2012 International Emission Inventory Conference "Emission Inventories - Meeting the Challenges Posed by Emerging Global, National, Regional and Local Air Quality Issues"

Biomass Burning Plume Injection Height Estimates using CALIOP, MODIS and the NASA Langley Back Trajectory Model.

Amber Soja, Duncan Fairlie, David Westberg, and George Pouliot in conversations with Ralph Kahn, Jim Szykman, Morgan Silverman, Sean Hopkins, Louis Giglio and Brian Stocks.

Photo courtesy of Brian Stocks

Fire Plume Injection Height
is important to fully assess.

If we don't get the injection height correct, the transport of pollutants will be incorrectly modeled resulting in:

* a mis-informed public (air quality reports), which could adversely affect human health;

* an inability to accurately assess the Exceptional Events Rule; and

* inaccurate tracking of elemental carbon could strongly affect our understanding of feedbacks to and from the climate system (i.e. BC transported to early season Arctic ice; above-, under- clouds affecting albedo and the radiation balance; alteration of patterns of precipitation, etc.).

This work serves as an example of the capacity of A-train data (CALIOP, MODIS and GEOS-5) to inform both Applications and Science.

Objectives of this talk

* Provide brief history
* Introduce the TWO products that can be generated using these data (smoke attribution and daily plume evolution) and briefly discuss the methodology.
* Illustrate verification & validation examples and results

Together with existing A-train MISR plume height data, we can inform the current understanding and modeling of fire plume injection height.

History

Historically, plume height had been based on the pioneering work of G.A. Briggs [1969; 1971] and verified with limited field campaign data [Clements et al., 2007].

We have an increasing number of ground-based lidar and aircraft verification measures.

There are currently 2 satellites that can provide the statistics necessary to understand and verify plume height.

I. *MISR - Multi-angle Imaging SpectroRadiometer*

II. *CALIPSO - Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation*

CALIPSO

** able to identify plume heights from extensive smoke fields;*

** increased capability of detecting optically thin smoke layers at a finer vertical resolution;*

** smoke plume identification with back trajectories are temporally random, representing the entire temporal range of fire plumes.*

MISR

** needs abrupt well-defined columns - relies on multi-view angles to estimate the stereo height of distinct features;*

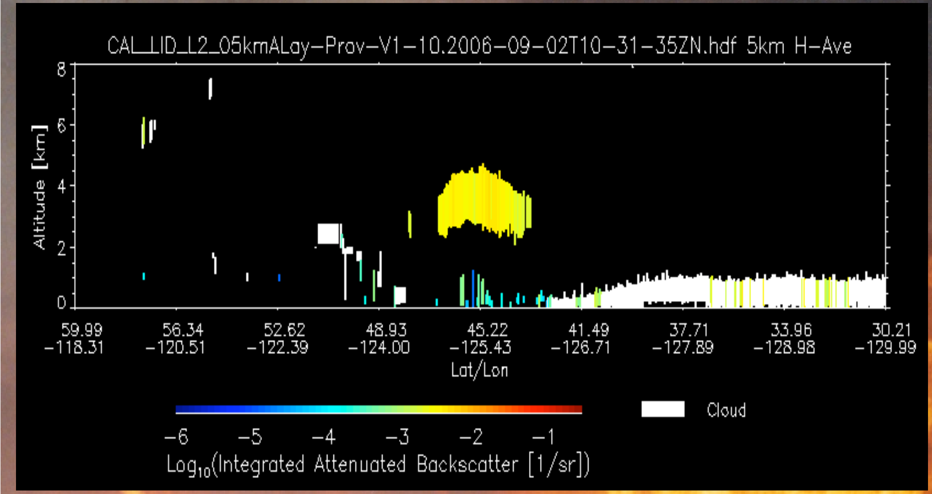
** substantially larger swath width than CALIPSO which results in a greater opportunity to capture smoke plumes [Kahn et al., 2007]; &*

** morning overpasses do not capture the natural temporal fire pattern.*

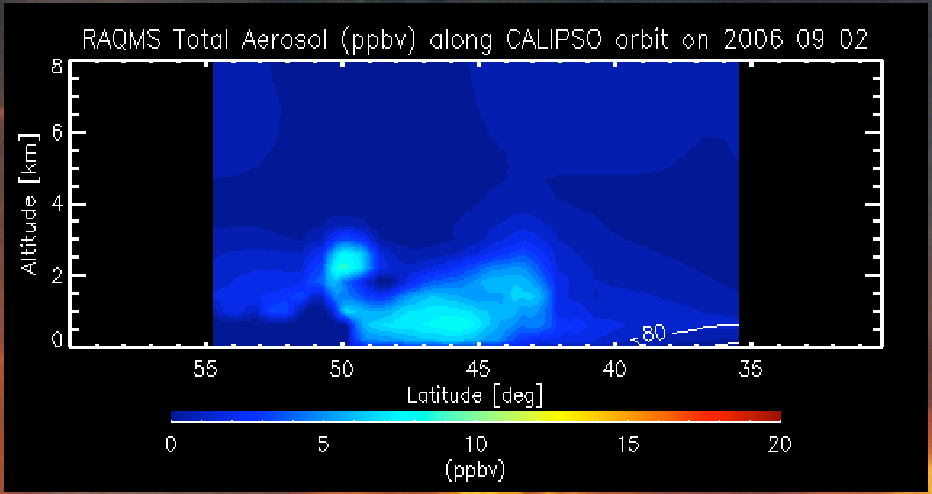
Sensor (spacecraft)	Product	Spatial Resolution	Satellite Overpass	Temporal Availability
MISR (Terra)	AOD, aerosol plume height	1.1 km horizontal x 500 m vertical	10:30 a.m.	~Once every 7 days
CALIOP (CALIPSO)	extinction profile	100 m diameter x 30 m vertical	1:40 p.m.	Once every 16 days

Example of the Problem

CALIPSO plume height



Chemical Transport Model



Courtesy of Brad Pierce and Chieko Kittaka

This model underestimates plume height by about 1/3 for this western fire.

If the plume height is incorrect, then the transport of those emissions will be incorrect potentially adversely influencing public health and the Exceptional Events Rule.

Photo courtesy of Brian Stocks

Recent work

Raffuse and colleagues [2012] compared smoke plume height estimates using the BlueSky smoke modeling system with observations from Multi-angle Imaging SpectroRadiometer (MISR) and CALIOP satellite sensors over the United States.
They found an ~50% low bias in simulated injection height for western states, and relatively low correlations overall for the United States compared with the observations [MISR $R^2 = 0.1$; CALIOP $R^2 = 0.22$].

Freitas, S.R., et al. [2007] has developed sub-grid scale plume rise for vegetation fires for use in low resolution atmospheric transport models.

Using Frietas sub-grid plume modeling embedded in the WRF-Chem model, Sessions et al. [2011] found significant improvement in smoke injection estimates.

Fire Regimes and Fuel Available Vary Widely

June 28 2008
Columns near
Lake Athabasca:
5-6 km

Photos courtesy P3 group

Climate → Weather → Available Fuel → Injection height

Fires between Athabasca and Reindeer Lakes

June 30 2008

5-7 km

Photos courtesy P3 group

Climate → Weather → Available Fuel → Injection height

Typical pyroCb convection columns (10-12 km)

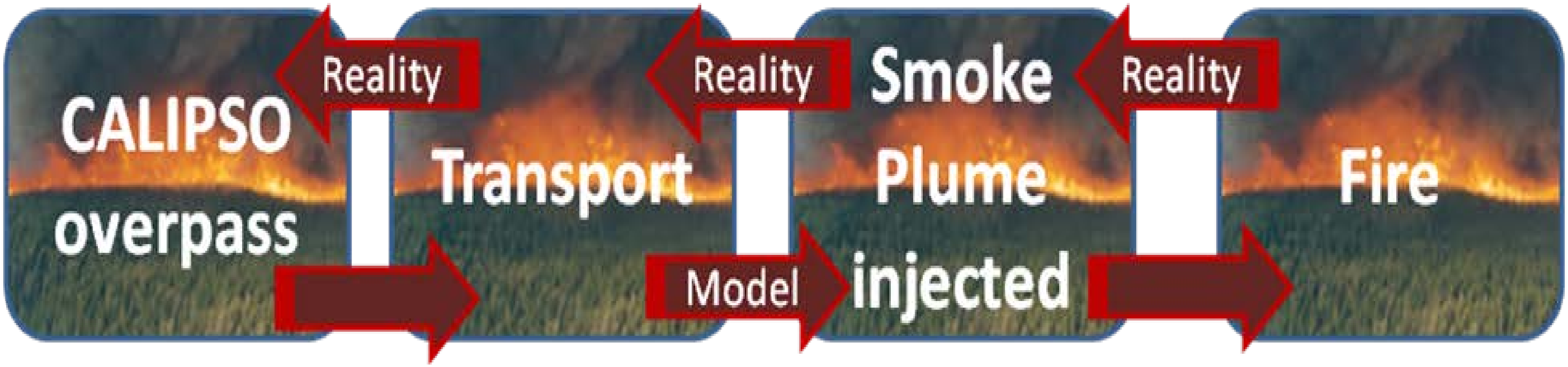




Typical pyroCb fire behavior: continuous high-intensity crown fires

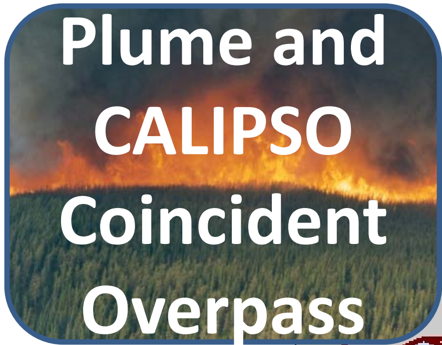
Climate → Weather → Available Fuel → Injection height

