Denver Water
August 19, 2010

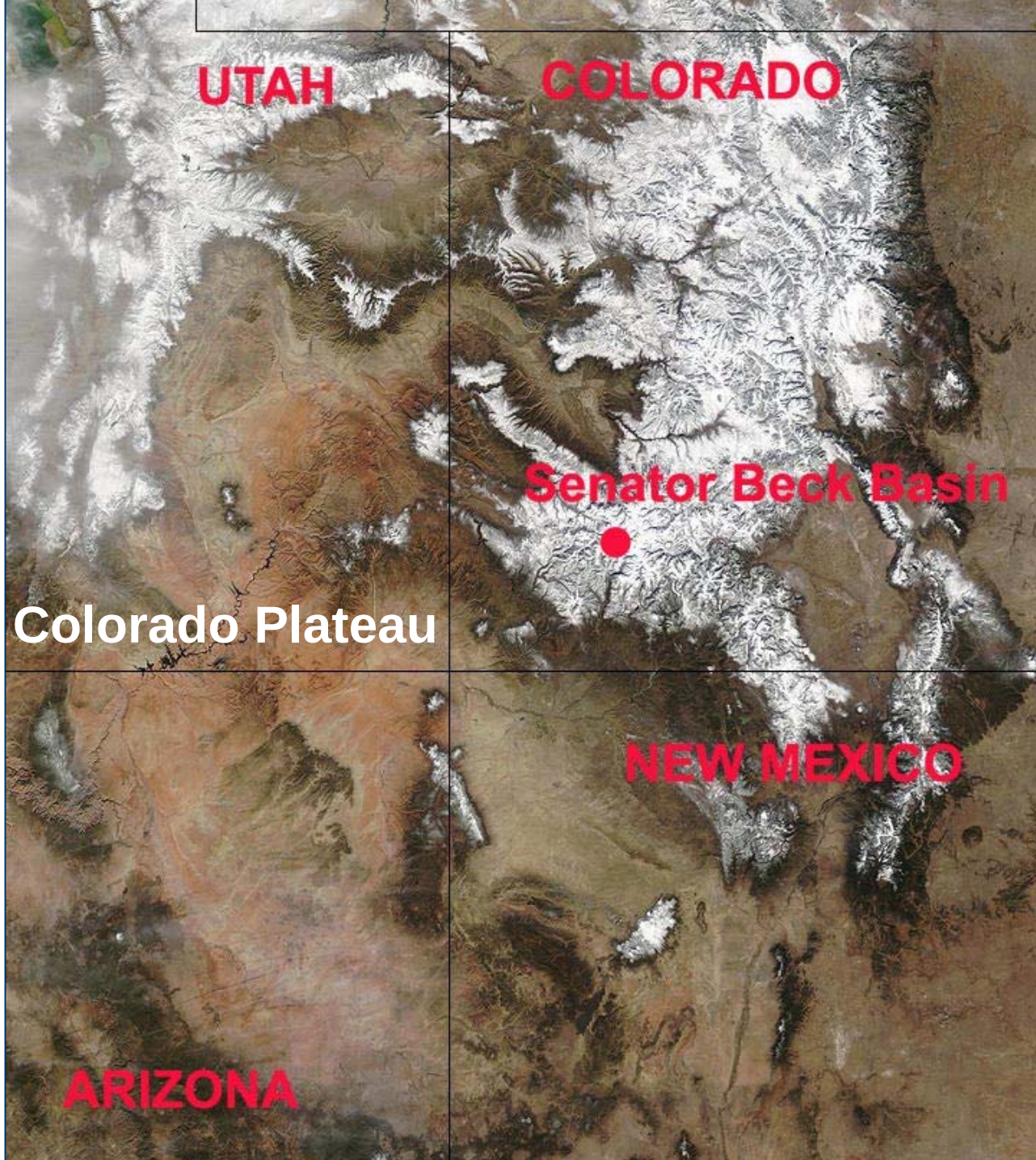
Dust-on-Snow in Colorado

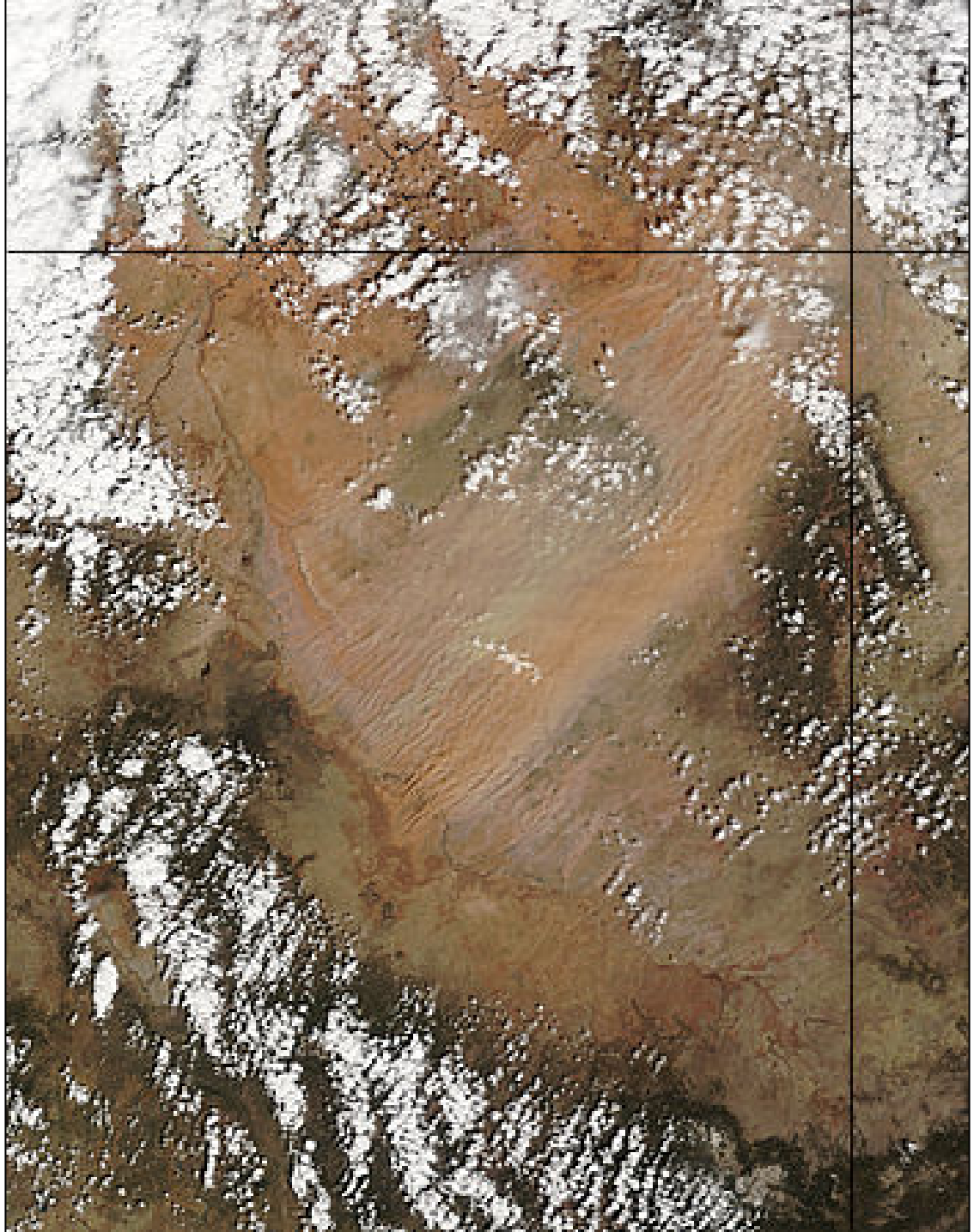
Colorado Dust-on-Snow Program (CODOS)

Chris Landry
Center for Snow and Avalanche Studies
Silverton, CO

in collaboration with
Tom Painter & Students
Jet Propulsion Lab – Cal Tech

Jeffrey S. Deems
Western Water Assessment

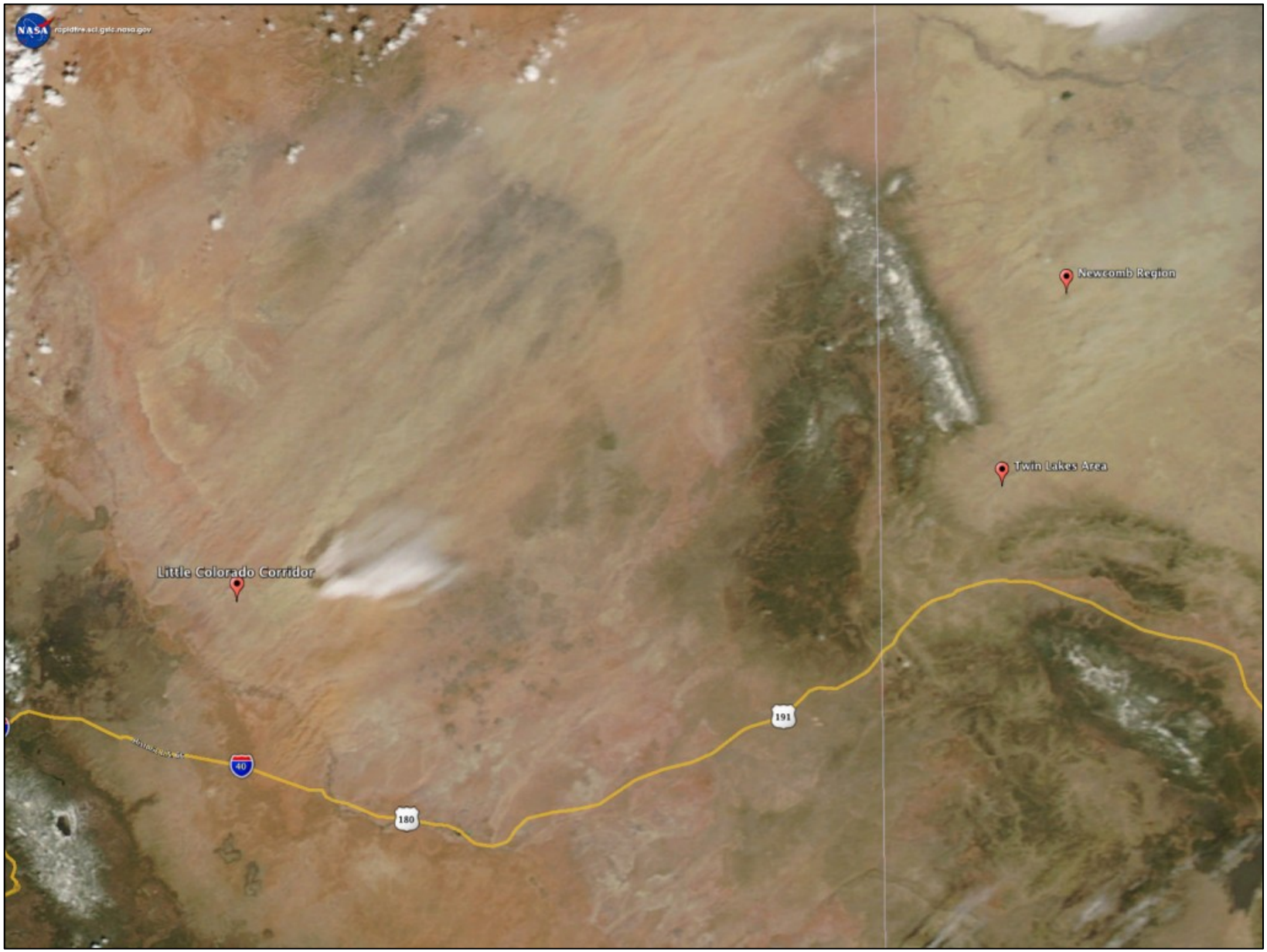




D8 – WY2009
April 3, 2009

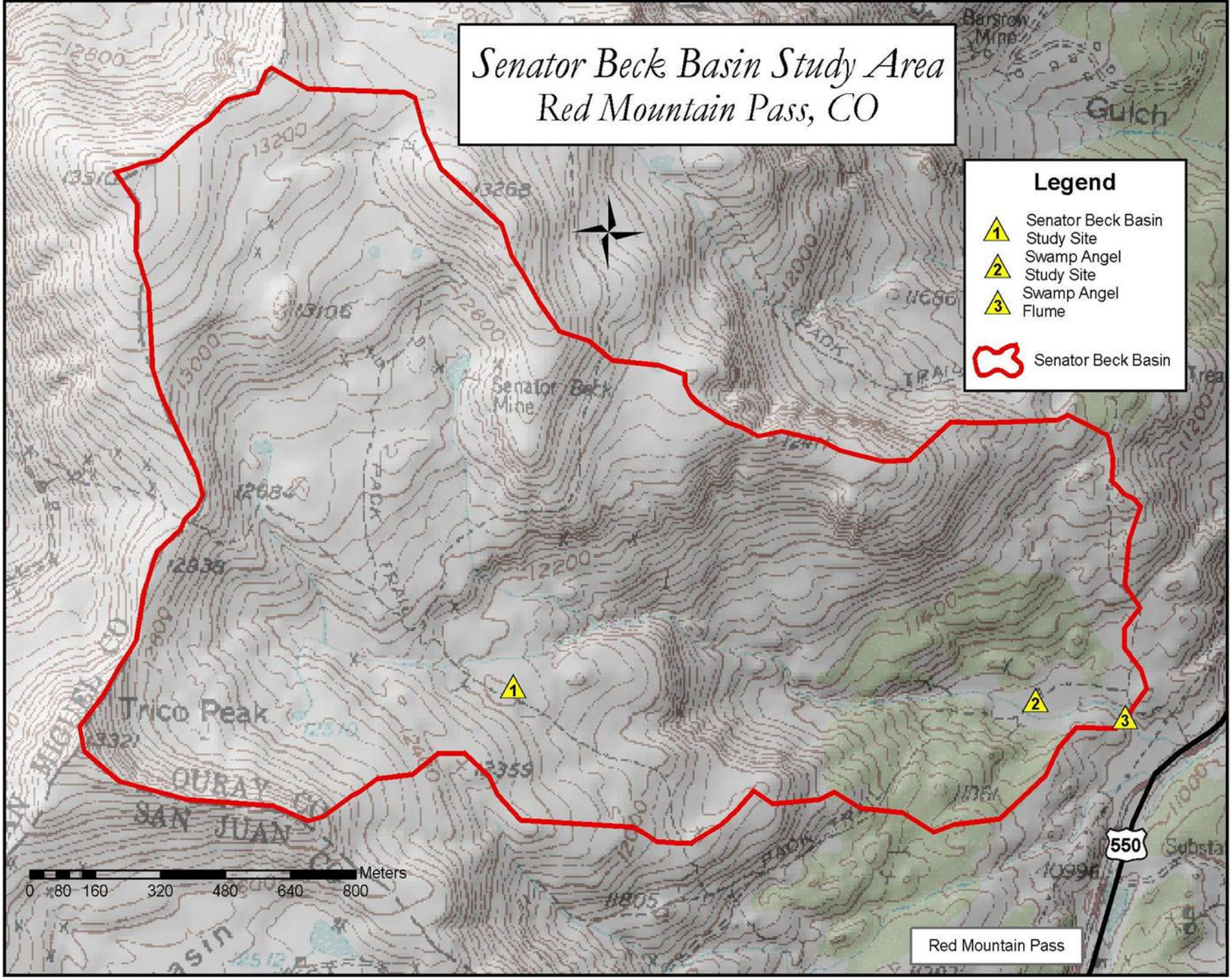

Silverton
April 3, 2009

D4 – WY2010
April 5, 2010




Silverton
April 5, 2010
THE WYMAN


May 21, 2004
Photo courtesy JPL - Ian McCubbin


Senator Beck Basin Study Area
Red Mountain Pass, CO
Legend
1 Senator Beck Basin Study Site
2 Swamp Angel Study Site
3 Swamp Angel Flume
Senator Beck Basin
Trico Peak
Senator Beck Mine
Gulch
550
Red Mountain Pass
0 80 160 320 480 640 800
Meters

