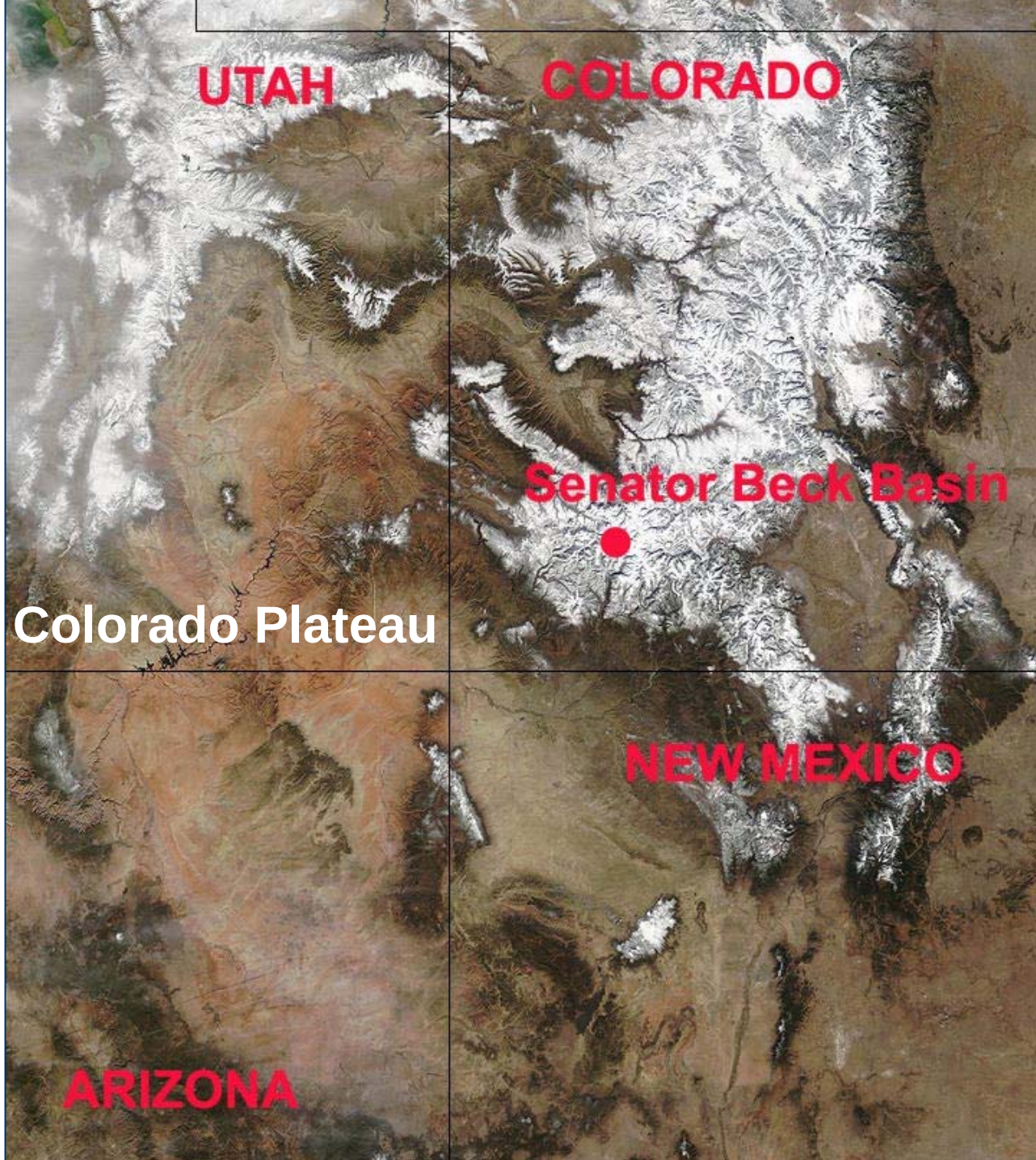
Dust-on-Snow is Affecting Colorado Snowmelt Water Supplies

