CO_2-USA ARL Modeling System Updates

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Introduction

- **Goal:**
  - Apply model to estimate carbon emissions and trends in different U.S. cities
- **1st Step:**
  - Construct an atmospheric modeling system that is scalable and transferable between cities
    - Enhance HYSPLIT with STILT routines
    - Compile urban/suburban scale datasets for testing updated HYSPLIT model
    - Host benchmark scenarios for future testing of model updates and model inter-comparisons
- **Benefits of HYSPLIT modeling system updates:**
  - Enhance HYSPLIT's capabilities
  - Host and maintain STILT routines with HYSPLIT code that will continue to be updated with the state of the science
  - Provide testing platform to evaluate and examine model similarities and differences to other Lagrangian models / model options. Testing platform can also be used to test inversion techniques to estimate source strength and location.

HYSPLIT features

- Lagrangian emission, transport, dispersion, and deposition. Eulerian complex chemistry.
- Automated method of simultaneously using multiple meteorological grids.
- Multiple parameterizations to estimate the stability from gradients of meteorological variables.
- Multiple options to convert stability into dispersion values (diffusivity profiles, turbulent kinetic energy, velocity variance).
- Modeling the turbulent particle motion directly (3D) or the change in the statistic of the particle distribution (puffs) or a combination of the two.
- Mixed-mode approach: 3D part to puff, 3D part to Eulerian, puff to 3D part, puff to Eulerian.

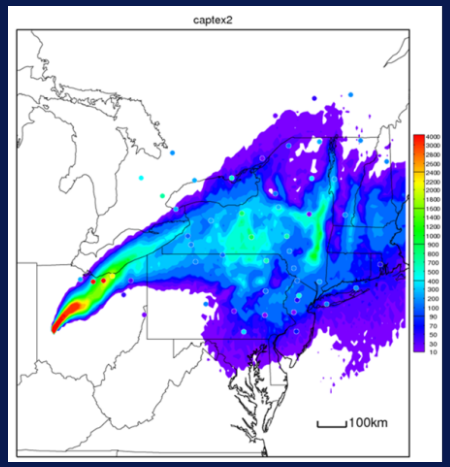
meteorological input files

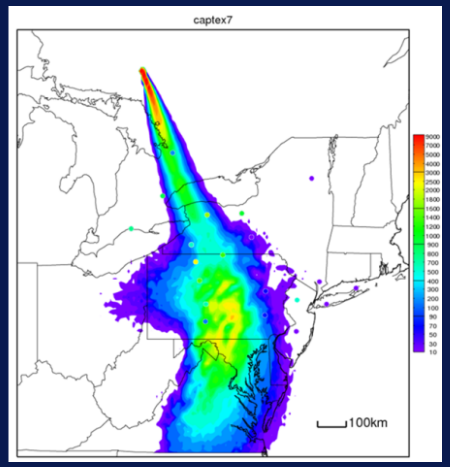
- Pre-processors for many different meteorological models and gridded analysis/reanalysis datasets (WRF, RAMS, MM5, ECMWF, GALWEM, MERRA, ERA interim, ERA5) to convert data to the ARL format, in addition to the archives of existing NOAA models and analysis/reanalysis (NAM, HRRR, GFS, SREF, NARR, GDAS, NCEP/NCAR reanalysis).
- ARL new WRF simulation
  - Resolution: 27 km (216 E->W, 174 S->N, 33 vertical from surface to 100mb)
  - Timeframe: 1980-2016 with plans to continue through 2017 and beyond
  - Domain covers all of CONUS
  - Model configured to obtain optimal transport results; not temperature
  - Some STILT specific optional inputs are available (mass conserving winds available, but no convection variables)
  - Converted to ARL formatted files and is publically available
- Future ARL WRF simulation
  - Resolution: 9 km, nested down from the 27 km domain described above
  - All STILT optional inputs will be available
  - Will be converted to ARL formatted files and made publically available

