Sensitivity of Optical-Flow-Retrieved Wind Speed and Cloud-Top Divergence of Convective Phenomena to Temporal Input Conditions

Theodore M. McHardy[1,2], David A. Peterson[2], Jason M. Apke[3], Steven D. Miller[3], James R. Campbell[2], Edward J. Hyer[2]

1. American Society for Engineering Education 2. U.S. Naval Research Laboratory Marine Meteorology Division 3. Cooperative Institute for Research in the Atmosphere

Background and Motivation

Cloud-top divergence (CTD) retrieved from Geostationary Operational Environmental Satellites (GOES) visible imagery has been shown to be intuitively related to convective dynamics and hazards within supercell thunderstorms (Apke et al., 2018; 2021).

Retrieved CTD maxima correspond with overshooting tops/convective cores as expected (Apke et al., 2018; 2021).

Computing divergence, especially on scales small enough to resolve overshooting tops, requires finite differencing, which in turn requires dense, fully-grided data. This cannot be done with traditional operational atmospheric motion vector algorithms which are tailored for assimilation.

Optical Flow, which comes from the computer vision community, retrieves pixel-level motions from imagery. This allows for finite differencing to be used, and for fine-scale features to be resolved.

Pyrocumulonimbus (pyroCb) - thunderstorms triggered by and anchored to wildfires, have far-reaching impacts that span a wide range of spatial and temporal scales:

- They inject wildfire smoke into the upper-troposphere/lower-stratosphere
- They impact stratospheric chemistry and dynamics
- They introduce convective hazards, such as lightning and tornadoes (Fire-generated tornadic vortices; FGTVs) to already dangerous wildfire events

Research Questions:

- **Can CTD analysis be applied to convective phenomena besides supercells?**
- **Does CTD relate to broader impacts (smoke plume injection, FGTVs) outside of typical severe weather hazards?**
- **When and where can 5- and 10-min data be used for optical flow retrieval of cloud-top motion?**

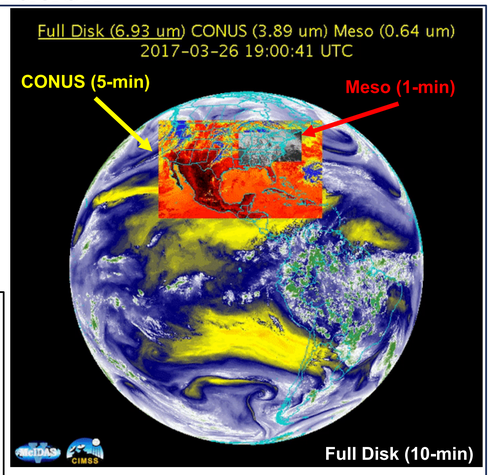


Figure adapted from NOAA NESDIS

Methodology

Cases

Case Name	Phenomenon	Date	Study period (UTC)	Approximate Location	Satellite Position	Scan Sector
Argentina	Supercell	12/10/2018	17:00 - 22:00	35°S 65°W	GOES EAST	Meso-1
Creek Fire	PyroCb	9/5/2020	19:30 - 00:30	37°N 119°W	GOES WEST	Meso-1
Cougar Peak Fire[1]	PyroCb	9/9/2021	21:00 - 02:30	42°N 120°W	GOES WEST	Meso-1
La Soufrière[1]	Volcanic Eruption	4/11/2021	10:00 - 22:00	13°N 61°W	GOES EAST	Meso-2
Florence	Tropical Cyclone	9/9/2018	14:00 - 21:00	24°N 57°W	GOES EAST	Meso-2

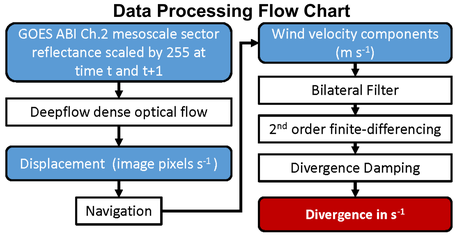
1. These cases contain multiple discrete pulses within the study period

