ATMOS 5010: Weather Forecasting
Forecasting Tools and Techniques

NOAA/weather.gov

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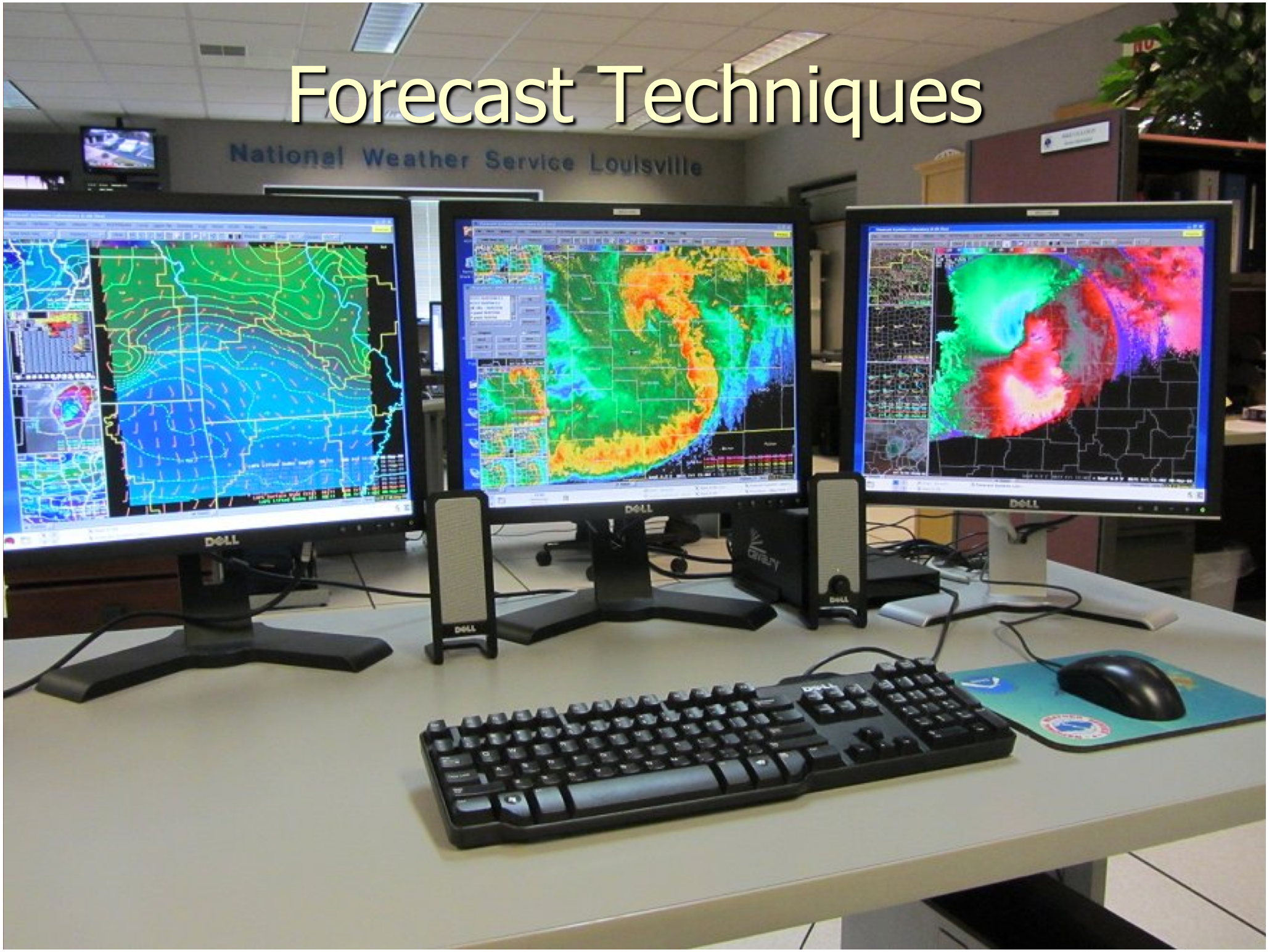
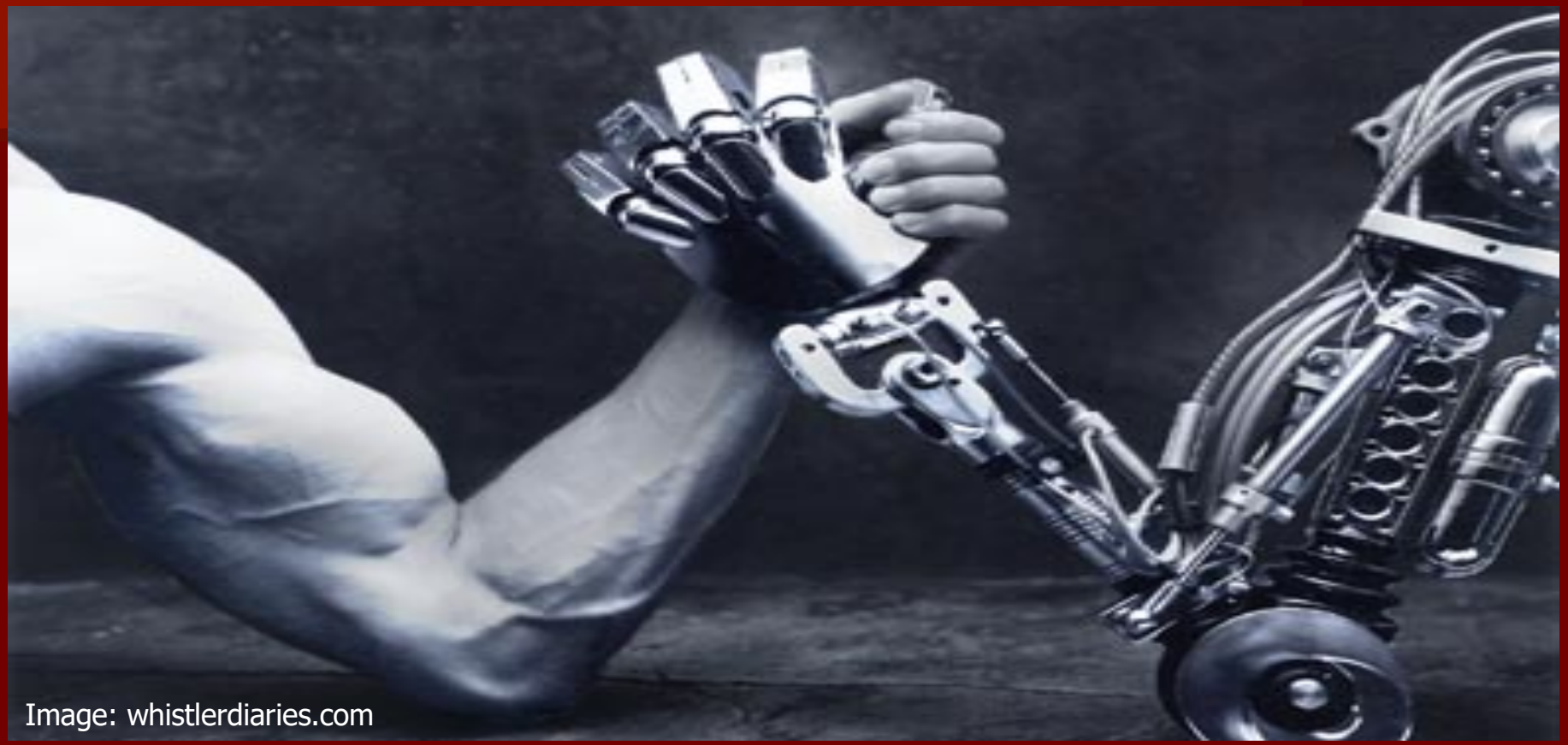
Forecast Techniques



Successful Forecasting Requires

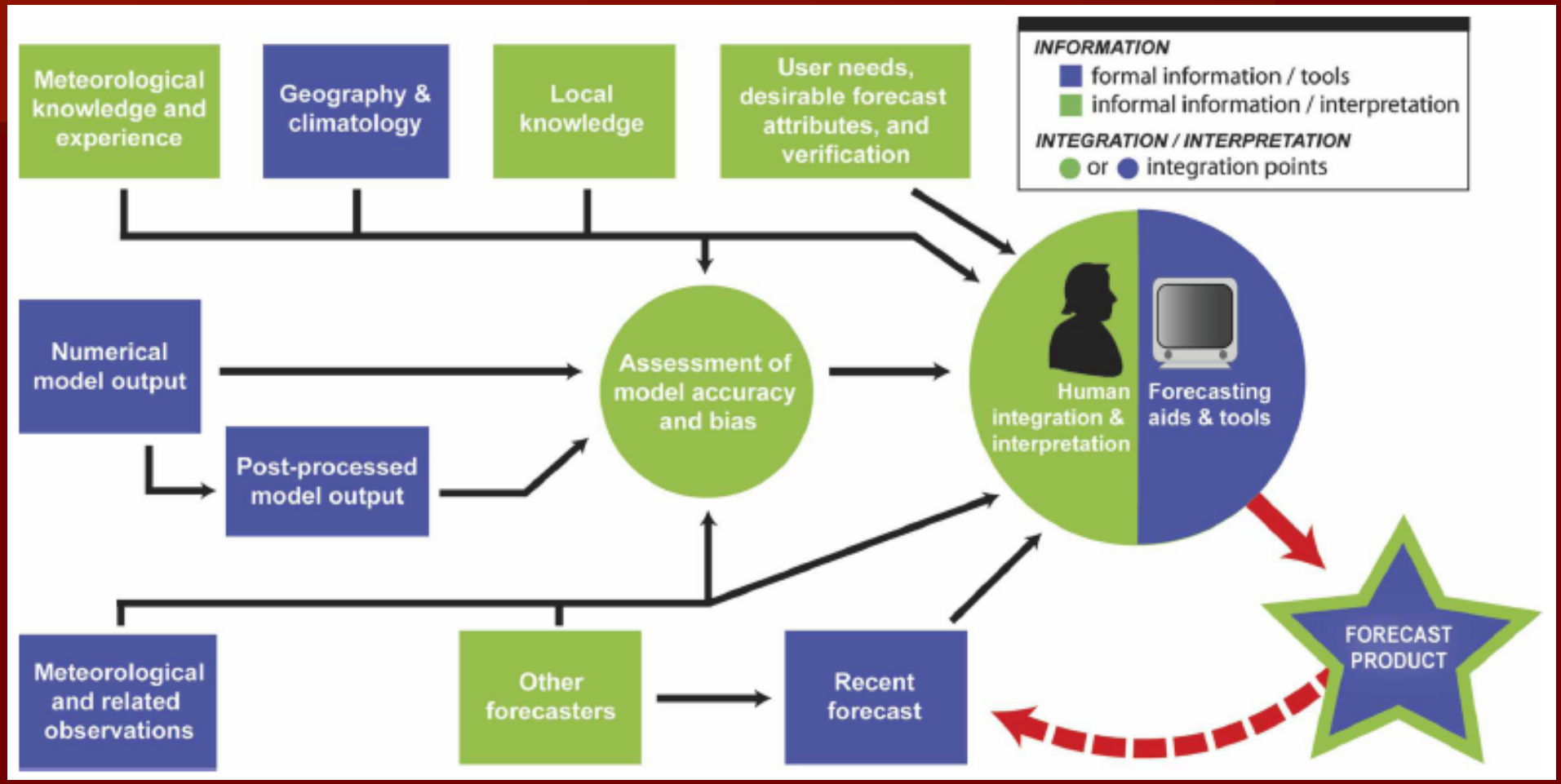
- Knowledgeable, well-trained, & engaged forecasters
  - Meteorological knowledge and experience
  - Local weather & climate knowledge
  - User need recognition
  - Model strength, weakness, and bias assessment
  - Human cognition and interpretation
- Skillful & reliable NWP guidance, forecast tools,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

Easy to concentrate only on this

Source: Bosart (2003)

Critical Forecast Questions

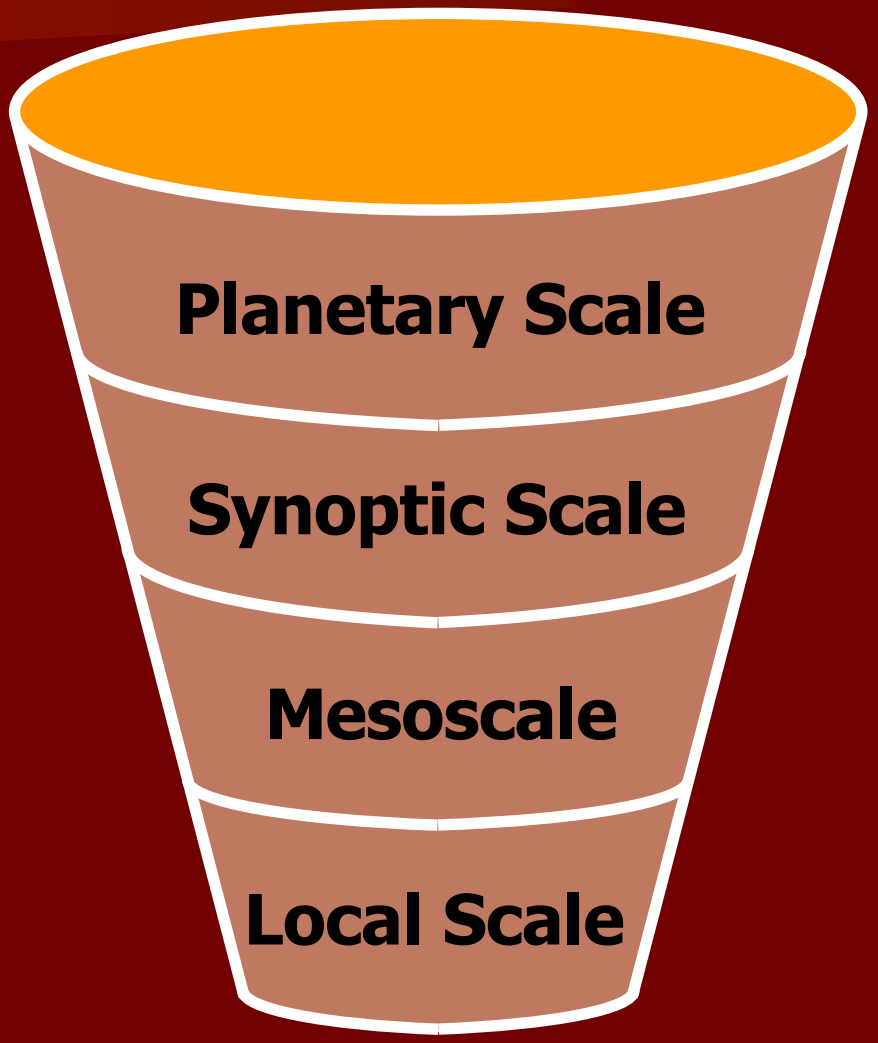
- What has happened?
- Why has it happened?
- What is happening?
- Why is it happening?
- What will happen?
- Why will it happen?

