Errors in top-down estimates of emissions using a known source

Wayne M. Angevine
CIRES, University of Colorado
NOAA ESRL
with contributions from many colleagues

Objectives

Examine top-down estimates using aircraft data and forward transport modeling

Identify and classify errors

Estimate uncertainty from remaining unknowns

Try to understand impact of errors on more complex inversions/retrieval methods

Method

Power plant emissions are well known (Location, Amount (hourly))

Some uncertainties remain (Plume rise, Transport time)

Use Martin Lake power plant (east Texas)

- Sampled several times over 16 years

Met data from ERA5 reanalysis

- Provides uniform quality over the time span
- 10-member ensemble plus one control run

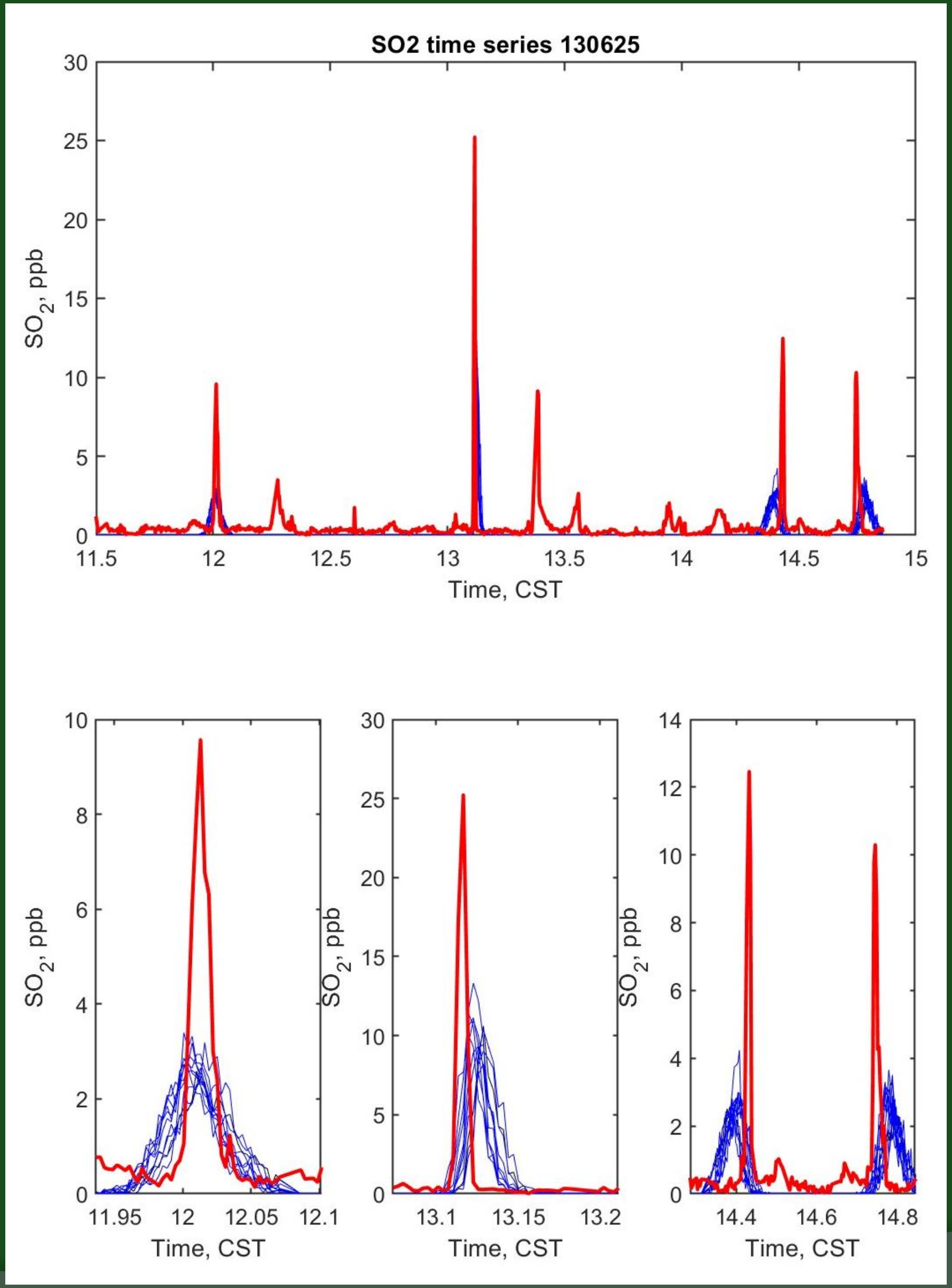
HYSPLIT Lagrangian dispersion model

- Forward mode
- Full time resolution of emissions (hourly)