Reality and the Methodological Process

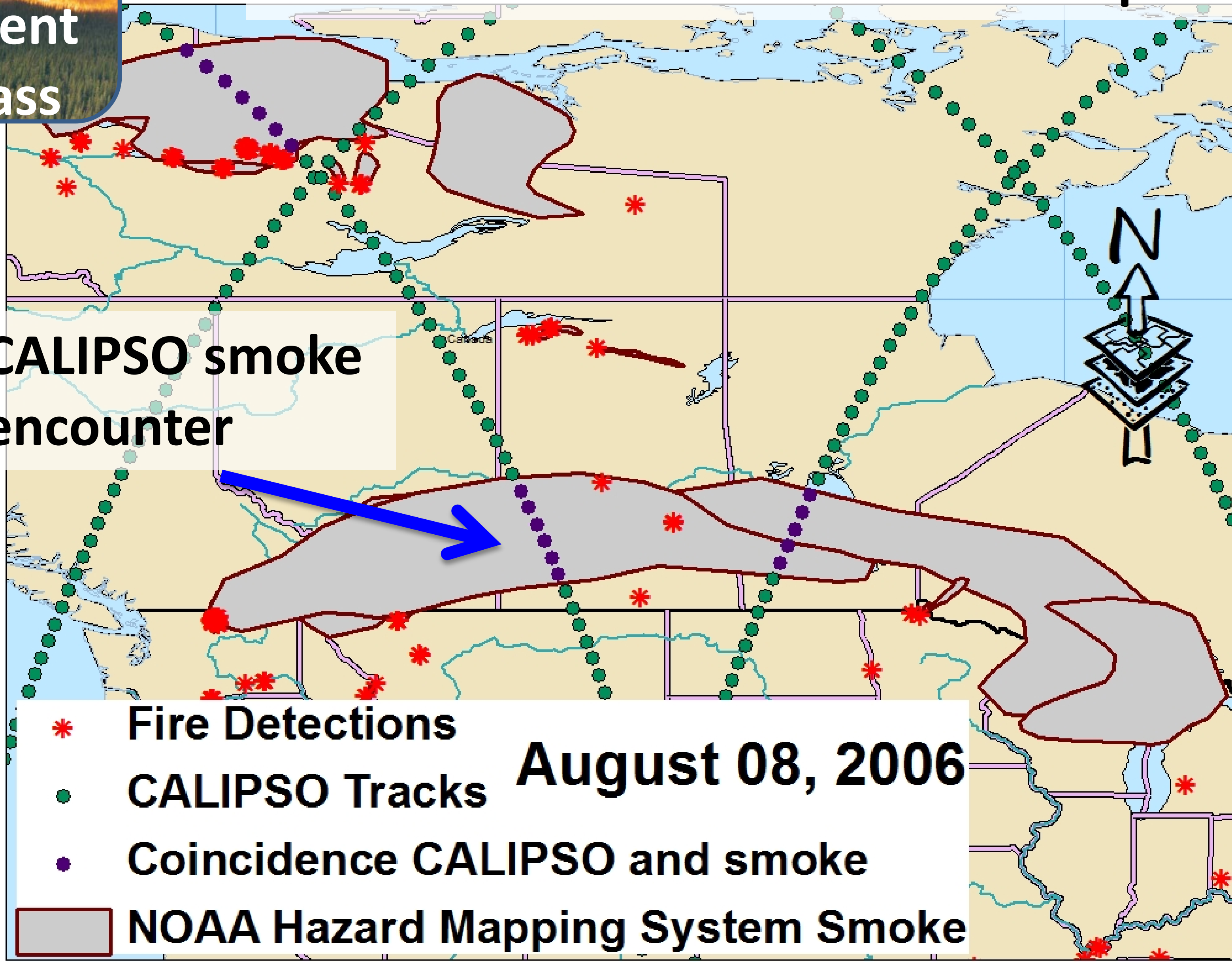


- Coincidence in CALIOP data and HMS smoke plume;
- Langley Research Center Trajectory Model (LaTM) to;
- Coincidence in space and time with MODIS fire detection.

All in 3-dimensional space and time

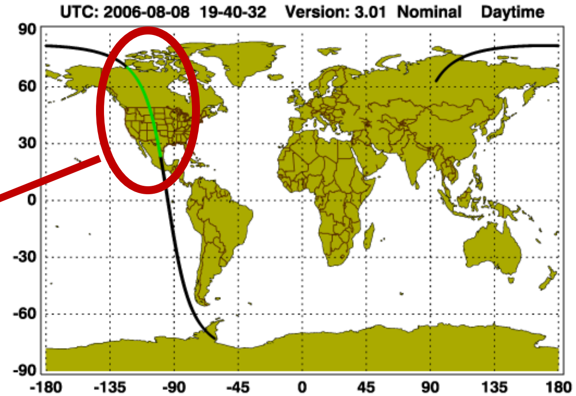


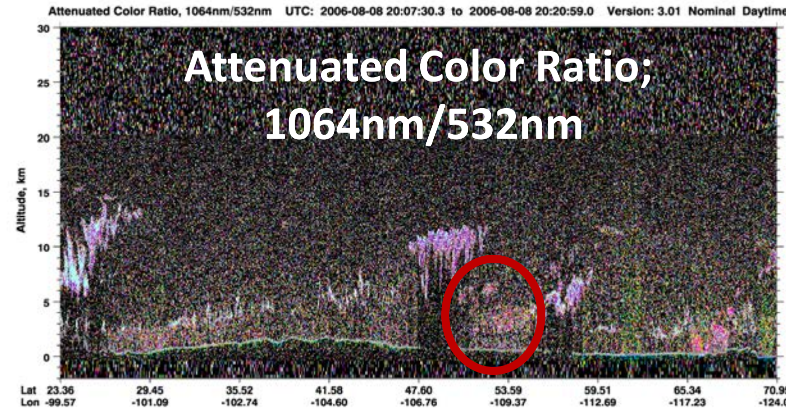
Coincident NOAA HMS smoke plume, and CALIPSO overpass.



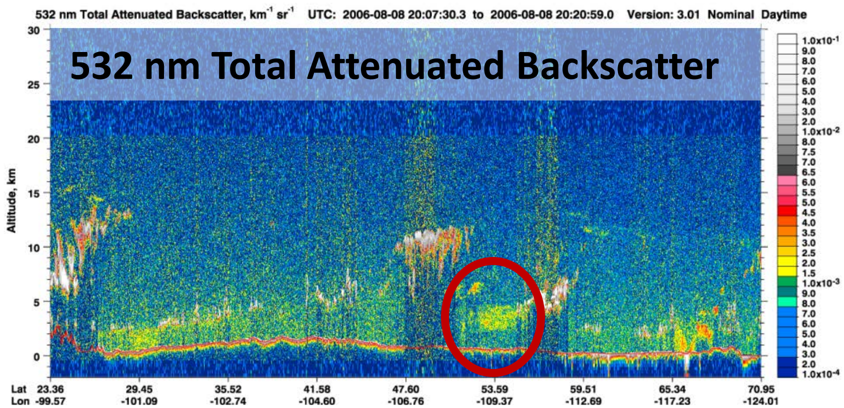
CALIPSO Curtains 08 Aug 2006 (v3)

