ALASKA DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Amendments to:

State Air Quality Control Plan

Volume III: Appendix III.K.13

Alaska Regional Haze State Implementation Plan

2nd Implementation Period

Appendix to Section III.K.13.I

Adopted

July 5, 2022

Mike J. Dunleavy, Governor

Jason W. Brune, Commissioner

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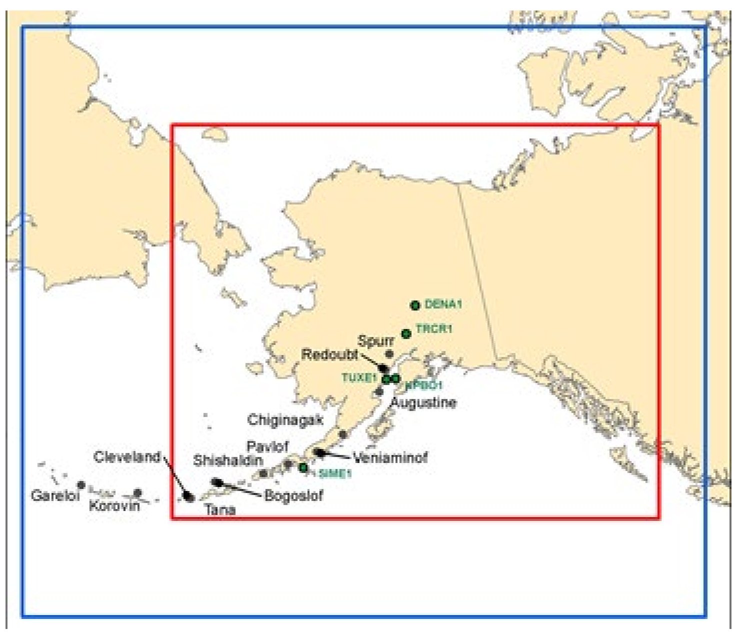
Appendix III.K.13.I.

International Anthropogenic Emissions Adjusted Glidepath accounting for episodic ammonium sulfate events

Alaska currently has 40 active volcanoes which are important sources of sulfur dioxide (Figure III.K.13.AA-1). Section III.K.13.E.4 describes how volcano emissions are variable in magnitude, frequency, and temporal distribution. The IMPROVE MID approach is a potentially flawed visibility impairment metric for Alaska since there can be a large component of natural sulfate from volcanos and DMS. The IMPROVE MID implicit assumption that, with the exception of sulfate in routine natural background, visibility extinction due to ammonium sulfate [$(NH_4)_2SO_4$] and ammonium nitrate [NH_4NO_3] are mainly anthropogenic in origin is not true in Alaska. Given this issue, an alternative MID was developed by screening out IMPROVE days with estimated high $(NH_4)_2SO_4$ to account for volcano emission impacts in a similar way to how fire and dust contributions are screened out using carbon and crustal measurements as proxies. New URP glidepaths were developed using the alternative MID with sulfur screening. This Appendix describes the screening approach and presents the resulting URP glidepaths.

Figure III.K.13.AA-1. Alaska Volcanoes and IMPROVE monitors



1. DEVELOPMENT OF ALTERNATIVE MID WITH LIMITED NATURAL EMISSION CONTRIBUTIONS TO AMMONIUM SULFATE

In the EPA approach, the IMPROVE MID are selected by screening out days with estimated high fire (using carbon PM measurements) and dust (using crustal PM measurements) contributions and identifying the 20% days that are most likely impaired by anthropogenic emissions under the assumption that $(NH_4)_2SO_4$ and NH_4NO_3 are mainly anthropogenic in origin. However, multiple volcanoes located near the Alaska IMPROVE sites are active providing episodic events due to volcano SO_2 emissions impacting visibility similar to fire and dust contributions. Volcanic sulfur dioxide (VSO_2) emissions alone contribute approximately half of 2016 total SO_2 emissions within the CMAQ 27-km grid resolution domain. The glidepaths need to limit influences from these volcano activities. One approach is to use the AVO's volcano activities report which identify days with seismic activities prior to eruptions. In 2016, nine of twenty-four MIDs at SIME1 are flagged as orange category (e.g., small-moderate eruptions, increased seismic activity) at Pavlof and Cleveland volcanos; eruption height below 15,000 ft was recorded on July 29 at Pavlof. However, the AVO data may not capture all passive degassing days. The satellite's derived VSO_2 emission inventory reports both degassing and erupting emissions but only at an annual basis. Neither approach considers transport of emissions to the IMPROVE monitors (e.g., back trajectory analysis).

EPA's 2018 Technical Guidance for tracking progress under the RH Rule described an approach that screens out natural episodic events with high haze levels related to wildfire (based on organic and elemental carbon) or dust storm impacts (based on fine crustal and coarse mass) that are frequently experienced at Class I areas in western half of the Continental U.S. The approach uses an episodic threshold determined by the lowest annual 95th percentile daily extinction from 2000-2014 at each IMPROVE site. EPA adopted this same approach to screen out natural episodic events related to volcanic activity (based on SO_4) at two Class I areas in Hawaii. Here, the same method is applied to Alaska. Note that this modified approach does not affect the 20% clearest days.

The SO_4 screening alters the days in the MID as demonstrated in Figure III.K.13.AA-2 for SIME1. The SO_4-adjusted MID removed days with exceptionally high ammonium sulfate (e.g., more than 100 Mm^{-1} in 2007 and 2009). Year 2010 (DENA1), 2012 (TRCR1, TUXE1), and 2013 (SIME1) had the lowest 95th percentile for Alaska IMPROVE sites so were used as a threshold (Figure III.K.13.AA-3). 2010 and 2012 had low volcano emissions so would support that the upper end of the variability is due to volcano emissions. Figure III.K.13.AA-4 shows a comparison of annual $(NH_4)_2SO_4$ extinctions on the MID that were considered episodic (i.e., screened out using the 95th percentile threshold) and annual VSO_2 emissions. Overall, the episodic extinctions at Alaska IMPROVE sites appear to reflect VSO_2 emissions.

Given the SIME1 location, commercial marine vessels contribute to $PM_{2.5}$ concentrations at the site to an extent but these sulfate spikes were not likely a result of shipping plume. Kotchenruther (2017)[1] quantified $PM_{2.5}$ impacts from marine vessel residual fuel oil (RFO) combustion at multiple coastal sites spanning a period from 2010 through 2015, which is a transition period from unregulated to 0.1% sulfur limit. The results suggested that the average decrease in annual average $PM_{2.5}$ from RFO combustion was by about 80% at the selected western coastal sites (i.e., AGTI1, PORE1, PUSO1, OLYM1). Although CMV impact was

[1] Kotchenruther, R.A., 2017. The effects of marine vessel fuel sulfur regulations on ambient PM2. 5 at coastal and near coastal monitoring sites in the US. *Atmospheric Environment*, *151*, pp.52-61.

significant (pre-2012), none of these sites had ammonium sulfate extinction exceeding 100 Mm^{-1} and when ammonium sulfate was elevated ammonium nitrate was also high suggesting that RFO contribution would likely be below 70 Mm^{-1} (Table III.K.13.AA-1). In a contrary, elevated sulfate influenced by volcanoes could exceed 100 Mm^{-1} as observed on many days at the HAVO1 in Hawaii (Figure III.K.13.AA-5). The peaks sulfate measured at SIME1 in 2007 and 2009 are likely associated with volcano. The 2007 sulfate peak on February 26 coincided with Redoubt steaming activities that last for several months in the first half[2]. The 2009 sulfate peak on April 28 coincided with eruptions (Code Red) at the Sheveluch in Russia[3].The sulfate peaks at other Alaska monitors were less and were not necessary occurring on the same days (Figure III.K.13.AA-6). Local scale transport of volcano plumes could post a challenge in modeling volcano impacts (e.g., back-trajectory analysis).

[2] 2007 Volcanic Activity in Alaska, Kamchatka, and the Kurile Islands—Summary of Events and Response of the Alaska Volcano Observatory. https://pubs.usgs.gov/sir/2010/5242/pdf/sir20105242.pdf
[3] 2009 Volcanic Activity in Alaska, Kamchatka, and the Kurile Islands—Summary of Events and Response of the Alaska Volcano Observatory. https://pubs.usgs.gov/sir/2013/5213/pdf/sir2013-5213.pdf

Figure III.K.13.AA-2. Daily ammonium sulfate extinction on default and sulfate-adjusted MID at SIME1 in 2007 and 2009.

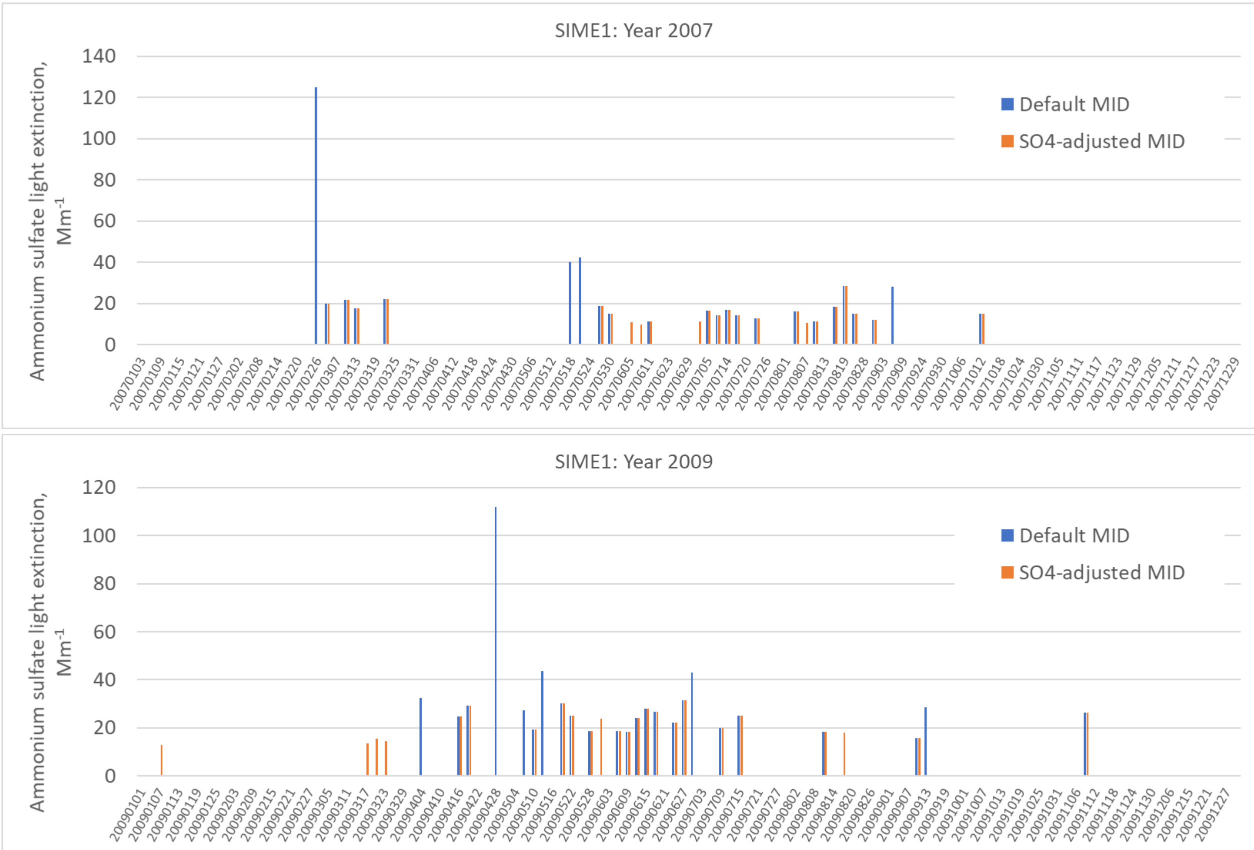


Figure III.K.13.AA-3. Episodic ammonium sulfate extinction on default MID (95th percentile threshold) and estimated volcano emissions during 2005-2018.

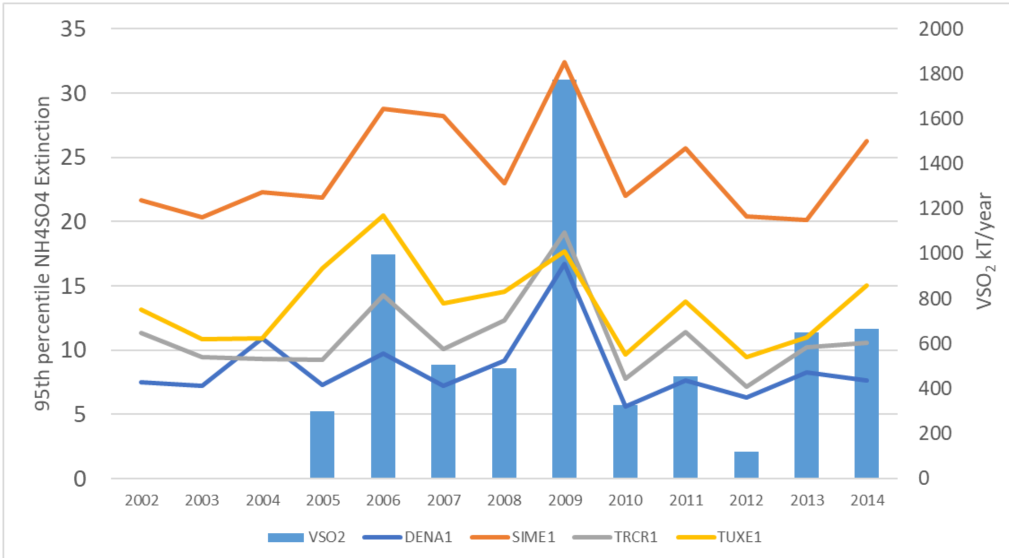


Figure III.K.13.AA-4. Episodic ammonium sulfate extinction on default MID (95th percentile threshold) and estimated volcano emissions during 2005-2018.

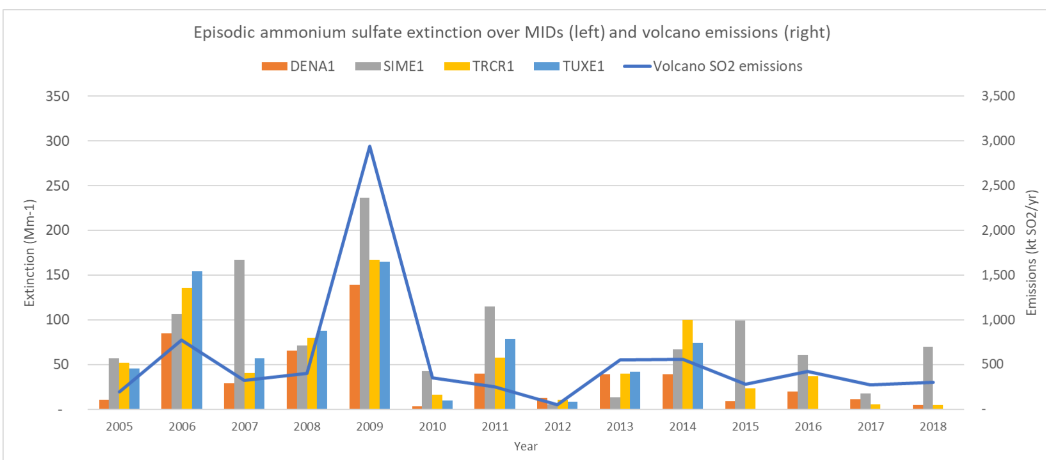
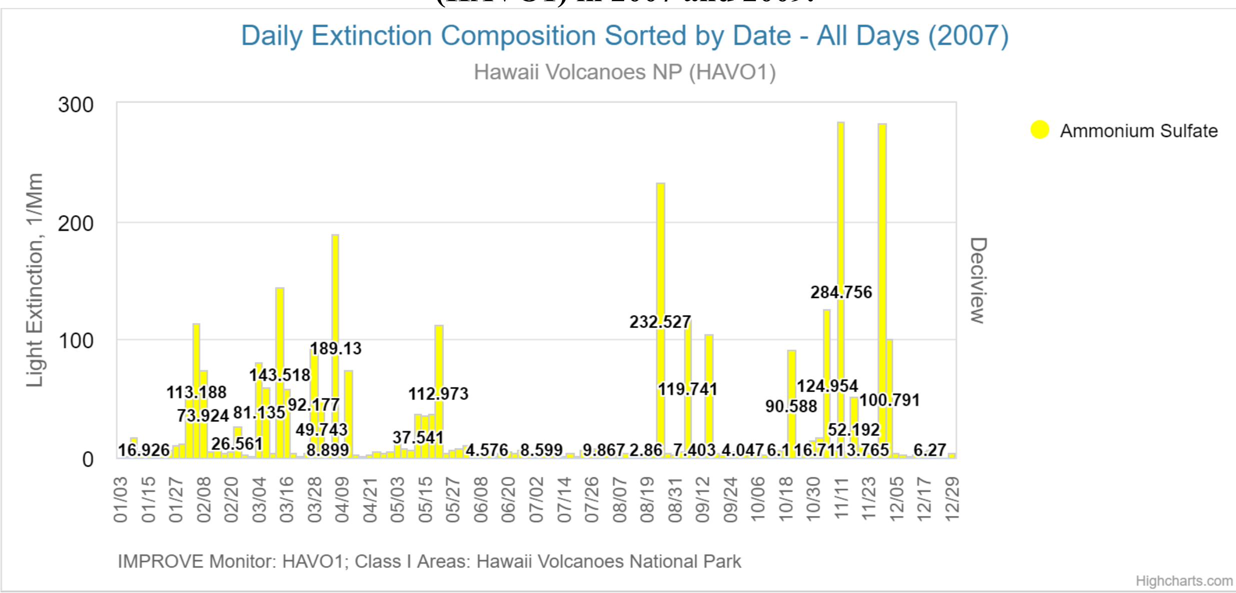


Table III.K.13.AA-1. Daily ammonium sulfate and ammonium nitrate at selected western coastal sites on days when ammonium sulfate extinction exceeded 70 Mm^{-1}

IMPROVE Sites	Date	Daily Max EAmm_SO4	Daily Max EAmm_NO3	Impairment Group
AGTI1	8/15/2002	72	10	70
AGTI1	10/6/2003	82	49	90
PORE1	1/22/2005	92	53	90
PUSO1	10/20/2002	87	119	50

PUSO1	10/23/2002	84	58	50
PUSO1	10/26/2002	85	110	90
PUSO1	10/3/2003	87	100	90
PUSO1	10/3/2004	91	75	30
PUSO1	12/17/2004	76	56	70
PUSO1	1/25/2005	71	25	30

Figure III.K.13.AA-5. Daily ammonium sulfate extinction at Hawaii Volcanoes NP (HAVO1) in 2007 and 2009.



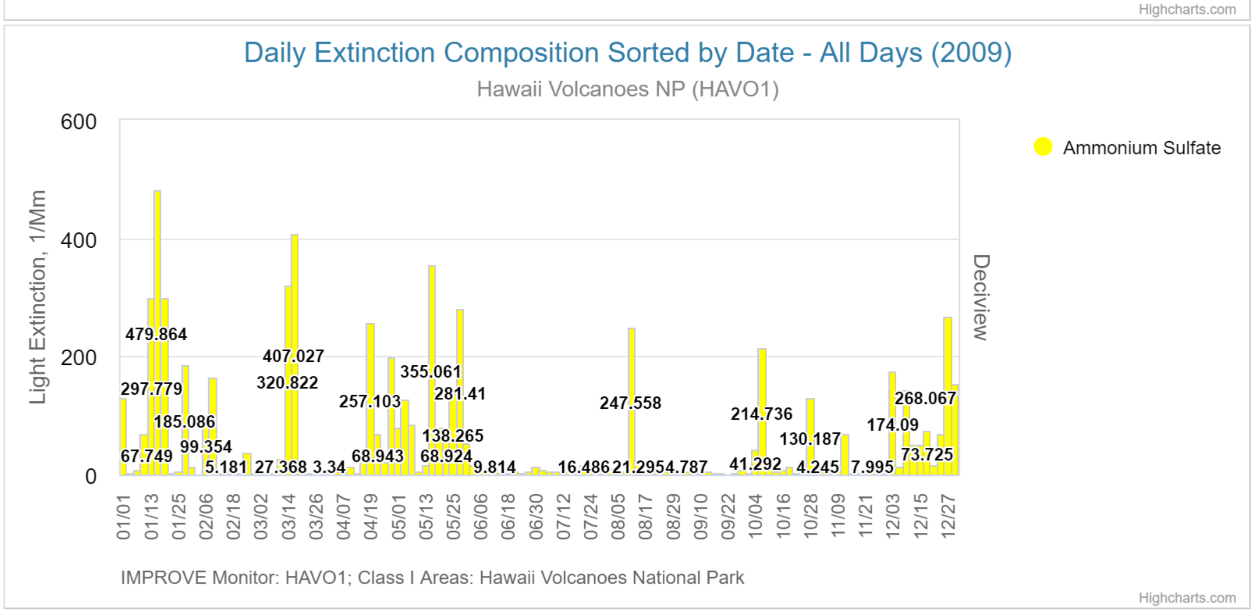
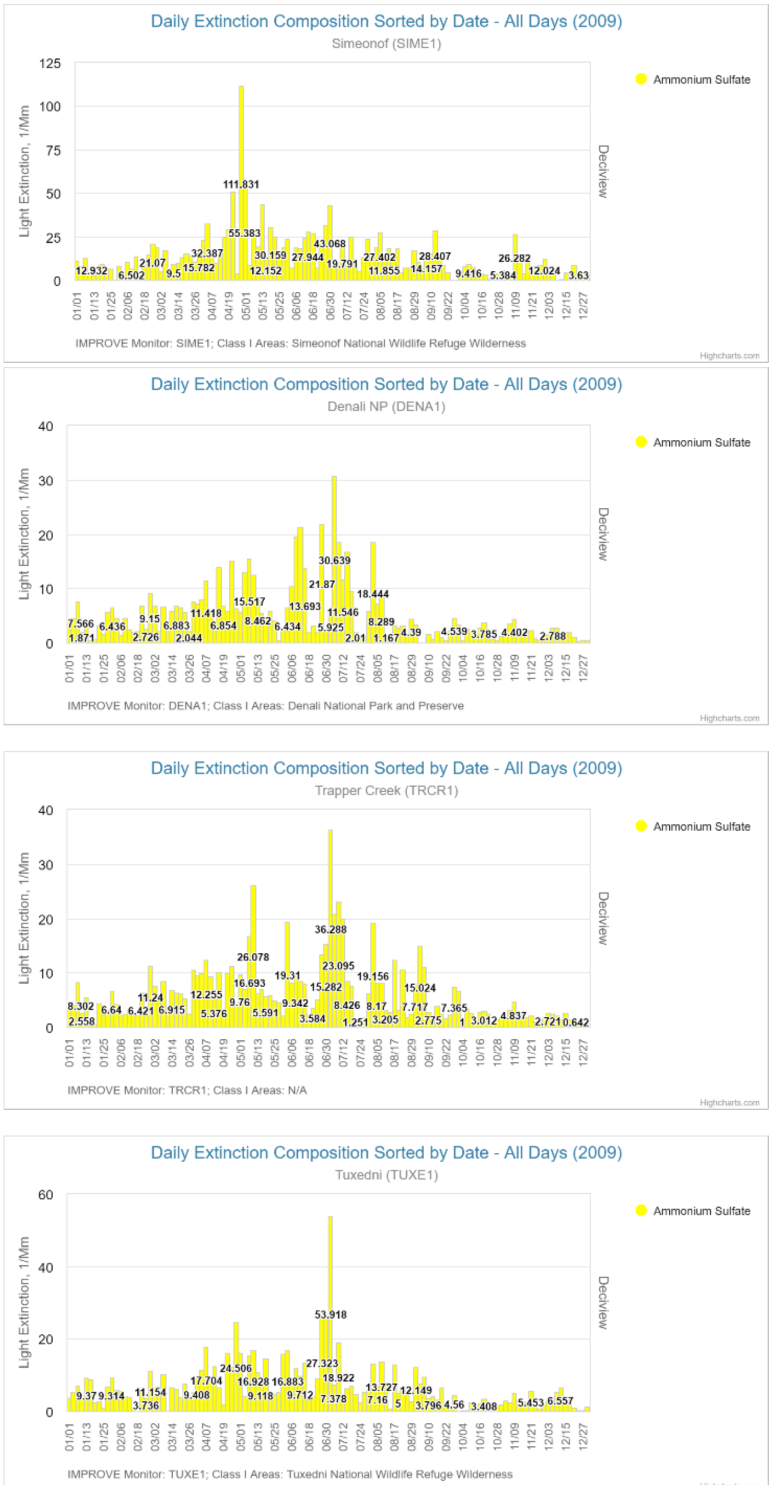


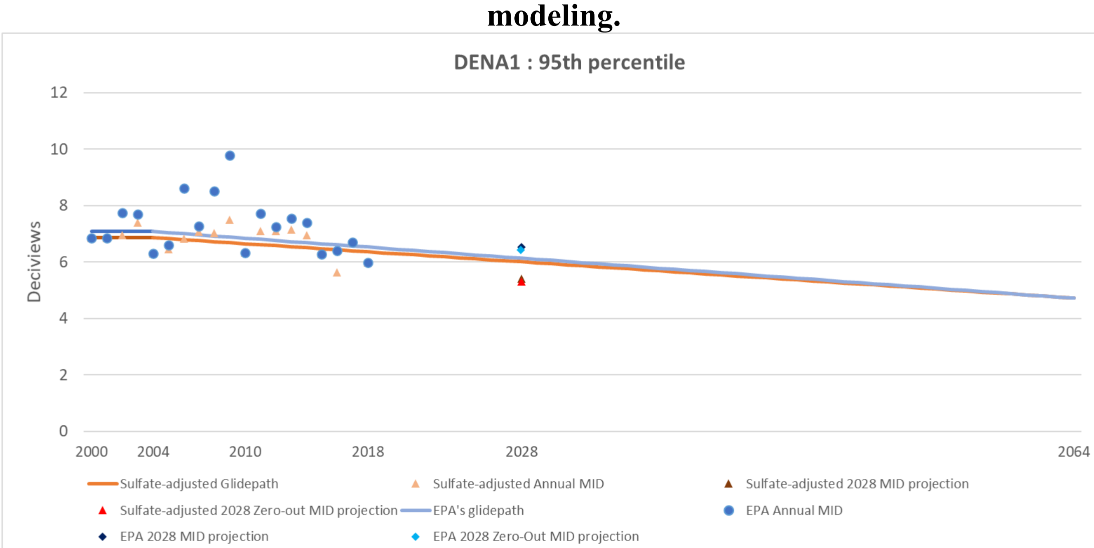
Figure III.K.13.AA-6. Daily ammonium sulfate extinction in 2009 at Alaska IMPROVE sites.

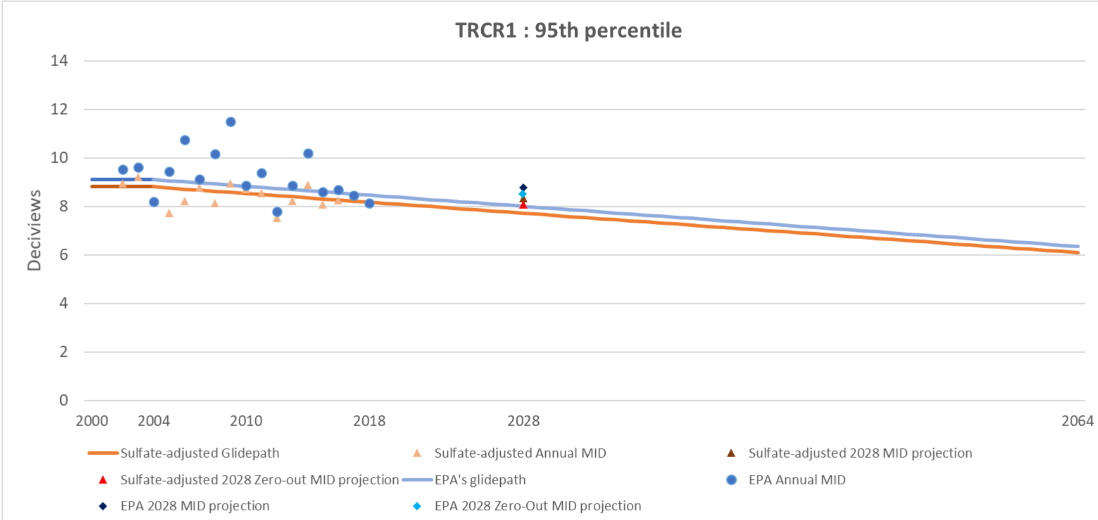


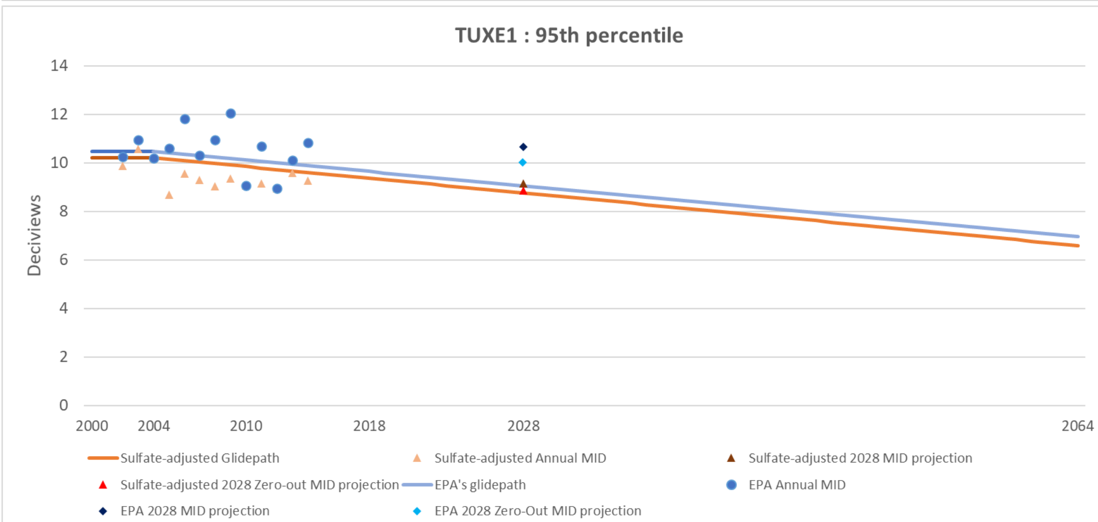
The SO_4 screening alters the days in the MID, 2028 visibility projections and the URP glidepath (hereinafter SO_4-adjusted glidepath) (Figure III.K.13.AA-7). The SO_4-adjusted glidepath (orange line) shows slightly lower slope than the default glidepath (blue line). Annual MID observations (orange triangle between 2000-2018) are less scattered and centered closer to the SO_4-adjusted glidepath which would indicate that SO_4 screening helps remove extreme volcano events. The SO_4-adjusted 2028 visibility projections lie closer to the 2028 point on the SO_4-adjusted glidepath than when the default glidepath is used.

While accounting for episodic SO_4 is appropriate, the screening approach is still flawed. Degassing emissions, although lower in magnitude than eruptive emissions (daily total), can last for days or months. For example, volcanic activities at Shishaldin Volcano located near Simeonof were classified as orange (e.g., small-moderate eruptions, increased seismic activity) continuously for 24 months between year 2014 to 2015 (Figure III.K.13.AA-8). This presents a situation similar to IMPROVE sites with persistent, low level wildfire impacts. The high number of days impacted by volcano (or fires) are not fully removed within the 95th percentile threshold because these situations may or may not qualify as extreme, since they are frequently present at these sites. Sites that experience long duration volcano impacts, such as these in Alaska, may need to consider a different approach. One approach is to use a lower threshold such as 80th percentile as more light extinction is pulled into the episodic category. Another option would be to explicitly model volcano and DMS impacts using source apportionment or brute-force approach to adjust the 2064 goal to account for them as natural.

Figure III.K.13.AA-7. Default and sulfate-adjusted URP Glidepath at each Class I area in Alaska and 2028 visibility projections for the MID and 2028 visibility projections starting with 2014-2018 default MID and sulfate adjusted MID using EPA's Alaska CMAQ modeling.




TRCR1 : 95th percentile
Deciviews
14
12
10
8
6
4
2
0
2000
2004
2010
2018
2028
2064
Sulfate-adjusted Glidepath
Sulfate-adjusted Annual MID
Sulfate-adjusted 2028 MID projection
Sulfate-adjusted 2028 Zero-out MID projection
EPA's glidepath
EPA Annual MID
EPA 2028 MID projection
EPA 2028 Zero-Out MID projection


TUXE1 : 95th percentile
Deciviews
14
12
10
8
6
4
2
0
2000
2004
2010
2018
2028
2064
Sulfate-adjusted Glidepath
Sulfate-adjusted Annual MID
Sulfate-adjusted 2028 MID projection
Sulfate-adjusted 2028 Zero-out MID projection
EPA's glidepath
EPA Annual MID
EPA 2028 MID projection
EPA 2028 Zero-Out MID projection

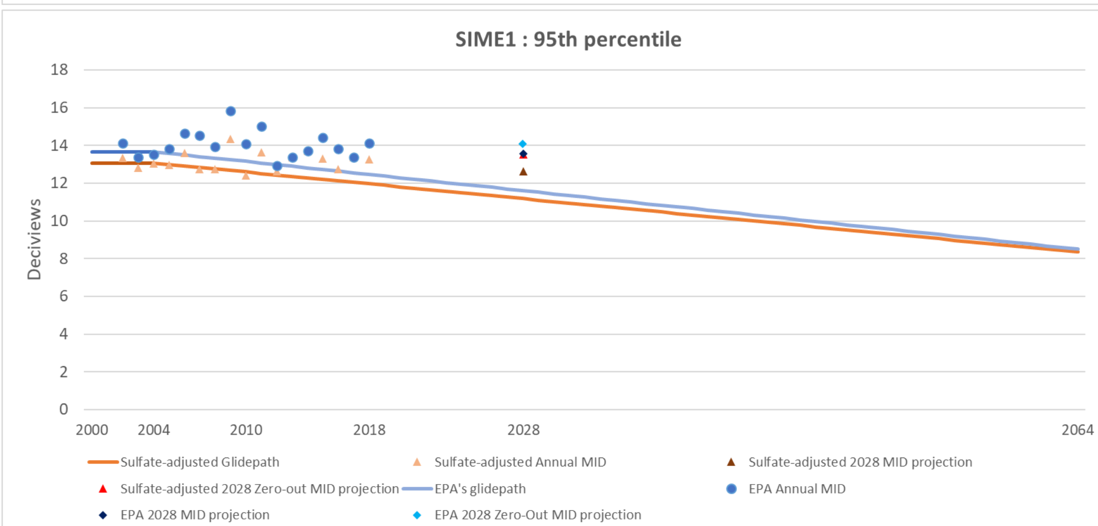
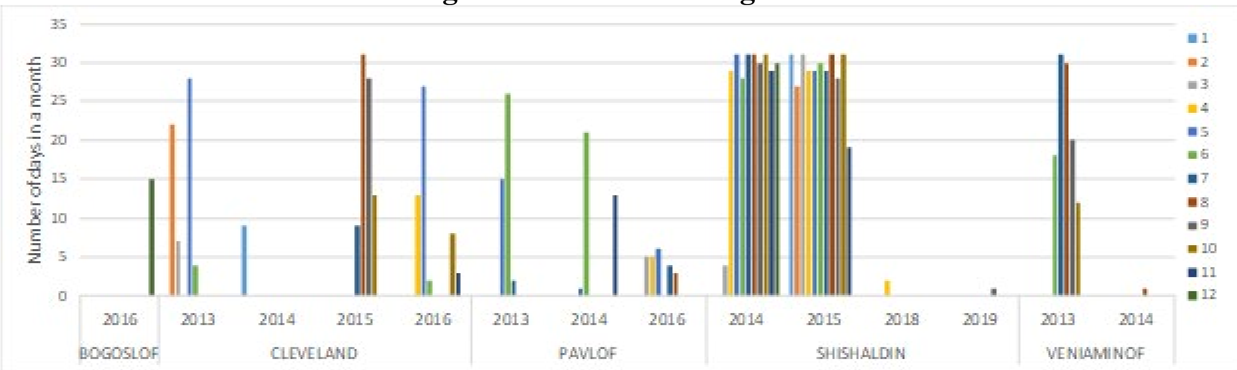

SIME1 : 95th percentile
Deciviews
18
16
14
12
10
8
6
4
2
0
2000
2004
2010
2018
2028
2064
Sulfate-adjusted Glidepath
Sulfate-adjusted Annual MID
Sulfate-adjusted 2028 MID projection
Sulfate-adjusted 2028 Zero-out MID projection
EPA's glidepath
EPA Annual MID
EPA 2028 MID projection
EPA 2028 Zero-Out MID projection

Figure III.K.13.AA-8. Monthly frequency of volcano activities between 2013-2016 categorized as either orange or red



2. GEOS-CHEM GLOBAL MODELING

Global models can estimate the contributions of international emissions to air quality and visibility. UAF ran GEOS-Chem (version 12.1.0) simulations for the 2016 calendar period for two emission scenarios, a 2016 baseline and a scenario with all anthropogenic emissions outside the U.S. eliminated (Zero Out Rest of World run; ZROW). The ZROW simulation excludes any anthropogenic emissions outside of the red boxes shown in Figure III.K.13.AA-9. The ZROW simulation provides modeling results to derive anthropogenic international contributions that can be used to adjust glidepaths in the same way EPA used the hemispheric scale CMAQ to adjust glideslopes described previously. GEOS-Chem was run using TropChem chemical mechanism, the MERRA-2 reanalysis meteorology, a horizontal grid resolution of 2°x2.5°, and 47 hybrid sigma-pressure vertical layers. Default emission inventories used by GEOS-Chem are listed in Table III.K.13.AA-2. No emission projections were applied.

Figure III.K.13.AA-9. Red box defines extent of the U.S. Emissions outside of these boxes are excluded from the ZROW simulation.

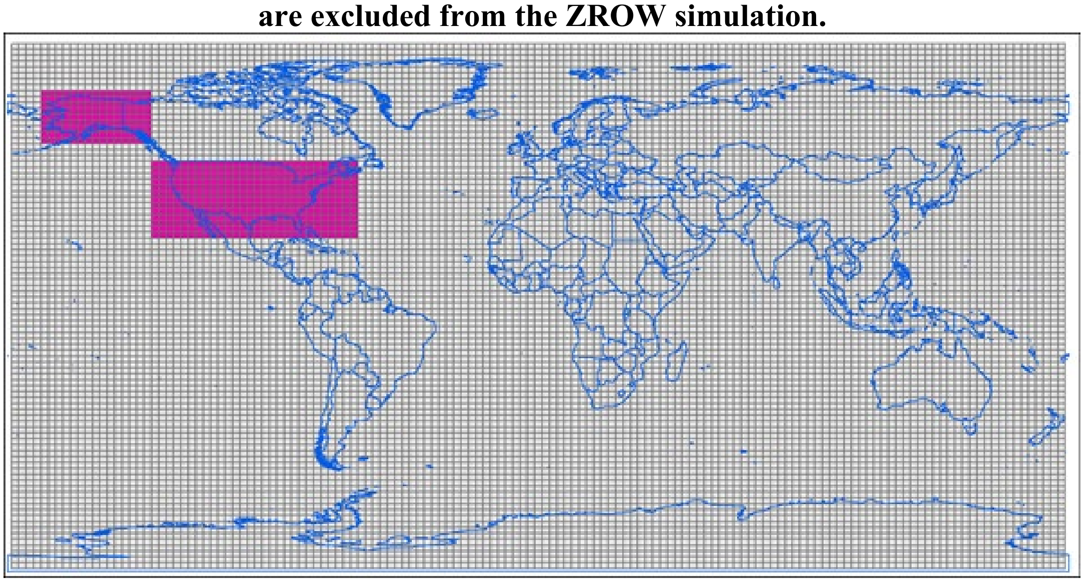


Table III.K.13.AA-2. Emission inventories used by GEOS-Chem 2016 simulations.

Region	Inventory	Inventory Year
US	US National Emission Inventory (monthly)	2013 (GEOS-Chem default scalers from 2011)
Canada	Canada Air Pollutant Emission Inventory (APEI)	2014
Asia	MIX Inventory developed for the East Asian Model Comparison Program (MICS-Asia) and the United Nations Hemisphere Air Pollution Transmission Program (HTAP)	2010
Europe	*European* Monitoring and Evaluation Programme (EMEP)	2012
Africa	Diffuse and Inefficient Combustion Emissions (DICE)	2013
Global; rest of the world	Community Emissions Data System (CEDS)	2014
Aircraft	Aviation Emissions Inventory (AEIC)	2005
Shipping	CEDS, EMEP (Europe)	2014, 2012
Biomass	Global Fire Emissions Database (GFED4; monthly)	2016
Volcanic SO_2	Satellite-derived	2009 (degassing only)
Other Natural (biogenic, lightning NOx, DMS, seasalt, halogen)	On-line	Meteorology-driven

TableIII.K.13.AA-3 presents the MID SO_4 NME at DENA1,TRCR1,and SIME1 are 62%, 108%, and 77%, respectively, exceeding the SO_4 goal and criteria for error (≤35% and ≤50%). The annual NME is higher at all three sites. The MID NMB implies over estimation of sulfate at all three sites (48% at DENA1, 105% at TRCR1, and 52% at SIME1) failing the SO_4 goal and criteria for bias (≤±10% and ≤±30%). Note, however, these performance benchmarks were recommended for regional modeling that typically has a grid resolution of 36 km or less. GEOS-Chem performance maybe limited by the grid resolution which is about 200 km which exceeds distance between Alaska IMPROVE sites and their nearby volcanoes and/or the ocean coastline (DMS contribution) so the transport of emissions cannot be adequately resolved. The overestimation of SO_4 for all days (annual average) at the three IMPROVE sites is even greater, 205% at DENA1, 272% at TRCA1 and 96% at SIME1. The high bias of sulfate could also suggest that the emission estimates for sulfate and sulfate precursors may be overestimated in the GEOS-Chem model. The highest SO_4 overestimation occurs at the DENA1 and TRCA1 IMPROVE monitor that are much less influenced by sulfur emissions from volcanos and DMS than SIME1 suggesting that the GEOS-Chem SO_4 overestimation is being mainly caused by other sulfur emission sources than volcanos and DMS.

TableIII.K.13.AA-3.2016 GEOS-Chem model performance of sulfate concentrations across all days and most impaired days.

Site/Days	Mean Obs ($\mu g/m^3$)	Mean Model ($\mu g/m^3$)	NMB (%)	NME (%)	MB ($\mu g/m^3$)	ME ($\mu g/m^3$)
DENA1						
All days	0.18	0.55	205%	212%	0.37	0.38
MIDs	0.44	0.65	48%	62%	0.21	0.27

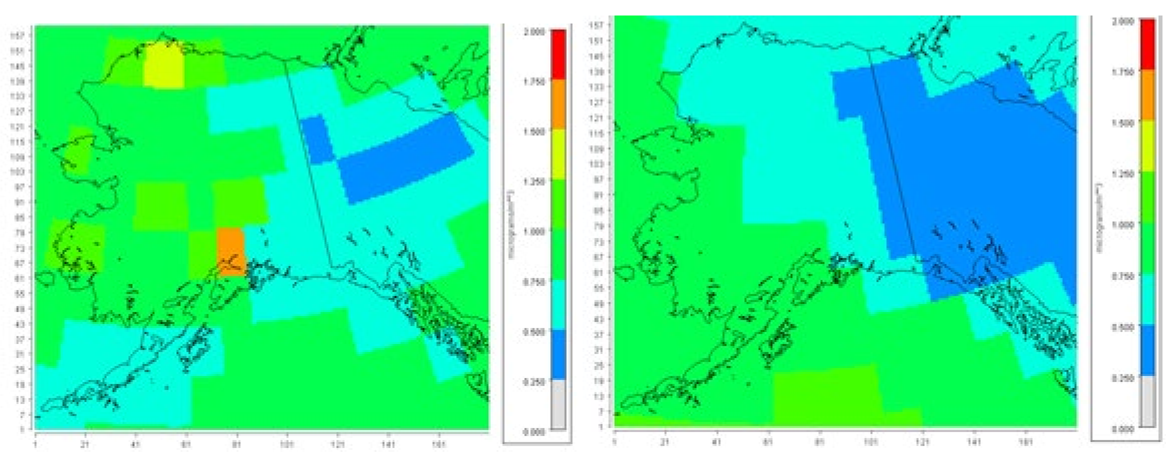
Site/Days	Mean Obs (µg/m^3)	Mean Model (µg/m^3)	NMB (%)	NME (%)	MB (µg/m^3)	ME (µg/m^3)
TRCR1						
All days	0.18	0.67	272%	274%	0.49	0.50
MIDs	0.46	0.95	105%	108%	0.49	0.50
SIME1						
All days	0.50	0.97	96%	108%	0.48	0.53
MIDs	1.03	1.57	52%	77%	0.54	0.79

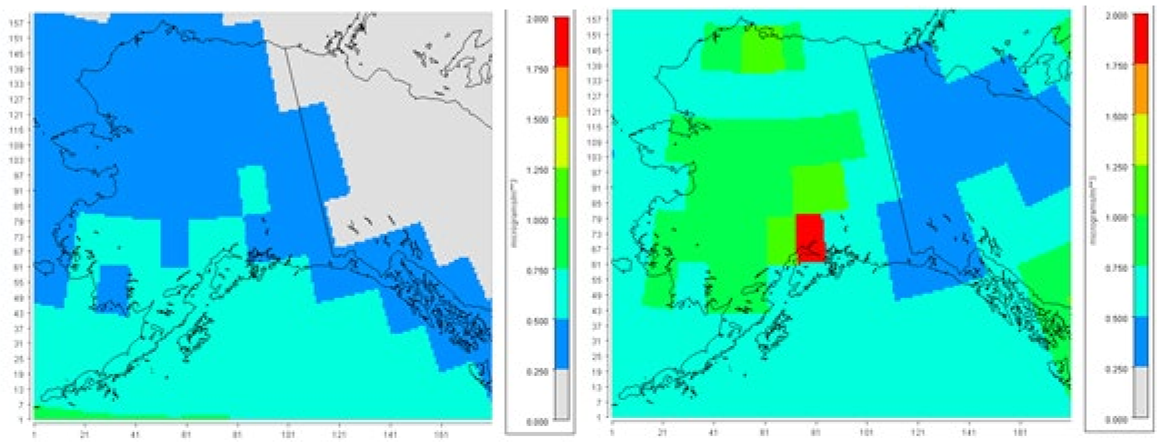
TableIII.K.13.AA-4.2016 GEOS-Chem model performance of $PM_{2.5}$ concentrations across all days and most impaired days.

