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Combining sentinel observations with plume backtrackings to improve wildfire detection

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Abstract

Satellite observations are helpful in detecting wildfires. Especially in areas far from populated regions, satellite observations support the identification of wildfires and issuing warnings in case of a developing event. Occurrences of omission and commission errors have decreased significantly over the years, currently used methods focus mainly on improving and refining the already existing algorithms. Combining state-of-the-art earth observation data, specifically data from Sentinel missions, with modelling approaches may contribute to reduce detection errors. Most of the current methods to detect wildfires by earth observations mainly use a single satellite-based data source to retrieve surface information. Sentinel-3 and Sentinel-5P can be used as complementing data sources, the former is able to detect thermal anomalies in the surface, and the latter is capable of detecting direct fire emissions such as CO and HCHO in the atmosphere. The combined use with the Lagrangian particle dispersion model FLEXPART will allow the backtracking of fire emissions plus the aerosol mid height from Sentinel-5P to better identify wildfires sources. For this purpose, so called 'source-receptor sensitivities' are calculated, that provide information on the times and areas potentially contributing to the observed plume. Finally, identified wildfires can be validated using Sentinel-2 images. The innovation of our approach is to combine sentinel observations with atmospheric smoke plume simulations, by applying a dispersion model in backward mode to backtrack the possible source region of the smoke plume.

1. Introduction

During the last decades, there has been an increase in wildfires around the globe (Liu et al., 2010, Jolly et al., 2015). Climate change, with higher temperatures, lower humidity and significant changes in precipitation patterns, is the main factor raising the fire risk. When detecting wildfires by means of satellite instruments, the occurrence of false alarms is unavoidable. Over the last years, major improvements have been achieved to mitigate false alarms. Regarding wildfire detection errors, there are two types: the commission error (a non-existing fire is identified) and omission error (an existing fire is not detected). The former is the known as false alarm. Currently used methods focus mainly on improving algorithms of existing detection methods.

The main goal of this work is to improve the detection of wildfires by using state-of-the-art earth observation data, specifically data from the Sentinel missions, together with modelling approaches in a combined new methodology. This research-based methodology aims at reducing the number of false alarms while exploiting the new Sentinel data.

2. Methodology

The innovation of this work is to combine sentinel observations with atmospheric smoke plume simulations, by applying a dispersion model (with the Lagrarian particle dispersion model FLEXPART) in backward mode to backtrack the possible source region of the smoke plume. If this region coincides with the ground observation of the satellite instrument, it is expected that the detection has been successful. The method consists of exploiting currently available data from Sentinel-5P (the first Sentinel instrument that observes atmospheric pollutants) combined with the fire confidence derived from the Fire Radiative Power (FRP) from Sentinel-3.

Figure 1 shows the designed work-flow of the methodology. Firstly, a smoke plume is identified with Sentinel-5P data, then the location of the actual fire can be confirmed or rejected by the fire confidence of Sentinel-3. Subsequently, with the dispersion model FLEXPART in backward mode the origin of the smoke plume can be confirmed. In case a high fire confidence is not given for the suspected fire location, the Sentinel 2 can provide evidence of a fire by showing the burned area.