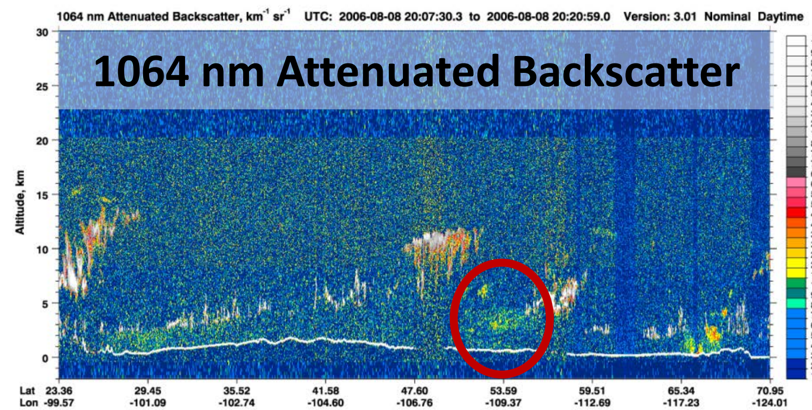
Swath from south to north

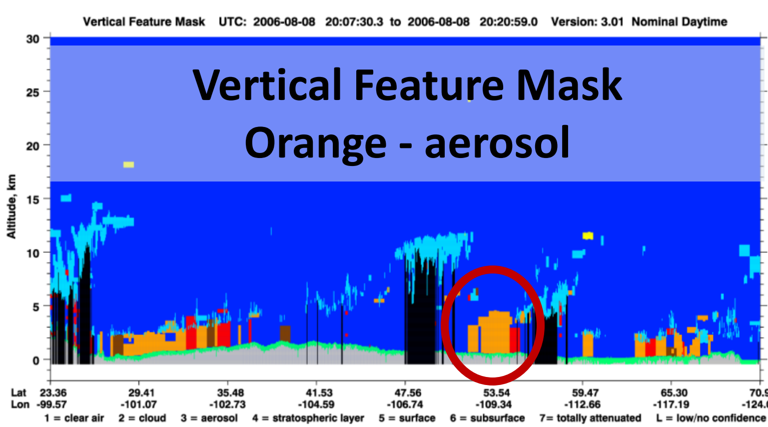


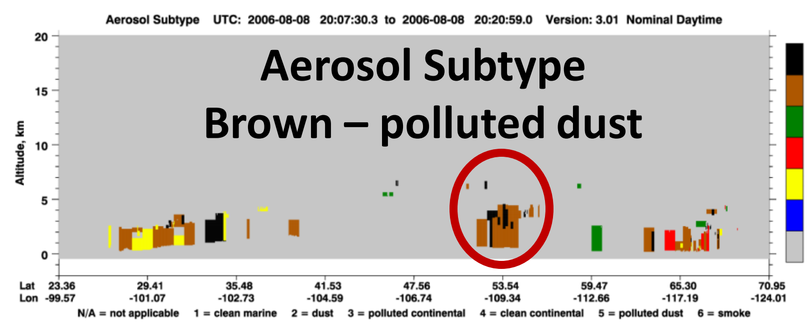


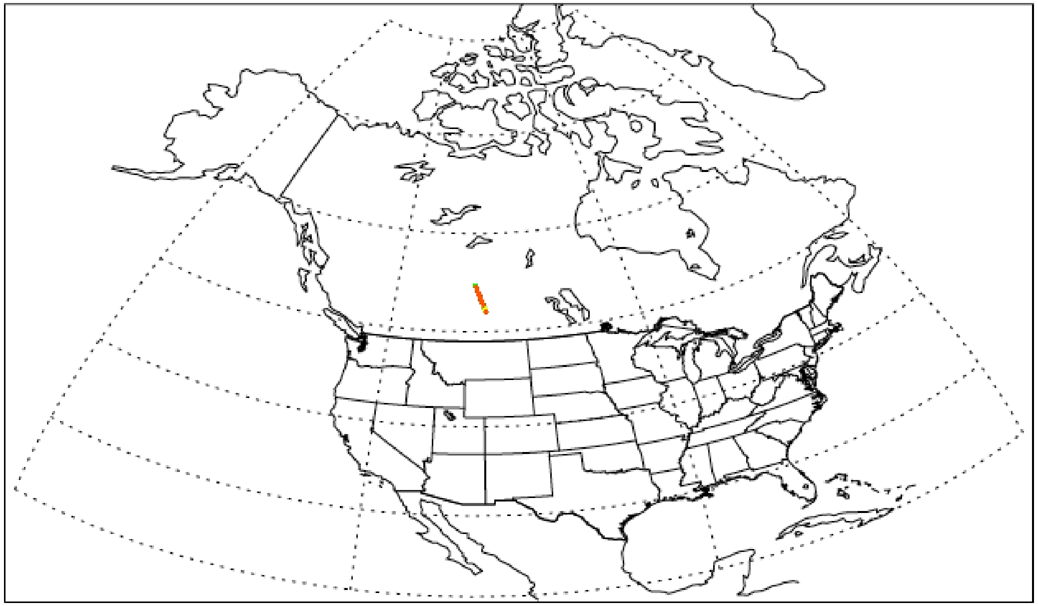
20:07 to 20:20

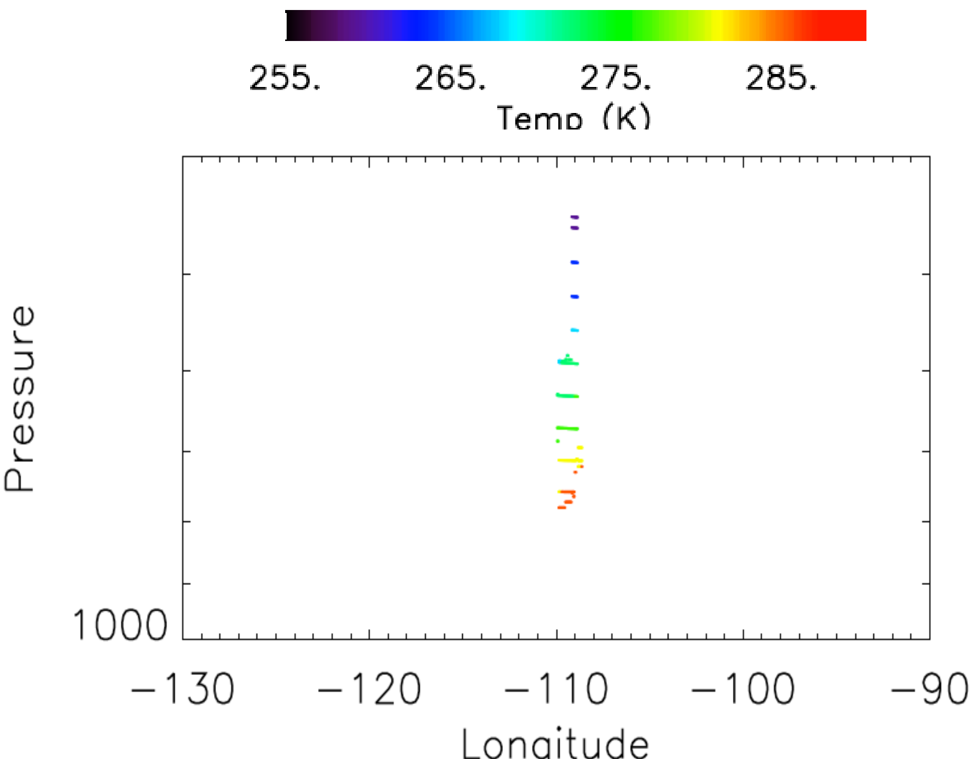








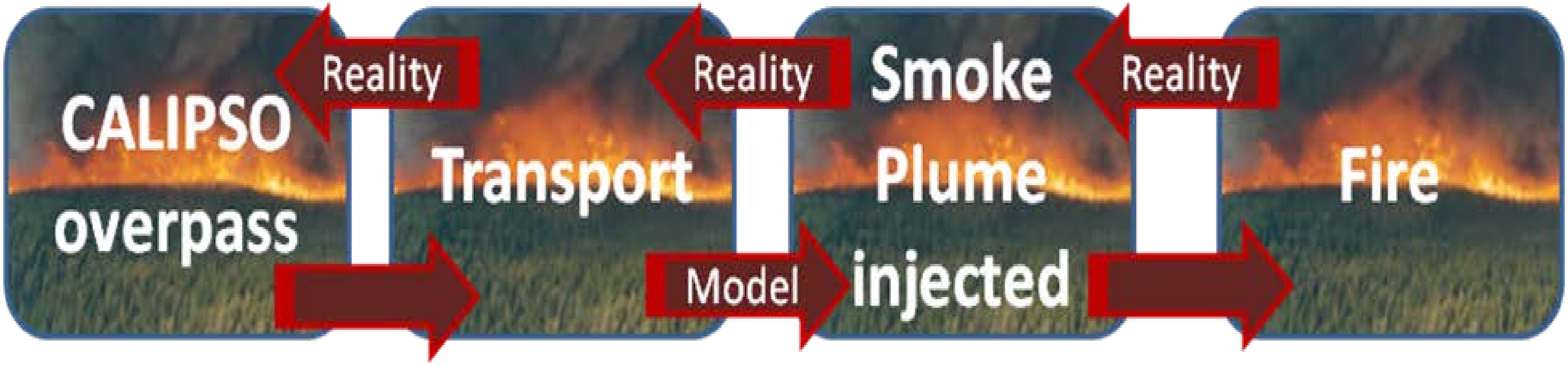




Smoke-filled air parcels are initialized in the LaTM at:
~1 second intervals along the CALIPSO smoke segment track;
at 100m vertical intervals within the smoke plume.

The LaTM uses a 15 minute time step and is driven by NASA Goddard Earth Observing System version 5 (GEOS-5) large-scale meteorological reanalysis data.

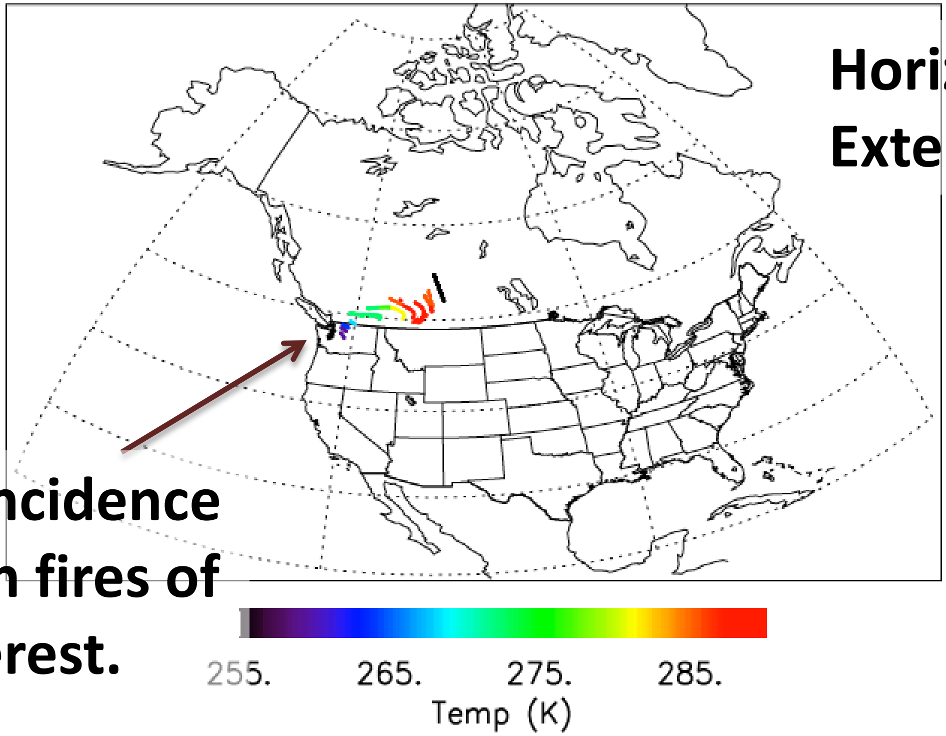
Current Criteria for Coincidence



Coincidence Criteria

- ❖ Coincidence between air parcel and fire detection in space (20 km) and time (day)
- ❖ Fire detection > 35% confident
- ❖ If above boundary layer, must be coincident with 6 or more detections