Site/Days	MeanObs (µg/m^3)	MeanModel (µg/m^3)	NMB (%)	NME (%)	MB (µg/m^3)	ME (µg/m^3)
DENA1						
Alldays	0.89	2.22	150%	166%	1.34	1.47
MIDs	1.69	2.15	27%	65%	0.46	1.09
TRCR1						
Alldays	1.13	2.64	134%	144%	1.51	1.62
MIDs	2.00	2.93	47%	65%	0.94	1.30
SIME1						
Alldays	2.60	2.68	3%	52%	0.08	1.34
MIDs	3.49	3.42	-2%	53%	-0.07	1.85

Figure III.K.13.AA-10 displays the differences in quarterly average model predictions of $PM_{2.5}$ for the 2016 base and ZROW simulations. International anthropogenic emissions (i.e., base minus ZROW) contribute 0.5-1.3 ug/m^3 (approximately 13%-50%) to annual average $PM_{2.5}$ in Alaska. The model tends to overestimate both SO_4 and NO_3 at the IMPROVE sites, therefore the international anthropogenic contributions may be overstated.

Figure III.K.13.AA-10. International anthropogenic emissions contributions to quarterly average $PM_{2.5}$ (□g/m^3) in Alaska estimated by GEOS-Chem.





The base year period is 2014-2018 following the EPA modeling guidance to use a five-year average centered on the base modeling year (2016). The visibility projections follow the procedures in Section 5 of the EPA's 2028 regional haze modeling guidance[4]. Alaska only considers the original IMPROVE monitor, designated TUXE1, for Tuxedni National Wildlife Refuge. The new site, designated KPBO1 (Kenai Peninsula Borough), appears to diverge from the concentration trends at TUXE1; thus, it is not included in the analysis. The international contributions estimated by the EPA's H-CMAQ and UAF's GEOS-Chem provide a range of adjustment to the 2064 endpoint.

3. CONTRIBUTION FROM INTERNATIONAL ANTHROPOGENIC SOURCES

The RH Rule allows states to optionally propose an adjustment of the 2064 URP glidepath endpoint to account for contributions of international anthropogenic emissions, if the adjustment has been developed using scientifically valid data and methods. The URP can be adjusted by adding an estimate of the visibility impact of international anthropogenic sources to the value of the natural visibility conditions in 2064 to get an adjusted URP glidepath.

The international contributions estimated by the EPA Hemispheric CMAQ (H-CMAQ) and UAF GEOS-Chem provide a range of adjustment to the 2064 endpoint. The H-CMAQ estimates only include SO_4, while the GEOS-Chem estimates also include nitrate and primary PM components. Table III.K.13.AA-5 shows the adjusted 2064 endpoint (i.e., natural conditions plus international anthropogenic contributions) from EPA's H-CMAQ for the default MID, GEOS-Chem for the SO_4-adjusted MID. Natural Conditions for the sulfate-adjusted MID was calculated using an episodic threshold determined by the lowest annual 95th percentile daily extinction from 2000-2014 (same approach applied to episodic events related to fires and dust).

Table III.K.13.AA-5. 2064 Natural Conditions for the MID with and without international contribution adjustment.

Class I Area	IMPROVE site	Default Natural Conditions for the default MID	H-CMAQ Adjusted Natural Conditions for the default MID	Natural Conditions for the sulfate-adjusted MID	GEOS-Chem Adjusted Natural Conditions for the sulfate-adjusted MID
Denali NP	DENA1	4.79	5.60	4.73	6.7
Denali NP	TRCR1	6.38	7.55	6.10	8.63
Tuxedni NWR	TUXE1	6.96	9.92	6.60	9.85
Simeonof WA	SIME1	8.49	12.86	8.35	11.93

The 2028 RPG for the MID is to be compared to the 2028 glidepath values that are adjusted to account for international contributions. Table III.K.13.AA-6 shows the 2028 glidepath values (in dv) at each Class I area for the sulfate-adjusted MID, including the 2000-2004 baseline deciview values. The CMAQ 2016 and 2028 were used to project 2014-2018 observed values to 2028 (EPA's TSD used observed 2014-2017 values to project to 2028). Both international "-adjusted" and "-unadjusted" glidepath values for 2028 are also provided. There are two adjusted glidepath values for 2028; one is based on the EPA H-CMAQ modeling (unadjusted MID) and another is based on the UAF GEOS-Chem modeling (sulfate-adjusted MID). Both adjusted glidepaths are less steep (almost flat) than the unadjusted glidepath signifying importance of sources outside of the state control to visibility progress in Alaska Class I areas. Glidepaths are shown for each of the Class I areas in Figure III.K.13.AA-11.

The future year 2028 deciview projections are compared to the adjusted visibility "glidepath" at each Class I areas:

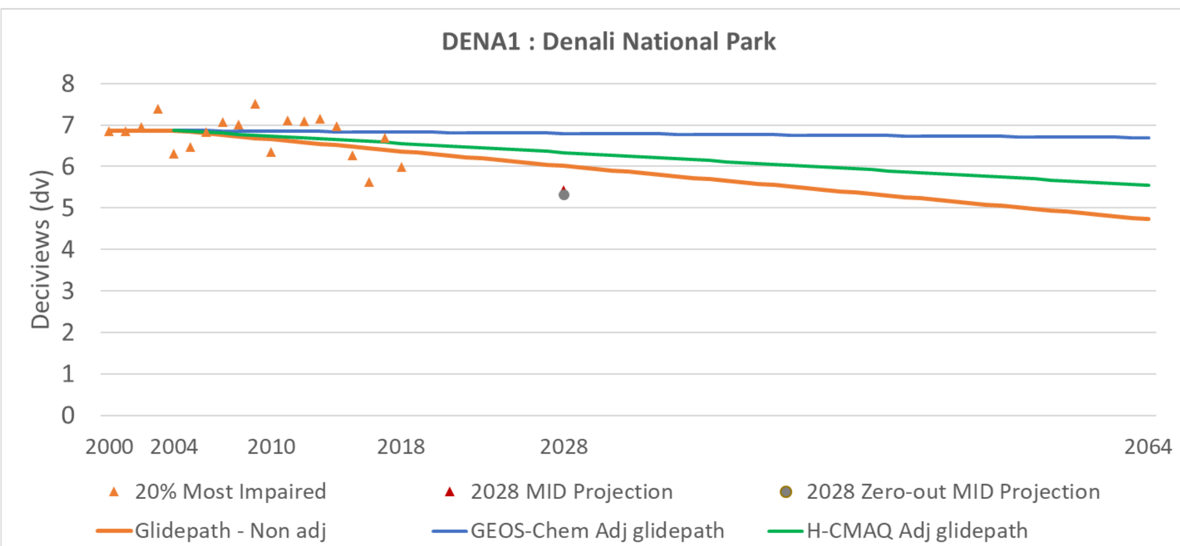
> *Denali NP:* At TRCR1, the 2028 projection (8.3 dv) is below the GEOS-Chem adjusted glidepath (8.7 dv) but slightly above the H-CMAQ adjusted glidepath (8.2 dv). At DENA1, the 2028 projection (5.4 dv) is below both the GEOS-Chem adjusted glidepath (6.8 dv) and the H-CMAQ adjusted glidepath (6.3 dv).
>
> *Tuxedni NWR:* The 2028 projection (9.2 dv) is below both GEOS-Chem adjusted glidepath (10.1 dv) and H-CMAQ adjusted glidepath (9.9 dv).
>
> *Simeonof WA:* The 2028 projection (12.6 dv) is below the H-CMAQ adjusted glidepath (12.9 dv) and is right on the GEOS-Chem adjusted glidepath (12.6 dv).

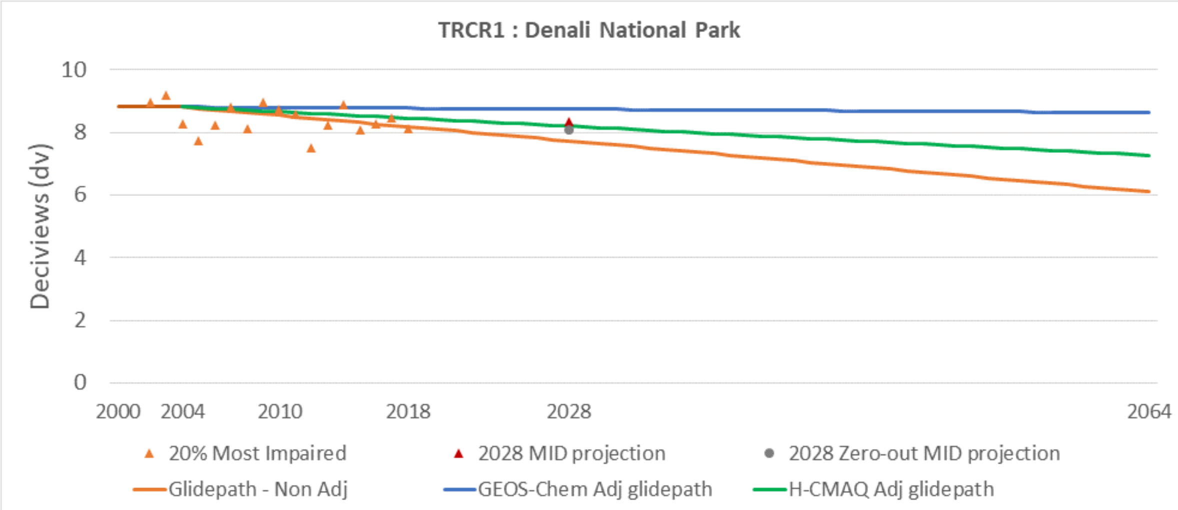
Table III.K.13.AA-6. 2000-2004 baseline visibility, 2028 projected visibility, and 2028 glidepath values (dv) for the sulfate-adjusted MID.

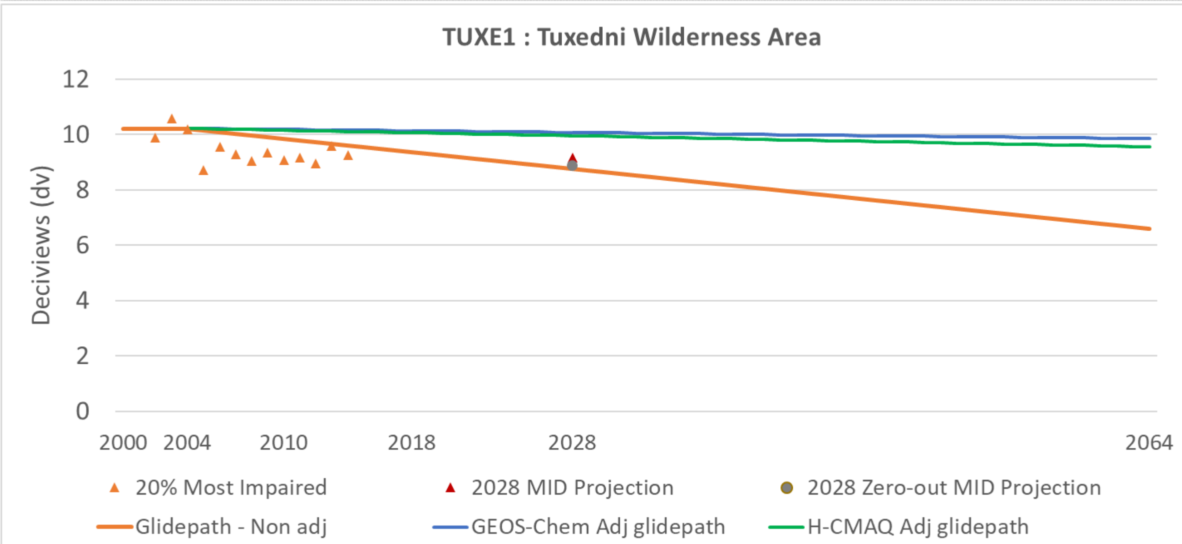
Class I Area	IMPROVE site	Observed 2000-2004 Baseline	Projected 2028	Projected 2028 zero-US	2028 Unadjusted Glidepath	2028 H-CMAQ Adjusted Glidepath*	2028 GEOS-Chem Adjusted Glidepath
Denali NP	DENA1	6.87	5.42	5.31	6.01	6.34	6.81
Denali NP	TRCR1	8.81	8.34	8.07	7.73	8.20	8.66
Tuxedni NWR	TUXE1	10.21	9.16	8.88	8.77	9.95	10.07
Simeonof WA	SIME1	13.07	12.63	13.52	11.18	12.92	12.58

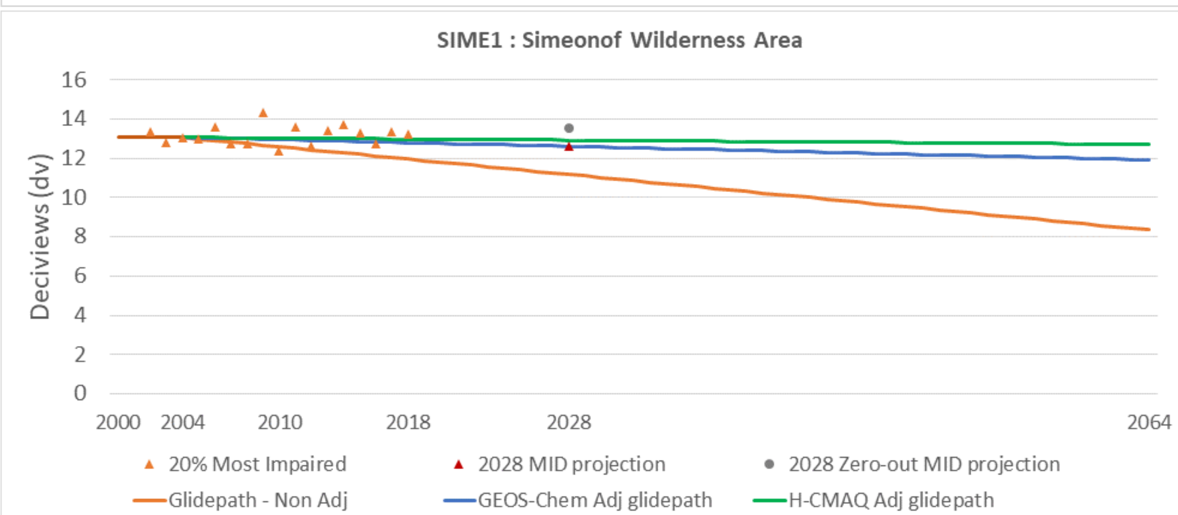
*based on the unadjusted MID. Other values presented in this table are based on the sulfate-adjusted MID.

Figure III.K.13.AA-11. Sulfate-adjusted URP Glidepaths at each Class I area in Alaska and 2028 visibility projections for the MID.




TRCR1 : Denali National Park
Deciviews (dv)
10
8
6
4
2
0
2000
2004
2010
2018
2028
2064
20% Most Impaired
2028 MID projection
2028 Zero-out MID projection
Glidepath - Non Adj
GEOS-Chem Adj glidepath
H-CMAQ Adj glidepath


TUXE1 : Tuxedni Wilderness Area
Deciviews (dv)
12
10
8
6
4
2
0
2000
2004
2010
2018
2028
2064
20% Most Impaired
2028 MID Projection
2028 Zero-out MID Projection
Glidepath - Non adj
GEOS-Chem Adj glidepath
H-CMAQ Adj glidepath


SIME1 : Simeonof Wilderness Area
Deciviews (dv)
16
14
12
10
8
6
4
2
0
2000
2004
2010
2018
2028
2064
20% Most Impaired
2028 MID projection
2028 Zero-out MID projection
Glidepath - Non Adj
GEOS-Chem Adj glidepath
H-CMAQ Adj glidepath

The inclusion of DMS and volcanic impairment as well as international contributions in the glidepaths causes a plateauing of the visibility progress needed. Given significant natural sulfur emissions that are highly variable and relatively small local anthropogenic emissions in the area, the concept of glidepath may not be appropriate for Alaska. While sulfate screening within the 95th percentile threshold helps remove extreme volcano events bringing 2028 projections closer to the unadjusted glidepath, it cannot effectively account for persistent degassing activities. Both CMAQ and GEOS-Chem modeling suggest significant contributions from the international anthropogenic emissions. The adjusted glidepaths are almost flat so would not signify any efforts and success in reducing local emissions.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

06/03/2020

TECHNICAL ADDENDUM

SUBJECT: Technical addendum including updated visibility data through 2018 for the memo titled "Recommendation for the Use of Patched and Substituted Data and Clarification of Data Completeness for Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program"

FROM: Richard A. Wayland, Division Director
Air Quality Assessment Division

TO: Regional Air Division Directors, Regions 1 – 10

Table 1: Summary of the baseline, most recent, and natural visibility condition estimates on the 20% clearest and 20% most impaired days for each IMPROVE site representing a Class I area in the Regional Haze Program

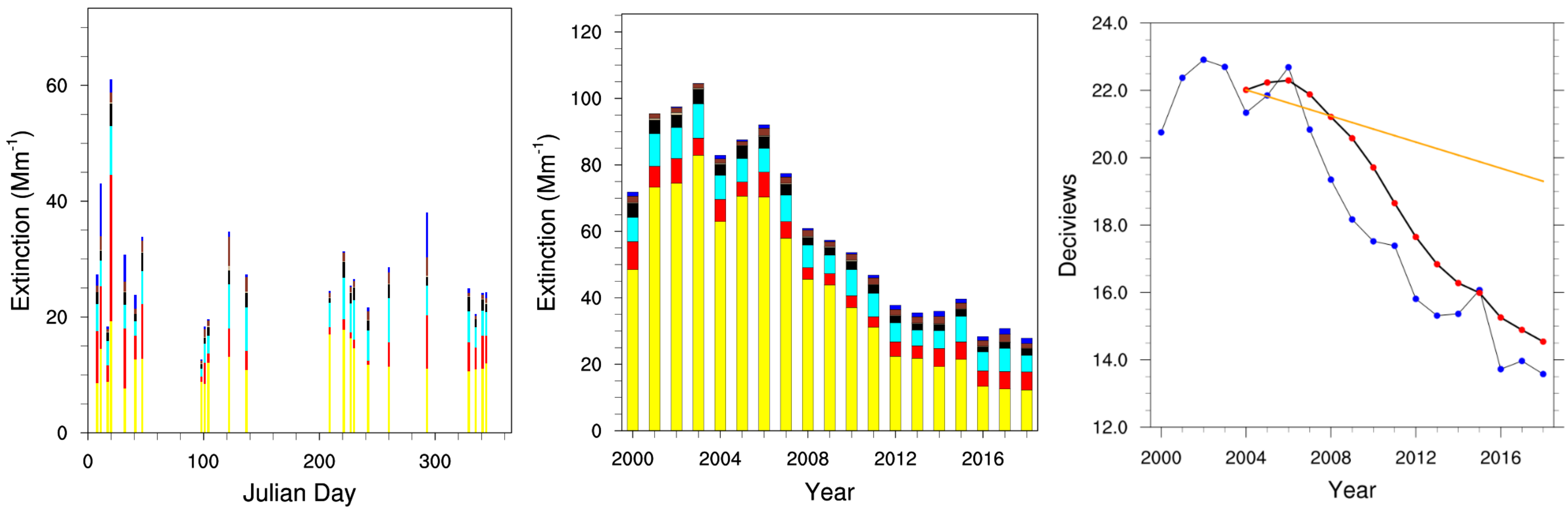
Site	20% Clearest Days			20% Most Impaired Days			e3 (Mm^{-1})	
	Baseline Visibility Condition (2000-2004)	Most Recent Visibility Condition (2014-2018)	Natural Conditions (20% Clearest Days)	Baseline Visibility Condition (2000-2004)	Most Recent Visibility Condition (2014-2018)	Natural Conditions (20% Most Impaired Days)	carbon	dust
ACAD1	8.78	6.58	4.66	22.01	14.54	10.39	10.44	3.11
AGTI1	9.58	7.10	2.93	21.60	16.34	7.66	10.85	8.86
BADL1	6.89	5.39	2.86	14.98	12.33	6.09	9.17	7.49
BALD1	2.98	1.78	0.54	8.80	7.29	4.18	6.65	5.37
BAND1	4.96	3.02	1.29	9.70	8.44	4.59	5.60	4.36
BIBE1	5.78	5.17	1.62	15.57	14.06	5.33	7.60	8.59
BLIS1	2.52	1.82	0.38	10.06	9.31	4.91	11.14	2.84
BOAP1	6.28	4.59	2.16	11.61	10.47	5.39	9.38	7.83
BOWA1	6.50	4.48	3.48	18.43	13.96	9.09	10.86	2.92
BRCA1	2.77	1.46	0.57	8.42	6.60	4.08	6.13	4.26
BRID1	2.10	0.88	0.29	8.01	6.77	3.92	7.94	2.83
BRIG1	14.33	11.26	5.52	27.43	19.31	10.68	20.15	9.07
BRIS1[a]	13.95	11.81	5.25	24.91	19.04	9.23	18.21	7.96
CABI1	3.62	2.46	1.48	10.73	9.87	5.64	13.14	4.13
CACR1	11.24	8.02	4.23	23.99	18.29	9.54	16.84	7.80
CANY1	3.75	2.20	1.05	8.79	6.76	4.13	5.53	5.02
CAPI1	4.10	2.38	1.28	8.78	7.18	4.00	5.07	5.14
CHAS1	15.60	12.41	6.00	24.52	17.41	9.03	24.69	6.28
CHIR1	4.91	3.95	1.83	10.50	9.41	4.93	4.81	7.87
COHU1	13.73	8.10	4.42	29.12	17.37	9.88	18.17	3.98
CRLA1	1.69	1.05	0.10	9.36	7.98	5.16	8.67	2.37
CRMO1	4.31	2.68	1.73	11.91	8.50	4.97	7.26	4.72
DENA1	2.43	2.19	1.77	7.08	6.55	4.72	3.58	1.60
DOME1	5.07	4.44	1.18	17.20	15.14	6.19	14.13	11.58
DOSO1	12.28	6.68	3.64	28.29	17.65	8.92	13.57	3.40
EVER1	11.69	10.37	5.22	19.52	14.90	8.33	10.00	7.90
GAMO1	1.71	0.66	0.32	8.95	7.47	4.53	10.17	3.03
GICL1	3.33	2.07	0.52	8.96	7.58	4.20	5.73	4.40
GLAC1	7.22	5.38	2.43	15.89	13.77	6.90	22.24	7.50
GRCA2	2.18	1.52	0.31	7.98	6.87	4.16	6.19	4.74
GRGU1	7.65	4.99	3.73	21.88	13.07	9.78	12.07	3.23
GRSA1	4.50	2.74	1.24	9.66	8.02	4.45	8.01	6.69
GRSM1	13.58	8.35	4.62	29.11	17.21	10.05	16.09	4.48
GUMO1	5.92	4.73	0.99	14.60	12.64	4.83	6.25	12.95
HACR1[b]	4.55	0.48	2.66	12.67	8.60	4.77	1.24	2.01
HAVO1	4.06	3.50	2.20	18.66	19.28	5.63	1.56	1.93
HECA1	5.52	4.00	2.52	16.51	12.33	6.57	13.88	5.00
HEGL1	12.84	9.71	4.69	25.17	18.72	9.30	20.30	6.84
HOOV1	1.44	1.05	0.07	8.93	7.65	4.90	8.92	4.00
IKBA1	5.40	4.16	1.92	11.19	9.47	5.22	6.78	6.14
ISLE1	6.77	5.30	3.72	19.63	15.54	10.17	12.05	4.22
JARB1	2.56	1.84	1.14	8.73	7.97	5.23	7.45	8.00
JARI1	14.21	9.47	4.39	28.08	17.89	9.47	26.22	2.94
JOSH1	6.08	4.69	1.68	17.74	12.87	6.09	7.82	9.81
KAIS1	2.29	1.55	0.04	12.93	10.98	6.06	11.16	5.19
KALM1	6.27	5.90	3.70	13.34	11.97	7.78	12.46	2.43
KPBO1[c]	3.99	5.47	3.15	10.47	11.24	6.96	3.39	2.32
LABE1	3.21	2.50	1.30	11.29	9.67	6.18	10.38	3.81
LAVO1	2.66	2.20	1.00	11.47	10.23	6.10	12.36	2.59
LIGO1	11.11	7.61	4.07	28.05	16.42	9.70	18.22	2.83
LOST1	8.19	7.45	2.92	18.27	16.18	5.87	10.17	9.28
LYEB1[d]	6.37	5.03	2.79	23.57	14.73	10.24	11.44	2.75
MACA1	16.51	11.31	5.00	29.83	21.02	9.80	19.44	4.28
MELA1	7.27	6.19	2.96	16.62	15.30	5.95	9.14	9.09
MEVE1	4.32	2.28	1.02	9.22	6.51	4.20	5.05	5.33
MING1	14.37	11.08	5.30	26.28	20.13	9.18	23.82	10.81
MOHO1	2.17	1.39	0.88	12.10	9.27	6.59	7.75	2.74

Site	20% Clearest Days			20% Most Impaired Days			e3 (Mm^{-1})	
	Baseline Visibility Condition (2000-2004)	Most Recent Visibility Condition (2014-2018)	Natural Conditions (20% Clearest Days)	Baseline Visibility Condition (2000-2004)	Most Recent Visibility Condition (2014-2018)	Natural Conditions (20% Most Impaired Days)	carbon	dust
MONT1	3.86	2.56	1.48	11.00	10.06	5.53	16.11	4.89
MOOS1	9.16	6.59	5.02	20.65	13.32	9.98	11.13	2.54
MORA1	5.48	3.88	2.56	16.53	12.66	7.66	13.33	2.53
MOZI1	1.61	0.23	-0.47	7.29	5.47	3.16	5.70	3.23
NOAB1	2.02	0.75	0.59	8.78	7.17	4.55	10.18	4.23
NOCA1	3.37	2.46	1.93	12.57	9.98	6.89	8.20	1.97
OKEF1	15.23	11.57	5.43	25.34	17.39	9.45	20.65	5.50
OLYM1	6.03	3.55	2.70	14.93	11.90	6.90	8.78	1.76
PASA1	2.71	1.65	1.16	10.41	9.46	5.96	9.42	2.58
PEFO1	5.02	3.25	1.07	9.82	8.16	4.21	6.75	7.84
PINN1	8.89	7.73	3.45	17.02	14.10	6.94	11.33	5.88
PORE1	10.54	8.16	4.82	19.38	15.33	9.74	6.78	8.23
RAFA1	6.45	4.93	1.77	17.27	14.11	6.80	7.65	8.20
REDW1	6.13	5.33	3.46	13.74	12.65	8.59	5.86	4.44
ROMA1	14.29	11.80	5.93	25.25	17.67	9.78	23.38	5.35
ROMO1	2.29	1.37	0.28	11.12	8.41	4.94	8.54	5.32
SACR1	7.84	6.62	2.13	16.50	14.97	5.49	9.01	13.51
SAGA1	4.82	2.77	0.43	17.89	13.19	6.12	8.49	7.11
SAGO1	5.40	3.33	1.24	20.43	14.45	6.20	11.94	7.77
SAGU1	6.94	6.09	2.23	12.64	10.75	5.14	6.15	9.62
SAMA1	14.34	11.15	5.37	24.68	17.39	9.13	22.16	5.22
SAPE1	1.46	0.37	-0.72	7.66	6.43	3.33	5.66	4.53
SAWT1	4.00	2.58	1.51	9.61	8.61	4.70	12.35	2.61
SENE1	7.14	5.27	3.74	23.58	17.57	11.11	13.67	2.52
SEQU1	8.76	7.02	2.29	23.17	18.43	6.29	23.11	11.47
SHEN1	10.96	6.85	3.15	28.32	17.07	9.52	15.06	3.92
SHRO1	7.70	4.40	2.49	28.13	15.49	10.25	13.99	3.09
SIAN1	6.16		2.03	10.76		5.11	6.77	5.91
SIME1	7.60	7.74	5.28	13.67	13.89	8.51	3.42	4.63
SIPS1	15.57	10.76	5.03	27.69	19.03	9.62	21.66	4.79
SNPA1	5.50	3.31	2.33	15.37	12.74	7.27	12.33	1.79
STAR1	4.49	2.79	1.48	14.53	11.19	6.58	13.10	5.66
SULA1	2.57	1.60	1.12	10.06	8.37	5.45	11.78	3.22
SWAN1	12.34	10.61	5.71	23.79	16.30	10.01	16.47	5.01
SYCA2[e]	5.58	4.18	0.98	12.16	11.63	4.68	13.12	15.93
THRO1	7.76	5.85	3.04	16.35	14.06	5.94	9.87	8.71
THSI1	3.04	2.61	1.86	12.80	11.28	7.30	12.62	4.01
TONT1	6.46	5.03	2.05	11.65	10.45	5.14	7.14	8.76
TRCR1	3.46	3.36	2.71	9.11	8.82	6.36	5.11	2.38
TRIN1	3.44	3.09	1.23	11.92	10.43	6.48	10.36	3.61
ULBE1	4.75	3.71	2.46	12.76	10.93	5.87	9.82	6.17
UPBU1	11.71	8.20	4.18	24.21	17.95	9.41	17.58	7.02
VIIS1	8.53	9.92	4.41	14.29	15.45	8.53	2.60	21.54
VOYA2	7.15	5.31	4.27	17.88	14.18	9.37	11.48	4.14
WEMI1	3.11	1.61	0.98	7.78	6.55	3.97	6.51	3.64
WHIT1	3.55	2.54	0.66	11.31	9.95	4.89	7.16	7.13
WHPA1	1.66	0.99	0.82	10.48	7.98	6.14	6.89	2.41
WHPE1	1.22	0.31	-0.57	7.34	5.95	3.50	5.13	3.50
WHRI1	0.70	-0.16	-0.81	6.30	4.98	3.02	4.92	3.56
WICA1	5.14	3.52	1.88	13.09	10.53	5.64	7.96	4.62
WIMO1	9.78	8.47	3.02	22.15	18.12	6.92	13.95	9.94
YELL2	2.58	1.43	0.43	8.30	7.52	3.97	10.08	3.06
YOSE1	3.40	2.87	0.99	13.51	11.57	6.29	13.14	5.19
ZICA1[f]	4.84	3.86	1.94	10.71	8.76	5.18	5.54	6.66

[a]Site data combined with BRET1 starting 01-01-08; [b]Site data combined with HALE1 starting 01-01-08; [c]Site data combined with TUXE1 starting 01-01-15; [d]Site data combined with LYBR1 starting 01-01-12; [e]Site data combined with SYCA1 starting 10-18-15; [f]Site data combined with ZION1 starting 01-01-04

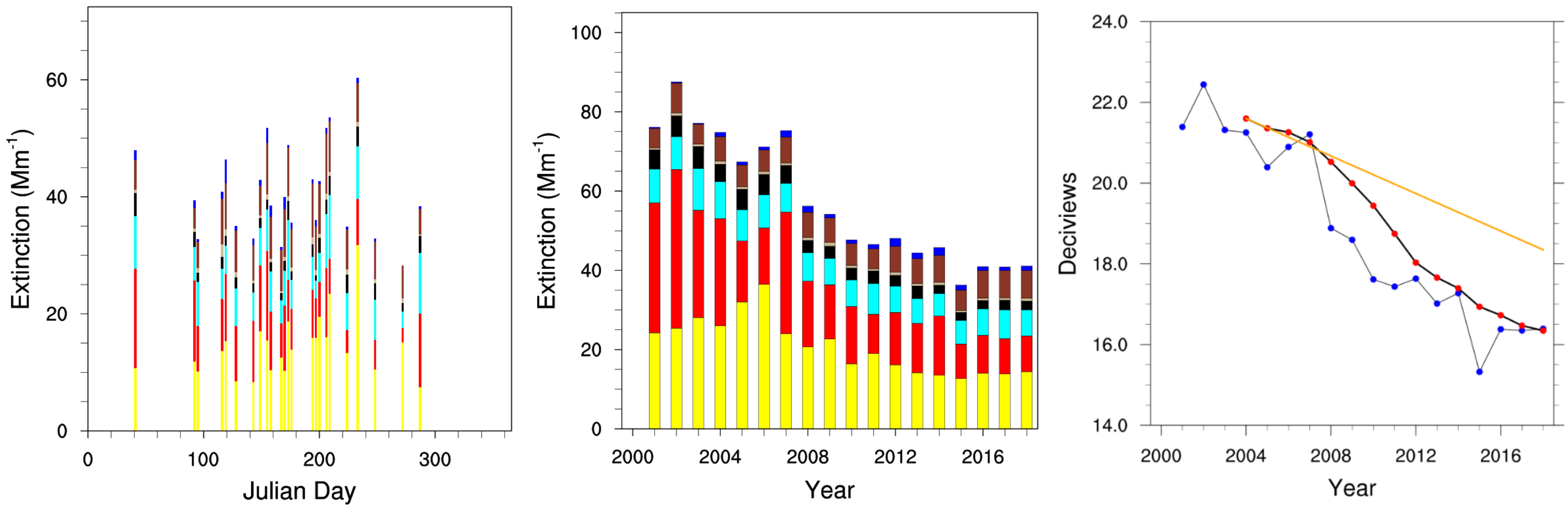
Figures. Light extinction by component for days classified as the 20 percent most impaired in 2018 unless otherwise noted (Left), average light extinction by component for days classified as the 20 percent most impaired from 2000-2018 (Middle), and annual average, 5-year average, and glidepath of the visibility index (in deciviews) on the 20 percent most impaired days from 2000 to 2018 (Right). For all extinction budget figures, the following color scale applies: sulfate (yellow), nitrate (red), OMC (teal), LAC (black), FS (tan), CM (brown), and sea salt (blue). For all visibility index figures, the blue points are annual average values; red points are 5-year averages and the orange line is the glidepath between 2000-2004 and 2060-2064.[1]

Acadia National Park, ME

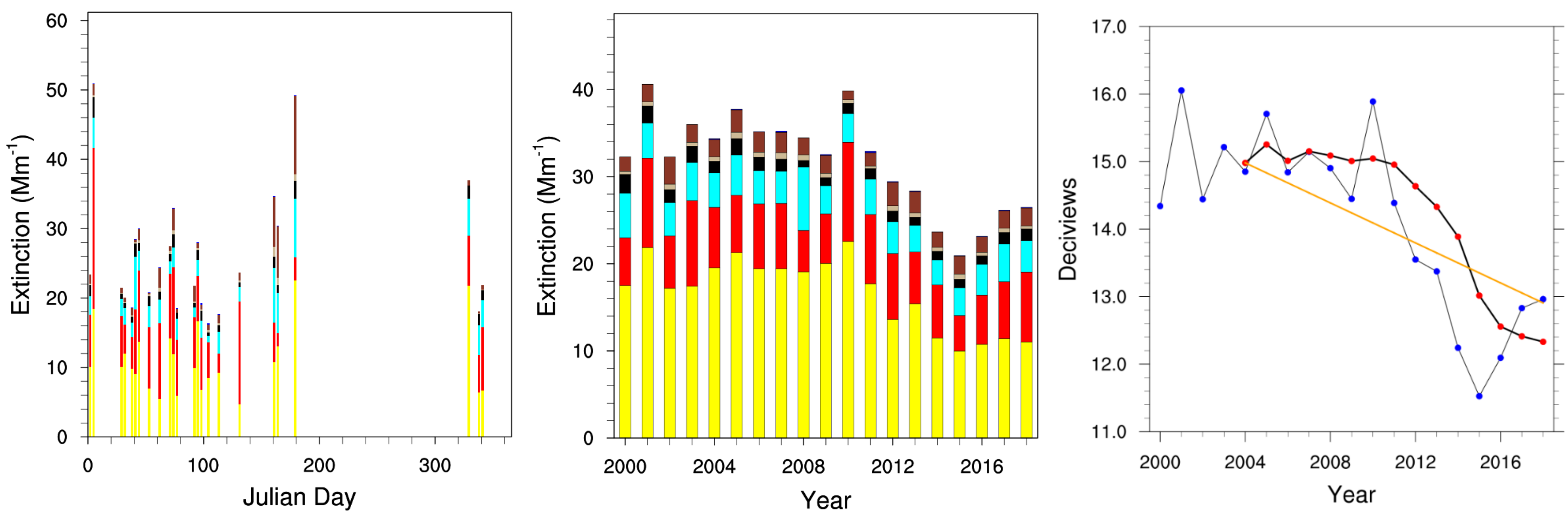


[1]Updated site-specific graphics summarizing visibility status and trends following the Regional Haze Rule metrics can be found at http://views.cira.colostate.edu/fed/SiteBrowser/Default.aspx?appkey=SBCF_VisSum.

