GE
Energy

Western Wind & Solar Integration Study:

Intra-hour Variability and Operations

Stakeholders Meeting
July 30, 2009

imagination at work

Introduction to Intra-hour Variability

Variability vs. Uncertainty

- Day-ahead forecast error is the major contributor to **Uncertainty**
- Subhourly changes in **net load** are the main source of **Variability**

- Subhourly **Variability** drives dynamic reserve **requirements**
- Handling of DAH **Uncertainty** dominates dynamic reserve **capability**

- In this section, we will focus on 10-min variability
    - 10 minutes is a good divider between running reserves and cold/standby reserves
    - We have 10-min data

Summary Statistics for 10-Minute Net Load Change (Delta) Footprint -> WECC

At study footprint level, overall 10-minute variability increase is relatively small

	In Footprint			WECC		
	IA	LP	MP	IA	LP	MP
Sigma (MW)						
Load-alone	239	239	239	731	731	731
Baseline (Existing)	240	240	240	734	734	734
10% Scenario	243	245	246	717	718	719
20% Scenario	259	260	268	716	718	722
30% Scenario	284	286	301	728	728	734
Max Pos Delta (MW)						
Load-alone	612	612	612	1786	1786	1786
Baseline (Existing)	710	710	710	1865	1865	1865
10% Scenario	899	873	770	2084	2093	2118
20% Scenario	1193	1075	1219	2211	2172	2203
30% Scenario	1430	1416	1542	2728	2681	2677

Severity of most extreme changes increases more

Corrected for 2/3 Data

Summary Statistics for 10-Minute Data

	Ariz			CO-E			CO-W			NM			NV			WY			In Foot Print			WECC		
	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP	IA	LP	MP
Sigma (MW)																								
Load-alone	97	97	97	61	61	61	6	6	6	25	25	25	52	52	52	15	15	15	239	239	239	731	731	731
Baseline (Existing)	97	97	97	65	65	65	6	6	6	31	31	31	52	52	52	23	23	23	240	240	240	734	734	734
10% In FP Scenario	107	105	97	69	69	69	11	10	7	33	36	43	57	56	53	24	31	49	243	245	246	717	718	719
20% In FP Scenario	128	116	100	80	81	71	19	16	7	43	46	54	68	63	55	34	56	108	259	260	268	716	718	722
30% In FP Scenario	146	128	106	98	89	72	25	20	10	54	56	70	79	69	57	46	93	157	284	286	301	728	728	734
Max Neg Delta (MW)																								
Load-alone	-348	-348	-348	-223	-223	-223	-20	-20	-20	-86	-86	-86	-200	-200	-200	-53	-53	-53	-708	-708	-708	-2239	-2239	-2239
Baseline (Existing)	-352	-352	-352	-412	-412	-412	-20	-20	-20	-260	-260	-260	-200	-200	-200	-334	-334	-334	-810	-810	-810	-2279	-2279	-2279
10% In FP Scenario	-901	-772	-406	-412	-420	-409	-134	-109	-41	-252	-240	-354	-367	-340	-250	-327	-340	-903	-843	-867	-991	-3744	-3734	-3706
20% In FP Scenario	-1367	-1052	-367	-825	-829	-490	-234	-205	-60	-394	-408	-532	-568	-565	-305	-401	-962	-1725	-1360	-1216	-1821	-3656	-3672	-3713
30% In FP Scenario	-1616	-1169	-418	-1082	-956	-559	-288	-239	-91	-516	-565	-708	-767	-633	-386	-501	-1476	-2274	-1576	-1641	-2325	-4266	-4270	-4308
Max Pos Delta (MW)																								
Load-alone	267	267	267	195	195	195	22	22	22	106	106	106	206	206	206	84	84	84	612	612	612	1786	1786	1786
Baseline (Existing)	269	269	269	306	306	306	22	22	22	147	147	147	207	207	207	228	228	228	710	710	710	1865	1865	1865
10% In FP Scenario	711	590	289	334	336	364	160	93	30	166	201	320	319	311	209	233	290	567	899	873	770	2084	2093	2118
20% In FP Scenario	917	784	887	548	555	360	211	197	51	323	358	448	455	449	233	459	630	1069	1193	1075	1219	2211	2172	2203
30% In FP Scenario	1169	1041	1207	1010	804	426	296	221	93	462	466	543	582	519	293	649	994	1805	1430	1416	1542	2728	2681	2677
No. Drops > 3* Ld Sigma																								
Load-alone	18	18	18	36	36	36	90	90	90	45	45	45	54	54	54	45	45	45	0	0	0	9	9	9
Baseline (Existing)	18	18	18	155	155	155	90	90	90	617	617	617	54	54	54	1458	1458	1458	12	12	12	9	9	9
10% In FP Scenario	203	158	21	296	323	302	2163	1367	294	822	1121	1938	219	185	59	1649	2979	6399	44	42	62	6	6	11
20% In FP Scenario	672	350	47	669	687	362	5426	4298	476	1977	2262	3188	680	464	117	3638	7836	12968	125	140	224	6	5	11
30% In FP Scenario	1172	632	159	1388	995	344	7884	6074	1415	3156	3452	5262	1317	684	156	5993	12185	15905	240	284	468	17	17	42
No. Rises > 3* Ld Sigma																								
Load-alone	0	0	0	36	36	36	72	72	72	107	107	107	27	27	27	405	405	405	0	0	0	0	0	0
Baseline (Existing)	0	0	0	66	66	66	72	72	72	449	449	449	35	35	35	1563	1563	1563	0	0	0	0	0	0
10% In FP Scenario	165	123	0	194	236	204	1956	1194	236	636	951	1940	198	138	45	1779	3144	6681	15	15	12	0	0	0
20% In FP Scenario	722	419	132	738	764	303	5663	4521	386	2043	2367	3611	714	468	74	3801	8039	13319	203	171	212	2	0	2
30% In FP Scenario	1284	782	357	1656	1209	435	7983	6146	1908	3497	3864	5850	1350	824	191	6288	12513	16353	521	476	599	63	48	50

Corrected for 2/3 Data

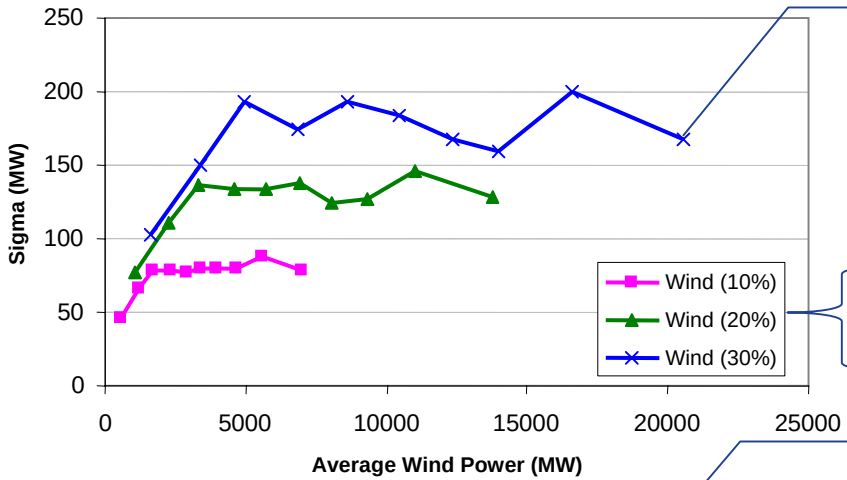
Summary Statistics for 10-Minute Delta Zone -> Wyoming -> Footprint -> WECC Local Priority Scenario

	BEPCWA	BHPLA	WYCENA	WYNWA	WYSWA	TRSTWYOA	WACMA	WY	In FootPrint	WECC
Sigma (MW)										
Load-alone	2	2	2	3	3	1	2	15	239	731
Baseline (Existing)	2	2	8	3	17	2	2	23	240	734
10% In FP Scenario	2	2	15	4	17	3	14	31	245	718
20% In FP Scenario	2	2	33	8	17	18	27	56	260	718
30% In FP Scenario	2	2	47	9	18	53	36	93	286	728
Max Neg Delta (MW)										
Load-alone	-7	-8	-10	-10	-11	-3	-8	-53	-708	-2239
Baseline (Existing)	-7	-8	-91	-10	-335	-29	-8	-334	-810	-2279
10% In FP Scenario	-7	-8	-162	-56	-335	-35	-369	-340	-867	-3734
20% In FP Scenario	-7	-8	-409	-170	-335	-439	-860	-962	-1216	-3672
30% In FP Scenario	-7	-8	-590	-170	-308	-809	-1128	-1476	-1641	-4270
Max Pos Delta (MW)										
Load-alone	11	13	16	17	19	6	7	84	612	1786
Baseline (Existing)	11	13	90	17	227	27	7	228	710	1865
10% In FP Scenario	11	13	168	50	227	31	264	290	873	2093
20% In FP Scenario	11	13	443	134	227	276	548	630	1075	2172
30% In FP Scenario	11	13	618	134	227	620	716	994	1416	2681

Corrected for 2/3 Data

10-minute Variability: Wind and Net Load (Local Priority Case)

Wind LP 2006

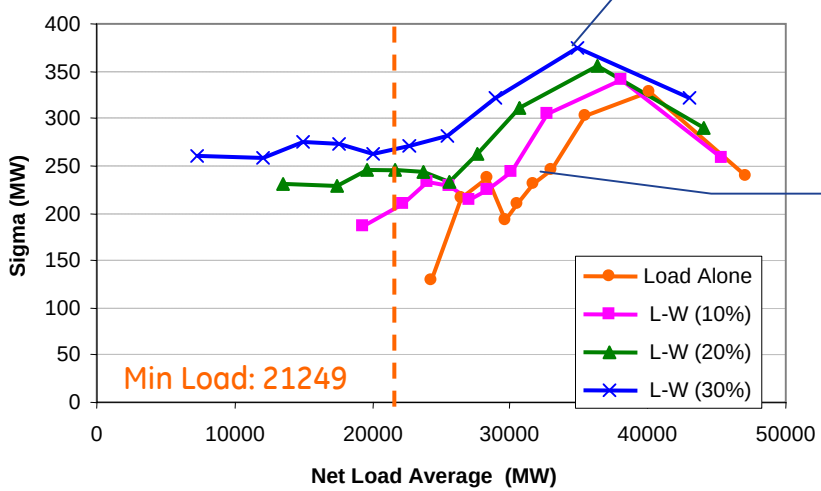


e.g. Average wind power of top 10% of hours is 20583 MW. σ 10-minute Δ for these 876 hours is 168MW

10% Nameplate	9600
20% Nameplate	18180
30% Nameplate	26760

- Wind variability not simply proportional to wind power level

Net Load* LP 2006



e.g. Average net load power of 2nd to top 10% of hours is 34821 MW. Sigma 10-minute delta for these 876 hours is 374MW

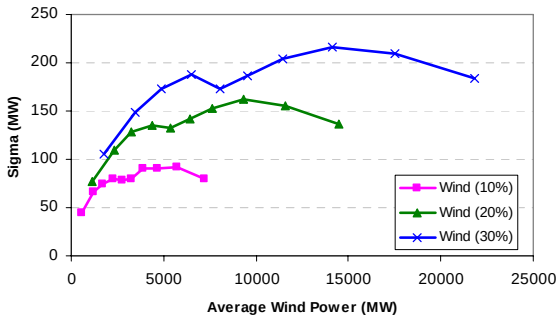
This curve is load only variability

- Variability increases with increased penetration
- Periods of low net load tend to have considerably more variability

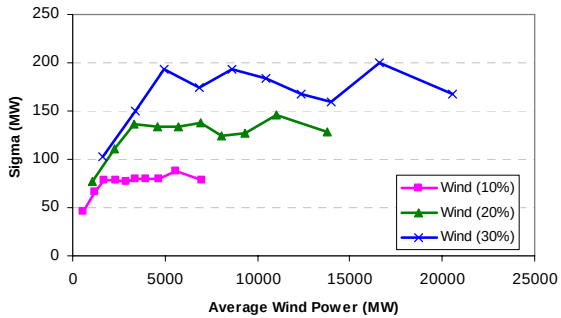
* For Balance of this portion of the presentation Solar is disregarded: Net Load = Load - Wind

