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The role of temporal evolution in modeling atmospheric emissions from tropical fires

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HIGHLIGHTS

- Daily and monthly resolution GFED fire emissions were modeled with GISS-E2-PUCCINI.
- Simulations with daily resolution emissions were better timed with meteorology.
- Effects on simulations of air quality exceedances and atmospheric heating patterns.

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ABSTRACT

Fire emissions associated with tropical land use change and maintenance influence atmospheric composition, air quality, and climate. In this study, we explore the effects of representing fire emissions at daily versus monthly resolution in a global composition-climate model. We find that simulations of aerosols are impacted more by the temporal resolution of fire emissions than trace gases such as carbon monoxide or ozone. Daily-resolved datasets concentrate emissions from fire events over shorter time periods and allow them to more realistically interact with model meteorology, reducing how often emissions are concurrently released with precipitation events and in turn increasing peak aerosol concentrations. The magnitude of this effect varies across tropical ecosystem types, ranging from smaller changes in modeling the low intensity, frequent burning typical of savanna ecosystems to larger differences when modeling the short-term, intense fires that characterize deforestation events. The utility of modeling fire emissions at a daily resolution also depends on the application, such as modeling exceedances of particulate matter concentrations over air quality guidelines or simulating regional atmospheric heating patterns.

1. Introduction

Fires are widely used throughout the tropics to create and maintain areas for agricultural systems, but are also significant contributors to atmospheric trace gas and aerosol concentrations (Andreae and Merlet, 2001). Emissions associated with deforestation averaged 1 Pg carbon per year over the past decade (Baccini et al., 2012), while also adding to atmospheric ozone (O_3) precursors such as carbon monoxide (CO), nitrogen oxides (NO_x) and VOCs, sulfur-containing compounds, and particulates (Langmann et al., 2009). In addition to the diversity in the type of emissions, the timing and magnitude of fire activity also varies interannually and by biome. This suggests that representing fire emissions at different temporal resolutions in atmospheric models could alter interactions between emissions and atmospheric chemistry and transport, which also vary significantly on several timescales.

The tropics comprise a critical region for global fire activity, but have varying fire behavior characteristics (van der Werf et al., 2010). Frequent but lower intensity fires are typical in savanna areas in Africa and South America (van der Werf et al., 2010). Fire emissions from Southern Hemisphere Africa are dominated by savanna burning, but the Amazon includes a mix of savanna and deforestation fires, which leads to higher rates of fuel consumption and fewer fire days per year (when emissions are aggregated at a 0.5°

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spatial resolution). Equatorial Asia has even fewer average fire days per year and higher daily rates of fuel consumption (Mu et al., 2011). On longer timescales, carbon-rich Equatorial Asian peatland forest fires have higher interannual variability than other biomes (van der Werf et al., 2010), with large pulses of emissions during El Niño droughts (van der Werf et al., 2008). These regional differences in emissions characteristics suggest that fire emissions inventories with monthly resolution may be able to adequately resolve dominant modes of variability of fire behavior in certain biomes, but could be insufficient in other areas. An important challenge for the atmospheric sciences community is to understand how this variability in fire behavior influences chemistry, radiative forcing, and air quality.

Monthly global gridded fire emissions inventories typically combine information from satellite observations of burned area, active fire detections, underlying vegetation characteristics, and meteorology. One example is the Global Fire Emissions Database version 3 (GFED3), which is available at a monthly resolution from 1997 to 2011 (van der Werf et al., 2010). From November 2000 onwards, it detects changes in 500-m Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance and 1-km MODIS active fires to inform an automated hybrid burned area mapping algorithm (Giglio et al., 2009). Before 2000, active fire detections from Tropical Rainfall Measuring Mission (TRMM) Visible and Infrared Scanner (VIRS) and the Along-Track Scanning Radiometer (ATSR) are used to estimate burned area by means of a regression with MODIS burned area during overlap periods, which necessitates the dataset's monthly resolution (Giglio et al., 2010). Duncan et al. (2003) used active fire data from ATSR and the Advanced Very High Resolution Radiometer (AVHRR) to estimate seasonal fire variability, with the Total Ozone Mapping Spectrometer (TOMS) Aerosol Index serving as a proxy for interannual variability in selected regions, which then scaled an existing biomass burning inventory. While these datasets capture important information on seasonal and interannual variability in fire activity, they may have important limitations when implemented into modeling systems which otherwise operate at sub-daily increments.

