British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Forecast Evaluation as Applied to Geomagnetic Activity Categories

Ellen Clarke and Alan Thomson

Outline

- The daily 1-3 day ahead geomagnetic forecast
  - WHAT we try to do and WHO we do it for
- Forecast verification against benchmark
  - Year by year comparisons (2000 to 2013)
  - Comparisons between individual forecasters
- Investigation of performance measures – skill scores
  - Important for on-going automated evaluation
  - What is the most appropriate for this type of forecast?
- Future Plans
  - Further comparisons and feedback to forecasters
  - Revision of the service and user perspectives

What is the Geomagnetic Activity Forecast?

- Predictions are of global average geomagnetic activity levels
- Forecasts are issued every weekday before noon
  - Weekends are not included - not a commercially funded service
- Predictions are for 1, 2 and 3 days (intervals) ahead
- Forecast intervals are 24 hours from noon to noon (UT)
  - More likely to capture storms in the local UK night time sector
- Use public domain space weather observations, models, alerts and forecasts
  - Tap into the specific expertise of various groups around the world
- There are four activity levels to choose from (based on *Ap*)
  - MAJOR STORM, MINOR-STORM, ACTIVE or QUIET-UNSETTLED

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ACTIVITY CLASS	Daily Planetary Activity Level (Ap)
QUIET – UNSETTLED	<=15
ACTIVE	16-29
MINOR STORM	30-49
MAJOR STORM	>=50

The Daily Geomagnetic Activity Forecast

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MAGIC

nationalgrid

Magnetic Activity | Solar Wind | 3-day Forecast | GIC Estimates | Home

Three-Day Global Geomagnetic Activity Forecast

Forecast Interval (GMT)	Forecast Global Activity Level
Noon 14-NOV-2012 to Noon 15-NOV-2012	QUIET-UNSETTLED
Noon 15-NOV-2012 to Noon 16-NOV-2012	QUIET-UNSETTLED
Noon 16-NOV-2012 to Noon 17-NOV-2012	QUIET-UNSETTLED

ADDITIONAL COMMENTS

Yesterday averaged MINOR-STORM globally with periods of MAJOR-STORM recorded between 00:00-09:00UT. In the UK, MINOR-STORM levels were recorded between 01:00-04:00UT at each observatory. This activity was due to a prolonged period of strongly southward pointing IMF in the solar wind following on from the CME shock arrival on the 12th.

The CMEs assocated with the M-class flares from region 11613 yesterday are not expected to be geoeffective. QUIET-UNSETTLED conditions are expected, with a chance of isolated ACTIVE periods as current activity subsides.

TODAYS FORECASTER: Sarah Reay
TIME OF FORECAST : Wednesday, 14 November 2012 11:37:05 GMT
BGS CONTACT PHONE: 0131 667 1000 (switchboard)

Who gets the Geomagnetic Activity Forecast?

Recipients of the daily forecast (over the years) include:

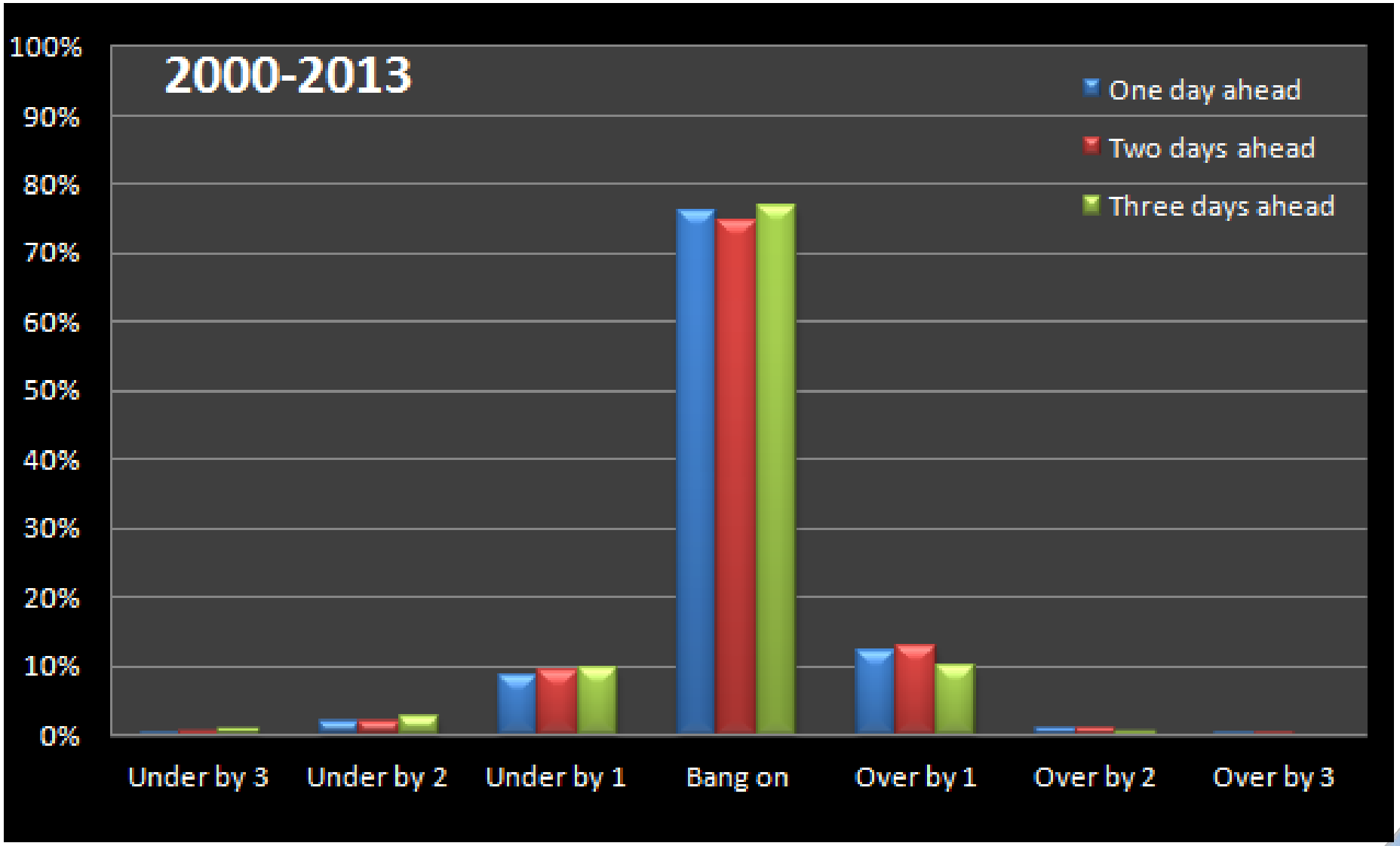
- **Met Office (UK)**
  - Part of the National Hazards Partnerships' Daily Hazard Assessment
  - Informing UK Cabinet Office Civil Contingencies Secretariat
- **Power companies concerned about Geomagnetically Induced Currents**
  - E.g. Scottish Power and National Grid
- **Oil and Gas industry companies using directional drilling techniques**
  - E.g. Halliburton Sperry Drilling and Baker Hughes
- **Geophysical prospecting companies**
- **Organisations working on instrument calibrations**
  - E.g. National Physical Laboratory and Bartington Instruments
- **Geomagnetism colleagues and partners**
  - Planning for field work or absolute observations at observatories

How can we verify the accuracy of our forecasts?

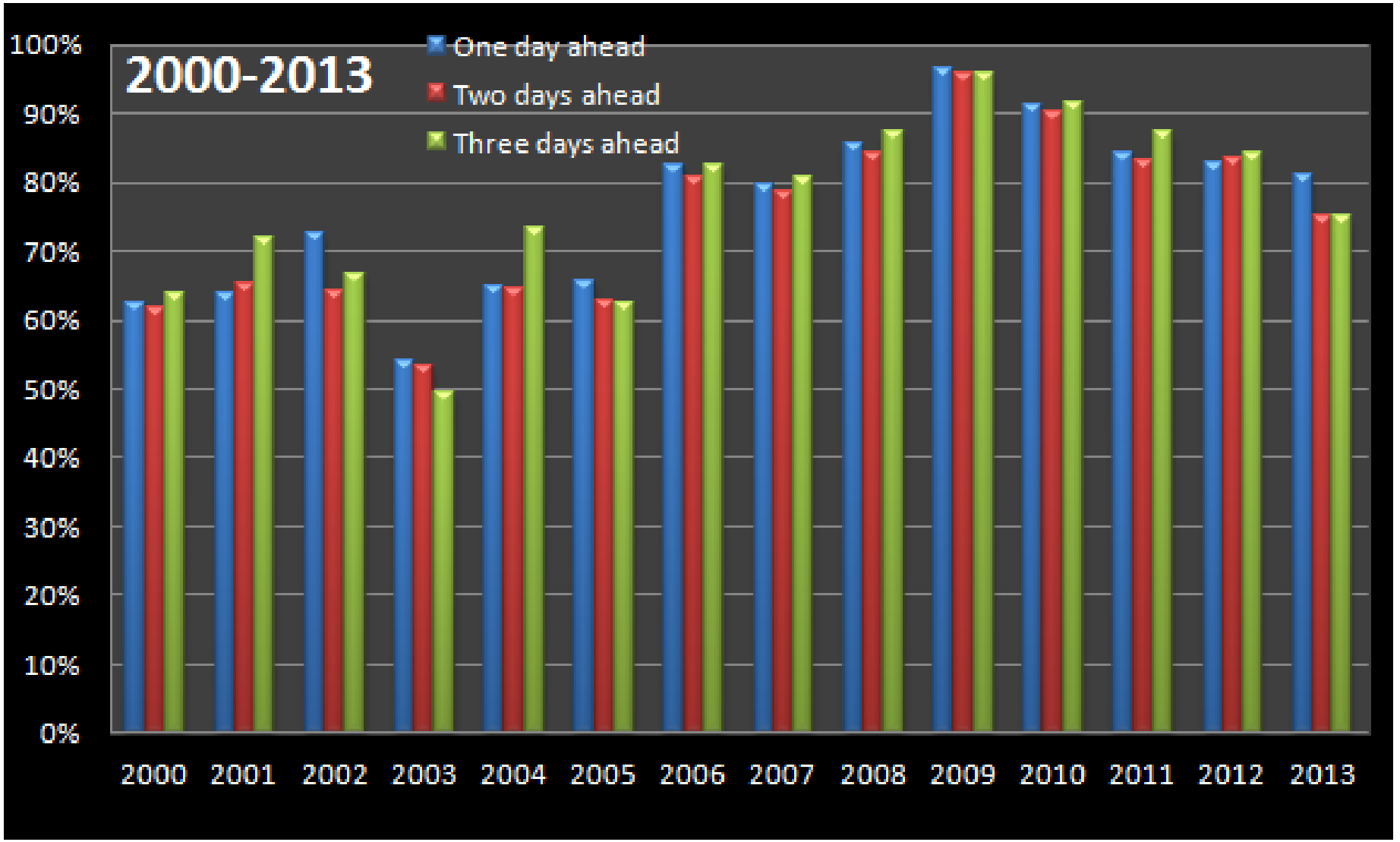
BRITISH GEOLOGICAL SURVEY: NATIONAL GEOMAGNETIC SERVICE
GEOMAGNETIC ACTIVITY FORECAST FOR SPERRY DRILLING

