Observation and simulation of methane (CH_4) plumes during the morning boundary layer transition

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Abstract

Methane (CH_4) is one of the most potent greenhouse gases (GHGs) responsible for global climate warming. However, accurate identification of CH_4 sources and their quantification for preventing/reducing CH_4 emissions are hampered by insufficient accuracy and spatiotemporal coverage of CH_4 measurements, and CH_4 modelling often has low spatial resolution and suffers from the lack of input data. In this study, a mini-field experiment was conducted in Pampa, Texas using two CH_4 sensors, a LI-COR 7810 and an optical gas imaging (OGI) camera, to detect controlled CH_4 releases. We investigate whether high-resolution simulations using the Weather Research and Forecasting (WRF) model with greenhouse gases (WRF-GHG) can accurately simulate the CH_4 plumes from the releases in the presence of evolving atmospheric processes from sunrise to noon. CH_4 plumes showed a substantial change through the morning. At a release rate of ~17.5 kg hr^{-1}, the maximum enhancement of CH_4 measured by LI-COR was 2.6 ppm at sunrise time, 250 m downwind of the release location at about 1 meter above ground. This enhancement decreased to <0.1 ppm after 11:30 AM. Due to the low temperatures at sunrise, the OGI camera at 15m above the release location failed to detect the CH_4 plume. Despite changing atmospheric conditions, the WRF-GHG simulation at a 32 m grid spacing, essentially in a large eddy simulation (LES) mode, successfully captured the observed CH_4 enhancements given the specified CH_4 release. Measurements together with numerical simulations illustrate the significant impact of meteorology, including the environmental conditions and boundary layer processes, on the variations in the CH_4 plumes and concentrations, and highlight the importance of taking into account meteorological conditions and their diurnal variations when estimating emissions based on CH_4 concentration measurements. Advanced inverse modeling techniques based on optimal estimation theories that couple weather and dispersion modeling are preferred.

Controlled CH_4 Release Field Experiment in TX

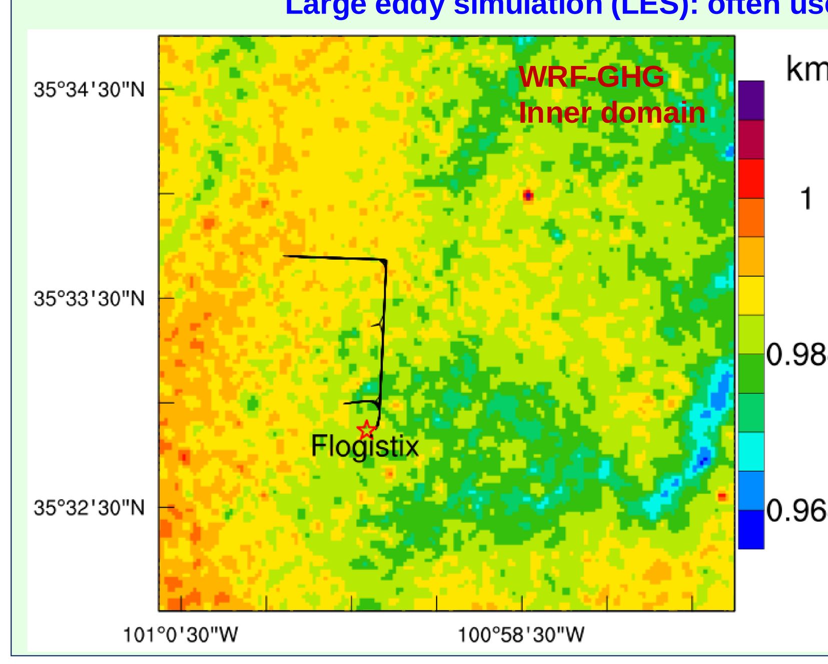
Guided by WRF-GHG real-time forecasting

Fig. 1. Satellite imagery of the experiment region with the driving path marked, including the short red route and long blue route, the west-east portion of which is 240 m and 1.45 km to the north of the Flogistix site, respectively .

