# ATMOS 5010: Weather Forecasting Forecasting Techniques and Tools

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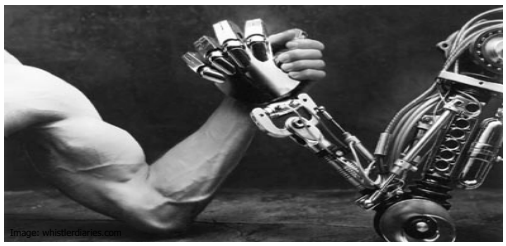
# Successful Forecasting Requires

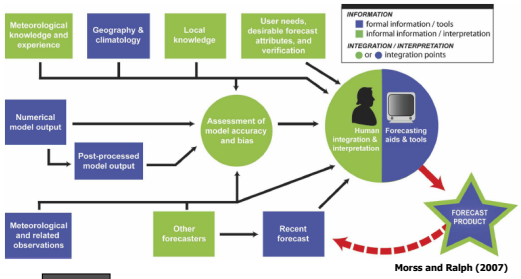
- Knowledgeable, well-trained, & engaged forecasters
  - Meteorological knowledge and experience
  - Local weather & climate knowledge
  - User need recognition
  - Model strength, weakness, and bias assessment
  - Human cognition and interpretation
- Skillful & reliable NWP guidance, forecast tools, and other aids

# AKA: The Human-Machine Mix



**Human Cognition** **Automated Systems**

# The Forecast Process




Morss and Ralph (2007)

= NWP, tools, aids, etc.

= Knowledgeable, well trained, & engaged forecasters

# Critical Forecast Questions

- What has happened?
- Why has it happened?
- What is happening?
- Why is it happening?
- What will happen? — **Easy to concentrate only on this**
- Why will it happen?

Source: Bosart (2003)

## Critical Forecast Questions

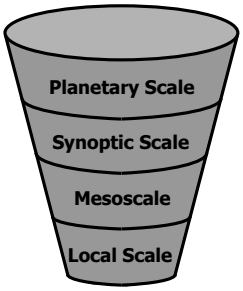
- What has happened?
- Why has it happened?
- What is happening?
- Why is it happening?
- What will happen?
- Why will it happen?

**Important when NWP goes awry or cannot resolve local orographic effects**

Source: Bosart (2003)

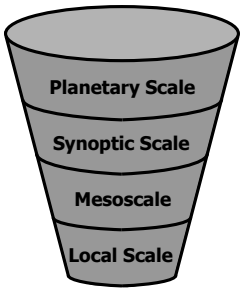
## The Forecast Methodology

- To answer these questions, use the ***forecast funnel***
  - Begin at planetary scale
  - Focus attention on progressively smaller scales
  - In complex terrain, build in orographic effects

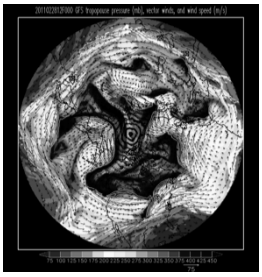


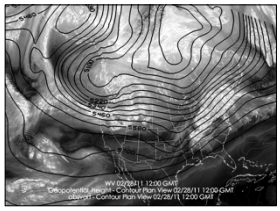

## The Forecast Methodology

- Answer the what and the why in the past, present, and future
- Avoid "meso-myopia"
  - Understand larger scales before progressing to smaller scales
  - When using high-resolution models, evaluate confidence in large-scale forecast before progressing to smaller scales
  - Expect limited local skill if large-scale is not well forecast
- Beware when the atmosphere is in ***outlier mode***
  - Generalizations break down



