Contract No:

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Disclaimer:

Using Atmosphere-Forest Measurements to Examine the Potential for Reduced Downwind Dose

A 2-D dispersion model was developed to address how airborne plumes interact with the forest at Savannah River Site. Parameters describing turbulence and mixing of the atmosphere within and just above the forest were estimated using measurements of water vapor or carbon dioxide concentration made at the Aiken AmeriFlux tower for a range of stability and seasonal conditions. Stability periods when the greatest amount of mixing of an airborne plume into the forest were found for 1) very unstable environments, when atmospheric turbulence is usually at a maximum, and 2) very stable environments, when the plume concentration at the forest top is at a maximum and small amounts of turbulent mixing can move a substantial portion of the plume into the forest. Plume interactions with the forest during stable periods are of particular importance because these conditions are usually considered the worst-case scenario for downwind effects from a plume. The pattern of plume mixing into the forest was similar during the year except during summer when the amount of plume mixed into the forest was nearly negligible for all but stable periods. If the model results indicating increased deposition into the forest during stable conditions can be confirmed, it would allow for a reduction in the limitations that restrict facility operations while maintaining conservative estimates for downwind effects. Continuing work is planned to confirm these results as well as estimate specific deposition velocity values for use in toolbox models used in regulatory roles.

Awards and Recognition

N/A

Intellectual Property Review

This report has been reviewed by SRNL Legal Counsel for intellectual property considerations and is approved to be publically published in its current form.

SRNL Legal Signature

Signature _______________________ **Date** _______________

Using Atmosphere-Forest Measurements to Examine the Potential for Reduced Downwind Dose

Project Team: B. J. Viner (Primary), and S. Goodlove

Subcontractor: N/A

Thrust Area: ST3

Project Type: Quick Hit

Project Start Date: April 27, 2015
Project End Date: September 30, 2015

A 2-D dispersion model was developed to simulate interactions between an airborne plume with the forest at Savannah River Site. Model parameters for atmospheric mixing were estimated using measurements of water vapor or carbon dioxide concentration for a range of stability and seasonal conditions. Stability periods which exhibited the greatest amount of plume mixing into the forest were very unstable and very stable environments. Plume interactions with the forest during stable periods are of particular importance because these conditions are usually considered the worst-case scenario for downwind effects from a plume. If the model results indicating increased deposition into the forest during stable conditions can be confirmed, it would allow for a reduction in the limitations that restrict facility operations while maintaining conservative estimates for downwind effects.

FY2015 Objectives

- Design a model which would predict atmospheric dispersion through a forest.
- Analyze measurements from a flux tower located at SRS to determine appropriate wind profiles within the forest canopy.
- Apply numerical modeling to assess the potential for plume loss due to mixing of the plume into the forest airspace.

Introduction

The Savannah River National Laboratory (SRNL) Atmospheric Technologies Group (ATG) conducted plume dispersion modeling for water vapor and carbon dioxide in order to understand how the forest environment at SRS impacts airborne plumes of hazardous material. Due to the nature of the work performed at SRS, there is a potential for airborne releases of hazardous material which could have potentially harmful impacts to exposed individuals. As such, regulatory dispersion modeling is routinely performed at SRS to assess the risk for negative impacts in the event of an airborne release. However, a limitation of many atmospheric dispersion models is that the wind information used by the model does not represent how surface heterogeneities such as a forested environment influence the plume. For instance, some models use a single wind speed and direction to determine plume dispersion.

One mechanism available in dispersion models to account for forest influences on the airborne plume is deposition velocity. Prior to 2011, regulatory models at SRS which were run for the purpose of determining potential downwind hazards used a deposition velocity of 0.5 cm s^{-1} to account for plume loss to the underlying forest and surface vegetation through deposition and uptake by plants. However, a report from the Defense Nuclear Facility Safety Board (DNFSB 2011) identified deposition velocity as an area for review at SRS, suggesting that the value of 0.5 cm s^{-1} was not sufficiently conservative. Consequently, the procedure for safety basis modeling for tritium oxide (HTO) at the Savannah River Site (SRS) was revised to recommend a deposition velocity of 0 cm s^{-1} (ie., no deposition occurs) to ensure conservatism (Murphy et al. 2012). This determination was based on modeling using assumptions including: 1) Any and all HTO absorbed by a forest canopy would be re-emitted to the atmosphere, resulting in negligible deposition; and 2) that wind speed and direction are the same within the canopy as above it. These assumptions do not reflect real-world conditions and, with improved science and understanding, a more realistic value could be determined while maintaining the conservative nature of the modeling.

