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Smoke Plume Trajectory from In Situ Burning of Crude Oil in Alaska --- Field Experiments and Modeling of Complex Terrain

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Smoke Plume Trajectory from *In Situ* Burning of Crude Oil in Alaska
Field Experiments and Modeling of Complex Terrain

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Abstract

A combination of numerical modeling and large scale experimentation has yielded a tremendous amount of information about the structure, trajectory and composition of smoke plumes from large crude oil fires. The model, ALOFT (A Large Outdoor Fire plume Trajectory), is based on the fundamental conservation equations that govern the introduction of hot gases and particulate matter from a large fire into the atmosphere. Two forms of the Navier-Stokes equations are solved numerically — one to describe the plume rise in the first kilometer, the other to describe the plume transport over tens of kilometers of complex terrain. Each form of the governing equations resolves the flow field at different length scales. Particulate matter, or any non-reacting combustion product, is represented by Lagrangian particles that are advected by the fire-induced flow field. Background atmospheric motion is described in terms of the angular fluctuation of the prevailing wind, and represented by random perturbations to the mean particle paths. Results of the model are compared with three sets of field experiments. Estimates are made of distances from the fire where ground level concentrations of the combustion products fall below regulatory threshold levels.

Executive Summary

A combination of numerical modeling and large scale experimentation has yielded a tremendous amount of information about the structure, trajectory and composition of smoke plumes from large crude oil fires. The model, ALOFT (A Large Outdoor Fire plume Trajectory), is based on the fundamental conservation equations that govern the introduction of hot gases and particulate matter into the atmosphere. Some major results of the ALOFT modeling effort and the experimental burns can be summarized as follows:

1. The results of the original plume modeling study, Reference [1], remain valid for flat terrain applications. "Flat" in this context refers to terrain that does not vary in height by more than about 10% of the expected plume height. Thus, for a single burn consuming up to about 1,000 barrels per hour in wind speeds less than 12 m/s (23 knots), the maximum ground level extent of the region where the concentration of PM-10 particulate would be in excess of 150 μg/m^3 (hour-averaged) is roughly 5 km (3.0 miles) over flat terrain.

2. The ALOFT model has been extended to accommodate scenarios involving both flat and complex terrain, and the conclusions of Reference [1] have been expanded. The maximum extent of the region where the hour-averaged, ground level PM-10 particulate concentration would be in excess of 150 μg/m^3 downwind of a burn consuming 1,000 barrels per hour can be as low as 1 km for a scenario with flat terrain and nearly adiabatic lapse rates, and as high as 20 km for a scenario where the terrain height extends above the mixing layer. More refined predictions for intermediate cases are included in the report. Also included are simple formulae for modifying the maximum ground level distances to accommodate changes in air quality thresholds and combustion product emission factors.

3. The uncertainty of ALOFT model predictions is largely a function of the uncertainty in the meteorological conditions and fire emission rates. The factor of safety of 2 that had been applied to the downwind distance predictions as an estimate of uncertainty for the original flat terrain modeling results has been replaced by more appropriate ways of assessing uncertainty, and these will be presented in the report.

4. The ventilation factor, which is the product of the wind speed and mixing layer depth used to characterize the dispersive potential of the atmosphere, is a reasonably good indicator of expected ground level concentration of smoke or combustion products from a large burn. This is true of both flat and complex terrain.

5. Smoke particulate is by far the most likely combustion product of crude oil burning to exceed ambient air quality standards at ground level beyond a few hundred meters from the fire.

6. Peak concentrations of ground level smoke particulate for the 1993 Newfoundland Offshore Burn Experiment, the 1994 Alaska Clean Seas Burning of Emulsions experiment, and the 1994 diesel fuel burns in Mobile, Alabama, never exceeded 100 μg/m^3 beyond a few hundred hundred meters from the fires, and in most cases were well below that level.

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