

# Role of Clouds in Moderate Resolution Land Observations: Western US Results

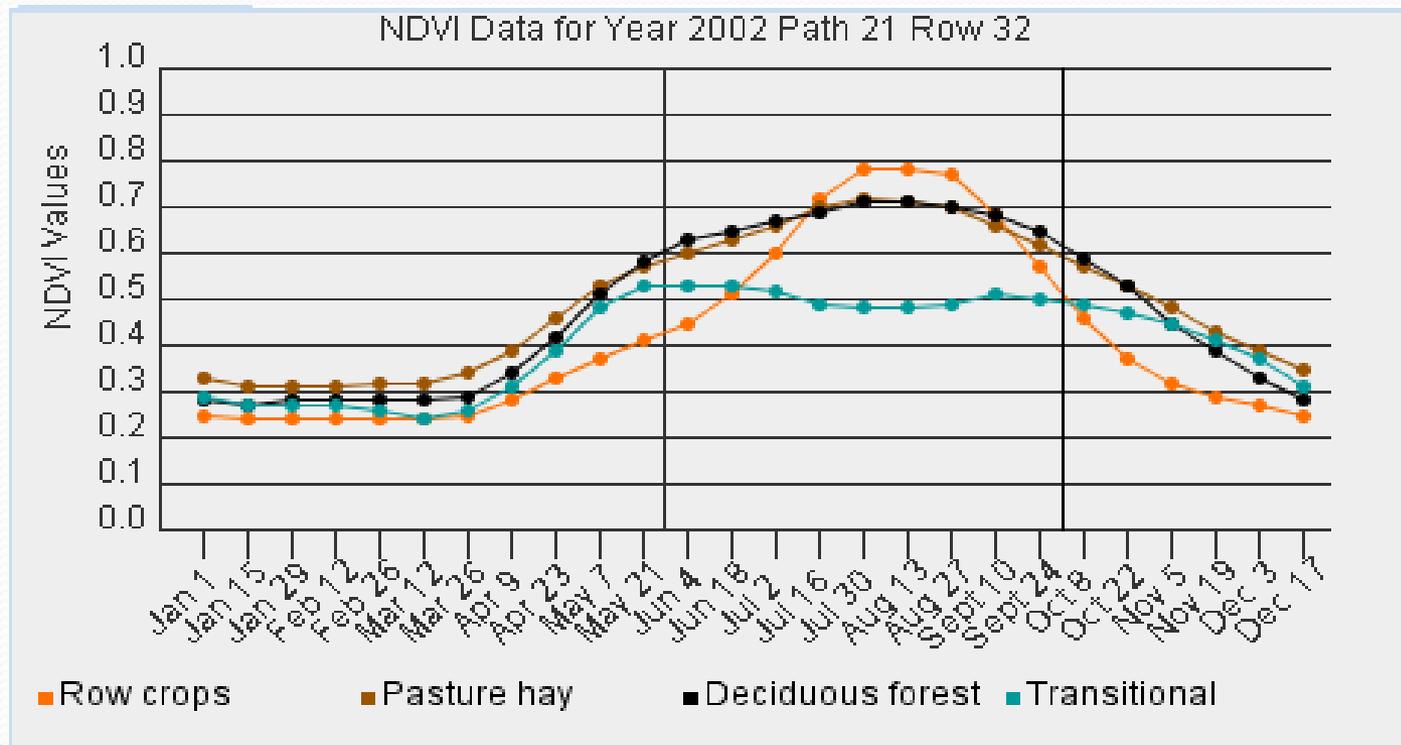
S. N. Goward, D. L. Williams and E. Denning

Landsat Science Team Meeting  
Sioux Falls, SD  
August 16-18, 2011

# Land Observation Requirements

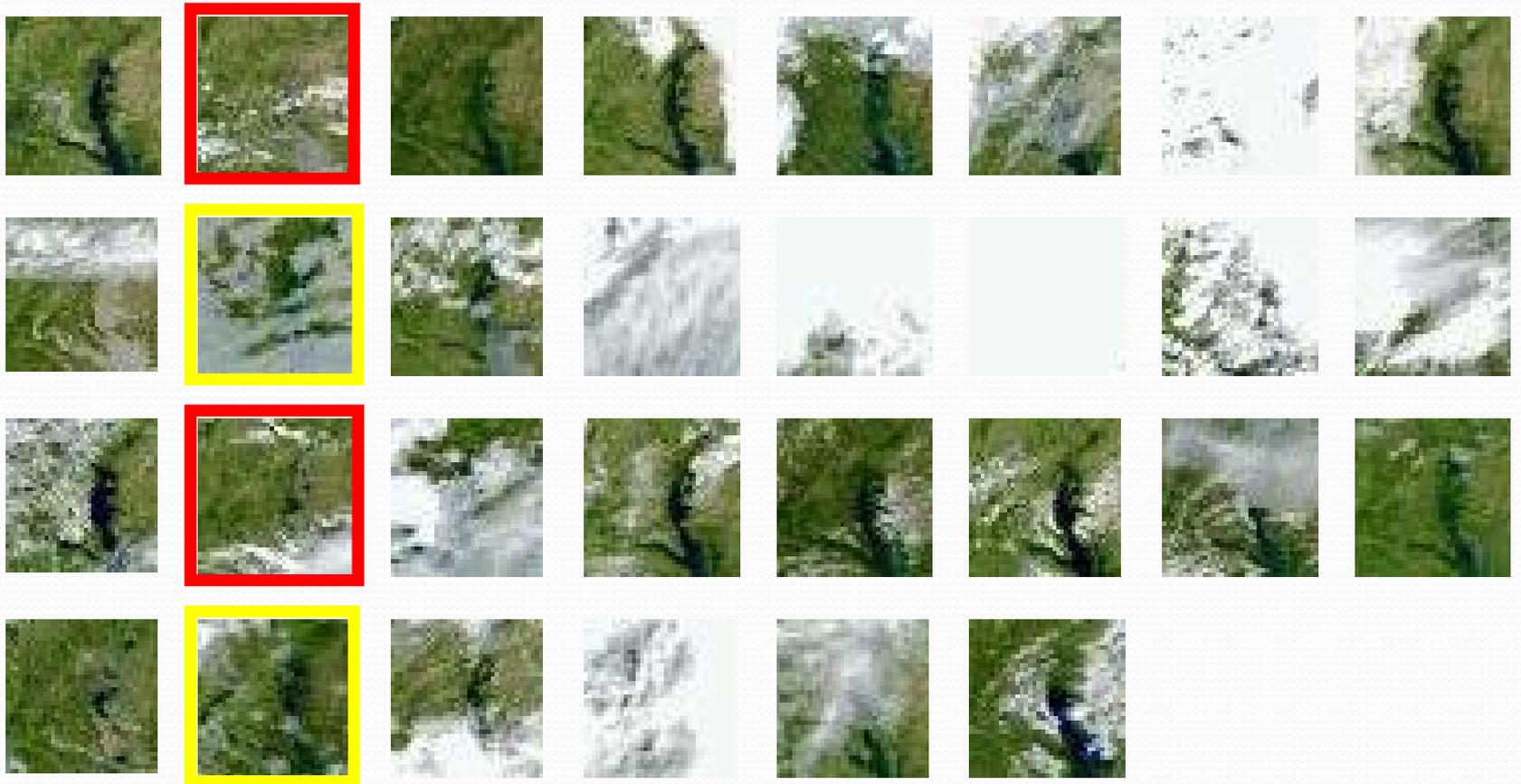
## Inter-annual land dynamics

- Defined by within-year (Intra-annual) vegetation seasonality



For best results, clear views ~ once each week

# MD p15r33 June 2002



# Maryland Results

## Daily Repeat

Year	Success Rate
2001	76.9%
2002	86.7%
2003	80%
2004	66.7%
2005	86.7%
2006	86.7%
2007	73.3%
2008	73.3%

Cumulative:  
78.8%

**Average of ~ 12 of  
15 possible clear  
views**

## Two Day Odd

Year	Success Rate
2001	69.2%
2002	80.0%
2003	66.7%
2004	26.7%
2005	60.0%
2006	53.3%
2007	53.3%
2008	26.7%

Cumulative:  
54.2%

**Significant range of results for two day repeat  
observations depending on weather cycles – these  
cycles can / will change over time**

## Two Day Even

Year	Success Rate
2001	69.2%
2002	66.7%
2003	66.7%
2004	46.7%
2005	66.7%
2006	73.3%
2007	66.7%
2008	73.3%

Cumulative:  
66.9%

# Purpose

- Clear satellite views: by orbital repeat frequency
- Potential of clear view compositing within an 8 day “week”
- Swath width impact acquiring clear view acquisitions

## Approach

- Analysis of 4-month growing season, 2002, 10 western U.S. sites
- Assess amount of clear views over land, including inland water bodies