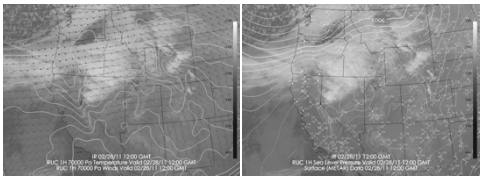

## Forecast Funnel in Practice

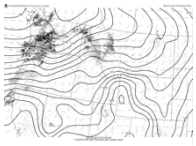




**Evaluate past, current, and future planetary scale setting**

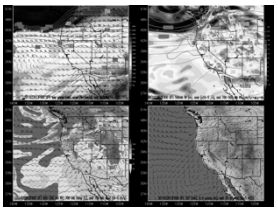
## The Forecast Funnel in Practice

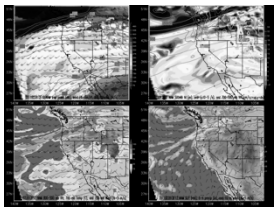




**Funnel to synoptic scale**

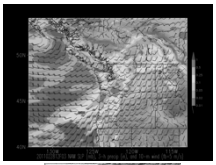
## The Forecast Funnel in Practice

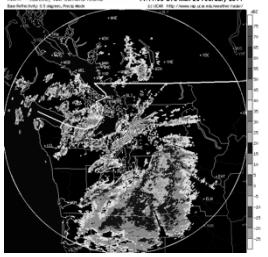




**Evaluate confidence in synoptic-scale forecast**

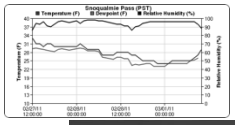
## The Forecast Funnel in Practice





**Funnel to mesoscale**
**Consider mesoscale, orographic, and land-surface processes**

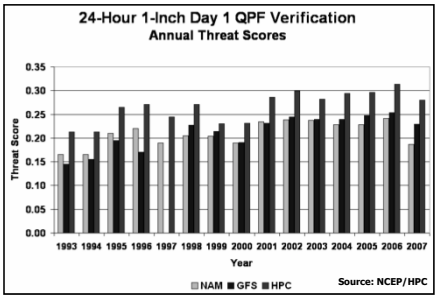
## The Forecast Funnel in Practice





**Adjust for local effects**

## Humans Make a Difference




"This continuing skill advantage [indicates] that ***dedicated and trained forecasters*** can extract maximum advantage from improvements in operational weather prediction models" -Bosart (2003)

## On the other Hand….


"Forecasters who grow accustomed to letting MOS and the models do their thinking…on a regular basis…are at high risk of "going down in flames" when the atmosphere is in an outlier mode"
- Bosart (2003)

## Don't be on Autopilot

*Forecasters who grow accustomed to letting MOS and the models do their thinking for them on a regular basis during the course of their daily activities are at high risk of "going down in flames" when the atmosphere is in an outlier mode*


## Don't be on Autopilot


***Although NWP is important, basic understanding, pattern recognition and climatology continue to play an essential role because of limitations in current NWP systems, including inadequate terrain representation, initial condition uncertainty, and parameterization uncertainty***

# Bottom Line

- "Forecasters have a clear role in the forecast process, by contributing a wealth of knowledge, tools and techniques that cannot be duplicated by computers or NWP"
  - McCarthy et al. (2007)
- But *forecasters need to be engaged and increasingly need an advanced education* to extract maximum benefit from today's sophisticated forecast tools
- This class begins that education


"The problem isn't your eyesight. The problem is you don't know the alphabet."

# Forecast Tools

***A meteorologist knows their tools, including their strengths and weaknesses***

***"All observations are bad, but some are useful"***

***"All models are wrong, but some are useful"***

"So what's this? I asked for a *hammer*! A hammer! *This* is a crescent wrench! ... Well, maybe it's a hammer. ... Damn these stone tools."

Source: Gary Larson, The Far Side

# Forecast Tools

- Climatology
- Persistence
- Observations
  - Your eyes
  - In-situ surface and upper-air
  - Wind profiler/RASS
  - Satellite
  - Radar
  - Weather cameras
- Manual analysis
- NWP Models
  - Numerical analyses
  - Global and mesoscale models
  - Ensemble forecast systems
- Model Output Statistics (MOS)
- Scientific analysis and visualization systems

"So what's this? I asked for a *hammer*! A hammer! *This* is a crescent wrench! ... Well, maybe it's a hammer. ... Damn these stone tools."