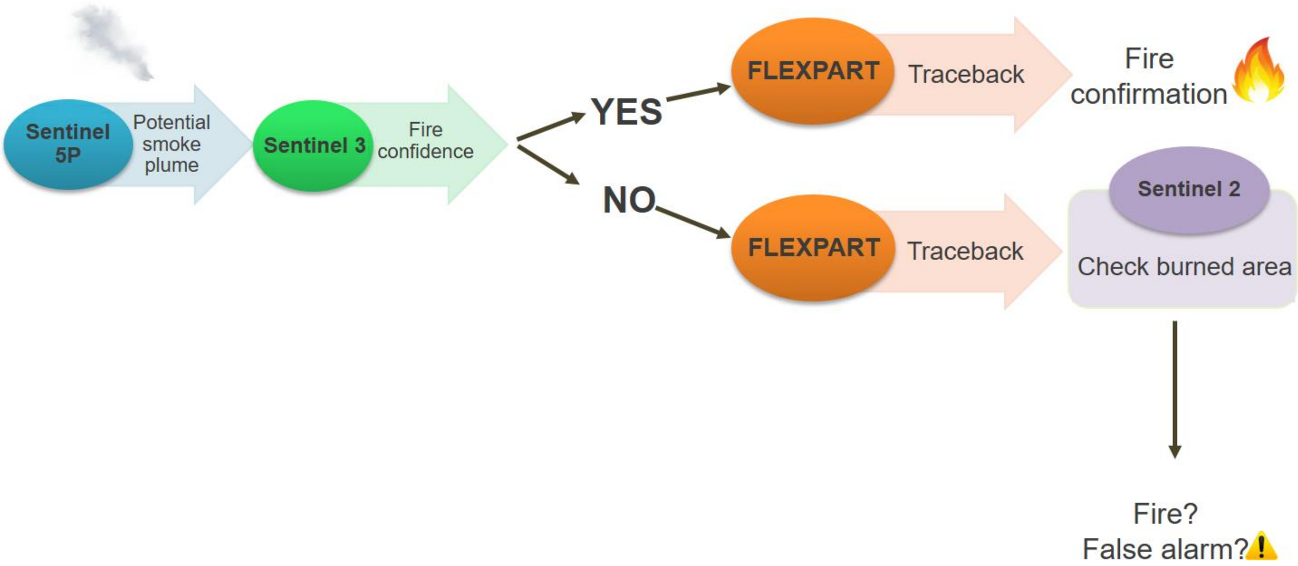


Figure 1. Work-flow including Sentinel-2,-3 and -5P products and dispersion model FLEXPART.

2.1. Sentinel satellites

For the development of this innovative method, the observations from three different Sentinel satellites will be used. Sentinel-5P and -3 provide observations for fire detection, while Sentinel-2 can be used for validation activities.

2.1.1. Sentinel 5P

Sentinel-5 Precursor (Sentinel-5P) is the first Copernicus satellite dedicated to monitor the troposphere, and provides daily global information on concentrations of trace gases (O_3, NO_2, SO_2, HCHO, CHOCHO, CO, CH_4) and aerosols. The mission consists of one satellite carrying the TROPOspheric Monitoring Instrument (TROPOMI) instrument. Its main objective is to perform atmospheric measurements with high spatial resolution (3.5 x 5.5 km), to be used for air quality, ozone and ultraviolet (UV) radiation, and climate monitoring. Because Sentinel-5P observes wildfires emissions (e.g. NO_2, CO, HCHO see figure 9), these observations could potentially be used for the early discovery of wildfires. Once a CO or HCHO plume is selected, in addition, the aerosol layer height product provides the altitude of localized layers of absorbing aerosols in the troposphere for cloud-free conditions.

2.1.2. Sentinel 3

Sentinel-3 has been developed to support ocean, land, atmospheric, emergency, security and cryospheric applications. Its main objective is to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour, with high accuracy and reliability, to support ocean forecasting systems, environmental monitoring and climate monitoring. It carries the SLSTR instrument, a dual-view scanning temperature radiometer, which flies in low Earth orbit (800 - 830 km altitude). There are currently two instruments in orbit, on board the Sentinel-3A and Sentinel-3B satellites. They provide observations across the VIS-to-LWIR spectral range that can be used for active fire detection and FRP retrieval. SLSTR possesses specially designed ‘fire’ channels in the MIR and LWIR, allowing global characterisation of landscape FRP. As stated above, in this work we use the fire confidence derived from FRP, which gives us the information of the probability of a fire pixel.

