Improved evaluation of atmospheric flow and transport over complex terrain at multiple scales with uncertainty

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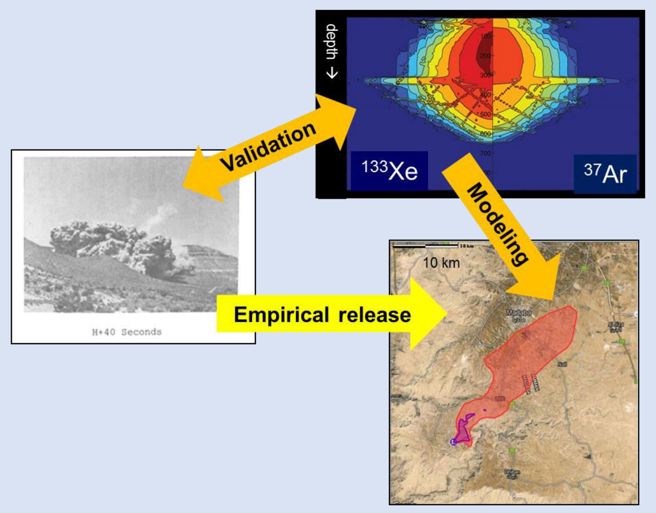
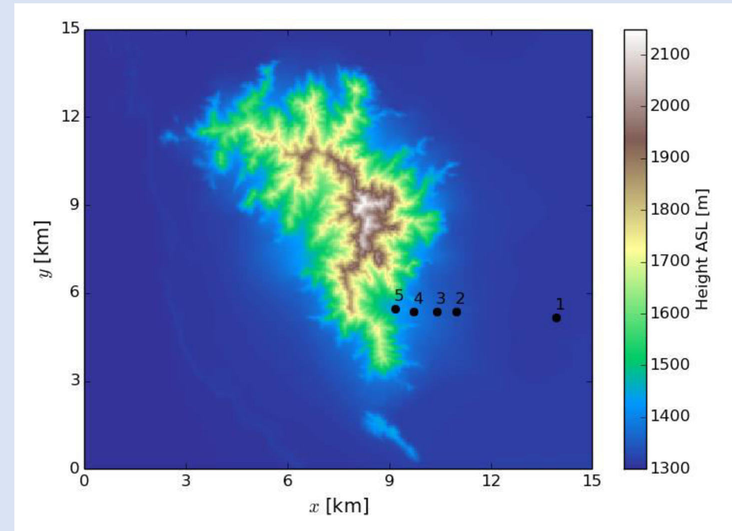
Complex terrain modeling with advanced sources can improve transport and dispersion predictions at sub-regional scales



New methodologies incorporating test data and simulated subsurface gas transport are better characterizing dynamic sources for atmospheric transport

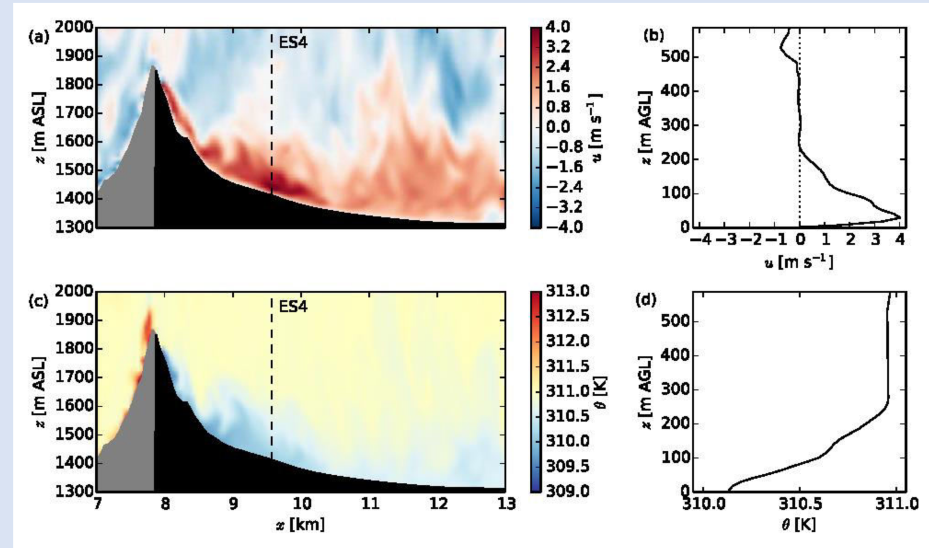
Topographic effects on radiation can influence the surface energy budget, creating large spatiotemporal heterogeneities. These effects include the following:

- **Topographic shading** where direct solar radiation is blocked by surrounding topography
- **Slope effects**, also known as "self shading", where the local slope angle modifies the incoming solar radiation based on the angle of incidence.

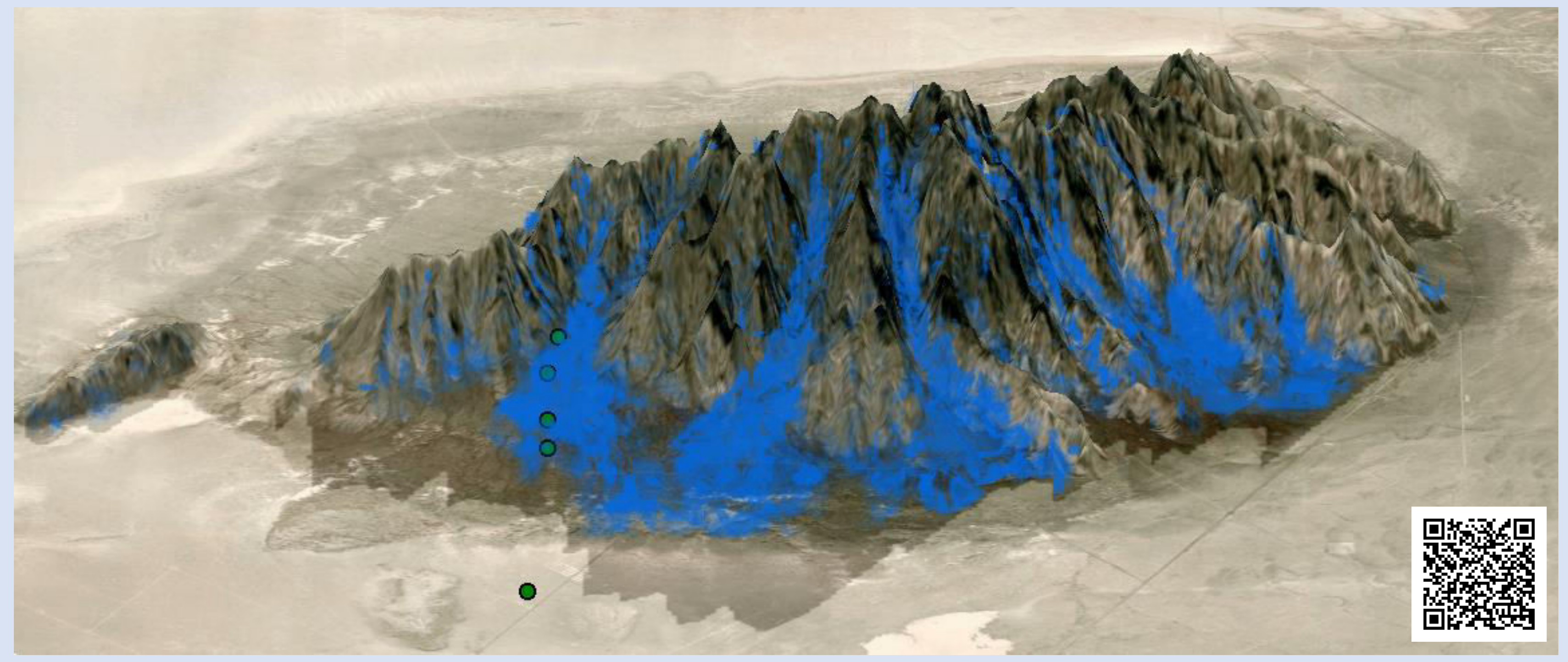


Granite Mountain is modeled in the domain shown above with 50 m horizontal resolution and 8-27 m resolution near the surface. At this resolution, local terrain slope values reach roughly 55 degrees. A high-resolution WRF-IBM simulation captures the strong horizontal heterogeneities in the surface sensible heat flux due to topographic shading and slope effects.

