Model Output Statistics (MOS) - Objective Interpretation of NWP Model Output

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OUTLINE

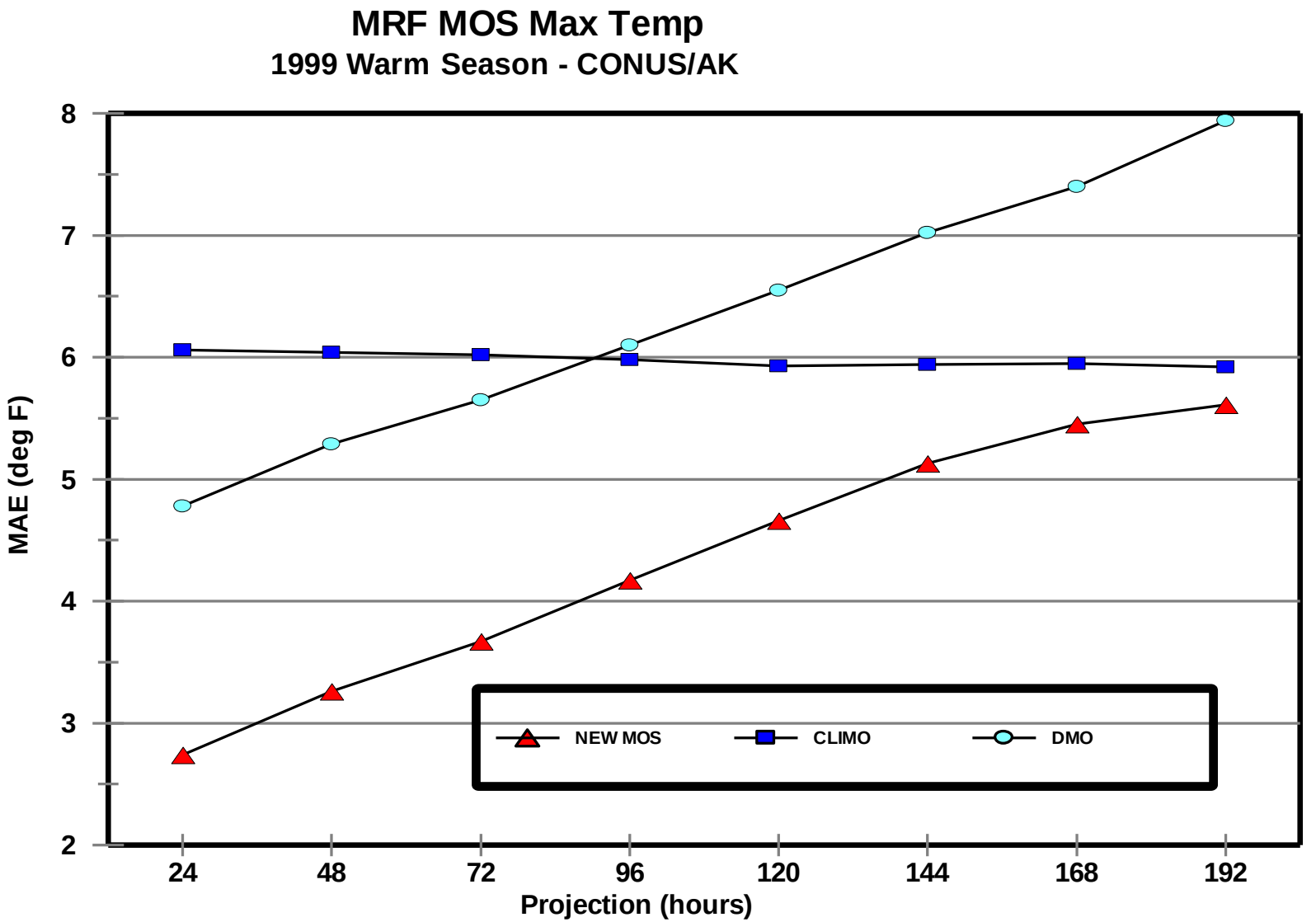
1. Why objective statistical guidance?
2. What is MOS?
   - Definition and characteristics
   - The "traditional" MOS product suite
     (NGM, eta, GFS)
   - Recent additions to the lineup
3. Simple regression examples / Probability
4. Development strategy -
   MOS in the "real world"
5. Verification
6. Where we're going - The future of MOS

WHY STATISTICAL GUIDANCE?

- **Add value to direct NWP model output**
  - **Objectively interpret model**
    - **remove systematic biases**
    - **quantify uncertainty**
  - **Predict what the model does not**
  - **Produce site-specific forecasts**
    - **(i.e. a "downscaling" technique)**

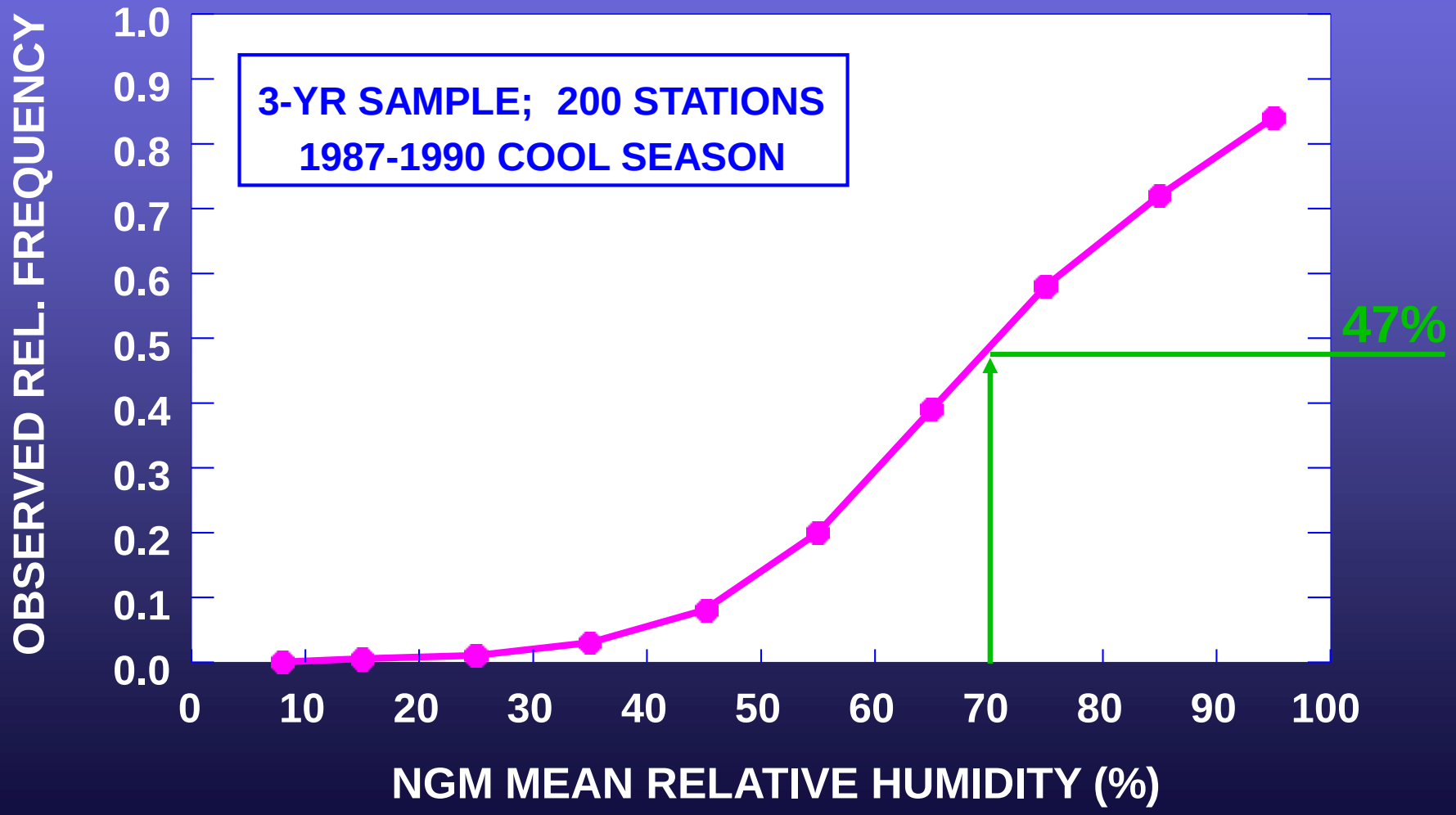
- **Assist forecasters**
  - **"First Guess" for expected local conditions**
  - **"Built-in" model/climo memory for new staff**

MOS Max Temp vs. Direct Model Output



A SIMPLE STATISTICAL MODEL

Relative Frequency of Precipitation as a Function of 12-24 Hour NGM Model-Forecast Mean RH



What is MOS?

MODEL OUTPUT STATISTICS (MOS)

Relates observed weather elements (PREDICTANDS) to appropriate variables (PREDICTORS) via a statistical approach.

Predictors are obtained from:

1. Numerical Weather Prediction (NWP) Model Forecasts
2. Prior Surface Weather Observations
3. Geoclimatic Information

Current Statistical Method:

MULTIPLE LINEAR REGRESSION
(Forward Selection)

MODEL OUTPUT STATISTICS (MOS)

Properties

- Mathematically simple, yet powerful
- Need historical record of observations at forecast points
  (Hopefully a long, stable one!)
- Equations are applied to future run of similar forecast model

MODEL OUTPUT STATISTICS (MOS)

Properties (cont.)

- Non-linearity can be modeled by using NWP variables and transformations
- Probability forecasts possible from a single run of NWP model
- Other statistical methods can be used
  e.g. Polynomial or logistic regression;
  Neural networks

MODEL OUTPUT STATISTICS (MOS)

- **ADVANTAGES**
  - Recognition of model predictability
  - Removal of some systematic model bias
  - Optimal predictor selection
  - Reliable probabilities
  - Specific element and site forecasts

- **DISADVANTAGES**
  - Short samples
  - Changing NWP models
  - Availability & quality of obs

“Traditional” MOS text products

GFS MOS GUIDANCE MESSAGE FOUS21-26 (MAV)

KLNS GFS MOS GUIDANCE 11/29/2004 1200 UTC

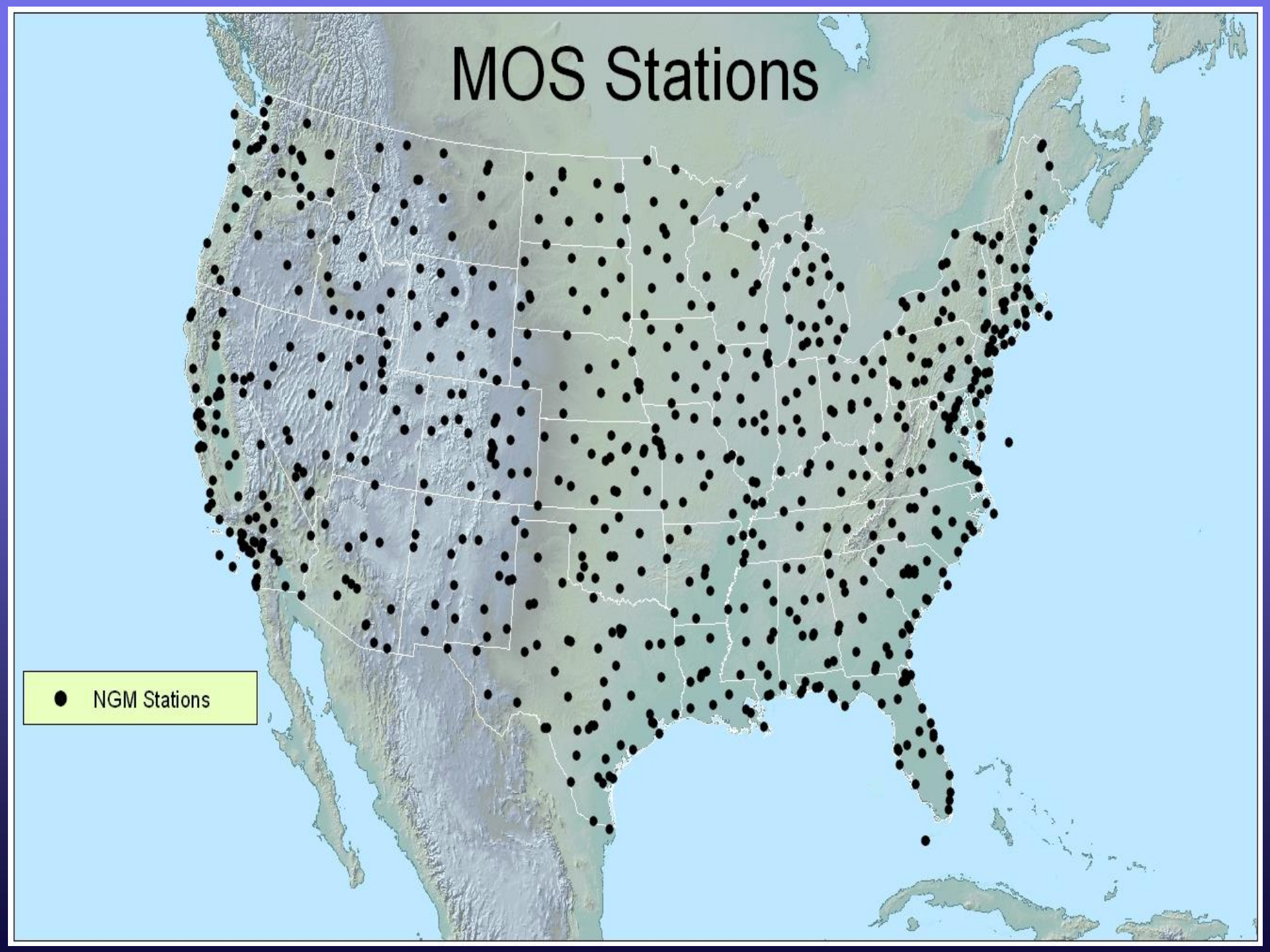
DT	/NOV		29/NOV			30					/DEC			1					/DEC		
HR	18	21	00	03	06	09	12	15	18	21	00	03	06	09	12	15	18	21	00	06	12
N/X							28				48				35				49		33
TMP	43	44	39	36	33	32	31	39	46	45	41	38	37	39	41	44	45	44	40	40	35
DPT	27	27	28	29	29	29	29	33	35	35	36	35	36	39	41	42	37	34	30	30	28
CLD	CL	BK	BK	BK	OV	OV	OV	OV	OV	OV	OV	OV	OV	OV	OV	OV	OV	BK	CL	CL	CL
WDR	34	36	00	00	00	00	00	00	00	14	12	12	10	11	12	19	28	29	29	29	28
WSP	06	02	00	00	00	00	00	00	00	01	02	04	04	06	07	08	15	17	18	09	05
P06			0		0		4		3		11		65		94		96		7	0	0
P12							6				19				94				96		0
Q06			0		0		0		0		0		3		4		4		0	0	0
Q12							0				0				4				2		0
T06		0/	0	0/18		0/	3	0/	0	0/	0	0/18		2/	1	10/	4	0/	3	1/	0
T12				0/26				0/17				0/27				10/25			1/38		
POZ	2	0	0	1	2	4	4	0	1	1	2	3	3	1	1	0	2	1	2	3	1
POS	13	2	1	2	1	0	0	0	0	0	0	0	0	2	0	0	0	3	0	9	28
TYP	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
SNW							0								0						0
CIG	8	8	8	8	7	7	7	8	8	7	7	7	4	2	3	3	6	7	8	8	8
VIS	7	7	7	7	7	7	7	7	7	7	7	7	5	5	4	2	6	7	7	7	7
OBV	N	N	N	N	N	N	N	N	N	N	N	N	BR	BR	BR	BR	N	N	N	N	N

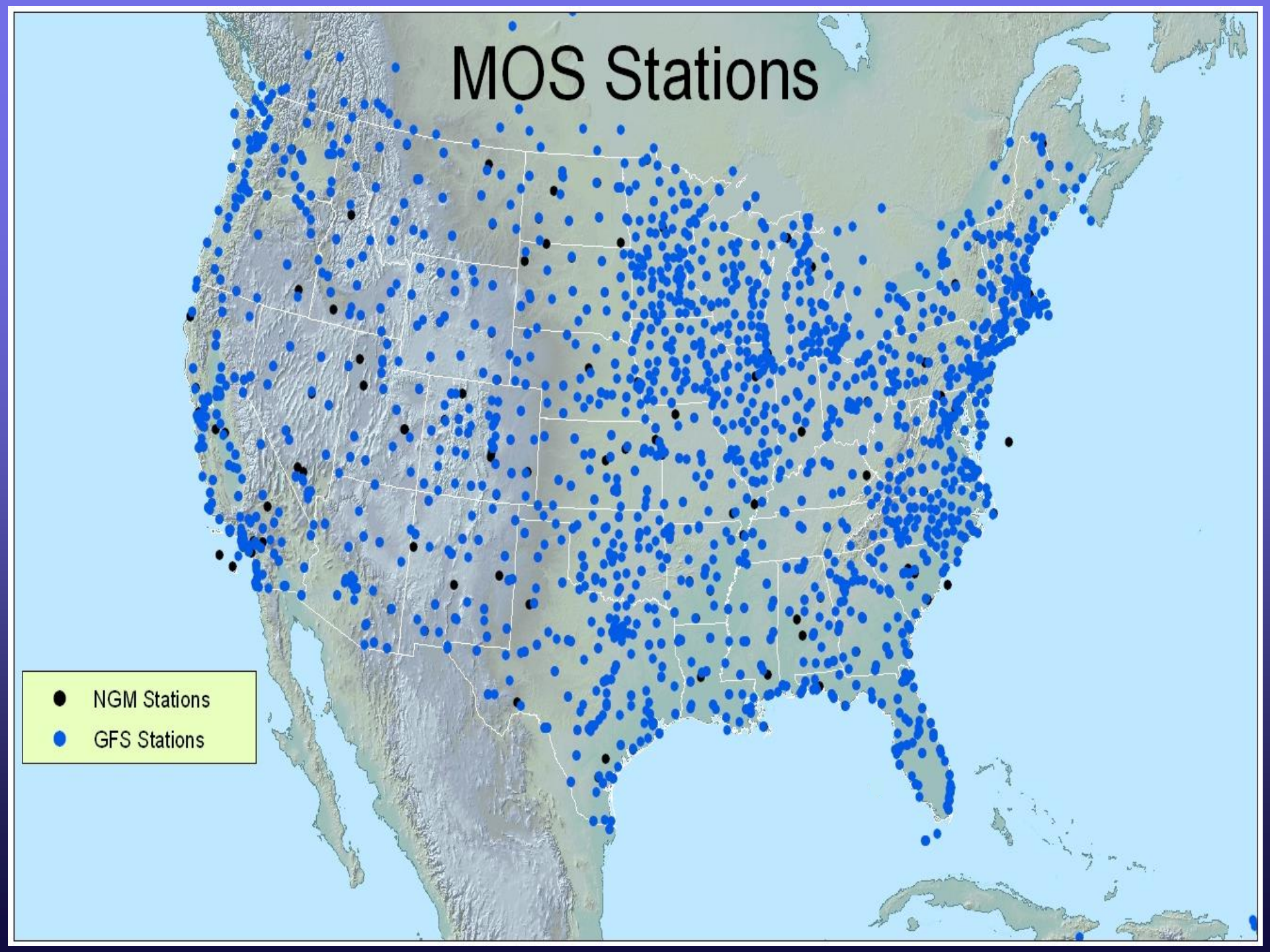
Eta MOS GUIDANCE MESSAGE FOUS44-49 (MET)

```
KTHV   ETA MOS GUIDANCE   11/28/2005  1200 UTC
DT /NOV  28/NOV  29                 /NOV  30                 /DEC   1
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
N/X                    60          65          52          54    28
TMP  58 60 58 61 65 66 66 60 62 61 62 61 59 57 54 52 53 50 41 35 32
DPT  50 52 52 54 57 58 58 55 58 59 57 56 54 52 49 43 39 36 34 29 27
CLD  OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV SC CL SC BK
WDR  15 13 12 14 16 15 13 17 16 15 15 16 18 24 29 29 31 32 30 27 32
WSP  05 07 07 10 12 12 10 10 10 09 08 08 07 07 05 10 09 06 03 01 03
P06     14    62    87    94    91    90    71    21     6  6  0
P12                  88         100         93          28     7
Q06      0     1     2     3     4     4     2     0     0  0  0
Q12                  1           4           4           0     0
T06    2/ 0  7/ 0  8/ 4 13/ 2 25/ 3 28/ 2 21/ 2  9/ 1  3/ 3999/99
T12          7/ 0        22/ 4       41/ 4       24/ 3  999/99
SNW                  0                       0                 0
CIG   3  5  3  3  2  2  2  3  5  4  3  3  3  4  5  6  6  8  8  8  8
VIS   5  6  6  5  5  3  3  3  5  5  4  2  3  3  7  7  7  7  7  7  7
OBV  BR  N BR BR BR BR BR BR HZ BR BR BR BR BR  N  N  N  N  N  N  N
```