Important when NWP goes awry or cannot resolve local orographic effects

Source: Bosart (2003)

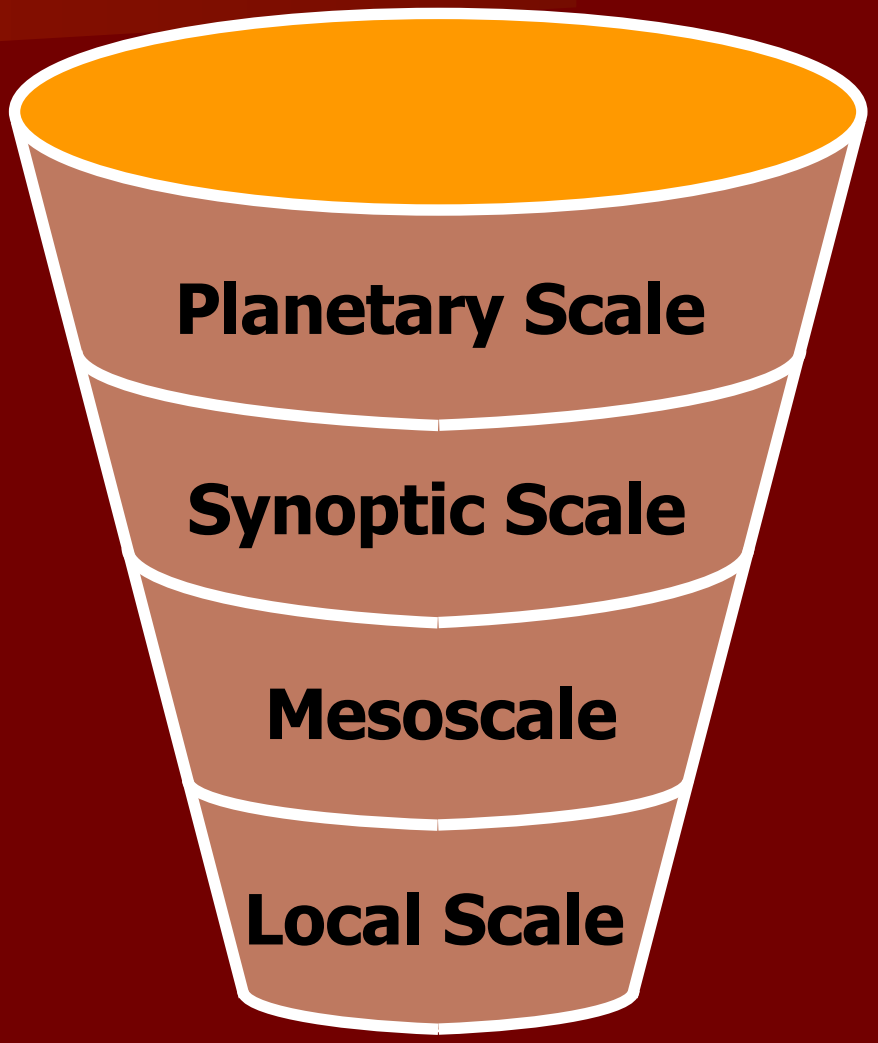
The Forecast Methodology

- 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

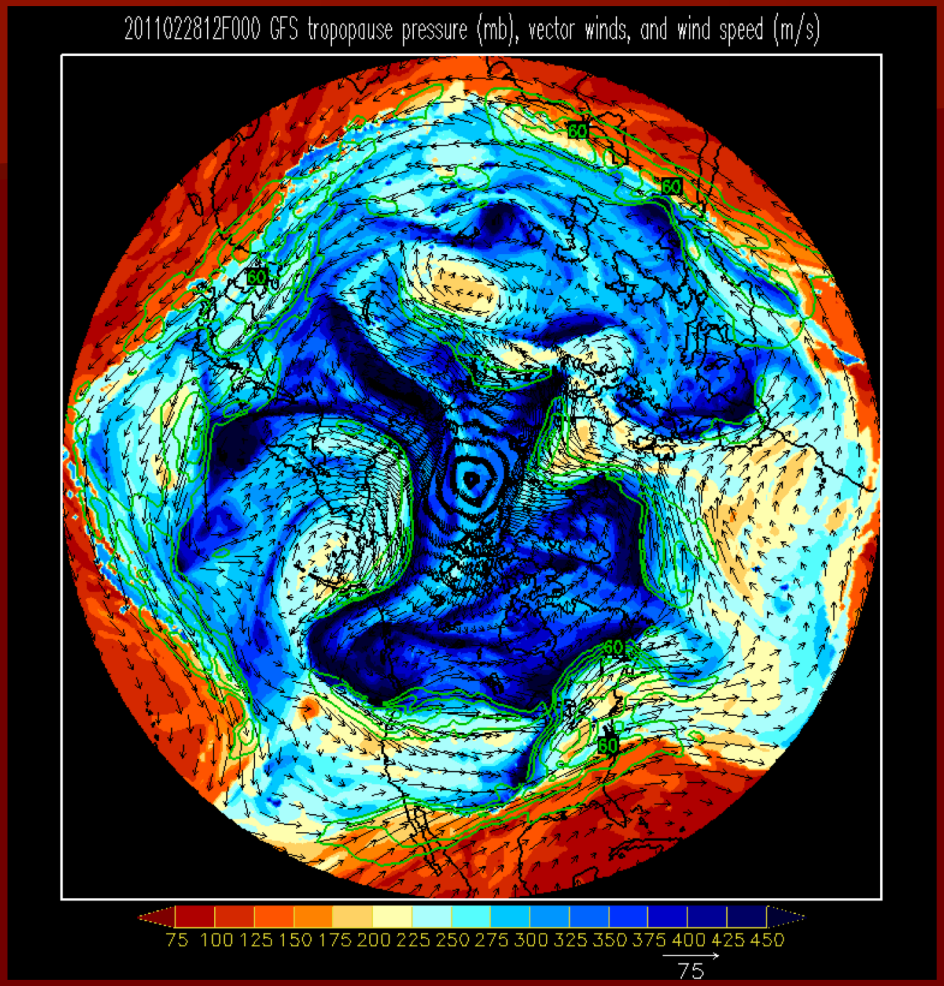


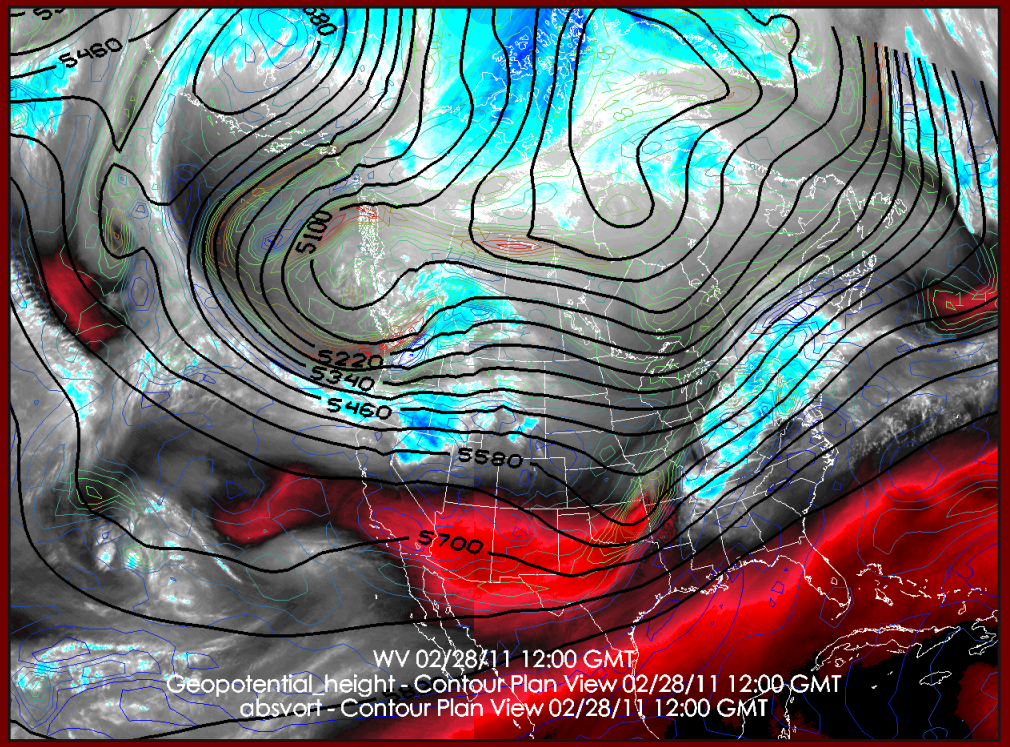
The Forecast Methodology

- 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



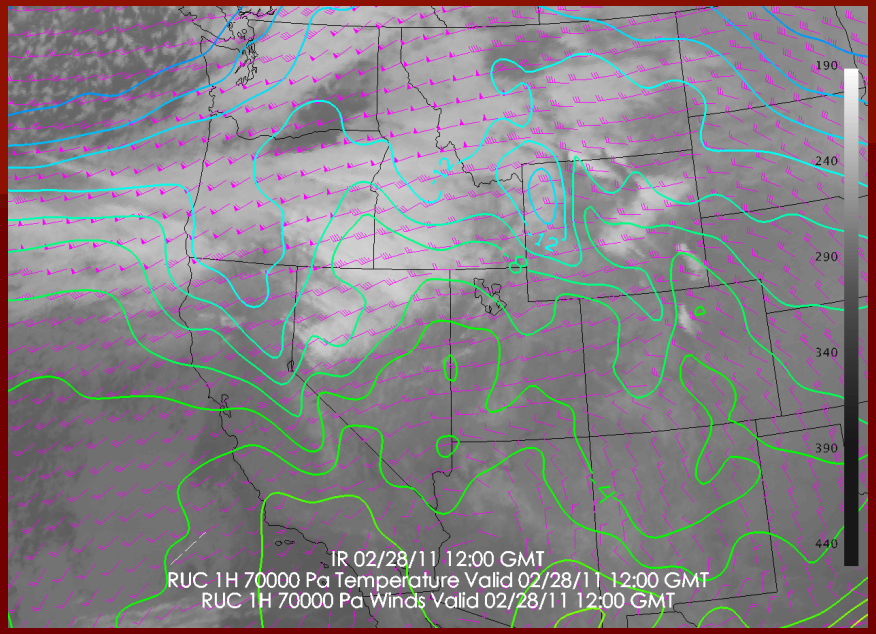
Forecast Funnel in Practice

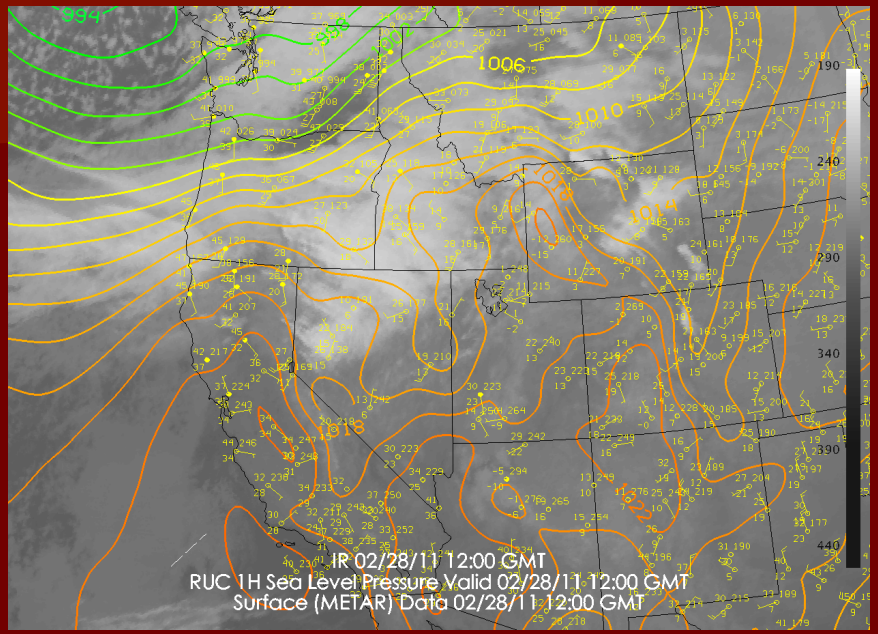


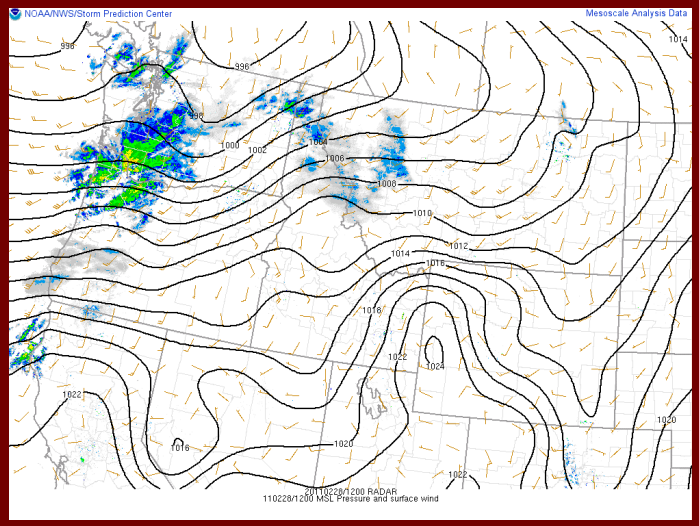


Evaluate past, current, and future planetary scale setting

The Forecast Funnel in Practice

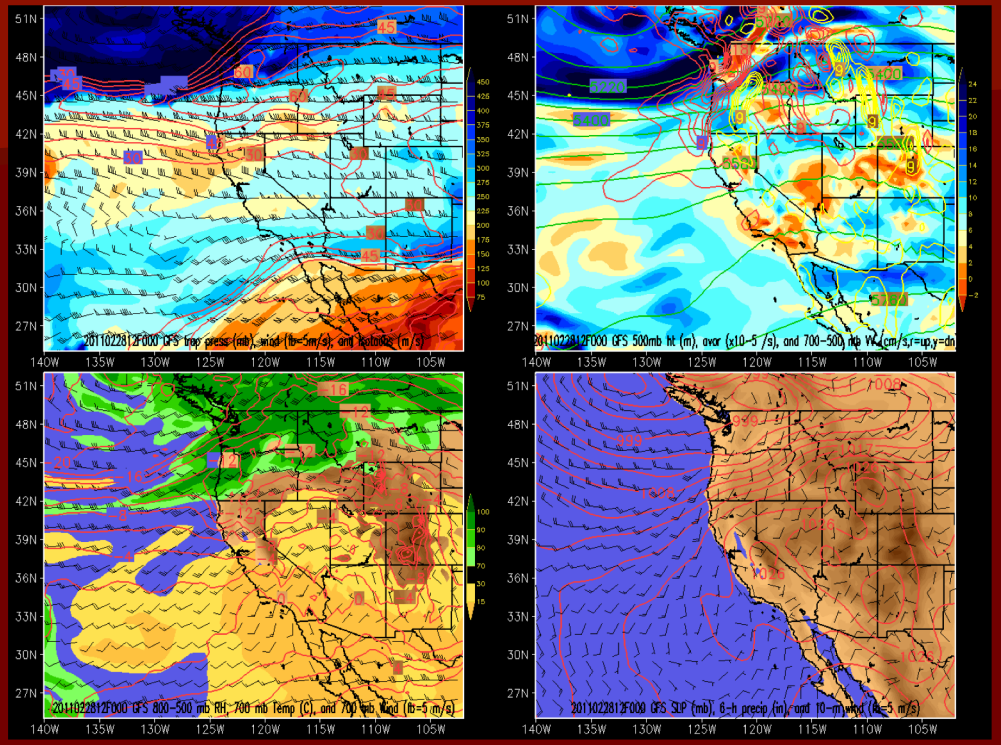