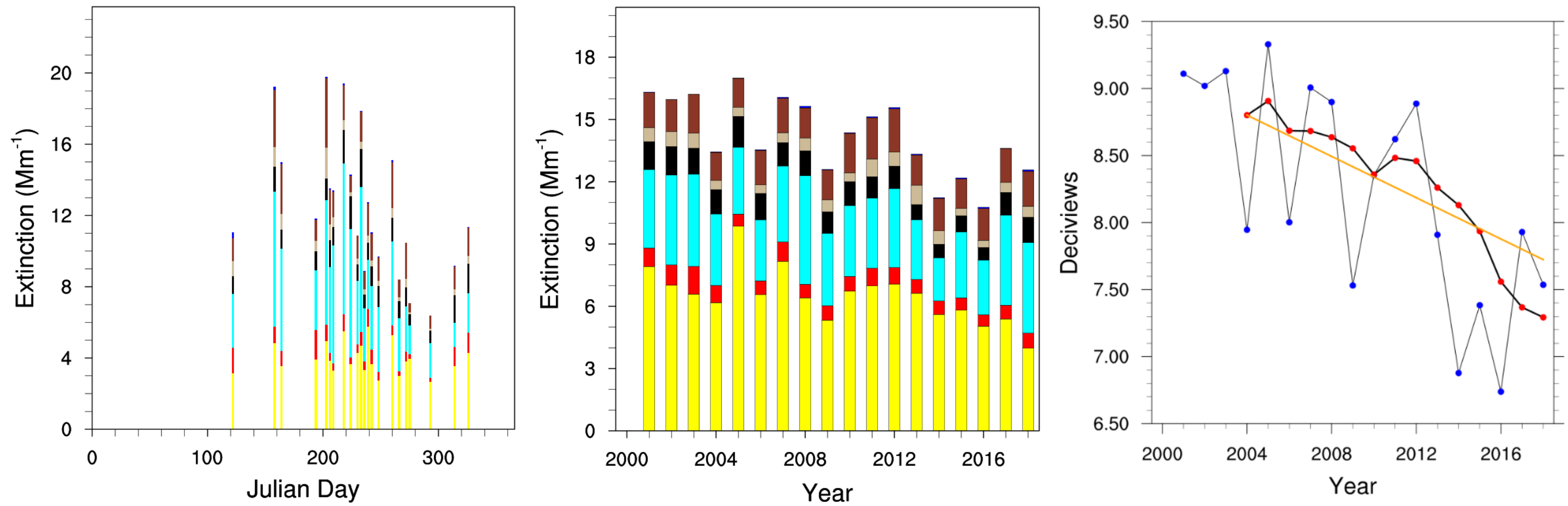
Agua Tibia, CA



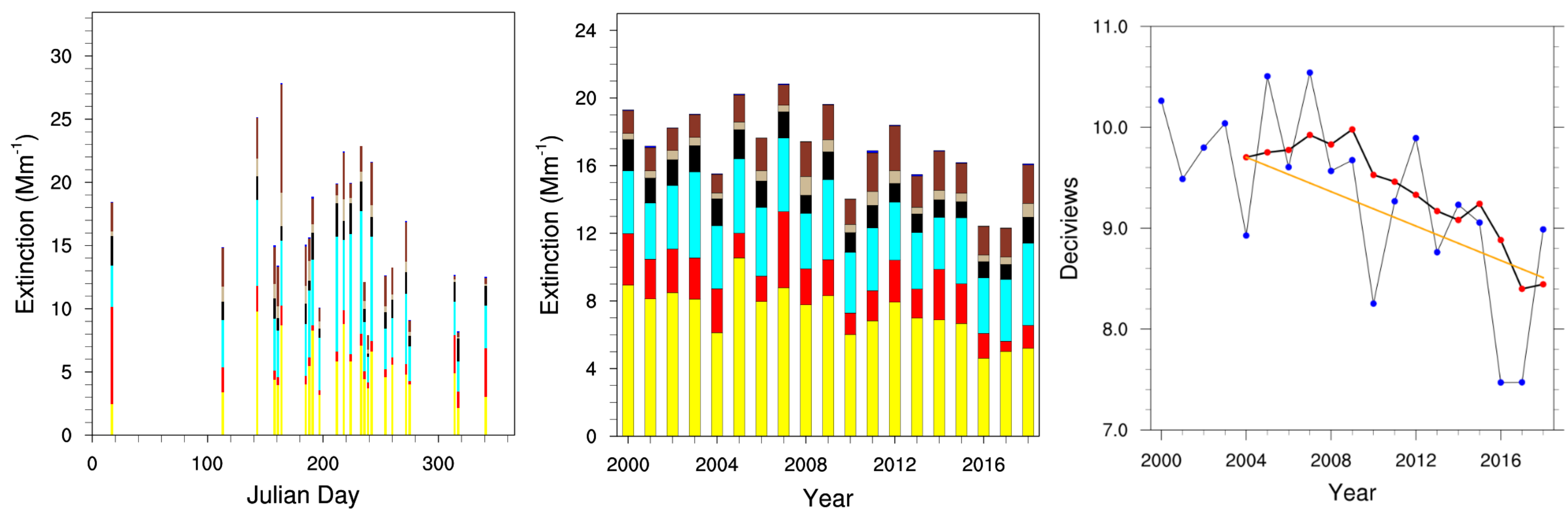
Badlands National Park, SD



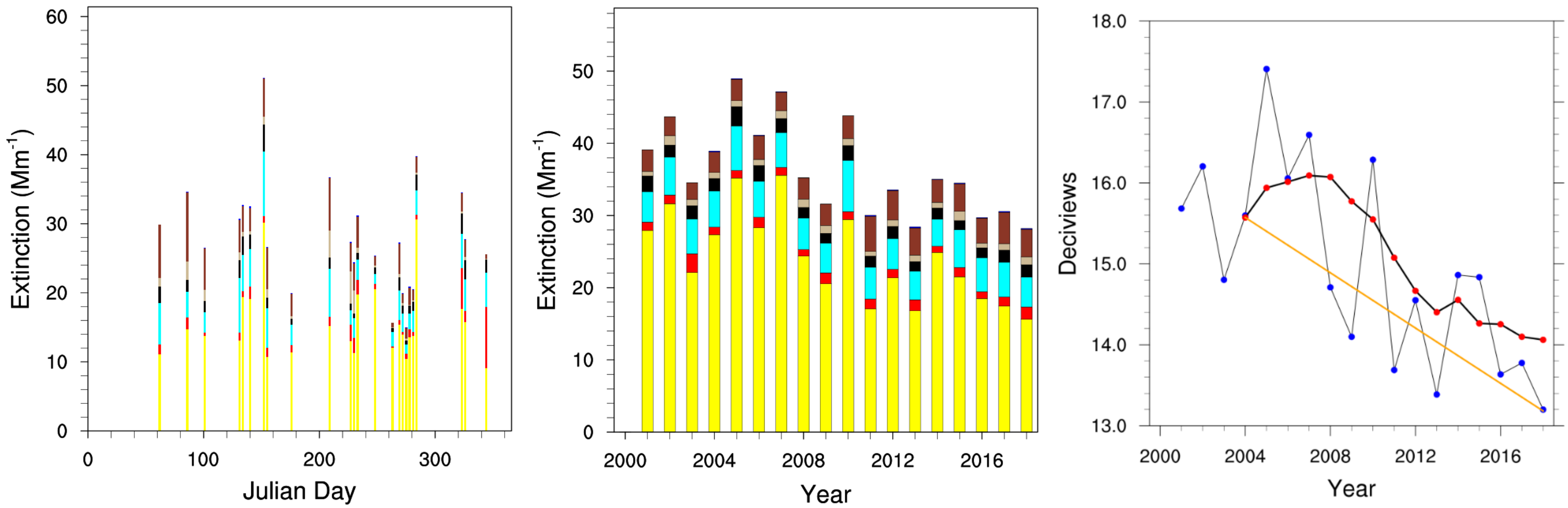
Mount Baldy, AZ



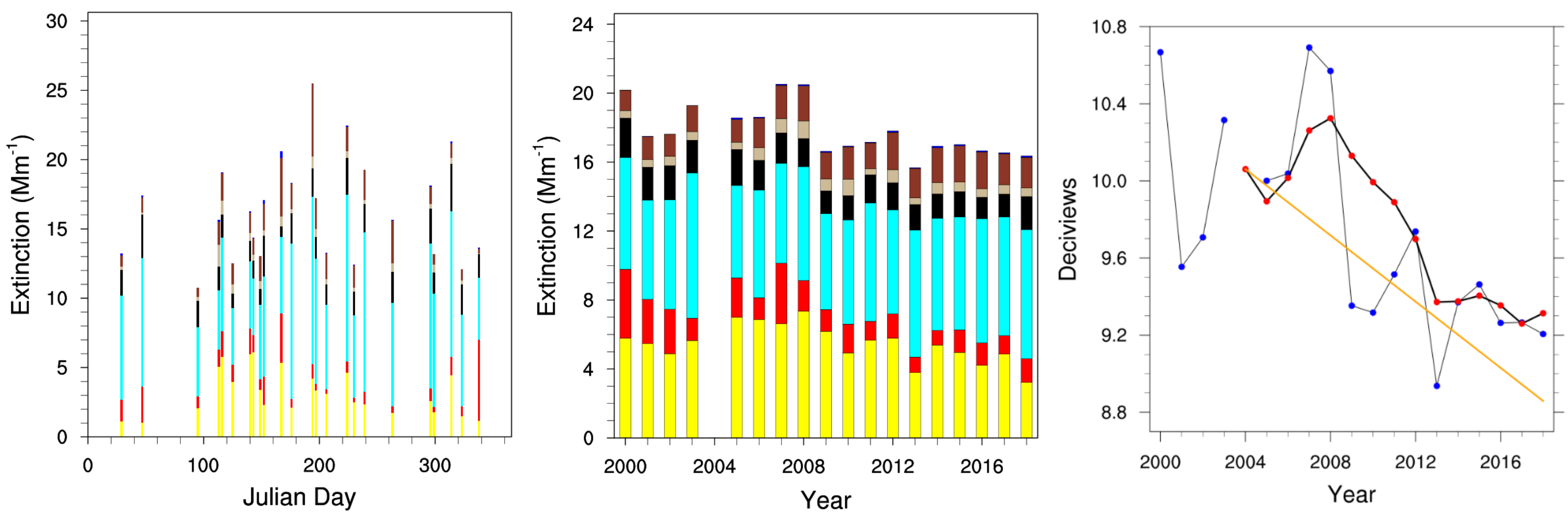
Bandelier National Monument, NM



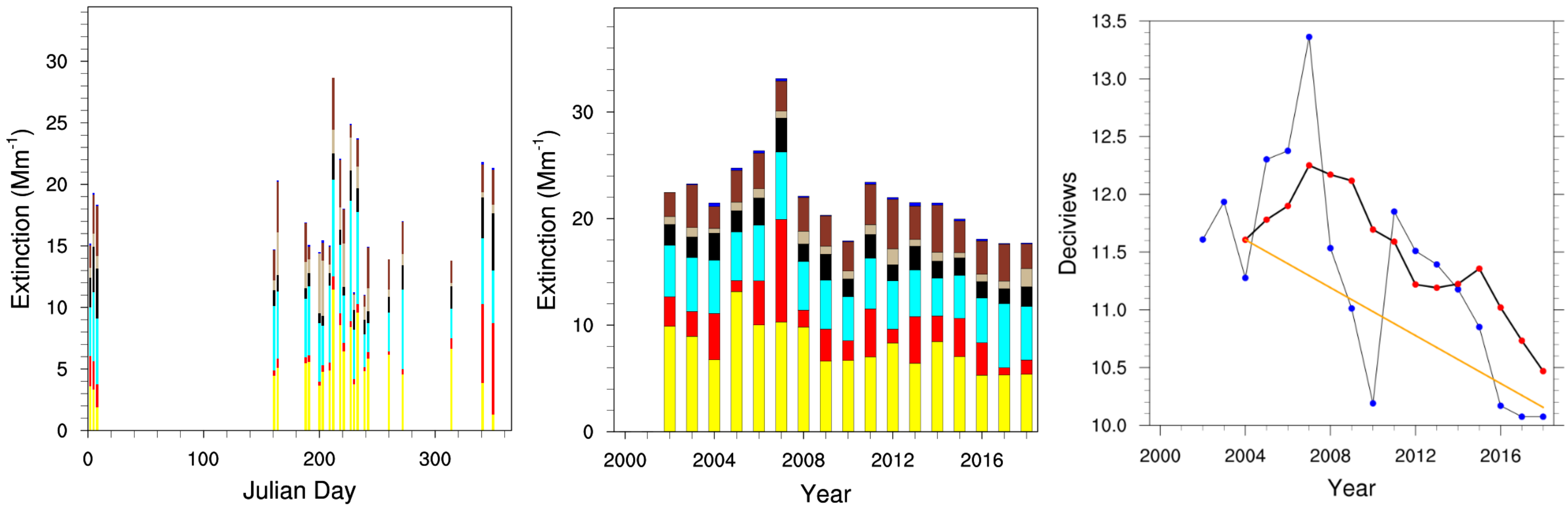
Big Bend National Park, TX



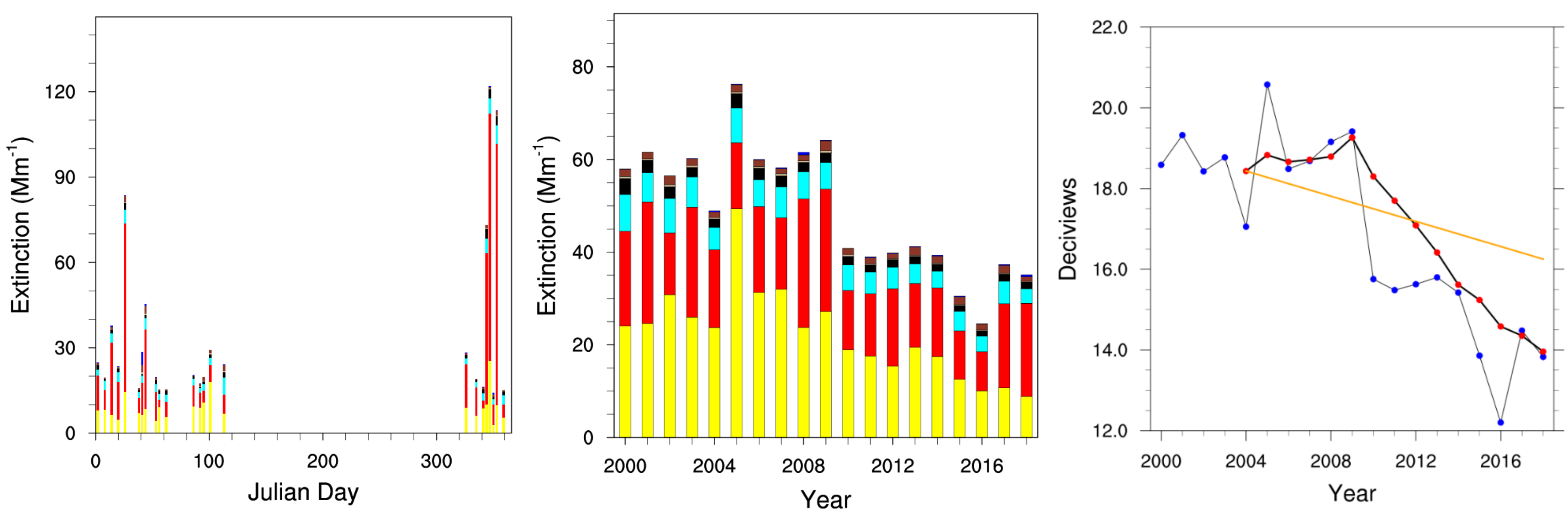
Bliss State Park, CA



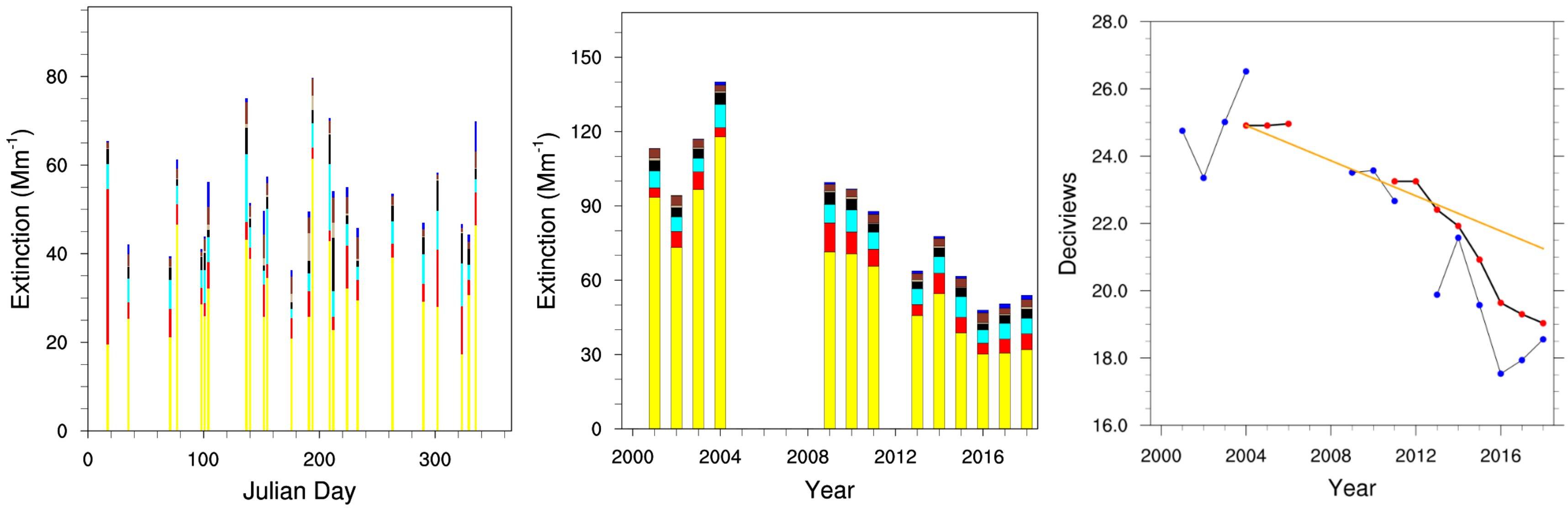
Bosque del Apache, NM



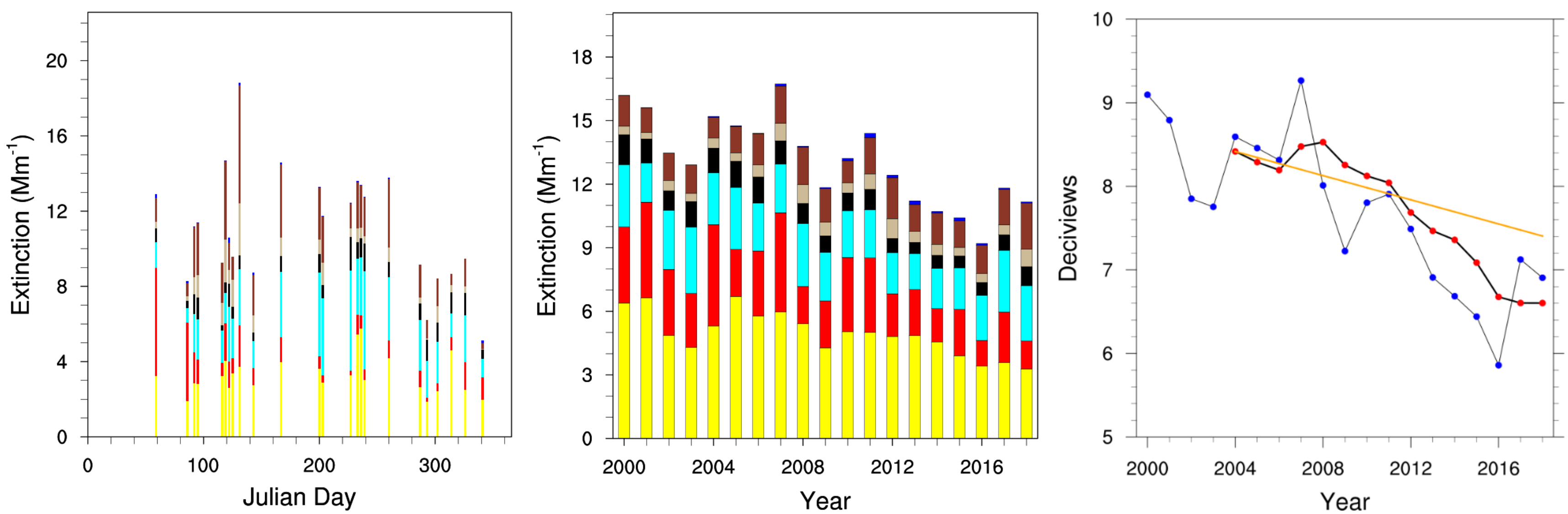
Boundary Waters Canoe Area, MN



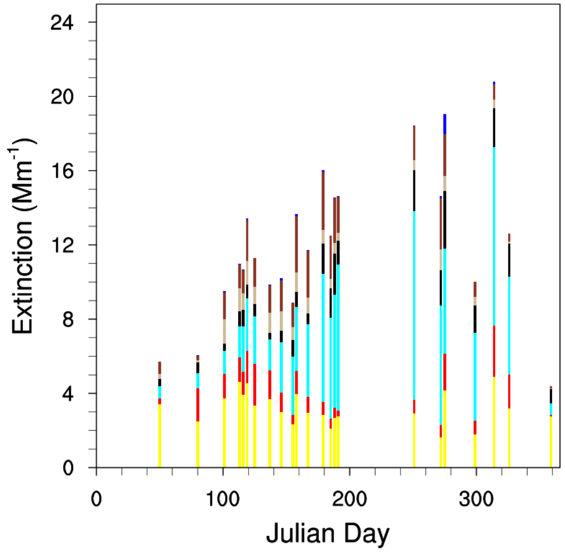
Breton Island, LA (combined BRET1 and BRIS1 starting on 01/01/2008)

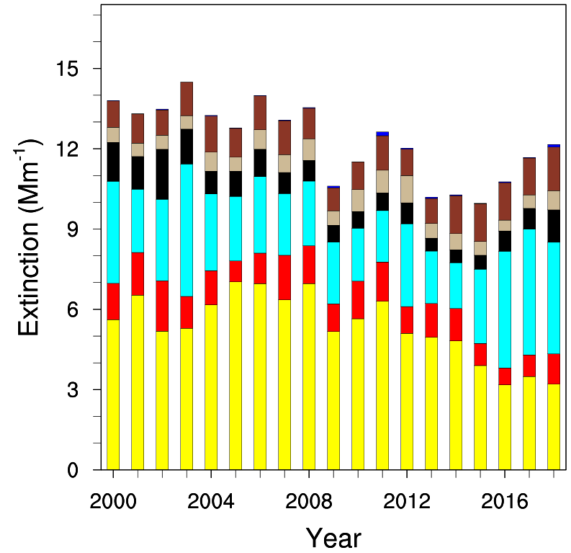


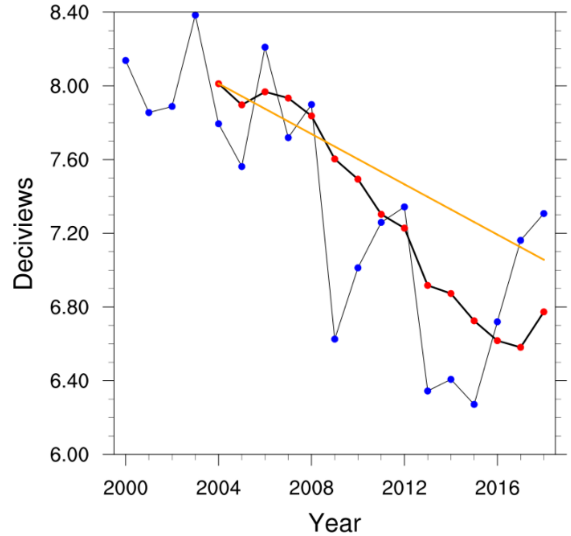
Bryce Canyon National Park, UT



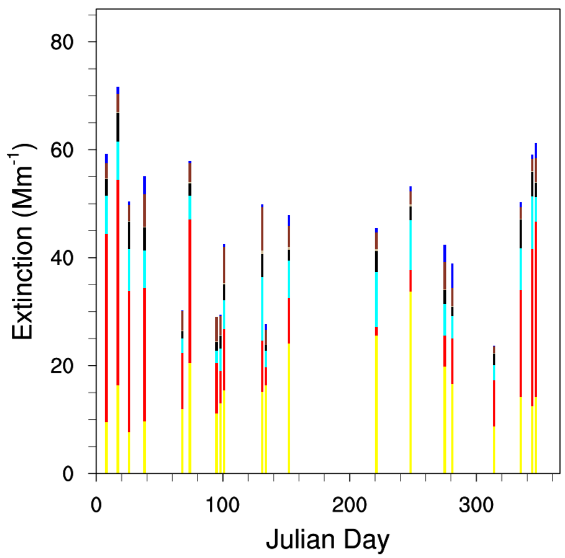
Bridger Wilderness, WY

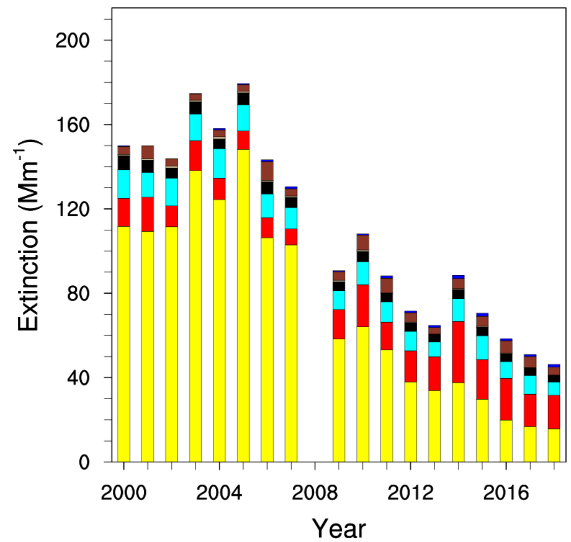


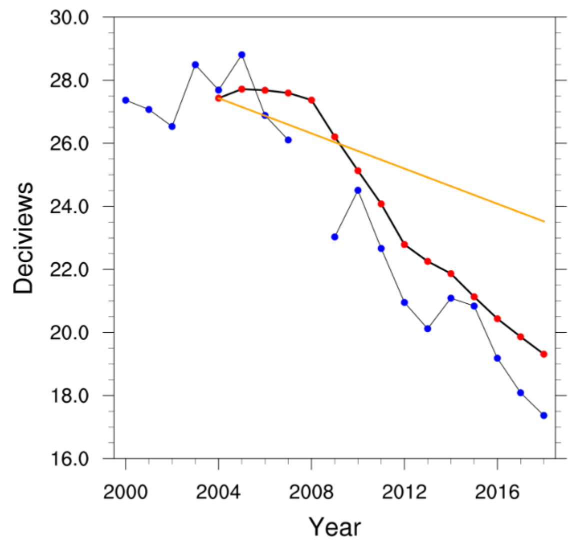




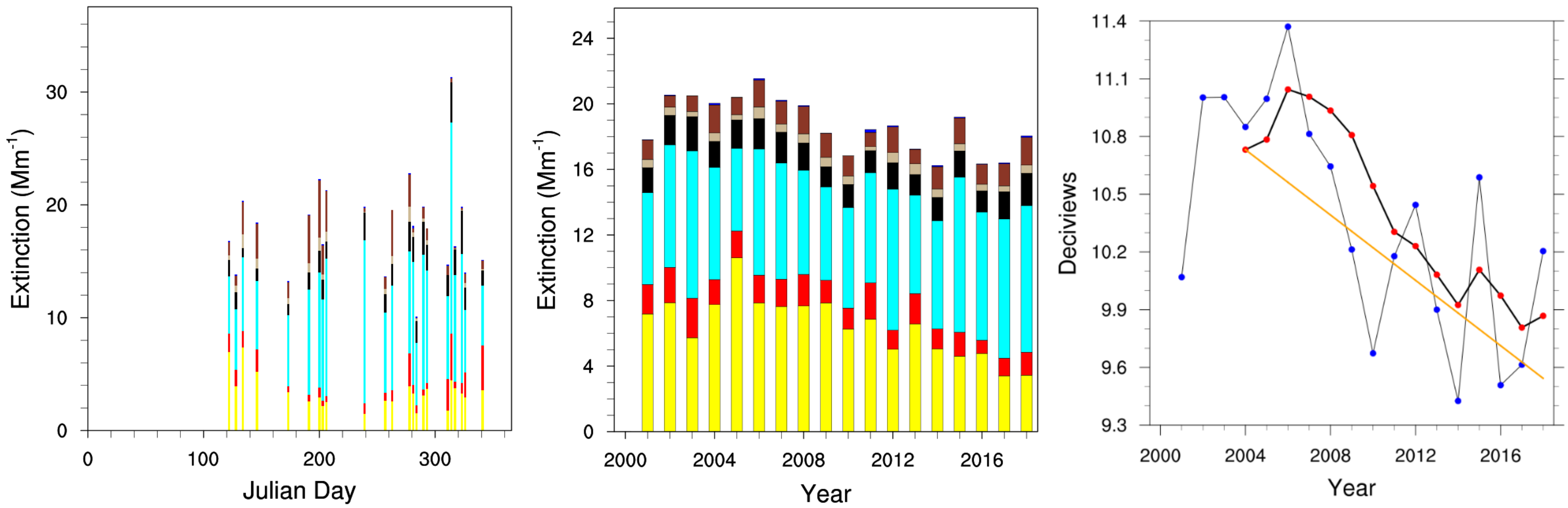
Brigantine National Wildlife Refuge, NJ



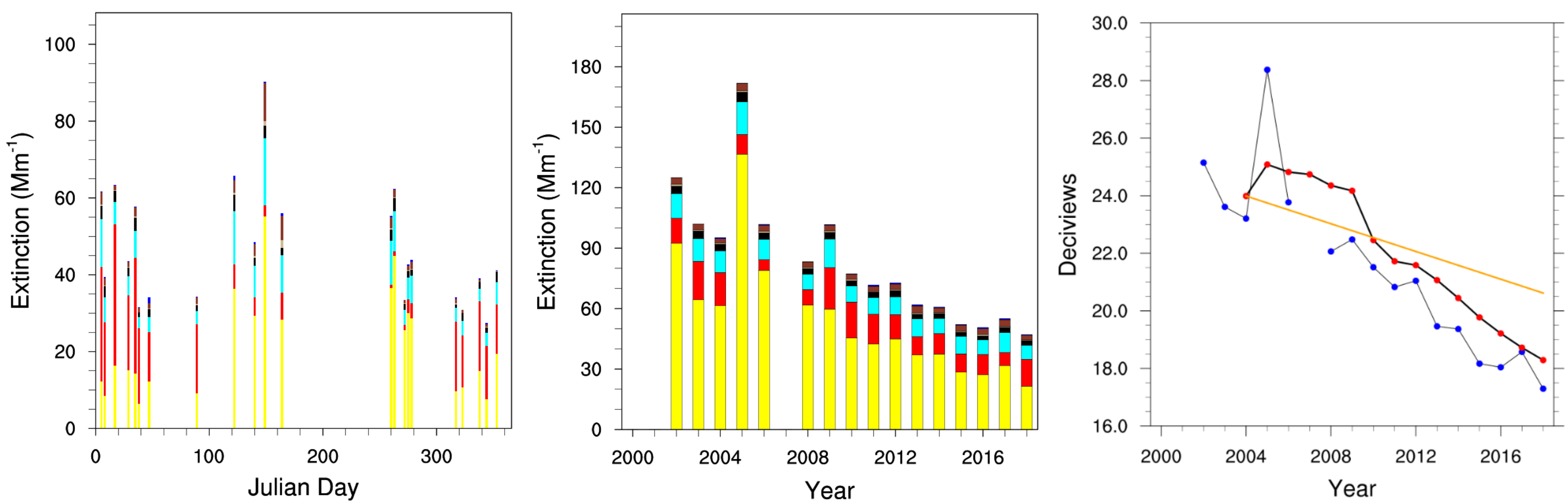




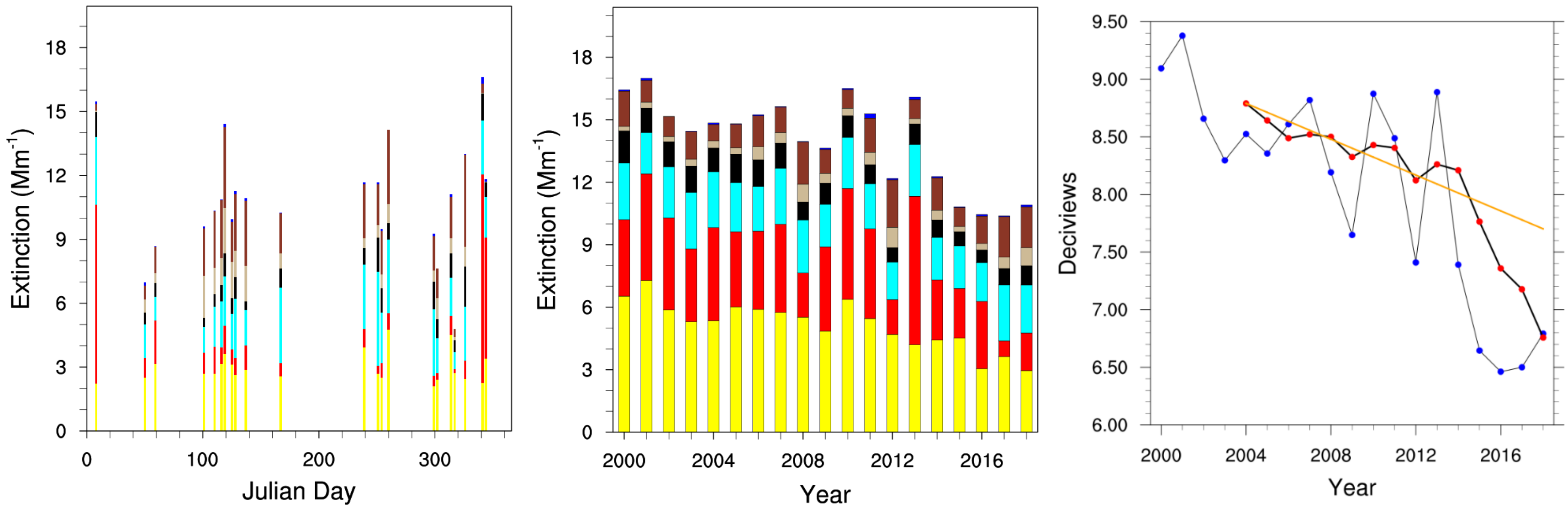
Cabinet Mountains, MT



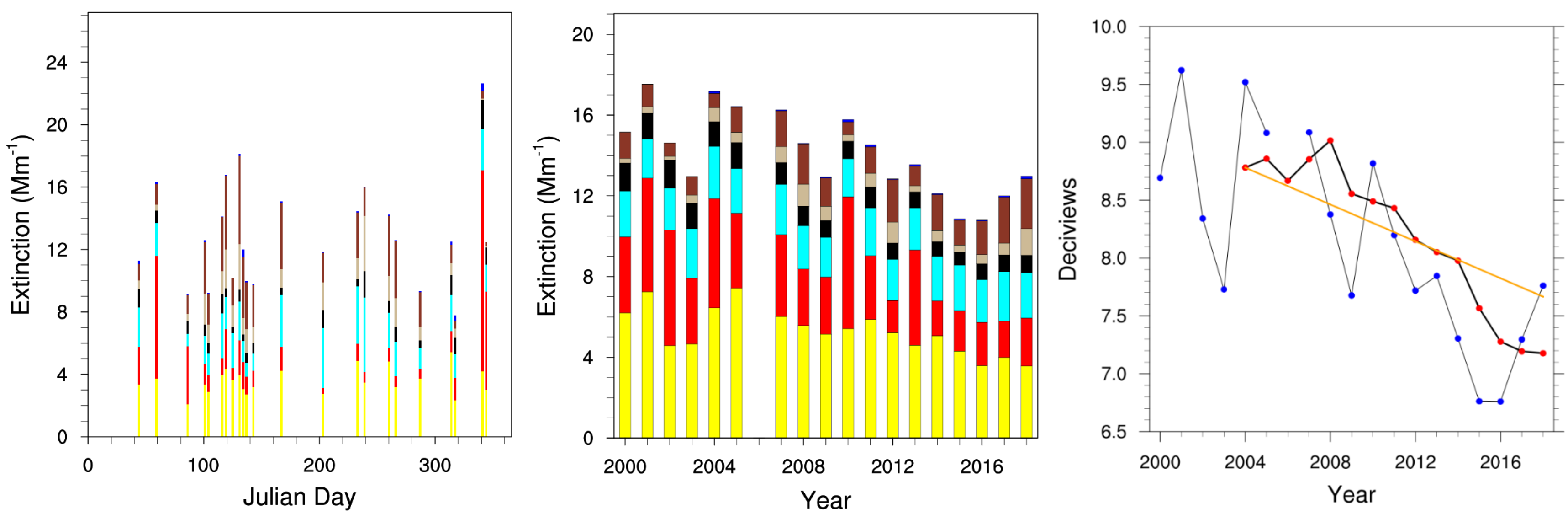
Caney Creek, AR



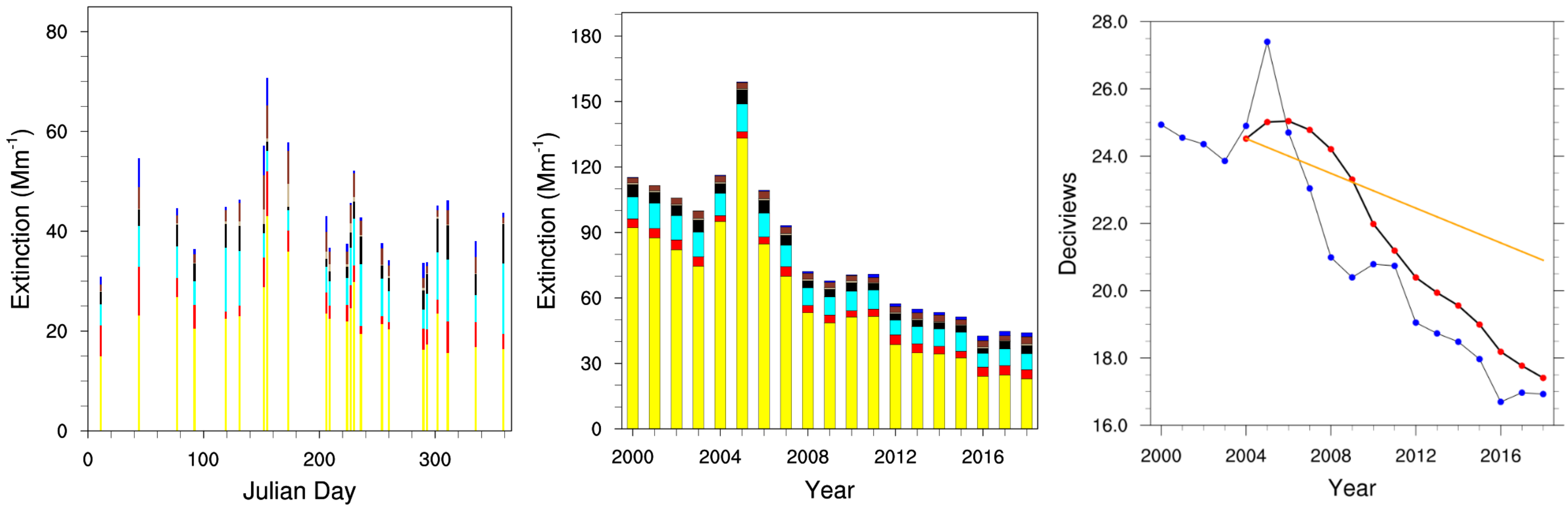
Canyonlands National Park, UT



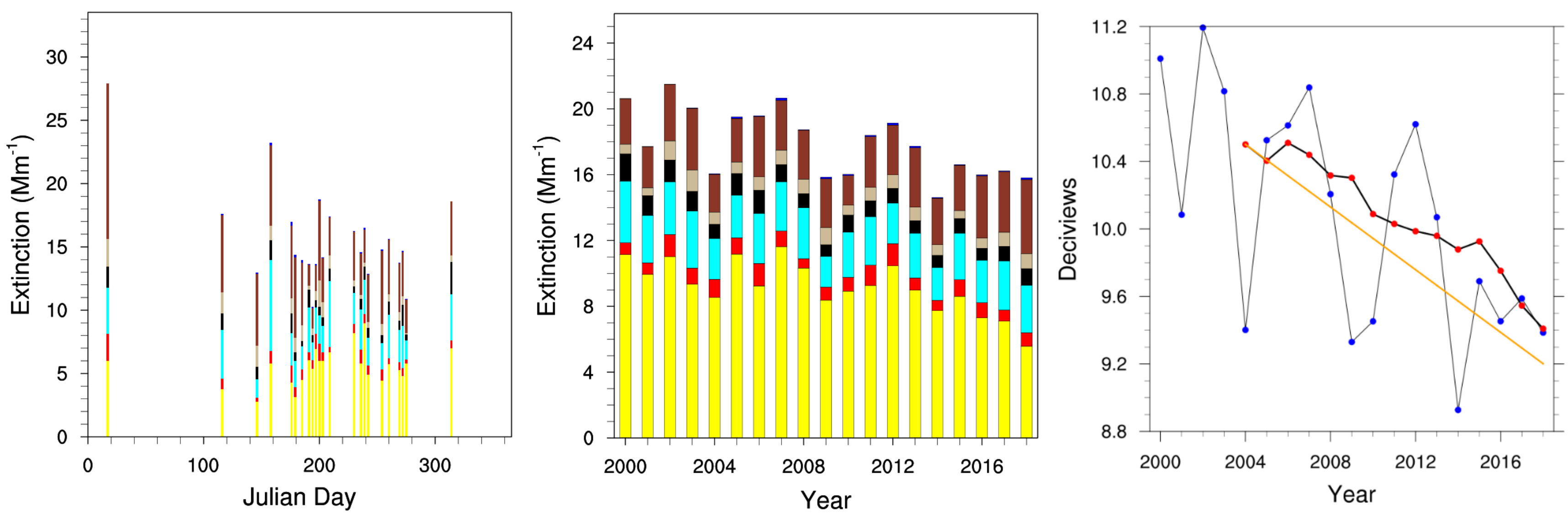
Capitol Reef National Park, UT



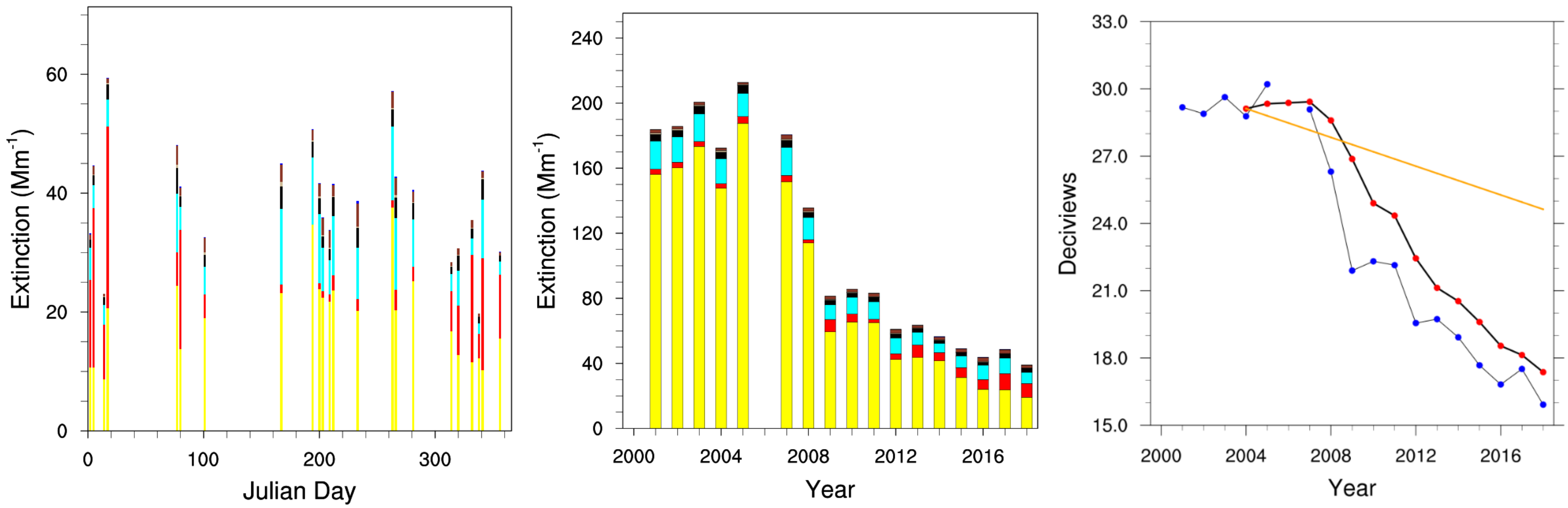
Chassahowitzka National Wildlife Refuge, FL



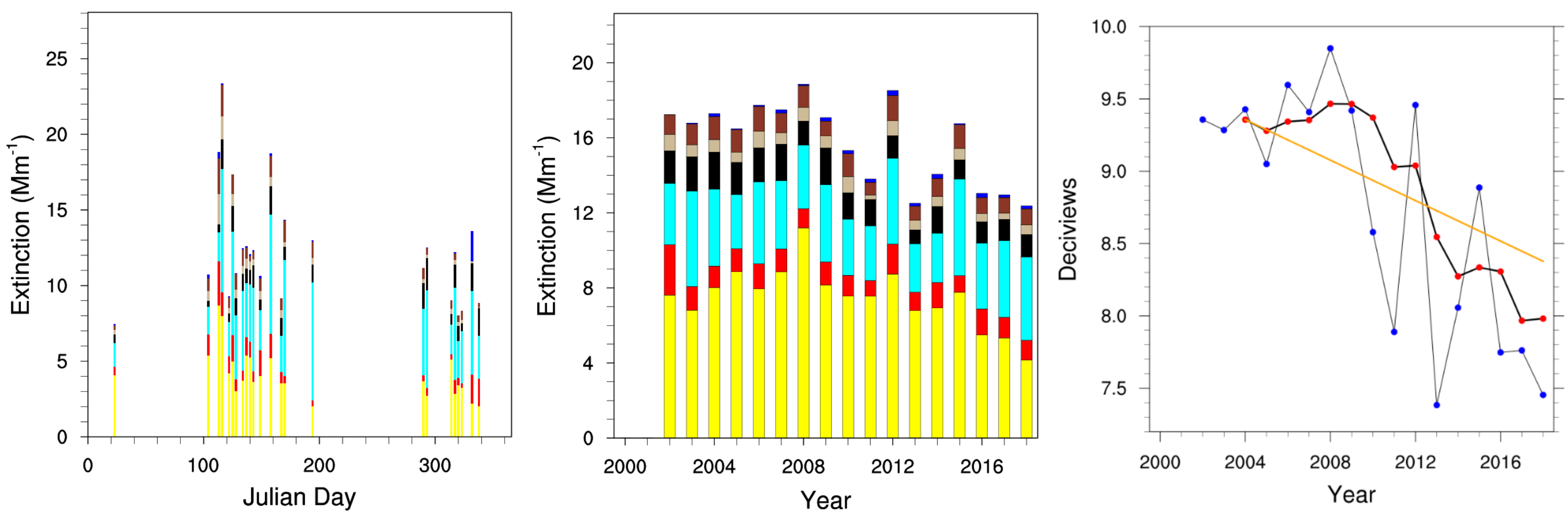
Chiricahua National Monument, AZ



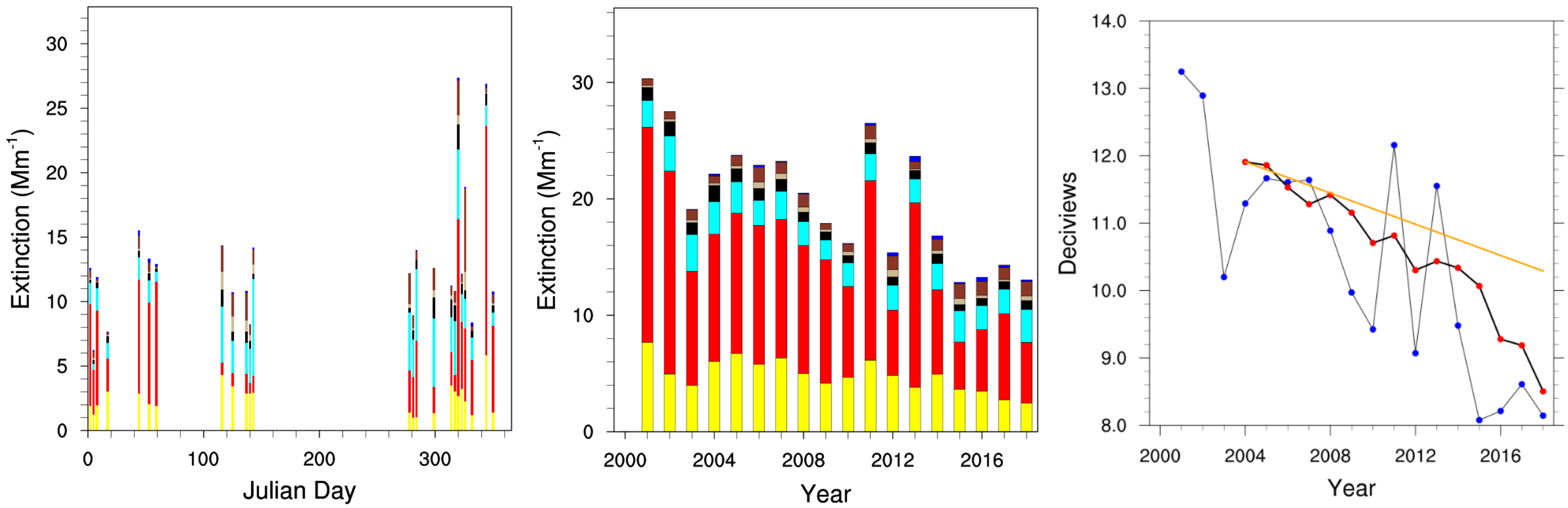
Cohutta, GA



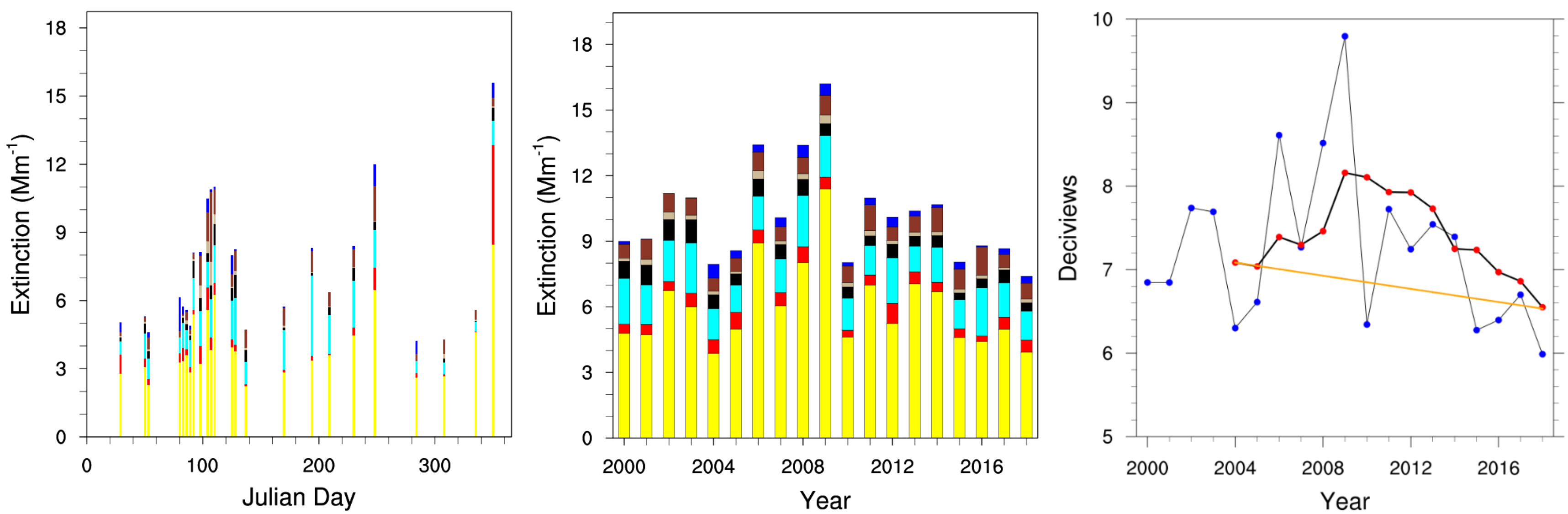
Crater Lake National Park, OR



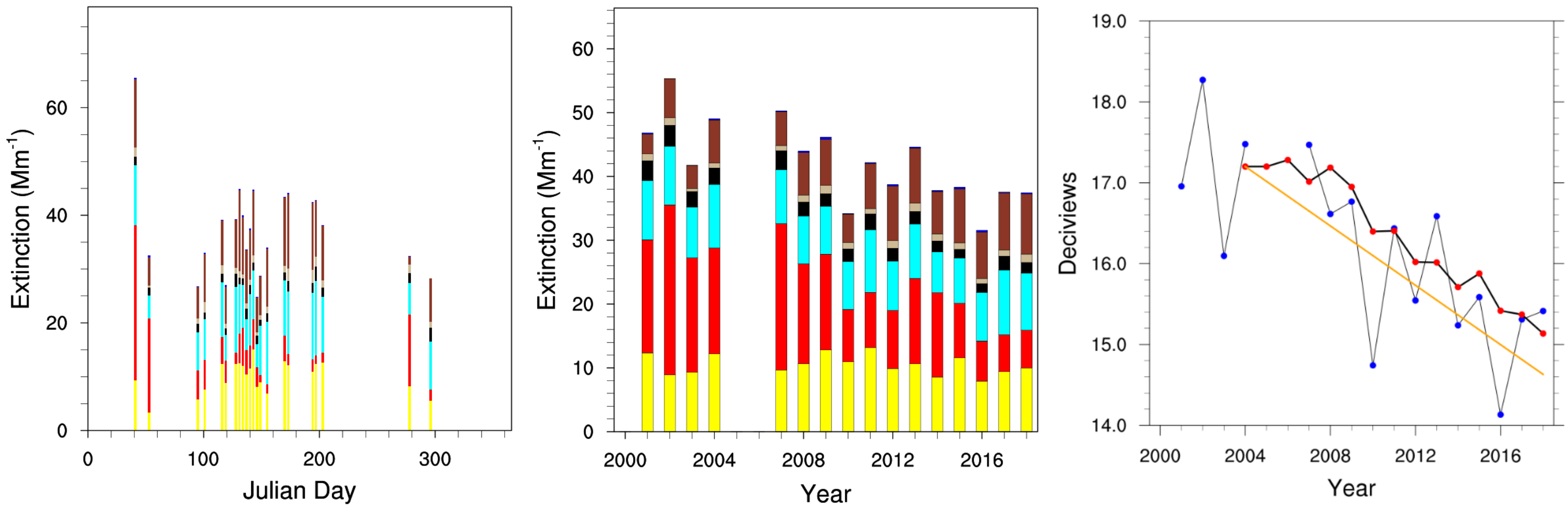
Craters of the Moon National Monument, ID