Source: Gary Larson, The Far Side

# Forecast Tools: Climatology

- The statistics of weather
- More than just long-term mean
  - Mean, variance, extremes, probabilities
  - Impacts of ENSO and modes of climate variability
    - PDO, NAO, etc.
- Local and mesoscale effects
  - Complex terrain results in large climatological gradients
  - Often poorly resolved by computer models
  - Climatology to used "downscale" or "bias correct" model forecasts for local effects
  - Can be overused
    - e.g., Not all storms have the climatological precipitation-altitude relationship

# Forecast Tools: Climatology

**KSLC Climatology**

| | J | F | M | A | M | J | J | A | S | O | N | D | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Max (F) | 37.3 | 43.4 | 52.4 | 61.5 | 72.2 | 83.1 | 92.8 | 90.4 | 79.4 | 65.7 | 50.0 | 38.6 | 63.9 |
| Mean Min (F) | 20.3 | 24.7 | 31.6 | 38.3 | 46.4 | 54.7 | 63.2 | 61.7 | 51.5 | 40.2 | 29.9 | 22.2 | 40.4 |
| Mean Precip (in) | 1.32 | 1.28 | 1.77 | 2.05 | 1.69 | 0.95 | 0.68 | 0.78 | 1.06 | 1.33 | 1.37 | 1.37 | 15.62 |
| Mean Snowfall (in) | 13.5 | 10.4 | 9.3 | 5.1 | 0.6 | 0.0 | 0.0 | 0.0 | 0.1 | 1.4 | 6.5 | 13.2 | 60.1 |
| Mean Snow Depth (in) | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 00Z Dew Point (F) | 21.0 | 22.9 | 26.7 | 31.6 | 37.9 | 42.3 | 47.4 | 46.6 | 41.0 | 34.2 | 26.9 | 21.1 | |
| 12Z Dew Point (F) | 23.3 | 25.1 | 27.4 | 31.0 | 33.8 | 37.1 | 41.4 | 41.5 | 38.9 | 35.1 | 29.8 | 23.8 | |
| 00Z Relative Humidity | 74 | 65 | 48 | 42 | 32 | 26 | 20 | 24 | 33 | 49 | 65 | 75 | |
| 12Z Relative Humidity | 81 | 78 | 70 | 67 | 61 | 53 | 45 | 48 | 59 | 67 | 75 | 79 | |
| Cloud Cover (Octas) | 6.0 | 5.9 | 5.5 | 5.3 | 4.8 | 4.0 | 3.7 | 3.8 | 3.4 | 4.1 | 5.2 | 5.8 | |
| 12Z Wind Speed (kt) | 7.6 | 7.9 | 8.2 | 8.3 | 7.8 | 8.0 | 8.0 | 8.8 | 8.0 | 7.8 | 7.4 | 8.0 | 8.0 |
| 00Z Wind Speed (kt) | 7.2 | 7.8 | 8.8 | 9.6 | 9.2 | 9.5 | 10.0 | 9.6 | 8.4 | 7.3 | 6.6 | 7.1 | 8.4 |
| 12Z Wind Direction | 93 | 71 | 99 | 92 | 103 | 88 | 84 | 93 | 116 | 123 | 90 | 70 | |
| 00Z Wind Direction | 317 | 261 | 203 | 220 | 107 | 35 | 40 | 350 | 109 | 197 | 10 | 356 | |
| Probability of Trace Precip | 46.6% | 45.7% | 37.2% | 41.8% | 32.6% | 25.8% | 21.4% | 28.7% | 24.1% | 27.0% | 33.3% | 41.1% | 33.6% |
| Probability of 0.01" Precip | 32.6% | 34.2% | 29.8% | 34.4% | 23.6% | 15.8% | 10.3% | 14.4% | 17.6% | 20.5% | 27.9% | 31.7% | 24.4% |
| Probability of 0.10" Precip | 14.0% | 17.7% | 16.4% | 19.4% | 12.6% | 8.8% | 3.8% | 5.0% | 9.3% | 14.1% | 13.0% | 16.4% | 12.5% |
| Probability of 0.25" Precip | 5.7% | 6.8% | 7.5% | 10.6% | 5.9% | 5.5% | 2.1% | 2.9% | 5.2% | 6.2% | 6.1% | 6.2% | 5.9% |
| Probability of TS | 0.3% | 1.3% | 1.8% | 7.9% | 9.7% | 14.8% | 16.7% | 22.0% | 13.6% | 6.7% | 3.0% | 1.5% | 8.3% |
| Probability of SN | 35.2% | 31.5% | 20.8% | 9.7% | 0.9% | 0.0% | 0.0% | 0.0% | 0.3% | 2.6% | 17.0% | 34.9% | 12.7% |
| Probability of RA | 20.2% | 24.8% | 28.2% | 38.8% | 31.7% | 24.2% | 17.6% | 24.0% | 20.9% | 25.8% | 23.0% | 16.4% | 24.6% |
| Probability of VIS < 1 mi | 31.4% | 22.8% | 12.3% | 6.7% | 0.0% | 0.6% | 1.5% | 0.6% | 0.3% | 1.5% | 10.9% | 30.2% | 9.9% |
| TS when precip is falling | 0.0% | 0.1% | 0.6% | 3.6% | 6.1% | 17% | 49% | 49% | 24% | 7.9% | 1.3% | 0.6% | |