GFS / Eta MOS vs. NGM MOS

- **MORE STATIONS:**
  - Now at approx. 1650 Forecast Sites (CONUS, HI, PR)
- **MORE FORECASTS:**
  - Available at projections of 12- 84 hours
  - GFS available for 0600 and 1800 UTC cycles
- **BETTER RESOLUTION:**
  - GFS predictors on 95.25 km grid; Eta on 32 km
  - Predictor fields available at 3-h timesteps
  - Predictors available beyond 48-h projection
  - * No extrapolative forecasts
- **DEPENDENT SAMPLE NOT "IDEAL":**
  - Fewer Seasons
  - Non-static underlying NWP model


MOS Stations
NGM Stations


MOS Stations
NGM Stations
GFS Stations

GFS / Eta MOS vs. NGM MOS

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GFSX MOS GUIDANCE MESSAGE FEUS21-26 (MEX)

```
KCXY    GFSX MOS GUIDANCE  11/26/2004  0000 UTC
FHR   24| 36  48| 60  72| 84  96|108 120|132 144|156 168|180 192
FRI   26| SAT 27| SUN 28| MON 29| TUE 30| WED 01| THU 02| FRI 03 CLIMO
X/N   43| 29  47| 40  55| 35  51| 29  45| 32  40| 36  42| 30  45 31 46
TMP   37| 32  43| 43  46| 37  41| 32  39| 35  36| 38  37| 33  37
DPT   24| 27  37| 40  32| 28  28| 26  31| 32  30| 32  27| 24  25
CLD   PC| OV  OV| OV  PC| CL  PC| PC  OV| OV  OV| PC  CL| CL  CL
WND   10|  5  11| 11  16| 10  10|  5   9|  6  10| 12  14| 12  12
P12    0|  5  13| 91  13|  3   9| 14  24| 52  54| 48  21| 12  25 20 18
P24     |     16|    100|      9|     26|     62|     72|     25    29
Q12    0|  0   0|  3   0|  0   0|  0   0|  2   2|  2    |
Q24     |     0|     3|      0|     0|      4|       |
T12    0|  0   0|  3   0|  0   0|  0   4|  6   4|  3   1|  1   1
T24     |  0    |  3    |  0    |  0    |  6    |  4    |  1
PZP   12|  9  12|  4   3|  5   6| 10   8|  8   3| 16  10| 12   8
PSN   62| 15   3|  0   0| 10   9| 15  24|  1   0|  9  32| 27  18
PRS   26| 24   7|  0  17| 18  20| 13  15|  1   2| 18   9| 11  11
TYP    S| RS   R|  R   R|  R   R|  R  RS|  R   R|  R  RS| RS   R
SNW     |     0|     0|      0|     0|       |       |
```

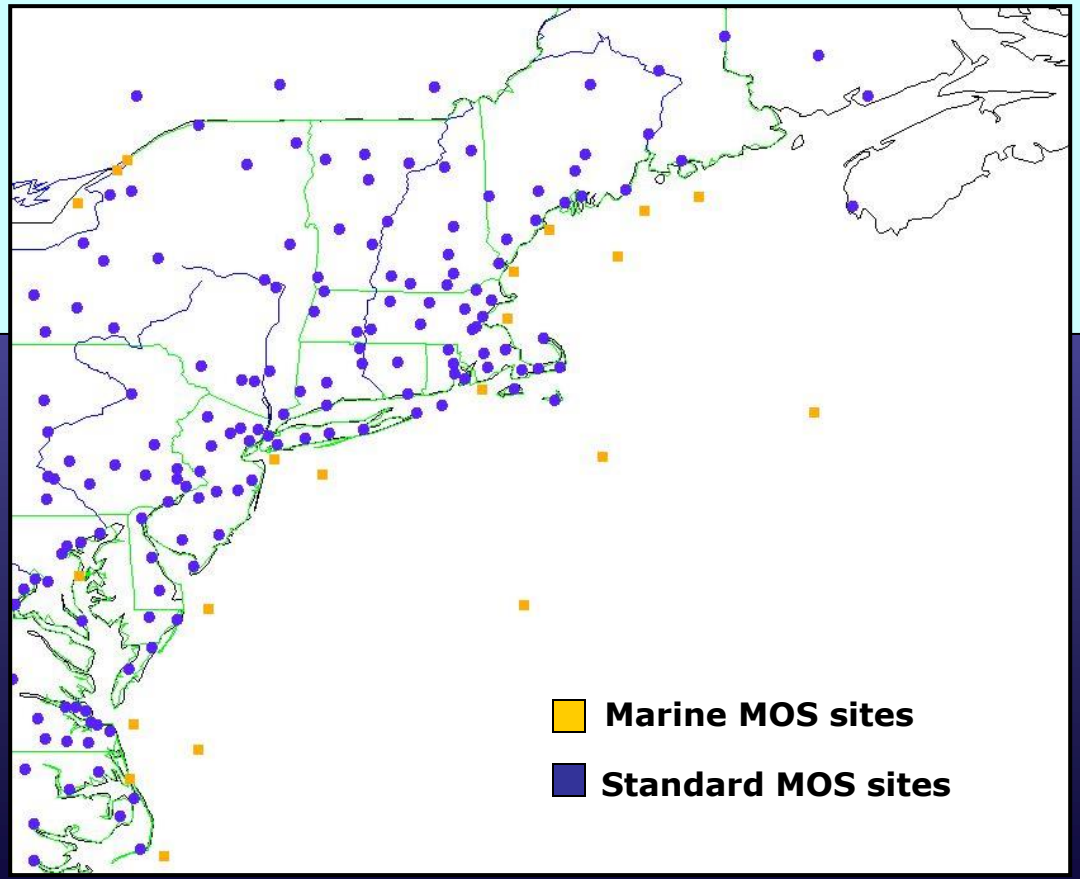
Recent additions to the MOS product lineup

Marine MOS

44004 GFS MOS GUIDANCE 11/22/2005 1200 UTC

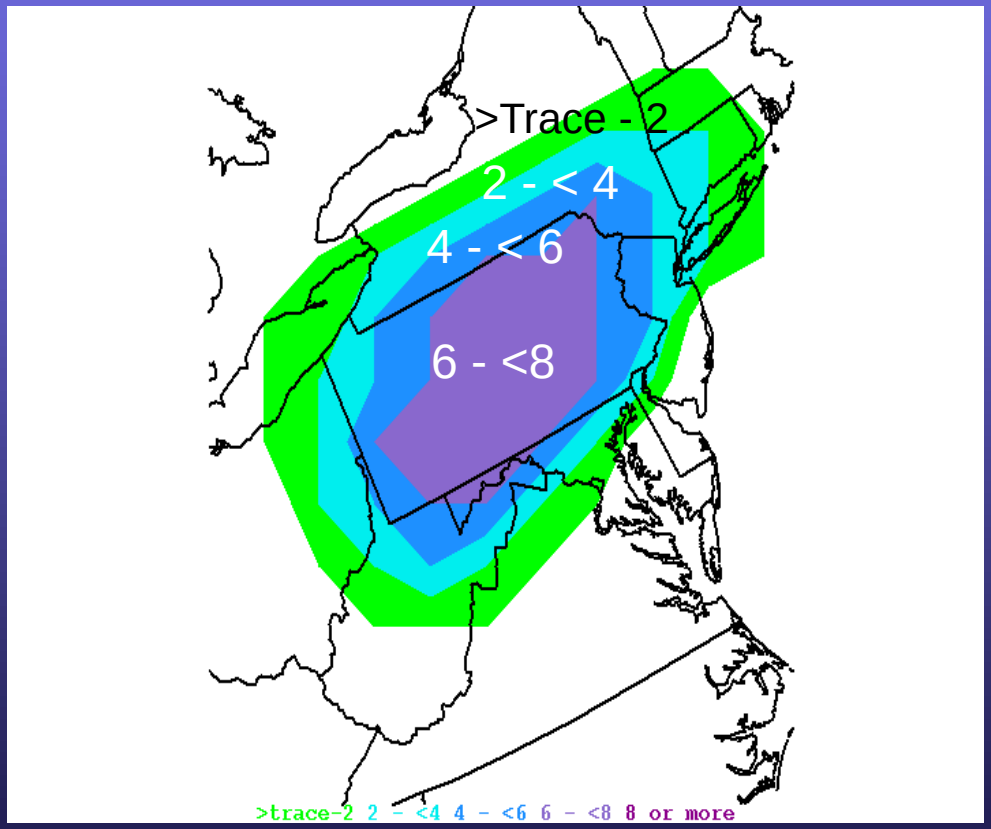
DT	/NOV 22						/NOV 23						/NOV 24						/NOV 25		
HR	18	21	00	03	06	09	12	15	18	21	00	03	06	09	12	15	18	21	00	03	06
TMP	58	53	49	49	50	48	46	44	44	45	47	48	51	54	56	60	62	61	59	51	47
WD	23	25	27	28	28	29	29	28	28	27	27	25	22	22	22	23	23	23	24	27	28
WS	33	31	29	25	23	22	24	25	23	18	14	12	14	19	26	29	30	29	29	28	24
WS10	36	34	31	26	25	24	26	27	25	19	15	13	15	21	28	31	32	31	31	30	26

DT	/NOV 25					/
HR	09	12	15	18	21	00
TMP	45	45	45	47	47	47
WD	29	29	28	30	29	34
WS	18	15	10	10	13	12
WS10	20	16	11	11	14	13

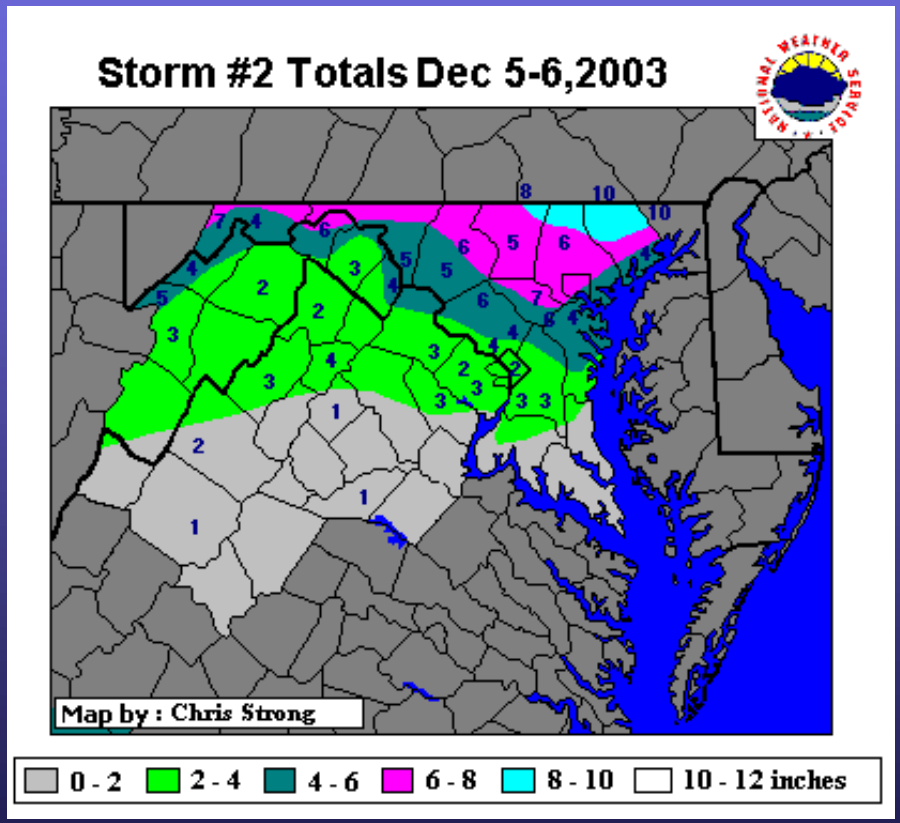


MOS Snowfall Guidance

Uses Observations from Cooperative Observer Network



36-hr forecast
12Z 12/05/03 – 12Z 12/06/03



Verification

Max/Min Guidance for Co-op Sites

GFS-BASED MOS COOP MAX/MIN GUIDANCE 12/01/04 1200 UTC

	THU 02		FRI 03		SAT 04	
GYLP1	30	41	29	41	28	46
HAWP1	28	42	24	39	20	38
HBGP1	34	47	28	45	27	43
HRBP1	35	45	29	44	29	43
INDP1	28	44	27	44	28	46
JMSP1	26	39	24	40	28	42
KANP1	24	34	22	33	22	36
LAPP1	27	37	25	35	22	36
LBGP1	33	45	28	42	25	42
LCRP1	33	46	27	46	27	46
LDVP1	29	49	25	45	23	42
LEBP1	30	46	26	43	24	45
LHGP1	30	45	24	44	25	41
LMPP1	26	36	25	37	26	41
LNVP1	28	38	27	38	27	41
LOKP1	32	43	27	43	27	41
LRLP1	29	47	24	43	23	40
LSTP1	34	46	29	45	29	42
MATP1	29	45	24	42	22	38
MCKP1	27	40	27	41	26	45
MERP1	22	40	22	41	24	43