Dust-on-Snow Deposition Log

Senator Beck Basin Study Area – Red Mountain Pass

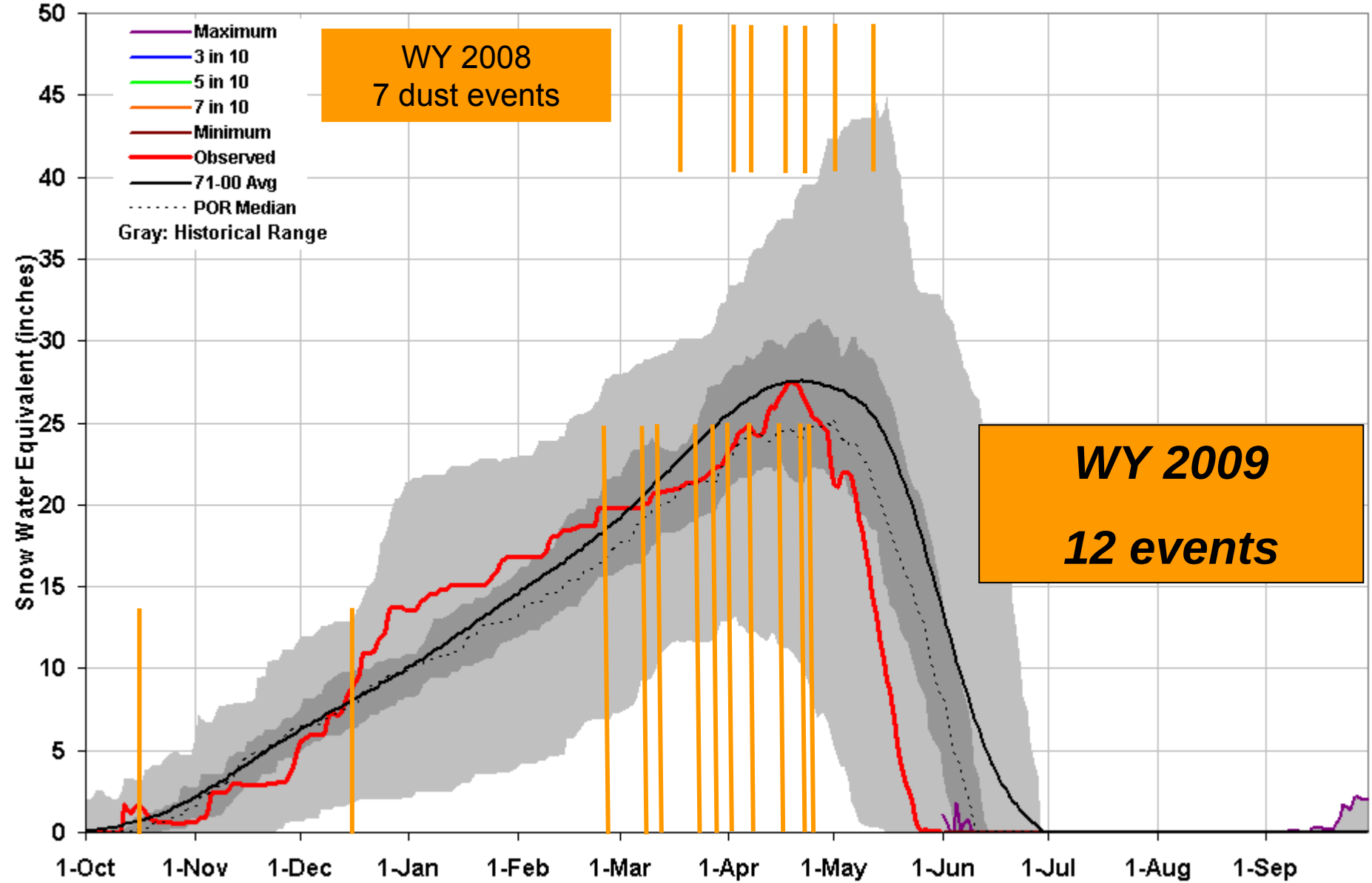
Dust-on-Snow Events Documented per Month, by Winter

Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
2002/2003					2		1			3
2003/2004							2	1		3
2004/2005	0	0	0	0	0	1	2	1	0	4
2005/2006	0	0	1	0	1	1	3	2	0	8
2006/2007	0	0	1	0	1	1	3	1	1	8
2007/2008	0	0	0	0	0	3	3	1	0	7
2008/2009	1	0	1	0	1	4	5	0	0	12
2009/2010	1	0	0	0	0	1	4	3	0	9

Created: 10:48 AM May 31, 2009

07M33S:Red Mountain Pass



NRCS

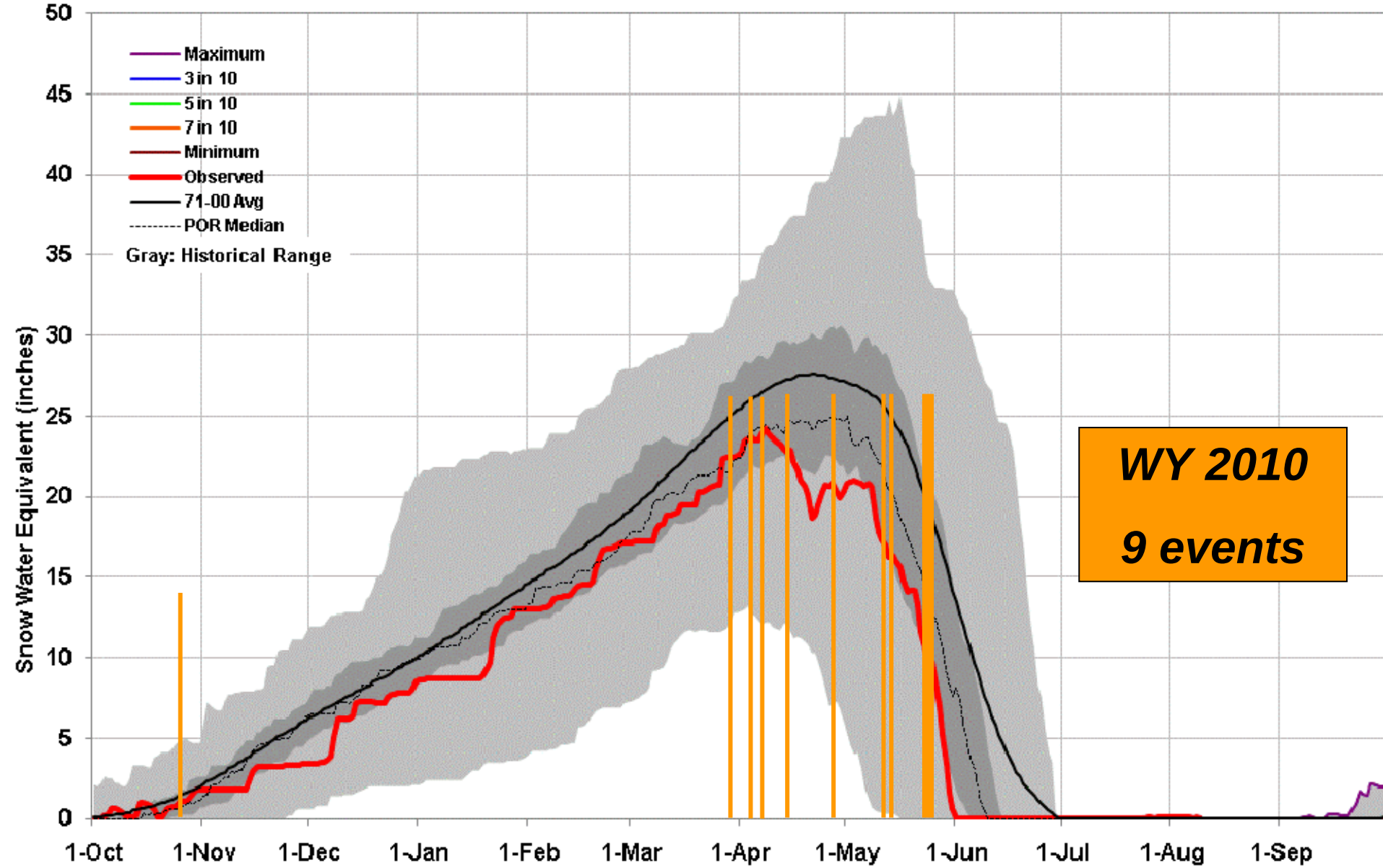
This is an automated product based on SNOTEL data, provisional data are subject to change.

This product combines the historical period of record data (**gray background**) with the recent daily data (**heavy red, left**) to project into the future (**colored lines, right**). This product does not consider climate information such as El Nino or short range weather forecasts and therefore should only be used as a seasonal planning tool. Contact Tom.Pagano@por.usda.gov 503 414 3010

May 12, 2009 – from Peak 13,510’ at top of Senator Beck Basin Study Area

07M33S: Red Mountain Pass

Created: 02:13 AM Aug 10, 2010



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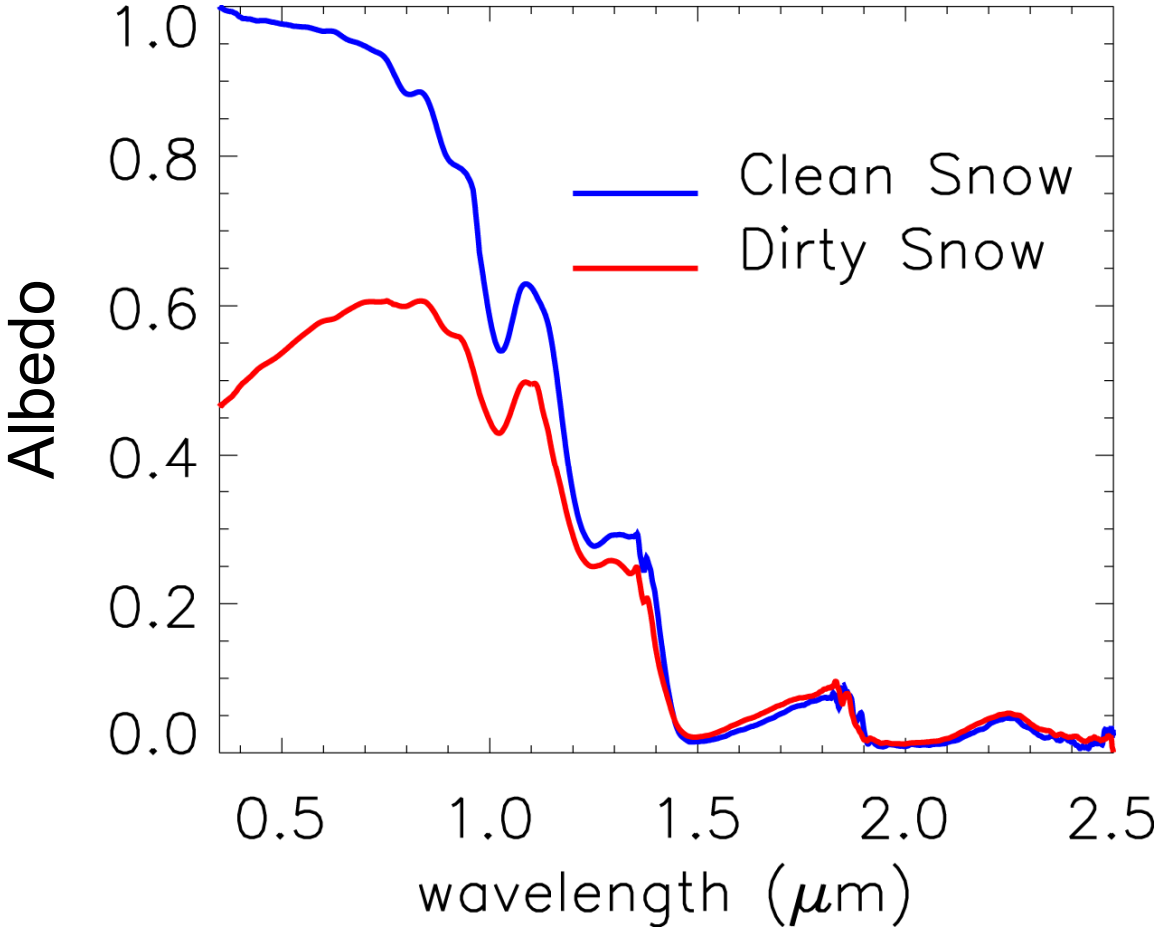
NRCS

Snow Albedo Measurement

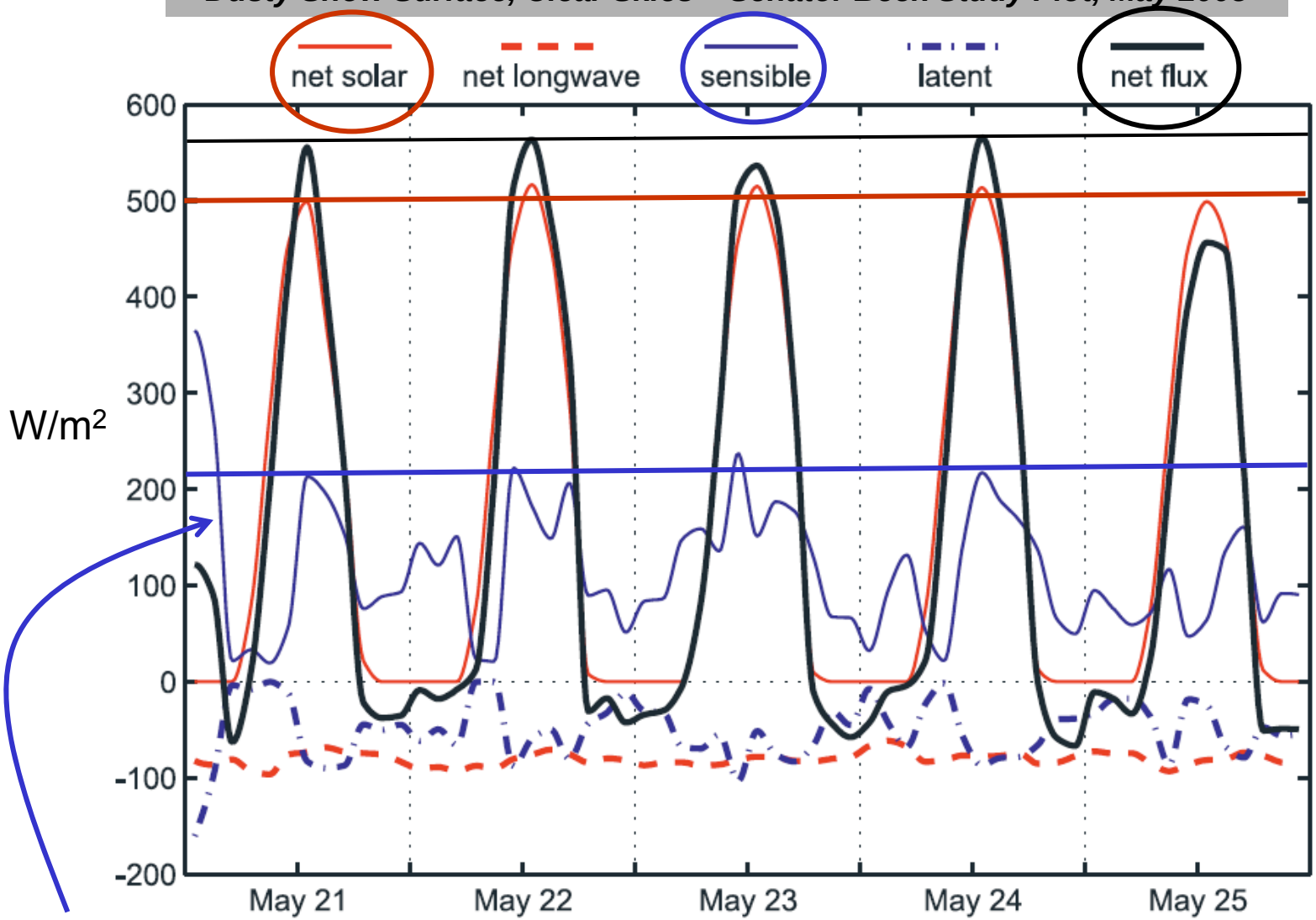
Senator Beck Study Plot 12,200’

Reduced Snow Albedo



Enhanced Snowmelt Energy Input

Dusty Snow Surface, Clear Skies – Senator Beck Study Plot, May 2005



Max Air T	**57 F**	**57 F**	**56 F**	**53 F**	**56 F**

Maximum Dust at Top of Snowpack
(all or most layers merged):