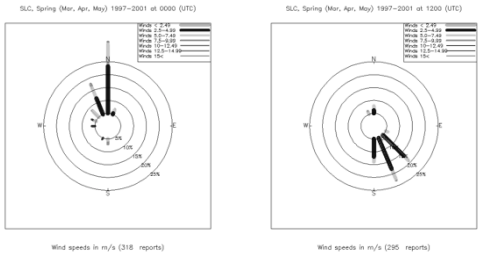
| Surface Temperature | Probability of snow given that precip is falling |
|---|---|
| >40 | 0.8% |
| 38-40 | 3.6% |
| 37-38 | 15% |
| 36 | 34% |
| 35 | 59% |
| 34 | 79% |
| 33 | 93% |

| | ANN |
|---|---|
| Probability of VIS<1 mi given that snow is falling | 25.0% |
| Probability of VIS<1 mi given that rain is falling | 0.9% |
| Probability of VIS<1 mi in TSRA | 1.6% |
| Probability of TS given that snow is falling | 0.5% |
| Probability of TS given that rain is falling | 9.1% |

Is this useful????

Means and Probabilities for Forecast Practicum Variables

# Forecast Tools: Climatology

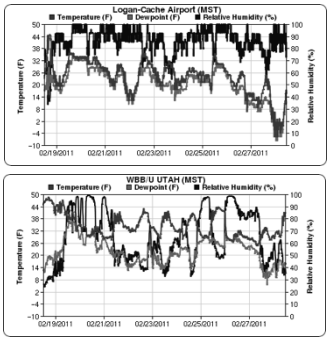


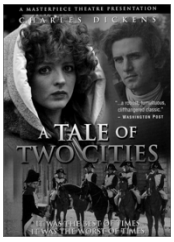

Think Beyond the Mean

# Forecast Tools: Persistence

- **Persistence: What has happened recently**
  - Including trends
- **Provides *context* for forecast**
- **Relevance for forecast varies from high to low**
  - High during slowly evolving patterns
  - Low during major pattern shifts

# Forecast Tools: Persistence



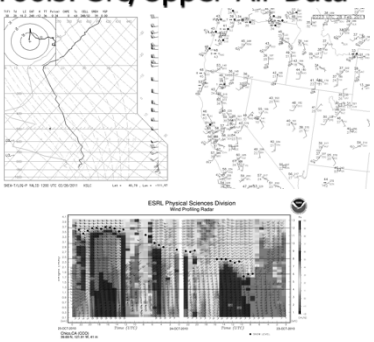

Context for forecast
During this period is
Different at LGU & WBB

# Forecast Tools: Your Eyes

- **Never underestimate the value of looking out the window or going outside to feel the weather**