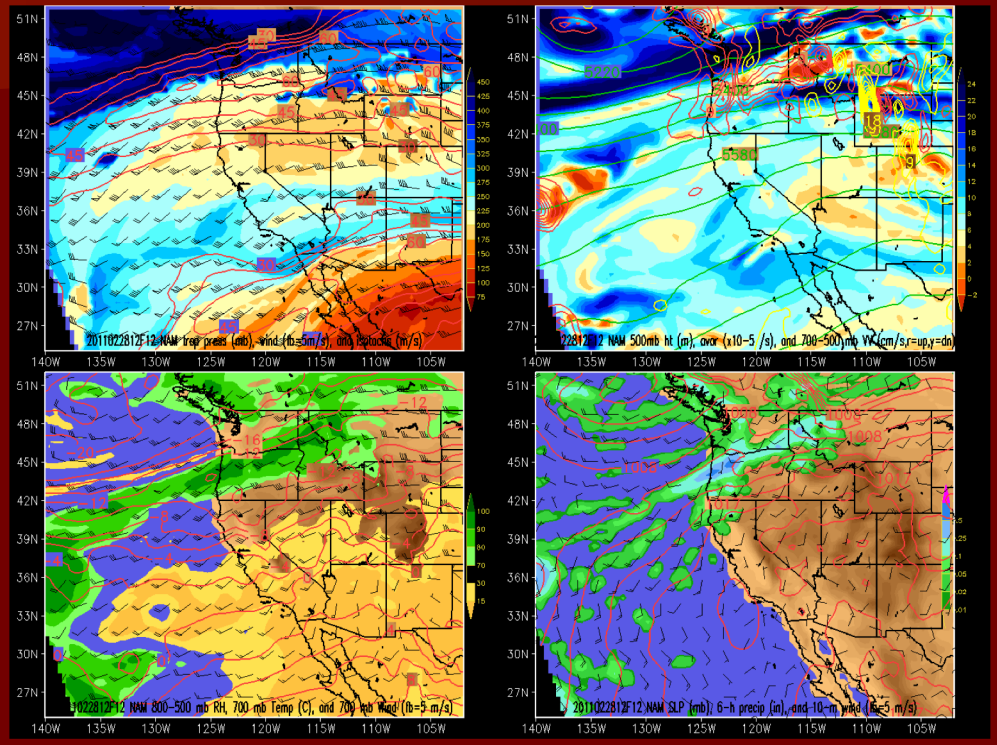




Funnel to synoptic scale

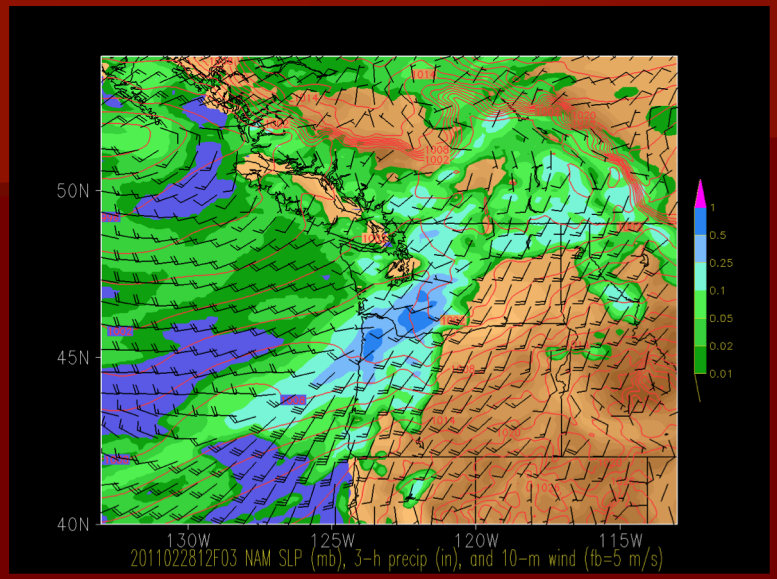
The Forecast Funnel in Practice

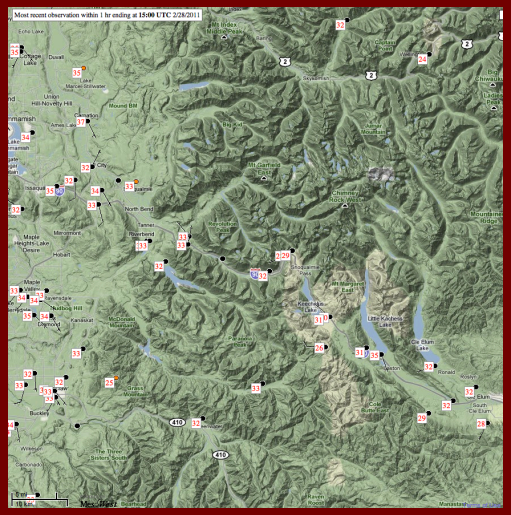


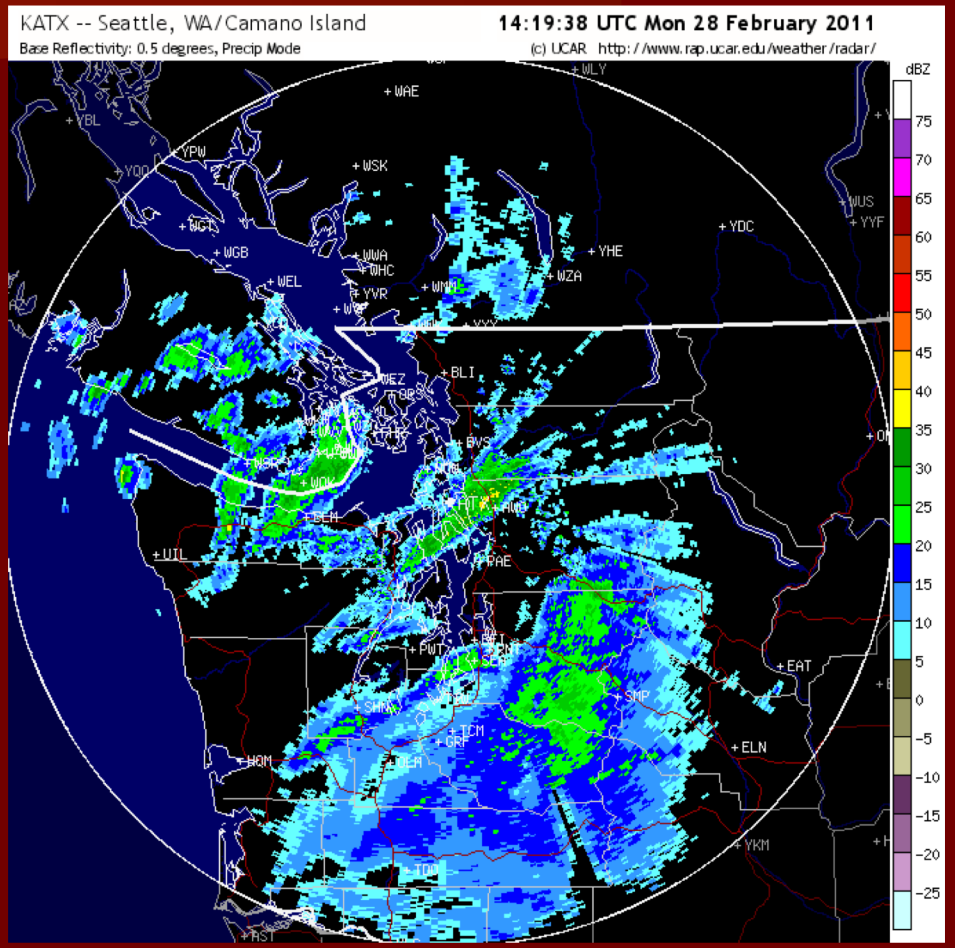


Evaluate confidence in synoptic-scale forecast

The Forecast Funnel in Practice

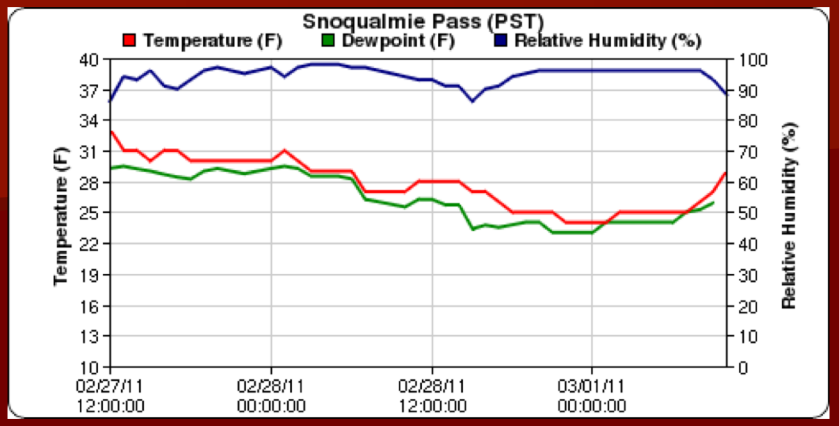


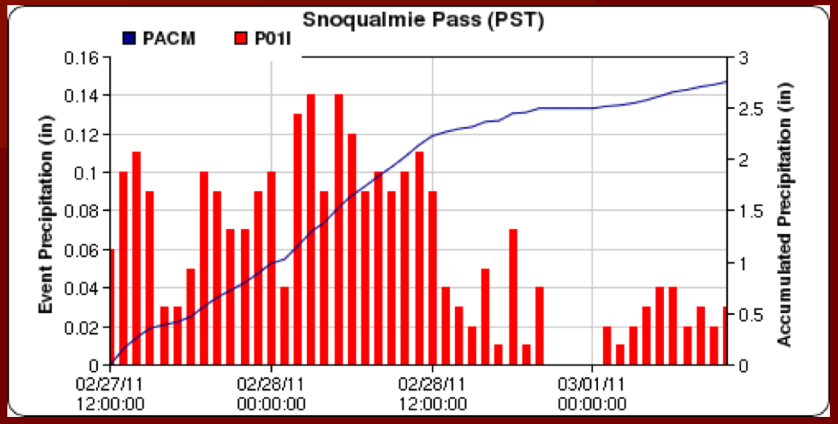




Funnel to mesoscale
Consider mesoscale, orographic, and land-surface processes

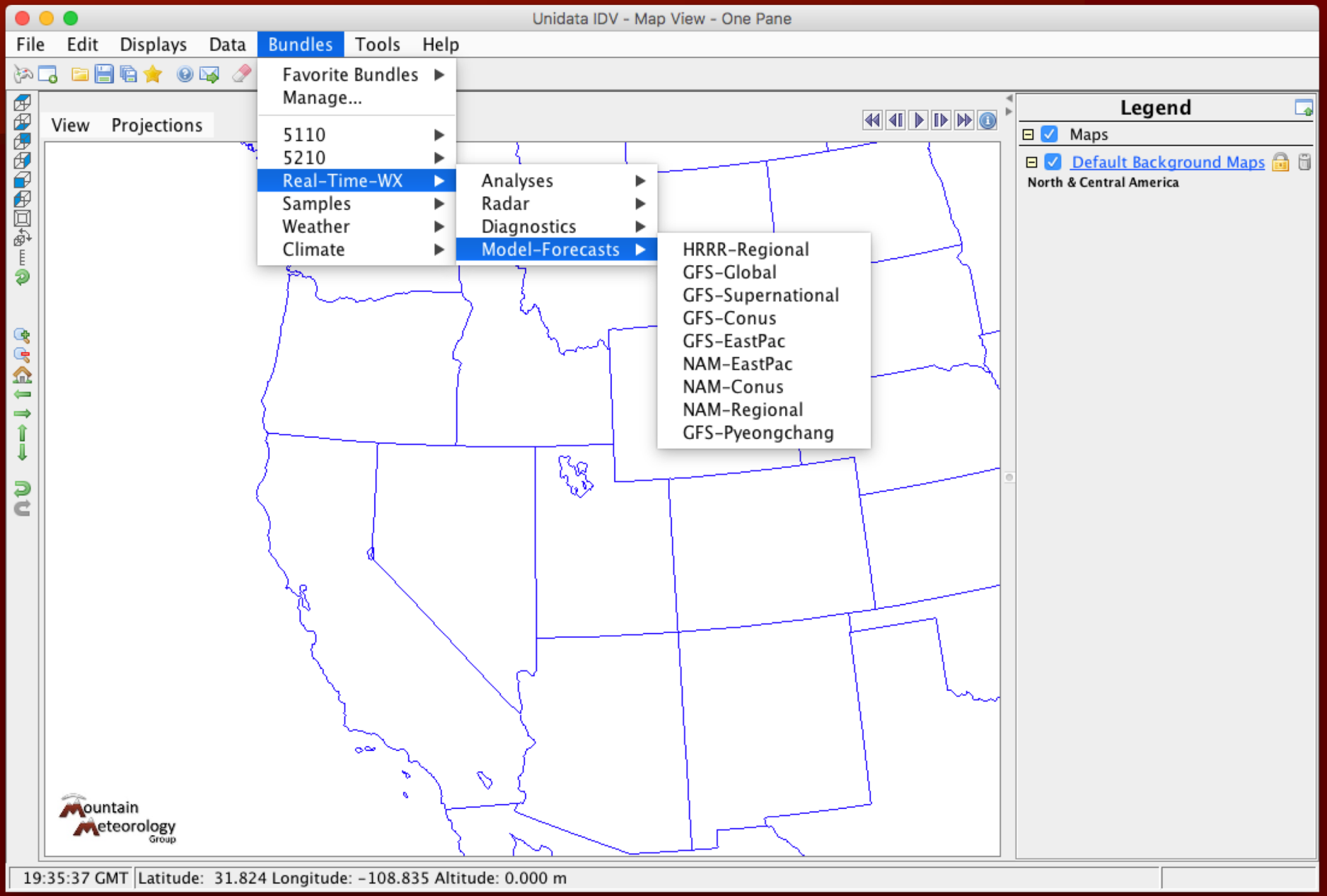
The Forecast Funnel in Practice



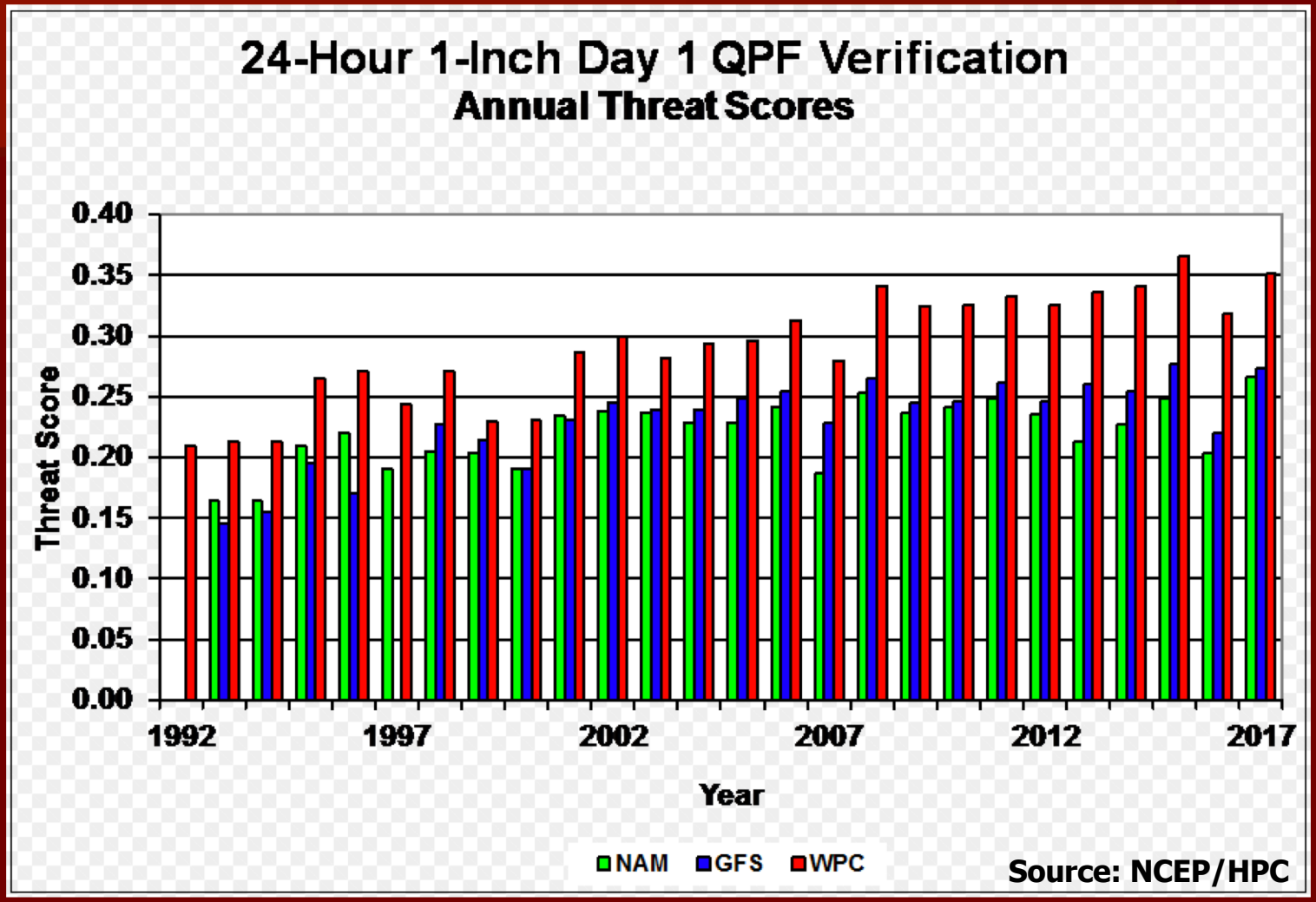


Adjust for local effects

Real-Time Example Using IDV



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)