The reversal of the surface sensible heat flux after sunset drives cooling of the near surface air. This air flows downslope due to its negative buoyancy.



In a cross section through the green dots, which represent measurement towers from the MATERHORN field experiment, the characteristic jet structure of the downslope flow can be seen.

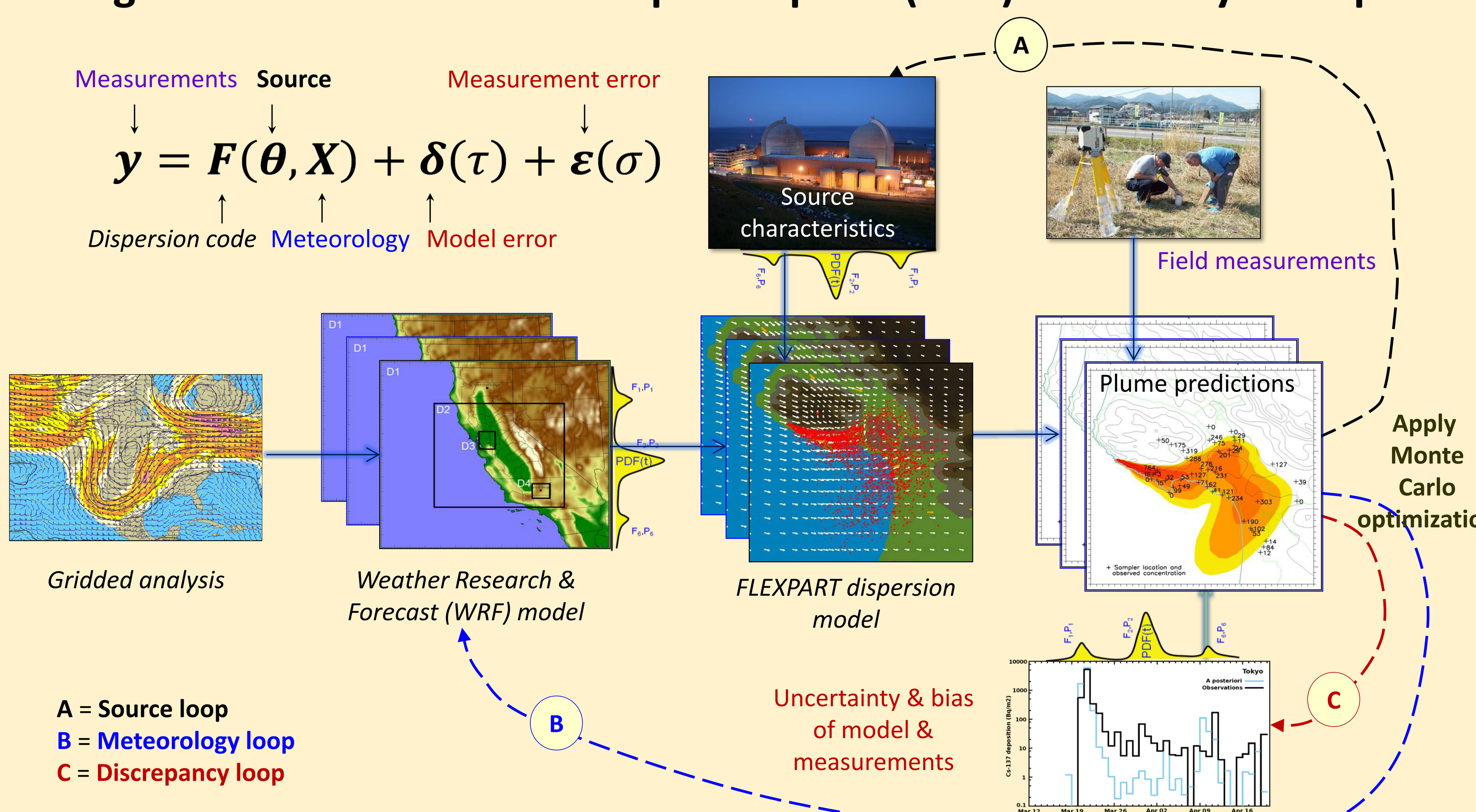


The image above shows isosurfaces of downslope velocity from the model at 18:55 MST. Darker blue surfaces represent faster flow. The terrain is shown by a real satellite image from Google Static Maps API. Topographic shading is shown as well. Follow the QR code to a watch an animation of the modeled downslope flow as it develops.

The simulation of atmospheric radionuclide plumes requires a holistic multiscale modeling approach that accounts for uncertainty. Such an approach is especially needed for close-range monitoring and for simulating time-varying releases over complex topography. Our multiscale approach will accommodate temporally and spatially variable source terms and the resolution of surface meteorological complexities through the development of advanced large-eddy simulation (LES) and immersed