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

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Mark S. Antolik
Meteorological Development Laboratory
Statistical Modeling Branch
NOAA/National Weather Service
Silver Spring, MD

(301) 713-0023 ext. 110
e-mail: mark.antolik@noaa.gov
MOS Operational System “Fun Facts”

With apologies to David Letterman, of course!

- 9 million regression equations
- 75 million forecasts per day
- 1200 products sent daily
- 400,000 lines of code – mostly FORTRAN
- 180 min. supercomputer time daily

- All developed and maintained by ~ MDL / SMB meteorologists!
1. Why objective statistical guidance?
2. What is MOS?
   - Definition and characteristics
   - The “traditional” MOS product suite (GFS, NAM)
   - Other additions to the lineup
3. Simple regression examples / REEP
4. Development strategy - MOS in the “real world”
5. Verification
6. Dealing with NWP model changes
7. Where we’re going – GMOS and the future
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
A SIMPLE STATISTICAL MODEL

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

3-YR SAMPLE; 200 STATIONS
1987-1990 COOL SEASON

47%
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
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 observations
MAJOR CHALLENGE TO MOS DEVELOPMENT:

RAPIDLY EVOLVING NWP MODELS AND OBSERVATION PLATFORMS

Can make for:

1. SHORT, UNREPRESENTATIVE DATA SAMPLES

2. DIFFICULT COLLECTION OF APPROPRIATE PREDICTAND DATA

New observing systems: (ASOS, WSR-88D, Satellite)
(Co-Op, Mesonets)

Same “old” predictands: The elements don’t change!
“Traditional” MOS text products
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GFS MOS GUIDANCE MESSAGE
FOUS21-26 (MAV)
# NAM MOS GUIDANCE MESSAGE
## FOUS44-49 (MET)

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STATIONS:
Now at approx. 1990 Forecast Sites
(CONUS, AK, HI, PR, Canada)
Short-range (GFS / NAM) MOS

- **STATIONS:**
  Now at approx. 1990 Forecast Sites (CONUS, AK, HI, PR)

- **FORECASTS:**
  Available at projections of 6-84 hours
  GFS available for 0600 and 1800 UTC cycles

- **RESOLUTION:**
  GFS predictors on 95.25 km grid; NAM on 32 km
  Predictor fields available at 3-h timesteps

- **DEPENDENT SAMPLE NOT “IDEAL”:**
  Fewer seasons than older MOS systems
  Non-static underlying NWP model
## GFSX MOS GUIDANCE MESSAGE

**FEUS21-26 (MEX)**

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MOS station-oriented products: Other additions
### Marine MOS

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- **Marine MOS sites**
- **Standard MOS sites**
# Max/Min Guidance for Co-op Sites

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Application of Linear Regression to MOS Development
MOS LINEAR REGRESSION

JANUARY 1 - JANUARY 30, 1994  0000 UTC

KCMH

18-H NWP MODEL 850-1000 MB THICKNESS (M)

TODAY'S MAX (°F)

10  20  30  40  50  60

0  -10

1150  1200  1250  1300  1350

18-H NWP MODEL 850-1000 MB THICKNESS (M)
MAX T = -352 + (0.3 x 850-1000 mb THK)

RV=93.1%
REDUCTION OF VARIANCE

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

\[ RV = \frac{\text{Variance} - \text{Standard Error}}{\text{Variance}} \]

UNEXPLAINED VARIANCE
Different site, Different relationship!

Same predictor, Different site, Different relationship!

RV=26.8%
12-24 H PRECIPITATION ≥ 0.1" vs AVG. 12-24 H NWP MODEL ~1000 - 500 MB RH
MOS LINEAR REGRESSION

DECEMBER 1 1993 - MARCH 5 1994 0000 UTC
KCMH

AVG. 12-24 H NWP MODEL ~1000 - 500 MB RH

12-24 H PRECIPITATION ≥ .01"

RV=36.5%
MOS LINEAR REGRESSION

DECEMBER 1 1993 - MARCH 5 1994   0000 UTC

KCMH

AVG. 12-24 H NWP MODEL ~1000 - 500 MB RH

12-24 H PRECIPITATION ≥ .01"

RV=36.5%

RV=42.4%
AVG. 12-24 H NWP MODEL ~1000 - 500 MB RH

POP = -0.234 + (0.007 X MRH) + (0.478 X BINARY MRH (70%))
EXAMPLE REGRESSION EQUATIONS

\[ Y = a + bX \]