Advisory Committee – CSU Southwestern Colorado Research Center

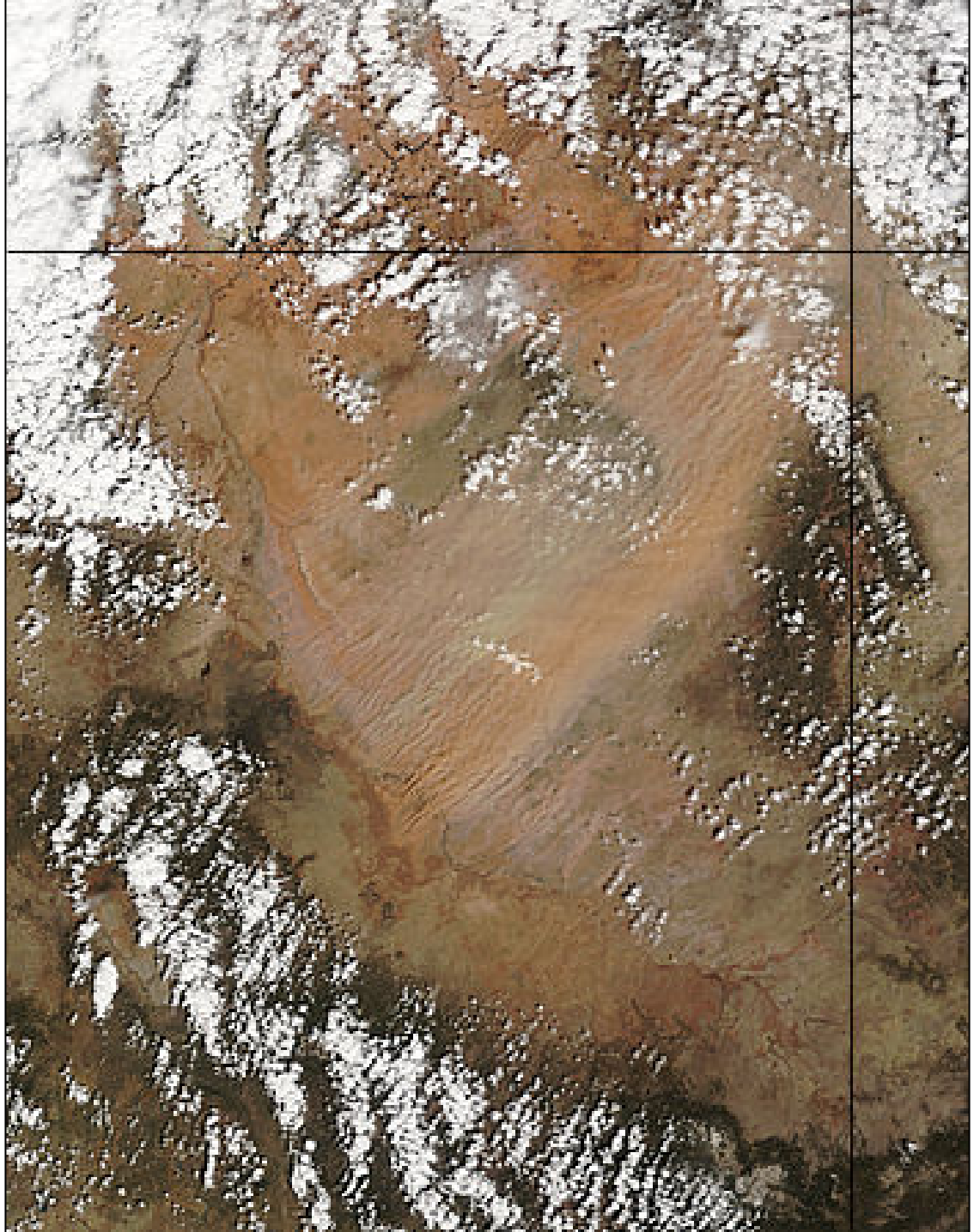
Chris Landry
CODOS

Center for Snow and Avalanche Studies
Silverton, CO

CSAS

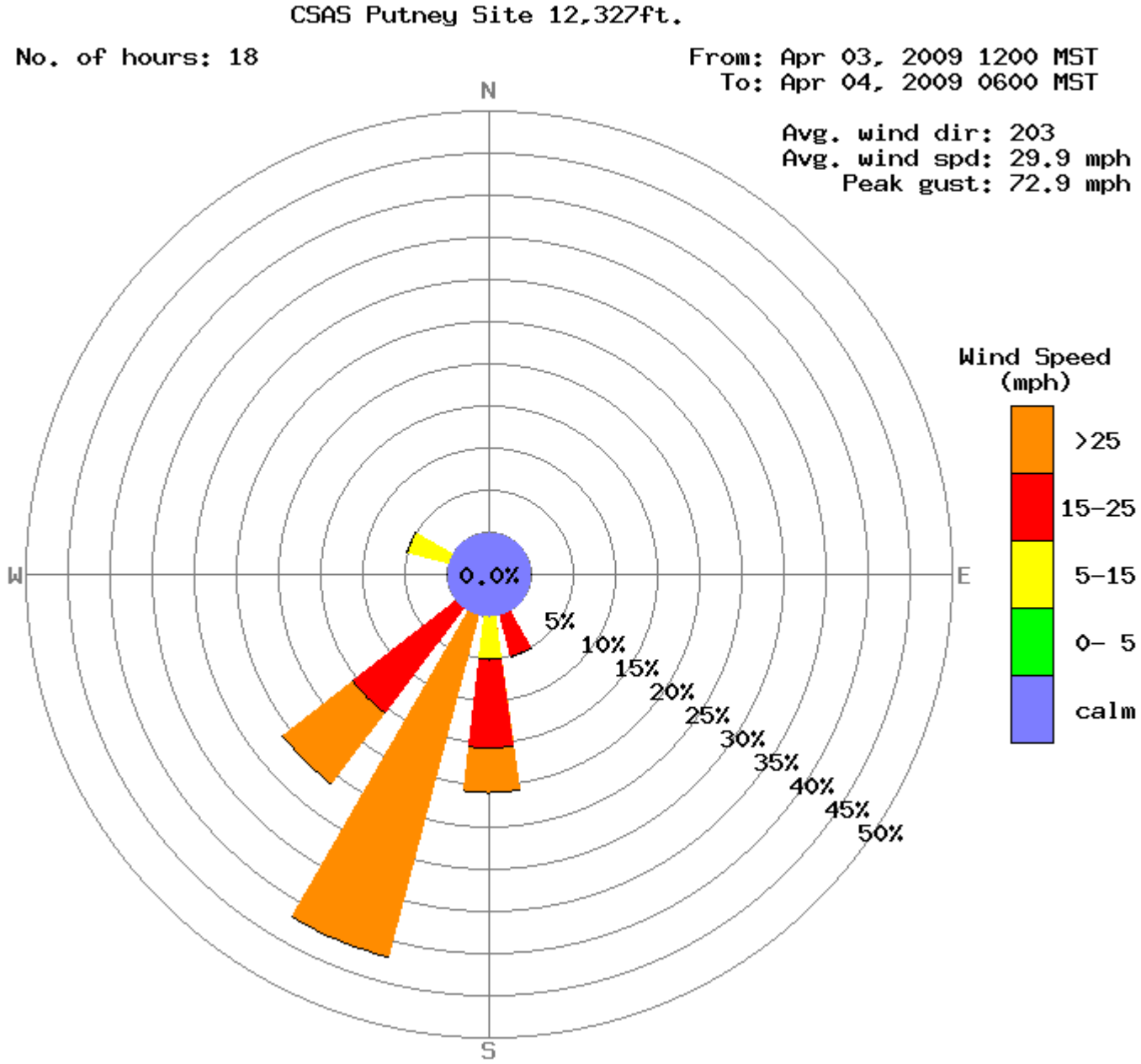


Spring 2009 – From Senator Beck Basin Study Area



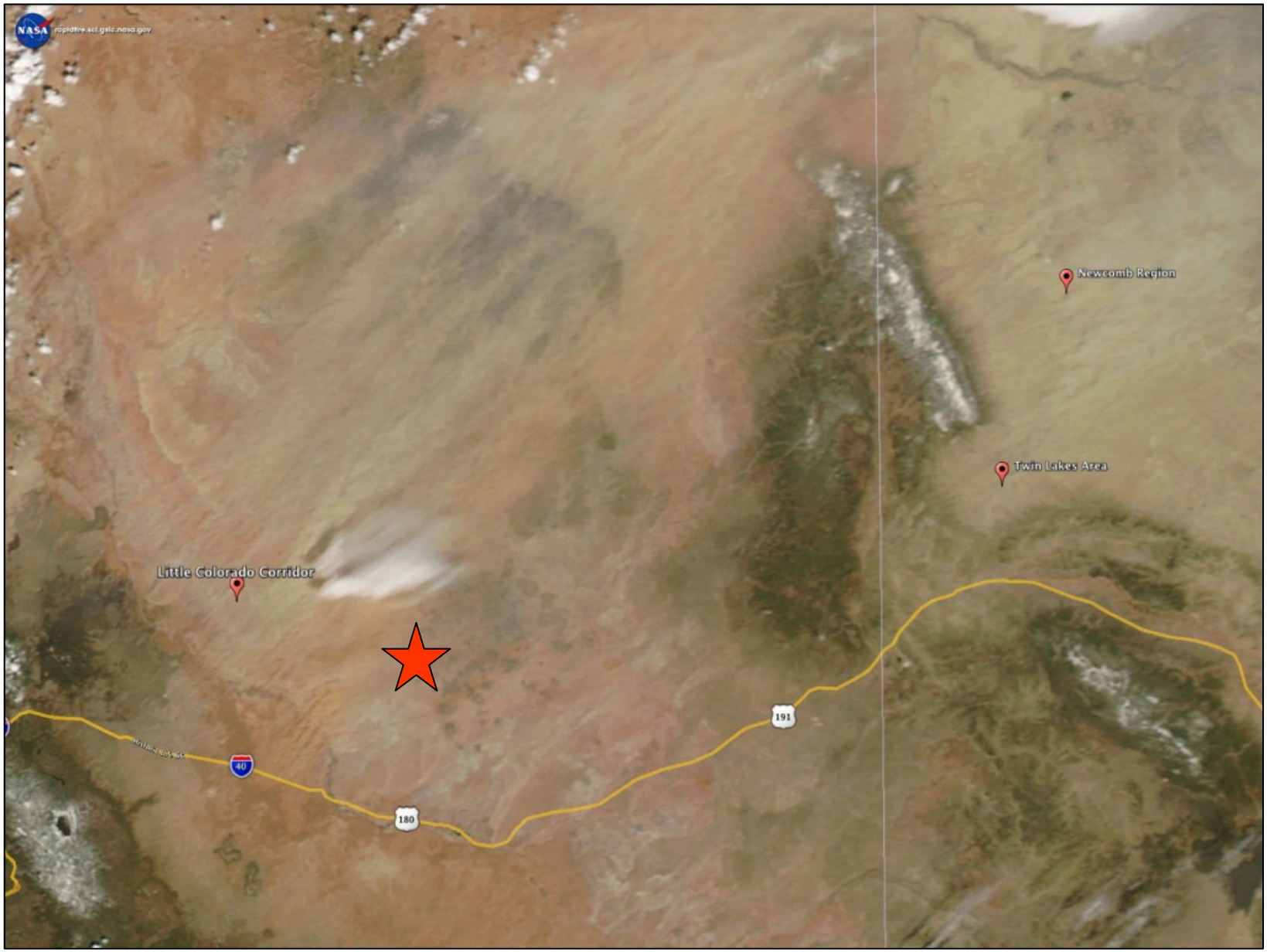
D8 – WY2009
April 3, 2009

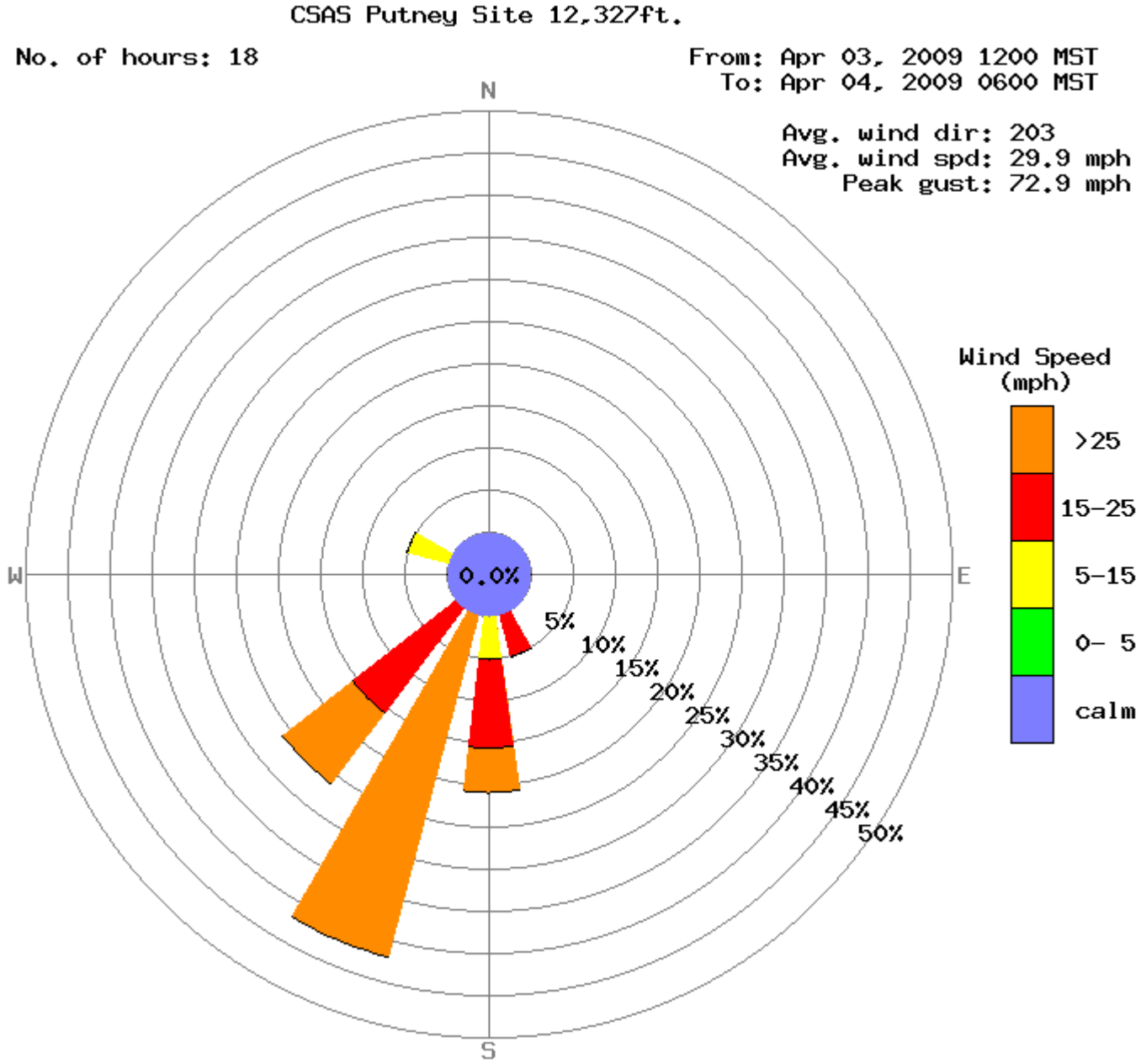

Silverton
April 3, 2009


CSAS Putney Site 12,327ft.
No. of hours: 18
From: Apr 03, 2009 1200 MST
To: Apr 04, 2009 0600 MST
Avg. wind dir: 203
Avg. wind spd: 29.9 mph
Peak gust: 72.9 mph
N
W
E
S
0.0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
Wind Speed (mph)
>25
15-25
5-15
0- 5
calm


Silverton
April 5, 2010
THE WYMAN

D4 – WY2010
April 5, 2010

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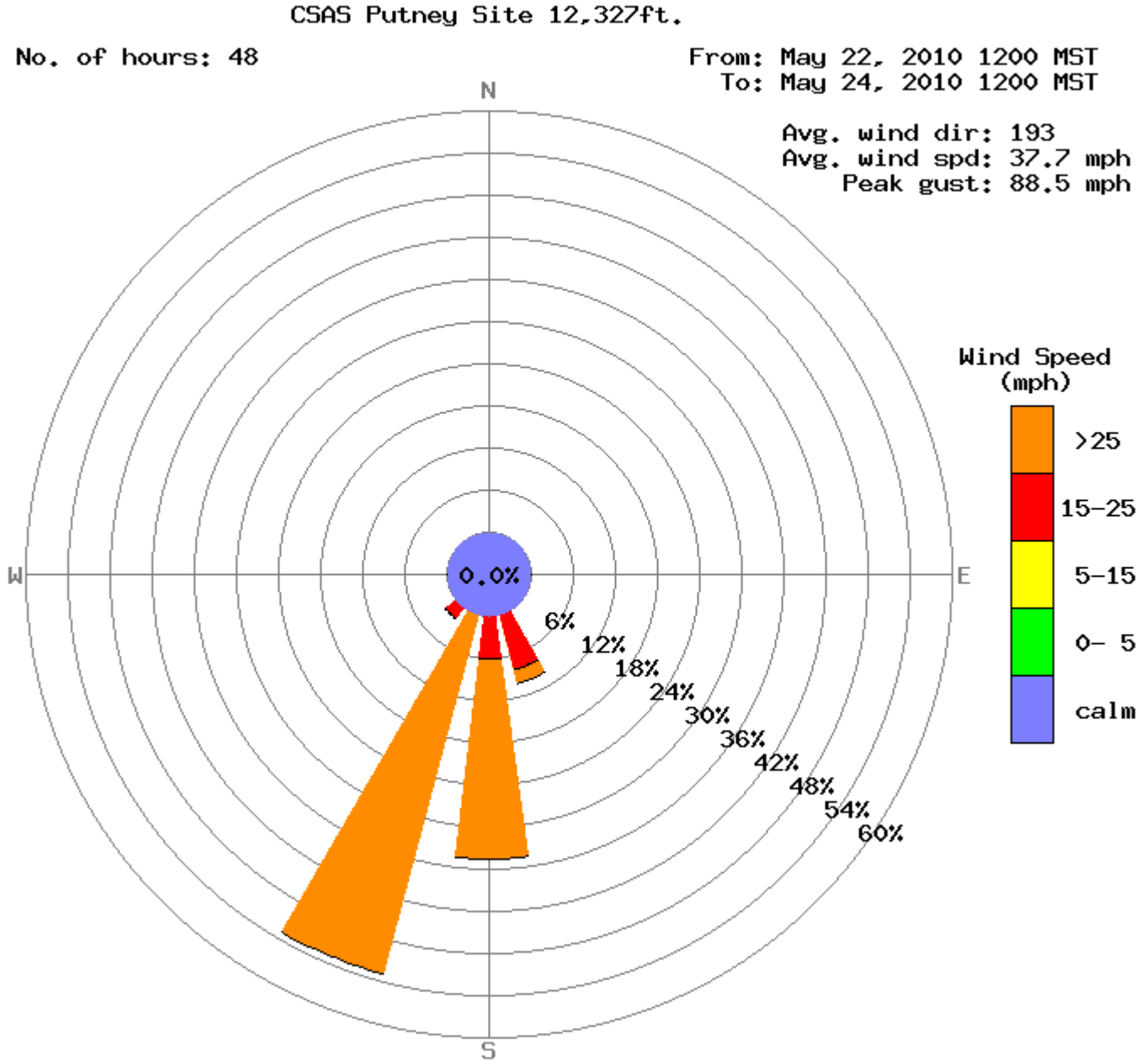
N
W
E
S
0.0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
Wind Speed (mph)
>25
15-25
5-15
0- 5
calm


CSAS Putney Site 12,327ft.
No. of hours: 48
From: May 22, 2010 1200 MST
To: May 24, 2010 1200 MST
Avg. wind dir: 193
Avg. wind spd: 37.7 mph
Peak gust: 88.5 mph
N
W
E
S
0.0%
6%
12%
18%
24%
30%
36%
42%
48%
54%
60%
Wind Speed (mph)
>25
15-25
5-15
0- 5
calm


Near USGS Research Site
February 15, 2011

Near Moab, routinely

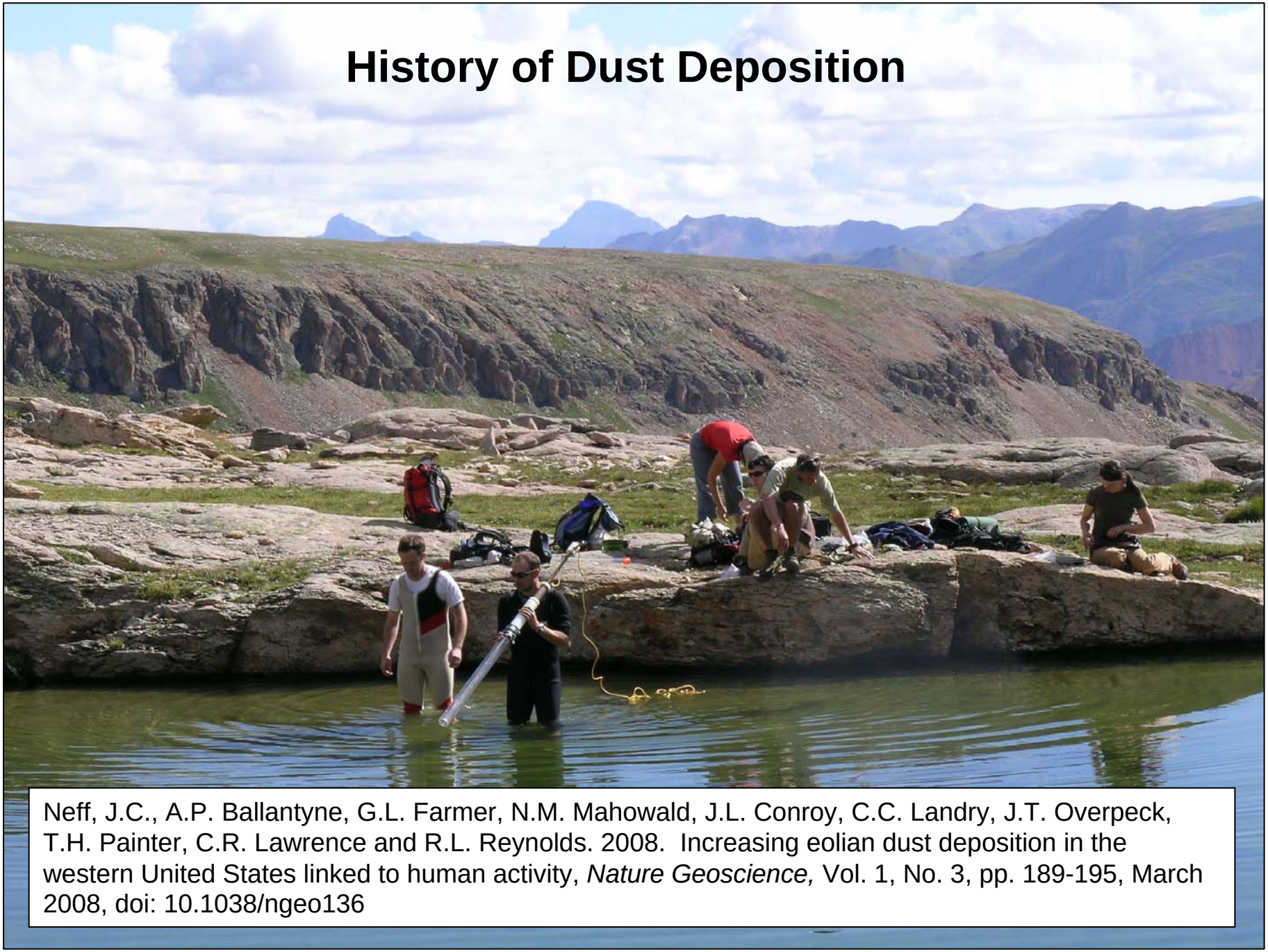

Near Center, CO – March 30, 2010

Rigorous DOS Event Monitoring

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
2010/2011	0	0	0	0	1	3	3	4	0	11

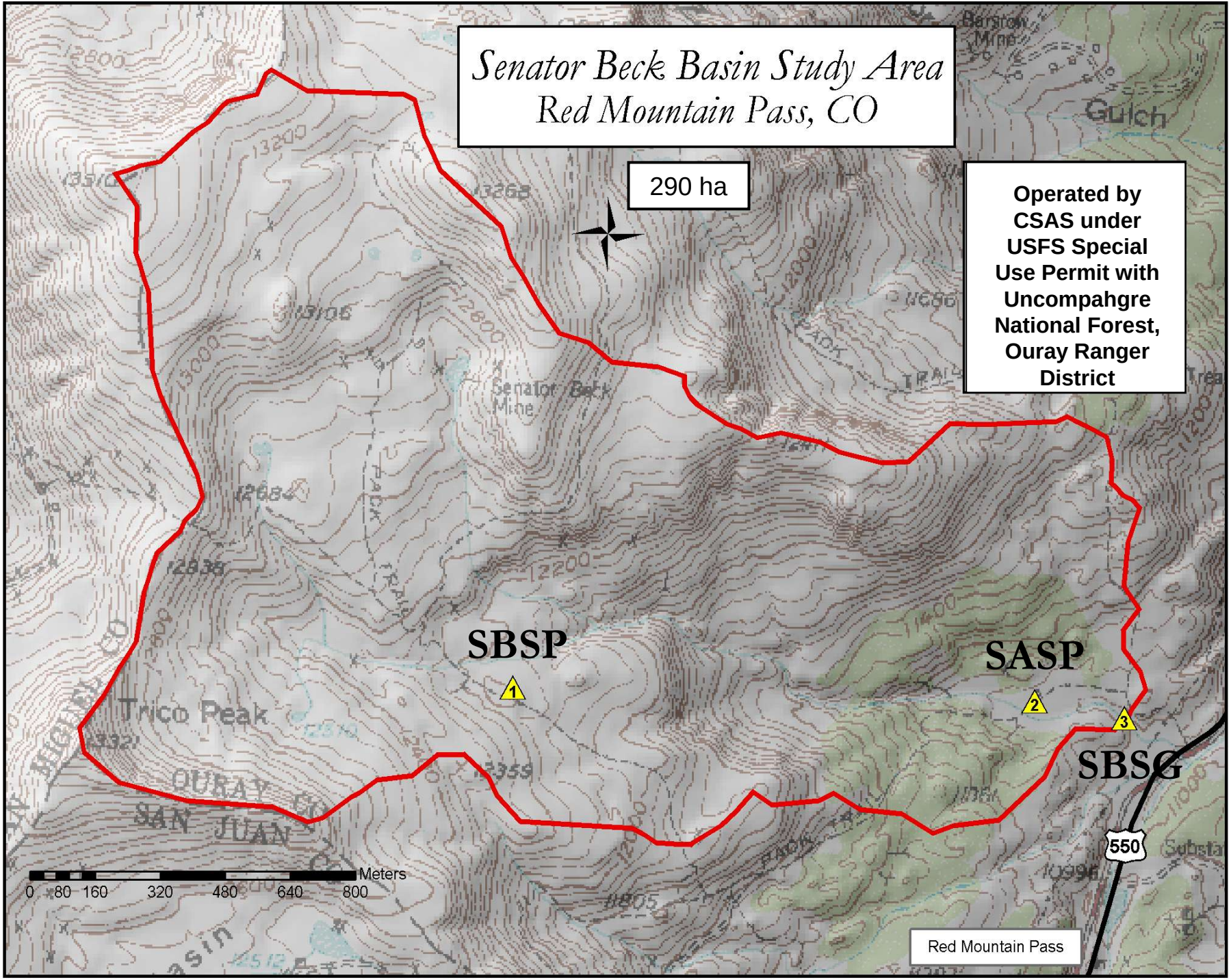
32

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


May 21, 2004
Photo courtesy JPL - Ian McCubbin


Senator Beck Basin Study Area
Red Mountain Pass, CO
290 ha
Operated by CSAS under USFS Special Use Permit with Uncompahgre National Forest, Ouray Ranger District
SBSP
SASP
SBSG
1
2
3
Trico Peak
OURAY CO
SAN JUAN CO
Senator Beck Mine
Gulch
550
Red Mountain Pass
Meters
0 80 160 320 480 640 800

SASP Instrumentation

6 m Mast

CR10X Dataloggers (2), Multiplexer (1)

ETI Precipitation Gauge

Wind Speed & Direction (2)

Air Temp and RH (2)

Barometric Pressure

Height of Snow

Broadband SW (2 up, 1 down, shadow array)

NIR SW (1 up, 1 down)

Pyrgeometer (1 up)