Retrieval methods

- Plume scaling
- Mass balance with observed winds & BLH
- Mass balance with modeled winds & BLH
- Full plane integration mass balance

25 June 2013
Time series



Four intercepts of SO2 plume

Obs in red

10 ensemble members plus control run shown (blue)

First intercept is well aligned, others displaced

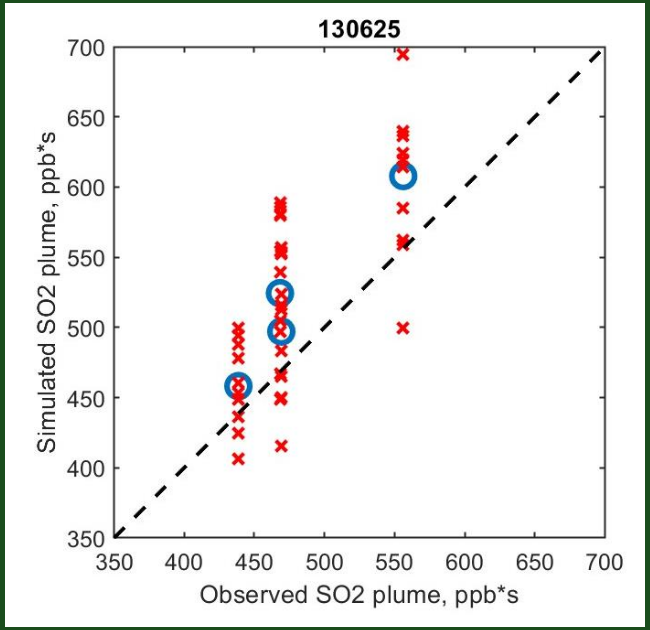
Simulated plumes are wider than observed