10-minute Variability: Wind and Net Load - 3 Scenarios

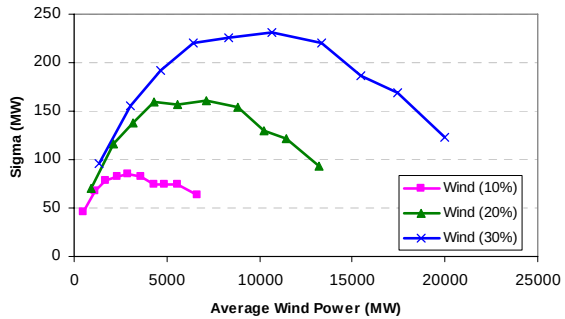
In Area 2006

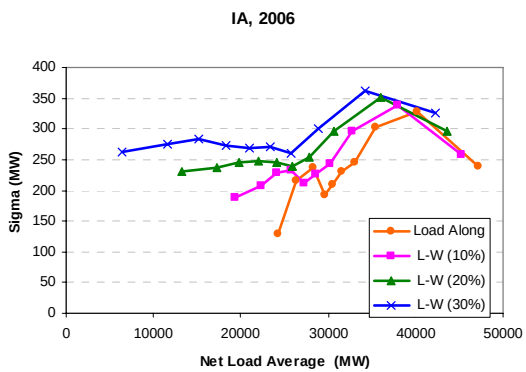


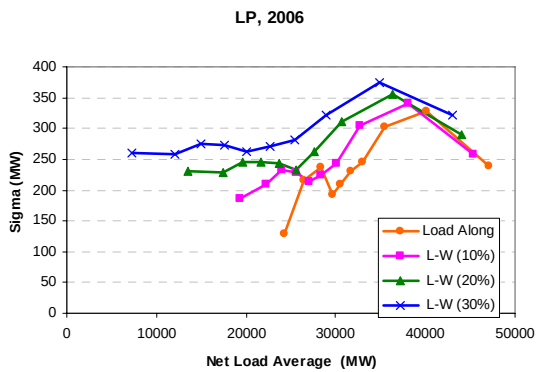
Local Priority 2006

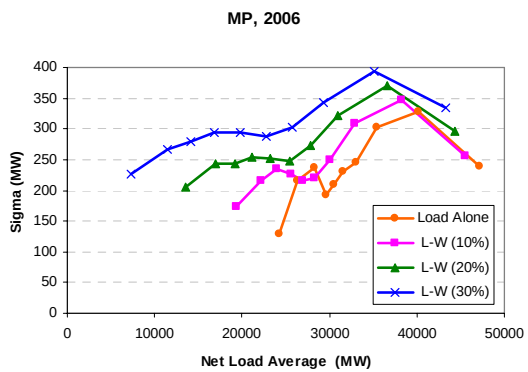


Mega Project 2006





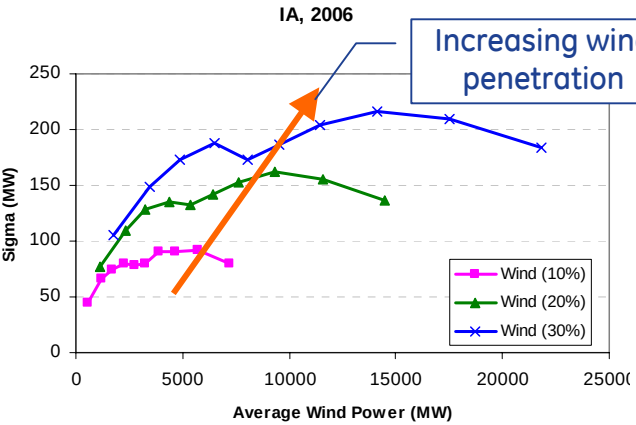




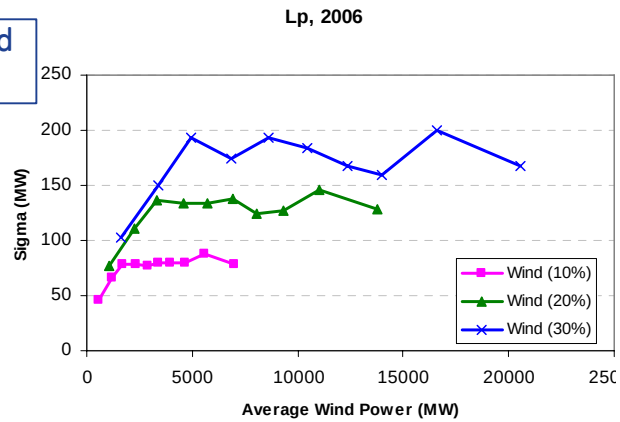
- Wind shapes vary with spacial diversity
  - Mega project more concentrated: looks more like a single plant
- Net load trends similar at study footprint level

imagination at work

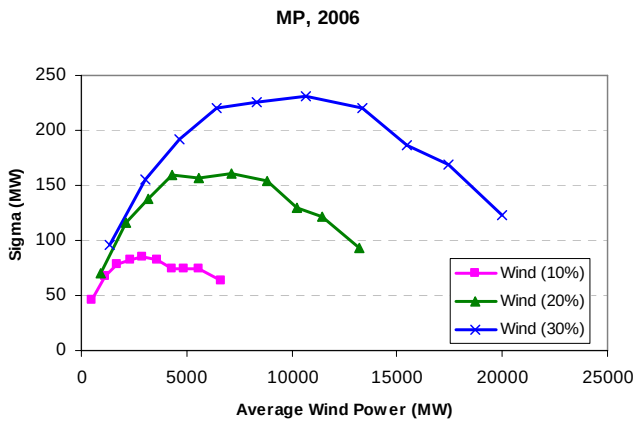
Wind Variability: Normalized to Installed Rating



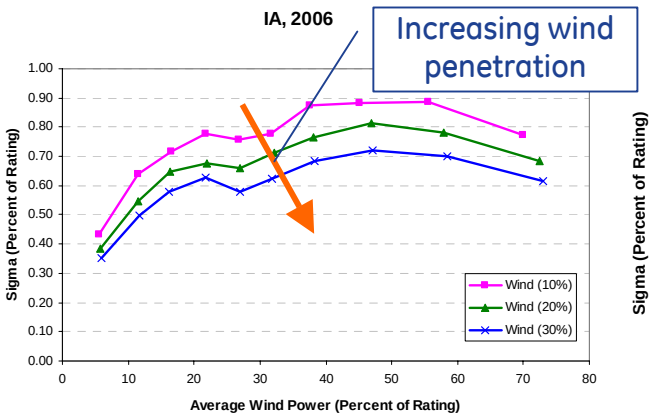
10% Nameplate	10290
20% Nameplate	19950
30% Nameplate	29940

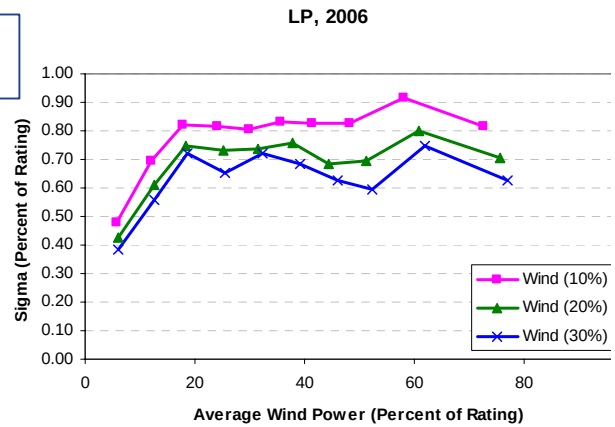


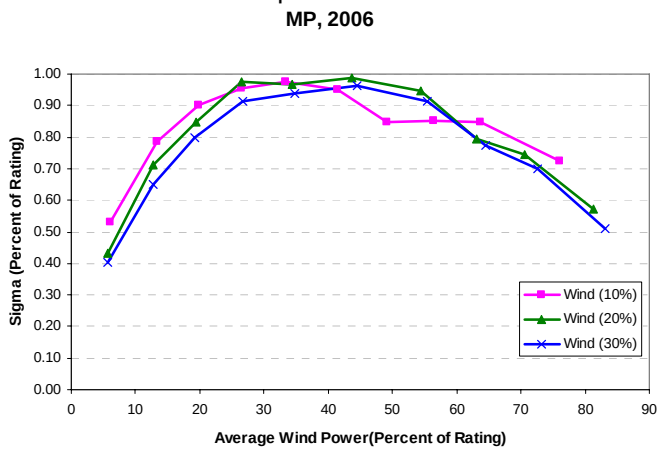
10% Nameplate	9600
20% Nameplate	18180
30% Nameplate	26760



10% Nameplate	8700
20% Nameplate	16260
30% Nameplate	24030







- Higher penetration – relatively less variability
- Wider distribution – less variability and less dependence on wind level

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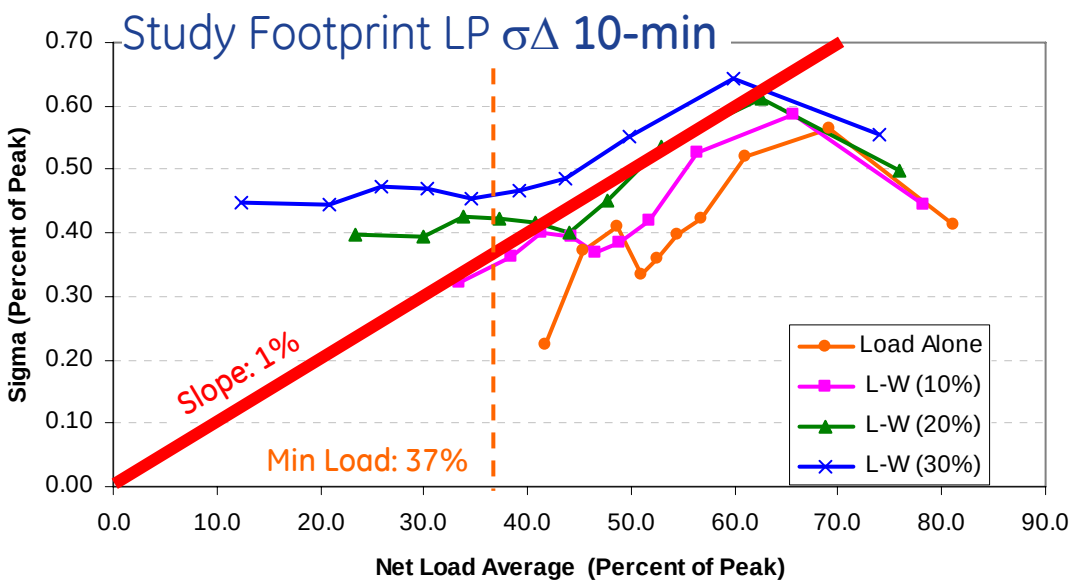
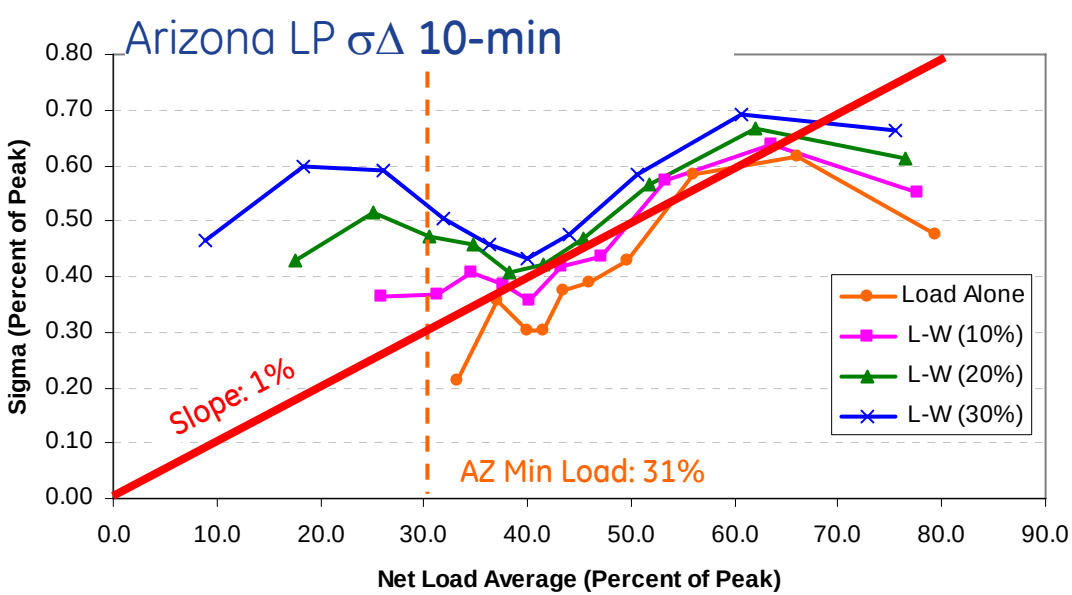
What do we do with σΔ 10-min?
What is relationship to 3% of load for spinning reserve?