Infrared Snow Surface Temp

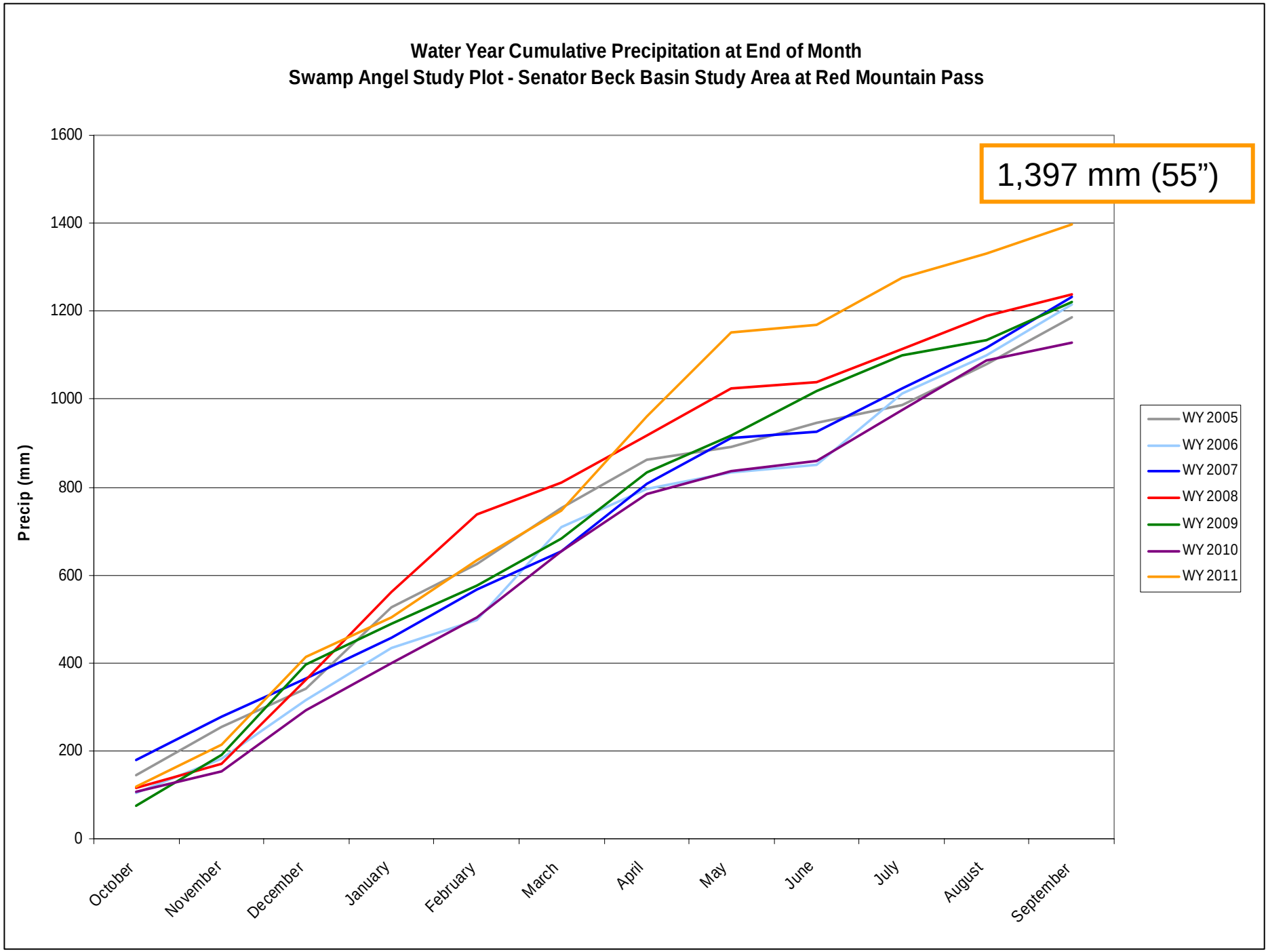
Snow Temperature (5)

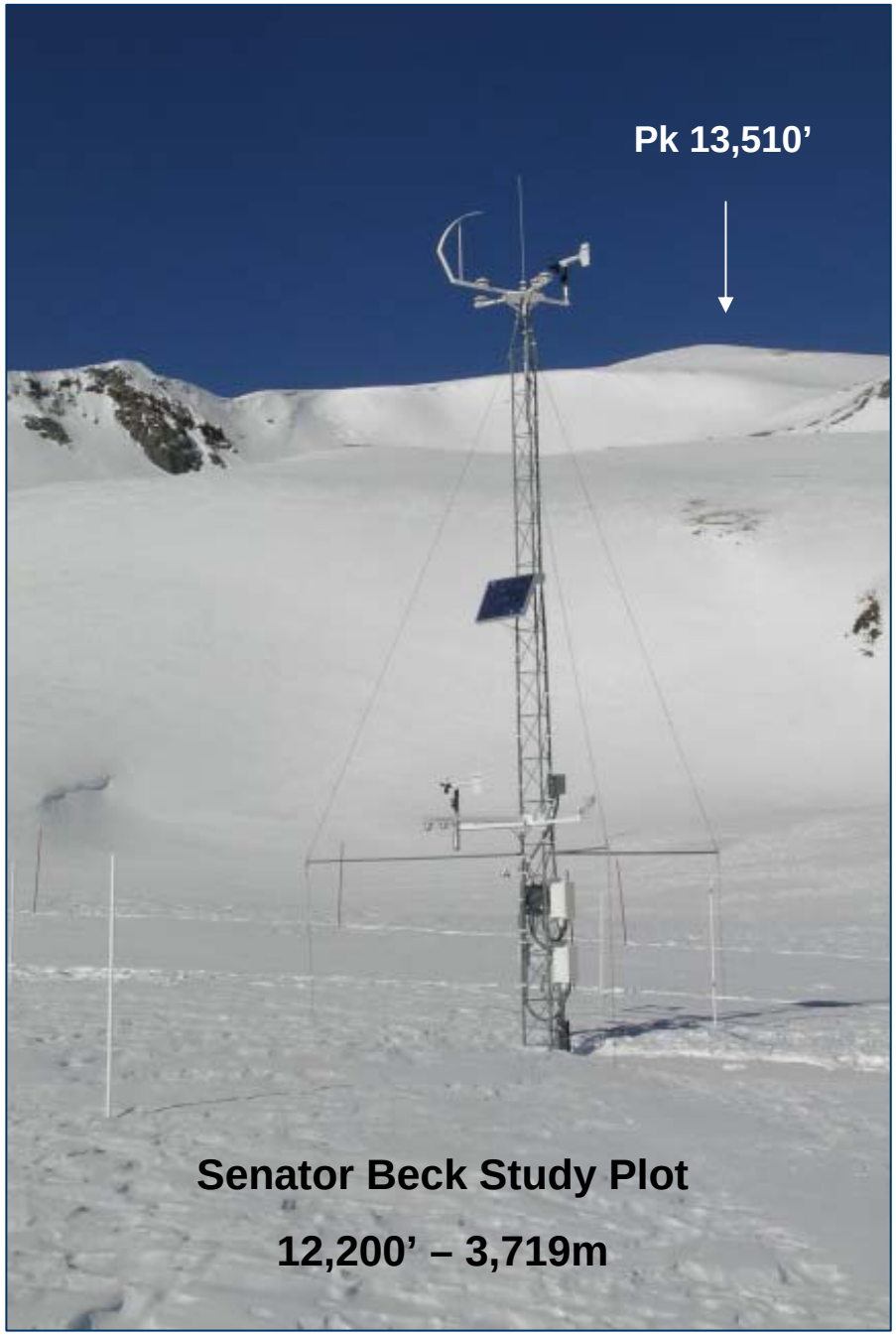
Snow Wetness Sensor

Soil Temperature (4)

Soil Volumetric Water Content

Soil Heat Flux


Water Year Cumulative Precipitation at End of Month
Swamp Angel Study Plot - Senator Beck Basin Study Area at Red Mountain Pass
1,397 mm (55”)
Precip (mm)
0
200
400
600
800
1000
1200
1400
1600
October
November
December
January
February
March
April
May
June
July
August
September
WY 2005
WY 2006
WY 2007
WY 2008
WY 2009
WY 2010
WY 2011



SBSP Instrumentation

10 m Mast

Campbell CR10X Dataloggers (2), Multiplexer (1)

Wind Speed & Direction (2)

Air Temp and RH (2)

Height of Snow

Broadband SW (2 up, 1 down, shadow array)

NIR SW (1 up, 1 down)

Pyrgeometer (1 up)

Infrared Snow Surface Temp

Snow Temperature (5)

Snow Wetness Sensor

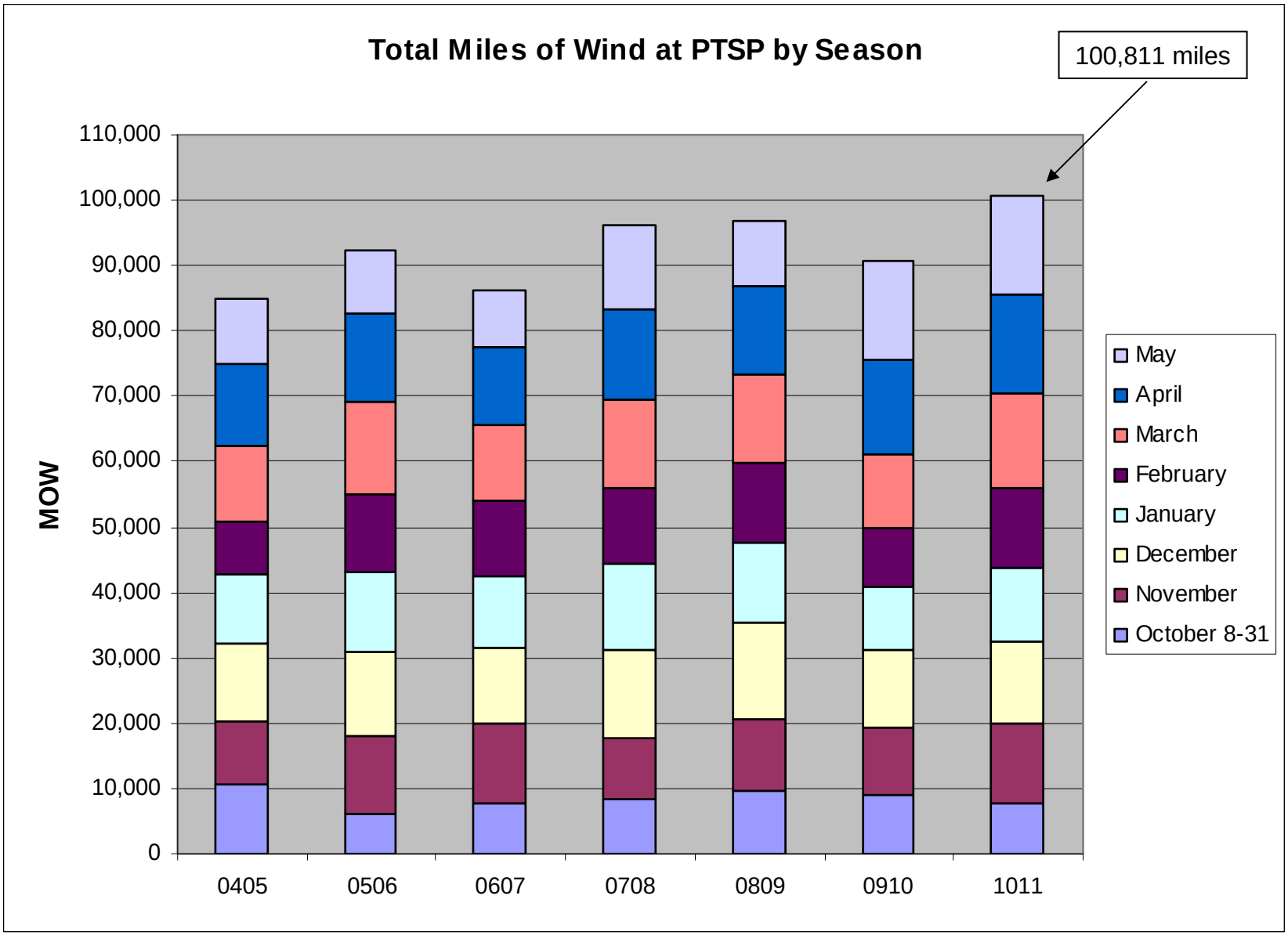
Soil Temperature (4)

Soil Volumetric Water Content

Soil Heat Flux

PTSP Instrumentation

10 m Mast
Campbell CR10X Datalogger
Wind Speed & Direction
Air Temp and RH


Total Miles of Wind at PTSP by Season
100,811 miles
MOW
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0405
0506
0607
0708
0809
0910
1011
May
April
March
February
January
December
November
October 8-31

