

CORPHU : CORrection of PHase Unwrapping errors



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- Problem and state of the art
- Method
- Results
- Conclusion

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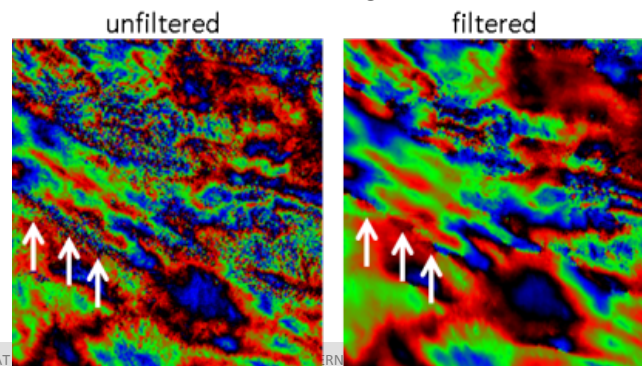
- Classical problem in InSAR
- Determination of the integer k such that:

$$\psi = \varphi + 2.k.\pi$$

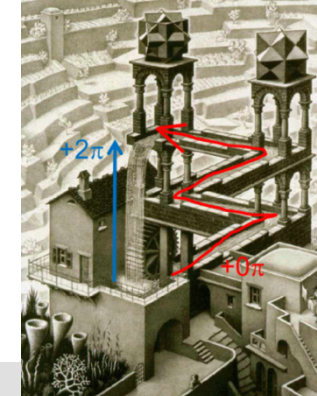
ψ : unwrapped phase

φ : wrapped phase

- Phase unwrapping algorithms sometimes fail due to aliasing, noise, filtering...
- Consequence of unwrapping errors : errors on deformation estimates
- CorPhU : **automatic** correction of unwrapping errors on a series of unwrapped interferograms.



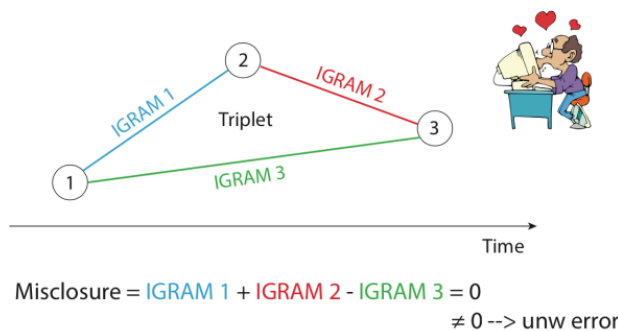
Maurits Cornelis Escher



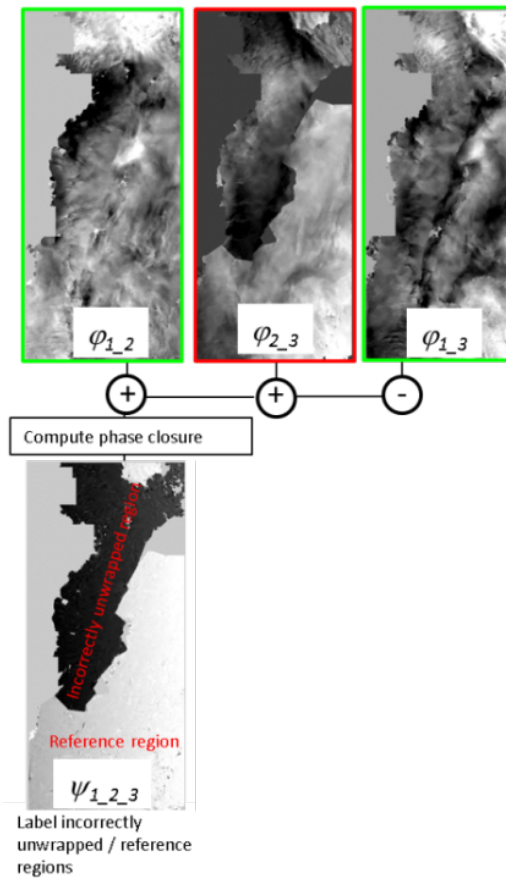
- Unwrapping algorithms
 - Residue cut-tree [Goldstein et al., 1988].
 - Weighted phase unwrapping : [Ghiglia and Romero, 1994].
 - Minimum Cost Flow algorithm : Costantini [1998], Pepe and Lanari [2006, 2010].
 - SNAPHU [Chen and Zebker, 2002].
 - Many others
- Algorithms for automatic correction of unwrapping errors :
 - NSBAS [Doin et al., 2011]
 - Hussain et al. [2016]
 - These algorithms also use phase closure.
 - They are pixel-based / CorPhU is region-based.