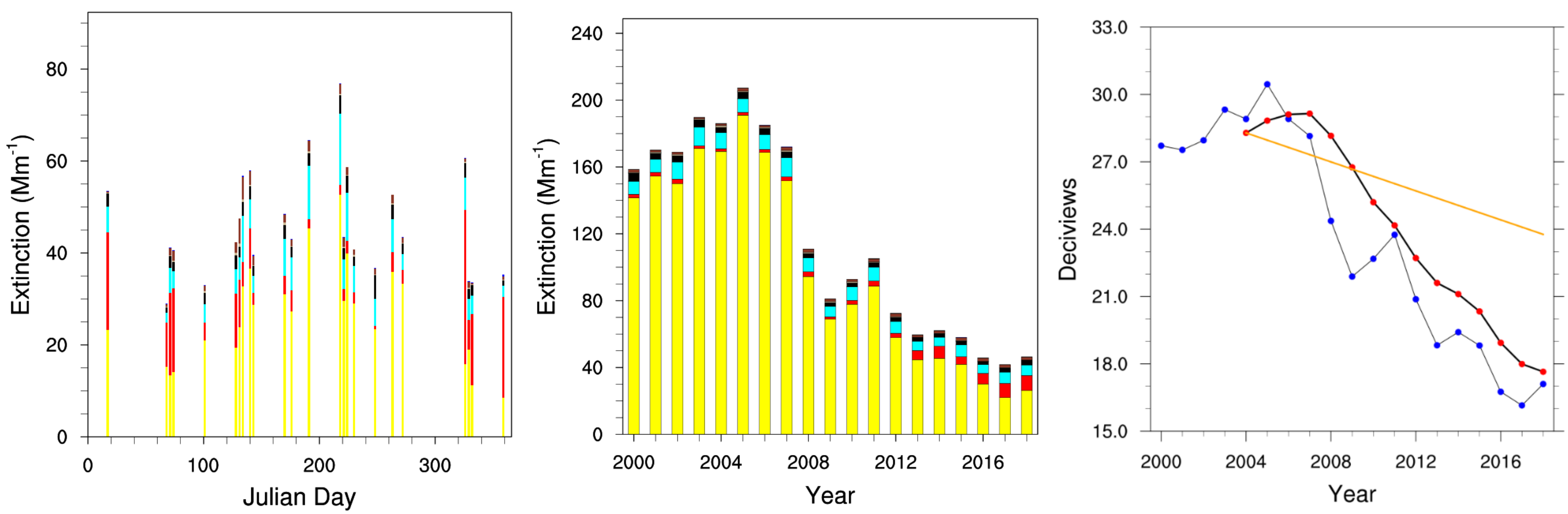
Denali National Park, AK



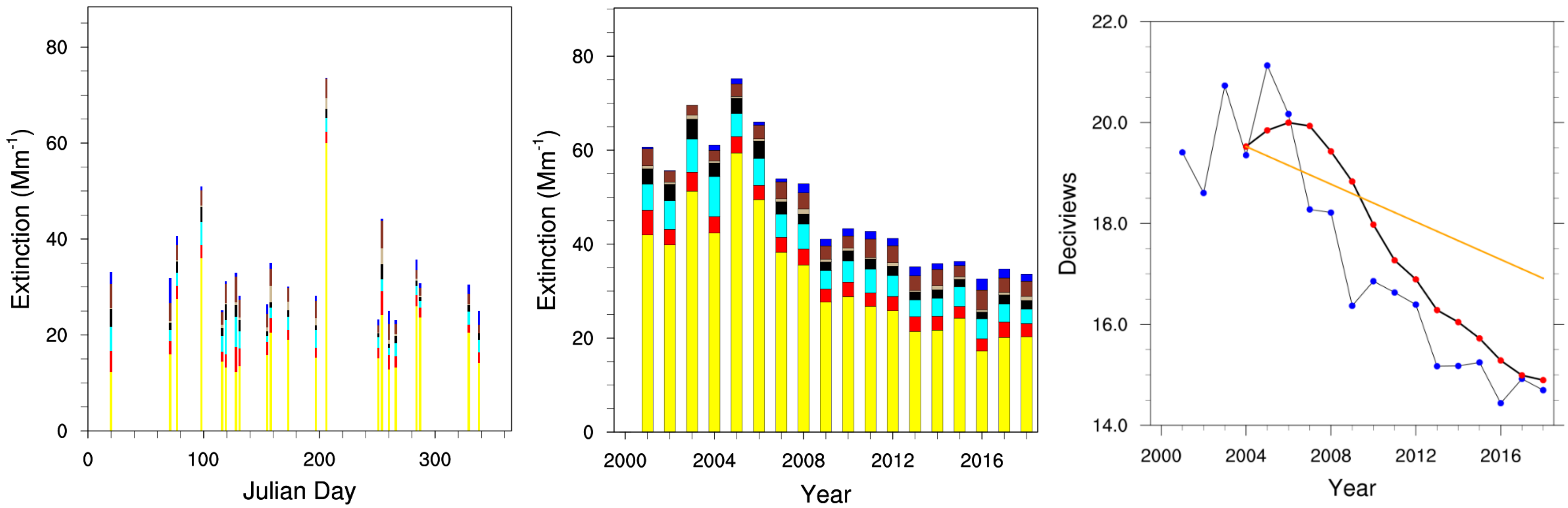
Dome Lands Wilderness, CA



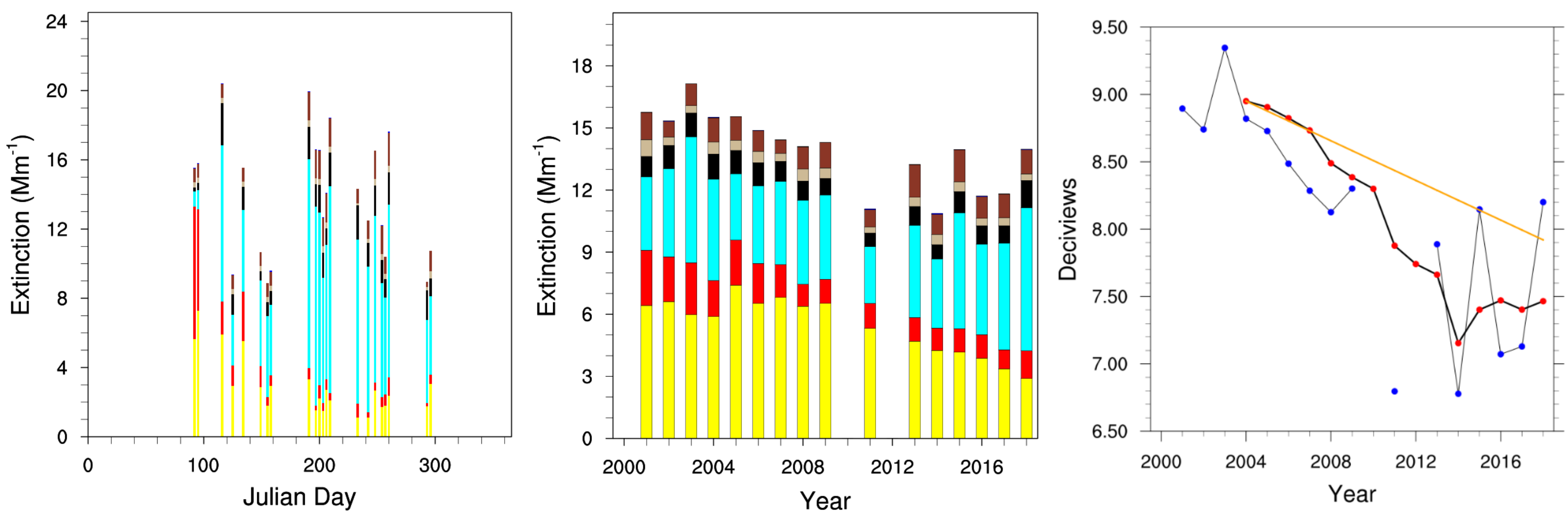
Dolly Sods Wilderness, WV



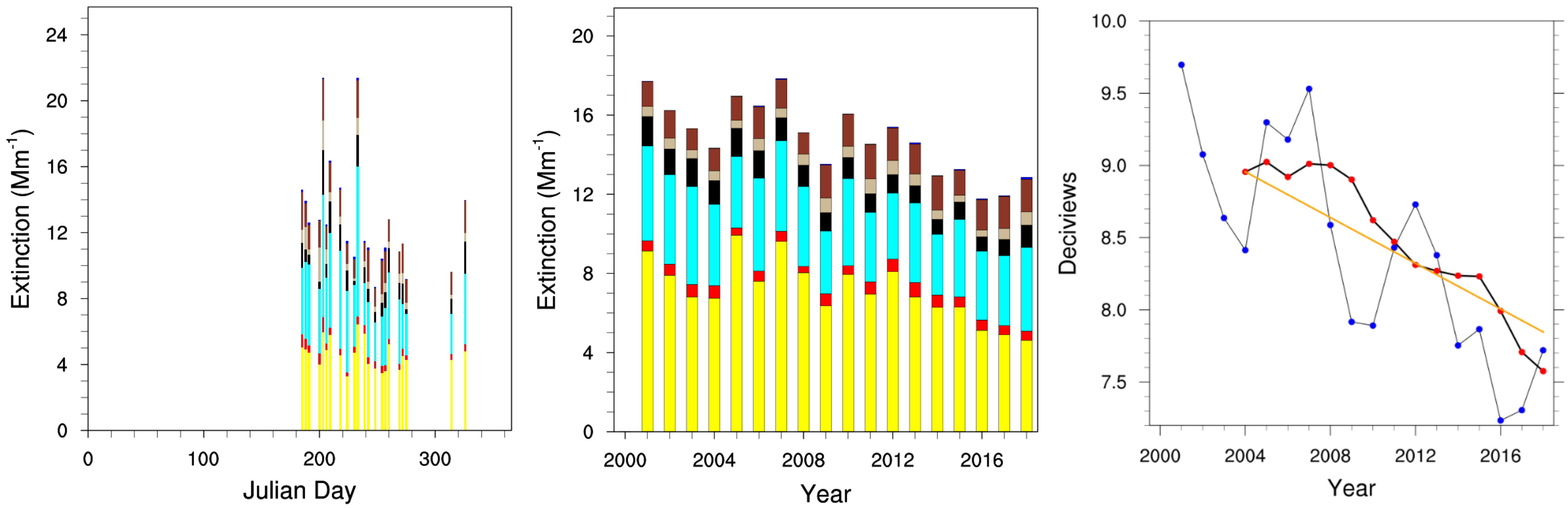
Everglades National Park, FL



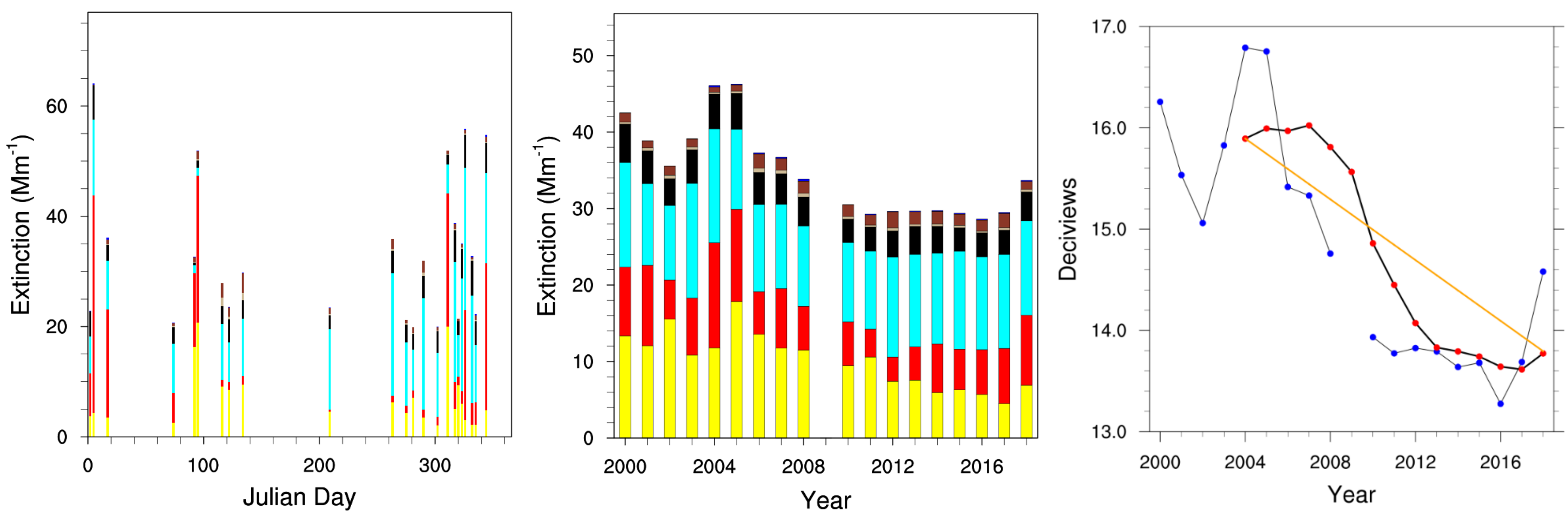
Gates of the Mountains, MT



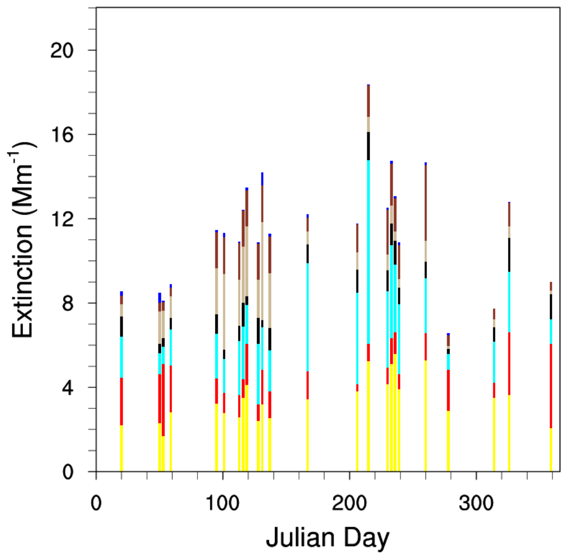
Gila Wilderness, NM

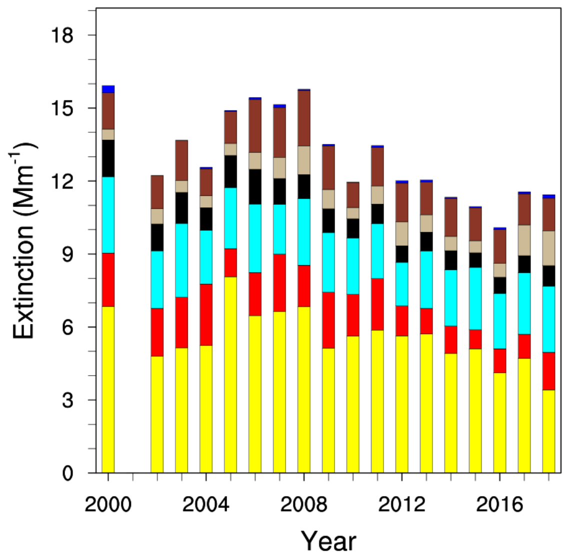


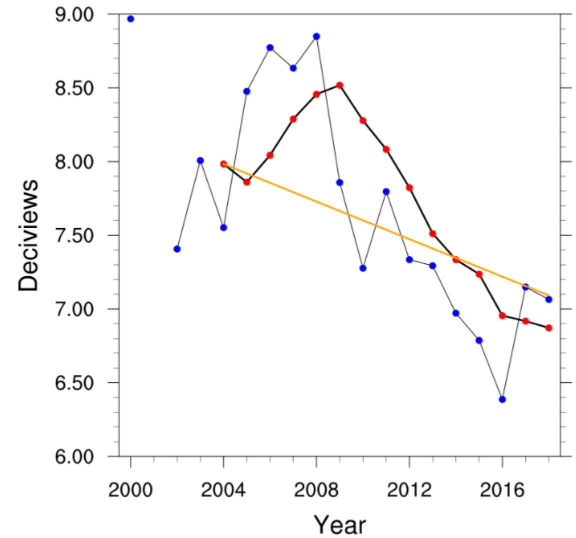
Glacier National Park, MT



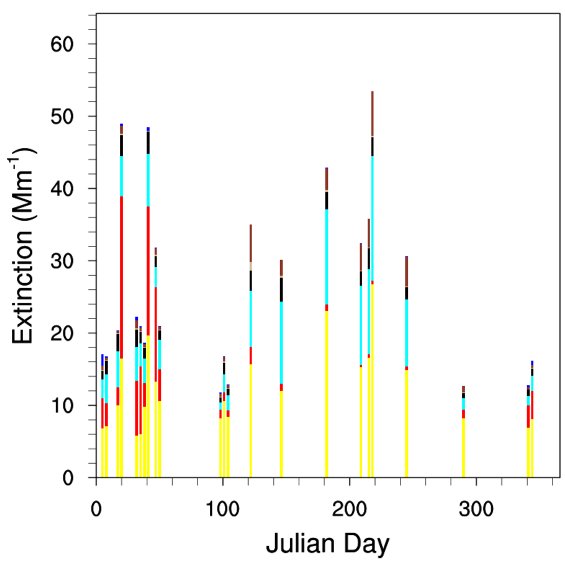
Grand Canyon National Park, AZ

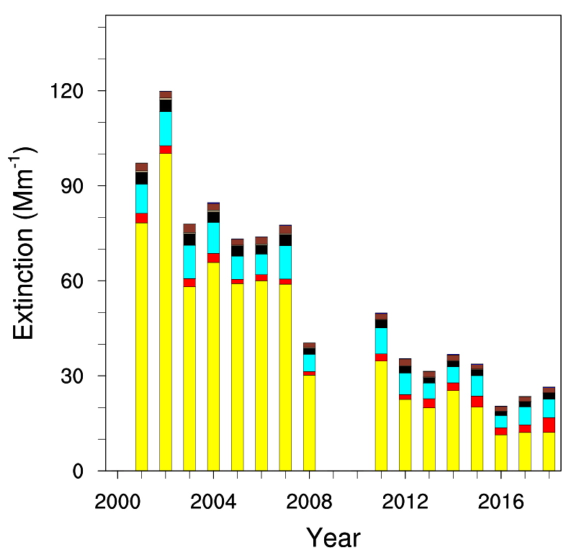


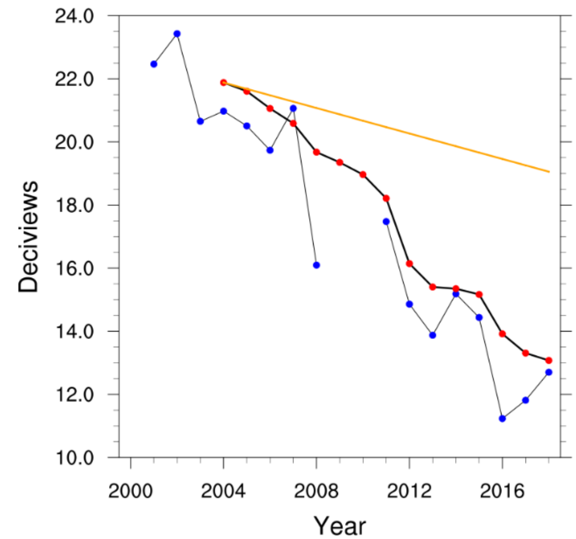




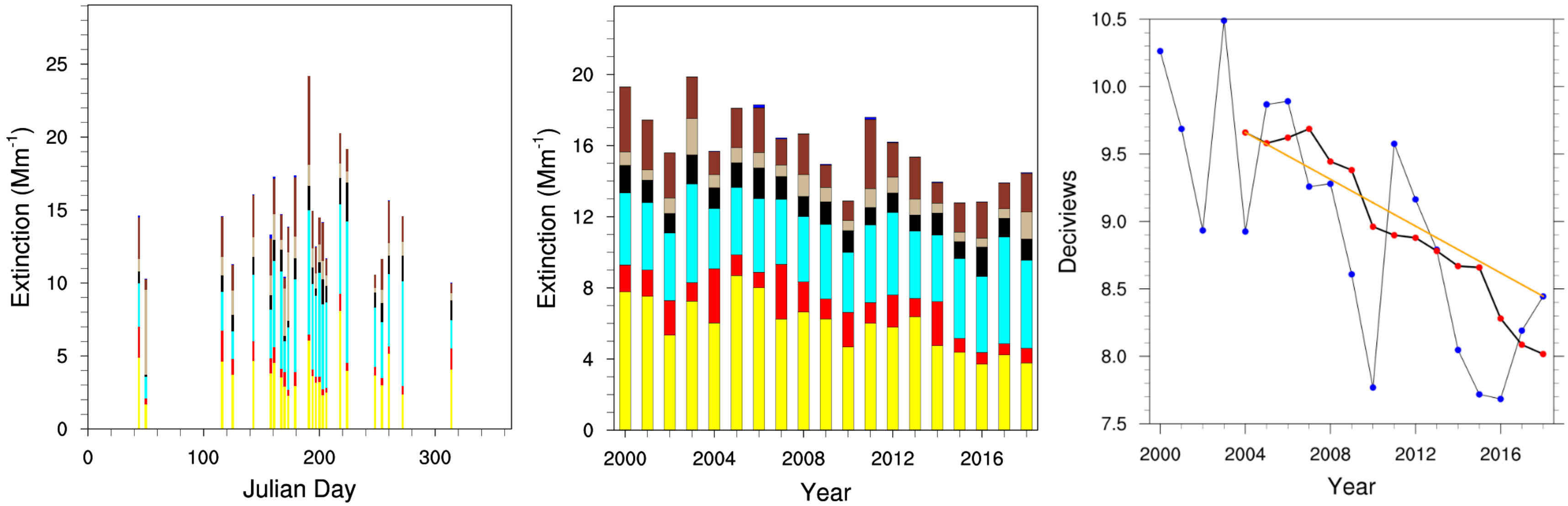
Great Gulf Wilderness, NH



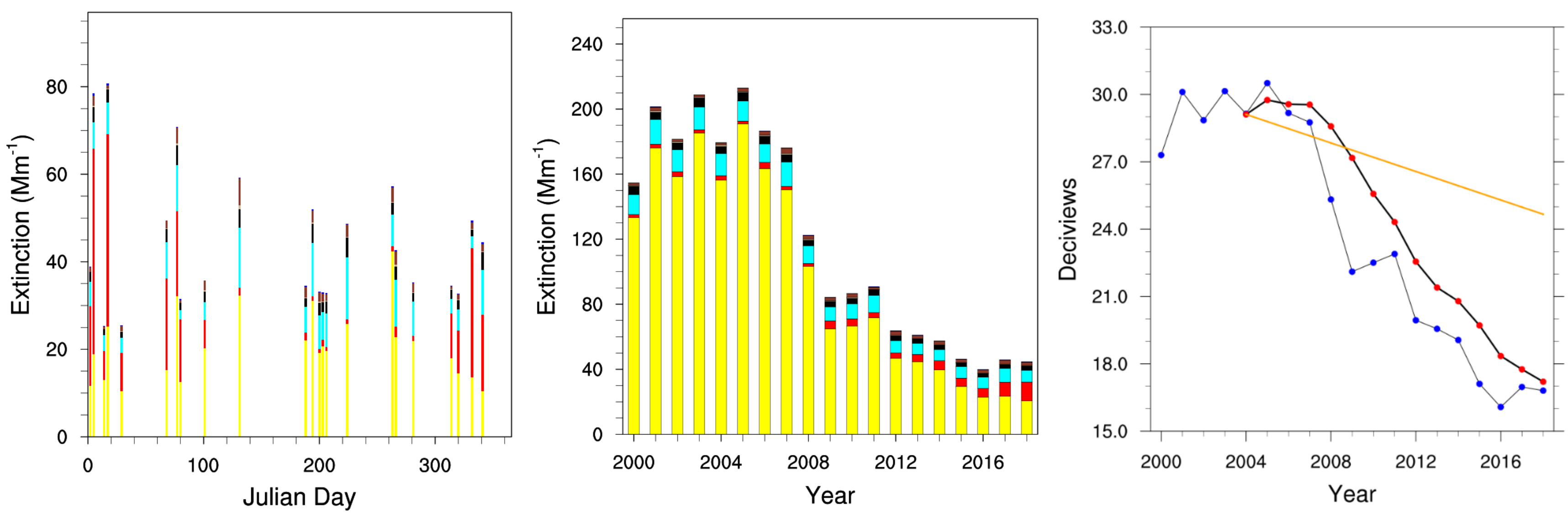




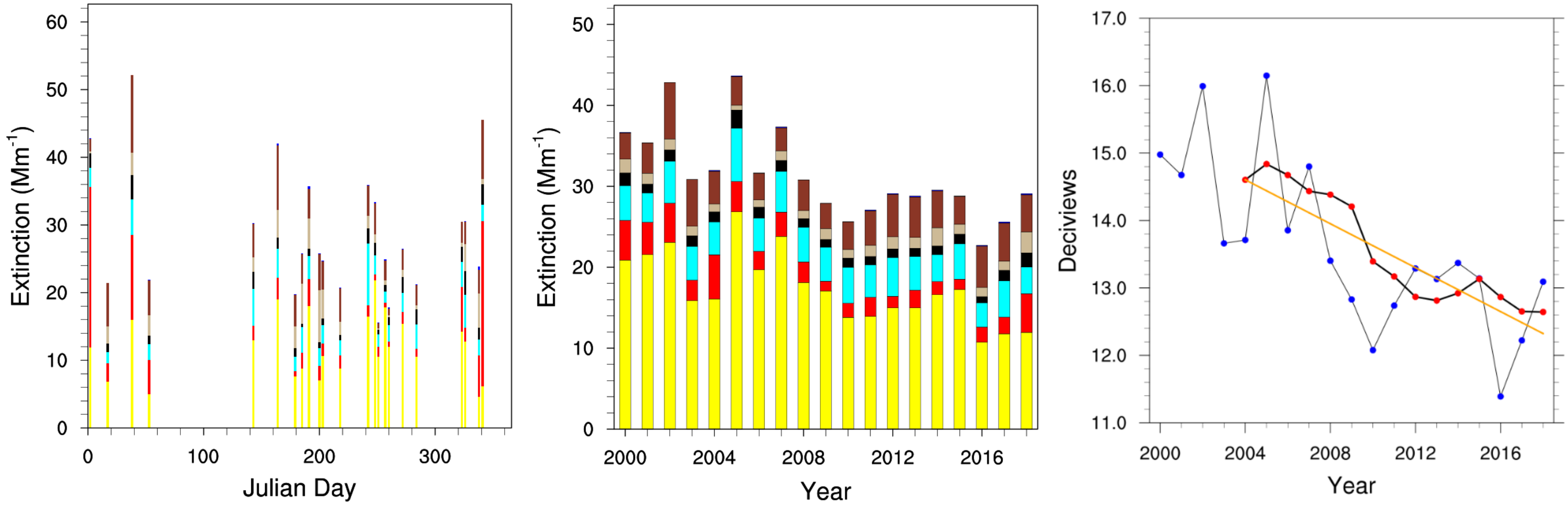
Great Sand Dunes National Monument, CO



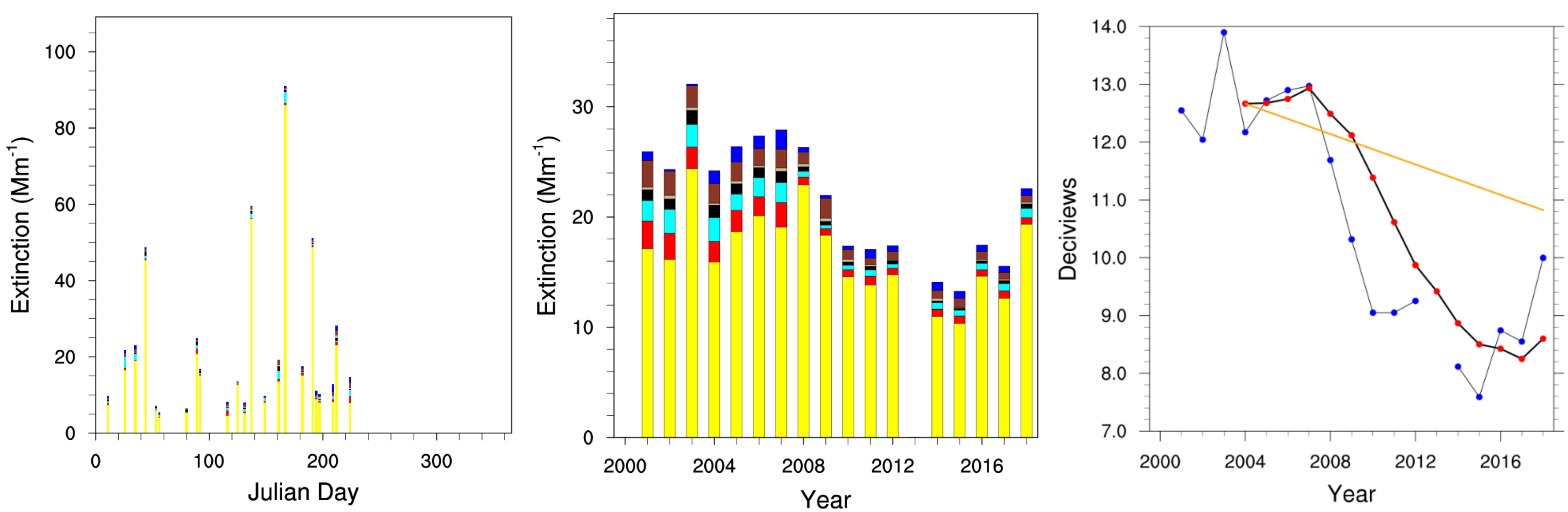
Great Smoky Mountains National Park, TN



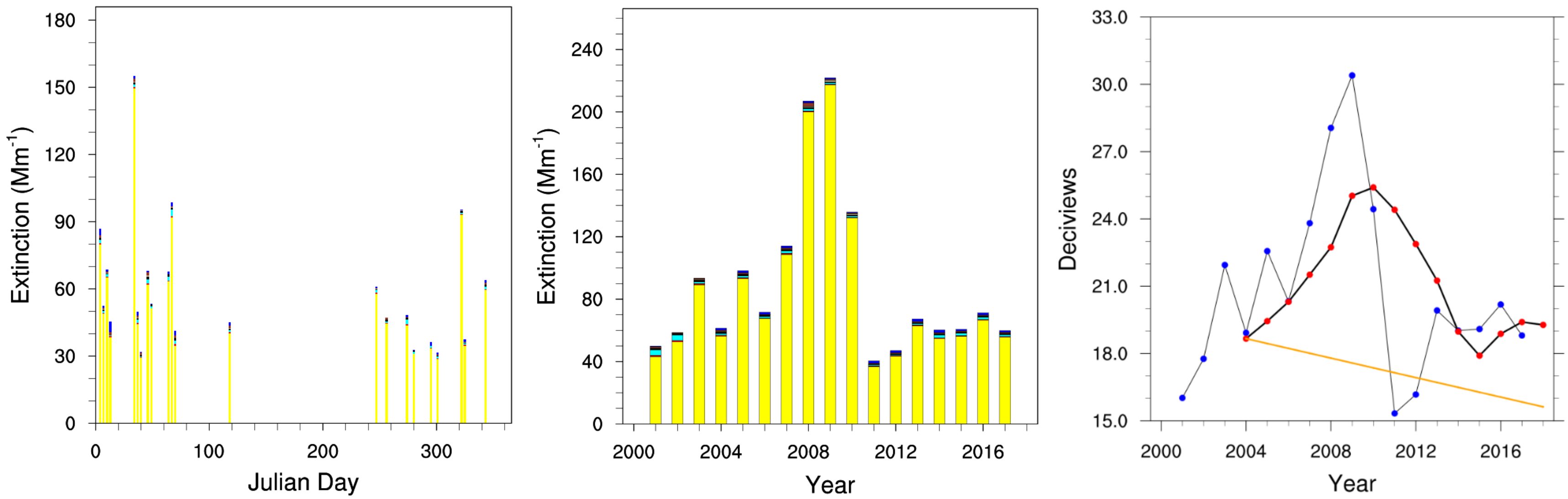
Guadalupe Mountains National Park, TX



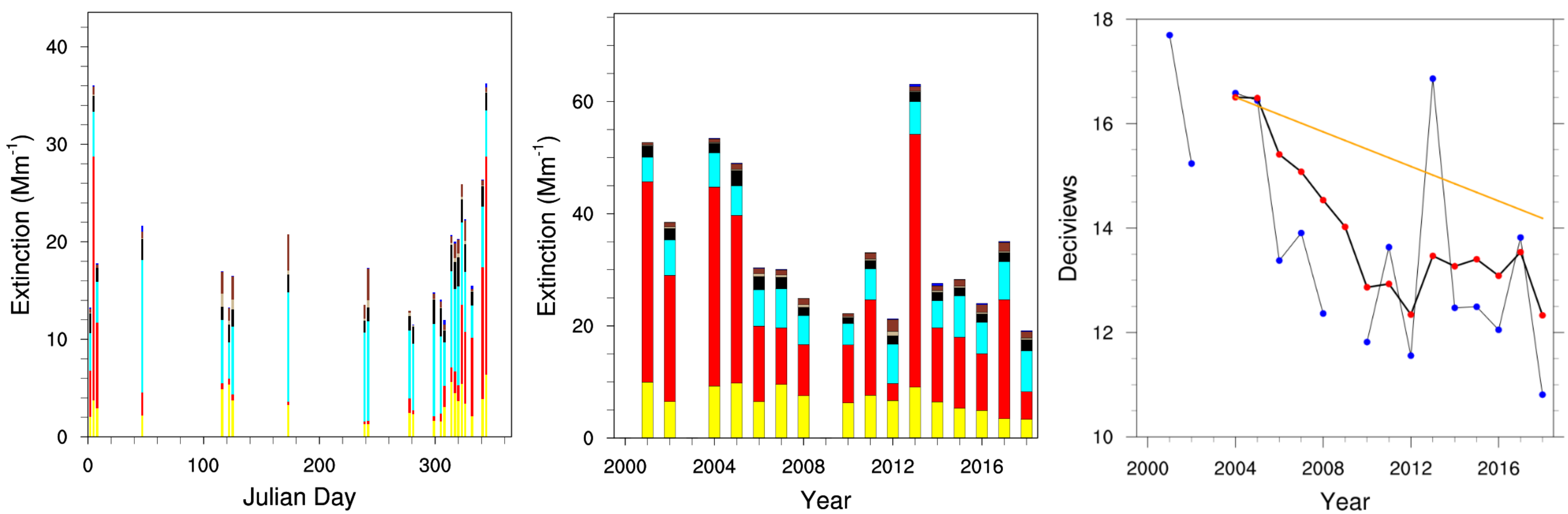
Haleakala National Park, HI (combined HALE1 and HACR1 starting 01/01/2007)



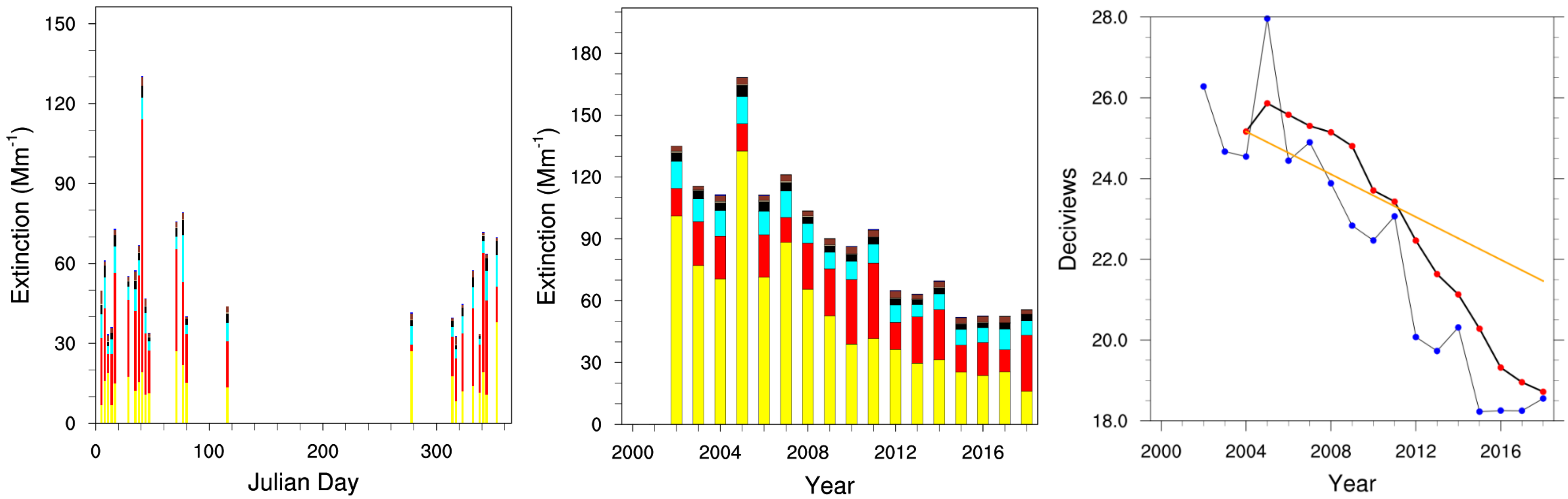
Hawaii Volcanoes National Park, HI (2017 data shown in figure to the left)