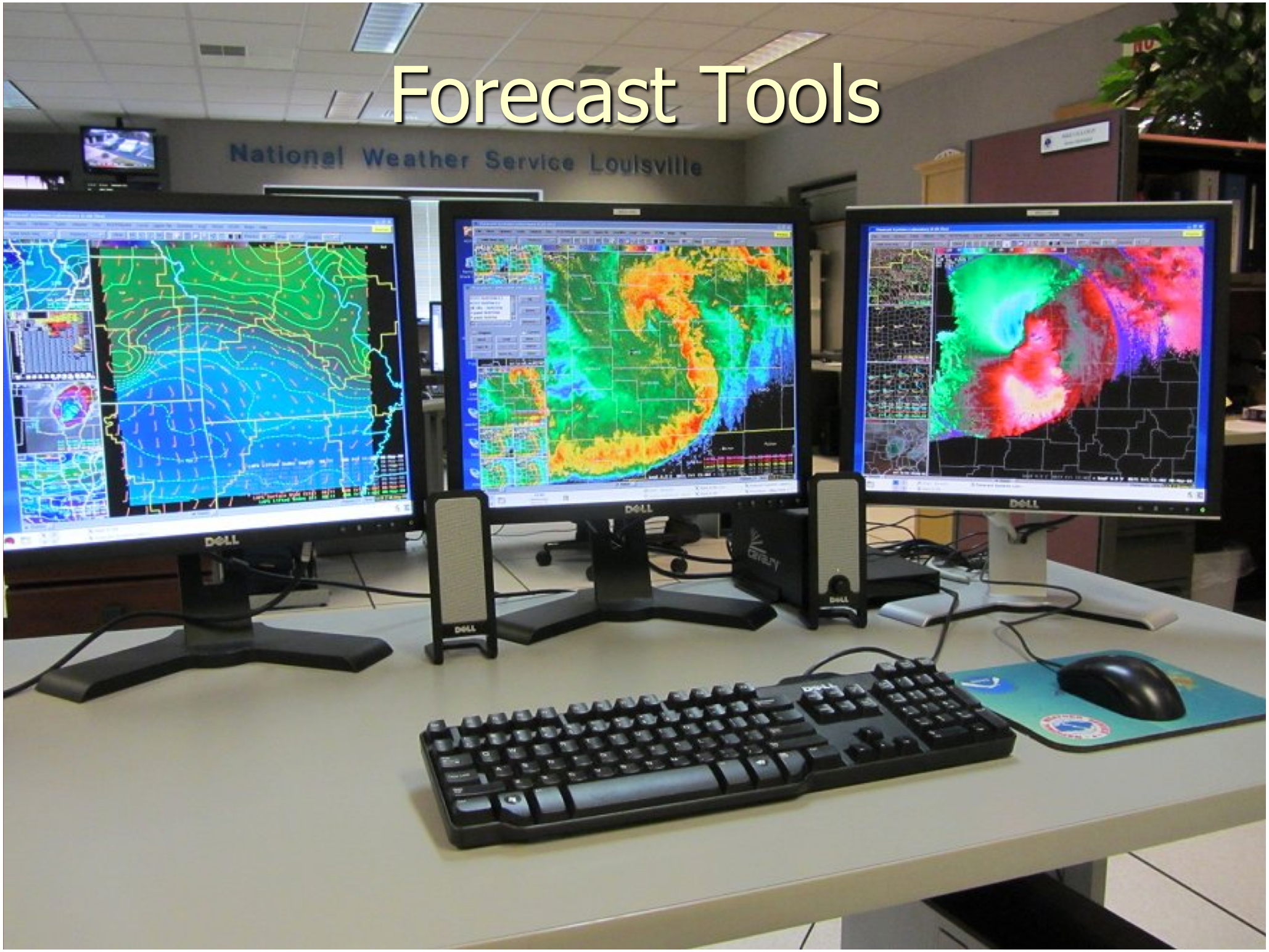
Don't be on Autopilot

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

Forecast Tools



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"

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

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%	2[illegible]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[illegible]3%	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%	9.1[illegible]	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%	5.5[illegible]	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[illegible]	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%	2.9%	1.3%	0.6%	

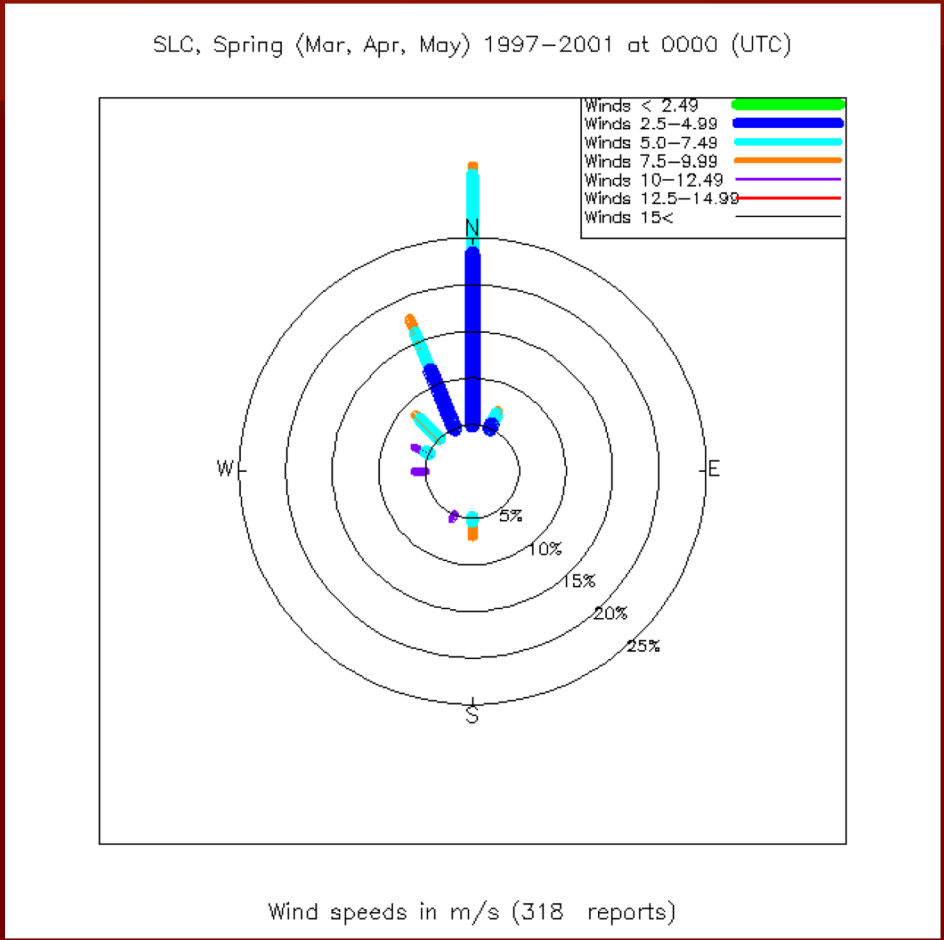
	ANN
Probability of VIS<1 mi given that snow is falling	25.0%
Probability of VIS<1 mi given that rain is falling	0.9%
Probability of VIS<1 mi in TSRA	1.6%
Probability of TS given that snow is falling	0.5%
Probability of TS given that rain is falling	9.1%

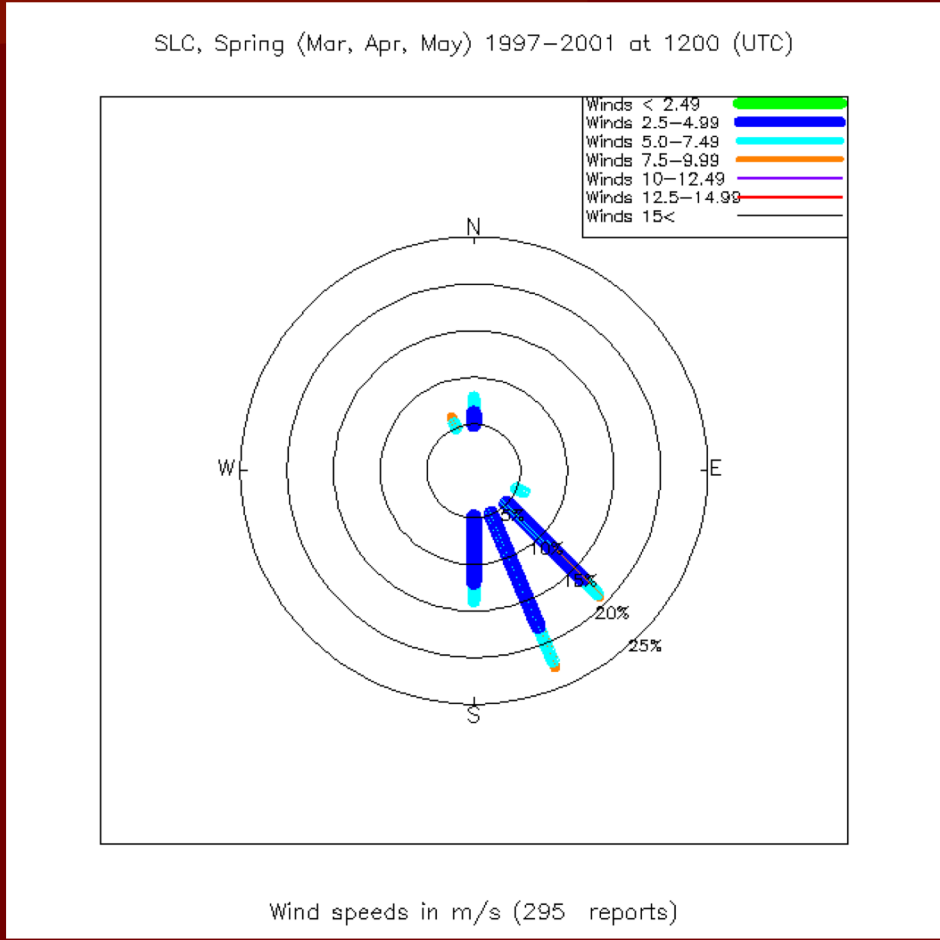
Surface Temperature	Probability of snow given that precip is falling
>40	0.8%
38-40	3.6%
37-38	15%
36	34%
35	59%
34	79%
33	93%

Is this useful????

Means and Probabilities for Forecast Practicum Variables

Forecast Tools: Climatology



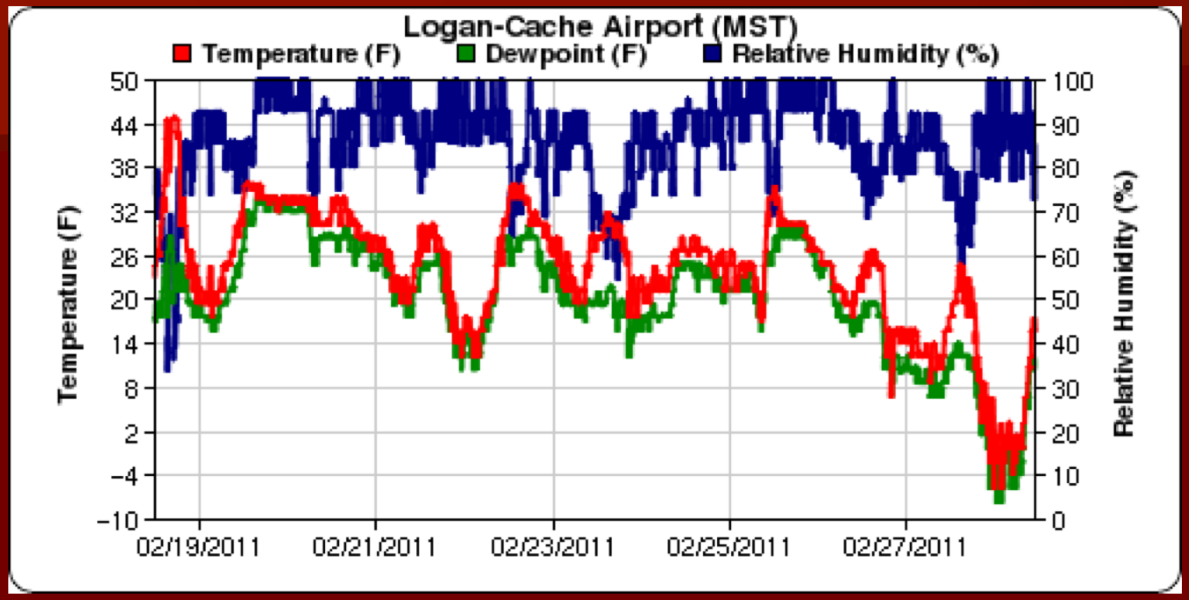


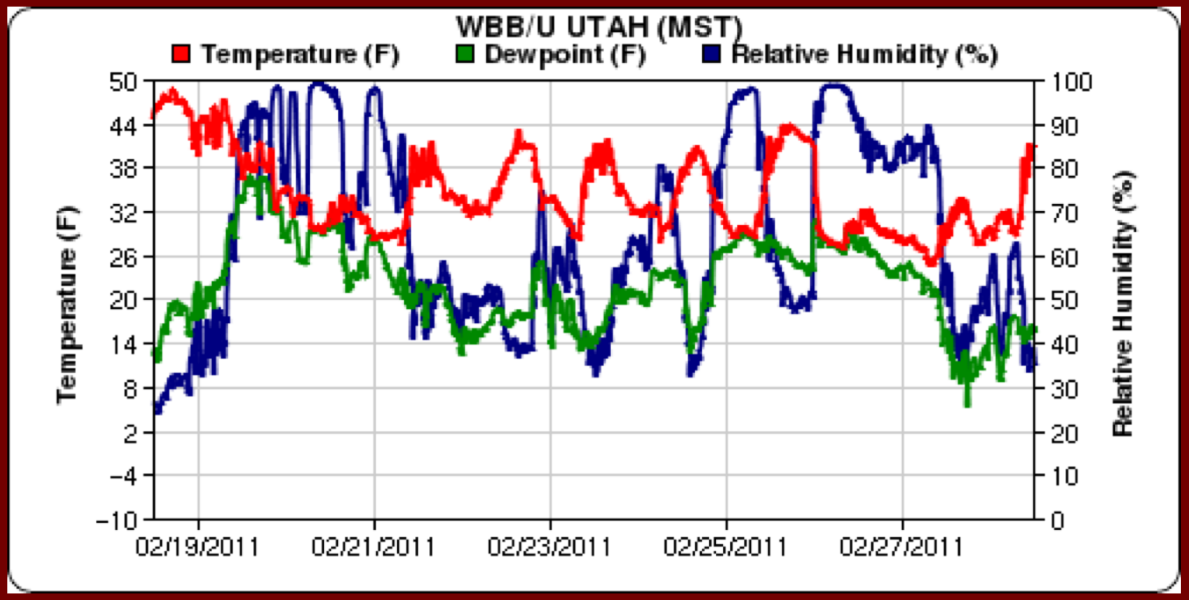
Think Beyond the Mean

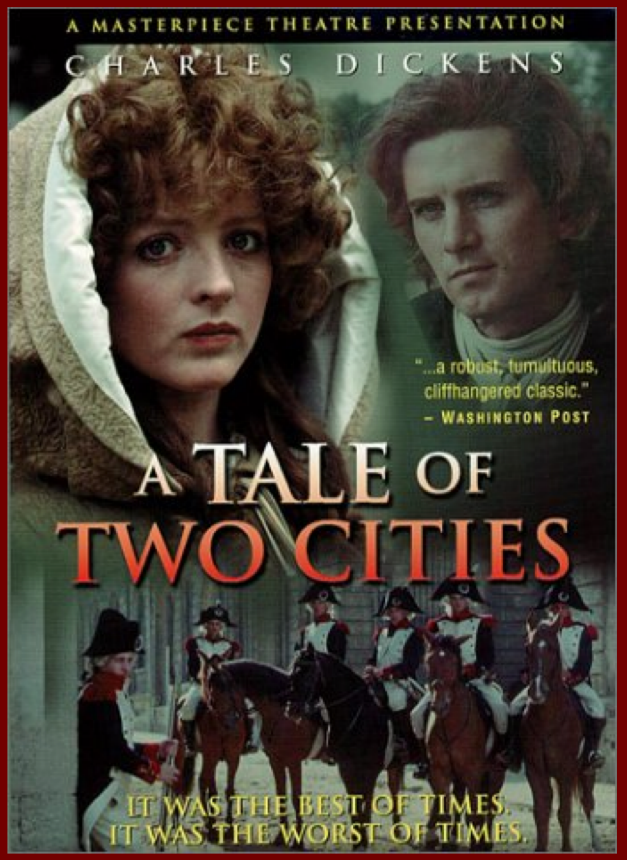
Forecast Tools: Persistence

- 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

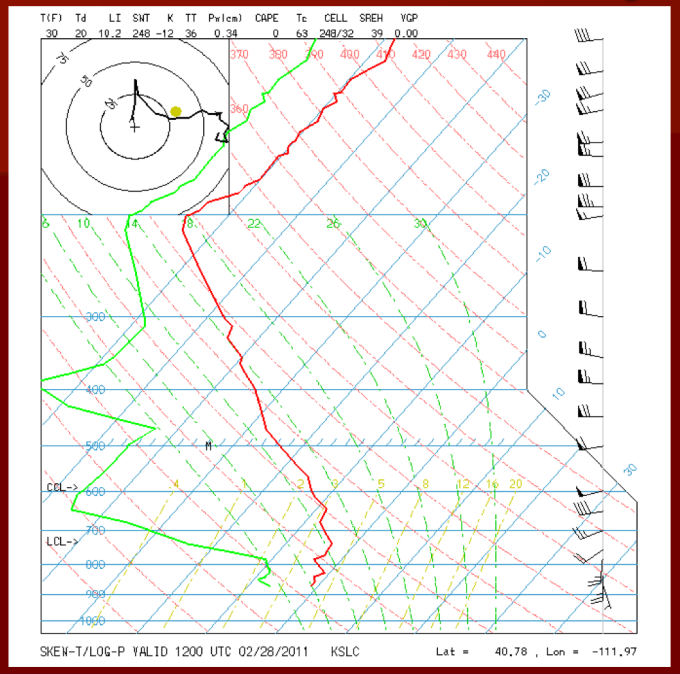
Source: cartoonstick.com, collaborativejourneys.com