Forecast Interval (GMT)	Forecast Global Activity Level
Noon 28-OCT-2003 to Noon 29-OCT-2003	ACTIVE
Noon 29-OCT-2003 to Noon 30-OCT-2003	MINOR-STORM
Noon 30-OCT-2003 to Noon 31-OCT-2003	MINOR-STORM

Simple Verification Statistic (% correct)



Simple Verification Statistic - % Correct by Year



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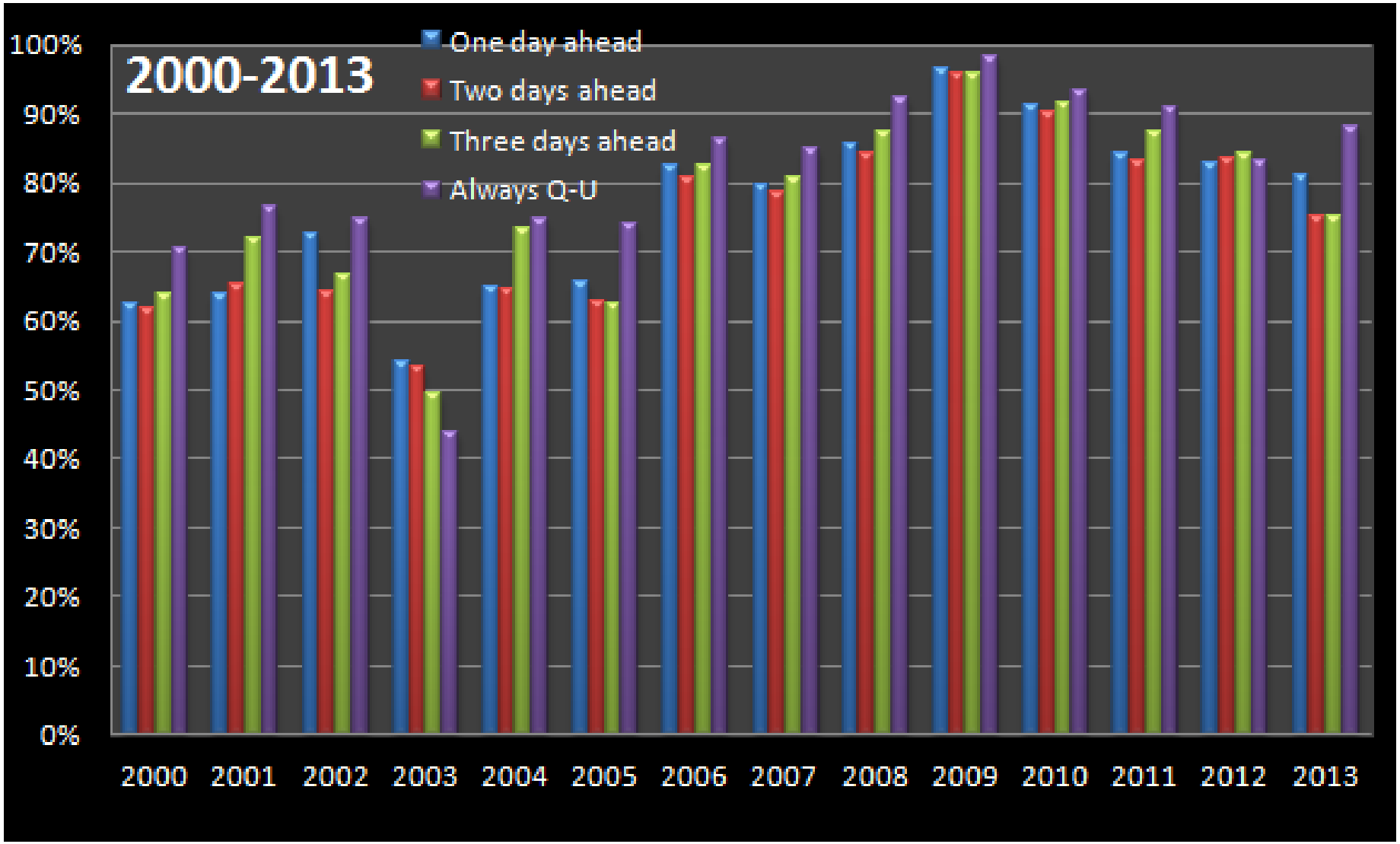

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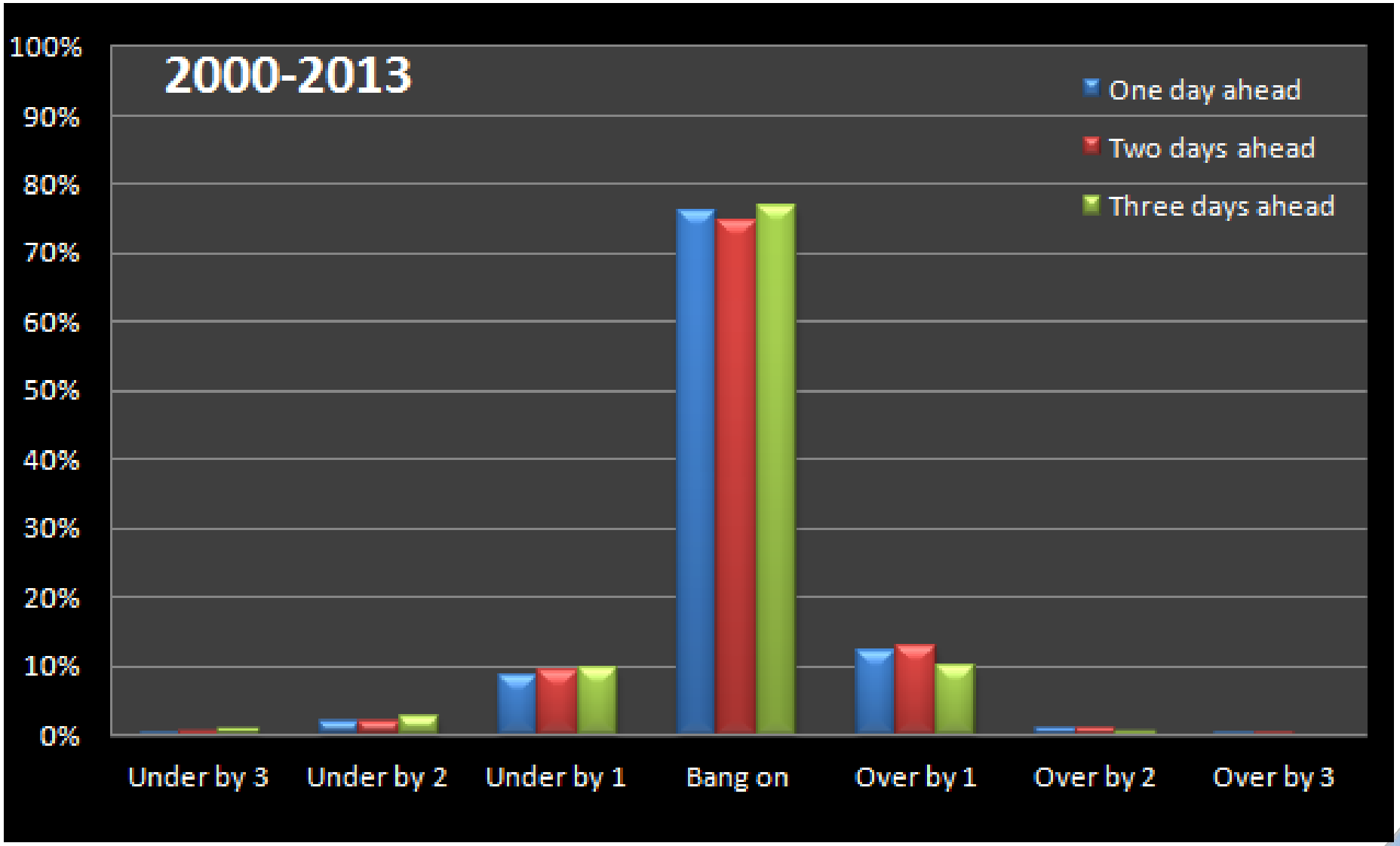

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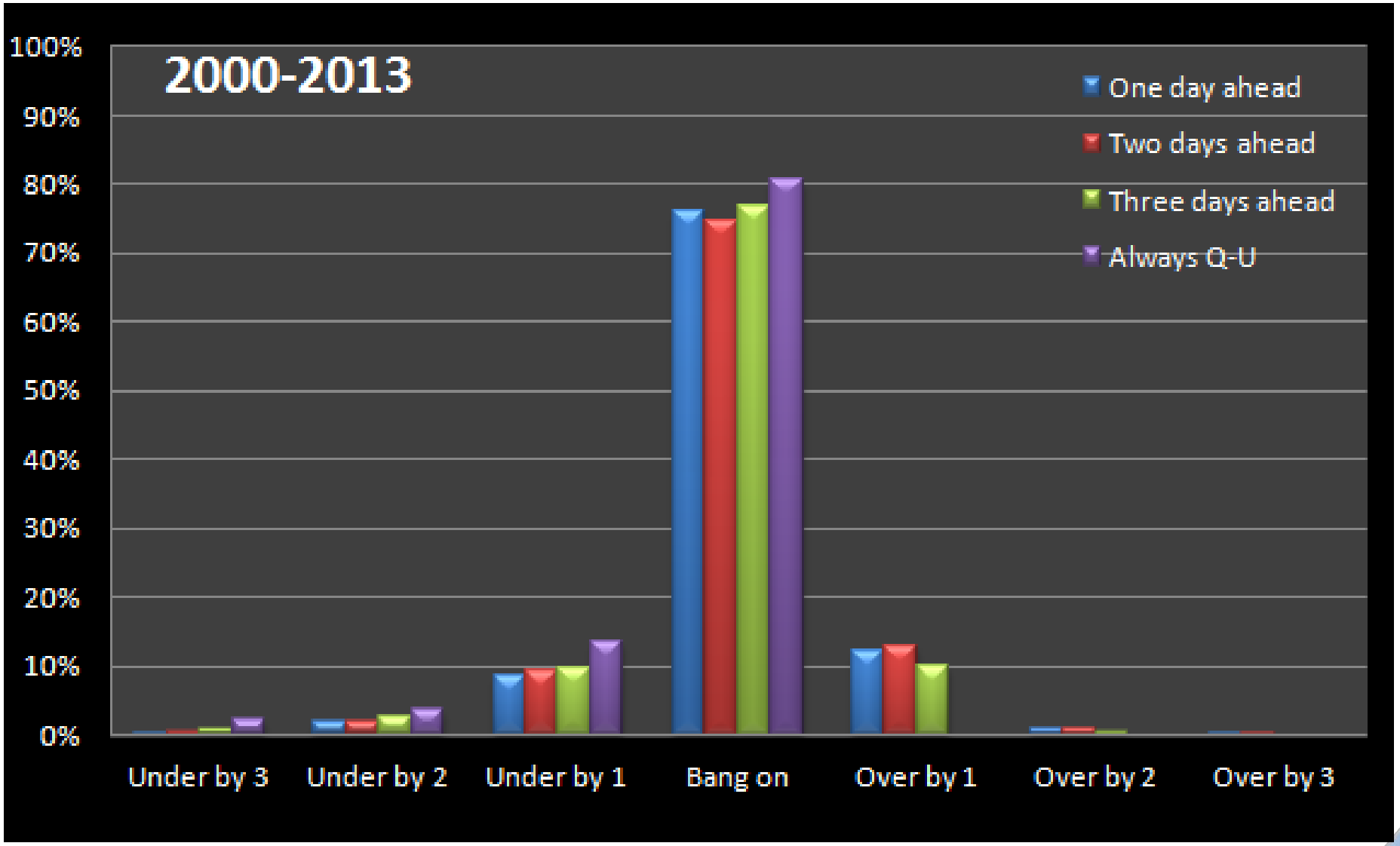

