Modeling environmental loading effects at the observation level in GPS processing

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PATHWAYS TO IMPROVED PRECISION

Modeling environmental loading effects at the observation level in GPS processing

- Except ocean tides, no other environmental loading effects are corrected in GNSS (and other geodetic techniques) processing.
- Loading effects can be modeled *a posteriori* or at the *observation level*, allowing the correction of high-frequency effects, such as air pressure tides.
- We investigate the modeling of the full loading effects (atmosphere + non-tidal ocean + hydrology, CM reference frame) on a global network of 117 GPS permanent stations over the 2002-2015 period, using GAMIT/GLOBK (v. 10.6).
- Ocean tidal loading modeled using FES2014a (1/16°).
- VMF1, zenith delays every 2 hours, cutoff=10°, 2 gradients per day.

Description of loading models

Atmosphere:

- ECMWF operational pressure fields at 3 hours & from 0.25° (2000) to 0.10° (2016) resolutions.

Ocean response:

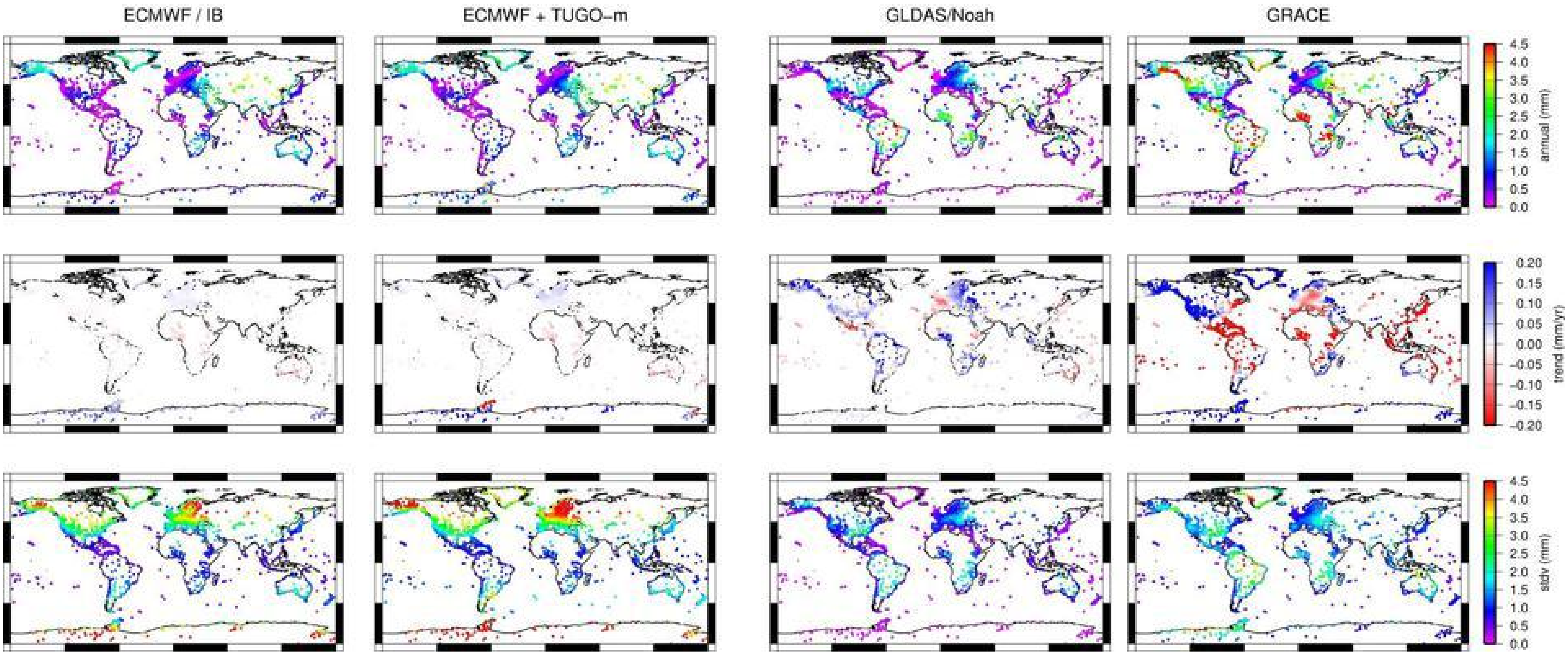
- Inverted Barometer (IB),
- TUGO-m (Carrère & Lyard, 2003) barotropic ocean model forced by ECMWF pressure and winds (3 hours & 0.25°).

Hydrology:

- GLDAS/Noah (Rodell et al., 2004) soil-moisture, snow and canopy water (3 hours & 0.25°); permanently ice-covered regions masked out.
- GRACE monthly 1-degree iterated global mascons (Luthcke et al., 2013; Loomis & Luthcke, 2016; GIA (Geruo et al., 2013) removed.

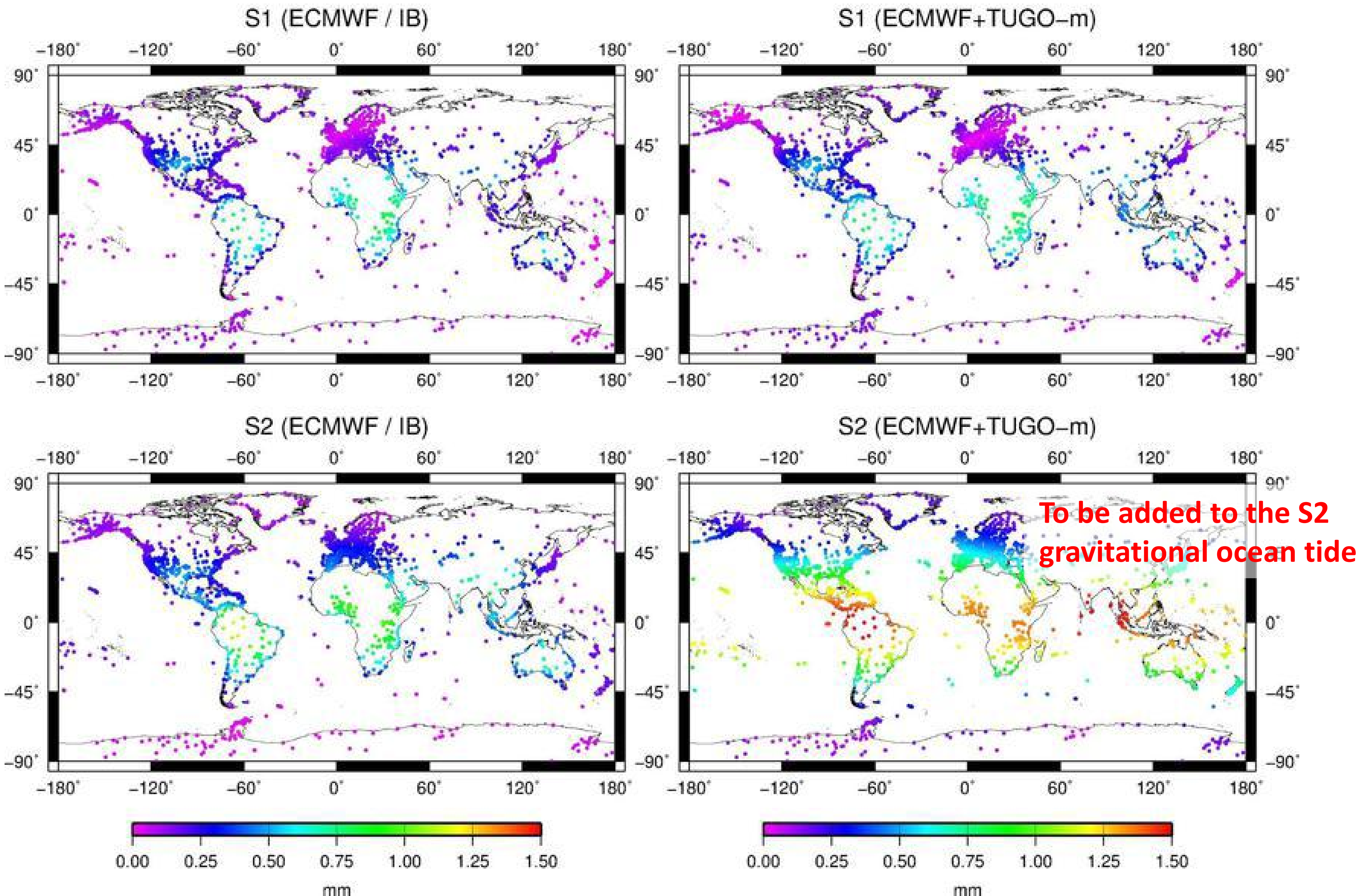
Modeled vertical displacements
CF Reference Frame

