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Uncertainties in SSB modeling and impact on MSL

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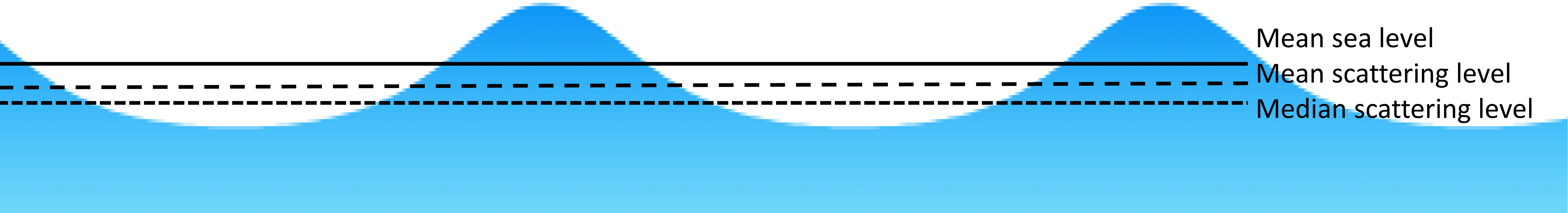
OUTLINE

- Questions to answer :
  - What is SSB ?
  - What are its sources of error and uncertainty ?
  - How to mitigate and evaluate errors coming from the SSB table choice to better address the sea level rise monitoring and the assessment of its uncertainty budget ?
  - Which projects are working on these aspects currently ?
- Reported results for 2D SSB on:
  - Impact of interannual variations on SSB models
  - Impact of 1-year based SSB models on MSL trend (global and regional)
  - Definition of a more appropriate length period to get satisfactory stability of SSB solutions for reprocessing exercises
  - First elements towards an assessment of the total uncertainty associated to SSB in GMSL uncertainty budget within an end-to-end approach
- Dataset used for most of the study:
  - 8 first years of Jason-2 mission on its nominal ground track (10/2008 to 10/2016)

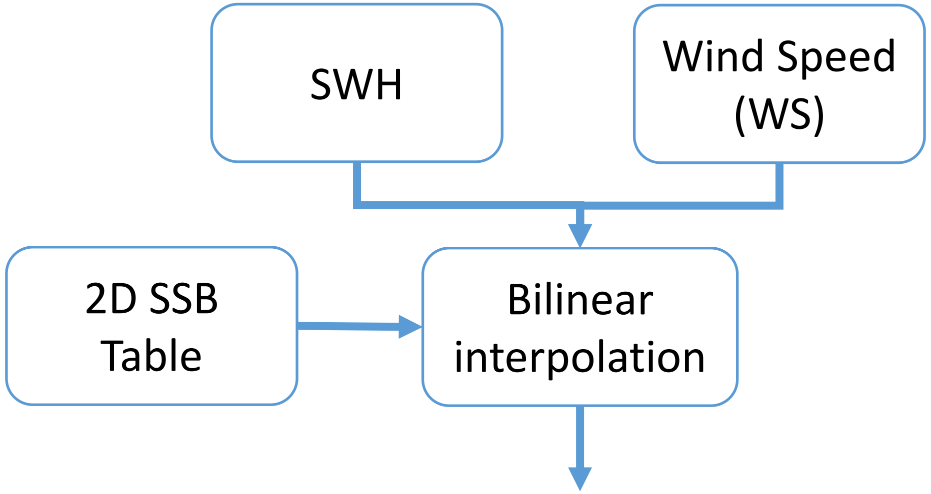
What is sea state bias (SSB) ?

- Negative error in range measurement due to the presence of ocean waves on the surface and that needs to be corrected for to get accurate SSH data
- Sum of different contributions:
  - Electromagnetic bias : radar backscattered power per unit area is larger from wave troughs than from wave crests → observation of a mean scattering level lowered than the true mean sea level
  - Skewness bias : nonlinear, non-Gaussian, and skewed nature of ocean → the median scattering level lies below the mean scattering level.
  - Tracker bias : errors coming from instrument processing and range computation methods related to sea state
- This bias is mission, frequency and processing dependent



SSB correction, errors and uncertainties

- Only empirical methods presently provide a practical solution to estimate SSB
- Operational models consist in 2D tables depending on (SWH, WS)
- Levels of errors and uncertainties in SSB come from various sources:



  - the measurement data
    - uncertainties from SWH and WS retrievals (e.g. natural variabilities, random error, measurement systematic error, …)
    - uncertainties in forming SSH (e.g. uncertainties related to range, orbit, geophysical corrections)
    - ways to extract the SSB signals from the SSH data (e.g. SSH differences with assumption about the 10-day errors, SLA)
  - the SSB modelling
    - choice of the statistical methods (e.g. model forms)
    - choice of the key inputs (e.g. knowledge limitations of physics)
    - parameter uncertainties (e.g. calibration related model errors)
    - Incomplete coverage of the domain by finite size of datasets used (e.g. temporal and spatial variabilities)
  - the interpolation scheme
    - choice of bilinear function
- The input data and modeling uncertainties are not independent of each other. They can interact in various ways.

Other way of classifying types of uncertainties

- Aleatoric uncertainty
  - property of the data
  - due to inherent randomness related to natural variabilities along with noises in measurement systems
  - **irreducible**
  - measured by associating averaged values and standard deviation from the observations

- Epistemic uncertainty
  - property of the model
  - caused by limited data, incomplete knowledge and numerical treatment in modelling
  - **reducible**
  - strategies to reduce it:
    - building a more accurate model (ex: 3D SSB version)
    - better representing the sea-state dynamics that cause the variations in observations (ex: additional use of mean wave period)
    - performing model calibration with a larger amount of data collection → single year-based solutions vs multi-year-based versions (focus of an on-going CNES SALP study; first results are reported here)
    - reducing input data uncertainties by improving instrument calibration to reduce the systematic error in measurement systems (ex: Jason-3 CNG calibration drift correction) or by improving their retrieval
  - a measure of it → standard deviation of the variability in ensemble modeling (focus of an on-going CNES SALP study; first results are reported here)