Forecast Verification using Skill Scores

- Binary Events - > Two-dimensional Contingency table
  (E.g. MAGNETIC STORM or NO MAGNETIC STORM)

2x2 contingency table		Magnetic Storm Observed		Marginal Total
		Yes	No	
Magnetic Storm Forecast	Yes	A	B	A + B
	No	C	D	C + D
Marginal Total		A + C	B + D	n (A+B+C+D)

- Many performance measures can be determined using the contingency table entries
- 3 properties we want out of a skill measure for Space Weather are:
  1. Equitability
  2. Discourages hedging
  3. Usefulness for relatively rare events

No single measure designed (so far) that is strong in all three

Forecast Verification using Skill Scores

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		Yes	No	
Magnetic Storm Forecast	Yes	A	B	A + B
	No	C	D	C + D
Marginal Total		A + C	B + D	n (A+B+C+D)

- **Peirce Skill Score** (PSS) also known as True Skill Statistic (TSS)

  PSS= (AD-BC)/(A+C)(B+D)

- **Gilbert Skill Score** (GSS) also known as Equitable Threat Score (ETS)

  GSS= (A-CH)/(A+B+C-CH)

  where CH (chance hit) = (A+B)(A+C)/n

- **Heidke skill score** (HSS)

  HSS= (A+D-E)/(n-E)

  where E (correct random forecast) = [(A+B)(A+C)+(B+D)(C+D)]/n

Forecasters and Skill Scores (Binary : STORM / NO STORM)

Geomag Forecasters		Storm Observed		Marginal Total
		Yes	No	
Storm Forecast	Yes	63	74	137
	No	139	3349	3488
Marginal Total		202	3423	3625

→PSS=0.29

Benchmark		Storm Observed		Marginal Total
		Yes	No	
Storm Forecast	Yes	62	111	173
	No	140	3312	3452
Marginal Total		202	3423	3625

→PSS=0.27

→HSS=0.34

→GSS=0.21

→HSS=0.29

→GSS=0.17

Forecasters and Skill Scores (Binary : STORM / NO STORM)

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Storm Forecast	Yes	63	74	137
	No	139	3349	3488
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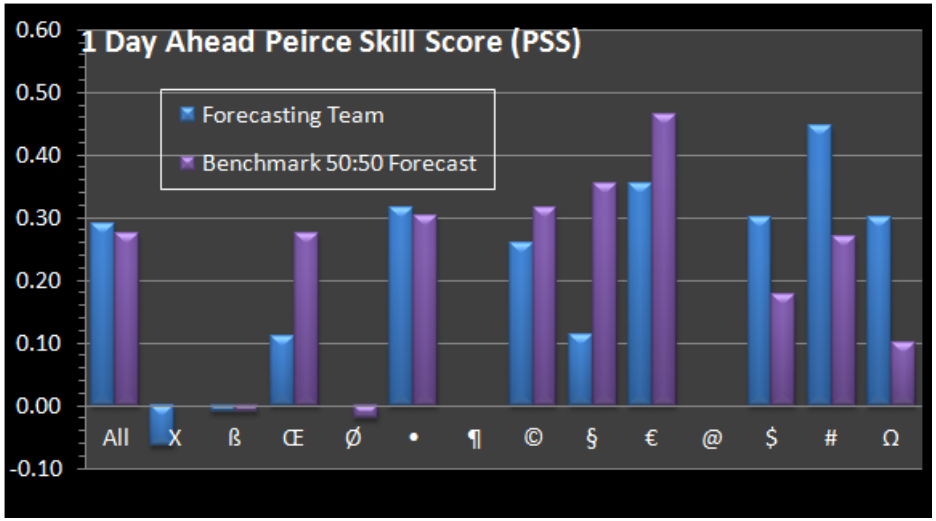
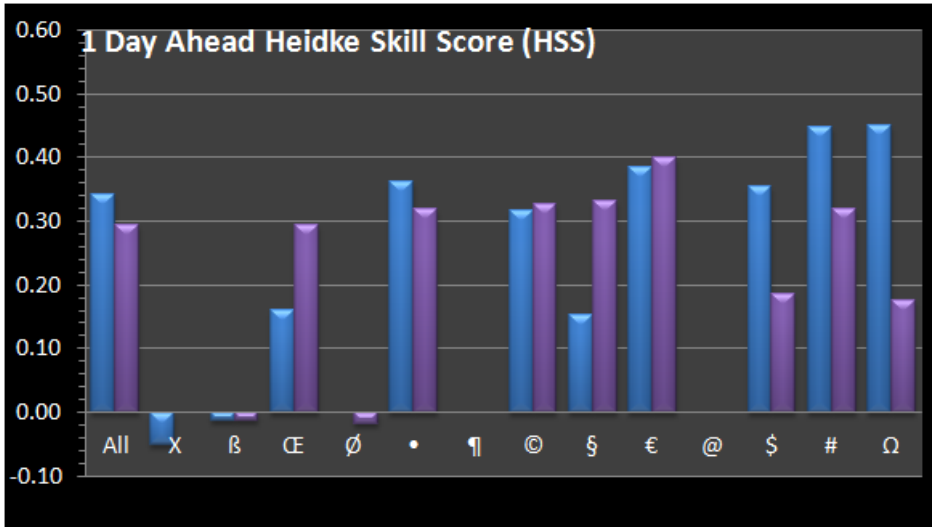
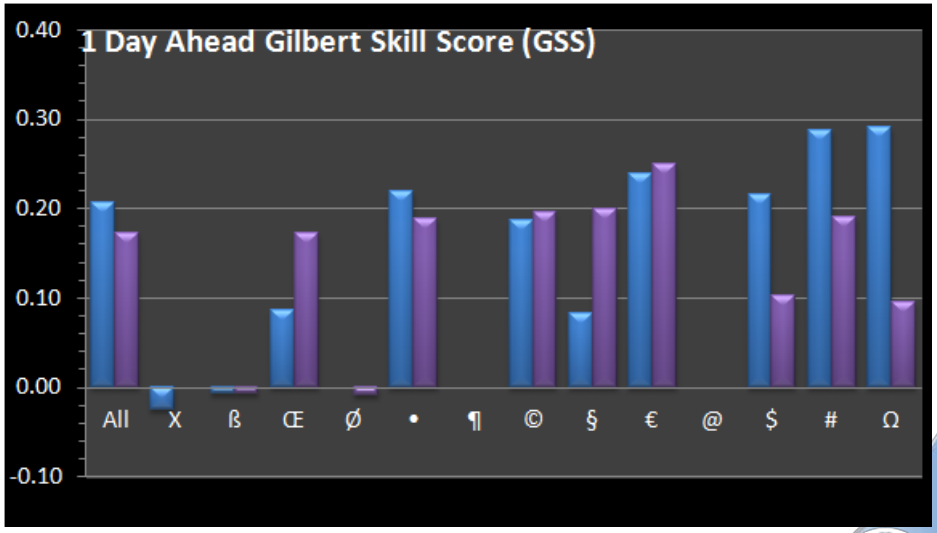






Forecast Verification including BIAS

2x2 contingency table		Magnetic Storm Observed		Marginal Total
		Yes	No	
Magnetic Storm Forecast	Yes	A	B	A + B
	No	C	D	C + D
Marginal Total		A + C	B + D	n (A+B+C+D)

Bias score or frequency bias

BIAS=(A+B)/(A+C)

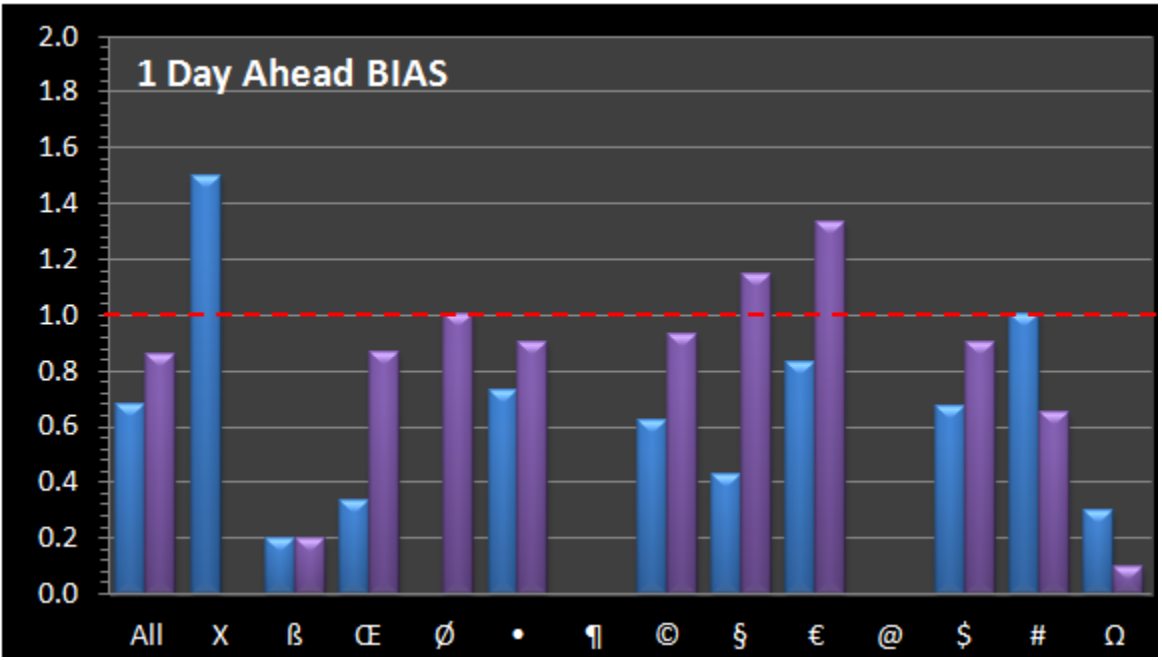
Geomag Forecasters		Storm Observed		Marginal Total
		Yes	No	
Storm Forecast	Yes	63	74	137
	No	139	3349	3488
Marginal Total		202	3423	3625