Model Evaluation System

Data Archive of Tracer Experiments and Meteorology (DATEM)

- **Approach**
  - Meteorology
    - North American Regional Reanalysis (NARR)
    - WRF runs
  - Common statistical evaluation protocols
- **Accomplishments**
  - Web access to run HYSPLIT for each experiment
  - Standardized model change testing in conjunction with version control





- **Cross Appalachian Tracer Experiment (CAPTEX)** Dayton, OH, and Sudbury, ONT, Sep., Oct., 1983
- **Atlantic Coast Unique Regional Atmospheric Tracer Experiment (ACURATE),** Savannah River Plant, SC, Spring 1982 – Summer 1983
- **Across North America Tracer Experiment (ANATEX)**, Glasgow, MT, and St. Cloud, MN, January through March 1987
- **Oklahoma Tracer Experiment**, Norman, OK, July, 08 1980
- **Metropolitan Tracer Experiment (METREX)** , Washington, DC, January – December 1984
- **European Tracer Experiment (ETEX)**, Rennes, France, October 23, 1994
- **Savannah River Plant Experiment** , Aiken, SC, Aug. 1975 through Sep. 1977
- **Atmospheric Studies in Complex Terrain (ASCOT)** , California, September 12-25, 1980
- **Colorado Springs Tracer Experiment (COSTEX)**, October 18, 21, 23, 2010
- **Sagebrush, Idaho, 2013**
- **Aliso Canyon well blowout, 2015**
- **Tracers of opportunity (e.g. SO2 flight data)**

STILT

- Built from the HYSPLIT code
- Major STILT features not currently in HYSPLIT:
  - Mass conservation
  - Hanna Lagrangian timescale
  - Convection scheme that utilizes WRF convective fluxes
  - A more complex turbulence module that includes a reflection/transmission scheme for Gaussian turbulence. This preserves well-mixed distributions of particles moving across interfaces between step changes in turbulence parameters.
  - Account for transport errors by incorporating uncertainties in winds into the motion of air parcels

HYSPLIT – STILT Comparison

Average rank results from 8 case studies from HYSPLIT and STILT simulations (Hegarty et al., 2013).

Model	NARR Only	WRF avg PBL=1	WRF avg PBL=0	WRF inst PBL=1	WRF inst PBL=0
HYSPLIT	2.13	2.42	2.34	2.29	2.29
STILT	2.12	2.39	2.26	2.26	2.27

$$RANK = R^2 + (1 - |FB/2|) + FMS/100 + (1 - KS/100)$$

- R^2 = Square of linear correlation coefficient
- FB=Fractional Bias defines a normalized measure of bias
- FMS = Figure of Merit in Space defines a percentage of overlap between measured and predicted areas
- KS = Kolomogorov-Smirnov parameter defines the maximum difference between two cumulative distributions