## Data

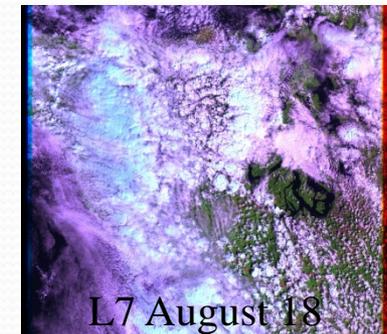
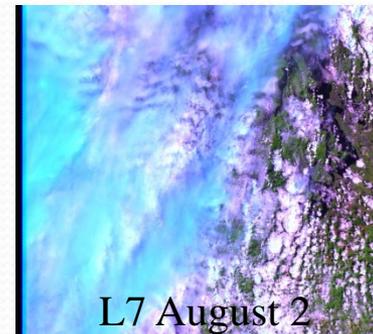
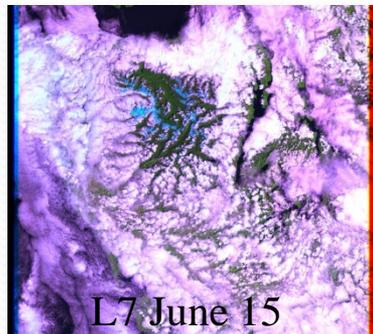
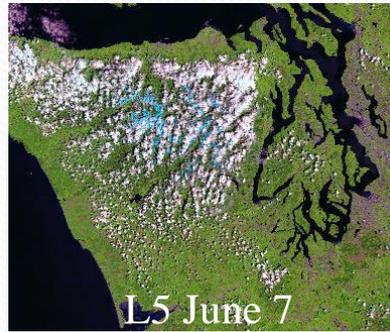
### **Landsat** (~200 images)

- ETM+ and TM used
- Visual analysis of cloud cover (0-100% scale)

### **MODIS** (~1200 images)

- MOD09GA (daily SR L2G Global 500M and 1km SIN Grid), Terra only
- Reproject and subset each MODIS swath to f Landsat chip
- state QA flags 1 km Scientific Data Set (SDS) bits for cloud cover (0-100%) in three categories (cloudy, clear, mixed)

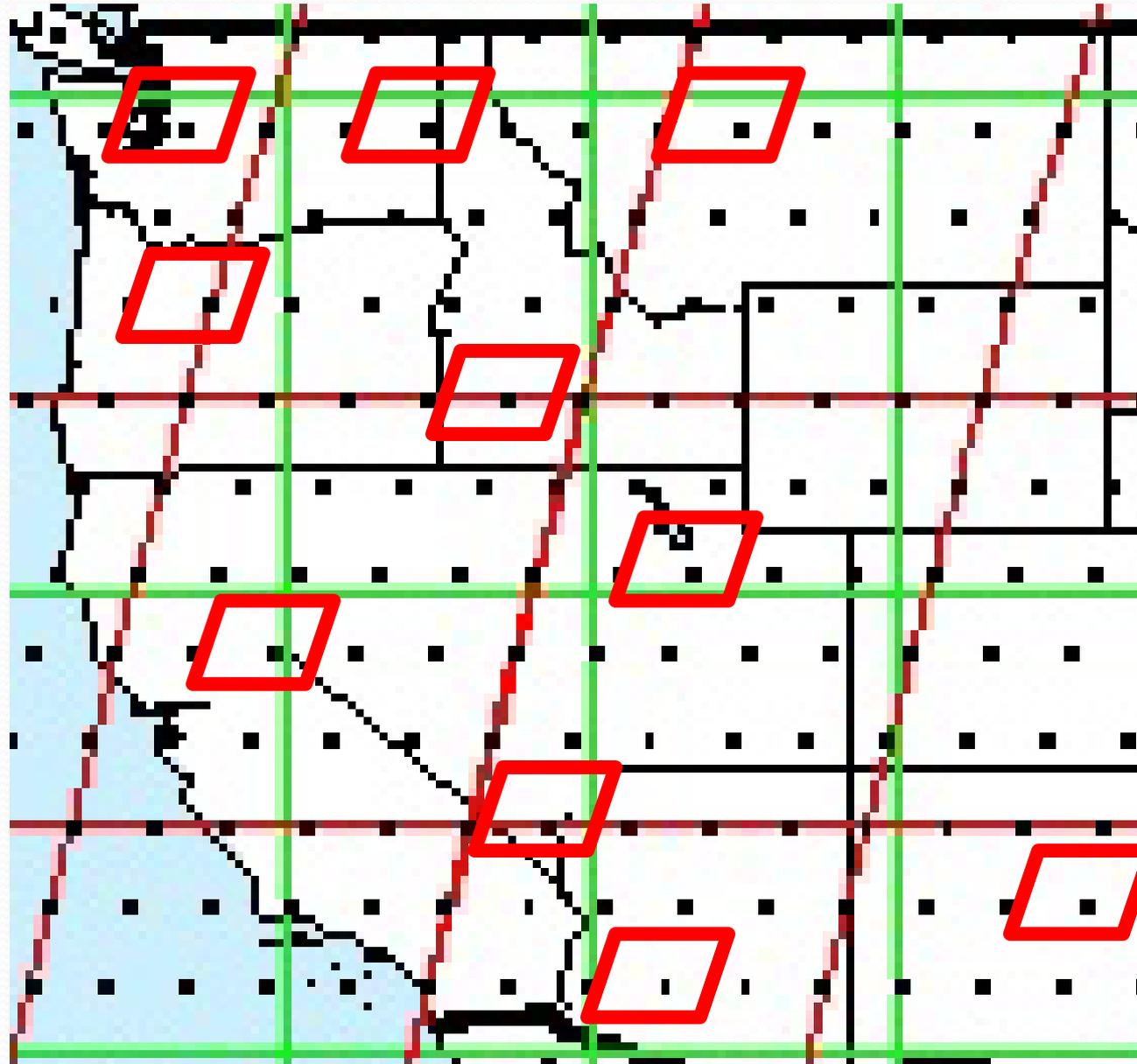
# 8-day repeat coverage for Olympic Peninsula, Washington



**These images were acquired by Landsat 5 and Landsat 7 from June through August, 2001. They illustrate how “successful coverage” by a satellite can vary significantly as a function of weather patterns. For this year, if you were relying on Landsat 5, you would be very happy – if Landsat 7, not so happy.**

# 10 Western United States Sites

1. East Puget Sound, WA (p46r27)
2. Eastern WA/Northern ID (p43r27)
3. Western/Central MT (p39r27)
4. Central OR (p45r29)
5. Southeastern ID (p41r30)
6. Central CA/Western NV (p43r33)
7. North Central UT (p38r32)
8. Southern NV (p39r35)
9. Southwestern AZ (p37r37)
10. East Central NM (p33r36)



# Landsat Scene (left) and MODIS Subset (right)

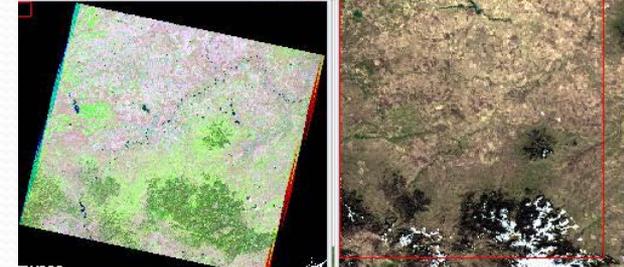
East Puget Sound, WA (p46r27)



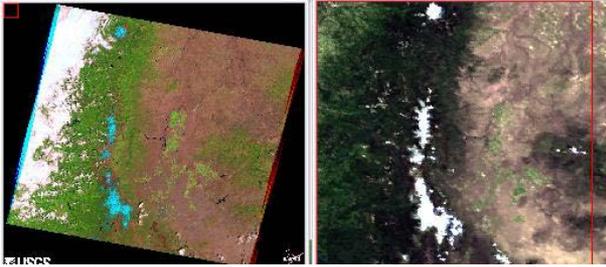
Eastern WA/Northern ID (p43r27)



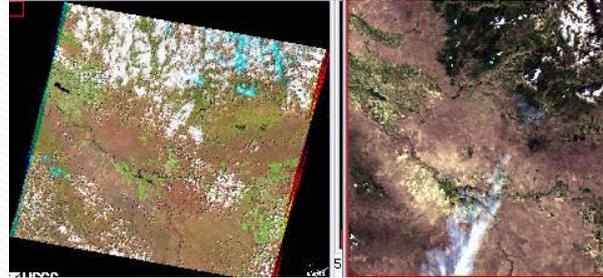
Western/Central MT (p39r27)



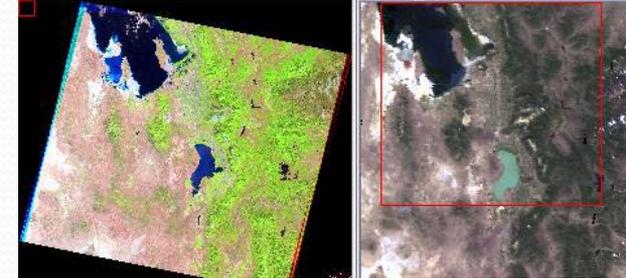
Central OR (p45r29)



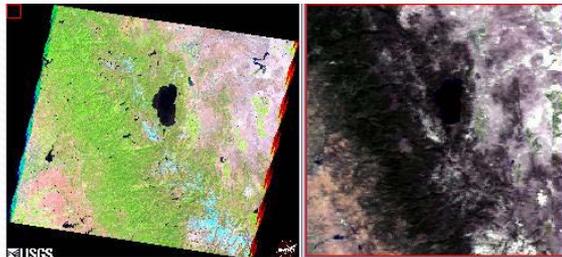
Southeastern ID (p41r30)