BIAS = 0.68

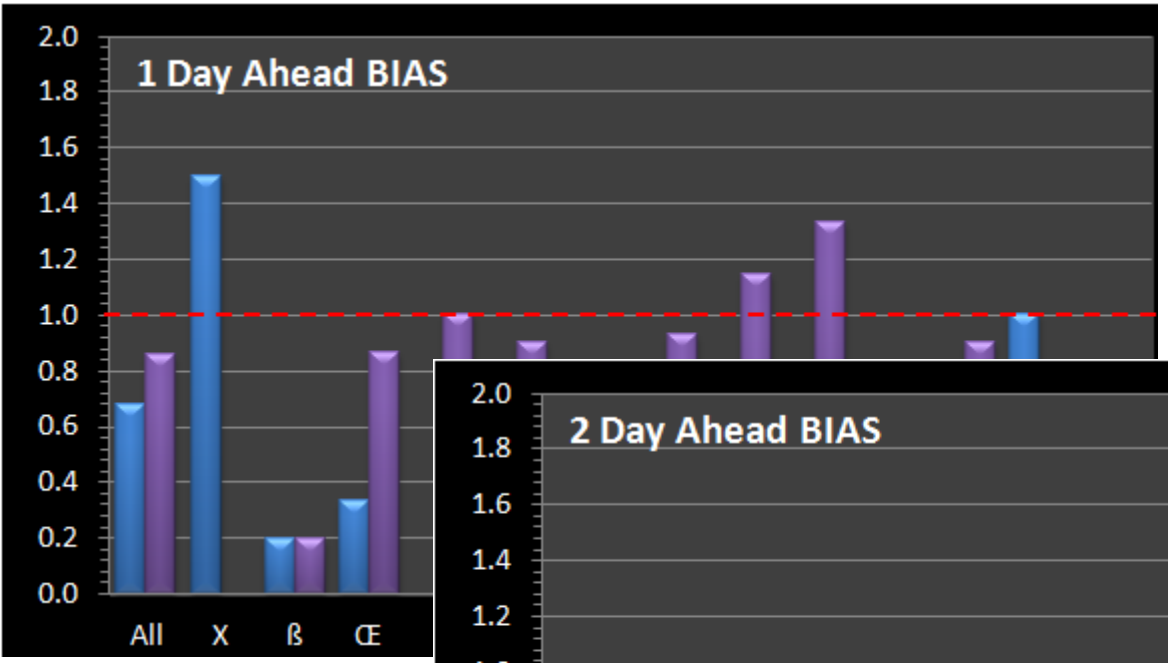
Benchmark		Storm Observed		Marginal Total
		Yes	No	
Storm Forecast	Yes	62	111	173
	No	140	3312	3452
Marginal Total		202	3423	3625

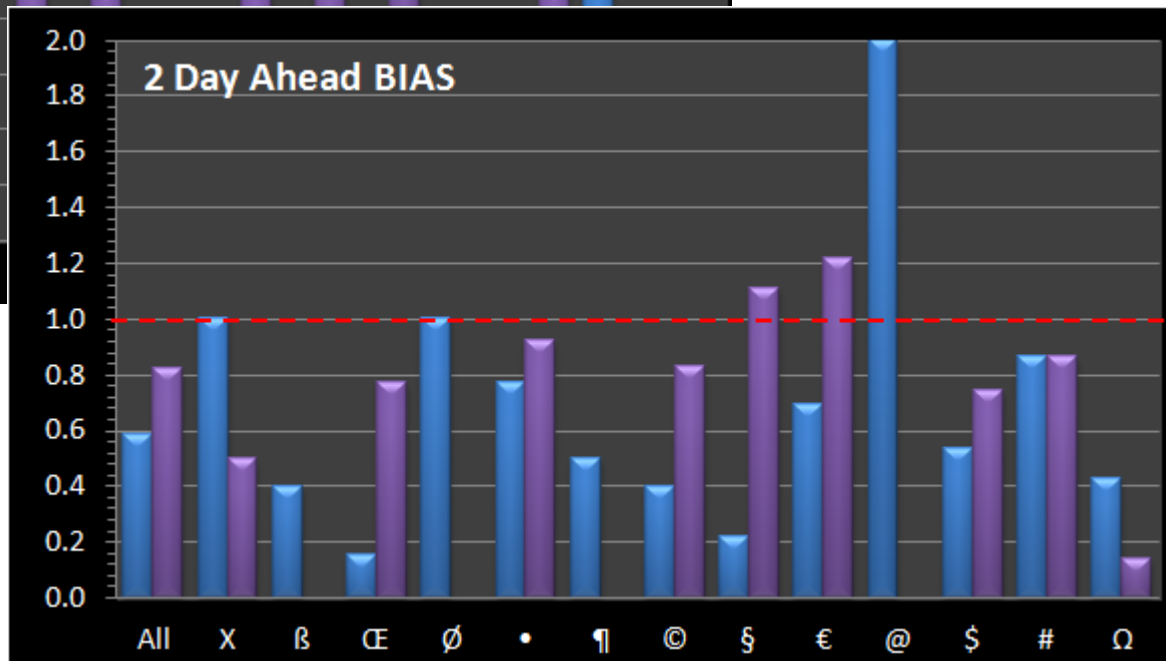
BIAS = 0.86

Individual Forecasters and BIAS



Individual Forecasters and BIAS





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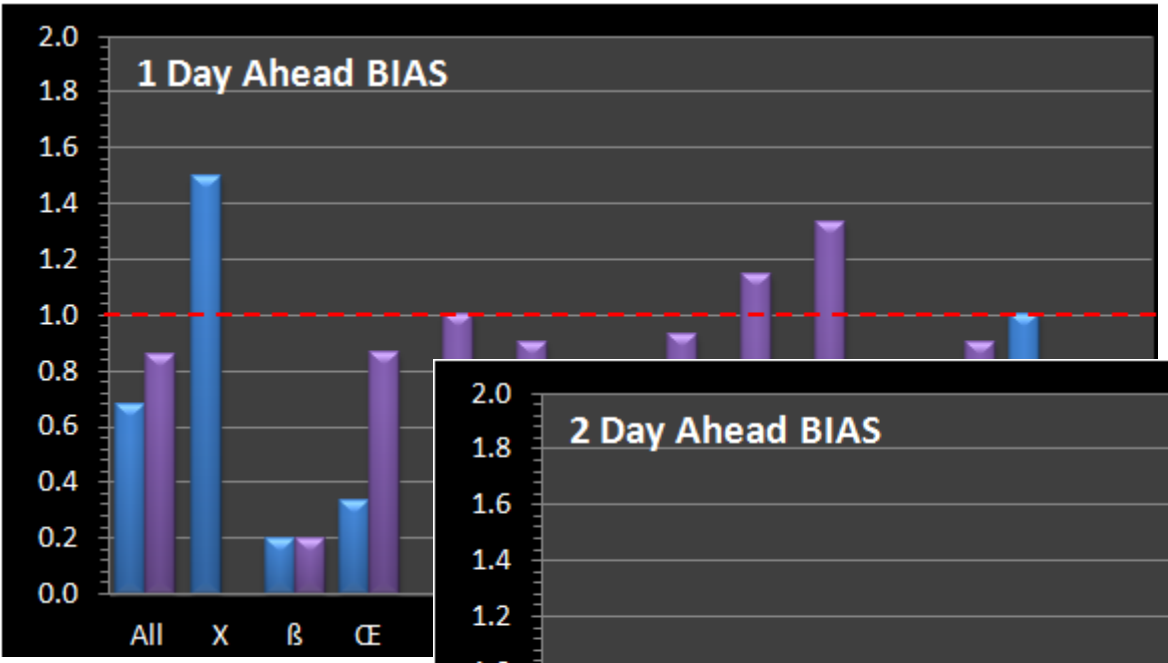
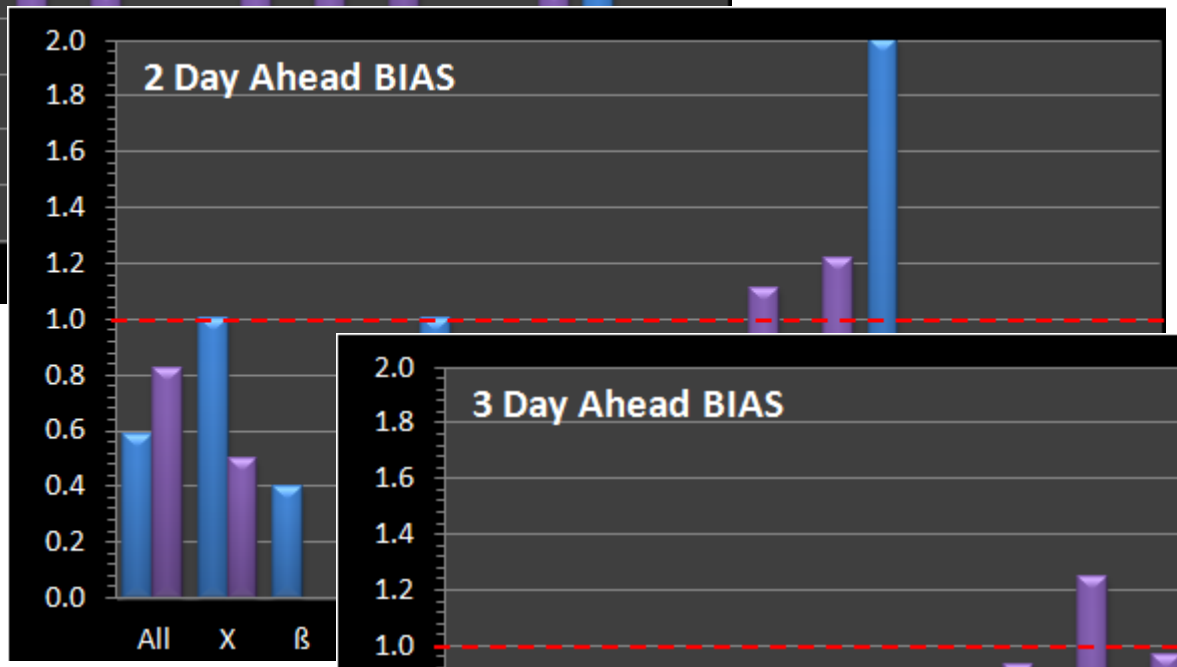
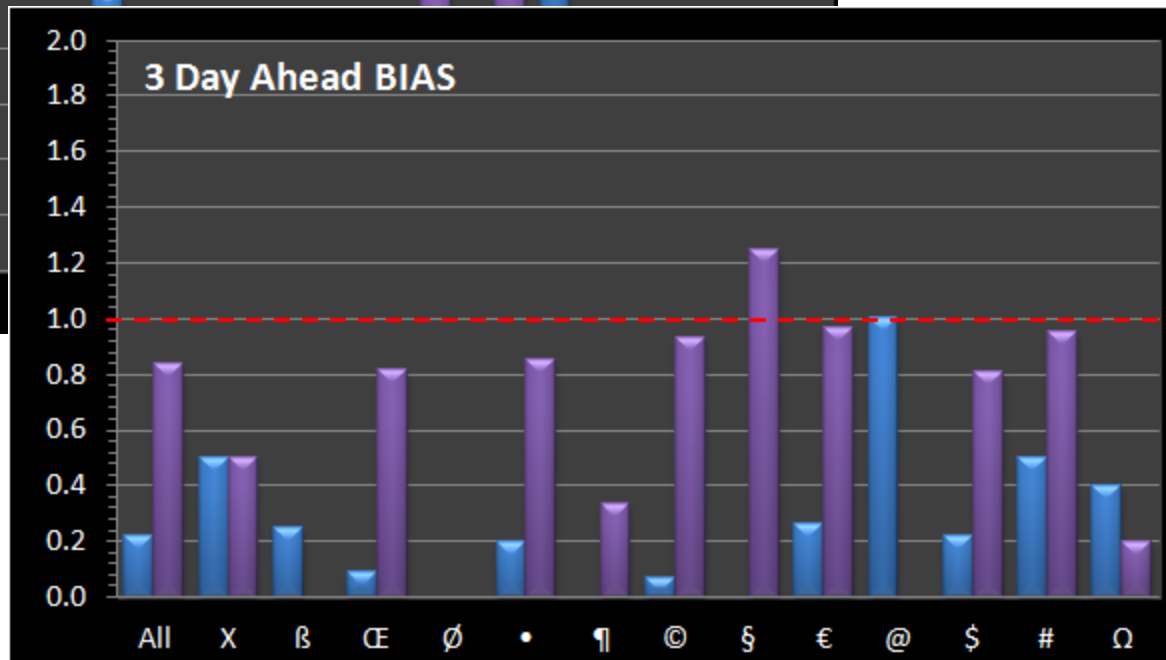