Western Pacific MOS Guidance


```
NSTU    GFS MOS GUIDANCE    12/05/2005  1200 UTC
DT /DEC    5/DEC    6                    /DEC    7                    /DEC    8
HR    18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
WDR   12 11 11 11 09 09 10 11 09 09 08 11 09 04 32 00 00 05 06 03 30
WSP   07 08 09 10 09 06 04 03 04 07 08 05 05 02 01 00 00 05 06 03 01
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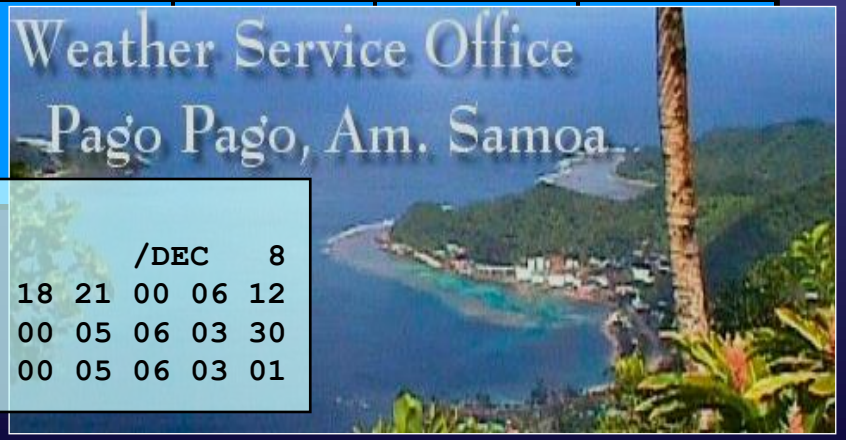


Very recent additions

New within the past year…

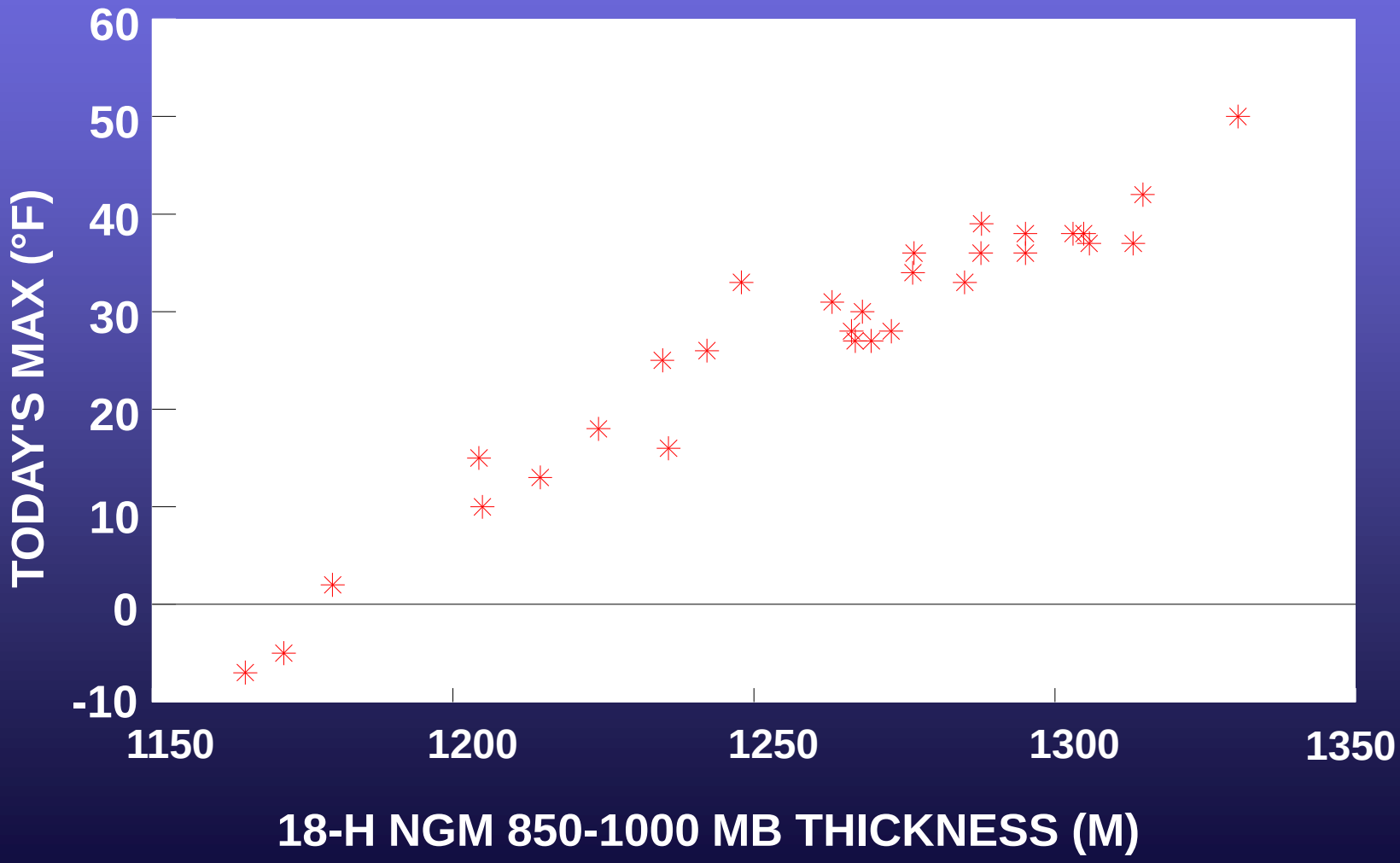
- **GFSX MOS:**
  New 1200 UTC package (no clds, wind, ptype)
- **Eta MOS:**
  Visibility and obstruction to vision forecasts
- **Marine MOS:**
  Temperature forecasts
- **Western Pacific MOS wind guidance**

Application of Linear Regression to MOS Development

MOS LINEAR REGRESSION

JANUARY 1 - JANUARY 30, 1994 0000 UTC

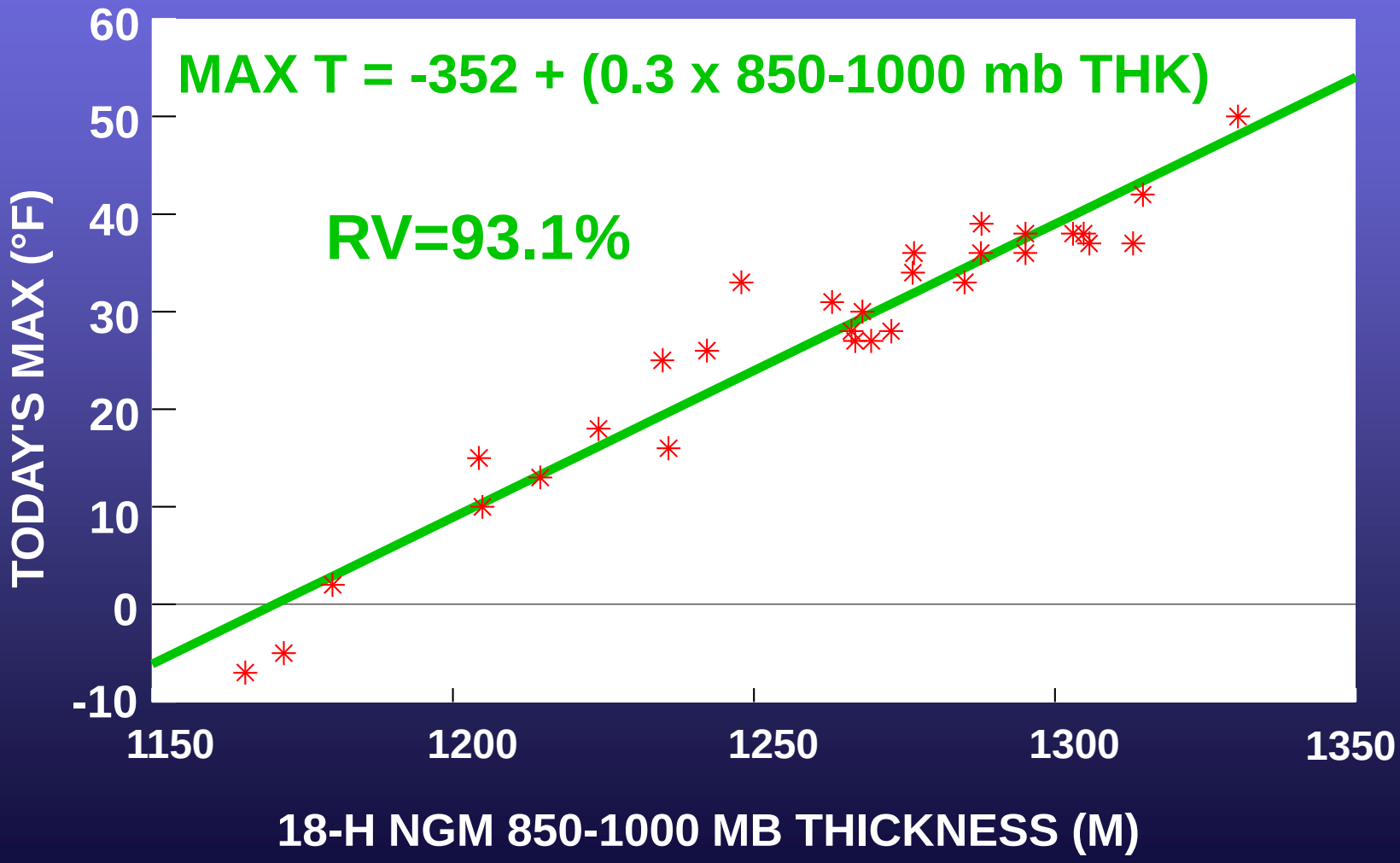
KCMH



MOS LINEAR REGRESSION

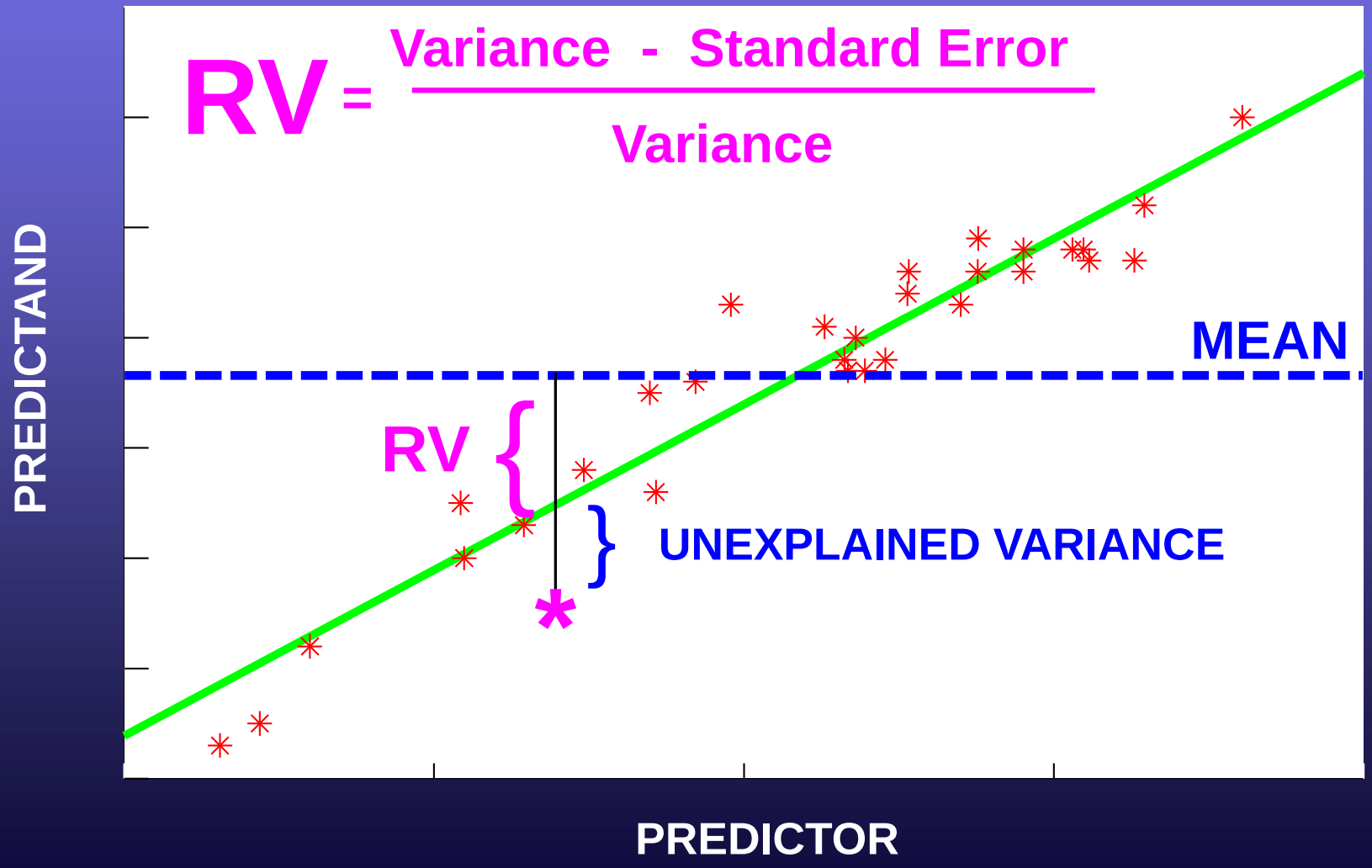
JANUARY 1 - JANUARY 30, 1994 0000 UTC

KCMH



REDUCTION OF VARIANCE

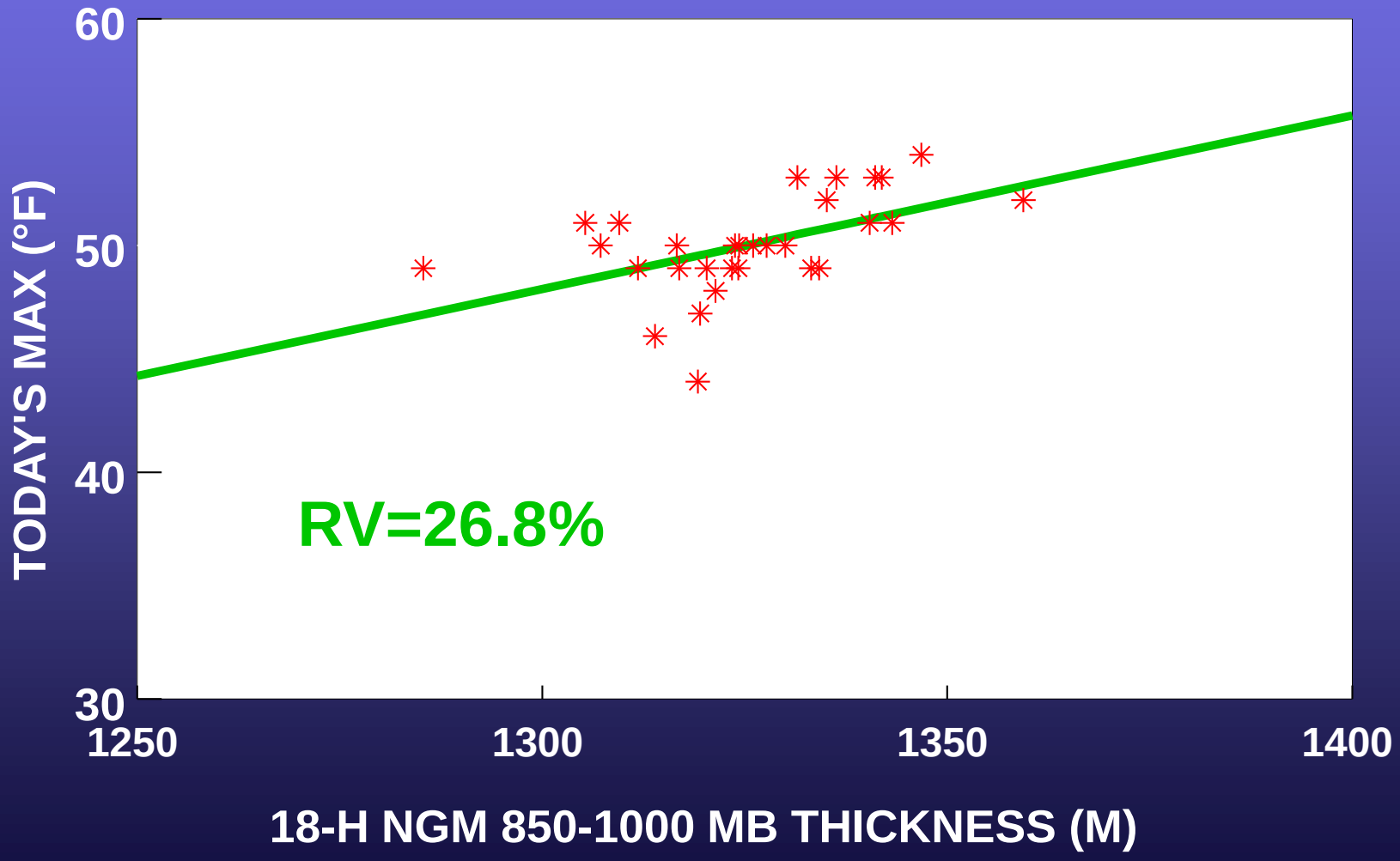
A measure of the “goodness” of fit and
Predictor / Predictand correlation



MOS LINEAR REGRESSION

JANUARY 1 - JANUARY 30, 1994 0000 UTC

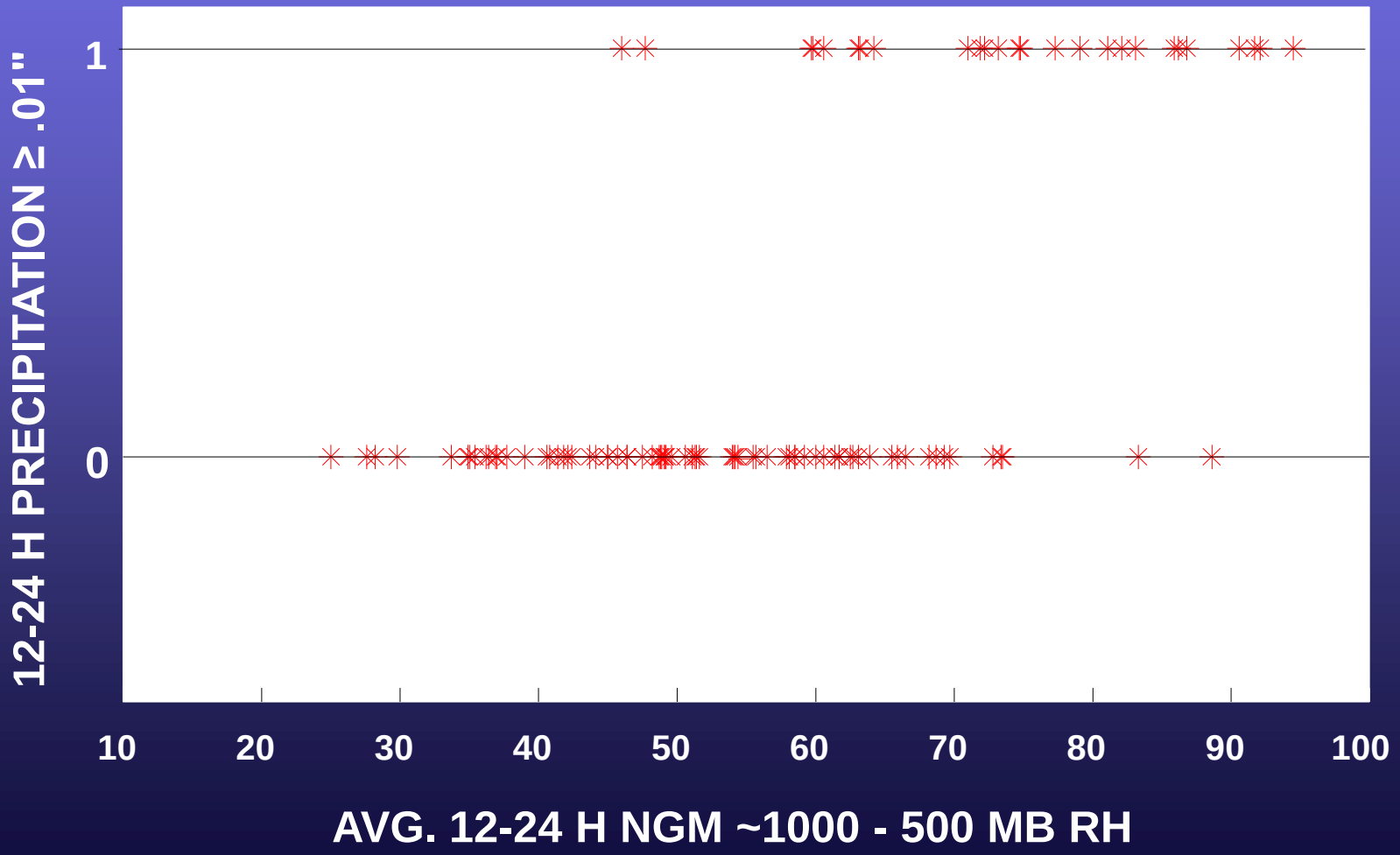
KUIL



MOS LINEAR REGRESSION

DECEMBER 1 1993 - MARCH 5 1994 0000 UTC

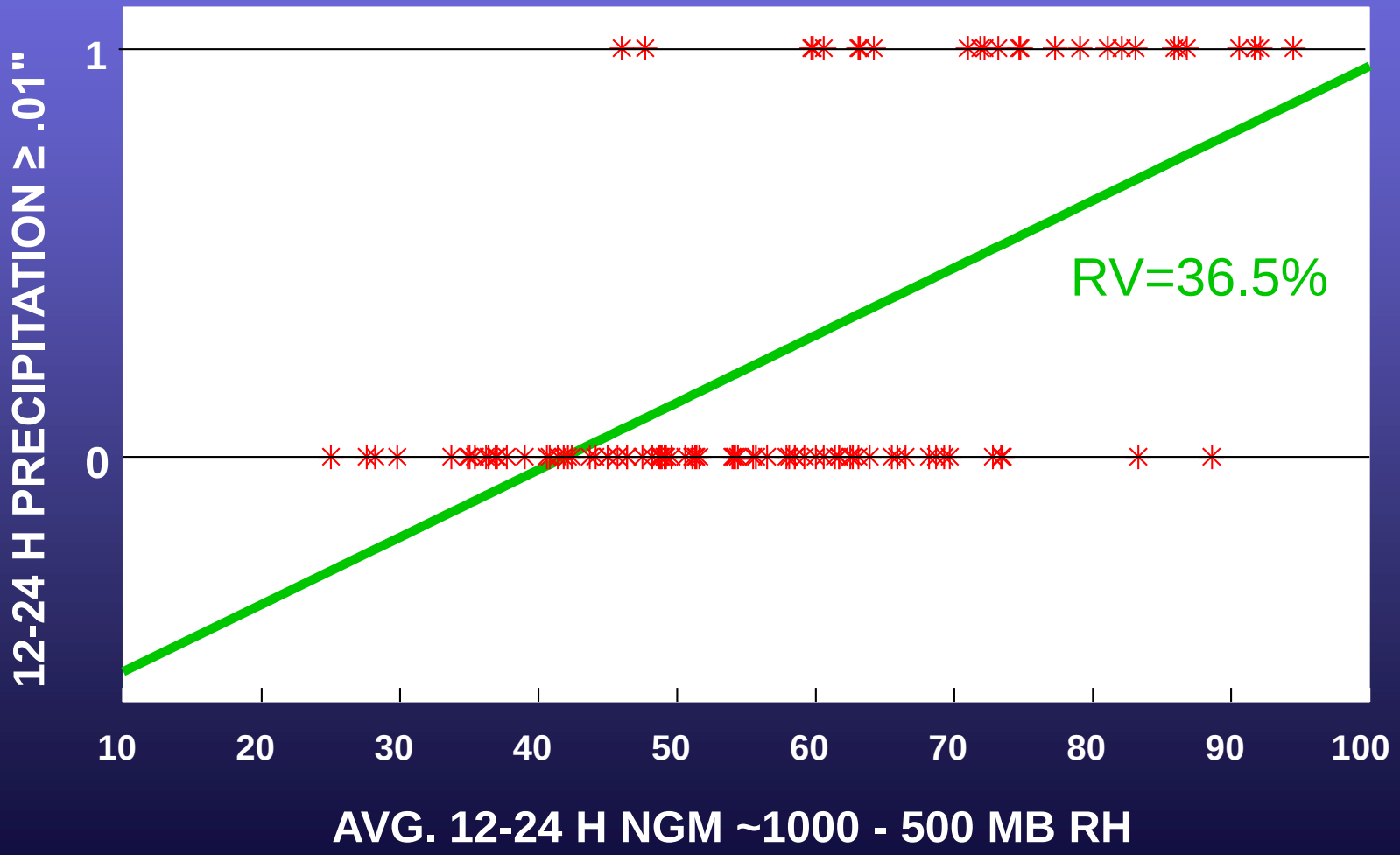
KCMH



MOS LINEAR REGRESSION

DECEMBER 1 1993 - MARCH 5 1994 0000 UTC

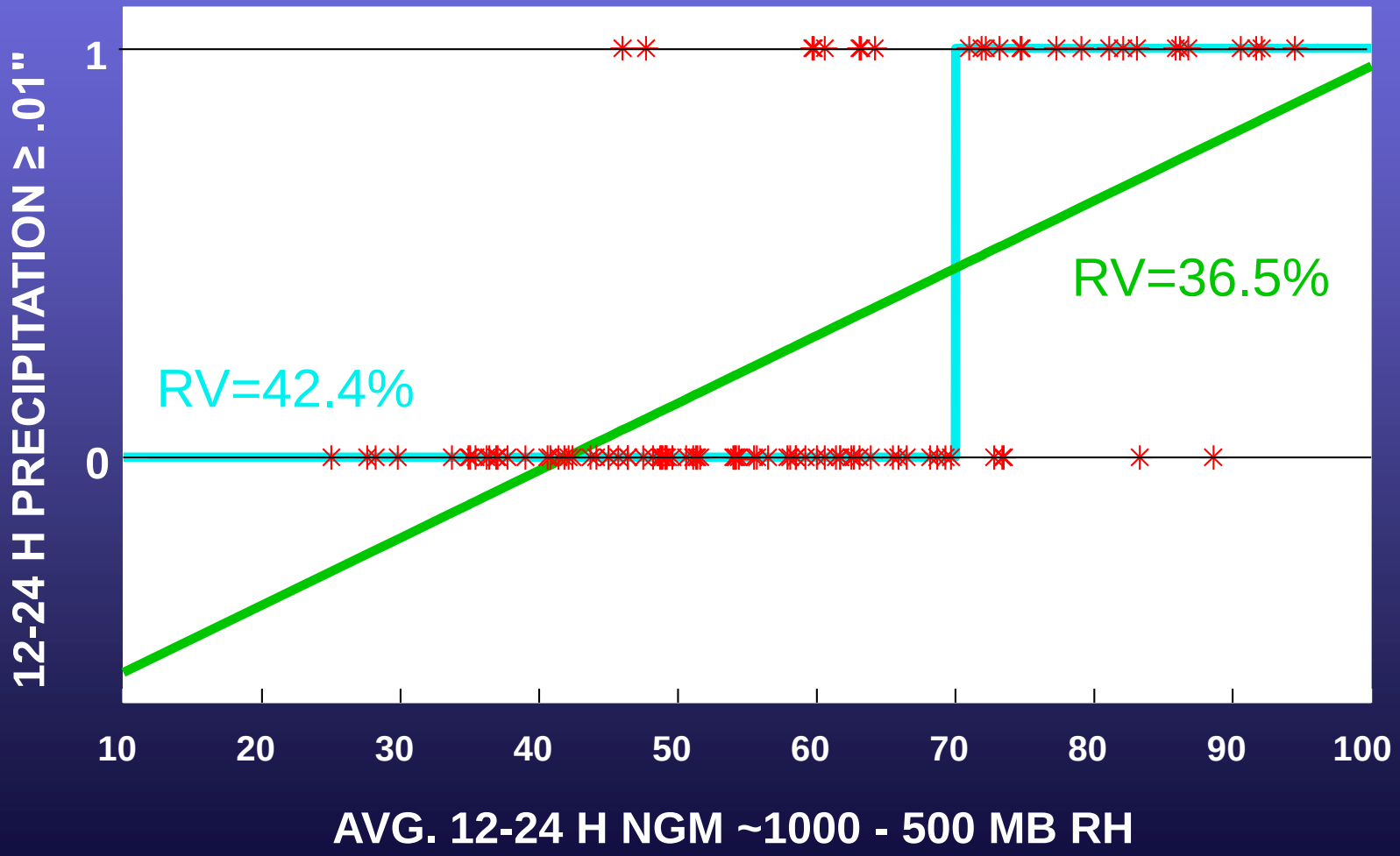
KCMH



MOS LINEAR REGRESSION

DECEMBER 1 1993 - MARCH 5 1994 0000 UTC

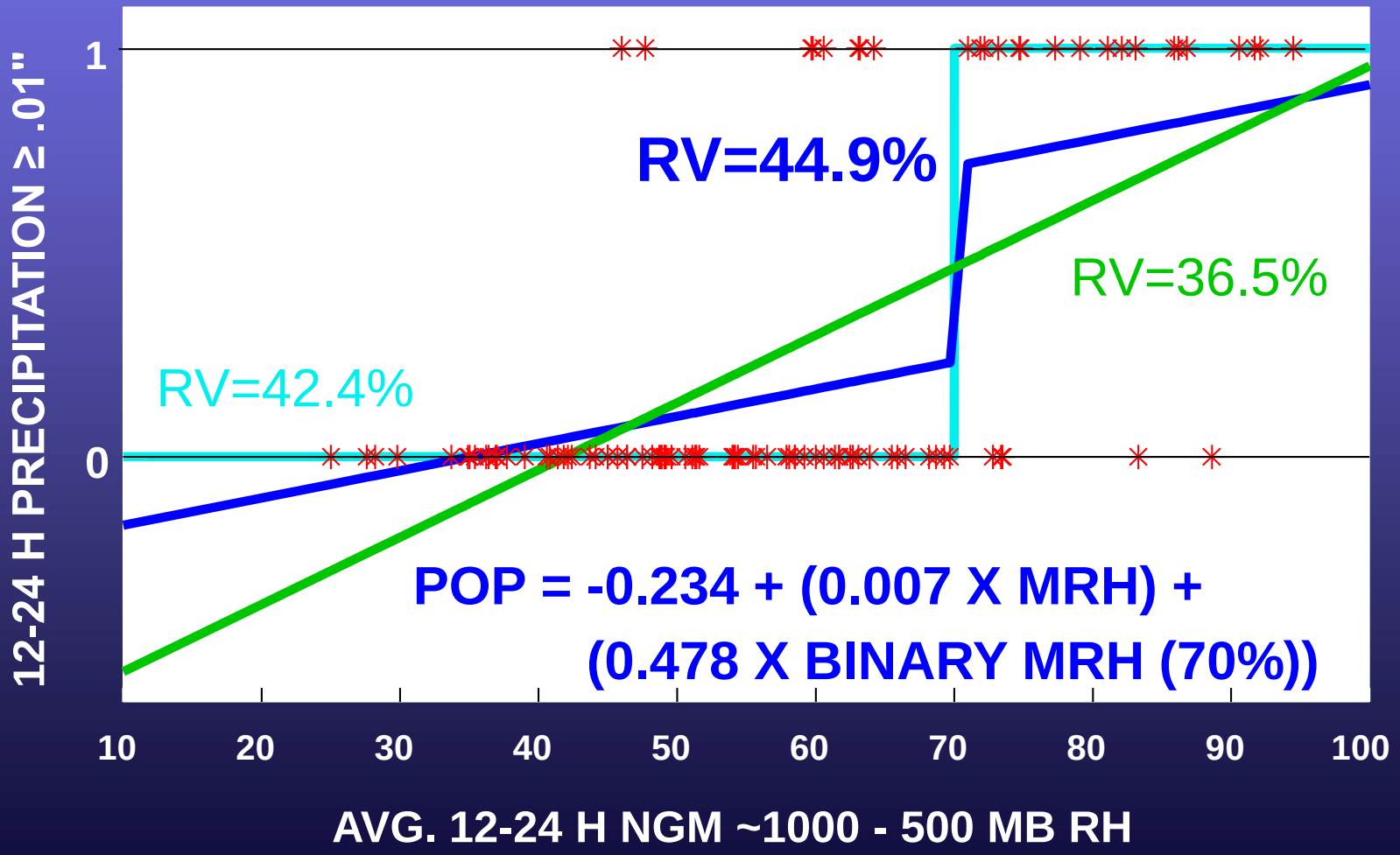