Wind characteristics within a forest canopy are distinctly different from those of unobstructed flow. In particular, wind speed is generally reduced within the forest airspace (Figure 1). Impeding the lower portion of a plume spreads the contaminant material over greater distances and timescales, leading to reductions in modeled downwind concentration and dose. The Aiken AmeriFlux Tower, operated by the SRNL Atmospheric Technologies Group and located within the forested environment at SRS, provides a wealth of data to examine the fate of airborne contaminants entering the forest airspace. Water vapor in particular is of interest because it provides a proxy for examining tritium oxide in the environment due to similarities in molecular structure and behavior in the environment such as uptake and transpiration in vegetation (Brudenell 1997; Ota and Nagai 2011). Modeling the behavior of airflow within and above the forest can lead to improved estimates of deposition velocity to be used in regulatory models. The goal of this work is to provide the modeling framework necessary to create deposition velocity estimates.

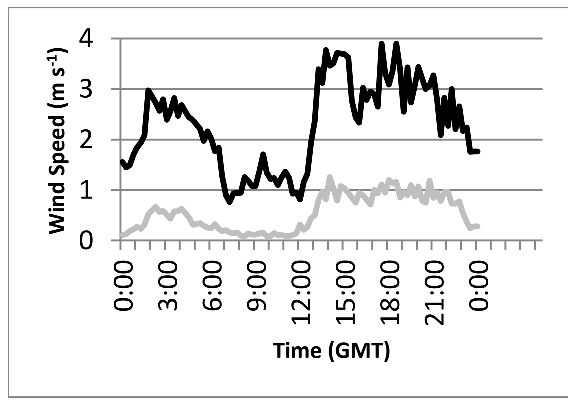

Figure 1: Comparison of wind speed in an open field (black line) and a pine forest (gray line).

Approach

The project was designed to predict the concentrations of tritium oxide at the boundaries of the site (10 kilometers) after a hypothetical plume release. To determine the appropriate mixing of airborne material into and out of the forest, mixing parameters were calculated from data measured at the Aiken AmeriFlux tower which recorded 3-dimensional winds, water vapor concentration, and carbon dioxide concentration at four levels within the forest (2m, 12m, 18m, and 25m) as well as one level above the forest (28m). This data was also used to determine how horizontal wind speeds within the forest were reduced compared to the free atmosphere winds above the forest which are usually the primary input to regulatory dispersion models.

The combination of a Gaussian Plume Model and a 2-D Advection-Diffusion model was used to determine the percent plume loss at a time and distance. For the unimpeded atmosphere above the forest, Gaussian models have routinely been used in regulatory modeling to describe the diffusion of an airborne plume along statistical guidelines dependent on the wind and atmospheric stability conditions. However, this approach is not appropriate for determining transport within a forested environment whose flow is subject to increased turbulence compared to the atmosphere above it due to the trees and other vegetative structures creating drag on the wind flow.

In this work, the free atmosphere was modeled as a steady state release lasting 30 minutes. Initially, the plume was modeled assuming the 'ground surface' was the top of the forest which acted as an impenetrable surface which would reflect the plume. After establishing the steady-state concentration of the Gaussian plume at the top of the forest, mixing coefficients calculated from the Aiken AmeriFlux tower were used to estimate the quantity of the plume that would mix from the free atmosphere into the forest. The loss of this material to the forest environment was modeled as a Gaussian plume with negative source value equal to the amount of the plume mixed into the forest.