boundary methods (IBM) for the Weather Research and Forecasting (WRF) model. Predicted plume trajectories over complex terrain can dramatically diverge as temporal and spatial details are unresolved, particularly in the near-field. Our improved multiscale WRF model facilitates better numerical representations of flow over complex terrain, capable of capturing diurnal up-slope and down-slope flow and representing a quantifiable improvement to predictions of plumes from a time-varying source in complex terrain. Uncertainty is quantified using an ensemble-based Bayesian methodology incorporating data and model perturbation. The utility of the Bayesian approach is described in detail for one multi-scale approach through a numerical weather and transport study of a tracer release experiment at a nuclear power plant in Central California. Here we describe our technique and how it quantifies the contribution of individual source and meteorological parameters to overall model-data variance.

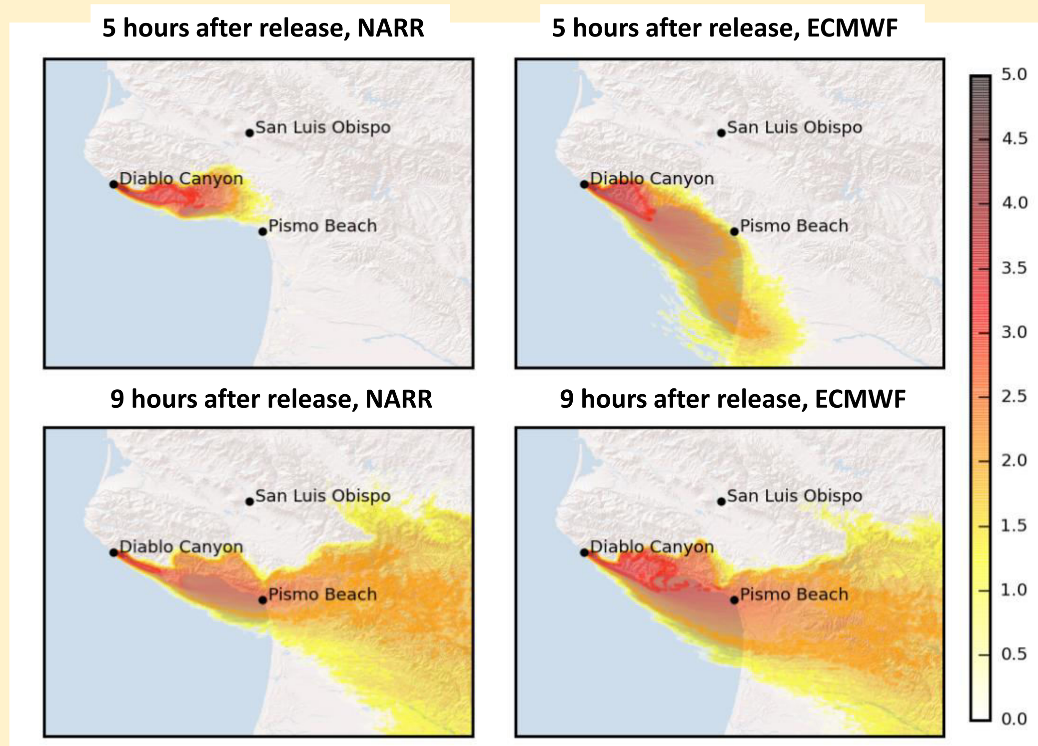
A regional-scale Bayesian inversion can characterize uncertain release and regional meteorological conditions: a nuclear power plant (NPP) field study example

