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Estimation of biomass consumption coefficients for FRP-based forest fires emission calculations

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Abstract

Near real-time emission estimations can be computed based on the fire radiated power (FRP) and the biomass consumption coefficients for each vegetation type. Therefore, the application of the methodology is limited by the knowledge of the biomass consumption (BC) coefficients, as the studies estimating the coefficients offer results on specific vegetation types. This study focuses on calculating biomass consumption coefficients for the most affected vegetation types in the Maule Region (Chile). We needed to estimate the biomass consumption rate to calculate the BC coefficients. Then, we computed the BC rate by estimating the biomass consumed in a specific burn time. We computed the time between VIIRS image acquisitions to assess the burning time. BC coefficients were obtained for four vegetation types: pine plantation, scrub, native oak-hualo forest, and arborescent scrub. In addition, we analyzed the variations of the BC coefficients by computing the BC coefficients on each time frame. Large variations were observed in the oak-hualo and pine plantation, which were related to the greater availability of biomass and variable fire behaviour.

1. Introduction

Forest fires are of great importance in the world because of the high emissions of aerosols and trace gases released into the atmosphere during their occurrence, directly affecting their chemical composition and the climate of the planet (Arora and Boer 2005). The increase in temperatures caused by climate change favours the proliferation of forest fires, being increasingly catastrophic (González et al. 2020). Chile has experienced an extension of the fire season in the last decade, going from 6 to 8 months. This change has produced significant impacts on CO_2 emissions into the atmosphere, biodiversity, and the country's economy (González et al. 2020).

Remote sensing has been widely used to estimate greenhouse gas, particulate matter, and trace gas emissions generated during a fire (Vadrevu and Lasko 2018; Wiedinmyer et al. 2006). These estimates have been obtained from two methods. The first, proposed by Seiler and Crutzen (1980), estimates the emissions by combining the burned area, the biomass available for burning, the consumption efficiency factors, and the emission factors by vegetation type (Oliva et al. 2019; Reid et al. 2009; Van Der Werf et al. 2017). The second method quantifies the biomass burned considering the integration over time of Fire Radiative Power (FRP) to obtain Fire Radiative Energy (FRE) (Vadrevu et al. 2019). The calculation of burned biomass is possible due to the linear relationship between the FRE and the rate of Biomass Consumption (BC) in a fire. The latter method considers within its variables the FRE and the specific biomass consumption coefficient for each type of vegetation (Wooster et al. 2005). The application of this method has shown promising results in southern Brazil (da Costa and da Fonseca 2017) in northern India (Vadrevu and Lasko 2018) and in global estimates (Vermote et al. 2009).

Visible Infrared Imaging Radiometer Suite (VIIRS) sensor provides data on active fires in near real-time thanks to its VNP14 product, which has a nominal spatial resolution of 375 m. Favouring the detection of a greater number of fires allows a more refined mapping of the largest fires (Schroeder 2018). Therefore, VIIRS has become the new tool to continue working more accurately on emissions estimates (Fu et al. 2020; Li, Zhang, and Kondragunta 2020).

This study proposes a methodology that allows obtaining the biomass consumption (BC) coefficients necessary to estimate biomass burning emissions from the FRP product of active fires of VIIRS. The BC coefficients obtained in this study for the vegetation types of Chile contribute to the use of the VIIRS FRP for the estimation of emissions in future events.

2. Methodology

2.1. Study area

The fire called "Tabunco-El Águila Convenio" located at 35°8,862' S and 71°58,315' W in the commune of Curepto, Maule Region, Chile. We chose this fire because it has crucial characteristics for the application of emissions estimation. Among these characteristics, the presence of endemic native species stands out, such as hazel (Gevuina avellana), peumo (Cryptocarya alba), boldo (Peumus boldus), and litre (Lithraea caustic) (CONAF 2017). The event began on January 25, 2017 and was finally controlled on February 8, 2017. It burnt 4,069.7 hectares, affecting native vegetation, grasslands, thickets, and plantations. This fire also presented a rich diversity of vegetation types and detailed coverage of active fire detections.

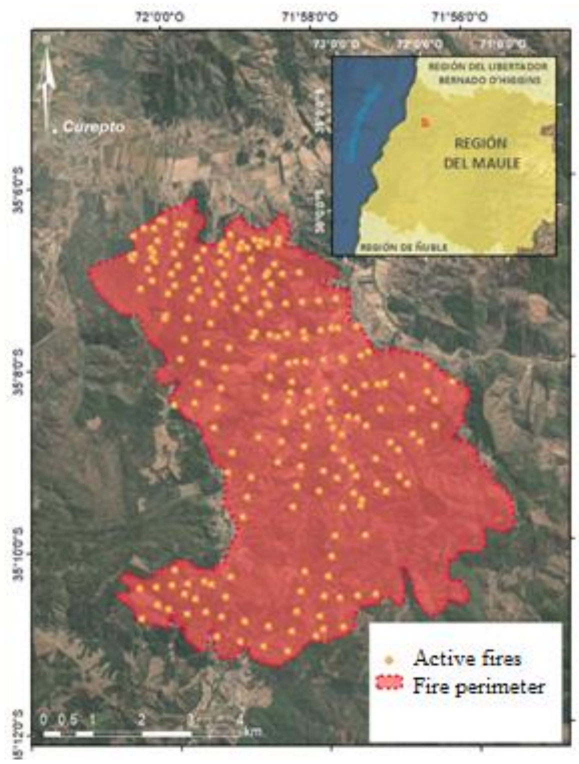

Figure 1- Location and extent of the Tabunco-el Aguila Convenio fire with the distribution of the active fires detected by VIIRS active fire product.