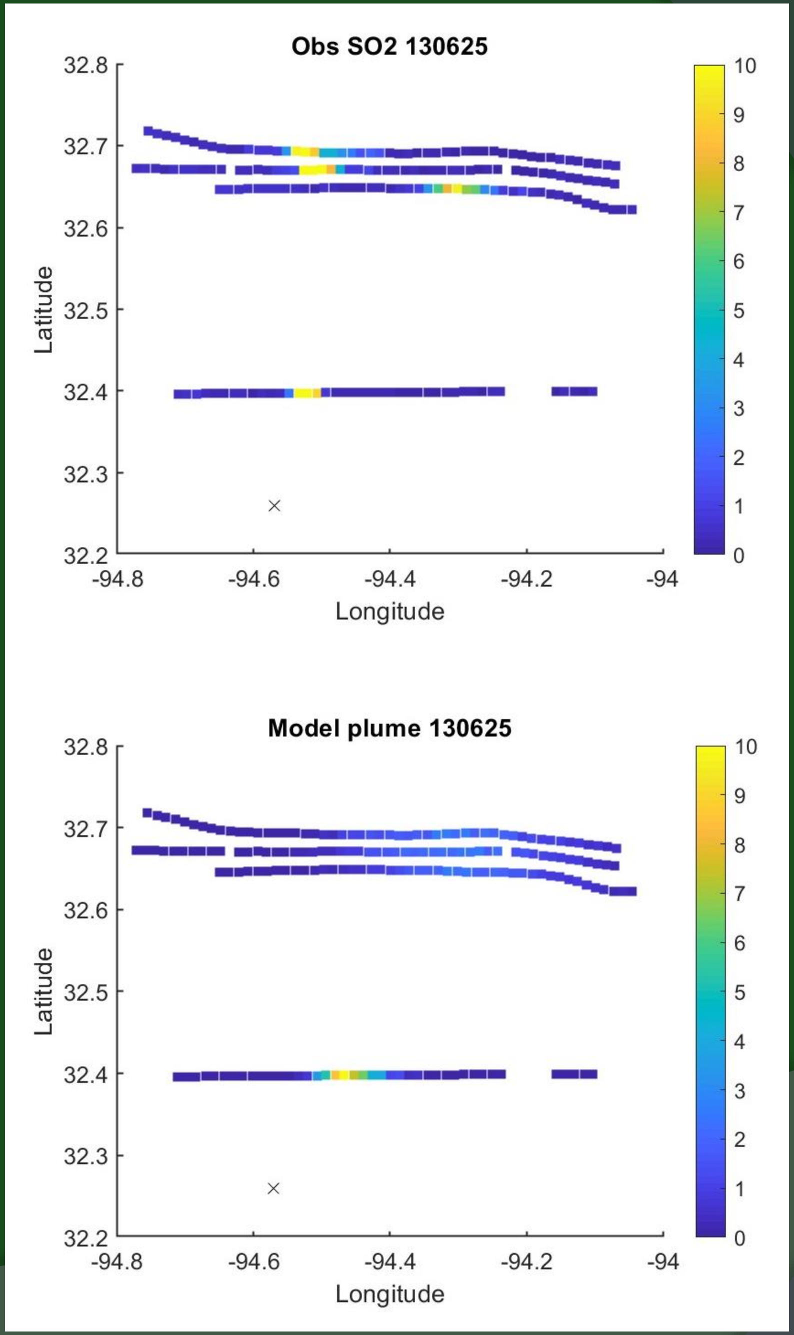
Little spread in ensemble

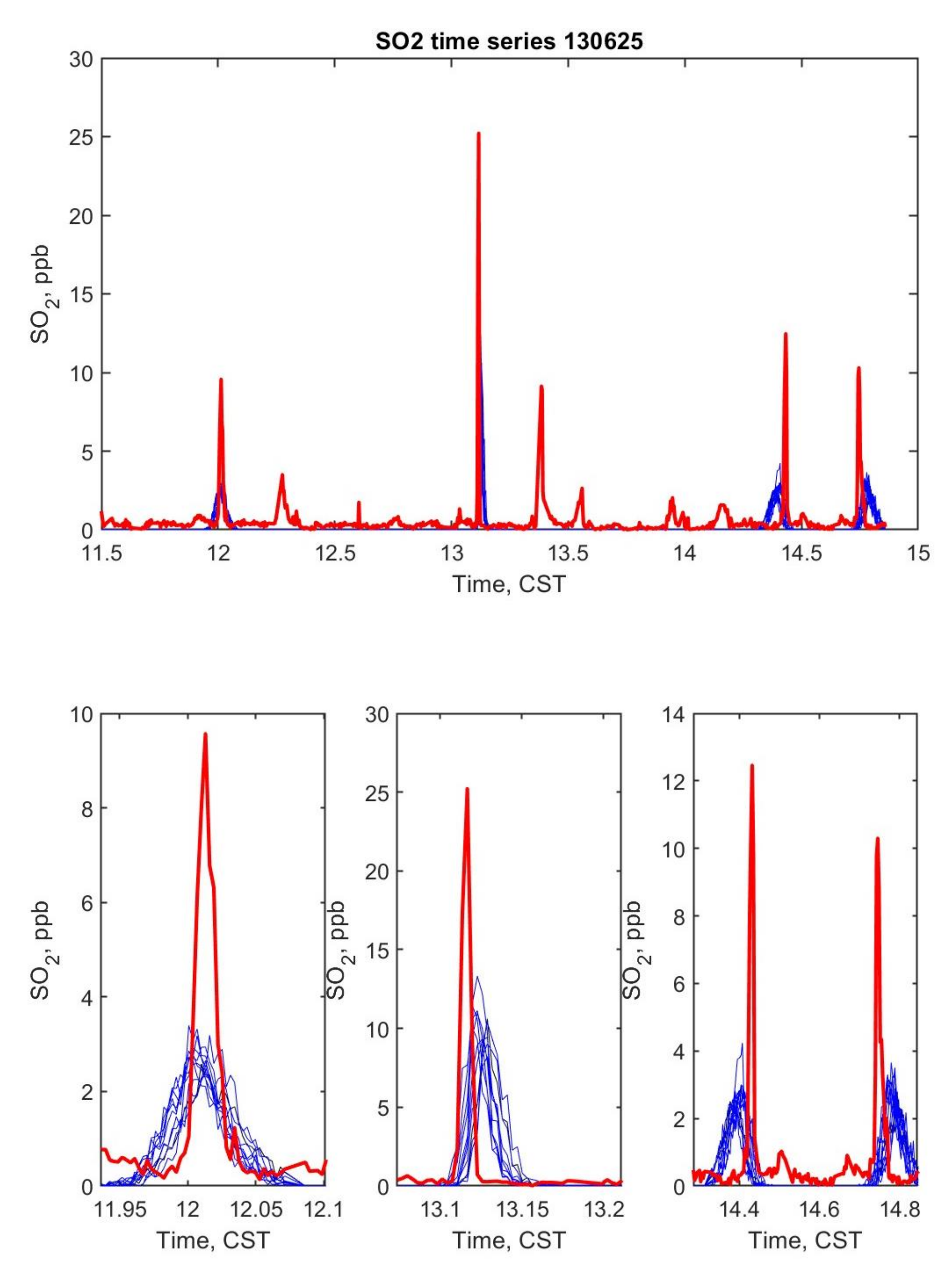
- Location
- Width

25 June 2013
Location and magnitude

Integrated concentrations match rather well
Control is within ensemble for all four intercepts
Ensemble spans 1:1 for all four