Spring 2008 = 12 gm/m^2

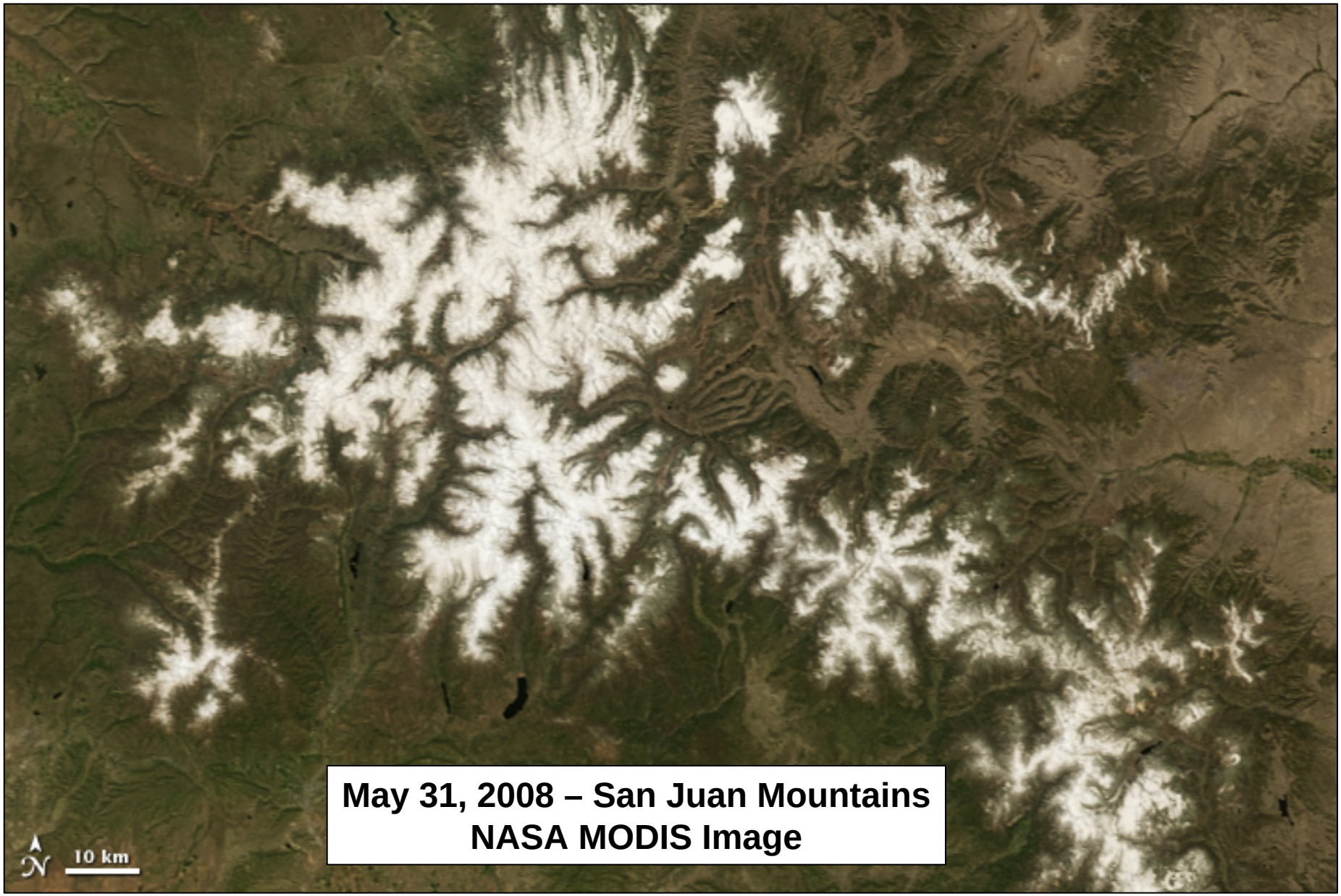
Spring 2009 = 55 gm/m^2

Spring 2010 = ~40 gm/m^2

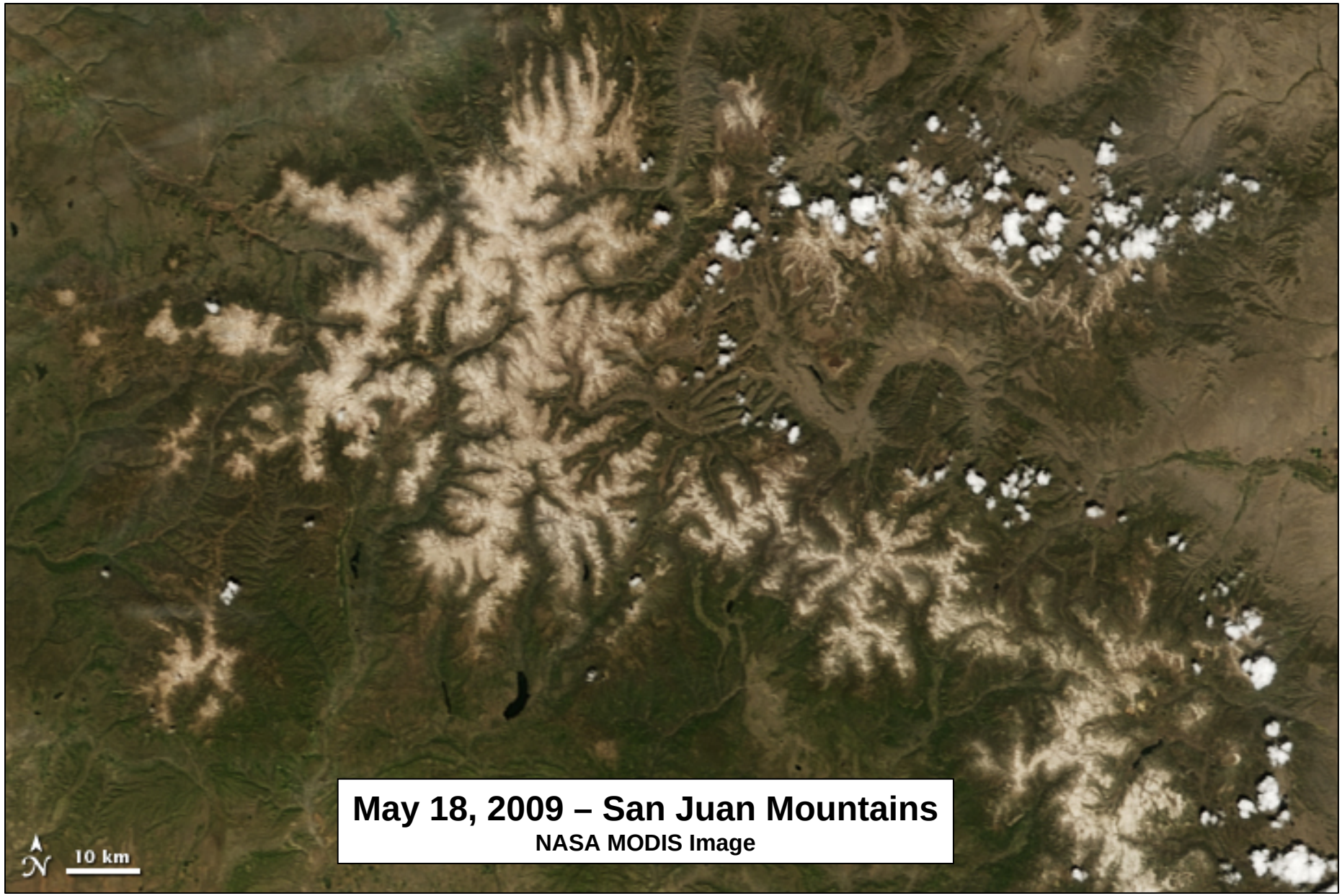
May 28, 2010 – Swamp Angel Study Plot

May 13, 2009 – Swamp Angel Study Plot

Large-Scale Albedo Reductions



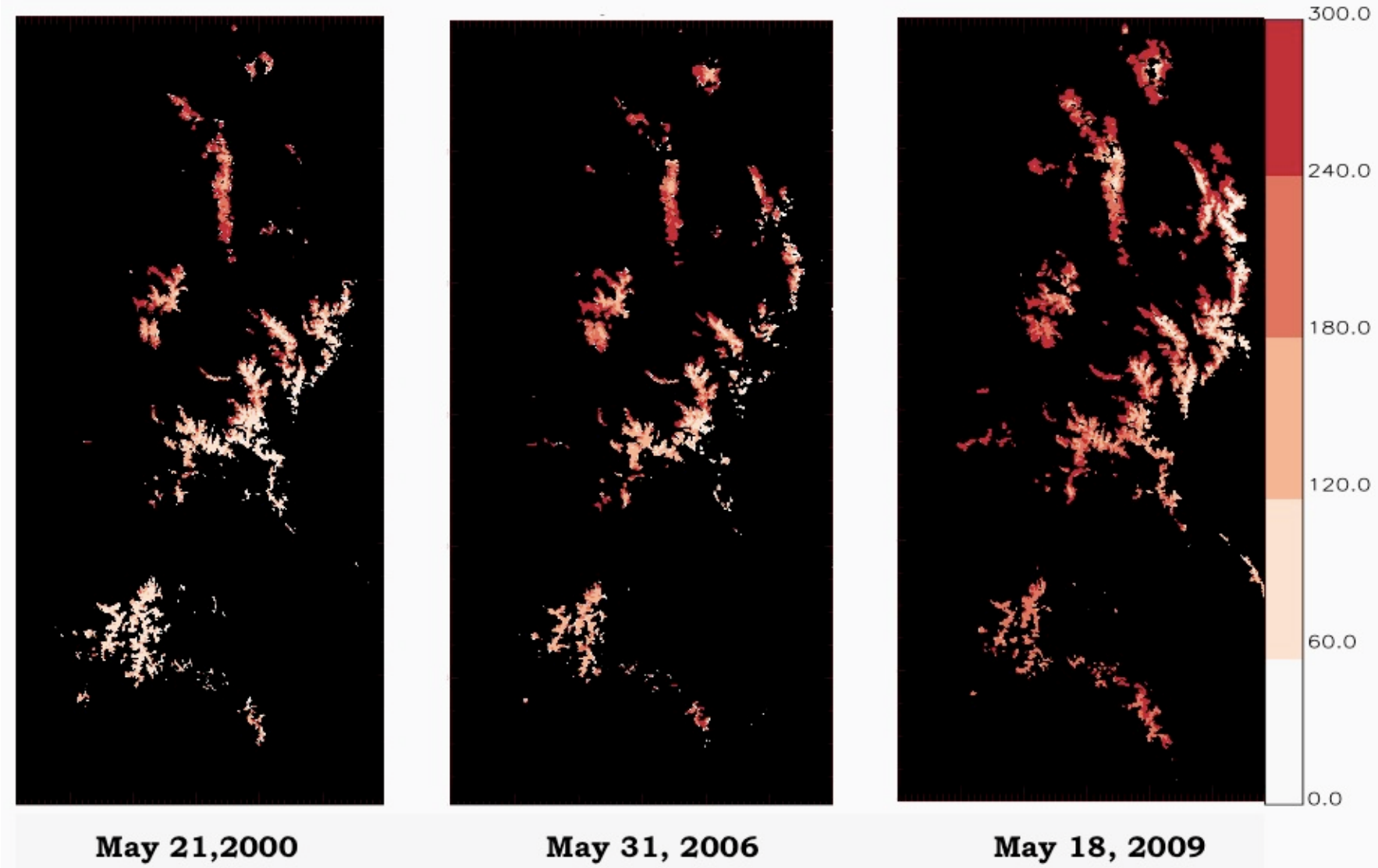
Large-Scale Albedo Reductions

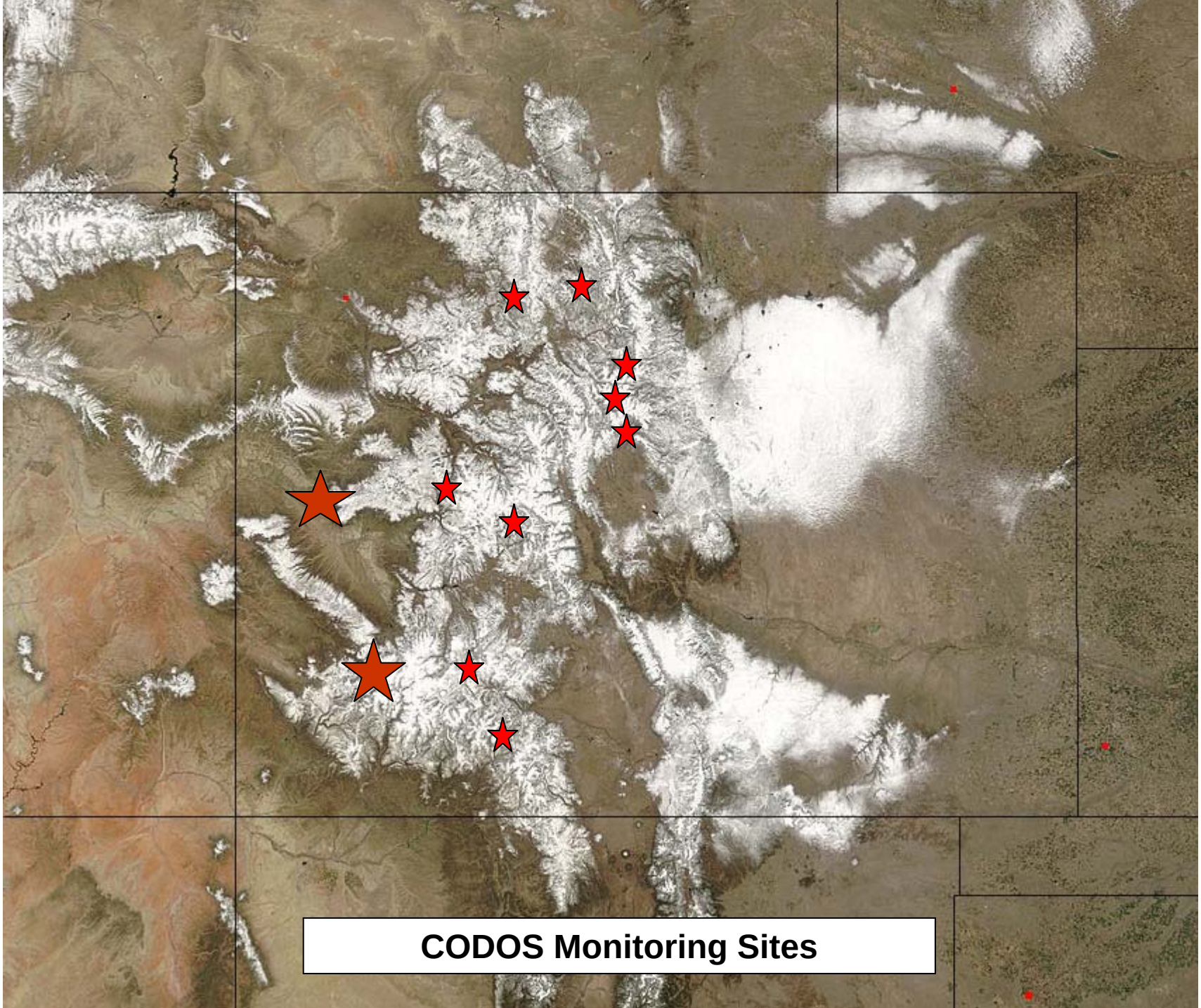


MOD-DRFS Analysis

MODIS – Dust Radiative Forcing in Snow

Courtesy Annie Bryant – Snow Optics Lab




CODOS Monitoring Sites

Senator Beck Basin: March 22, March 29, April 3, April 8, April 15 2009 layers

Below Treeline – April 22, 2009

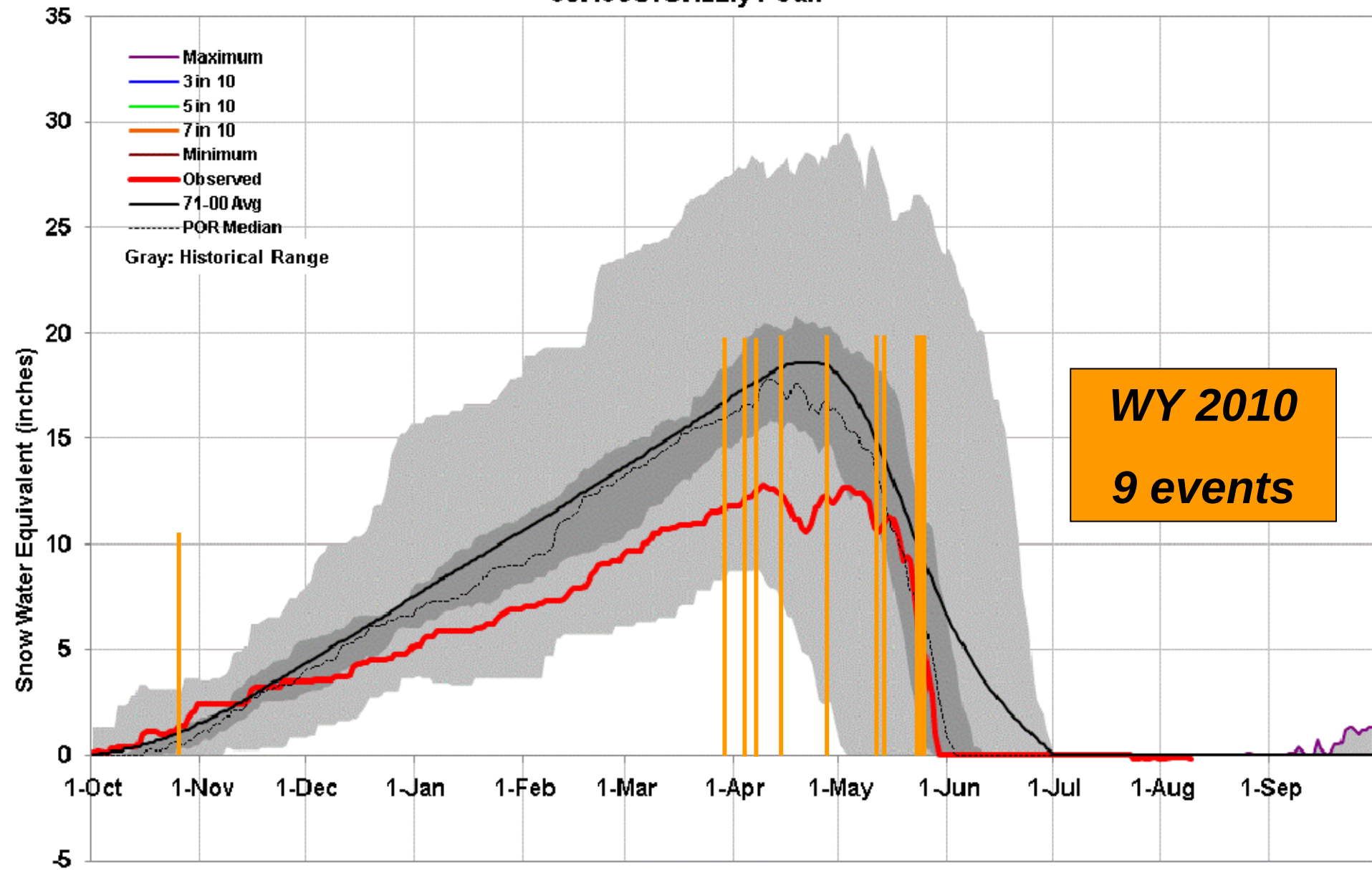
Above Treeline – April 24, 2009


April 17, 2009 – Berthoud Pass

March 23, 2010 – Grizzly Peak Snotel

05K09S:Grizzly Peak

Created: 02:05 AM Aug 10, 2010