Atmosphere & induced ocean response | **Continental hydrology (no ice sheet for GLDAS)**

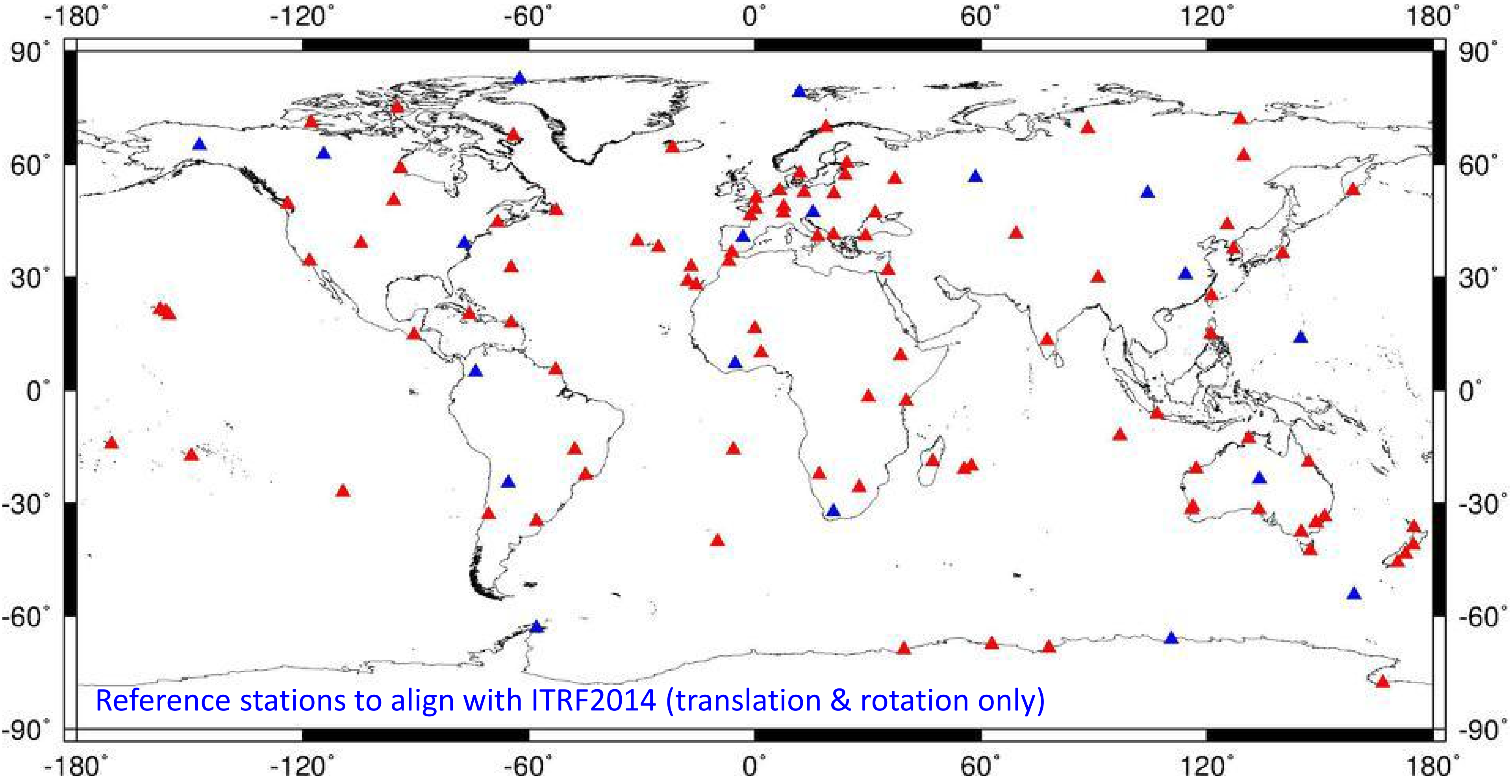


All series available at http://loading.u-strasbg.fr
Period: 2002-2016

Vertical displacement due to S1 & S2 tides



GPS global network (117 stations)



Methodology

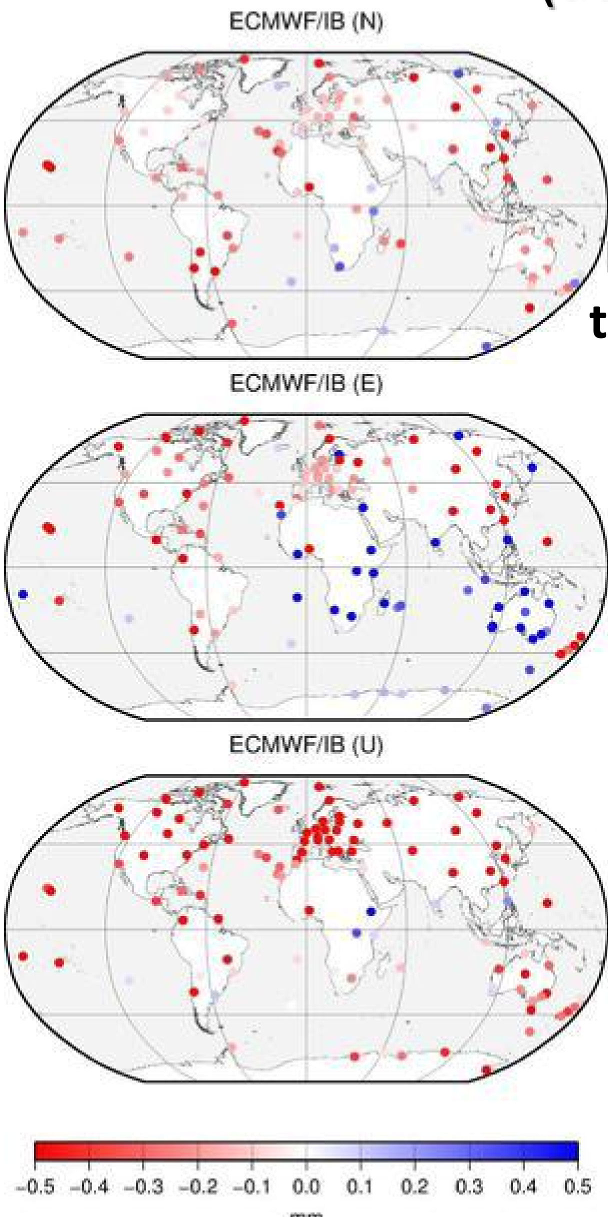
5 GPS solutions (different loading models) computed :

- Without environmental loading (classical approach)
- ECMWF / IB
- ECMWF + TUGO-m
- ECMWF + TUGO-m + GLDAS/Noah
- ECMWF + TUGO-m + GRACE

We compare the solution with loading to the solution without loading, focusing on the high-frequency variability, the annual components & the linear trends