SBSG Instrumentation

Broad-crested, notched weir

0.1 – 30 cfs capacity

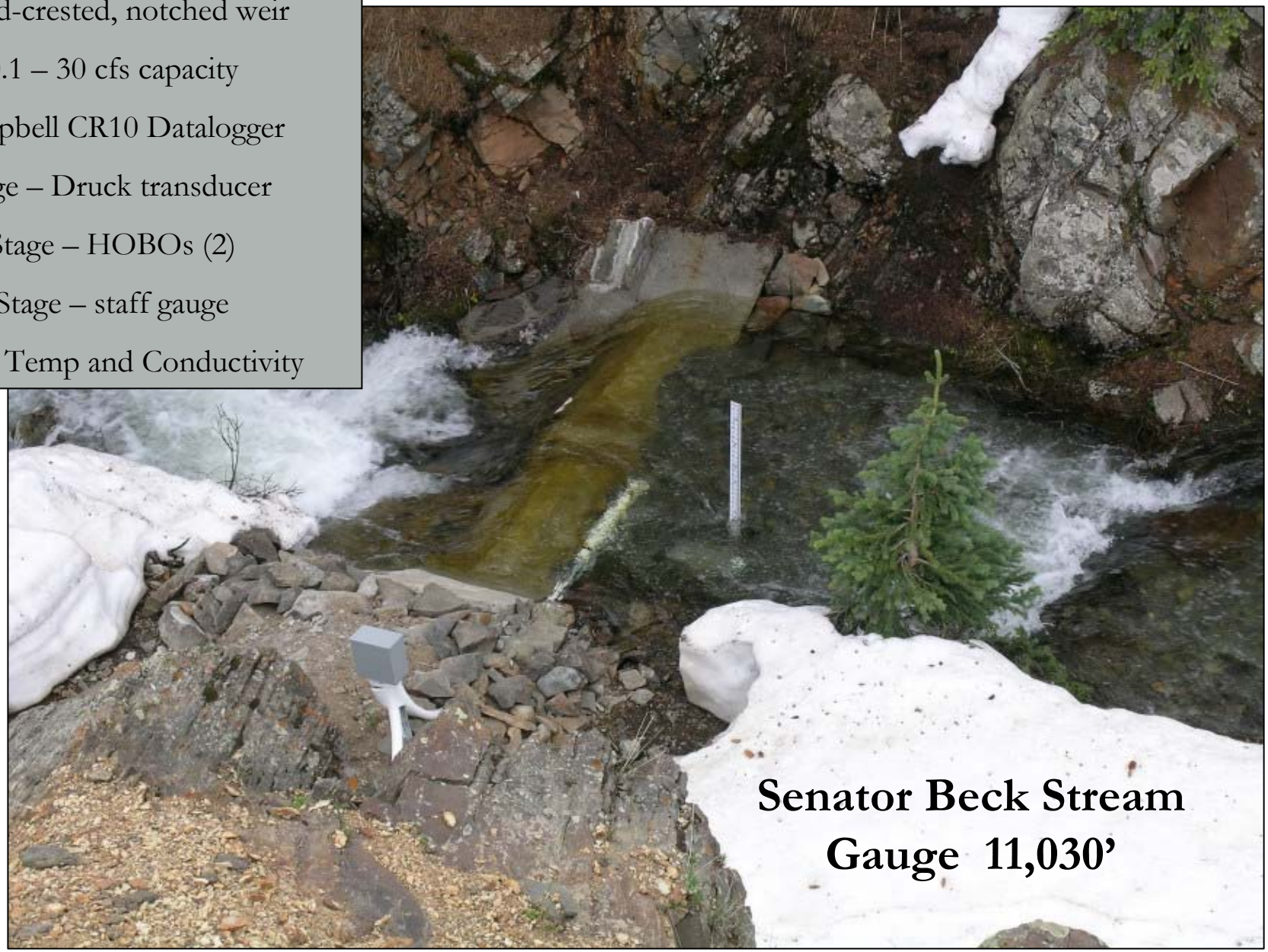
Campbell CR10 Datalogger

Stage – Druck transducer

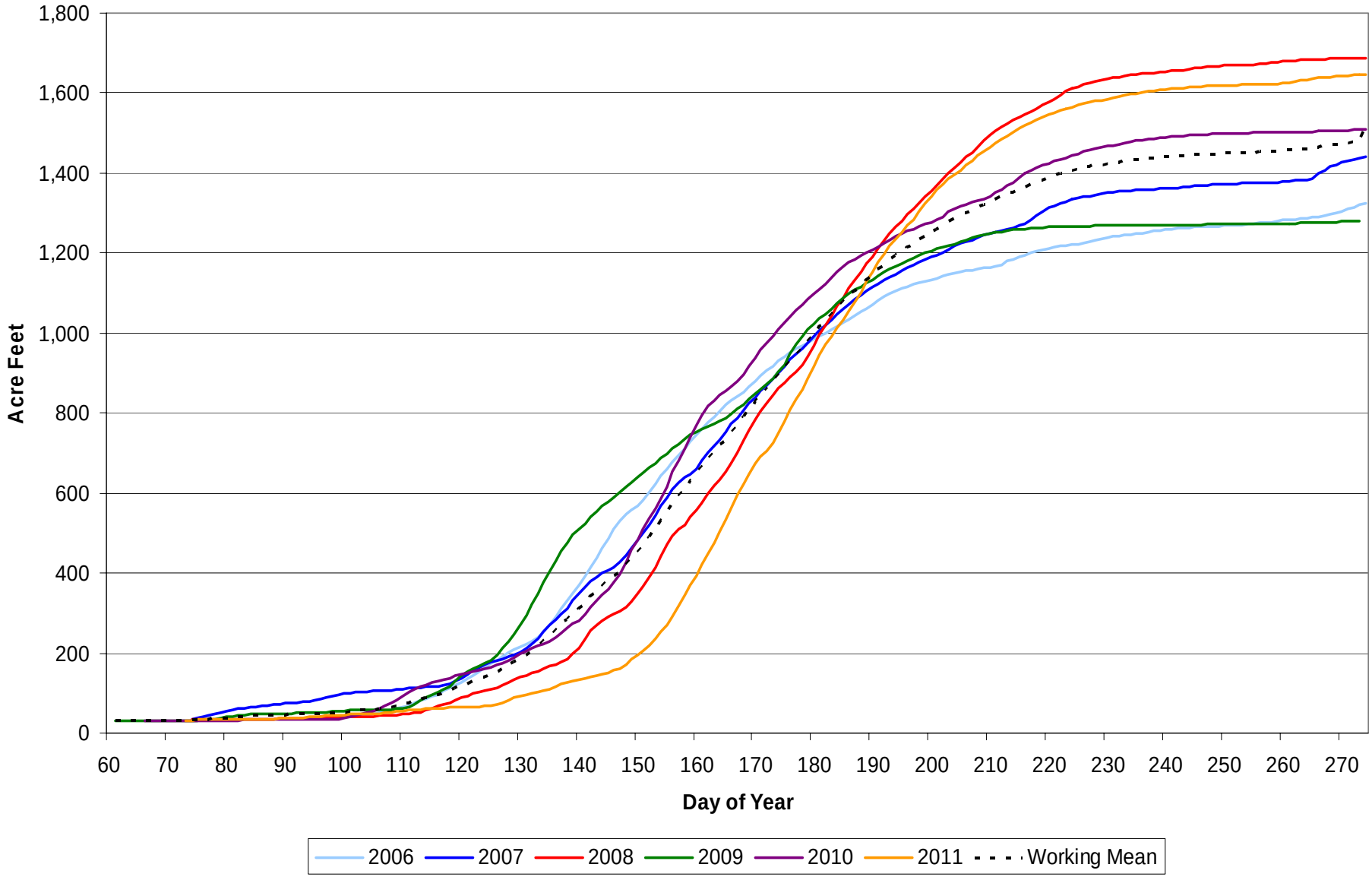
Stage – HOBOs (2)

Stage – staff gauge

Water Temp and Conductivity



Senator Beck Basin Cumulative Discharge - 2006, 2007, 2008, 2009, 2010, 2011

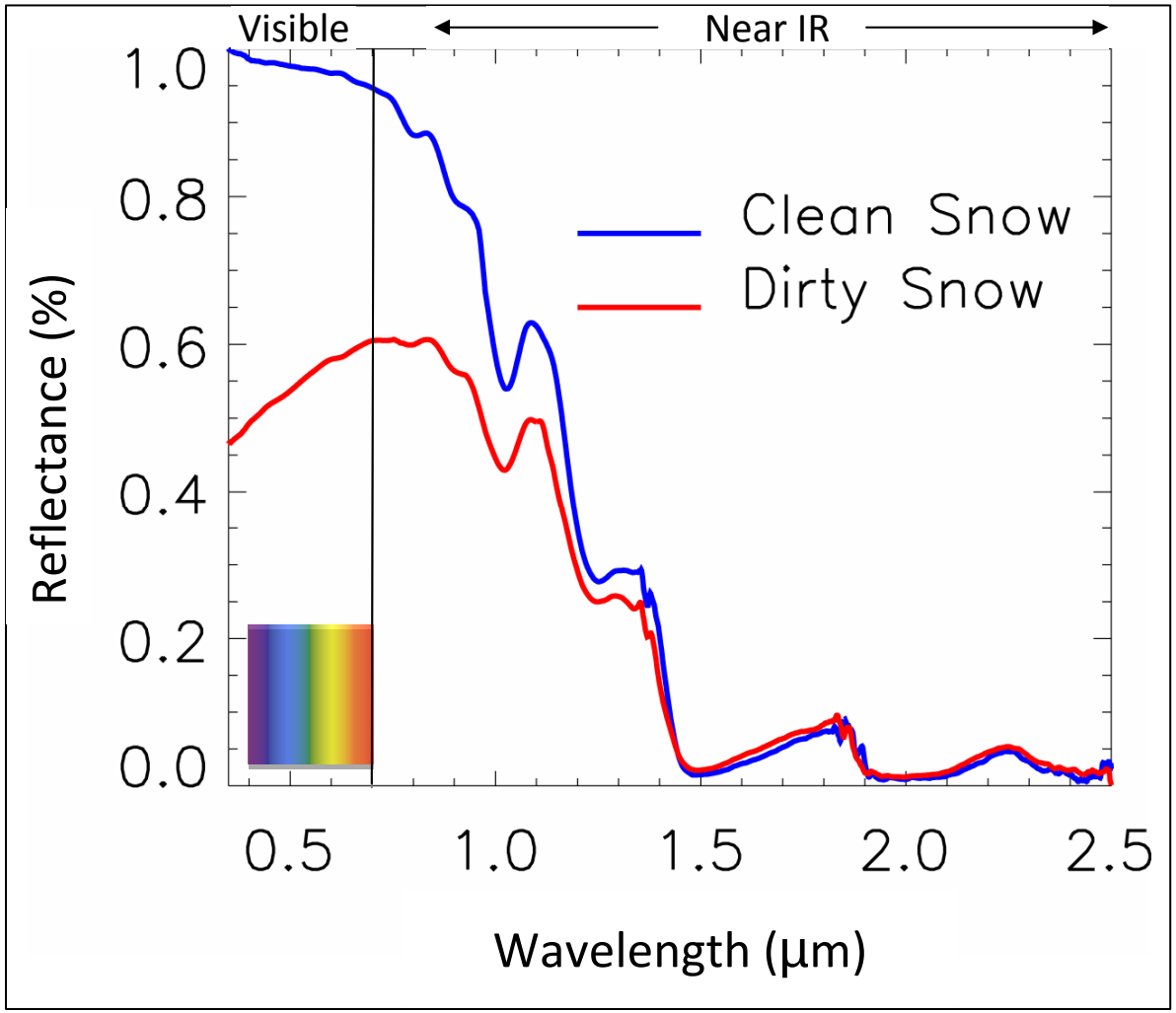


Snow Albedo Measurement

Senator Beck Study Plot 12,200’