Classes of error

Wind direction -> plume displacement

Wind speed -> magnitude, timing w.r.t. time varying emissions

Horizontal dispersion -> plume width

Vertical dispersion -> magnitude

Background -> magnitude

Discretization

Temporal variation of wind can result in “storage” of pollutant and other errors when winds are not updated often enough

Mass balance flux comparison (130625)

Mass balance by several methods:

Observed plume, BLH, wind speed

Simulated plume, BLH, wind speed

-- and combinations

CEMS data (reality) also shown

BLH is the dominant difference in deterministic runs

Ensemble members differ substantially, but using different BLH estimates separates them for plumes 1 and 2

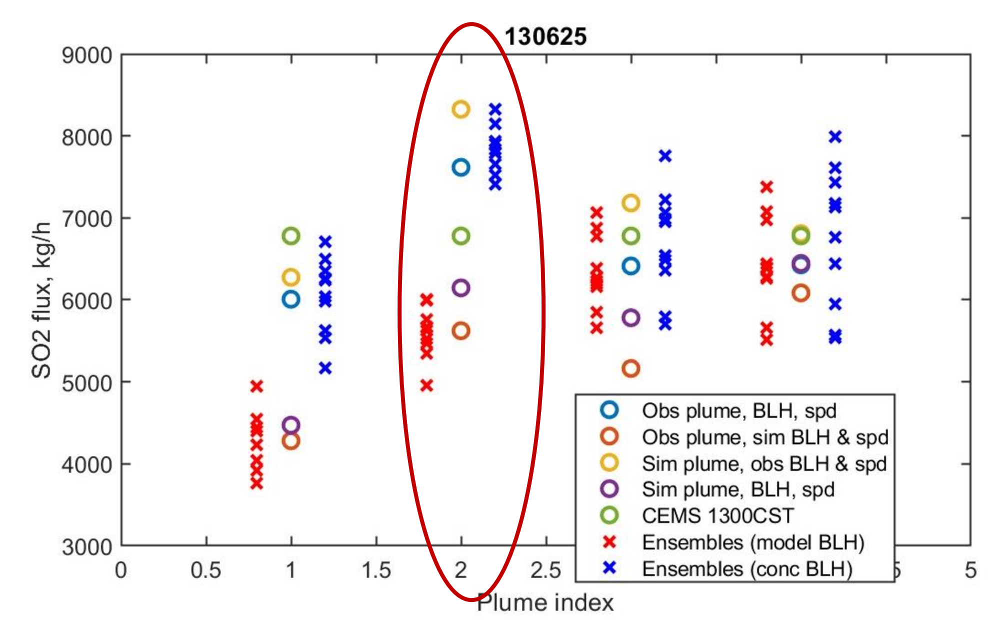
BLH range 27%

Wind speed range 21%

Small correlation (R = -0.23)