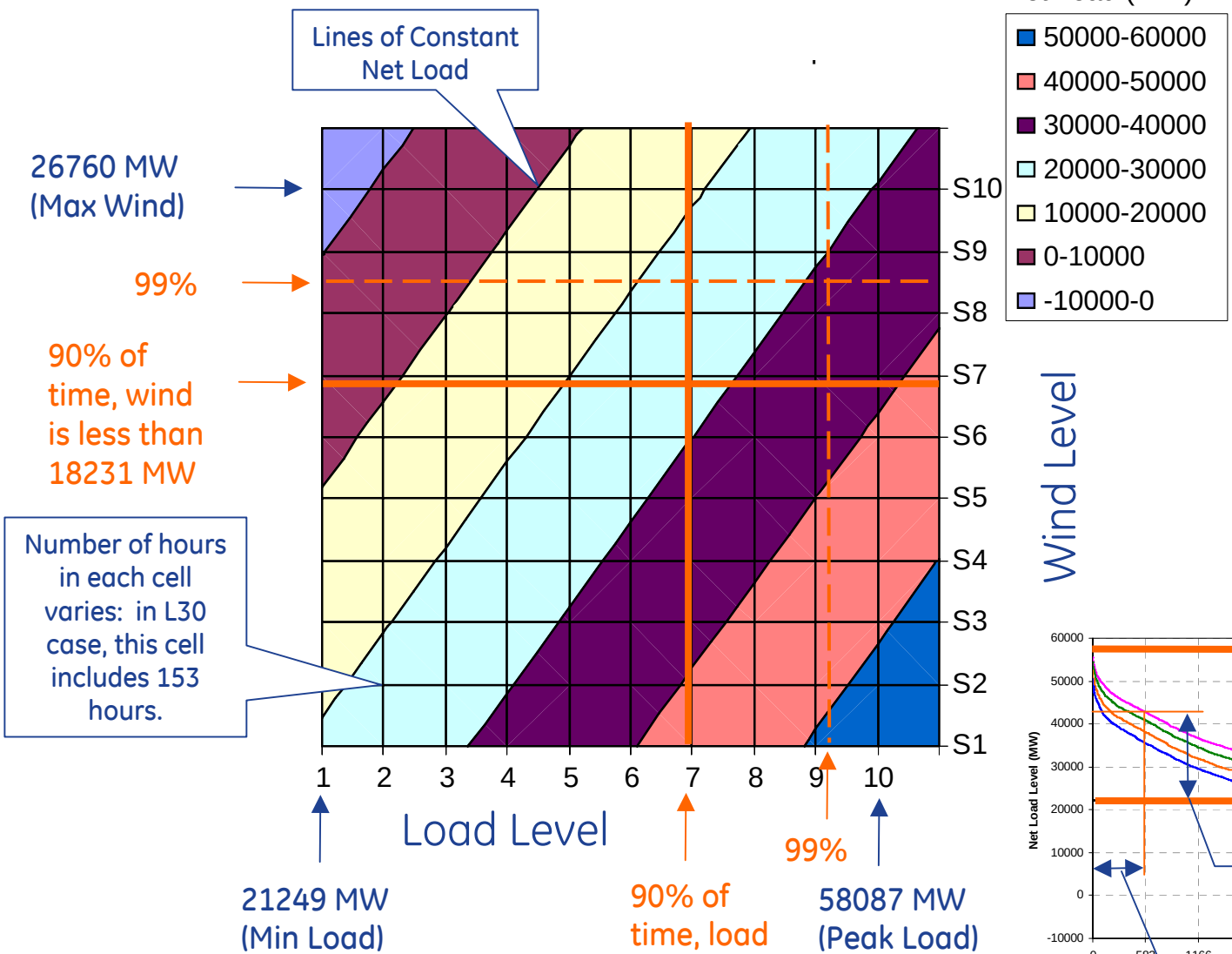


Relationship between 10-min load delta and present spin practice (3% rule):

- Load variability roughly proportional to Load level (up to moderately high loads
- On a large area basis (e.g. AZ), proportionality is ~ 1% of load
- Therefore, 3% of load rule roughly corresponds to 3σ of 10-min variability
- We will build on this relationship, that is:

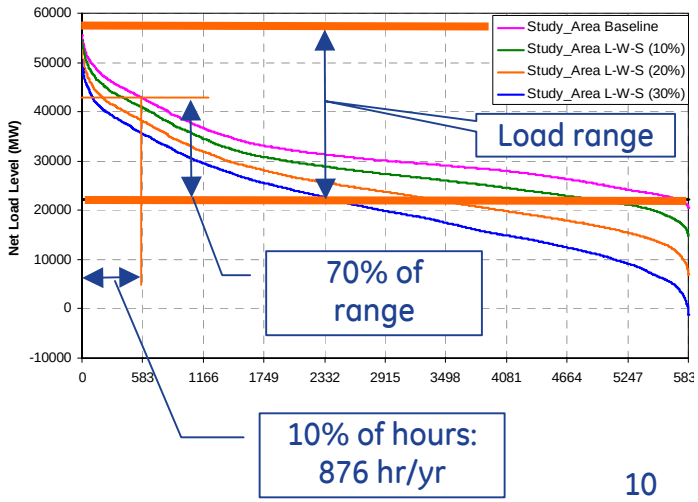
For all operating conditions there is an implied reserve requirement: 3 x σ 10-min Δ Net Load

L30 Load - Wind - Net Load Relationship



What is this plot ???

a. Each year has 8760 hours.
b. Load varies between a minimum and maximum
c. Wind power varies between zero and a maximum
d. The range of load and wind are each divided into 10 equal sized buckets
e. So, there are 100 combinations of load & wind
f. The value (color) at each intersection is the Net Load for that combination



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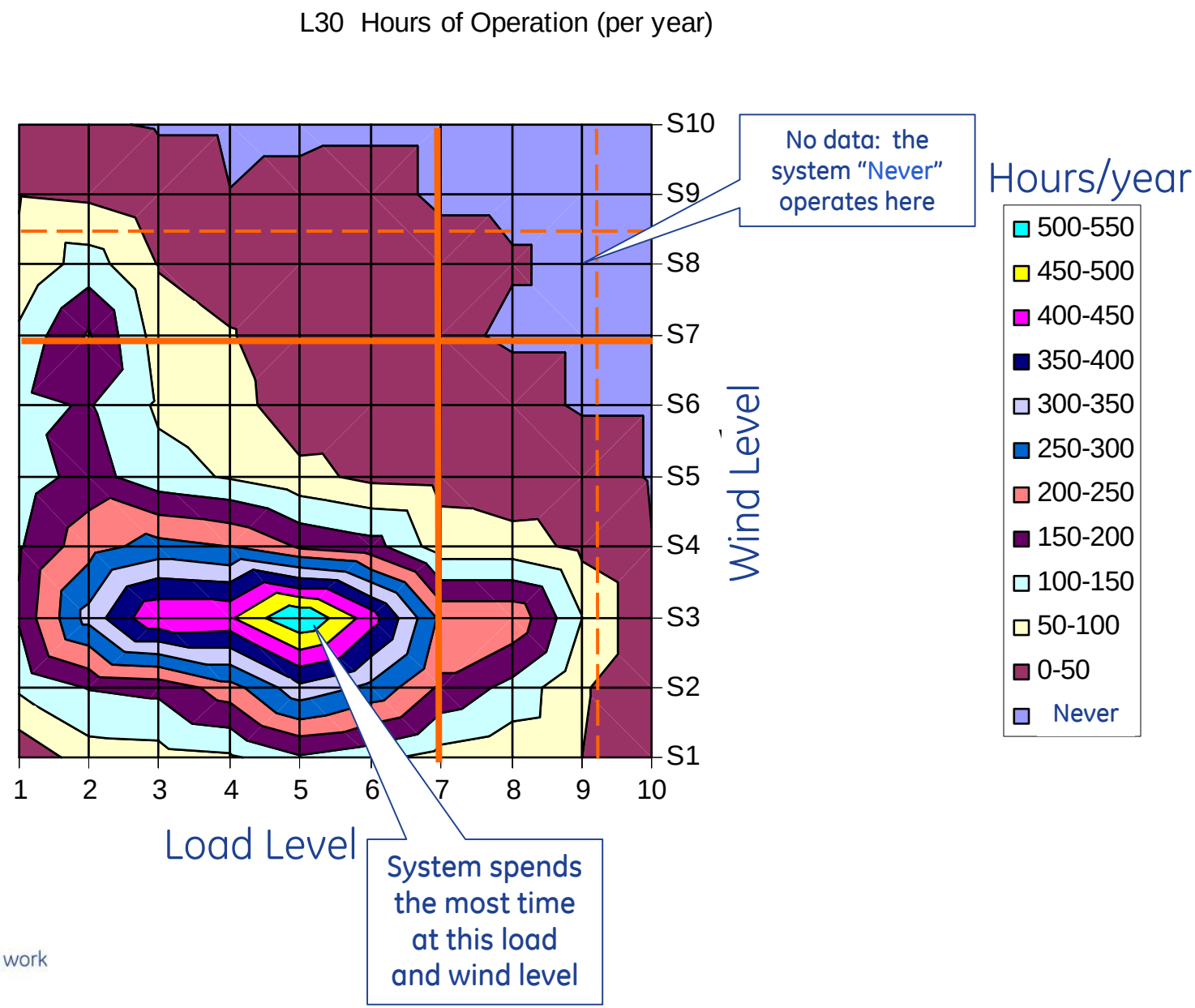
Operations L30: Hours of Load & Wind Combinations



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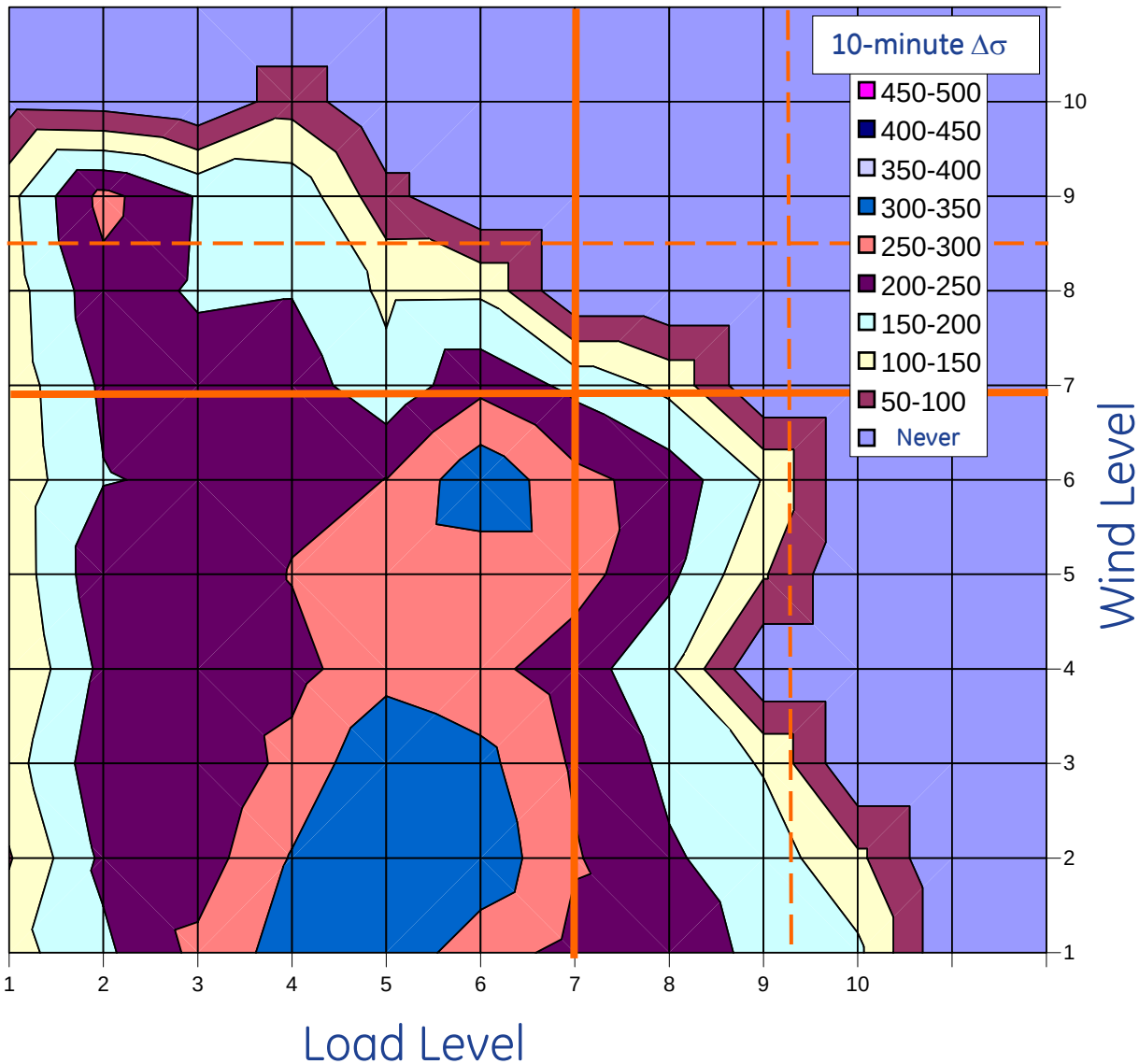
Load Only Variability L30