KCMH



MOS LINEAR REGRESSION

DECEMBER 1 1993 - MARCH 5 1994 0000 UTC

KCMH



EXAMPLE REGRESSION EQUATIONS

$$Y = a + bX$$

CMH MAX TEMPERATURE EQUATION

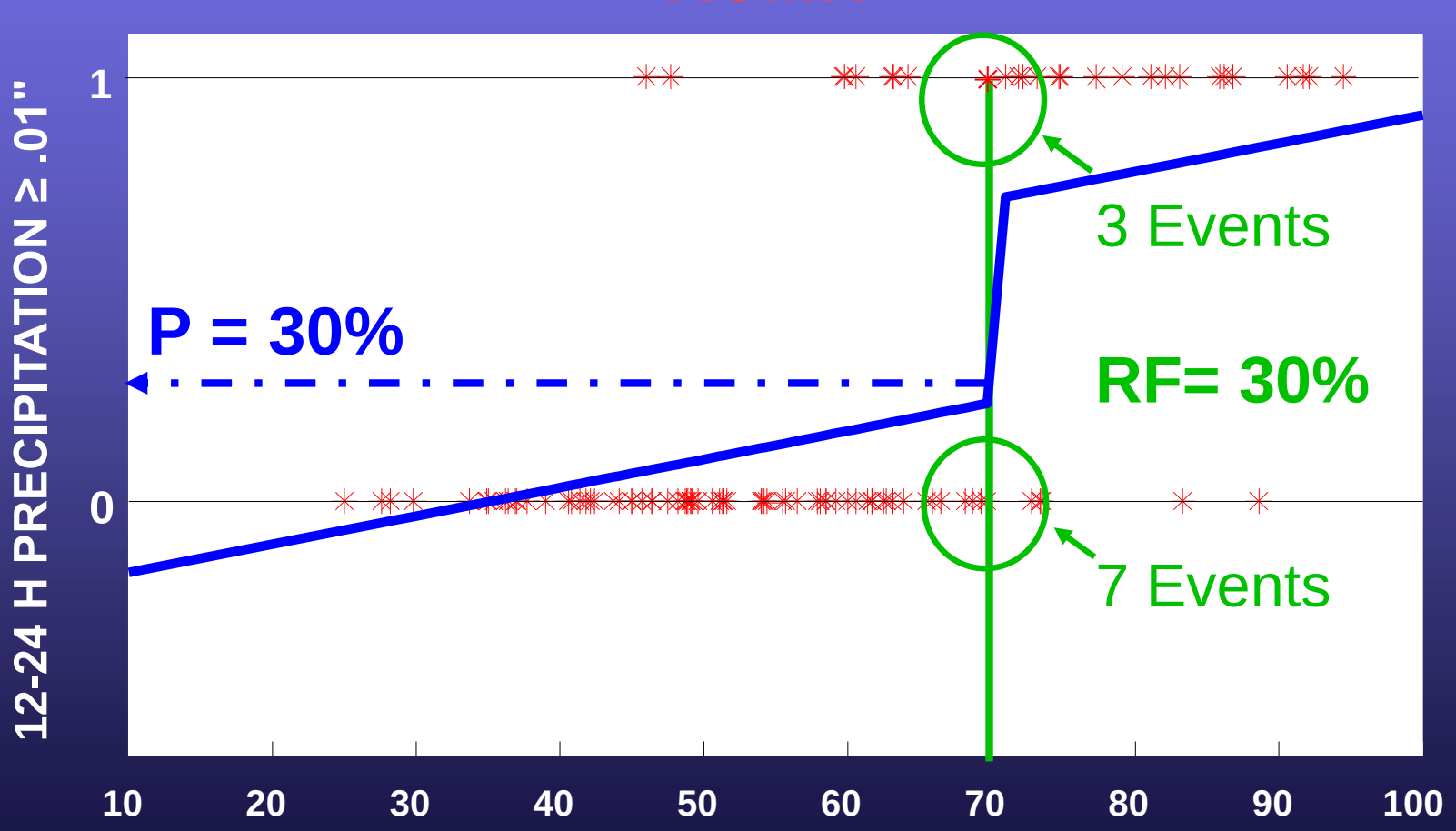
MAX T = -352 + (0.3 x 850 -1000 mb THICKNESS)

CMH PROBABILITY OF PRECIPITATION EQUATION

POP = -0.234 + (0.007 x MEAN RH)
+ (0.478 x BINARY MEAN RH CUTOFF AT 70%)*

*(IF MRH ≥ 70% BINARY MRH = 1; else BINARY MRH = 0)

If the predictand is BINARY, MOS regression equations produce estimates of event PROBABILITIES...



Making a PROBABILISTIC statement...

Quantifies the uncertainty !

DEFINITION of PROBABILITY

(Wilks, 1994)

- LONG TERM RELATIVE FREQUENCY OF AN EVENT
- DEGREE OF BELIEF OR QUANTIFIED JUDGMENT ABOUT THE OCCURRENCE OF AN UNCERTAIN EVENT

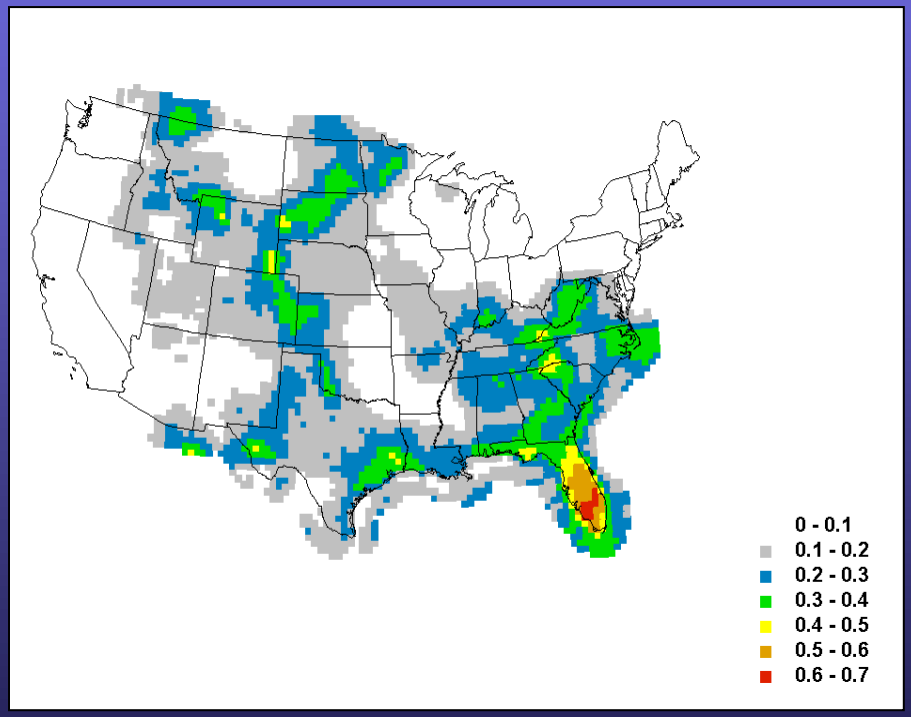
KEEP IN MIND:

Assessment of probability is ***EXTREMELY*** dependent upon how predictand "event" is defined:

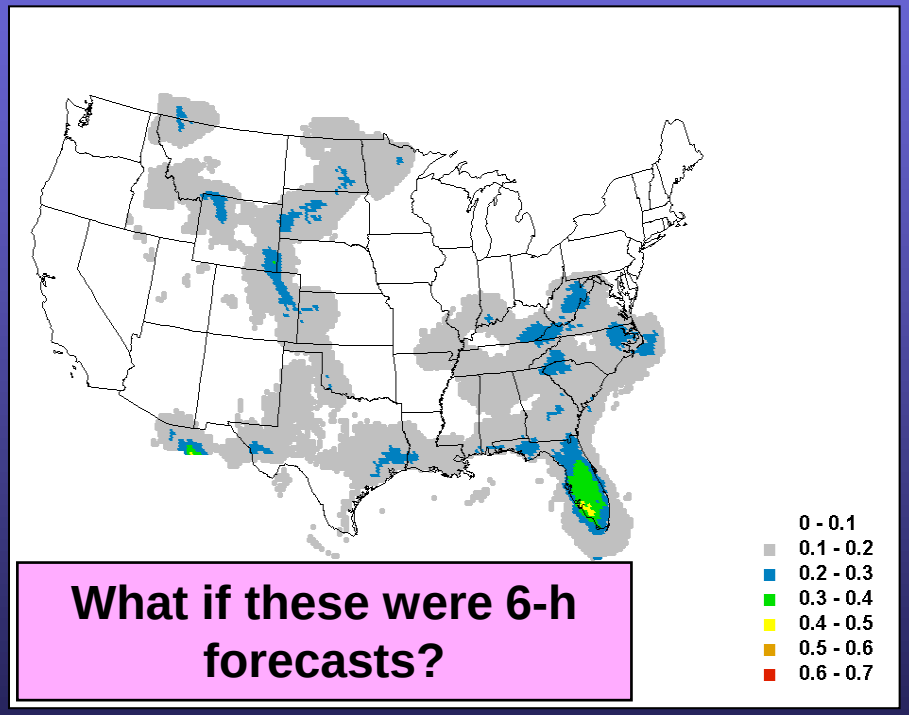
- Time period of consideration
- Area of occurrence
- Dependent upon another event?
  - POINT PROBABILITY
  - AREAL PROBABILITY
  - CONDITIONAL PROBABILITY

AREAL PROBABILITIES

3H Eta MOS thunderstorm probability forecasts
valid 0000 UTC 8/27/2002 (21-24h proj)



40-km gridbox
10% contour interval



What if these were 6-h forecasts?

20-km gridbox
10% contour interval

Designing an Operational MOS System:

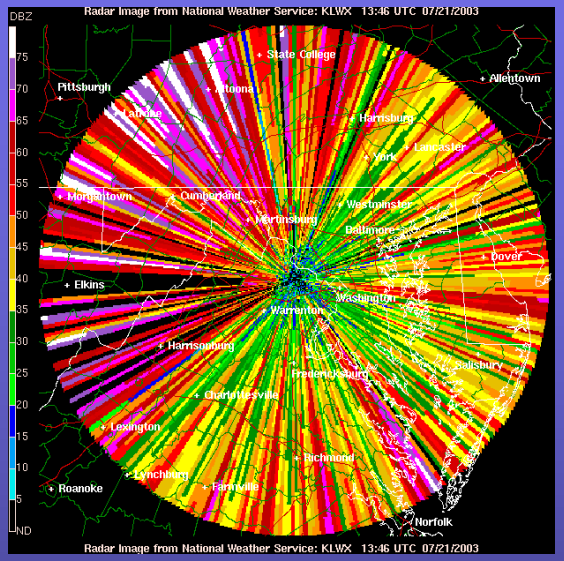
Putting theory into practice…

DEVELOPMENTAL CONSIDERATIONS

MOS in the real world

- **Selection (and QC!) of Suitable Observational Datasets**
  - **ASOS?**
  - **Remote sensor?**