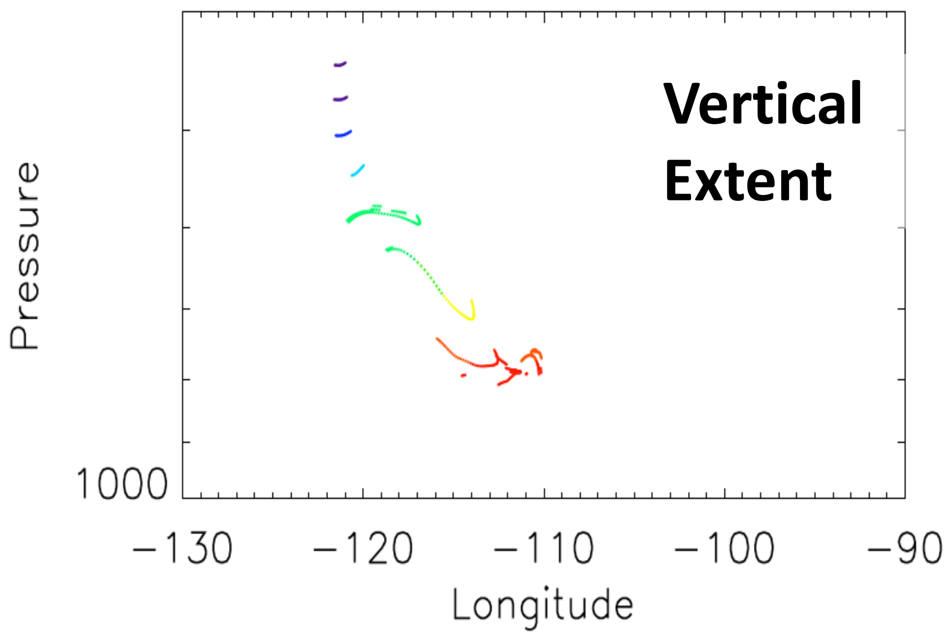
Horizontal Extent



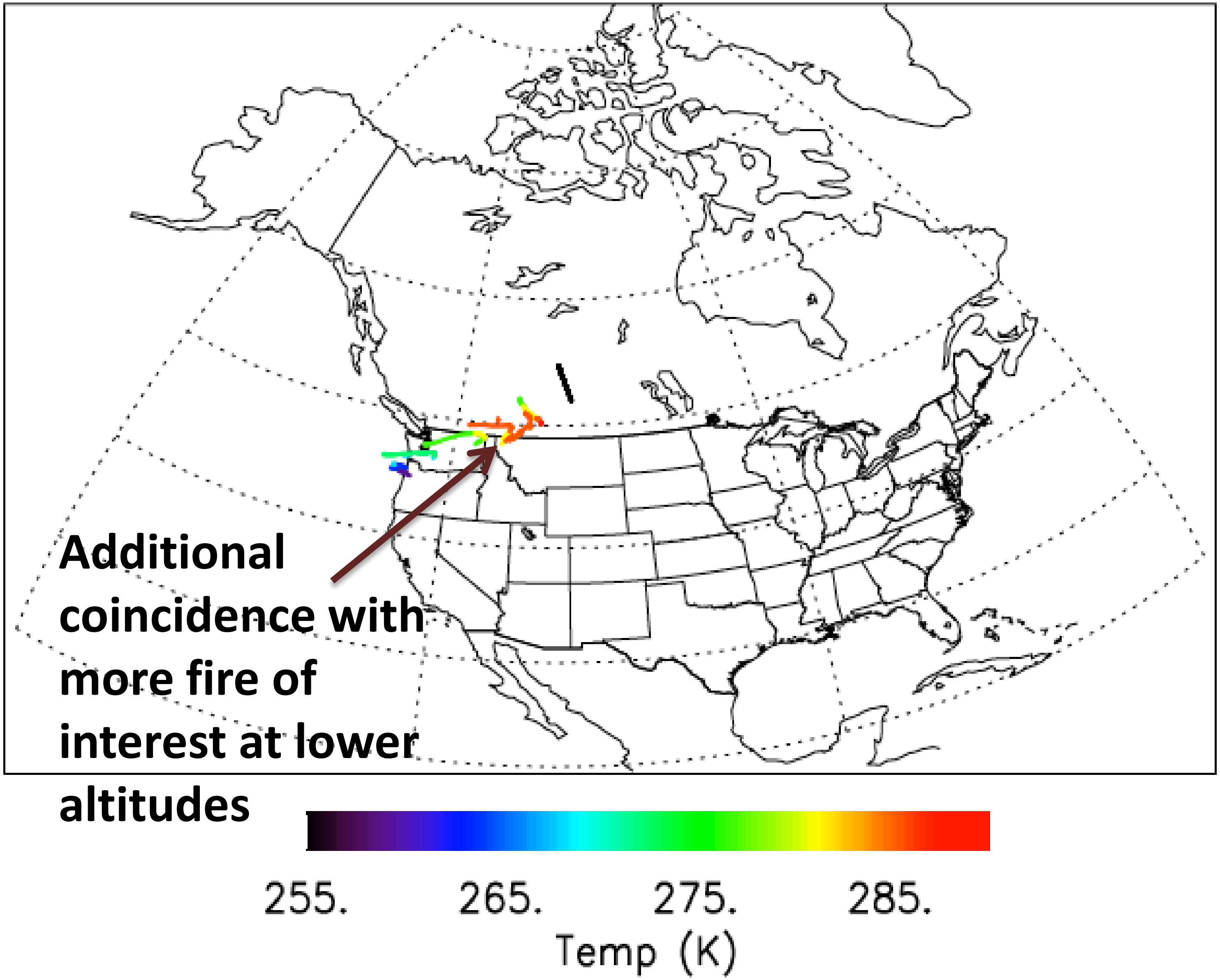
Coincidence with fires of interest.

Initialization Time minus -24 hrs: Back trajectories pass over “fire of interest” in North-Central Washington in the mid troposphere (~ 500 mb, ~17000 ft, ~5.2 km).

Vertical Extent



T – 36 hrs: Back trajectories pass over “fire of interest” in North-West Montana, in the lower trop. (~ 800 mb, ~ 6500 ft, ~ 2 km)



Additional coincidence with more fire of interest at lower altitudes

CALIPSO Data and Associated Fire and Meteorological Variables

Active fire size or area burned
(source)
Number of active fire detections
(MODIS Terra and Aqua)
Fire radiative power or energy

CALIPSO curtains
Top, median and bottom of
CALIOP plume height

MODISv4 vegetation 1km
MODIS
Elevation
Available fuel

Air parcel counts , mean range

Relative Humidity (2m, 10m)
Temperature (2m, 10m)
Wind speed and direction
Precipitation
Fire weather
(US?, CFFWIS)
Time of day

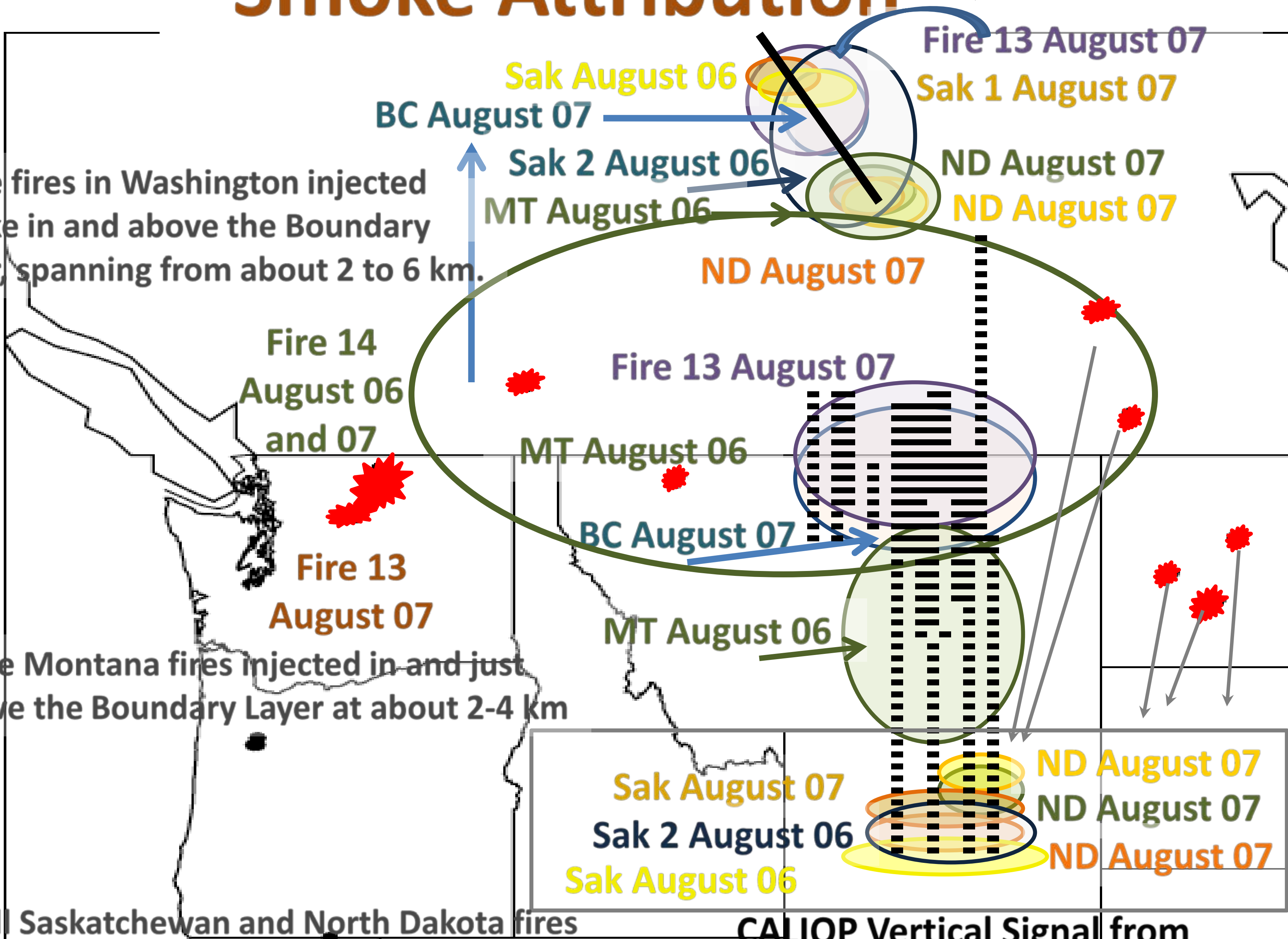
Atmospheric soundings
(radiosonde NWS – normal 0z
12z and fire weather; GOES-5
PBL