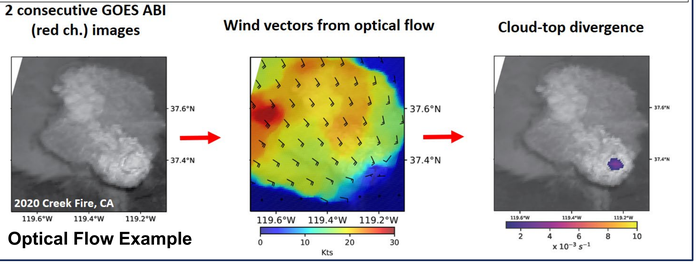
This study uses GOES ABI red channel visible imagery from the Mesoscale sector scans which has high nominal spatial (500m) and temporal (1 min) resolutions.

This study uses **Deepflow** (Weinzaepfel et al., 2013; Revaud et al., 2016), which is a dense optical flow estimation technique designed to better retrieve small features with large pixel displacement that blends a feature matching algorithm with a variational optical flow approach. Deepflow has been used in numerous earth science applications.

Smoothing of the winds before computing CTD is performed via bilateral filter. Computed CTD values are dampened based on the thermal infrared brightness temperature gradient, to remove large values due to differencing across altitudes.

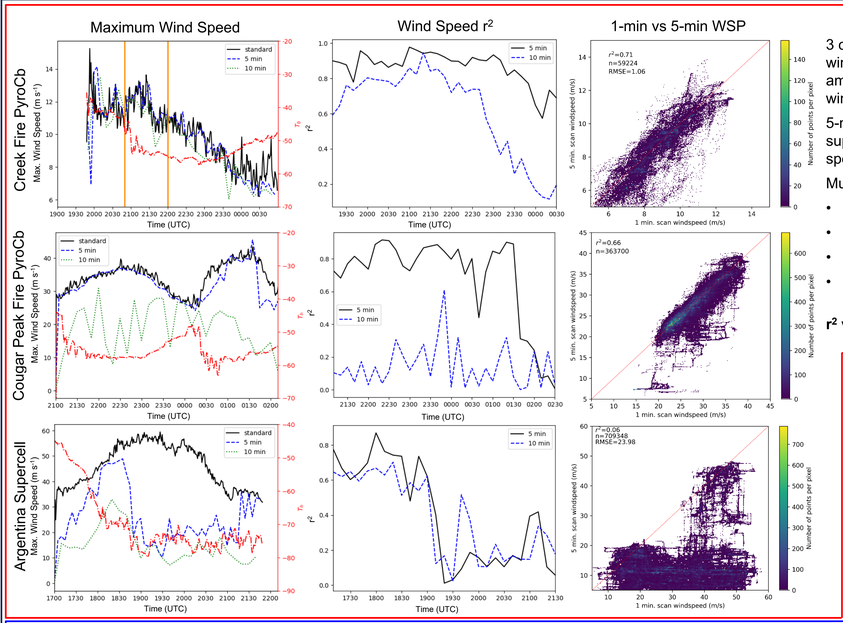
Data Processing Flow Chart





Optical Flow Example

When and Where are 5- and 10-min Data Usable?



When They Don't Work

3 cases are shown – Creek Fire pyroCb (top; low ambient wind speed), Cougar Peak Fire pyroCb (mid; moderate ambient wind speed), Argentina Supercell (bot; high ambient wind speed)