CMH MAX TEMPERATURE EQUATION

\[ \text{MAX } T = -352 + (0.3 \times 850 - 1000 \text{ mb THICKNESS}) \]

CMH PROBABILITY OF PRECIPITATION EQUATION

\[ \text{POP} = -0.234 + (0.007 \times \text{MEAN RH}) \]
\[ + (0.478 \times \text{BINARY MEAN RH CUTOFF AT 70\%})^* \]

*(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, 2006)

- The degree of belief, or quantified judgment, about the occurrence of an uncertain event.

OR

- The long-term relative frequency of an event.
PROBABILITY FORECASTS

Some things to keep in mind

Assessment of probability is \textit{extremely} dependent upon how predictand “event” is defined:

- Time period of consideration
- Area of occurrence
- Dependent upon another event?

MOS forecasts can be:

- \textbullet\ POINT PROBABILITIES
- \textbullet\ AREAL PROBABILITIES
- \textbullet\ CONDITIONAL PROBABILITIES
AREAL PROBABILITIES

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

40-km gridbox 10% contour interval

20-km gridbox 10% contour interval

What if these were 6-h forecasts?
PROPERTIES OF MOS PROBABILITY FORECASTS

- **Unbiased**
  Average forecast probability equals long-term relative frequency of event

- **Reliable**
  Conditionally or “Piecewise” unbiased over entire range of forecast probabilities

- **Reflect predictability of event**
  Range narrows and approaches event RF as NWP model skill declines
  - extreme forecast projection
  - rare events
Reliable Probabilities...

Even for rare events

Reliability of 12-h PQPF > 0.25”, 48h Forecasts
Cool Seasons 05-06 and 06-07, 335 sites

12-h Precip > 0.25”

Mean: 4.7%
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?
MOS Snowfall Guidance

Uses Observations from Cooperative Observer Network

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

Verification

Map by: Chris Strong
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 *

* CONUS – differs in AK

Probability of Precipitation
Precipitation occurrence is accumulation of ≥ 0.01 inches of liquid-equivalent at a gauge location within a specified period
Determined from 13 consecutive hourly ASOS observations, satellite augmented

Assign value to each METAR report:
- CLR; FEW; SCT; BKN; OVC
  - 0; 0.15; 0.38; 0.69; 1

Take weighted average of above

Categorize:
- CL < .3125 ≤ PC ≤ .6875 < OV
Creating a Gridded Predictand

Lightning strikes are summed over the “appropriate” time period and assigned to the center of “appropriate” grid boxes.

A thunderstorm is deemed to have occurred when one or more lightning strikes are observed within a given gridbox:

- [ ] = thunderstorm
- [ ] = no thunderstorm
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

- “MIMIC” FORECASTER THOUGHT PROCESS
  (VERTICAL VELOCITY) × (MEAN RH)
# POINT BINARY PREDICTOR

24-H MEAN RH   CUTOFF = 70%
INTERPOLATE ; STATION RH ≥ 70% ,  BINARY = 1
BINARY = 0 OTHERWISE

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RH ≥70% ;  BINARY AT KCMH = 1
GRID BINARY PREDICTOR

24 H MEAN RH      CUTOFF = 70%
WHERE RH ≥ 70% ; GRIDPOINT = 1 ; INTERPOLATE

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0 & 0 & 0 & 0 & 1 \\
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\]

\(0 ≤ \text{VALUE AT KCMH} ≤ 1\)
Logit Transform Example

KPIA (Peoria, IL) 0000 UTC; 18-h projection

\[ \text{POZ} = -0.01 + 0.9444 \left( \logit \text{TRAN (850 T)} \right) \]

\[ RV = 0.7209 \]

\[ \frac{1}{1 + e^{-(a + bx)}} \]

\[ \text{POZ} = 12.5 - 0.0446 (850 \text{ T}) \]

\[ RV = 0.6136 \]
DEVELOPMENTAL CONSIDERATIONS

(cont.)

