Model Evaluation and Improvement

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Model Evaluation and Improvement

- There are numerous sources of uncertainty in transport and dispersion modeling:
  - Emissions
  - Meteorology used to drive the HYSPLIT model
  - Model physics (e.g., horizontal and vertical mixing)
  - Model configuration (e.g., user-selected grid size)
- A fundamental part of our HYSPLIT model R&D involves comparison of simulation results with observations
- This allows us to assess how well the model is working and helps guide efforts to improve model performance
- We evaluate the HYSPLIT model using intentional tracer experiments, tracers of opportunity, and other observations
- We also evaluate the meteorological data used to drive the HYSPLIT model against observations, as this can be a significant source of uncertainty (e.g., wind speed and direction, stability, and mixing parameters)
- These model evaluation exercises help us to characterize, quantify and ultimately reduce uncertainties in HYSPLIT simulations
Relevance to OAR Strategic Goals

- **Design tools and processes to forecast high-impact weather, water, climate, ocean, and ecosystem events**
  -- OAR Strategy 2020-2026

- **Improve weather & climate predictions by increasing our understanding of Planetary Boundary Layer (PBL) processes**
  -- OAR Implementation Plan 2021-2026
Tracer Experiments

Controlled tracer experiments use passive tracer releases (with known emission rate and location) and employ well-designed sampling networks for meteorological parameters and tracer concentration.

Tracer measurements (ground and flights) for CAPTEX 2 release.
Tracer Experiments Conducted by ARL

Wide range of spatial scales in ARL tracer experiments, ranging from sub-kilometer to synoptic scale

- Atlantic Coast Unique Regional Atmospheric Tracer Experiment (**ACURATE**) – Savannah River Plant, SC, March 1982 through October 1983.
- Across North America Tracer EXperiment (**ANATEX**) – Glasgow, MT and St. Cloud, MN, January through March 1987
- Cross APpalachian Tracer EXperiment (**CAPTEX**) – Dayton, OH and Sudbury, ONT, September through October 1983
- OKlahoma Tracer EXperiment (**OKTEX**) – Oklahoma City, OK, July 1980
- MEtropolitan Tracer EXperiment (**METREX**) – Rockville, MD and Vernon, VA, January 1984 through January 1985
- Colorado Springs Tracer Experiment (**COSTEX**) – Colorado Springs, CO, October 2010
- Idaho Field Experiment (**IFEX**) – Idaho Fall, ID, July 1981
- Atmospheric Studies in Complex Terrain (**ASCOT**) – Anderson Creek Valley, CA, September 1980
- Project Sagebrush Phase 1 (**PSB1**) – Idaho Fall, ID, October 2013
Meteorological analysis datasets in HYSPLIT compatible format

**North American Regional Reanalysis (NARR)**

NCEP Eta Model product, converted to HYSPLIT format, 32-km, 3-hour and CONUS, 1979 – 2019

**Global Reanalysis (GBL)**

NCEP/NCAR Reanalysis Project, converted to HYSPLIT format, 2.5 deg, 6-hourly and global, 1948 – present year

The two analysis datasets above do not have momentum flux that HYSPLIT needs to diagnose some mixing parameters, so we have generated a new, long-term meteorological analysis dataset for research and development.

**WRF analysis dataset**

- WRF-ARW model output converted to HYSPLIT format
- Tailored for dispersion applications based on statistical evaluation of tracer experiments (see figures at right)
- 27-km, Hourly, CONUS, 1980 – present
- Available fields include: friction velocity, TKE, time-averaged wind fields, turbulent exchange coefficient

*Normalized Taylor diagrams of surface wind speed and temperature. (Ngan and Stein, 2017)*

Different WRF configurations were examined to see which provided the best data for dispersion modeling during various tracer experiments.
DATEM is an essential tool for HYSPLIT evaluation and development.

Available to the public since the early 2000s.