Multi-Category Equitable Skill Scores

k x k contingency table with elements A_{ij}		Forecast (F) Category (j)				Marginal Total
		1	2	...	k	
Observed (O) Category (i)	1	$A_{1,1}$	$A_{1,2}$	$A_{1,...}$	$A_{1,k}$	$n(O_1)$
	2	$A_{2,1}$	$A_{2,2}$	$A_{2,..}$	$A_{2,k}$	$n(O_2)$
	...	$A_{...,1}$	$A_{...,2}$	$A_{..,..}$	$A_{...,k}$	$n(O_{..})$
	k	$A_{k,1}$	$A_{k,2}$	$A_{k,...}$	$A_{k,k}$	$n(O_k)$
Marginal Total		$n(F_1)$	$n(F_2)$	$n(F...)$	$n(F_k)$	N

4 x 4 probability matrix (P) where $p_{ij} = A_{ij}/N$		Forecast (F) Category (j)				Climatological probability
		1	2	3	4	
Observed (O) Category (i)	1	$p_{1,1}$	$p_{1,2}$	$p_{1,3}$	$p_{1,4}$	$p(O_1)$
	2	$p_{2,1}$	$p_{2,2}$	$p_{2,3}$	$p_{2,4}$	$p(O_2)$
	3	$p_{3,1}$	$p_{3,2}$	$p_{3,3}$	$p_{3,4}$	$p(O_3)$
	4	$p_{4,1}$	$p_{4,2}$	$p_{4,3}$	$p_{4,4}$	$p(O_4)$
Forecast probability		$p(F_1)$	$p(F_2)$	$p(F_3)$	$p(F_4)$	1

Gandin and Murphy (1992) devised a way of extending equitable skill scores to more than two categories. The general formula is

$$ESS = \sum_{i=1}^{k}\sum_{j=1}^{k} p_{ij}s_{ij}$$

s_{ij} are the elements of a reward-penalty matrix Known as the scoring matrix (S).

Scoring Matrix for Multi-Category Equitable Skill Scores

Gerrity (1992) extended this further and derived formulas for populating the S matrix for >3 categories.

4 x 4 probability matrix (P) where $p_{ij} = A_{ij}/N$		Forecast (F) Category (j)			
		1	2	3	4
Observed (O) Category (i)	1	$p_{1,1}$	$p_{1,2}$	$p_{1,3}$	$p_{1,4}$
	2	$p_{2,1}$	$p_{2,2}$	$p_{2,3}$	$p_{2,4}$
	3	$p_{3,1}$	$p_{3,2}$	$p_{3,3}$	$p_{3,4}$
	4	$p_{4,1}$	$p_{4,2}$	$p_{4,3}$	$p_{4,4}$

$$D(n) \equiv \frac{1 - \sum_{r=1}^{n} p(r)}{\sum_{r=1}^{n} p(r)}$$

$$R(n) = \frac{1}{D(n)}$$

Scoring Matrix for Multi-Category Equitable Skill Scores

Gerrity (1992) extended this further and derived formulas for populating the S matrix for >3 categories.

4 x 4 Scoring Matrix (S)		Forecast (F) Category (j)			
		1	2	3	4
Observed (O) Category (i)	1	$s_{1,1}$	$s_{1,2}$	$s_{1,3}$	$s_{1,4}$
	2	$s_{2,1}$	$s_{2,2}$	$s_{2,3}$	$s_{2,4}$
	3	$s_{3,1}$	$s_{3,2}$	$s_{3,3}$	$s_{3,4}$
	4	$s_{4,1}$	$s_{4,2}$	$s_{4,3}$	$s_{4,4}$

$$D(n) \equiv \frac{1-\sum_{r=1}^{n} p(r)}{\sum_{r=1}^{n} p(r)}$$

$$R(n) = \frac{1}{D(n)}$$

$$s_{m,n} = \frac{1}{k-1}\left[\sum_{r=1}^{m-1} R(r) + \sum_{r=m}^{n-1}(-1) + \sum_{r=n}^{k-1} D(r)\right] \quad ; \quad n = (1,\ldots,k)$$

$$s_{n,n} = \frac{1}{k-1}\left[\sum_{r=1}^{n-1} R(r) + \sum_{r=n}^{k-1} D(r)\right] \quad ; \quad 1 \le m < k, \quad m < n \le k$$

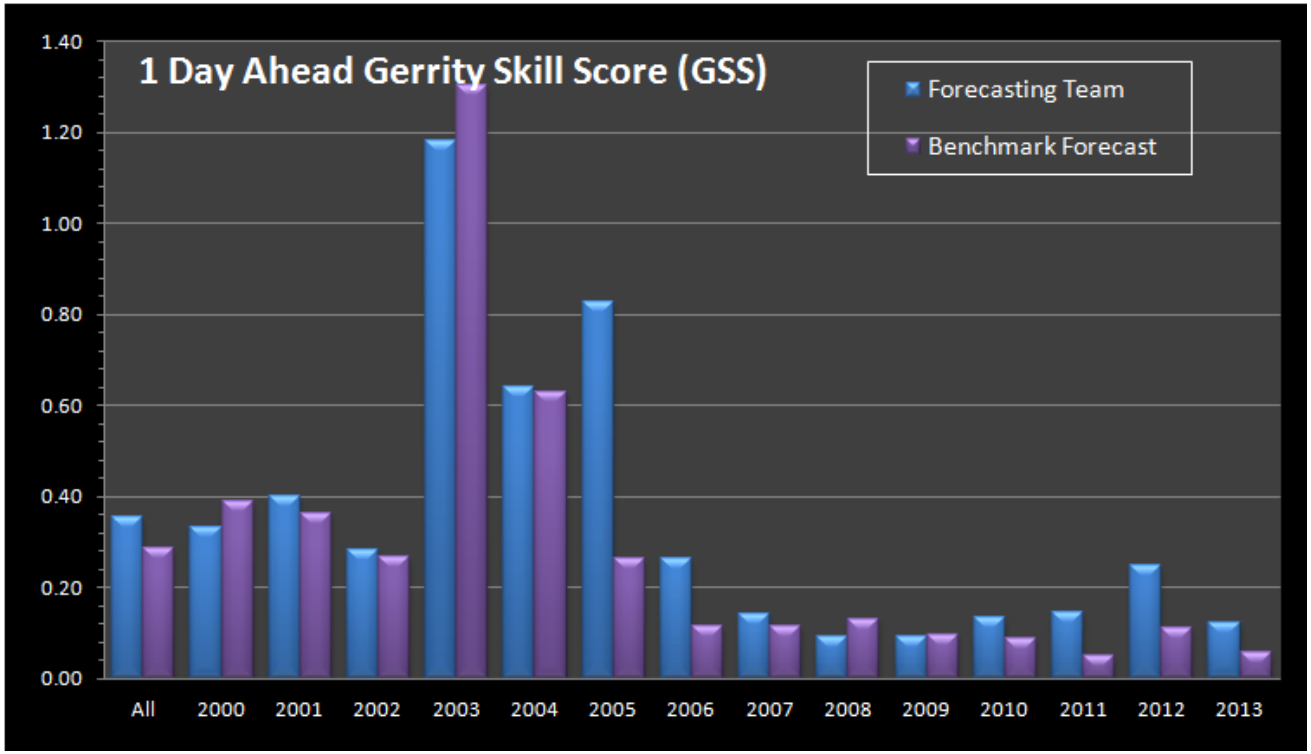
Scoring Matrix for Multi-Category Equitable Skill Scores

4 x 4 contingency matrix		Forecast Category				Marginal Total
		Q-U	ACTIVE	MINOR	MAJOR	
Observed Category	Q-U	3604	422	96	31	4153
	ACTIVE	414	169	46	9	638
	MINOR	96	55	22	9	182
	MAJOR	51	24	11	6	92
Marginal Total		4165	670	175	55	5065

4 x 4 Probability matrix (P)		Forecast Category				Climatological probability
		Q-U	ACTIVE	MINOR	MAJOR	
Observed Category	Q-U	0.7115	0.0833	0.0190	0.0061	0.8199
	ACTIVE	0.0817	0.0334	0.0091	0.0018	0.1260
	MINOR	0.0190	0.0109	0.0043	0.0018	0.0359
	MAJOR	0.0101	0.0047	0.0022	0.0012	0.0182
Forecast probability		0.8223	0.1323	0.0346	0.0109	1.0000

4 x 4 reward-penalty or scoring matrix (S) as per Gerrity (1992)		Forecast Category			
		Q-U	ACTIVE	MINOR	MAJOR
Observed Category	Q-U	0.0984	-0.3081	-0.6605	-1.0000
	ACTIVE	-0.3081	1.5431	1.1907	0.8512
	MINOR	-0.6605	1.1907	7.3525	7.0130
	MAJOR	-1.0000	0.8512	7.0130	25.3645

Yearly Forecast Verification using ESS (Gerrity)