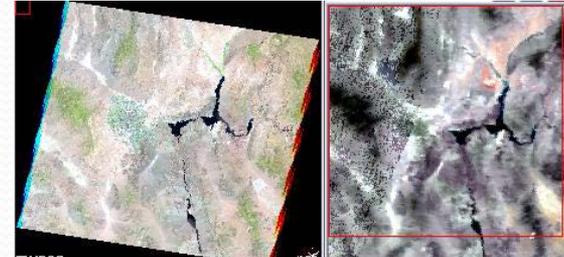
North Central UT (p38r32)



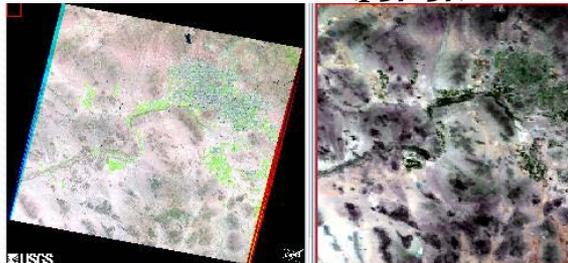
Central CA/Western NV (p43r33)



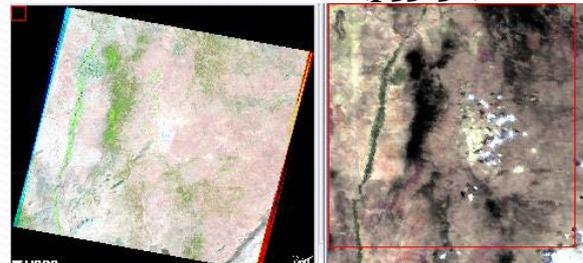
Southern NV (p39r35)



Southwestern AZ (p37r37)



East Central NM (p33r36)

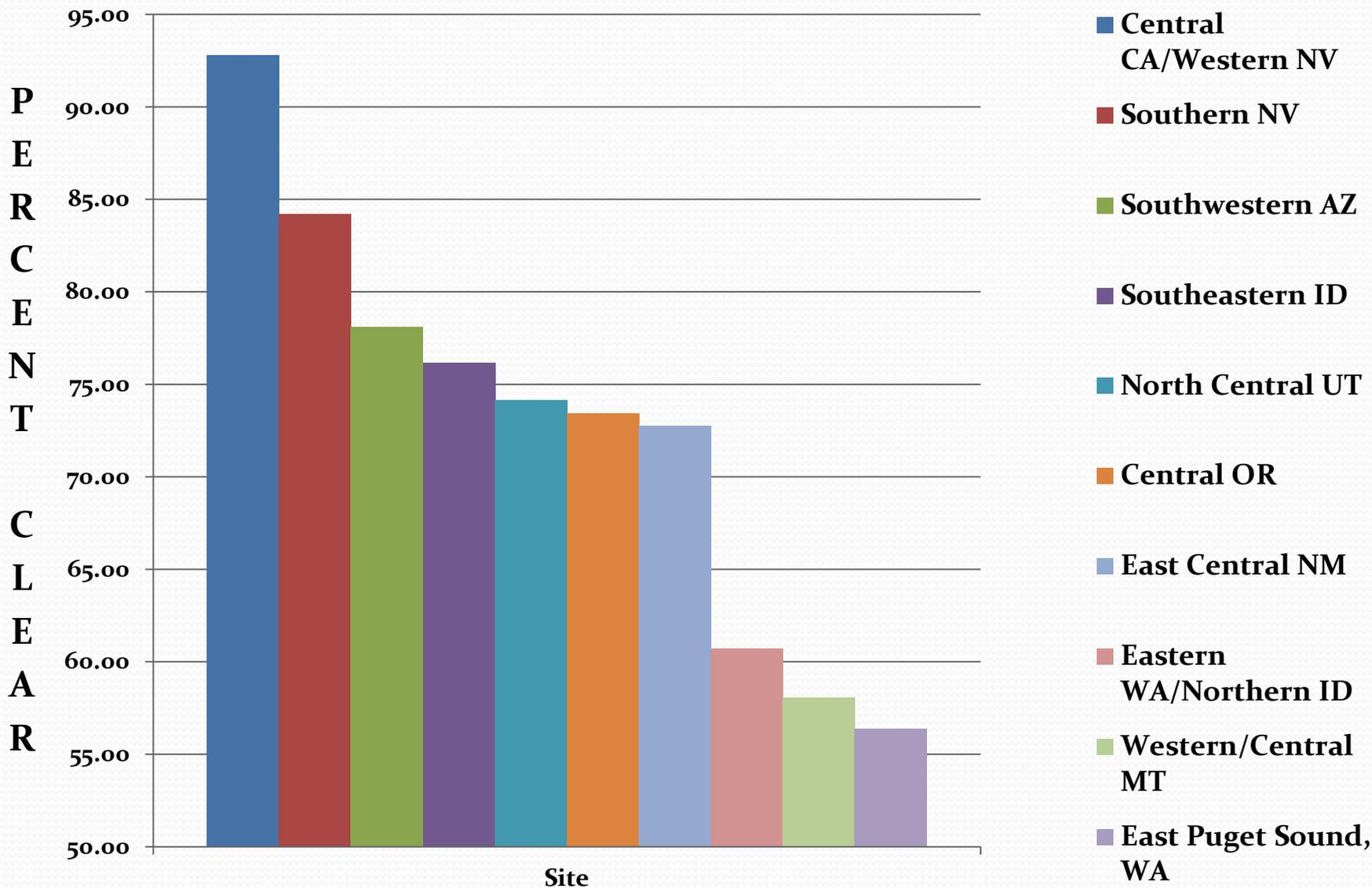


# Landsat Scenes Acquired

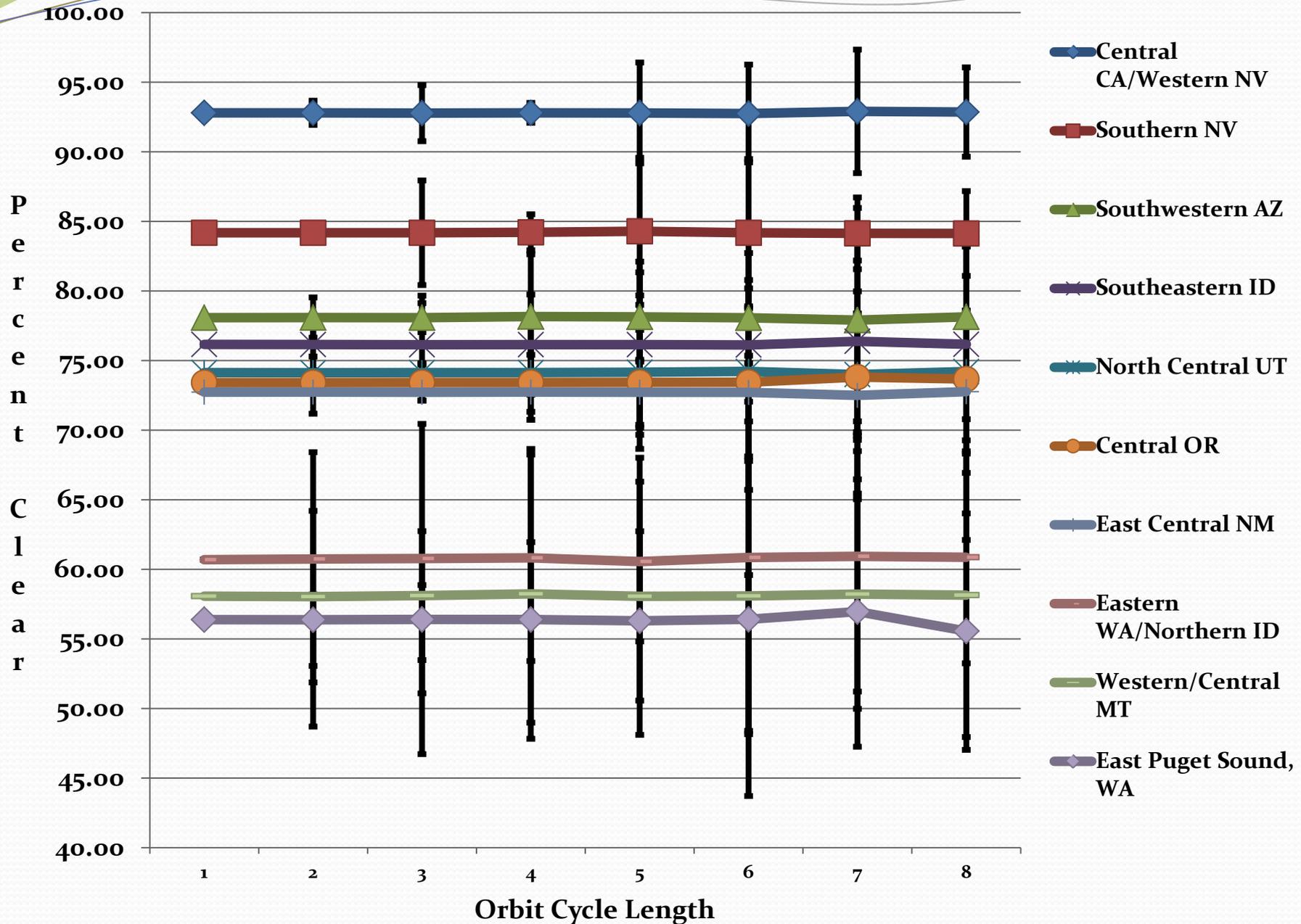
## % Clear

	L5 +L7	L5	L7
	8 DAY AVG	16 DAY AVG	16 DAY AVG
CITY_NAME	CLEAR	CLEAR TM	CLEAR ETM
East Puget Sound, WA	55.21	73.00	41.87
Central OR	64.31	65.60	63.50
Western/Central MT	64.53	54.86	73.00
Eastern WA/Northern ID	66.07	71.83	62.22
North Central UT	76.07	83.86	69.25
East Central NM	80.00	77.75	82.57
Southeastern ID	82.27	75.86	87.87
Southwestern AZ	82.33	79.00	86.14
Southern NV	92.27	85.14	98.50
Central CA/Western NV	95.20	93.00	97.12