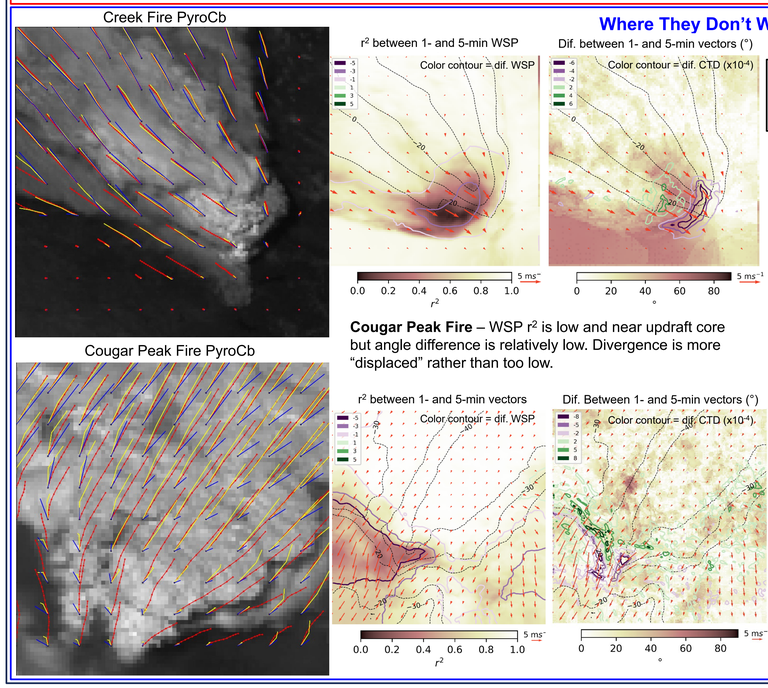
5-min data cannot be used to retrieve wind speed for the supercell, and 10-min data cannot be used to retrieve wind speed for the supercell or the Cougar Peak fire pyroCb event

Multiple factors at play:

- **Ambient wind speed**
- Optical flow parameters (e.g. pyramid sizes)
- Viewing and solar parameters (e.g. SZA, VZA, pixel size)
- Other phenomenon, such as above-anvil cirrus plume and gravity wave motion

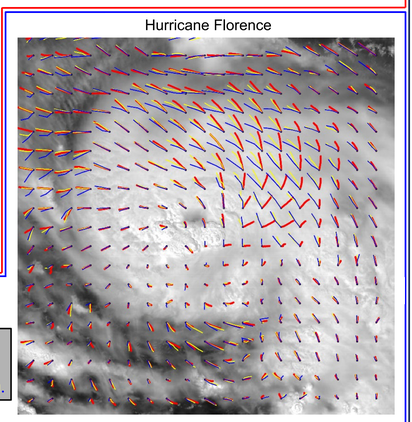
r^2 values plummet when the scene becomes dark

Where They Don't Work



Cougar Peak Fire – WSP r^2 is low and near updraft core but angle difference is relatively low. Divergence is more "displaced" rather than too low.

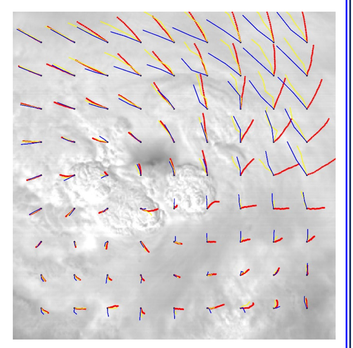
Creek Fire – WSP r^2 is low and angle difference is high near the updraft core. Wind speed and divergence mean error approaches ~50% in this region.



- 1 min.
- 5 min.
- 10 min.

Left
black contour = mean BT_{11}
Vectors = mean dif. 1-min and 5-min vectors

Hurricane Florence – 5-min and 10-min data do poorly, seemingly dependent on which quadrant (storm motion is WNW). Poor performance appears more related to angle than WSP. 1-min data captures NE motion of outflow.

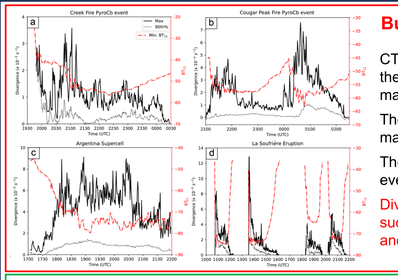


5-min cloud-top motion retrievals appear to perform well for anvil regions and poorly for rapidly-evolving updraft regions

10-min cloud-top motion retrievals may be usable in anvil-type regions depending on ambient wind speed