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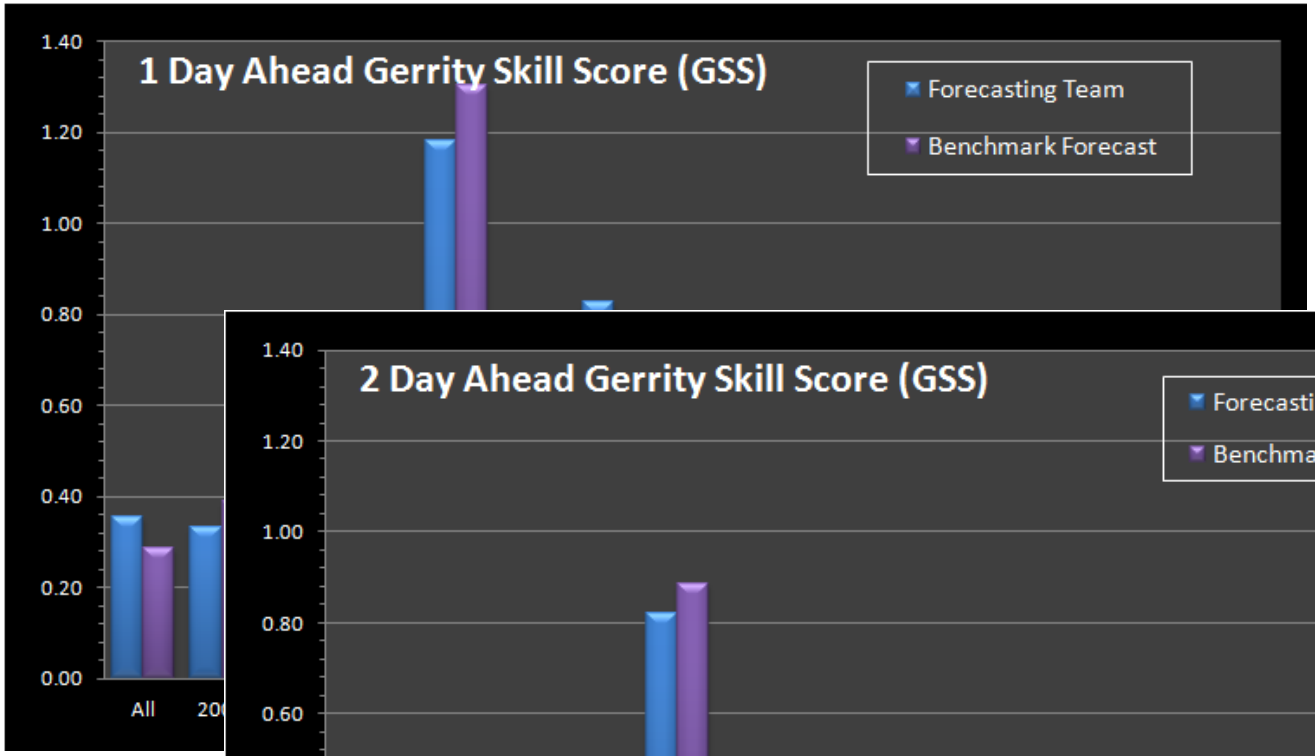

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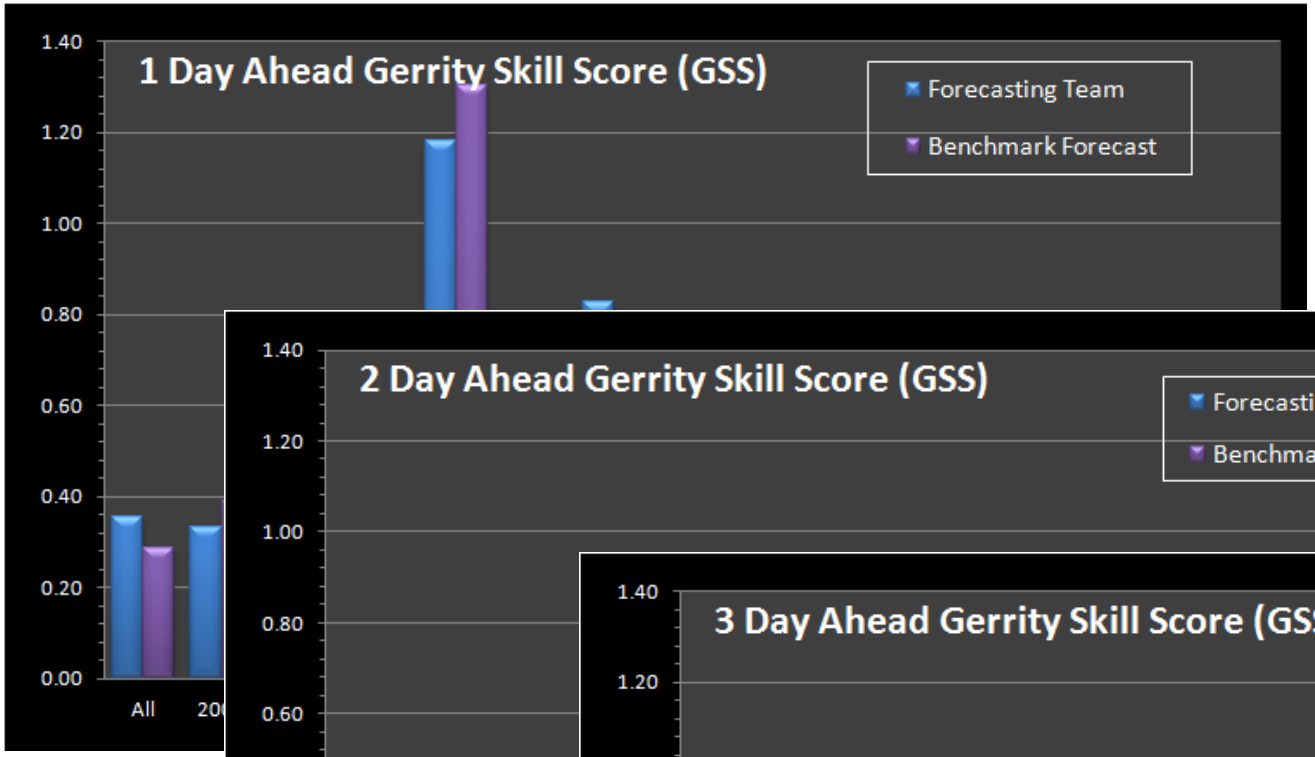
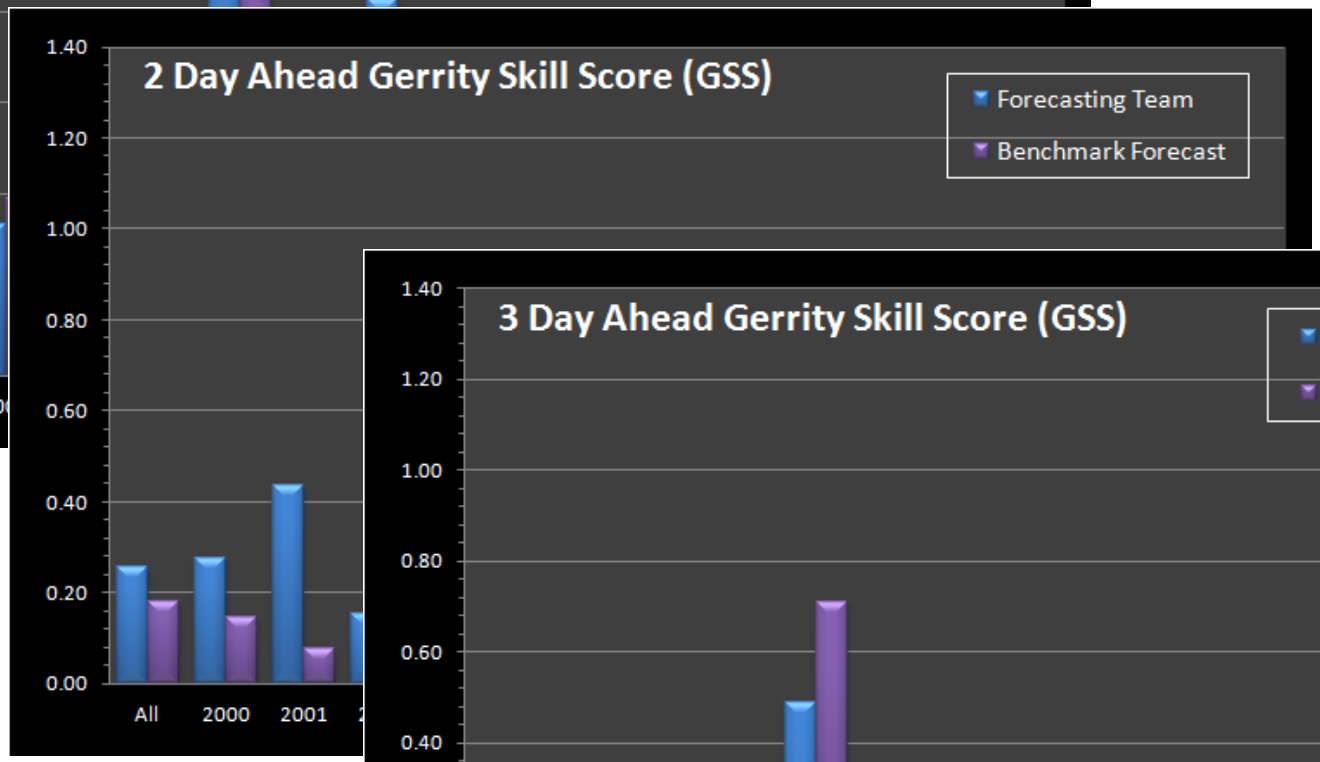
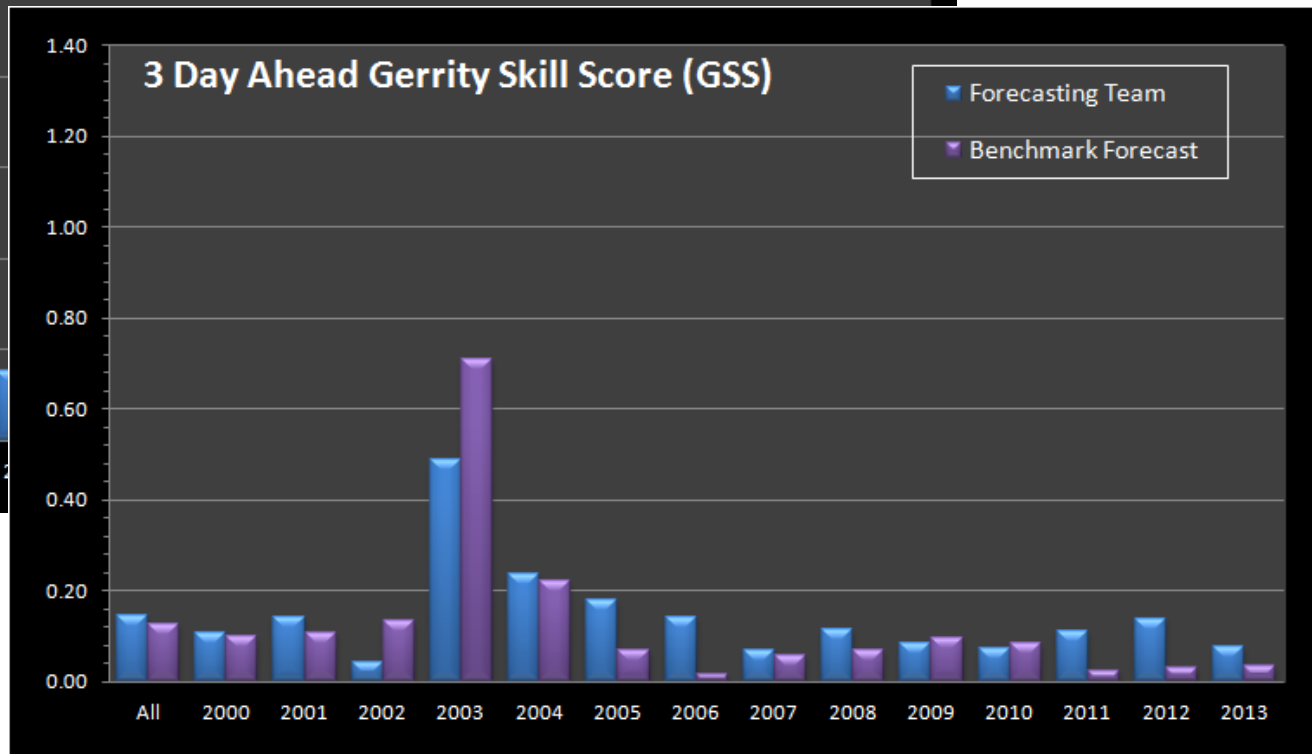
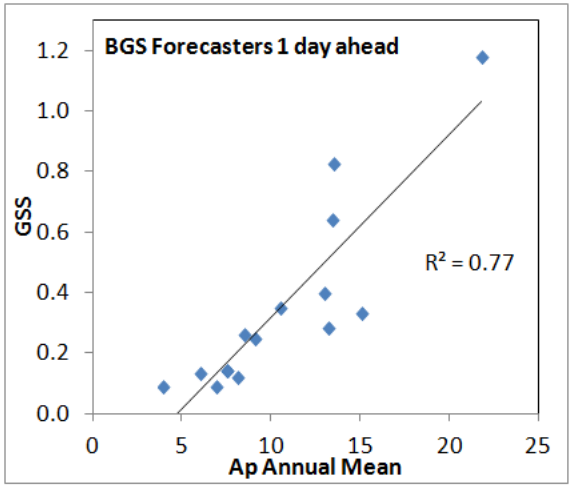
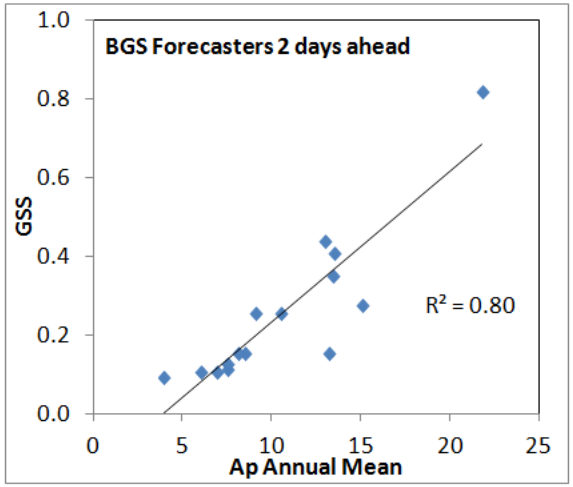