$$y = F(\boldsymbol{\theta}, \boldsymbol{X}) + \boldsymbol{\delta}(\tau) + \boldsymbol{\varepsilon}(\sigma)$$

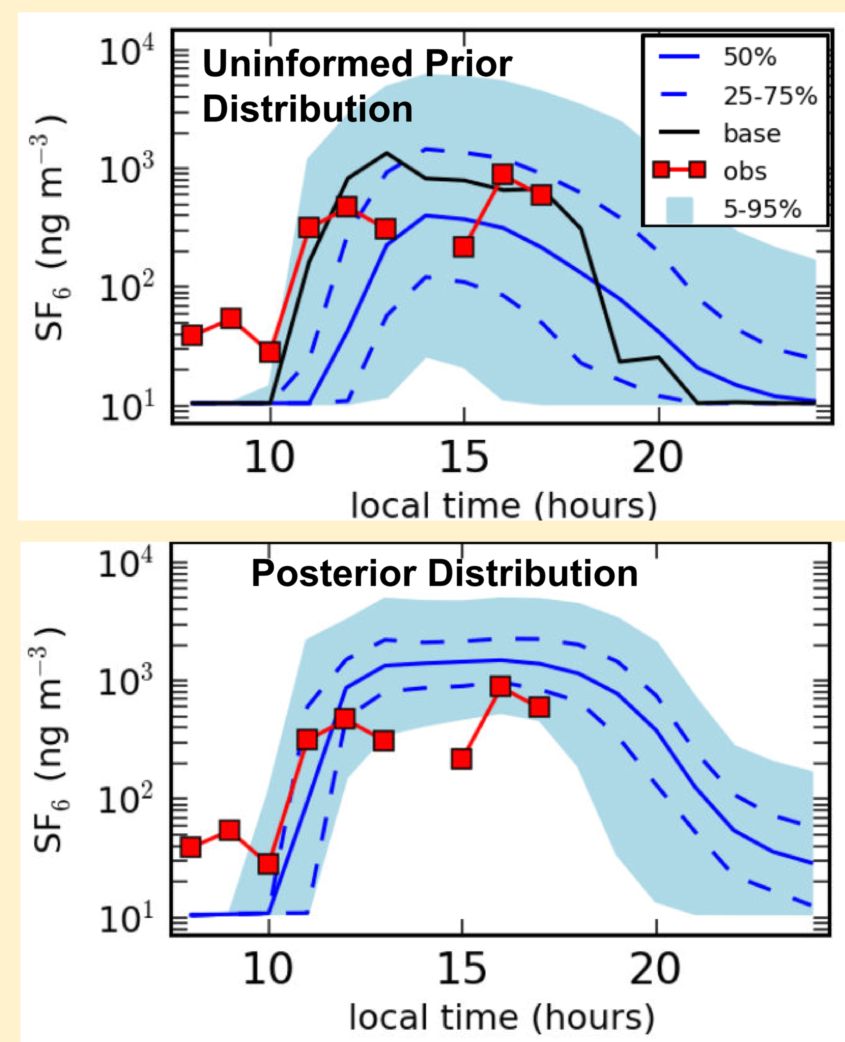


Bayesian inversion methodology accounts for uncertainty in meteorology and source characteristics (see D. D. Lucas, Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-336, in review, 2017).