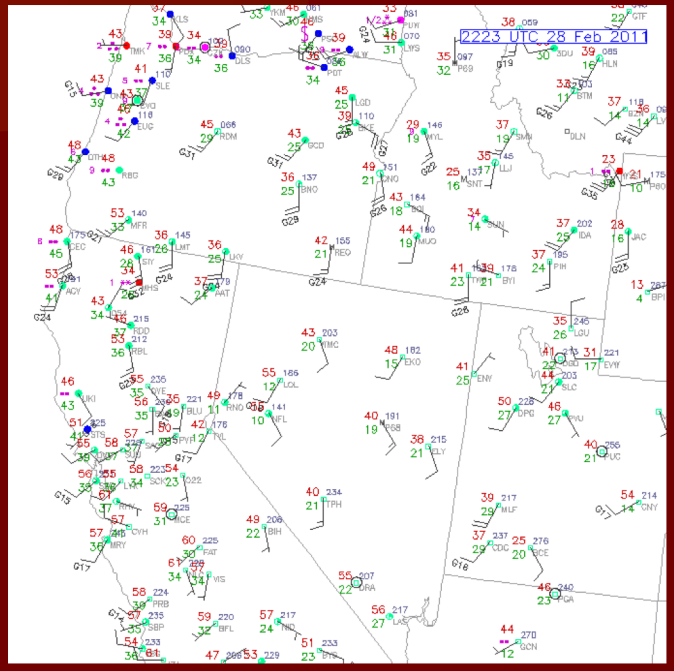
Forecast Tools: Sfc/Upper-Air Data

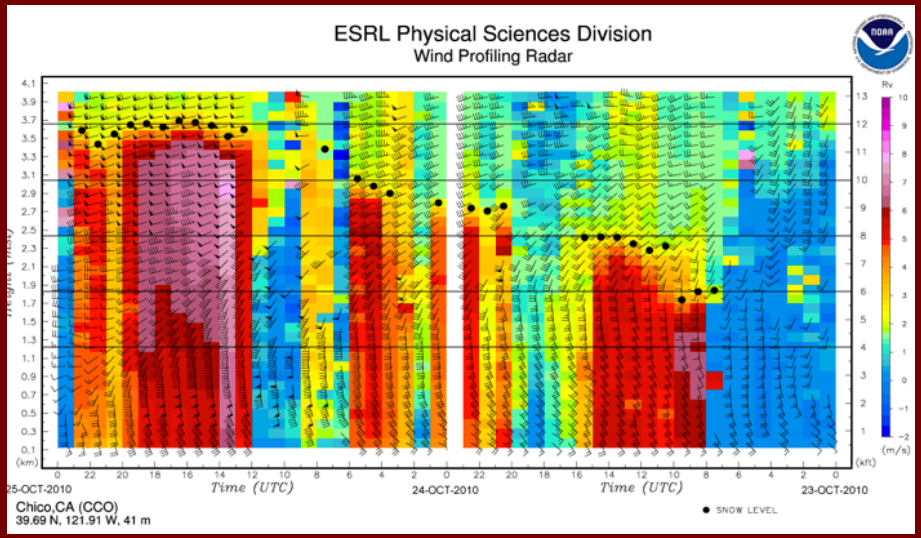

ASOS, Springfield, IL (NWS)


Weather Balloon (NWS)


Wind Profiler (Wikipedia)

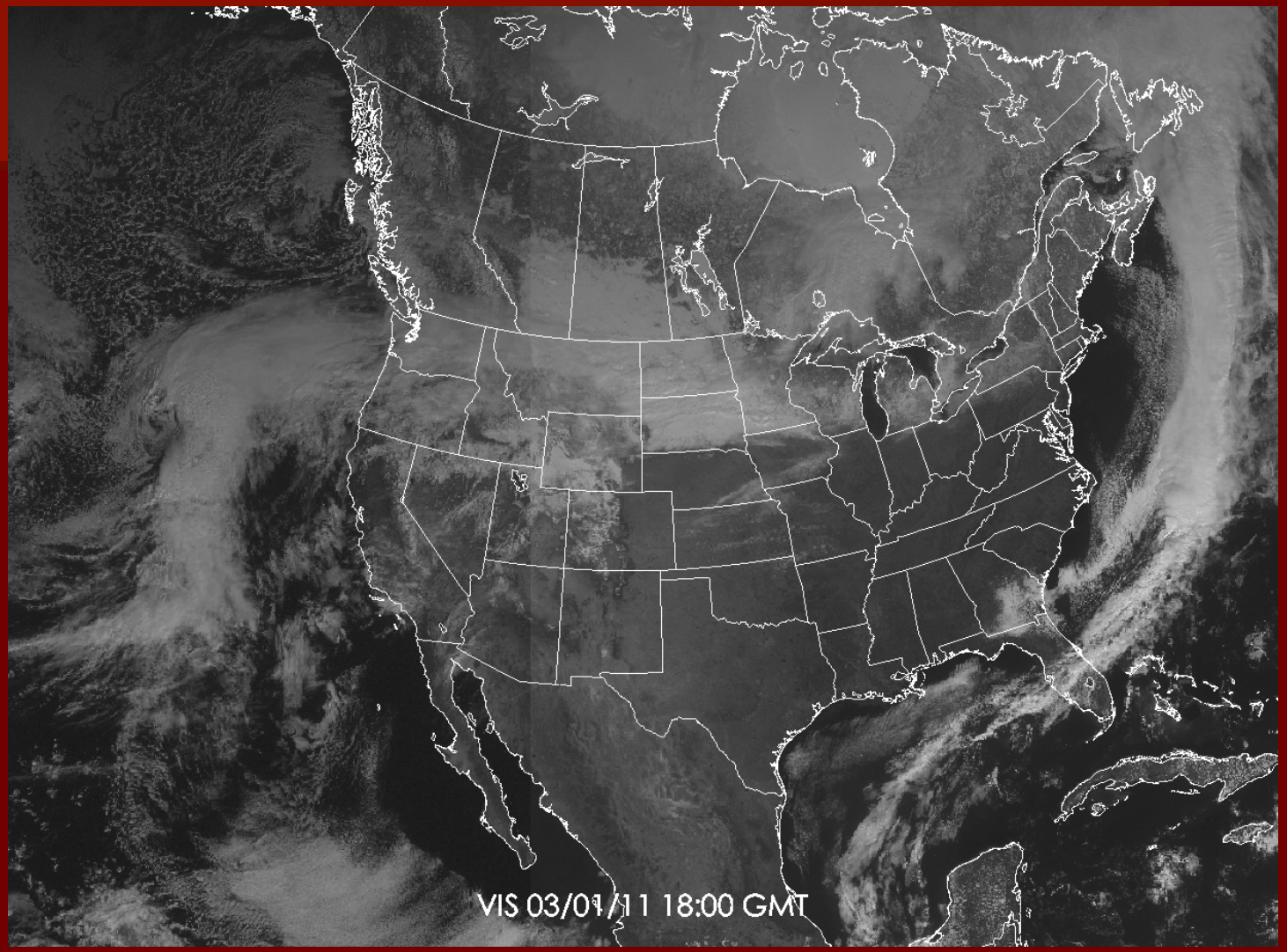






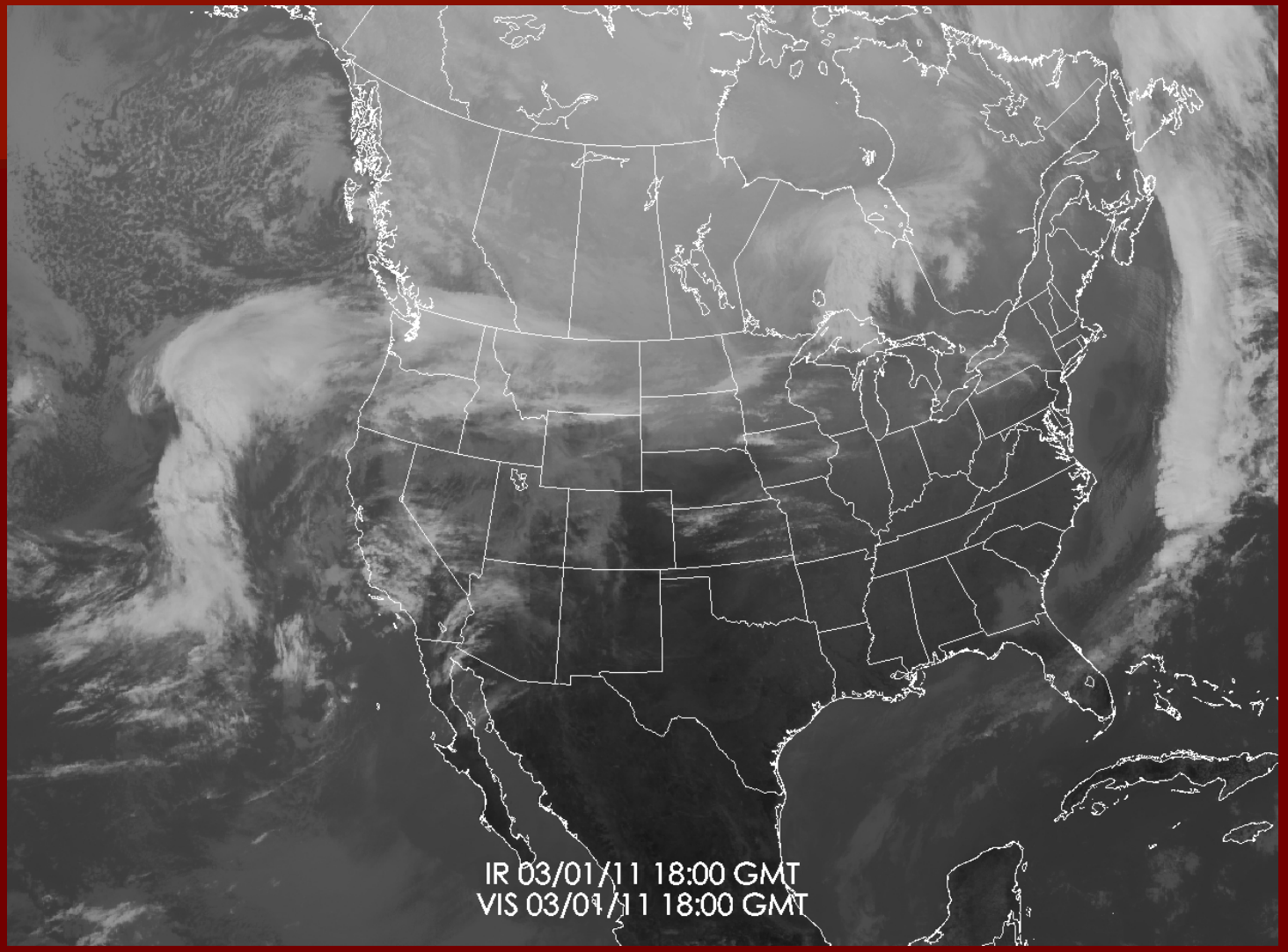
Wind profilers provide more than wind!

Forecast Tools: Satellite



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

Forecast Tools: Satellite

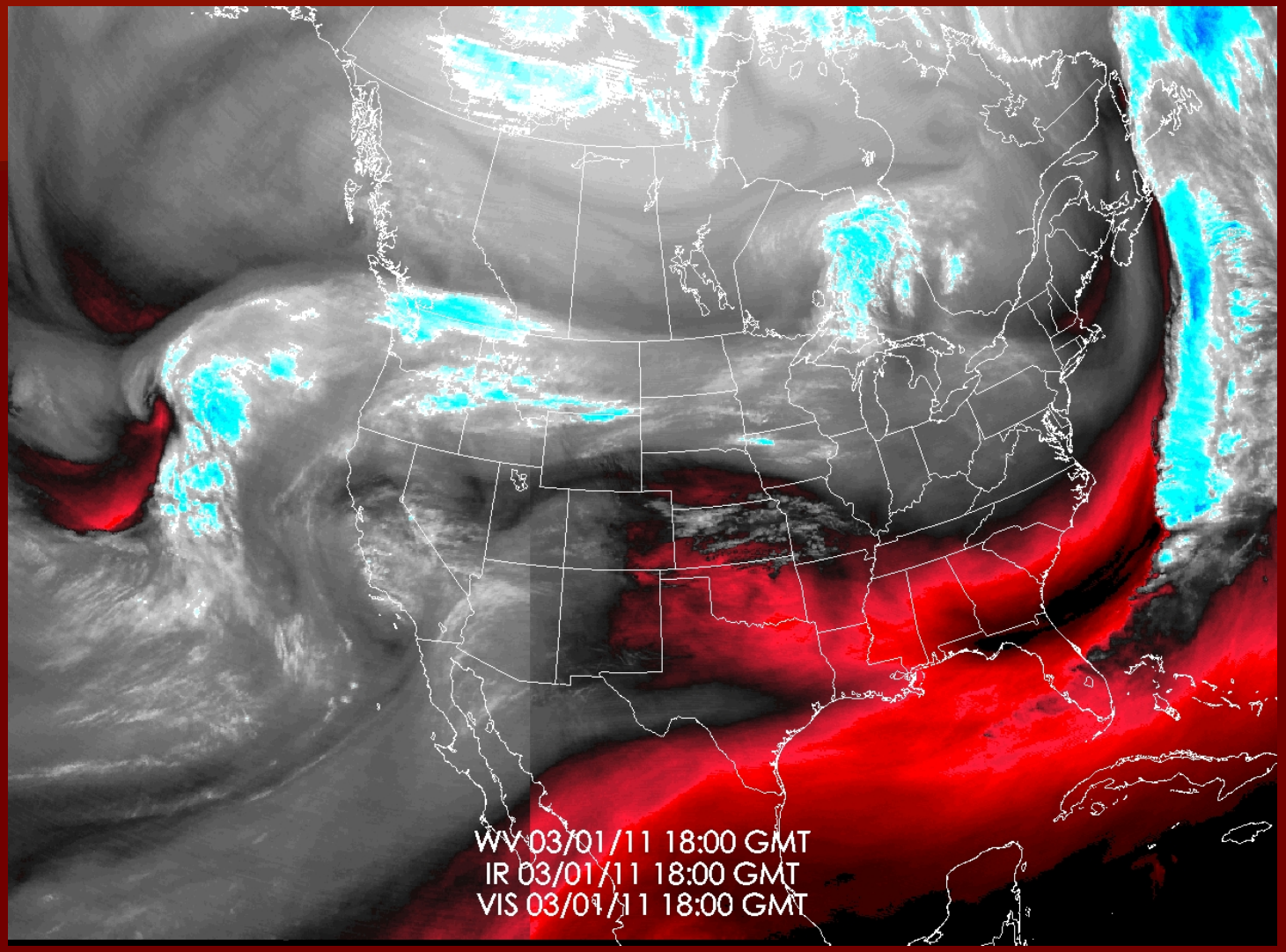


"Window" IR Imagery

Long-wave radiation emitted primarily by clouds, land-surface, etc.