  - **Which mesonet?**

Suitable observations?



Appropriate Sensor?

Good siting?

Real or Memorex?

DEVELOPMENTAL CONSIDERATIONS

MOS in the real world

- **Selection (and QC!) of Suitable Observational Datasets**
  - **ASOS? Remote sensor? Which mesonet?**
- **Predictand Definition**
  - **Must be precise !!**

PREDICTAND DEFINITION

Max/Min and PoP

Daytime Maximum Temperature

"Daytime" is 0700 AM - 0700 PM LST

Nighttime Minimum Temperature

"Nighttime" is 0700 PM - 0800 AM LST

Probability of Precipitation

Precipitation occurrence is accumulation of ≥ 0.01 inches of liquid-equivalent at a gauge location within a specified period

DEVELOPMENTAL CONSIDERATIONS

MOS in the real world

- **Selection (and QC!) of Suitable Observational Datasets**
  - ASOS? Remote sensor? Which mesonet?
- **Predictand Definition**
  - Must be precise !!
- **Choice of Predictors**
  - "Appropriate" formulation
  - Binary or other transform?

“APPROPRIATE” PREDICTORS

- DESCRIBE PHYSICAL PROCESSES ASSOCIATED WITH OCCURRENCE OF PREDICTAND

  i.e. for POP:

  PRECIPITABLE WATER
  VERTICAL VELOCITY
  MOISTURE DIVERGENCE
  MODEL PRECIPITATION

  1000-500 MB THK
  TROPOPAUSE HGT

- “MIMIC” FORECASTER THOUGHT PROCESS

  (VERTICAL VELOCITY) X (MEAN RH)

DEVELOPMENTAL CONSIDERATIONS

(cont.)

- Terms in Equations; Selection Criteria

"REAL" REGRESSION EQUATIONS

MOS regression equations are MULTIVARIATE , of form:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + \ldots + a_N X_N$$

Where,

the "a's" represent COEFFICIENTS

the "X's" represent PREDICTOR variables

The maximum number of terms, N, can be ***QUITE*** large:

For NGM QPF, N = 15 For NGM VIS, N = 20

The **FORWARD SELECTION** procedure determines the predictors and the order in which they appear.

DEVELOPMENTAL CONSIDERATIONS

(cont.)

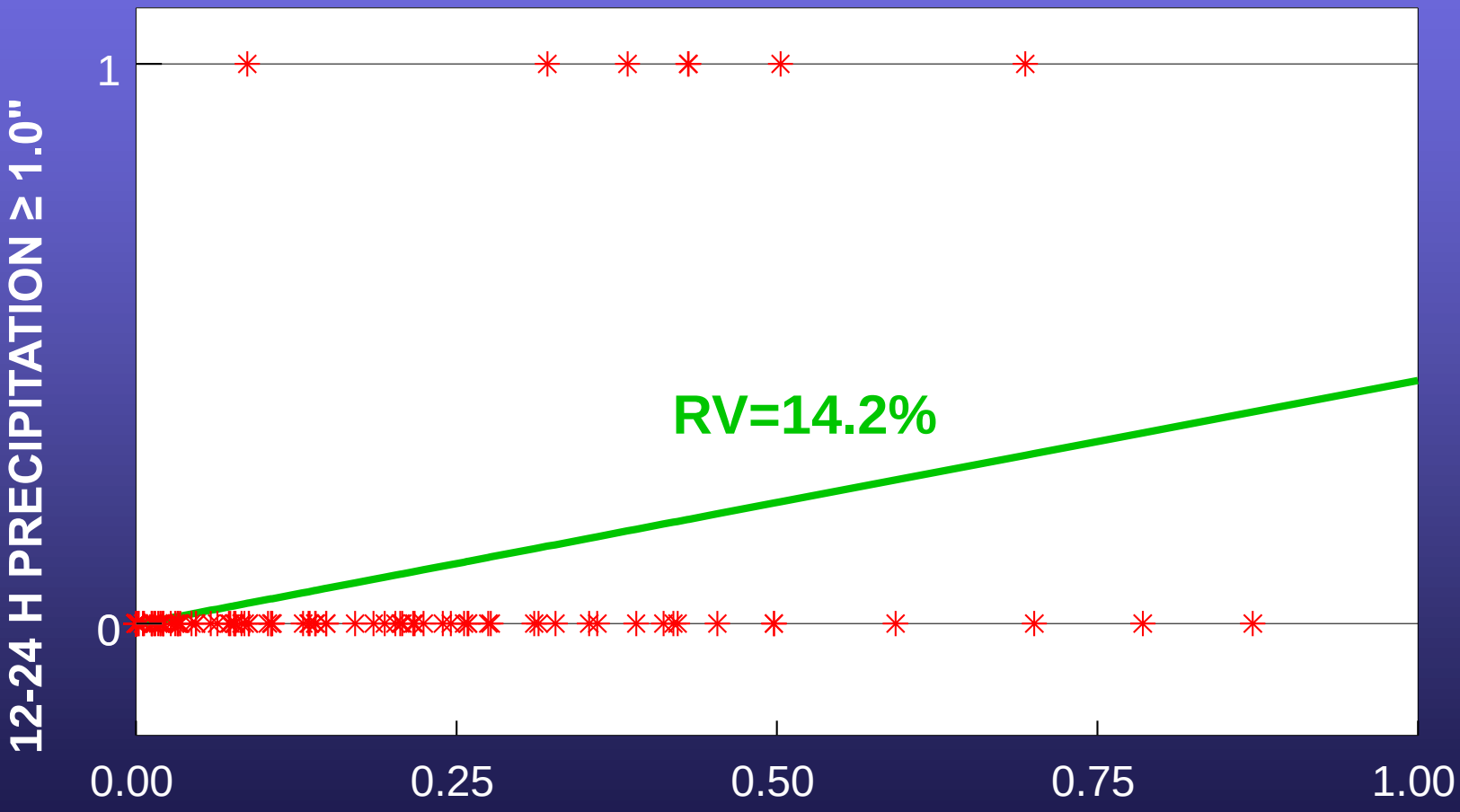
- Terms in Equations; Selection Criteria

- Dependent Data
  - Sample Size, Stability, Representativeness
    - AVOID OVERFIT !!
  - Stratification - Seasons
  - Pooling – Regions

MOS LINEAR REGRESSION

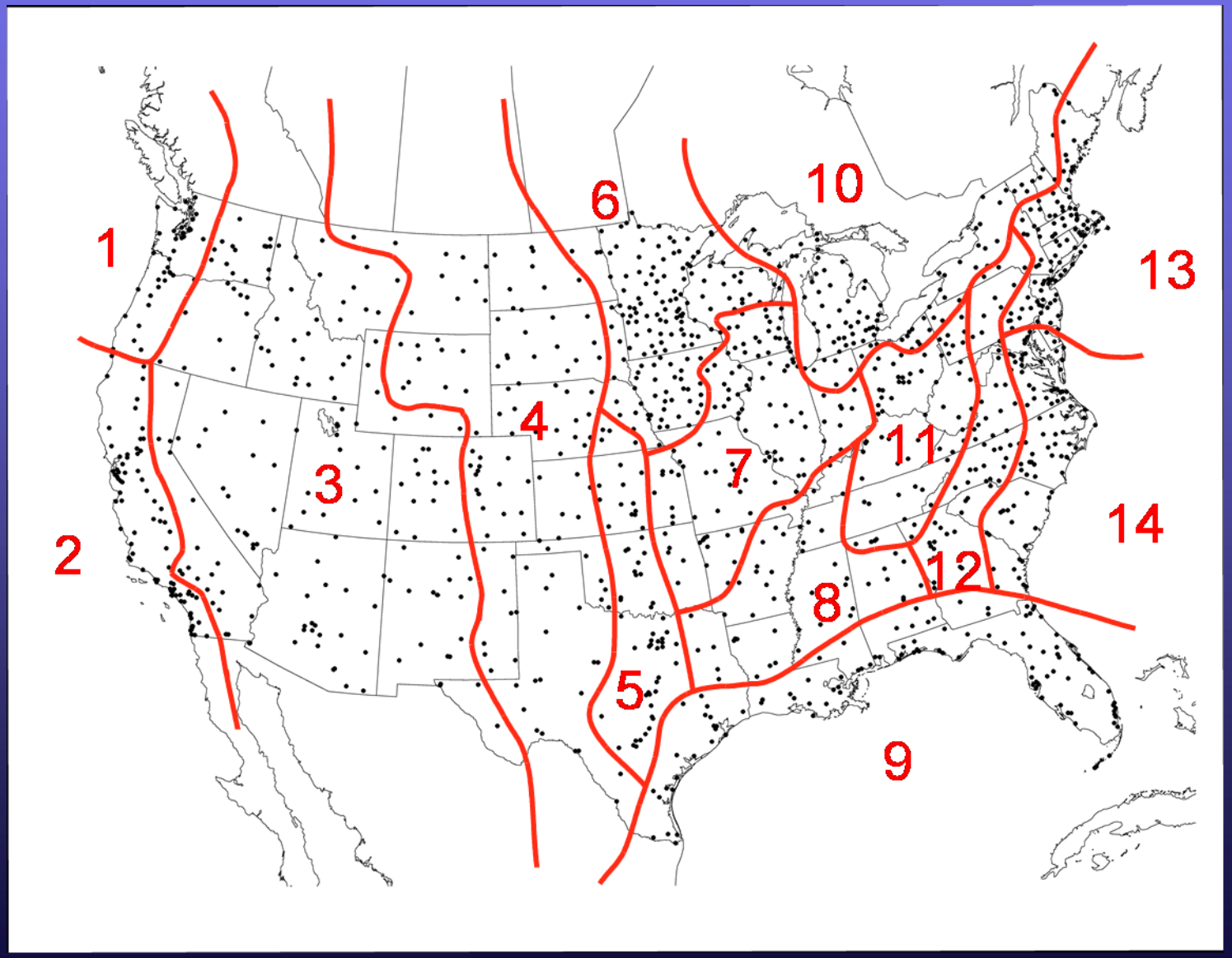
OCTOBER 1 1993 - MARCH 31 1994 0000 UTC

KUIL



AVN/GFS Cool Season PoP/QPF Regions

With AVN MOS forecast sites (1406)



DEVELOPMENTAL CONSIDERATIONS

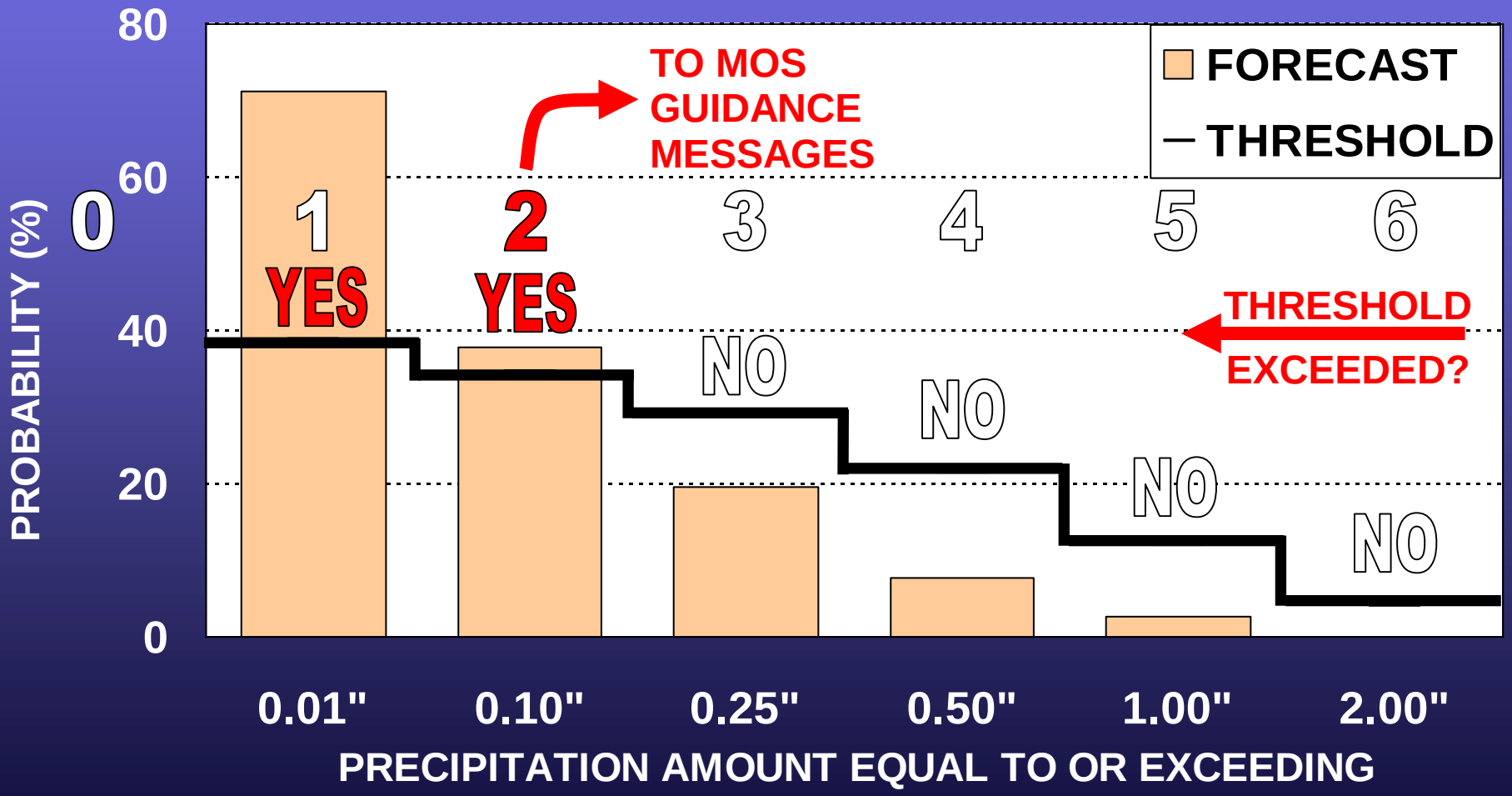
(cont.)

- Terms in Equations; Selection Criteria
- Dependent Data
  - Sample Size, Stability, Representativeness
    - AVOID OVERFIT !!
  - Stratification - Seasons
  - Pooling – Regions
- Categorical Forecasts?

MOS BEST CATEGORY SELECTION

KDCA 12-Hour QPF Probabilities

48-Hour Projection valid 1200 UTC 10/31/93

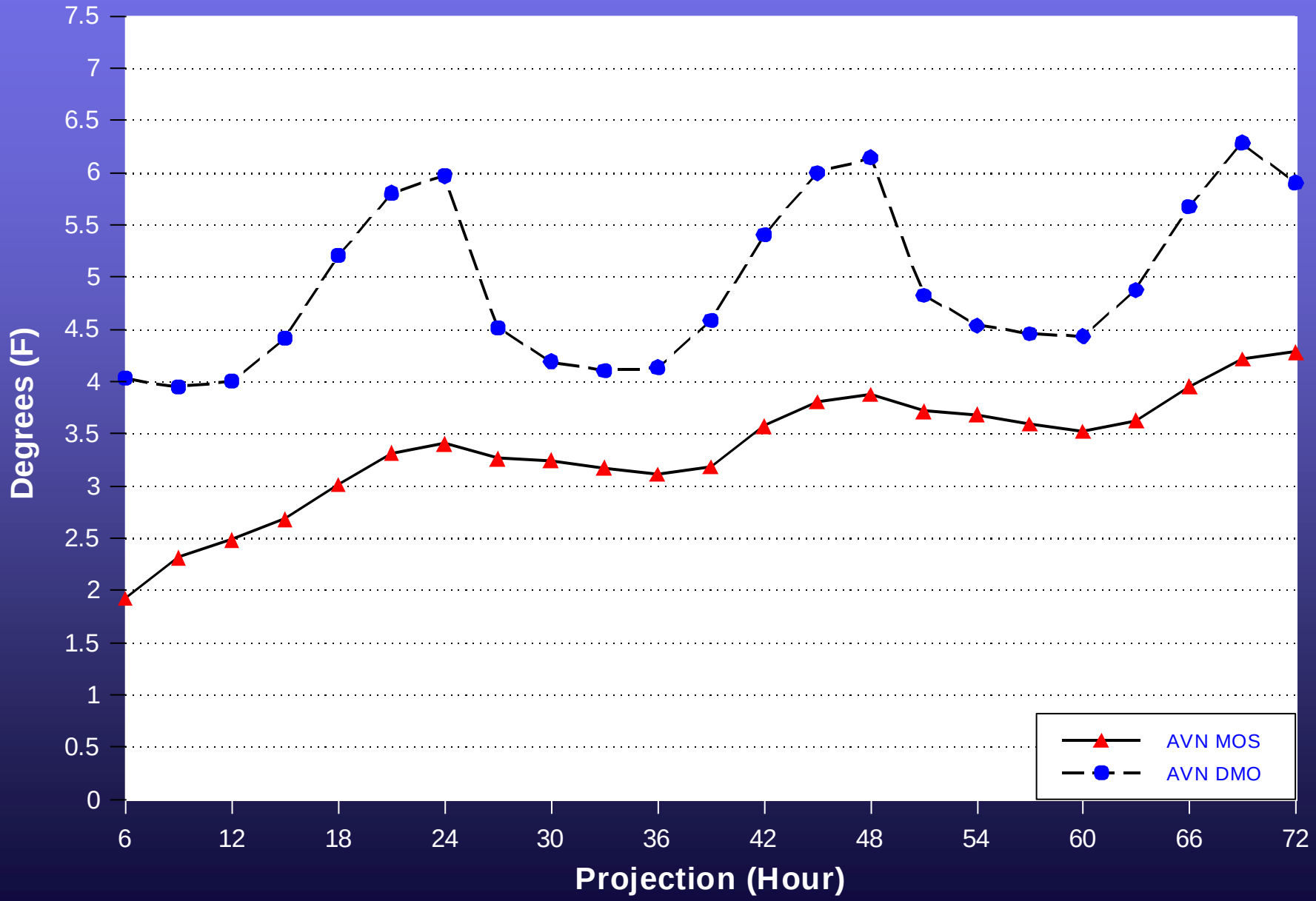


How well do we do?

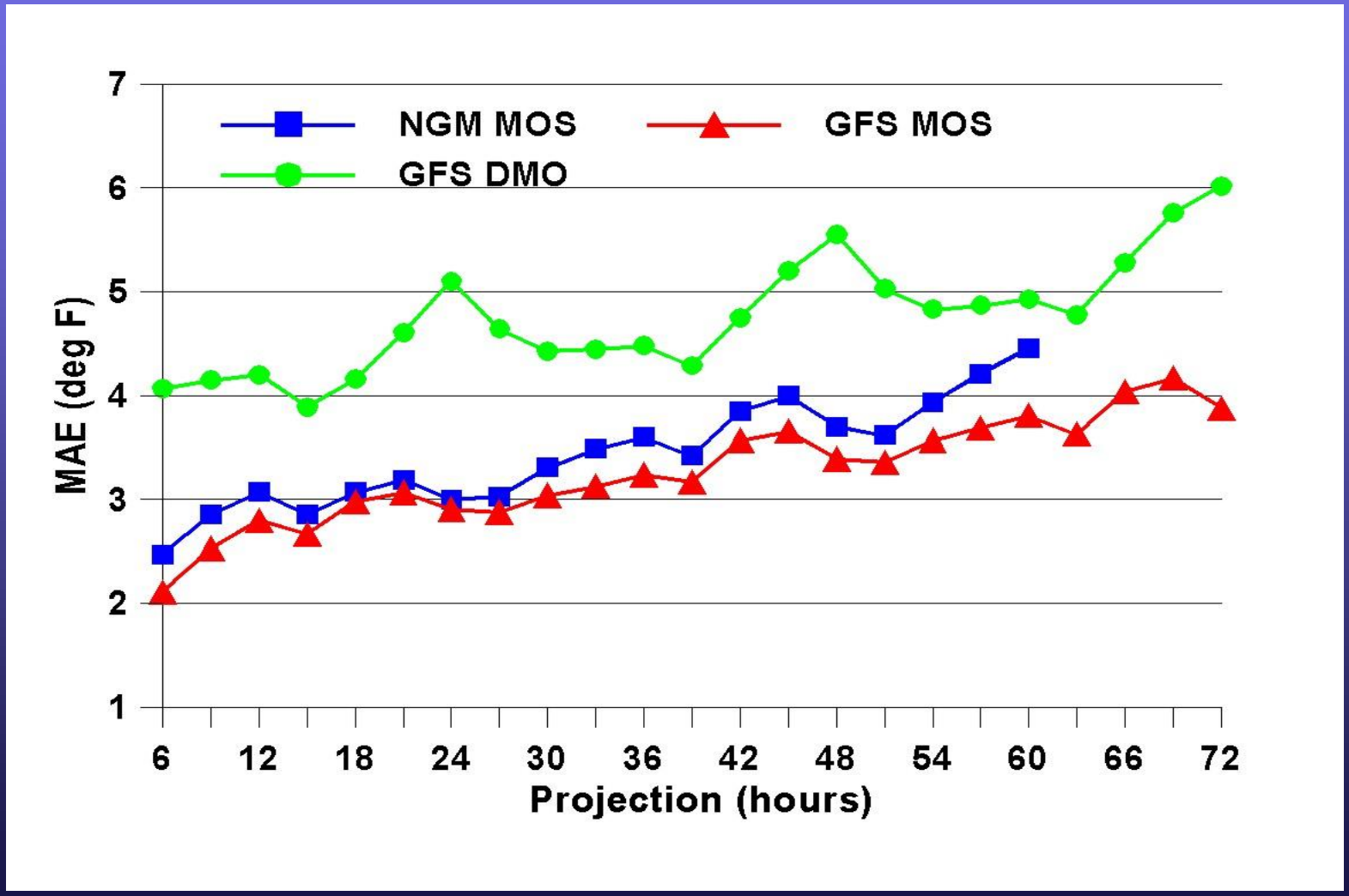
MOS Verification

Dew Point Mean Absolute Error

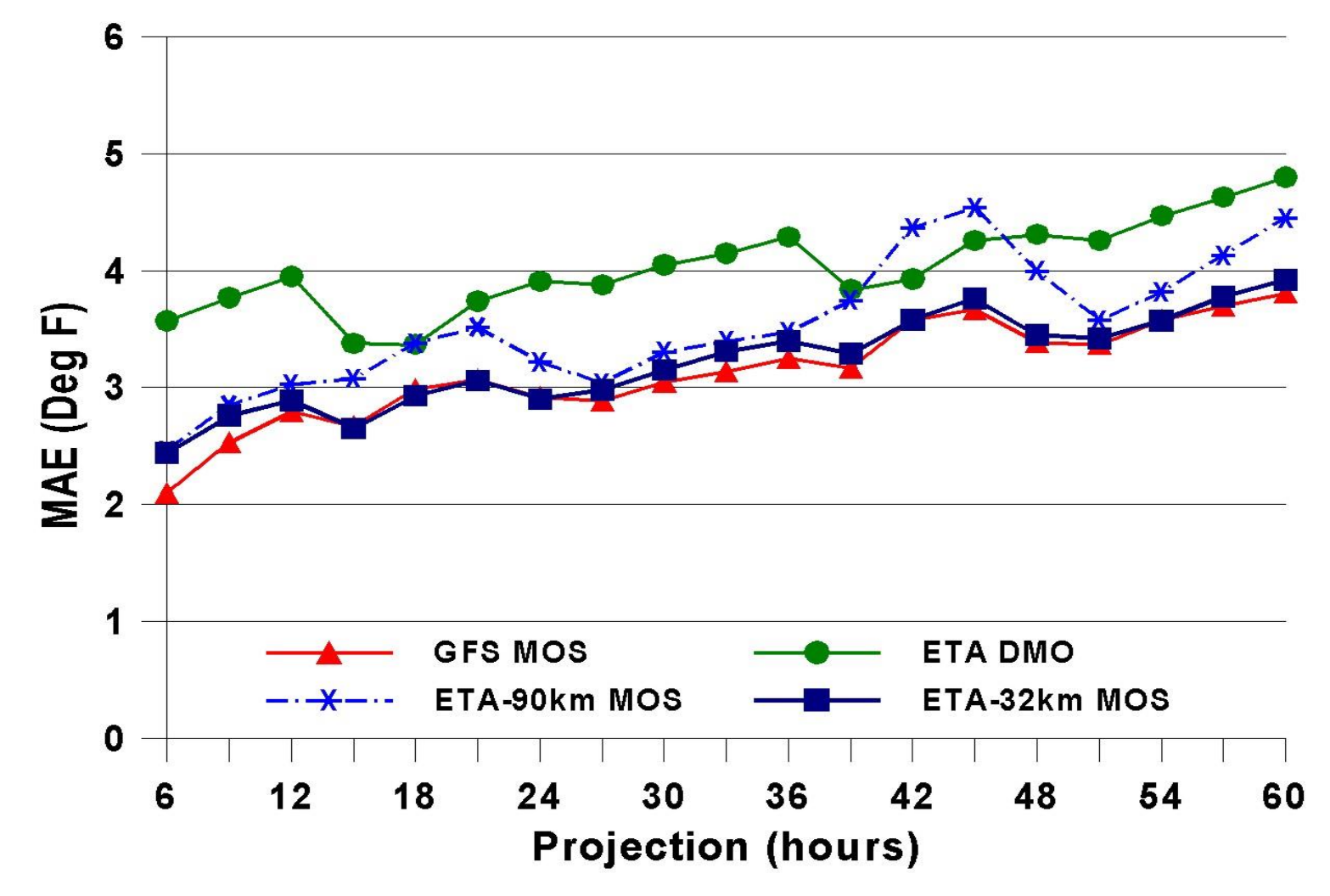
CONUS and Alaska 00z Apr.1 - Sept.30, 1999



Temperature Verification - 0000 UTC
Cool Season 2002 -2003

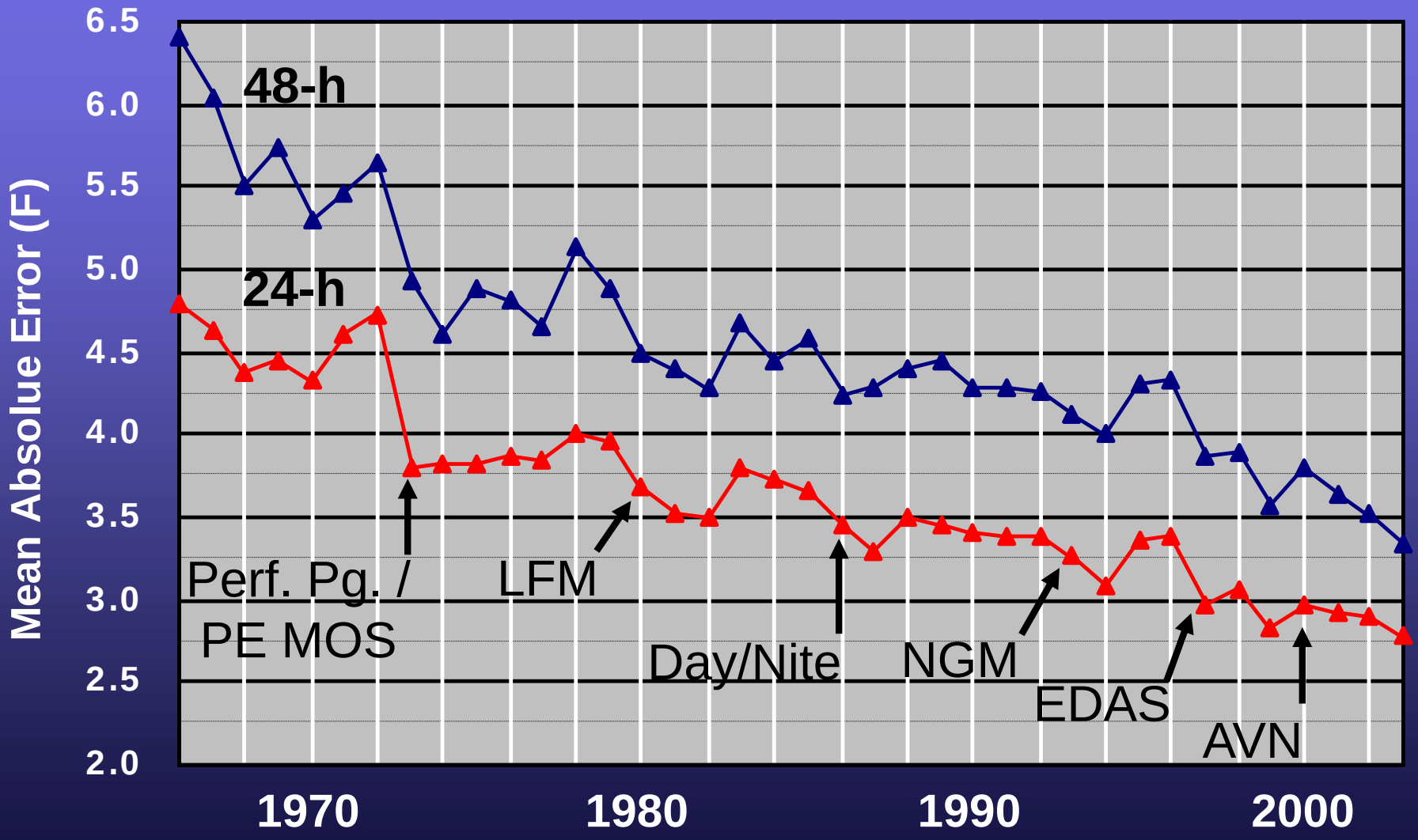


Temperature Verification - 0000 UTC
Cool Season 2002 -2003



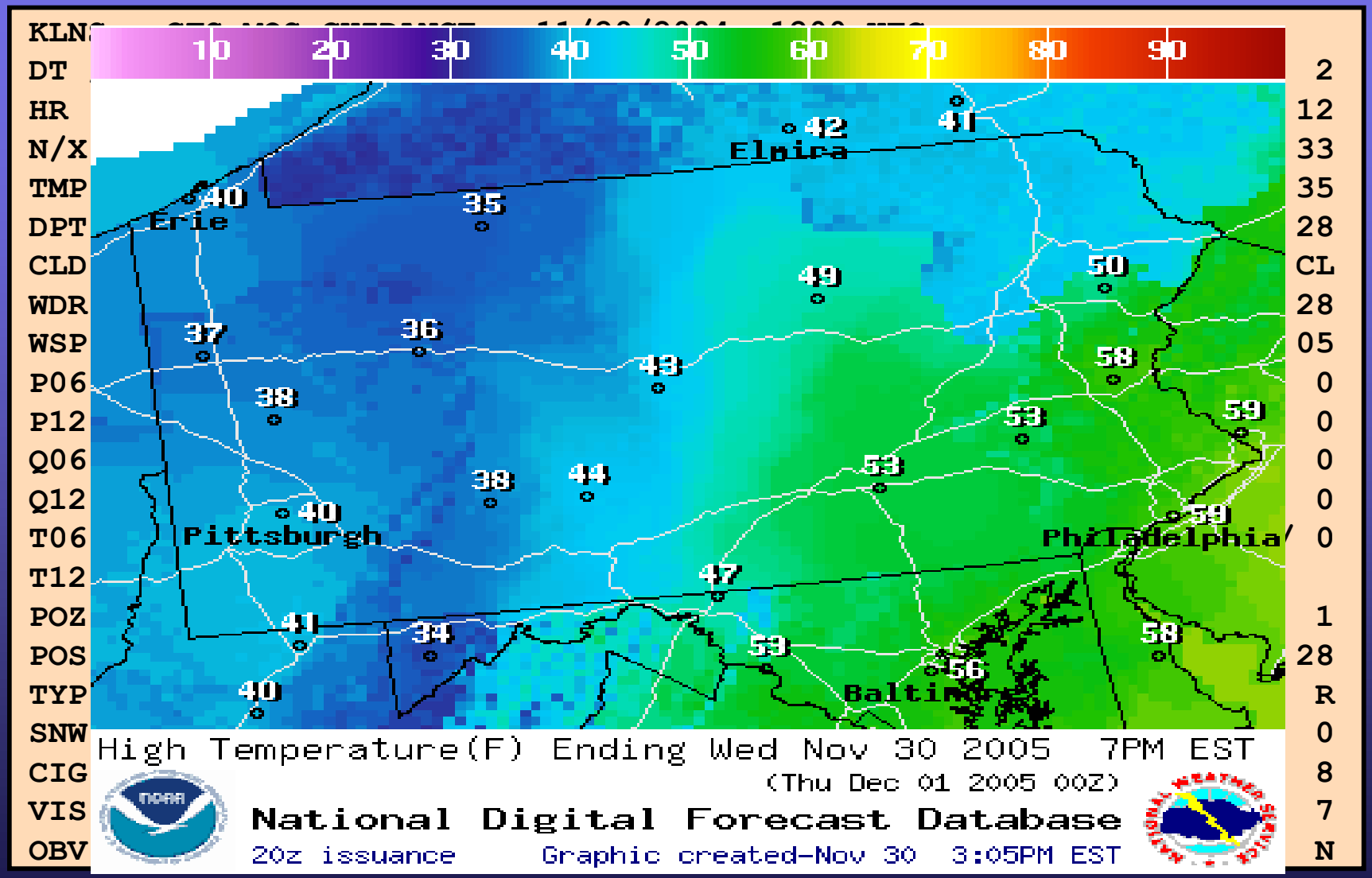
Max Temperature Verification

Cool Season; 1966 - 2003



MOS: Today and Beyond

End of an era?



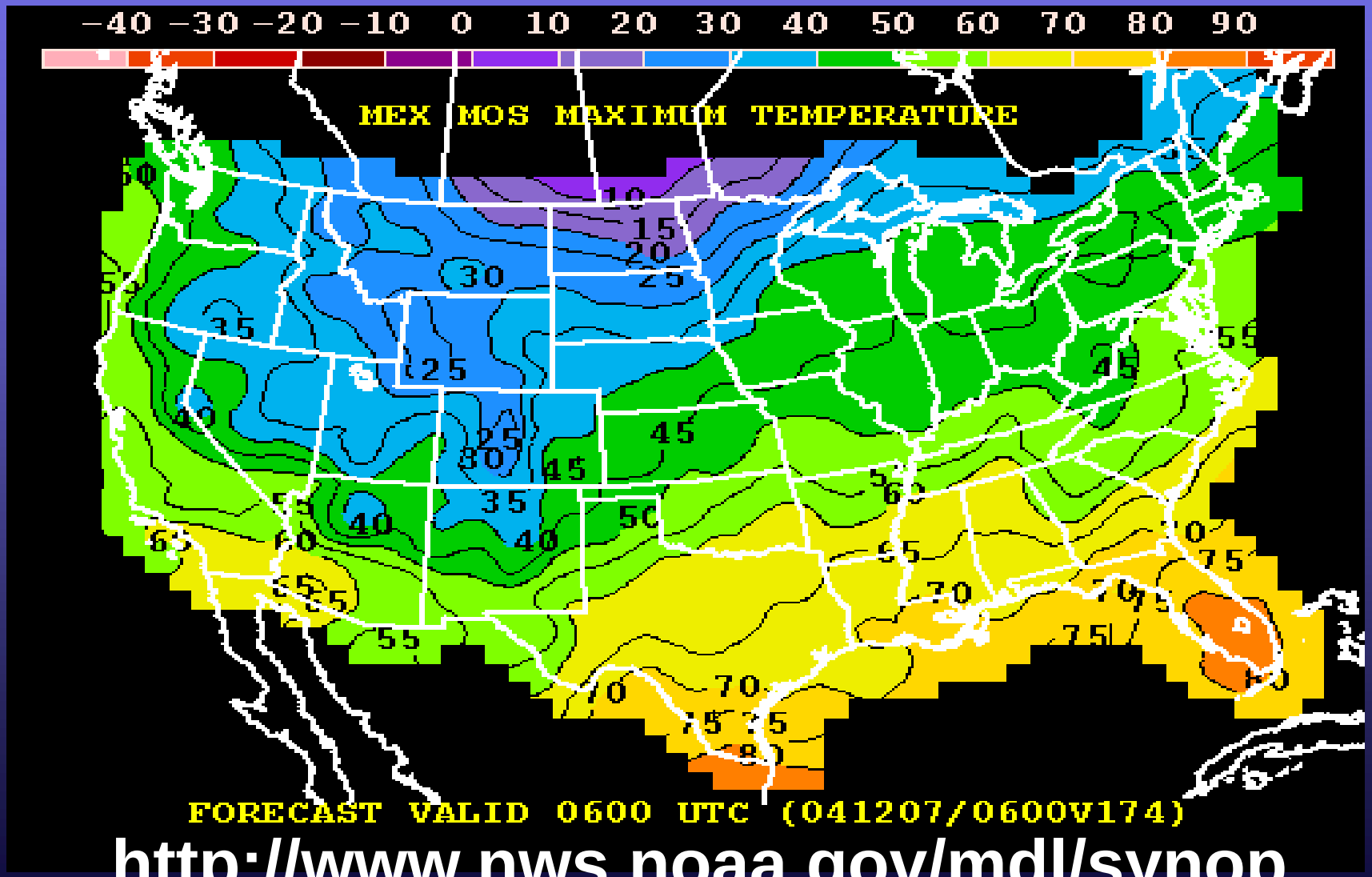