Neither ensemble spans reality for plume 2

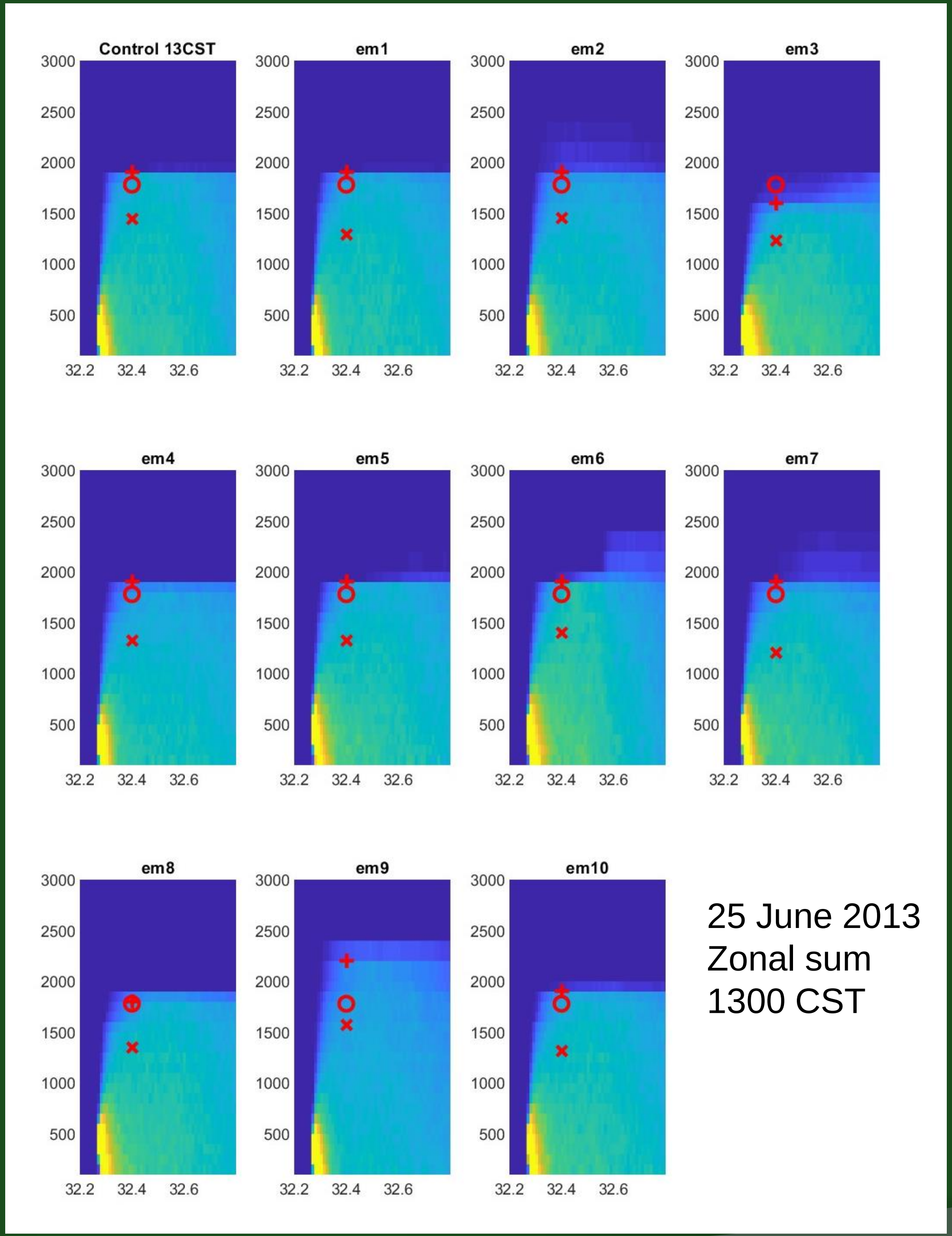
Deterministic estimates range 40%



Why doesn't mass balance using all simulated data reproduce reality perfectly? Violations of MB assumptions (constant wind speed, perfect vertical mixing, known BLH)

Check by integrating entire plume? Flux=7500 (within range of det. estimates and within 11% of reality)

Vertical dispersion



Ensemble of vertical cross-sections showing substantial differences

Mixing height estimates differ strongly:

Obs o (one value)

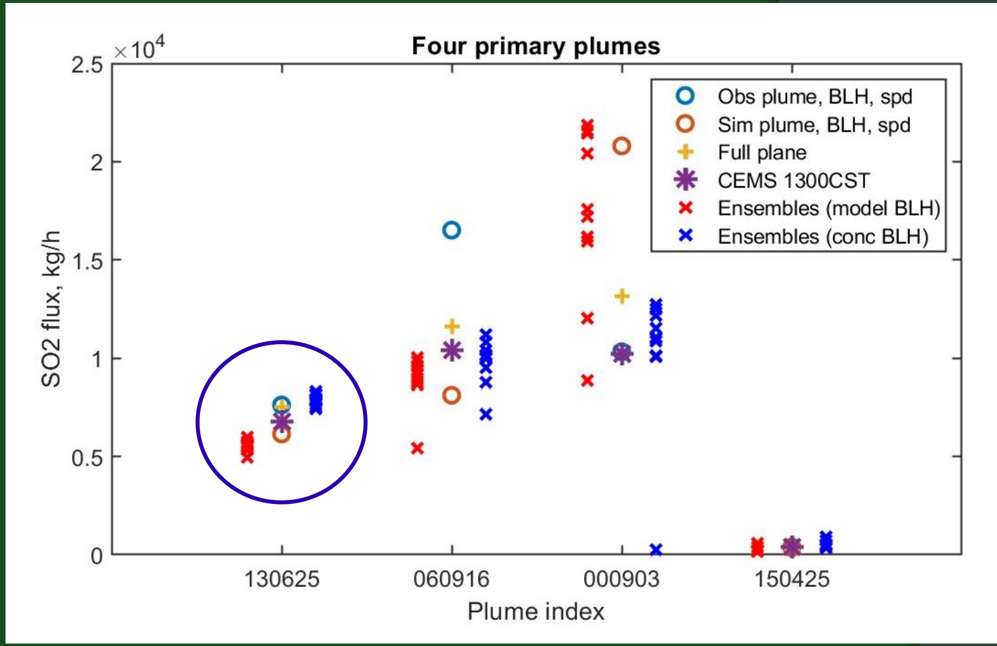
Model x

Concentration profile +

These patterns are similar if model emissions are limited to 1200-1300 CST, or if constant emissions are used