STILT features being incorporated into HYSPLIT

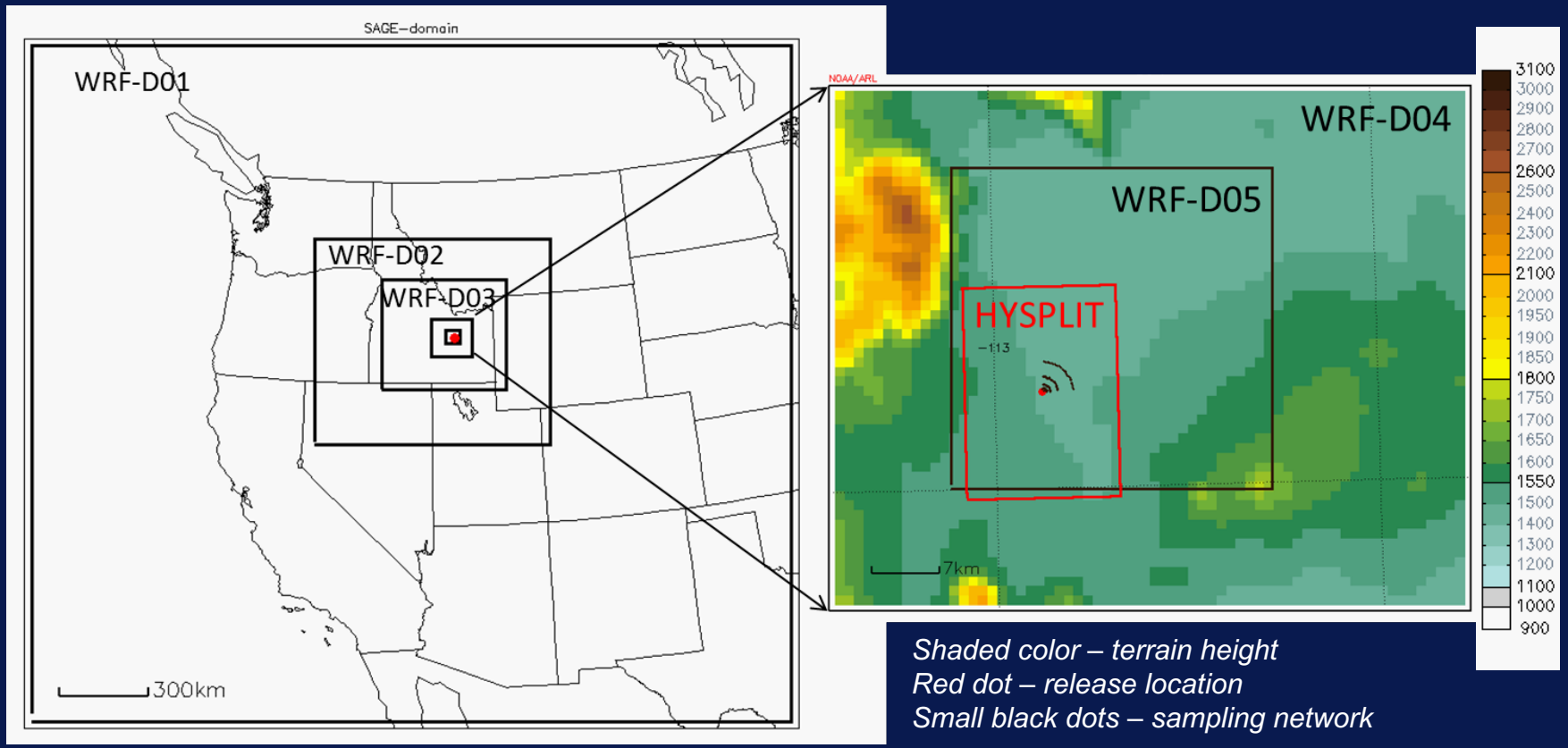
- Mass Conservation
- Convection scheme
- Hanna Lagrangian timescale
- Complex turbulence module
- Account for transport errors

- Allow for updated features to be modular

Testing updated HYSPLIT with STILT features

- Evaluate individual model options over a range of scenarios (field campaigns and computational experiments).
  - What are the differences and similarities between different model options.
  - Document differences in computational time for each model option (speed is of great importance for operational purposes).
  - When is it necessary to use the more complex model option that requires more computational resources?
- Expand the DATEM archive to incorporate field campaign data on the urban / suburban spatial scale.
- Provide meteorological datasets and HYSPLIT simulations for benchmarking to the Lagrangian modeling community. Can be used to test atmospheric dispersion models and inversion techniques.

