Pyroconvection and Climate Change

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Introduction: In March 1998, the Naval Research Laboratory (NRL) launched a satellite instrument named Polar Ozone and Aerosol Measurement (POAM) III. Just a few months after launch, POAM III started detecting mysterious clouds in the stratosphere in the sub-Arctic northern hemisphere. It was obvious that an unusual phenomenon was being recorded. We now know that these mysterious aerosol-cloud layers were smoke from forest fires that erupted like a volcano into what is now called pyrocumulonimbus (pyroCb for short). This initial discovery has been followed by more research and discovery by NRL's Remote Sensing and Marine Meteorology Divisions. In this article we summarize highlights of our pyroCb research and its importance.

Until the discovery of pyroCb, the common wisdom was that there was only one natural terrestrial force that could inject material into the lower stratosphere—a volcanic eruption. Volcanic eruptions are well known and their impact on climate can be significant. The tropopause is still considered by many to be an effective lid for any force except a strong volcano.

With the recent work at NRL we now have characterized the unique and formidable power of the pyroCb in action and even found a nuclear winter/volcano type link between stratospheric smoke layers and cooling near the Earth's surface.

The PyroCb, Up Close and Personal: On August 17, 2003, a large fire in Alberta near Conibear Lake, Canada, erupted into deep pyroconvection. On that day, the Conibear Lake pyroCb created a large, thick, deep plume in the lowermost stratosphere.

Imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) shows the Conibear Lake pyroCb in its maturity (Fig. 1). Three visible bands give a true-color scene. A near-infrared (NIR) channel shows the flaming fires in red outline. Thermal infrared (THIR) brightness temperature (good for cloud-top height) is displayed as the blue contour, enclosing the cloud surface colder than –45 °C.

Notice two dominant flaming spots in the scene. The Conibear Lake fire is upstream of the convective cloud complex, and another fire to the west is emitting a long smoke plume. The pyroCb consists of two cumulonimbus anvils. The easternmost is from an earlier pulse of intense pyroconvection. The western anvil has a sharp, perturbed texture distinct from the glaciated eastern anvil. The "older" eastern anvil has smoothed after detaching from the vigorous updrafts and by wind shear. The active western anvil shows turrets of strong tropopause-penetrating upheaval. Perhaps the most remarkable visible feature, on both anvils, is the smoky coloration in comparison to nearby pristine airmass convection. Obviously, this pyroCb has injected enough smoke to the cloud top to visibly pollute it.

The THIR component to this image shows that both anvils are dense and top out at the tropopause. The contour also signifies a temperature so low that the cloud top particles "inside" the contour are exclusively ice. Another feature of the THIR contour is a second appearance near the very center of the western anvil. Inside this contour, the cloud-top temperature actually increases. This "warm core" is a well known (albeit poorly understood) "enhanced V" signature of extreme

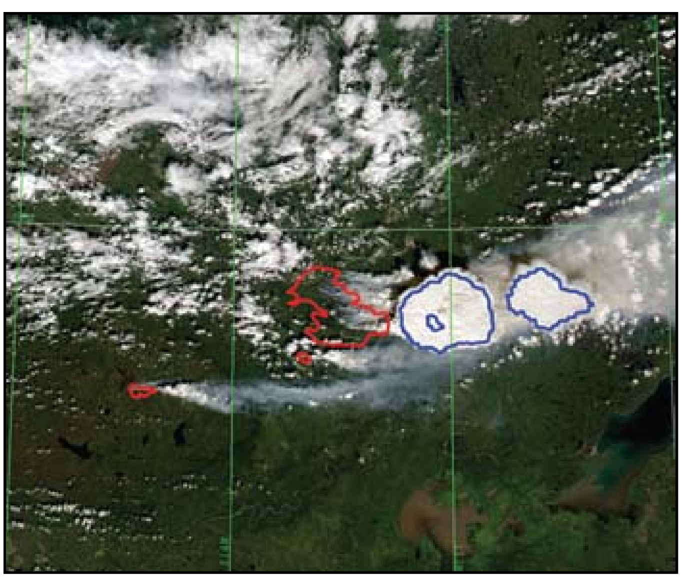

FIGURE 1
Conibear Lake pyroCb (August 17, 2003, in Canada) true-color image with fires (red) and –45 °C IR temperature contour (blue).