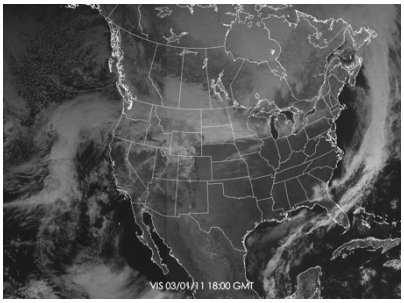

Source: cartoonstick.com, collaborativejourneys.com

# Forecast Tools: Sfc/Upper-Air Data

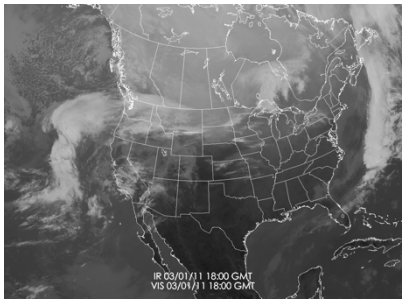

Wind profilers provide more than wind!

# Forecast Tools: Satellite



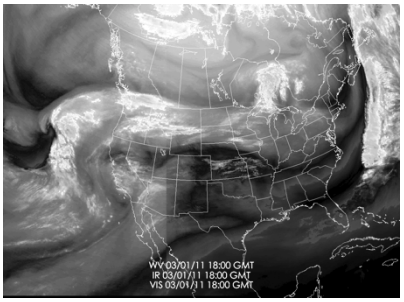

Visible Imagery
Visible radiation reflected back to space by clouds, aerosols, snow, land surface, etc.

# Forecast Tools: Satellite



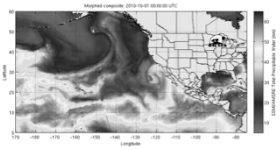

"Window" IR Imagery
Long-wave radiation emitted primarily by clouds, land-surface, etc.
Cloud-top temperature and land-surface temperature

# Forecast Tools: Satellite

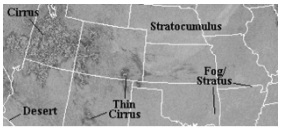



Water Vapor Channel (IR) Imagery
Long-wave radiation emitted primarily by upper-tropospheric clouds and water vapor
Upper-level flow, troughs, etc.

# Forecast Tools: Satellite



Precipitable Water from
Polar-orbiting microwave sensors

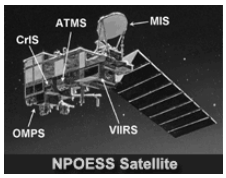



GOES Fog Detection
Longwave IR (10.7 micron)-Shortwave IR (3.9 micron)

MODIS

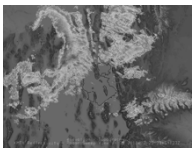
Sources: SSEC, NESDIS

# Forecast Tools: Satellite

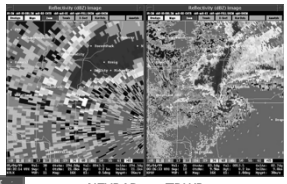




More Coming Soon – Remote Sensing Background is Important!