Onion layer for GMSL uncertainty budget → 2 complementary on-going studies

Assessing the sea level rise stability uncertainty budget from a metrological approach
(ESA ASELSU project)

Assessing the error propagation uncertainty budget

Assessing the SSB uncertainty budget

SSB input data uncertainty

SSB model uncertainty
(CNES SALP project)

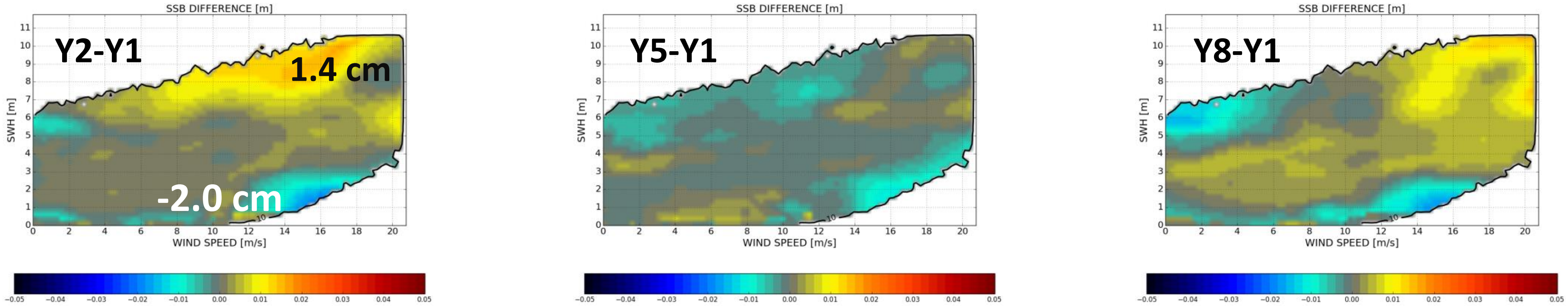
Figerou et al's presentation

Sajedeh Behnia et al's poster

Emma Woolliams et al's presentation

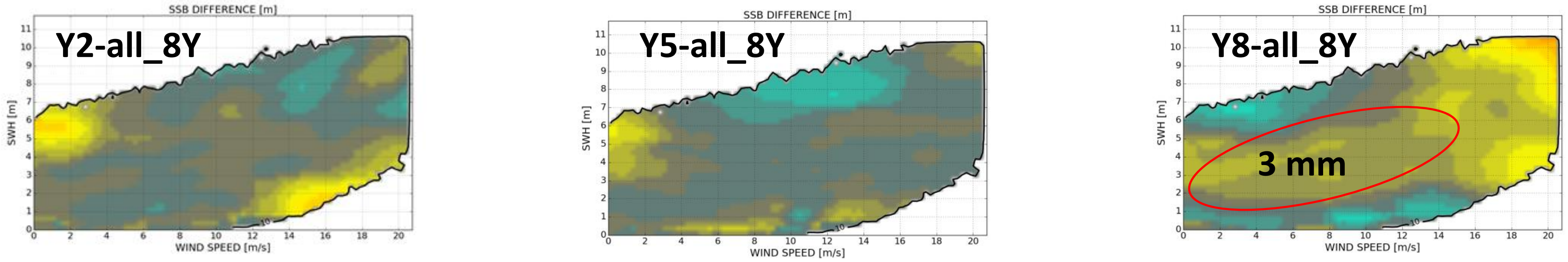
Interannual variability comparison between different 1-year based SSB models → evidence of epistemic uncertainty related to limited data size

- SSB solution from year 1 (10/2008 – 10/2009) is used as reference



Y8: 10/2015-10/2016

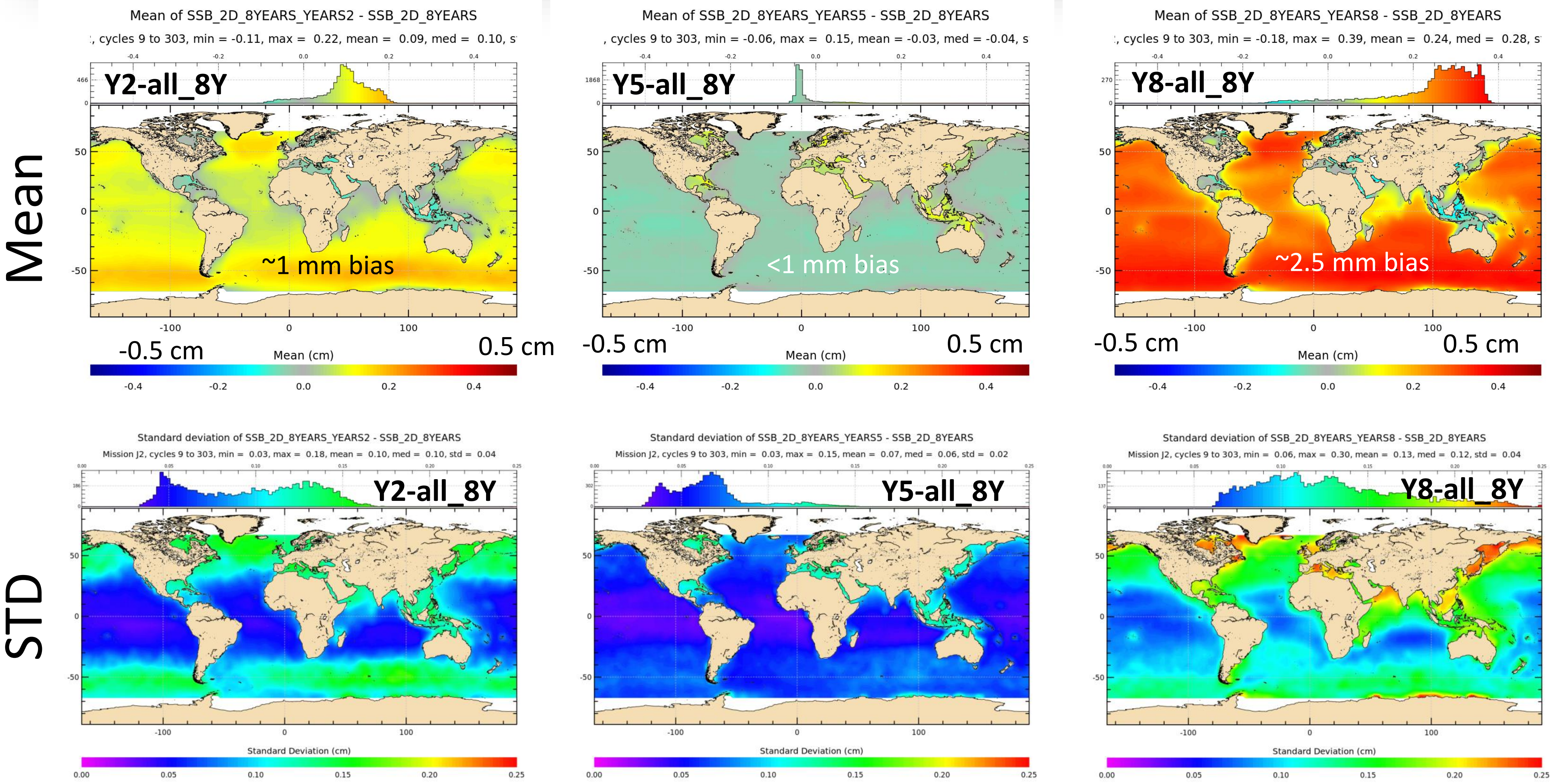
- SSB solution evaluated from the 8-year period is used as reference