# MODIS Clear Views Daily Repeat Frequency - Means

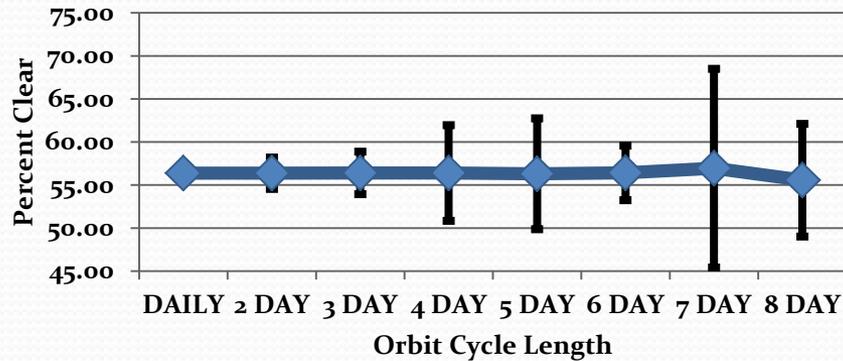


# MODIS – Means and Standard Deviations

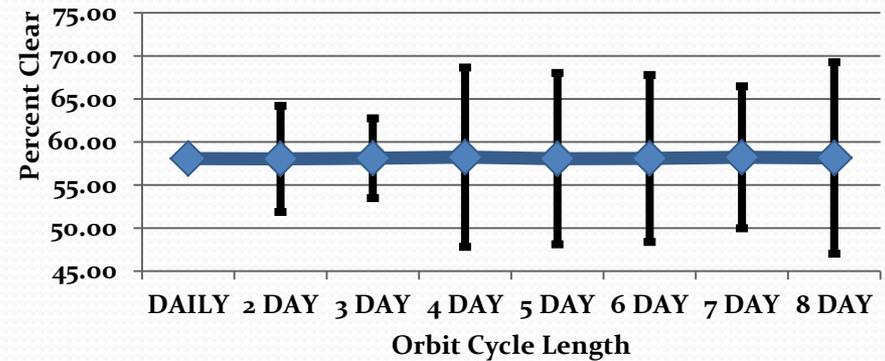


# MODIS – Means and Standard Deviations Cloudier Sites

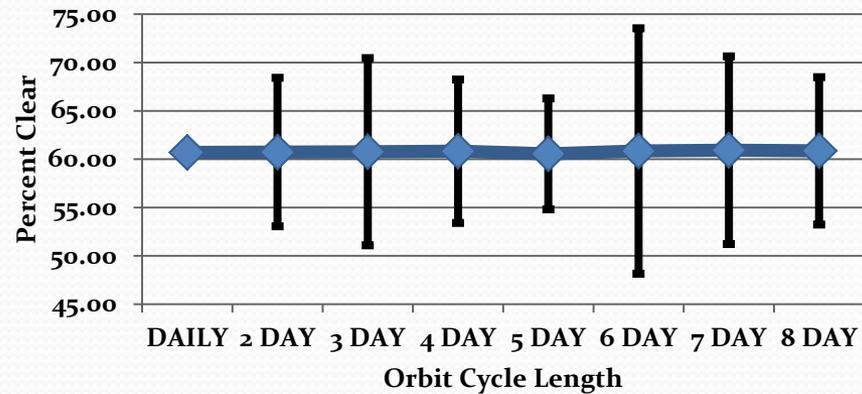
## East Puget Sound, WA



## Western/Central MT

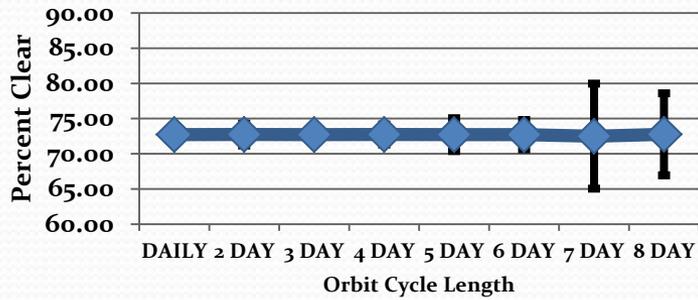


## Eastern WA/Northern ID

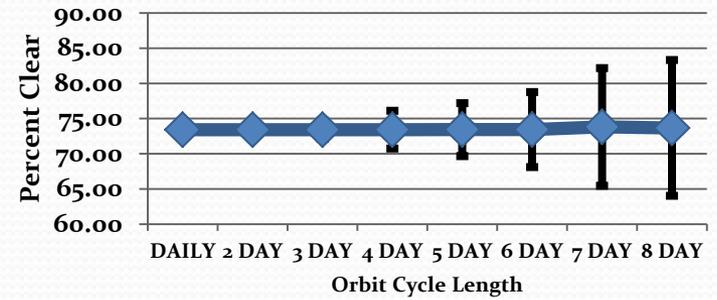