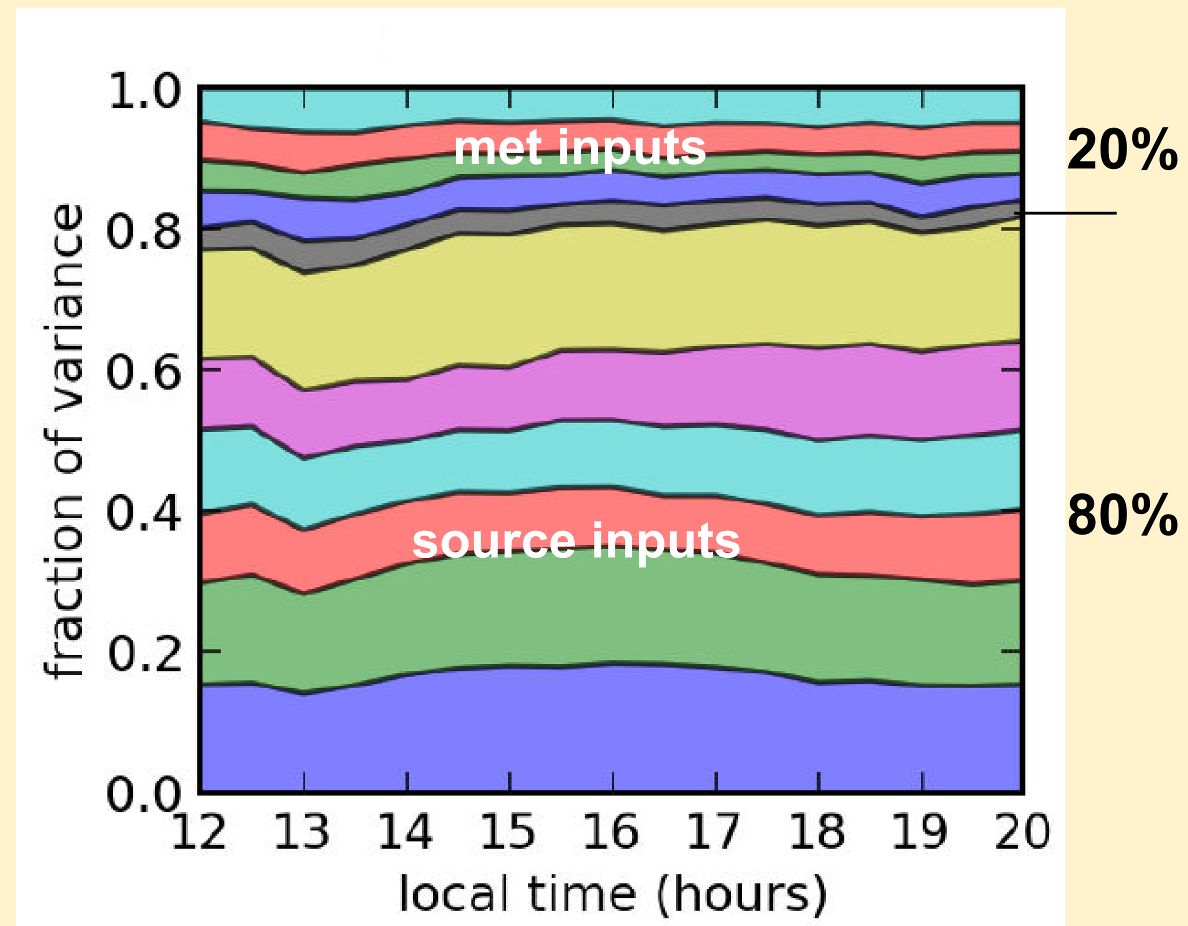
40,000 Monte Carlo simulations considered meteorological uncertainty and source term variations for a tracer released from the Diablo Canyon NPP reactor on the Central California coast.



30-minute average plumes of SF_6 with the actual release parameters. The plumes on the left and right use NARR and ECMWF reanalysis fields, respectively. The color scale shows the logarithm of the SF_6 concentrations between 1 ng/m^3 and 10^5 ng/m^3.



Time series of the prior and posterior probability distribution functions of SF_6 about 10 km downwind of the release.



Time series of the fractions of variance in the prior SF_6 distribution about 10 km downwind of the release. Each colored band represents the fraction of the variance caused by an individual meteorological or source input. About 80% and 20% of the variance is due to source and meteorological inputs, respectively.

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