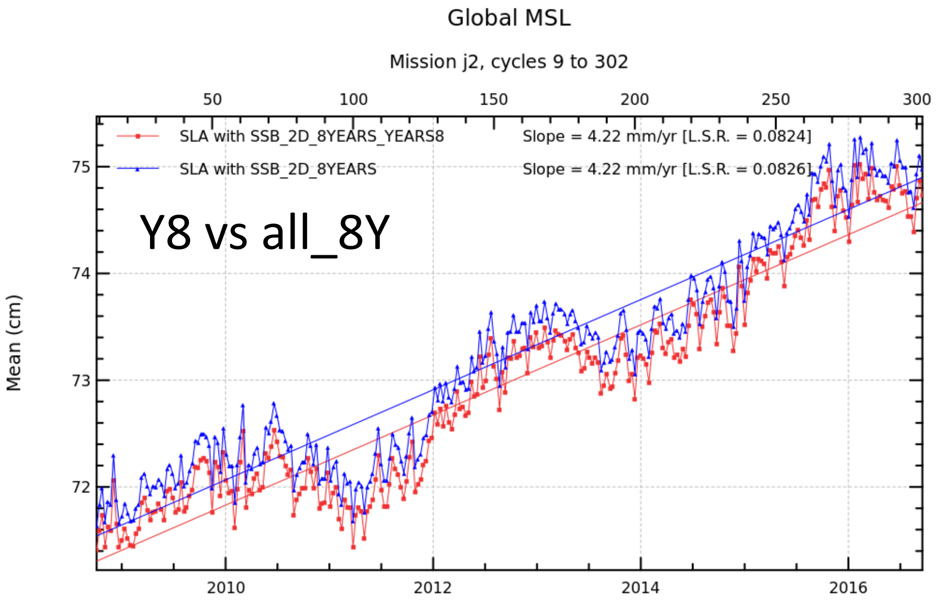
- Differences can reach ~2 cm and are largest in low data density regions of (SWH, WS) plan between 1-year based solutions; there are lower when they are compared to the 8-year models as expected
- Excepted for Y8 where 3 mm differences are observed in high data density regions because of a very strong El Nino event that displays atypical relationship between SSH and sea state conditions

Comparison between 1-year based solution and the reference 8-year one

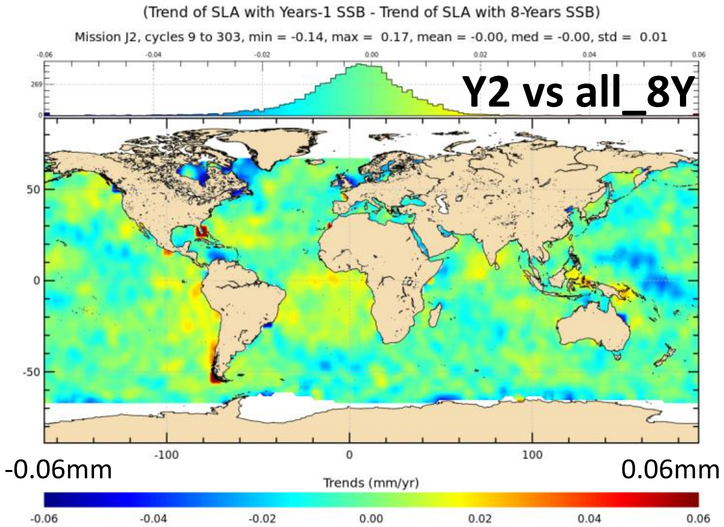
→ this epistemic uncertainty displays geographical patterns and changes with time

