Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

Weather Hazard Modeling Research and development: Recent Advances and Plans

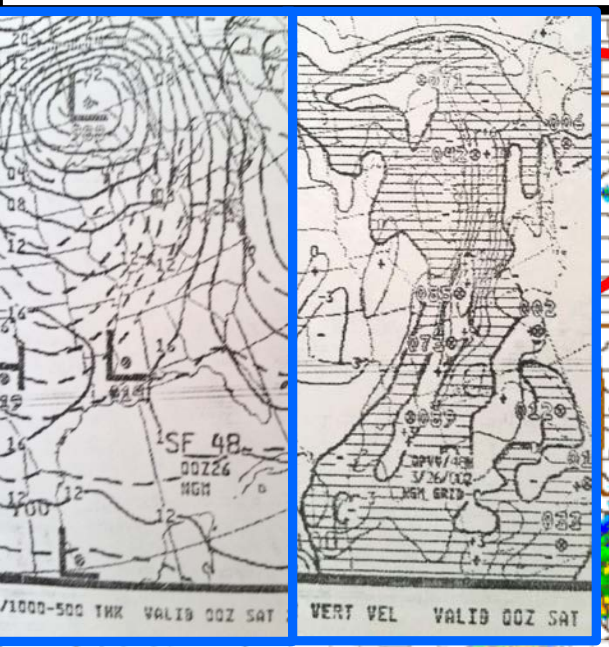
Stephen S. Weygandt

Curtis Alexander, Stan Benjamin,
Geoff Manikin, Tanya Smirnova, Ming Hu*
NOAA Earth System Research Laboratory
**NOAA National Centers for Environmental Prediction*

Friends and Partners of Aviation Weather
NBAA Convention, Nov 2-3, 2016

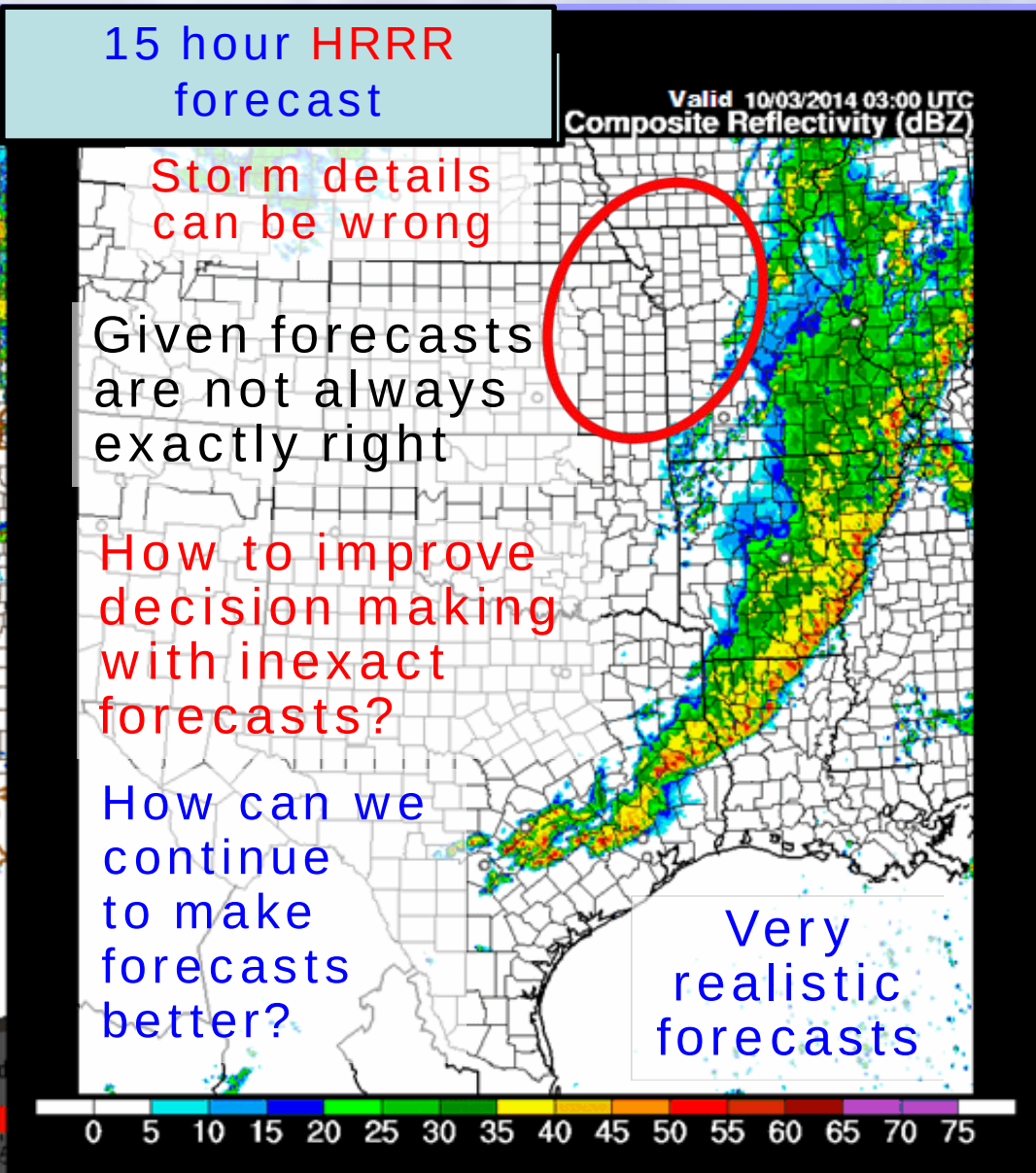
High-resolution models of hazardous weather now making very realistic forecasts

Loop of radar reflectivity Observations



NGM model guidance ...around 1990

15 hour HRRR forecast



Storm details can be wrong

Given forecasts are not always exactly right

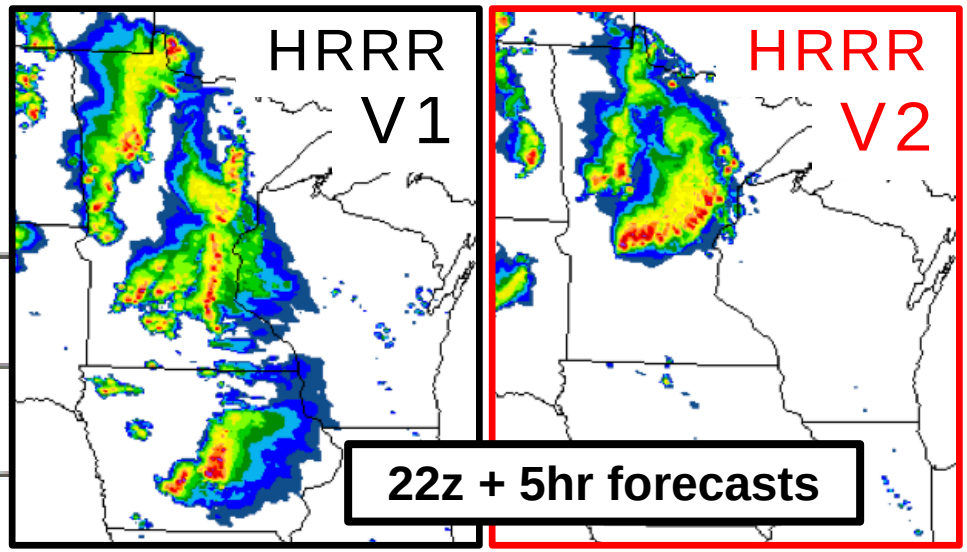
How to improve decision making with inexact forecasts?

