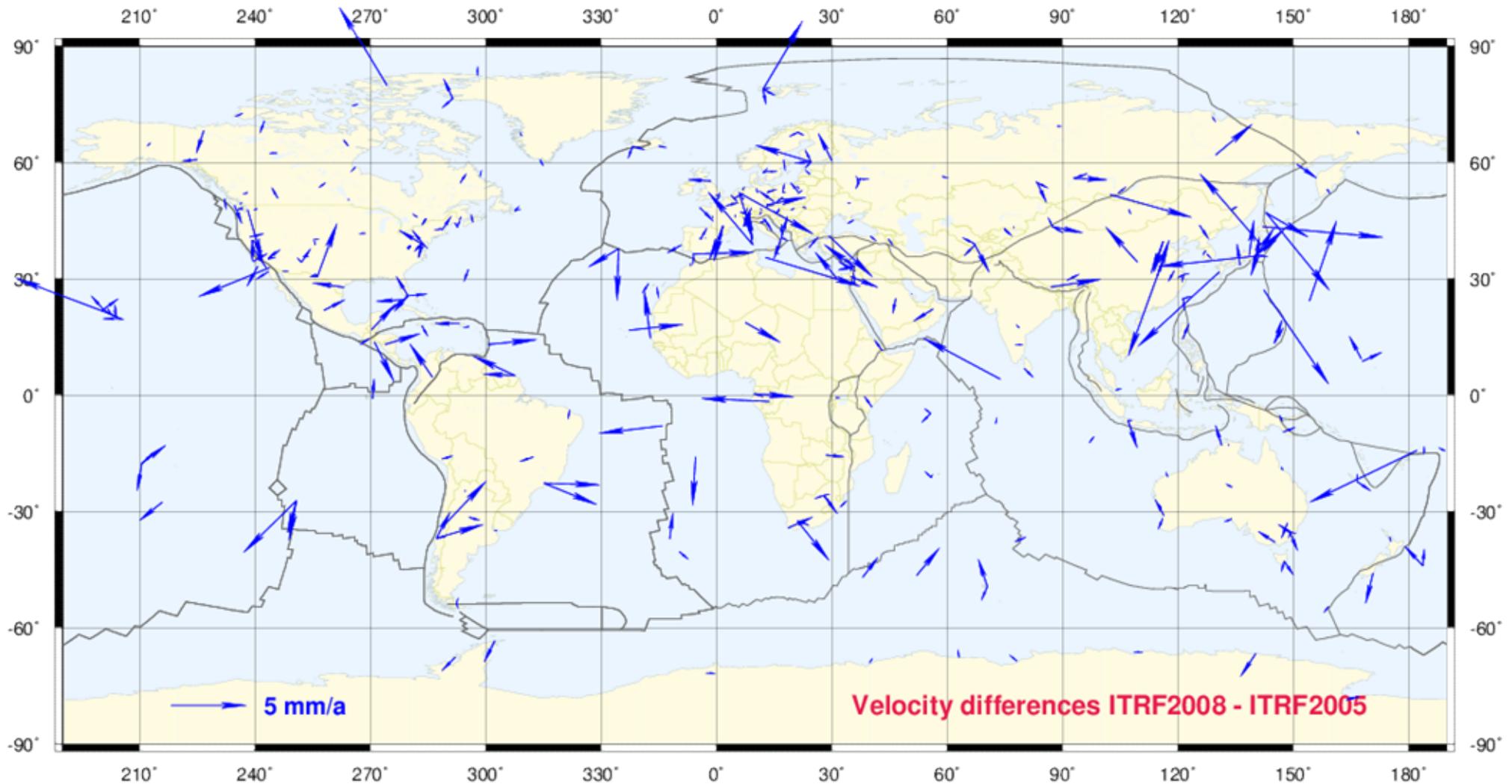


3. Seasonal, long-periodic or irregular coordinate variations



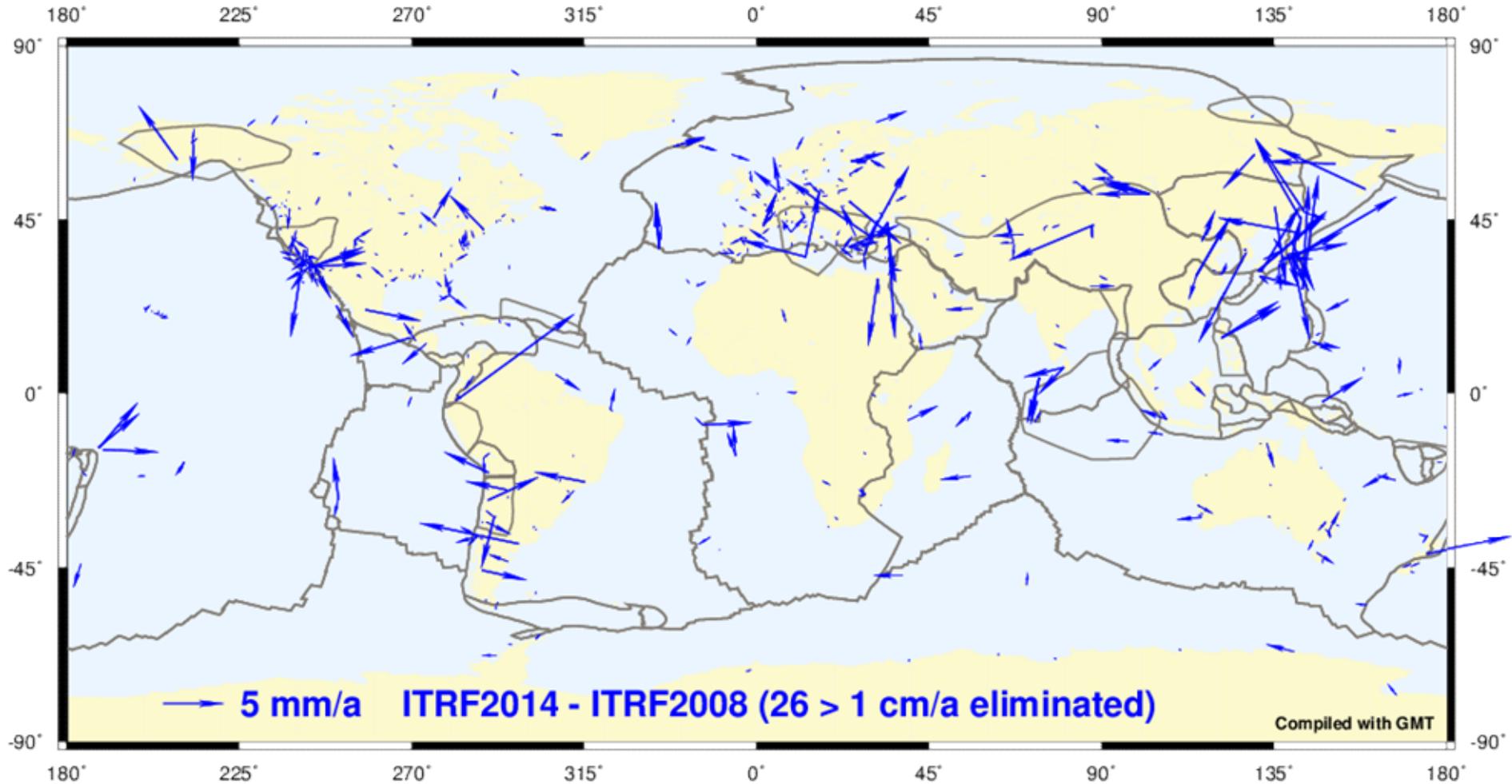
Effect of variable station velocities on the ITRF

Velocity differences ITRF2008 - ITRF 2005 (outliers > 1 cm/a not included)



Effect of variable station velocities on the ITRF

Velocity differences ITRF2014 – ITRF 2008 (outliers > 1 cm/a not included)