● Terms in Equations; Selection Criteria
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 GFS QPF, \( N = 15 \)
- For GFS VIS, \( N = 20 \)

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

● METHOD OF PREDICTOR SELECTION ACCORDING TO CORRELATION WITH PREDICTAND
● “BEST” OR STATISTICALLY MOST IMPORTANT PREDICTORS CHOSEN FIRST

• **FIRST** predictor selected accounts for greatest reduction of variance (RV)
• Subsequent predictors chosen that give greatest RV in conjunction with predictors already selected
• **STOP** selection when desired maximum number of terms is reached or new predictors provide less than a user-specified minimum RV
DEVELOPMENTAL CONSIDERATIONS

(cont.)

- Terms in Equations; Selection Criteria
- Dependent Data
  - Sample Size, Stability, Representativeness
  - AVOID OVERFIT !!
  - Stratification - Seasons
  - Pooling – Regions
12-24 H NWP MODEL PRECIPITATION AMOUNT (IN.)

12-24 H PRECIPITATION ≥ 1.0"

Short sample,
Few observed cases,
Limited skill!

RV=14.2%
GFS MOS Cool Season PoP/QPF Regions

With GFS MOS forecast sites (1720) + PRISM
DEVELOPMENTAL CONSIDERATIONS

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

PROBABILITY (%) vs. PRECIPITATION AMOUNT EQUAL TO OR EXCEEDING

1. YES
2. YES
3. NO
4. NO
5. NO
6. NO

TO MOS GUIDANCE MESSAGES

FORECAST
THRESHOLD

THRESHOLD EXCEEDED?
How well do we do?

MOS Verification
Temperature Verification - 0000 UTC
GFS MOS vs. GFS DMO (10/2011 - 3/2012)

2-M Temperature MAE at 1315 CONUS Stations

MAE (Degrees F)

Projection (Hours)

GFS DMO
GFS MOS
MOS Temperature Verification - 0000 UTC

Mean Absolute Error - 00Z Temperatures
CONUS (300 stations)
April 1 - September 30, 2010

MAE (degrees F)

Projection (hours)
MOS Temperature Verification - 0000 UTC
MOS Temperature Bias - 0000 UTC
2012 warm season (4/2012 – 9/2012)

BIAS – 0000 UTC Temperature
CONUS (300 Stations)
4/2012 – 9/2012

Mean Alg. Error (°F)

Projection (Hours)

NAM MOS
GFS MOS
Having a representative verification sample is important, too!
GFSX 12-h Forecast Skill - 0000 UTC
Max Temperatures and PoP

% Improvement over Climate
Cool Season 1997 - 2003

Max T

PoP
Dealing with NWP model changes
Mitigating the effects on development

To help reduce the impact of model changes and small sample size, we rely upon...

1. Improved model realism
   better model = better statistical system

2. Coarse, consistent archive grid
   smoothing of fine-scale detail
   constant mesh length for grid-sensitive calculations

3. Enlarged geographic regions
   larger data pools help to stabilize equations

4. Use of “robust” predictor variables
   fewer boundary layer variables
   variables likely immune to known model changes;
   (e.g. combinations of state variables only)
Responding to NWP Model Changes

- Parallel evaluation
  Run MOS...new vs. old NWP model
  Assess impacts on MOS skill
Responding to NWP Model Changes

GFS: Hybrid EnKF parallel evaluation

Nov-Dec 2011 Temperature Bias: GFS MOS Oper vs. Para
(Overall - 344 Stations)
Parallel evaluation
Run MOS…new vs. old NWP model
Assess impacts on MOS skill

Do nothing?
OK if impacts are minimal
But, often they aren’t! (GFS wind / temps)
Responding to NWP Model Changes

- **Parallel evaluation**
  - Run MOS…new vs. old NWP model
  - Assess impacts on MOS skill

- **Do nothing?**
  - OK if impacts are minimal
  - But, often they aren’t! (GFS wind / temps)

- **OK, now what?**
  - Model changes may be recent
    - i.e. limited sample available from newest version
  - Error characteristics significantly different
  - Undesirable effects on MOS performance
Responding to NWP Model Changes

- Bias Correction for MOS?
Daily Bias Correction
based on past N (7, 10, 20 or 30)-day forecast errors

Bias correction:
\[ F' = F(t) - \text{Bias} \]

\[ \text{Bias} = \frac{1}{N} \sum_{t=1}^{N} [F(t) - O(t)] \]

F = Forecasts; O = Observations
N = Days in training sample
(typically, N = 7, 10, 20, or 30)

Daily biases can be treated equally or weighted to favor most recent days, etc.
Raw / Corrected GFS MOS Wind MAE

KABQ – 00UTC, 96-h Projection
Raw / Corrected GFS MOS Temp MAE

Southwest U.S. – 00UTC, 48-h Projection
Responding to NWP Model Changes

• **Bias Correction for MOS?**
  Apply to Temps? Winds?
  Run continuously in background?
  Satisfactory in rapidly-varying conditions?