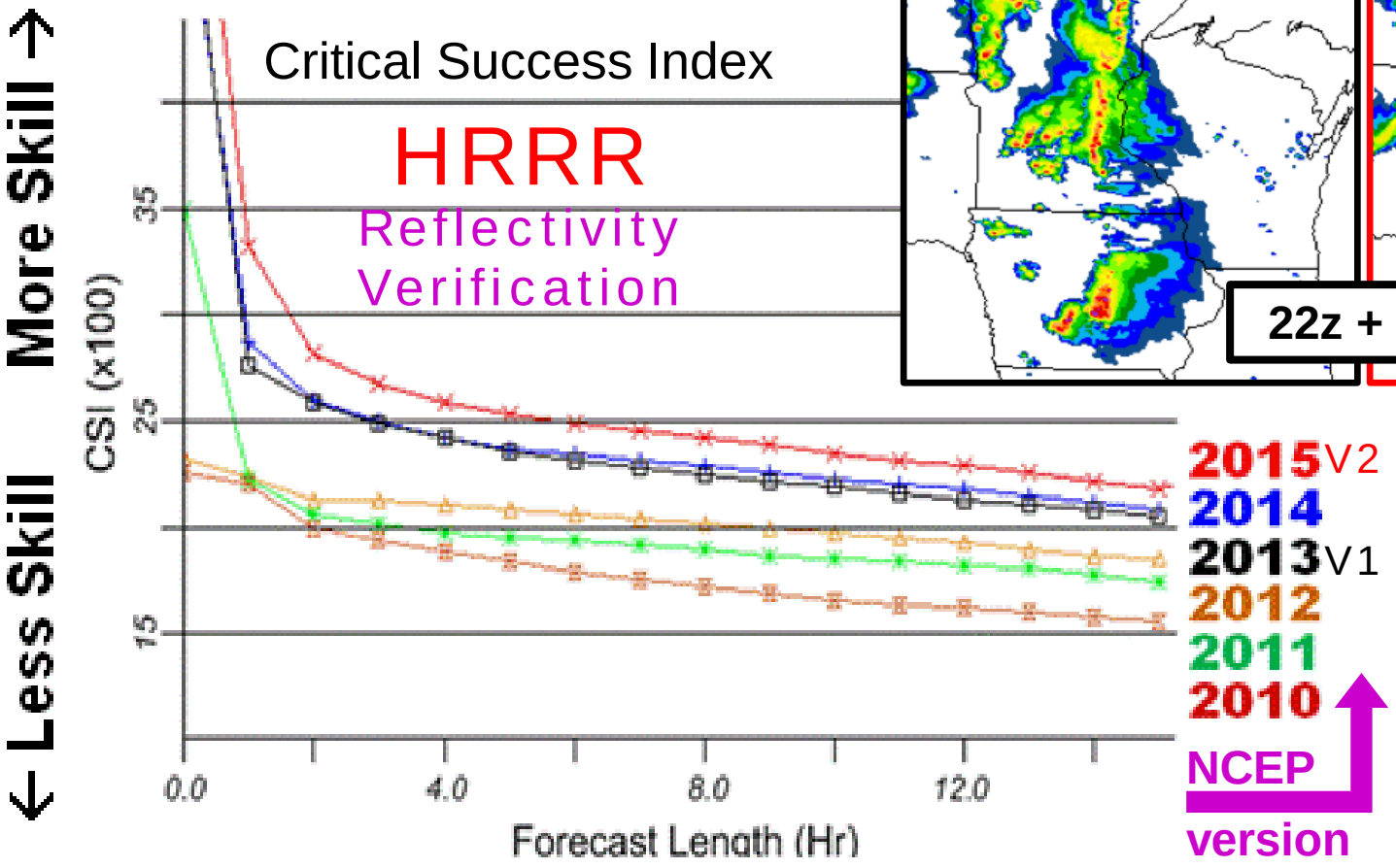
How can we continue to make forecasts better?

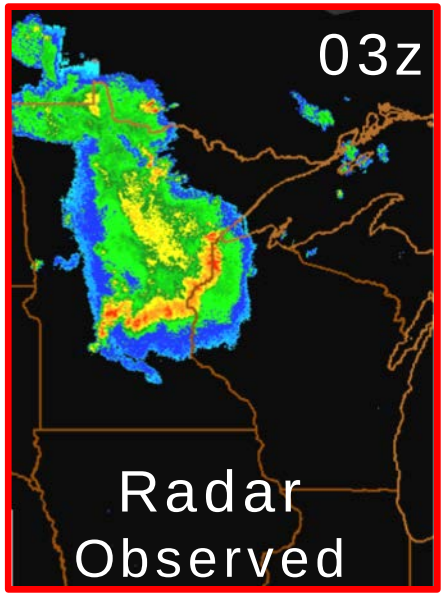
Very realistic forecasts

Continued forecast improvement for Rapidly updated, High-resolution models

Improvement each year…







HRRR precipitation location skill improves by 50% over past 5 years

Continued forecast improvement for Rapidly updated, High-resolution models

Newer Version

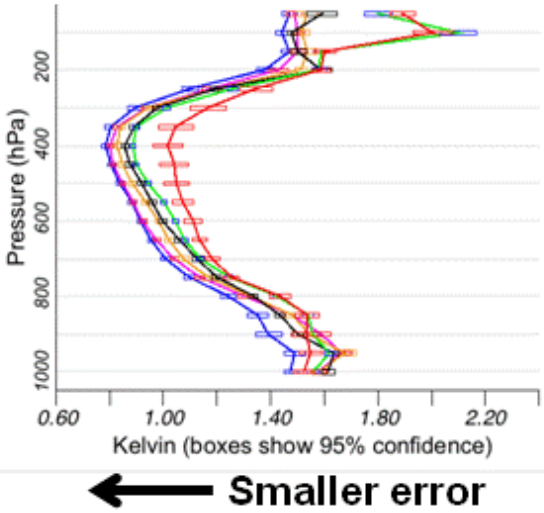
- 2010
- 2011 (v1)
- 2012
- 2013 (v2)
- 2014
- 2015 (v3)