Latitude/longitude
fire location and plume
FIPS
Fire name

CALIPSO Data and Associated Fire and Meteorological Variables

On August 9th, there were 18 CALIPSO orbit segments, which resulted in 261,580 AP run backwards in time to intercept with 2724 fire detections (multiple days), resulting in 38,494 total lines of data and 328 lines of mean statistics. Mean statistics are collected from only 3 days from the CALIPSO orbit, and any additional days may be used for specific fire event analysis.

Smoke Attribution



* The fires in Washington injected smoke in and above the Boundary Layer, spanning from about 2 to 6 km.

* The Montana fires injected in and just above the Boundary Layer at about 2-4 km

* All Saskatchewan and North Dakota fires injected in the Boundary Layer at around 1 km

CALIOP Vertical Signal from August 08 2006

This plume can be attributed to 9 separate fires, burning on different days (12 event days):

Product Two

Washington - large fire

August 6th (~ 3400 m);

August 7th (mean 3300 m, range 1900 – 6300 m);

Washington - medium-sized fire

August 7th (range 2200 – 4400 m)

British Columbia

August 7th about 3400 m

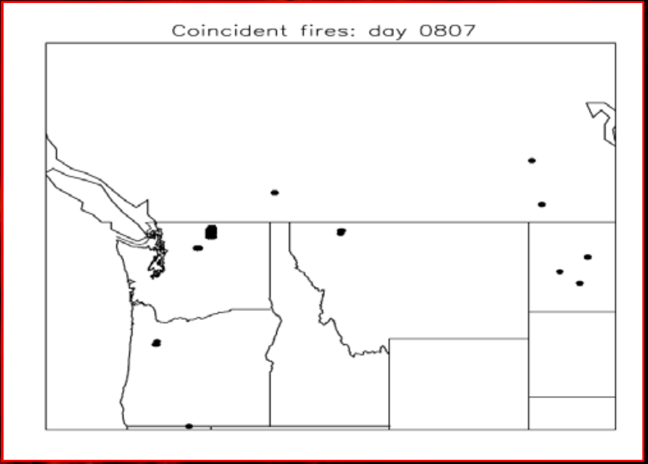
Montana fires – 2 of them

August 6th – mean 1980 m

Saskatchewan (2 fires)

