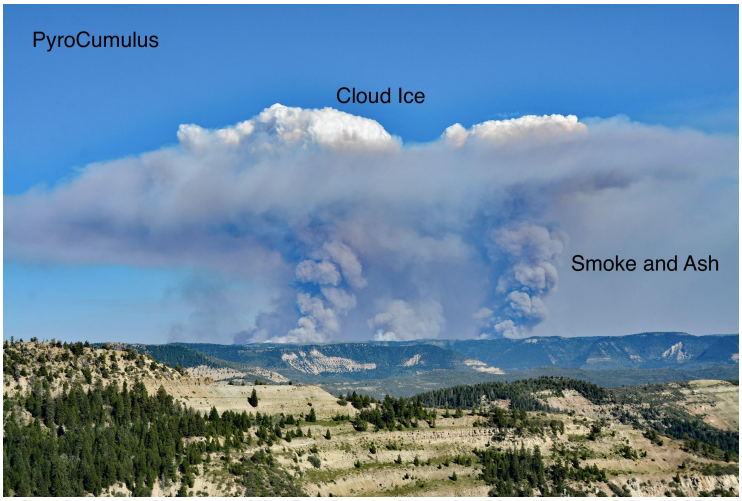
Using Fuzzy Logic and Polarimetric Radar to Better Understand Pyrocumulus Clouds

Project Overview

Around the world, climate change has of late been responsible for increasingly devastating droughts and wildfires, taking many lives, and in many cases also causing immense damage to towns. As wildfires continue to remain a destructive force of nature, the necessity to understand them in a more complete and scientific manner must become a priority, in order to both preserve future lives as well as to have a better knowledge of the inner mechanisms of the pyrocumulus (PyCu) clouds and smoke plumes that are generated from the fires. PyCu clouds typically are composed mainly of smoke and ash, but can sometimes contain a mixture of ice with the smoke and ash, as shown in the example to the left for the Pine Gulch, Colorado fire during the summer of 2020. The cloud ice above the smoke/ash plumes allows PyCu clouds like the one shown to sometimes generate naturally occurring lightning. When ice is not involved in the cloud mixture, lightning is still possible, but must have an external triggering mechanism such as an aircraft or rocket passing through the cloud, leading this type of discharge to be called "triggered lightning." Natural and triggered lightning threats are of great interest to fire weather forecasters and aviation and space launch range meteorologists, including at NASA and the US Space Force. The priority of this project is to generate the ability to determine, using radar, the composition of PyCu clouds (i.e. whether the cloud is composed of only smoke and ash, or if ice is involved in the mixture). To accomplish this, a type of classification logic known as fuzzy logic will be used to more accurately determine the composition of the PyCu clouds. Fuzzy logic will allow polarimetric radar data to be interpreted in such a way that the particles in the air will be evaluated more thoroughly than traditional radar currently allows. A similar process has already been undertaken for hydrometeors (rain, hail, etc.) in order to more accurately identify the precipitation suspended within clouds. The ultimate goal of this project is to adapt that technique to evaluate particles other than water-based, like smoke and ash, in order to classify and understand the internal composition of the PyCu clouds that they make up. The outcomes of this research could be used to improve fire weather forecasts, including the diagnosis and nowcasting of wildfire state and assessment of the natural and triggered lightning threats from developing PyCu.



Smoke/Ash plumes and PyCu clouds from the Pine Gulch, CO wildfire in 2020, from https://en.wikipedia.org/wiki/2020_Colorado_wildfires

Tools

An already existing algorithm from Dr. Brenda Dolan (Colorado State University, CSU) and Dr. Timothy Lang (NASA Marshall Space Flight Center, MSFC), created for classifying precipitation using fuzzy logic, will be adapted in such a way that will allow smoke and ash to be recognized using polarimetric radar, and thus, identifying PyCu clouds as well as their internal composition. Once the new algorithm is created, open source Python tools from CSU and NASA MSFC will be adapted and used to analyze data pulled from Level II Next Generation Weather Radar (NEXRAD) polarimetric radars. GR2Analyst will facilitate manual analysis of this radar data in a three-dimensional space, allowing an independent evaluation of PyCu composition and testing of the Python-based algorithm. Additionally, the open source Python ARM Radar Toolkit (PyART) will be used in conjunction with the CSU/NASA MSFC modified fuzzy logic-based particle identification (PID) Python program. PyART will allow radar data from the PyCu events to be gridded and visualized, including a breakdown of the particle types of which the PyCu is composed.

Implementation

The project will begin on Tuesday, June 1 and continue through Thursday, August 5, 2021, in accordance with the ten-week UAH Summer 2021 semester. The first two weeks will be used to get familiarized with software (Python tools including CSU Radar Tools, PyART, GR2Analyst) and scientific concepts necessary to complete the project (fuzzy logic, PyCu clouds, wildfire formation/product, etc.). After that, the majority of the project duration will be spent building, testing and refining the new radar algorithm and software modifications in the SWIRLL Operations Center computer lab. In the event that the COVID-19 pandemic renders in-person work impossible, coordination with the NSSTC IT department will allow remote access to the necessary software, and arrangement of at least weekly Zoom meetings will ensure the project continues on track. Throughout the duration of the project, progress will be shared with NASA MSFC and CSU so that other users interested in the characterization of PyCu will benefit from this research. Time permitting, the modified PyCu detection and PID Python program, now adapted to recognize smoke and ash in polarimetric radar observations will be used in application studies of specific wildfire events over the western United States during the summer of 2020, including over Colorado as pictured above, in order to facilitate a more thorough understanding of the phenomena in a way that has not been previously accomplished.