Experimental RAP RMSE 6-hr Forecasts

RAP - upper-air verification

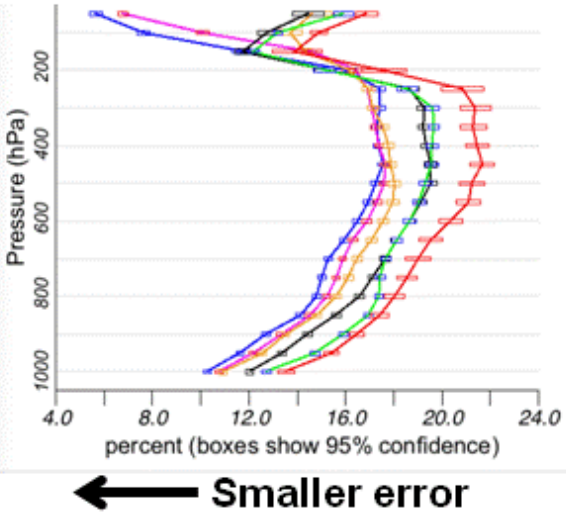
~25% RMSE Reduction in 5 years

Temperature



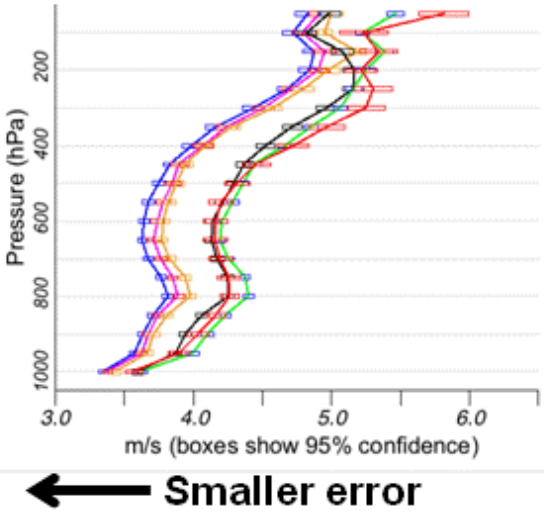
← Smaller error

Humidity



← Smaller error

Wind



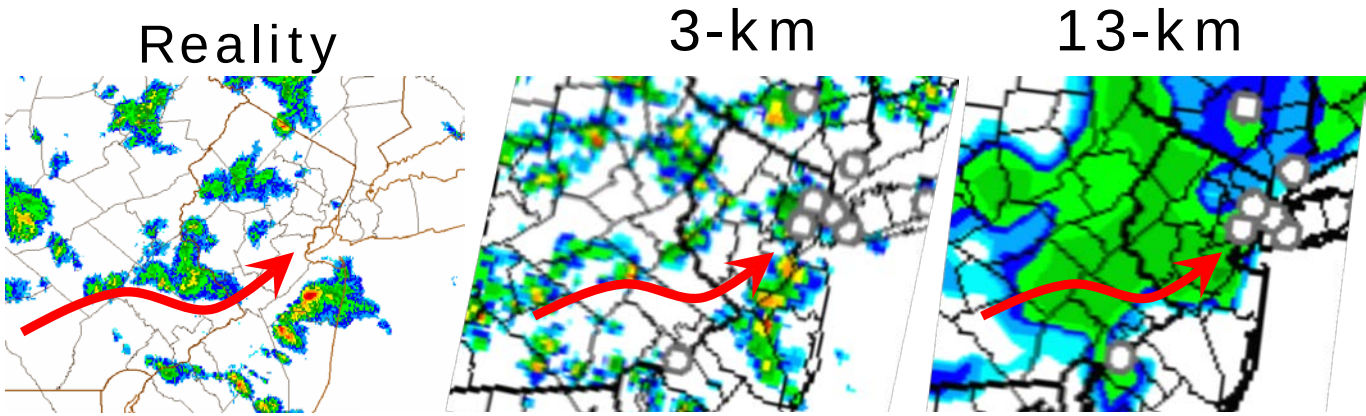
← Smaller error

Improvement to moisture / microphysics / precipitation, boundary layer / surface energy balance, ensemble assimilation

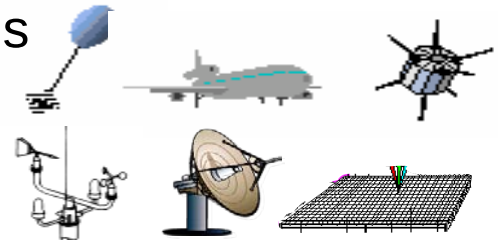
➔ ***Ongoing study to evaluate how forecast improvements map to aviation decision-making improvements (GSD, AvMet)***

Accurate prediction of hazardous weather
What are the key requirements?

Higher resolution models with better physics



Best use of observations (Ensemble data assimilation)