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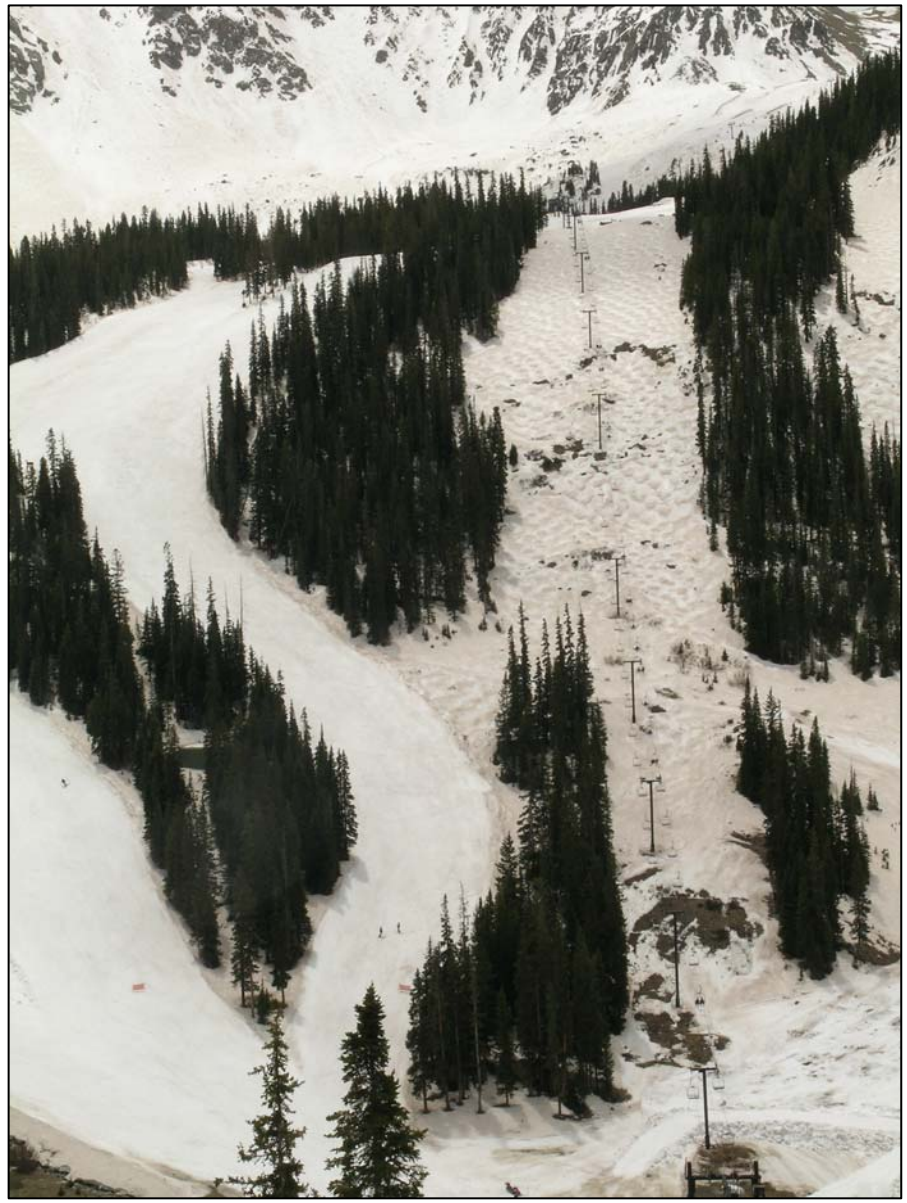
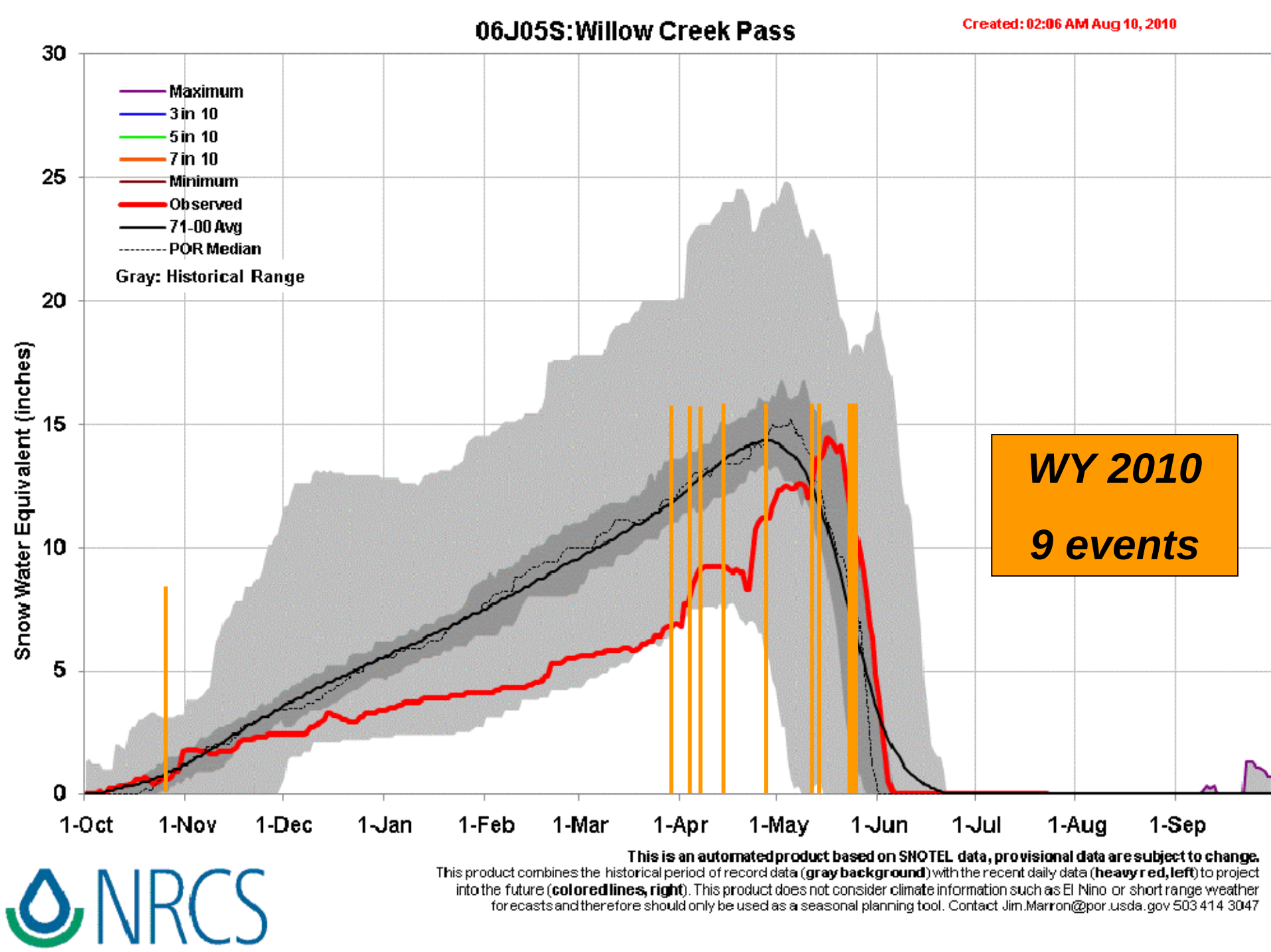
May 26, 2010 – Grizzly Peak Snotel, A-Basin



Dust Loading in Spring 2009 & Spring 2010

CODOS Monitoring Site	Spring 2009 Total Dust Load in Column Sample, (*mg*)	Spring 2010 Total Dust Load in Column Sample, (*mg*)
Swamp Angel Study Plot	584	325
Wolf Creek Summit	393	349
Hoosier Pass	106	172
Grizzly Peak	109	270
Berthoud Summit	110	189
Rabbit Ears Pass	217	111


06J05S:Willow Creek Pass
Created: 02:06 AM Aug 10, 2010
Maximum
3 in 10
5 in 10
7 in 10
Minimum
Observed
71-00 Avg
POR Median
Gray: Historical Range
Snow Water Equivalent (inches)
30
25
20
15
10
5
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
WY 2010
9 events
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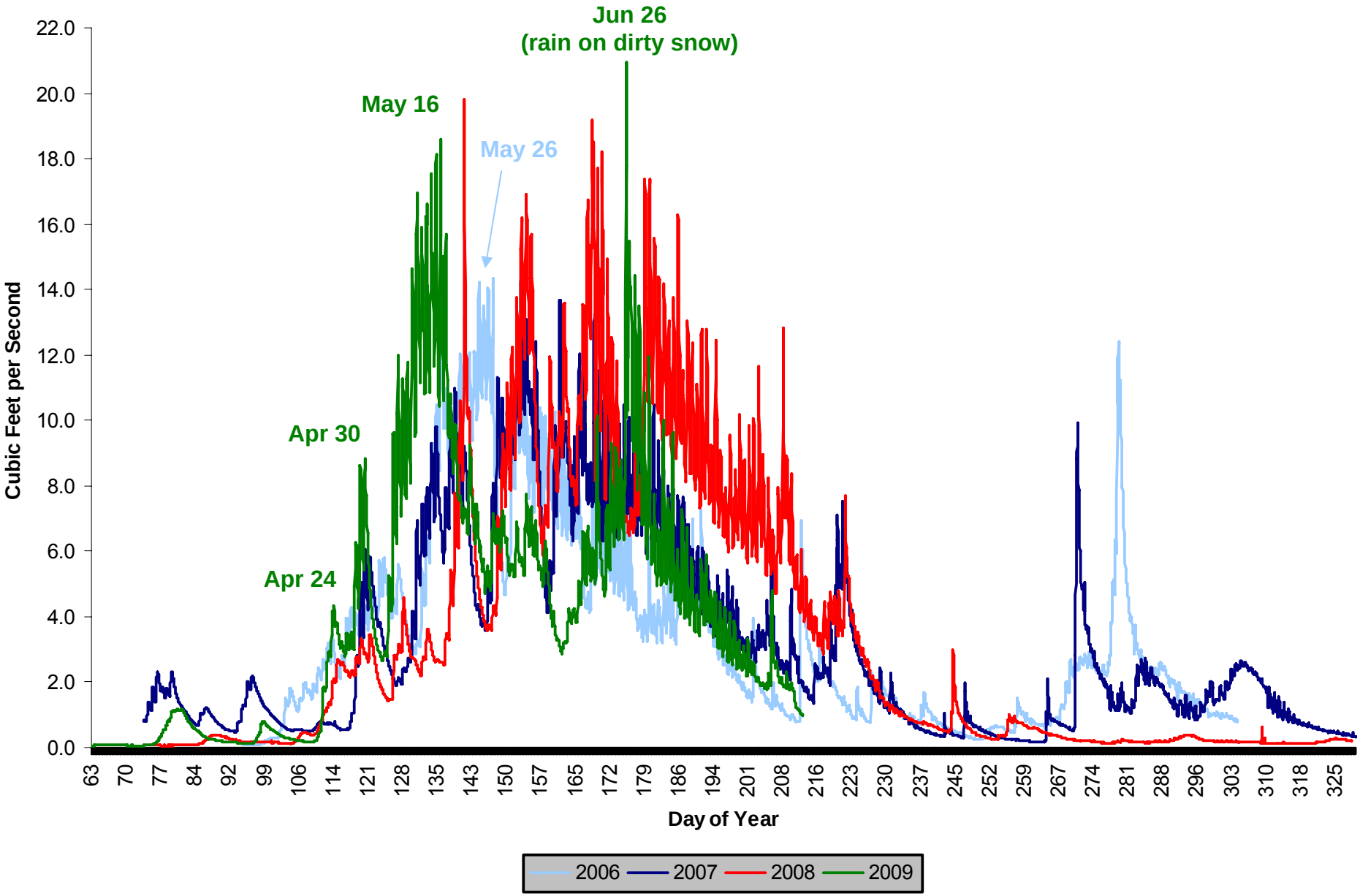
NRCS