- Load variability highest at moderate loads
- Dominated by diurnal load cycle

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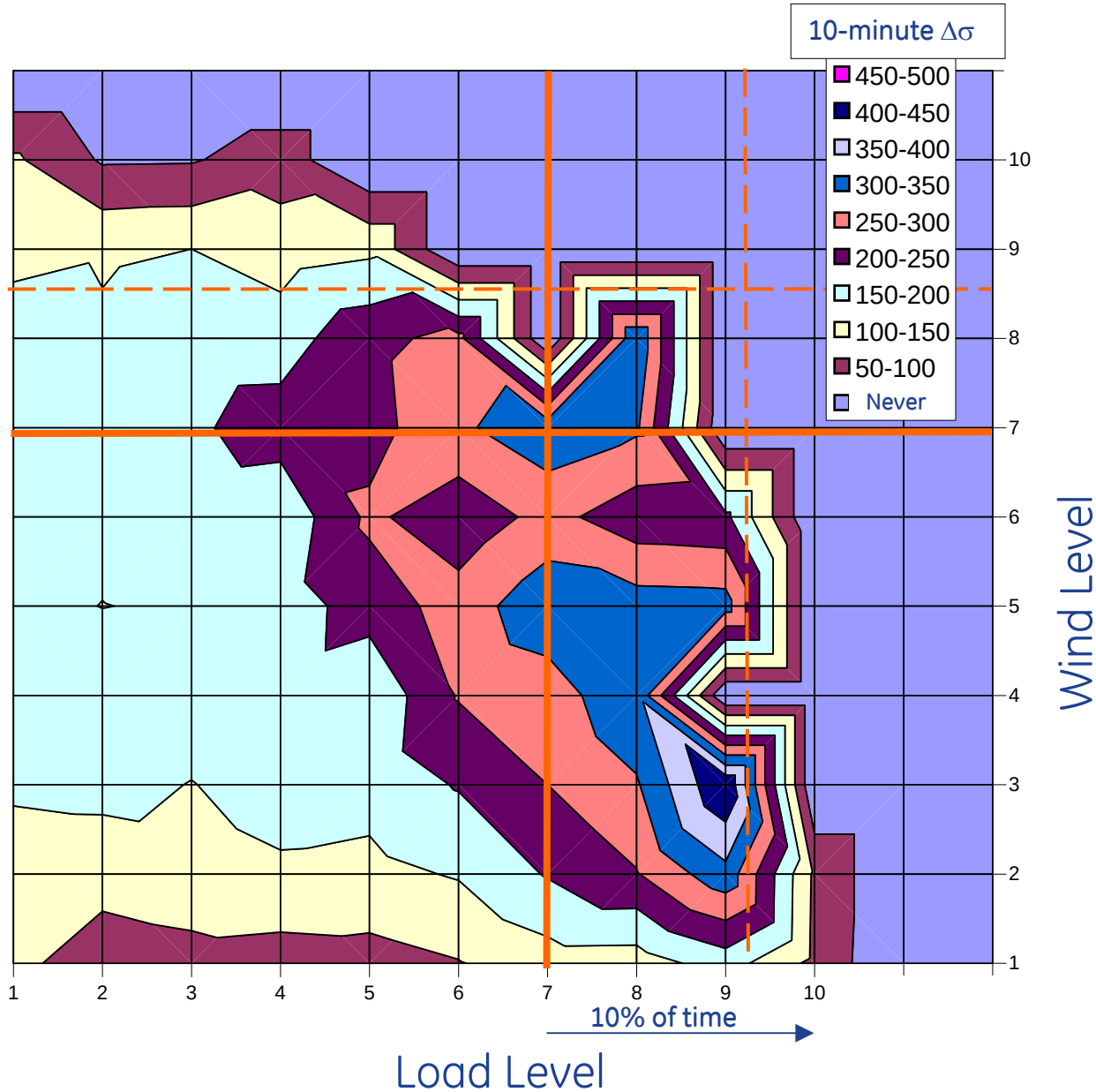
Wind Only Variability L30

- Wind variability appears to be affected by load level
- Not Intuitive
- But maybe it makes sense…
- Diurnal patterns suggest wind is more variable during periods of high load: i.e. during the day



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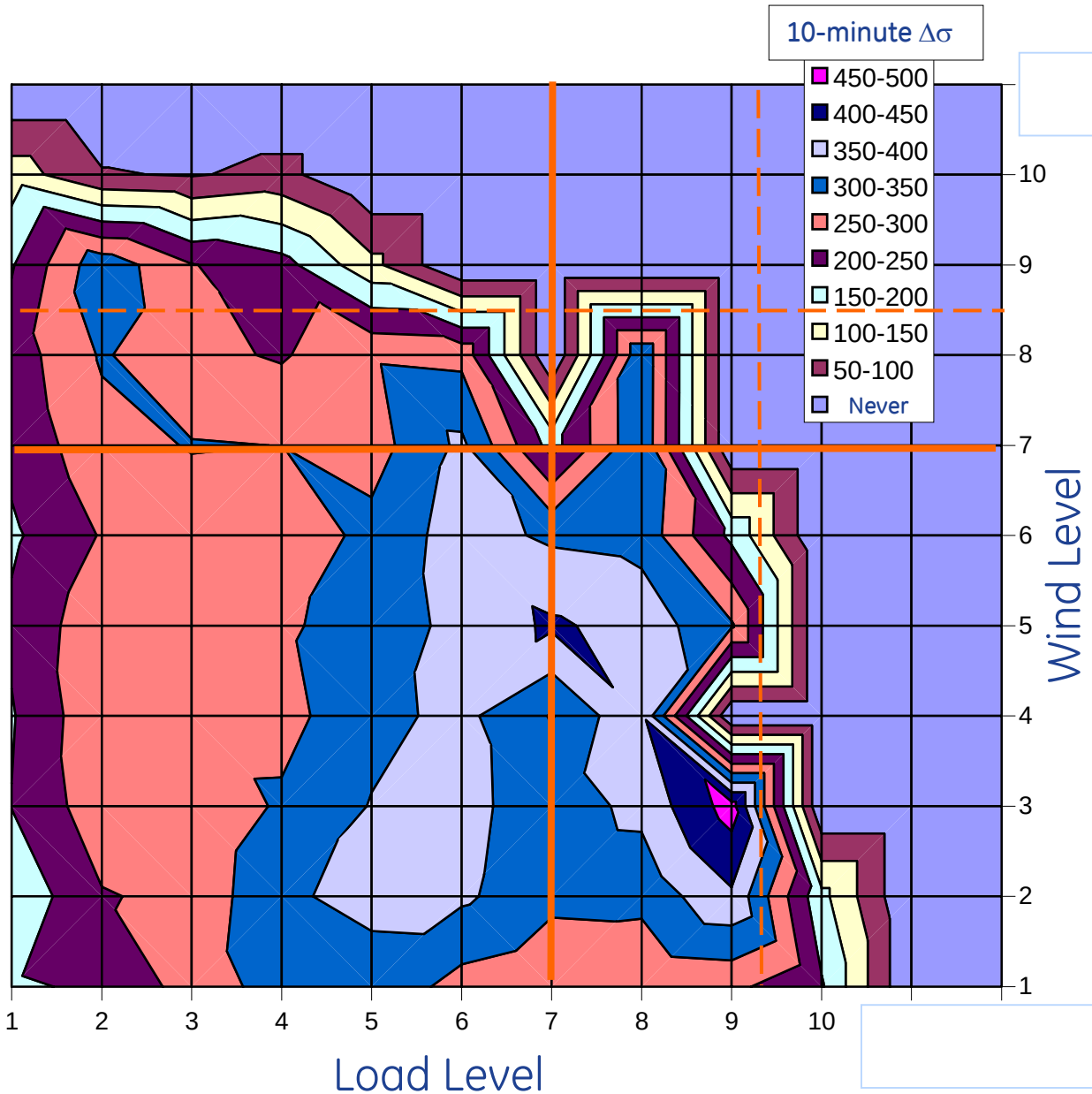
Net Load Variability L30

- Net load variability increases with wind
- Implied reserve requirement is 3 x $\Delta\sigma$
- Requirement is a function of both load level and wind level



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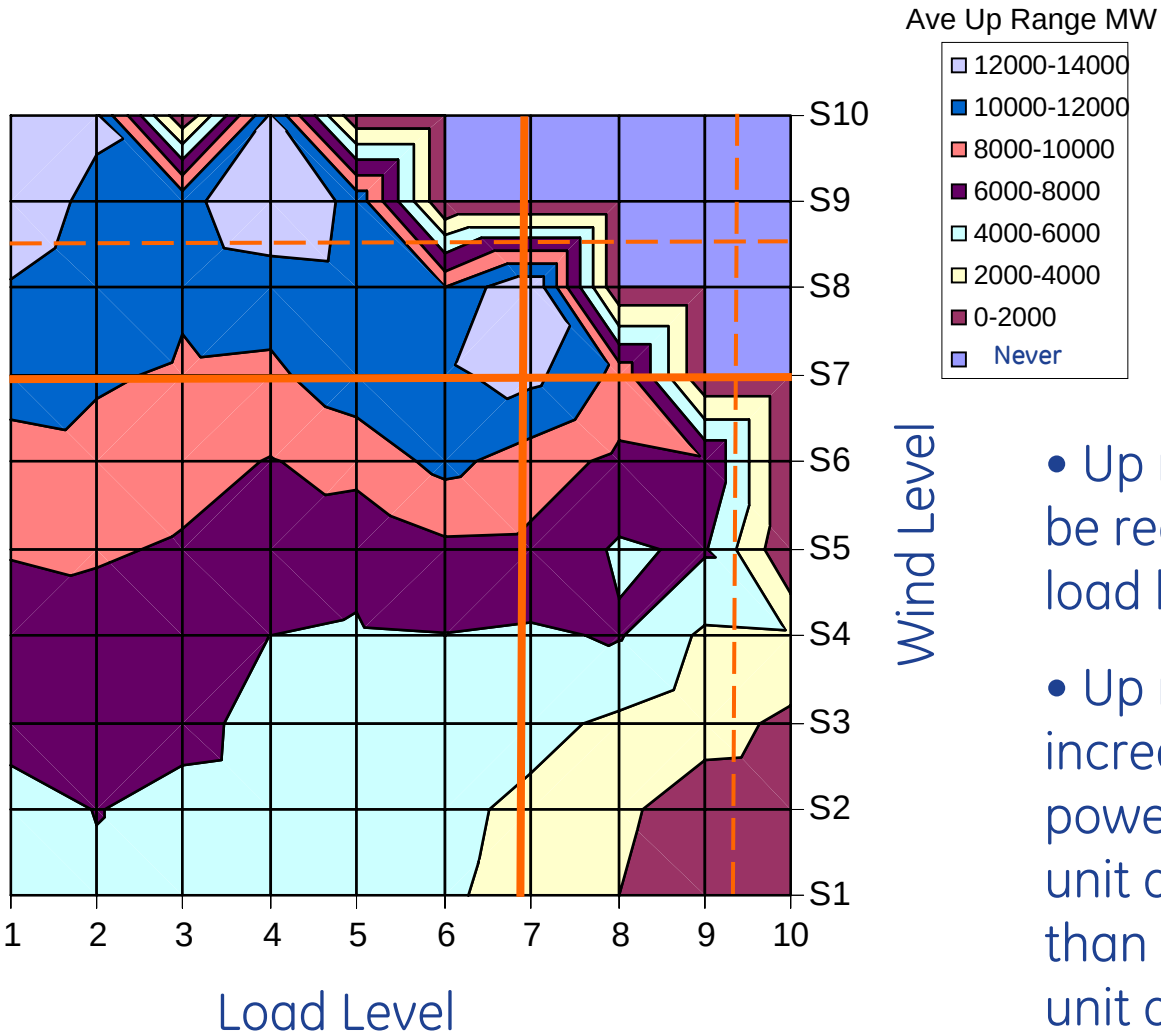
Intra-hour Variability Performance

- How did the system 'naturally' in MAPS perform?
- We show how L30R MAPS case results compare to implied reserve requirements.

