How uncertain are regional sea level trends?
Context and goals

**GMSL trend and acceleration uncertainties**
- Ablain et al., 2019,
- From an error budget approach,
- comprehensive error description,
- consistent uncertainty estimates,

**Large regional SLR variability**
- Can we use a similar methodology?
- Can we constrain the error budget at regional scales?
- What does that mean for regional trend uncertainty levels?
Why does it matter?

Regional budget studies

Regional sea level rise detection and attribution

As a data provider error should come with the data

"Quantitative uncertainty information should be provided with the observations."

C. Merchant, Fiduceo outcome

Rietbroek et al., 2015
C3S sea level grids
• Inherits from Sea Level CCI,
• Stability oriented,
• From 1993 to 2018

Spatial filter
• Remove mesoscale signals,

Yearly averages and sub-sampling
• Filter high frequency variability,
• Reduce problem dimension,

NOT corrected for a TOPEX-A drift
Uncertainty estimation

Extended OLS formulation

\[ \hat{\beta} \sim N(\beta, (X^t X)^{-1}(X^t \Sigma X)(X^t X)^{-1}) \]

Where \( \Sigma \) is the error covariance matrix

**Approach**
- For each grid cell
- Estimate local error budget,
- Fill the error covariance matrix accordingly,
- Derive local uncertainty on SL trend

**Limitations**
- No spatial error covariances, time only
- For trends only
- Altimetry errors only, no natural variability
Filling the error covariance matrix

Three elementary error constituents

Correlated errors
• Decaying covariance,
• Amplitude & time scale

Biases
• Anti-correlates before/after bias
• Amplitude and timing,

Drifts
• Covarying over the whole time series
• Amplitude

Under a no cross-covariance hypothesis, we sum individual contributions
Medium frequency errors

- Correlated at $T < 1$yr
- Geophysical corrections,
- Orbit errors,
- Derived from Xovers and Xcal empirical corrections,
- Can’t be inferred from signal at regional level
Medium frequency errors

Large frequency errors – wet troposphere

- Accounting for long term WTC errors
- Correlated at $T = 10$ yrs
- Scaled to the variance in radiometer minus model differences,
- Latitude dependent (more error in the tropics)
- eg Thao et al. 2014, Legeais et al. 2014
Error budget

Medium frequency errors

Large frequency errors – wet troposphere

Orbit drift

• Uniform at 0.33 mm/yr
• Includes gravity field and ITRF contributions,
• From Couhert et al., 2015, Rudenko et al., 2018
• Likely conservative estimate
Error budget

Medium frequency errors
Large frequency errors – wet troposphere
Orbit drift
GIA

- Should be corrected for detection of present day changes,
- 0.3 mm/yr +/- 0.12 globally,
- Large regional variations
- Derived from spread of different runs (Spada, 2017)
Medium frequency errors
Large frequency errors – wet troposphere
Orbit drift
GIA
Biases
• 10 mm for TP-A/TP-B & TP-B/J1,
• 6 mm for J1/J2 and J2/J3,
• No indication of a spatial pattern,
• See also Zawadzki et al., 2018
Given at 90% confidence level

- For SL trends,
- Could be applied to any metric (acceleration, ...)

Median value 0.83 mm/yr

- Ranging from 0.75 to 1 mm/yr
- Twice as much as the GMSL trend uncertainty (0.38 mm/yr, from Ablain et al., 2019)
Significant trends

Compare trends with confidence levels

- Significant if trend > uncertainty
- t-test

98% of the ocean experiences significant rise

- Over 1993-2018
- For a filtered C3S dataset

Few non significant patches

- Southern Pacific Ocean,
- Northern Atlantic Ocean
Results depend on error budget accuracy
- Main contributions are here,
- We may omit some contributions,
- Simplified error covariance description

How sensitive is the uncertainty estimate?

Explore the impact of error budget changes
- Draw in range of « plausible » error values
- Main drivers are orbit drift and low-freq decorrelation scales

Despite uncertainty changes, trends remain significant
- Values ranging from 0.6 up to 1.5 mm/yr,
- With little impact on the ratio of significant trends (96 to 99%)
Regional SL accelerations - WIP

Acceleration uncertainty is generally below 0.07 mm/yr²
Accelerations are dominated by natural ocean variability
Conclusions & Future work

Quantitative confidence levels on regional trends

• Accounts for temporal error covariance,
• Arising from measurement system errors only,
• Based on current knowledge of regional altimeter error budget,
• Should be revisited according to new findings,
• Sensitivity study suggests current results are robust,

Foreseen upgrades

• Improve representation of orbit errors,
• Introduce heteroskedasticity,
• Consider spatial error covariance,
• Provide a full space/time error covariance matrix and/or ensemble of realisations,
• Include internal variability