2.1.3. Sentinel 2

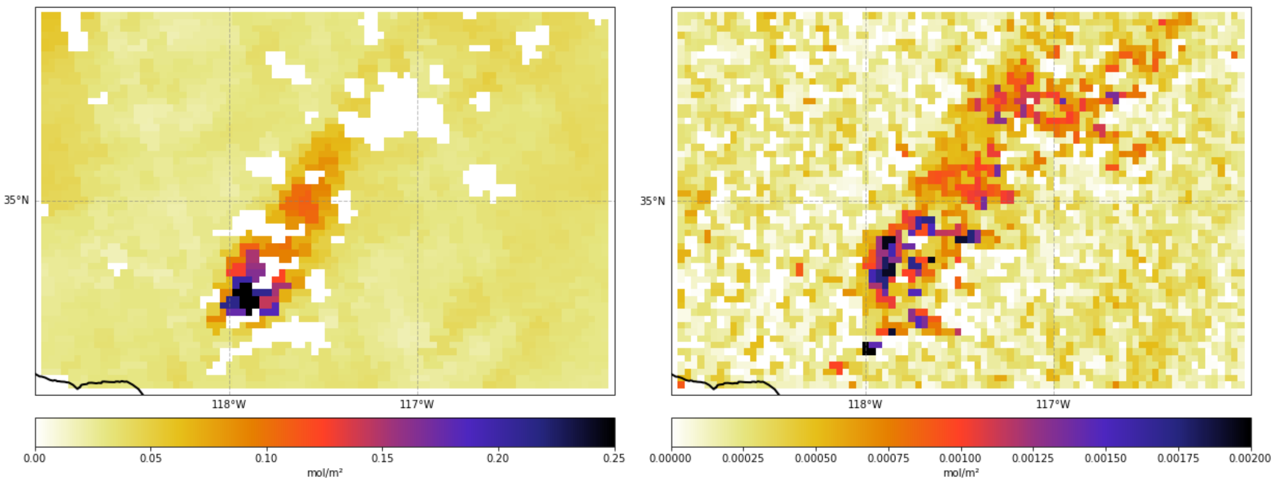
Sentinel-2 consists of two polar-orbiting satellites, and carries an innovative wide swath high-resolution multispectral imager with 13 spectral bands for a new perspective of land and vegetation. The sensor owns one spectral band (band 12, SWIR, 2.190 µm, 20m resolution) that can be used to identify thermal anomalies on the ground. Forest management is included in its main applications. However, using it for validation purposes is not obvious, since it has a long repetition cycle (5 days) and it is difficult to define the fire detection thresholds for SWIR and MIR channels. Therefore, in this work, when available, Sentinel 2 will be used mainly to confirm fires detected by Sentinel 3 and Sentinel 5P and evaluate the accuracy of the method.

2.2. FLEXPART set-up

FLEXPART 10 (Pisso et al., 2019) has been used to simulate the atmospheric transport of wildfire smoke (Pisso et al., 2009, Alvarado et al., 2019 among others), and other types of plumes such as volcanic ash and radionuclides. It can be run in backward mode to provide information on possible source locations. For this purpose, so called 'source-receptor sensitivities' (SRS) are calculated, these provide information on the times and areas potentially contributing to the observed plume. FLEXPART output will also be processed further using a linear regression method. This method is suitable for poorly observed areas, for example, for source apportionment of unusual radionuclides observations, and will here be tested for wildfire plumes. Three selected Sentinel-5P products (CO and HCHO columns and aerosol mid-height) will provide information on plume characteristics needed for the FLEXPART simulations. For this effort, running the backtracking simulations with a tracer is sufficient, while any effort to quantify the sources is out of the scope of this work. FLEXPART will run with meteorological input from the ECMWF fields of the operational stream with a resolution of 0.125°.

3. Results and discussion

Two different test cases will be used from the Californian summer 2020 fire season. To test the developed methodology, the first test case concerns a fire for which observations from all three sentinels will be available. As a second test case, a comission error will be selected: where the Sentinel-3 fire confidence is high, however the combination of Sentinel-5P observations, FLEXPART simulations and, if available, Sentinel 2 data could not provide an estimation of the location of the fire. Here we present the observations of the first test case, where we selected a plume in southern California sensed on the 18th of September 2020. Figure 2 shows the Sentinel-5P CO and HCHO plumes, and in the second row, the Sentinel-5P Aerosol mid-height product and Sentinel 3 Fire confidence are shown.



