Atmospheric water vapour effects on SPACEBORNE Interferometric SAR imaging: an experiment to compare ground-based measurements, spaceborne radiometers and numerical weather prediction model at different scales

THE METAWAVE TEAM:
Nazzareno Pierdicca, Fabio Rocca, Bjorn Rommen, Patrizia Basili, Stefania Bonafoni, Domenico Cimini, Piero Ciotti, Fernando Consalvi, Rossella Ferretti, W. Foster, Frank Silvio Marzano, Vinia Mattioli, Augusto Mazzoni, Mario Montopoli, Riccardo Notarpietro, Sharmela Padmanabhan, Daniele Perissin, Emanuela Pichelli, Steven Reising, Sahoo Swaroop and Giovanna Venuti
The ESA project

METAWAVE

Mitigation of Electromagnetic Transmission errors induced by Atmospheric WAter Vapour Effects

ESTEC 21207/07/NL/HE
Introduction and objectives

• Objectives
  – Correct, at list partially (mitigate), the atmospheric WV artefacts in InSAR
  – Assess usefulness of InSAR for atmospheric applications

• Very challenging task
  – Requirements for InSAR are very demanding:
    • resolution order of 100 m
    • thematic accuracy order of mm $\Delta ZWD \approx 0.16 \text{ mm } \Delta IWV$
    • Timeliness
  – It does not exist a technique to provide WV information matching InSAR requirements
Team organization

ESA_ESTEC
Customer

Scientific responsibility:
Prof. Fabio Rocca
Prof. Nazzareno Pierdicca

CSU
External services
Task: Tomography by ground based radiometry

SAP-DIE
Prime Contractor
Techn. Mng: N. Pierdicca
Tasks: management, downscaling, radiometry

POLIMI-DEI
Sub-contractor
Techn. Mng: F. Rocca
Task: InSAR

UNIPG-DIEI
Sub-contractor
Techn. Mng: P. Basili
Task: Radiometry, kriging

CETEMPS
Sub-contractor
Techn. Mng: R. Ferretti
Task: NWP, validation

POLIMI-DIIAR
Sub-contractor
Techn. Mng: G. Venuti
Task: GPS network

CINFAI-TO
Sub-contractor
Techn. Mng: R. Notarpietro
Task: GPS tomography
PS displacement time series

Non linear motion or noise or atmospheric path delay changes

Linear motion

\[ \Delta \Phi \frac{\lambda}{4\pi} [\text{mm}] \]

\[ 1 \text{ rad} \approx 5 \text{mm} \]
Phase residuals (APS): examples

Winter

Summer
Project rationales

• As for no sudden ground motion, *multi-pass technique* can mitigate WV artifacts and provide WV to meteorologists. APS on stable PS can be interpolated in the point to be monitored.

• For sudden ground motion and/or traditional (few passes) InSAR, two framework are identified:
  – Regional scale applications
    • Relaxed spatial resolution (goal 1 km)
    • Integration of many sources (GPS, spaceborne microwave or infrared radiometers ....) by interpolation, downscaling, NWP
  – Local scale applications
    • Small coverage
    • Support of ground based systems (GPS, ground based radiometer, ...)
Numerical Weather Prediction

• Objective:
  – Produce **regional scale maps** (500-1000 m) based on **microphysics** information (MM5 or WRF, 3-DVAR and/or nudget assimilation)
  – Try to **assimilate InSAR** APS, at least with short temporal baseline, and produce local scale maps (few hundreds meters)

• Models and methods
  – MM5 and WRF non hydrostatic NWP systems
  – 3-DVAR and/or nudget assimilation
  – Exploitation of WV differences
Data integration

- **Objective:**
  - Produce *regional scale maps* based on *statistical* a priori info integrating different sources
- **Candidate sources**
  - GPS receivers ZWD, Meris/Modis, MW radiometers
- **Candidate methods:** a proper combination of
  - Statistical interpolation (kriging)
  - Statistical downscaling (disaggregation)
- **Candidate prior information for WV variogram and power spectrum**
  - InSAR APS, NWP outputs, MERIS/Modis
Local scale problem

- **Objective:**
  - Correct InSAR for *local scale applications* by exploiting *ground based* instruments

- **GPS receiver network**
  - Project the slant path delay from few receivers along InSAR line-of-sight (to monitor motion of a small area)

- **Ground based Mw radiometer**
  - Scanning multifrequency radiometers (by Colorado State University) to produce 3-D WV maps by tomography
• Rome:
  – 15-day experiment including the two SAR overpasses Sept. 20 and Oct. 3, 2008

• Como:
  – 10-day experiment including the SAR overpass over Como on Oct. 12, 2008
METAWAVE campaign in Rome

- About 15 days of observations
- Surface sensor (Press., Temp., Humid.)
- 1 two-channel radiometer (by Radiometrics)
- 3 four-channel radiometers (CMR) for WV tomography (by Colorado State University)
- Portable radiosonde station
- 2 weather radars (C- and X-band) (CETEMPS)
- GPS stations (operational low resolution network)
- Operational radiosonde from Pratica di Mare (AM)
- Images from satellite: 2 SAR, 9 MERIS, 28 MODIS (14 AQUA, 14 TERRA)
Rome experiment setup

- Radiosonde launch
  - 8 launched from Sapienza, 6 successful
  - 4 Daytime, 2 nighttime
  - 75 from nearby operational station
- Radiometers and LIDARS
  - One 2-channel + one 4-channel
  - LIDAR nearby
  - Further two 4-channel forming a triangle
MW radiometers in Rome