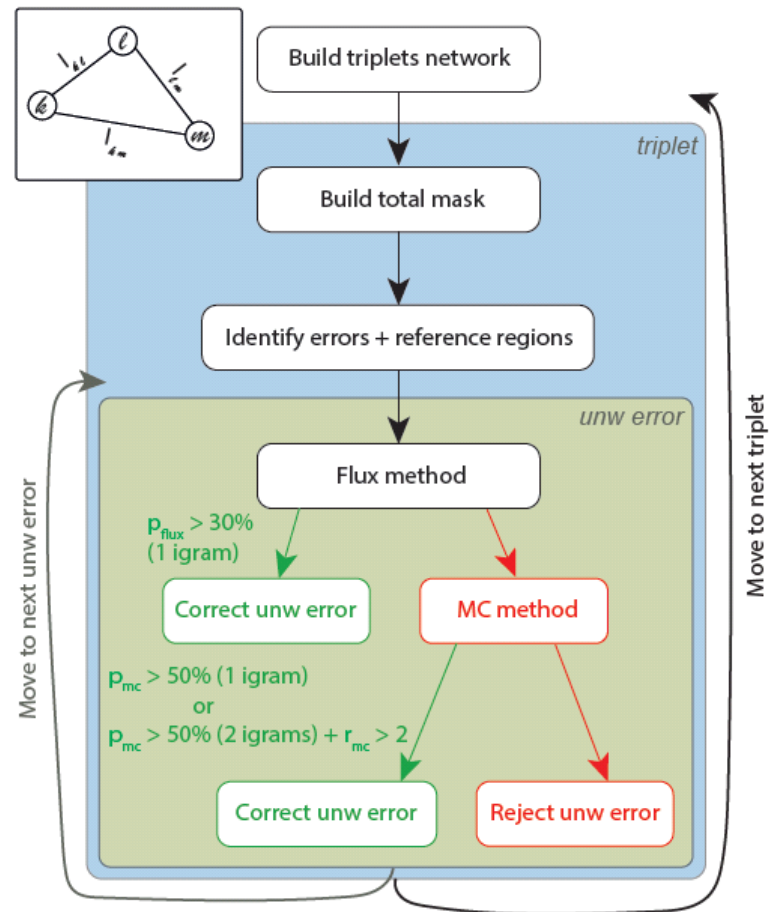
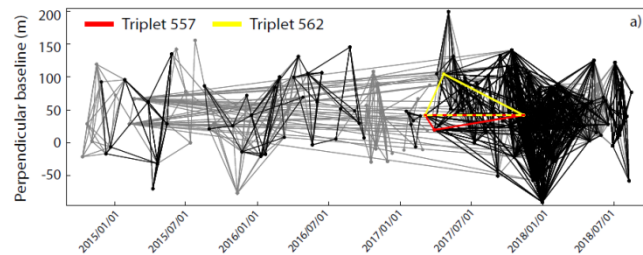
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- Input : series of unwrapped interferograms.
- Phase unwrapping algorithms may generate incorrectly unwrapped **regions**.
- Error regions are easily identified by computing the triplet closure.
- Which of the 3 interferograms is wrong?
=> 2 methods