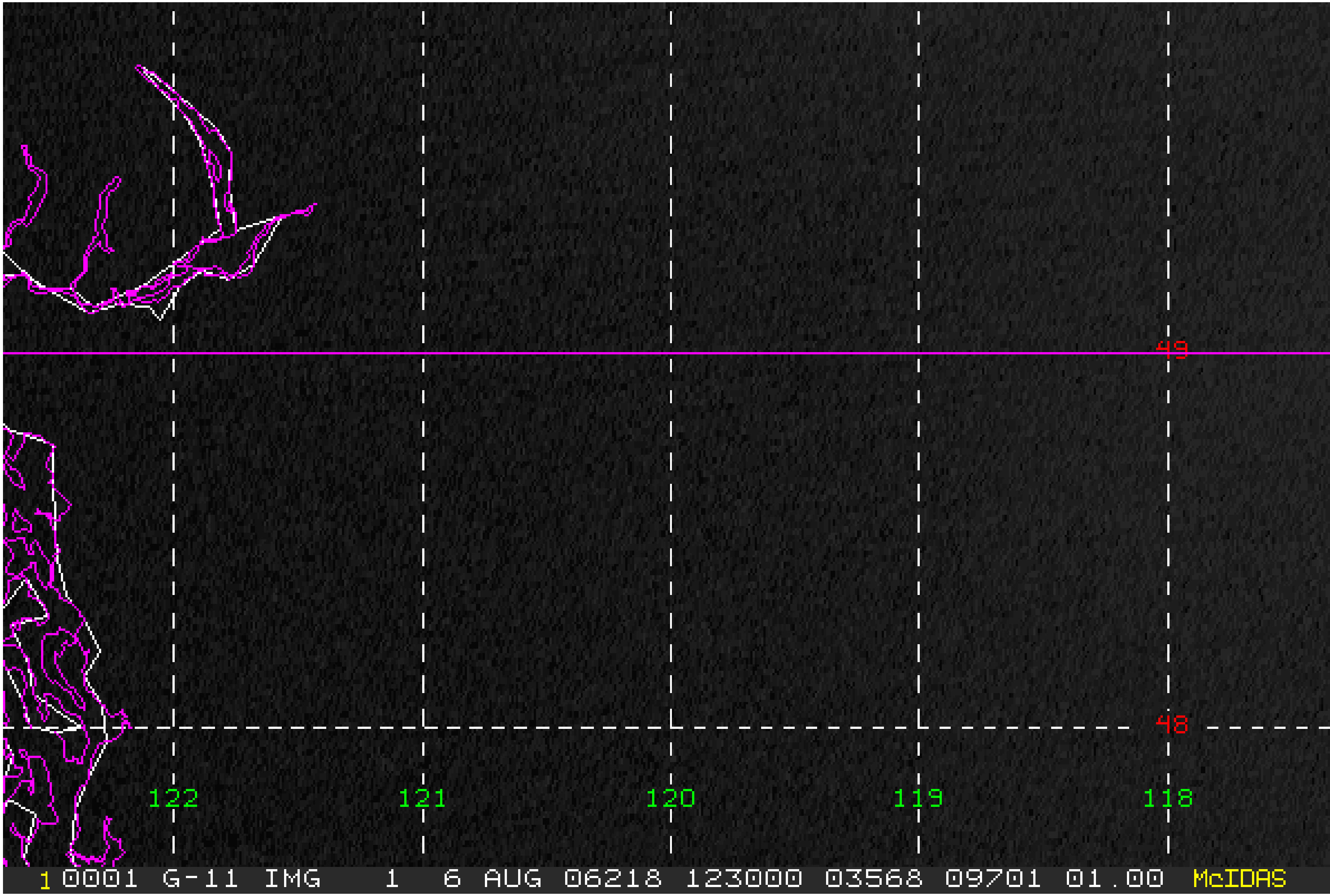
August 6th and 7th ~ 1000 m

North Dakota (2 fires) August 7th ~ 2000 m

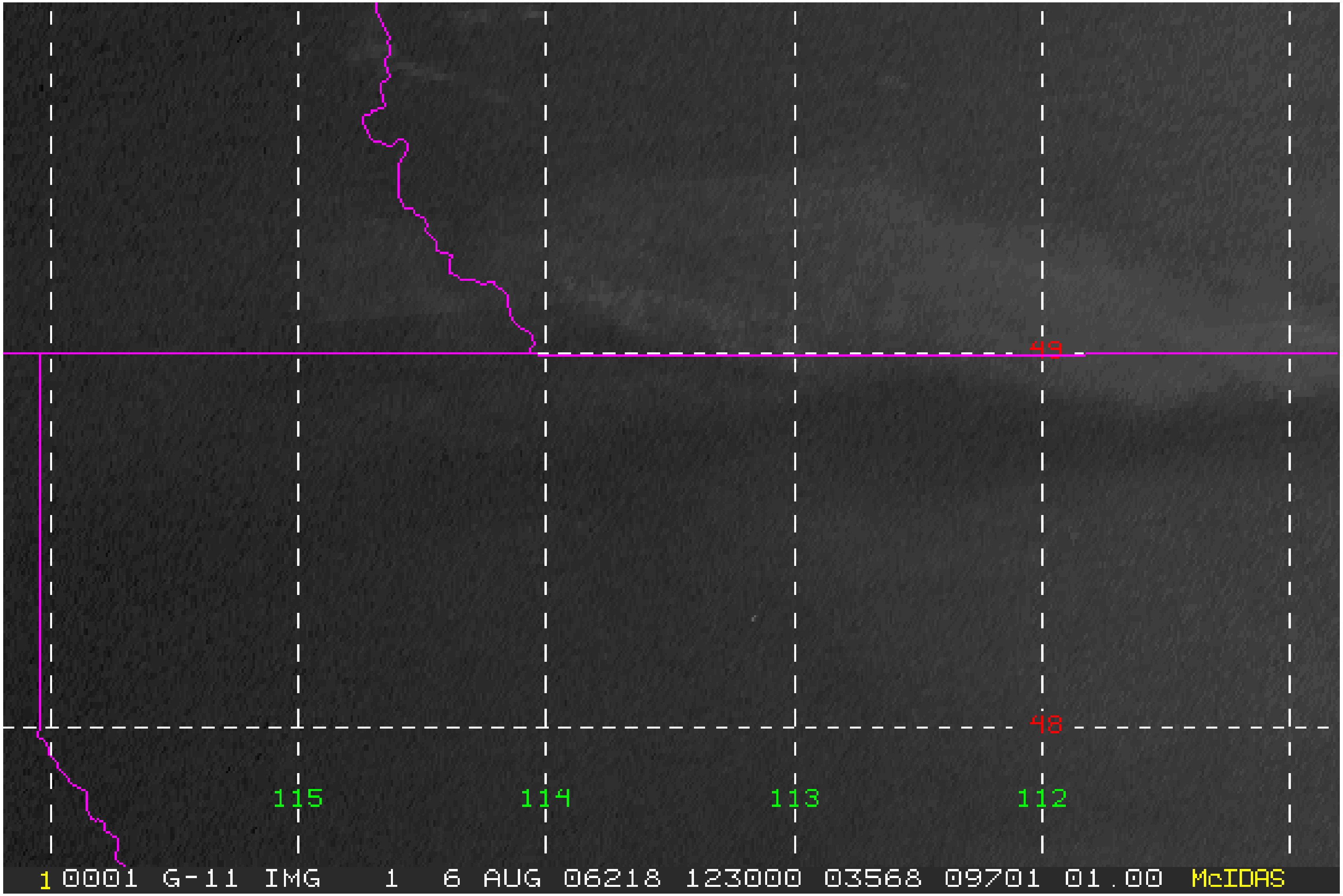


One coincident MISR overpass – within 100's of m in Montana

Movie Verification using 15 minute GOES data
August 06, 2006; Two larger fires burning in Washington.

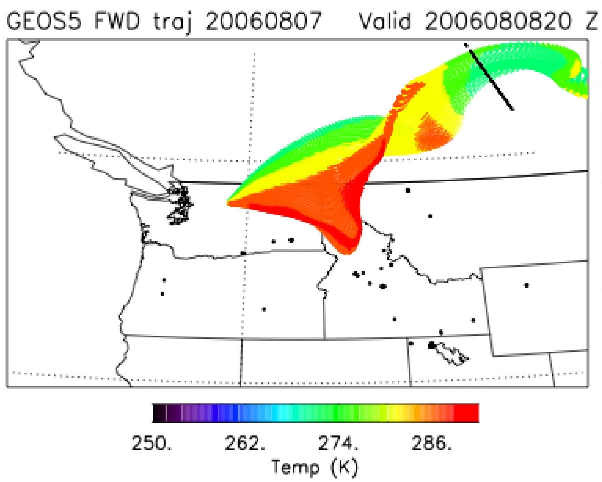


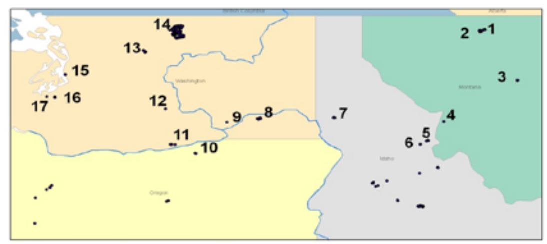
Movie Verification using 15 minute GOES data
August 06, 2006; Two smaller fires burning in Montana.



Verification

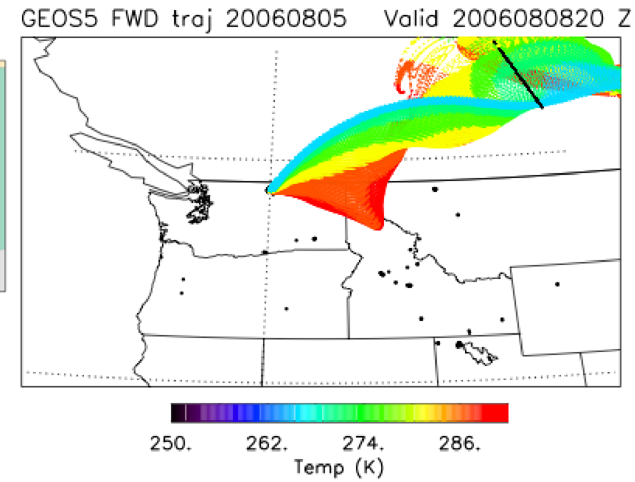
Forward trajectory from fires in Washington

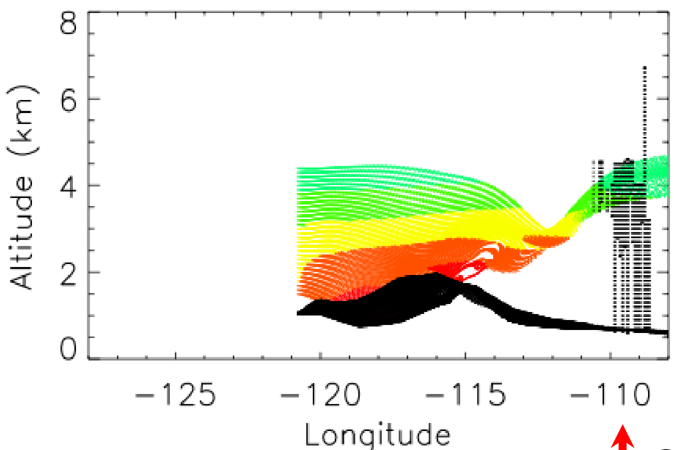




Latitude Longitude Fire Locations

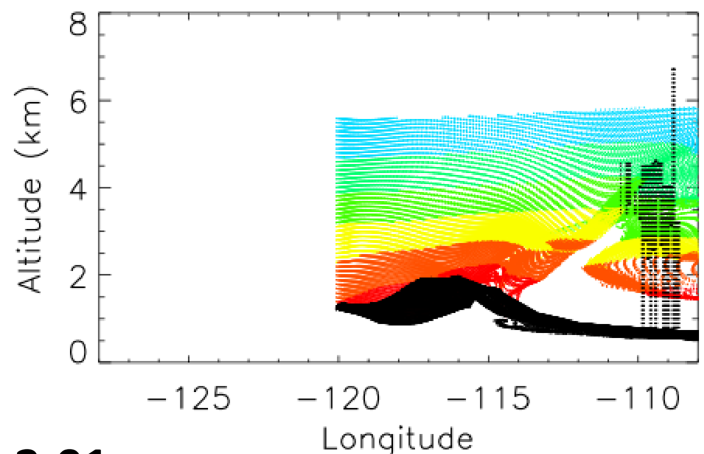
ID	Latitude	Longitude
MT		
1	48° 39' 16.	113° 26' 15.
2	48° 37' 42.	113° 31' 31.
3	47° 25' 30.	112° 43' 58.
4	46° 25' 25.	114° 18' 2.
ID		
5	45°57'33.	114°39'10.
6	45°51'56.	114°48'11.
7	46°30'54.	116°39'28.
WA		
8	46°29'21.	118°14'24.
9	46°24'46.	118°55'26.
OR		
10	45°39'9.	119°35'51.
WA		
11	45°51'39.	120°4'49.
12	46°43'56.	120°14'36.
13	48°8'6.	120°41'15.
14	48°37'13.	119°59'53.
15	47°34'4.	122°22'12.
16	47°0'44.	122°36'1.
17	47°1'42.	122°46'4.





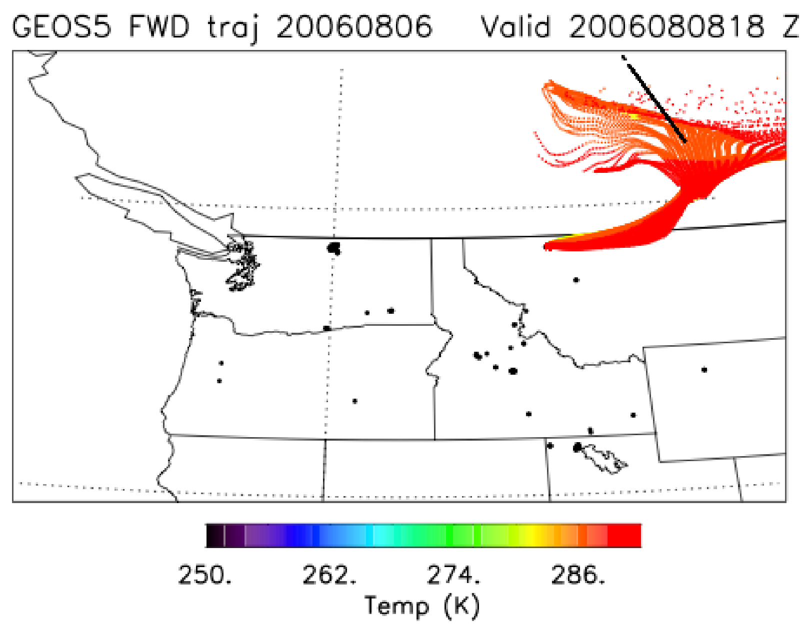
Contribution at a range of altitudes across the entire horizontal swath