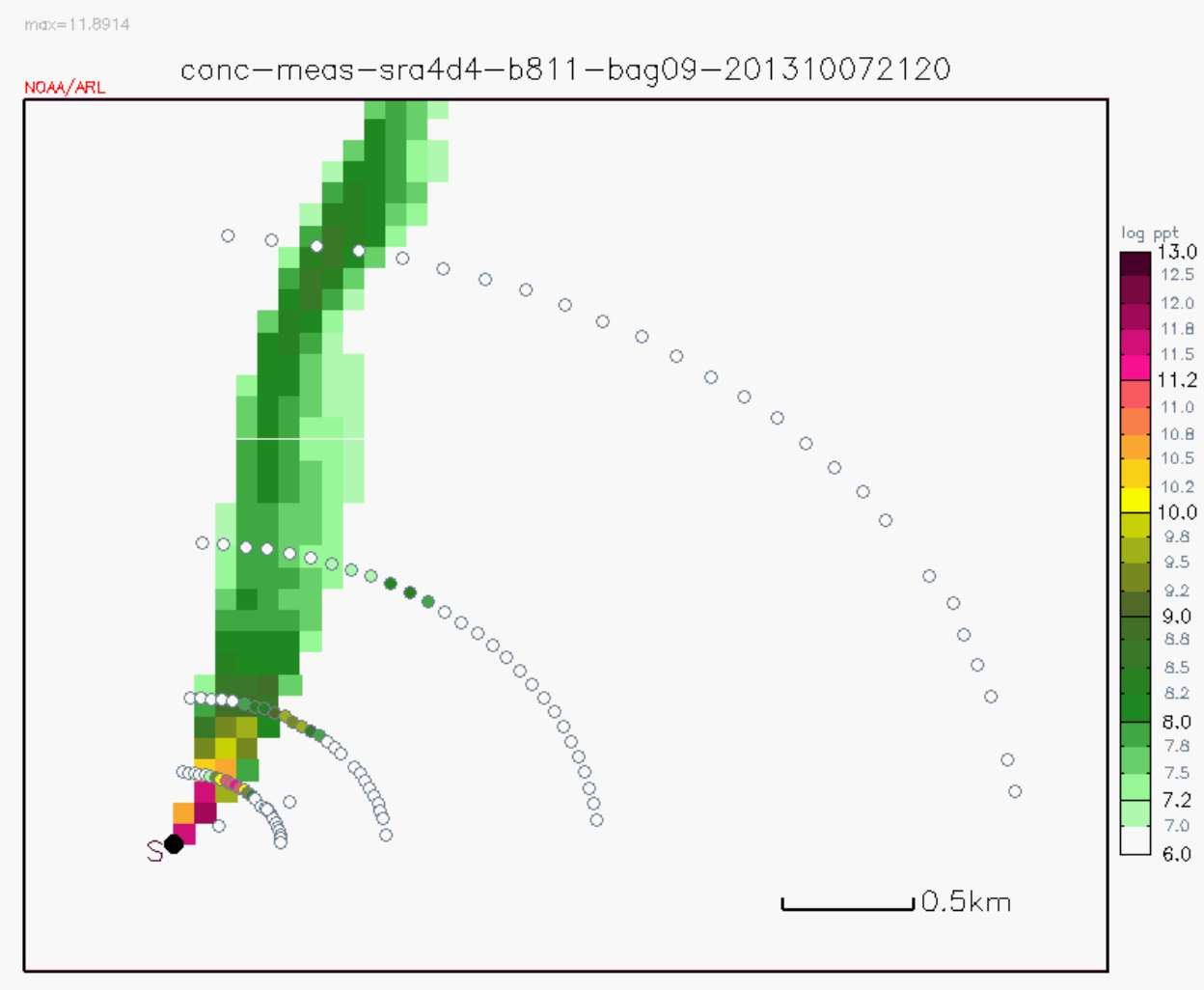
HYSPLIT simulation of Sagebrush experiment



Shaded color – terrain height
Red dot – release location
Small black dots – sampling network