Available data include emissions, tracer measurements, and meteorological data (WRF recently added) for each tracer experiment.

Evaluation tools allows users to assess HYSPLIT’s performance themselves.

DATEM benefits the dispersion modeling community, allowing sensitivity studies and model intercomparison studies to be carried out.

**Examples of DATEM format and analytical results, for the CAPTEX tracer experiment**

**Tracer releases**

```
\datem\exp_data\captex\emit-t1.txt
year mm dy shr dur lat lon pmch
1983 02 18 1700 0300 39.80 -84.22 260100
1983 02 18 1700 0300 39.80 -84.22 260100
1983 10 02 1900 0300 39.90 -84.22 260100
1983 10 14 1600 0300 39.90 -84.22 100000
1983 10 26 0400 0300 46.62 -80.78 100000
1983 10 28 1300 0630 39.90 -84.22 320000
1983 10 29 0500 0300 46.62 -80.78 163000
```

**Tracer concentrations**

```
\datem\exp_data\captex\meas-t1.txt
year mm dy shr dur lat lon pmch      5tn
1983 09 10 1800 0300 39.65 -80.42 0.302
1983 09 10 1800 0300 40.38 -80.63 0.306
1983 09 10 1800 0300 40.77 -80.75 0.308
1983 09 18 1800 0600 40.92 -81.48 0.310
1983 09 18 1800 0600 41.33 -81.15 0.312
1983 09 18 1800 0600 41.42 -81.87 0.314
1983 09 18 1800 0600 41.38 -82.22 343.2 316
1983 09 18 1800 0600 41.27 -82.62 0.318
1983 09 18 1800 0600 41.33 -83.12 0.320
1983 09 18 1800 0600 40.68 -79.08 0.402
1983 09 18 1800 0600 40.43 -79.15 0.404
1983 09 18 1800 0600 41.63 -79.70 0.410
1983 09 18 1800 0600 42.48 -80.18 0.412
1983 09 18 1800 0600 42.67 -81.15 0.454
```

**Statistics summary**

- 55.33% Average bias (C/M/N)
- 127.50 Lo 99% confidence interval
- 17.11 Hi 99% confidence interval
- 0.30 Fractional bias [EB/C-M]
- 28.15 False Alarm Rate [FA/(FA+Hit)]
- 54.46 Probability of Detection [hit/(hit+miss)]
- 46.80 Threat Score [hit/(hit+FA+miss)]
- 45.18 Fig of merit in space (%)
**Statistical Analysis**

**Statistical rank**

Rank, a cumulative statistical score (range between 0-4)

\[
rank = R^2 + 1 - \left(\frac{FB}{2}\right) + \frac{FMS}{100} + \left(1 - \frac{KSP}{100}\right)
\]

- \(R\) – Correlation coefficient
- \(FB\) – Fractional bias
- \(FMS\) – Figure of merit in space
- \(KSP\) – Kolmogorov-Smirnov parameter

<table>
<thead>
<tr>
<th>name</th>
<th>Met data</th>
<th>Model wind</th>
<th>HYSPLIT PBL stability</th>
<th>HYSPLIT mixing</th>
</tr>
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<tbody>
<tr>
<td>karr</td>
<td>NARR</td>
<td>Instantaneous wind</td>
<td>Wind/Temp profiles</td>
<td>Kantha-Clayson</td>
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<td>narr</td>
<td>NARR</td>
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<td>TKE</td>
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<td>Heat/momentum flux</td>
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<td>wrf-tke</td>
<td>WRF</td>
<td>Time-averaged wind</td>
<td>Heat/momentum flux</td>
<td>TKE</td>
</tr>
</tbody>
</table>
WRF Modeling Project for SORD and FRD

- An operational WRF modeling system to provide forecasts for daily operations, special experimental support, and emergency response components of the ARL Western Division missions (SORD and FRD).

- A coupling of modeling and measurements provides a platform to increase understanding of PBL dynamics, with attention to phenomena that impact the transport and dispersion of pollutants.