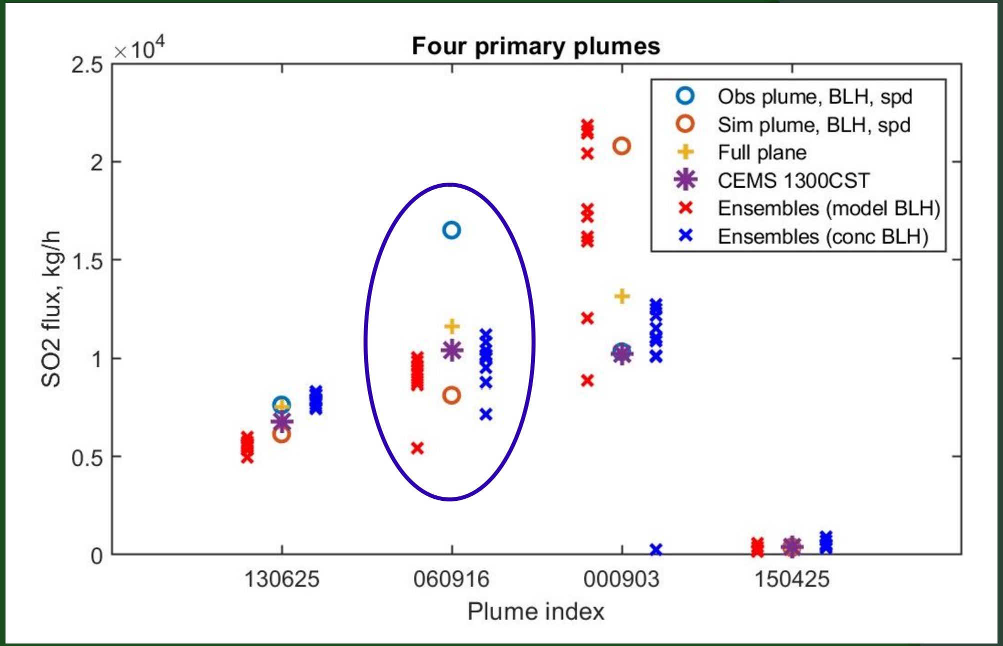
Summary of four main plumes

2013 0625
Obs mass balance bias +12%
Sim mass balance bias -9%
Full plane integration bias +10%
Ensemble ranges 19%, 12% (do not overlap CEMS value)
Sim mixing height biased low, partially offset by high wind speed



Summary of four main plumes

2006 0916
Obs bias +59%
Sim bias -22%
Full plane bias +12%
Ensemble ranges 51%, 41% (concentration BLH overlaps CEMS)
Plume not well mixed



Summary of four main plumes

2000 0903

Obs bias +0.9% (nearly perfect)

Sim bias +100% (not nearly perfect)

Full plane bias +28%

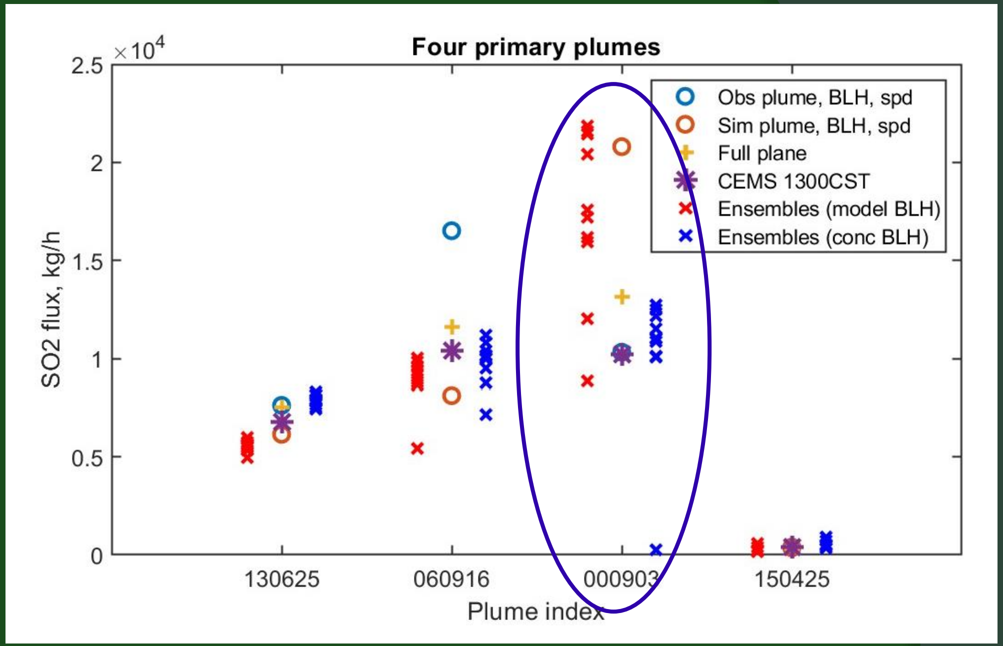
Ensemble ranges 75%, 122% (both overlap CEMS)

