Generic Atmospheric Correction Online Service for InSAR (GACOS)

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Motivation – Why atmospheric correction?

- Spatio-temporal variations in T, P and water vapour result in tropospheric effects on InSAR observations.
- Surface displacements caused by tectonic/volcanic activities can be masked by tropospheric effects!
- Impacts on time series analysis

\[ \phi_{bg} = [\phi_{defo} + \phi_{tropo} + \phi_{ono} + \phi_{dem} + \phi_{base} + \phi_{noise}]_{2\pi} \]

Quantifying and mitigating tropospheric effects is vital for InSAR!
## Motivation - Data

<table>
<thead>
<tr>
<th></th>
<th>GNSS</th>
<th>HRES-ECMWF analysis</th>
<th>ERA-Interim reanalysis</th>
<th>ERA-5 reanalysis*</th>
<th>MODIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal 10 - 200 km, discrete</td>
<td><del>9</del>12 km, regular grid</td>
<td>~75 km, regular grid</td>
<td>~31 km</td>
<td>~ 1 km</td>
</tr>
<tr>
<td>Vertical</td>
<td>1</td>
<td>137 levels</td>
<td>61 levels</td>
<td>137 levels</td>
<td>1</td>
</tr>
<tr>
<td>Temporal</td>
<td>5 Minutes</td>
<td>00,06,12,18 UTC</td>
<td>00,06,12,18 UTC</td>
<td>Hourly (2010-2016, other data to be released soon)</td>
<td>Daily</td>
</tr>
<tr>
<td>availability</td>
<td>Near real-time</td>
<td>Near real-time</td>
<td>latency 3-4 months</td>
<td>Near real-time</td>
<td>latency 1-2 months</td>
</tr>
<tr>
<td>Limitation</td>
<td>Coverage</td>
<td>Temporal resolution</td>
<td>• Temporal resolution</td>
<td></td>
<td>Clouids</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Spatial resolution</td>
<td></td>
<td>Temporal resolution</td>
</tr>
</tbody>
</table>
Key Questions & Objective

- **How do we best use of data?**
  - Assessment, Integration, Interpolation

- **How to evaluate the model performance?**
  - Main factors affecting atmospheric correction
  - Performance indicator

- **How do we best implement the model?**
  - Availability, efficiency

**Objective:** Generic Atmospheric Correction Model

- Globally and at all times available
- In near real time
- Aimed for ~1 cm accuracy (250 by 250 km)
- With reliable quality control indicators
Tropospheric delay = Hydrostatic delay + wet delay

Tropospheric delay = Stratified delay + turbulence delay

(a) Stratified delay by GPS + ECMWF
(b) Turbulent delay by GPS + ECMWF
(c) Total delay by GPS + ECMWF

(d) Raw IFG1–UK
(e) IFG after correction
Stratified: Topography-dependent component

Turbulent: Topography-independent component resulting from turbulent processes

\[ \Delta L_{ij}^k = T(x^k) + L_0 e^{-\beta h^k} + \epsilon \]

Iterative tropospheric decomposition

(Yu et al., 2017, JGR)

Significant improvement after separating stratified and turbulence component
Iterative tropospheric decomposition

\[ \Delta L_{ij}^k = T(x^k) + L_0 e^{-\beta h^k} + \epsilon \]

- **Stratified**: Topography-dependent component
- **Turbulent**: Topography-independent component resulting from turbulent processes

More improvements in strong turbulence seasons

**Methodology**

- **Stratified**: Topography-dependent component
- **Turbulent**: Topography-independent component resulting from turbulent processes

(Yu et al., 2017, JGR)
Cross Interpolation weight determination.

Automatic weighting strategy.

The relative weighting between GNSS and HRES-ECMWF are controlled by the precision and station distribution of the GNSS network.
GACOS (Version 1.5)

Daily First time visitors
Over 12 thousand jobs

Popular Study Areas
Model Evaluation - Data Quality

~1cm ZTD RMS (GPS vs HRES ECMWF)

~1.5mm PWV RMS (MODIS vs GPS)

~2mm PWV RMS (MODIS vs HRES ECMWF)

Motivation & Objective

<table>
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<tr>
<th>Method</th>
<th>Performance</th>
<th>Indicator</th>
<th>Conclusion</th>
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Newcastle University
❖ The topography related atmosphere errors in the east and west mountain areas are significantly mitigated.
❖ The residuals in central area were most likely related to un-modelled tropospheric turbulence.
Northern Tibet:
- Raw IFGs
  - STD=1.15mm
- ZTD maps
- Corrected IFGs
  - STD=0.45mm

Landslide:
- Raw IFGs
- ZTD maps
- Corrected IFGs
  - STD=0.45mm

250 km
8 km

Motivation & Objective
Method
Performance
Indicator
Conclusion
Identify Small Co-Seismic Signal

Raw IFGs  | GACOS Map  | After Correction

Feng, et al., 2018
### Model Evaluation - Post-Seismic

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</table>

Before | After | Before | After | Before | After |

![Images showing before and after comparisons](image1.png)

![Images showing before and after comparisons](image2.png)

![Images showing before and after comparisons](image3.png)
Weather models show @Agung InSAR fringes are atmospheric NOT deformation. Thanks @falbino @GACOS_Newcastle @USGSVolcanoes @NERC_COMET.

Agung example 2. Also mostly atmosphere NOT deformation. We're investigating the slight underestimate.@FabienAlbino @GACOS_Newcastle.

Significant elevation dependent signal around volcano.
Performance Matrix (Indicators)

- Cross RMS
- Correlation coefficients
- ECMWF time difference
- Topography variation
- Extreme weather

Model performance decreases as Cross RMS increases.

(Yu et al., 2018, RSE)
Conclusions

- Generic Atmospheric Correction Online Service for InSAR (GACOS) is free for the InSAR research community: (http://ceg-research.ncl.ac.uk/v2/gacos/).

- Our GPS/HRES-ECMWF integrated model can achieve over 50% improvement with RMS < 1 cm for InSAR displacements over a 250x250 km region, which can be applied globally and at all times, in near real time.

- Indicators such as correlation analysis, cross test and time differences have been developed to assess model performances, which can inform users when and where atmospheric correction is feasible.

- For an interferogram extending 250 by 250 km =>

  - Total delays ~2 meter
  - Spatio-temporally differenced 5 - 20 cm
  - After GACOS ~1 cm
  - Time series constrain/filtering mm level