- The system will be a testbed for ARL research projects such as general PBL parameterizations, direct mesonet data inclusion, and the study of desert climate.

- The system has been operating since May 2021 to produce a 4-day forecast, every six hours.

- A web app was implemented to display the graphics for the daily use of the Western Divisions.
  
  https://apps.arl.noaa.gov/wrff/

- Individual domains for Nevada area and Idaho regions, sharing the same 18-km outer domain.
Six months of forecasting results were evaluated by comparison against the mesonet data collected by the ARL Western Divisions.
Tracers of Opportunity

- A **tracer of opportunity** can be any atmospheric release of a substance where the emissions rate has been measured or can be independently estimated, and for which downwind concentration measurements exist and/or which can be made.
  - industrial accidents (e.g., Fukushima nuclear accident)
  - natural processes (e.g., volcanic eruptions)
  - byproduct of industrial facilities (e.g., emissions from power plants)
- Example: SO$_2$ and CO$_2$ emissions from power plants -- emissions and downwind concentrations are measured; extended met measurements are also sometimes available (mesonets; Doppler Lidar, etc).
- Chemical transformations can be modeled or are relatively unimportant at time scales of less than a day (close to the source).

An ensemble of 5 model runs using different met datasets

Black: Time series of hourly SO$_2$ measurements at station A1

Blue: Fraction of ensemble runs with concentrations above a threshold of 2.5 ppb

Peak modeled concentrations (not shown in this figure) were underpredicted, but the use of an using ensemble can improve the detection of peaks – for most of the observed peaks, at least one model-ensemble member showed a peak at or above 2.5 ppb.
Tracers of Opportunity

A study for the area around Ponca City, OK

Vertical velocity variance observations and model results

Vertical velocity variance profile Doppler Lidar at E39 (OBS) August 2nd, 2016

Vertical velocity variance profile from HYSPLIT “KG mixing”

Vertical velocity variance profile from HYSPLIT “TKED mixing”

Vertical velocity variance profile from HYSPLIT “EXCH mixing”

Modeled SO$_2$ concentrations (4 different mixing methods) and measurements

Geographical setting of emissions sources, concentration measurements, and meteorological measurements

Oklahoma

Mesonet site BLAC* Other SO$_2$ sources
Ponca City
ARM sites – E39, C1, E41 (Atmospheric Radiation Measurement)
LIDAR for turbulent variance

Soonier Power Plant 2 units, 152 m stack height

Mesonet site REDR*

METAR site – KSWO

SO$_2$ site
Quality and Performance: Publications


Quality and Performance: *Presentations*


- Ngan, F., Christopher Loughner, and A. Stein, 2019: Evaluating the mixing characteristics in HYSPLIT with controlled tracer experiments. 23rd Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling, Fairfax, VA, George Mason University.

- Ngan, F., A. Stein, and Christopher Loughner, 2018: The evaluation of mixing methods in HYSPLIT using measurements from Sagebrush Tracer Experiment. 22nd Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling, Fairfax, VA, George Mason University.


Future Plans

**DATEM and Meteorological Analysis Datasets**
- Major updates to the DATEM and evaluation webpages.
- The WRF dataset will be updated using the latest WRF version and new landuse data.

**Western WRF Modeling Project**
- Expand the forecast period to 5 days and add new graphics
- Additional comparisons of the model results with the mesonet data
- Assimilation of mesonet data into WRF to improve model performance

**Tracers of Opportunity**
- Build up database of areas and time periods where emissions and measurements exist and for which interferences from uncharacterized sources are minimal
- Classify by meteorological conditions, terrain type, distance from source to station
- Apply new statistical and evaluation methodologies, e.g., object-based statistics (e.g., analysis using plume features rather than fixed gridded concentration results)
- Additional meteorological and concentration measurements (ground, mobile, drones, aircraft)