Measuring CH_4 in the presence of DANGER

Ultra high-resolution WRF-CH_4 Simulation: WRF-GHG LES

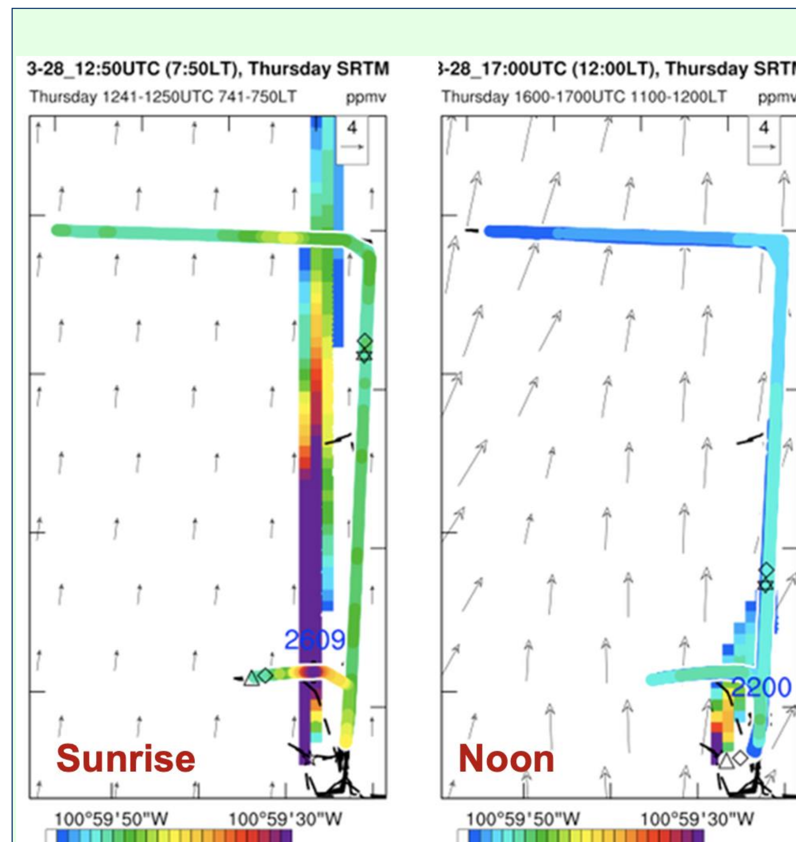
Large eddy simulation (LES): often used for high-resolution turbulence simulations



Real case WRF-GHG LES at a 32 m grid spacing - 1st attempt in the world

High-resolution terrain based on SRTM 1 Arc Second (~30m)

Fig. 2. Land elevations over the fourth domain, taken from the Shuttle Radar Topography Mission (SRTM) data at a resolution of 1 arc-second (30 meters).



CH_4 Plumes at sunrise VS. noon

- **Observation and simulation agreement is good.**
- **Once the turbulence became mature after 10:30AM, rarely observed CH_4 enhancement >100ppb beyond 200m**

Fig. 3 Observed and simulated CH_4 Plumes with emission of 18 kg/hr

Evaluation of Meteorology

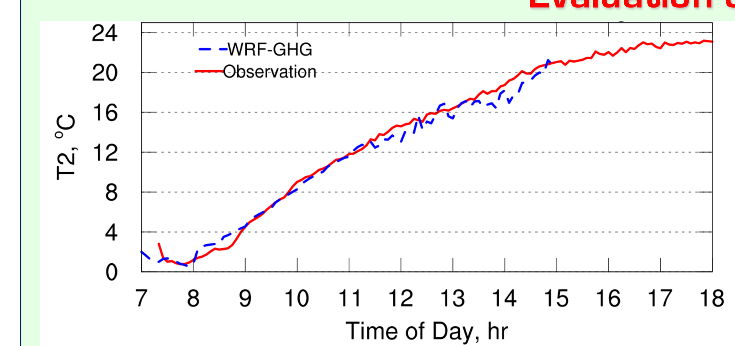


Fig. 4. Observed and simulated surface temperature at 2 m above the ground (T2) at the Flogistix site on March 28, 2024.

- **WRF-GHG LES nicely reproduces the surface temperature variation.**
- **WRF-GHG captures boundary layer structure**

