18 YEARS OF INTERFEROMETRY, AS SEEN FROM MILANO

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The first studies on interferometry were carried out at JPL and the seminal papers by Richard Goldstein, Paul Rosen, Jacob Van Zyl, Scott Hensley, Howard Zebker, and so many others, should be remembered first. Their attention was centred on short term interferometry as the observations were always carried out using either airplanes or manned satellites. Even in the following years, it is an useful simplification to state that European observations used mostly satellites and therefore were multi pass and excelled in studies on long term Differential Interferometry. The initial studies carried out in the US dealt mostly with two passes interferometry, and therefore excelled in InSAR. The very first civilian satellite that had also interferometric capabilities was the L band SEASAT, launched in 1978. In its 78 days life, it produced numerous splendid images. The manned radar imaging missions SIR A (1981, analog), B (1984, digital), and then SIR - C (1994, multi band L, C, X in cooperation with DLR and ASI) should be also remembered. Then, an orbiting radar imaged the same areas in two successive days, showing interferograms.
These interferograms made nice images but visible problems were due to atmospheric delays, noticeable right away and badly spoiling InSAR Digital Elevation Models; further Phase Unwrapping was unsolvable, at least with just one interferogram. Interferometry indeed has to be either single pass, to remove the atmospheric bias as it is just the same for the two images, or multi-pass, but then the passes should be sufficient to abate the bias by exploiting statistics. Then PU can be solved too. Therefore, unmanned satellites were key for interferometric advances.

The important results obtained with SEASAT had induced the European Space Agency to launch in July 1991 a satellite for earth resources, ERS – 1, hosting many instruments among which a C band radar sensor. We received in Milano the first couple of ERS 1 images on August 25, 1991, and less than one week later we produced the very first interferogram on the Gennargentu area. ERS – 1 interferometry was born, and it was full of surprises. The first surprise was the coherence, as we called it, following the geophysicists. The coherence proved to be complementary to image amplitudes: water was always black even in windy days. The second surprise were the good baselines, and the first DEM's.
Steve Coulson convened in autumn 1991 a meeting in Frascati to show these results, and looking at the forthcoming launch of ERS – 2 in 1995, we proposed what was later to be called the TANDEM experiment, namely the imaging of the two satellites in rapid sequence so to create coherent interferometric pairs. The multiplicity of passes would compensate for atmospheric delays. One of the most important applications of the TANDEM data set was forestry. The TANDEM data have been very well and exhaustively studied by several experts: Jan Askne and his students Patrick Dammert and Maurizio Santoro in Sweden, and then Lars Ulander, from the CARABAS team who independently of the geophysicists, had rediscovered the ω – k focusing technique in 1987, and then Christiane Schmullius, and Urs Wegmueller and Charles Werner who named Gamma (the symbol for coherence of the geophysicists) their start up company in 1995.
With the year 2000, SRTM came and we have to thank NASA and JPL, as well as DLR and ASI for their effort in creating that data set and then processing it. Among the important results in PU, and used for this data set, we must remember the contribution of Mario Costantini who first used minimum flow methodologies. Further, the great effort of Michael Eineder and his team to unwrap and create the DEM's from the SRTM X band data using multi baseline and ascending descending views should also be remembered.
Meanwhile ESA was providing more and more data ready for interferometry: phase preserving SLC's, catalog of normal baselines, interferometric quick looks were made available to offer an ever better service to the researchers. Two significant reference papers on SAR interferometry were

published: the first by Bamler and Hartl in 1998, and a second by Goldstein et al. in 2000, just on time for SRTM. The book by Ramon Hanssen on Radar Interferometry (and the atmospheric effects) was published in 2001, and our ESA Manual on InSAR Principles, written before ENVISAT, would then published in 2007. But our best was still to come.

The concept of Differential Interferometry had been proved by Richard Goldstein from the very beginning. Extreme interest among the seismologists would be generated by the beautiful interferogram of the co-seismic motion of the Landers earthquake, made by Didier Massonnet's team in 1993. The very first active experiment to measure millimetre ground motion had been the so called Bonn experiment: a cooperation of ESA, Milano, and the Stuttgart University team led by Prof. Ph. Hartl and Prof. K. H. Thiel. 18 Corner Reflectors were installed along a line in February March 1992, and then one or two were moved of a couple of centimetres. In a blind experiment, we would tell, from the satellite data, which ones had been moved. The final results were evident.

Meanwhile, in Milano we looked for stable targets, that were there all the time, as natural CR's, that we named the Permanent Scatterers (PS). These points changed in a predictable way phase and amplitude of their reflection with time or baseline. Thus, we could use them in all the interferograms as pivots on which to determine the local atmospheric bias (the Atmospheric Phase Screen, APS). The extraction of information from a set of coherent points was also proposed in a paper by Stefania Usai, in TU Delft, at IGARSS 1999. Her activity was followed by the formation of a very significant research group there, headed by Ramon Hanssen who had spent part of his PhD studies with Howard Zebker, at Stanford since 1995.

After that, the long term interferometry technologies of PS, SBAS (Small Baselines) as proposed in Naples by the IREA group coordinated by Riccardo Lanari and Gianfranco Fornaro, and that of interferogram stacking proposed by David Sandwell provided a flurry of results, all over the world.

To size the scientific audience, the number of quotations of interferometry papers rounds today to 600 for the paper by Goldstein et al. on 2D phase unwrapping (1988), and the one by Massonnet on Landers (1993), to 500 for our paper on Permanent Scatterers (2001, see further on) and the two by Zebker et al. on baseline decorrelation (1992), and topographic mapping (1986), and so on.

Steve Coulson first and then Yves Louis Desnos both contributed to interferometry by organizing the Fringe Meetings, starting from 1991, and then 1992 (both in Frascati), then in Zurich, 1996, Liège 1999, and Frascati in 2003, 2005, 2007. Starting from Fringe 2003, there were more and more papers related to *PS-like* algorithms. Also during Fringe 2003, with Richard Bamler we proposed to establish a comparison among different PS techniques: the PSIC4 concept.

Although it wouldn't be fair to say that the commercial exploitation of SAR interferometry started with the PS technique, Persistent Scatterers Interferometry, PSI, was a boost for space geodesy. ESA supported the creation of a market for PSI applications from the very beginning and financed several projects based on PSI products and services. Among them, it is worth mentioning Terrafirma (www.terrafirma.eu.com). ESA focused on two key concepts: validation and standardization. Looking back to the last ten years, both action lines by ESA were successful, since they forced somewhat all actors involved in PSI to: (a) improve quality and reliability of PS results; (b) figure out any possible application of PS data, and (c) learn how to speak in layman's terms about this remote sensing technology.

We conclude by pointing out the importance of SAR data availability and data acquisition policies for the development of SAR interferometric technologies/applications. All PSI algorithms owe much to the ESA ERS missions. The ERS-1 and ERS-2 satellites were not complicated, manageable using simple acquisition policies. Since interferometric data stacks were available over many areas of the world, with dozens of image acquisitions, the development of the second generation DInSAR algorithms became possible. Finally, the existence of an up-to-date archive of speculative scheduled raw data acquisitions stimulates the confidence of the end-user community in using InSAR. The market benefit of speculative scheduled SAR surveys stimulates satellite owners and distributors to become co-interested in such programmes.