Average Up Range L30R case



- Up reserves tend to be reduced at high load levels
- Up reserves tend to increase with wind power: reduction in unit dispatch more than compensates for unit de-commitments

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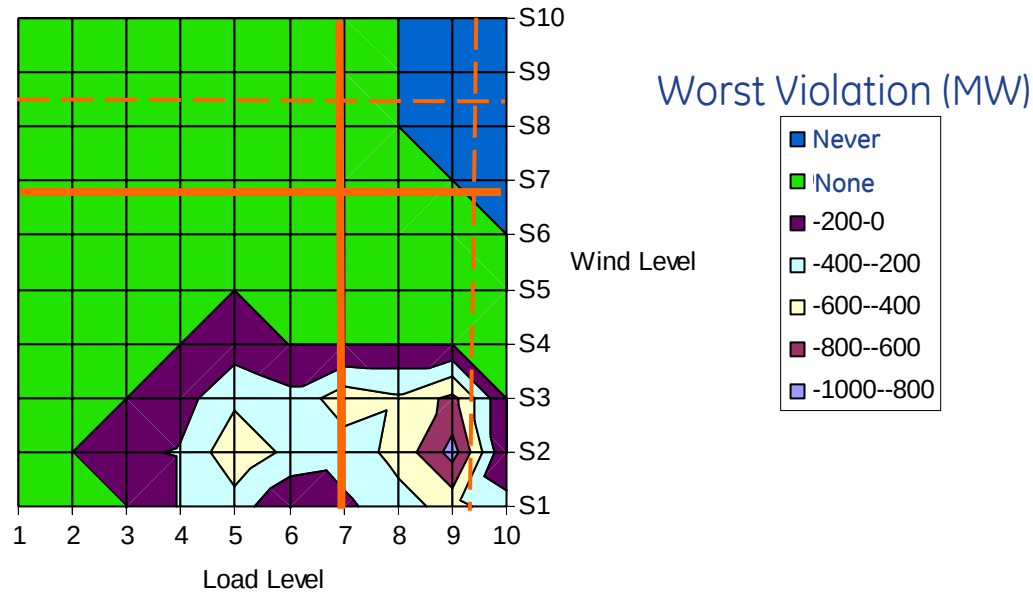
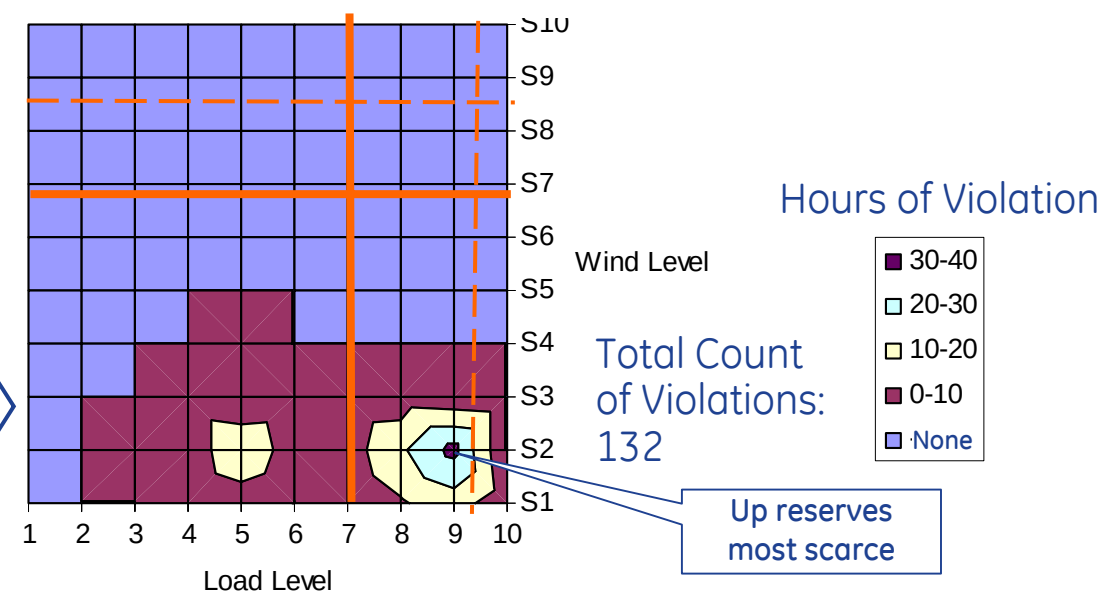
L30R Case Up Reserve Violations

- Implied reserve requirement is 3 x σ 10-min Δ Net Load
- Violation if **Up Range** (from MAPS case) < 3σ
- Violation means hour has insufficient reserves to meet implied requirement. Load is still served.





Scarcity of reserves at very high load aggravated by increased reserve requirement due to wind variability

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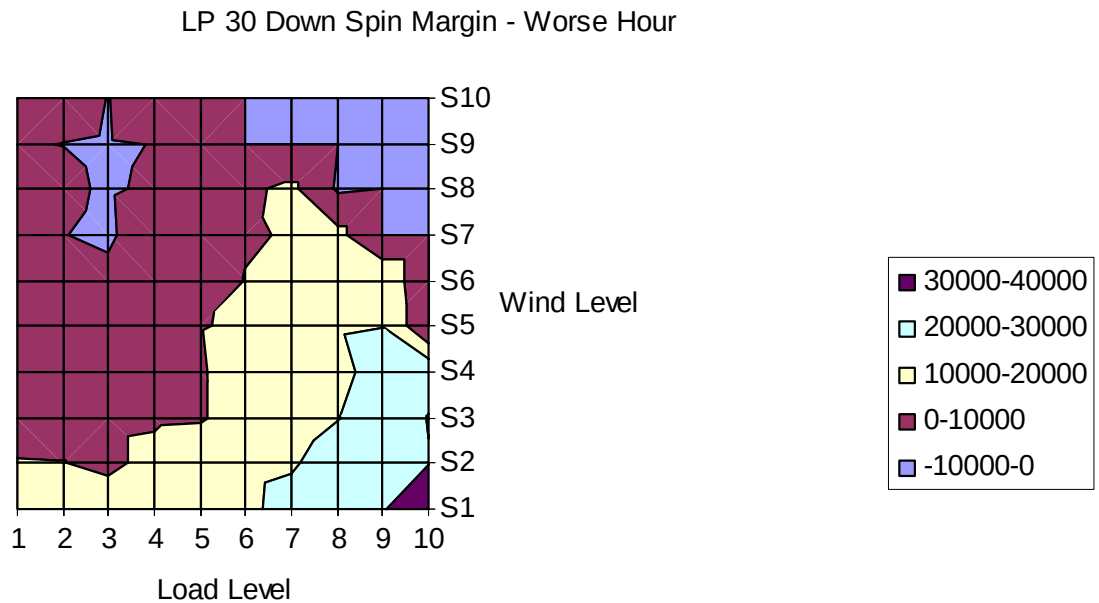
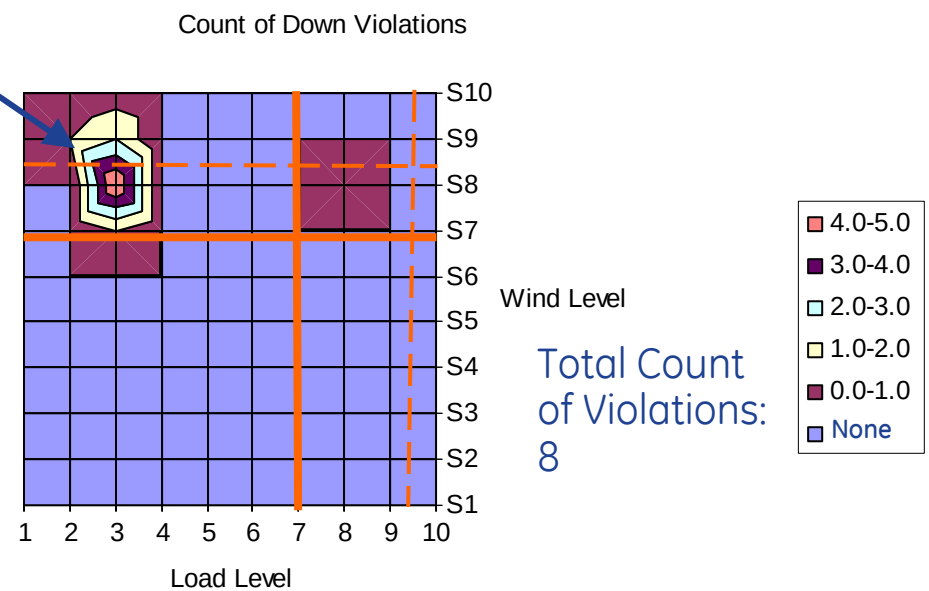
L30R Case Down Reserve Violations

- Scarcity of down reserves at very high wind and relatively light load is consistent with other results





Total Count of Violations: 8

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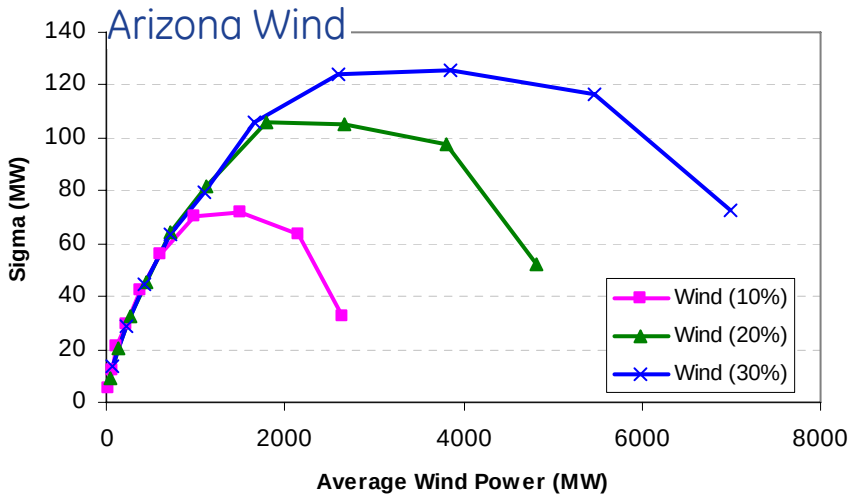
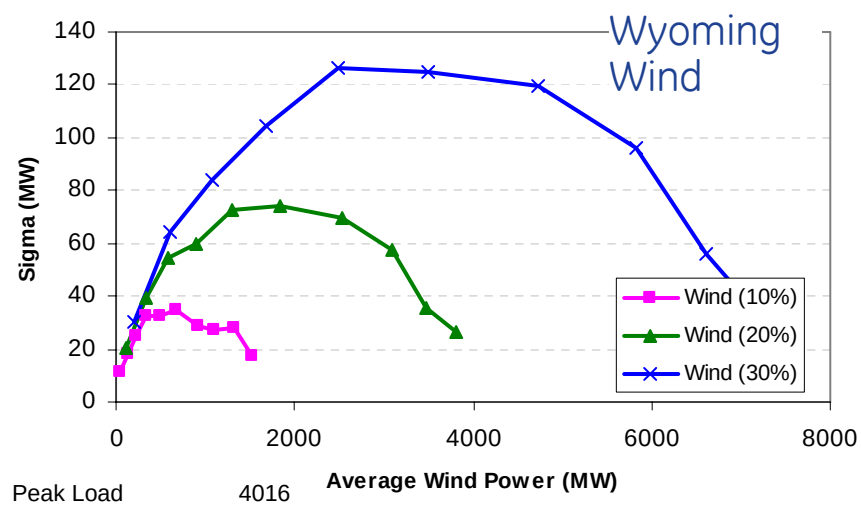
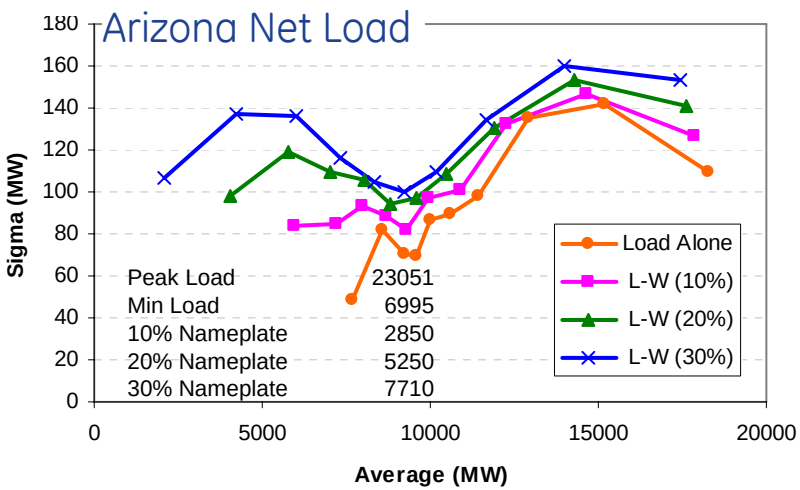
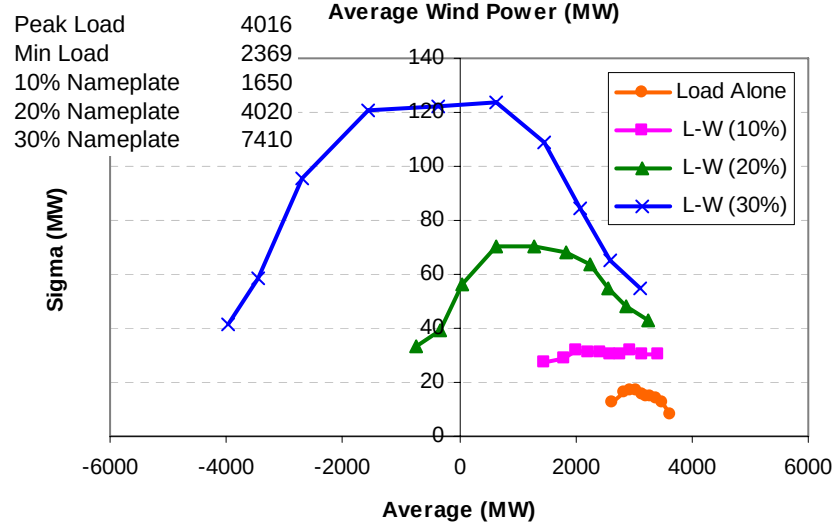
Arizona & Wyoming: Average (MW) vs Sigma of 10-min Delta (MW)