Reduction of high-frequency variability

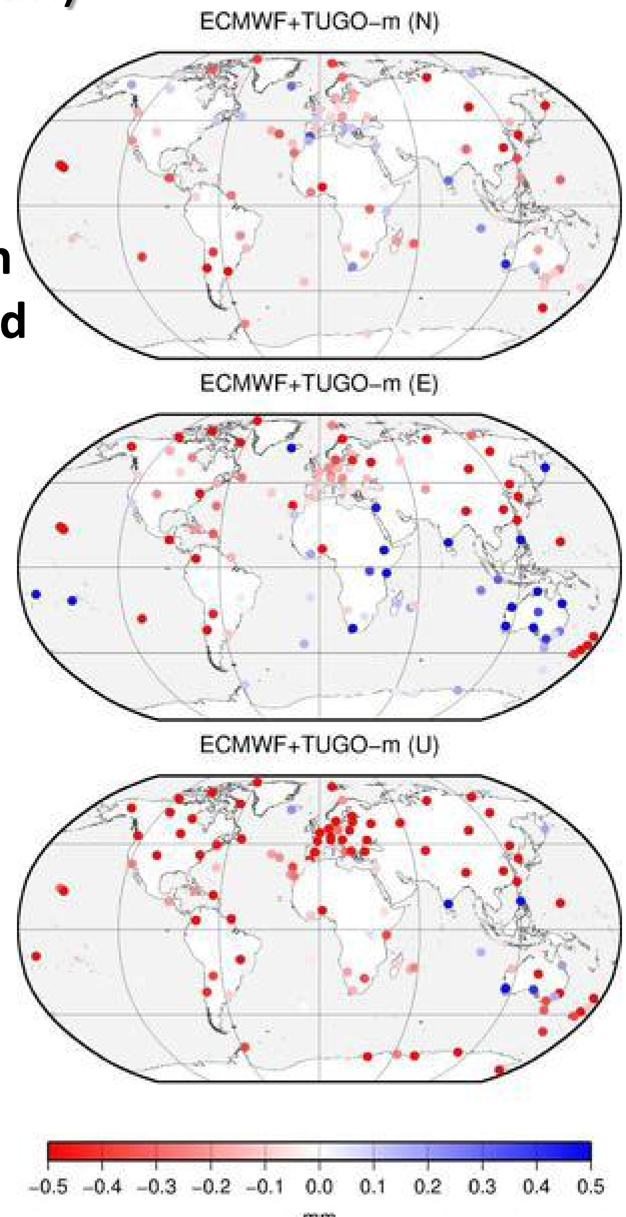
(atmosphere + ocean)



Differences between the solution corrected for loading & the classical solution

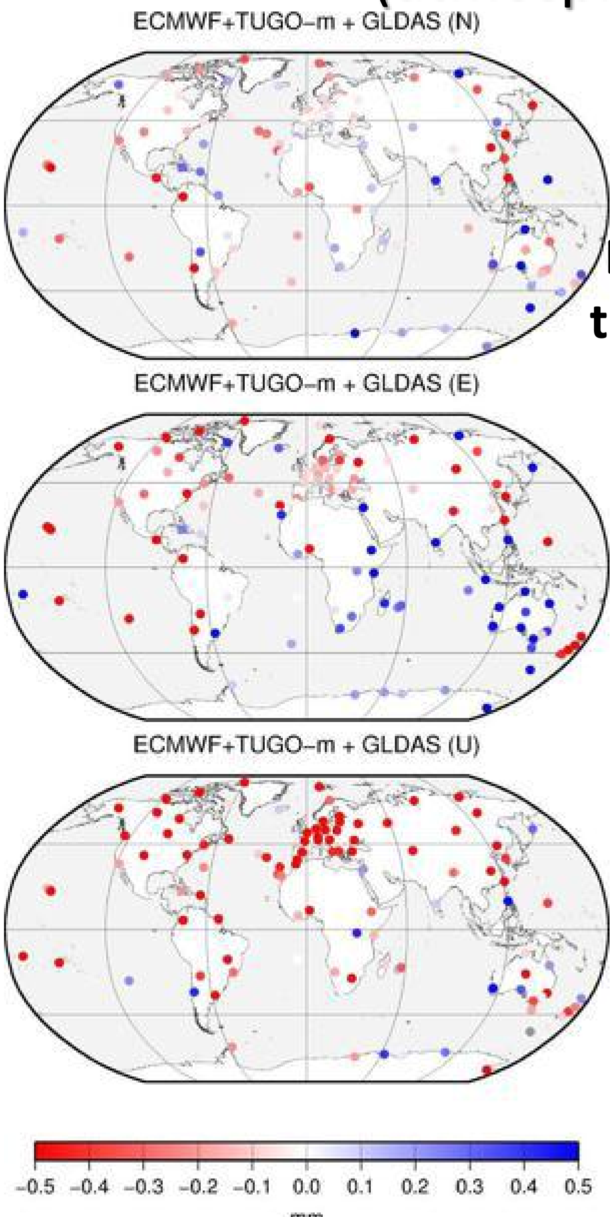
Red: decrease of the variability when loading are taken into account.

Blue: increase of the variability when loading are taken into account.



Reduction of high-frequency variability

(atmosphere + ocean + hydrology)



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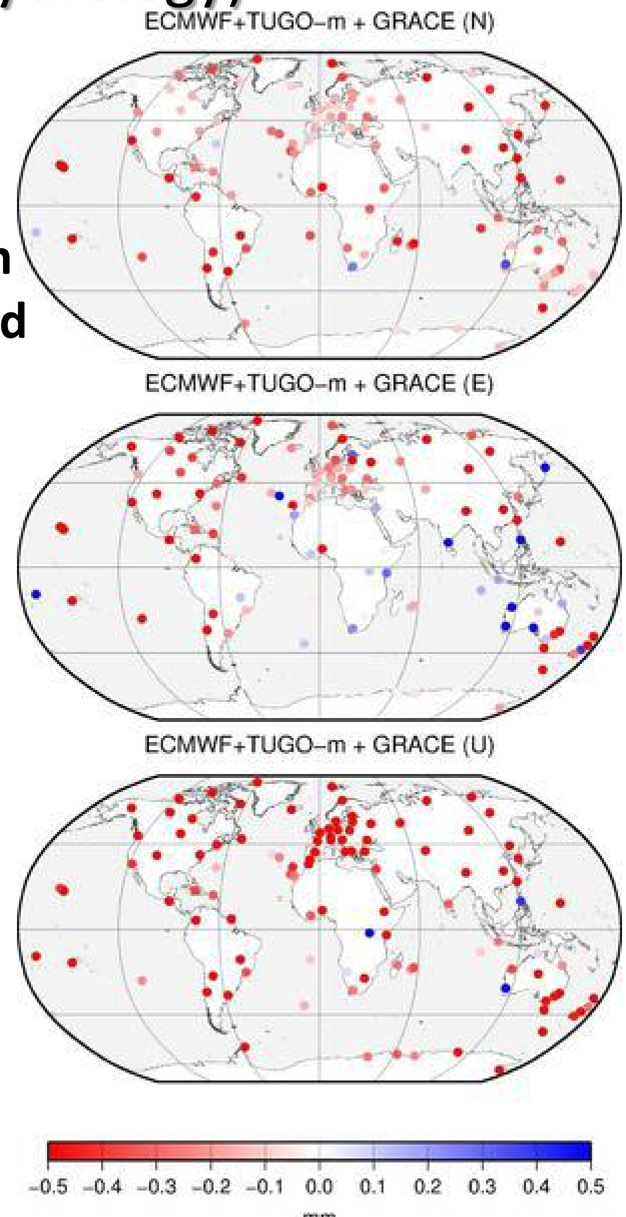
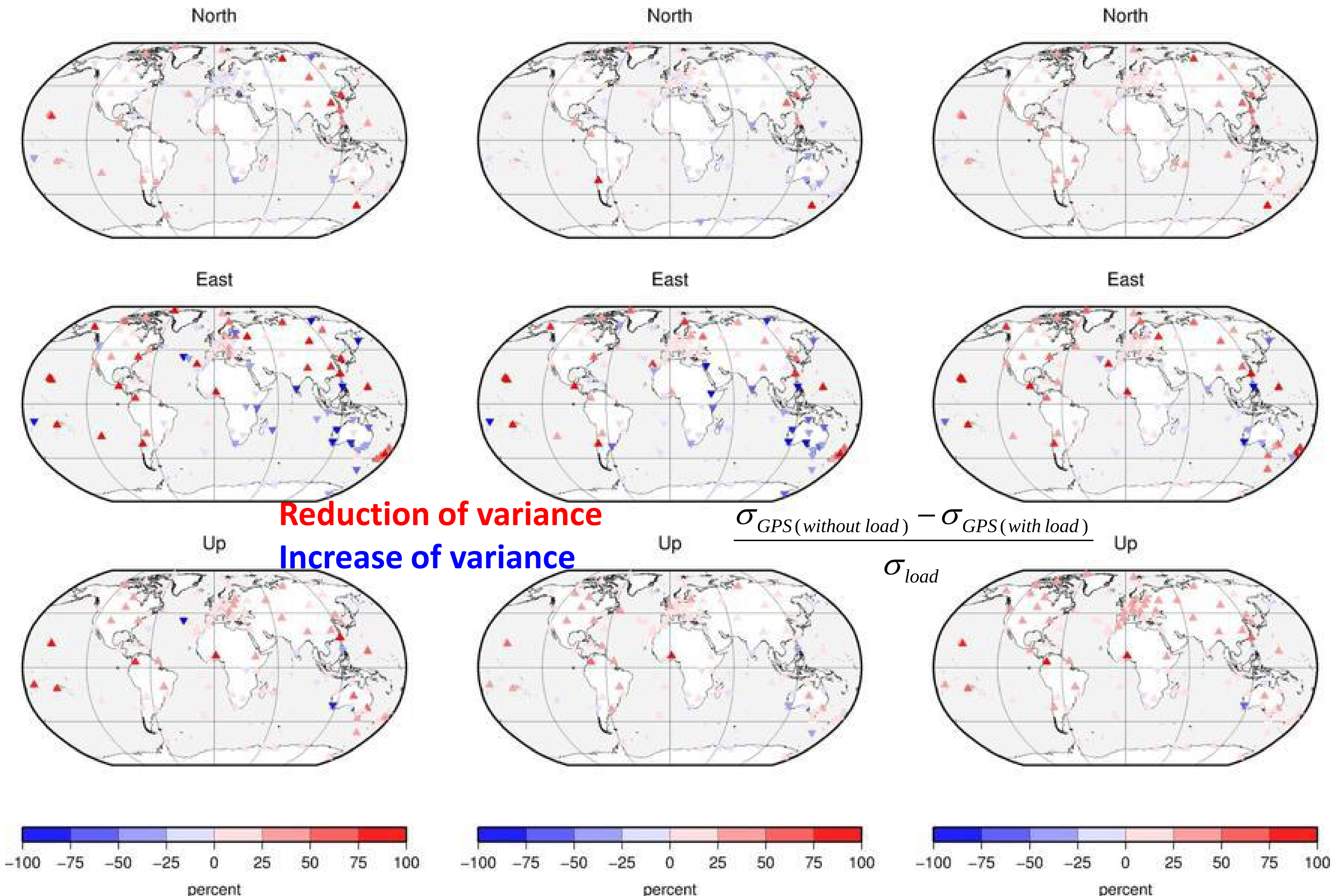