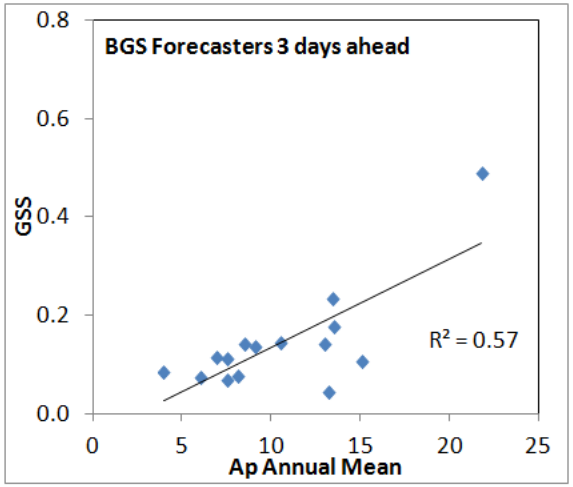


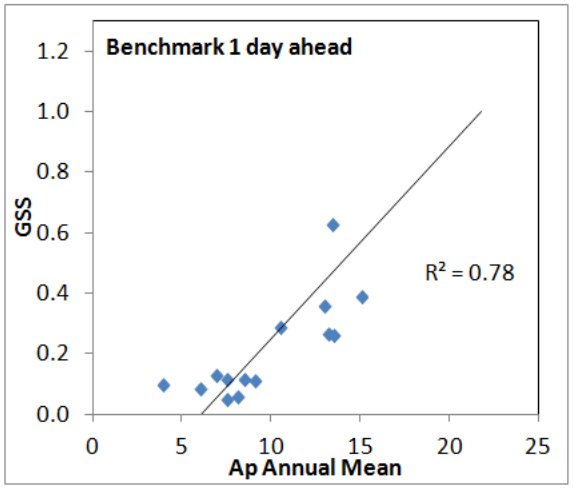


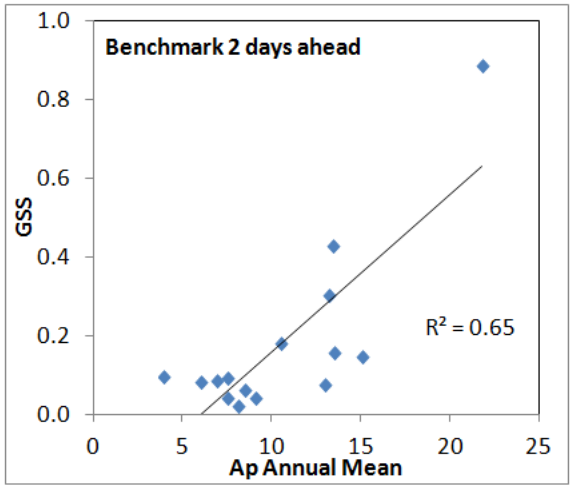
Correlation of Annual Mean A_p (AMV) and GSS

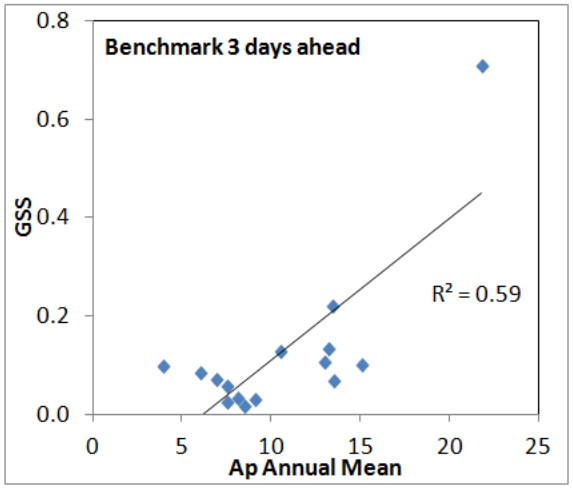












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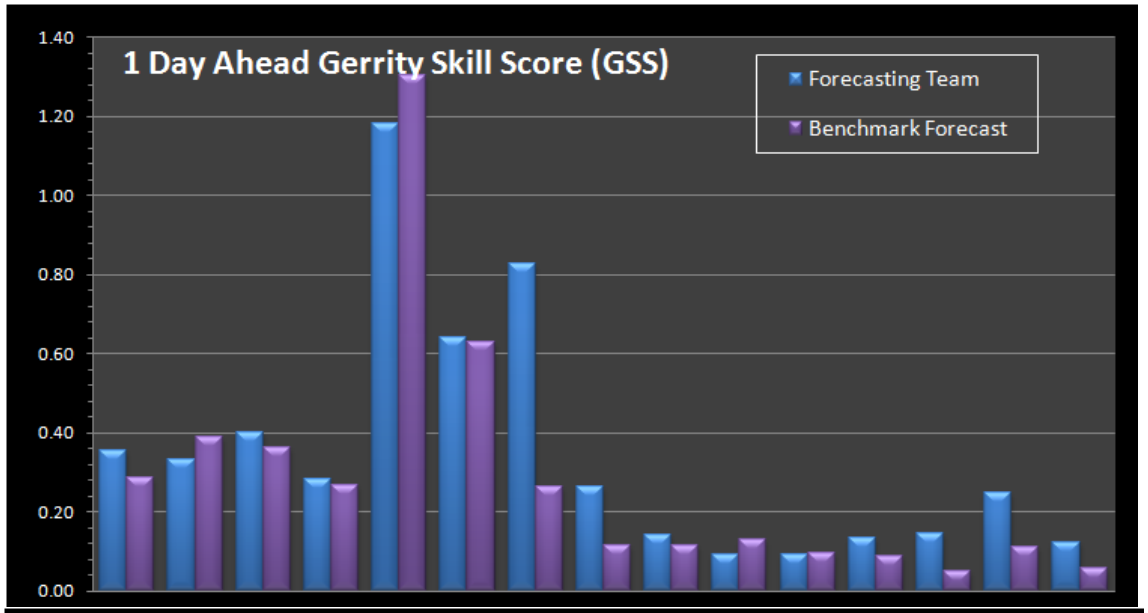