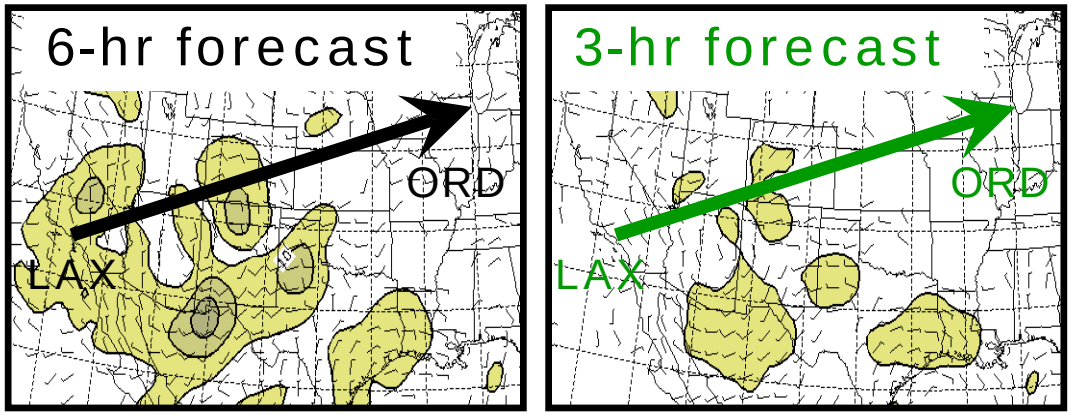


Rawins *Satellite*
Aircraft *Radar*
Surface *Profiler*

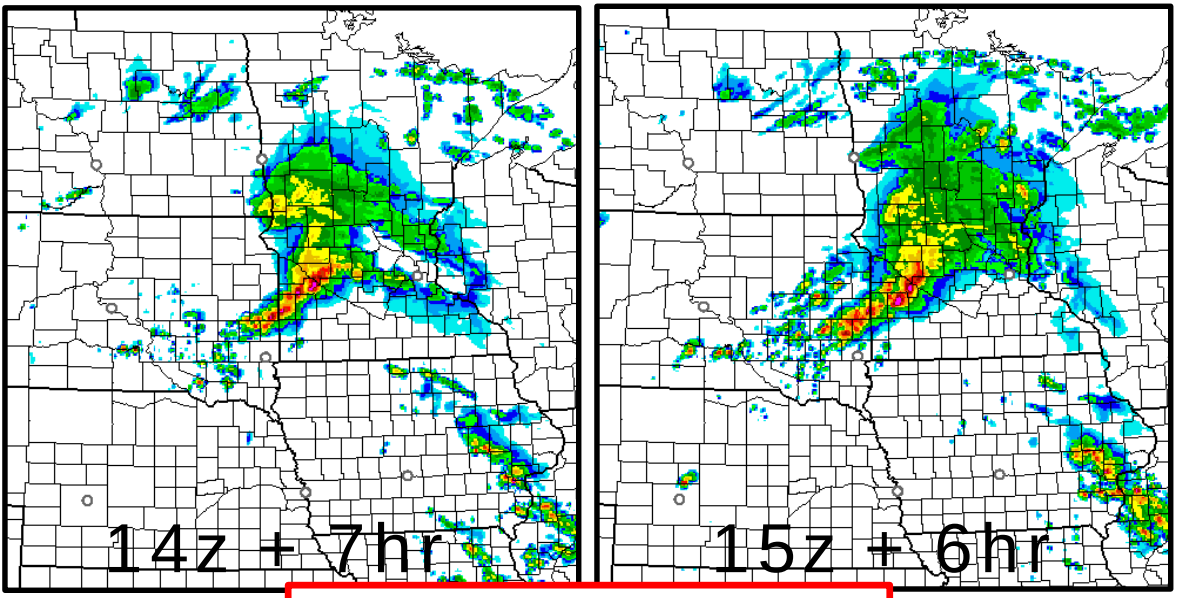
Rapid updating

-- **Fresher forecasts**
-- **Time-lagged ensembles**

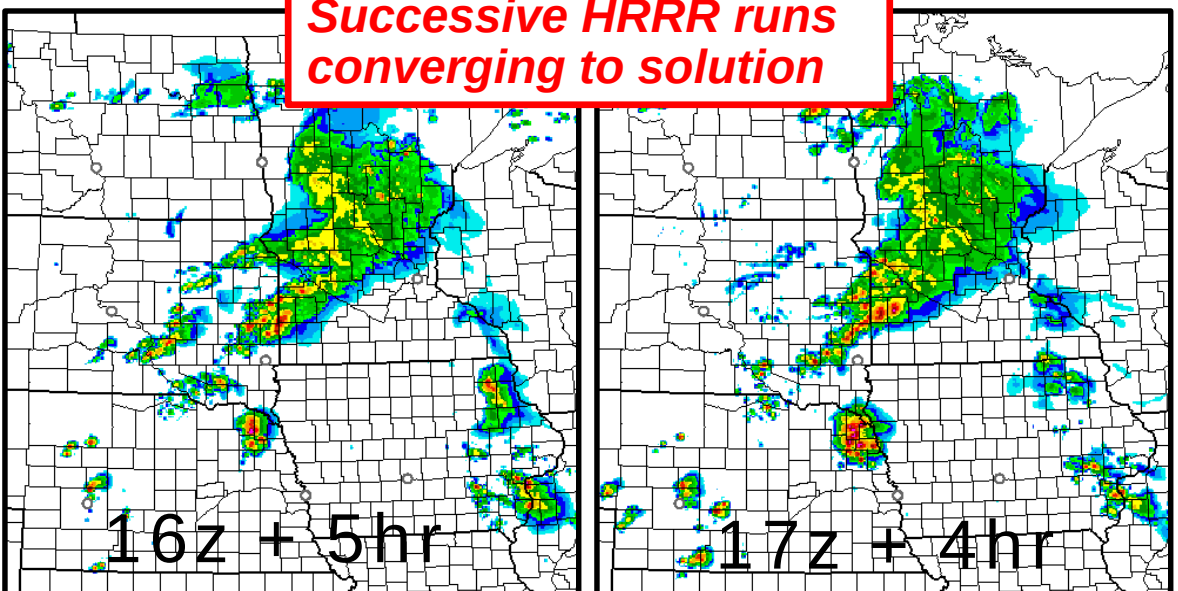
Wind Errors

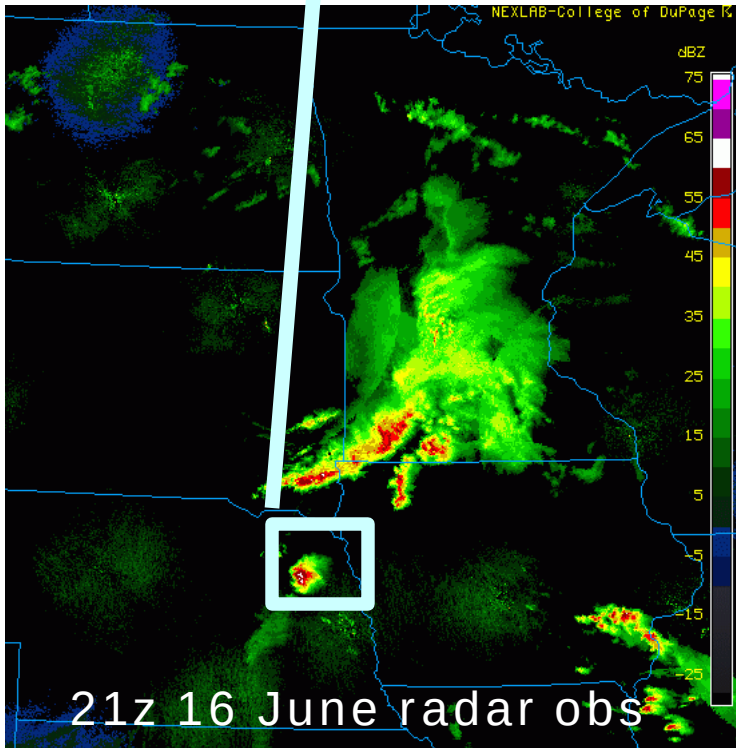


The benefits of rapid updating: June 16, 2014 NE twin tornadoes

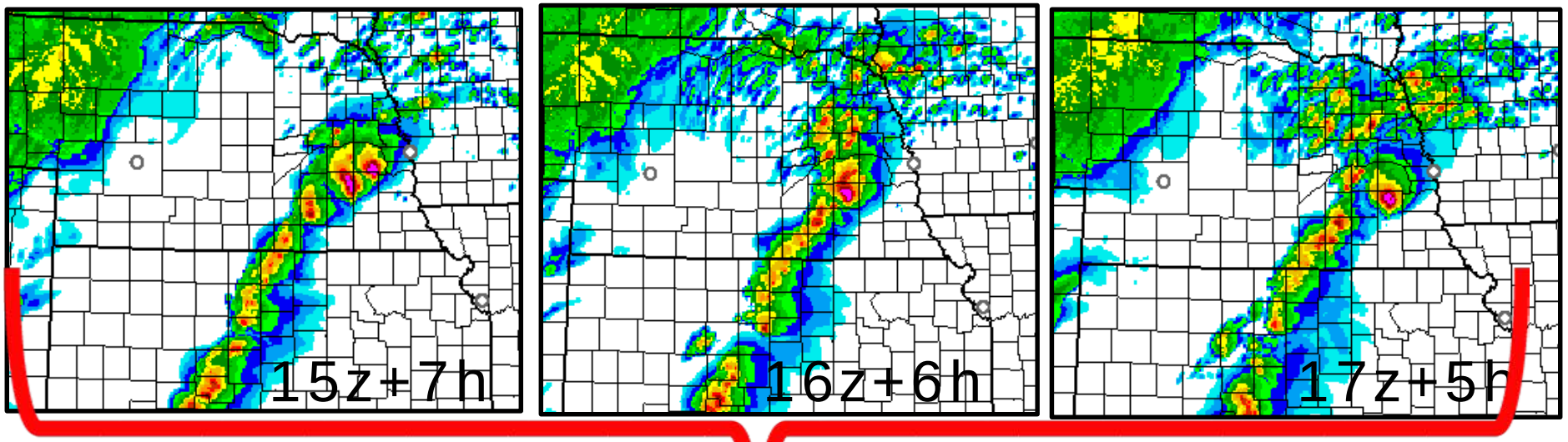