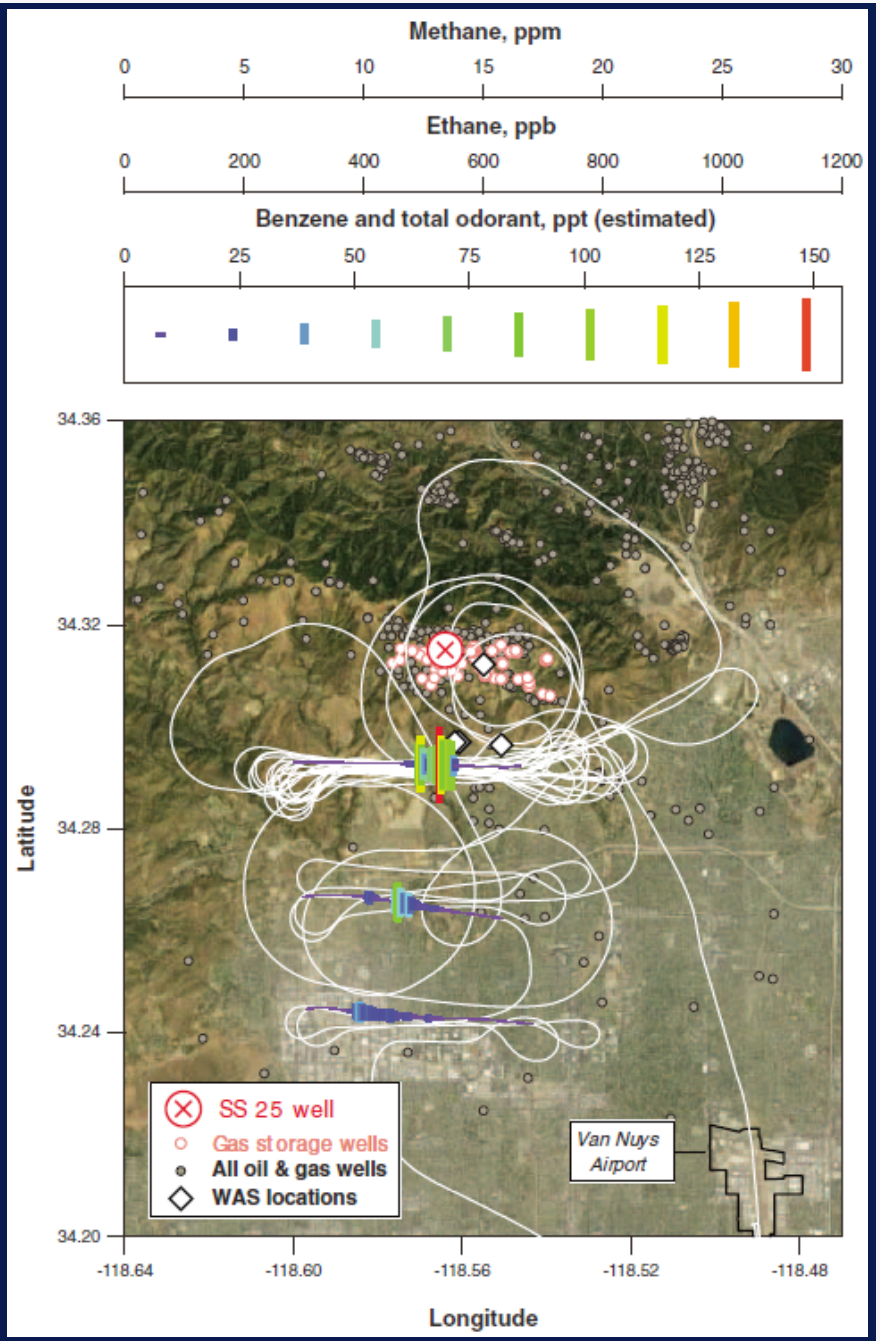
- Horizontal grid: 27km, 9km, 3km, 1km and 333m
- Vertical coordinate: 33 layers with the 1st mid-layer at around 8m and 20 layers included below 850 hPa.
- Simulation period: 2013/10/07 00UTC – 10/08 00UTC