Cloud-top temperature and land-surface temperature

Forecast Tools: Satellite

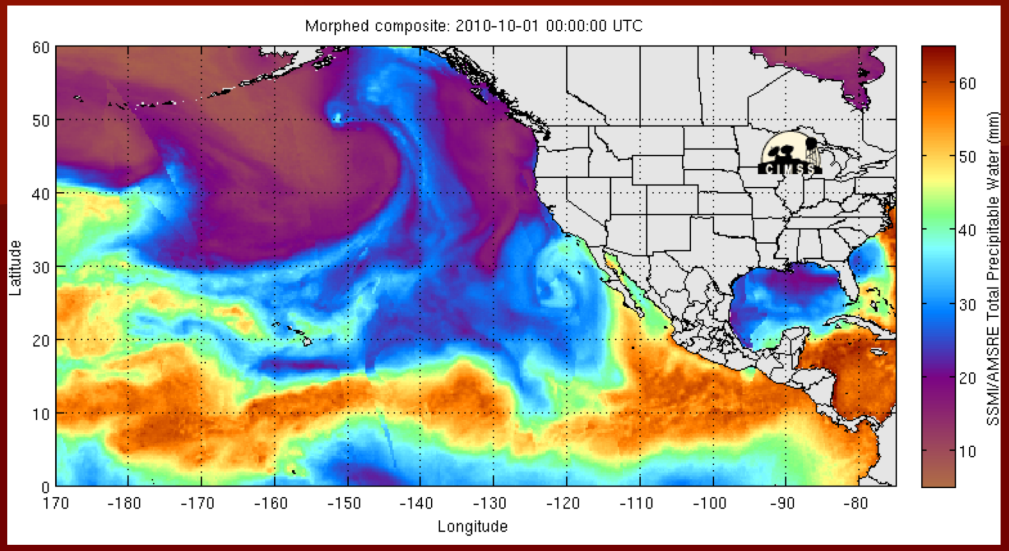


Water Vapor Channel (IR) Imagery

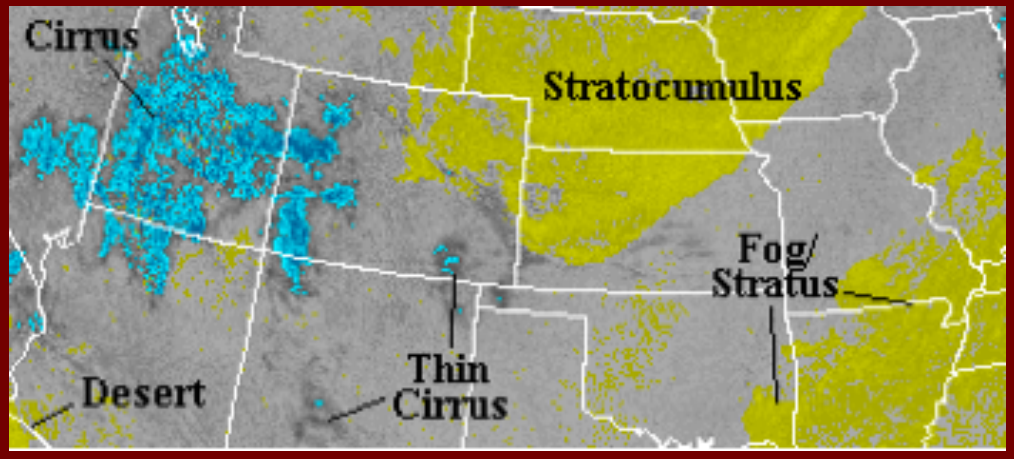
Long-wave radiation emitted primarily by upper-tropospheric clouds and water vapor

Upper-level flow, troughs, etc.

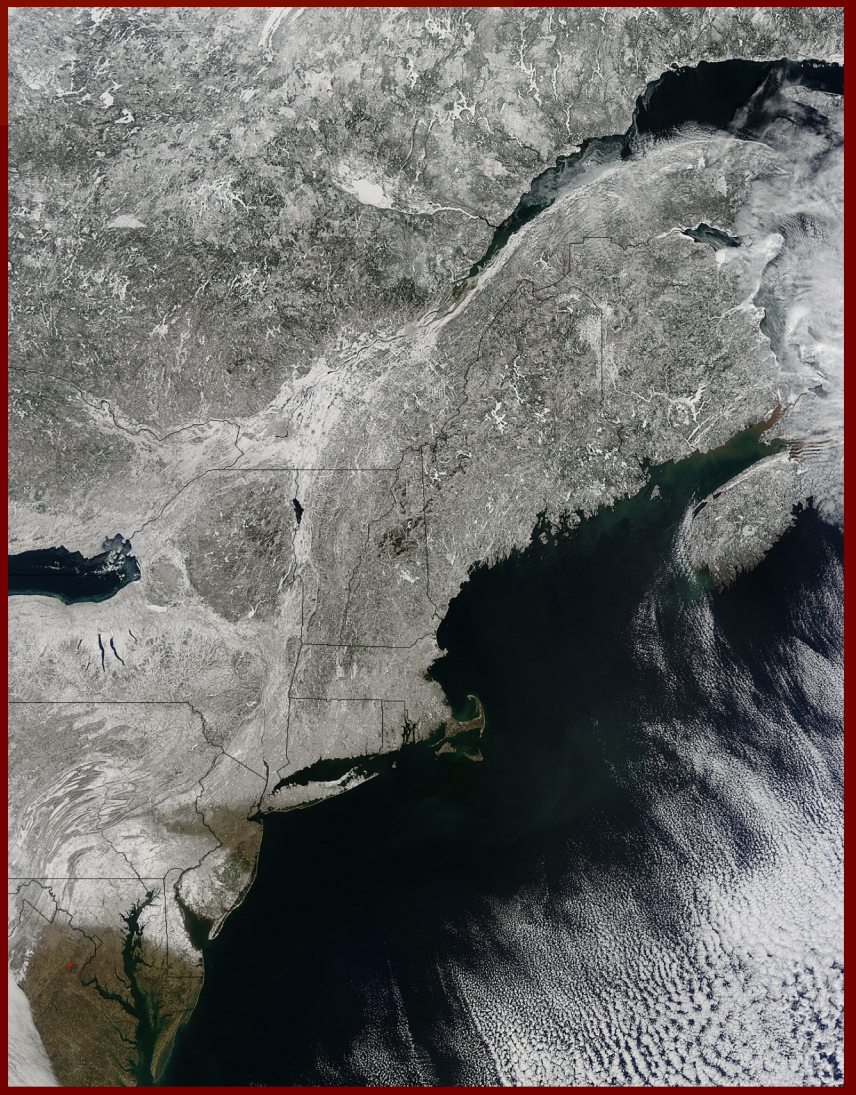
Forecast Tools: Satellite



Precipitable Water from
Polar-orbiting microwave sensors



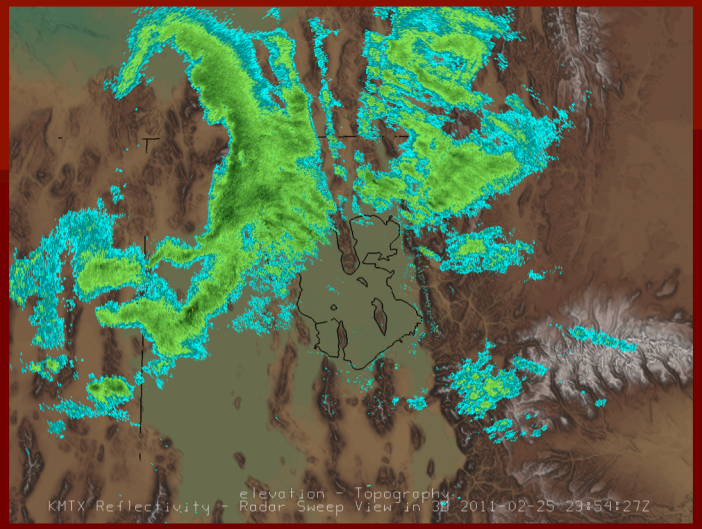
GOES Fog Detection
Longwave IR (10.7 micron)-Shortwave IR (3.9 micron)



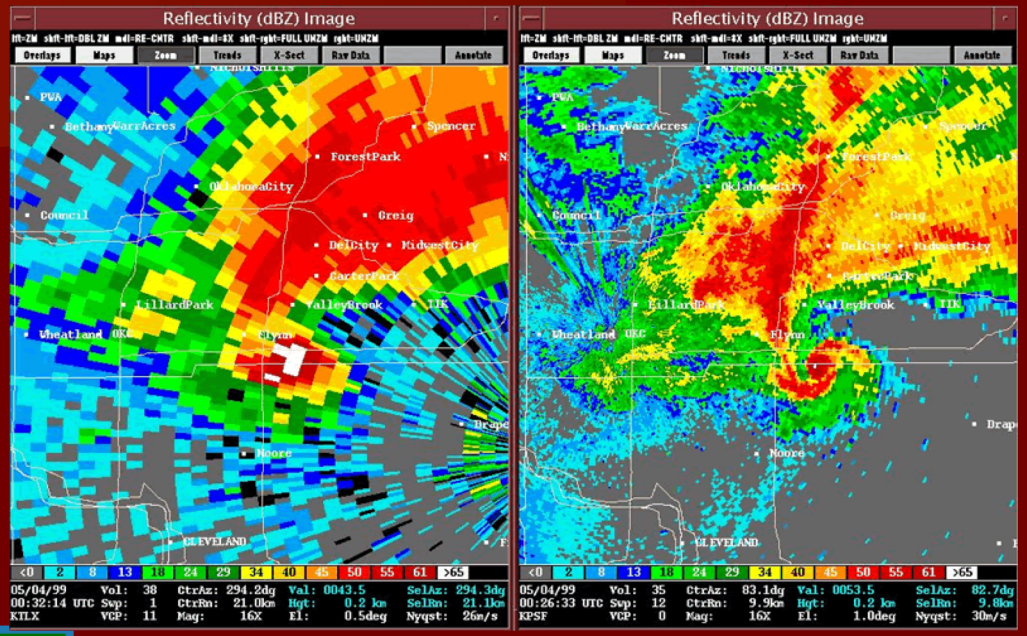
MODIS

Sources: SSEC, NESDIS

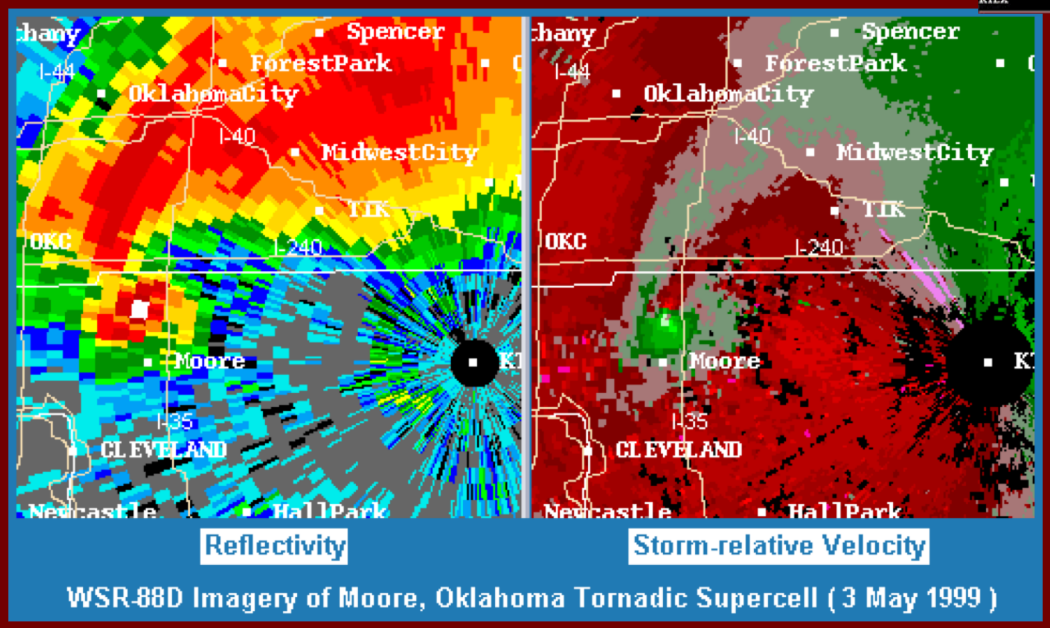
Forecast Tools: Radar



NEXRAD Doppler Radar



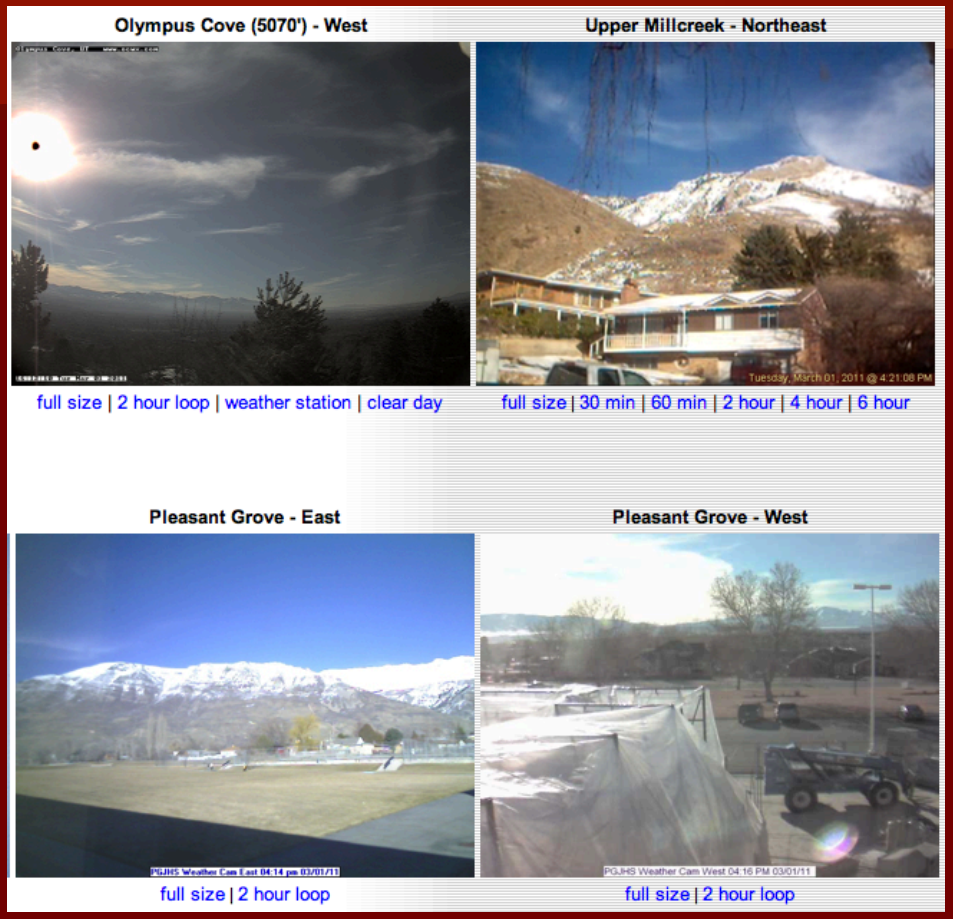
NEXRAD vs. TDWR



Now: Polarimetric NEXRAD

Sources: NOAA/SPC

Forecast Tools: Weather Cameras



Click for Animation

Forecast Tools: Manual Analysis

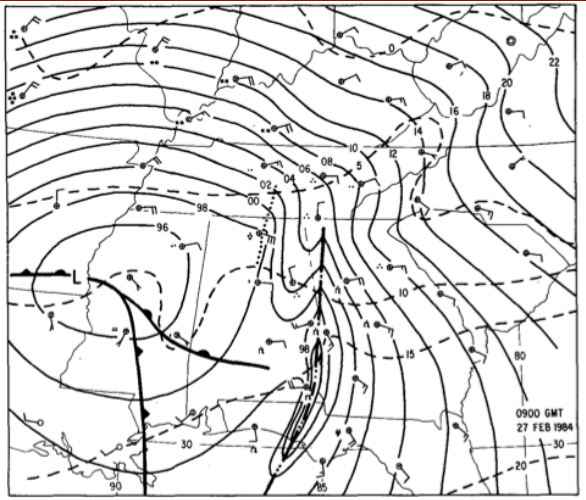


FIG. 12d. As in (a) except for 0900 UTC.