Successive HRRR runs converging to solution

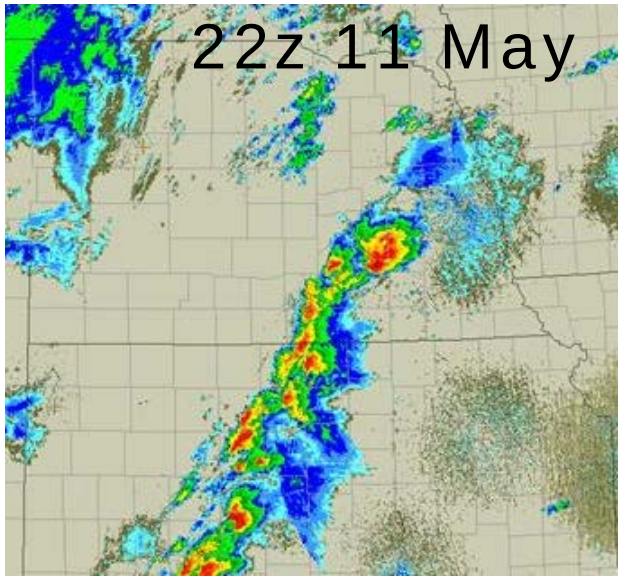


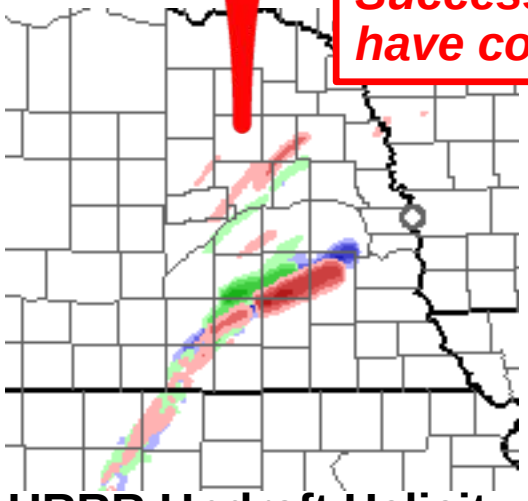


HRRR example of consistent solutions: May 11, 2014 NE squall-line

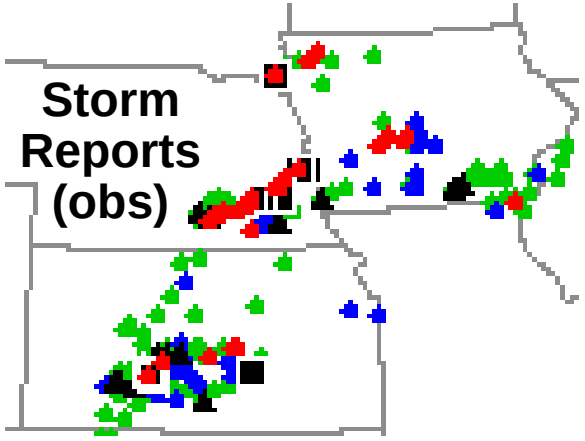


Successive HRRR runs have consistent solution



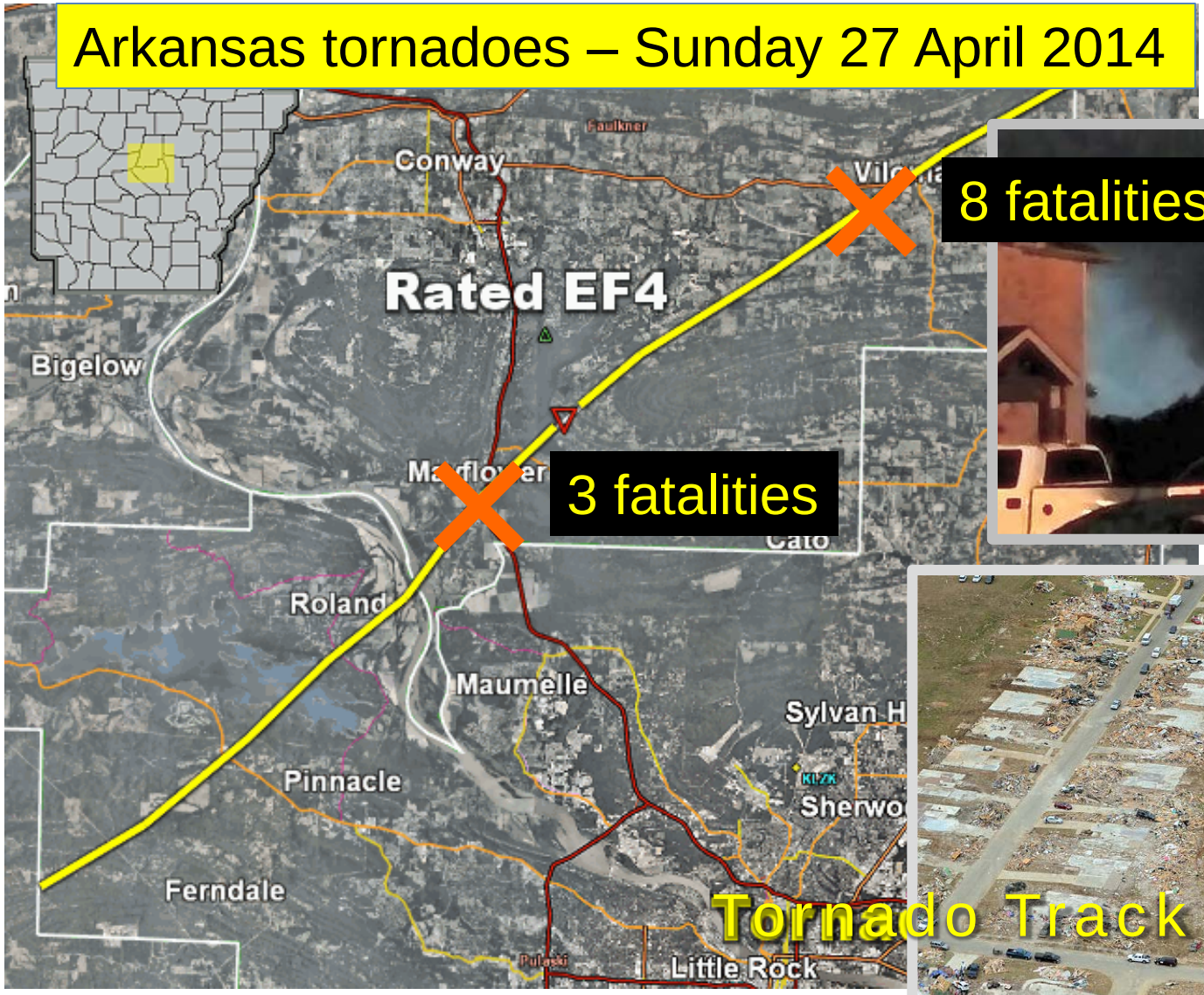


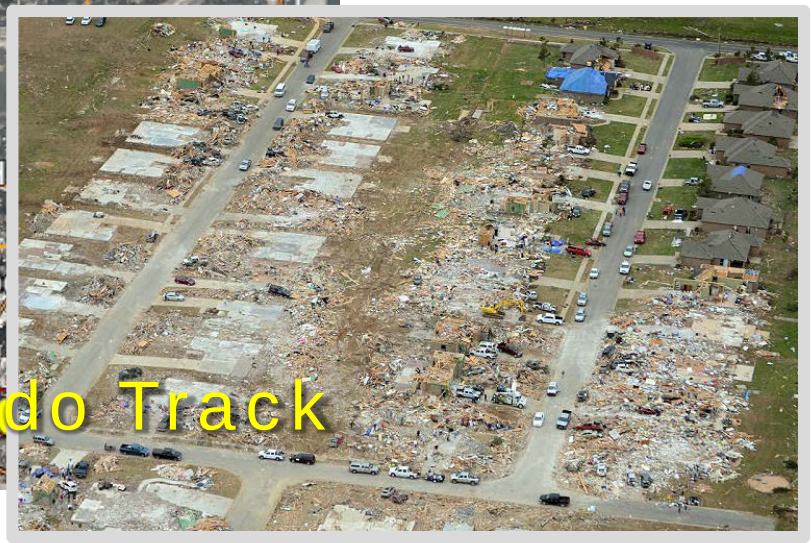
HRRR Updraft Helicity Time-Lagged Ensemble