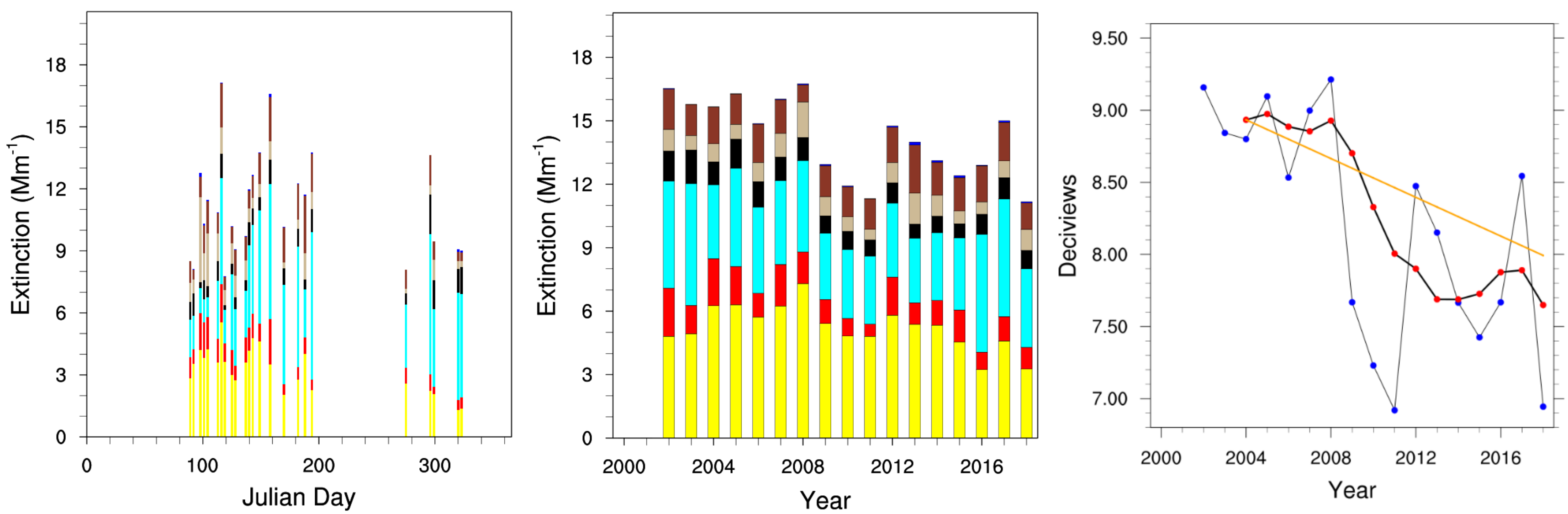
Hells Canyon, OR



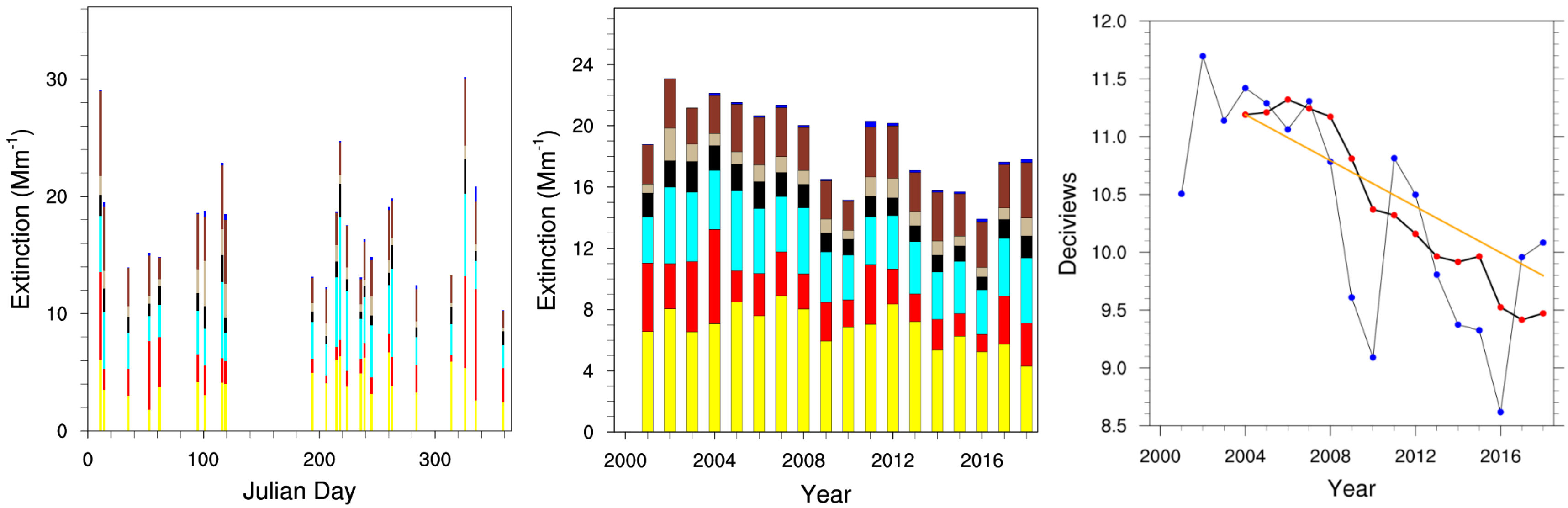
Hercules-Glades, MO



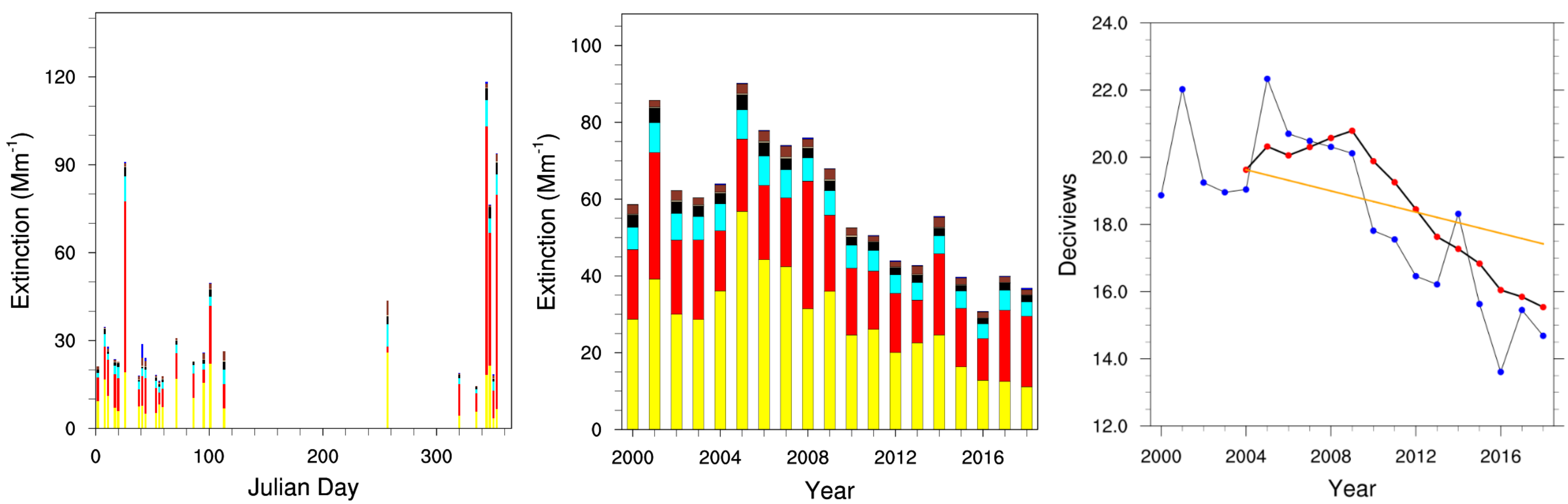
Hoover, CA



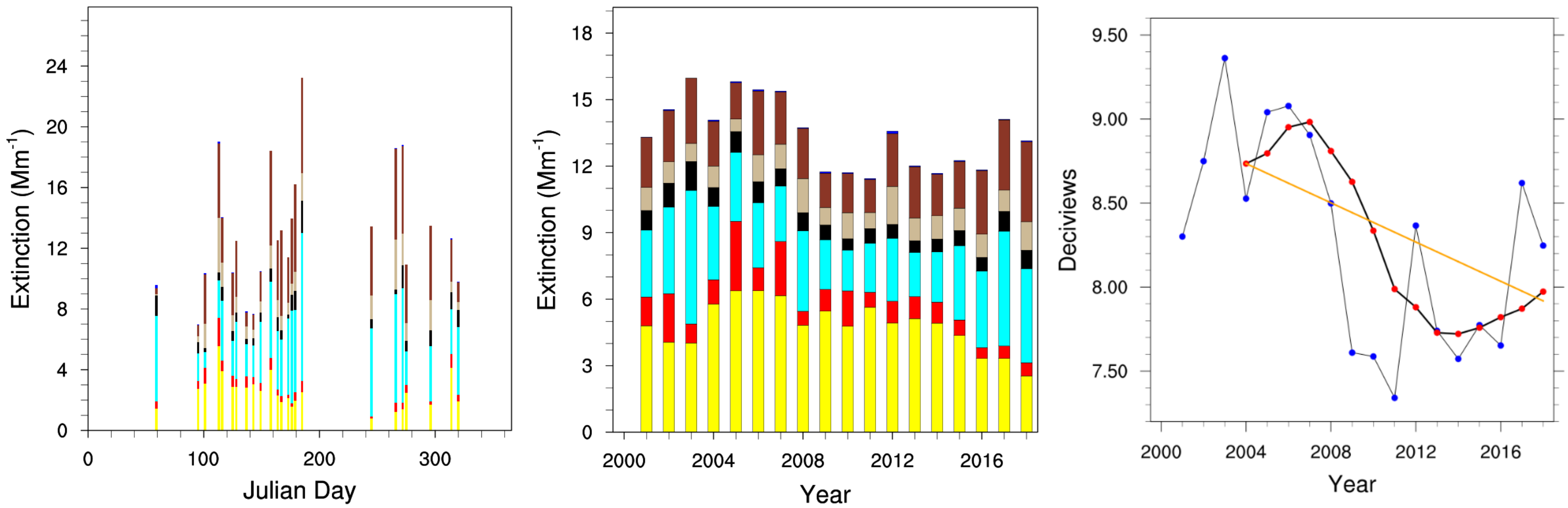
Ike's Backbone, AZ



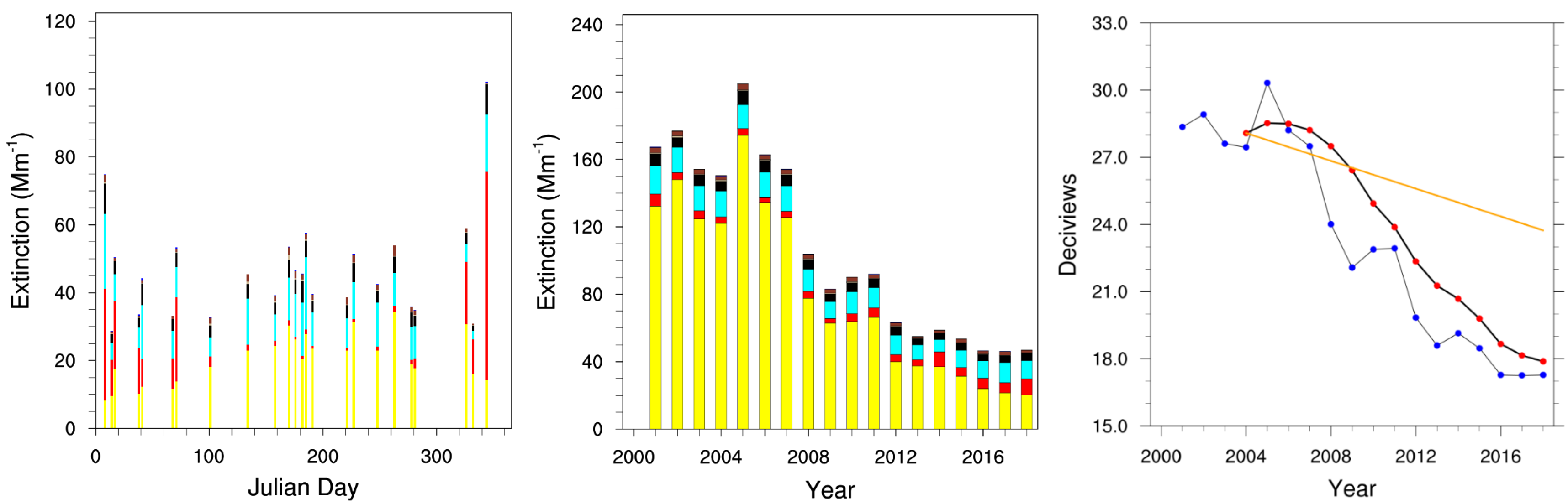
Isle Royale National Park, MI



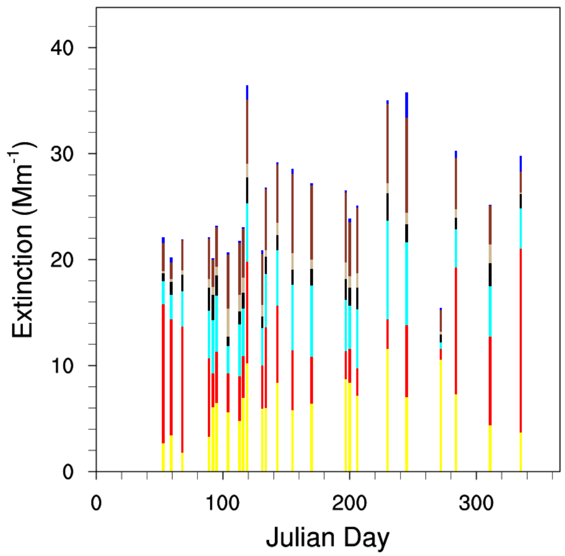
Jarbidge Wilderness, NV

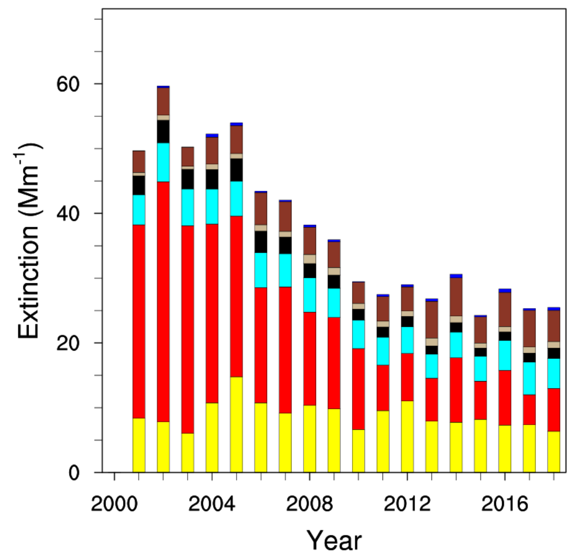


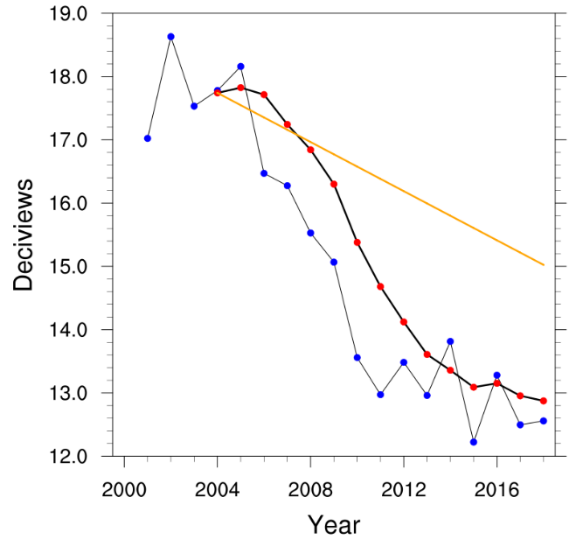
James River Face Wilderness, VA



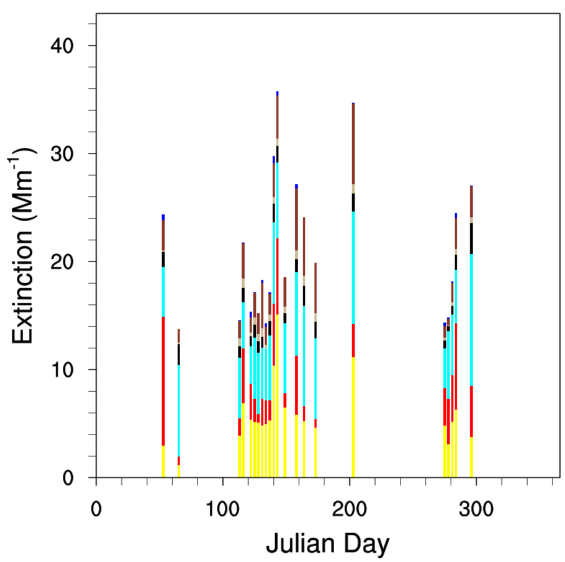
Joshua Tree National Park, CA

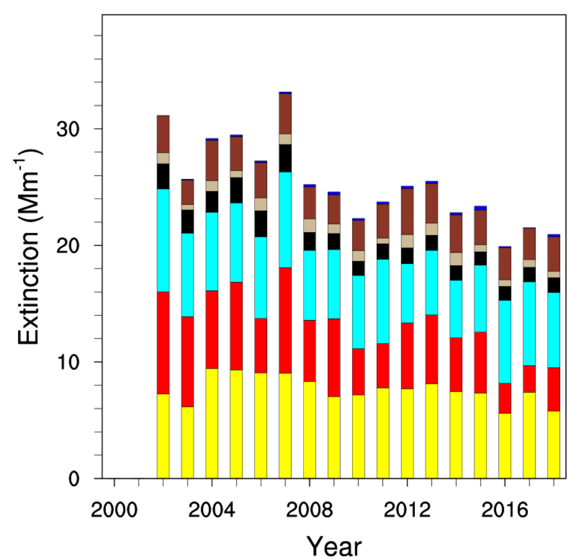


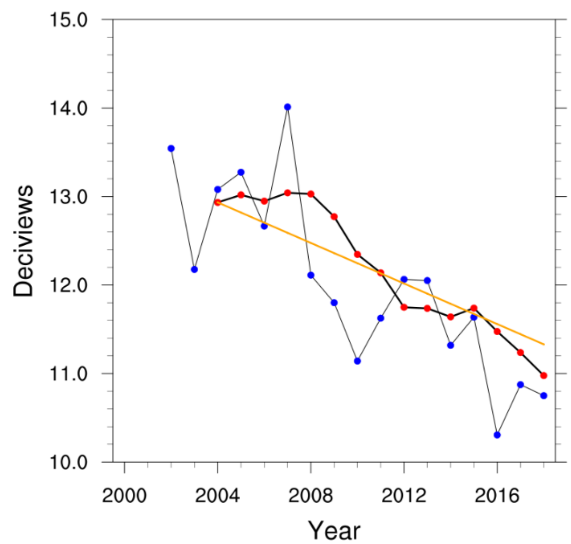




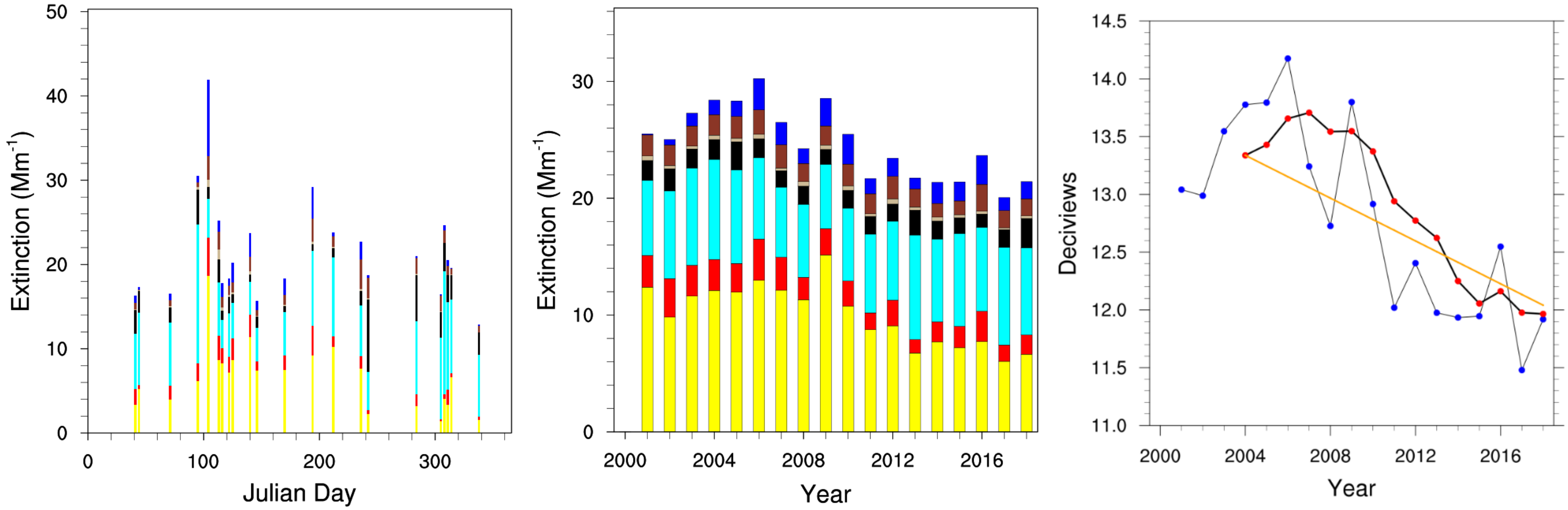
Kaiser, CA



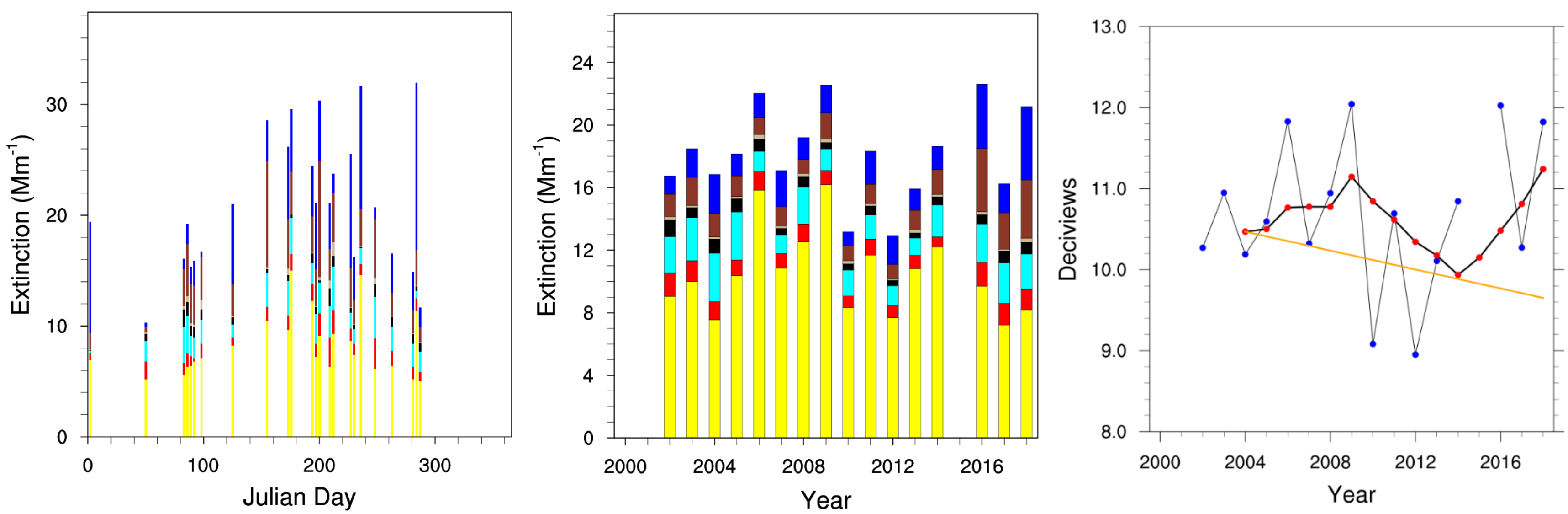




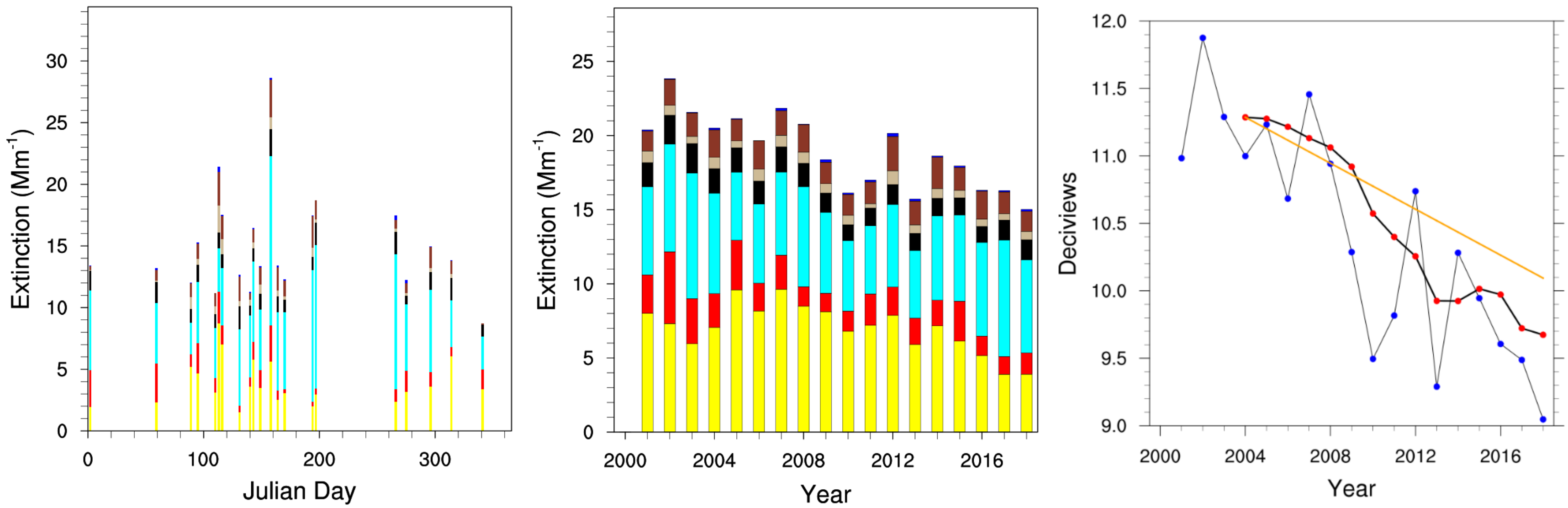
Kalmiopsis, OR



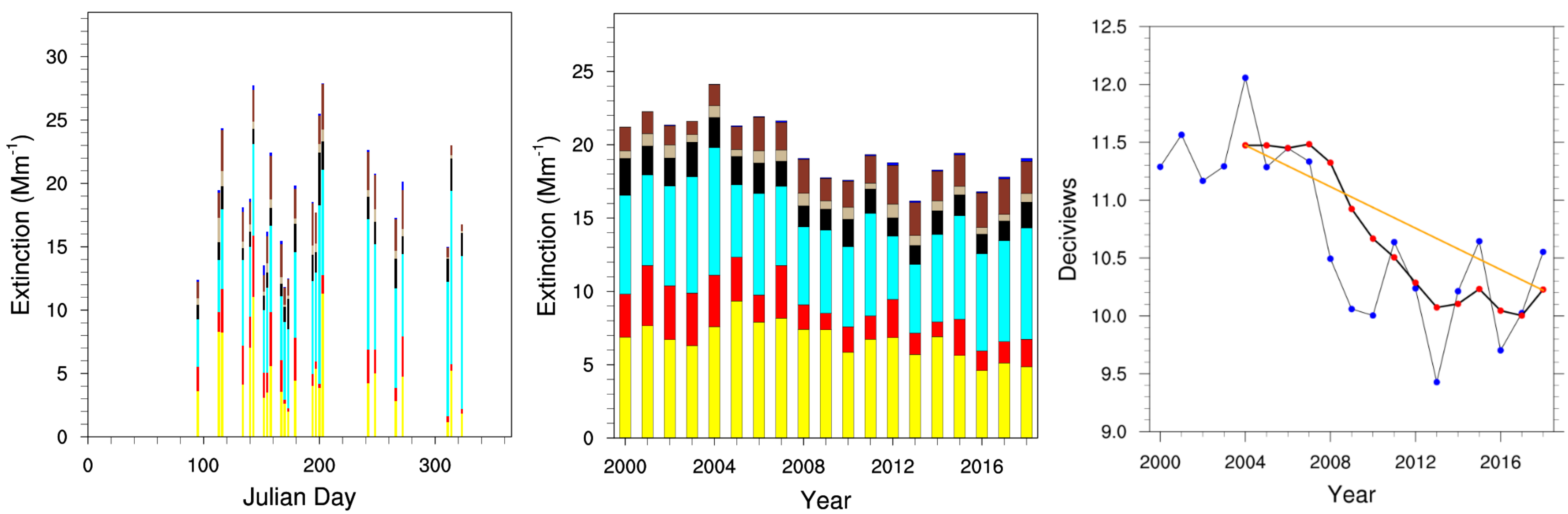
Kenai Peninsula Borough, AK (combined TUXE1 and KPBO1 starting 01-01-15)



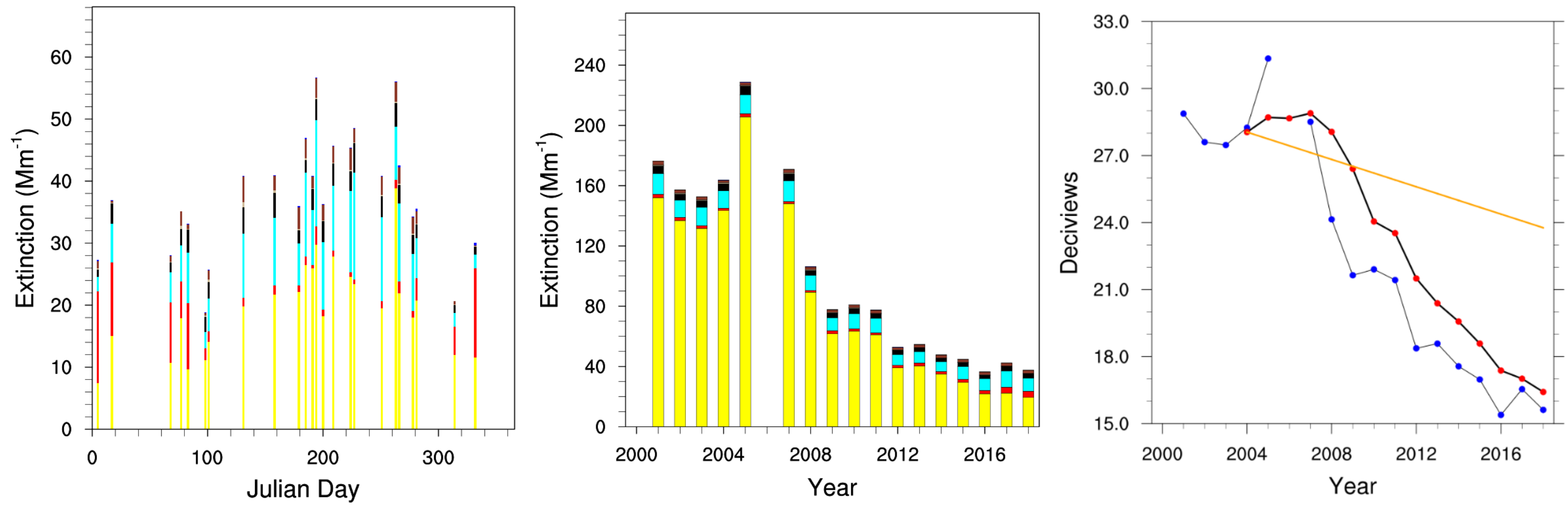
Lava Beds National Monument, CA



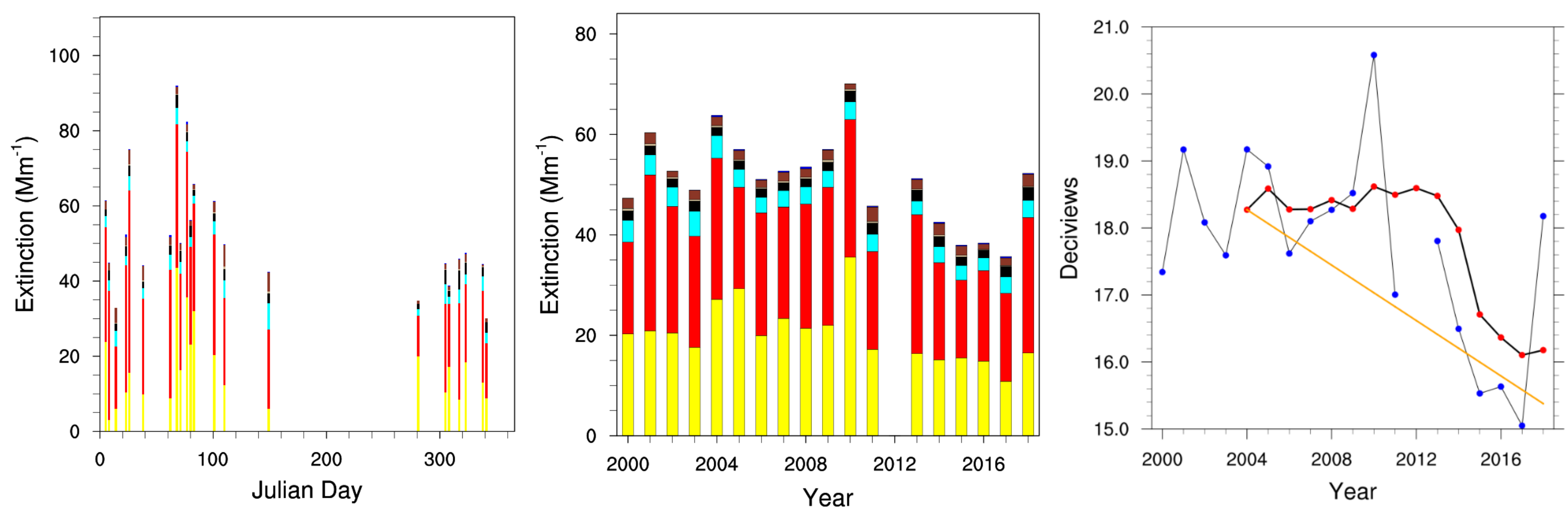
Lassen Volcanic National Park, CA



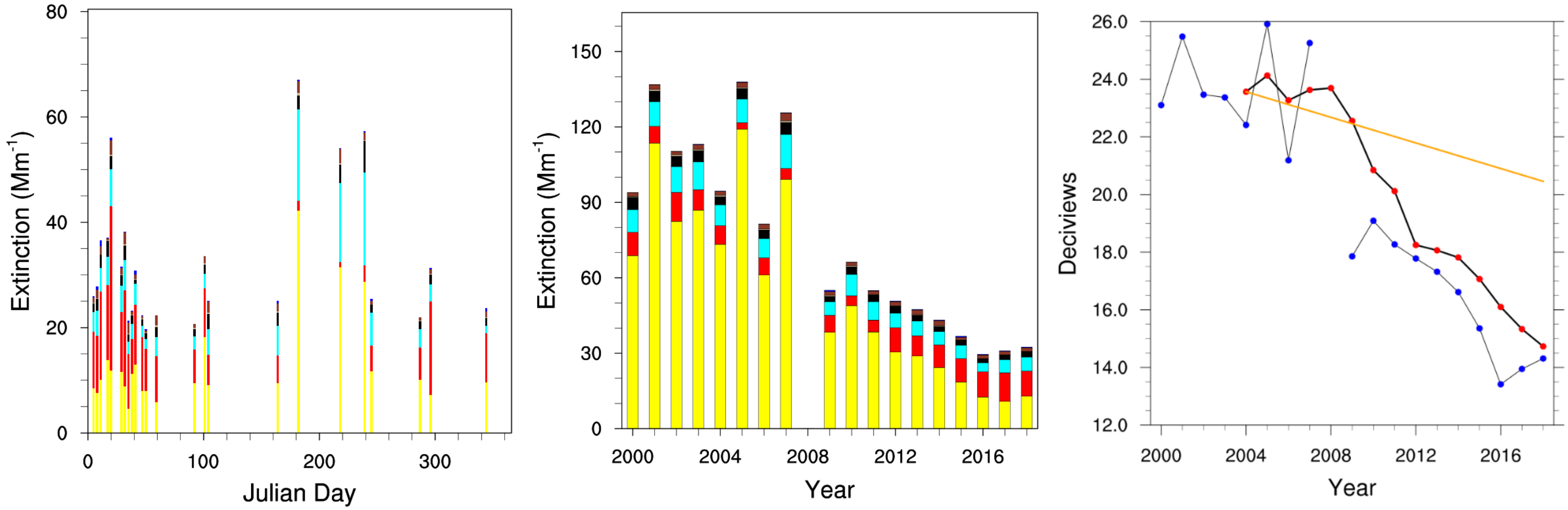
Linville Gorge, NC



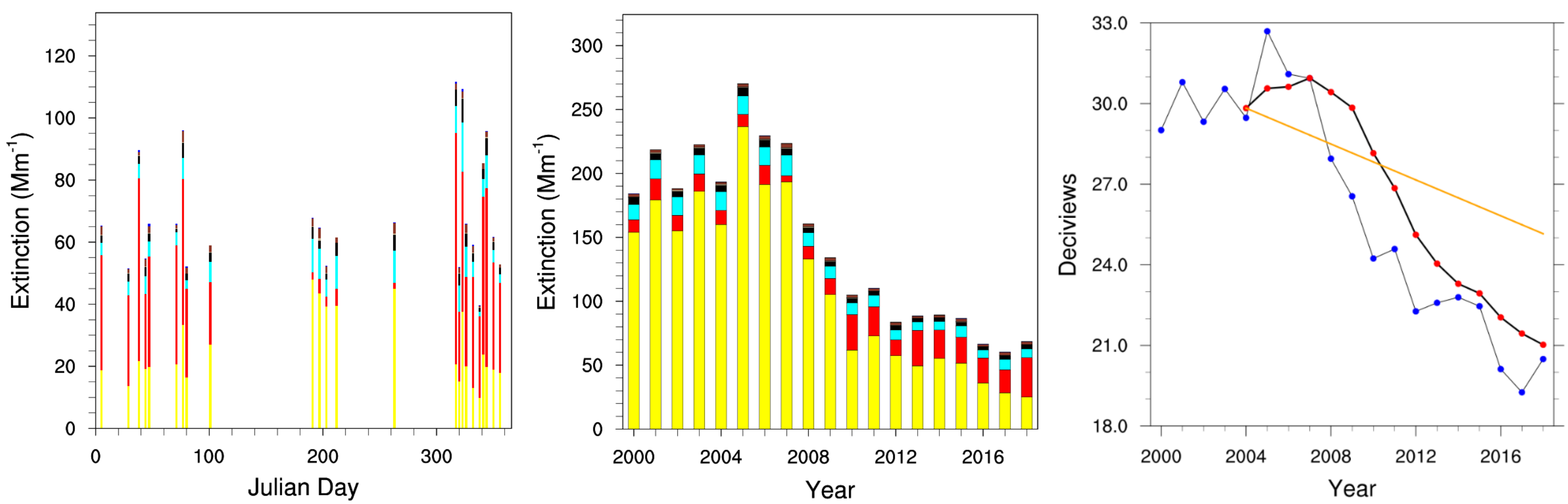
Lostwood, ND



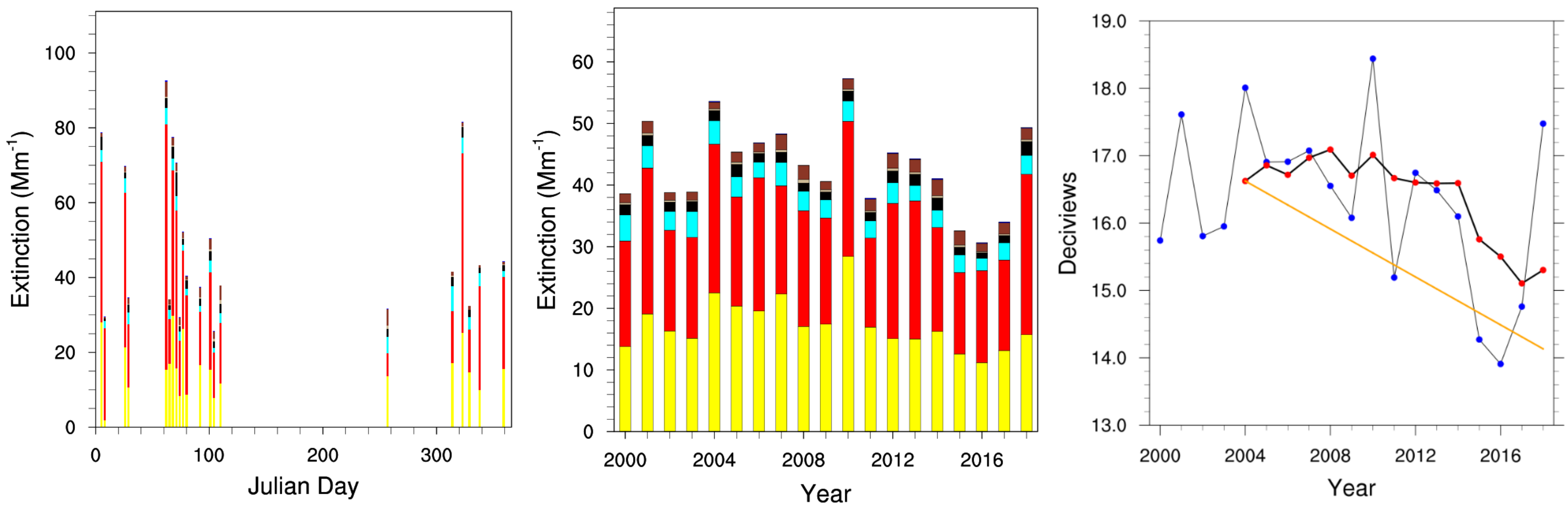
Lye Brook Wilderness, VT (combined LYBR1 and LYEB1 starting 01/01/2012)