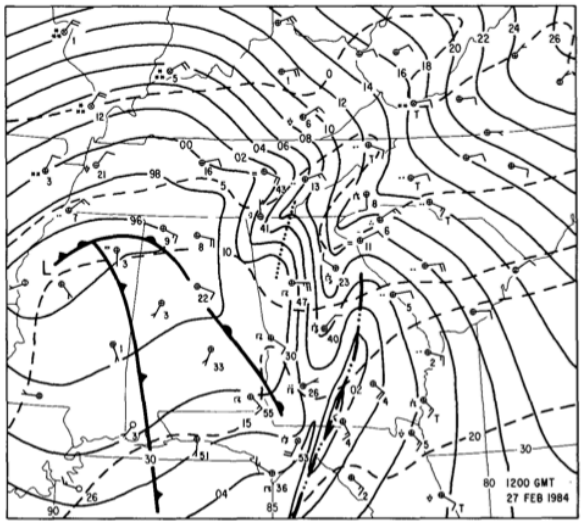
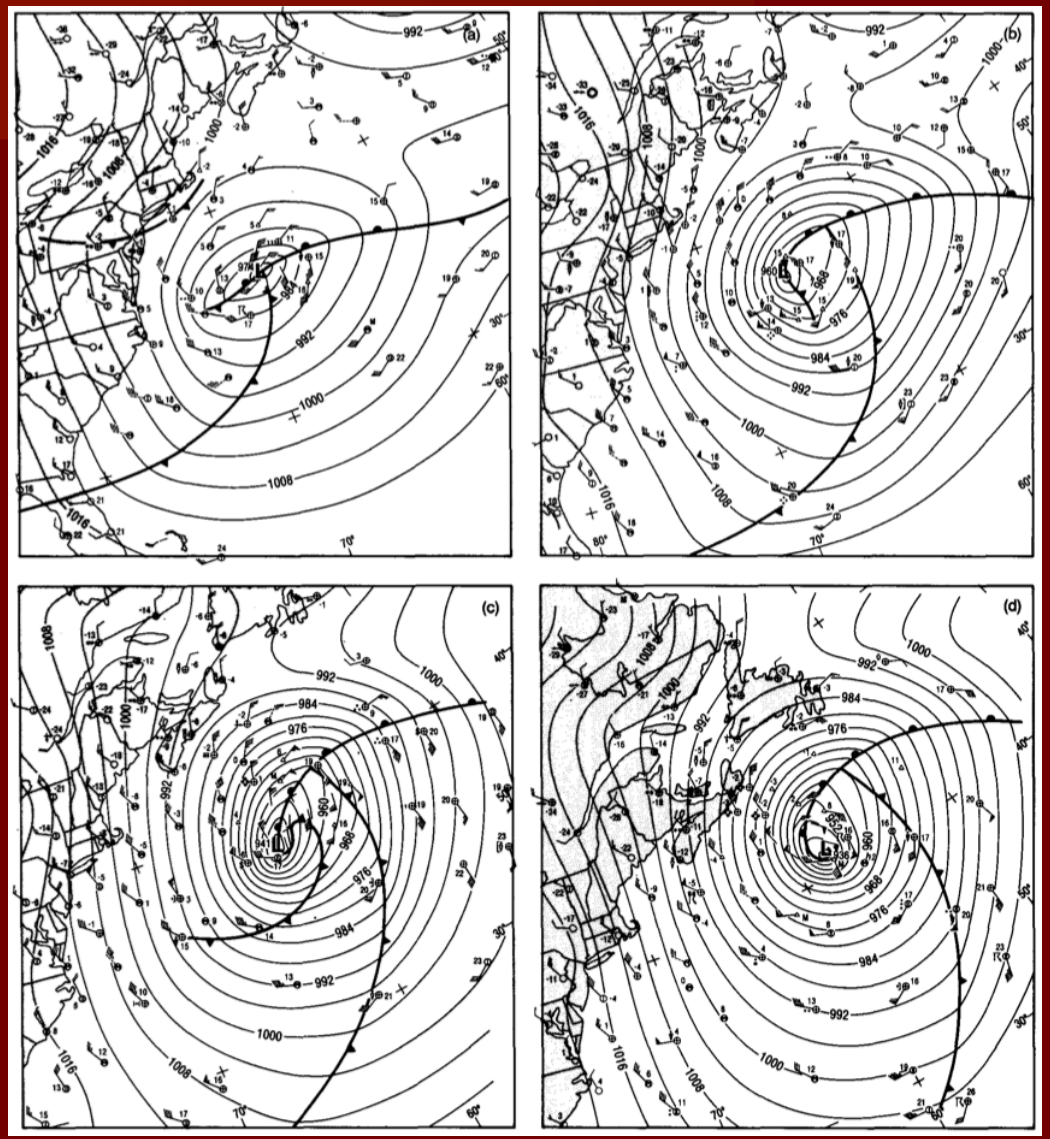


FIG. 12e. As in (a) except for 1200 UTC.



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

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

Useful Sites for Observations

- http://mesowest.utah.edu
  - Surface observations & time series
  - Radar overlays
- http://weather.rap.ucar.edu
  - Satellite, radar, surface maps, upper-air maps
- http://www.spc.noaa.gov/exper
  - Upper-air soundings, upper-air maps, surface mesoanalysis
- http://www.wunderground.com/wundermap/
  - You name it
- http://weather.cod.edu/satrad/
  - Satellite and radar

Useful IDV Bundles for Obs

- Real-Time-WX>Radar>
  - KMTX-3DTopo
  - KMTX-2D-Obs+Anal
- Real-Time-WX>Analyses>
  - Global-10day
  - Global-2day
  - SuperNational
  - Conus-East
  - Conus-West

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 ~13 km to 192 h (lower resolution 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
    - Higher resolution 4-km CONUS nest available
      - Supposed to be upgraded to 3-km soon
  - 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 Refresh (RAP)
  - 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

- High Resolution Rapid Refresh (HRRR)
  - Analyses for CONUS every hour
  - Short-range (out to 18 hours) forecasts for CONUS every hour
  - Grid spacing of ~3 km
  - 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
  - Strengths
    - Resolution and terrain representation
  - Weaknesses
    - Limited area, often lousy initial condition generation

Forecast Tools: NWP Models

- Short Range Ensemble Forecast System (SREF)
  - 26 members @ 16-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

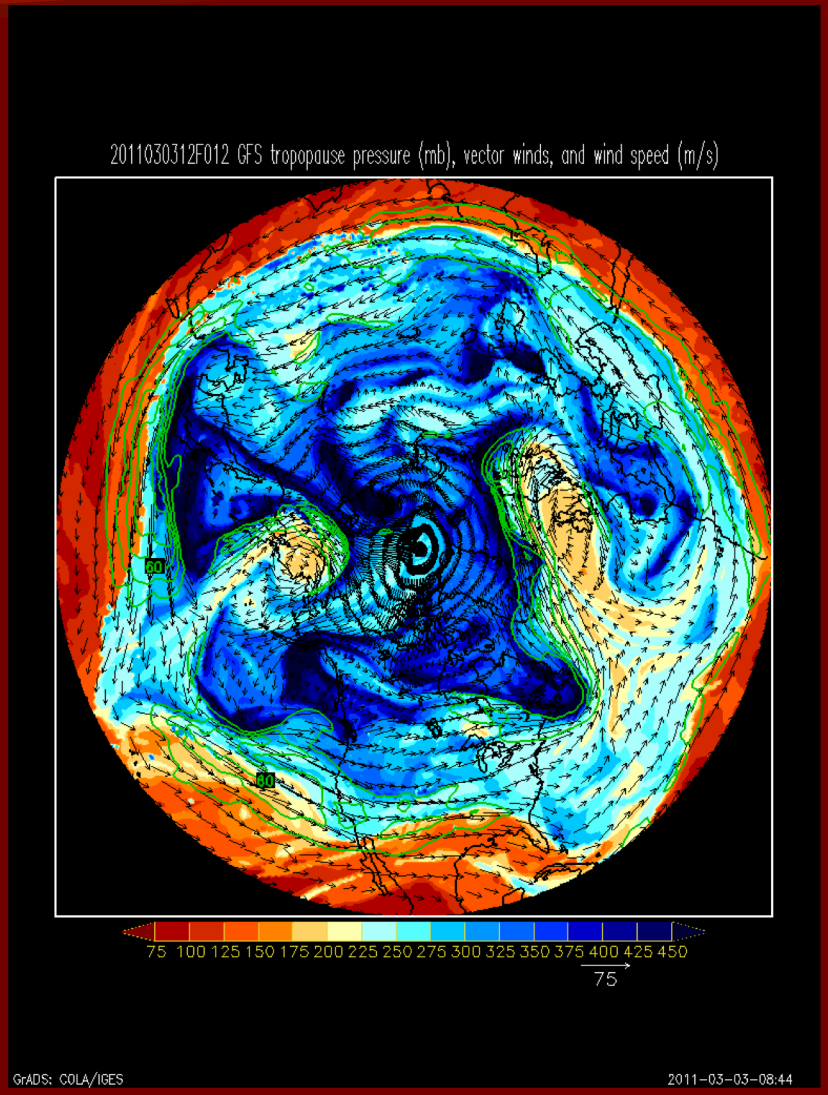
- Global Ensemble Forecast System (GEFS)
  - 20 members @ an effective grid spacing of 55 km based on different initial conditions
  - Forecasts out to 384 h every 12-h
  - Strengths
    - Probabalistic information, allows assessment of confidence in large-scale forecast
  - Weaknesses
    - Not calibrated, mean and spread of ensemble may be biased
    - Spread slow to develop
    - Low resolution

Useful Sites for Model Data

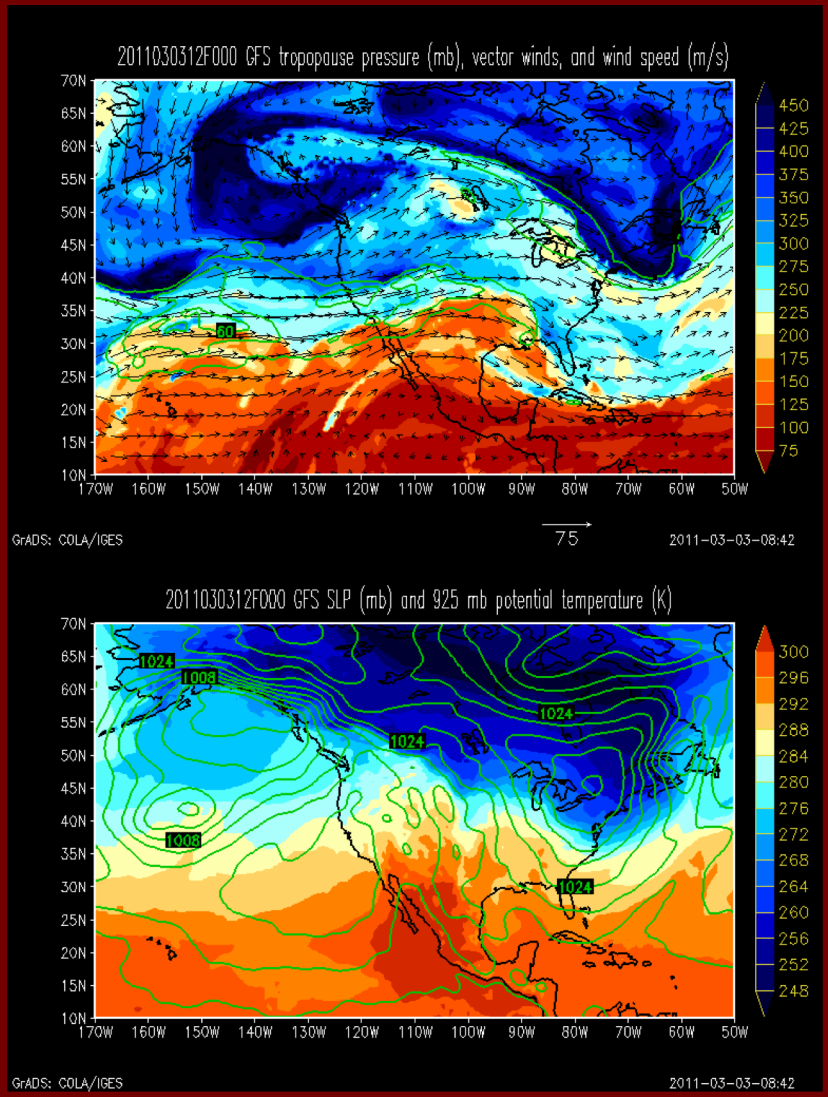
- http://weather.utah.edu
  - GFS/NAM/SREF/NAEFS
    - Downscaling applied in some instances
- http://weather.rap.ucar.edu
  - GFS/NAM/RAP
- http://www.spc.noaa.gov/exper
  - SREF
- http://www.wunderground.com/wundermap/
  - ECMWF

http://weather.utah.edu

Dynamic Tropopause (Jet Stream)



Dynamic Tropopause & Near SFC (Jet Stream)

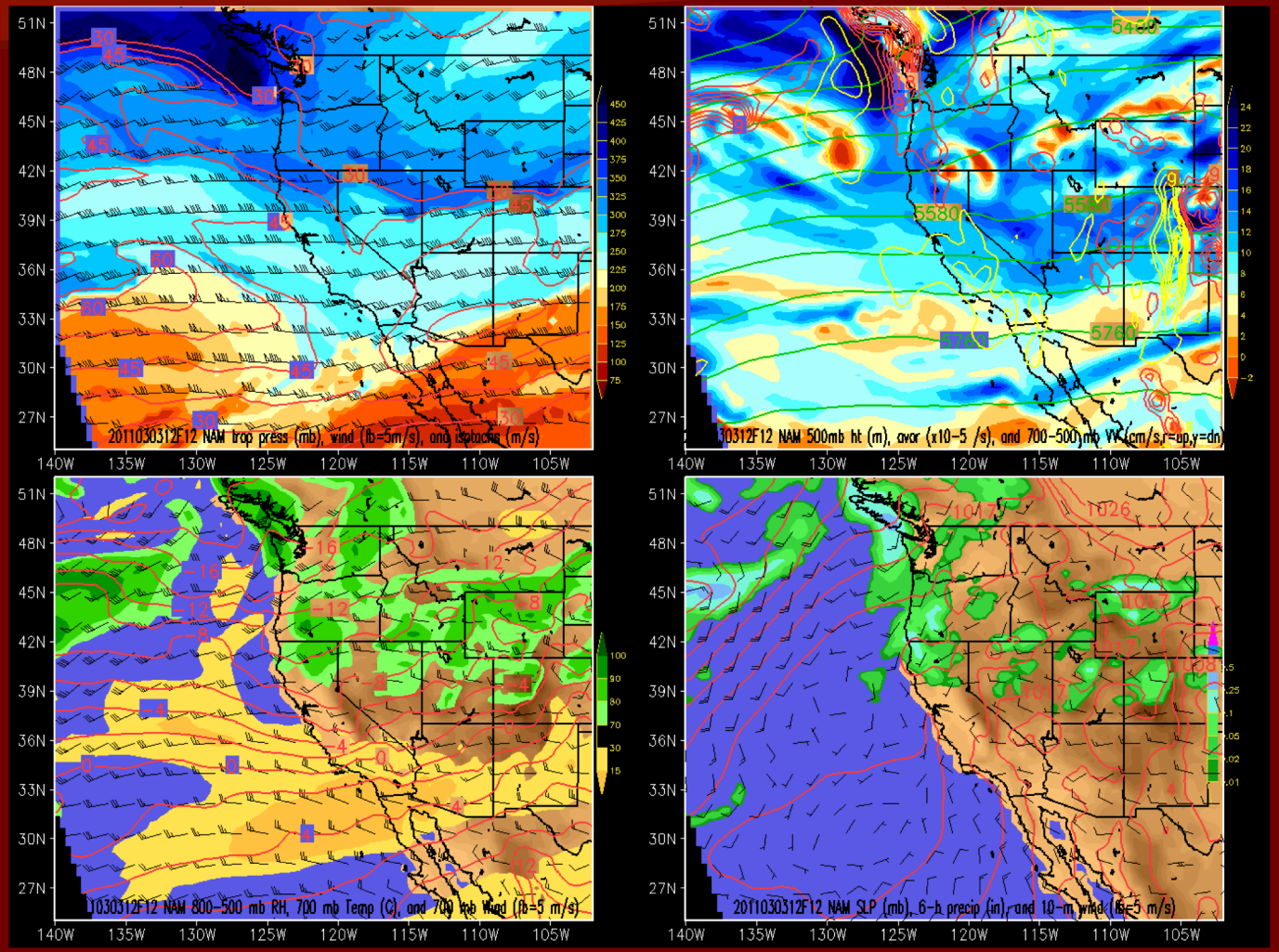


http://weather.utah.edu

"Synoptic Diagnostic"

Dynamic Tropopause (Jet Stream)