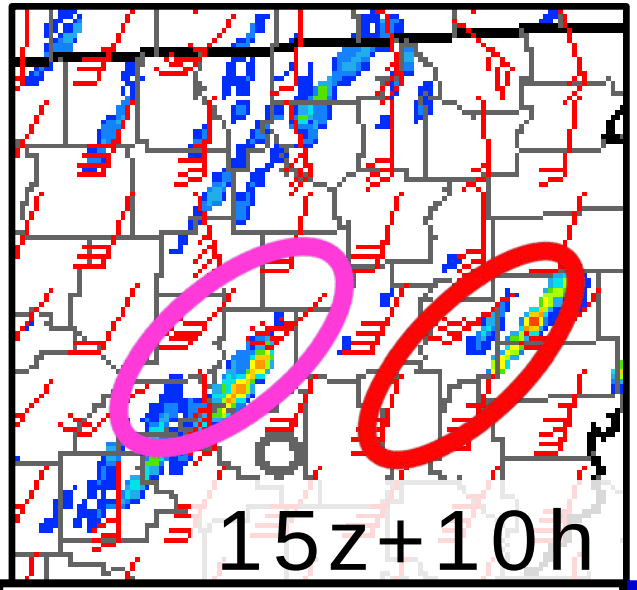
Arkansas Tornadoes April 27 2014

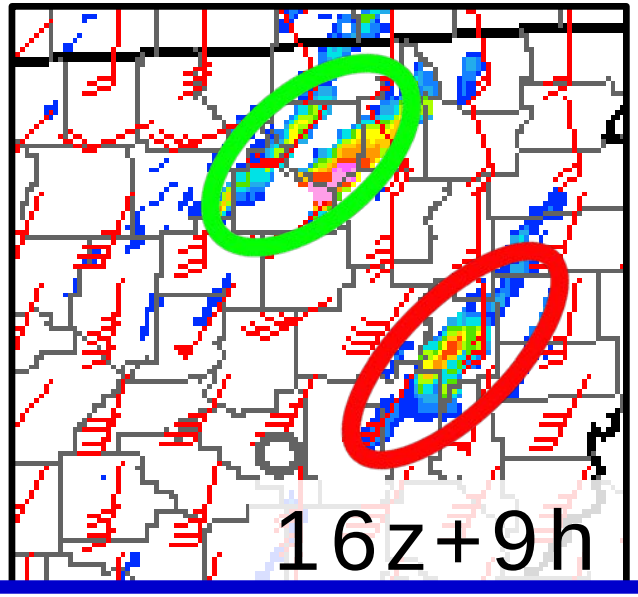
Arkansas tornadoes – Sunday 27 April 2014

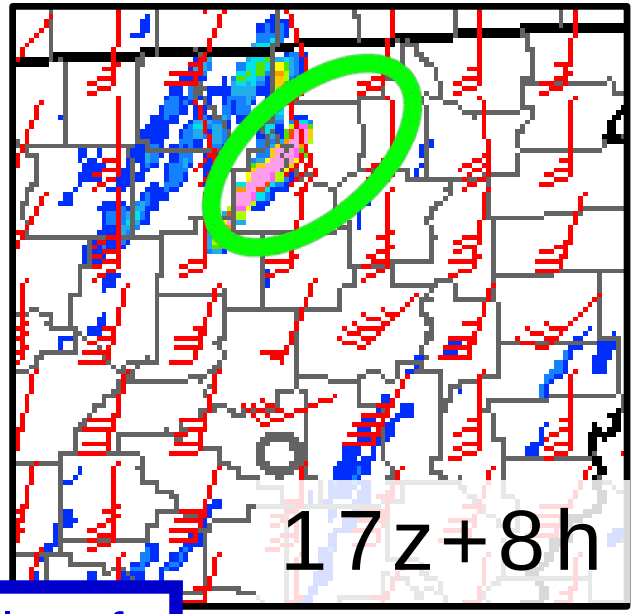




Arkansas tornadoes: very challenging case

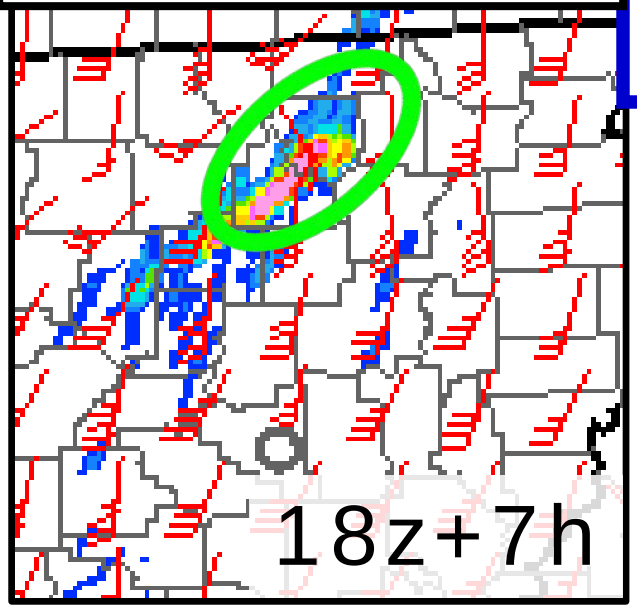


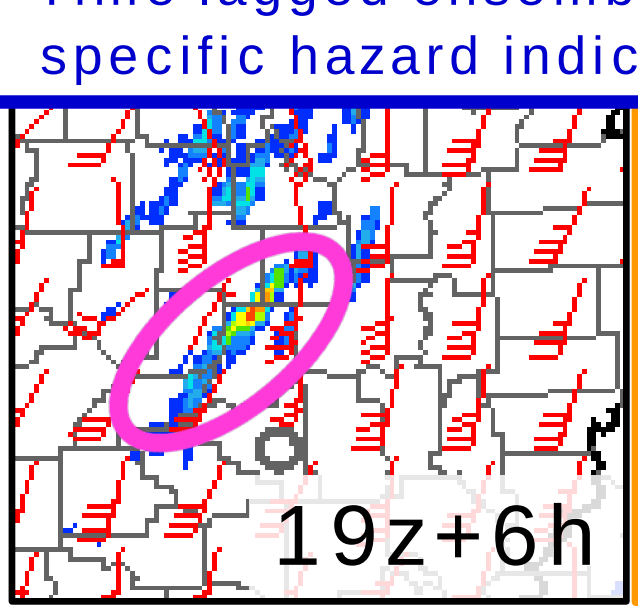


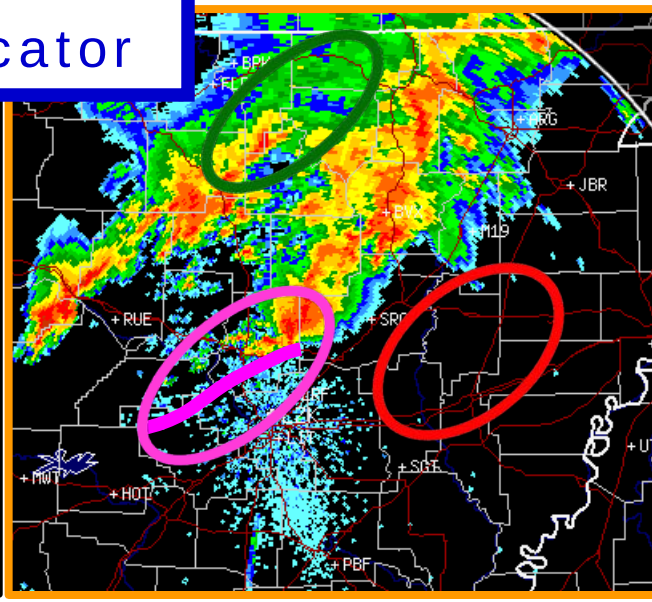


HRRR Updraft Helicity

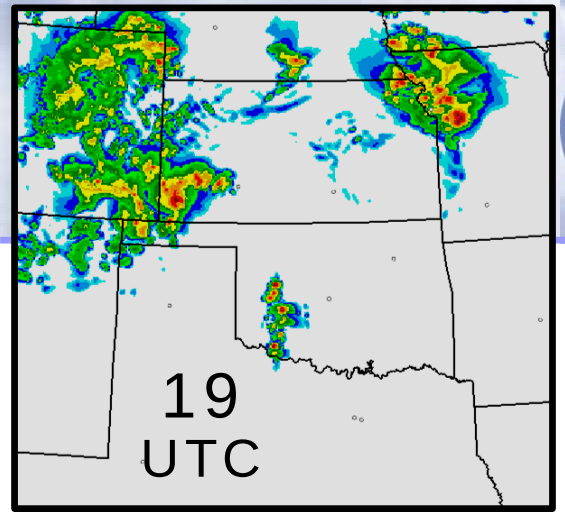
Time-lagged ensemble of specific hazard indicator