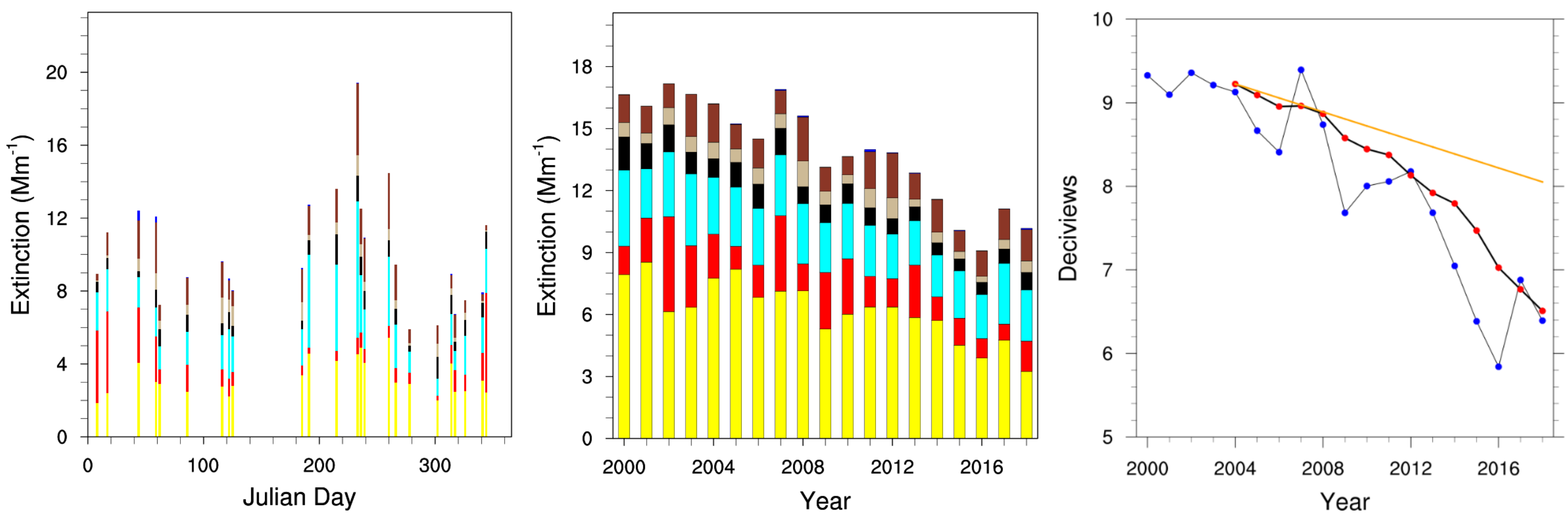
Mammoth Cave National Park, KY



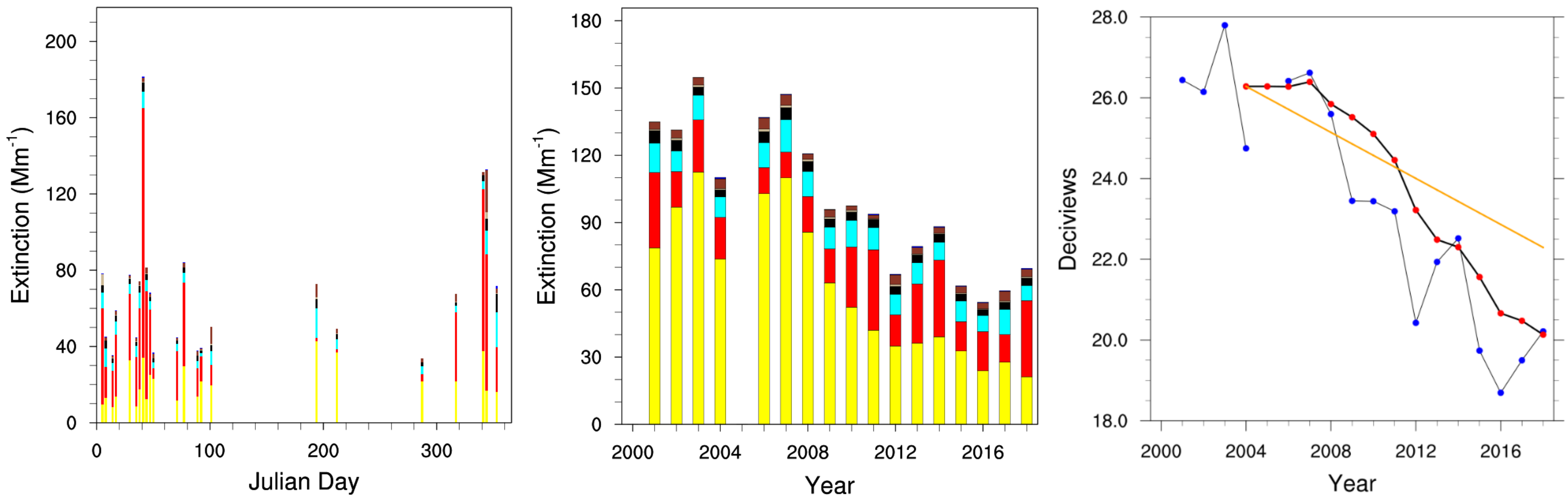
Medicine Lake, MT



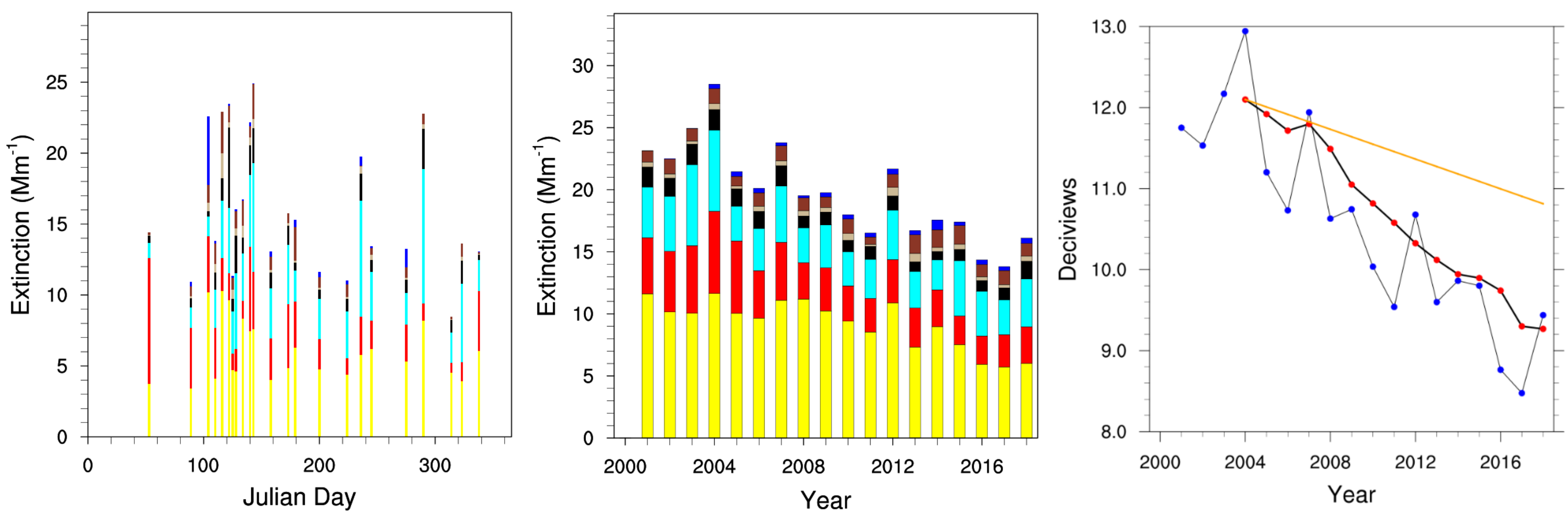
Mesa Verde National Park, CO



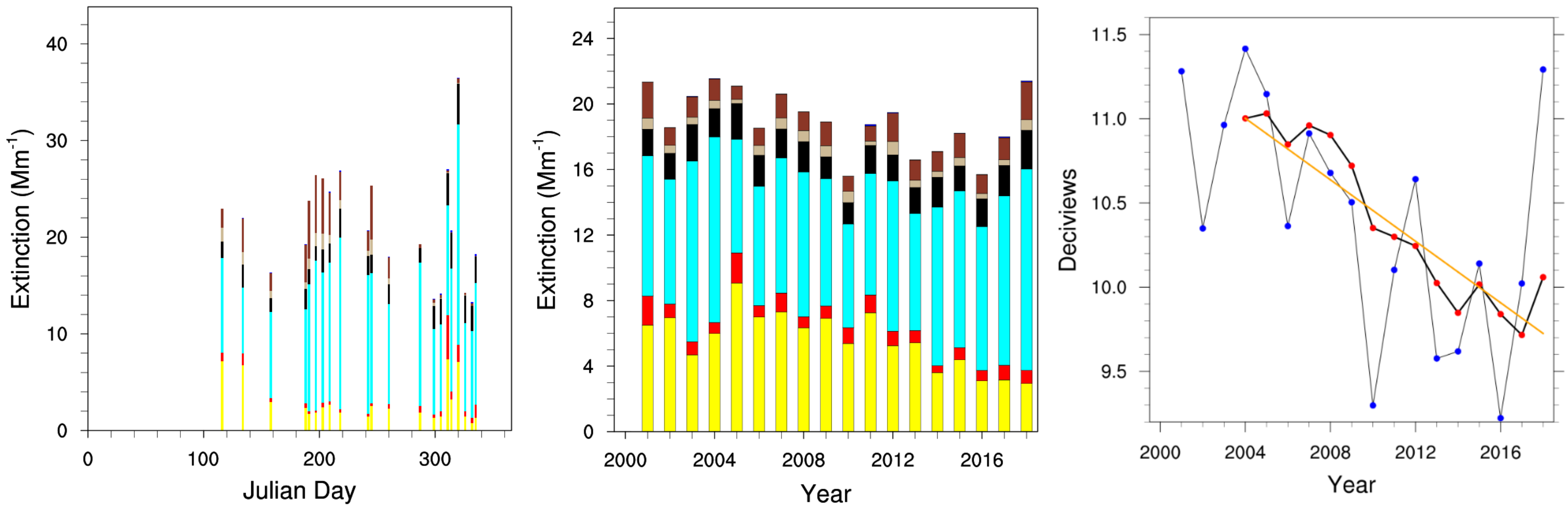
Mingo, MO



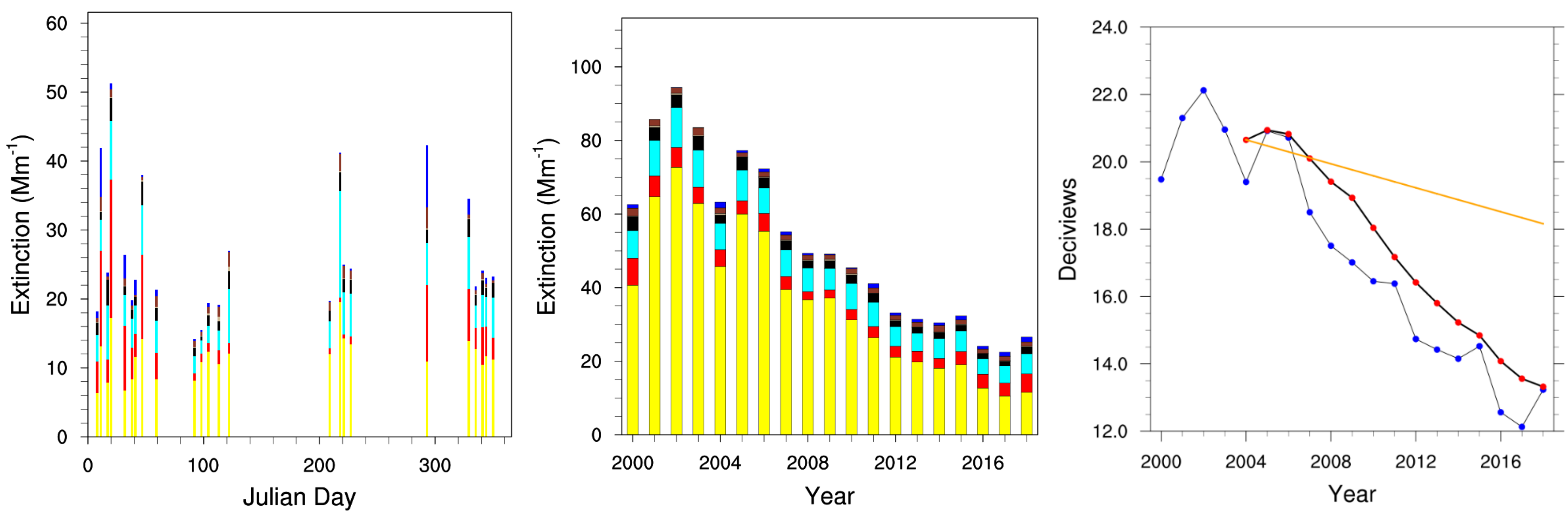
Mount Hood, OR



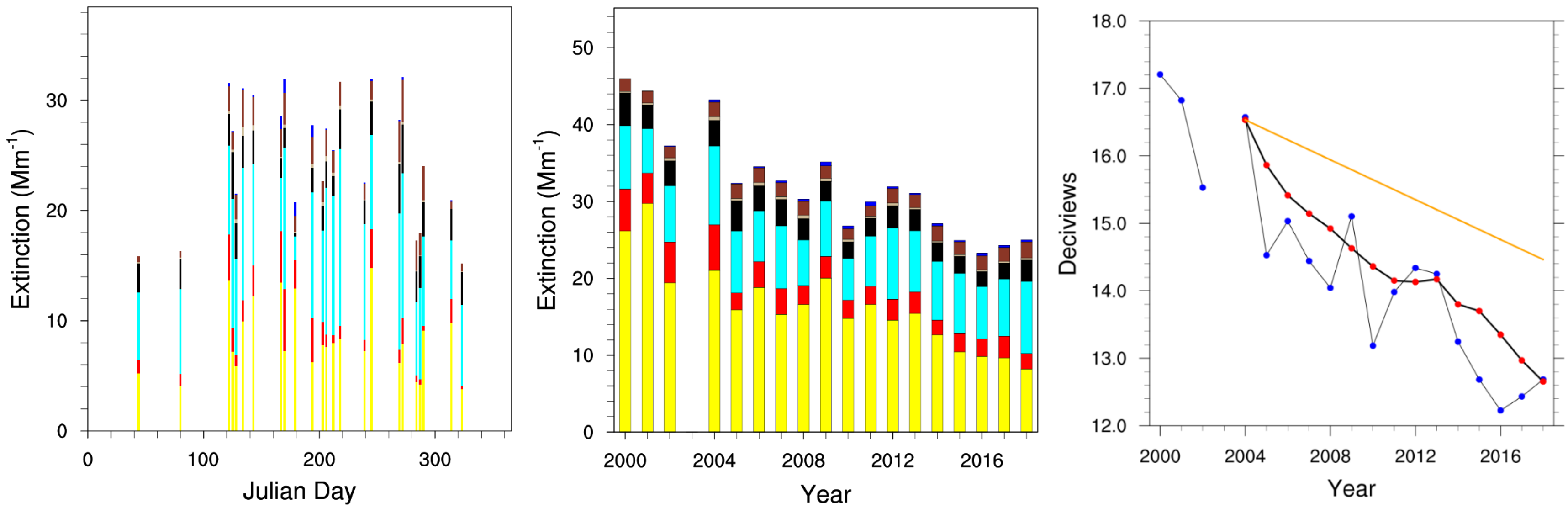
Monture, MT



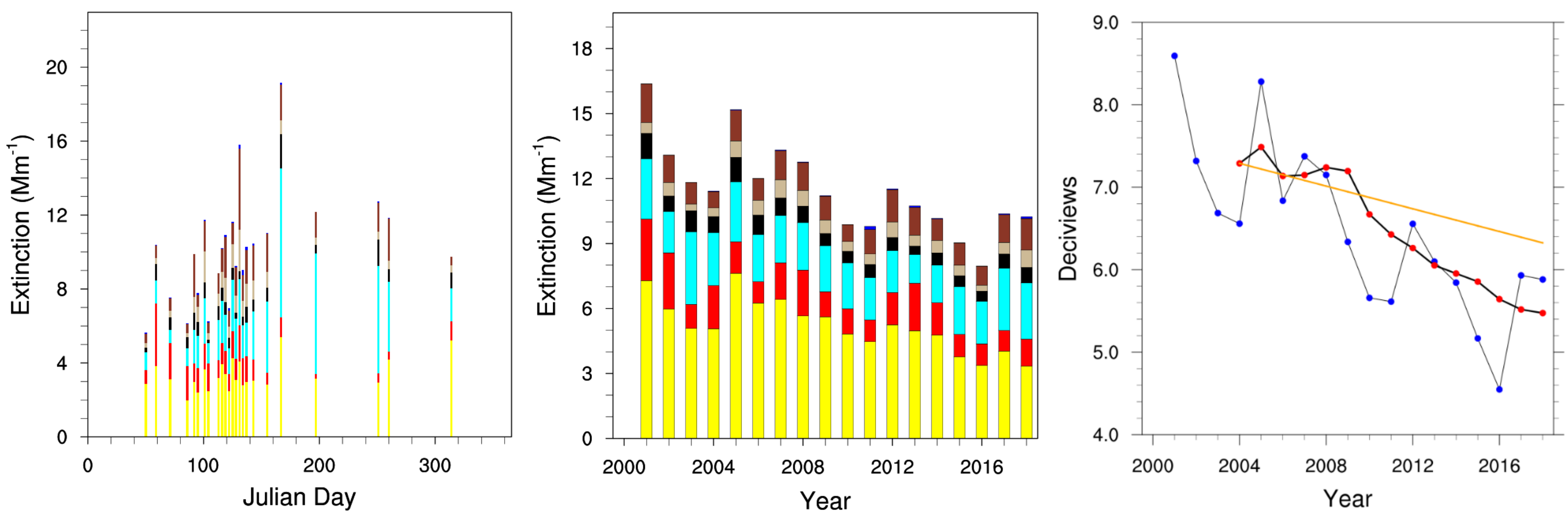
Moosehorn National Wildlife Refuge, ME



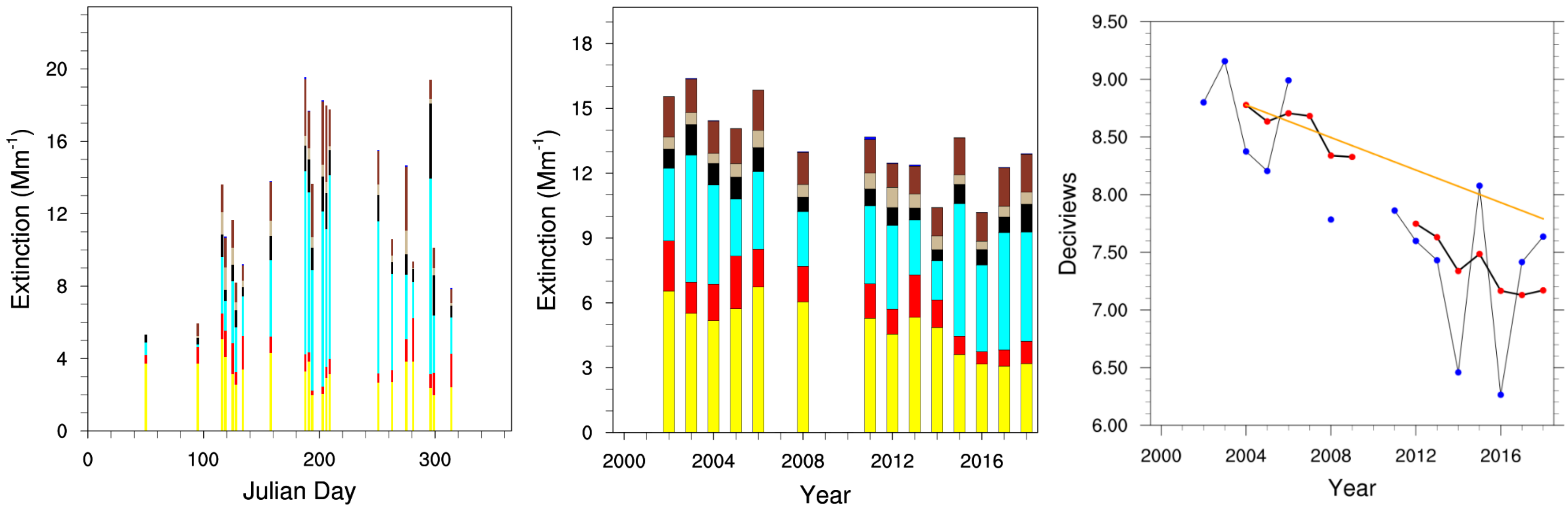
Mount Rainier National Park, WA



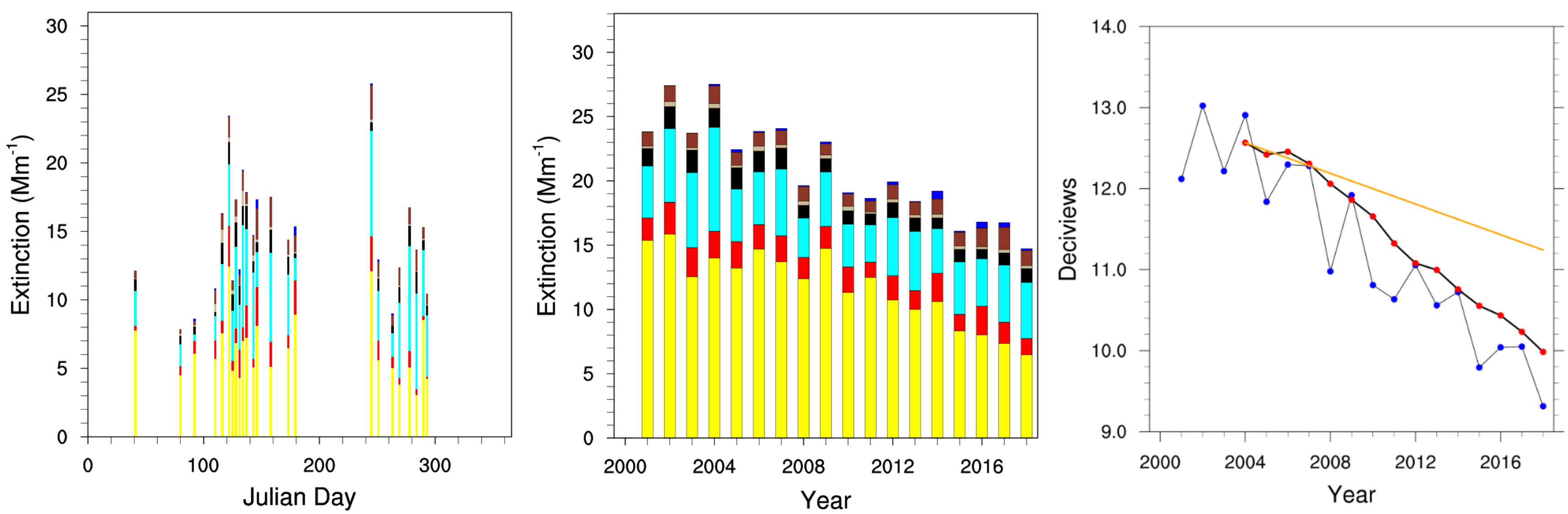
Mount Zirkel Wilderness, CO



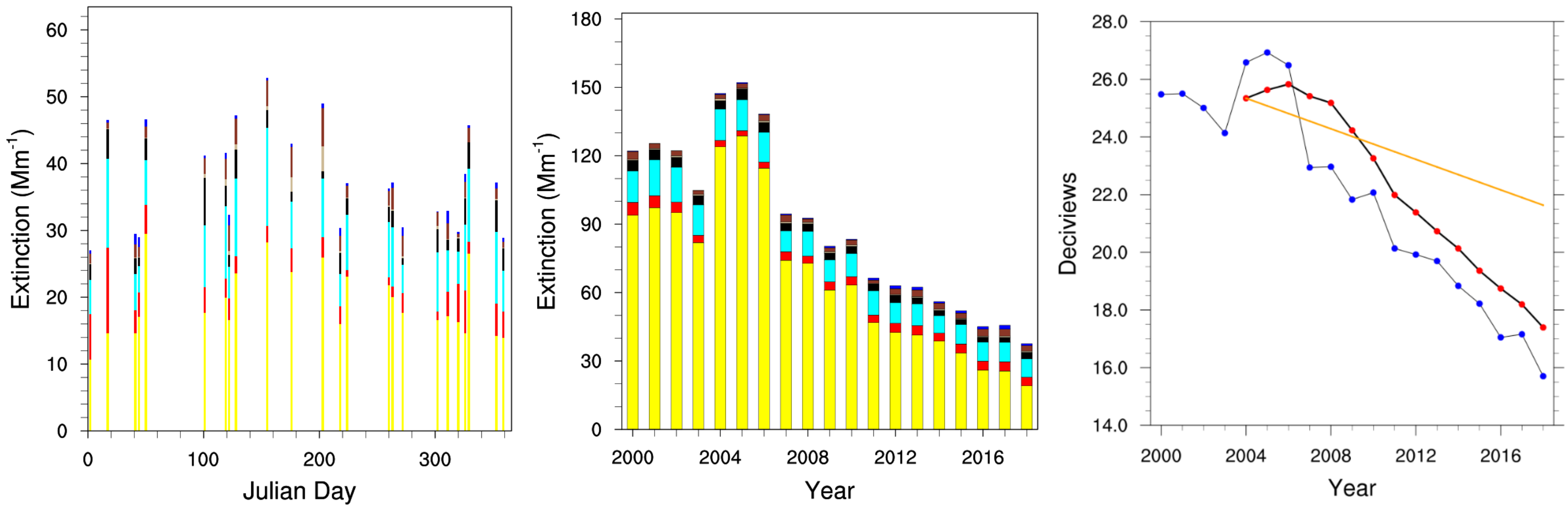
North Absaroka, WY



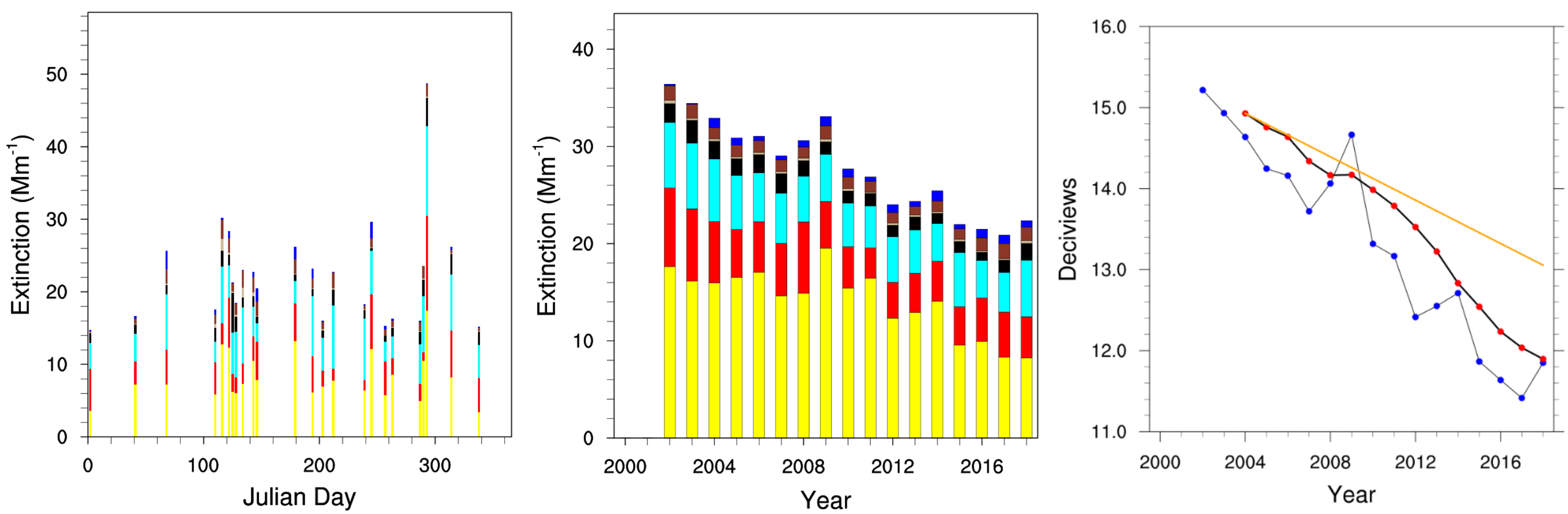
North Cascades National Park, WA



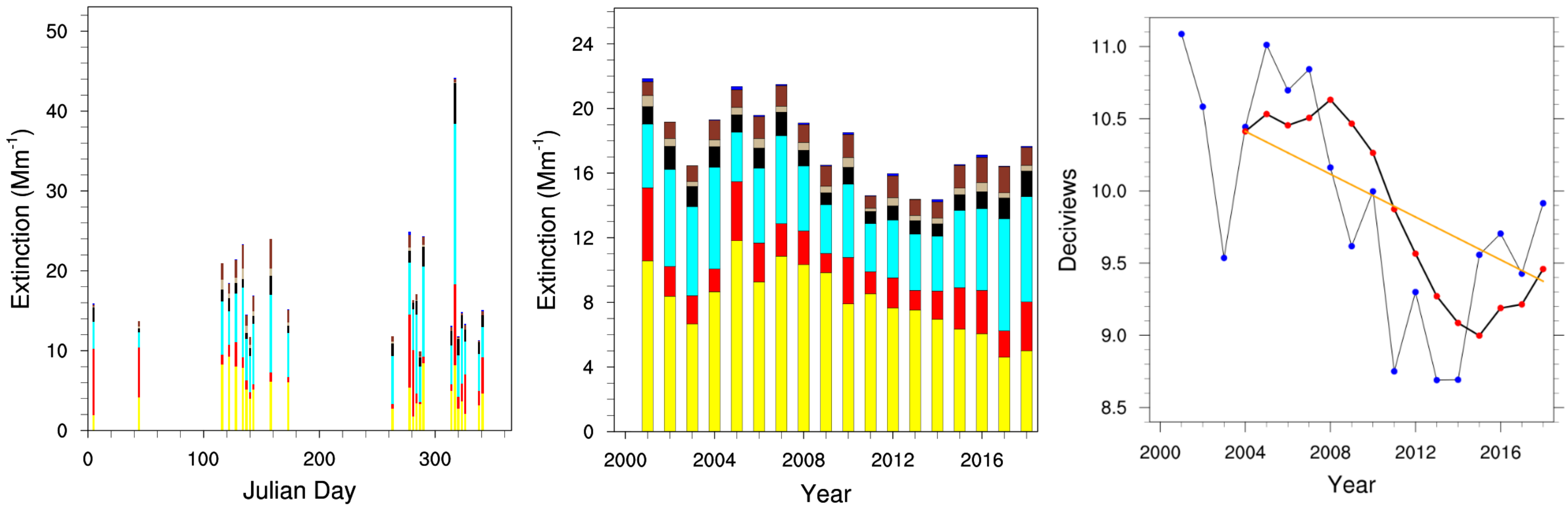
Okefenokee National Wildlife Refuge, GA



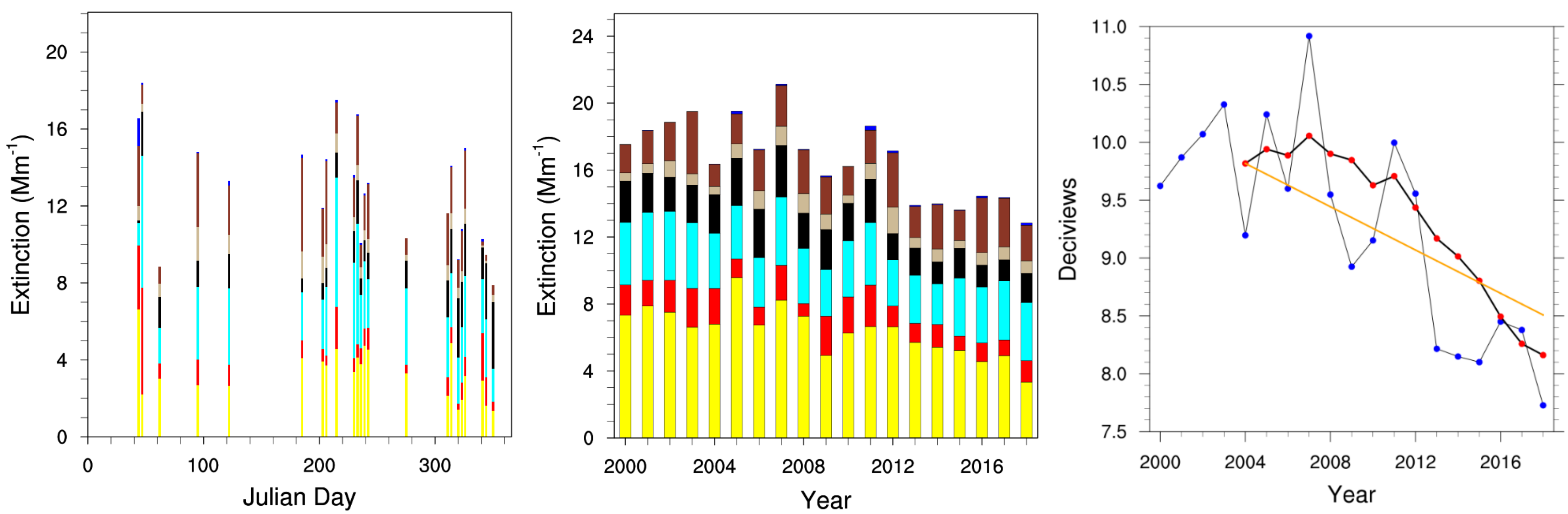
Olympic National Park, WA



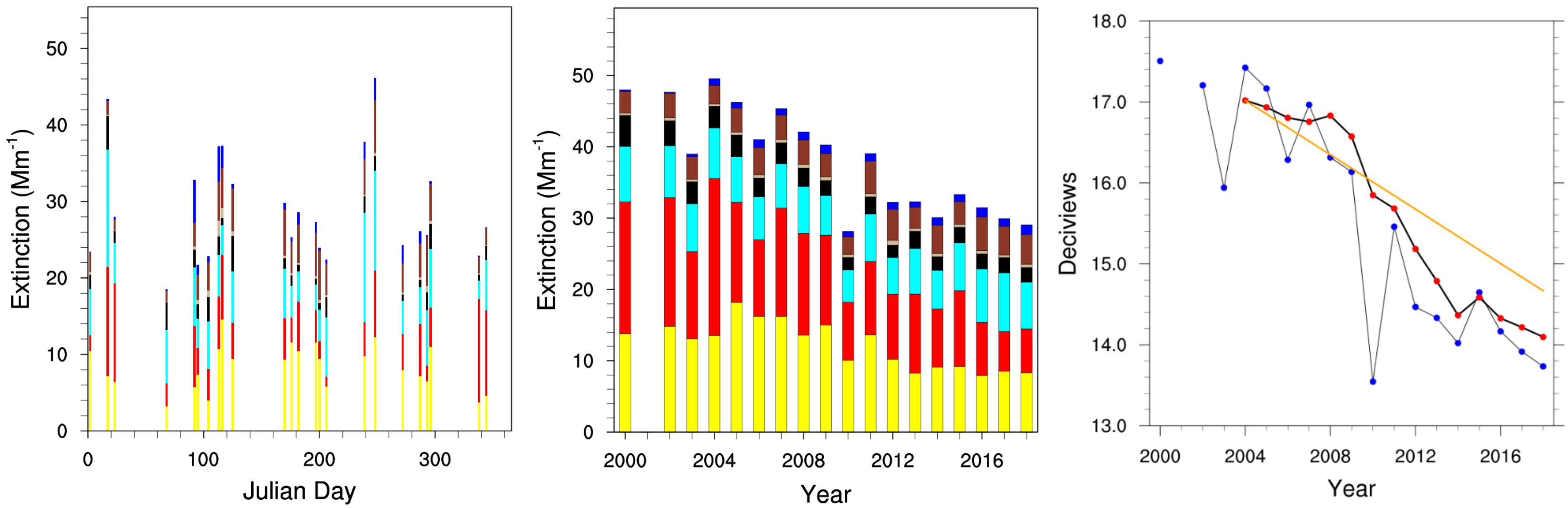
Pasayten, WA



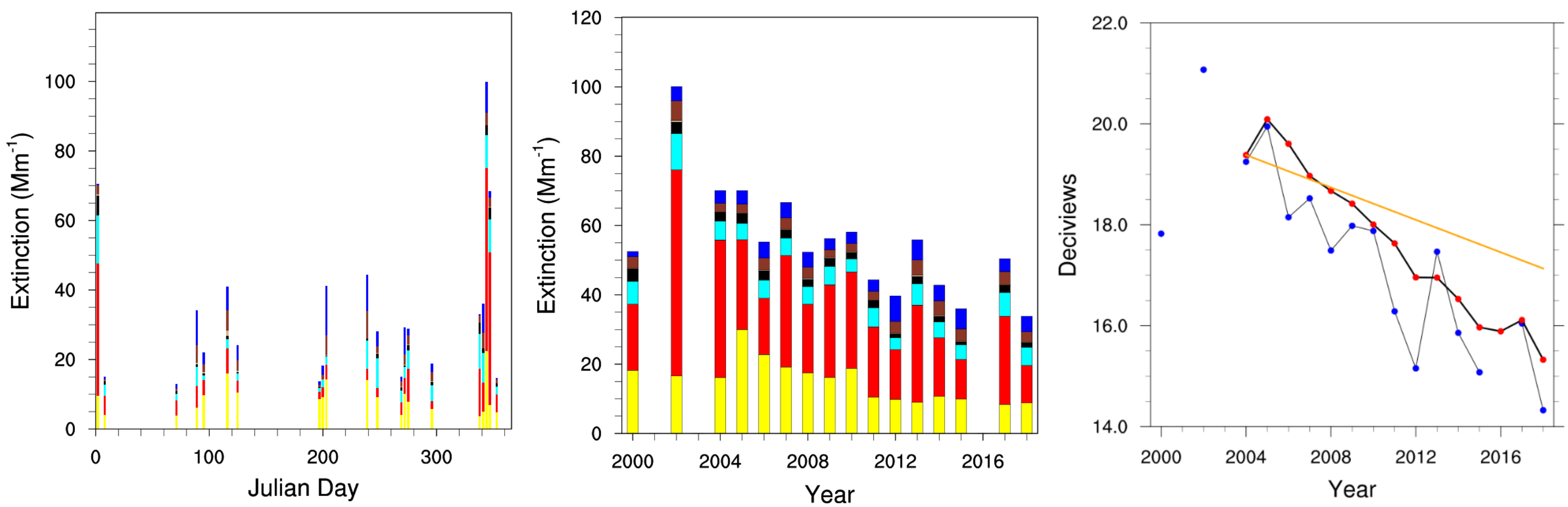
Petrified Forest National Park, AZ



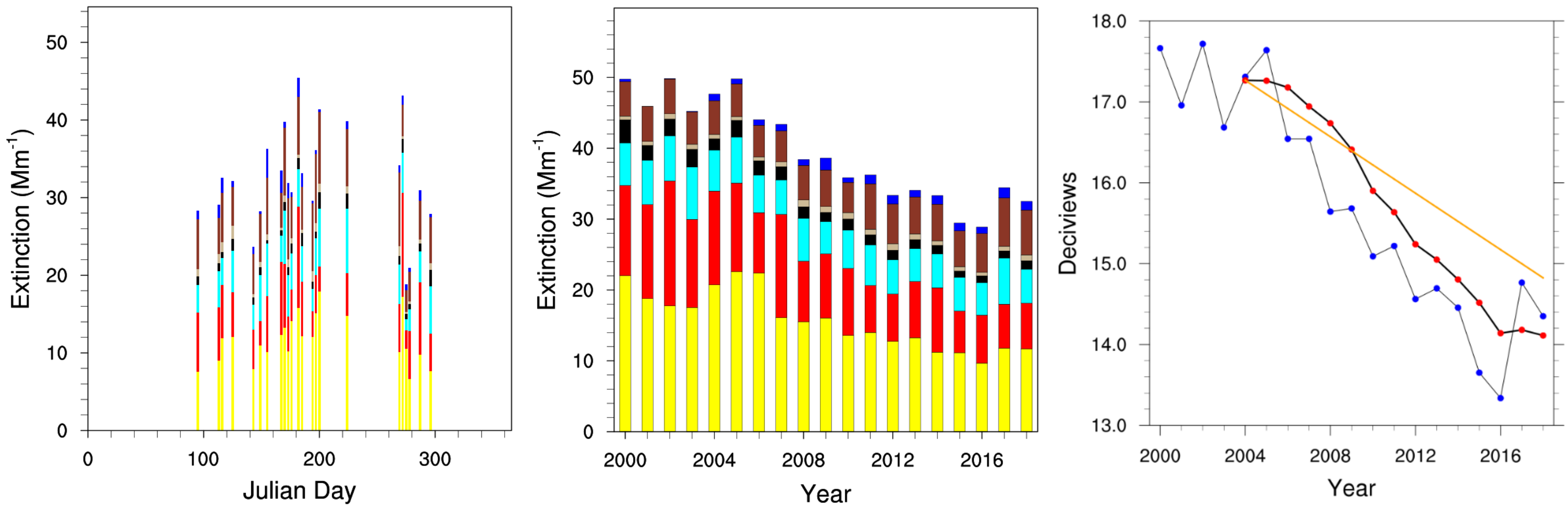
Pinnacles National Monument, CA



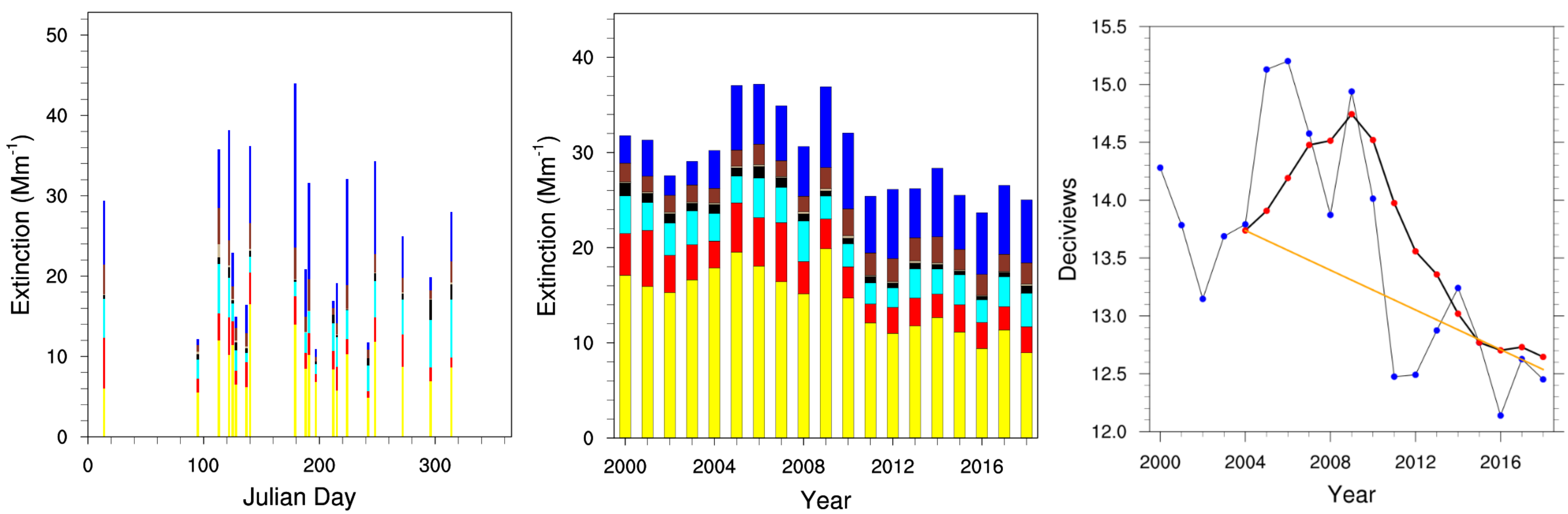
Point Reyes National Seashore, CA



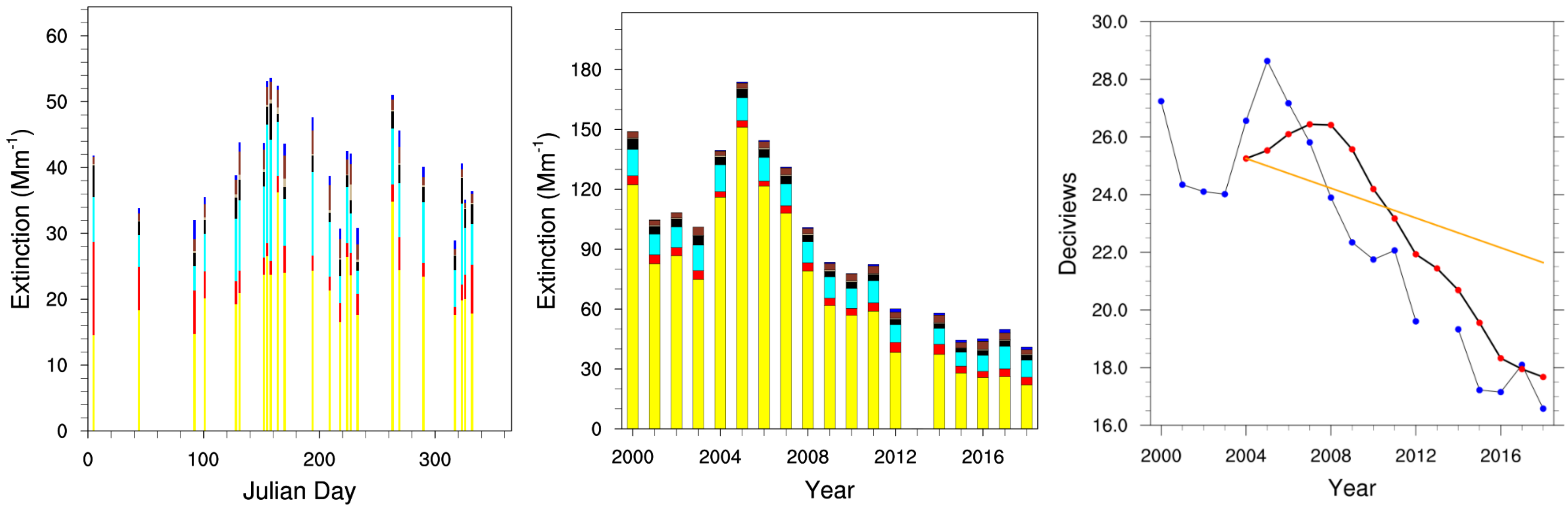
San Rafael, CA



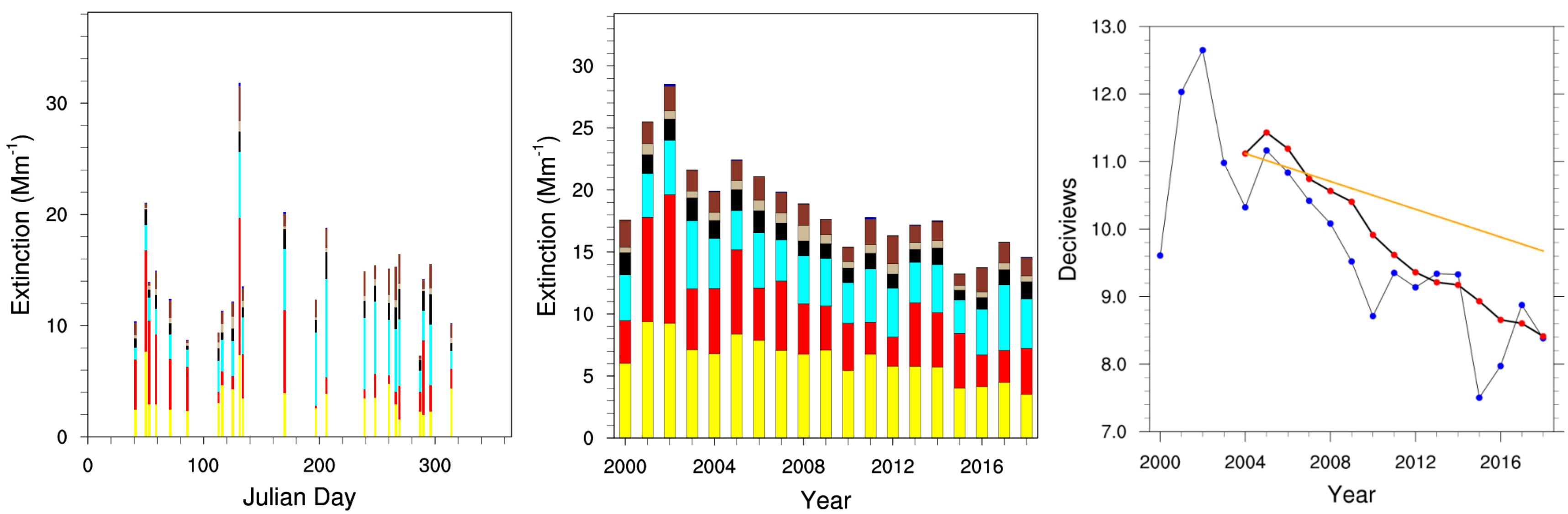
Redwood National Park, CA



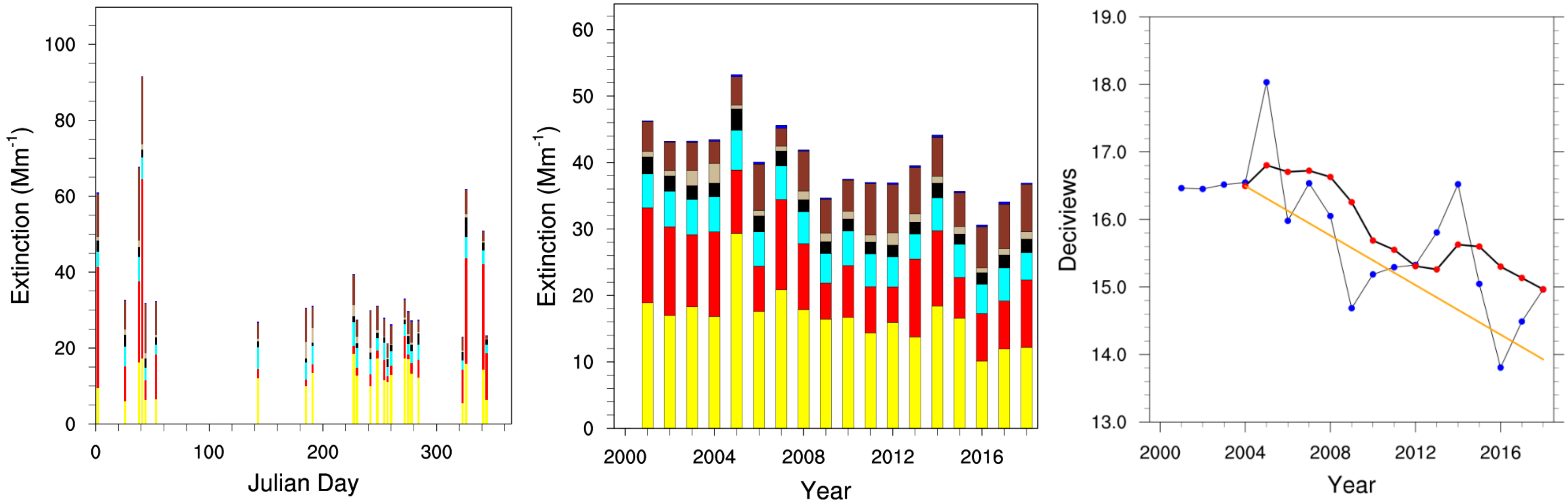
Cape Romain National Wildlife Refuge, SC