Within the forest canopy, a 2-D advection-diffusion model was used to model dispersion using an Eulerian framework (Figure 2). The forest was modeled as four vertical levels with calculated mixing parameters from the AmeriFlux tower data. At each model timestep, the change in concentration at each grid cell was modeled by predicting the transfer of material by diffusion between vertical levels and by advection of the mean wind speed horizontally. In the event that the concentration at the top of the forest was greater than the concentration in the free atmosphere above the forest, positive Gaussian sources were used to model the additional material being released to the free atmosphere.

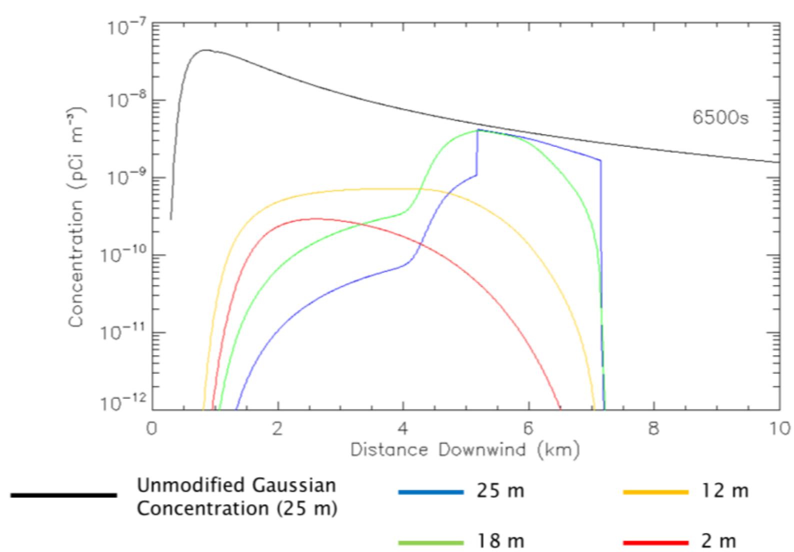

Figure 2: An example of model output showing the unmodified Gaussian plume at the top of the forest as well as the predicted concentration at the forest top and at model levels within the forest using the 2-D Advection-Diffusion Model

Results/Discussion

The impact of the forest on an airborne plume was described by estimating the fraction of an airborne plume mixed from the free atmosphere into the forest when the plume first reached 10 km (approximately the site boundary). This was done for a range of seasonal and atmospheric stability conditions (Figure 3). Conditions where a greater fraction of the plume mixed into the forest were found to be under very stable conditions (E/F Stability) or under very unstable conditions (A/B Stability). Less mixing was found to occur under near-neutral conditions (C/D Stability).

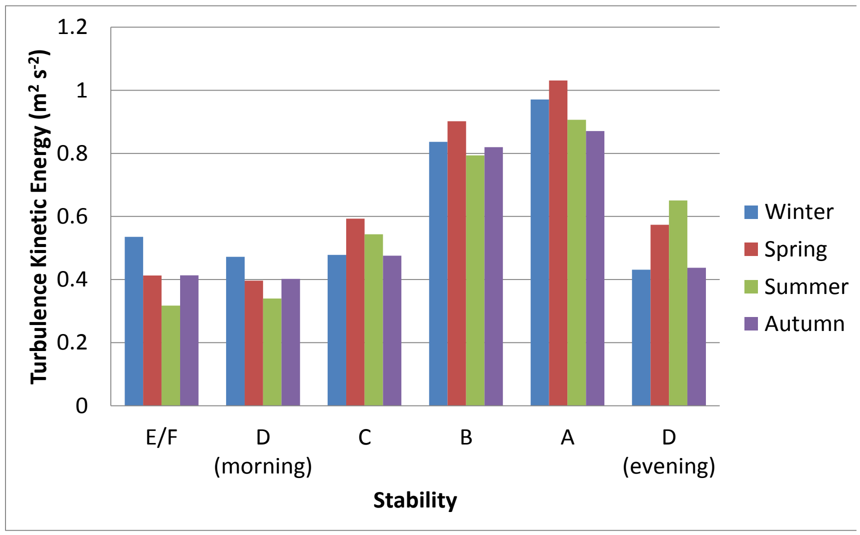

Figure 3: Fraction of the free-atmosphere plume which has been mixed into the forest environment when the plume reaches 10 km. The stability categories are arranged such that they generally move from night (left) to morning, afternoon and evening (right).