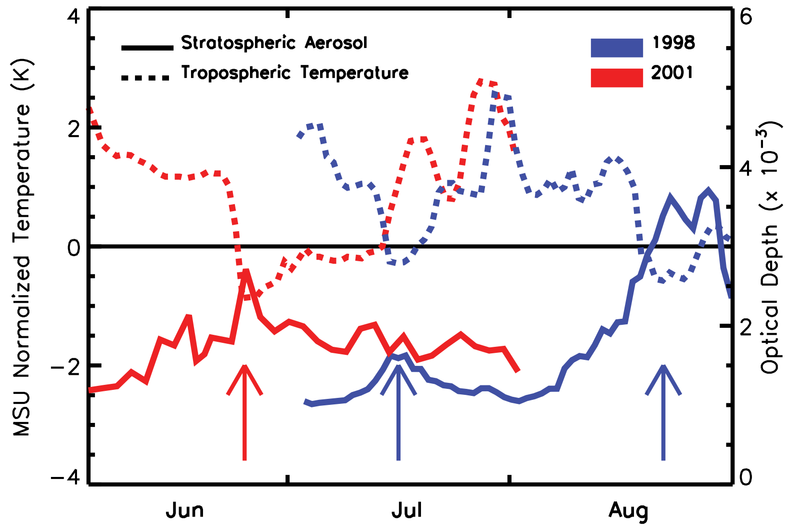

FIGURE 2
Time series of POAM III stratospheric aerosol optical depth and MSU tropospheric normalized temperature. Arrows indicate pyroCb-caused aerosol increases.

convection. Taken together, the THIR and true-color analyses reveal that this is a vigorous convective cloud with a unique smoke/ice mixture.

Climate Implications of PyroCb: A fundamental question about pyroCb is whether they have an important impact on weather or climate. We find strong circumstantial evidence that the stratospheric smoke from pyroCb cools the lower troposphere. Figure 2 shows how we determined this. We invoked an independent satellite-based temperature record from the Microwave Sounding Unit (MSU). We compare zonal average MSU temperature with POAM zonal average stratospheric aerosol optical depth (AOD). The simultaneous, strong departure of both AOD and temperature from the norm implies a hemispheric anomaly. Figure 2 shows three instances (indicated by arrows) where corresponding MSU tropospheric temperature reveals a sudden, obvious drop coincident with a spike in AOD. Each of these represents a plume we traced to pyroCb.[1,2] In each case, the drop in temperature apparently persists on the order of weeks. This impact of a hemispheric smoke pall on the lower atmosphere is consistent with first principles—the aerosols reflect additional solar energy back to space, reducing the energy absorbed at the Earth's surface. The multi-week persistence of this cooling underscores the important contribution pyroCbs make to hemispheric weather and climate patterns.

Climate change projections that show global warming place the largest temperature increases at high latitudes. The boreal zone will be thusly impacted. Forest fire experts project that forest fire size and frequency will increase due to this forcing. Obviously, this provides us with great motivation to explore the pyroCb phenomenon more fully.

[Sponsored by ONR]

References

[1] M. Fromm and R. Servranckx, "Transport of Forest Fire Smoke Above the Tropopause by Supercell Convection," *Geophys. Res. Lett.* **30**(10), 1542 (2003). doi: 10.1029/2002GL016820

[2] M. Fromm, R. Bevilacqua, R. Servranckx, J. Rosen, J. Thayer, J. Herman, D. Larko, and R. Servranckx, "Pyro-cumulonimbus Injection of Smoke to the Stratosphere: Observations and Impact of a Super Blowup in Northwestern Canada on 3-4 August 1998," *J. Geophys. Res.* **110**, D08205 (2005). doi: 10.1029/2004JD005350