# MODIS – Means and Standard Deviations Average Sites

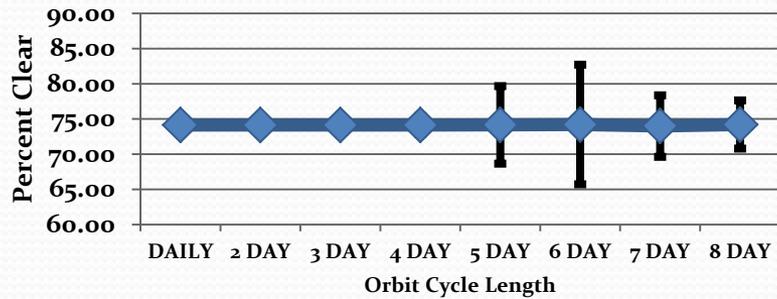
## East Central NM



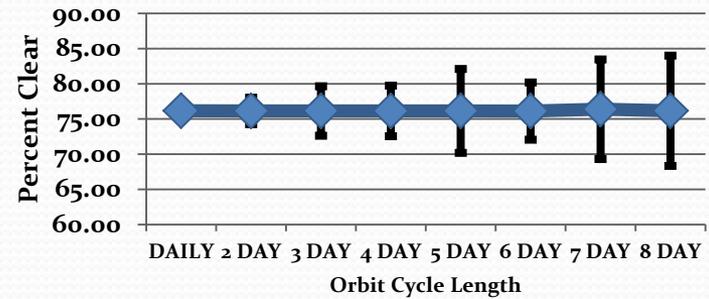
## Central OR



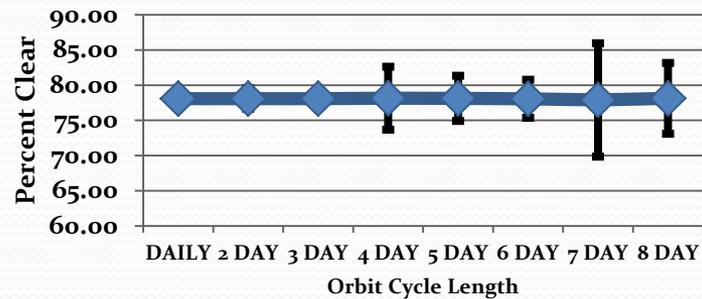
## North Central UT



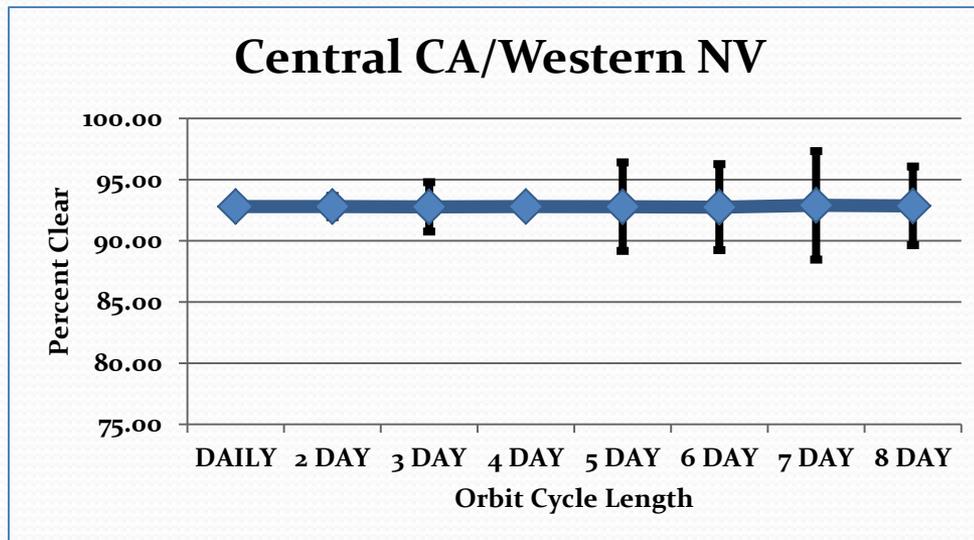
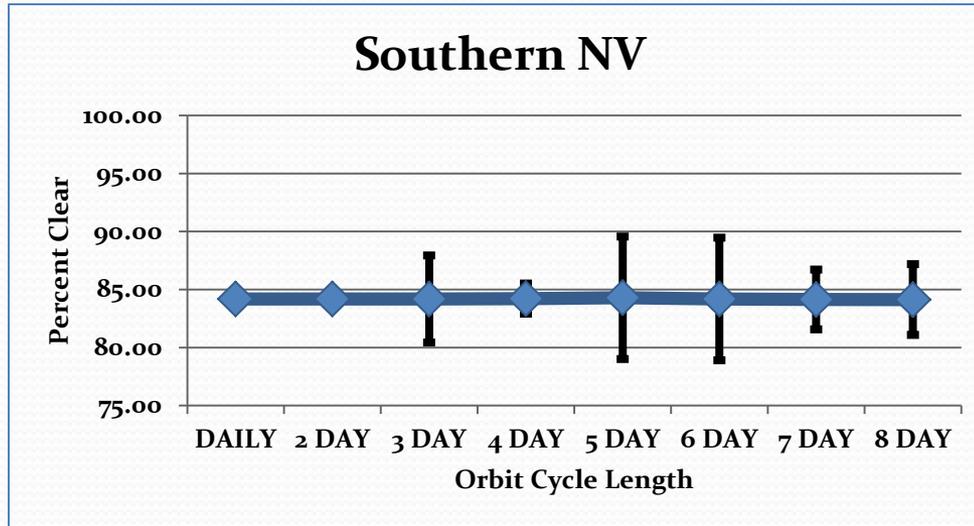
## Southeastern ID



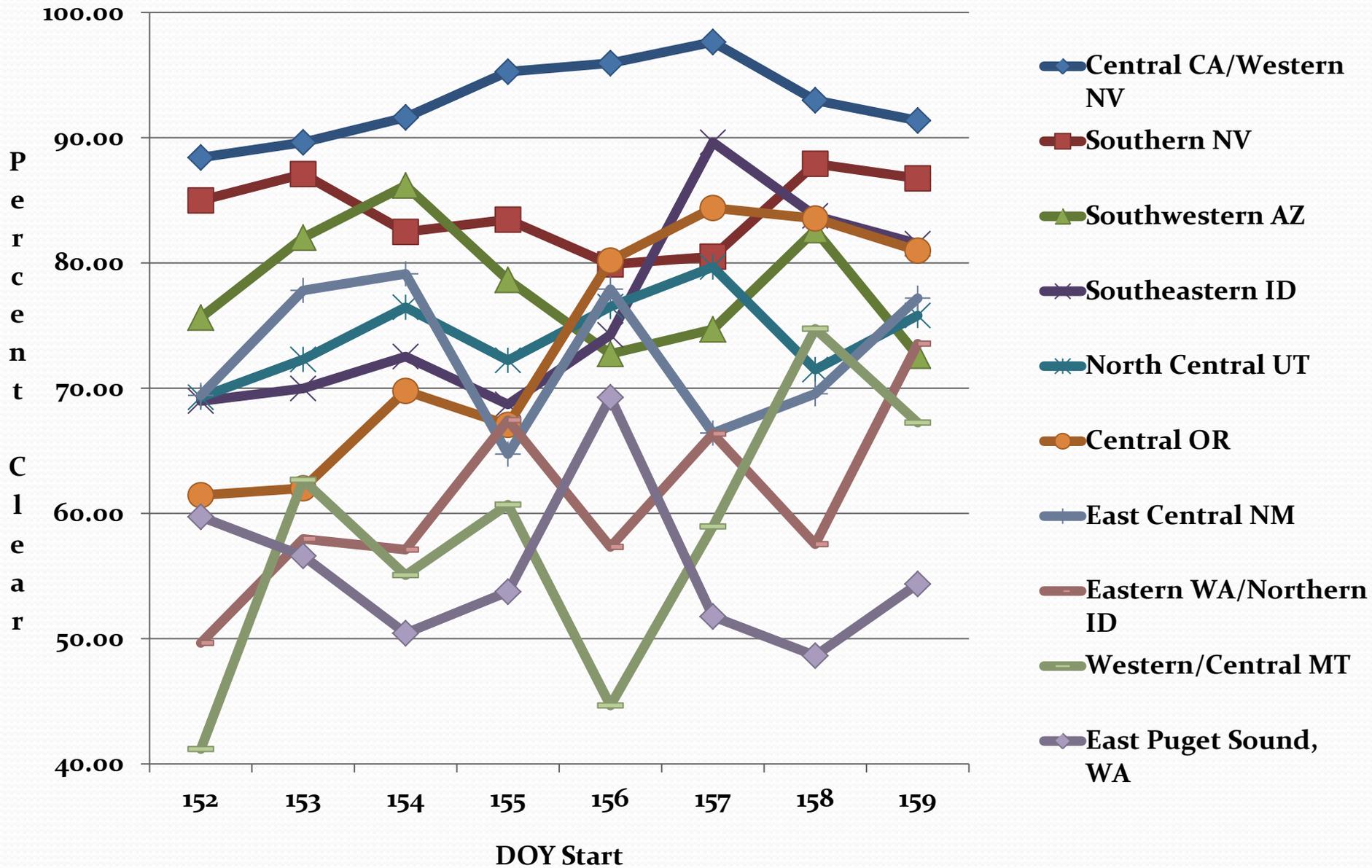
## Southwestern AZ



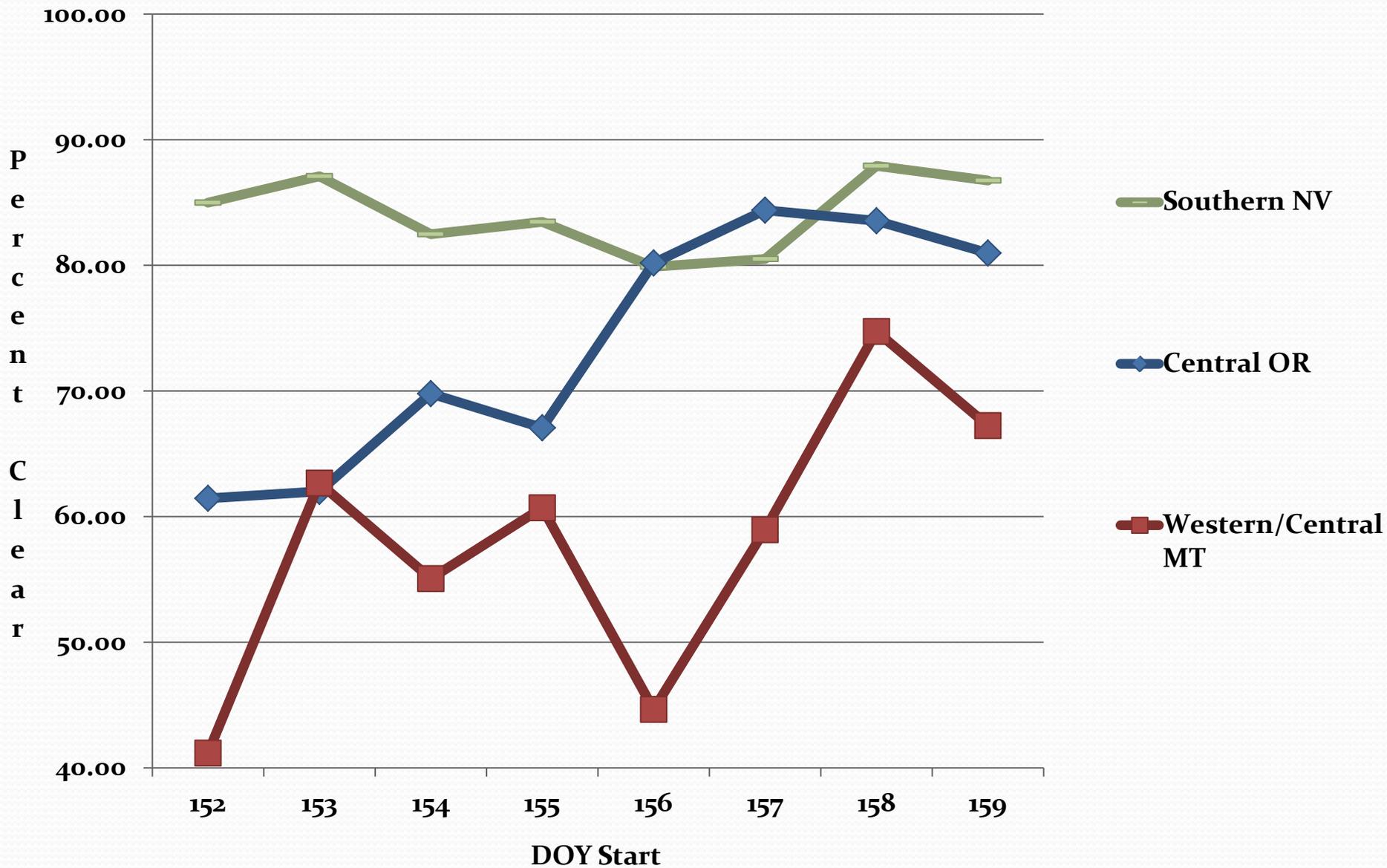
# MODIS – Means and Standard Deviations Clearer Sites