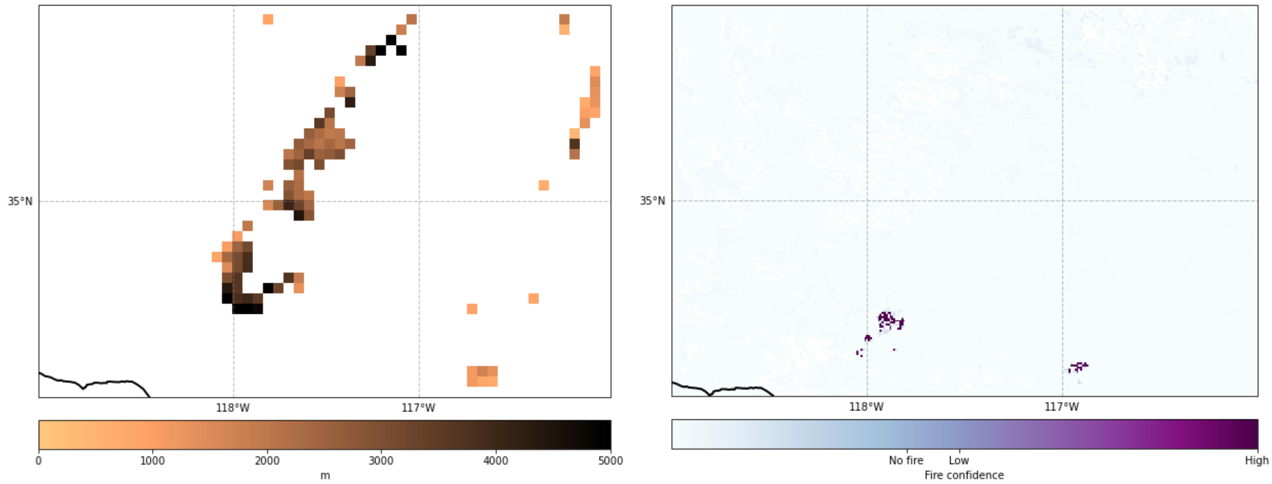


Figure 2. Plots of selected Sentinel satellite products of September 18, 2020. Top left: Sentinel 5P CO column in mol/m^2; Top right: Sentinel 5P HCHO column mol/m^2. Bottom left: Sentinel 5P Aerosol mid-height product in metres; bottom right: Sentinel 3 Fire confidence product derived from FRP.

Subsequently, from the Sentinel-5P products displayed in figure 2, the edges of the CO and HCHO plumes plus the maximum value(s) of the plume will be used as release points in the FLEXPART simulations. Information on the height of the plume will be obtained from the aerosol mid-height product. To evaluate the estimated location of the source of the plume, both the Sentinel-2 images and the Sentinel-3 fire confidence will be used. Finally, the detection is considered successful, if the estimation of the source location coincides with the location identified by the Sentinel-2 images and the Sentinel-3 fire confidence.

The Sentinel-5P CO observations provide relatively clear plume edges, see figure 2, top left, while the HCHO plot (top right) is more noisy yet not interrupted by clouds, hence complementing the CO observations. Circumventing the loss of information due to clouds, can partly abate the disadvantage of long revisiting times, at least of the Sentinel-5P satellite. When successfully tested, our approach paves the way for future applications with Sentinel-4 (launch expected in 2023), which will provide earth observations on a very high temporal resolution (hourly).

The innovation of this work is to combine satellite observations with atmospheric smoke plume observations, and by applying a dispersion model in backward mode to backtrack the possible source region of the smoke plume. To the authors´ knowledge, there are no other studies combining satellite observation and backtracking modelling technique.

4. References

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