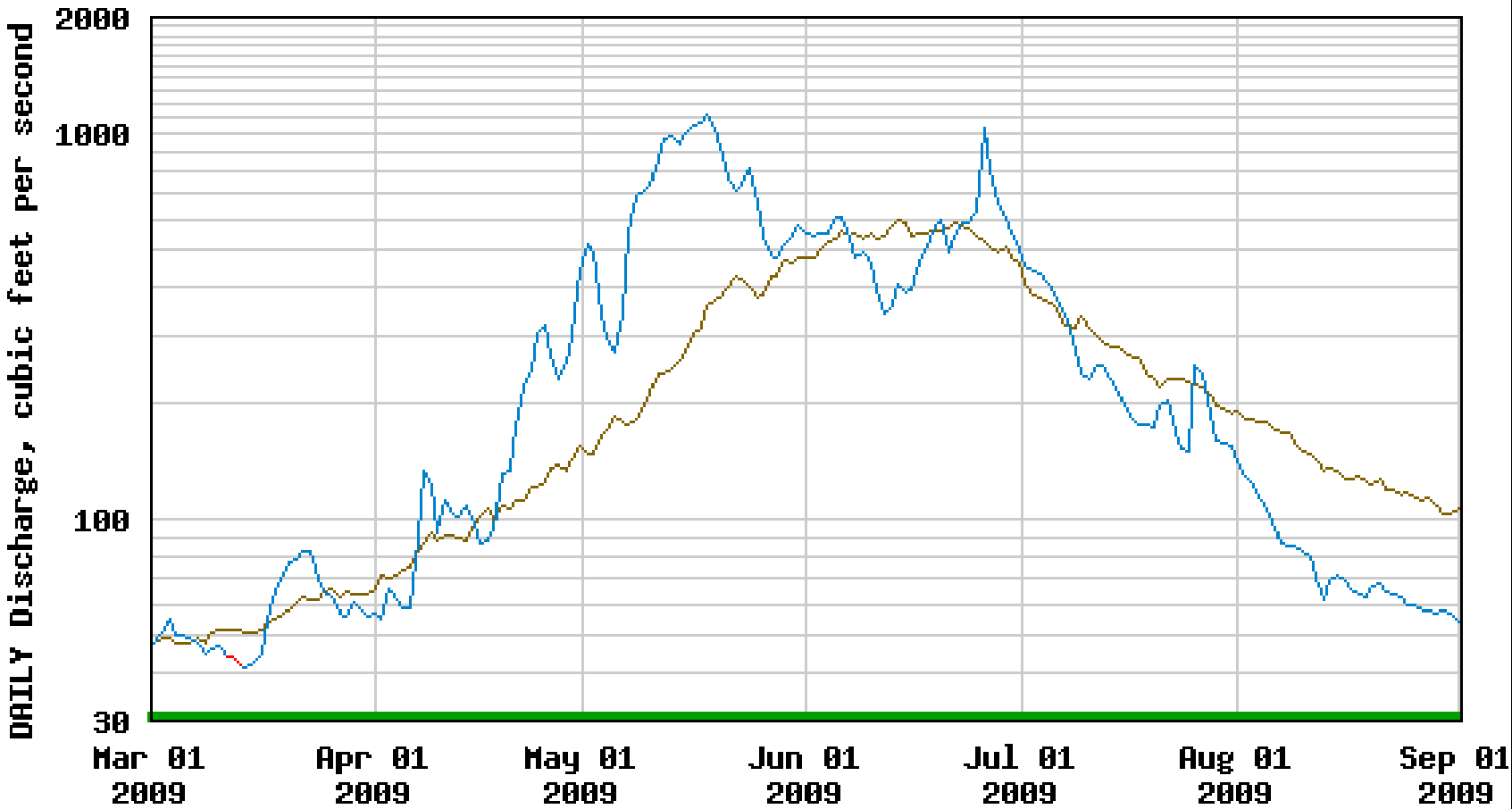
May 13, 2009 –Senator Beck Stream Gauge at 16 cfs

Senator Beck Basin Discharge – WY 2006, 2007, 2008 & 2009



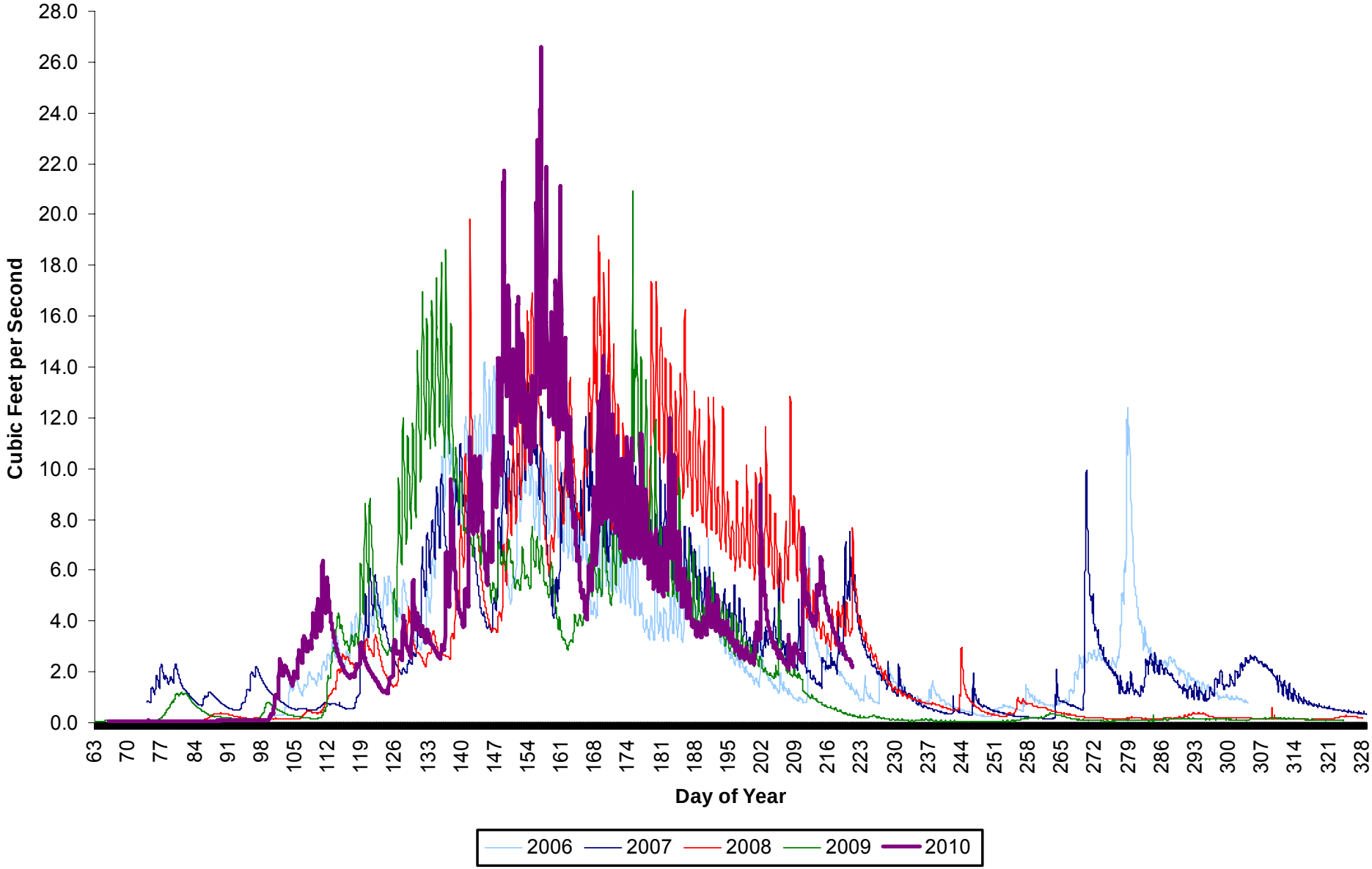
USGS

USGS 09146200 UNCOMPAHGRE RIVER NEAR RIDGWAY, CO.



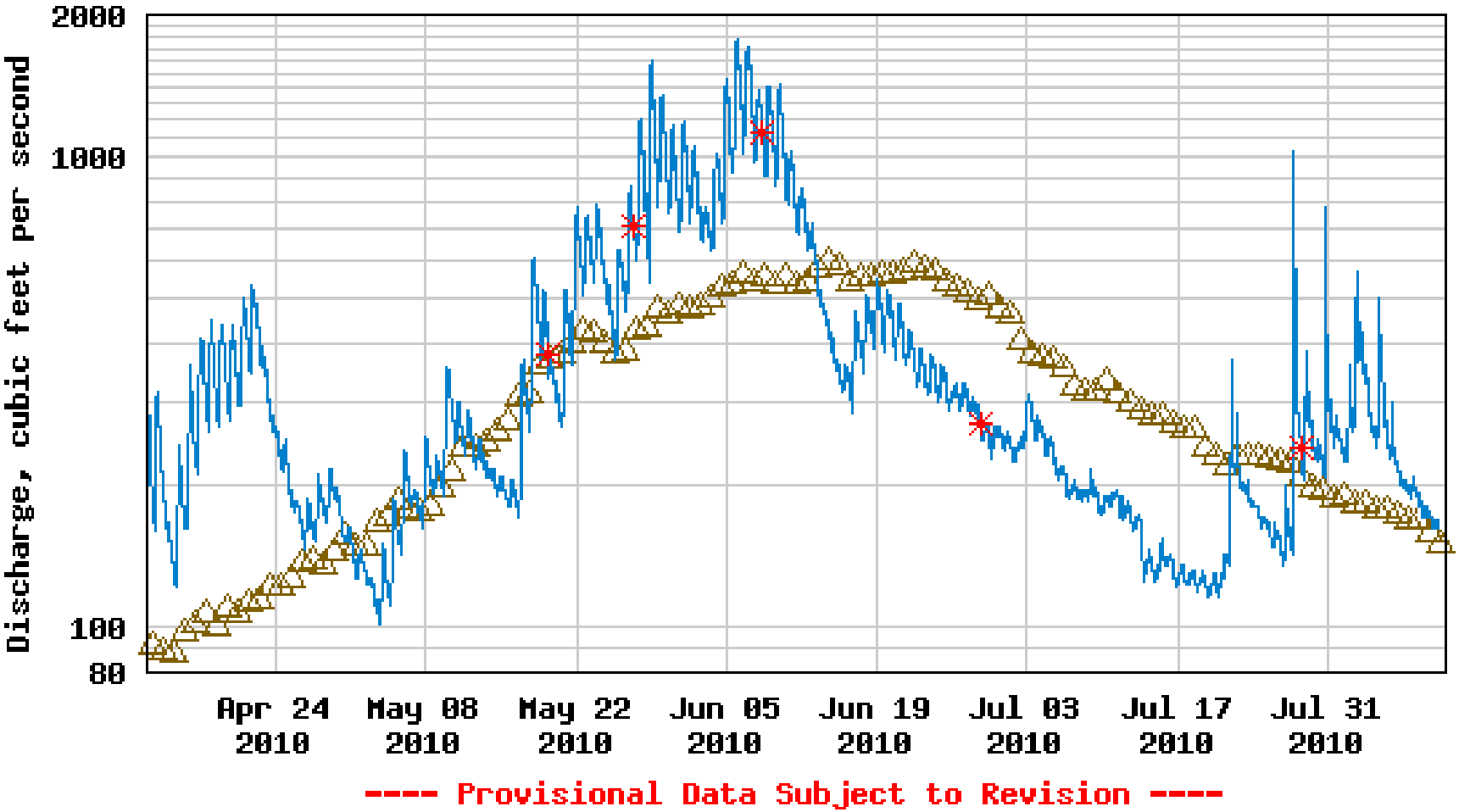
June 5, 2010 –Senator Beck Stream Gauge at 26 cfs

Senator Beck Basin Discharge – WY 2006, 2007, 2008 & 2009, 2010



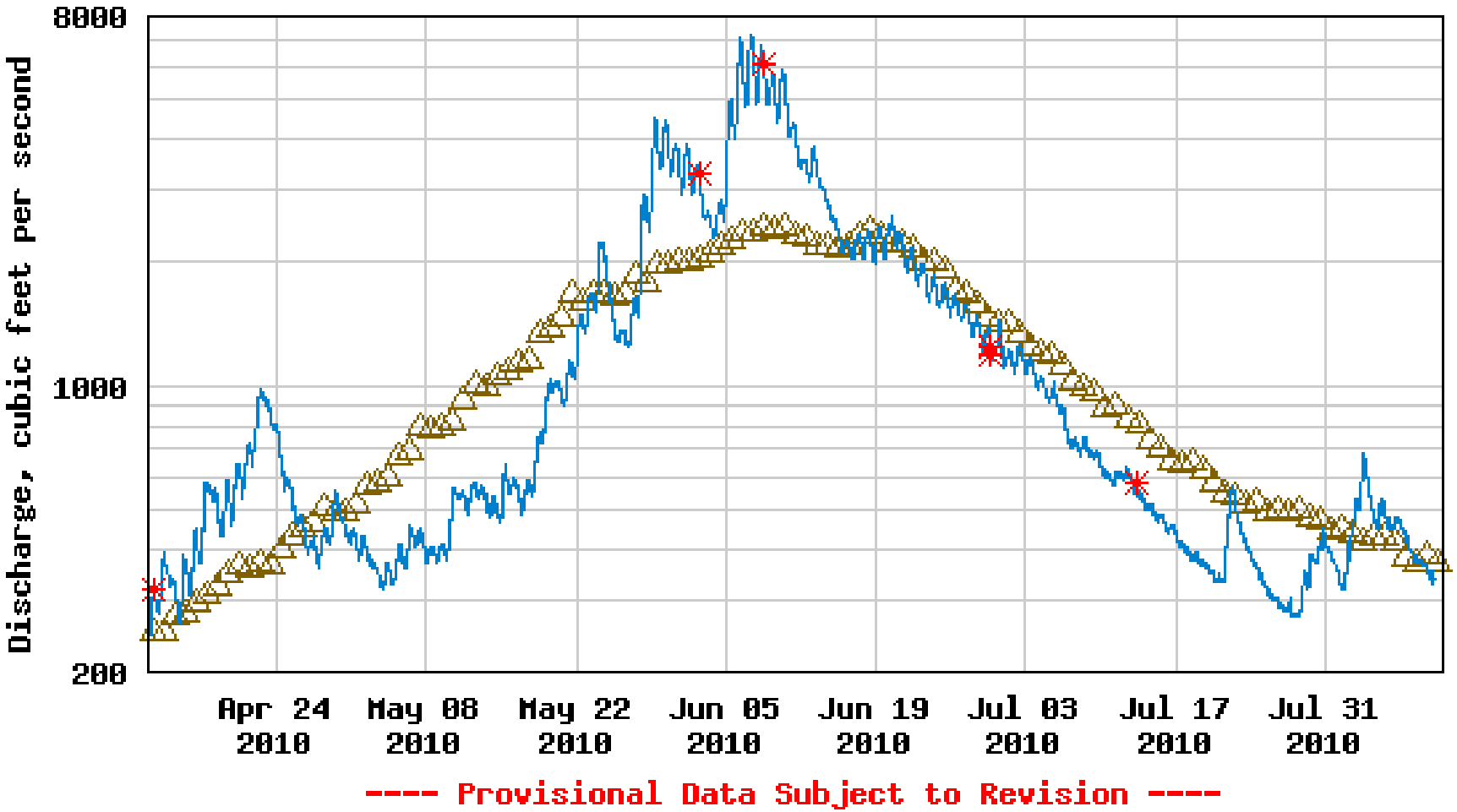
USGS

USGS 09146200 UNCOMPAHGRE RIVER NEAR RIDGWAY, CO.



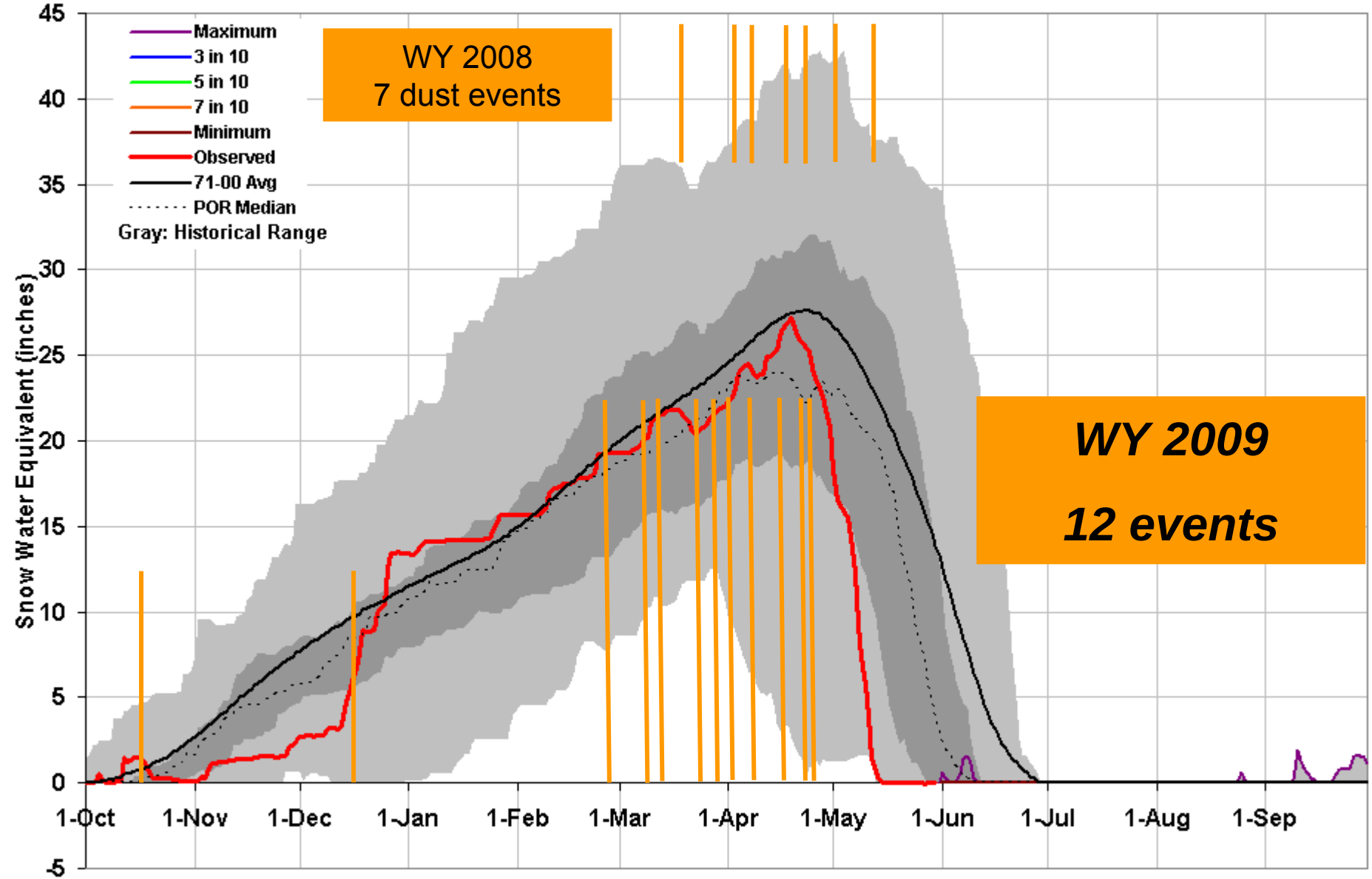
USGS

USGS 09070000 EAGLE RIVER BELOW GYPSUM, CO.