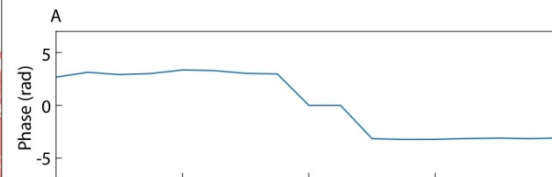
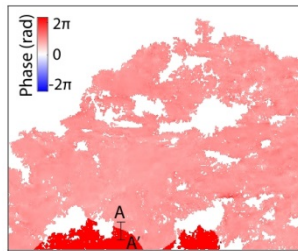


Which interferogram is incorrectly unwrapped?

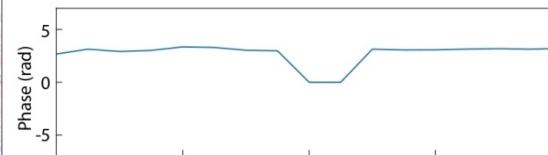
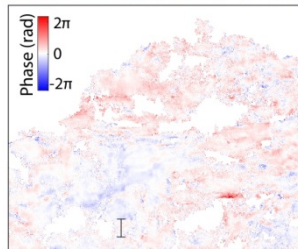




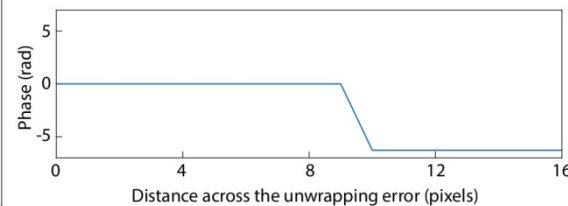
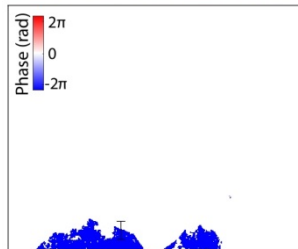
Total closure



