ABSTRACT
Isoprene Flux Measurements Above a Northern Hardwood Forest
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Isoprene is an important trace gas species that is naturally emitted by various vegetation and it affects the oxidative capacity of the atmosphere. Isoprene emissions are regulated by many environmental variables; the most important variables are thought to be temperature and light. The proposed work seeks to improve our understanding of isoprene emissions from forest ecosystems as a basis for advancing our ability to describe the role of isoprene in regional and global atmospheric chemical cycles.

This research will continue the isoprene flux measurements made during the three previous years at the Program for Research on Oxidants: Photochemistry, Emissions, and Transport (PROPHET) /Ameriflux site, located at the University of Michigan Biological Station (UMBS). Measurements involve employing a fast isoprene analyzer along with fast CO_2, water vapor, and temperature sensors to obtain continuous flux measurements above the canopy throughout the growing season.

One specific objective of this research is to explore a potential relationship between the surface energy budget (primarily sensible heat flux) and isoprene emissions. Our hypothesis is that the surface energy flux is a better model parameter for isoprene emissions at the canopy scale than temperature and light levels, and the link to the surface energy budget will provide a significant improvement in isoprene emission models. Since surface energy budgets are an integral part of meteorological models, this will significantly improve our ability to describe the role of isoprene in regional and global atmospheric chemical cycles.

Isoprene Flux Measurements Above a Northern Hardwood Forest

Research Prospectus for
Biosphere Atmosphere Research and Training (BART)

submitted by:
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Introduction

The importance of isoprene at urban, regional, and global scales of atmospheric chemistry is well established (Fehsenfeld et al., 1992; Guenther et al., 1995; Cowling et al., 1998; Guenther et al., 1999a; Fuentes et al., 1999a). In rural areas, isoprene is almost always the dominate reactive hydrocarbon. In order to understand the chemistry of rural atmospheres, it is essential that the emissions of isoprene be well characterized. However, the details of how much isoprene, from what ecosystems, and under what conditions, remain troublesome aspects of accurately portraying isoprene in chemical cycles. In many cases, our ability to model isoprene and other biogenic hydrocarbons is limited to an accuracy of approximately a factor of two.

We know that isoprene is emitted at high rates from oak, aspen, poplar and at lower rates from other deciduous vegetation and from spruce (Guenther et al., 1994; Geron et al., 1994; Guenther et al., 1996; Kempf et al., 1996). We know that isoprene is emitted in the presence of sunlight and exhibits an exponential increase with temperature to a maximum level near 40 ^{o}C (Guenther et al., 1993). At the same time, we know that isoprene is not directly tied to photosynthesis; isoprene emissions can increase while photosynthesis ceases—at least in the short term (Monson and Fall, 1989). We know that the basal isoprene emission rate can be different from sunlit leaves in the top of a canopy compared to shady leaves deep in a canopy (Harley et al., 1996, 1997). We know that the onset of isoprene emissions is delayed for several weeks after bud break in the spring and that isoprene emissions decrease in the fall at the approach of leaf senescence (Monson et al., 1994; Goldstein et al., 1998; Fuentes et al., 1999b). However, our understanding of the biological or physiological controls on the emission of isoprene is limited, in particular when incorporating isoprene emissions into atmospheric chemical cycles.

Proposed Research

Our overall goal is to improve our understanding of isoprene emissions from forest ecosystems as a basis for advancing our ability to describe the role of isoprene in regional and global atmospheric chemical cycles. We propose to continue our isoprene flux measurements at the PROPHET/Ameriflux site during the next two growing seasons. This work will build on the flux measurements of isoprene collected during the past three summers as part of the Program for Research on Oxidants: Photochemistry, Emissions, and Transport (PROPHET), located at the University of Michigan Biological Station (UMBS). These measurements will encompass the planned PROPHET summer intensives during each year. We will employ a fast isoprene analyzer along with fast CO_2, water vapor, and temperature sensors to obtain continuous flux measurements throughout the growing season.

One specific objective of this research is to explore a potential relationship between the surface energy budget (primarily sensible heat flux) and isoprene emissions. Our hypothesis is that the surface energy flux is a better model parameter for isoprene emissions at the canopy scale than temperature and light levels, and the link to the surface energy budget will provide a significant improvement in isoprene emission models. Since surface energy budgets are an integral part of meteorological models, this will significantly improve our ability to describe the role of isoprene in regional and global atmospheric chemical cycles.