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

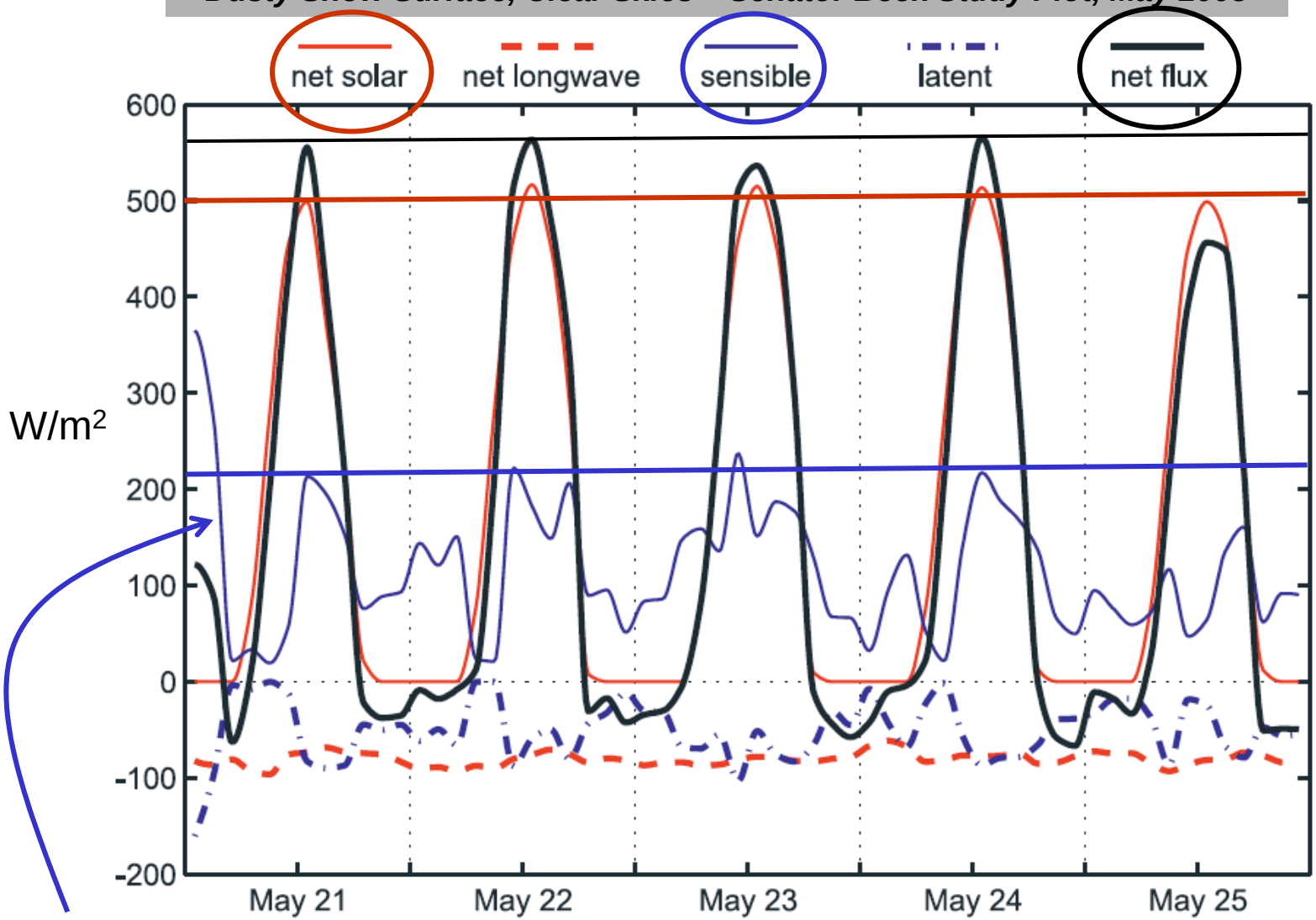
Dust decreases snow albedo



Courtesy Jeff Deems

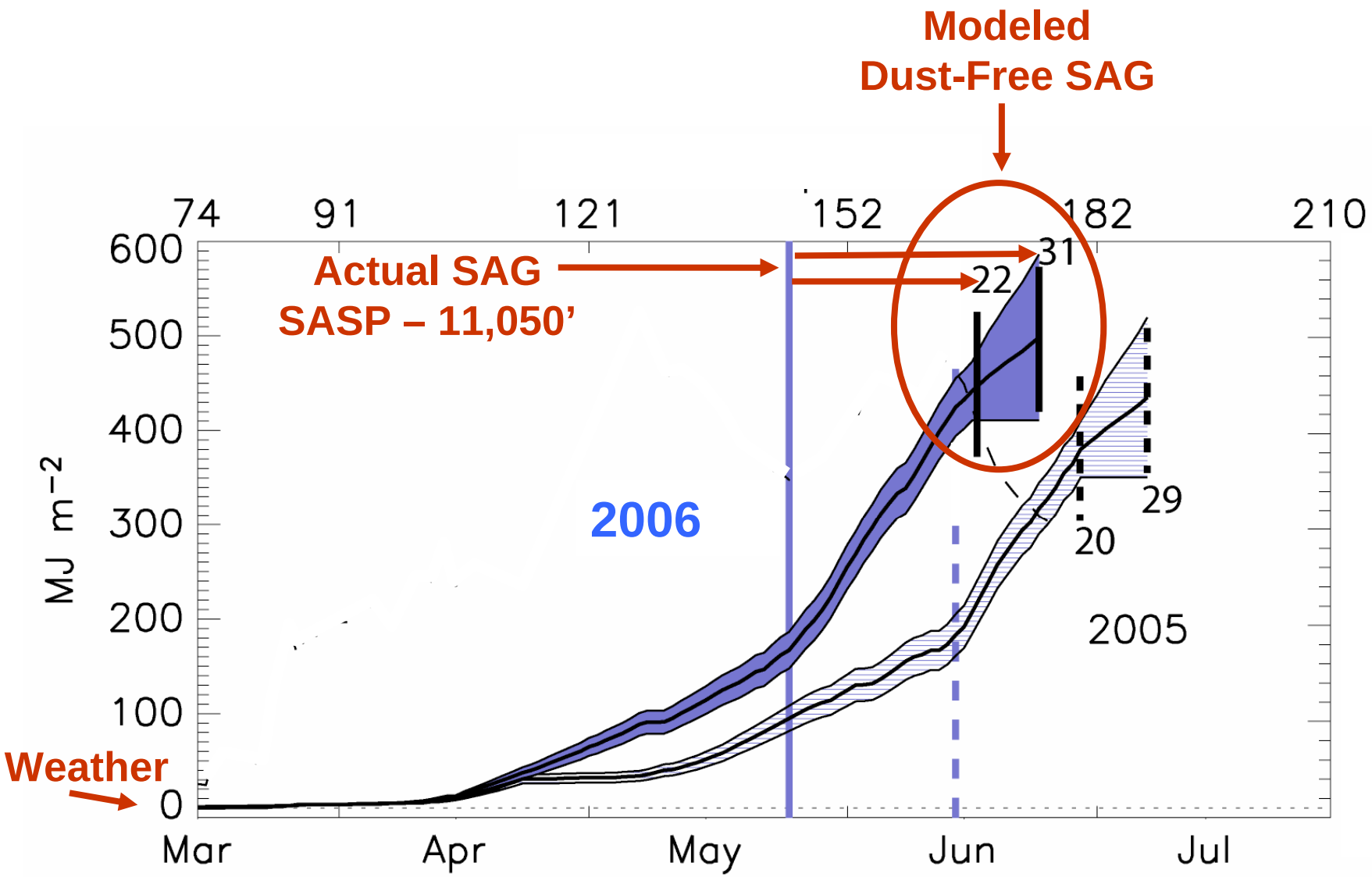
Enhanced Snowmelt Energy Input

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

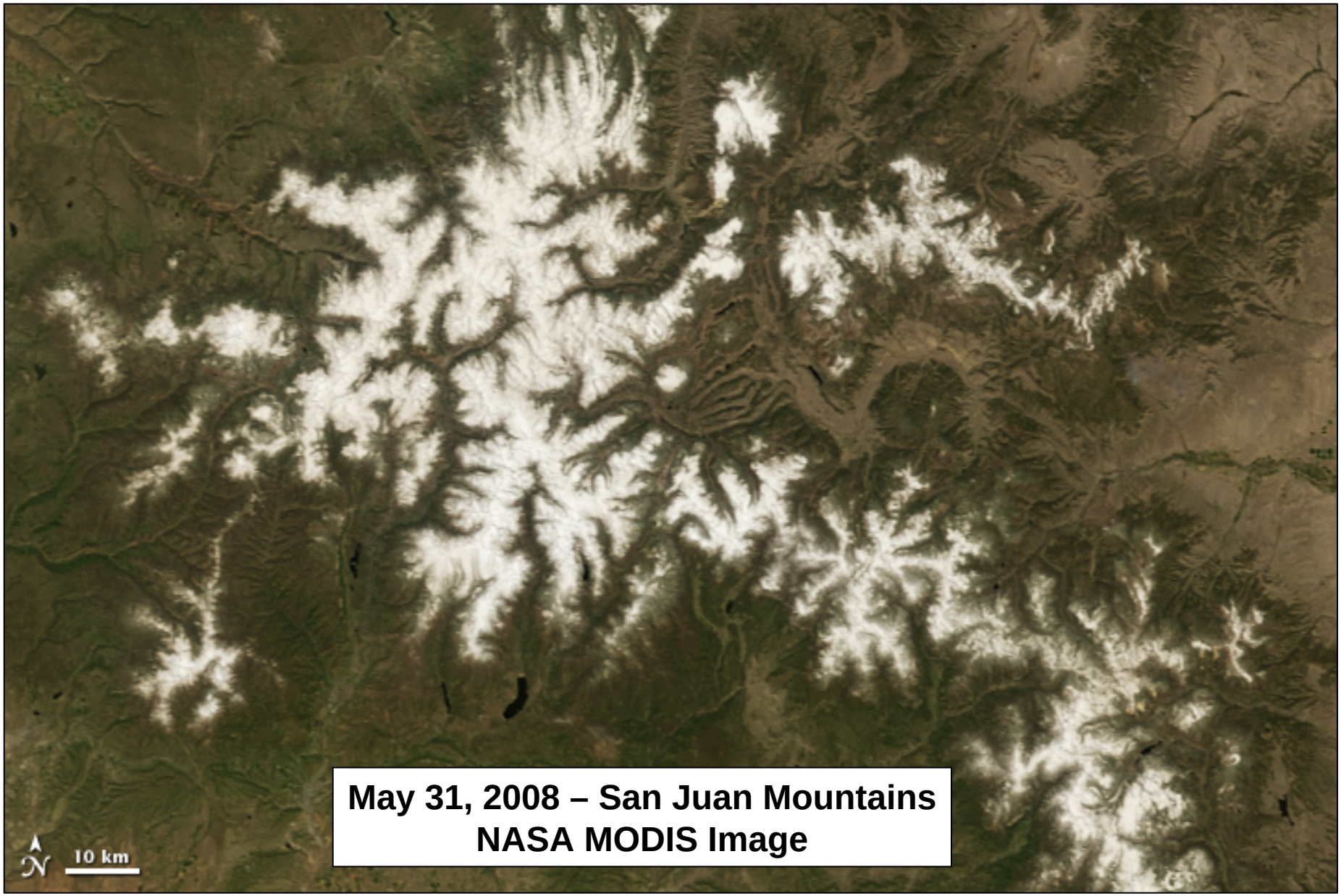


Max Air T	**57 F**	**57 F**	**56 F**	**53 F**	**56 F**

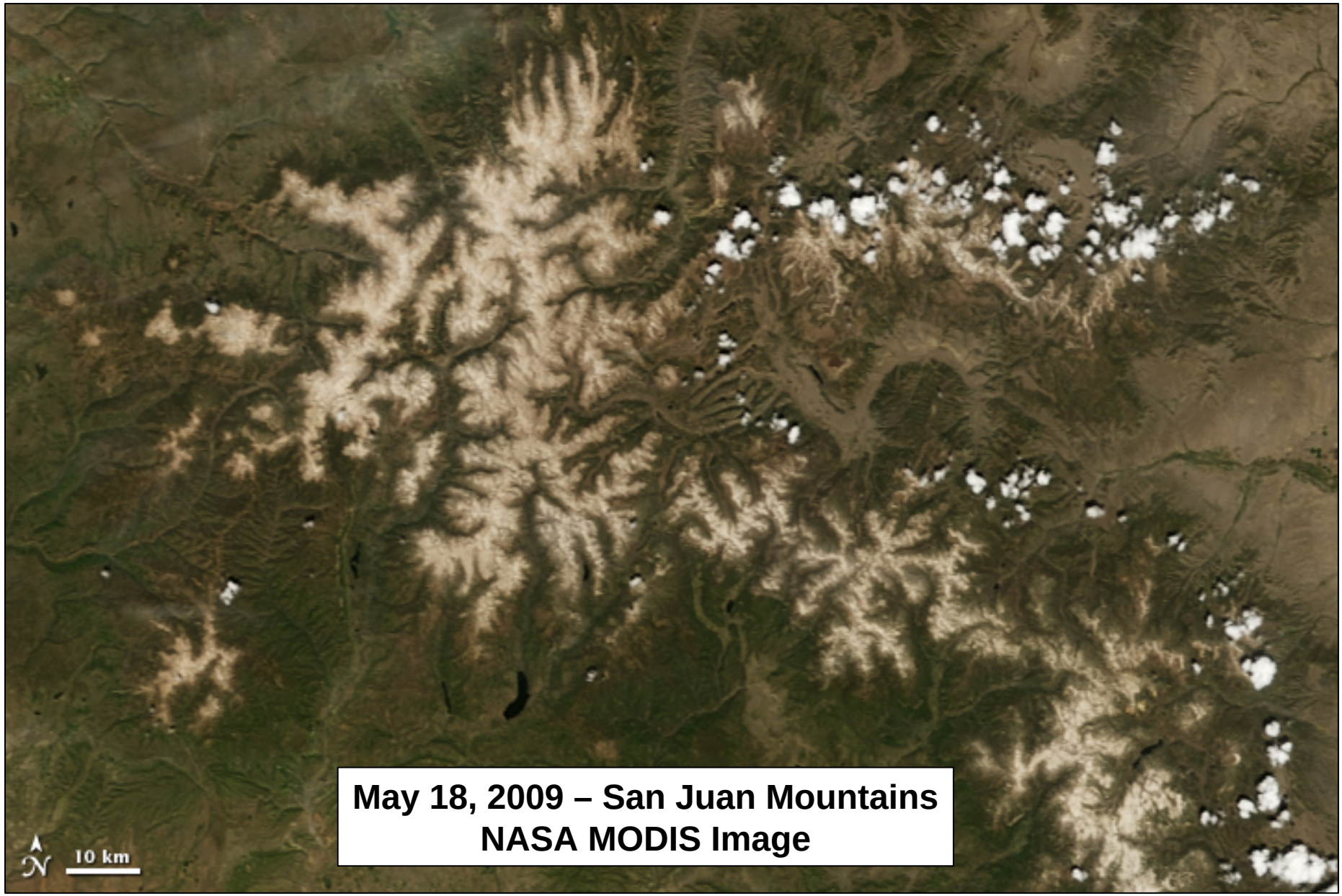
Reduced Albedo = Snowmelt "Forcing"

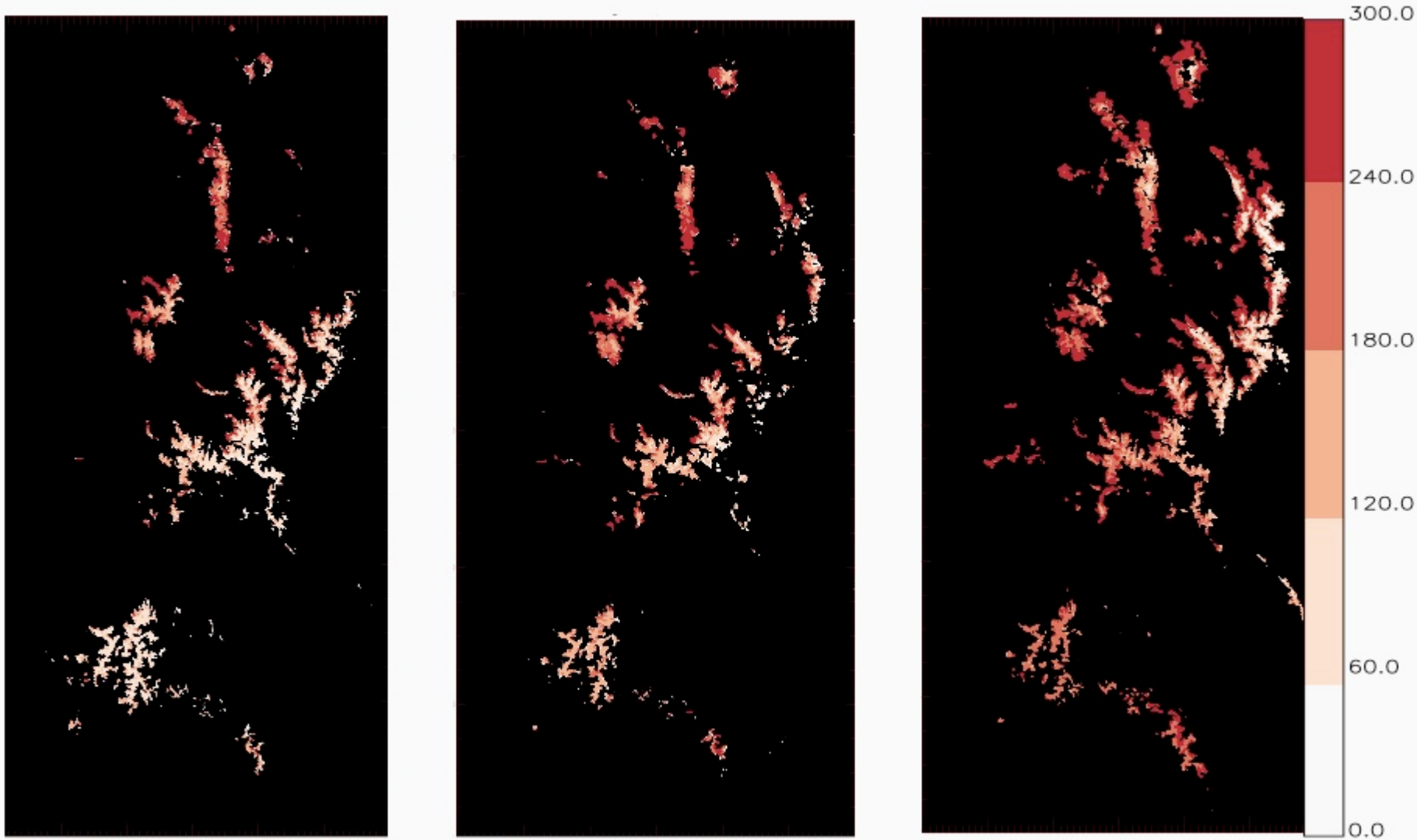


Large-Scale Albedo Reductions



Large-Scale Albedo Reductions




300.0
240.0
180.0
120.0
60.0
0.0
May 21,2000
May 31, 2006
May 18, 2009

CSAS Colorado Dust-on-Snow (CODOS) Program

Timely, iterative monitoring and analysis of dust effects on snowmelt timing and rates throughout the Colorado mountains … supplemental to CBRFC forecasts.

Spring 2009 – From Senator Beck Basin Study Area

CSAS Colorado Dust-on-Snow Program

CODOS Program Funders	WY 2007	WY 2008	WY 2009	WY 2010	WY 2011	**Proposed WY 2011**
Colorado River Water Conservation District	8,000	8,000	8,000	10,000	10,000	**10,000**
Southwestern Water Conservation District	5,000	5,000	4,000	5,000	5,000	**5,000**
Rio Grande Water Conservation District		3,000	4,000	5,000	5,000	**5,000**
Upper Gunnison River Water Conservancy Dist.		5,000	7,500	7,500	7,500	**7,500**
Northern Colorado Water Conservancy District			1,500	2,500	2,000	
Tri-County Water Conservancy District	1,000	1,000	1,500	2,500	2,500	**2,500**
Animas-La Plata Water Conservancy District			500	600	600	**750**
Dolores Water Conservancy District				600	600	**750**
Denver Water	2,500	2,500	2,500	5,000	5,000	**5,000**
Bureau of Reclamation – Western Colorado Area			5,000	7,500	7,500	**7,500**
Bureau of Reclamation – Lower Colorado Region				7,500	10,000	**10,000**
Bureau of Reclamation – Eastern Colorado Area					2,500	**2,500**
Bureau of Reclamation – Albuquerque Area						**2,500**
Western Water Assessment – Univ of Colorado			20,072			
Colorado Water Conservation Board				28,034	15,000	**25,000**
City of Grand Junction					2,500	**2,500**
TOTAL	16,500	24,500	54,572	81,734	75,700	**86,500**

Colorado Dust-on-Snow Program – Water Year 2011

Update #6 - Monday, June 13, 2011

***Figure 1**: a headwater tributary of Walton Creek at Rabbit Ears Pass on June 9, 2011 showing the very dark May 29th D11-WY2011 dust layer merged with underlying dust layers.*

This season's largest reductions in snowcover albedo are currently contributing to Colorado's high rates of snowmelt runoff. Recent observations at most Colorado Dust-on-Snow (CODOS) monitoring sites found all of this season's desert dust layers merged and exposed at the snowpack surface, augmented in many locales by the last dust-on-snow event, D11, of May 29th, 2011. That amalgamation of all dust layers into a single, merged layer at the snowpack surface, on all aspects and at all elevations, occurred earliest in the southern mountains but is more recent (or underway) at most northern sites. The following photos illustrate the magnitude of albedo reductions at the snowpack surface at several recently visited CODOS sites, in dramatic contrast to the cleaner snow immediately below the surface. The Park Cone, McClure Pass, and Spring Creek Pass CODOS monitoring sites have lost their snowcover entirely, as has the Willow Creek Pass site. However,

Post-Peak SWE, produced the highest rate of "Mean Daily Loss SWE". Finally, the later the date of Peak SWE, the higher the mean snowmelt period temperature, as would be expected.

Last, a comparison of WY 2011 short term snowmelt rates (Table 5 below), using a 5-day moving average beginning on the 5th day after Peak SWE and running until SAG, provides additional insight into the effects of dust-reduced snow albedo seen in the photographs in Update #6 – WY 2011.

CODOS and Other SNOTEL Sites WY 2011 Snowmelt Season Summary Data		
SNOTEL Site	*Highest 5-Day Moving Average Loss SWE*	*Final Day of 5-Day Period*
Red Mtn Pass	1.74" (2x)	June 17, 19
Slumgullion Pass	1.28"	June 4
Wolf Creek Summit	1.48"	June 19
Beartown	1.74" (2x)	June 8, 9
Lizard Head	1.40"	May 31
Park Cone	1.00"	May 11
Schofield Pass	2.44"	June 29
McClure Pass	1.78"	May 30
Independence Pass	1.54"	June 7
Hoosier Pass	1.20"	June 16
Grizzly Peak	1.38"	June 6
Berthoud Summit	1.46"	June 12
Willow Creek Pass	2.40"	June 11
Rabbit Ears Pass	1.94"	June 7
Mesa Lakes	1.52"	June 9
Non-CODOS SNOTEL sites shown in italics		

***Table 5**: showing the highest 5-day period snowmelt rates, as loss of SWE, during Spring 2011 at 11 CODOS SNOTEL sites and 4 additional SNOTEL sites. Units of snowmelt (Loss SWE) are inches of water.*

Park Cone displays the slowest 5-day average rate of snowmelt; as previously discussed, Park Cone was noted as the cleanest snowpack, with the least dust, among the 11 sites monitored by CODOS during Spring 2011 (dust event D11, on May 29th, came just two days before SAG at Park Cone). Schofield Pass displays the highest 5-day average, but Willow Creek Pass is not far behind. Some of the 15 SNOTEL sites recorded their highest 5-day rate of SWE loss near the very end of snowmelt, when radiation may have penetrated through the thinning snowcover and been absorbed