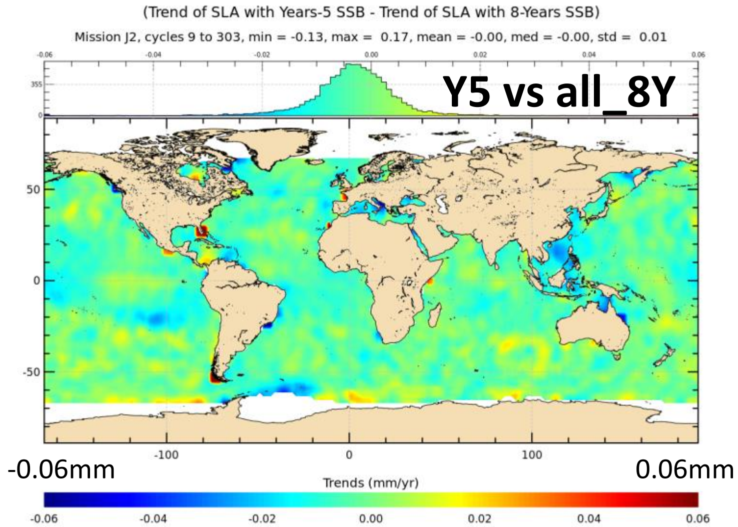


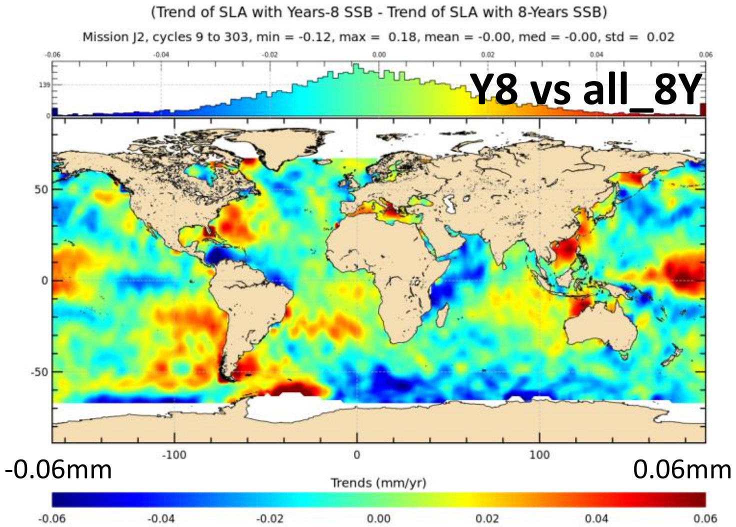
Impact of 1-year based SSB choice on MSL
→ no impact on GMSL, but some are observed on regional MSL



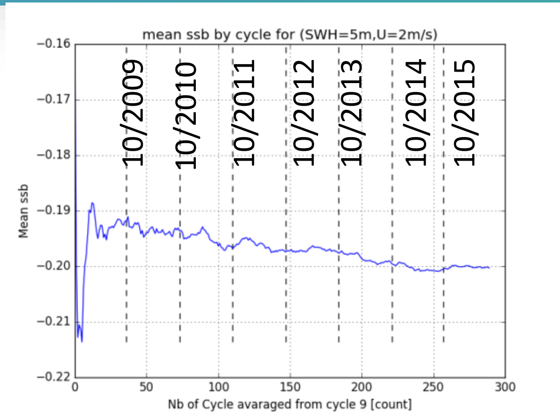
- No impact on GMSL trend but a bias shift can be observed depending on the 1-year SSB solution used
- For regional MSL, differences can reach +/- 0.06 mm, when one compares Y8 SSB with SSB from all 8 years, which are small in MSL trend budget Error
- Y5 SSB is close to the SSB version from all 8 years, but it is not possible to know it without comparing them

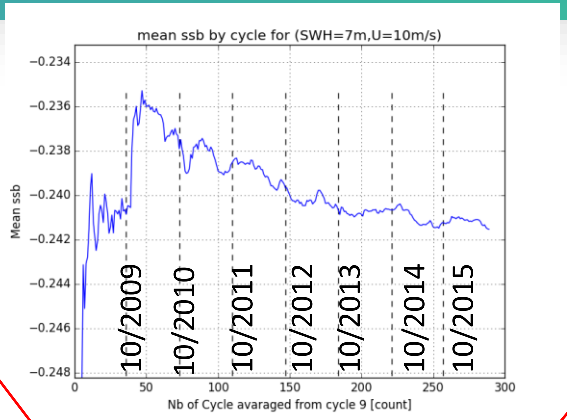


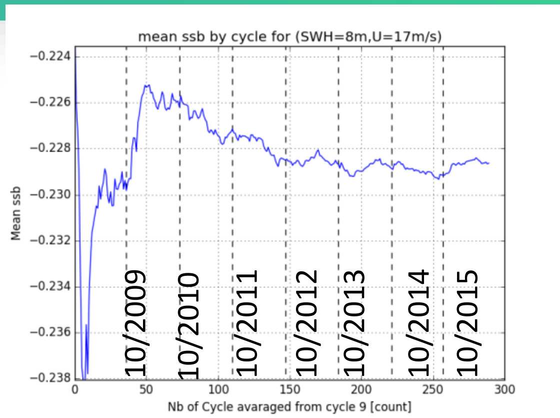




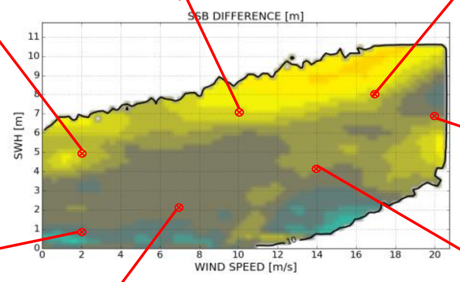
Mean(SSB) w.r.t. the number of cycles considered to compute it