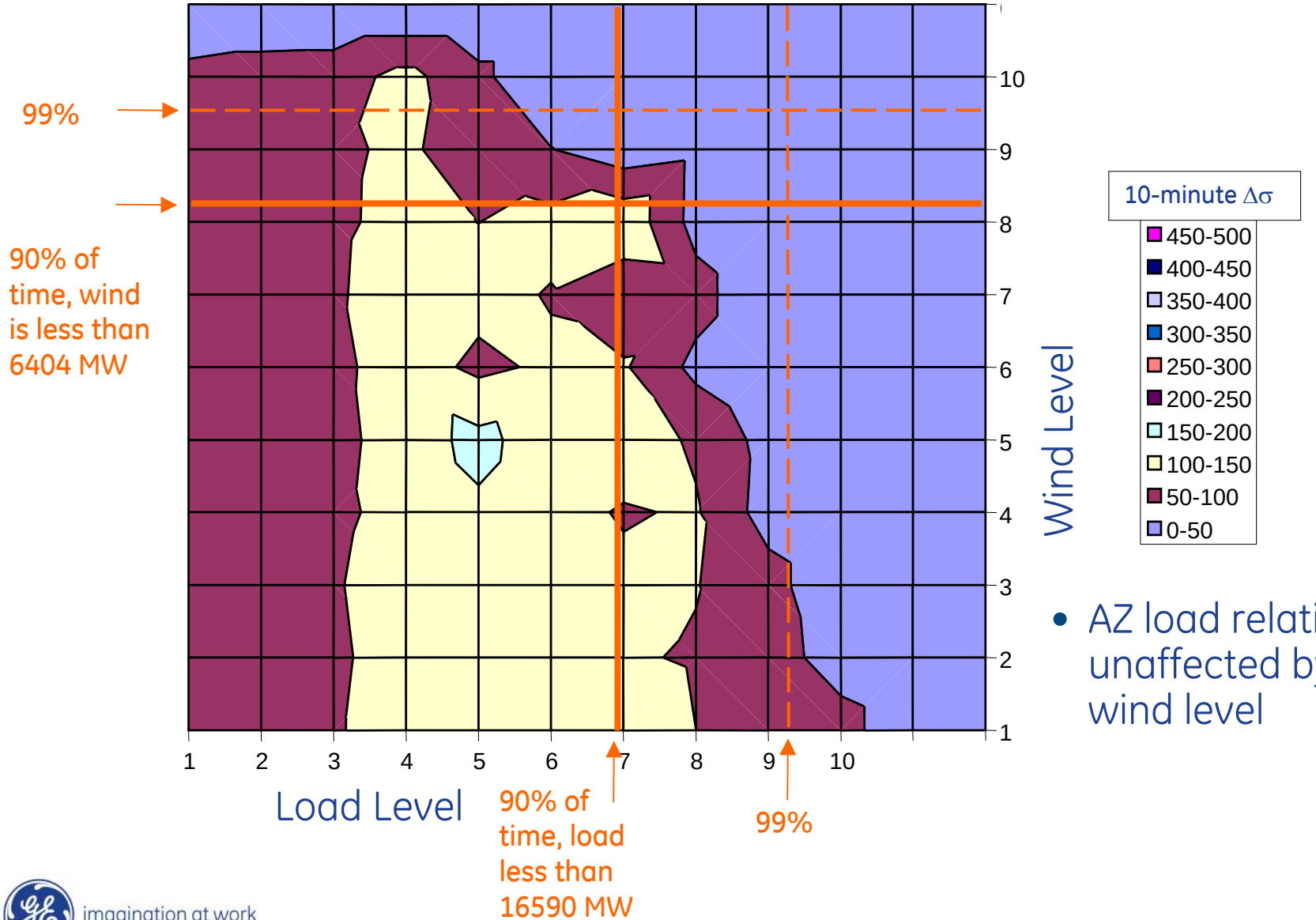




- At area level wind impact is more observable
- By the time that we get to a very high system like Wyoming, wind dominates

Arizona L30R results

Arizona L30R Load Variability



- AZ load relatively unaffected by wind level

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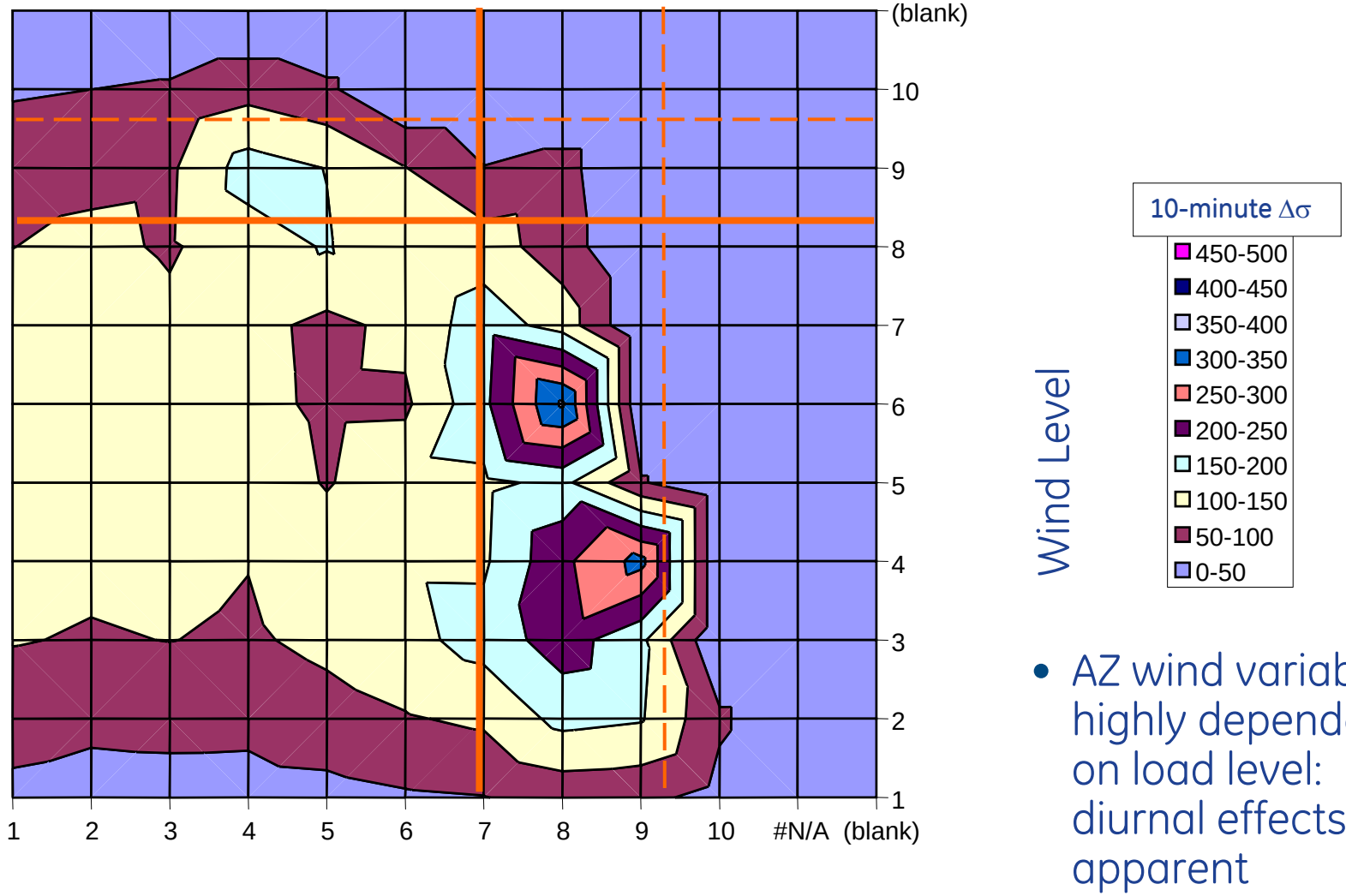
Arizona L30R Wind Variability