HYSPLIT simulation of Sagebrush experiment



2015 Aliso Canyon blowout

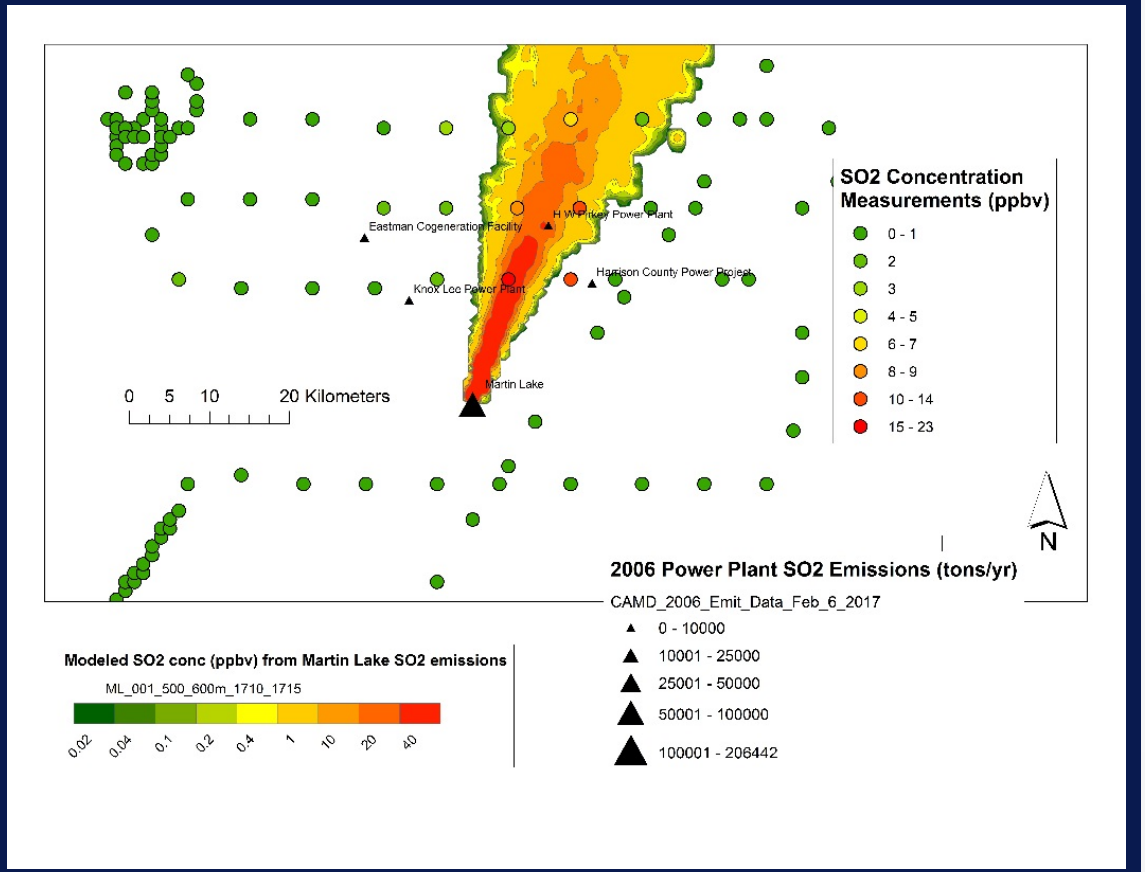
- Large natural gas emissions released from a well blowout of connected to an underground storage facility
- 13 research aircraft flights sampled the plume
- Atmospheric leak rates up to 60 metric tons of methane and 4.5 metric tons of ethane per hour (Conley et al., 2016)



Tracers of Opportunity

- Observations downwind of an isolated source with known emissions rates
- Continuous Emissions Monitoring Systems (CEMS) measures actual emissions from stationary sources.

TEXAQS II



Conclusion

- Add new features (from STILT) into HYSPLIT
- Maintain HYSPLIT's computational efficiency / speed for operational use.
- Provide infrastructure for maintaining STILT features within HYSPLIT
- Test individual model options to seek out model differences / similarities
- Create new DATEM on urban / suburban spatial scales
- Provide meteorological datasets and HYSPLIT benchmark runs for future testing