In addition to collecting canopy scale isoprene fluxes, we will be collaborating with Hans Peter Schmid and Jennifer Hutton from Indiana University who will be measuring subcanopy isoprene emissions and vertical concentration profiles of isoprene. The link between the subcanopy measurements and the canopy scale measurements will help us to understand the biological controls on the emission of isoprene and the fate of isoprene in the atmosphere.

Research Details

Flux measurements collected at the UMBS during the past three summers indicate several important features related to isoprene emissions. First, there is considerable variability in the emission pattern from day to day; a significant portion of the variability cannot be explained using temperature and/or light effects as given in current emission models. Second, there is still considerable discussion about the nature of decay in isoprene concentration from afternoon into evening. The patterns can be quite different from one evening to the next, and it is not clear whether this is due to dilution, deposition, or chemistry. Collectively, the PROPHET team is trying to confirm that this rapid decay is consistent with the rapid transition from unstable to stable conditions and with the measured chemical reactive mix during this period of the day. Third, we have discovered a very strong correlation between the surface energy flux (sensible heat flux) and isoprene flux on a daily basis. Correlations with other parameters, such as latent heat flux were not as strong. The strong correlation suggests that sensible heat flux may be an excellent parameter to use in modeling isoprene fluxes. If this tie between isoprene and sensible heat flux can be determined, using the surface energy flux as a model parameter for isoprene emissions will be a significant advancement. Surface energy flux is an inherent surface layer parameter predicted in all mesoscale meteorological models and global circulation models. Thus, it is readily available for modeling isoprene on regional and global scales. Finally, our database of isoprene emissions covers parts of two summers and all of a third. We thus have the beginning of a good basis for examining how isoprene emissions change from month to month and year to year. This combined with the proposed two growing seasons provides a very long term dataset for evaluation of emission inventory methods and investigating changes in emissions through various growing seasons and years. This is especially true since our measurements can be incorporated into the continuous forest ecosystem database being collected at the site as part of the DOE Ameriflux program. This will provide a strong link to understanding the biological aspects of the isoprene emissions, such as reduced photosynthesis, drought stress, or nutrient deficiencies. Curtis and Vogel (located on-site) will be instrumental in providing this link to understanding the forest ecosystem dynamics.

Specific objectives include the following:

1) Obtain two additional years of isoprene emission flux data as part of the PROPHET summer campaigns (our measurements will cover the entire growing season);
2) Determine the relationship between isoprene flux and surface energy flux, both above the canopy and within the canopy through collaboration with Indiana University;
3) Develop and evaluate methods for implementing isoprene/energy flux relationships as part of regional atmospheric meteorological and chemical models;
4) Employ the isoprene multi-year data set (1997-01) to investigate seasonal changes in isoprene emissions and linkages to forest ecosystem dynamics;
5) Continue to contribute to PROPHET activities in terms of collaborative examination of the role of isoprene in atmospheric chemistry at the UMBS site; and

6) Continue our collaboration with the Ameriflux program as a basis for understanding the role of biogenic hydrocarbons in terrestrial carbon exchange.

The end products of this research will be an improved ability to model isoprene emissions and fate in the atmosphere. Because of the importance of isoprene in regional and global atmospheric chemistry, this leads directly to a better understanding of tropospheric ozone formation on regional and global scales. This work will make a substantial and essential contribution to the PROPHET database. In particular, the data will provide a basis for determining the relationship between isoprene flux and surface energy flux, and for investigating seasonal and long-term changes in emissions. Finally, our collaboration with the Ameriflux operations will also contribute to a more complete understanding of the carbon cycle in this northern deciduous forest.