EUDOSSIANA
CSU radiometer
2-channel radiometer
RAOB’s
Meteo station
GPS

PICCO 3 SIGNORI
CSU radiometer

TOR VERGATA
CSU radiometer
GPS

By Colorado State University
MM5 frames and GPS network
Data collection sequence

<table>
<thead>
<tr>
<th>Date</th>
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<tr>
<td>19/09/2008</td>
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- AMSR
- MODIS
- MERIS
- ASAR
- RAOB
- Radio
- CSU

Legend:
- CSU
- Radiom.
- RAOB
- ASAR
- MERIS
- AMSRE
- MODIS
• A general agreement of MM5, MWR, GPR, RAOB is observed versus time
• MM5 is capable to follow the IWV evolution detected by the microwave radiometer MWR
Integrated Water Vapour

Different data (MWR, RAOB, GPS) and model output (MM5) provide comparable values within \( \approx 1 \) mm IPWV and 6-7 mm ZWD.
## Overall comparison of IWV

<table>
<thead>
<tr>
<th></th>
<th>AVG [cm]</th>
<th>STD [cm]</th>
<th>RMS [cm]</th>
<th>COR</th>
<th>SLP</th>
<th>INT</th>
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<tbody>
<tr>
<td>RAOB DIESAP vs MWR</td>
<td>-0.04</td>
<td>0.08</td>
<td>0.10</td>
<td>0.99</td>
<td>1.04</td>
<td>-0.03</td>
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<tr>
<td>RAOB DIESAP vs ECMWF</td>
<td>-0.07</td>
<td>0.18</td>
<td>0.20</td>
<td>0.98</td>
<td>1.10</td>
<td>-0.14</td>
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<tr>
<td>RAOB DIESAP vs MM5</td>
<td>-0.04</td>
<td>0.18</td>
<td>0.18</td>
<td>0.97</td>
<td>0.99</td>
<td>0.05</td>
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<tr>
<td>RAOB PdM vs ECMWF</td>
<td>-0.07</td>
<td>0.16</td>
<td>0.17</td>
<td>0.93</td>
<td>0.94</td>
<td>0.18</td>
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<tr>
<td>RAOB PdM vs MM5</td>
<td>-0.09</td>
<td>0.20</td>
<td>0.22</td>
<td>0.90</td>
<td>0.91</td>
<td>0.25</td>
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<tr>
<td>MWR vs ECMWF</td>
<td>-0.02</td>
<td>0.13</td>
<td>0.14</td>
<td>0.95</td>
<td>0.99</td>
<td>0.04</td>
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<tr>
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<td>-0.11</td>
<td>0.16</td>
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</table>

**REMINDE**: Zenith Wet Delay, Excess path, APS

\[
\text{ZWT [mm]} \times \Pi (0.15) \sim \text{IPWV [mm} = \text{kg/m}^2]\]

\[
\text{IWV [mm} = \text{kg/m}^2] \times 6.5 \sim \text{ZWD [mm]}
\]
• 600 AMSR-E/ ECMWF images (2002-2007) compared with ECMWF

• *IWV RMS error*: around 0.25 cm for Como
  around 0.33 cm for Rome (coast effects)
MM5 vs RAOB WV profiles

MM5 (blue lines, at different times) is more able to capture the main features of the vapour vertical profile from RAOB’s (red line) than ECMWF (cyan line).

**Temperature profile**

**Relative humidity profile**
Profiles of water vapour density along the yellow transect (Rome urban area)
WV 3D tomography from CMR

Water Vapor density profiles [g/m³]

@ 20 Sep 2008 21:30
CMR vs RAOB profiles

CSU @ 20-Sep-2008 21:30:00 RAOB @ 20-Sep-2008 21:30:00

CSU @ 03-Oct-2008 10:10:00 RAOB @ 03-Oct-2008 09:55:00

Height [km] vs WV density [g/m³]
Satellite vs modelled IWV

ECMWF

MODIS

MM5

MERIS
Satellite vs ground based

**MERIS** (RED dots) and **MODIS** (cyan and magenta) compared to MWR (left) and GPS (right) IWV
The question is distinguishing resolving capability from noise.
The dataset enables a deep characterization of spatial properties of different sources of IWV: resolution vs noise.
Where we are: height signature

- The main signature in APS/IWV maps is related to topography \( (h) \)
  \[
  IWV_t(x, y, h) \iff \Phi_t(x, y, h) = \varepsilon_t(x, y) + k_t h
  \]

- The vertical gradient has a stationary and a time varying component
  \[
  k_t = k_0 + \delta_t
  \]

- InSAR (differential) APS only contains time varying gradient. NWP may provide the stationary one
  \[
  \Delta \Phi_{\Delta t}(x, y, h) = \Delta \varepsilon_{\Delta t} + \Delta (\delta_{\Delta t}) q
  \]

- NWP model may also provide the right \( \delta_{\Delta t} \) to remove the related error in the InSAR phase
Summary 1

- A large data set of observations and simulations is allowing us to characterize different sources of WV data for InSAR correction purposes
- Preliminary results data consistency
  - RAOB-MM5 profiles rms ~1 K and ~15-20% in Troposphere.
  - RAOB-MWR IWV rms ~0.10 cm
  - MWR-MM5 IWV rms ~0.18 cm
  - MWR-GPS IWV rms ~0.16 cm
- Comparison with InSAR APS in another presentation (by D. Perissin)
Summary 2

- Preliminary results show the potential of MM5 and GPS to provide the non-stationary component of the APS vertical gradient.
- This may result at least in a reduction of the number of required SAR images to estimate it.
- Only in few cases MM5 was able to predict the turbulent component appearing in the APS map.
- Integration/assimilation of further data (i.e., MERIS) is expected to be fruitful.