Relative reduction of variability

ECMWF/IB + GLDAS | **ECMWF + TUGO-m + GLDAS** | **ECMWF + TUGO-m + GRACE**



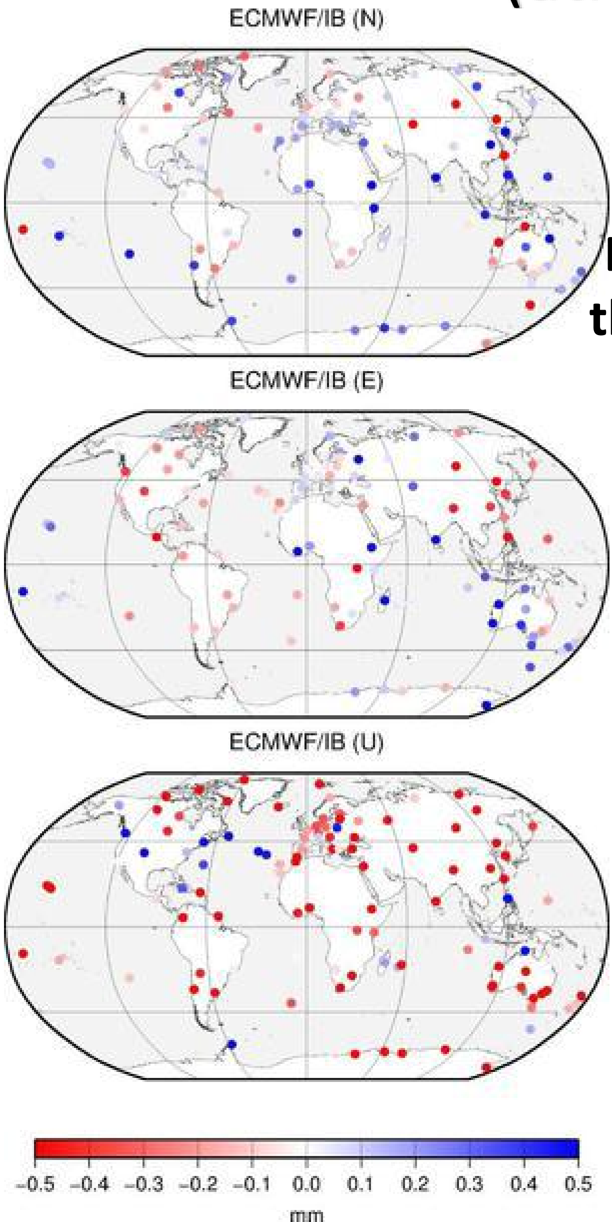
Reduction of variance

Increase of variance

$$\frac{\sigma_{GPS(without\ load)} - \sigma_{GPS(with\ load)}}{\sigma_{load}}$$

Reduction of annual component

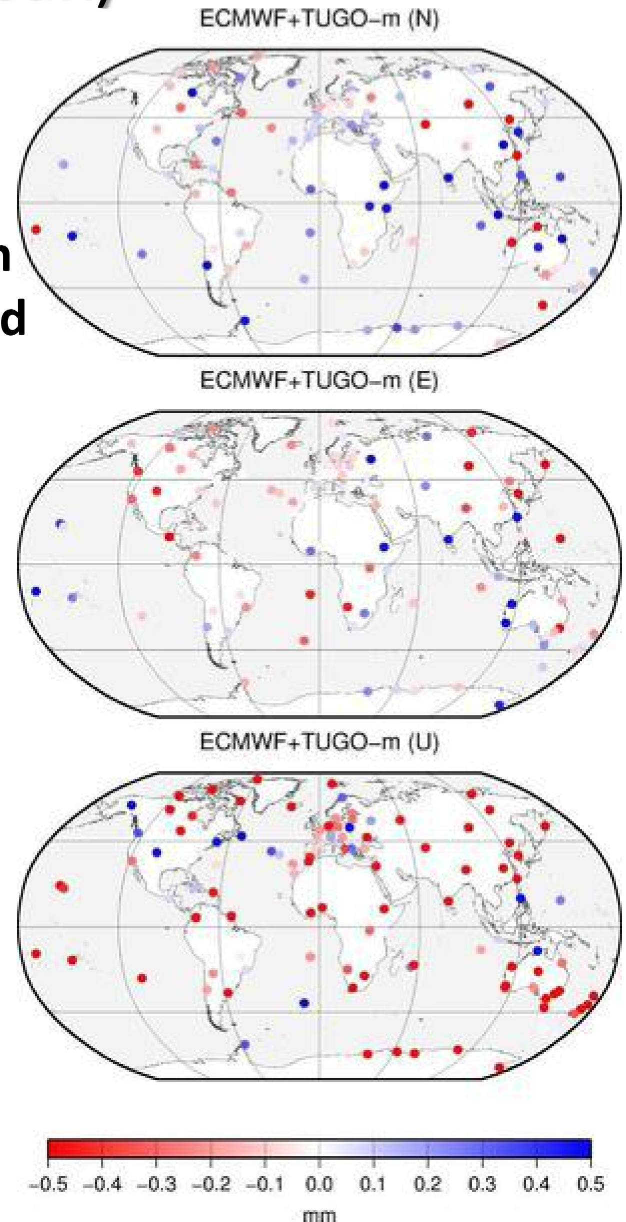
(atmosphere + ocean)