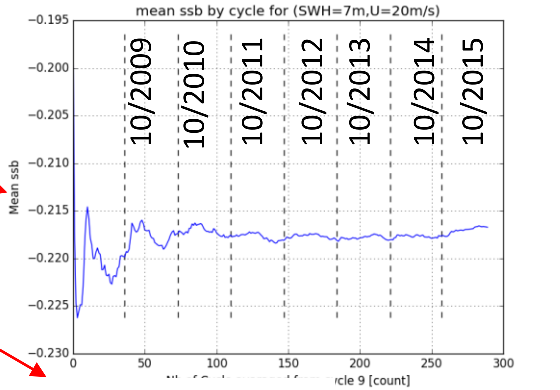


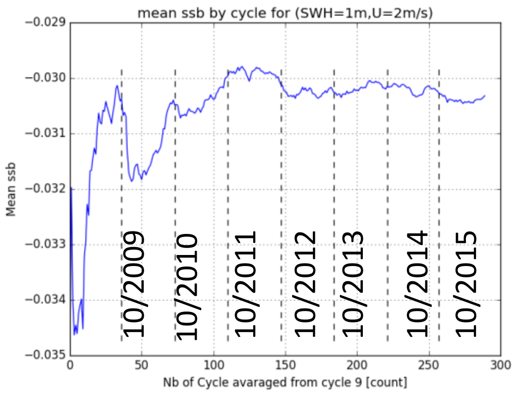


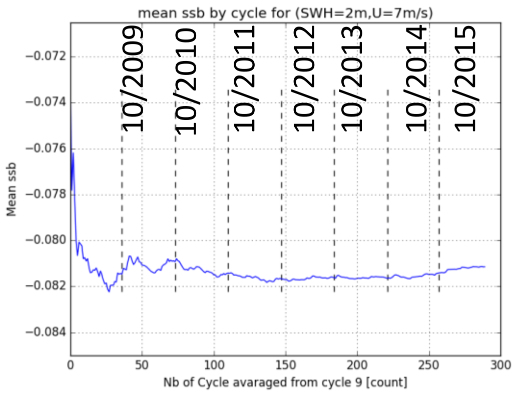


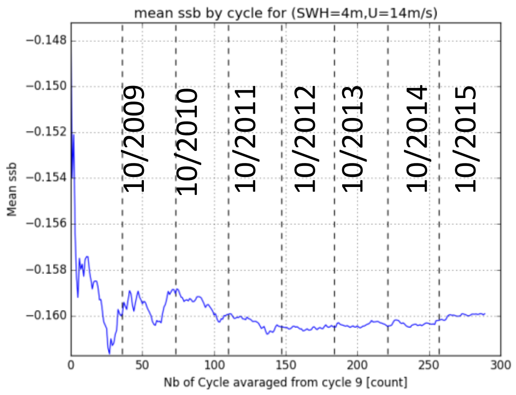
- ➢ The SSB mean values seem to reach some stabilized values after 3-4 years for most of the grid points



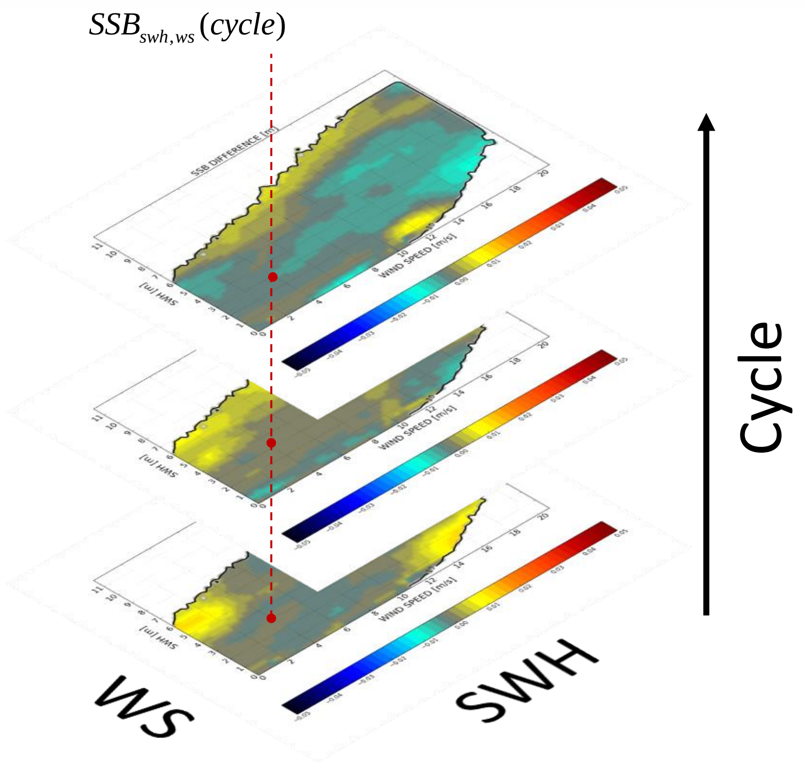


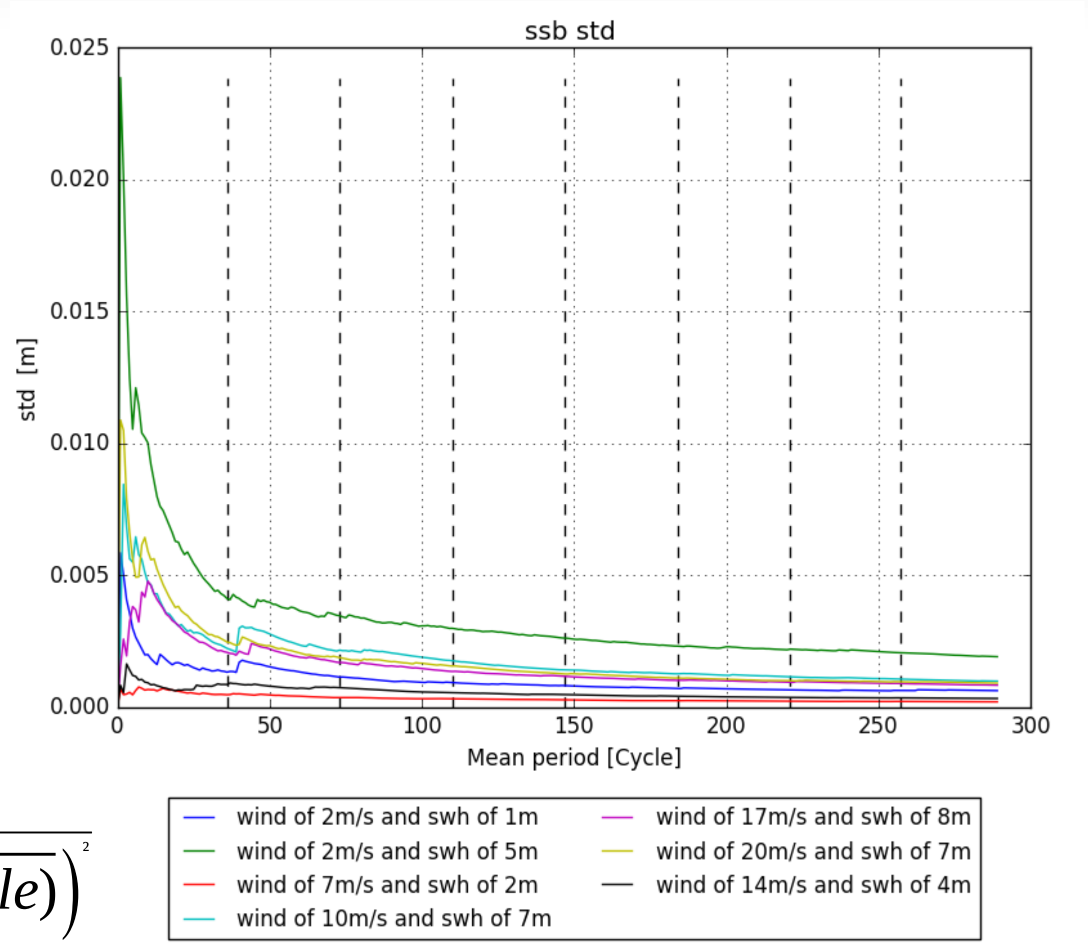






STD(SSB) w.r.t. the number of cycles considered to compute Mean(SSB)