Model ensembles:
Key to assessing likelihood



Deterministic

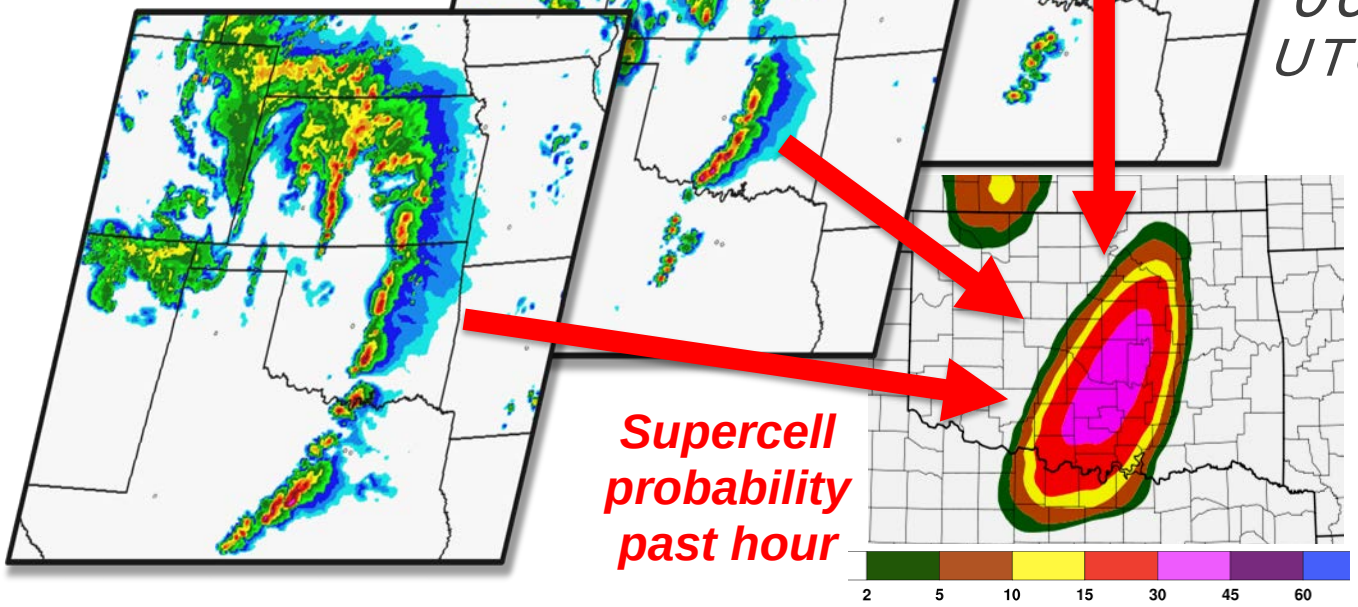
Member 1

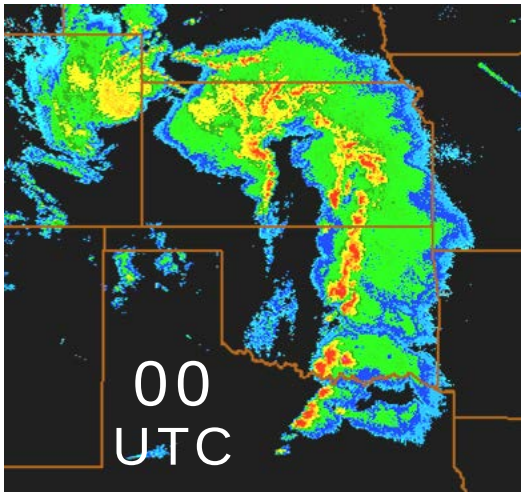
Member 2

Member 3

00
UTC

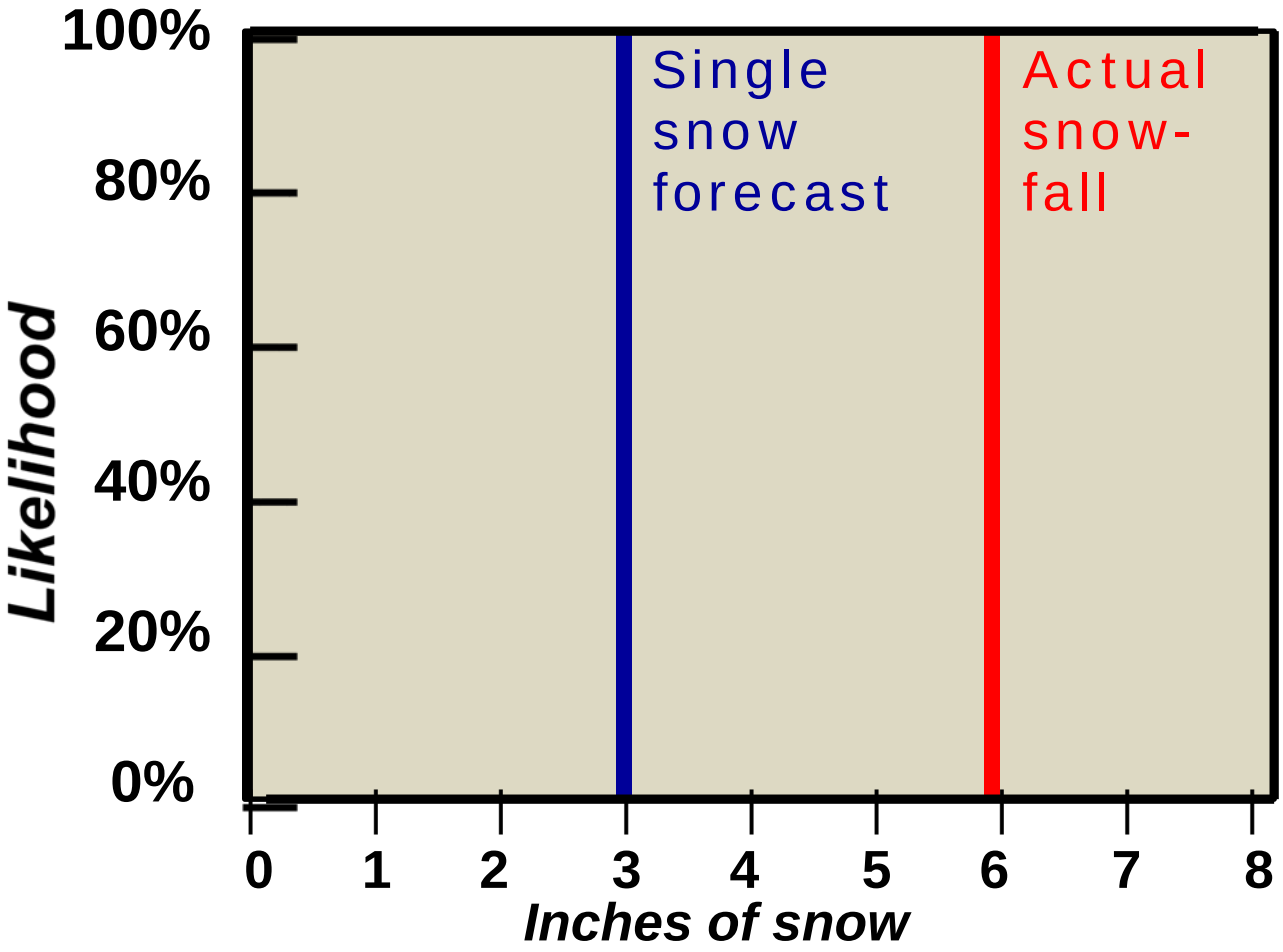
Observations





How do ensembles forecasts help?