Created: 10:48 AM May 31, 2009

07M32S:Beartown



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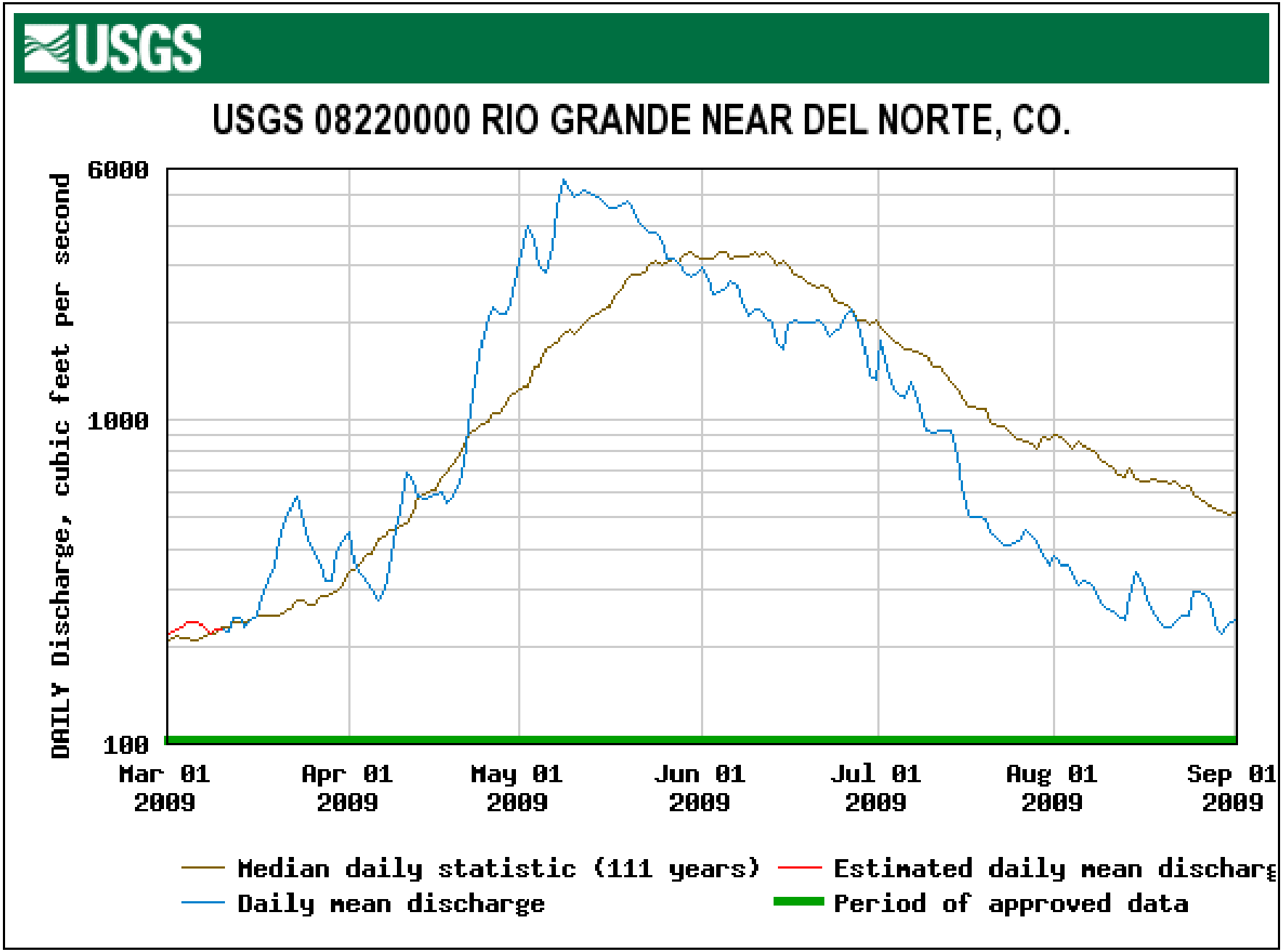
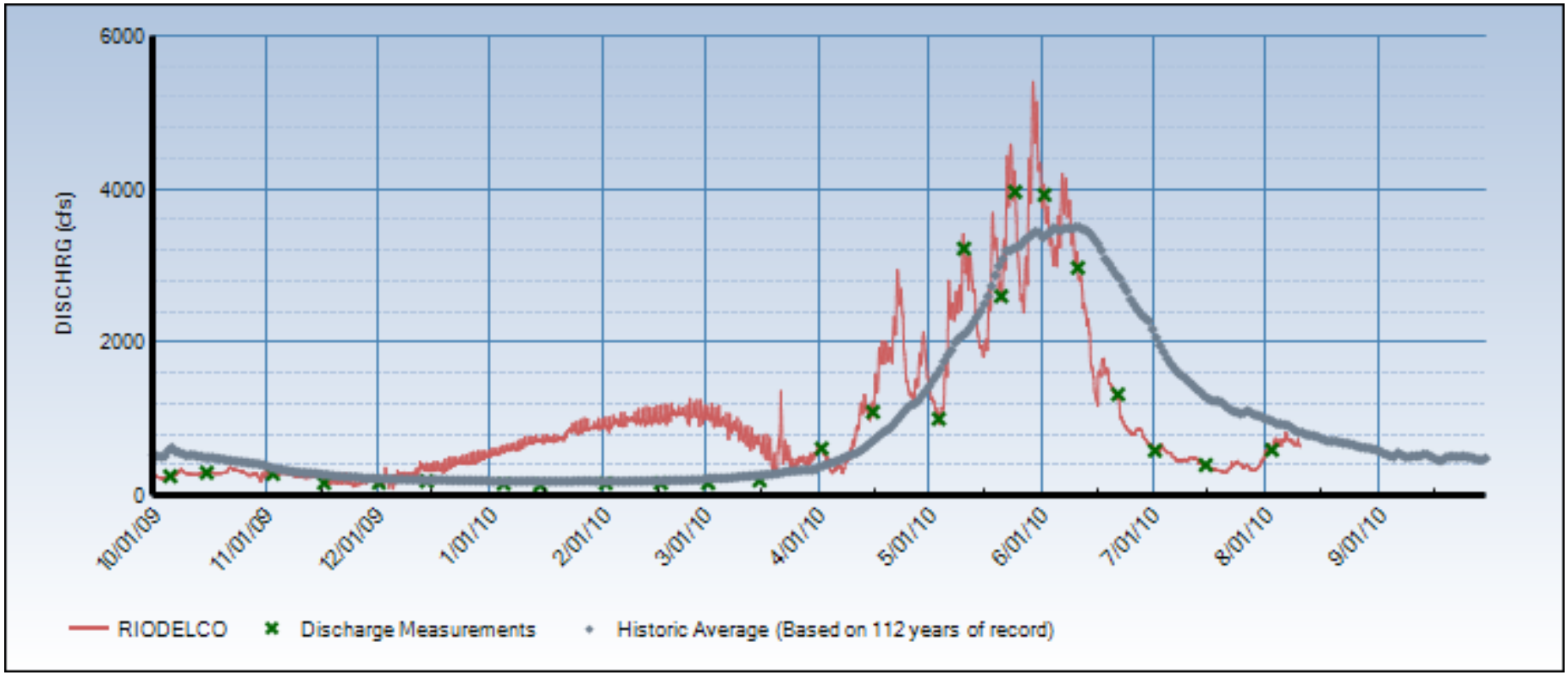
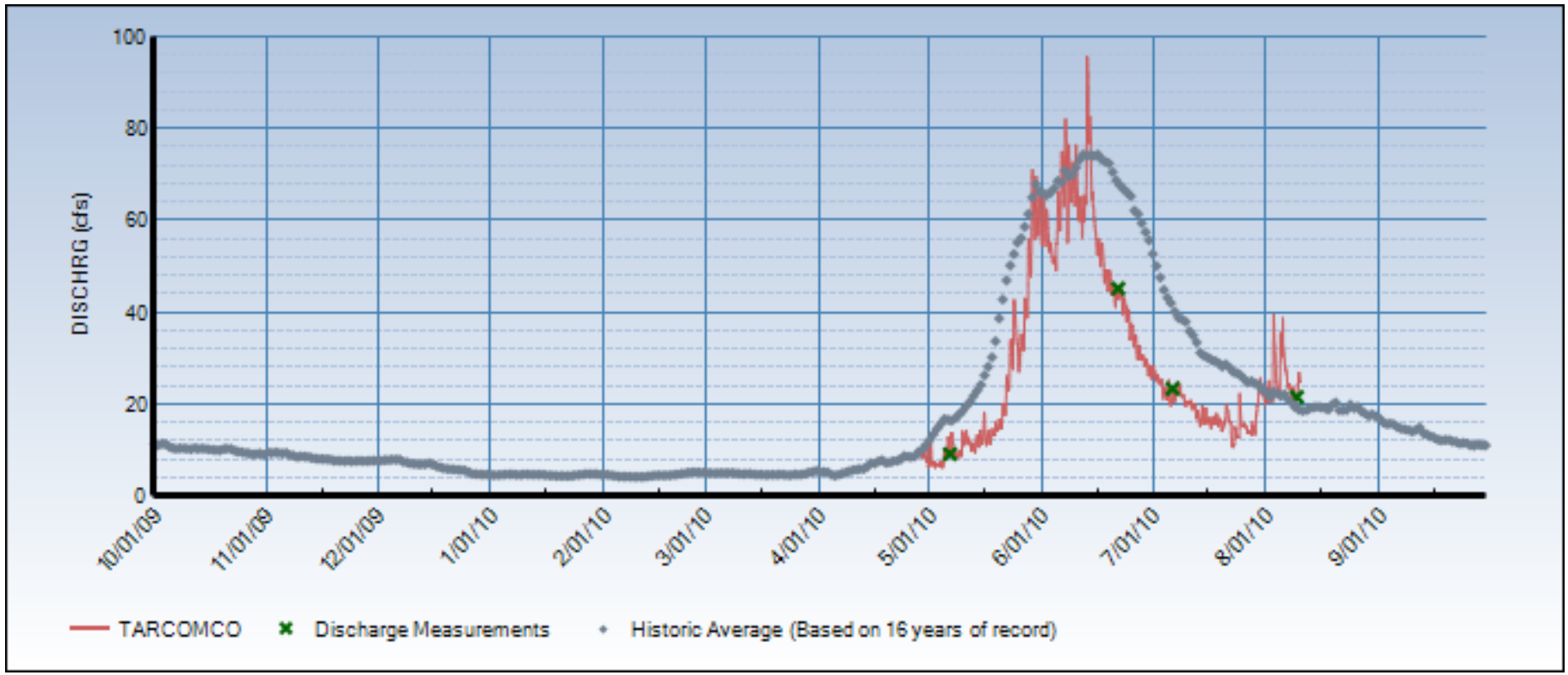

USGS
USGS 08220000 RIO GRANDE NEAR DEL NORTE, CO.
DAILY Discharge, cubic feet per second
6000
1000
100
Mar 01 2009
Apr 01 2009
May 01 2009
Jun 01 2009
Jul 01 2009
Aug 01 2009
Sep 01
Median daily statistic (111 years)
Estimated daily mean discharg
Daily mean discharge
Period of approved data