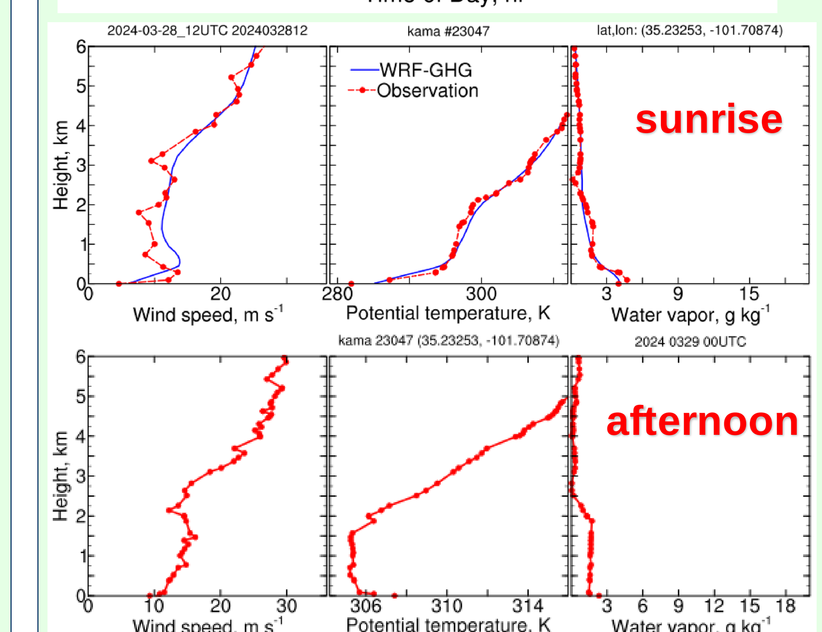
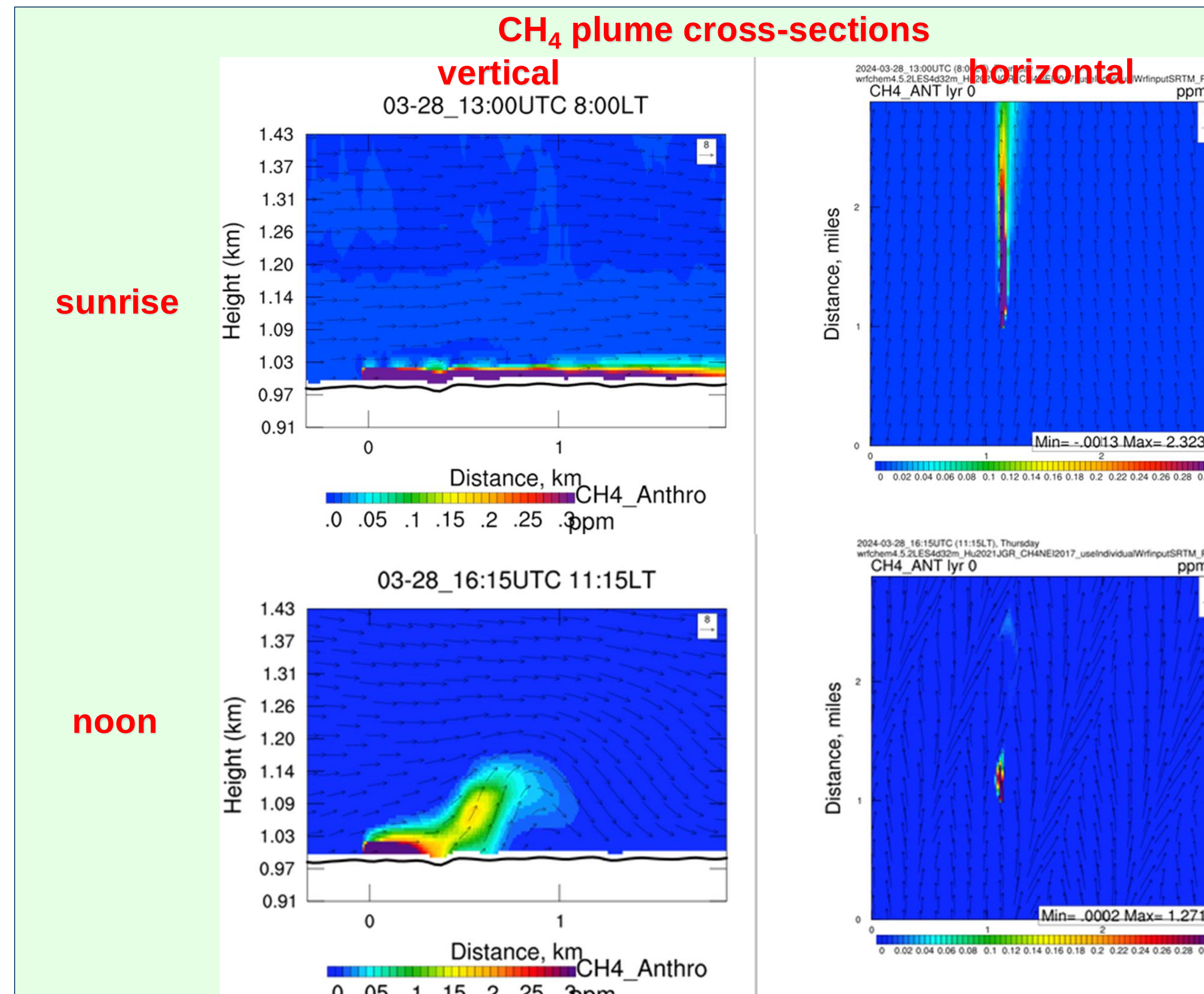


Fig. 5. Observed and simulated profile of (left to right) wind speed, potential temperature, and water vapor mixing ratio at Amarillo, TX (75 km to the southwest of the Flogistix site) at (top) 7 and (bottom) 19 local time.

CH_4 plume cross-sections



- **Strong stability at sunrise, CH_4 plume barely dispersed vertically**
- **Once the turbulence (large eddies) became mature after 10:30 AM, rarely observed CH_4 enhancement >100ppb beyond 300m, because of ubiquitous eddies**

Key points/Highlights

1. **Large eddy simulation is conducted to assist emission estimation of CH_4 from mobile measurements**
2. **For a 17.5 kg hr^{-1} emission rate, temporal variations of CH_4 enhancement are between 2.6 ppm to tens of ppb at 250 m downwind.**
3. **CH4 enhancement barely exceeds tens of ppb beyond 300 m during daytime because of ubiquitous large eddies.**

Hu, X.-M. et al. (2024), **Observation and simulation of methane (CH4) plumes during the morning boundary layer transition,** to be submitted.

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