Recognizing these potential limitations, several fire emissions inventories at daily or sub-daily resolution are also available, using satellite active fire detections to represent emissions at a finer temporal resolution. Mu et al. (2011) recently applied active fire counts from MODIS and the Geostationary Operational Environmental Satellite (GOES) Wildfire Automated Biomass Burning Algorithm (WF_ABBA) to create daily and 3-hourly emissions inventories, respectively, from the original GFED3 monthly dataset. Heald et al. (2003) applied AVHRR active fire observations to the Duncan et al. (2003) inventory to create a daily emissions dataset for early 2001. The Fire Inventory from NCAR (FINN) is a daily 1-km global dataset of trace gas and particulate emissions from fires, available from 2005 to 10 (Wiedinmyer et al., 2011). FINN primarily uses MODIS active fire detections, an assumed burned area per detection (to allow the product to be released close to real-time), and MODIS land cover types to estimate fuel loadings. Fire Locating and Modeling of Burning Emissions (FLAMBE) combines GOES WF_ABBA, near real-time MODIS active fire products, and 1-km AVHRR land cover maps to create hourly emissions inventories, from 2005 onwards (Reid et al., 2009). Kaiser et al. (2012) developed the $0.5 \times 0.5°$ Global Fire Assimilation System (GFASv1.0), available from 2003, by calculating biomass burning emissions based on MODIS fire radiative power and land cover-specific combustion factors derived from the GFED3 emissions inventory.

Many daily or sub-daily emissions products rely on MODIS active fire detections and are therefore only available since late 2002, when both Terra and Aqua were in operation together. Therefore, for modeling studies before the MODIS era, monthly inventories may still be the only option. Some chemical transport models are moving towards using daily or hourly fire emissions (Mu et al., 2011), although most global composition-climate models currently implement monthly resolution emissions (Lee et al., 2013). It remains unclear which aspects of atmospheric modeling are most sensitive to this choice of temporal resolution, because in previous studies, using finer temporal resolution emissions over coarser resolution datasets have offered variable improvements when compared with observations. Model simulations focusing on CO have found improvements with daily over monthly fire emissions but not sub-daily resolution emissions (Mu et al., 2011), monthly over climatological, but not daily (Heald et al., 2003), and 8-day instead of monthly, but not diurnal (Chen et al., 2009). Simulations of shorter-lived species like NO_2 improve from sub-daily emissions that capture the afternoon peak of biomass burning emissions (Boersma et al., 2008). In boreal North America, Chen et al. (2009) found that aerosols were more sensitive to using 8-day versus monthly resolution emissions than was found with CO (also without further improvements with diurnal resolution). In areas such as Singapore, where biomass burning aerosol transport from Indonesia is highly variable over the fire season, both with respect to shifts in geographic patterns of burning and atmospheric transport patterns, detailed temporal resolution of fire emissions inventories may improve modeled regional aerosol concentrations (Atwood et al., 2013). Modeling the interactions between smoke aerosols by changing absorption patterns of radiation can also vary strongly on sub-daily timescales (Wang and Christopher, 2006; Wu et al., 2011).

In this study, we examine the sensitivity of multiple endpoints to using daily and monthly resolution fire emissions: modeling trace gases and aerosols, assessing air quality and public health effects, and estimating climate impacts. We hypothesize that changing from monthly to daily fire emissions will: 1) produce a varied response throughout the tropics, depending on biome-specific fire behavior (for example, continuous low intensity fires would lead to smaller atmospheric differences in savanna regions), 2) allow for higher peak concentrations since short-lived fire events can be concentrated over several days and not averaged over a month, and 3) more realistically synchronize emissions with meteorology, with fires predominately occurring on sunny, precipitation-free days, which would lower wet deposition of aerosols and could increase the speed of some chemical reactions. Section 2 describes the model framework and observational datasets; Section 3 presents our results for atmospheric composition, air quality, and radiative forcing; Section 4 describes our conclusions.

2. Materials and methods

2.1. Model set-up

Baseline monthly fire emissions estimates were from GFED3, which combines surface reflectance and active fire detections from several satellites to detect the spatiotemporal variability of burned area (Giglio et al., 2010). This drives a biogeochemical model that estimates fuel loads, combustion completeness, and emissions (van der Werf et al., 2010). GFED3 is available for 1997 onwards at $0.5° \times 0.5°$ horizontal resolution. This dataset comprised the fire input for our monthly fire emissions (MF) run.

To isolate the influence of the temporal resolution of fire emissions instead of variations among fire emissions inventories, we used a daily emissions dataset with the same bulk total emissions as the monthly GFED3 dataset. Mu et al. (2011) used MODIS active fire detections aboard the Terra and Aqua satellites to parse the monthly GFED3 emissions to a daily resolution. Due to gaps in