↑ **CALIPSO Lidar Version 3.01**



Fire 13, Washington, August 07, 2006

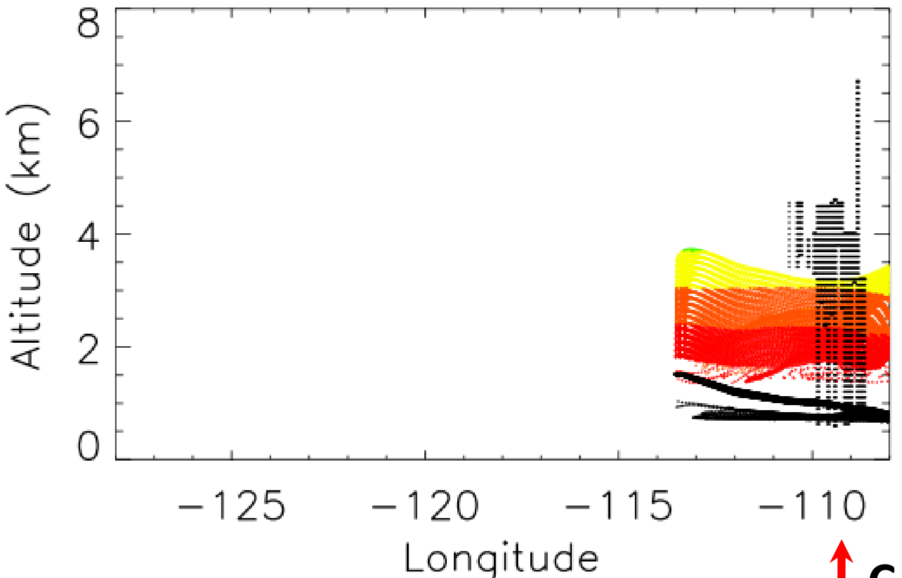
Tripod Fire 14, Washington, August 05, 2006



Verification

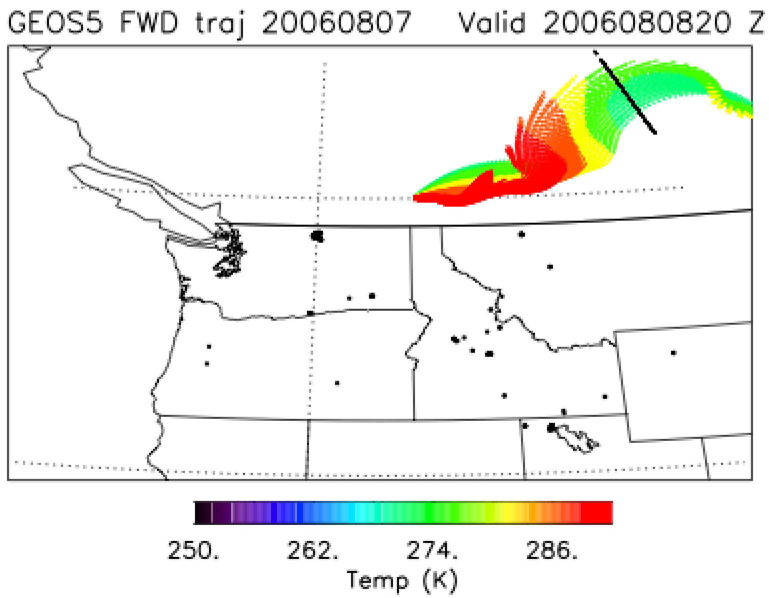
Forward Trajectory from Montana

CALIPSO Lidar Version 3.01



Contributions to the southern section of the overpass at about 1 to 3 km

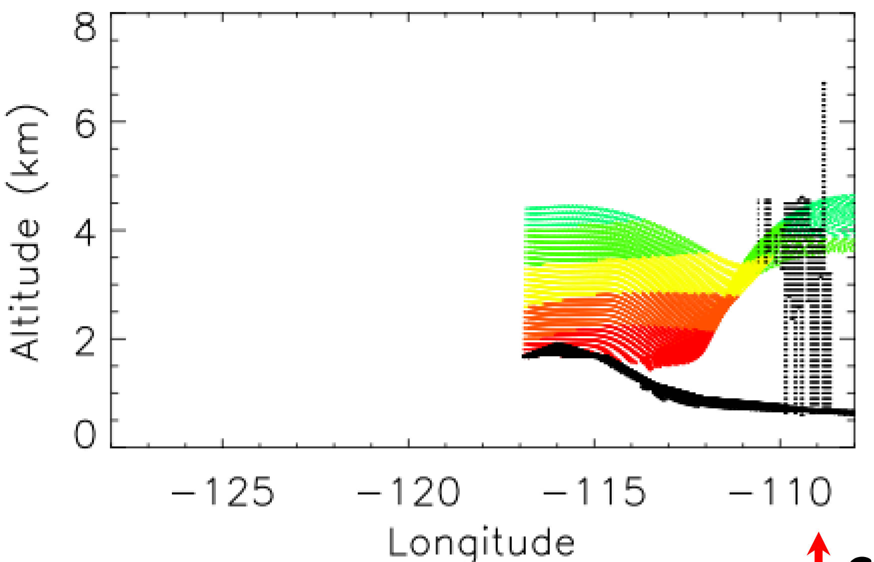
CALIPSO Lidar Version 3.01



Verification

Forward Trajectory contribution from British Columbia

CALIPSO Lidar Version 3.01



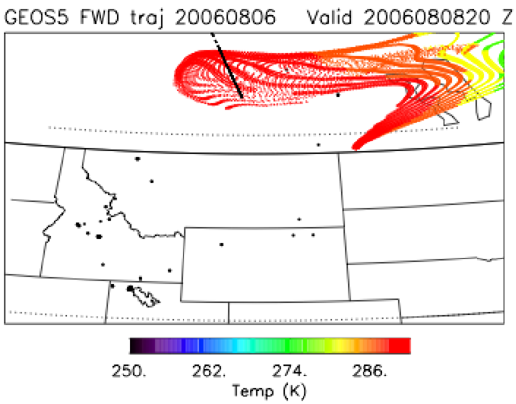
Contribution to mid-altitudes in the mid-range of the overpass.