ERA5 mixing heights unrealistically large

HYSPLIT plumes not well mixed

Observed profiles show large change in mixing height during the flight

Plume rise is important and variable on this day



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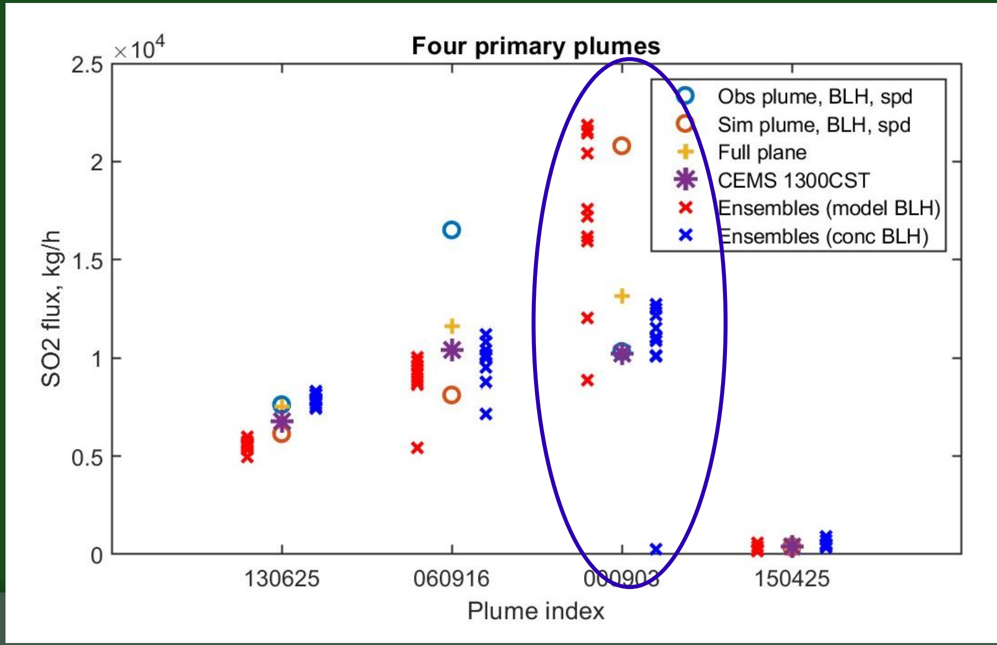
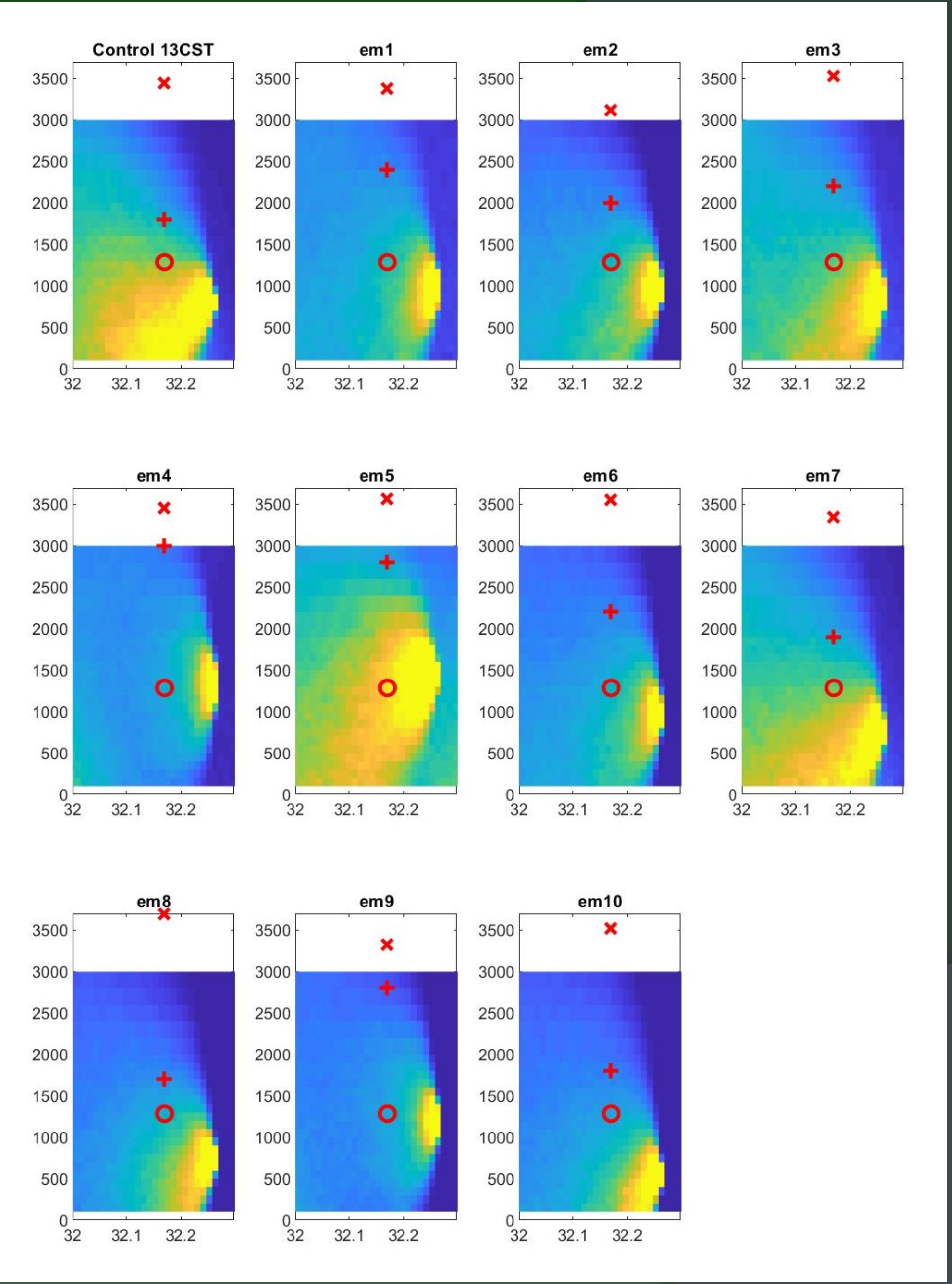
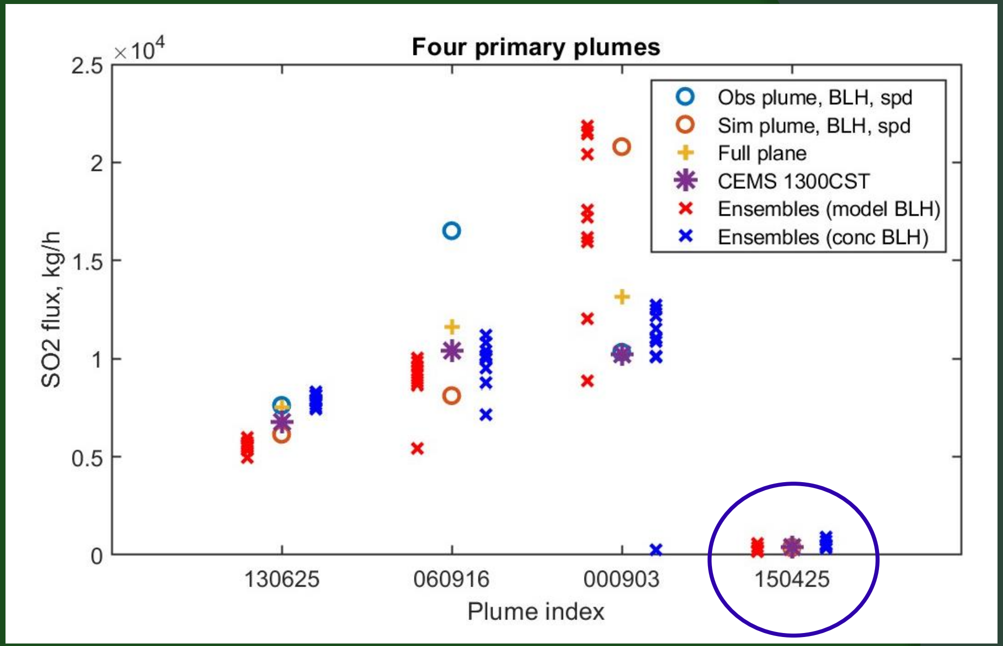




Summary of four main plumes

2015 0425
Obs bias +5%
Sim bias -2%
Full plane bias -20%
Ensemble ranges 146%, 105% (both overlap CEMS)
Simulated plumes not well mixed, variable
Not accounting for background uncertainty



Conclusions

No general uncertainty estimate emerges from this study
Peischl et al. (2015) estimate 35% uncertainty for methane from this area, which seems realistic

Vertical mixing is the largest source of uncertainty:
Plumes not well-mixed (possibly in reality, no data to compare)
All retrievals using single-level observations are sensitive to vertical dimension
- Full-plane integration sometimes gets closer to reality

All retrievals (period) are sensitive to time-varying winds (storage)

Background uncertainty matters (to observations) when plume-to-background ratio is low

Ensemble:
- Spread not always sufficient
- Doesn’t always span control run (time discretization?)
- Adds value by flagging more uncertain situations

Remaining issues:
- CEMS uncertainty (can you help?)