HYSSPLIT Dispersion Model and Its Inverse Modeling System

The HYSSPLIT Lagrangian model developed at NOAA’s Air Resources Laboratory has been widely used to study the atmospheric pollutant transport and dispersion in both forward and backward modes. It allows representations of the transported air masses with 3D particles, puffs, or a hybrid of the two. Applications include the simulation of atmospheric tracer releases, radiocollides, smoke originated from wild fires, volcanic ash, mercury, and wind-blown dust, etc. A HYSSPLIT inverse modeling system has been developed to quantify the source characteristics by utilizing the concentration information.

Summary

- A HYSSPLIT inverse system based on a 4D-Var approach has been built and successfully applied to estimate caesium-137 release during the Fukushima nuclear accident.
- The system is also used to solve the effective volcanic ash release rates as a function of time and height by assimilating satellite mass loadings and ash cloud top heights. Using the Kasatochi eruption in 2008 as an example, we show that the estimated releases help to improve the volcanic ash predictions with both GDAS and ECMWF meteorological fields.
- The feasibility of applying the method to objectively and optimally estimate wildfire smoke sources based on satellite observations of fire plumes is demonstrated using a set of twin experiments. They show promising results although missing observations in key regions could hinder the effectiveness.

Acknowledgement

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References


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HYSSPLIT Inverse Modeling Methodology

In this top-down approach, the unknown emission terms are obtained via searching the emissions that would provide the best model predictions closely matching the observations by minimizing a cost function. For the applications shown here, the emission locations are mostly identified, the unknown emission rates and sometimes the release heights are left to be determined. The emission rates may vary significantly with time. Thus, the unknowns of the inverse problem are the emission rates \( q_k \) at each location \( i \), at different height \( h \) and period \( t \). The cost function \( F \) is defined as,

\[
F = \frac{1}{2} \sum_{i=1}^{N} \sum_{h=1}^{H} \sum_{t=1}^{T} \left( \frac{\left( q_k - q_{k,i} \right)^2}{\sigma_{q,i}^2} + \frac{\left( c_{m,h} - c_{m,i} \right)^2}{\sigma_{c,i}^2} \right) + \frac{1}{2} \sum_{i=1}^{N} \sum_{h=1}^{H} \sum_{t=1}^{T} \varepsilon_{i}^2 + F_{\text{other}}.
\]

where \( c_{m,i} \) is the \( m \)-th observed concentration or mass loading at time \( t \) and \( c_{m,i} \) is the HYSSPLIT counterpart. As shown in Equation (1), a background term is included to measure the deviation of the emission estimation from its first guess \( \varepsilon_{i} \). The background terms ensure that the problem is well-posed even when there are not enough observations available. The background error variance \( \sigma_{q,i}^2 \) measure the uncertainties of both the model and observations as well as the representative errors. \( F_{\text{other}} \) refers to the other regularization terms that can be included in the cost function. The optimization problem can be solved using many minimization tools, such as L-BFGS-B package, to get the final optimal emission estimates.

Improving Volcanic Ash Predictions with HYSSPLIT and Satellite Retrievals - 2008 Kasatochi Eruption

Wildfire Smoke

HYSSPLIT is used for the operational smoke forecasts in support of the National Air Quality Forecast Capability (NAQFC). While most wild fire locations are well identified by the NOAA NWSD Hazardous Mapping System (HMS), the current US Forest Service (USFS) BlueSky emission prediction may bring large uncertainties. This research aims to objectively and optimally estimate the wildfire smoke source strengths and their temporal variations based on NOAA NWSD GOES Aerosol/Smoke products (GASP).

Table 1. Source term error statistics of the two experiments.

<table>
<thead>
<tr>
<th>Sources</th>
<th>MAE</th>
<th>MAPE</th>
<th>RMSE</th>
<th>Normalized Error</th>
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<td>Case 1: Observations at all 48 h</td>
<td>130 6.7</td>
<td>246.2 4.7</td>
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<td>Case 2: Observations at all 24 h</td>
<td>130 6.7</td>
<td>246.2 4.7</td>
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<tr>
<td>Case 3: Observations at all 24 h</td>
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<td>246.2 4.7</td>
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<tr>
<td>Case 4: Observations at all 24 h</td>
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<tr>
<td>Case 5: Observations at all 24 h</td>
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