• **Redevelop?**
  Short sample from new model or “mixed”?
  Full System, selected elements?
  Biggest impacts on single-station equations (Temp, Wind)
GFS MOS Wind Verification Results*
5/10/2011 – 9/30/2011

Using even just a little data from the new NWP model version can be helpful!

Responding to NWP Model Changes

• Bias Correction for MOS?
  Apply to Temps? Winds?
  Run continuously in background?
  Satisfactory in rapidly-varying conditions?

• Redevelop?
  Short sample from new model or “mixed”?
  Full System, selected elements?
  Biggest impacts on single-station equations (Temp, Wind)

• Reforecasts?
  1-2 year sample probably sufficient for T, Wind
  Rare elements need longer or “mixed” sample?
  Requires additional supercomputer resources
Responding to NWP Model Changes

Four recent examples

- **GFS/GFSX MOS Wind replacement (6/2012)**
  Fix errors introduced by 5/2011 GFS roughness length change (2-season sample)

- **NAM MOS T/Td/Max-Min refresh (pending)**
  NMM-b implementation (12/2011); SW US cool bias fix

- **GFS MOS full-system update (3/2010)**
  Correct accumulated drift from several minor model changes

- **NAM MOS (12/2008)**
  Respond to Eta/NMM transition
  “Mixed” samples except for sky, snow (Eta-based)
MOS: Today and Beyond
The Future of MOS

“Traditional” Station-oriented Products

● GFS / GFSX MOS:
  Update GFSX Sky Cover equations  
  (Completes 1200 UTC text message)
  Make Day 10 GFSX elements available to public
  Update climate normals (1981-2010 NCDC)
  Bias-corrected T, Td, Max/Min?

● NAM MOS:
  Add precipitation type suite (TYP, POZ, POS)
  Add 0600 and 1800 UTC cycles?
  Update remaining eta-based elements
  Update temperature suite with NMM-b data
The Future of MOS

“Traditional” Station-oriented Products (contd.)

● Western Pacific MOS
  Add new elements (Sky Cover, CIG)

● “Consensus” MOS:
  Weights based on recent performance
  Blends GFS, NAM, ECMWF, Ensemble MOS
  Use Bayesian Model Averaging (BMA)

● General:
  Evaluate impacts of NWP model changes
  Periodic addition of new CONUS sites
  New products utilizing station probabilities
End of an era?

WANTED! High-resolution, gridded guidance for NDFD
Gridded MOS

GFS-based  CONUS-wide @ 2.5km

Max / Min
PoP
Temp / Td
RH
Tstm
Winds
QPF
Snowfall
Gusts
Sky Cover

2.5-km vs. 5-km

2.5-km CONUS GMOS introduced Feb. 27, 2012

Max Temperature
15 UTC 02/13/12

5 km

Max Temperature
15 UTC 02/13/12

2.5 km
Alaska / Hawaii Gridded MOS

AK: GFS-based, 3-km grid

HI: GFS-based, 2.5-km grid

3-km grid

2.5-km grid

All CONUS elements

Max / Min
PoP
Temp / Td
RH
Winds
Gusts
The Future of MOS

“Enhanced-Resolution” Gridded MOS Systems

- “MOS at any point” (e.g. GMOS)
  Support NWS digital forecast database
  2.5 km - 5 km resolution
  Equations valid away from observing sites
  Emphasis on high-density surface networks
  Use high-resolution geophysical data
Surface observation systems used in GMOS

- METAR
- Buoys/C-MAN
- Mesonet (RAWS/SNOTEL/Other)
- NOAA cooperative observer network
- RFC-supplied sites
Approx. 11,000 sites!
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

Day 1 Max Temp 00 UTC 03/03/05

Day 1 Max Temp 00 UTC 03/03/05
Developing the “First Guess” Field

Some options

• Generalized operator equation (GOE)
  Pool observations regionally
  Develop equations for all elements, projections
  Apply equations at all grid points within region