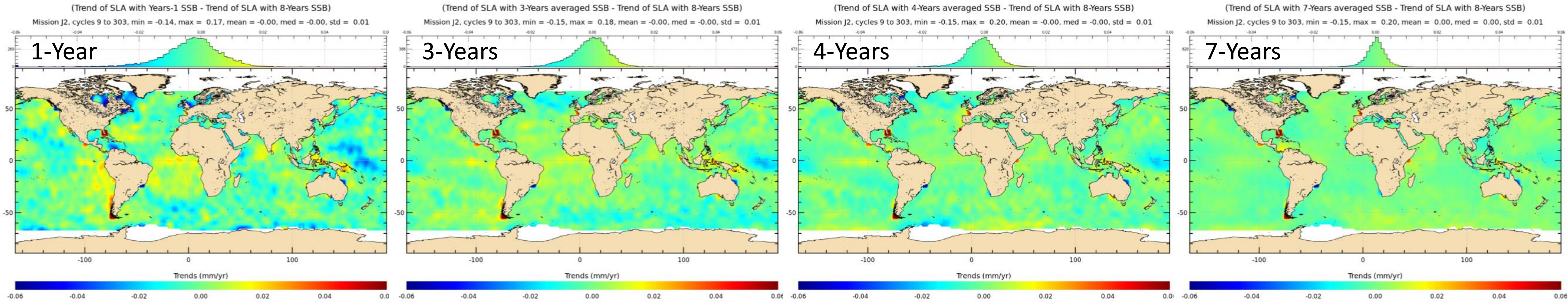




$$STD(SWH,WS) = \frac{1}{Nb_{cycle}} \sum_{cycle} \sqrt{\overline{SSB_{SWH,WS}(cycle)^2} - \left(\overline{SSB_{SWH,WS}(cycle)}\right)^2}$$

- STD(SSB) are below 2 mm after 4 years

Impact of multiple-year based SSB on regional MSL

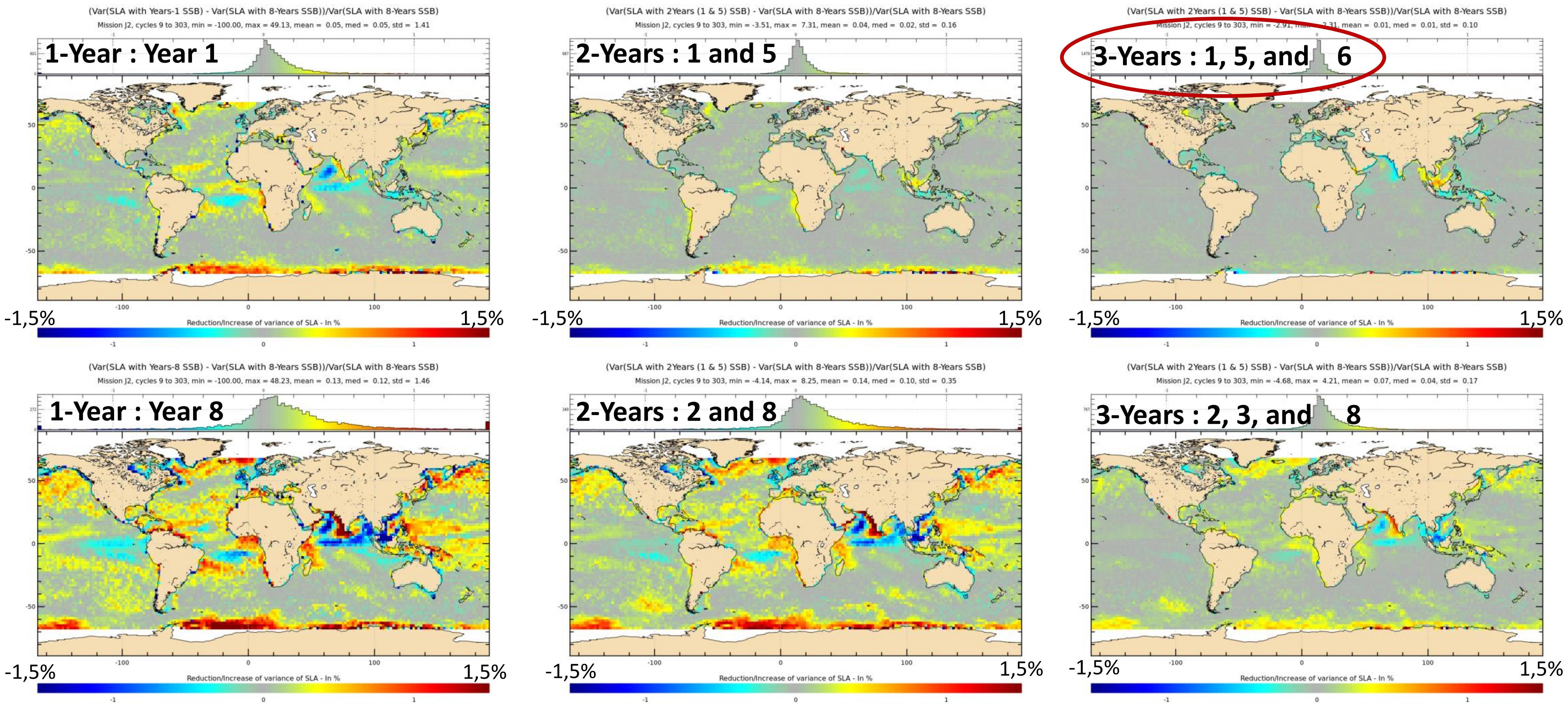


- Reduction of the impact of interannual variations in SSB solutions based on multiple-year periods leads to reduce differences in regional MSL when one compares with trend observed with the all-8 years SSB version