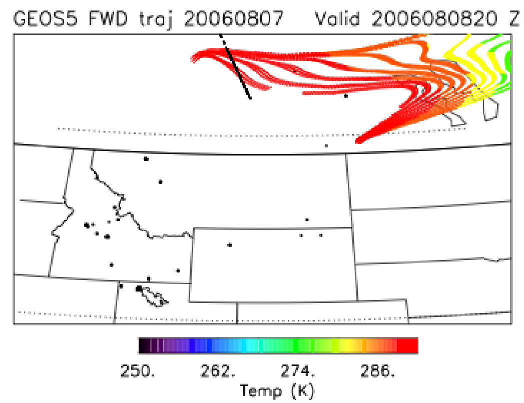
CALIPSO Lidar Version 3.01

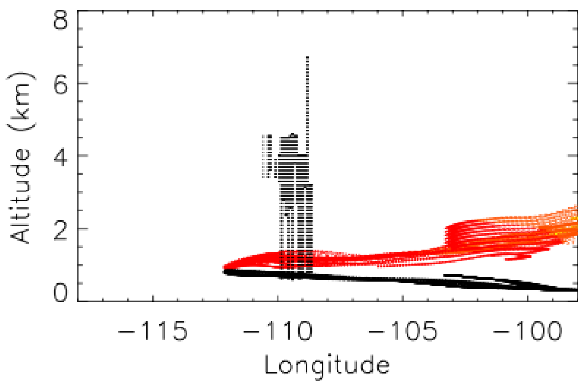
Verification

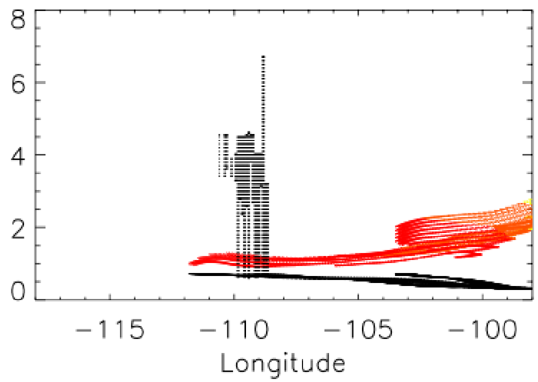
Boundary layer fires from the east

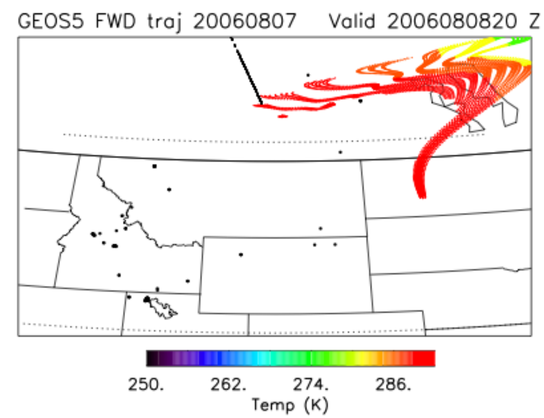
CALIPSO Lidar v3.01



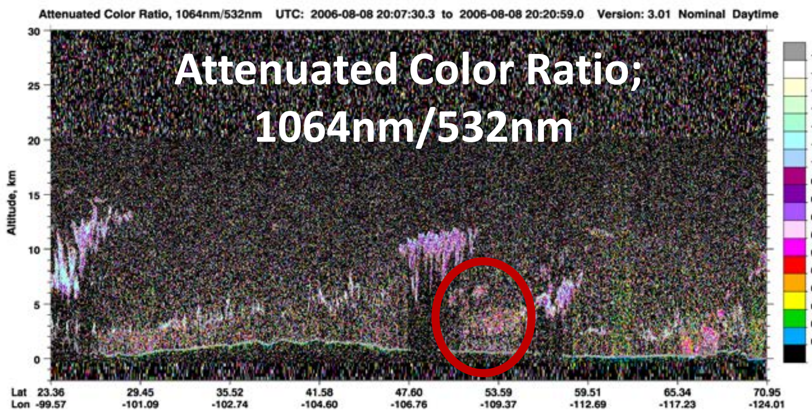


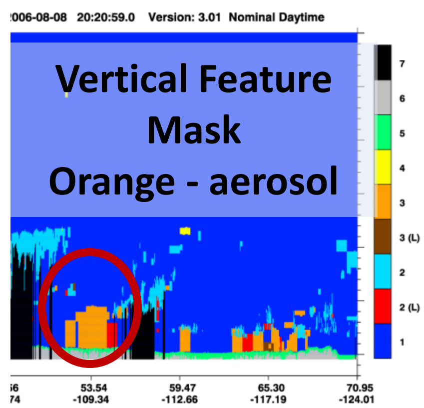


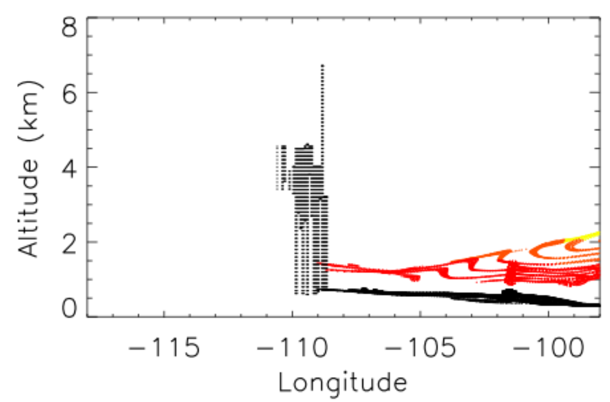




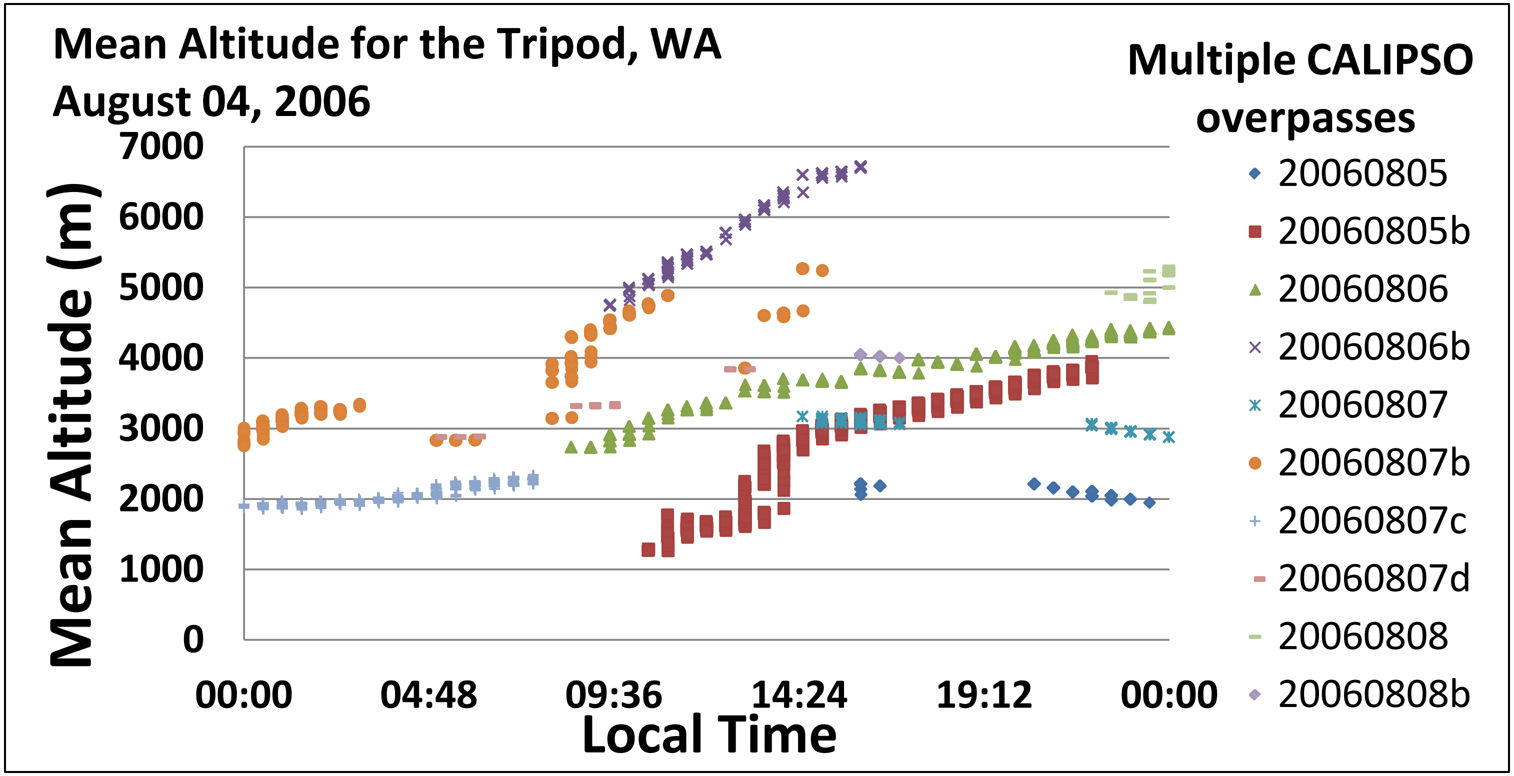
Contribution to altitudes ~1 km and below.





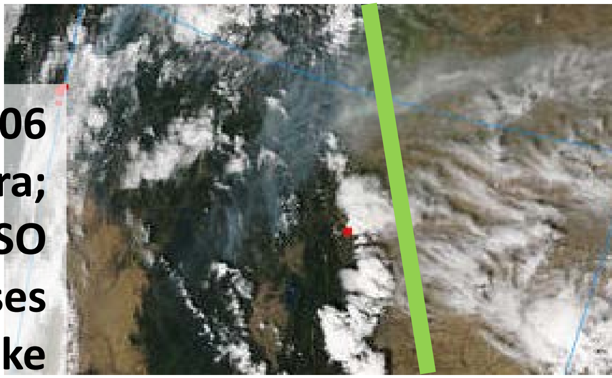


Product Two: Example One fire using Several CALIPSO Granules



Aug 04 2006, MODIS Aqua with fires and smoke transport

August 08 2006 MODIS Terra; CALIPSO overpasses river of smoke



MISR data - extensively interrogated – excellent work

-5 years obs. from North American (2002 and 2004–2007).
-plumes range from a few hundred meters to over 5000m
-largest - boreal (median values of 850 m),
-smallest cropland-grassland (median values of 530 m).
-A significant fraction (4–12%) were injected above the boundary layer (BL); and most of the plumes located above the BL (>83%) were trapped within stable layer.

MISR data likely underestimate plume IH:
* morning overpass, so the peak of the fire day is missed;
* MISR needs distinct boundaries (large fires - irregular boundaries, smoky cloud-like features)

Example - Tripod fire burned in Washington in 2006 and was one of the largest fires in the lower 48 in recent U.S. history. It burned vigorously in July (started ~ July 3rd) and August, and MISR IH was able to capture data for 4 days during that 2-month period [27 July (1 IH); 18 August (6 IH), 25 August (3 IH) and 27 August (5 IH)].

<u>Spatial and Temporal Coincidence between CALIOP/MISR</u>

August 25th, - 3 MISR assessments - 4 CALIOP-LaTM segments and 2 of these coincide with MISR overpass time.
-CALIOP IH: 1300-1400 m ASL; 3800-4000 m ASL;
- mean MISR heights are 2040 m, 3060 m and 4260 m ASL.

August 27th, -one CALIOP segment - coincident with 5 MISR
CALIOP: smoke injected at the surface, and this is
MISR injection at & just above surface .

The MISR and CALIOP-based methodologies produce strikingly similar results, which argues for the accuracy of both products.

Limited number of plumes analyzed with CALIOP (all in North America, August 2006).

- the entire plume is injected in the boundary layer in 21% of cases (88- 96% for MISR),
- the lower portion of the plume is injected in the boundary layer in 44% of cases (mean height 34% of cases).

CALIOP data provide the opportunity to determine smoke plume IH, randomly, from all times of day, as well as from all ecosystems, fuel types and meteorological conditions, so these data, paired with MISR BB IH data, would be optimal.

Conclusions

- ❖ CALIPSO data provide a spatially and temporally random view of fire plume data, one that is not limited to particular fire types or times of day.
- ❖ One CALIOP swath can be representative of a complicated 3-D temporal and spatial story that incorporates several days, several fire events and a range of fire types from agricultural to large wildfires.
- ❖ Most of emissions are from the few larger fires, so if BB IH is misrepresented for larger fires, then a large portion of the emissions are misplaced in CTMs and climate models, with implications for air quality predictions and climate feedbacks.

Conclusions

❖ In concert, CALIOP and MISR data will add to the statistical knowledge necessary to improve our knowledge of the dynamics of fire plume injection height.

Thanks!

to the Environmental Protection Agency;
the CALIPSO Team specifically
Dave Winker, Mark Vaughn, Chip Trepte and Ali Omar;
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the NOAA HMS team;
Brian Stocks; Mike Fromm; Sean Raffuse; and

a NASA funded Air Quality Applications Project:

Linking NASA Satellite Data and Science to Enhance Fire Emissions within the EPA's National Emissions Inventory: Developing Agricultural/Rangeland Fire Emissions Estimates, Connecting Models to Plume Injection Height Data, and Verifying Modeled Emissions Estimates

Co-Investigators: Jassim Al-Saadi, T. Duncan Fairlie, Nancy H. F. French, Joe Kordzi, Jessica McCarty, Tom Pace, Tom Pierce, George Pouliot, James Szykman and David Westberg

Collaborators: Richard Ferrare, Louis Giglio, Scott Goodrick, Ralph Kahn, Chris Schmidt, Shawn Urbanski, Tom Moore, Sean Raffuse, Mike Fromm, Brian Stocks and Charles R. Trepe.


Spotting
Fire
Thank-you!
Questions ?
amber.j.soja@nasa.gov
Photo courtesy of Brian Stocks