Kriging-based Mapping of Space-borne CO$_2$ Measurements by Combining Emission Inventory and Atmospheric Transport Modelling

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Outline

• Problem definition and objectives
  – Sparse sampling of OCO-2 measurement (including XCO₂)
  – Regional mapping of XCO₂

• Solution approach
  – Multivariate kriging with STILT-based atmospheric transport modeling

• Results

• Conclusions and future works
Problem Definition

- The Orbiting Carbon Observatory-2 (OCO-2) is offering unprecedented accuracy for the space-based measurements of atmospheric CO₂ concentration.

- Problem: The Level-2 retrieval is irregular in space and time. Sparse sampling, gap between two OCO-2 swaths on a single day: ~2558 km, missing footprints in 8 cross-track.

A Small Regional Scenario

- Measurements on October 13, 2017
- Area of the region 92 km × 135 km
- Number of samples: 464
- Almost 89% of the total area is unmeasured.
Objectives

- Mapping of available XCO$_2$ measurements for local regions: Generate Level-3 product
- Solution approach: Mapping with the help of densely sampled correlated information

For example:
- ODIAC monthly CO$_2$ emission estimates (Bhattacharjee and Chen, 2020)
- ODIAC + Wind transport (STILT)

Method

- Geostatistical interpolation method: Traditional Kriging/ Cokriging

ODIAC: Open-source Data Inventory for Anthropogenic CO$_2$. STILT: Stochastic Time-Inverted Lagrangian Transport model
CoKriging

- XCO$_2$ interpolation = \( f(\text{Euclidean distance, Emission estimates, Atmospheric transport}) \)

Semivariograms: Lag distance vs. primary variable

Cross-variograms: Lag distance vs. (primary + secondary) variables

- Advantage
  - Additional domain knowledge for the estimation process
  - Higher prediction accuracy

<table>
<thead>
<tr>
<th>Method</th>
<th>Kriging</th>
<th>CoKriging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>Level-2 XCO$_2$</td>
<td>Level-2 XCO$_2$</td>
</tr>
<tr>
<td></td>
<td>ODIAC emission</td>
<td>ODIAC emission</td>
</tr>
<tr>
<td></td>
<td>STILT footprint</td>
<td>STILT footprint</td>
</tr>
<tr>
<td>Output</td>
<td>Level-3 XCO$_2$ mapping</td>
<td>Predicted mapping surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level-3 OCO-2’s XCO$_2$</td>
</tr>
</tbody>
</table>

Primary Variable
(OCO-2’s Level-2 XCO$_2$)

Secondary Variable
(ODIAC estimates)

Coordinate Locations
(X, Y)

Multivariate CoKriging

Secondary Variable
(wind transport
(STILT))
STILT Simulation

- It is a Lagrangian particle dispersion model (LPDM)
- Footprint map: Represents the upstream area that influences the air arriving at the receptor point considering the other pixels for the whole SR

footprint
m² s ppm/μmol

footprint

One receptor point •
Optimization of STILT Parameters

- Wind data sources (Default: ERA5)
- Backward time
- Particle number
Study Regions

- Chosen as per the availability of the Total Carbon Column Observing Network (TCCON) measurement data for validation

<table>
<thead>
<tr>
<th>SR</th>
<th>Locations</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamont, USA</td>
<td>36.604 N, 97.486 W</td>
<td>20171013</td>
</tr>
<tr>
<td>Karlsruhe, Germany</td>
<td>49.1002 N, 8.4385 E</td>
<td>20170421</td>
</tr>
<tr>
<td>Lauder, New Zealand</td>
<td>45.038 S, 169.684 E</td>
<td>20170123</td>
</tr>
<tr>
<td>Ascension, Island</td>
<td>7.933333 S, 14.416667 W</td>
<td>20170130</td>
</tr>
<tr>
<td>Rikubetsu, Japan</td>
<td>43.4567 N, 143.7661 E</td>
<td>20170605</td>
</tr>
</tbody>
</table>

STILT Parameters

<table>
<thead>
<tr>
<th>SR</th>
<th>Wind Data Sources</th>
<th>Backward time</th>
<th>Particle number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamont, USA</td>
<td>GDAS (0.5 degree)</td>
<td>-16h</td>
<td>2500</td>
</tr>
<tr>
<td>Karlsruhe, Germany</td>
<td>ERA5 (31 km)</td>
<td>-12h</td>
<td>1000</td>
</tr>
<tr>
<td>Lauder, New Zealand</td>
<td>GDAS (0.5 degree)</td>
<td>-16h</td>
<td>1500</td>
</tr>
<tr>
<td>Ascension, Island</td>
<td>GDAS (0.5 degree)</td>
<td>-24h</td>
<td>3000</td>
</tr>
<tr>
<td>Rikubetsu, Japan</td>
<td>GDAS (0.5 degree)</td>
<td>-12h</td>
<td>2000</td>
</tr>
</tbody>
</table>
Result: Study Region: Karlsruhe, Germany

<table>
<thead>
<tr>
<th>SR</th>
<th>Predicted by Simple Kriging</th>
<th>Predicted by Cokriging with ODIAC estimates</th>
<th>Predicted by Cokriging with ODIAC + wind transport (STILT)</th>
<th>Legends (predicted XCO₂ in ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karlsruhe, Germany</td>
<td><img src="image1" alt="Simple Kriging" /></td>
<td><img src="image2" alt="Cokriging with ODIAC" /></td>
<td><img src="image3" alt="Cokriging with ODIAC + wind transport" /></td>
<td><img src="image4" alt="Legend" /></td>
</tr>
</tbody>
</table>

Legend:
- 392.295 – 399.374
- 399.374 – 403.388
- 403.388 – 405.664
- 405.664 – 406.955
- 406.955 – 407.687
- 407.687 – 408.102
- 408.102 – 408.337
- 408.337 – 408.47
- 408.47 – 408.546
- 408.546 – 408.679
- 408.679 – 408.915
- 408.915 – 409.333
- 409.333 – 410.061
- 410.061 – 411.352
Result Summary: All Study Regions: Prediction Error

- Comparison using Root Mean Square Error (RMSE): 15 mins window of TCCON measurement
Result Summary: All Study Regions: Prediction Error

- Comparison using Root Mean Square Error (RMSE): 30 mins window of TCCON measurement
Conclusions

• We have developed a cokriging method using emission inventories and atmospheric transport information (footprints)

• This new approach is more accurate compared to the univariate mapping

• Mainly suitable for the extrapolation in the whole study region

• Extrapolated results agree well with TCCON measurements.
References

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Thank you for your attention...

Any question?