500 mb ~5500 m/18000 ft MSL



700 mb ~3000 m/10000 ft MSL

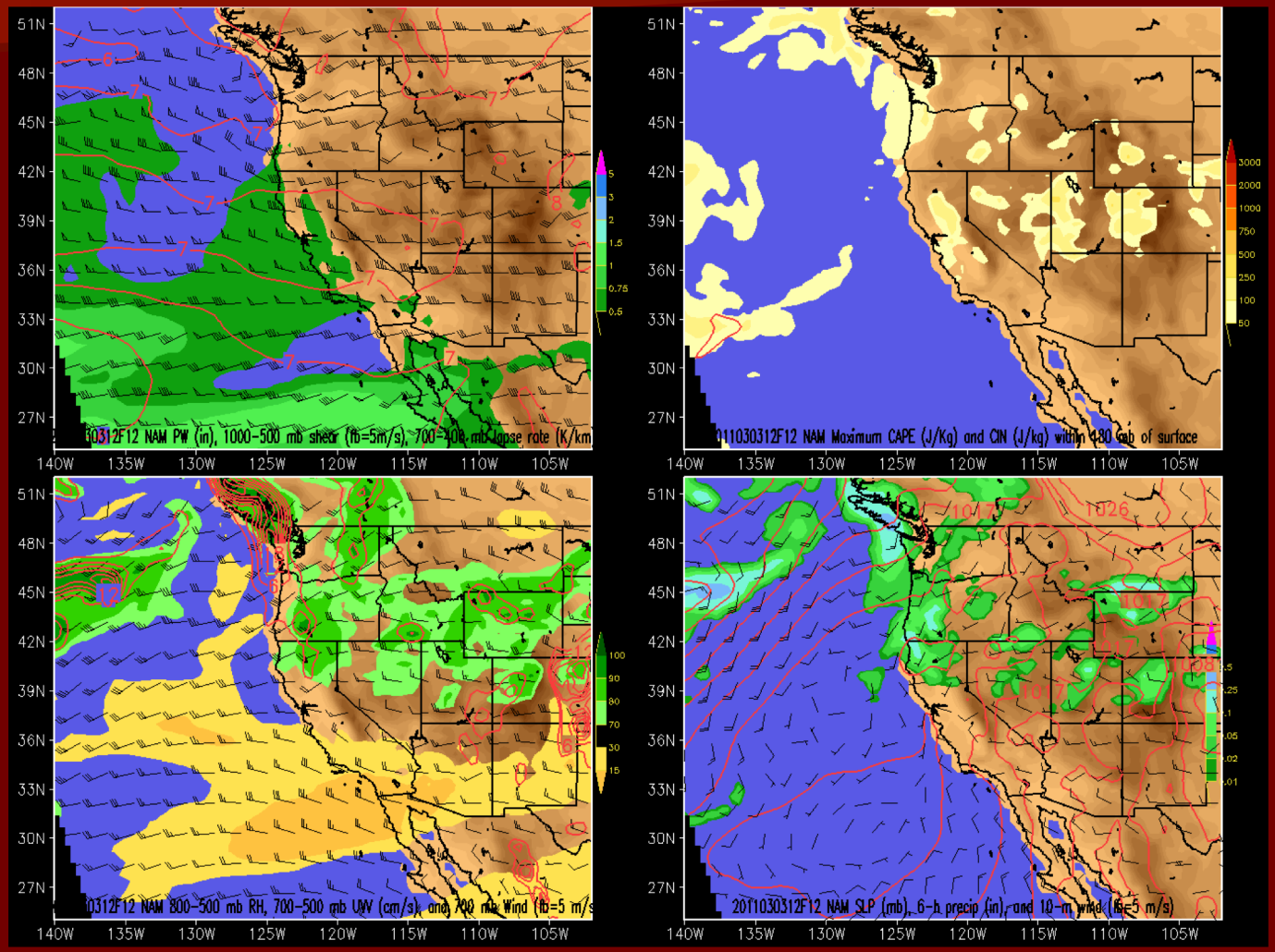
Surface

http://weather.utah.edu

"Convective Diagnostic"

PW, Shear, Lapse Rate

CAPE/CIN

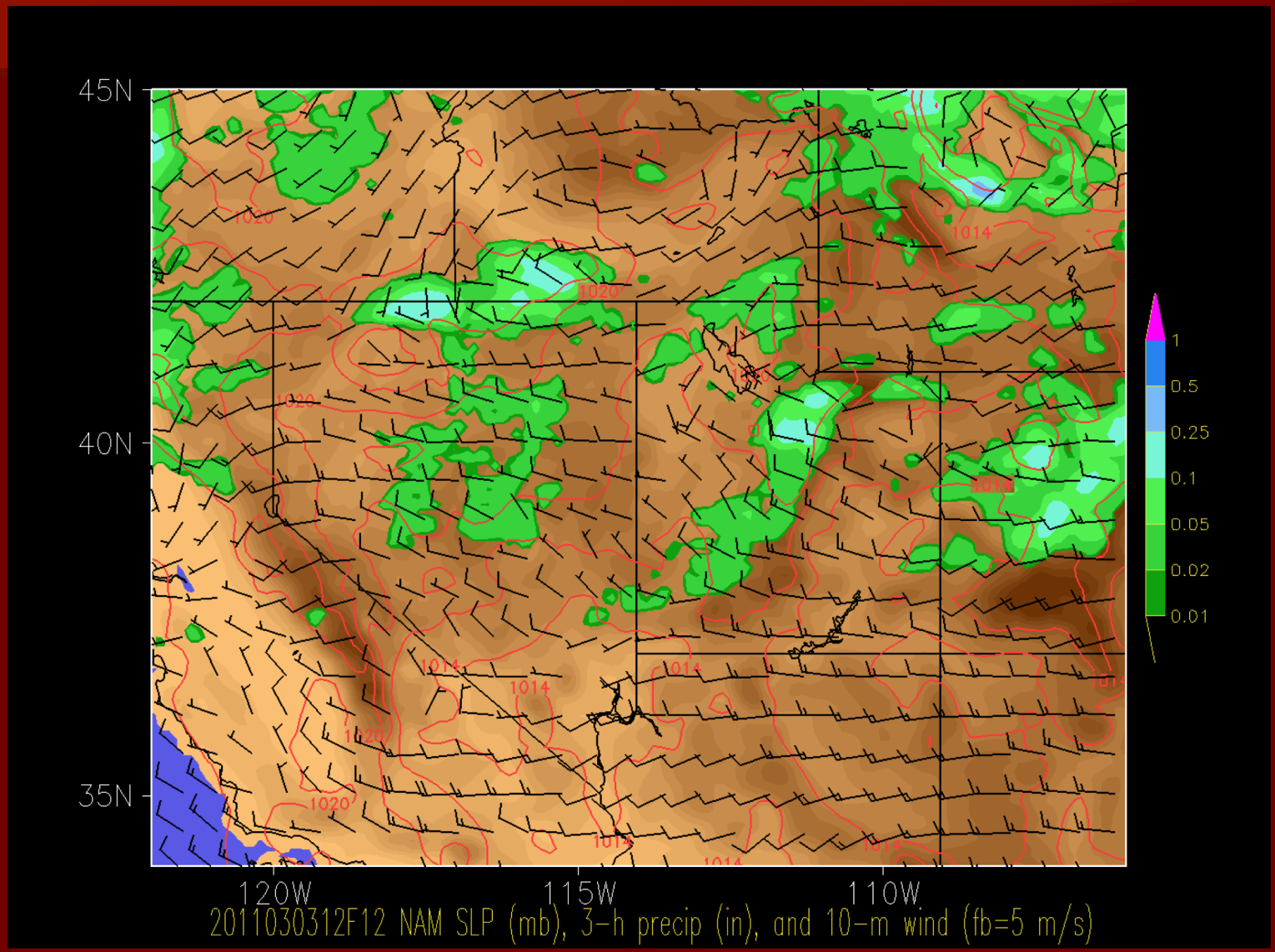


Lower-Mid Trop

Surface

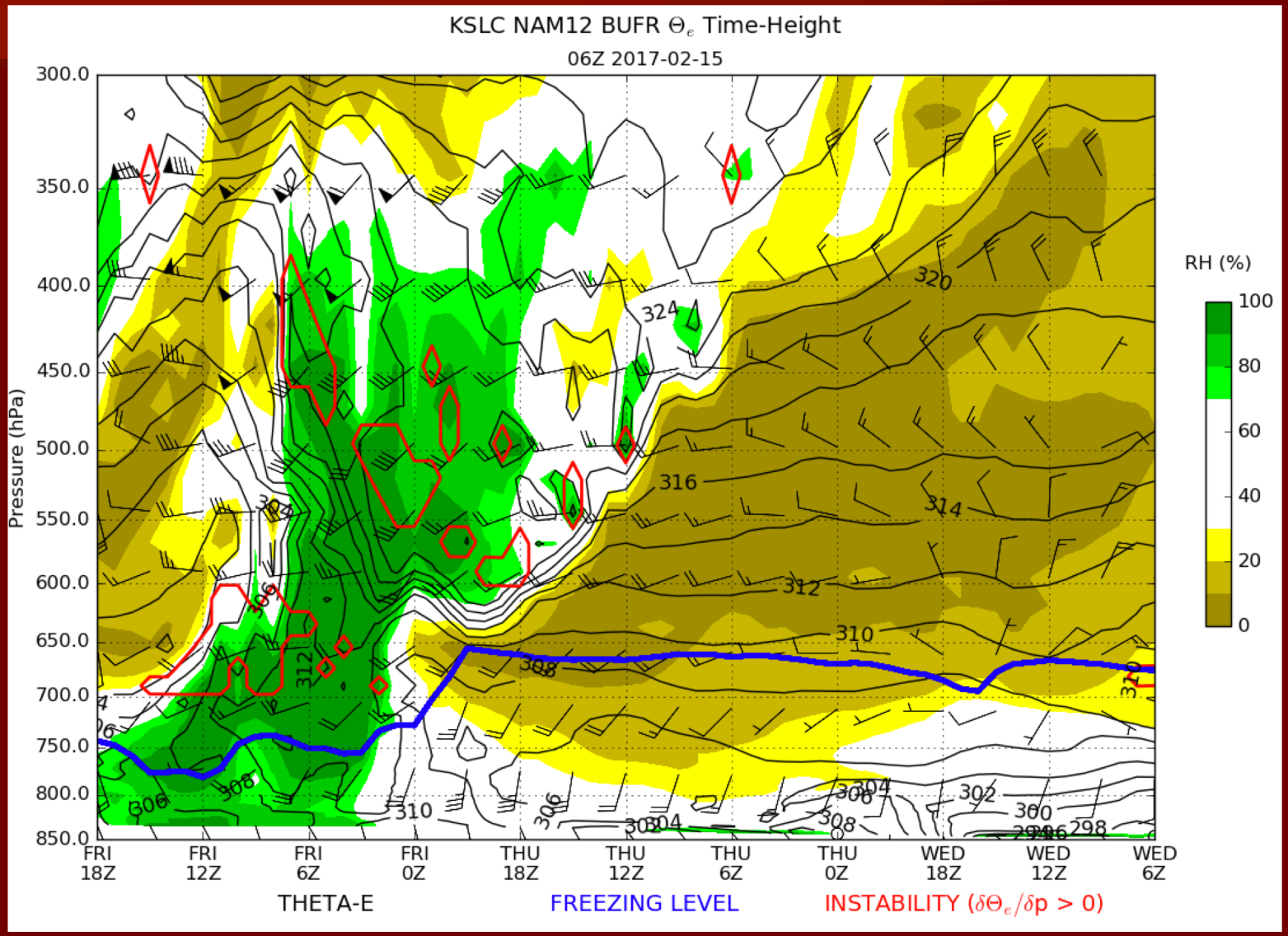
http://weather.utah.edu

Surface



http://weather.utah.edu

Theta-E Time Height



Model Output Statistics (MOS)

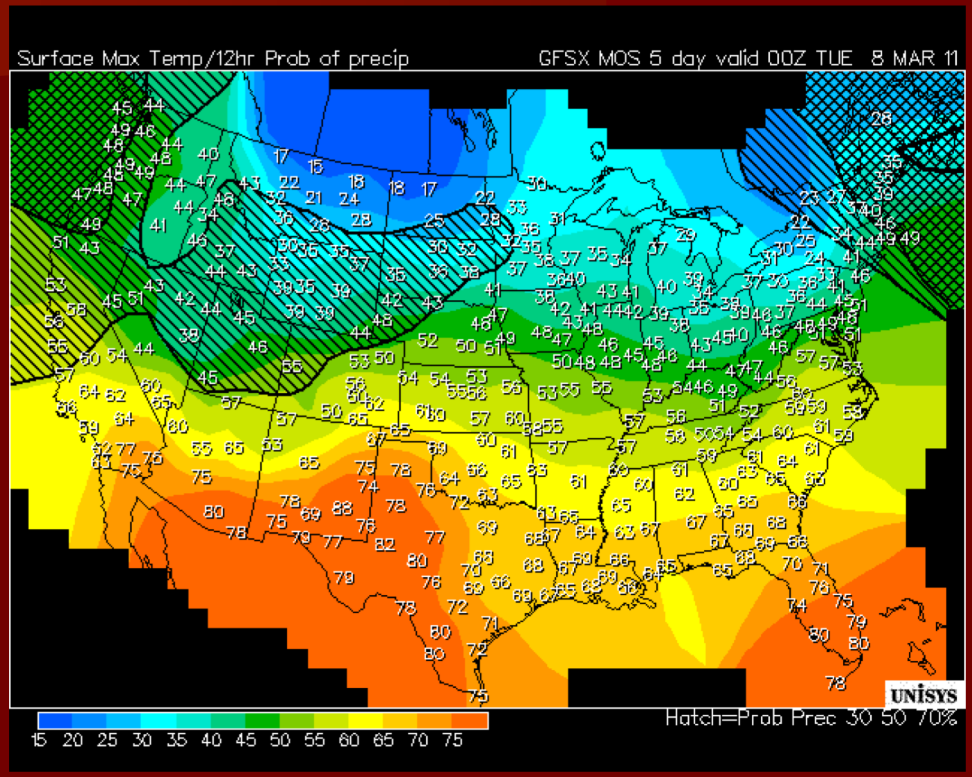
- Based on statistical relationships between model forecast variables and actual weather in the past
- Relationships then applied to latest model run
- Usually based on stepwise multiple linear regression
- Performs better than NWP or Statistics alone
  - Blends the best of both worlds
- Available for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

Model Output Statistics (MOS)

SALT LAKE CITY

KSLC GFS MOS GUIDANCE 3/03/2011 1200 UTC

DT	/MAR		3/MAR		4					/MAR		5						/MAR	
HR	18	21	00	03	06	09	12	15	18	21	00	03	06	09	12	15	18	21	00	06	12
N/X							32				47				28				51		35
TMP	43	45	45	39	37	36	35	35	42	47	47	38	34	32	32	34	44	50	50	40	39
DPT	35	33	31	32	31	30	29	28	25	22	20	22	21	20	20	22	23	22	23	27	27
CLD	SC	BK	BK	BK	BK	SC	BK	BK	SC	BK	BK	SC	SC	BK	BK	BK	OV	BK	OV	OV	OV
WDR	16	31	33	26	14	13	12	11	19	32	33	17	15	16	15	15	17	19	22	15	15
WSP	07	07	06	04	04	05	05	04	04	05	05	03	08	11	09	09	08	09	07	06	06
P06			40		21		7		2		1		0		2		2		6	5	7
P12							21				2				2				7		8
Q06			1		0		0		0		0		0		0		0		0	0	0
Q12							0				0				0				0		0
T06		26/	2	8/	0	0/	2	0/	0	0/	4	0/	0	0/	1	0/	2	0/	2	0/	0
T12				30/	4			0/	2			0/	4			0/	2		0/	4	
POZ	0	0	1	0	0	0	1	2	0	0	0	0	2	0	1	1	1	0	1	0	1
POS	5	11	22	83	94	98	96	86	77	51	45	83	95	90	95	86	43	17	28	54	56
TYP	R	R	R	S	S	S	S	S	S	S	R	S	S	S	S	S	R	R	R	S	S
SNW							0								0						0
CIG	8	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7
VIS	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
OBV	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N



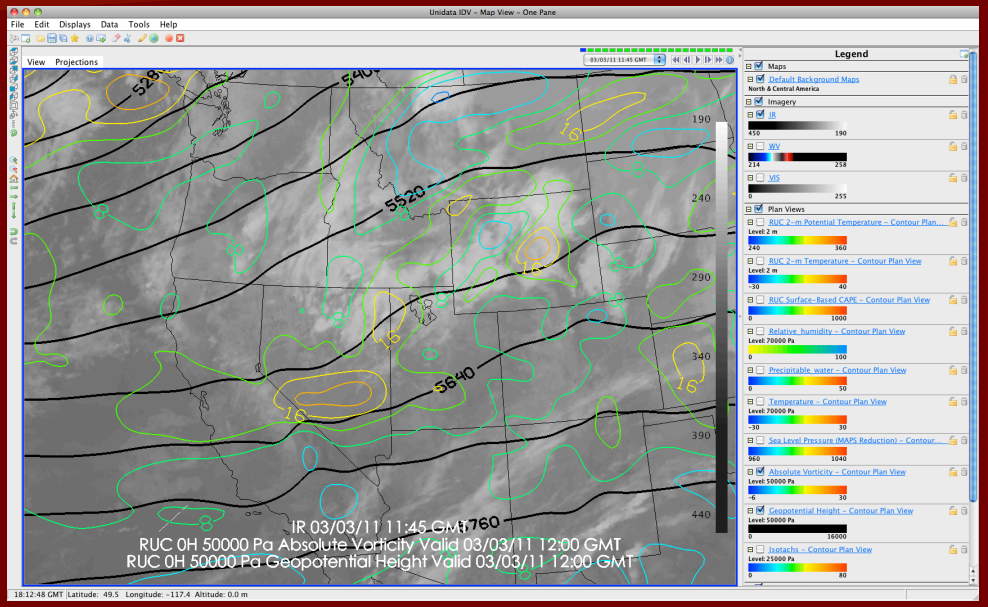
Sources: NOAA/MDL, weather.unisys.com

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 rigormortis of skill

Forecast Tools: Scientific Visualization

AWIPS/AWIPS-II



IDV

Advantage: Integration of Diverse Atmospheric/Earth Data

Sources: Wikipedia Commons, Unidata

Concluding Thoughts

- Learn to sip from the firehouse
- Find what sites/products you like, bookmark them, and develop a system
- Use IDV or similar software to integrate products when possible
- Time management is a critical aspect of forecasting