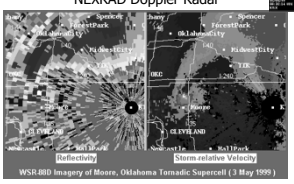
# Forecast Tools: Radar



NEXRAD Doppler Radar



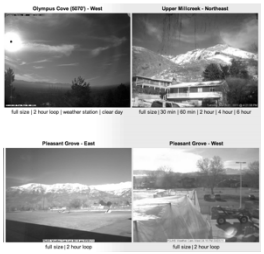
NEXRAD vs. TDWR




Coming Soon:
Polarimetric NEXRAD

Sources: NOAA/SPC

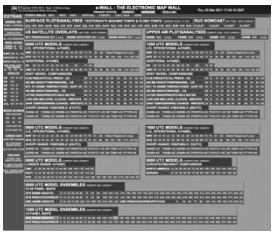
# Forecast Tools: Weather Cameras



Click for Animation

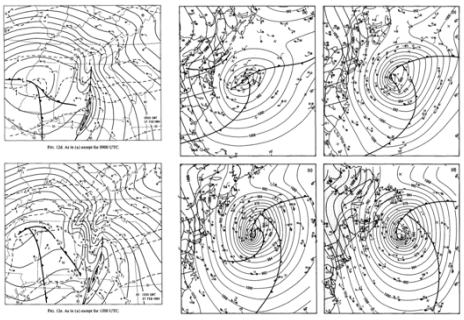
## Useful Sites for Observations

RAL Real-Time Weather Data
http://www.ral.ucar.edu/weather/



Penn State e-Wall
http://www.meteo.psu.edu/~gadomski/ewall.html

## Forecast Tools: Manual Analysis



Sources: Bosart and Seimon (1988); Neiman et al. (1988)

A manual surface analysis helps you "feel the weather in your veins"

## Forecast Tools: NWP Models

- Global Forecast System (GFS)
  - Medium range (out to 384 hours) global analyses and forecasts every 6-h
  - Effective grid spacing of ~25 km to 192 h and 70-km thereafter
  - Available on lower-resolution grids
  - Strengths relative to other NCEP models
    - Accuracy of large-scale forecast
  - Weaknesses
    - Terrain representation
    - Precip structure

## Forecast Tools: NWP Models

- North American Mesoscale Model (NAM)
  - Based on the "WRF-NMM"
  - Short-range (out to 84 hours) forecasts for North America every 6-h
  - Grid spacing of ~12 km
  - Available on lower-resolution grids
  - Strengths relative to other NCEP models
    - Terrain representation, mesoscale detail
  - Weaknesses
    - Limited area, large-scale accuracy

## Forecast Tools: NWP Models

- Rapid Update Cycle (RUC)
  - Analyses for CONUS every hour
  - Very-Short-range (out to 18 hours) forecasts for CONUS every 3-h
  - Grid spacing of ~13 km
  - Available on lower-resolution grids
  - Strengths relative to other NCEP models
    - High frequency analyses and forecasts
    - Resolution, terrain representation, mesoscale details
  - Weaknesses
    - Limited area, large-scale accuracy

## Forecast Tools: NWP Models

- Weather Research and Forecast Model (WRF)
  - Run in various configurations at NCEP and other locations
  - Some configurations provide high resolution (<10 km) short-range (48 h or less) forecasts
    - UW: 4 km
    - UU: 1.3 km
  - Strengths
    - Resolution and terrain representation
  - Weaknesses
    - Limited area, often lousy initial condition generation

## Forecast Tools: NWP Models

- Short Range Ensemble Forecast System (SREF)
  - 21 members @ 32 km grid spacing based on differing models, model configurations, and initial conditions
  - Forecasts out to 87 h every 6-h (0300 UTC, etc.)
  - Strengths
    - Probabalistic information, allows assessment of confidence in large-scale forecast
  - Weaknesses
    - Not calibrated, mean and spread of ensemble may be biased

## Forecast Tools: NWP Models

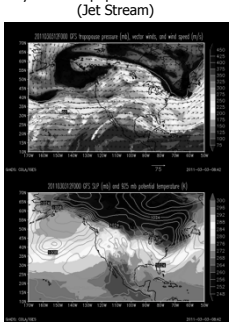
- Global Ensemble Forecast System (GEFS)
  - 20 members @ an effective grid spacing of 70 km based on different GFS initial conditions and resolutions
  - Forecasts out to 384 h every 12-h
  - Strengths
    - Probabalistic information, allows assessment of confidence in large-scale forecast
  - Weaknesses
    - Not calibrated, mean and spread of ensemble may be biased
    - Spread slow to develop
    - Low resolution