Differences between the solution corrected for loading & the classical solution

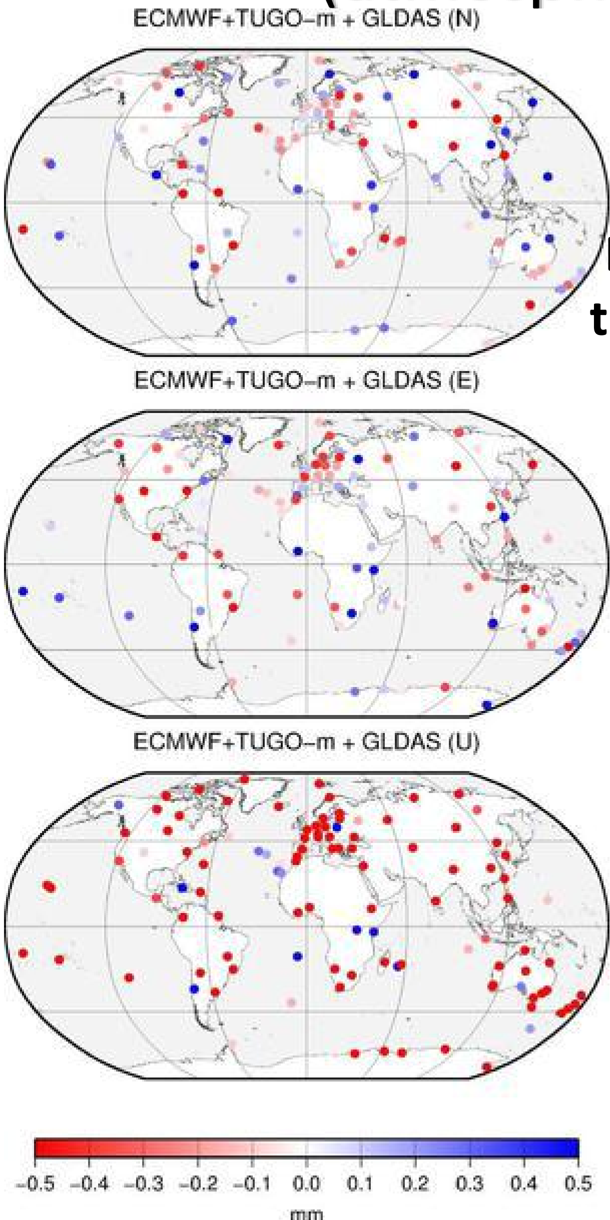
Red: decrease of the annual amplitude when loading are taken into account.

Blue: increase of the annual amplitude when loading are taken into account.

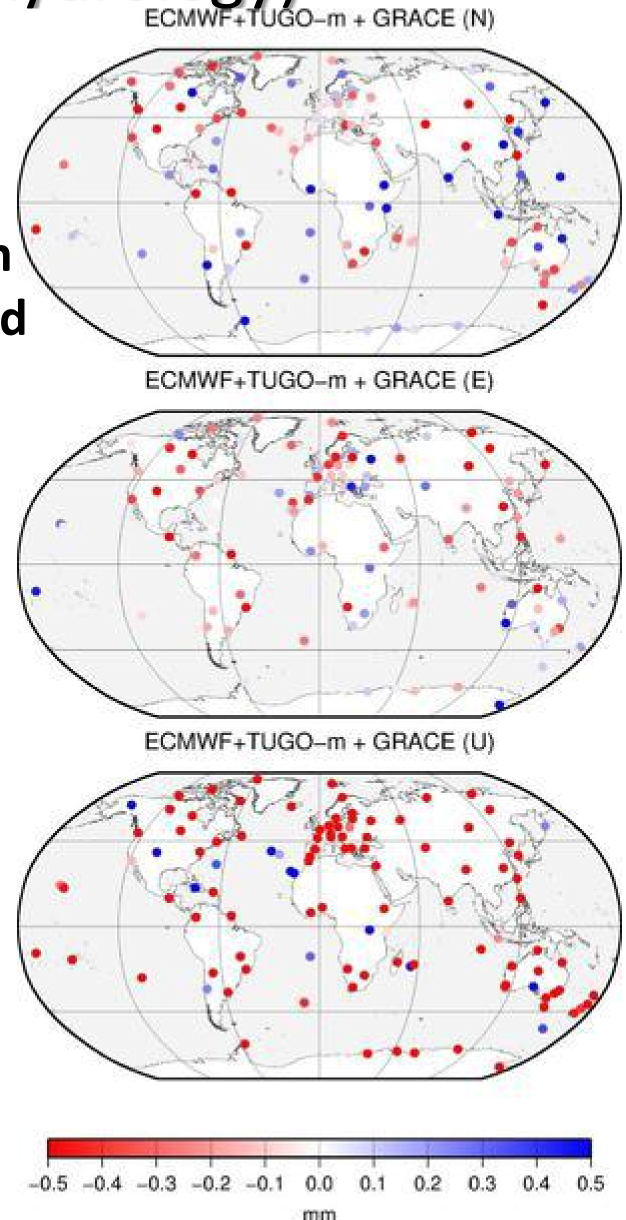


Reduction of annual component

(atmosphere + ocean + hydrology)



Differences between the solution corrected for loading & the classical solution

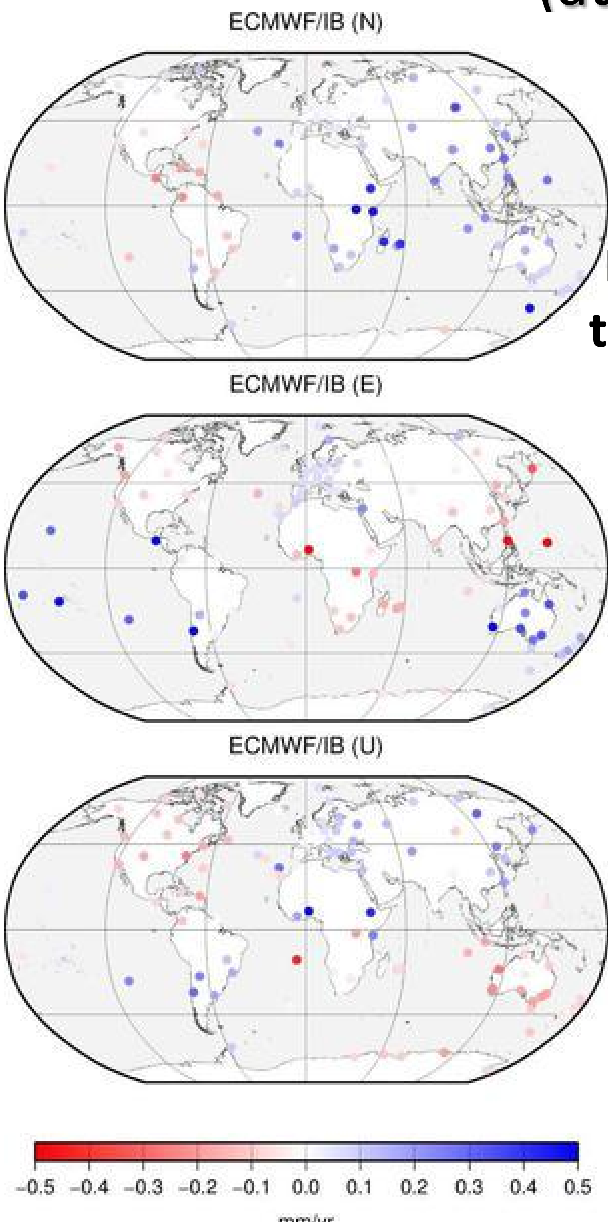


Red: decrease of the annual amplitude when loading are taken into account.

Blue: increase of the annual amplitude when loading are taken into account.

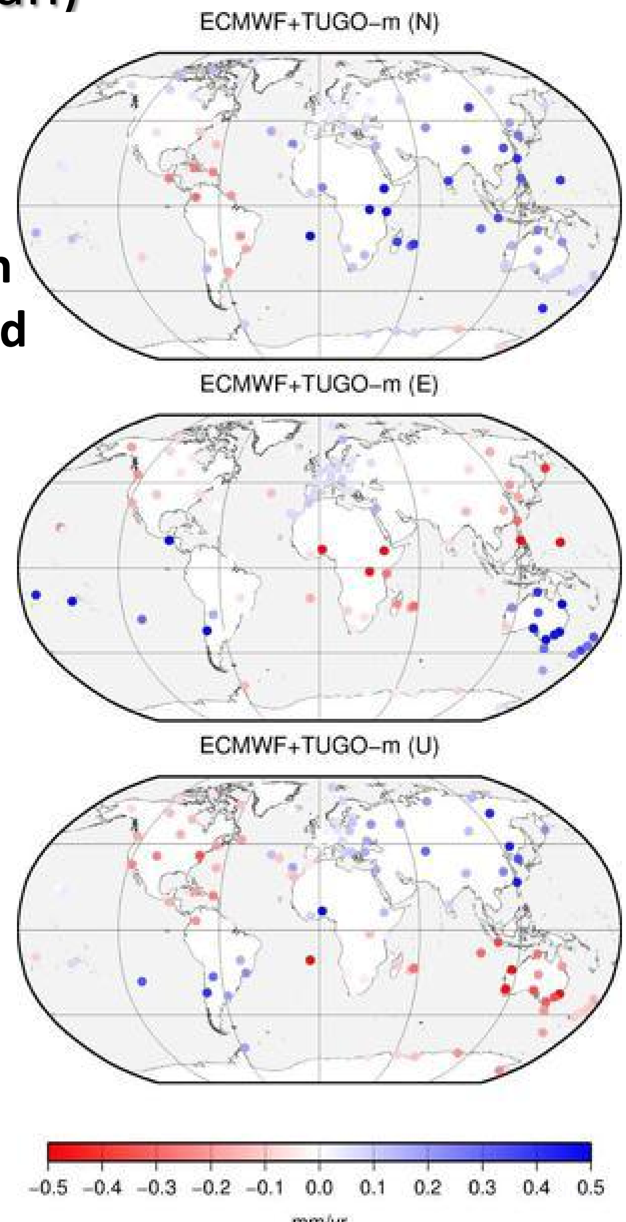
Changes in linear trends

(atmosphere + ocean)



