Validating Time Series of a combined GPS and MERIS Integrated Water Vapor Product

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Research targets.

Previous Goal: compare GPS and MERIS water vapor observations

⇓

Previous Goal: Develop method to fuse GPS and MERIS water vapor observations

⇓

Goal here: Validate 2 months of fusion results

⇓

Final Target: near real time water vapor product with high temporal and spatial resolution
Contents

• Introduction

• GPS Integrated Water Vapor (IWV)

• MERIS IWV

• Spatio-temporal fusion

• Validation methods: double cross-validation

• Validation results

• Conclusions and outlook
Why to monitor water vapor?

- Water vapor is the dominant greenhouse gas and enhances climate warming significantly.
- Substantial change (+40 %) is expected during this century.
- Moreover, it influences e.g. GPS and (In)SAR observations.
- Knowledge of water vapor can improve numerical weather prediction (Thunderstorms).
- The water vapor contents in the atmosphere is strongly varying.
Integrated Water Vapor from GPS

Satellite

Observed delay

Computed hydrostatic delay

$T = (M_d(e) \cdot T^z_d) + M_w(e) \cdot T^z_w$

Known mapping function

Unknown tropospheric zenith wet delay
Two months long time series of GPS IWV

GPS IWV at 39 ground stations in and around The Netherlands

Every hour a new GPS IWV observations (precision 1-2 kg/m$^2$)

Measurement period: March 20 - May 19, 2006

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In total appr. 39 $\times$ 24 $\times$ 60 $\sim$ 55 000 observations
(In practice: 5 000 observations less, due to missing data)
# MERIS spectral channels

<table>
<thead>
<tr>
<th>No.</th>
<th>Wavelength (nm)</th>
<th>Bandwidth (nm)</th>
<th>Application</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>412.5</td>
<td>10</td>
<td>Yellow substance and detrital pigments</td>
</tr>
<tr>
<td>2</td>
<td>442.5</td>
<td>10</td>
<td>Chlorophyll absorption maximum</td>
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<tr>
<td>3</td>
<td>490</td>
<td>10</td>
<td>Chlorophyll and other pigments</td>
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<td>4</td>
<td>510</td>
<td>10</td>
<td>Suspended sediment, red tides</td>
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<tr>
<td>5</td>
<td>560</td>
<td>10</td>
<td>Chlorophyll absorption minimum</td>
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<td>620</td>
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<td>Suspended sediment</td>
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<td>Chlorophyll absorption and fluo. reference</td>
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<td>681.25</td>
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<td>Chlorophyll fluorescence peak</td>
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<td>9</td>
<td>708.75</td>
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<td>Fluo. reference, atmospheric corrections</td>
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<td>753.75</td>
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<td>Vegetation, cloud</td>
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<td>11</td>
<td>760.625</td>
<td>3.75</td>
<td>Oxygen absorption R-branch</td>
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<td>778.75</td>
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<td>865</td>
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<td>Vegetation, water vapour reference</td>
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<td>885</td>
<td>10</td>
<td>Atmosphere corrections</td>
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<tr>
<td>15</td>
<td>900</td>
<td>10</td>
<td>Water vapour, land</td>
</tr>
</tbody>
</table>
Integrated Water Vapor from MERIS

$L_{14}, L_{15}$ - radiances measured in channels 14 and 15 resp.

\[ \text{IWV} = k_0 + k_1 \log \frac{L_{15}}{L_{14}} + k_2 \log^2 \frac{L_{15}}{L_{14}}; \quad (1) \]

$k_0, k_1, k_2$ - regression constants, depending on

A. viewing geometry

B. land algorithm/ water algorithm

Over water:

- Signal absorption is stronger
  \[ \Rightarrow \] Aerosol reflections gain influence

- Amount of aerosol, $L_9, L_{12}, L_{13}$, is incorporated.
Data fusion approach

↑ time

→ space

GPS epoch

MERIS snapshot time
Additional Value of MERIS IWV

Create two sets of time series

**interpolated GPS IWV:** Use GPS IWV of other stations to estimate GPS IWV at station considered

**fused GPS + MERIS:** Not only use GPS IWV of other stations but also use MERIS IWV observations

Compare both resulting time series to reference data: the observed GPS IWV at a station

Additional value of MERIS IWV $\iff$ decrease in difference with reference data.
Interpolated GPS IWV

blue: Reference time series of GPS IWV at station DOUR.

red: IWV time series at DOUR obtained by Ordinary Kriging interpolation from GPS IWV from other stations.

gray: Ordinary Kriging st.dev. at DOUR obtained by Ordinary Kriging interpolation from GPS IWV from other stations.
Direct vs. interpolated GPS IWV

Histograms of differences between direct GPS IWV values and cross-validated GPS IWV values at DELF and DOUR

Possible biases: Difference in mean

Precision: Differences in st.dev.
Fused GPS + MERIS IWV

Determine for each MERIS scene and for each station the (collocated) MERIS IWV value

Incorporate collocated MERIS IWV in the data fusion if the MERIS IWV is not older than 10 hours.

Figure: Temporal spreading of the MERIS scenes and number of stations covered by at least one MERIS pixel per scene.
‘Improvements‘ of adding MERIS IWV

Mean diff. OK <-> measurement
(length of bar <-> 1 kg/m²)

St.Dev. diff. OK <-> measurement
(length of bar <-> 1 kg/m²)

Mean OK variance
(length of bar <-> 2 (kg/m²)²)

Improvement in IWV by adding MERIS
(length of bar <-> 0.05 kg/m²)

Improvement in st.dev. IWV
(length of bar <-> 0.05 kg/m²)
Validation outcomes

Mean: no significant improvement:
+ 0.005 kg/m² average improvement over two months at 39 stations.

Standard deviation: no significant improvement:
-.02 kg/m² average improvement over two months at 39 stations.

Kriging variance: kind of theoretical expected improvement:
1.364 (kg/m²) before adding MERIS
1.341 (kg/m²) after adding MERIS
⇒ An expected improvement of 1.67 %.
Conclusions and further developments

Conclusions

• In this particular setting: adding MERIS IWV gives no significant improvement
• Introduced: method of double cross validation
• Introduced: Expected improvement (via Kriging variances)
• Many processing issues remain

Remarks

• GPS + MERIS IWV fusion very interesting over remote areas (less GPS)
• GPS IWV can be used to fill cloud gaps in MERIS IWV
• Even more dense GPS IWV networks expected
• Next steps: processing issues, weather prediction + (In)SAR
Questions?