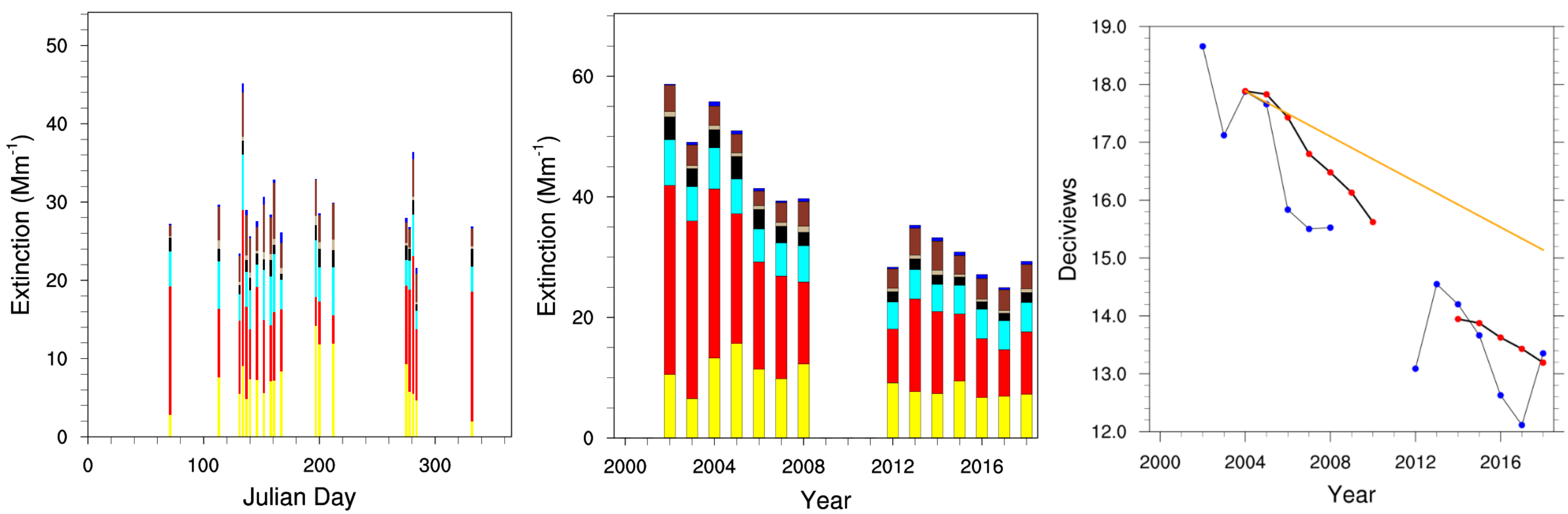
Rocky Mountain National Park, CO



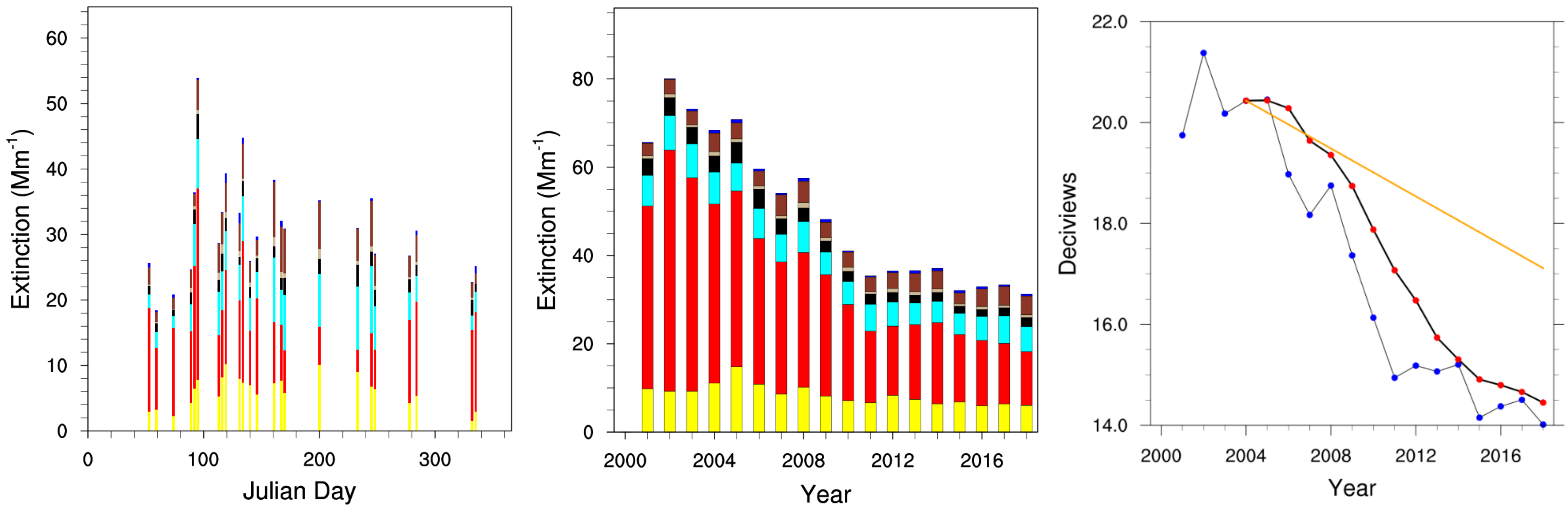
Salt Creek, NM



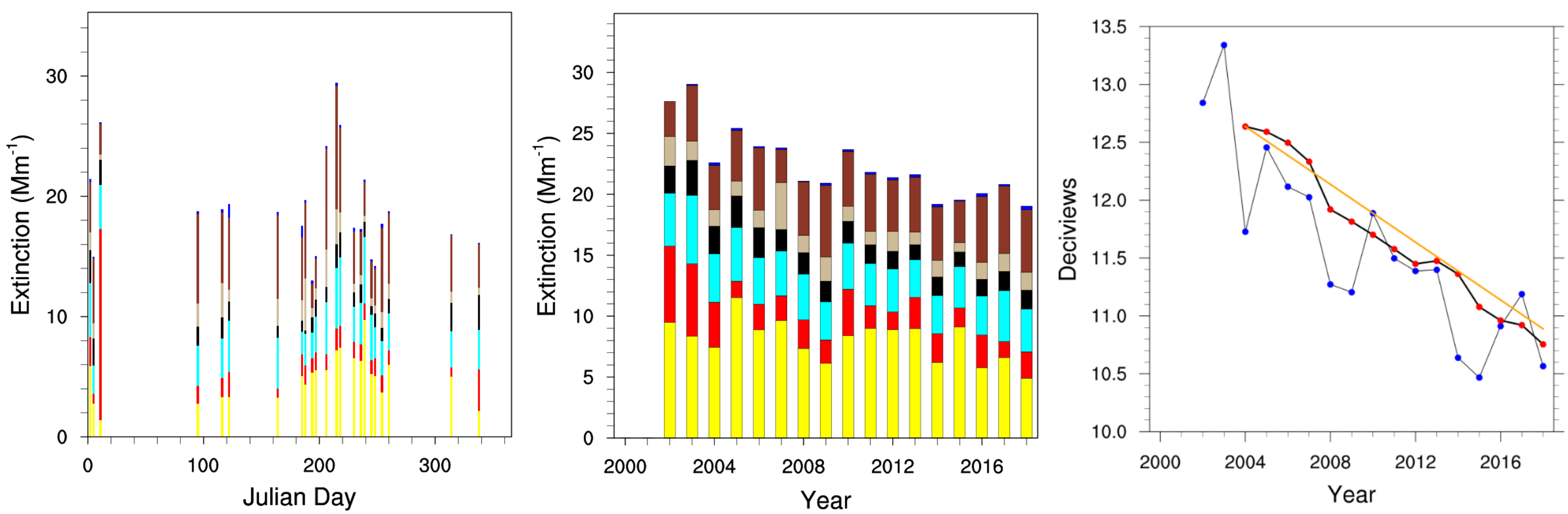
San Gabriel, CA



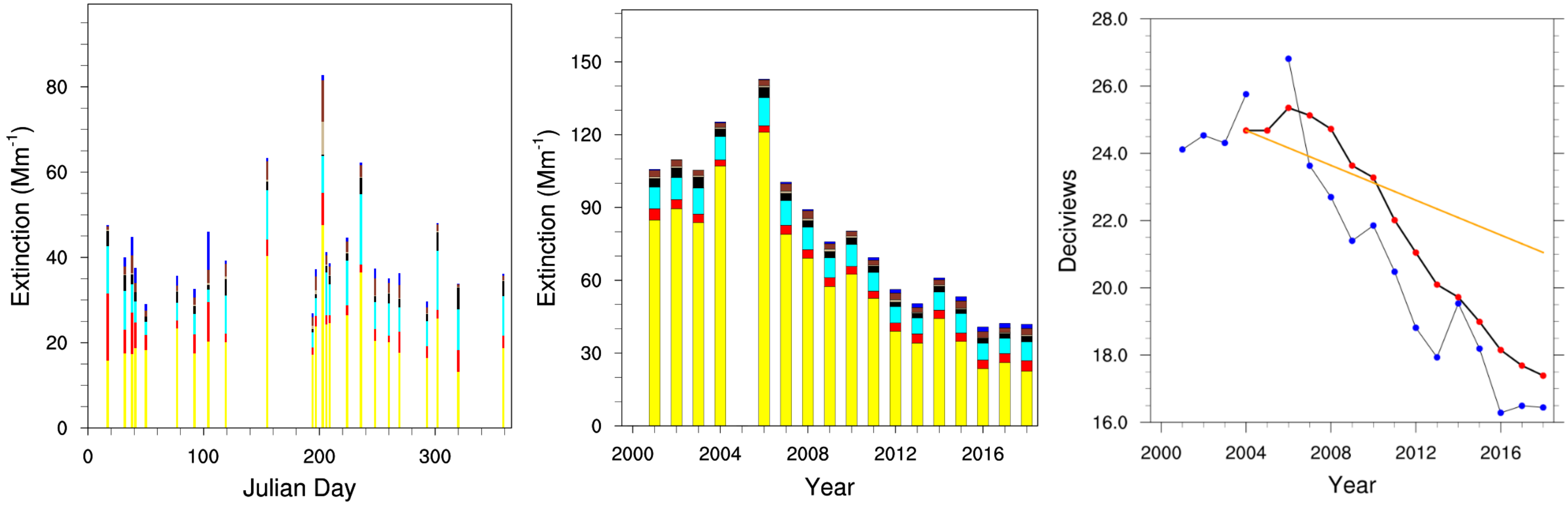
San Gorgonio Wilderness, CA



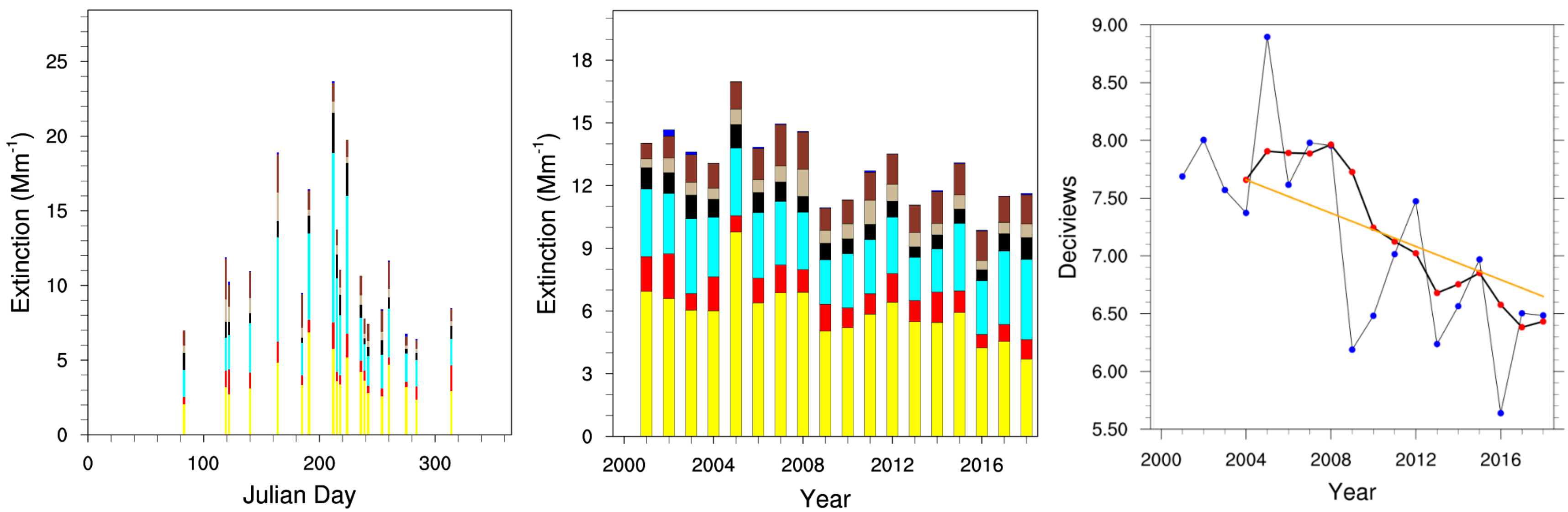
Saguaro National Monument, AZ



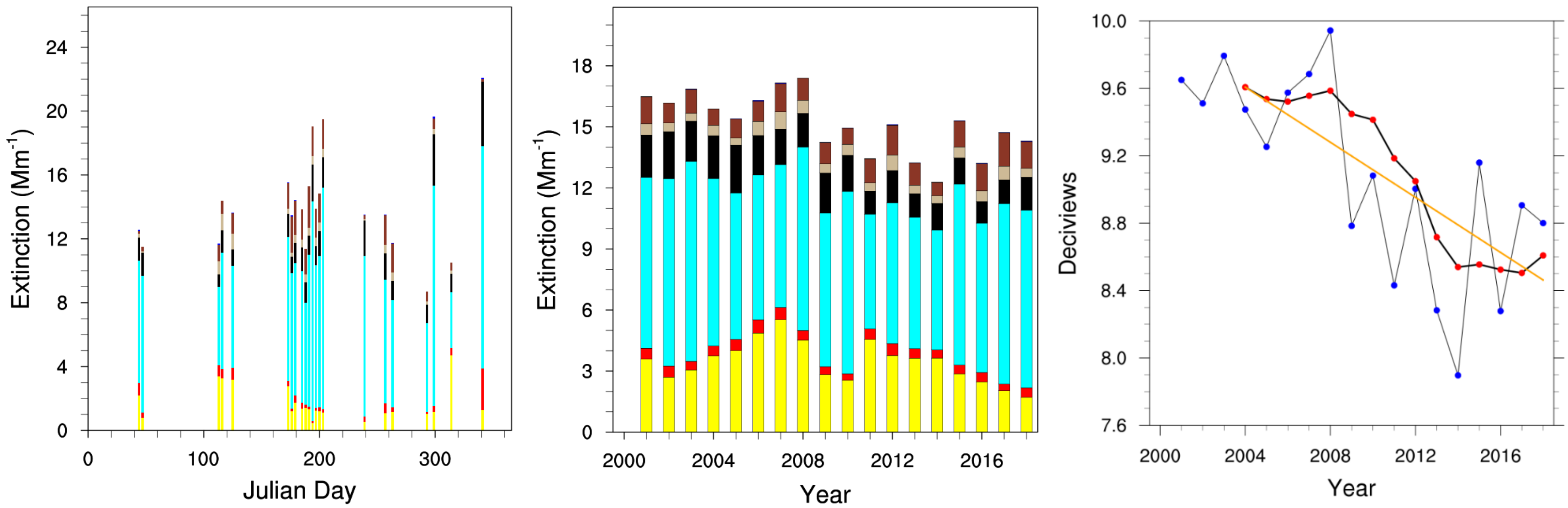
St. Marks, FL



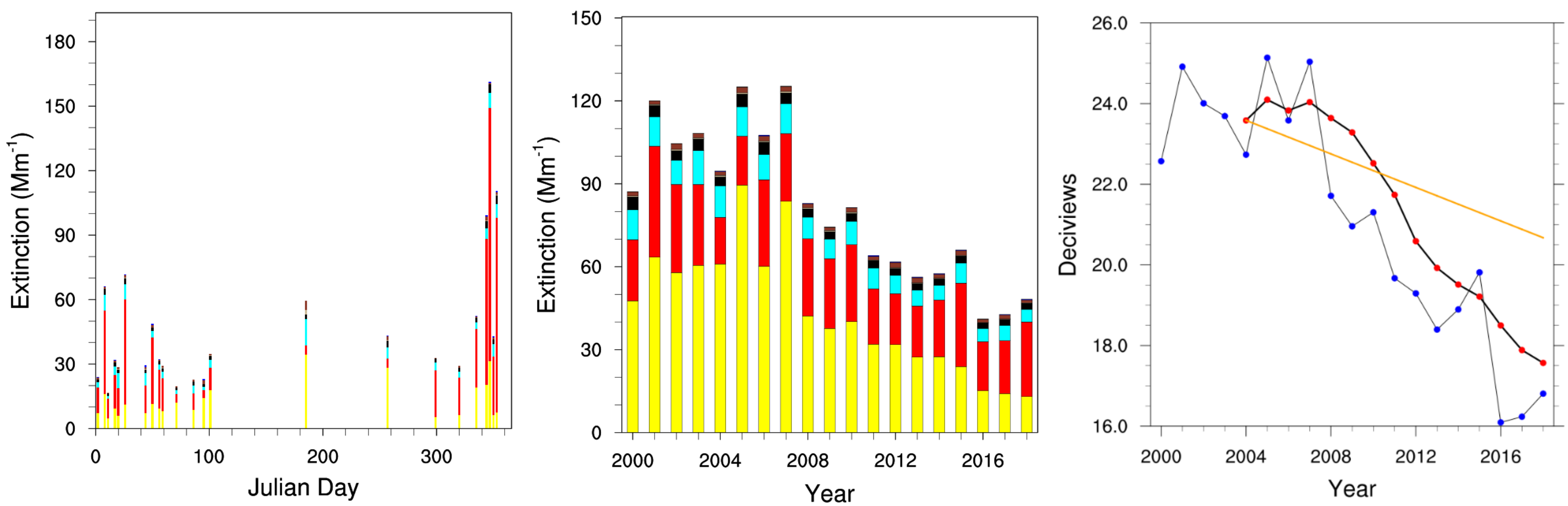
San Pedro Parks, NM



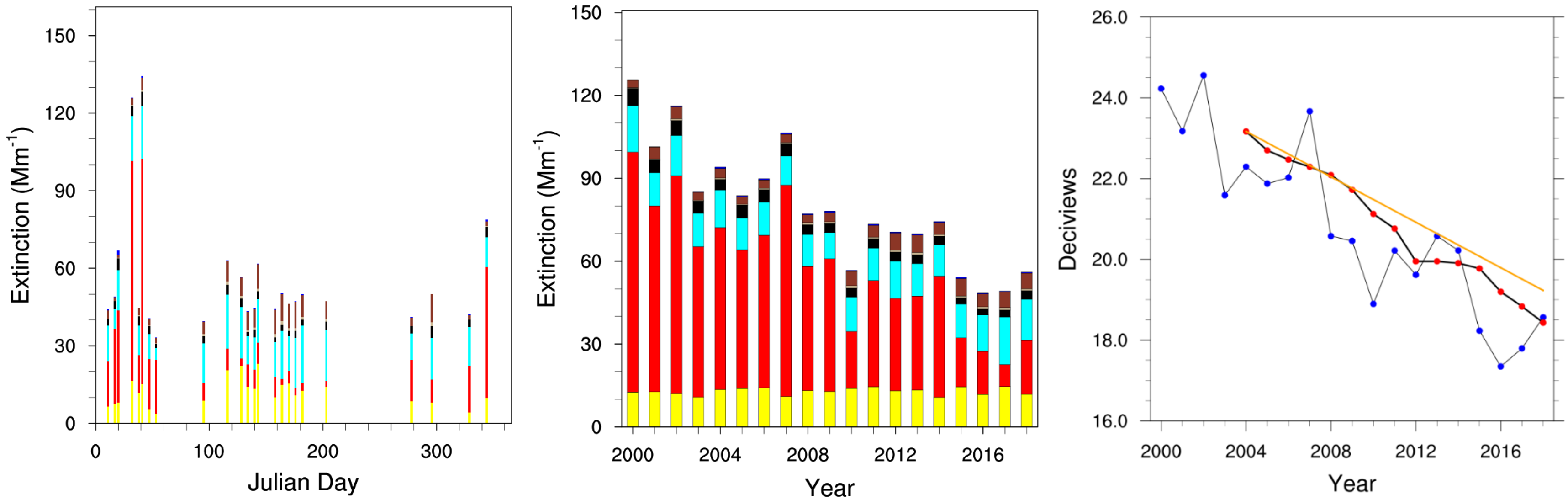
Sawtooth National Forest, ID



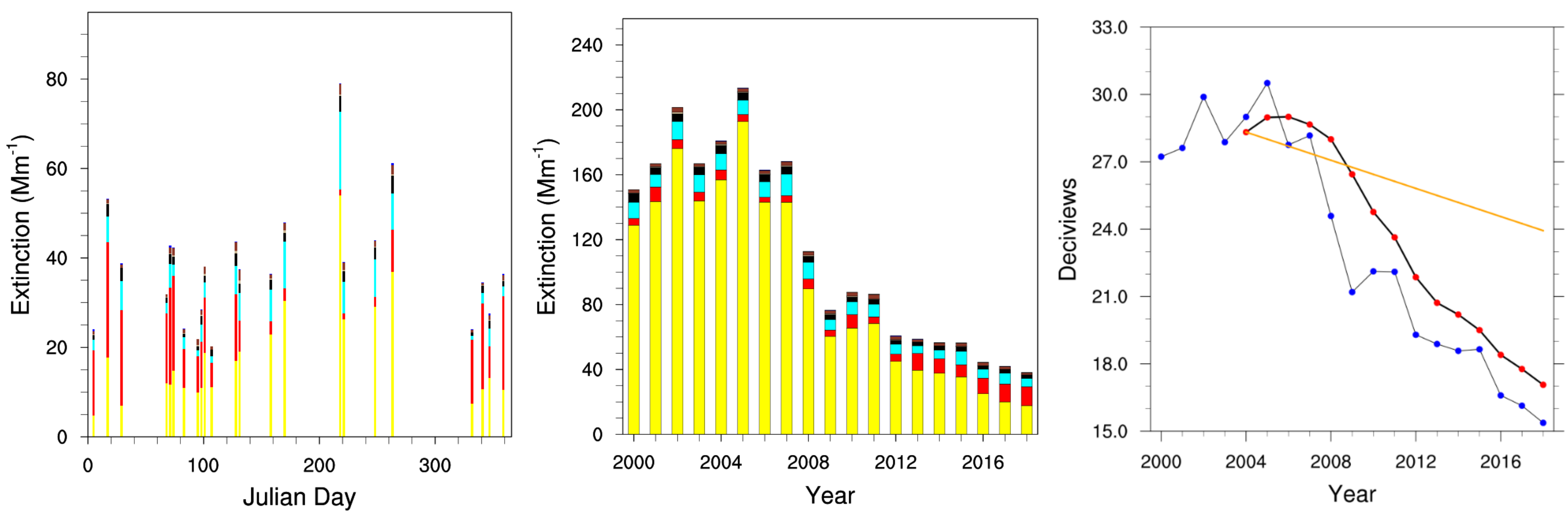
Seney, MI



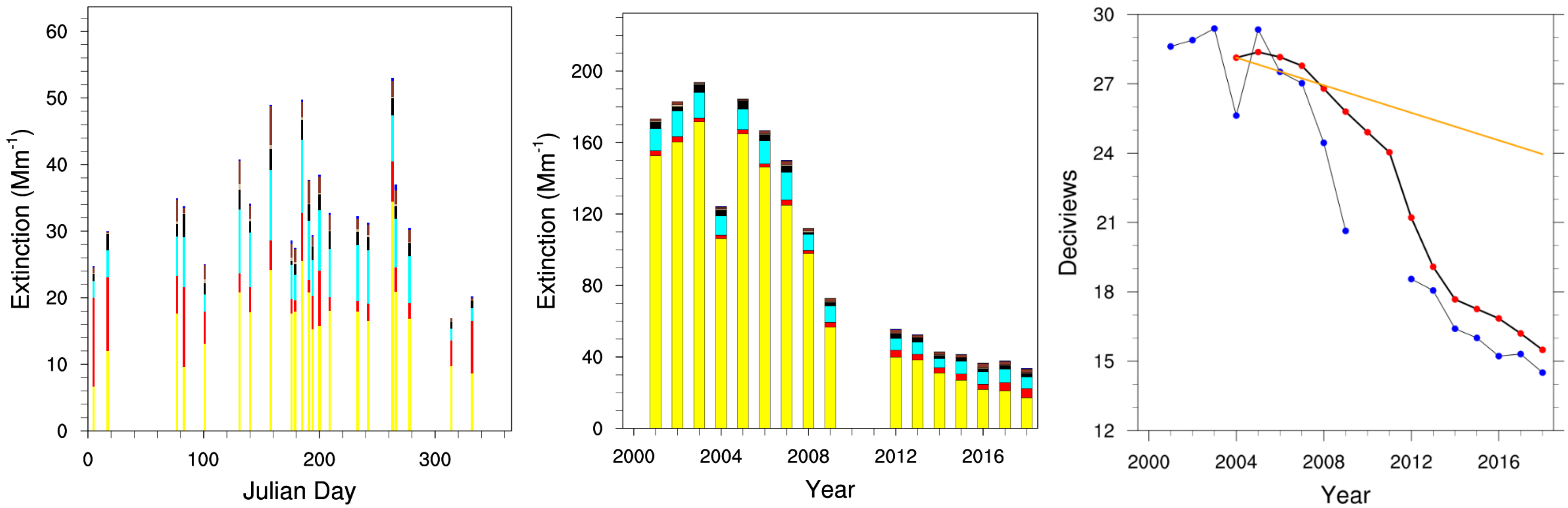
Sequoia National Park, CA



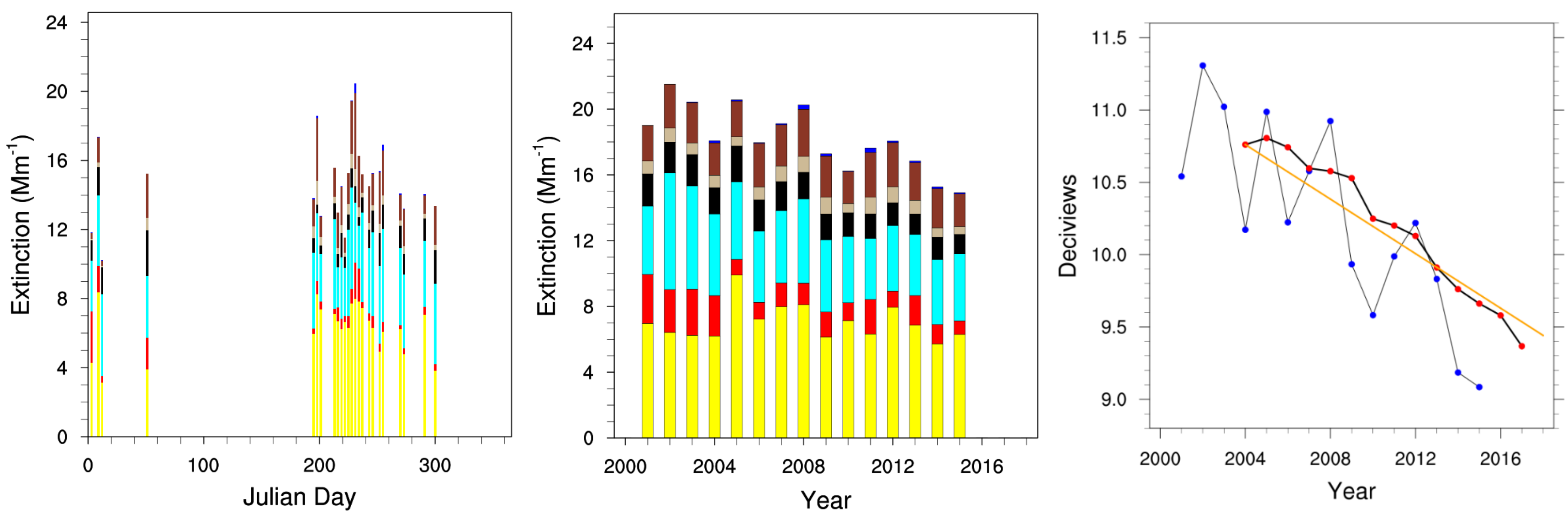
Shenandoah National Park, VA



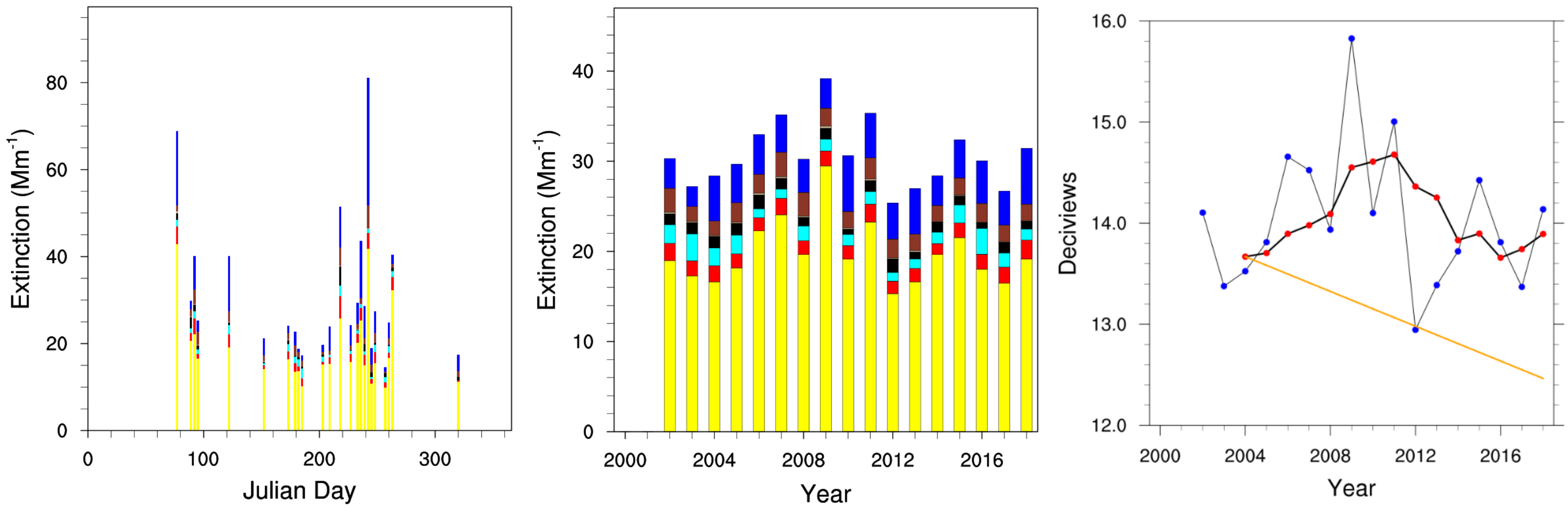
Shining Rock Wilderness, NC



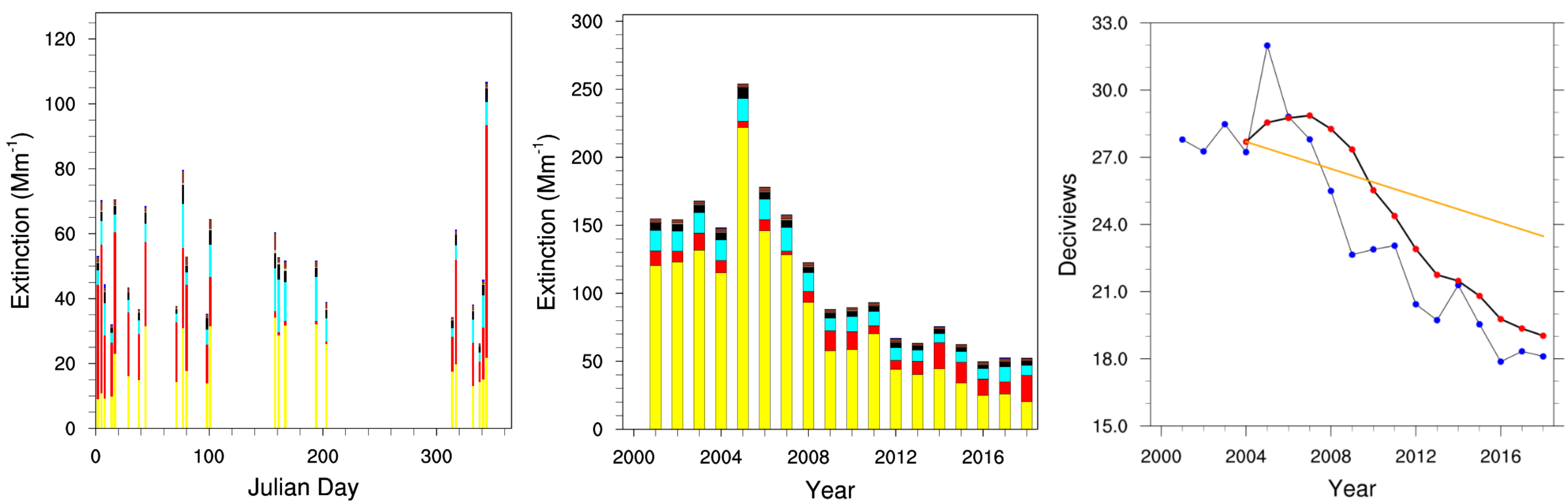
Sierra Ancha, AZ (2015 data shown on figure to the left)



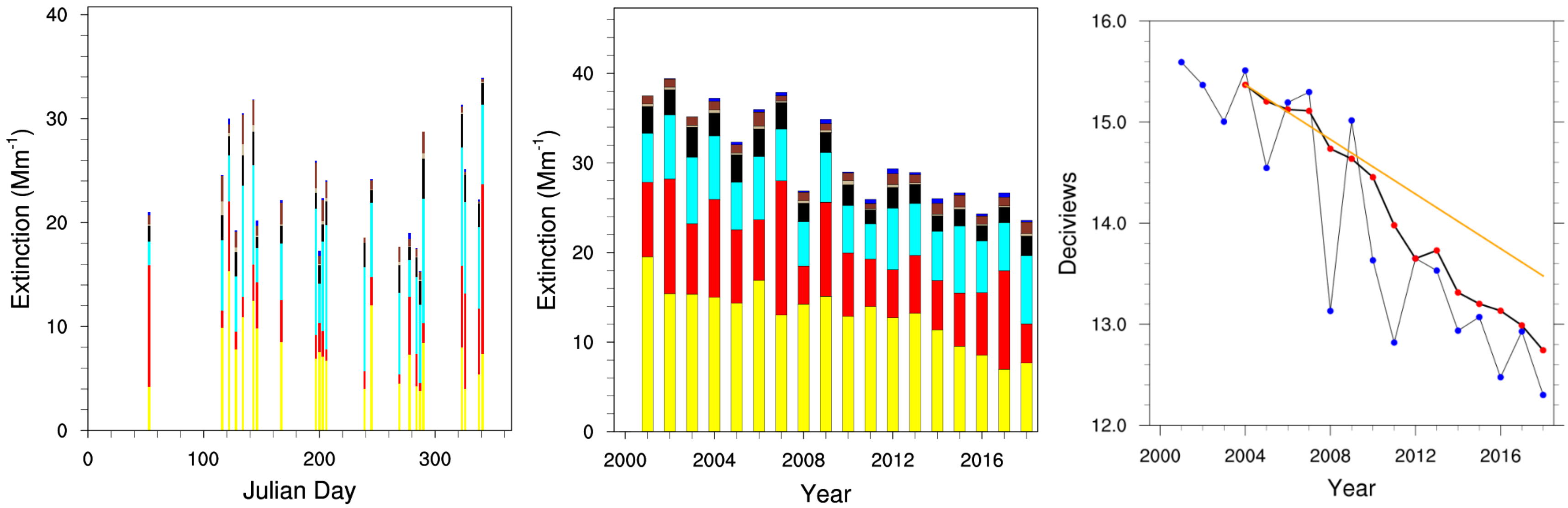
Simeonof, AK



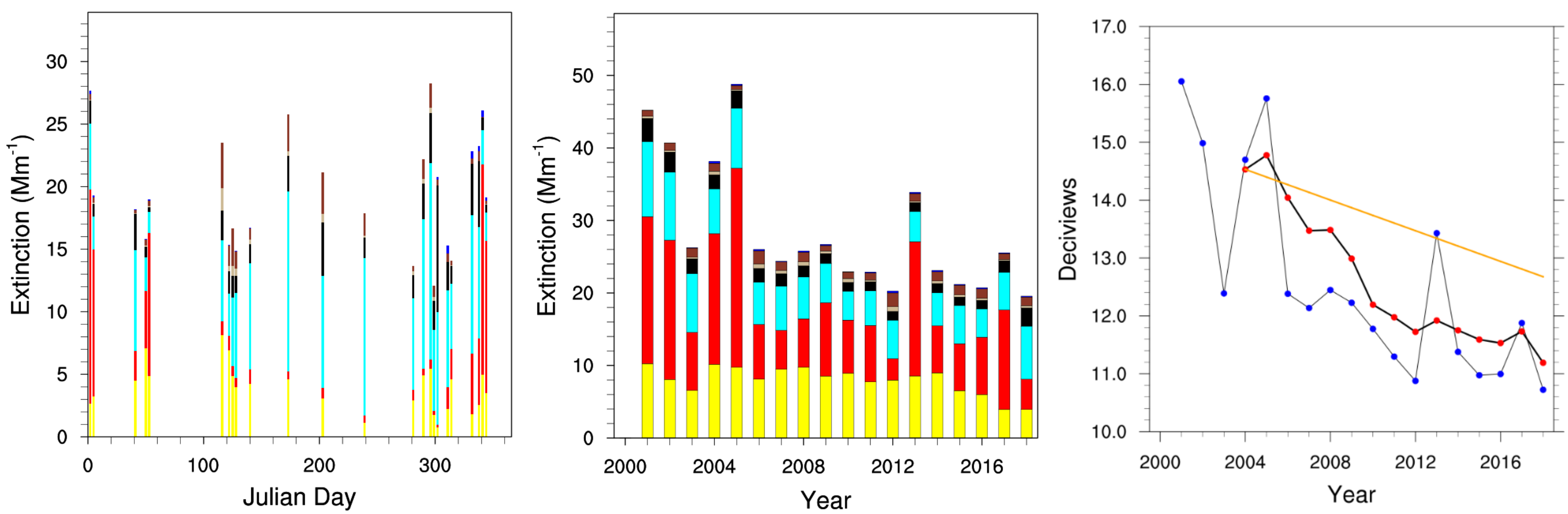
Sipsey Wilderness, AL



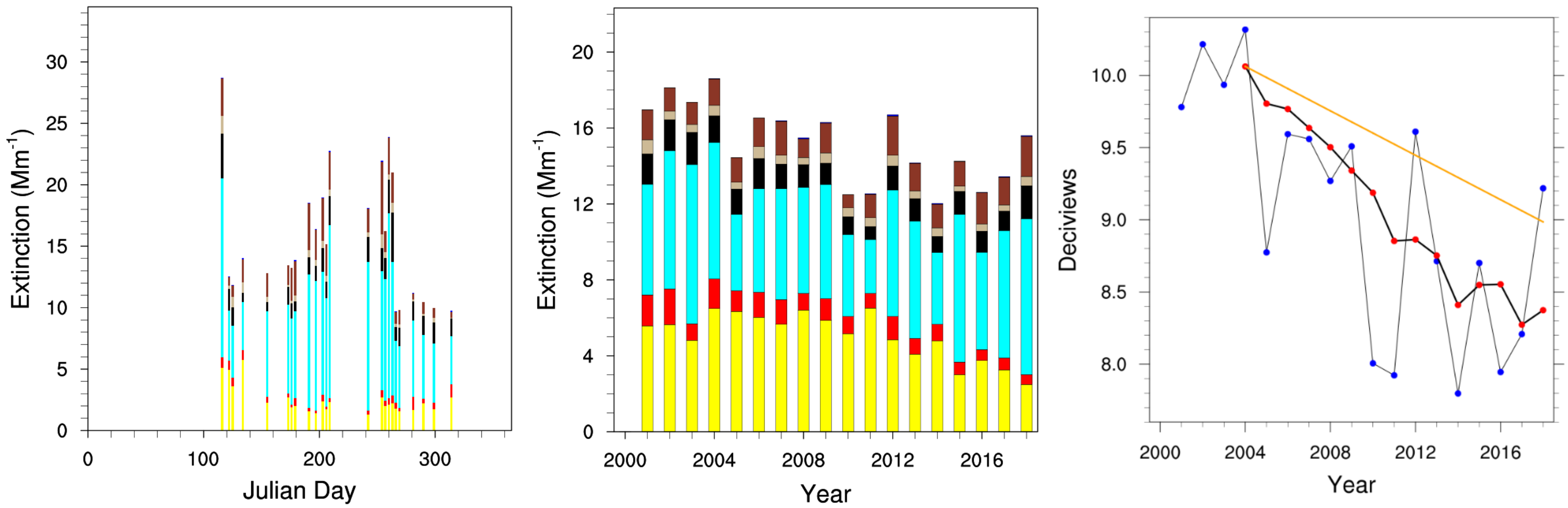
Snoqualmie Pass, WA



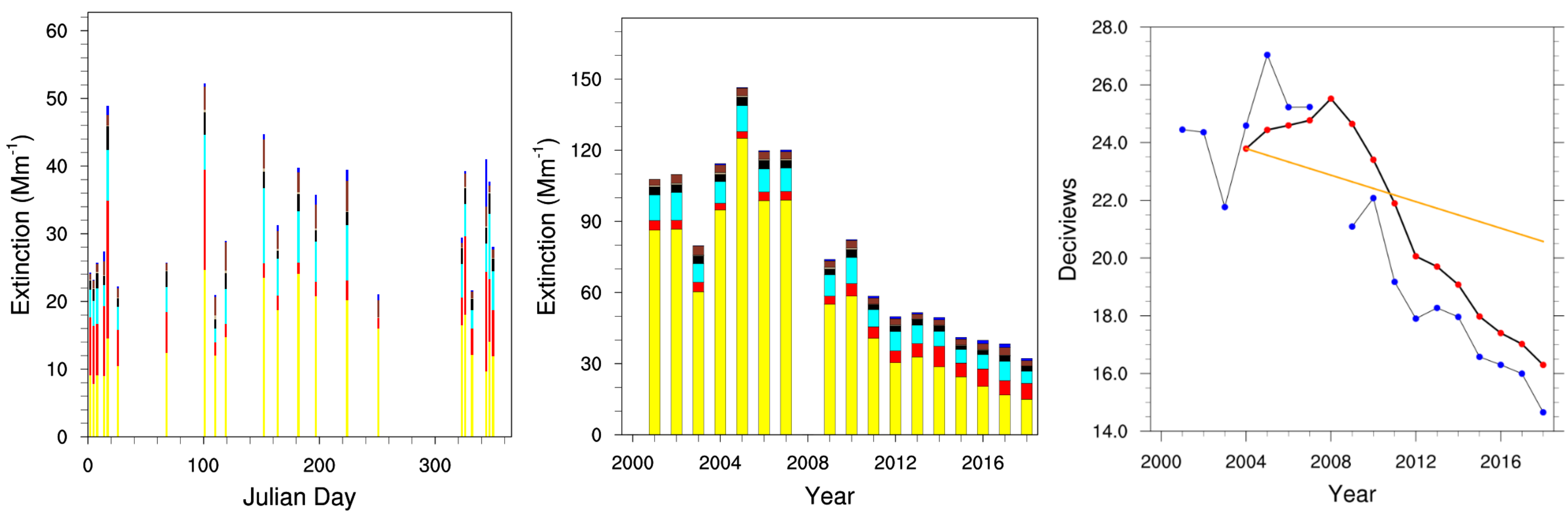
Starkey, OR



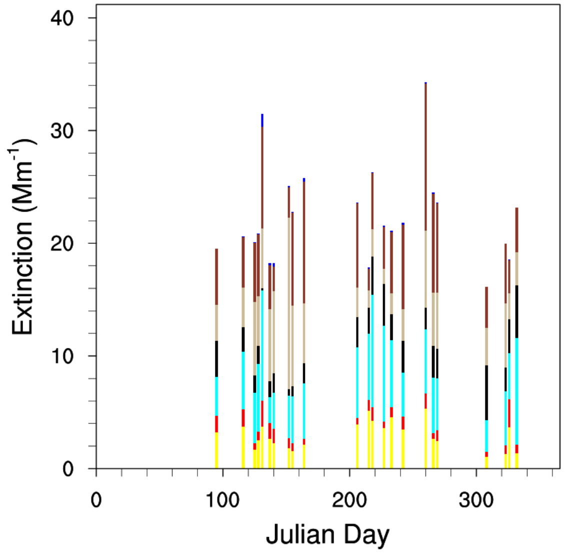
Sula Peak, MT

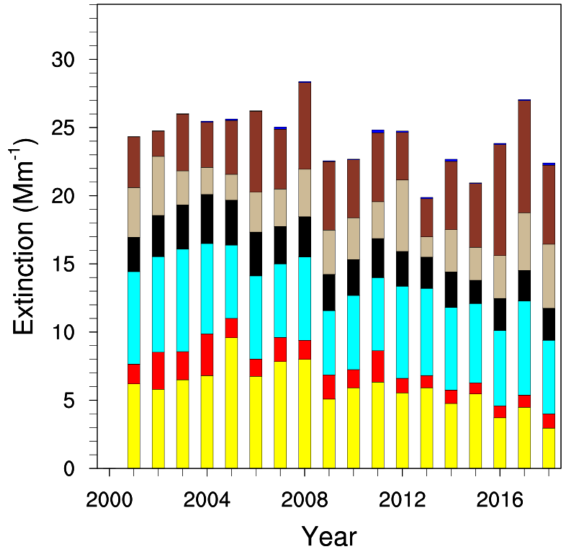


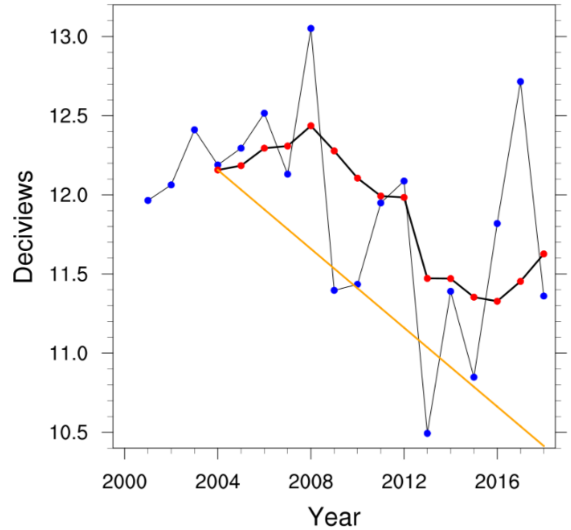
Swanquarter, NC



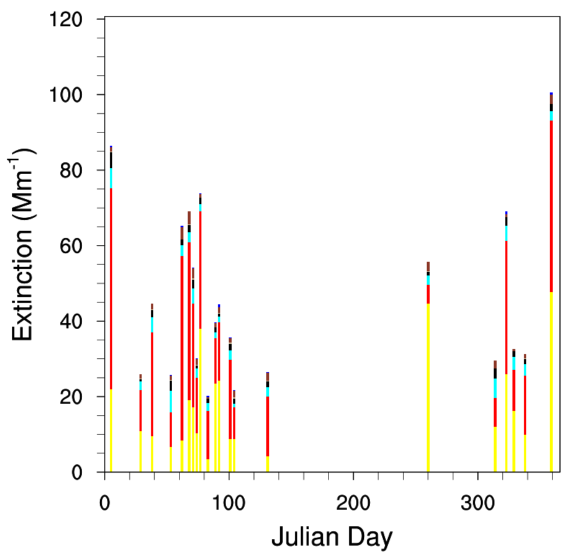
Sycamore Canyon, AZ (combined SYCA1 and SYCA2 starting 10-18-15)