ITRF precision: goal of 0.1 mm/yr

Differences between the solution corrected for loading & the classical solution

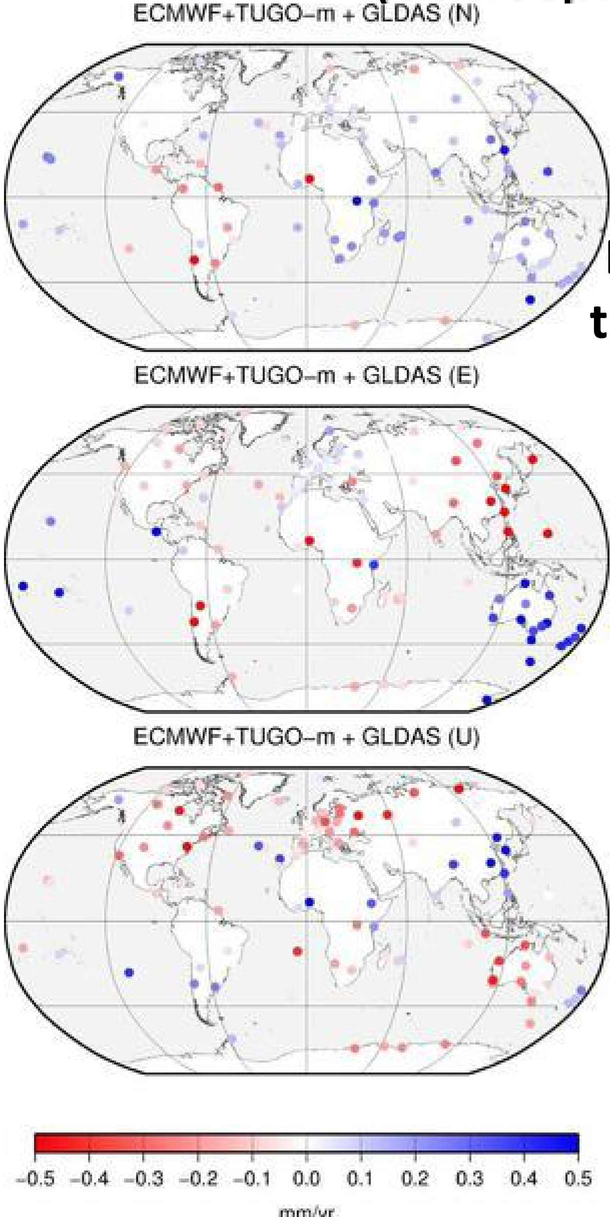


Red: decrease of the linear trend when loading are taken into account.

Blue: increase of the linear trend when loading are taken into account.

Changes in linear trends

(atmosphere + ocean + hydrology)



ITRF precision: goal of 0.1 mm/yr

Differences between the solution corrected for loading & the classical solution

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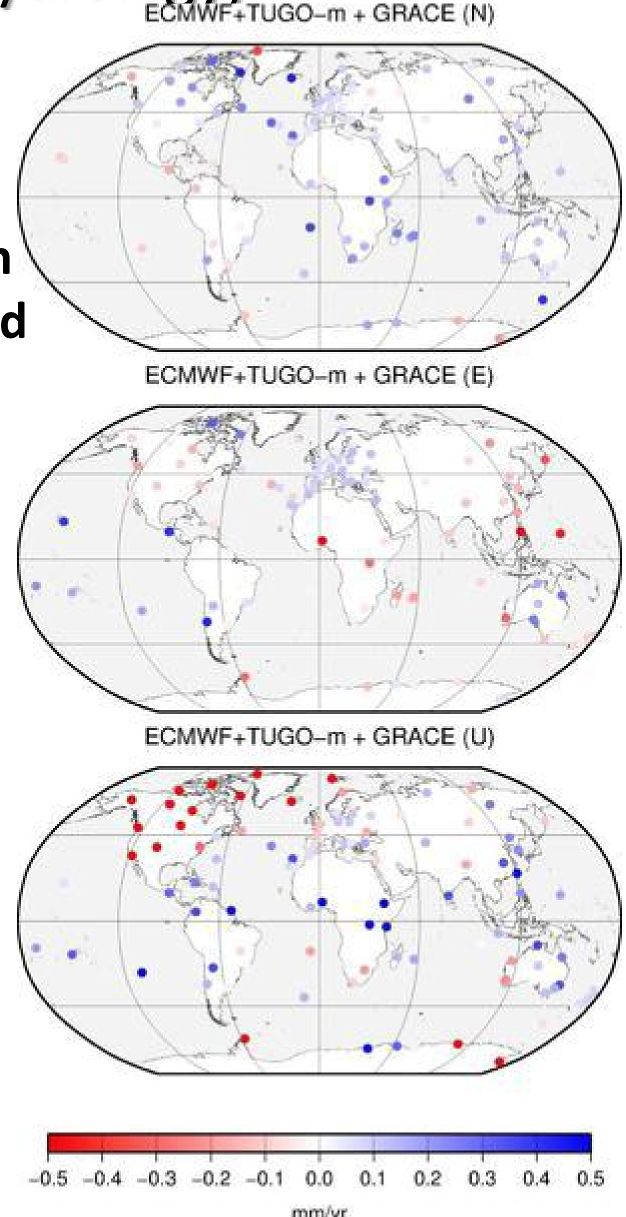
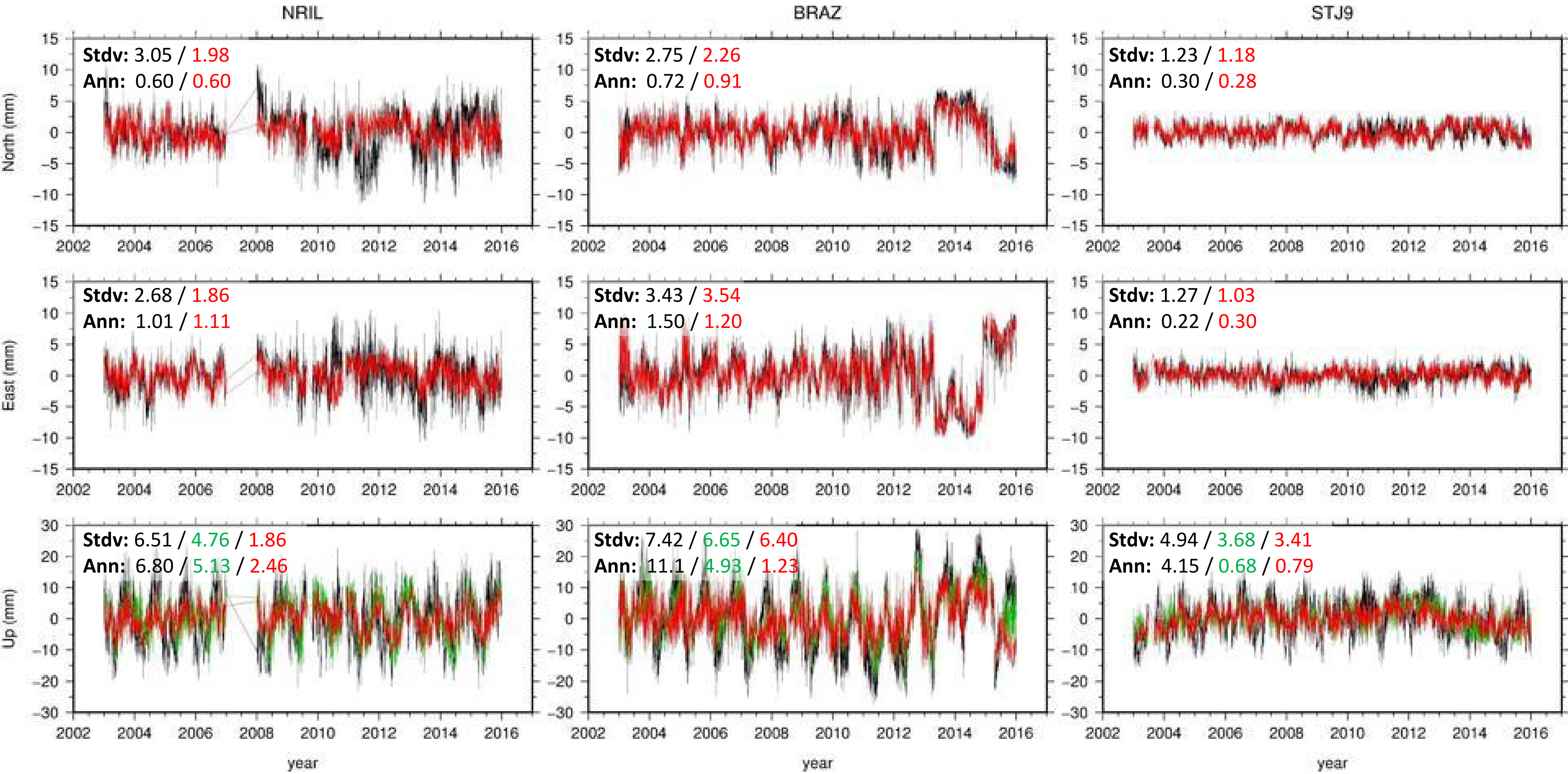