# MODIS - Differences in Clearness of Image 8 Day Orbit Cycles



# Highest, Average, and Lowest Variation 8 Day Orbit Cycle



# High Variation Within an 8 Day "Week"

## % Clear View

Western/Central MT – 99.93 percentage points range



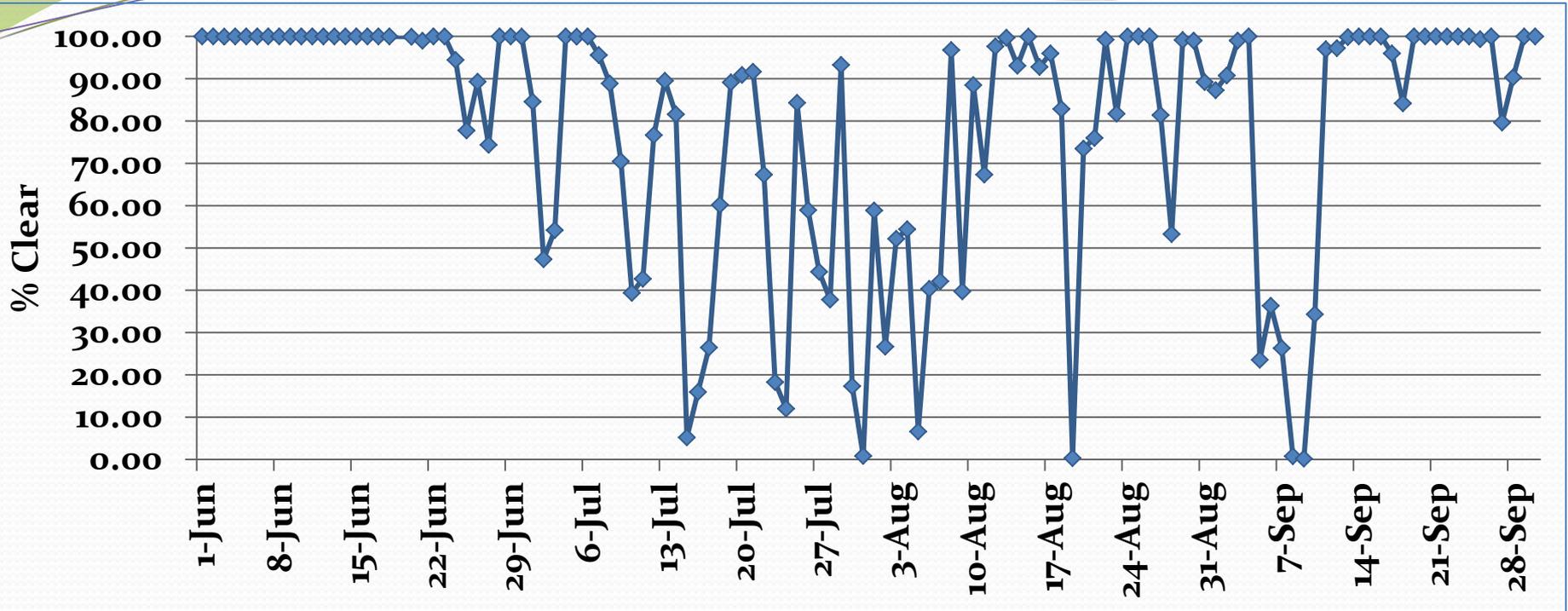
260	261	262	263	264	265	266	267
0.00	10.10	99.93	88.64	35.52	63.98	84.09	2.25
					<b>Landsat Date</b>		

Central AZ – 92.43 percentage points range



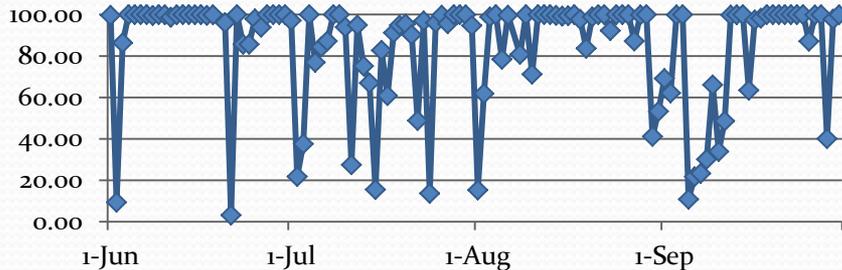
205	206	207	208	209	210	211	212
12.01	84.29	58.93	44.35	37.76	93.25	17.31	0.81
						<b>Landsat Date</b>	

# Central AZ Growing Season

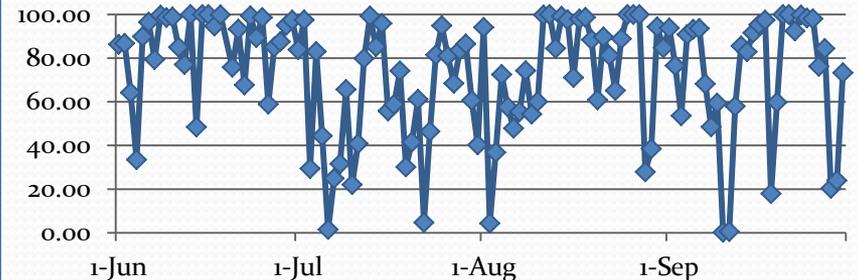


**High range of clear views in Central AZ, possibly due to summer monsoon.  
Neighboring sites show variation, as well.**

## Southern NV



## East Central NM



# MODIS - Potential for Clear View Success

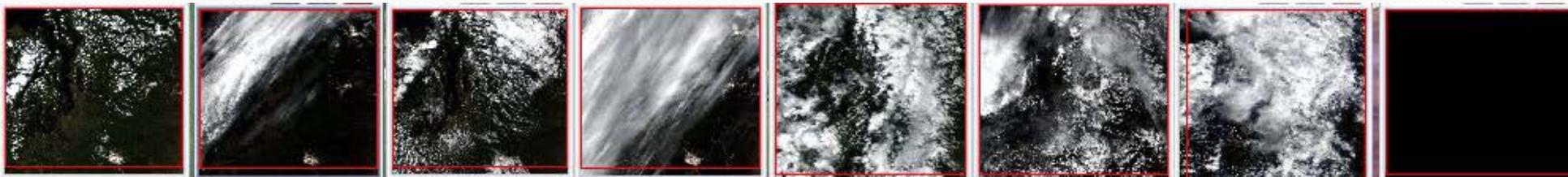
# **Unsuccessful** Outcomes out of 115 Attempts  
(June 8 – Sept. 30, 2002):

	<u>From 1 Image</u>	<u>From 2 Images</u>
East Puget Sound, WA	26	0
East Central NM	17	0
Southwestern AZ	17	0
Western/Central MT	3	0
Eastern WA/Northern ID	0	0
Central OR	0	0
Southern NV	0	0
Southeastern ID	0	0
North Central UT	0	0
Central CA/Western NV	0	0

**Criteria: 1 image 95% or more clear or 2 images 75% or more clear in every 8 day “week,” using a rolling window of 7 days preceding the date to 7 days after**