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

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

Spring 2008 = 12 gm/m^2

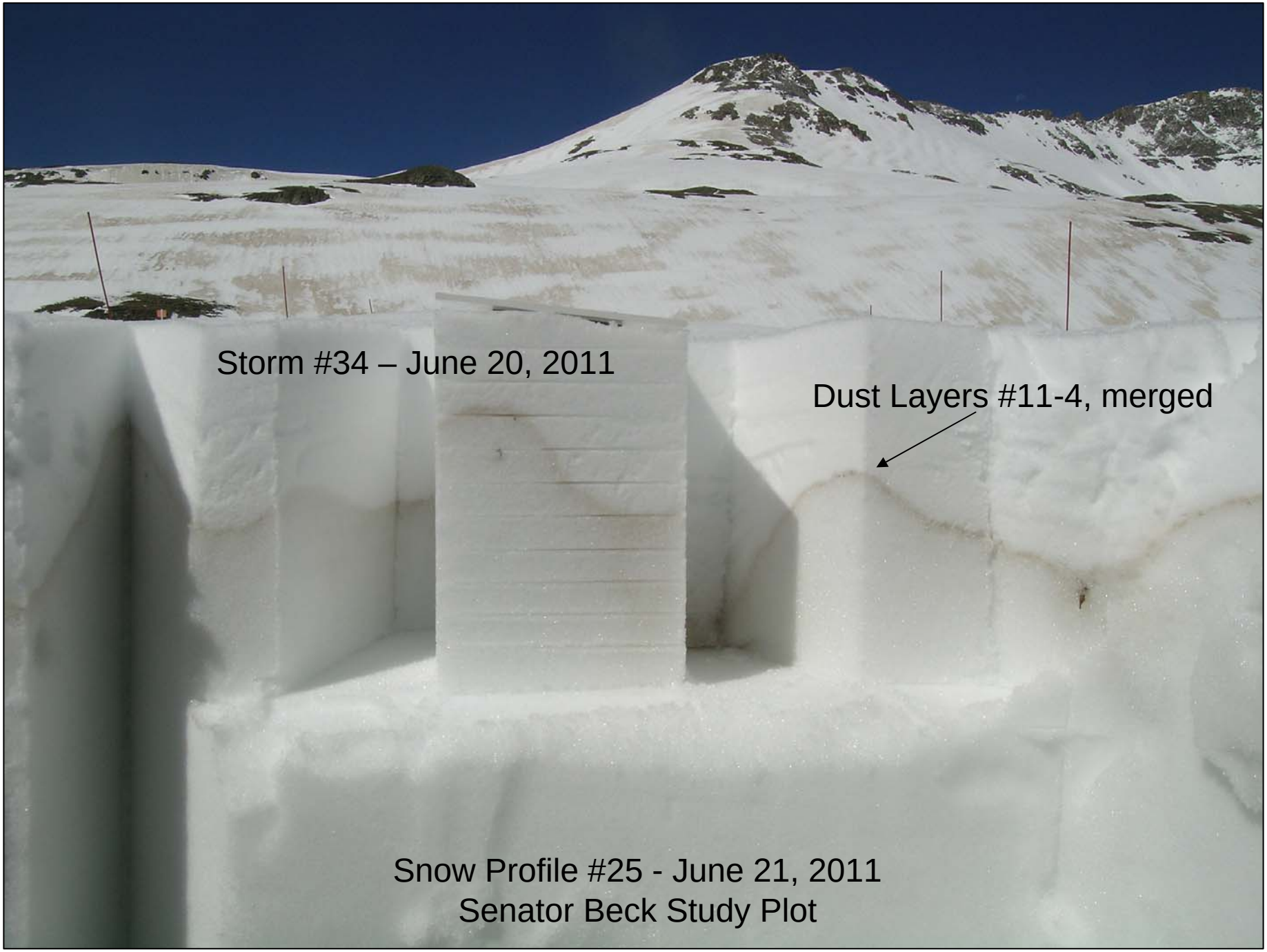
Spring 2009 = 55 gm/m^2

Spring 2010 = ~40 gm/m^2

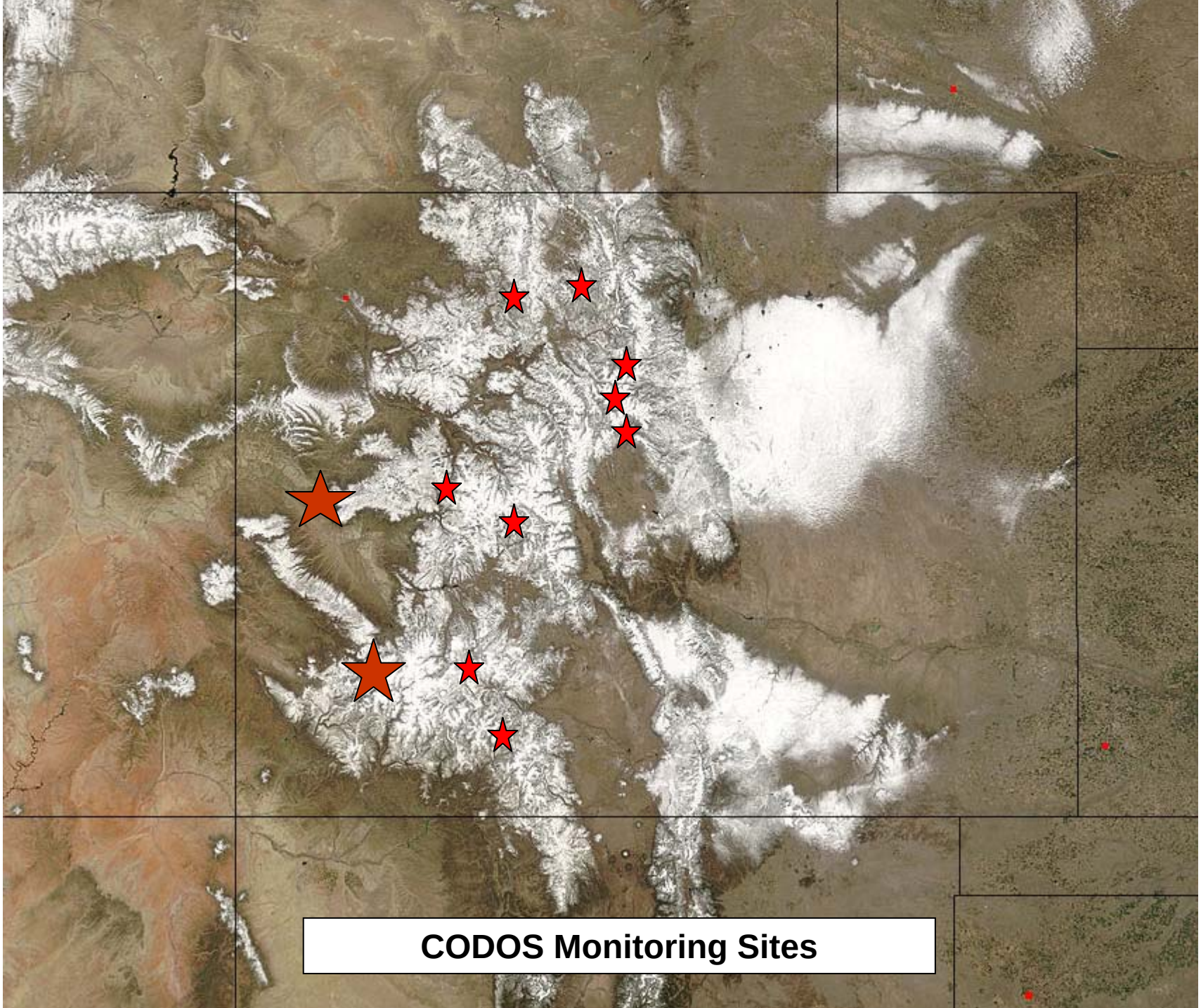
May 28, 2010 – Swamp Angel Study Plot

May 13, 2009 – Swamp Angel Study Plot

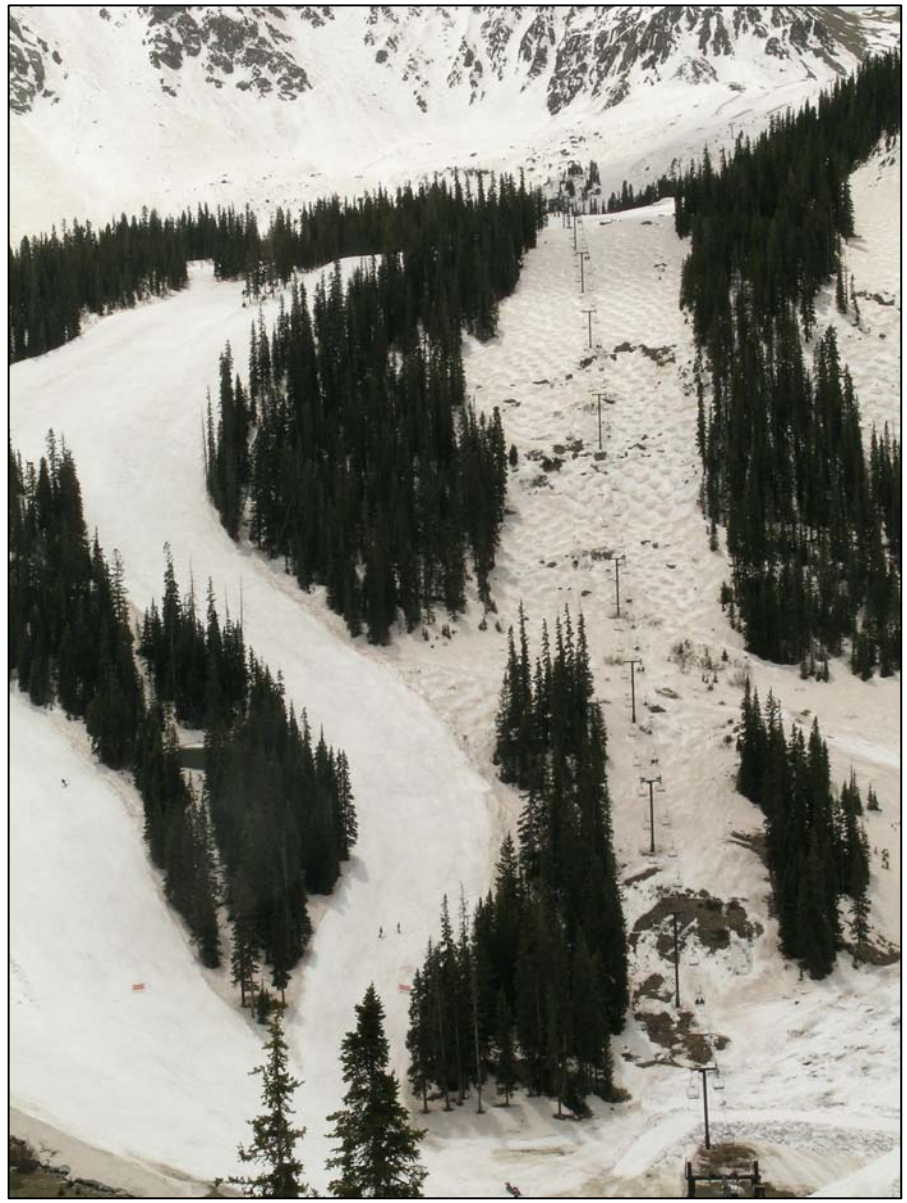
Snow Profile #24 - June 14, 2011
Swamp Angel Study Plot



Snow Profile #25 - June 21, 2011
Senator Beck Study Plot


CODOS Monitoring Sites

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



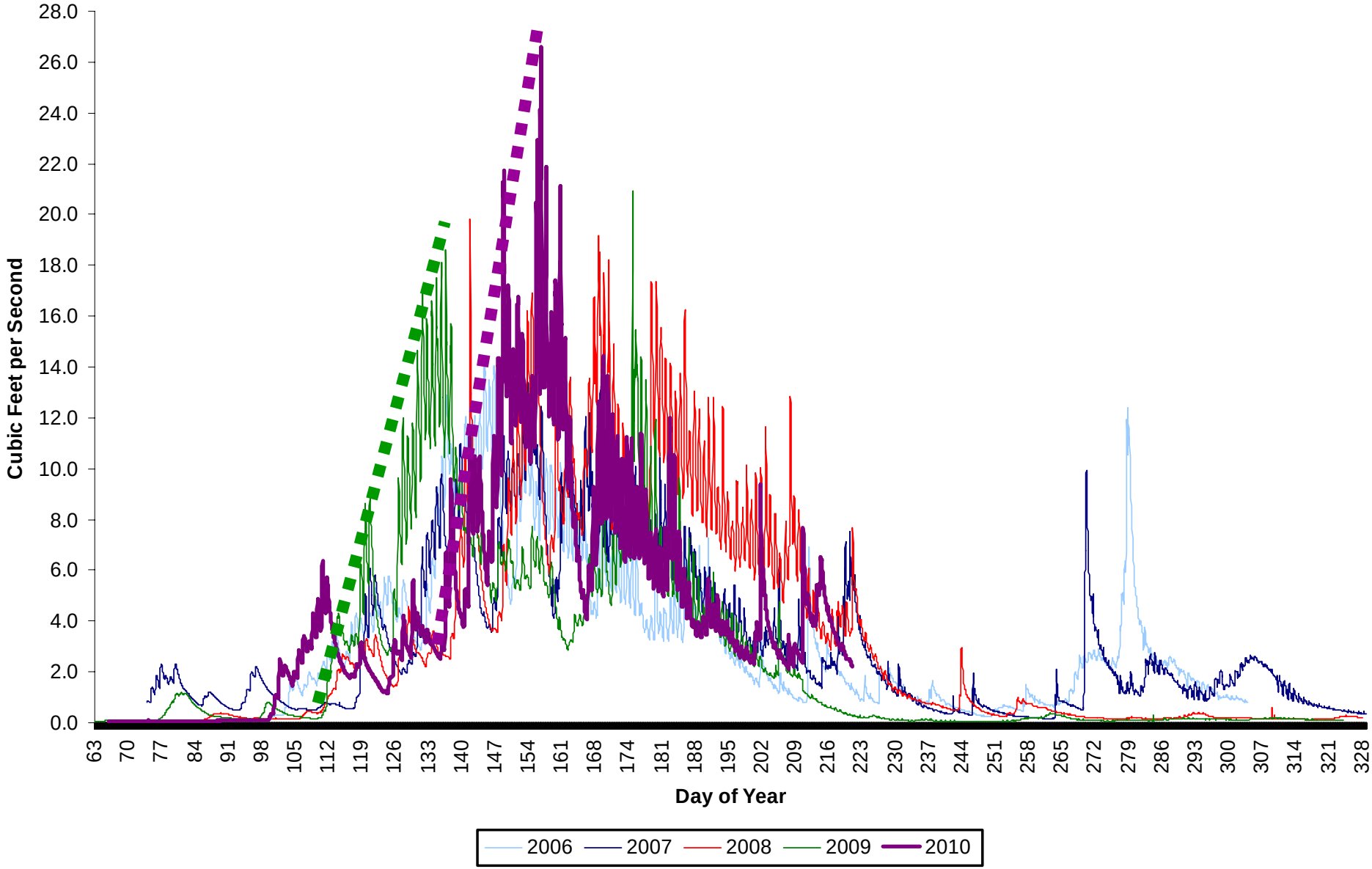

April 17, 2009 – Berthoud Pass

April 18, 2009 – Willow Creek Pass

May 27, 2010 – Grand Mesa

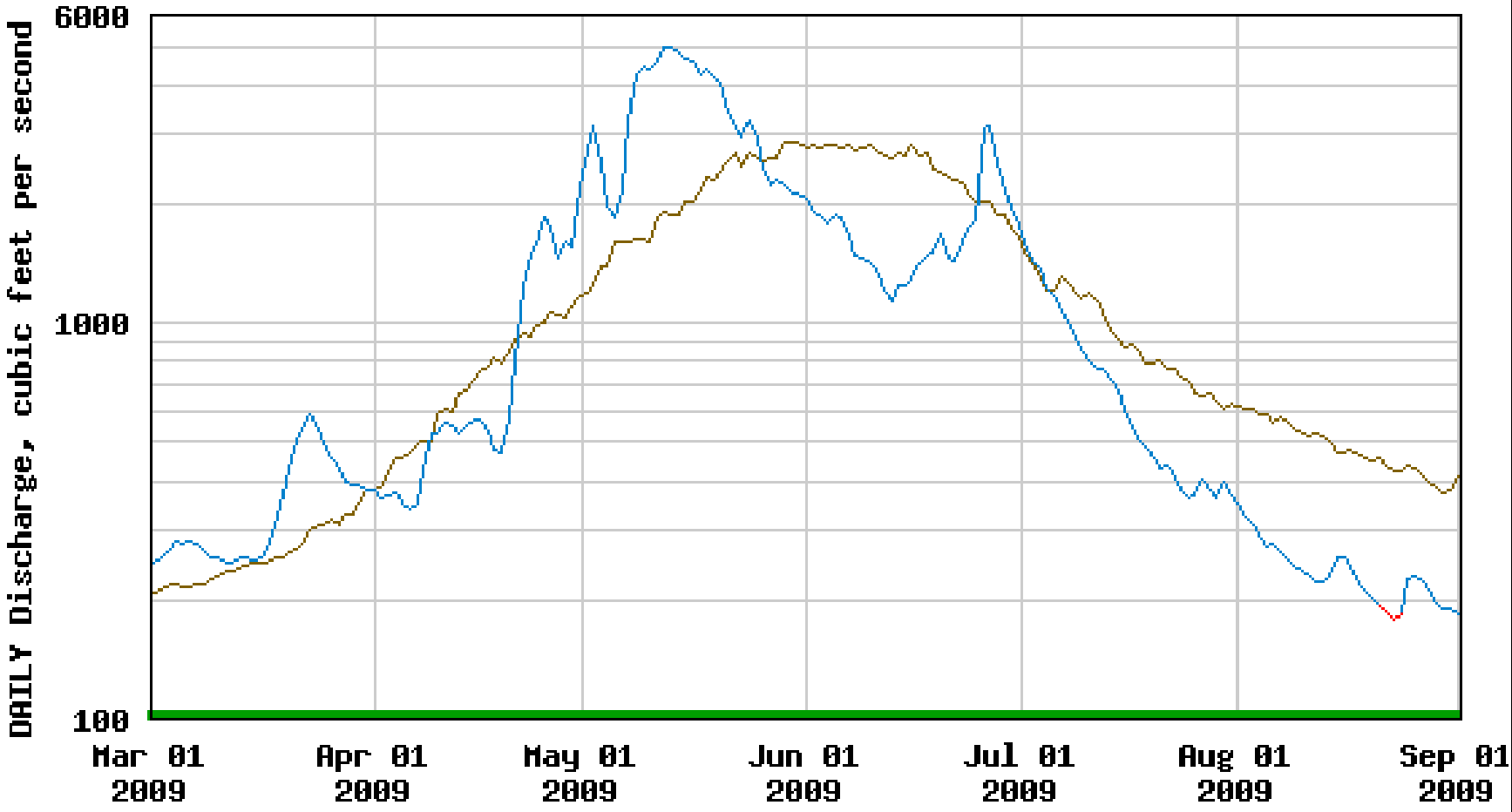
June 5, 2010 –Senator Beck Stream Gauge at 26 cfs