De-trended GPS time series with/without loading corrections



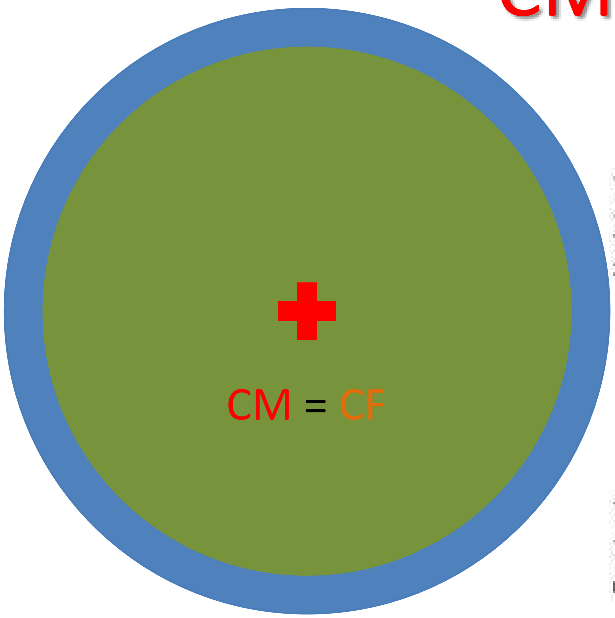
No load correction **ECMWF+TUGO-m + GLDAS** **ECMWF+TUGO-m + GRACE**

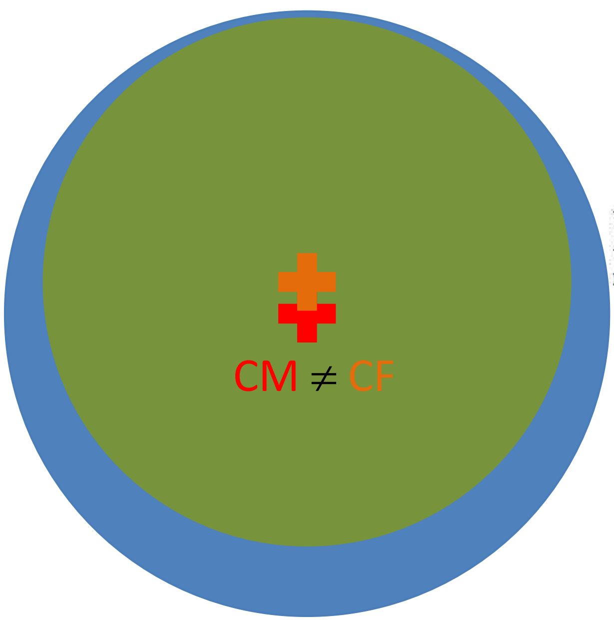
Conclusions & Perspectives

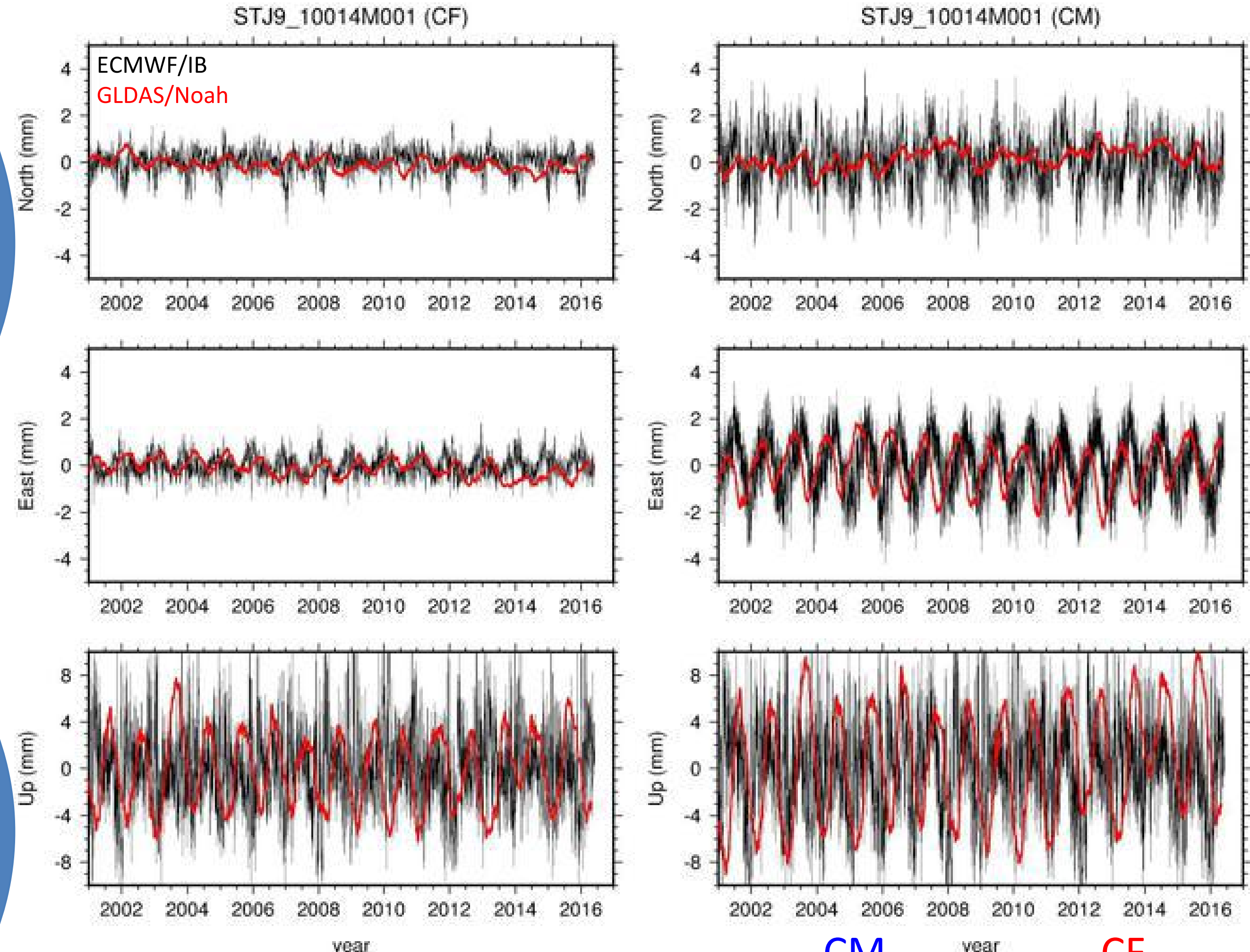
- Implementation of all loading models (atmosphere, ocean and hydrology) into GAMIT/GLOBK (directly from station files, not grid interpolation).
- TUGO-m (barotropic ocean model forced by air pressure and wind) allows smaller residues than the classical inverted barometer assumption (especially for the vertical).
- Adding hydrology helps reducing the seasonal signal, but also slightly the high frequency variability. GRACE global mascons (monthly & 1°, and GIA corrected) perform much better than the GLDAS/Noah model (3 hrs & 0.25°), as it includes more components, such as ice-sheets at high latitudes and surface (rivers) & ground-water (See Nicolas et al. poster #PS07-12)
- A large part of the GPS variability cannot be explained by loading effects; tropospheric wet delay is probably one of the causes.