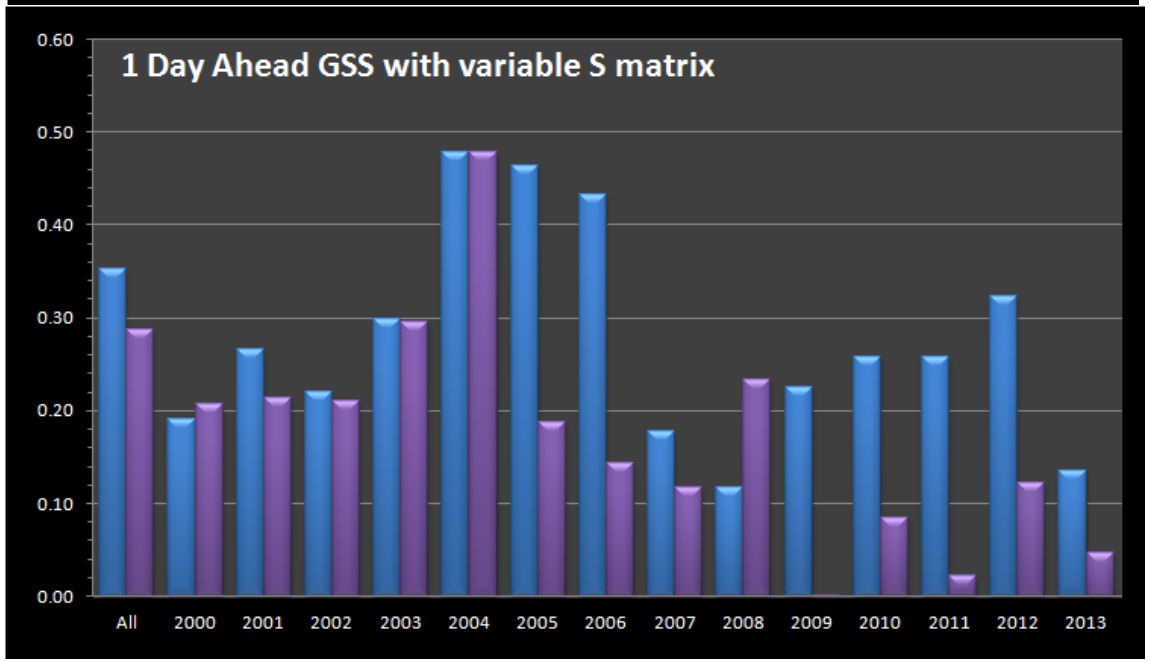

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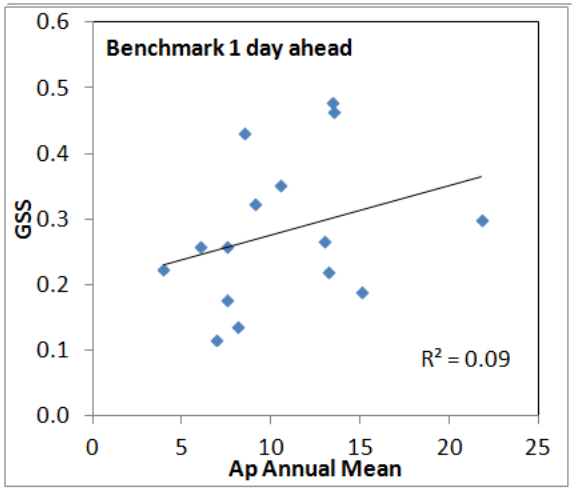
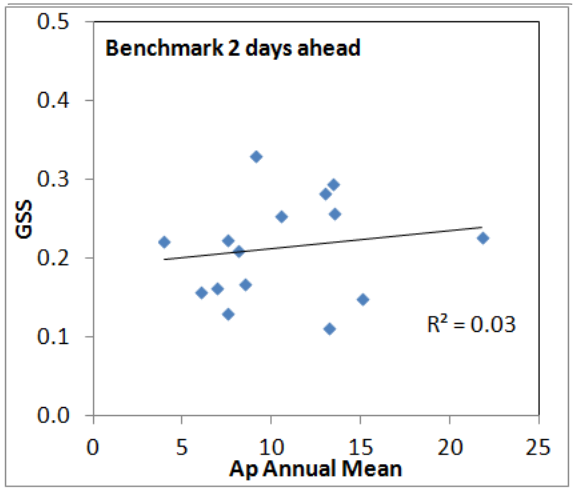
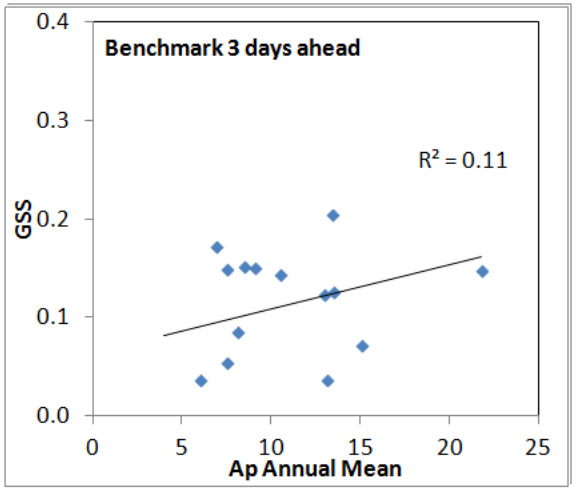
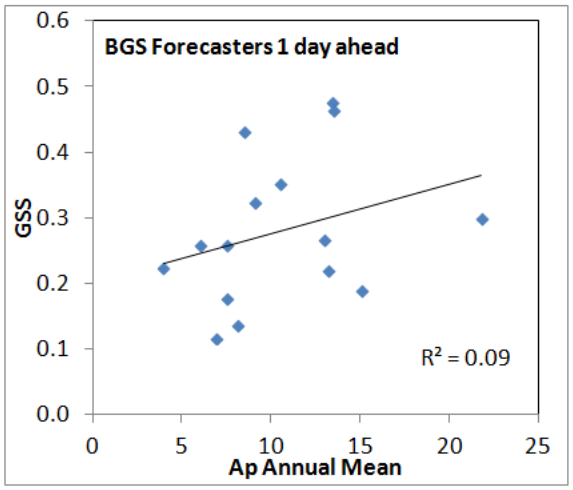
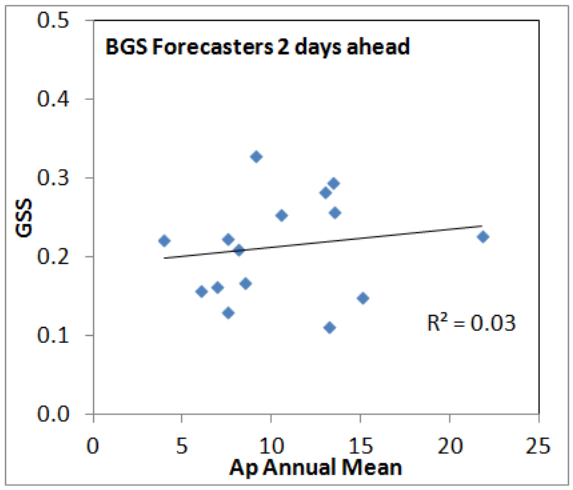
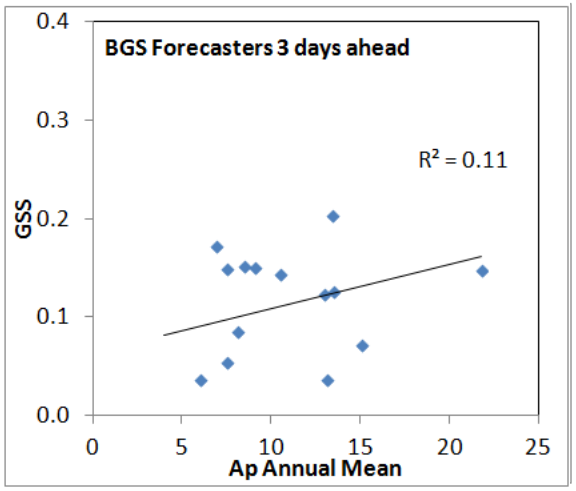




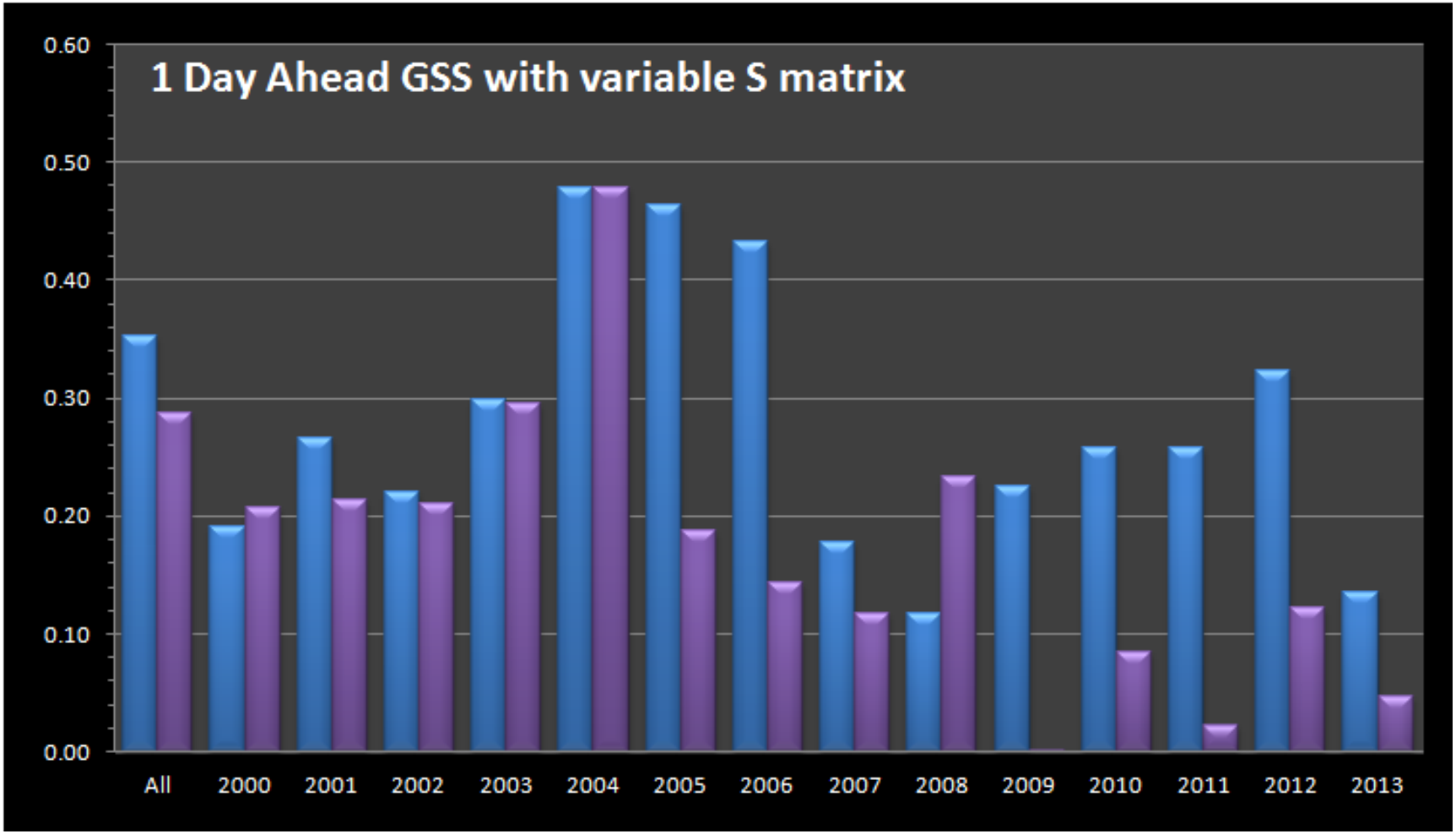








Yearly Forecast Verification using ESS (Gerrity)



Summary and Future Plans

- Analysed the performance of 1-3 day ahead forecasts, 2000 to 2013
- Suitable performance measures for on-going verification have been found
- Measures of both skill and bias are required to fully evaluate performance
- Results show an overall bias indicating tendency to under-forecast storms
- In most cases forecasters have higher skill scores for predicting storms than a simple forecast model of persistence and recurrence

Plans

- Adapt the forecast to predict maximum activity levels at any point in the day, as well as the current daily average
- Alter the categories to match the NOAA/SWPC G scale
- Devise suitable means of providing (motivatory) feedback to forecasters
- Obtain feedback from users and if required adjust verification measures
- Measure forecast performance against other BGS models (E.g. NeuralNet)
- Investigate the possible use of Extreme Dependency Scores
- Include error bars/confidence limits on the skill and bias scores

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