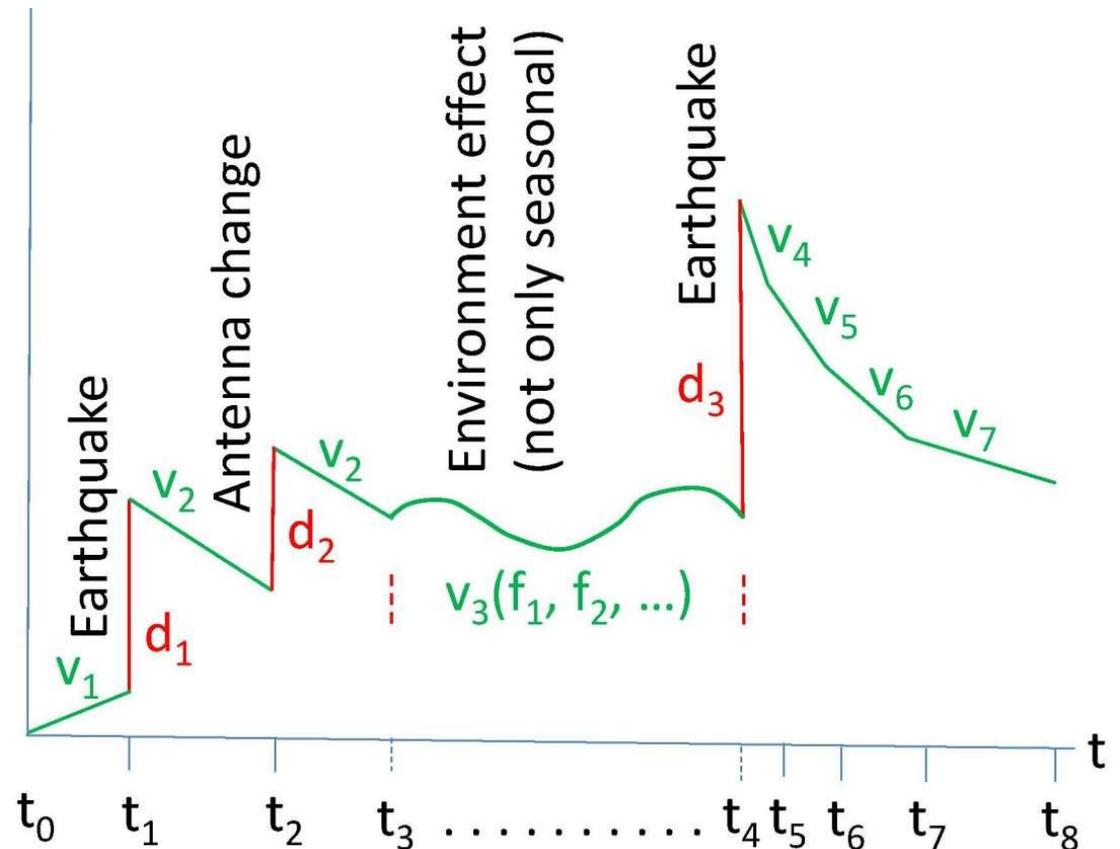
Where are time-dependent coordinates needed?

- Satellite orbit determination:
 - satellite orbit is independent of crustal movements, tracking stations not;
 - tracking station coordinates must refer to the actual (real) position;
 - > e.g., missing seasonal effects falsify sea level estimates of satellite altimetry.
 - Geodynamics and global change studies:
 - studies are based on time-dependent station coordinates (deformation);
 - > seismic precursors and effects of climate change (e.g. sea-level rise) are at the mm-level.
 - Precise point positioning, e.g. cadastre, engineering (tubes, power lines), precise navigation:
 - actual station coordinates are required to relocate the positions ;
 - > e.g., Japan and Chile could not use the ITRF after the 2010 earthquakes.
- Geographical and temporal inter- / extrapolation is required.

Compute ITRF coordinates of an arbitrary point at an arbitrary epoch (geographic and time extrapolation)

In principle, a consecutive extrapolation with different dislocations and velocities is required.

- The ITRF provides the coordinates and velocities at different epochs via the corresponding “**solutions**”.
- There are new solutions (coordinates, velocities) after each discontinuity.
- For non-ITRF stations we have to perform a geographic and consecutive time extrapolation.



➤ Instead of irregular “new solutions” at discontinuities we can introduce frequent regular epochs (every week, month, ...) and quit the velocities.

Epoch reference frames must fulfil the IERS conventions, in particular:

- They must be **geocentric** at any time (without “geocentre motion”); (“geocentre motion” is its motion relative to the varying ITRF positions)
 - it is realised by SLR if we don’t add any constraint (e.g. NNR, NNT).
- There must be **no global rotation** of stations (over the entire Earth’s crust); (present ITRFs rotate ~ 0.06 mas/a (max. 1.8 mm/a) due to rotating NUVEL-1A);
 - it can be realised by integrating an epoch grid over all the Earth surface.
- They must be **consistent with the ICRF** (EOP determined by VLBI);
 - the present time resolution might not be sufficient;
 - sub-daily EOP are already in discussion.
- The **time resolution** of epoch reference frames should be 1 month;
 - this is necessary for precise geocentric realisation (SLR);
 - it is sufficient because maximum velocities are ~ 10 cm/a.
- For **global accessibility** they should include continental reference frames;
 - AFREF, APREF, EUREF, NAREF, SIRGAS refer to the ITRF;
 - It can be done by decentralised data processing.

- There are many ITRF stations with abrupt co-seismic dislocations.
 - There are many ITRF stations with abnormal velocities after earthquakes.
 - There are many ITRF stations with non-linear environmental effects.
 - There are many ITRF stations with antenna changes producing jumps.
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- All these effects make the determination of velocities difficult.
 - The proposal is to replace velocities by frequent epoch reference frames!

Thank you very much for your attention!