2.2. VIIRS active fire product

In this study we used the VNP14 thermal anomaly product of the NPP-VIIRS sensor. VIIRS active fire product provides detections at least twice a day, crossing the equator at 13:30 PM on the ascending node and at 01:30 AM on the descending node. The download of VIIRS data is done through the Fire Information for Resource Management System (FIRMS) service (https://firms.modaps.eosdis.nasa.gov/download/, last access date on February 27, 2022), from where you can access a global coverage of data from 2012 to date, in different formats.

The VIIRS active fire product provides information regarding fire coordinates, FRP measures (MW), brightness temperature in their respective bands, confidence level, date, time, and sensor characteristics. The time interval defined for this study was based on the days of higher fire activity, which runs from January 26, 2017, to January 29, 2017.

2.3. Estimation of the biomass consumption rate

We worked over a grid o 375x375m to relate the FRP measurements with the area covered by each vegetation type. The mean FRP values for each date and time of acquisition were assigned to one cell. Subsequently, we calculated the percentages of the area for each type of vegetation, the biomass value, and the burn efficiency factor associated with each cell. The amount of biomass consumption per type of vegetation was obtained for each of the time interval measurements applying equation 1.

$$M=A\times B\times \beta \qquad (1)$$

Where M is the total amount of biomass consumed (kg), A is the total area burned (m^2), B is the dry organic matter by vegetation type (kg m^2), and β is the fuel efficiency (dimensionless).

Next, we applied the equation 2 to estimate the biomass consumption rate.

$$BCR = M / BT \qquad (2)$$

Where BCR is the biomass consumption rate, and BT is the burning time in seconds. We considered as the burning time the time between two consecutive image acquisitions. The time interval considered ranged from January 26, 2017, to January 29, 2017. In that time, eleven VIIRS images were acquired, so we computed the BCR on eleven periods.

2.4. Estimation of the biomass consumption coefficient

Following the methodology of previous studies, we estimated the BC coefficient by vegetation type applying a linear regression equation between the BC rate and the FRP measured at each burning time period. The slope of the liner regression line is assigned as the BC coefficient value. Although a variety of vegetation types were present in the fire, only four vegetation types offered enough data to compute the linear regression line: open shrublands, forested shrublands, pine plantations and native forest oak-hualo.

We also computed the BC coefficients applying the following equation:

$$C_{ex} = BCR / FRP \qquad (3)$$

Where C_{ex} is the BC coefficient by vegetation type x, and FRP the Fire radiative power measured within the burning time of each period (eleven periods considered). We called this BC coefficients, dynamic coefficients as their value change depending on the characteristics of the vegetation and the fire behaviour.

3. Results

The results of the linear regressions by vegetation type indicate that BNRH and open scrub have an R^2 of 0.6 and 0.5, respectively. This indicates that the predicted BC coefficients achieved a better fit, with respect to what is observed in the cases of pine and arborescent scrub plantation with an R^2 of 0.3 and 0.2, respectively. We also analysed the behaviour of the dynamic BC coefficients (see Table 1). We observed that, in certain cases, for the same vegetation type, these BC coefficients have values higher than the observed average. This situation affects BNRH with two high values on the second day, forested shrubs and pine plantation. These higher values are related to higher values of biomass consumption rate.

Table 1. Result of dynamic and static biomass coefficients by vegetation type. BNRH refers to the native oak-hualo forest.

Type of Coefficient	DD-HH code:MM	GNRH	Open Scrub	Shrub Arbolado	Pine Plantation
	26-05:31	0.45	0.06	0.21	0.32
	26-17:53	0.04	0.03	0.17	0.11
	26-19:33	1.16	0.11	0.39	0.94
	27-05:13	0.41	0.01	0.40	0.74
	27-06:53	11.33	-	3.02	2.13
Dynamic Biomass Coefficient	27-17:34	0.0	0.00	0.05	0.07
	27-19:14	17.65	0.00	0.40	0.85
	28-04:54	-	-	0.22	3.07
	28-06:34	-	0.19	0.42	10.28
	28-18:56	-	-	0.05	0.09
	29-18:37	-	-		0.10
Static Biomass Coefficient	-	1.33	0.01	0.07	0.28

4. Conclusions

This study lays the foundation for the application of emissions calculation from FRP measurements of active fires, allowing near real-time estimates. The objective of this study was to obtain the BC coefficients by type of vegetation affected by the fire studied. This was obtained for four of the affected vegetation types. In addition, this study allowed an interesting analysis based on the dynamic BC coefficients. We could then evaluate the error that might be produced by applying the linear regression BC coefficients. The BC coefficients with the most variability was found in the BNRH and in the pine plantation. This result is related to the greater amount of biomass of these vegetation covers and the greater intensity that the fire can reach. Therefore, in those vegetation types, the BC coefficient estimated from the regression analysis does not reflect the natural variation derived from the fire behaviour and the characteristics of the vegetation.

The continuation and extension of this work on other fires and other types of vegetation present in the country are necessary to obtain the biomass coefficients by type of vegetation and use this methodology to estimate fire emissions in almost real-time throughout the country.

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