Rio Grande at Del Norte
WY 2010



Tarryall Creek At US 285 Near Como
WY 2010



Well-constrained, plot-scale snowmelt models

$$\frac{dU}{dt} + Q_m = (1-\alpha)S + L^* + Q_s + Q_v + Q_g + Q_r$$

where (1-α) = albedo

S = solar irradiance

L^* = net longwave flux

Q_s = sensible heating flux

Q_v = latent heating flux

Q_g = ground heating flux

Q_m = melting energy flux

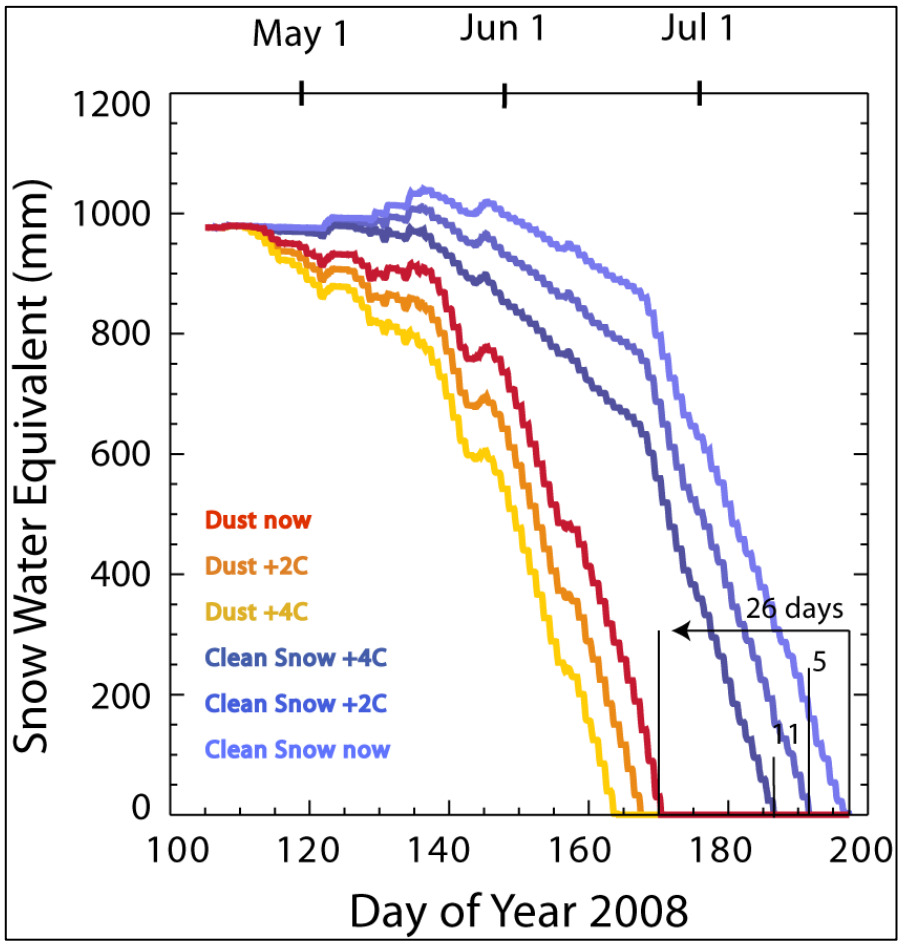
dU/dt = change in internal energy

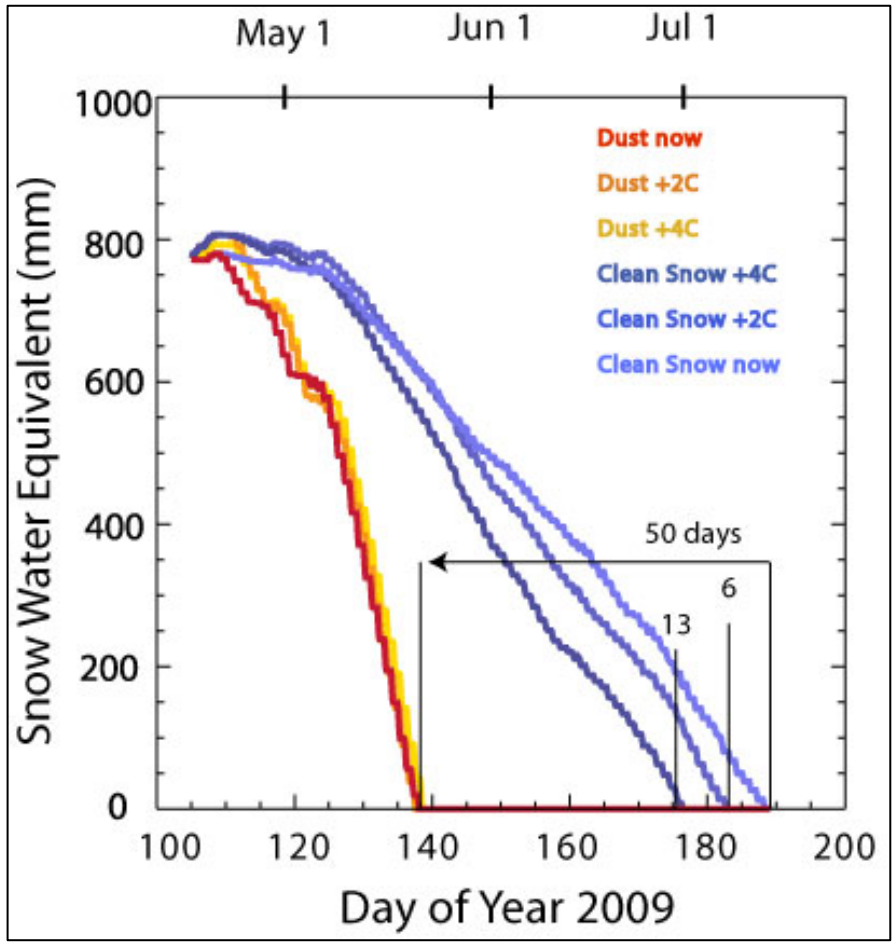
Painter, T. H., A. P. Barrett, C. C. Landry, J. C. Neff, M. P. Cassidy, C. R. Lawrence, K. P. Thatcher, L. Farmer. (2007) Impact of disturbed desert soils on duration of mountain snow cover. *Geophysical Research Letters.* V34, 12, L12502, 10.1029/2007GL030208.

Advances in Snow All Gone, aka SAG

from *Skiles et al,* in preparation

… using measured SWE to initiate the modeling and actual weather data to drive the modeling …





Advances in SAG

2005 - 2009

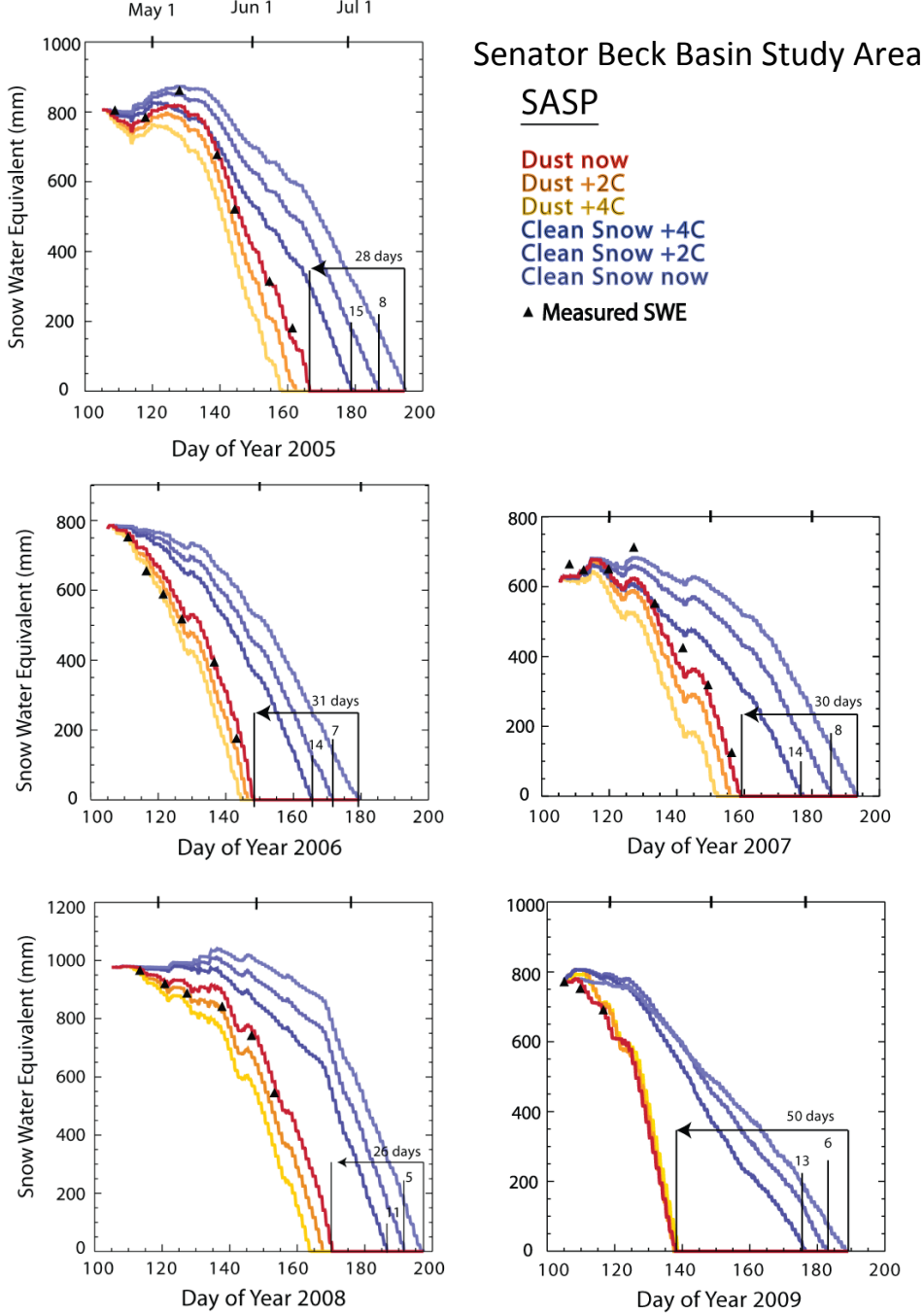
Dust Forcing

26-50 Days

Dust Plus 2º	Clean Plus 2º
0-2 Days	5-8 Days

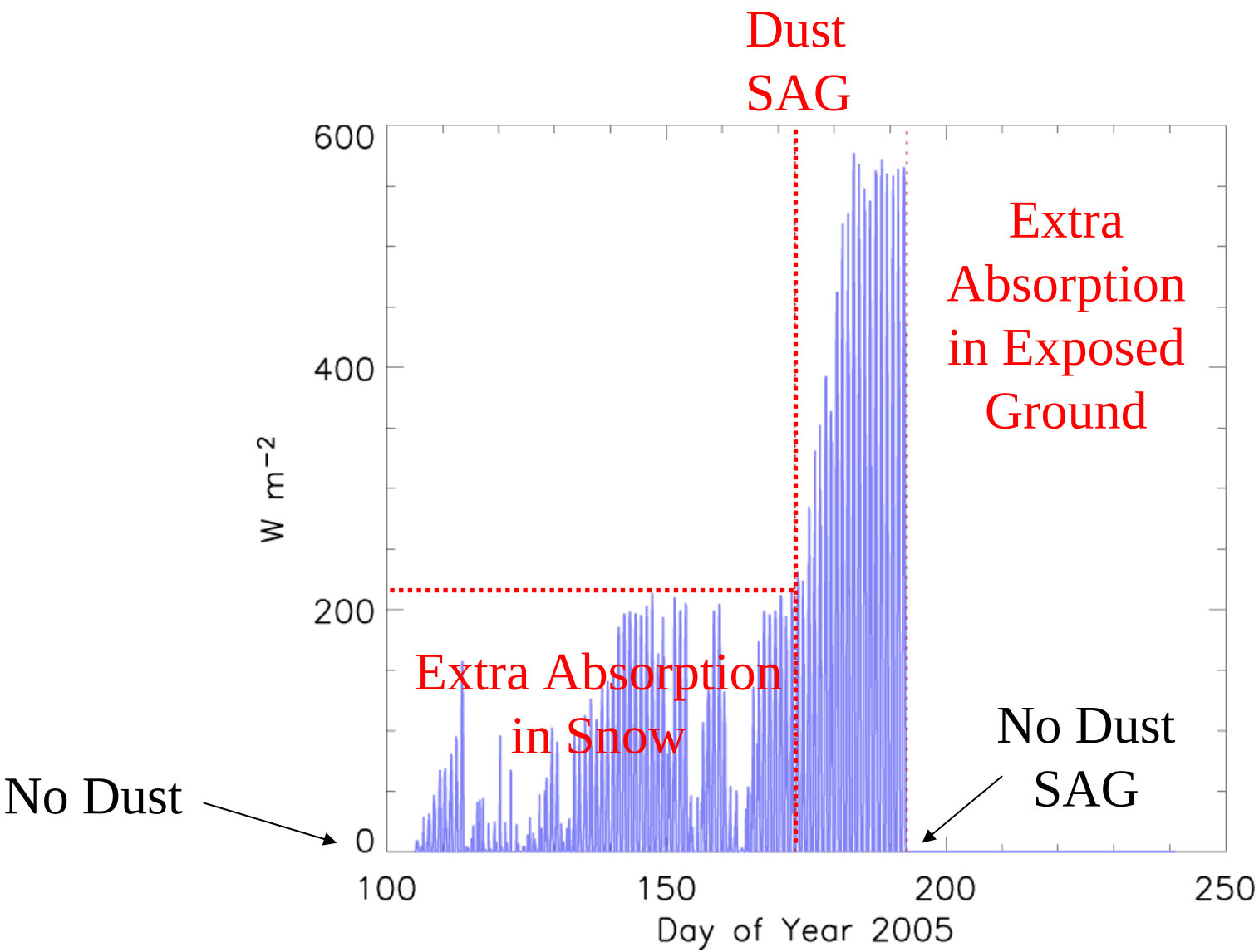
Dust Plus 4º	Clean Plus 4º
1-4 Days	11-15 Days

from *Skiles et al,* in preparation

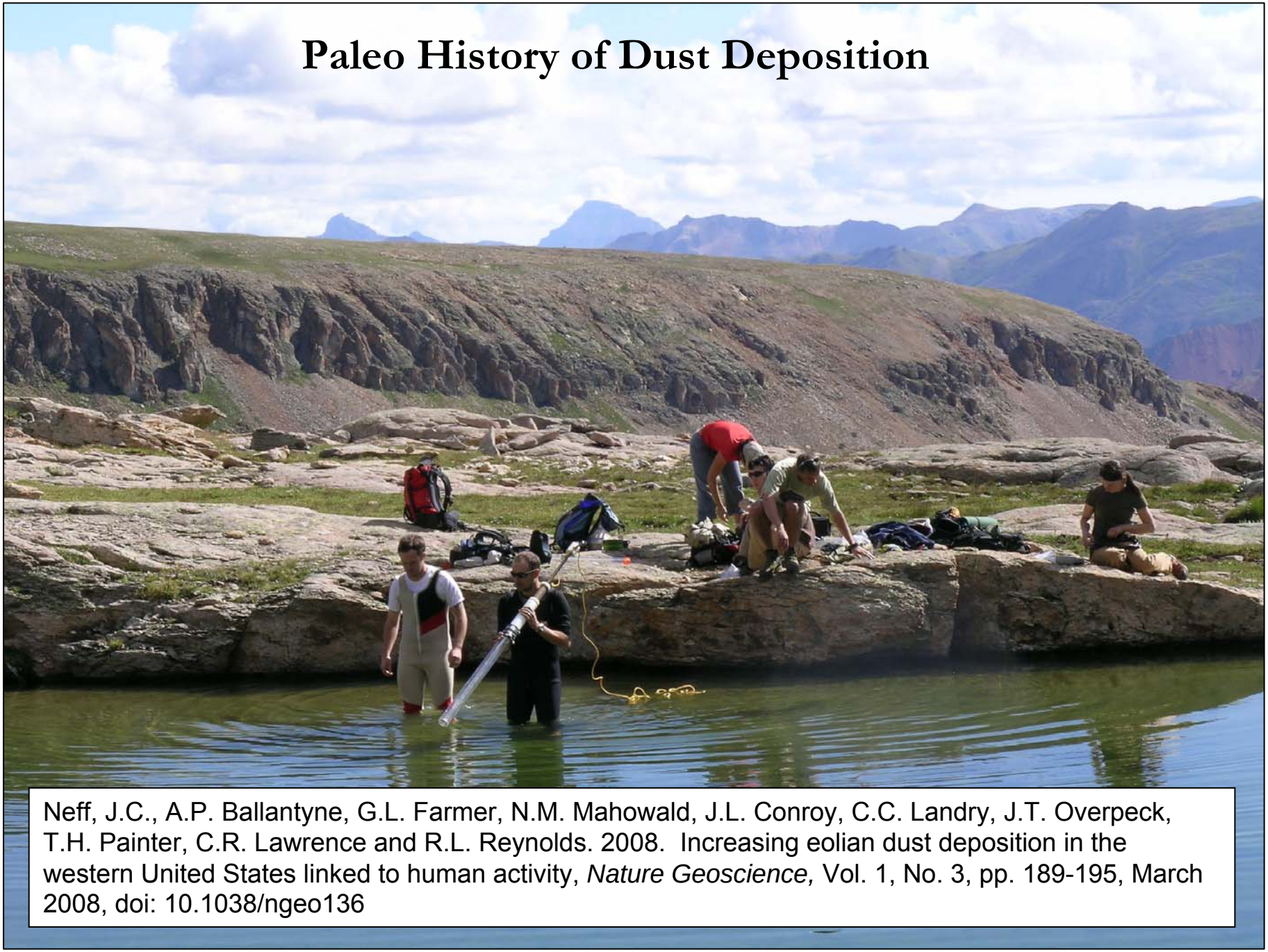


Dust Effects on Alpine Energy Budget – 2005

Senator Beck Study Plot



Paleo History of Dust Deposition



Neff, J.C., A.P. Ballantyne, G.L. Farmer, N.M. Mahowald, J.L. Conroy, C.C. Landry, J.T. Overpeck, T.H. Painter, C.R. Lawrence and R.L. Reynolds. 2008. Increasing eolian dust deposition in the western United States linked to human activity, *Nature Geoscience,* Vol. 1, No. 3, pp. 189-195, March 2008, doi: 10.1038/ngeo136