• Use average field value at all stations

• Use other user-specified constant

• Use NWP model forecast
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
GMOS Analysis

Basic Methodology (Glahn, et al. 2009, WaF)

• Method of successive corrections ("BCDG")
  Bergthorssen and Doos (1955); Cressman (1959); Glahn (1985, LAMP vertical adjustment)

• Elevation ("lapse rate") adjustment
  Inferred from forecasts at different elevations
  Calculations done “on the fly” from station data
  Can vary by specific element, synoptic situation

• Land/water gridpoints treated differently
GMOS Analysis

Other Features

• Special, terrain-following smoother

• ROI can be adjusted to account for variations in density of observed data

• Nudging can be performed to help preserve nearby station data

• Parameters can be adjusted individually for each weather element
GMOS Analysis

Some Issues

• Not optimized for all weather elements and synoptic situations
  Need situation specific, dynamic models?

• May not capture localized variations in vertical structure
  Vertical adjustment uses several station “neighbors”

• May have problems in data-sparse regions over flat terrain
  Defaults to pure Cressman analysis with small ROI
  Can result in some “bulls-eye” features
NDGD vs. NDFD

Which is “better”?

NDGD Max T

NDFD Max T
NDGD vs. NDFD

Which is “better”?

Relative Humidity
21 UTC 03/10/06

GFS-MOS RH(%) For Fri Mar 10 2006 4PM EST
(Fri Mar 10 2006 21Z)

National Digital Guidance Database
12z model run Graphic created-Mar 09 11:42AM EST

NDGD RH
Fewer obs available to analysis = less detail in GMOS
Forecasters adding detail: Which is “better”? More accurate?

Relative Humidity
21 UTC 03/10/06

Relative Humidity(%) Fri Mar 10 2006 4PM EST
(Fri Mar 10 2006 21Z)

National Digital Forecast Database
19z issuance Graphic created-Mar 09 2:52PM EST

NDFD RH
Even fewer obs available – Yikes!
The Future of MOS

“Enhanced-Resolution”, Gridded MOS Systems

● “MOS at any point” (e.g. GMOS)
  Support NWS digital forecast database
  2.5 km - 5 km resolution
  Equations valid away from observing sites
  Emphasis on high-density surface networks
  Use high-resolution geophysical data

● “True” gridded MOS
  Observations and forecasts valid on fine grid
  Use remotely-sensed predictand data
  e.g. WSR-88D QPE, Satellite clouds, NLDN
Remotely-sensed precipitation data

HRAP 24 hour Total Accumulated Precip. (in.)
Period Ending: 1200 UTC 10/30/2000
Gridded MOS: Where do we go from here?

- Additions to current CONUS GMOS system
  - “Predominant” weather grid
  - NAM-based companion system (short-range)
  - Probabilistic and/or ensemble-based products
NAM gridded snow amount probability

Probability of snow > 4”
GFS/NAM MOS 24-h snow amount probabilities

KIAD  00 UTC, 3/06/13

<table>
<thead>
<tr>
<th>Snowfall Probability</th>
<th>KIAD</th>
<th>WASH-DULLES</th>
<th>VA</th>
<th>NAM SnowPrb</th>
<th>GFS SnowPrb</th>
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Forecast trend for valid time: 00Z Thursday, March 07

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Sample Forecast as Quantile Function (CDF)
(72-h Temp KBWI 12/14/2004)
The Future of MOS

Gridded MOS: Where do we go from here?

- Additions to current CONUS GMOS system
  - “Predominant” weather grid
  - NAM-based companion system (short-range)
  - Probabilistic and/or ensemble-based products

- Expand GMOS for AK / HI; add other OCONUS
  - AK: Increase grid extent; improve marine winds
  - Hawaii: add QPF, Sky Cover
  - Puerto Rico

- Improve GMOS interpolation procedures
The Future of MOS

Gridded MOS: Where do we go from here?

- Increase utilization of mesonet data
  Investigate MADIS archive (NCO/TOC/ESRL)
  ~20,000 additional sites?

- Incorporate remotely-sensed data where possible
  SCP augmented clouds / WSR-88D QPF (in use)
  NSSL MRMS (Multi-radar, Multi-sensor) dataset?
  New lightning datasets: Global, “Total” (CC & CG)
REFERENCES...the “classics”