Backup slides

Differences between the CM & CF reference Frames







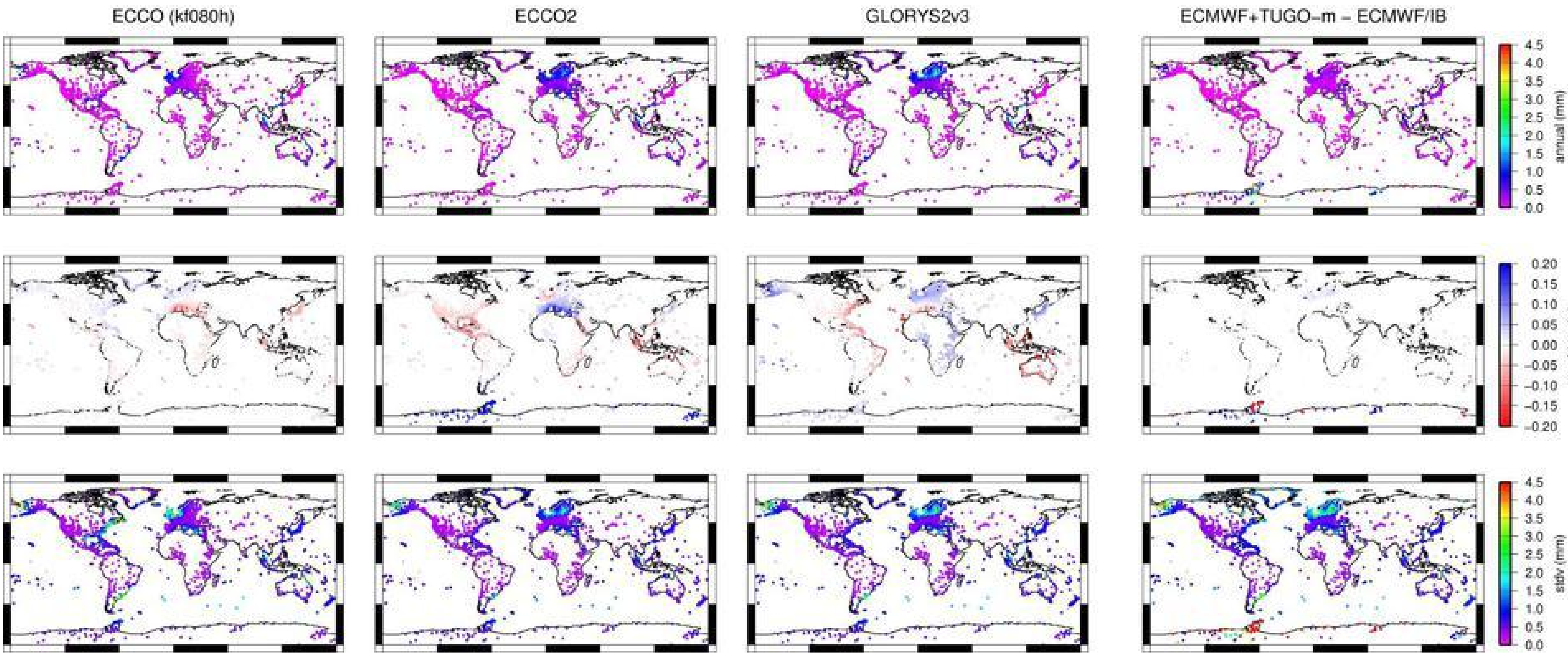
(elastic) Love numbers of degree 1

CM	CF
$h_1^{'} = -1.286$	$h_1^{'} = -0.286$
$l_1^{'} = -0.896$	$l_1^{'} = +0.104$

Modeled vertical displacements
CF Reference Frame / ocean

Baroclinic models forced by winds, heat and fresh water fluxes

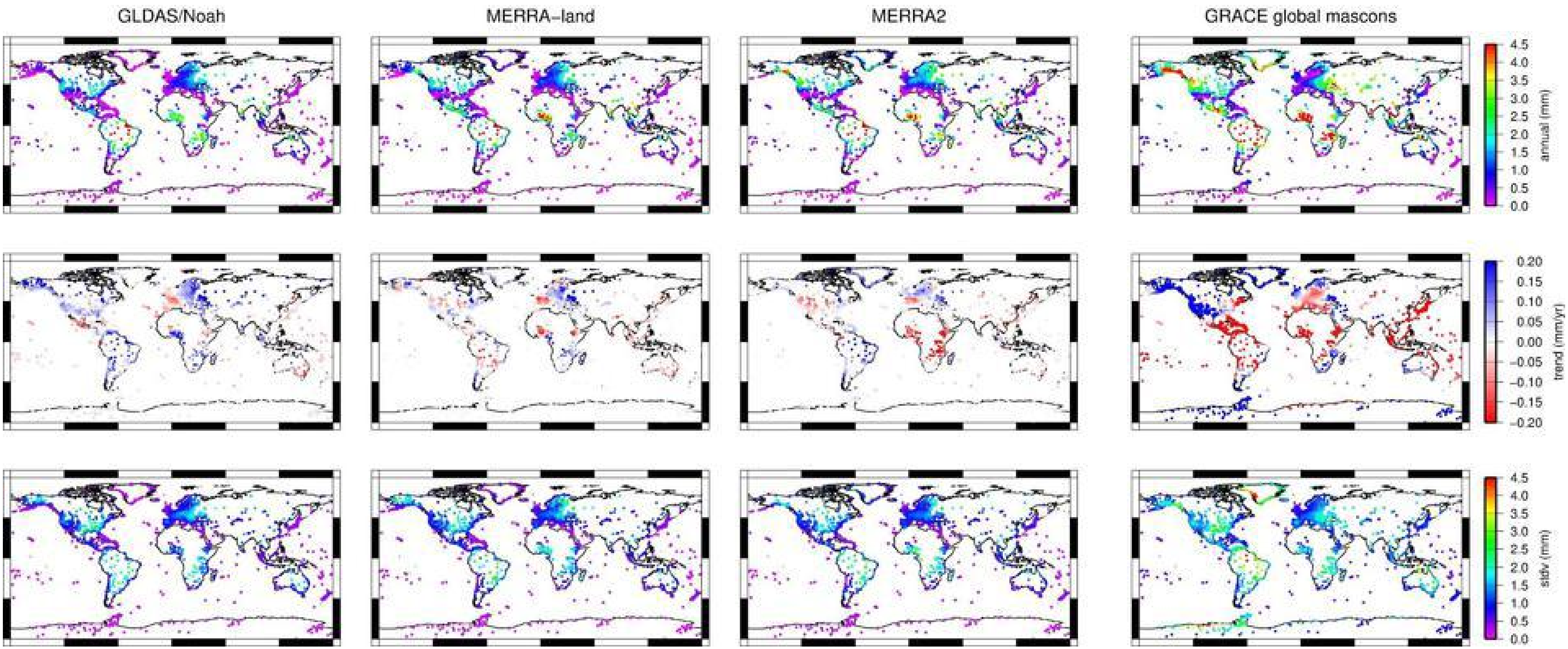
Barotropic model forced by winds and pressure



Mass conservation enforced

All series available at http://loading.u-strasbg.fr
Period: 2002-2016

Modeled vertical displacements
CF Reference Frame / hydrology



Mass conservation enforced

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