Cloud-top Divergence Analysis

Bulk Comparison



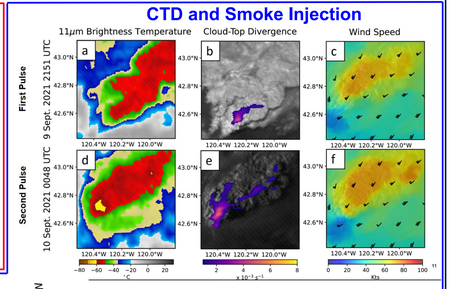
CTD_{max} values for the two pyroCb events are comparable to the supercell and volcanic eruption in terms of absolute magnitude

The La Soufrière eruption and Argentina supercell have event-maximum CTD_{max} that are larger than the pyroCb events.

The discrete pulses of the Cougar Peak fire and La Soufrière events are easily recognizable.

Divergence values are higher for the more intense pulses, such as the 2nd pulse of the Cougar Peak fire pyroCb event and the 2nd eruption of the La Soufrière event.

CTD and Smoke Injection



When comparing BT_{11} (a,d) for each pulse, the second, stronger pulse has a larger anvil cloud, but only slightly colder BT_{11} (5°C). CTD values (b,e) are larger and more widespread during the second pulse.

Derived wind speed (c, f) suggest that the plume during the second pulse reached a higher altitude.

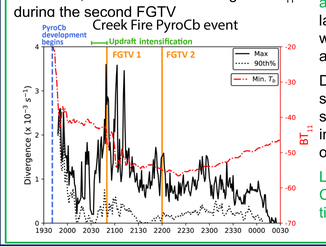
The second pulse had higher maximum CTD_{max}, elevated CTD_{max} values for a longer period.

UVAI and back-trajectories show that the much larger smoke plume likely originated from the second pulse of the Cougar Peak fire pyroCb.

These higher CTDmax values associated with the second pulse correspond with much larger UVAI values.

CTD and FGTVs

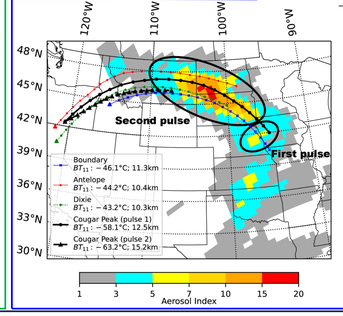
A local BT_{11} minima occurs at the time as the first FGTV, but there is little change in BT_{11} during the second FGTV



The absolute minimum BT_{11} occurs after the most vigorous convective activity as indicated by CTD. This lag is noteworthy because BT_{11} is widely used for analysis of pyroCb activity.

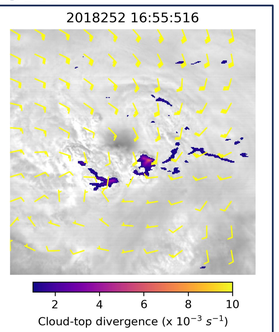
Decreases in BT_{11} correlate very strongly with pyroCb development, strongly but less so with updraft intensification, and weakly with the occurrence of the second FGTV

Local maxima of CTD_{max} and CTD_{90} correspond closely with the times of both FGTVs.



Conclusions and Future Work

- Cloud-top divergence (CTD) derived from optical flow techniques can quantitatively distinguish between relatively consistent updrafts (supercell), more violent "updrafts" (volcano), and relatively smaller and more intermittent updrafts (pyroCb).
- CTD captures variations in convective activity (distinct pulses) and provides additional value to brightness temperature.
- CTD appears to be relatable to smoke injection magnitude.
- 5-minute and 10-minute data (simulating CONUS and full disk ABI scans) may be usable to retrieve cloud-top motion depending on multiple factors, such as viewing/solar geometry, ambient wind speed, and how rapidly a scene is changing (i.e. updraft region vs anvil region)
- **Future work will investigate use of different spectral channels, other potential applications of optical flow using satellite imagery, and further utilization of cloud-top-motion-based parameters such as CTD**



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