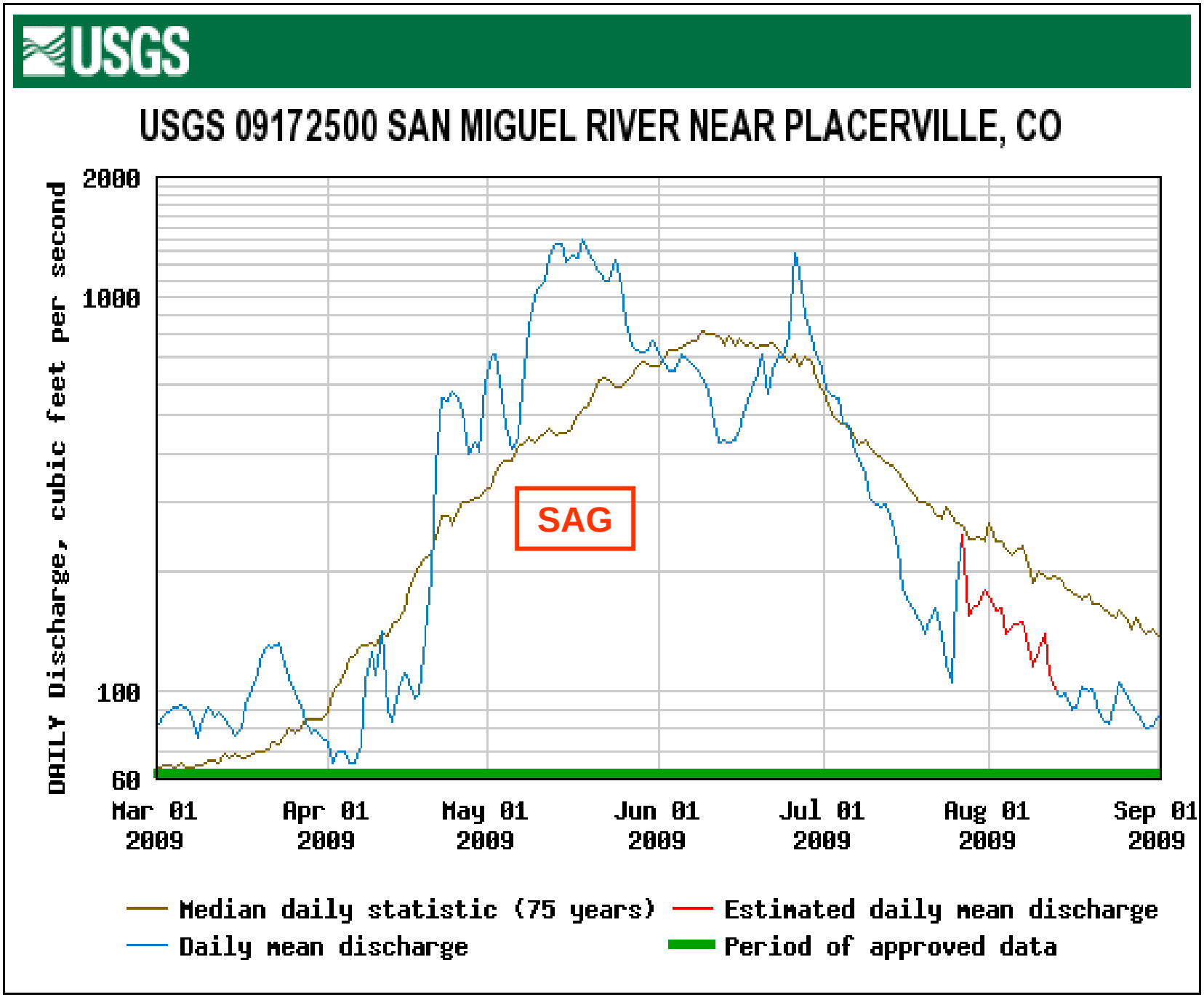
Senator Beck Basin Discharge – WY 2006, 2007, 2008 & 2009, 2010