- Good stability of the SSB solutions is confirmed when they are computed from at least 3-4 years of data

Impact of selecting years in SSB development on differences of SLA variance

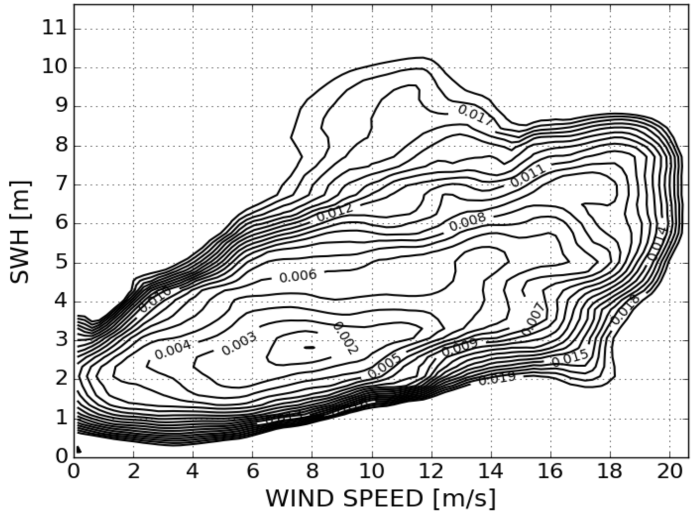
- To limit cost in reprocessing exercise, selecting 3 years amongst the 8 available years for SSB computation represents an even better option than taking 3 successive years



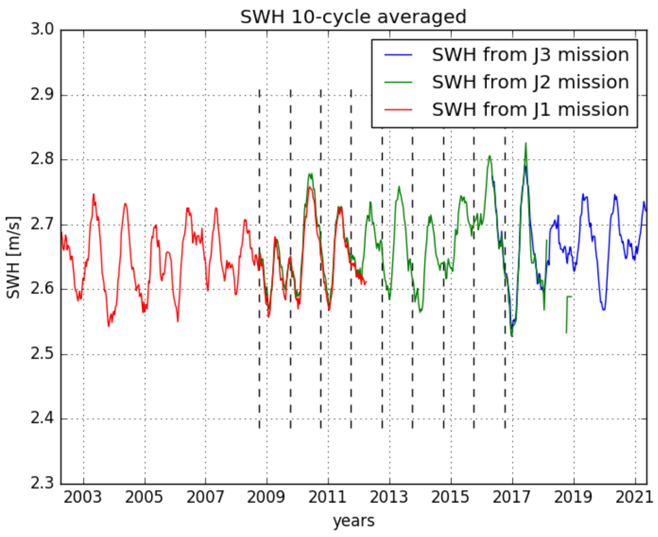
Total uncertainty associated to the SSB estimations

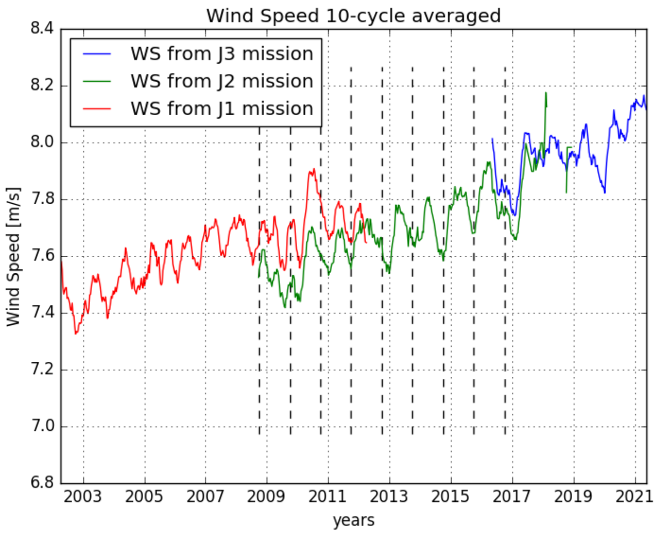
- Sum of the uncertainty due to the input data + uncertainty related to the SSB model
- Ensemble modelling provides the standard deviation of individual cyclic SSB models as a 2D table depending on (SWH, WS) as a proxy of the uncertainty related to the model
- Uncertainties coming from the input data can be accessed by propagating the SWH and WS uncertainties through the SSB model → computation performed by NPL in the ASELSU project [Behnia et al, OSTST 2022's poster]

SSB STD 2D table
J2 mission, Y1 model

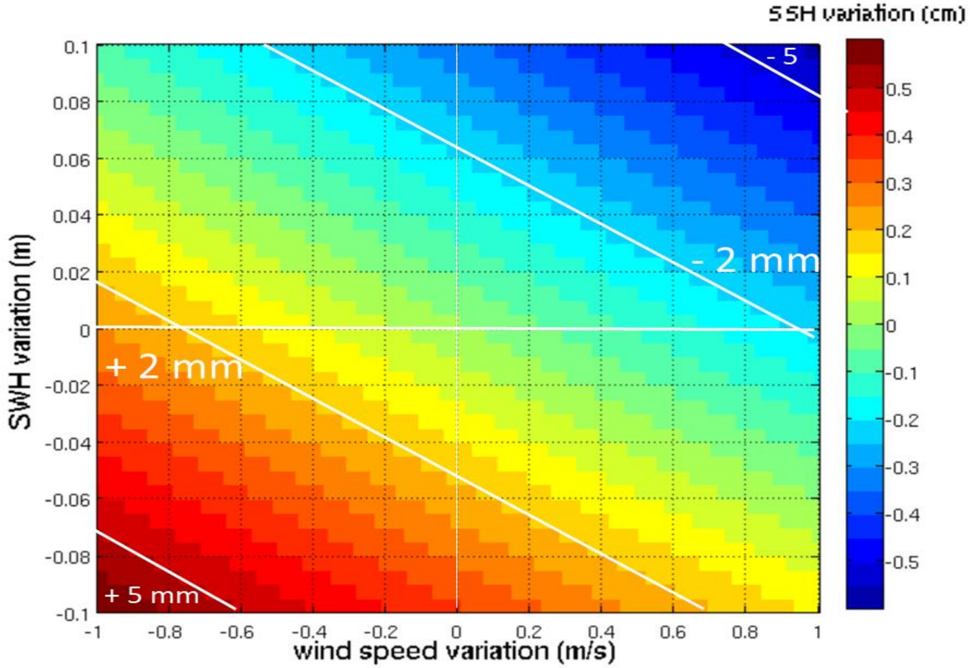


First look at uncertainty propagation through the SSB - Impact on SSH of shifts on both SWH and WS