Work Plan

Our approach will be to deploy a fast isoprene analyzer (FIS, Hills Scientific, Inc., Hills and Zimmerman, 1990; Guenther and Hills, 1998), an open path infrared CO_2/H_2O gas analyzer (IRGA, Auble and Meyers, 1992), and a 3-d sonic anemometer (Applied Technologies, Inc.) as an eddy covariance system on the 31 m level of the Ameriflux tower. We have worked on this platform in 1998 and 1999 and have good working relations with Curtis and colleagues who have responsibilities for the Ameriflux operations at this site. Detailed biomass surveys around these towers indicate that the distribution of isoprene emitters (oak and aspen) is quite similar. Aspen accounts for approximately 90% of the isoprene emitting biomass at the site in the prevailing westerly upwind direction. As part of the DOE carbon exchange program, there are very detailed data on the distribution of trees and biomass within the immediate vicinity of the Ameriflux tower. In addition, detailed vertical surveys of leaf area index (LAI) have been conducted at the Ameriflux site.

The FIS/IRGA/EC system will be operated continuously throughout the growing season during 2000 and 2001 (May through October). Data will be collected to allow determination of fluxes on a continuous 30-min average basis. We have found that the simplest, most reliable way for operating this system is to collect raw data with a PC data acquisition system and to post-process the data on a second PC to calculate fluxes and related parameters.

The flux data set will include 30 min averages of isoprene flux, sensible heat flux, latent heat flux, and CO_2 flux, plus we will access data from the Ameriflux tower which includes net radiation above the canopy, and vertical PAR and temperature profiles within and above the tower. Our data will be incorporated into the PROPHET database after the appropriate processing and quality assurance tasks are completed.

Mentoring

My primary mentors will be Brian Lamb and Hal Westberg. I have recently completed a Master's degree under the supervision of both of them and we have developed a very strong working relationship. I anticipate working very closely with Hans Peter Schmid throughout the entire program, and for biospheric mentoring I will be working with Peter Curtis and John Bassman. I am also familiar with working at an Ameriflux site (the Wind River Canopy Crane Research Facility) and I expect a tremendous amount of interaction/mentoring from the various other PROPHET investigators. I attended the special PROPHET session during the December AGU conference and was very impressed with the collaboration that seems to occur from those involved.

Relevant Experience

During my Master's degree research at Washington State University, I have been involved in several field campaigns similar to the work proposed here. The majority of my Master's research was conducted at an Ameriflux site (Wind River Canopy Crane Research Facility) under DOE's Western Global Environmental Change (WESTGEC) program. My research involved developing a branch enclosure system and analytical technique for measuring monoterpene emissions from various heights within the canopy. I have also worked at a managed poplar plantation collecting leaf-level isoprene emission measurements. I have attended and presented the results from this research at many conferences and workshops, including the A&WMA 37th Pacific North West International Section Conference: Environmental Management (1997), the AMS 23rd Conference on Agricultural and Forest Meteorology (1998), the Fall meeting of the American Geophysical Union (1999), and the annual WESTGEC workshops. I received a first place award for a poster presented in the Physical Sciences and Engineering division of the Dr. William R. Wiley Research Exposition located on campus at Washington State University. I am currently working on submitting two papers for publication as a result of my research, both of which are part of my thesis (Pressley, S. 1999). Collaborative work with investigators from U.C. Davis is currently underway to compare two canopy models (both incorporating monoterpene emissions) with measured CO_2 fluxes from the Wind River canopy.

Interaction with Other Programs

Because this work is proposed as part of the PROPHET program, we will be involved in the very strong collaborative efforts, which are hallmarks of PROPHET (AGU Special Session, 1999). Beyond this cooperative research, we will also continue our collaboration with Curtis, Vogel, Teeri and others involved in the Ameriflux Terrestrial Carbon Exchange program. An essential aspect of this collaboration will be to determine the relative contribution of isoprene to the net ecosystem exchange of carbon at the site on an accumulated basis. This work will extend to include comparison of our results at PROPHET with studies we are conducting at a managed poplar plantation and with measurements we are making in an old growth Douglas fir forest as part of the DOE WESTGEC Climate Change program at the Wind River Canopy Crane Research facility (Pressley et al., 1998,1999). In our WESTGEC project, we have found that isoprene accounts for approximately 1.6% of the accumulated carbon during a growing season at the rapidly growing poplar plantation. In sharp contrast, monoterpene emissions at the Douglas fir forest account for as much as 20% of the accumulated net ecosystem exchange of carbon during a growing season. Beyond these existing projects, we are continuing to collaborate informally with Guenther at NCAR and with Geron and Pierce at EPA on efforts to improve BEIS emission modeling.

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