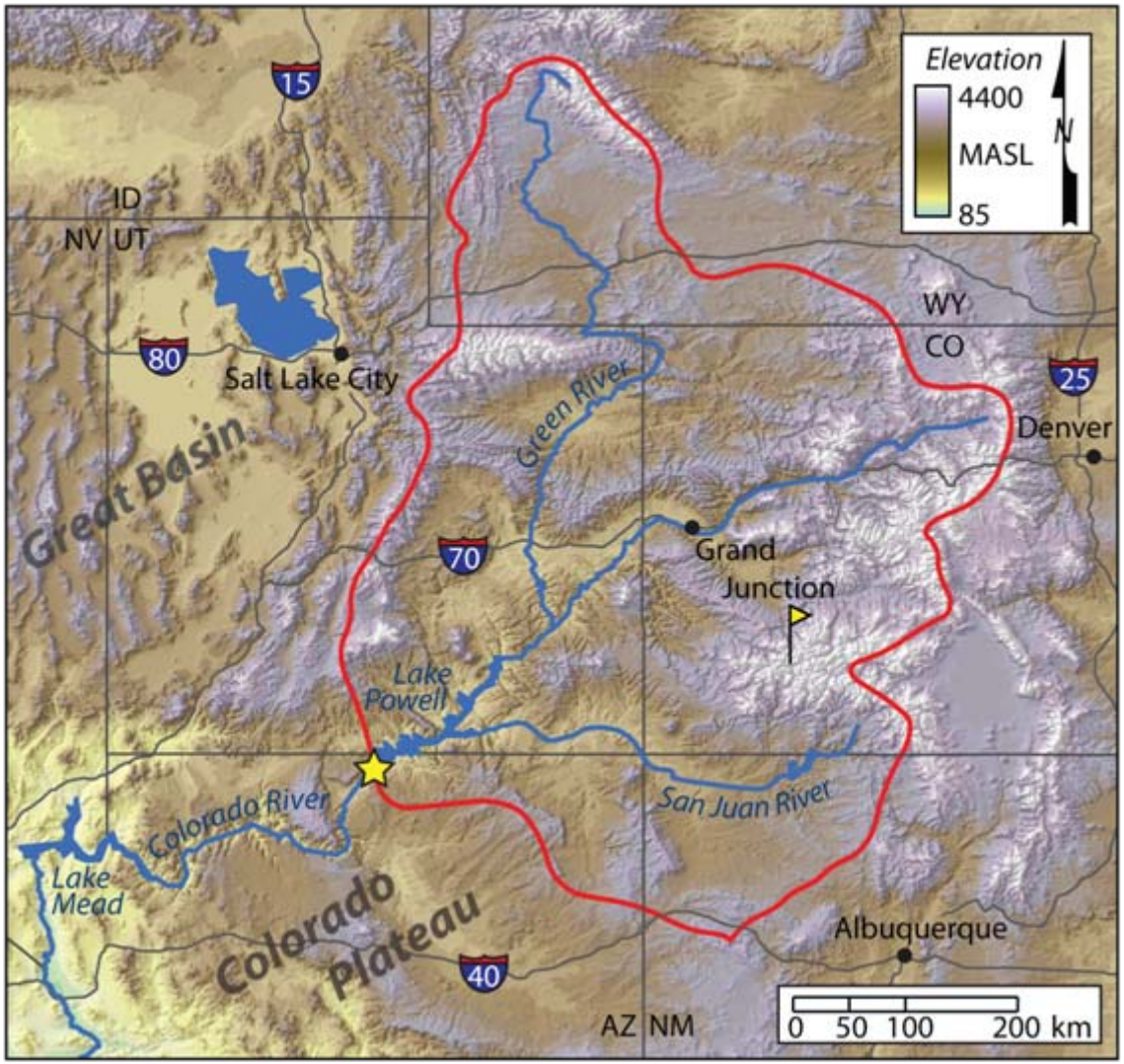
Biogeochemistry of Dust Deposition

Lawrence, C. R., T. H. Painter, C. C. Landry, and J. C. Neff (2010), Contemporary geochemical composition and flux of aeolian dust to the San Juan Mountains, Colorado, United States, *J. Geophys. Res.,* 115, G03007, doi:10.1029/2009JG001077.

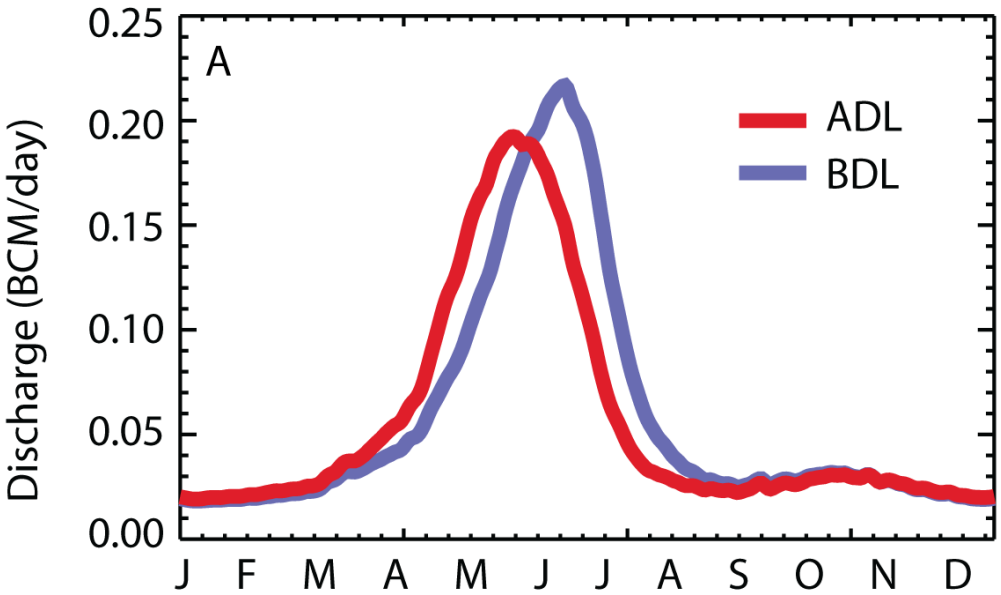

Early SAG Effects on
Alpine Phenology
Add ~ 50 gm/m2
Spring 2008

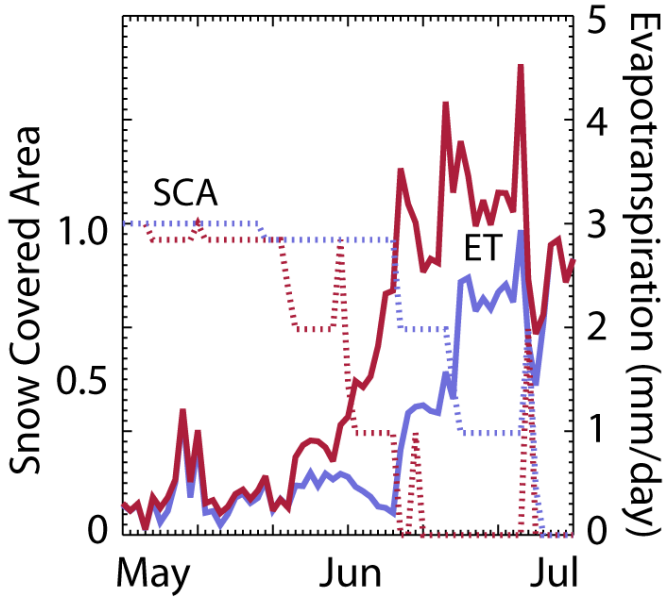
Steltzer, H., C, Landry, T. H. Painter, J. Anderson, and E. Ayres. 2009.Biological consequences of earlier snowmelt from desert dust deposition in alpine landscapes. *Proceedings of the National Academy of Sciences.* 106: 11629-11634, doi_10.1073_pnas.0900758106.

What do we know from the not-as-constrained modeling? (VIC)



Runoff at Lees Ferry, AZ





Painter et al., PNAS, in press

What we have learned *since 2003/2004 …*

- **Dust-on-snow is extensive, affecting all Colorado mountain watersheds**
- **Dust deposition rates are about 5-6X higher than pre-settlement rates**
- **The Colorado Plateau is the dominant source of dust on Colorado snow**

When dust is present at or near the snowpack surface …

- **Reduced albedo = 2x to 3x more melt energy available (*vs*. air temp only)**
- **Snowpack ripening and snowmelt onset are advanced (*vs*. air temp only)**
- **Melt rates accelerate, advancing SAG up to 50 days (*vs*. air temp only)**
- **Dust effects already exceed climate forcing (warming) effects**

What we <u>do not</u> yet know …

- **Exactly why the winters of 2008/2009 and 2009/2010 were so dusty**
- **Whether the rate of dust deposition in recent decades is changing**
- **Shares of dust attributable to the variety of agents disturbing CP soils**

CODOS Updates

CENTER FOR SNOW & AVALANCHE STUDIES

WESTERN WATER ASSESSMENT

SOL Snow Optics Laboratory

CODOS – Colorado Dust-on-Snow – WY 2010
Update #7, Thursday, May 20, 2010

Snotel and stream gauge data throughout the state reflect divergence, from north to south, in snowmelt progress this spring. Many Snotel sites north of I-70 have recently benefited from storms that have maintained or produced gains in SWE in late April and early May (Figures 1 and 2) while simultaneously restoring and sustaining a high snowpack albedo. In contrast, after much less new snow, Snotel sites in the southern mountains have experienced large (or total) losses of SWE (Figures 3 and 4), under more prolonged periods of exposed dust-on-snow and low albedo.

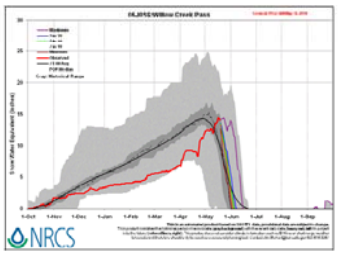


Figure 1: *Willow Creek Pass Snotel, at 9,540', WY2010 graph showing brief episodes of dust-enhanced snowmelt during late April and May followed by significant increases in SWE.*

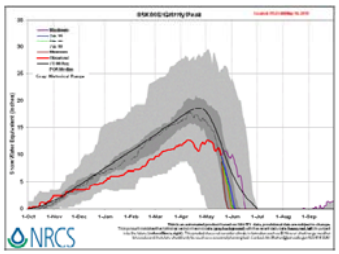


Figure 2: *Grizzly Peak Snotel, on Loveland Pass at 11,100', WY2010 graph showing rebounds in SWE produced by storms after episodes of dust-enhanced snowmelt in late April and early May.*

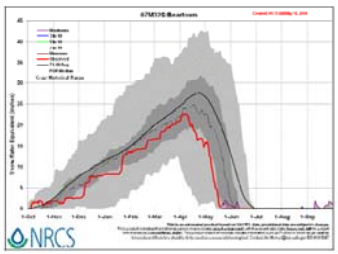


Figure 3: *Beartown Snotel WY2010 graph, at 11,600' near the headwater of the Rio Grande River, approaching "snow all gone" (SAG) as of May 18.*

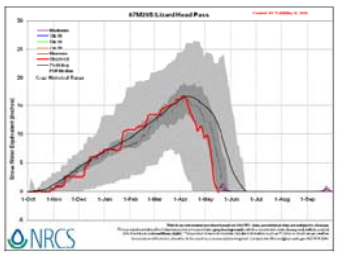


Figure 4: *Lizard Head Pass Snotel, at 10,200', WY2010 graph showing "snow all gone" (SAG) as of May 18.*

CENTER FOR SNOW & AVALANCHE STUDIES

WESTERN WATER ASSESSMENT

SOL Snow Optics Laboratory

Following a surge in runoff throughout most mountain watersheds during mid-April, a north/south divergence appears in stream gauge data as well. Since that mid-April surge, most northern, Front Range, and central mountain watersheds have fallen and remained below median flows, as managers in those locales well know (Figures 5 and 6).

Figure 5: *Yampa River hydrograph showing the mid-April surge and subsequent below-median flows.*

Figure 6: *Eagle River hydrograph showing the mid-April surge and subsequent below-median flows.*

Farther south, following the mid-April surge streamflows have shown more frequent response to periodic exposure of dust, reduced albedos, and warmer air temperatures, as the storms that affected the northern portion of the state produced less new snow and less sustained cloudcover farther south. In the Rio Grande watershed, flows have exceeded median rates at Del Norte several times this season (Figure 7) and other San Juan Mountains watersheds show a similar pattern (Figures 8 and 9).

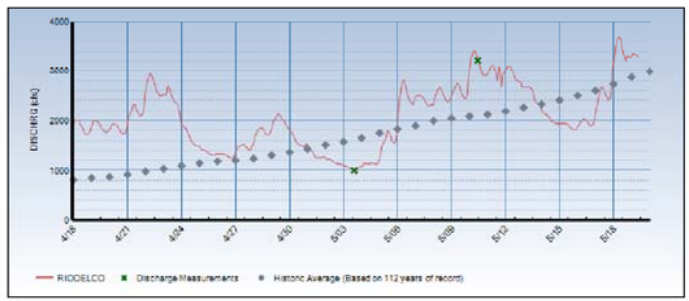


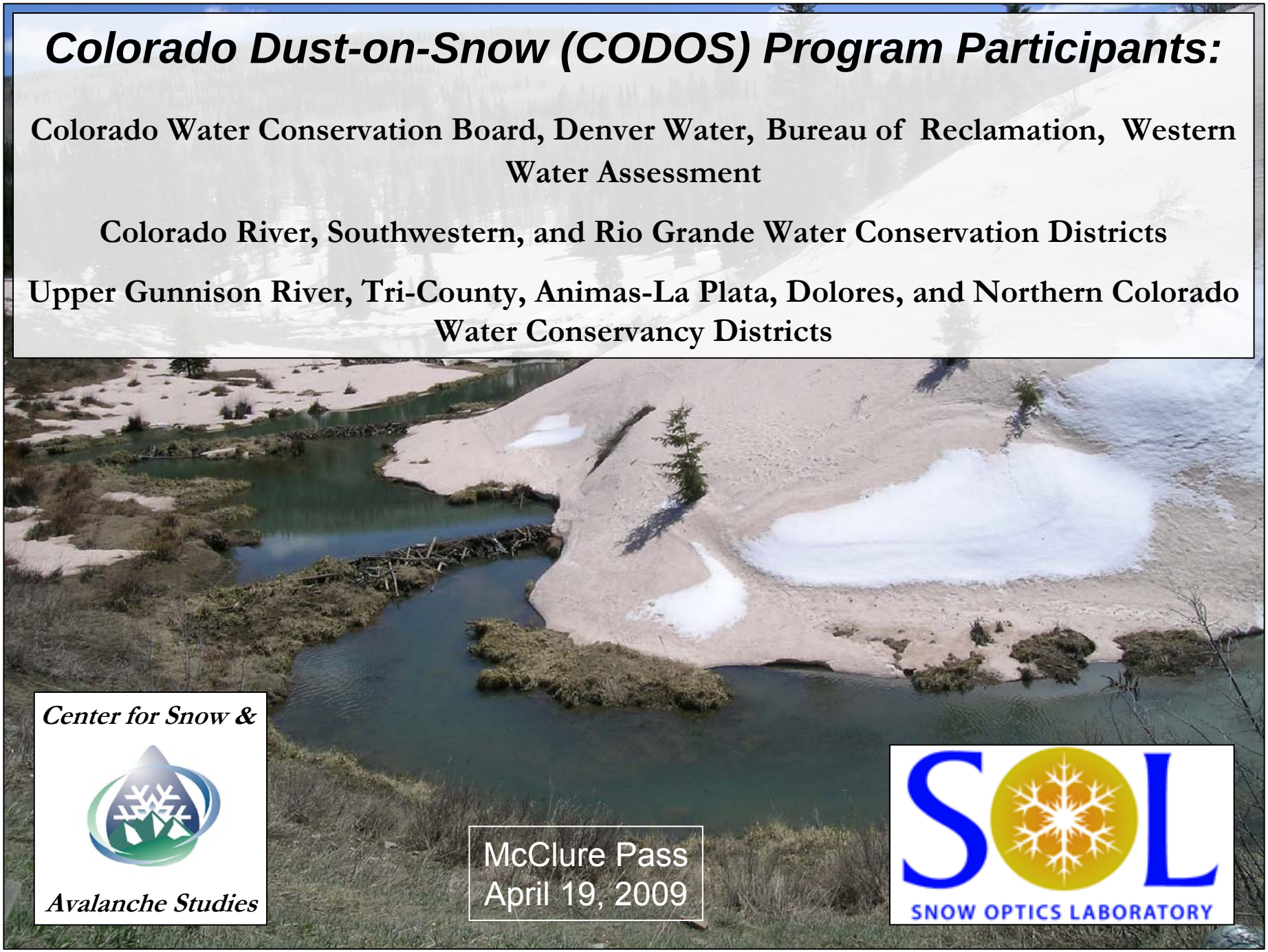
Figure 7: *Rio Grande gauge at Del Norte, showing multiple episodes of surging flows followed by storm-related decreases temporarily restoring a higher snowcover albedo and cooler air temperatures.*

Colorado Dust-on-Snow (CODOS) Program Participants:

Colorado Water Conservation Board, Denver Water, Bureau of Reclamation, Western Water Assessment

Colorado River, Southwestern, and Rio Grande Water Conservation Districts

Upper Gunnison River, Tri-County, Animas-La Plata, Dolores, and Northern Colorado Water Conservancy Districts



Center for Snow & Avalanche Studies

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