# MODIS - Compositing Success Within 8 Day "Week"

## East Puget Sound % Clear



212  
84.76

213  
53.97

214  
53.29

215  
25.02

216  
15.48

217  
11.1

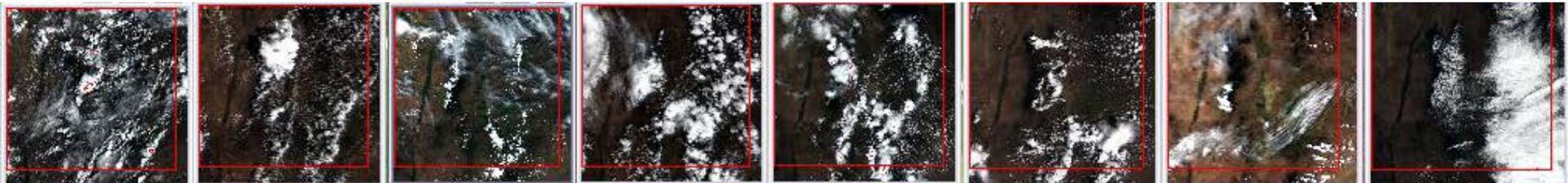
218  
15.74  
Landsat Date

219  
no data

If a rolling window was not used, this  
week would have no composite

# MODIS - Compositing Success Within 8 Day "Week"

## East Central NM % Clear



215

216

217

218

219

220

221

222

36.81

72.51

57.65

47.85

55.42

74.28

54.31

60.03

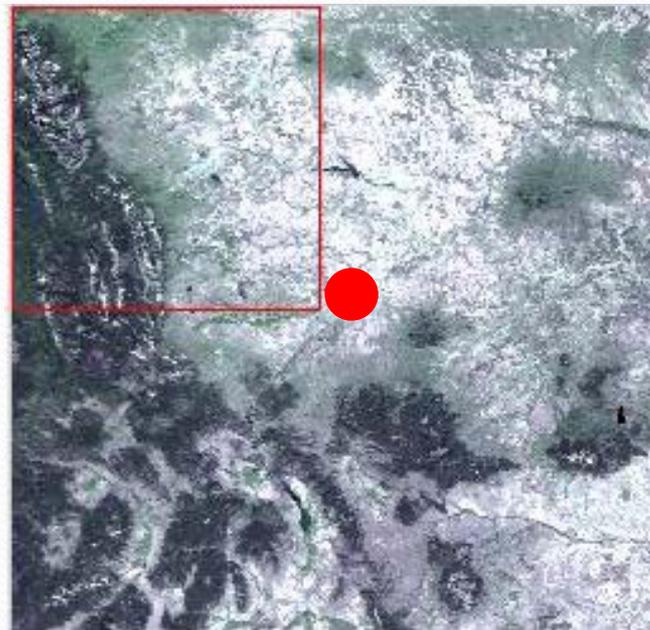
Landsat Date

If a rolling window was not used, this week  
would have no composite

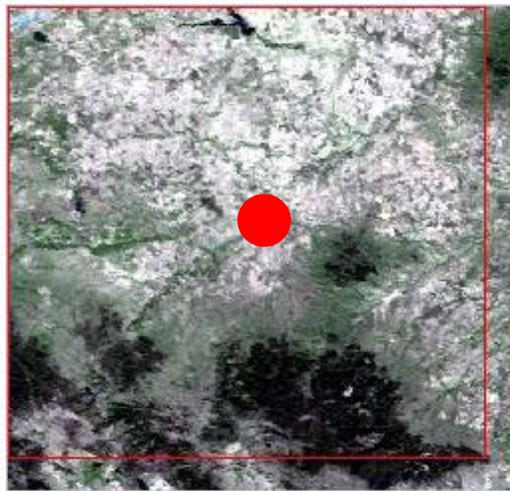
# Varied Swath Width Test

## Western/Central MT

Swath Subset  
~375 km



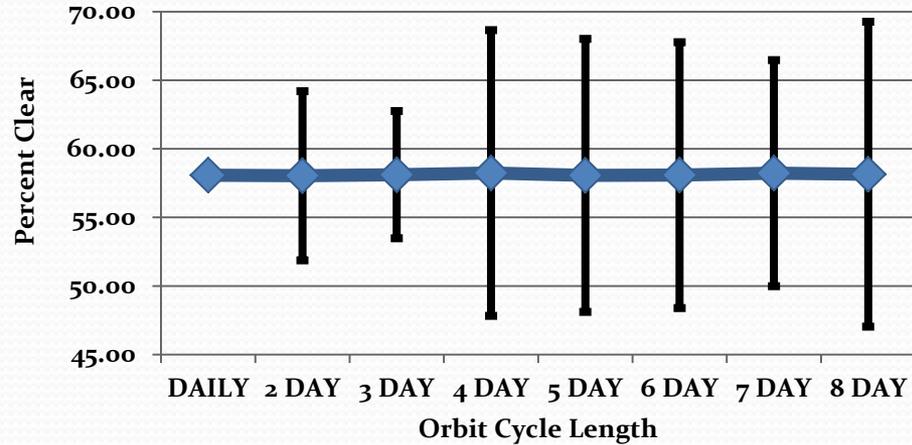
Swath Subset  
~185km  
(Landsat size)  
(p39r27)



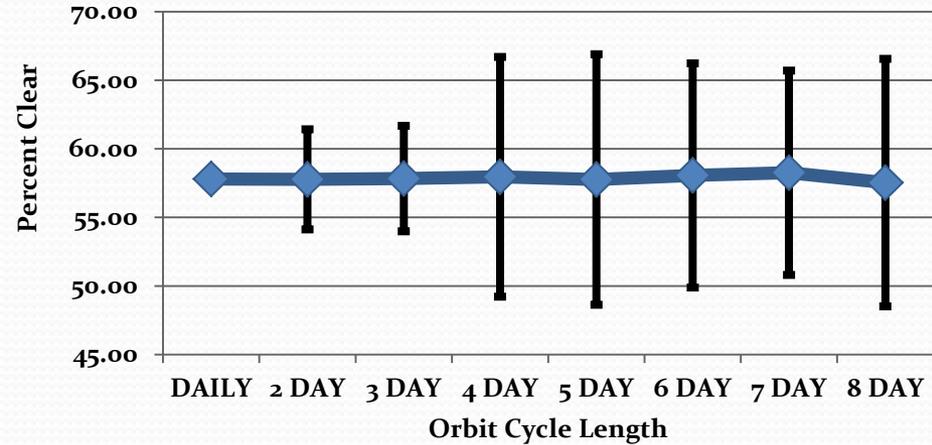
**Note: Red dot  
is the general  
location of  
Great Falls, MT**

# Results of Varied Swath Width Test

Western/Central MT ~185km Swath



Western/Central MT ~375km Swath



~185km swath:

	DAILY	2 DAY	3 DAY	4 DAY	5 DAY	6 DAY	7 DAY	8 DAY
Mean	58.07	58.04	58.12	58.24	58.06	58.09	58.22	58.15
SD	0.00	6.16	4.63	10.41	9.96	9.69	8.24	11.12

~375km swath:

	DAILY	2 DAY	3 DAY	4 DAY	5 DAY	6 DAY	7 DAY	8 DAY
Mean	57.80	57.78	57.84	57.96	57.77	58.06	58.26	57.54
SD	0.00	3.65	3.85	8.74	9.13	8.17	7.45	9.02

# Conclusions

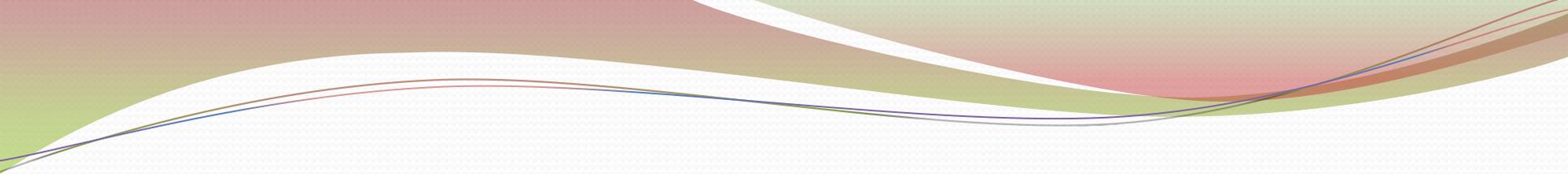
## MODIS Data

- Clear views for a site: **Standard deviations increase with decreasing repeat frequency**
- **Means across sites but generally not within a site and**
- Cloudier sites may have more variation.
- **Obtaining a clear image using an 8 day rolling window was not always possible, even for generally clear sites. Compositing always was successful using an 8 day rolling window.**
- This was **not the case if the composite had to be made within a certain week.**
- For the Western/Central MT, **the ~375km swath was slightly clearer than the ~185km swath, but less successful in finding clear view images.**

## Landsat Data

- There can be high **variation within the same site on the amount of clear views captured by TM or ETM+, even for clearer sites.**

**Need daily views to overcome these difficulties and obtain a clear view or several partial clear views in one 8 day “week.”**



**BACKUP SLIDES**

# MODIS results: % chance of clear view by repeat frequency (1<sup>st</sup> five sites)

	DAILY	2 DAY	3 DAY	4 DAY	5 DAY	6 DAY	7 DAY	8 DAY
<b>Seattle</b>								
Mean	56.38613	56.37529	56.40454	56.39726	56.30558	56.41221	56.96152	55.56649
SD		1.824602	2.465433	5.560142	6.434636	3.174934	11.53391	6.542393
<b>Great Falls</b>								
Mean	58.07205	58.03602	58.11543	58.23526	58.06436	58.08674	58.22281	58.14951
SD		6.164685	4.633864	10.41438	9.956836	9.692834	8.242608	11.11825
<b>Spokane</b>								
Mean	60.69363	60.7385	60.77297	60.82624	60.55743	60.85217	60.92981	60.8647
SD		7.678557	9.680221	7.416076	5.738276	12.6984	9.70784	7.61737
<b>Albuquerque</b>								
Mean	72.7289	72.7380	72.7257	72.7379	72.7242	72.7180	72.5026	72.7674
SD		1.557568	0.601008	1.42001	2.337036	2.093527	7.468399	5.834007
<b>Bend</b>								
Mean	73.4142	73.41408	73.42202	73.42914	73.43706	73.43889	73.81472	73.67551
SD		0.02051	1.300822	2.685653	3.770703	5.327631	8.371785	9.653808