- AZ wind variability highly dependent on load level: diurnal effects apparent

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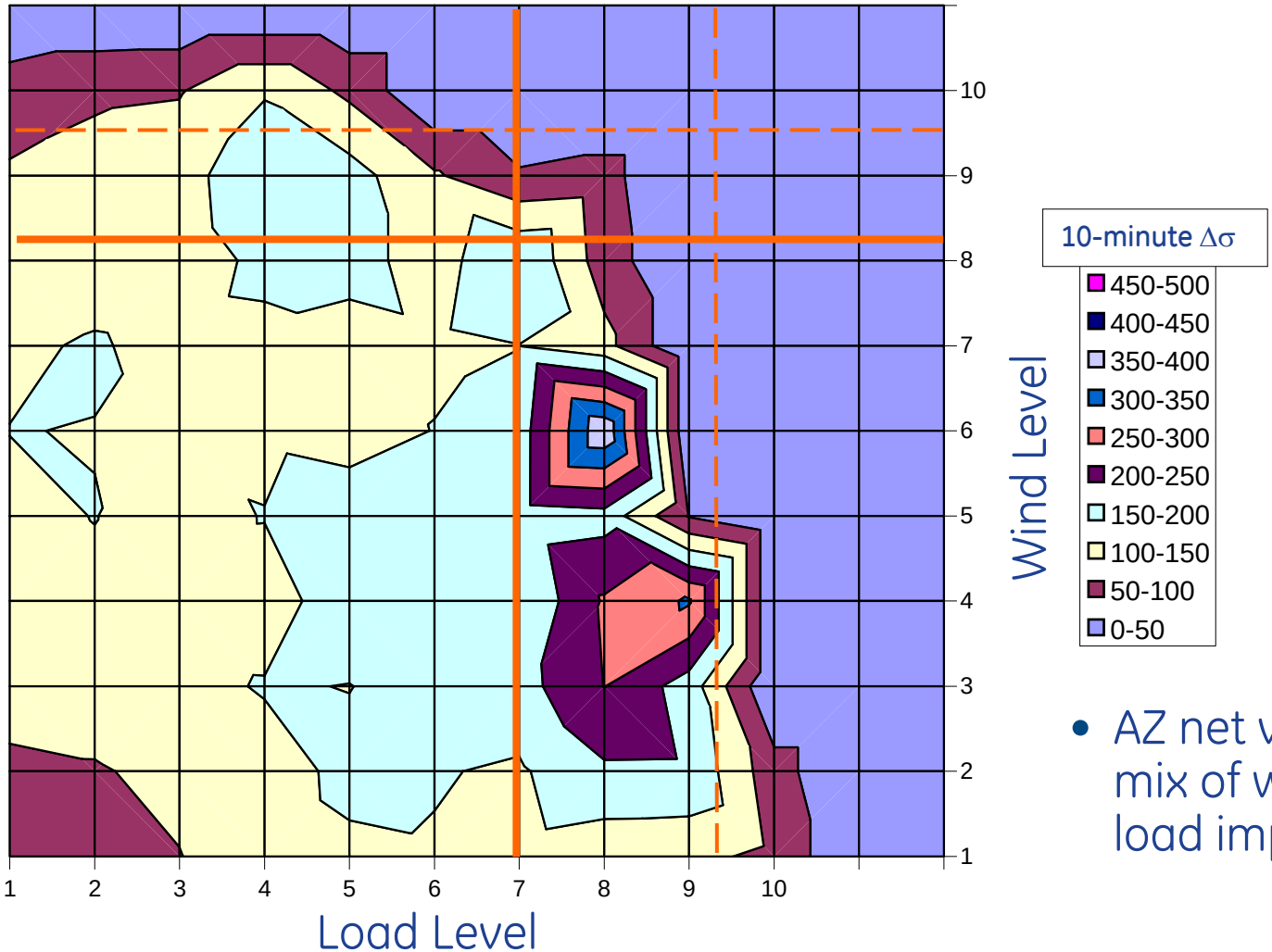
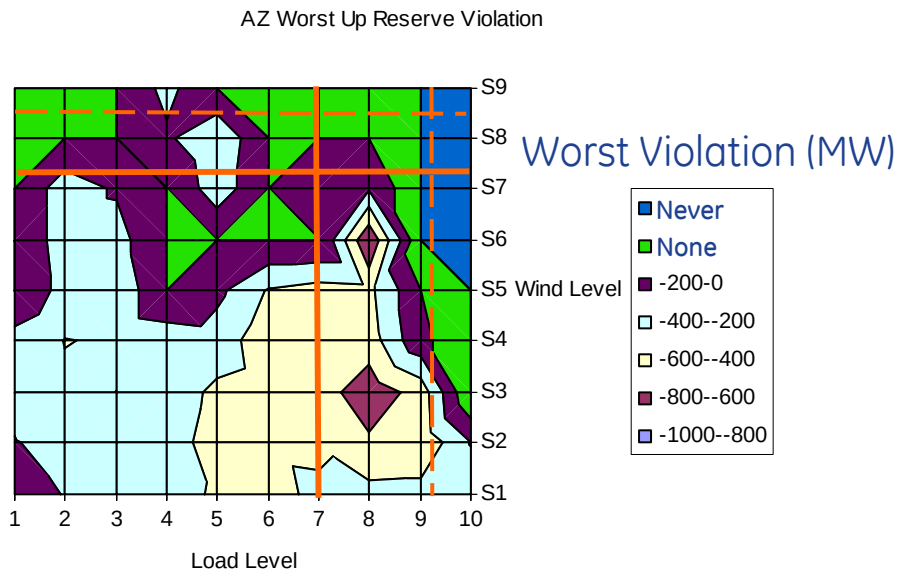
Arizona L30R Net Load Variability

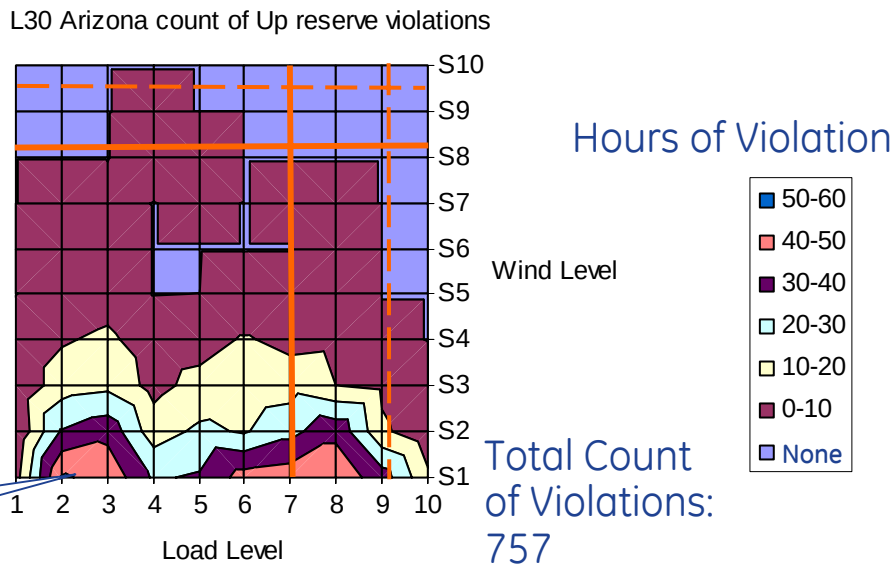


- AZ net variability a mix of wind and load impacts

Arizona L30R Case up Reserve Violations

- Worst violations at high load and moderate wind
- Frequent violations at low wind moderate load: due to Forecast error (?)





Total Count of Violations: 757

Up reserves short due to over-forecast of wind power ?

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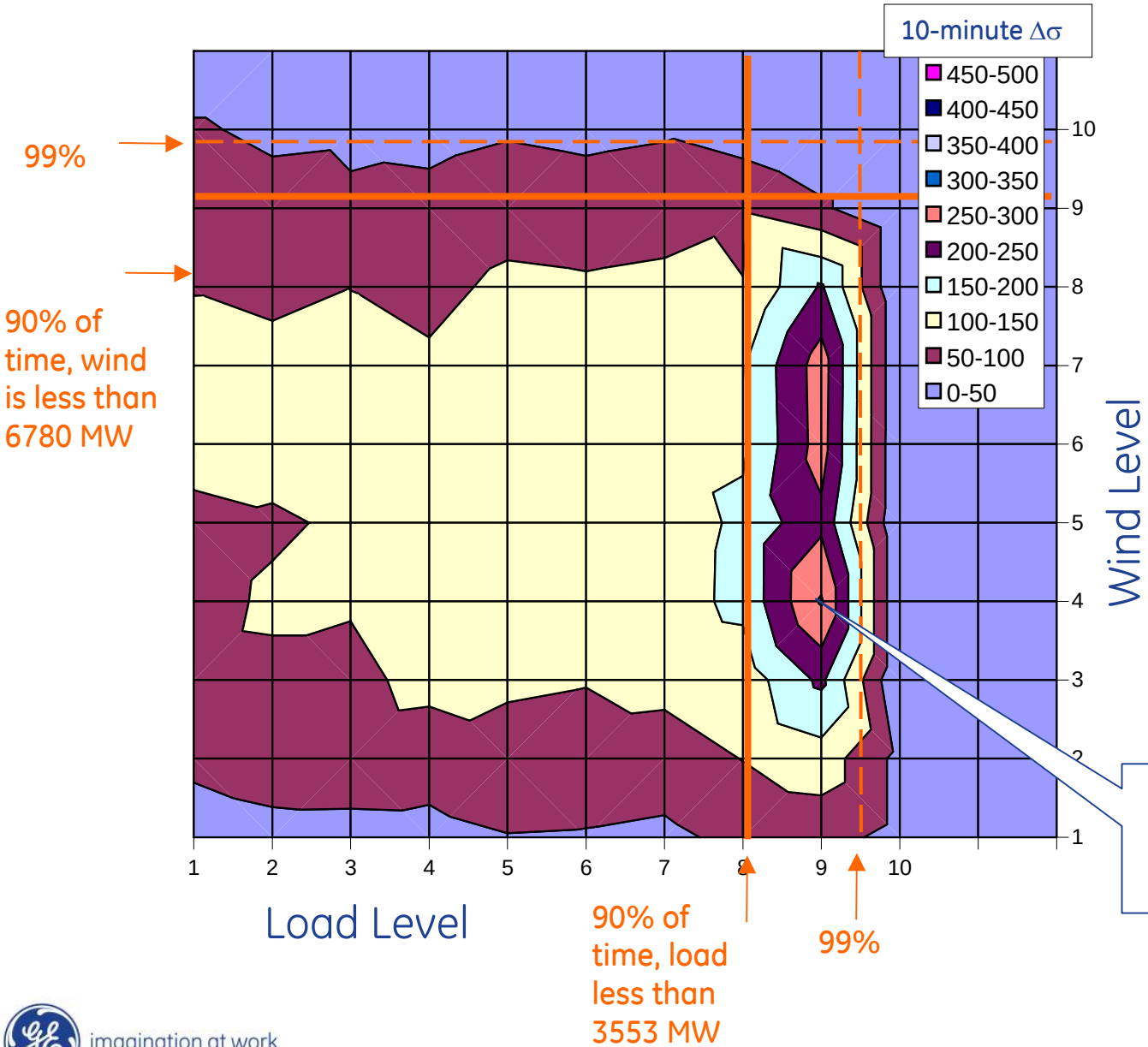
Wyoming L30R results

Wyoming L30R Wind Variability



- Wind variability slightly dependent on load level – except at very high loads (small sample?)
- High variability at middle of wind power range is an expected characteristic

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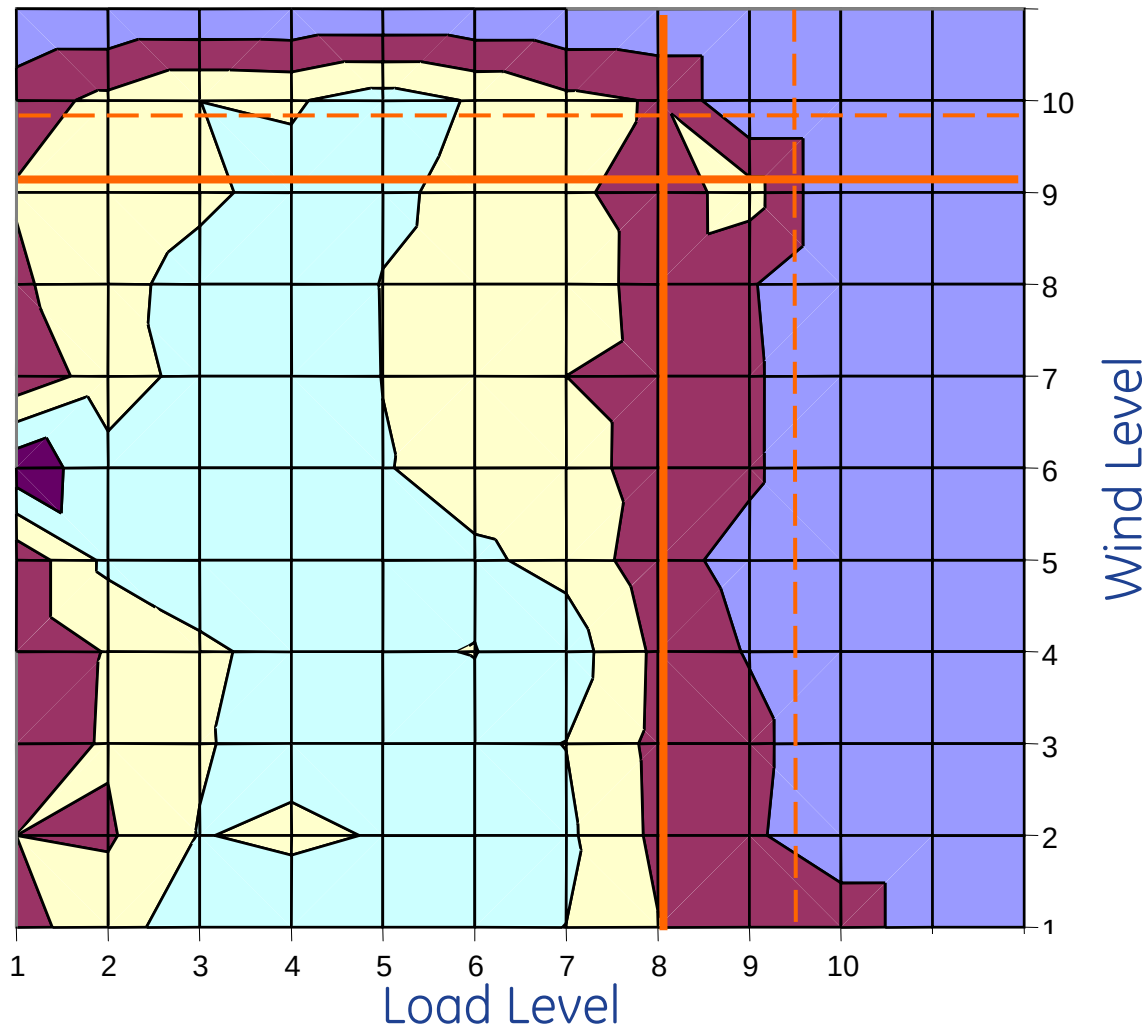
Wyoming L30R Load Variability