Phase inconsistencies

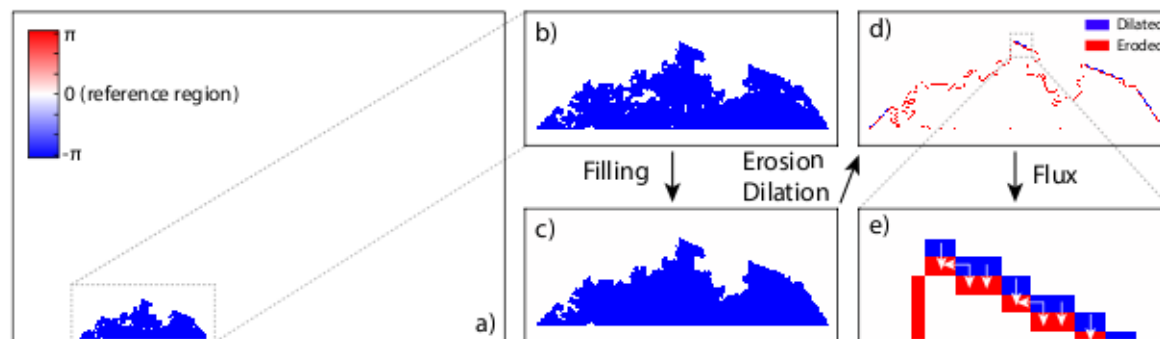


Misclosure due to phase unwrapping errors



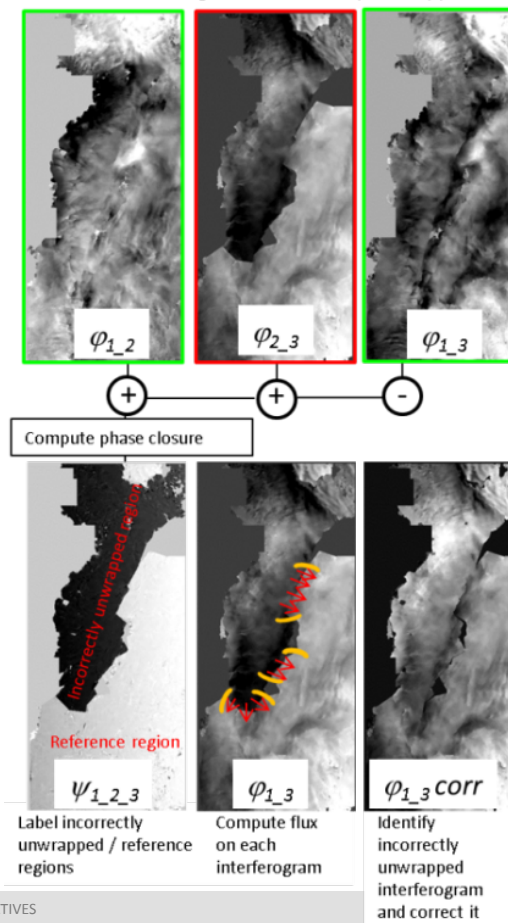
- Total closure = phase inconsistencies + misclosure due to unwrapping errors
- Phase inconsistencies are removed to obtain triplet misclosure equal to $2k\pi$, with k integer.

- First method to determine which interferogram is incorrectly unwrapped.
- Filling of the error region, dilation and erosion (morphological operators) to obtain the boundary.
- Determination of a neighbouring reference region.
- Computation of the flux between the error region and the reference region through the boundary for each of the 3 interferograms.
- Correction if the flux is significant (beyond a threshold) for one of the 3 interferograms. Otherwise, no correction and use the second method.



EXAMPLE OF FLUX CORRECTION

Which interferogram is incorrectly unwrapped?



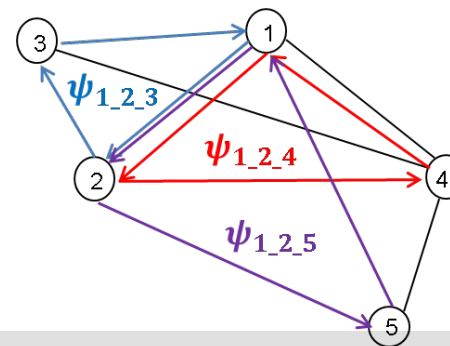
- Second method to determine which interferogram is incorrectly unwrapped.
- Hypothesis : if an interferogram belongs to several loops with errors, it is probably incorrectly unwrapped.
- Computation of the mean phase closure for each pixel of the error region and for each interferogram of the triplet.
- Correction if for one of the 3 interferograms, a significant percentage of pixels has an anomalous mean phase closure (beyond a threshold).
- Complementary information from flux.
- Problem if 2 links of the same triplet are false : further work.

Phase closure on a loop:

$$\psi_{1_2_3} = \varphi_{1_2} + \varphi_{2_3} + \varphi_{3_1}$$

Mean phase closure:

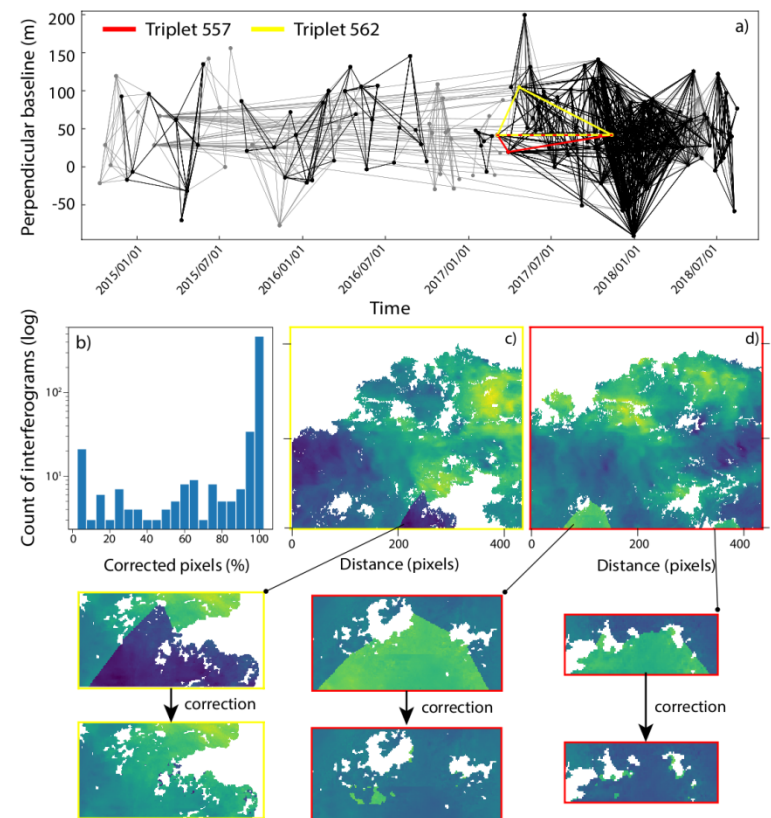
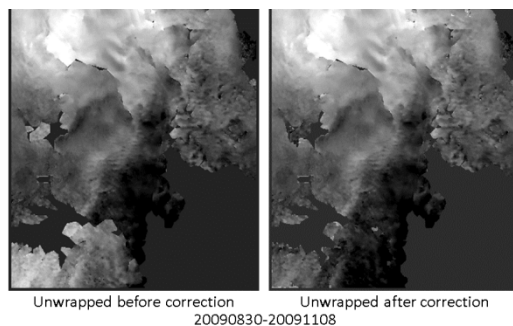
$$\eta_{1_2} = \psi_{1_2_3} + \psi_{1_2_4} + \psi_{1_2_5} / 3$$



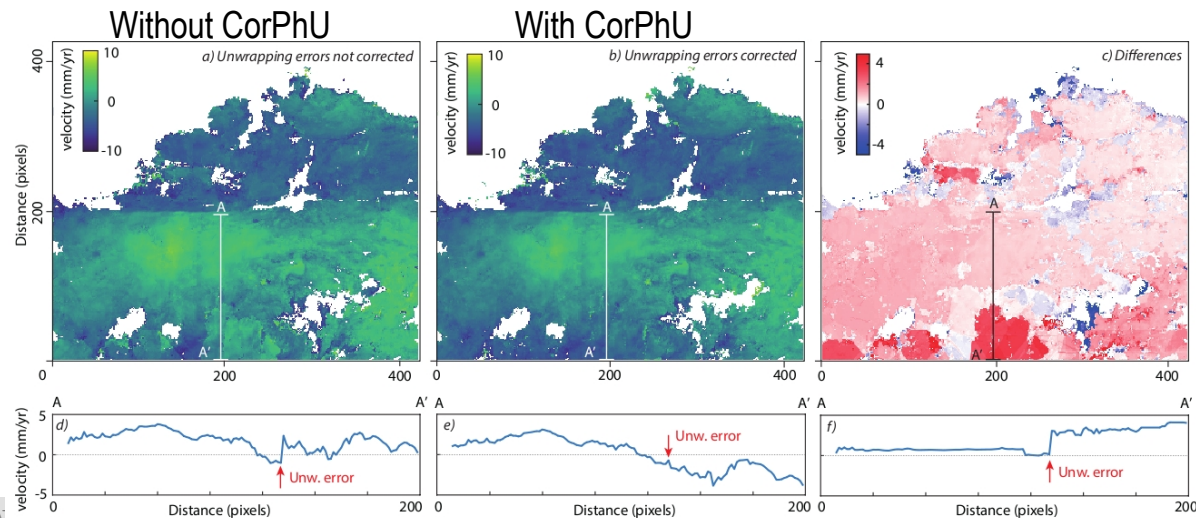
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Two databases :

- 165 ENVISAT interferograms on Lebanon : 186 triplets corrected / 282 triplets
- 686 Sentinel-1 interferograms on Turkey: 986 triplets corrected / 5645 triplets



- Inversion of the time series on the North Anatolian Fault using NSBAS approach implemented in GIANt to obtain mean deformation rate.
- Better results when the time series is corrected with CORPHU.
- Unwrapping errors imply an error of 20% on the fault velocity.