## Useful NWP Products: UU Server

http://weather.utah.edu

Dynamic Tropopause (Jet Stream)

Dynamic Tropopause & Near SFC (Jet Stream)

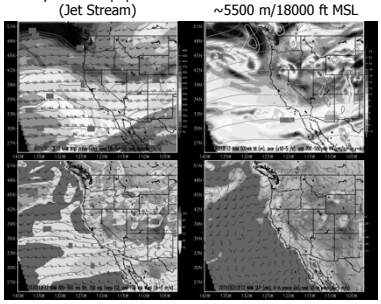


## Useful NWP Products: UU Server

Dynamic Tropopause (Jet Stream)

500 mb ~5500 m/18000 ft MSL

"Synoptic Diagnostic"



700 mb ~3000 m/10000 ft MSL

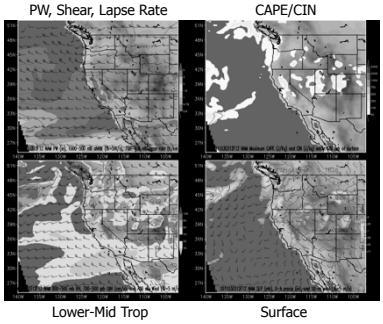
Surface

## Useful NWP Products: UU Server

PW, Shear, Lapse Rate

CAPE/CIN

"Convective Diagnostic"

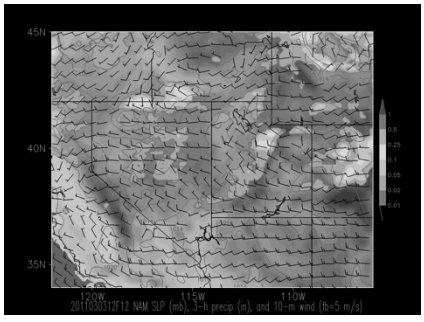


Lower-Mid Trop

Surface

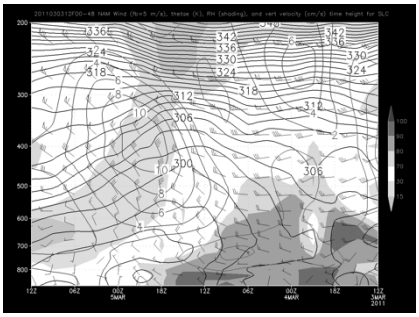
## Useful NWP Products: UU Server

Surface



# Useful NWP Products: UU Server

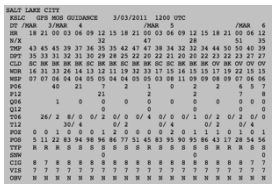
Theta-E Time Height

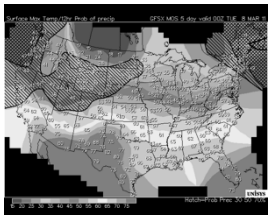


# Model Output Statistics (MOS)

- Based on statistical relationships between model forecast variables and actual weather in the past
- Relationships then applied to latest model run
- Usually based on stepwise multiple linear regression
- Performs better than NWP or Statistics alone
  - Blends the best of both worlds
- Available for NAM and GFS

# Model Output Statistics (MOS)





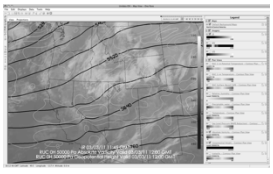
Sources: NOAA/MDL, weather.unisys.com

# Model Output Statistics

- Advantages
  - Cheap and easy
  - Corrects for systematic model biases
  - Blends best of NWP and Statistics
  - Does well in generic weather patterns
- Disadvantage
  - Doesn't handle model changes well
    - i.e., shifts in biases
  - Doesn't handle outlier or unusual events well
  - Forecaster overreliance on MOS leads to rigamortis of skill

# Forecast Tools: Scientific Visualization

AWIPS



IDV

Advantage: Integration of Diverse Atmospheric/Earth Data

Sources: Wikipedia Commons, Unidata