- ➢ Jason-3 GDR-F 2D SSB table computed from 1-year period (table also used for S6-MF since the launch of the mission)



- ➢ For SWH changes within ± 10 cm and WS changes within ± 1 m/s, the impact on SSH is up to 5 mm in absolute value
- ➢ 5 mm is quite greater than SSH trend budget error (0.1mm/yr)

CLS

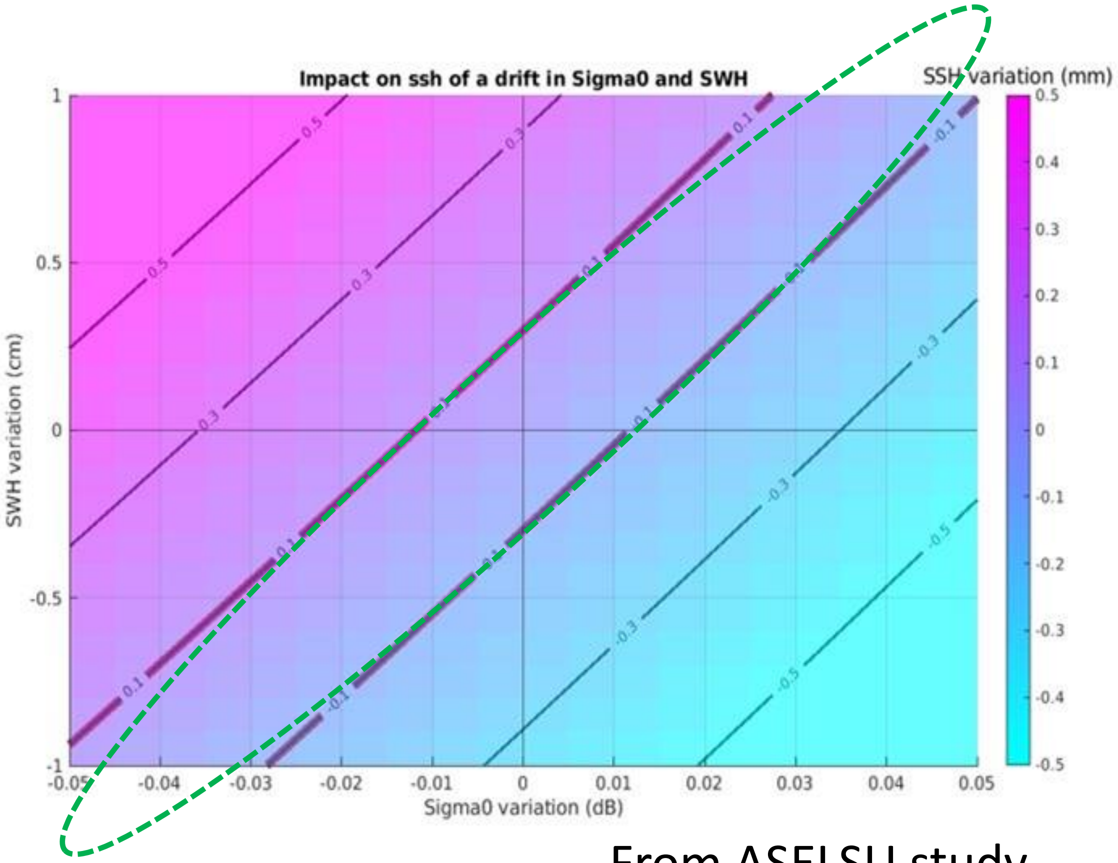
First look at uncertainty propagation through (WS + SSB) - Impact on SSH of shifts on both SWH and sigma-0

- Given a target precision on GMSL, it is possible to define the corresponding constraint in SWH and sigma-0 stabilities to achieve the objective

- Evaluation performed through:
  - Application of shift on typical 1-year distributions of Jason-3 sigma-0 and SWH
  - Propagation of the shifted distributions through the WS and SSB tables
  - Observation of the shift created in SSB ~ SSH ~ GMSL

- To reach 0.1 mm/yr stability in GMSL (S6-MF requirement on SSB), it is necessary to have:
  - 0.01 dB/yr stability on sigma-0 @ very stable SWH
  - or to respect some relationship between SWH and sigma-0 variations

- The requirement on sigma-0 stability of S6-MF seems large (0.1 dB/year) from this point of view



From ASELSU study

Conclusions

- This presentation provides a documentation on some aspects of the SSB error/uncertainty budget
- Main outcomes concern the reduction of the uncertainty in the SSB modelling related to the limited dataset size used (1-year period) to develop most of the operational solutions
- Due to interannual variabilities in the relationship between SSH and sea state parameters (SWH and WS), more stable SSB models are obtained if they are computed with at least 3 years of data
- This seems to be a reasonable trade-off between satisfactory stability in SSB solution with cost involved in reprocessing exercise; while the ‘best’ solution is still to derive a SSB table from the entire mission data
- SSB solutions are already computed through ensemble mean and the provision of the spread (not done so far) of the ensemble members in the 2D (SWH, WS) plan can be used as an estimate of the uncertainty associated to each along-track SSB correction to help project as ASELSU to evaluation the contribution of each component in the GMSL uncertainty budget
- This stability assessment exercise will be performed next with 3D SSB versions

Thank you

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