WANTED! High-resolution, gridded guidance for NDFD

The Future of MOS

"Traditional" Station-oriented Products

- **GFSX MOS:**
  Changes to cloud and wind predictands
  (Instantaneous values, post-process to avg.)
- **Eta MOS:**
  Eta/WRF re-evaluation, possible phaseout
- **Western Pacific MOS:**
  Add new elements (PoP, T, T_d, Max/Min, Cld)
- **General:**
  Periodic addition of new CONUS sites
  Gradual phaseout of station-oriented graphics

GFSX MOS Day 7 Maximum Temperature



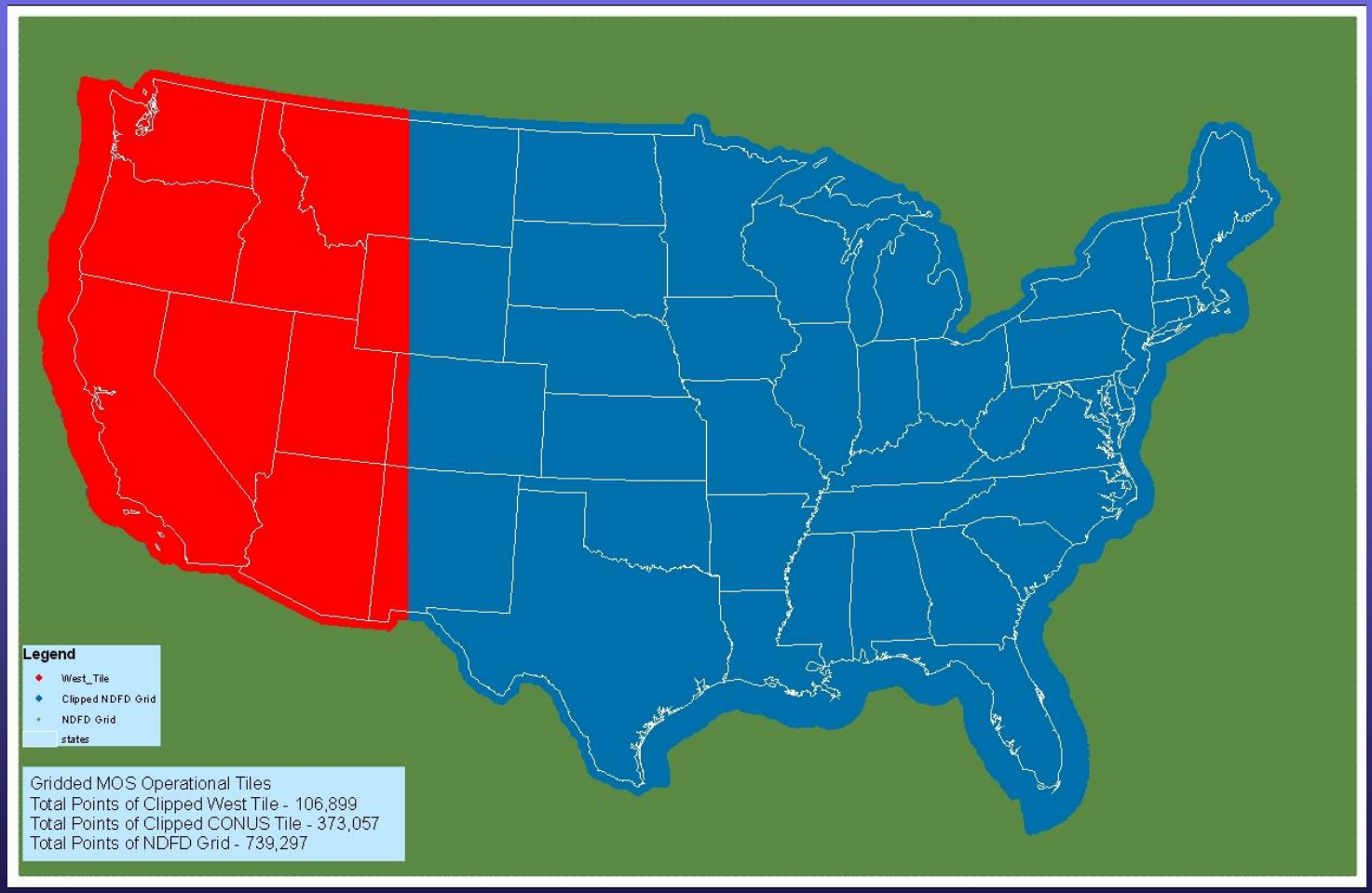
http://www.nws.noaa.gov/mdl/synop

The Future of MOS

"Enhanced-Resolution" MOS Systems

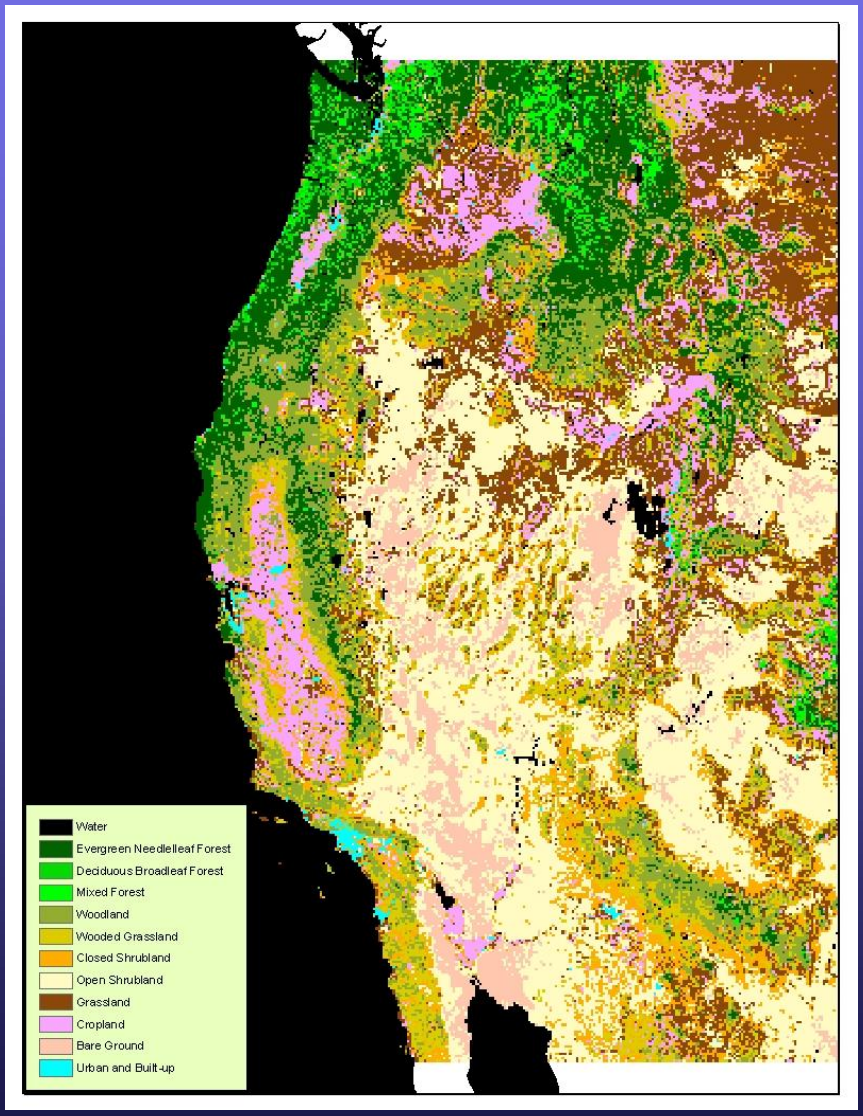
- "MOS at any point"
  - Support new NWS digital forecast database
    - 2.5 km - 5 km resolution
  - Emphasis on high-density surface networks
    - Co-Op, buoy, mesonet
  - Equations valid away from observing sites
  - Use high-resolution geophysical data

Gridded MOS Domains

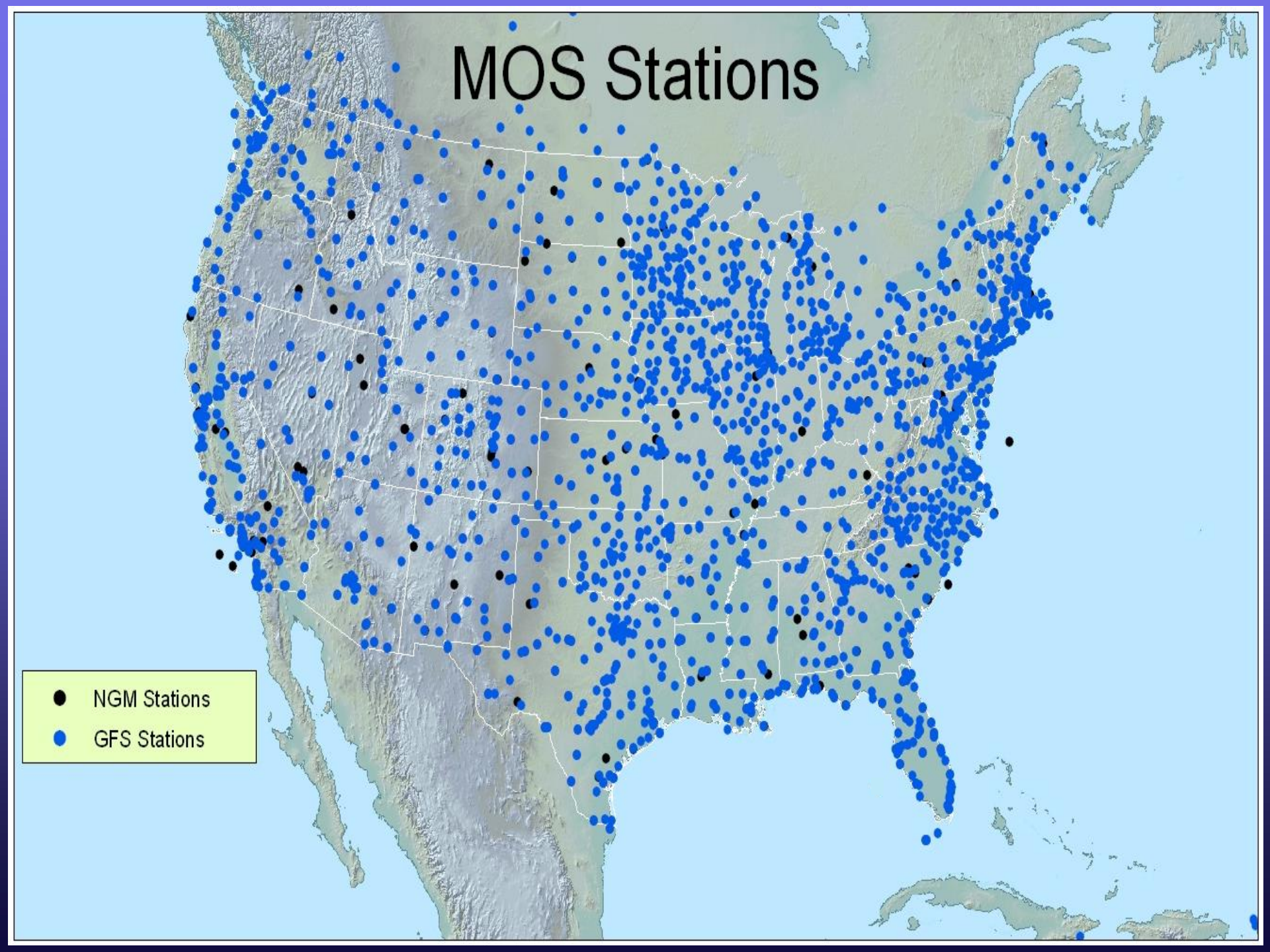


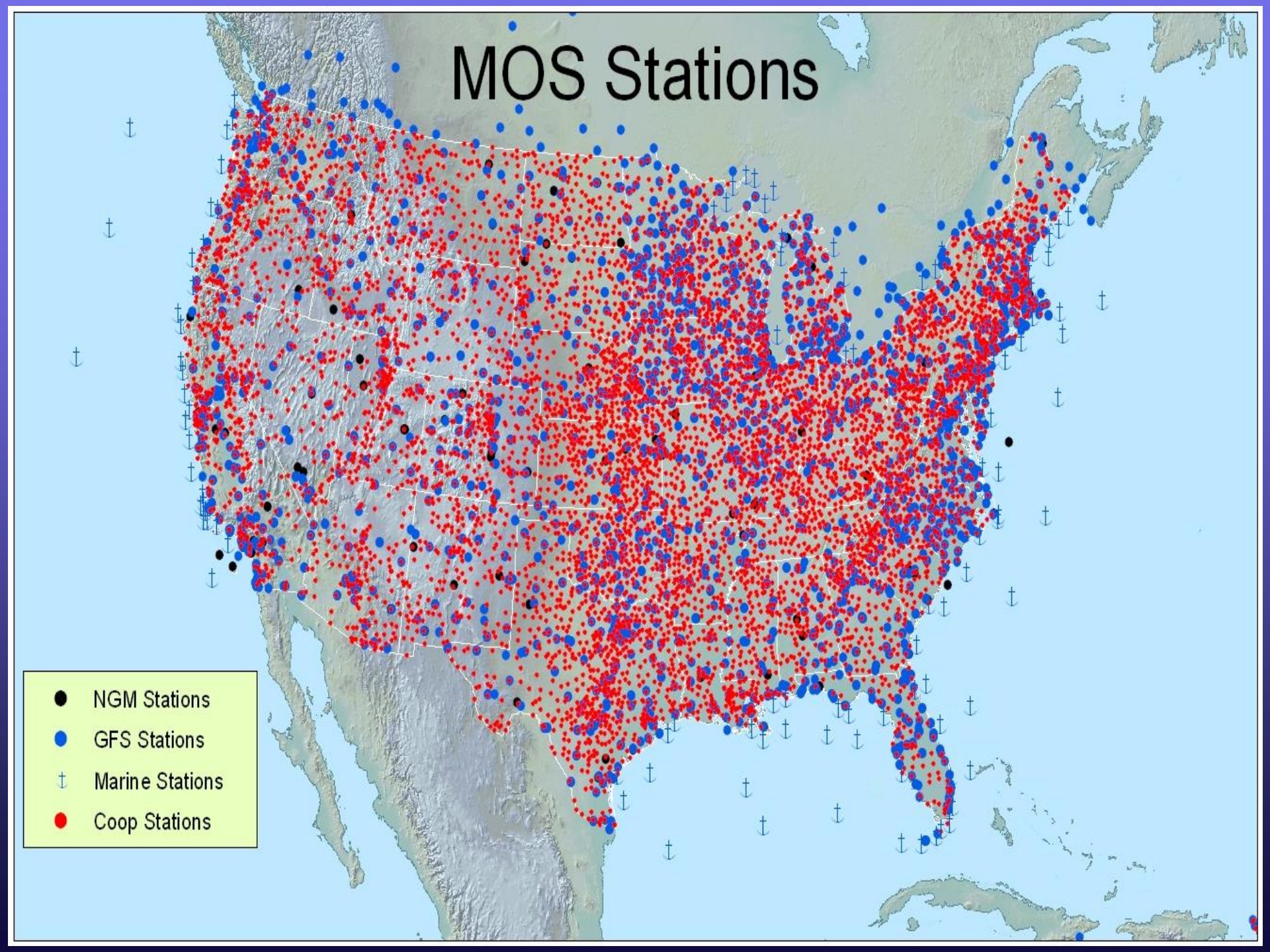
Geophysical Datasets

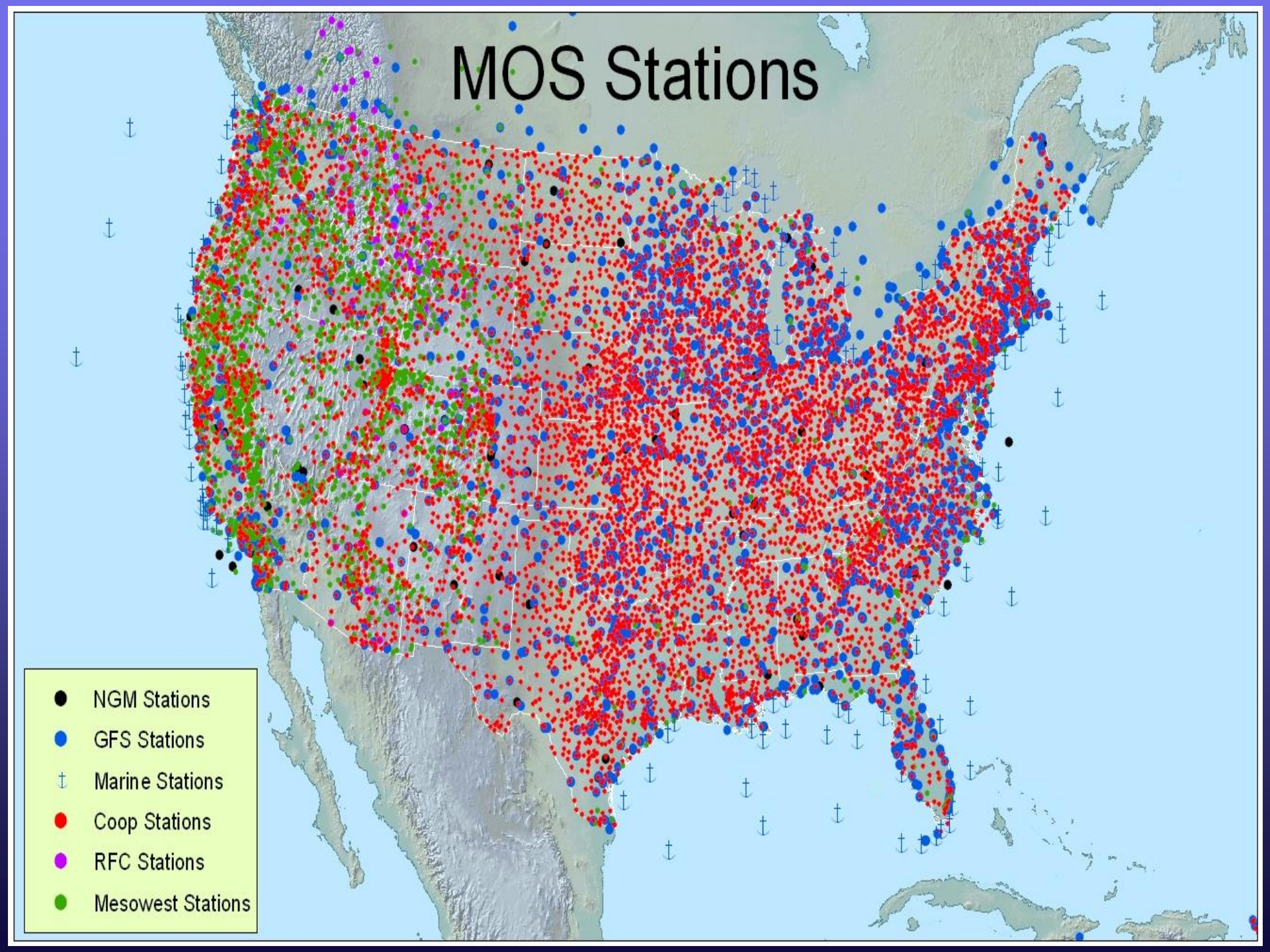
5-km Terrain



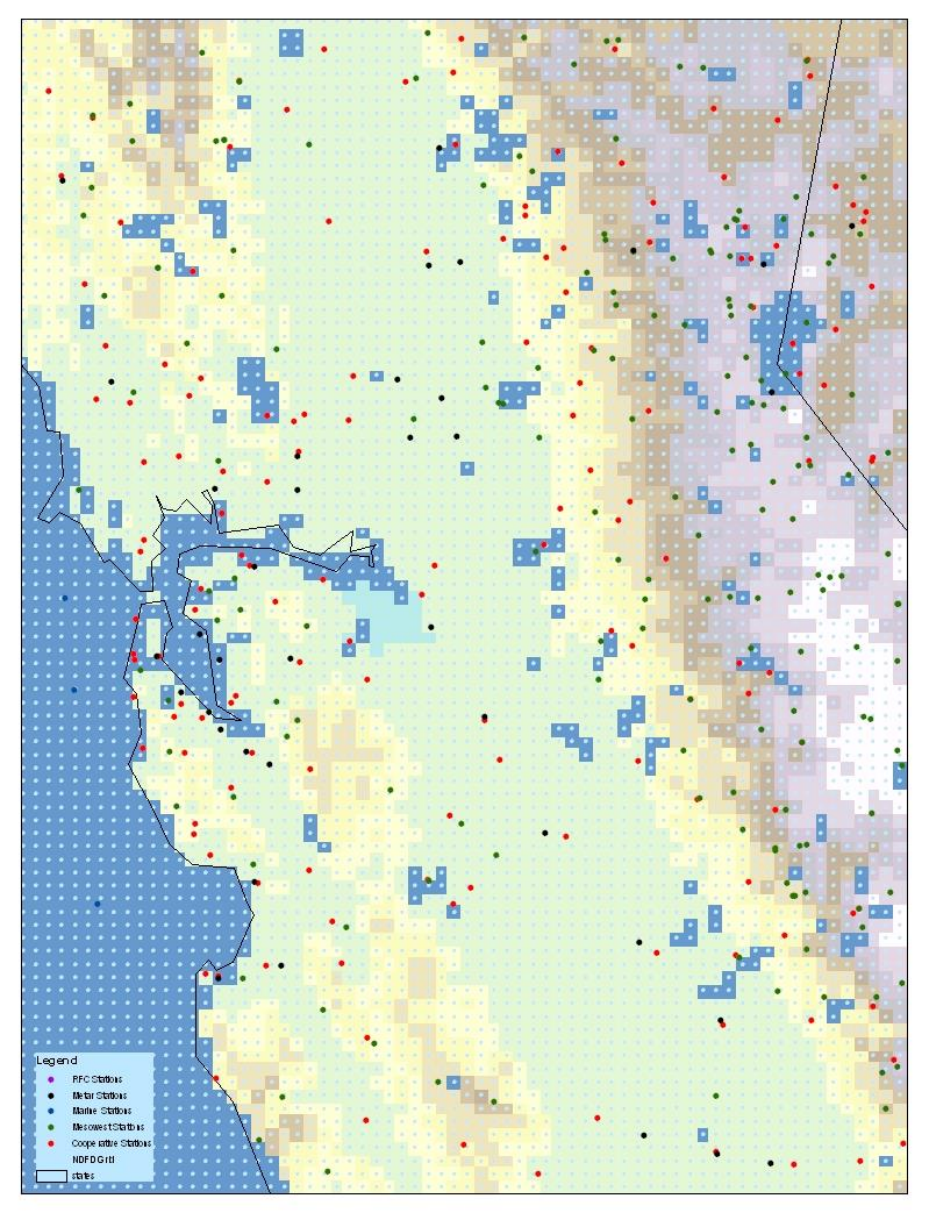
5-km Land Cover


MOS Stations
NGM Stations
GFS Stations


MOS Stations
NGM Stations
GFS Stations
Marine Stations
Coop Stations

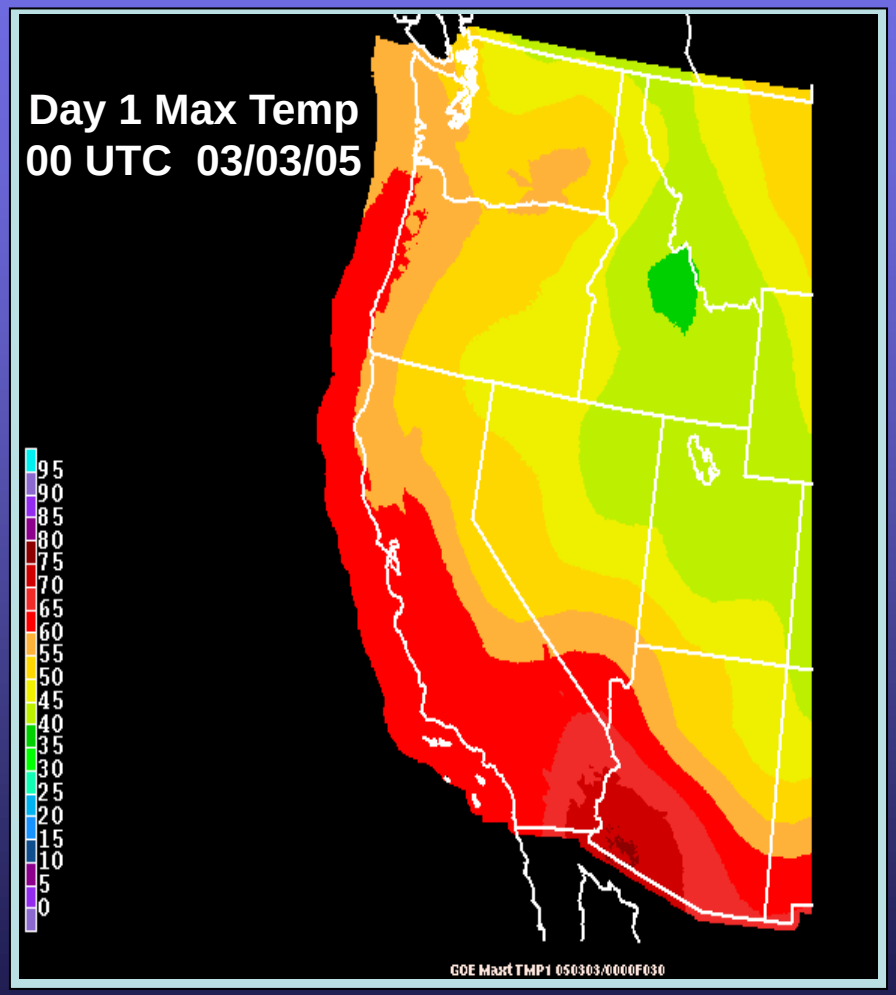

MOS Stations
NGM Stations
GFS Stations
Marine Stations
Coop Stations
RFC Stations
Mesowest Stations

Gridded MOS – Central CA

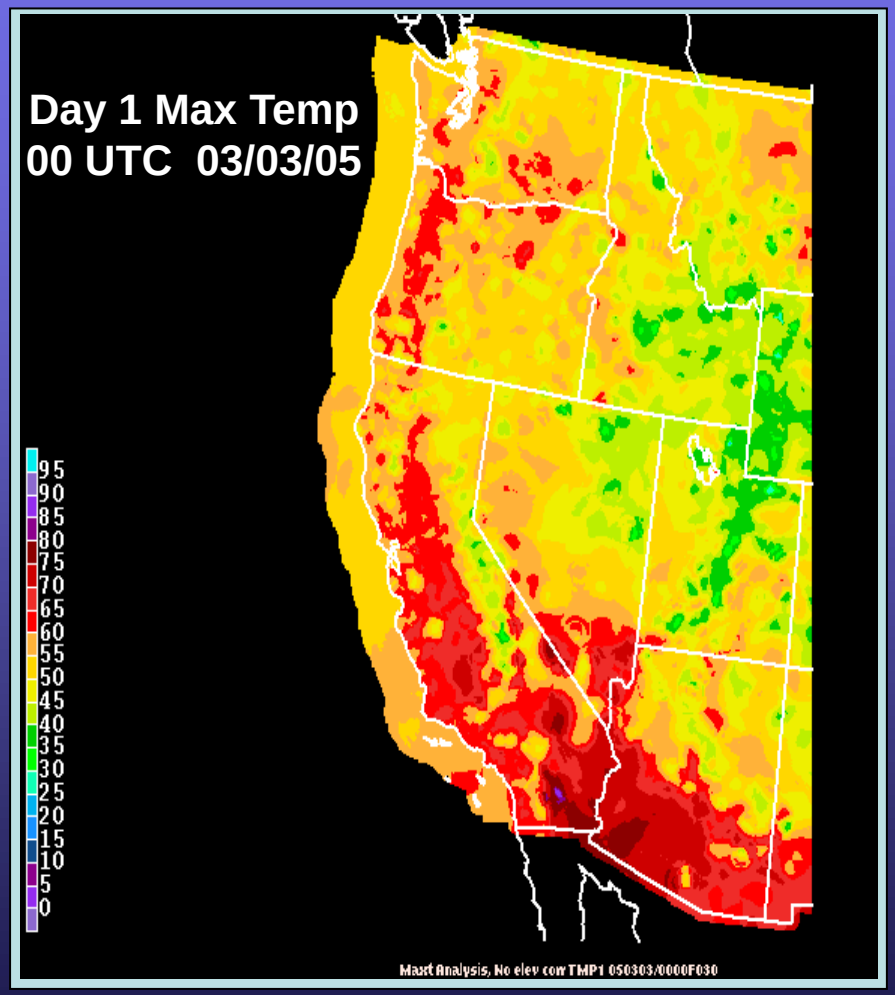


Gridded MOS Concept - Step 1

“Blending” first guess and high-density station forecasts



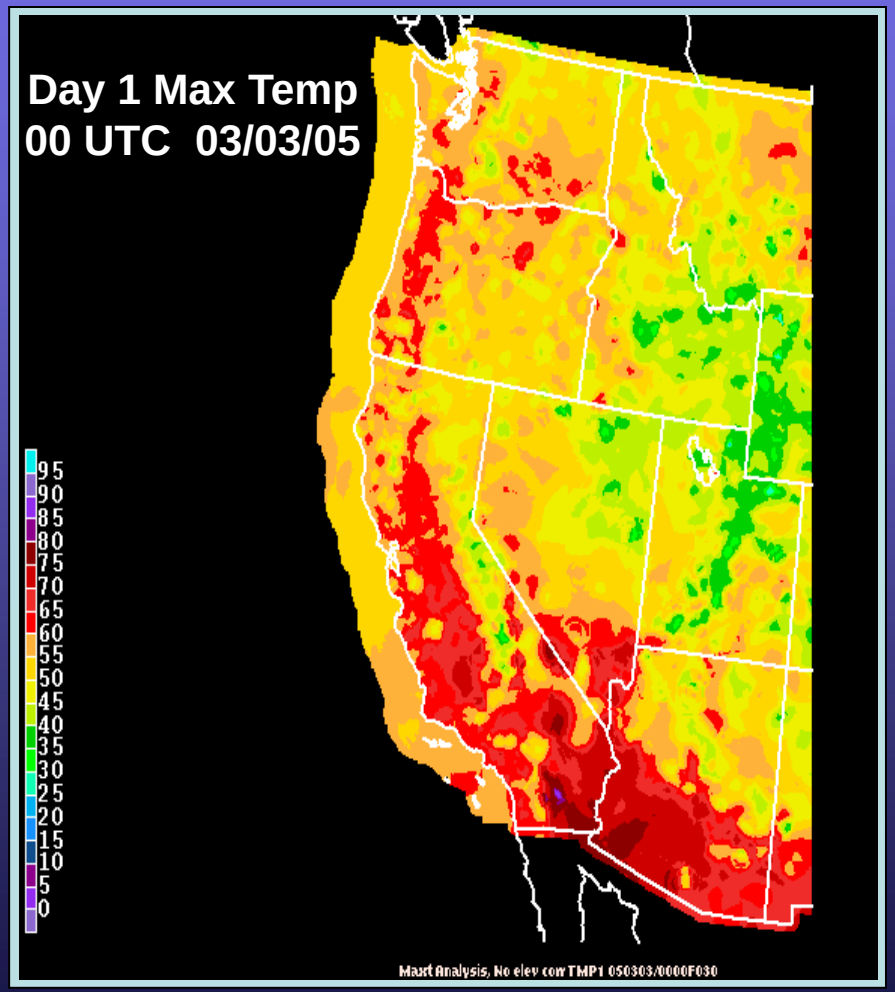