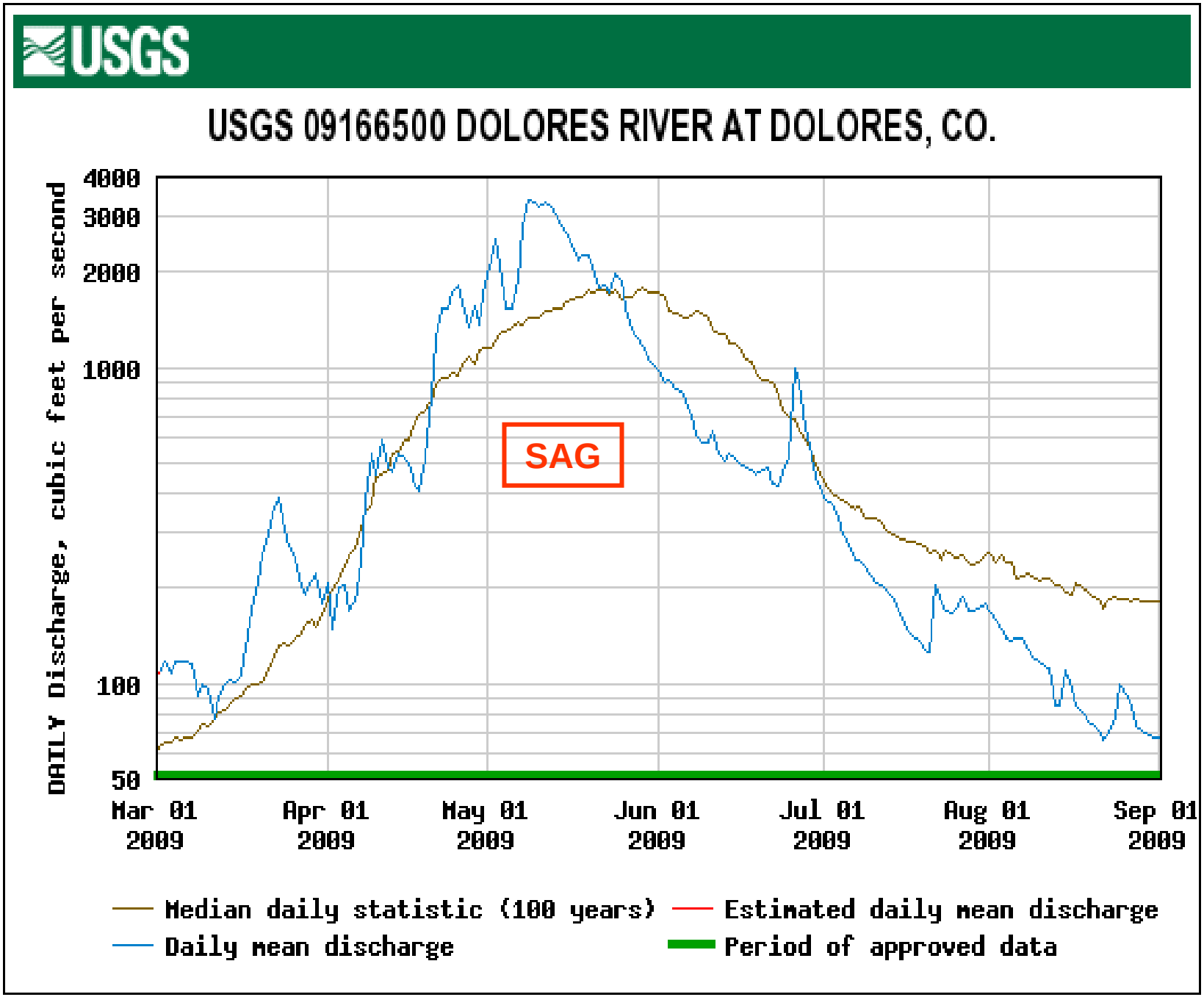


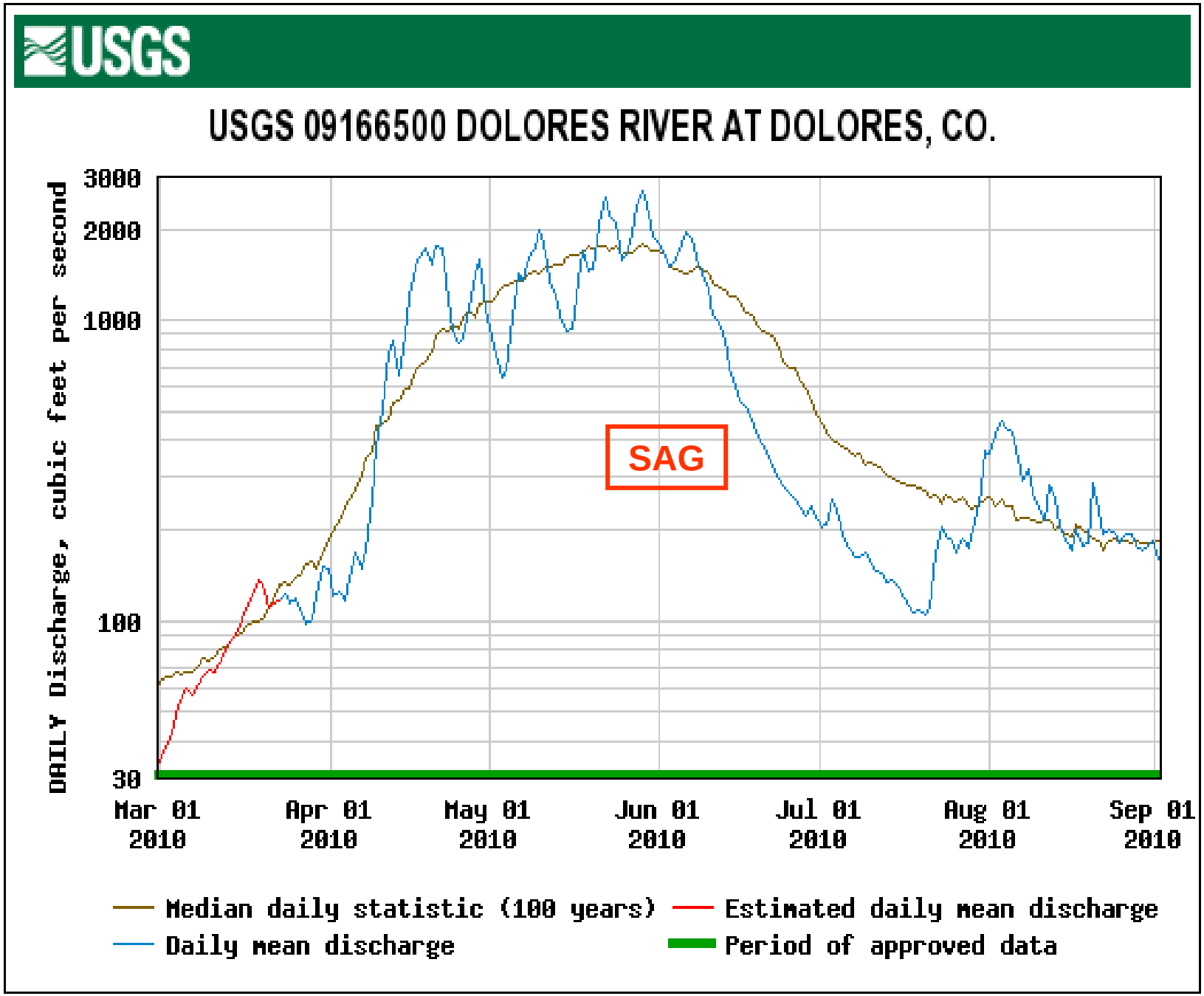
USGS

USGS 09361500 ANIMAS RIVER AT DURANGO, CO

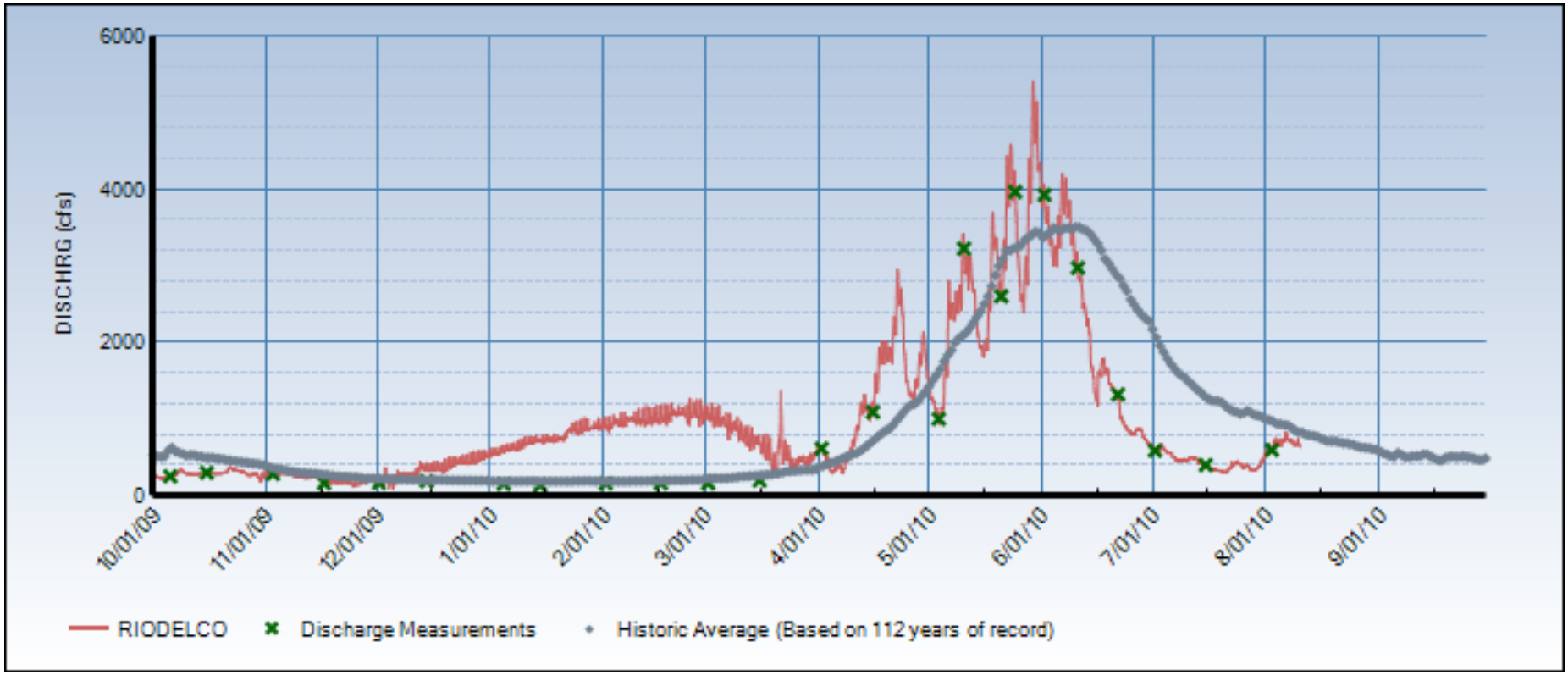


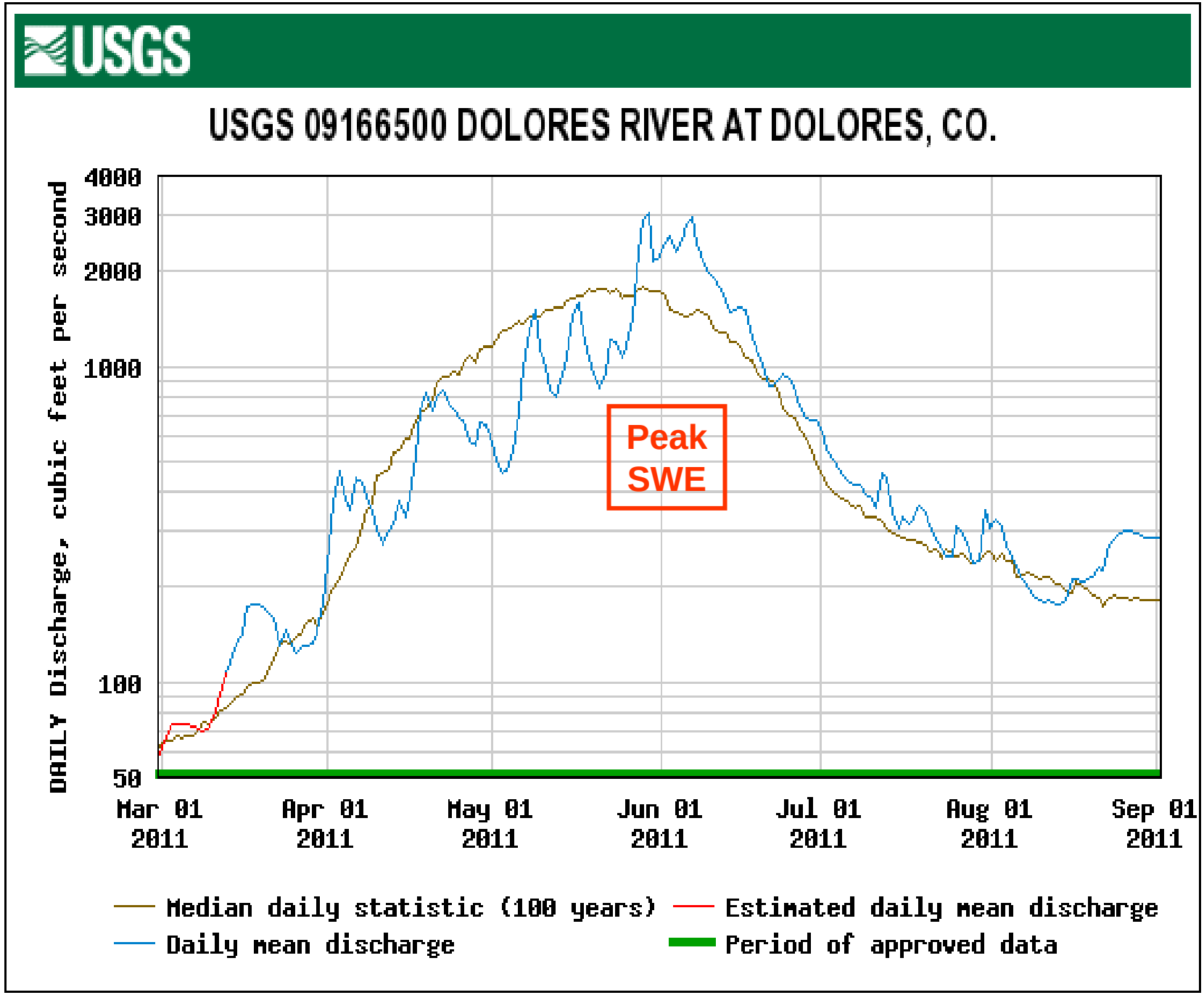

USGS
USGS 09172500 SAN MIGUEL RIVER NEAR PLACERVILLE, CO
DAILY Discharge, cubic feet per second
2000
1000
100
60
SAG
Mar 01 2009
Apr 01 2009
May 01 2009
Jun 01 2009
Jul 01 2009
Aug 01 2009
Sep 01 2009
Median daily statistic (75 years)
Estimated daily mean discharge
Daily mean discharge
Period of approved data


USGS
USGS 09166500 DOLORES RIVER AT DOLORES, CO.
DAILY Discharge, cubic feet per second
4000
3000
2000
1000
100
50
SAG
Mar 01 2009
Apr 01 2009
May 01 2009
Jun 01 2009
Jul 01 2009
Aug 01 2009
Sep 01 2009
Median daily statistic (100 years)
Estimated daily mean discharge
Daily mean discharge
Period of approved data

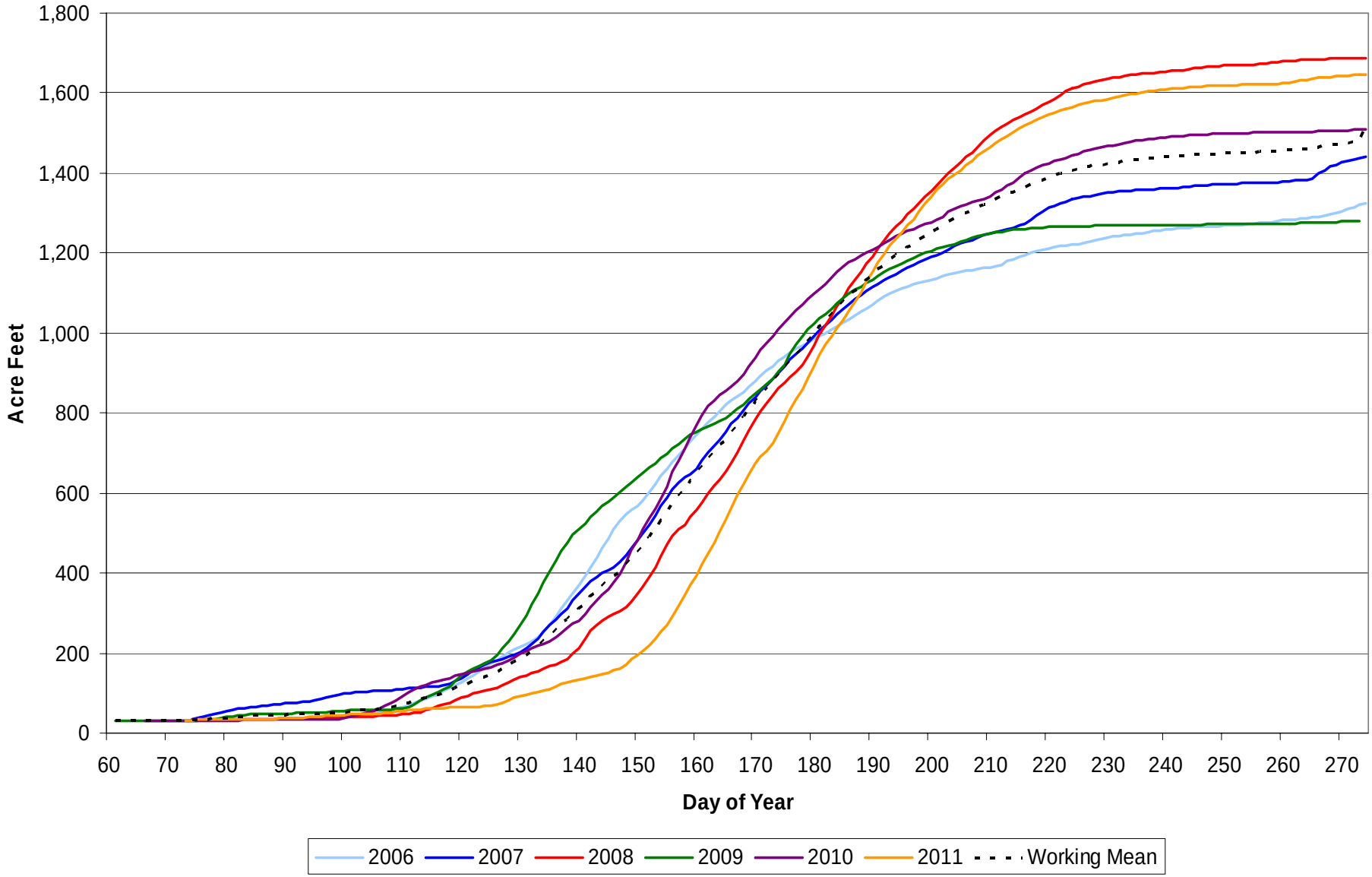

USGS
USGS 09166500 DOLORES RIVER AT DOLORES, CO.
DAILY Discharge, cubic feet per second
3000
2000
1000
100
30
SAG
Mar 01 2010
Apr 01 2010
May 01 2010
Jun 01 2010
Jul 01 2010
Aug 01 2010
Sep 01 2010
Median daily statistic (100 years)
Estimated daily mean discharge
Daily mean discharge
Period of approved data

Rio Grande at Del Norte
WY 2010



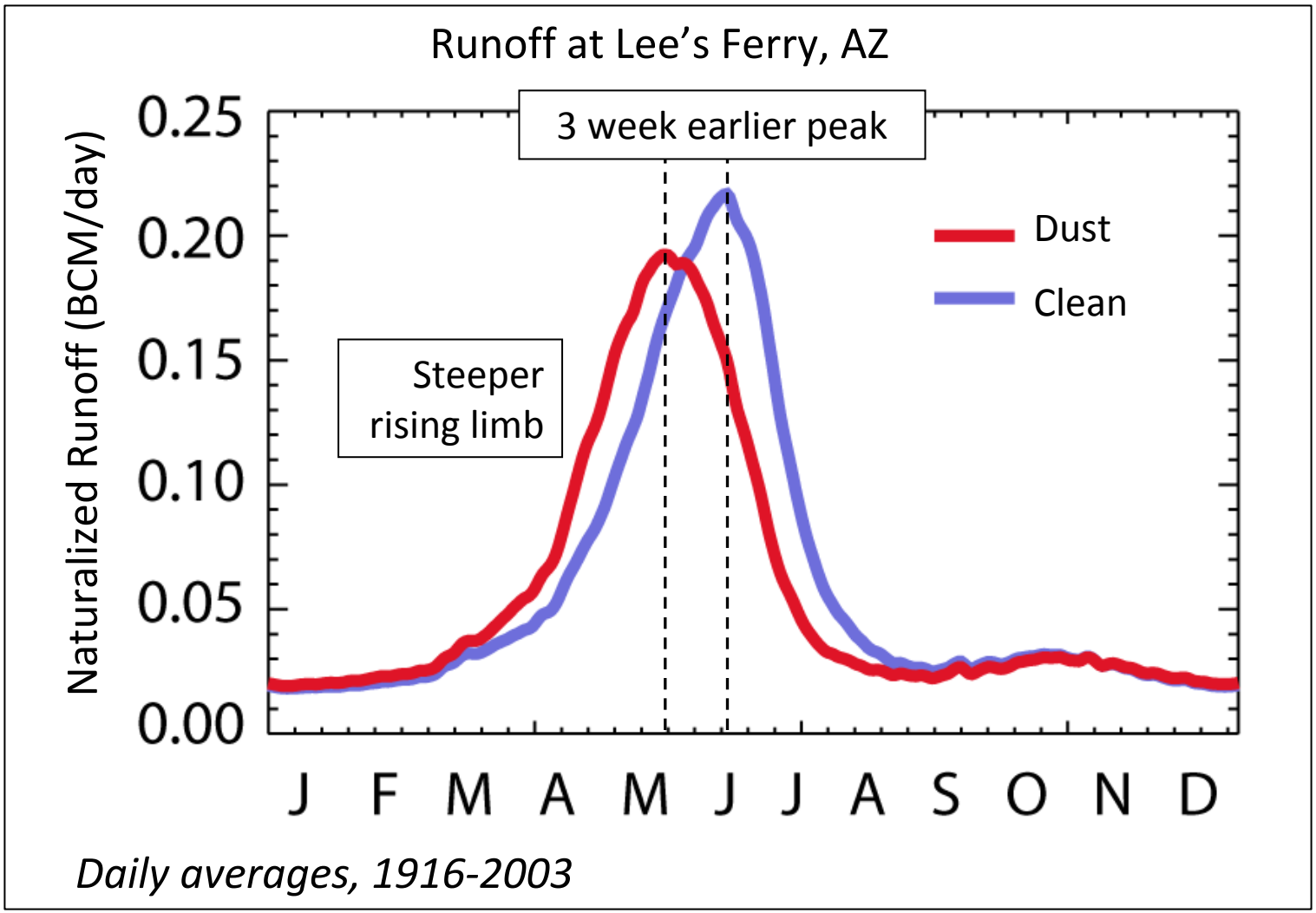

USGS
USGS 09166500 DOLORES RIVER AT DOLORES, CO.
DAILY Discharge, cubic feet per second
4000
3000
2000
1000
100
50
Peak SWE
Mar 01 2011
Apr 01 2011
May 01 2011
Jun 01 2011
Jul 01 2011
Aug 01 2011
Sep 01 2011
Median daily statistic (100 years)
Estimated daily mean discharge
Daily mean discharge
Period of approved data

Senator Beck Basin Cumulative Discharge - 2006, 2007, 2008, 2009, 2010, 2011



Dust-on-Snow Shifts Upper CRB Hydrograph*

*not including 2009, 2010 dust deposition rates

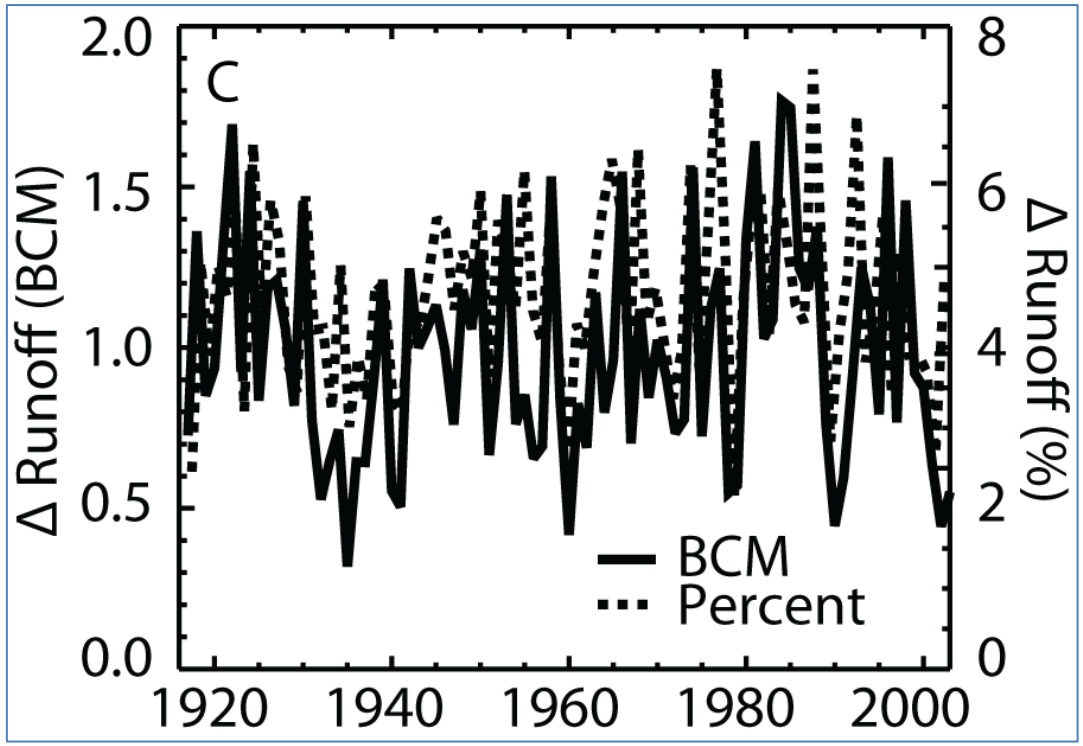


Painter, Deems, *et al.*, *PNAS* (*2010*)

At the scale of the Upper CRB, modeling shows:

DOS = Earlier SAG = Increased ET = Reduced Runoff

- Mean Δ Runoff:
  - -4.9%
  - -811,000 acre-ft
- Range:
  - -2.3 to -7.6%
  - -243k to -1,460k acre-ft



**based on pre-2009 dust loading*

Painter, Deems, *et al.*, *PNAS* (2010)

What we have learned *since 2003/2004 …*

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

Dust effects vary year-to-year …

- **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 <u>already exceed</u> projected climate forcing effects**
- **Dust-on-snow has reduced Upper CRB flows at Lees Ferry by 3-7%**

What we <u>do not</u> yet know …

- **Exactly why 2008/2009 , 2009/2010 and 2010/2011 were so dusty**
- **Whether 2008/2009, 2009/2010 and 2010/2011 are a new normal**
- **Shares of dust attributable to the variety of agents disturbing CP soils**

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