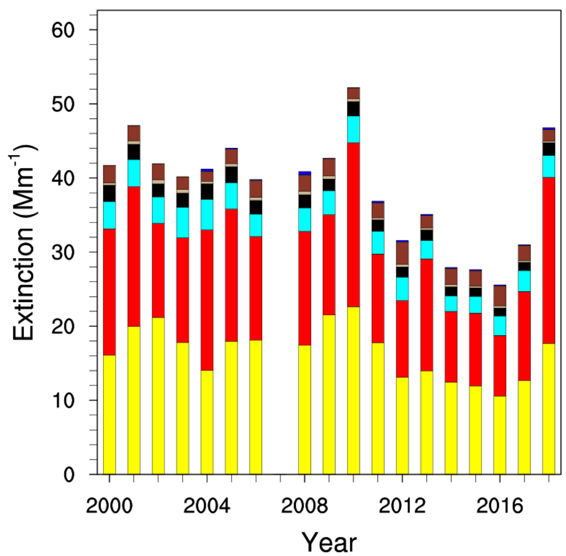


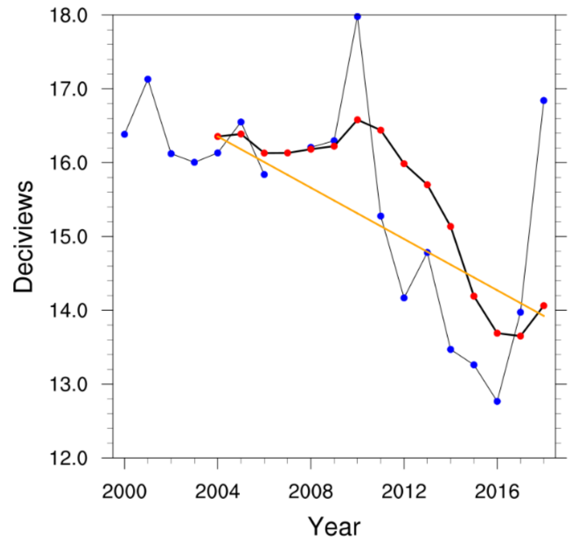




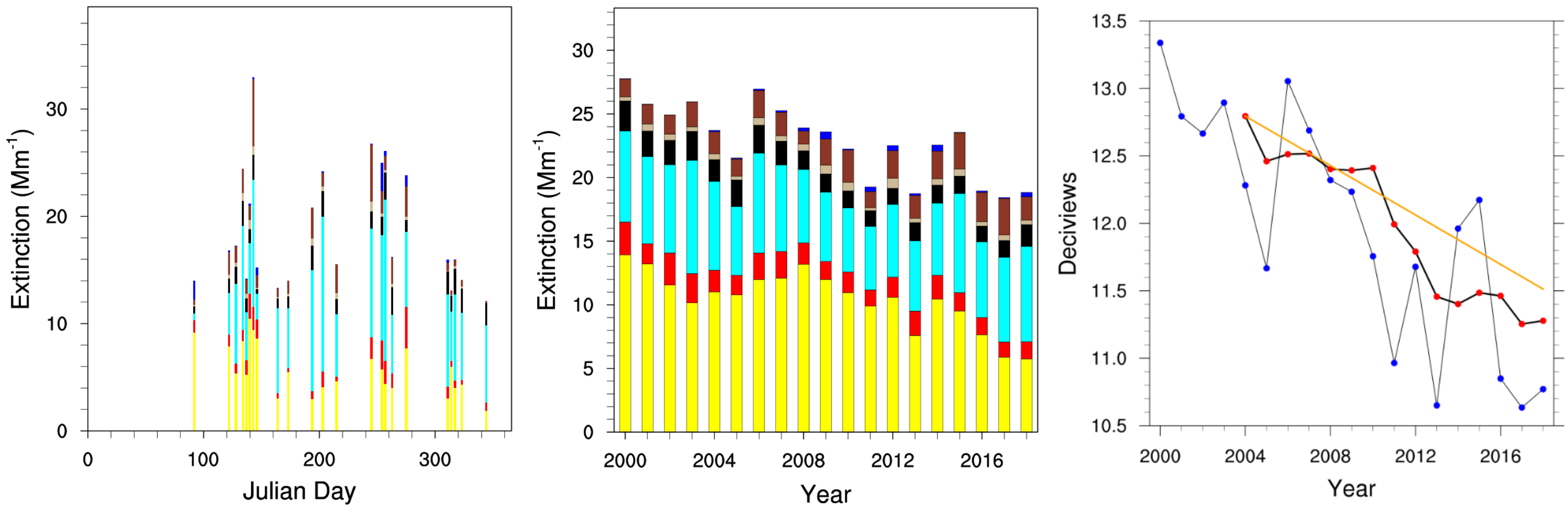
Theodore Roosevelt, ND



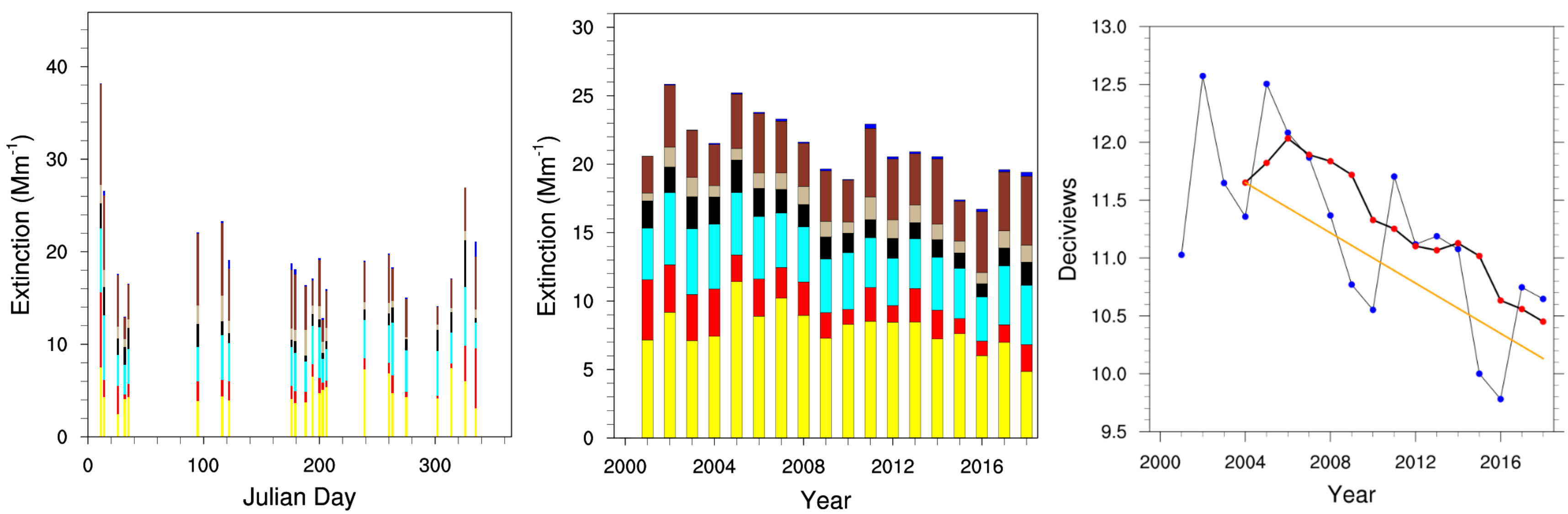




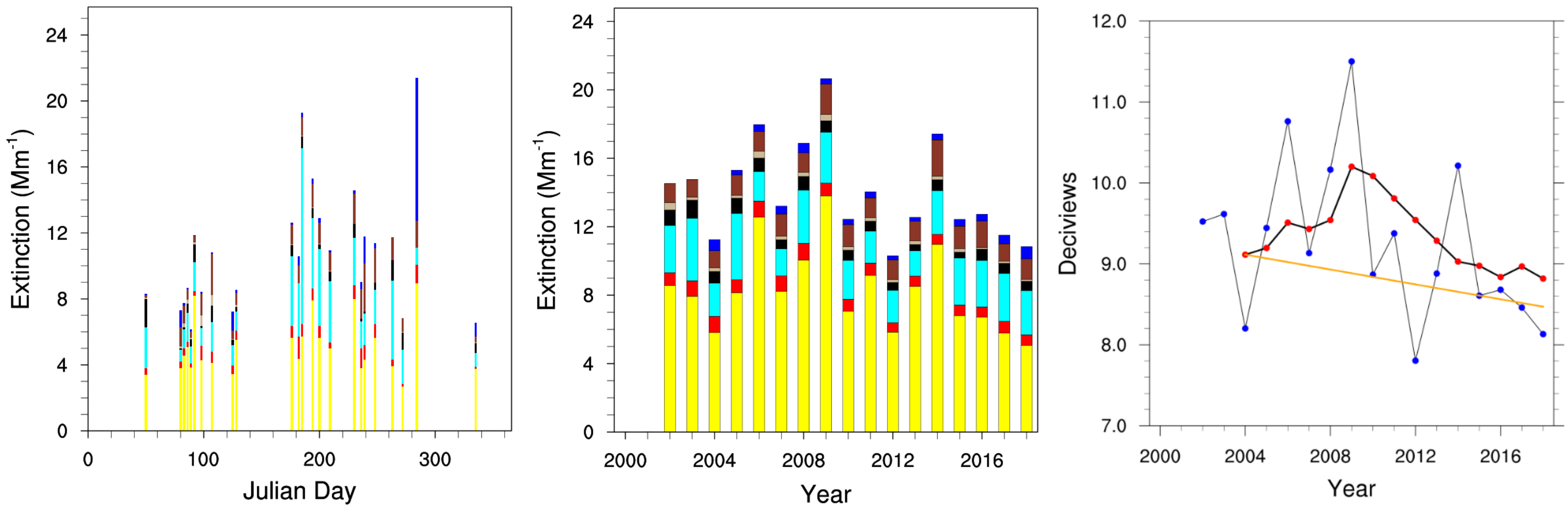
Three Sisters Wilderness, OR



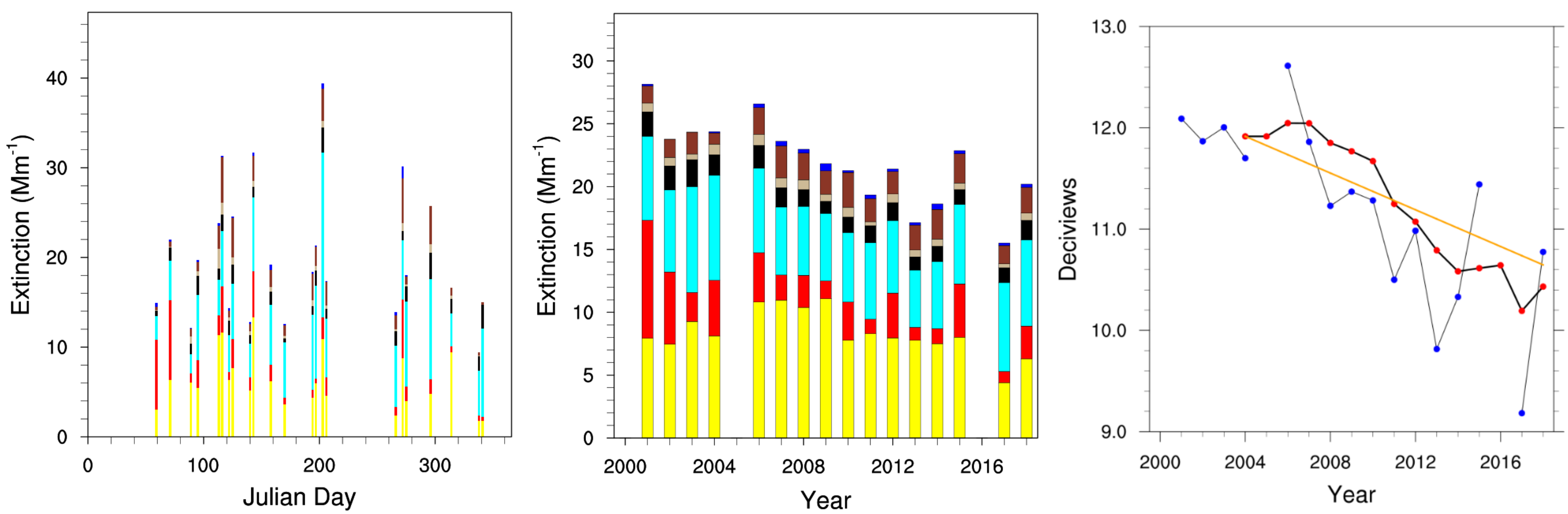
Tonto National Monument, AZ



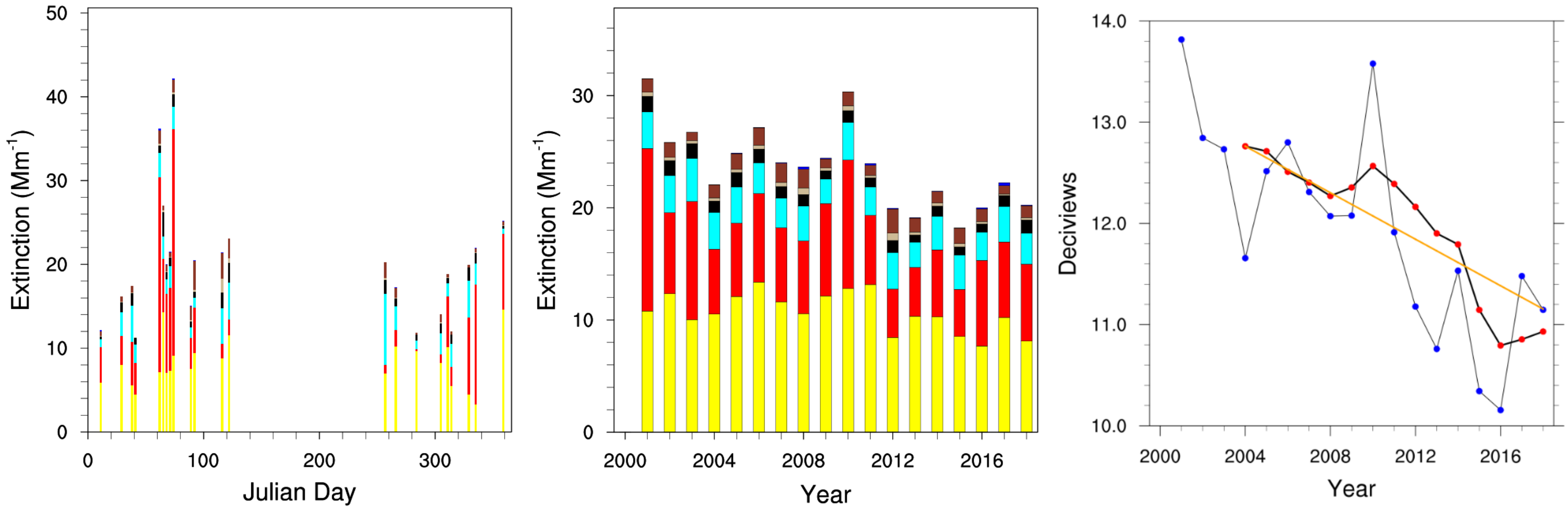
Trapper Creek, AK



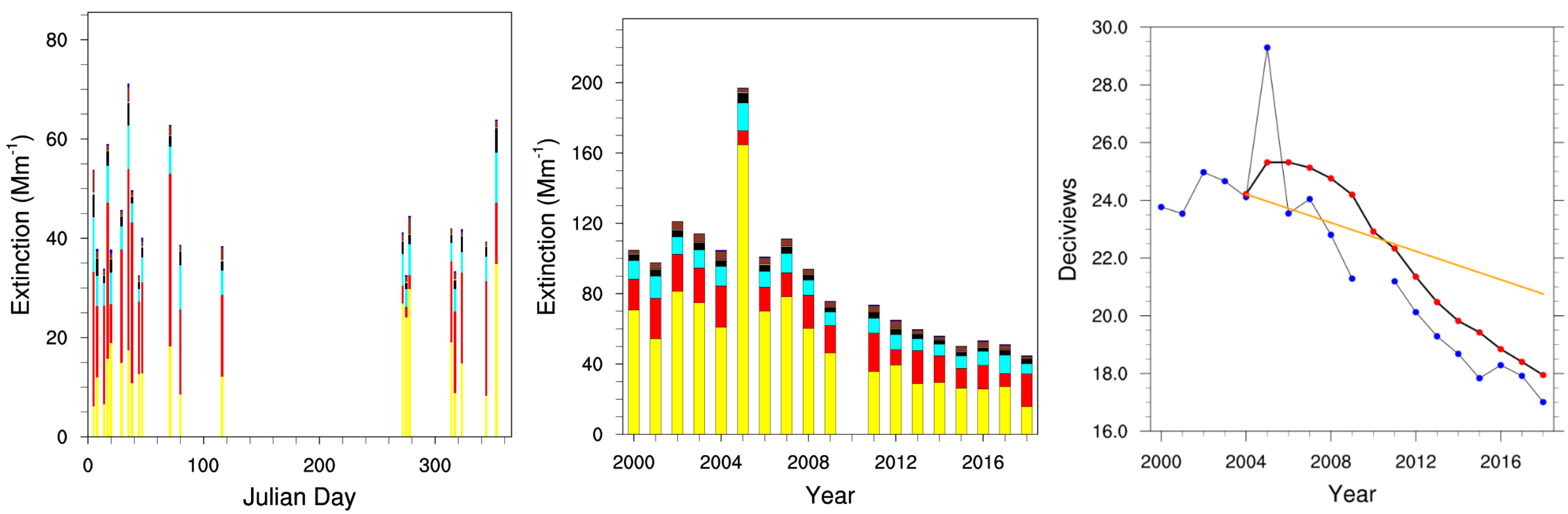
Trinity, CA



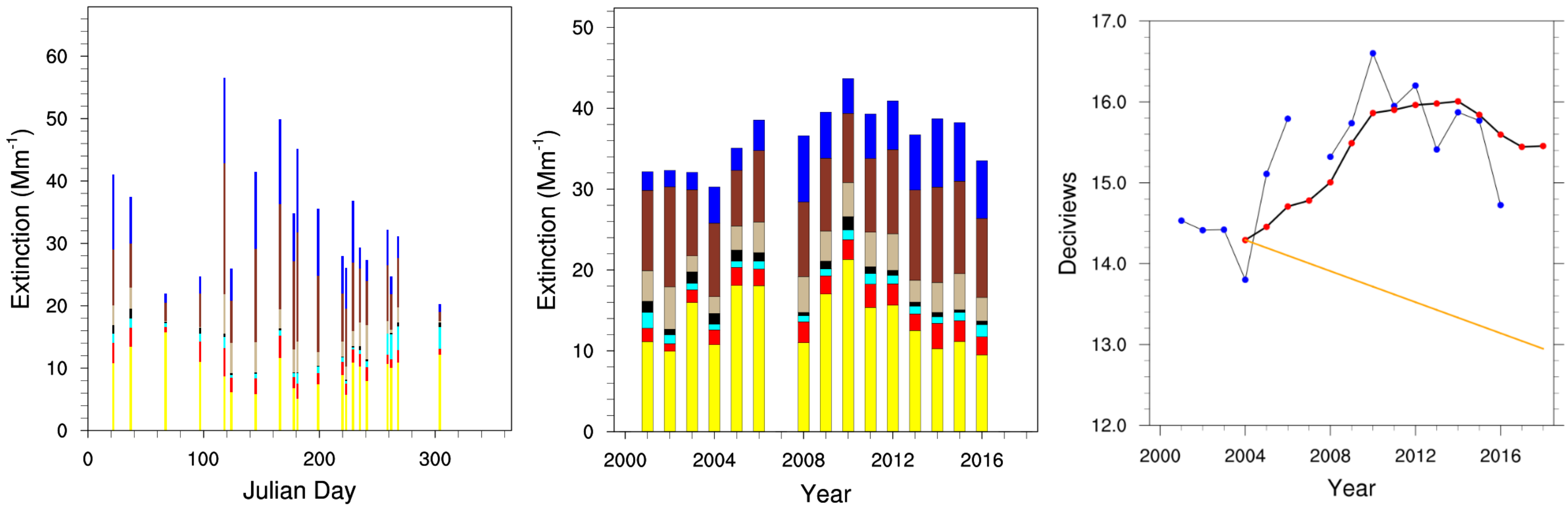
UL Bend, MT



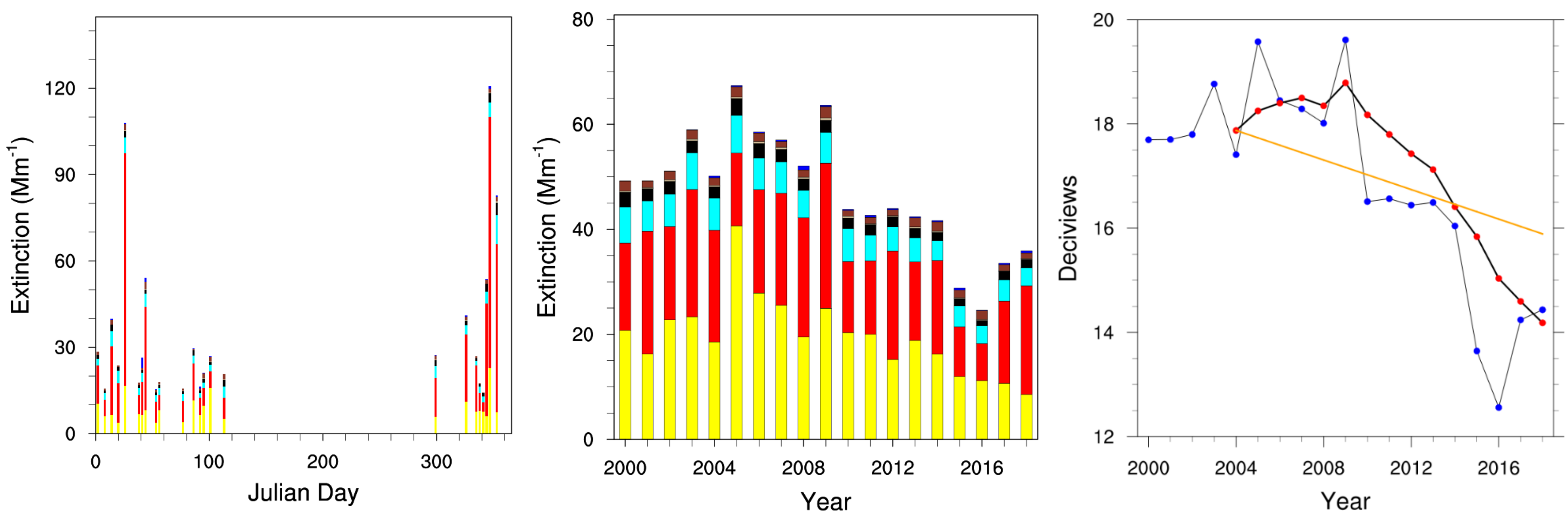
Upper Buffalo Wilderness, AR



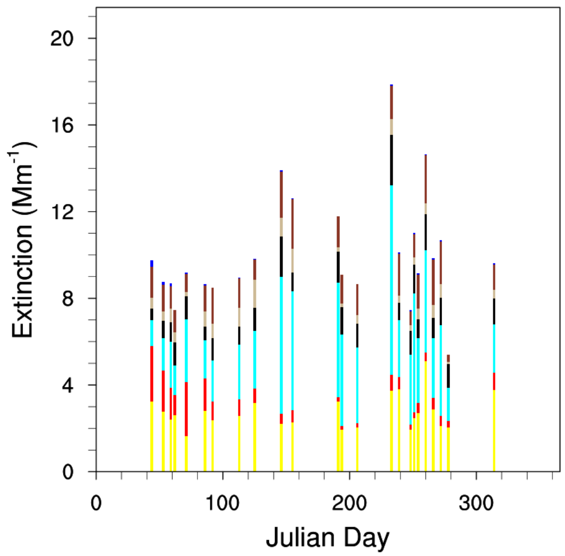
Virgin Islands National Park, VI (2016 data shown on figure to the left)

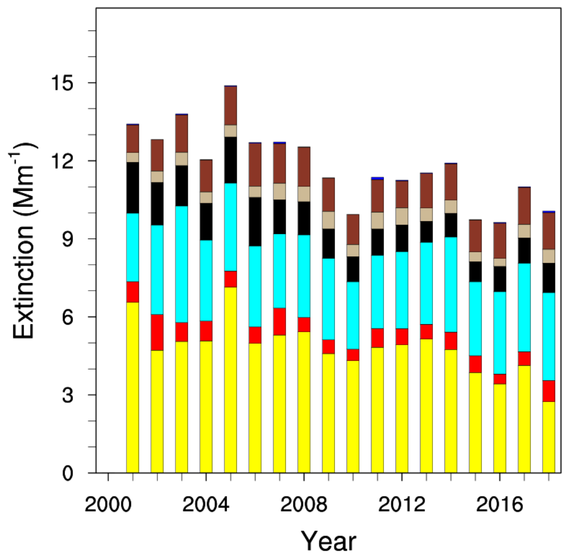


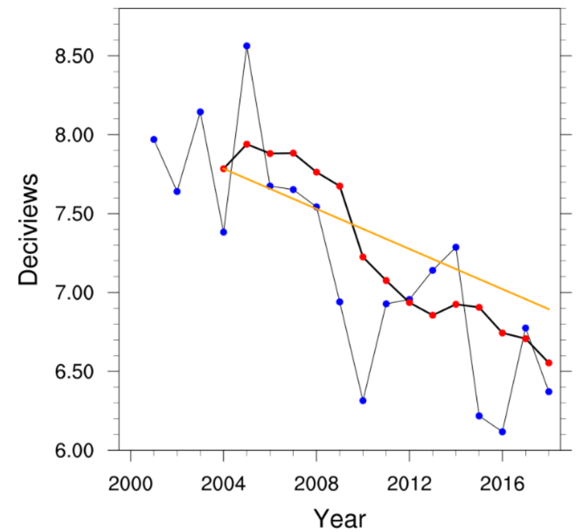
Voyageurs National Park, MN



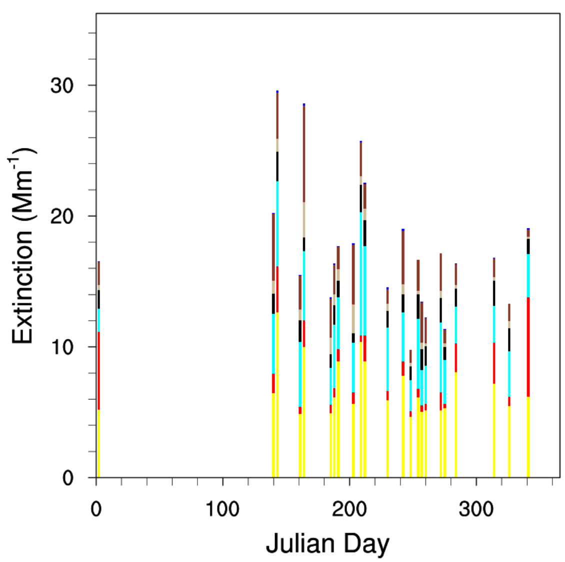
Weminuche Wilderness, CO

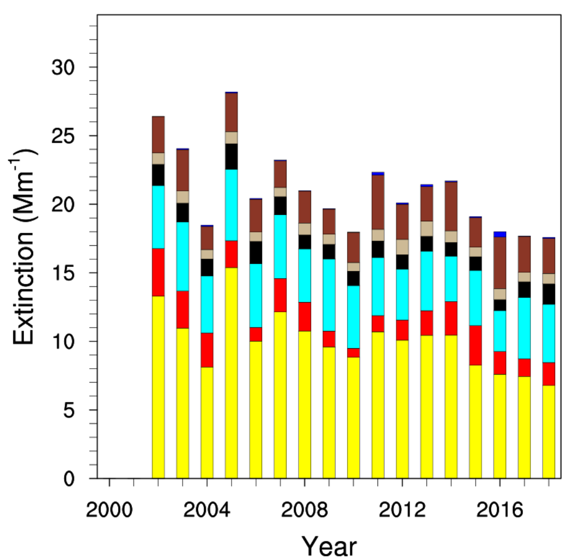


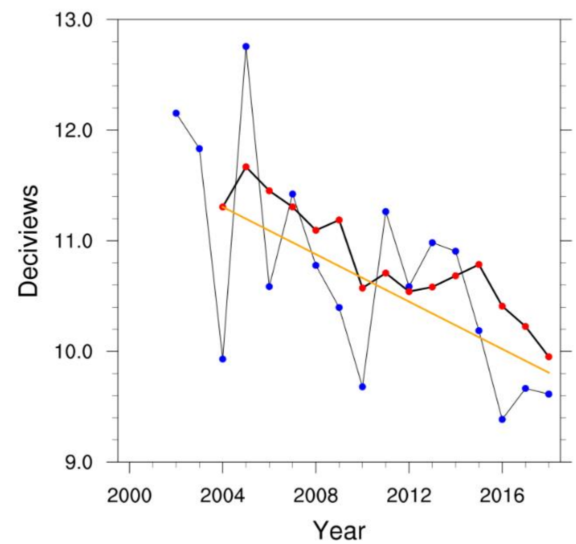




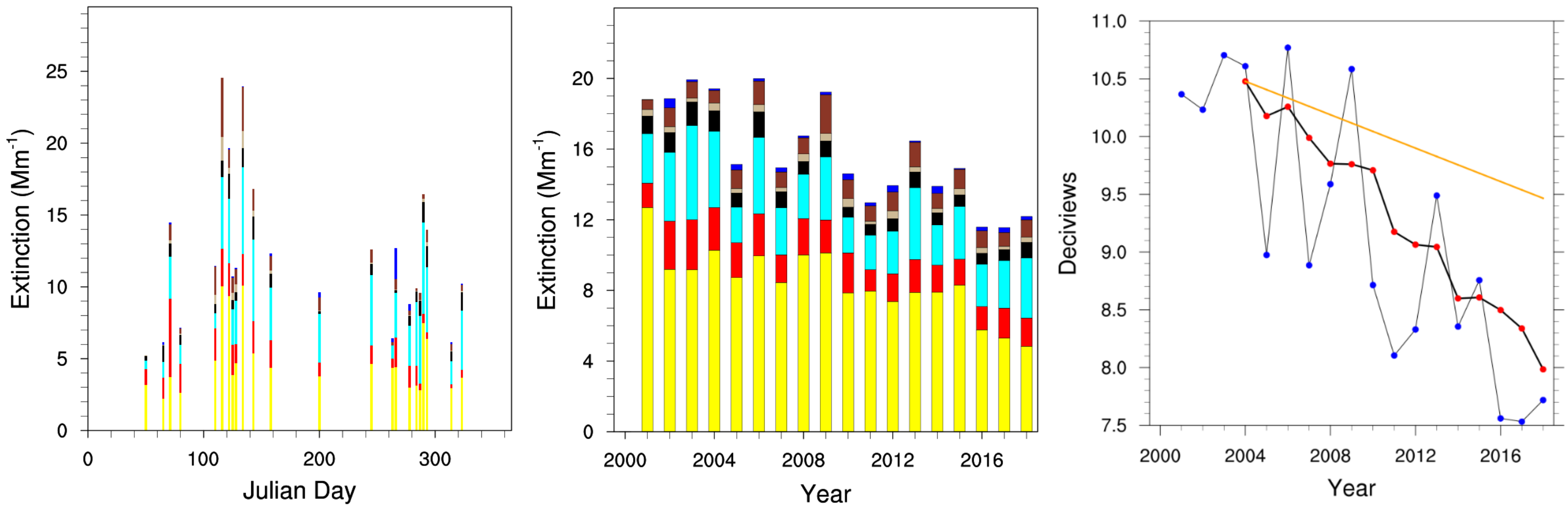
White Mountain, NM



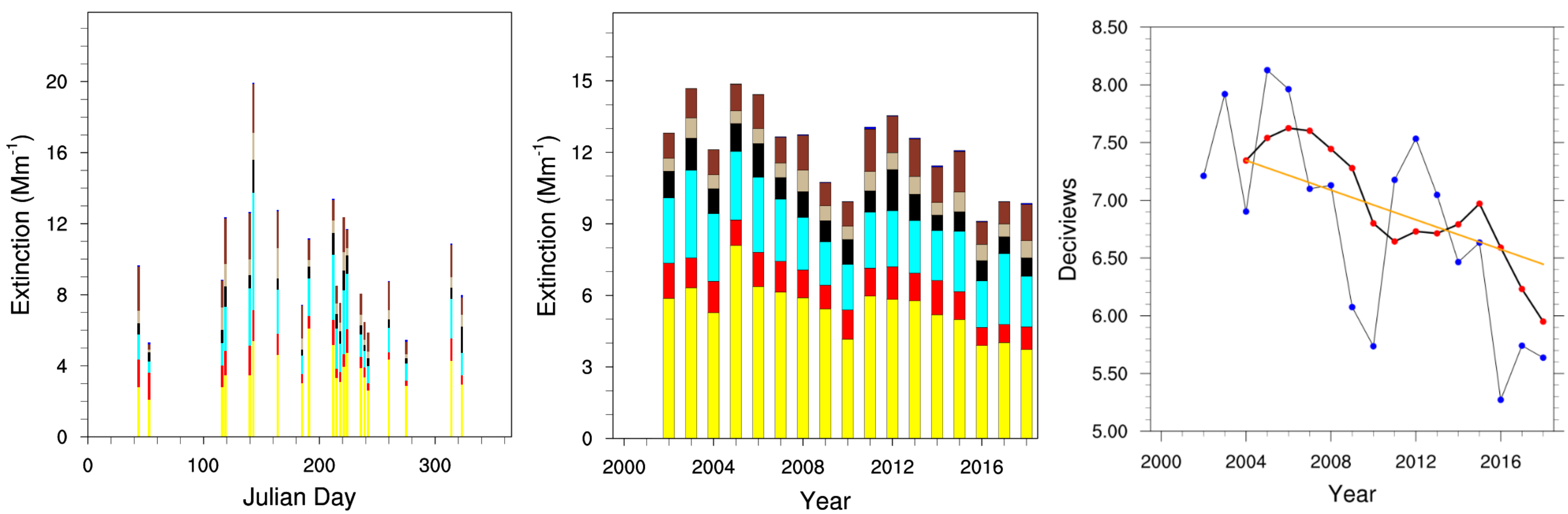




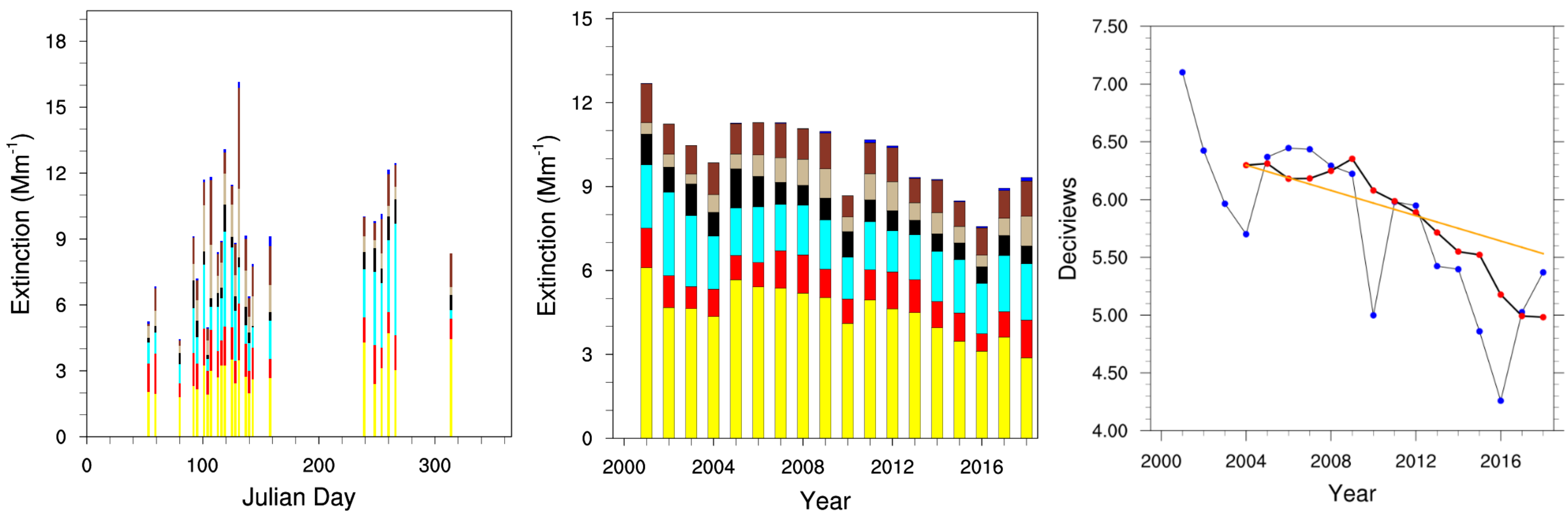
White Pass, WA



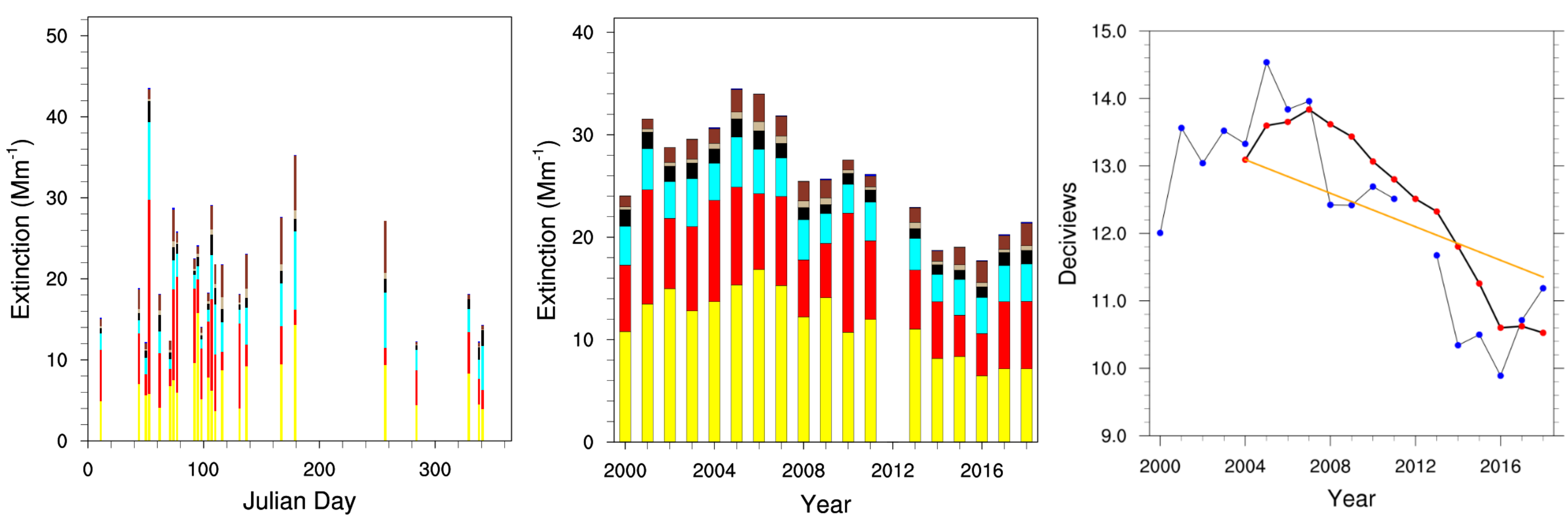
Wheeler Peak, NM



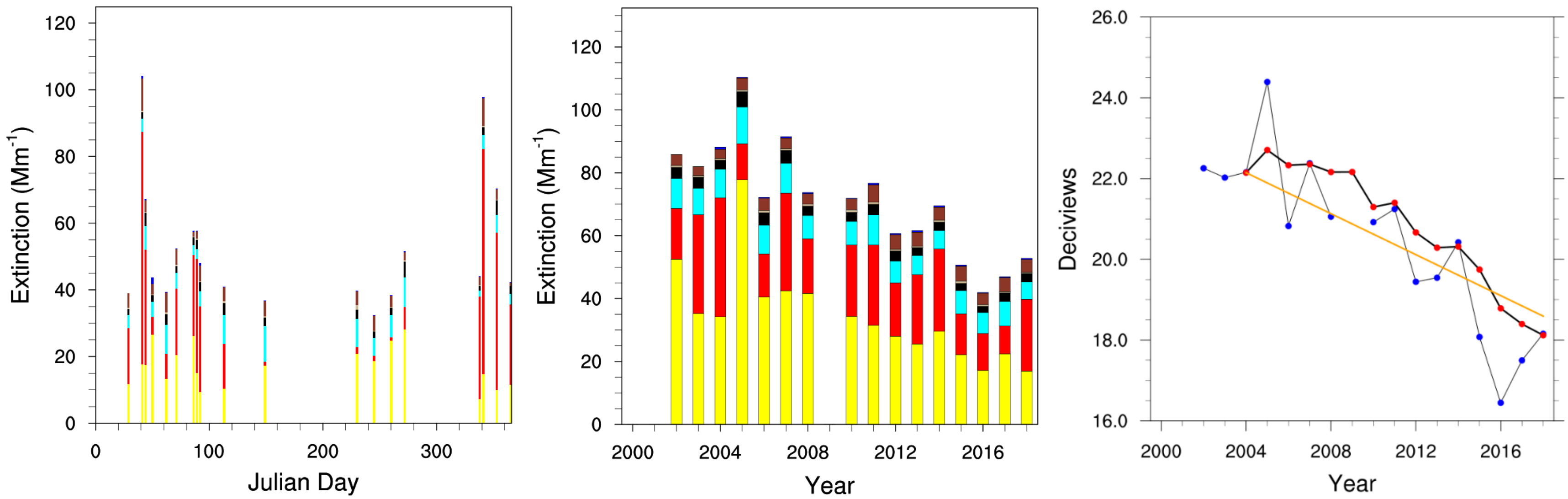
White River National Forest, CO



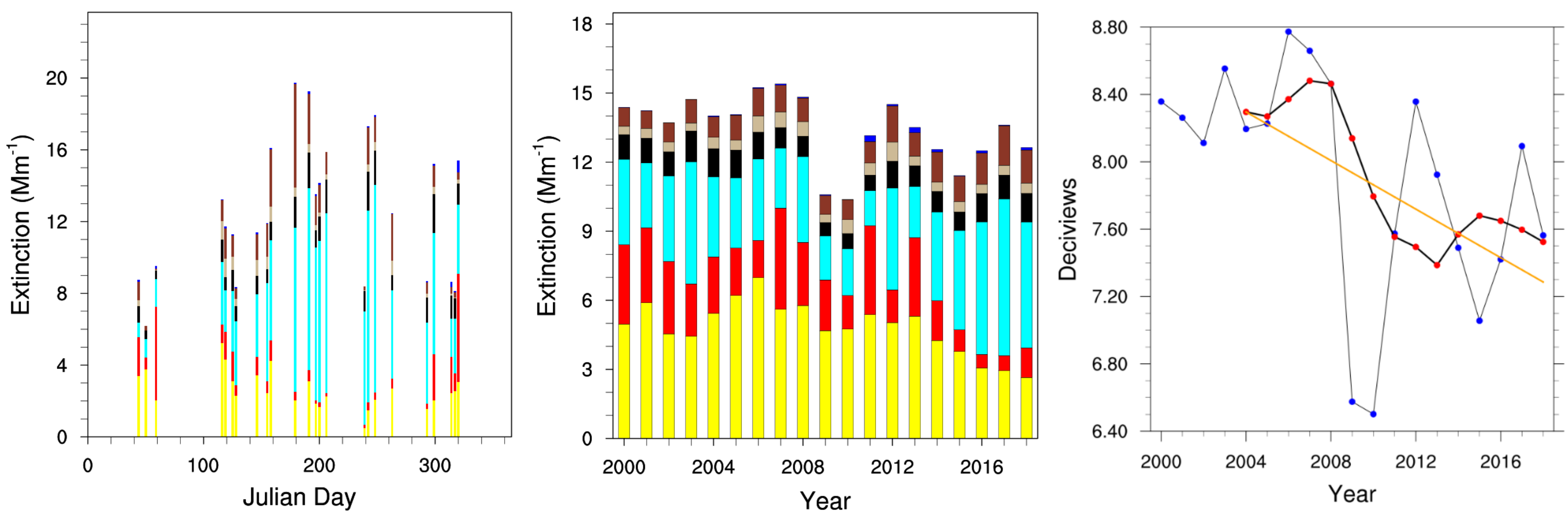
Wind Cave, SD



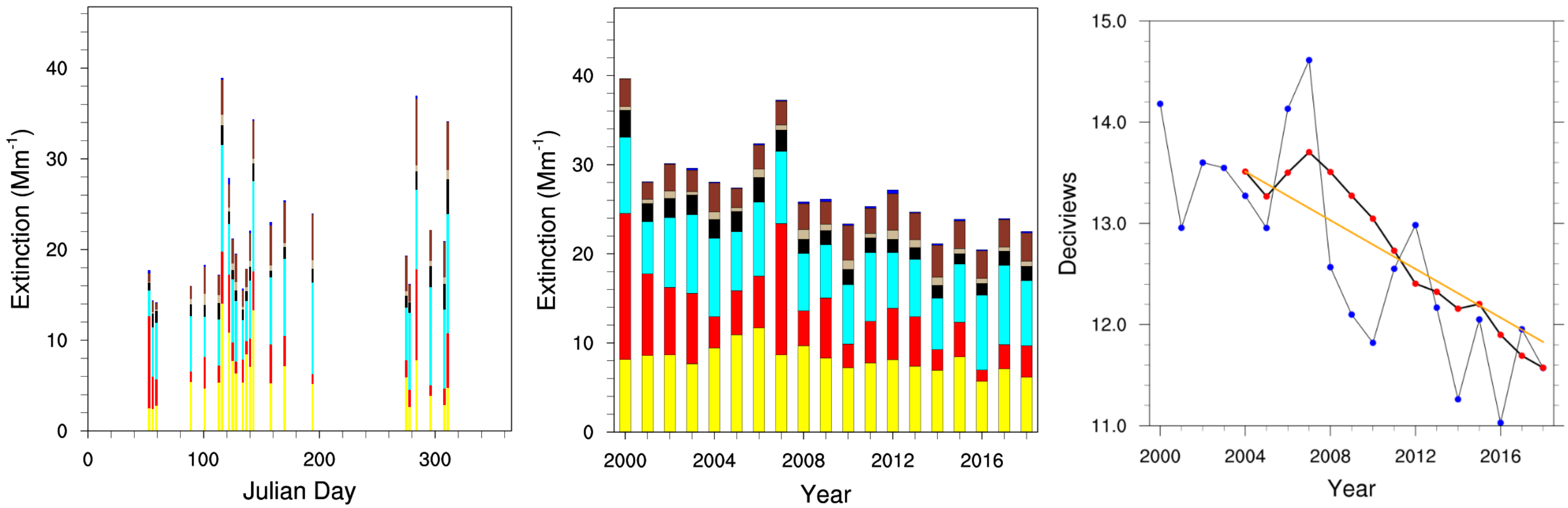
Wichita Mountains, OK



Yellowstone National Park, WY



Yosemite National Park, CA



Zion National Park, UT (combined ZION1 and ZICA1 starting 01/01/04)