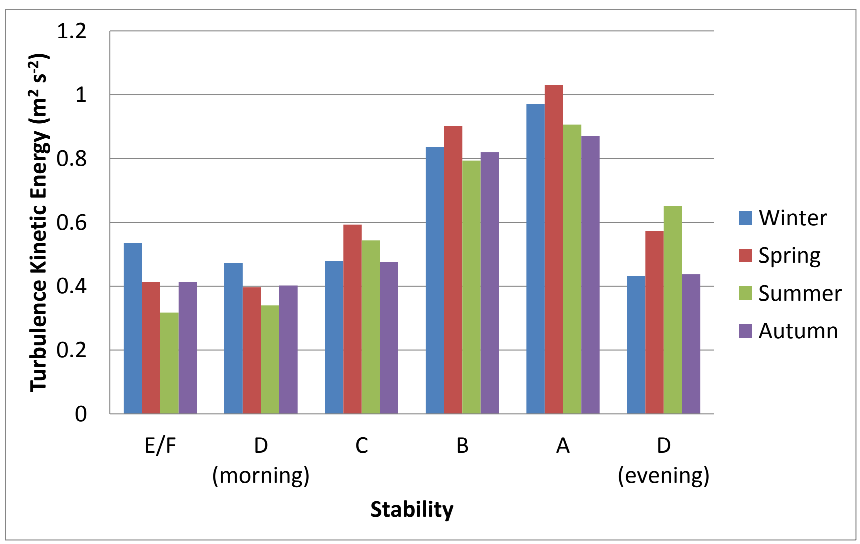

Figure 4: Rates of turbulent mixing sorted by atmospheric stability category. The stability categories are arranged such that they generally move from night (left) to morning, afternoon and evening (right).

The increased mixing during the day is attributed to increased turbulence kinetic energy present during the day (Figure 4) and that the plume diffuses horizontally to a much greater extent, allowing the plume to mix with the forest over a much wider area. Even so, stable conditions consistently provided the greatest amount of plume loss to the forest canopy.

Under stable atmospheric conditions, the turbulent mixing in the atmosphere is reduced, but the increased mixing into the forest can be attributed to a narrower plume which forms under Gaussian conditions. Under these conditions, a greater concentration is present at the interface between the top of the forest and the atmosphere. In addition, the roughness of the forest top interacts with the airflow to mechanically create turbulence, mixing the high concentration plume into the forest airspace.

FY2015 Accomplishments

- Developed and tested an advection-depletion model to predict how an airborne plume interacts with a forested environment.
- Predicted the fraction of an airborne plume that may become trapped in forest airspace under a range of seasonal and stability conditions.

Future Directions

- Additional work is expected to be performed under an accepted grant proposal to the NNSA NSR&D program in FY16 pending funding availability.
- Additional assessment of the model framework will be performed to ensure that the model is as accurate as possible.
- Data generated from this project using the plume depletion model will be used to determine an estimated deposition velocity for tritium oxide based.
- The estimated deposition velocity will be used in toolbox models such as MACCS2 to determine what the potential impact is to regulatory dose models.

FY 2015 Publications/Presentations

- Presentation to the Atmospheric Technologies Group Staff Meeting (presented by Sydney Goodlove, ATG Summer Intern)
- Planned presentation at the 11th International Conference on Tritium Science and Technology (April 2016)
- Planned presentation at the 32nd Conference on Agricultural and Forest Meteorology (June 2016).
- Planned report/manuscript documenting the developed model and predicted results as well as applying those results to predicted downwind dose for hypothetical affected individuals.

References

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Acronyms

ATG	Atmospheric Technologies Group
DNFSB	Defense Nuclear Facility Safety Board
HTO	Tritium Oxide
SRNL	Savannah River National Laboratory

Intellectual Property

N/A

Total Number of Post-Doctoral Researchers

N/A