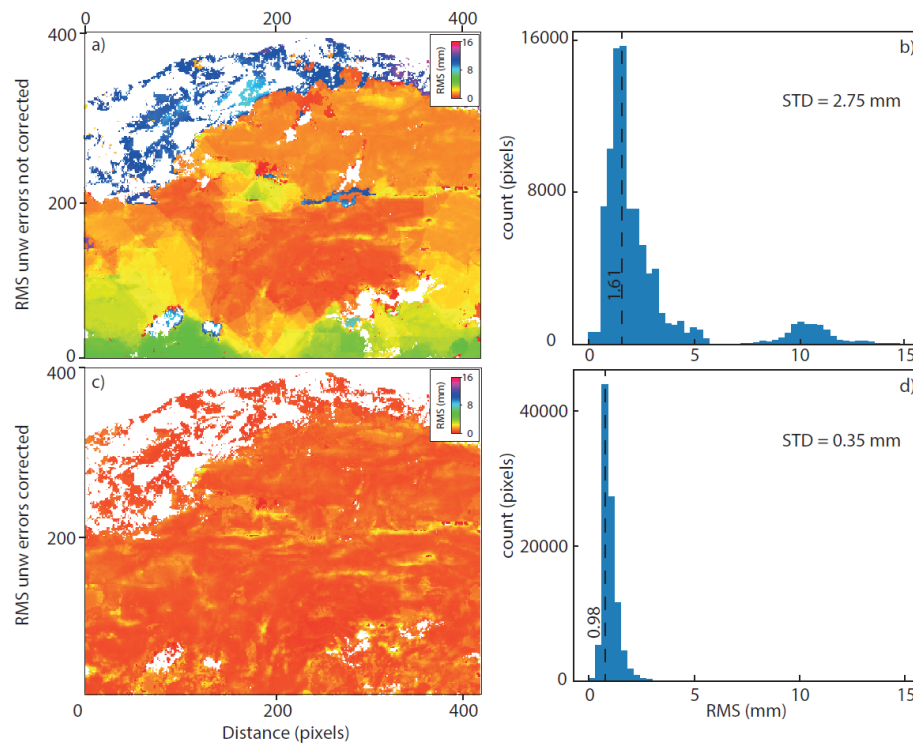
RMS error of the interferograms after time series inversion [Lopez-Quiroz et al., 2009]

$$\Phi_{RMS} = \frac{1}{N} \left[\sum_N \left(\phi_{ij} - \sum_{k=i}^{j-1} m_k \right)^2 \right]^{1/2}$$

N : number of interferograms

ϕ_{ij} : interferogram between dates i and j

m_k : inverted phase difference between date k and $(k+1)$



A. Benoit, B. Pinel-Puysségur, R. Jolivet and C. Lasserre, CorPhU: an algorithm based on phase closure for the correction of unwrapping errors in SAR interferometry, submitted to Geophysical Journal International

Pinel-Puysségur, B., Lasserre, C., Benoit, A., Jolivet, R., Doin, M.-p., & Champenois, J., 2018. A Simple Phase Unwrapping Errors Correction Algorithm Based on Phase Closure Analysis, in IGARSS 2018 - 2018 IEEE Int. Geosci. Remote Sens. Symp., vol. 1, pp. 2212–2215, IEEE.

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- CorPhU is an efficient algorithm to automatically correct unwrapping errors.
- Can be applied to large datasets.

- Comparison to other methods, tests on more databases.
- Performance assessment :
 - Influence of the different thresholds should be studied.
 - Difficult and very time-consuming to determine if a correction is correct or not and if some errors remain.
 - Generation of a synthetized database => ground truth.



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