# MODIS results: % chance of clear view by repeat frequency (2nd five sites)

<b>Salt Lake City</b>								
Mean	74.1389	74.1322	74.1372	74.1338	74.1655	74.2181	73.9953	74.2142
SD		1.157061	0.665527	1.277615	5.512769	8.507579	4.385724	3.426603
<b>Boise</b>								
Mean	76.16336	76.15219	76.1376	76.14682	76.14541	76.11896	76.38808	76.16644
SD		1.879532	3.525691	3.597218	5.968304	4.068788	7.084434	7.842501
<b>Phoenix</b>								
Mean	78.0844	78.0929	78.0823	78.1654	78.1345	78.0746	77.9054	78.1395
SD		1.4456	1.0411	4.4764	3.2073	2.7145	8.0598	5.0436
<b>Las Vegas</b>								
Mean	84.1852	84.1852	84.1852	84.2188	84.2891	84.1852	84.1442	84.1340
SD		0.4642	3.7581	1.2939	5.2834	5.2905	2.5786	3.0483
<b>Reno</b>								
Mean	92.7960	92.8012	92.7777	92.8011	92.7924	92.7514	92.9021	92.8579
SD		0.866561	2.015983	0.714424	3.620005	3.51281	4.435058	3.211155

# Variation between sites and DOY starting orbit – 1, 2, 3 day orbits

		DOY	DOY	DOY	DOY	DOY
		152 start	153 start	152 start	153 start	154 start
	Daily	2 day even	2 day odd	3 day	3 day	3 day
<b>Seattle</b>						
Lsat orbit 153	<b>56.3861</b>	<b>57.6655</b>	<b>55.0851</b>	<b>53.7349</b>	<b>56.8833</b>	<b>58.5955</b>
<b>Great Falls</b>						
Lsat orbit 153	<b>58.0720</b>	<b>53.6769</b>	<b>62.3951</b>	<b>61.6394</b>	<b>52.8665</b>	<b>59.8404</b>
<b>Spokane</b>						
Lsat orbit 157	<b>60.6936</b>	<b>55.3089</b>	<b>66.1681</b>	<b>51.1724</b>	<b>60.6156</b>	<b>70.5309</b>
<b>Albuquerque</b>						
Lsat orbit 159	<b>72.7289</b>	<b>73.8393</b>	<b>71.6366</b>	<b>72.0327</b>	<b>73.1041</b>	<b>73.0404</b>
<b>Bend</b>						
Lsat orbit 153	<b>73.4142</b>	<b>73.4286</b>	<b>73.3996</b>	<b>71.9357</b>	<b>73.9775</b>	<b>74.3529</b>
<b>Salt Lake City</b>						
Lsat orbit 154	<b>74.1389</b>	<b>73.3140</b>	<b>74.9503</b>	<b>74.6702</b>	<b>74.3501</b>	<b>73.3912</b>
<b>Boise</b>						
Lsat orbit 153	<b>76.1634</b>	<b>74.8232</b>	<b>77.4812</b>	<b>73.0722</b>	<b>79.9904</b>	<b>75.3501</b>
<b>Phoenix</b>						
Lsat orbit 155	<b>78.0844</b>	<b>79.1150</b>	<b>77.0707</b>	<b>78.9689</b>	<b>78.3421</b>	<b>76.9359</b>
<b>Las Vegas</b>						
Lsat orbit 161	<b>84.1852</b>	<b>83.8570</b>	<b>84.5135</b>	<b>88.4821</b>	<b>82.5627</b>	<b>81.5110</b>
<b>Reno</b>						
Lsat orbit 157	<b>92.7960</b>	<b>92.1884</b>	<b>93.4139</b>	<b>93.1538</b>	<b>94.5792</b>	<b>90.6002</b>

# 4 and 5 day orbits

	DOY								
	152 start	153 start	154 start	155 start	152 start	153 start	154 start	155 start	156 start
	4 day	4 day	4 day	4 day	5 day				
<b>Seattle</b>									
Lsat orbit 153	64.1777	54.2649	51.1532	55.9932	55.9731	57.2335	46.4012	57.5527	64.3674
<b>Great Falls</b>									
Lsat orbit 153	42.8584	60.8700	65.2416	63.9711	65.5518	50.9848	46.0782	57.5417	70.1652
<b>Spokane</b>									
Lsat orbit 157	53.3596	62.0211	57.3232	70.6010	66.5548	61.5282	51.0457	61.0904	62.5681
<b>Albuquerque</b>									
Lsat orbit 159	73.5276	72.2939	74.1726	70.9574	70.7920	74.7270	75.5585	72.2336	70.3101
<b>Bend</b>									
Lsat orbit 153	70.1932	72.8372	76.6640	74.0222	74.6597	70.3764	68.7278	77.8060	75.6154
<b>Salt Lake City</b>									
Lsat orbit 154	72.7801	75.8620	73.8847	74.0083	78.3381	70.1806	66.4438	77.5670	78.2979
<b>Boise</b>									
Lsat orbit 153	71.4323	79.4883	78.3309	75.3357	76.6584	72.7537	69.0718	77.1747	85.0684
<b>Phoenix</b>									
Lsat orbit 155	74.2317	78.4747	84.3351	75.6199	78.0129	76.5442	79.6720	82.4775	73.9657
<b>Las Vegas</b>									
Lsat orbit 161	82.5189	83.9053	85.2874	85.1636	84.9781	75.2463	85.1281	87.5615	88.5315
<b>Reno</b>									
Lsat orbit 157	92.0600	93.4988	92.3257	93.3200	87.1975	94.3264	91.1756	95.5068	95.7555

# 6 and 7 day orbits

	DOY	DOY												
	152 start	153 start	154 start	155 start	156 start	157 start	152 start	153 start	154 start	155 start	156 start	157 start	158 start	
	6 day	7 day												
<b>Seattle</b>														
Lsat orbit 153	56.8678	55.3593	57.7214	50.6019	58.4072	59.5156	51.9251	38.7777	46.0503	64.6412	70.2917	63.1007	63.9439	
<b>Great Falls</b>														
Lsat orbit 153	64.8984	56.3092	46.8808	58.3805	49.2517	72.8000	54.5334	47.5689	54.3397	58.5770	58.2378	74.4275	59.8753	
<b>Spokane</b>														
Lsat orbit 157	41.6687	71.0017	74.7107	61.1513	50.2295	66.3512	65.0623	43.1983	54.2907	60.7432	69.2699	62.1099	71.8343	
<b>Albuquerque</b>														
Lsat orbit 159	74.0988	74.0351	75.2926	69.9667	72.1266	70.7882	72.1748	81.0137	77.7729	69.7503	58.5776	77.8335	70.3954	
<b>Bend</b>														
Lsat orbit 153	78.4612	78.5602	72.4297	65.4102	69.3949	76.3773	74.0298	60.7856	67.9380	74.9004	87.7573	78.2822	73.0098	
<b>Salt Lake City</b>														
Lsat orbit 154	68.7861	64.6326	66.6024	80.5542	84.5534	80.1800	76.8887	76.5057	76.6896	72.4663	64.7188	74.5072	76.1910	
<b>Boise</b>														
Lsat orbit 153	70.8352	83.1352	76.5892	75.1974	76.8457	74.1111	74.6964	73.4276	71.2213	81.7417	82.1729	85.7238	65.7329	
<b>Phoenix</b>														
Lsat orbit 155	82.8873	79.2625	77.0821	75.0504	77.3757	76.7897	87.0598	83.2746	73.8305	68.8915	66.6871	84.4660	81.1281	
<b>Las Vegas</b>														
Lsat orbit 161	86.8291	77.8257	77.4421	90.1350	87.2997	85.5798	85.3469	83.2050	84.4803	89.1631	81.9809	83.3154	81.5178	
<b>Reno</b>														
Lsat orbit 157	89.9148	96.1150	93.6070	96.3927	93.0435	87.4352	86.6278	93.4107	97.6691	95.8091	96.7748	92.7961	87.2268	

# 8 day orbits

	DOY							
	152	153	154	155	156	157	158	159
	8 day							
<b>East Puget Sound, WA</b>								
Lsat orbit 153	59.7286	56.6061	50.4239	53.7414	69.2625	51.7676	48.6399	54.3619
<b>Western/Central MT</b>								
Lsat orbit 153	41.1726	62.6685	55.0638	60.7003	44.6566	58.9516	74.7408	67.2419
<b>Eastern WA/Northern ID</b>								
Lsat orbit 157	49.6508	57.9613	57.1085	67.4467	57.3157	66.3516	57.5380	73.5449
<b>East Central NM</b>								
Lsat orbit 159	69.4246	77.8076	79.1235	64.7280	77.9041	66.4127	69.5517	77.1868
<b>Central OR</b>								
Lsat orbit 153	61.4521	62.0039	69.7836	67.0673	80.1829	84.3927	83.5444	80.9772
<b>North Central UT</b>								
Lsat orbit 154	69.2775	72.2889	76.4605	72.2180	76.5162	79.6733	71.4807	75.7986
<b>Southeastern ID</b>								
Lsat orbit 153	68.9660	69.9761	72.5268	68.6972	74.2511	89.6347	83.7481	81.5317
<b>Southwestern AZ</b>								
Lsat orbit 155	75.6319	82.0183	86.1770	78.6497	72.7383	74.6949	82.6160	72.5901
<b>Southern NV</b>								
Lsat orbit 161	84.9876	87.0934	82.4757	83.4599	79.8855	80.5046	87.9116	86.7538
<b>Central CA/Western NV</b>								
Lsat orbit 157	88.4145	89.6200	91.6180	95.2678	95.9487	97.6361	92.9862	91.3722