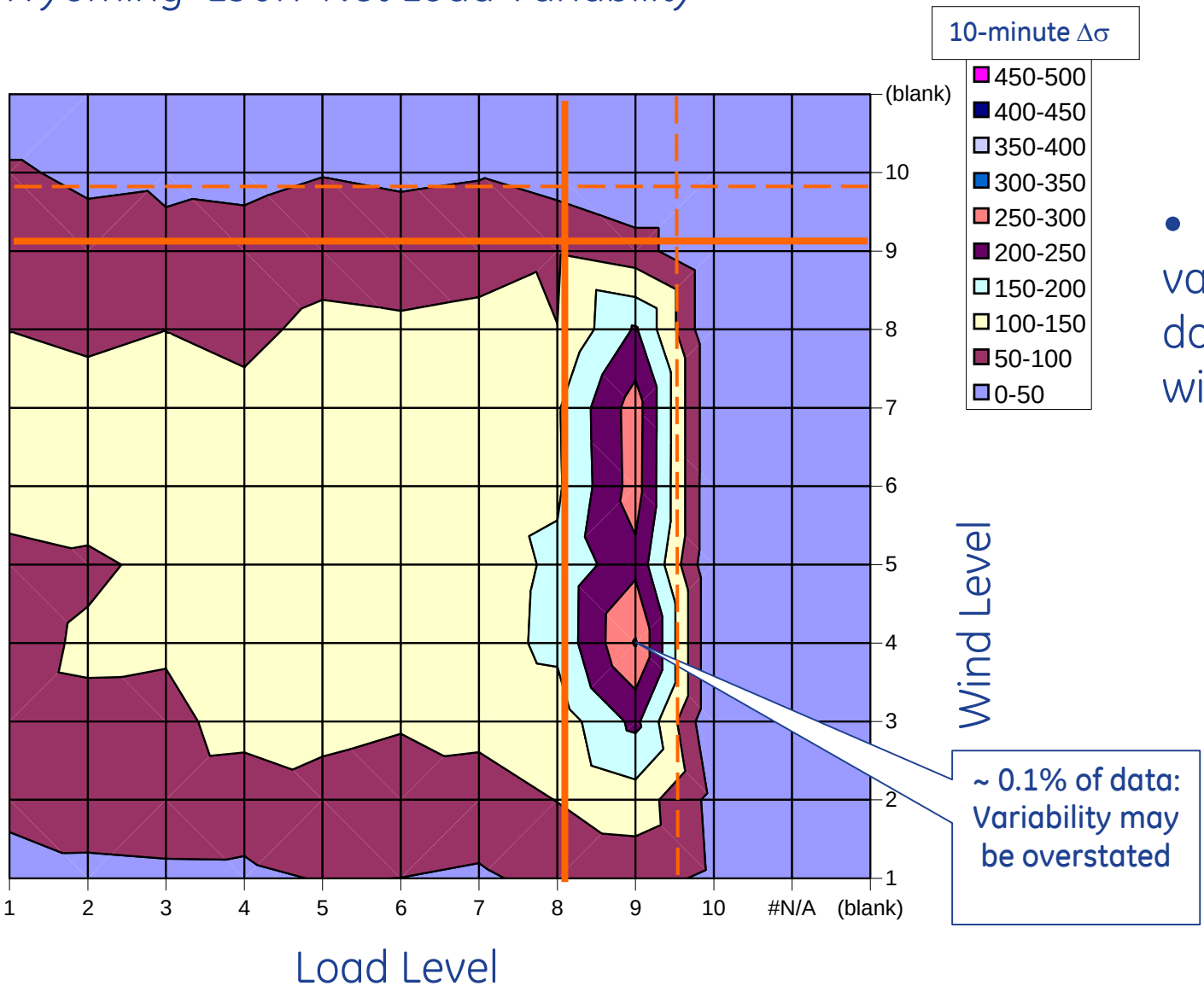


Note scale

- 20.0-25.0
- 15.0-20.0
- 10.0-15.0
- 5.0-10.0
- 0.0-5.0

- Load variability basically insignificant compared to wind variability

Wyoming L30R Net Load Variability



- Net Load variability totally dominated by wind variability

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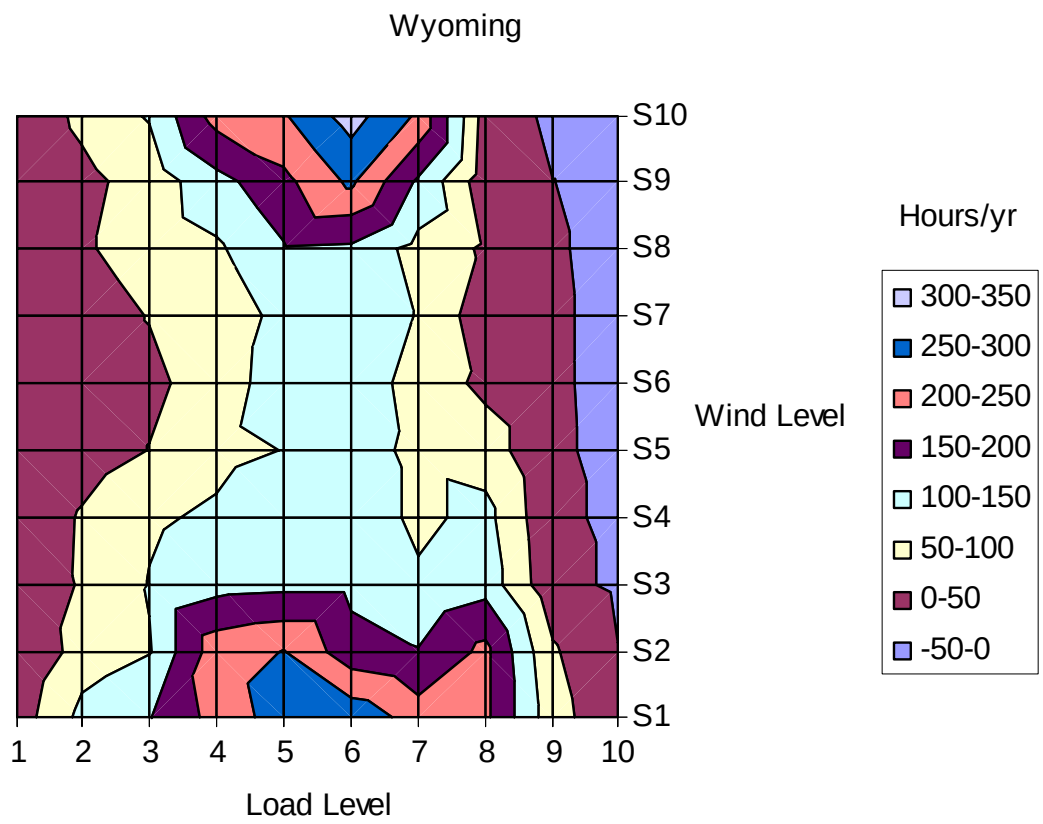
Wyoming L30R Time Space

- Wyoming wind bi-modal:

Relatively light wind or relatively strong wind

- Periods of highest implied reserve requirements are less common, but…



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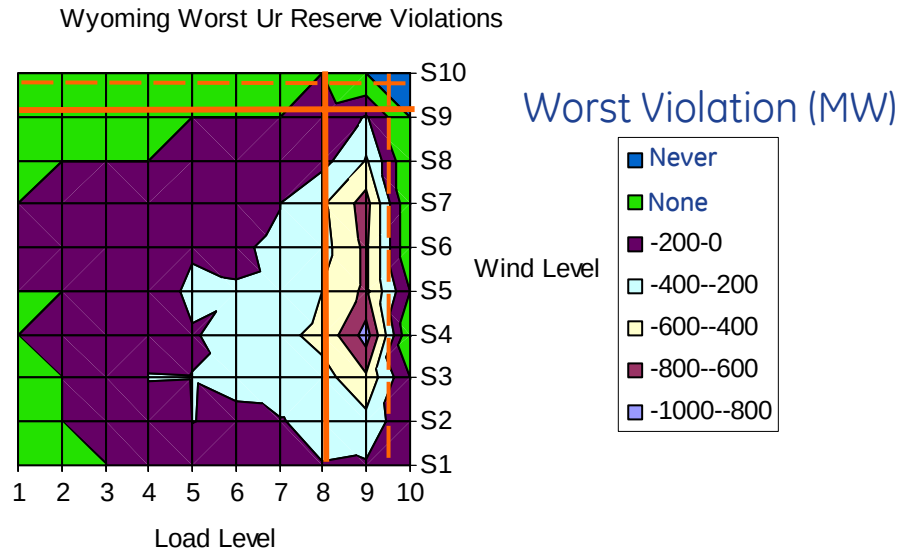
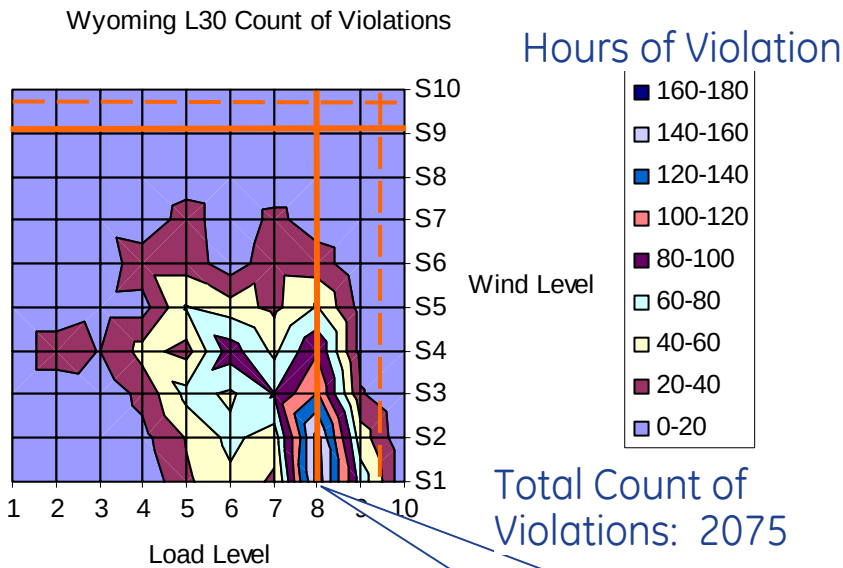
Wyoming L30R Case up Reserve Violations

- Wyoming, with about twice as much wind as load, doesn't come close to meeting implied reserve requirement with in-state resources in this case





Total Count of Violations: 2075

100% of hours at Load Level 8 in violation

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Intra-hour Variability - Summary

- Intra-hour variability increases with wind
- Smaller the ‘circle’, bigger the effect
- On FP or WECC level, variability ‘looks’ similar..change is incremental, not revolutionary
- On Area (state) level, variability starts to look very different…eventually dominated completely by wind (e.g. WY)
- On smaller (e.g. zonal) basis, variability clearly intractable…2 orders of magnitude increase…old rules unsuitable/impossible
- Examination of subhourly performance suggests that rationally committed and dispatched systems, using imperfect DAH wind forecasts, can work well, if reserve resources are shared.
- Modified (usable, practical) rules for spin appear possible

Intra-hour Variability – Next Steps

- Develop additional understanding of implications of day ahead wind forecast error on reserve capabilities
- Examine other states, scenarios and renewable levels
- Expand concepts to solar
- Test implications of reserve sharing on inter-area performance, particularly CPS2
- Explore concepts for addressing inter-area performance issues
- Examine allocation of reserve resources, by generation type and dynamic capability
- Test performance with QSS time simulations
- Further develop concepts for modified, simple rules for spinning reserves