First guess field from Generalized Operator Equation or other source



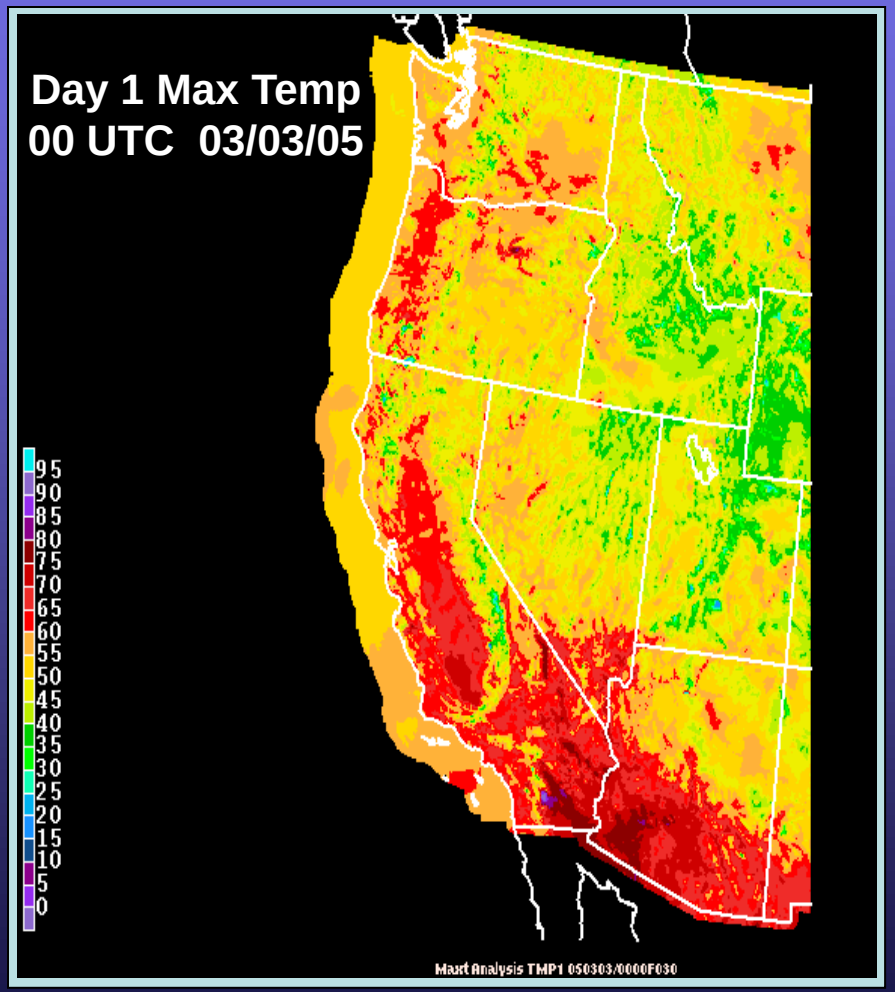
First guess + guidance at all available sites

Gridded MOS Concept - Step 2

Add further detail to analysis with high-resolution geophysical data and “smart” interpolation



First guess + guidance at all available sites

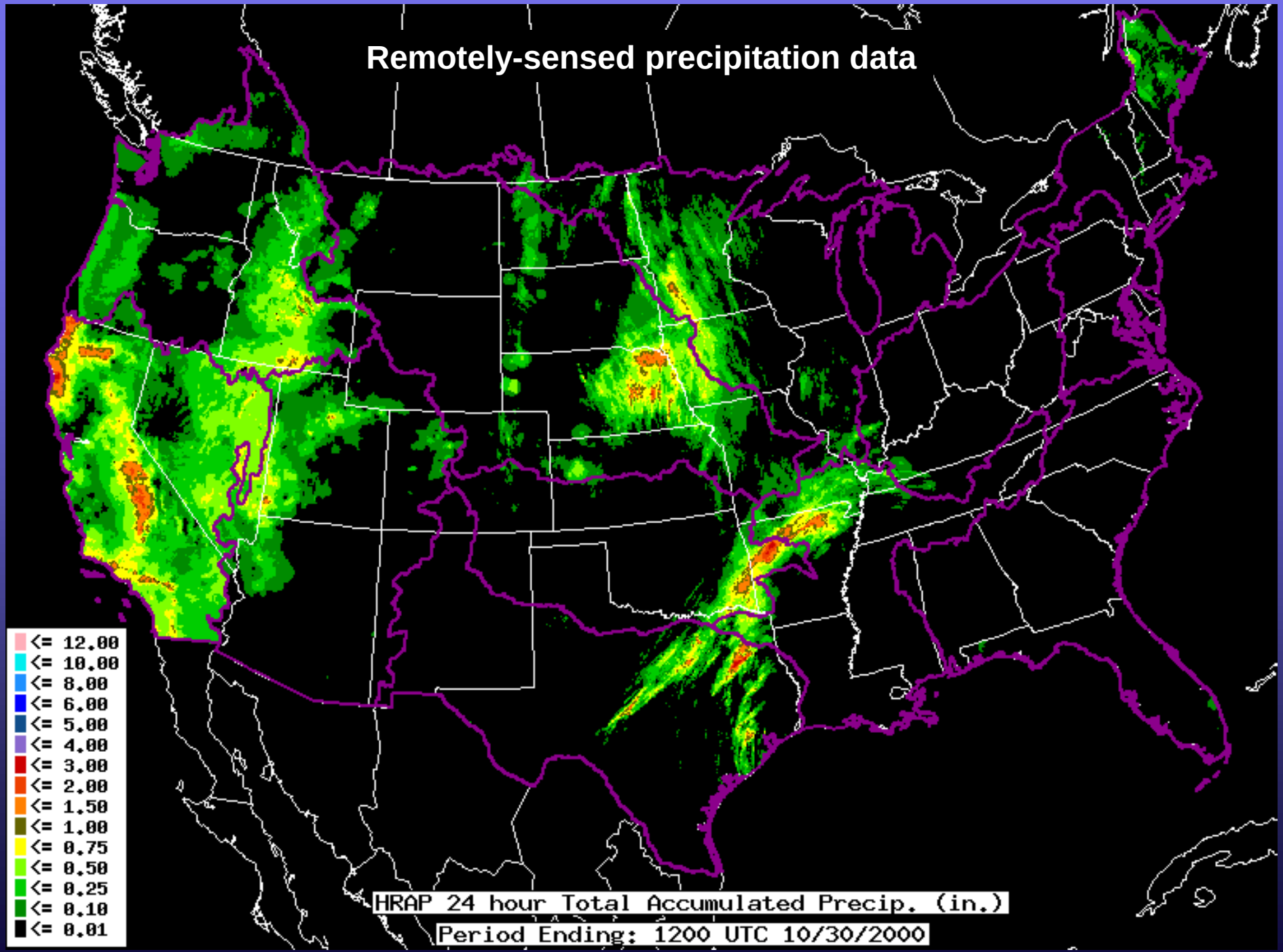


First guess + station forecasts + terrain

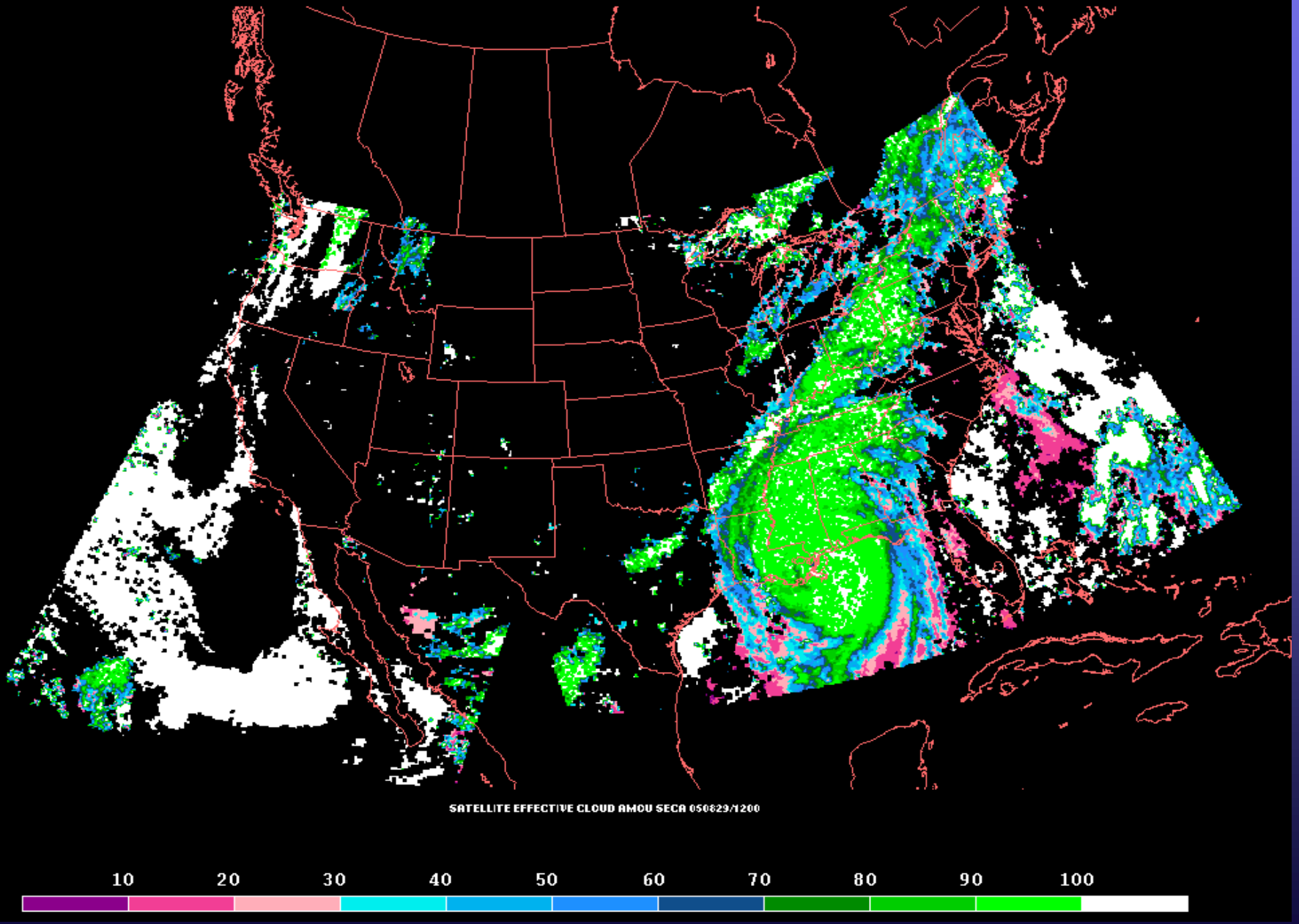
The Future of MOS

"Enhanced-Resolution" MOS Systems

- **"MOS at any point"**
  - Support new NWS digital forecast database
    - 2.5 km - 5 km resolution
  - Emphasis on high-density surface networks
    - Co-Op, buoy, mesonet
  - Equations valid away from observing sites
  - Use high-resolution geophysical data
- **"True" gridded MOS**
  - Observations and forecasts valid on fine grid
  - Use remotely-sensed predictand data
  - e.g. PoP/QPF "Demonstration" System
    - 4-km HRAP grid; WSR-88D


Remotely-sensed precipitation data
<= 12.00
<= 10.00
<= 8.00
<= 6.00
<= 5.00
<= 4.00
<= 3.00
<= 2.00
<= 1.50
<= 1.00
<= 0.75
<= 0.50
<= 0.25
<= 0.10
<= 0.01
HRAP 24 hour Total Accumulated Precip. (in.)
Period Ending: 1200 UTC 10/30/2000

Satellite-based effective cloud amount



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Draper, N.R., and H. Smith: Applied Regression Analysis, Chap. 6, p. 307 - 308.

Glahn, H.R., and D. Lowry, 1972: The use of model output statistics in objective weather forecasting, JAM, 11, 1203 - 1211.

Carter, G.M., et al., 1989: Statistical forecasts based on the NMC's NWP System, Wx. & Forecasting, p. 401 - 412.