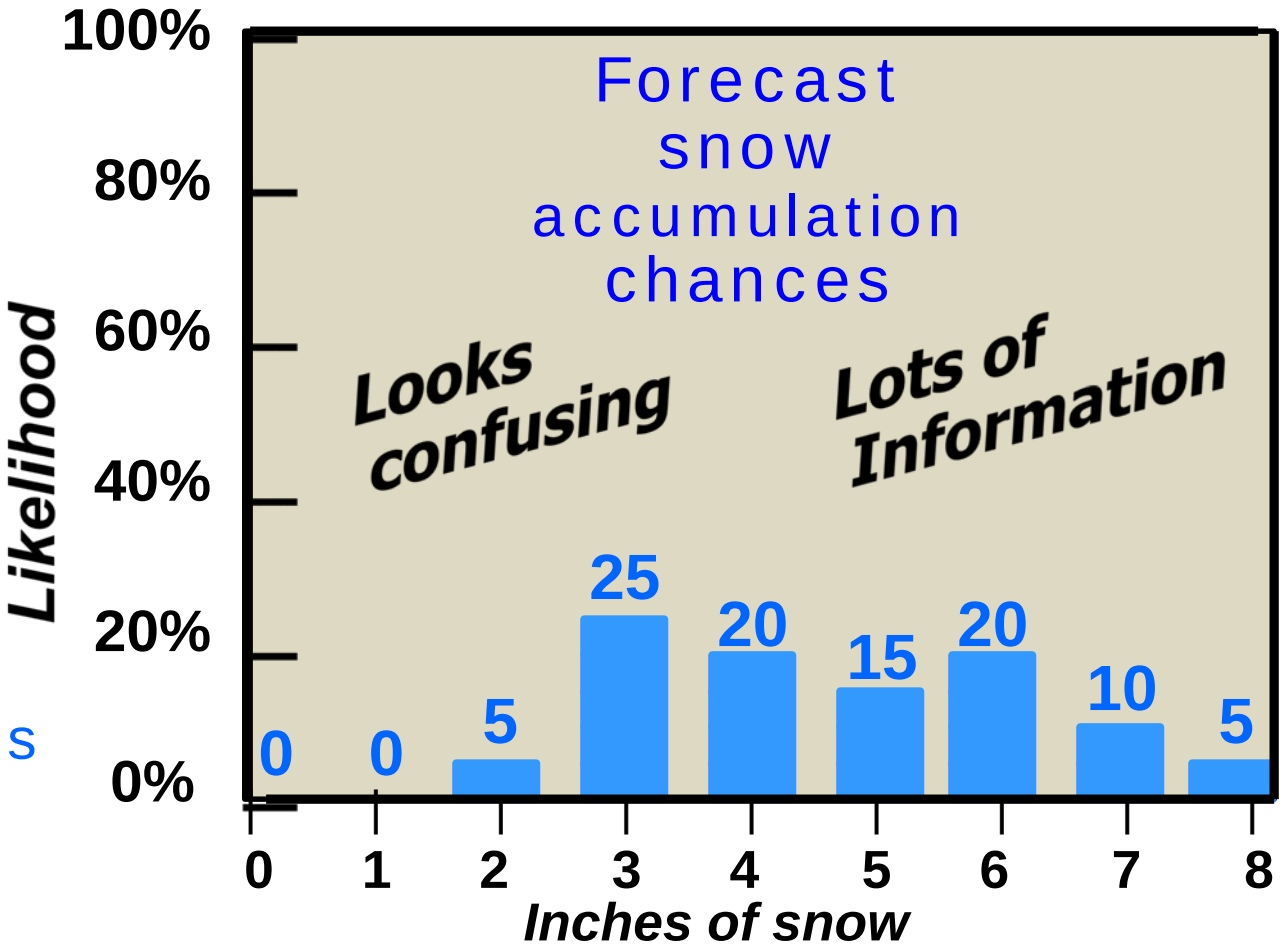
Old way – one "deterministic" forecast



How do ensembles forecasts help?

Old way – one "deterministic" forecast

New way – run an "ensemble" of forecasts – get information about range of possible outcomes

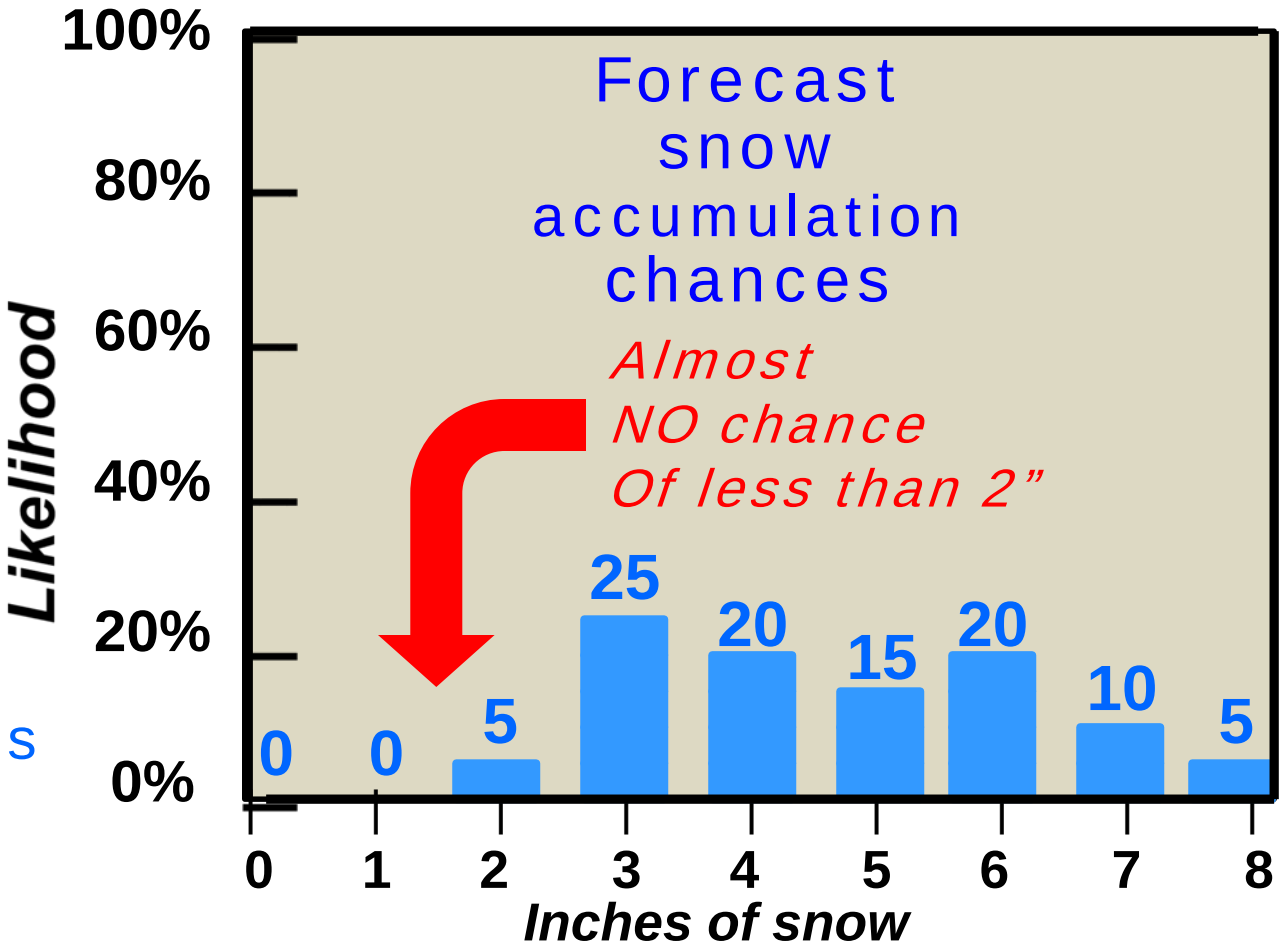


Example: Run model 100 times with slightly different "settings"

How do ensembles forecasts help?

Old way – one "deterministic" forecast

New way – run an "ensemble" of forecasts – get information about range of possible outcomes

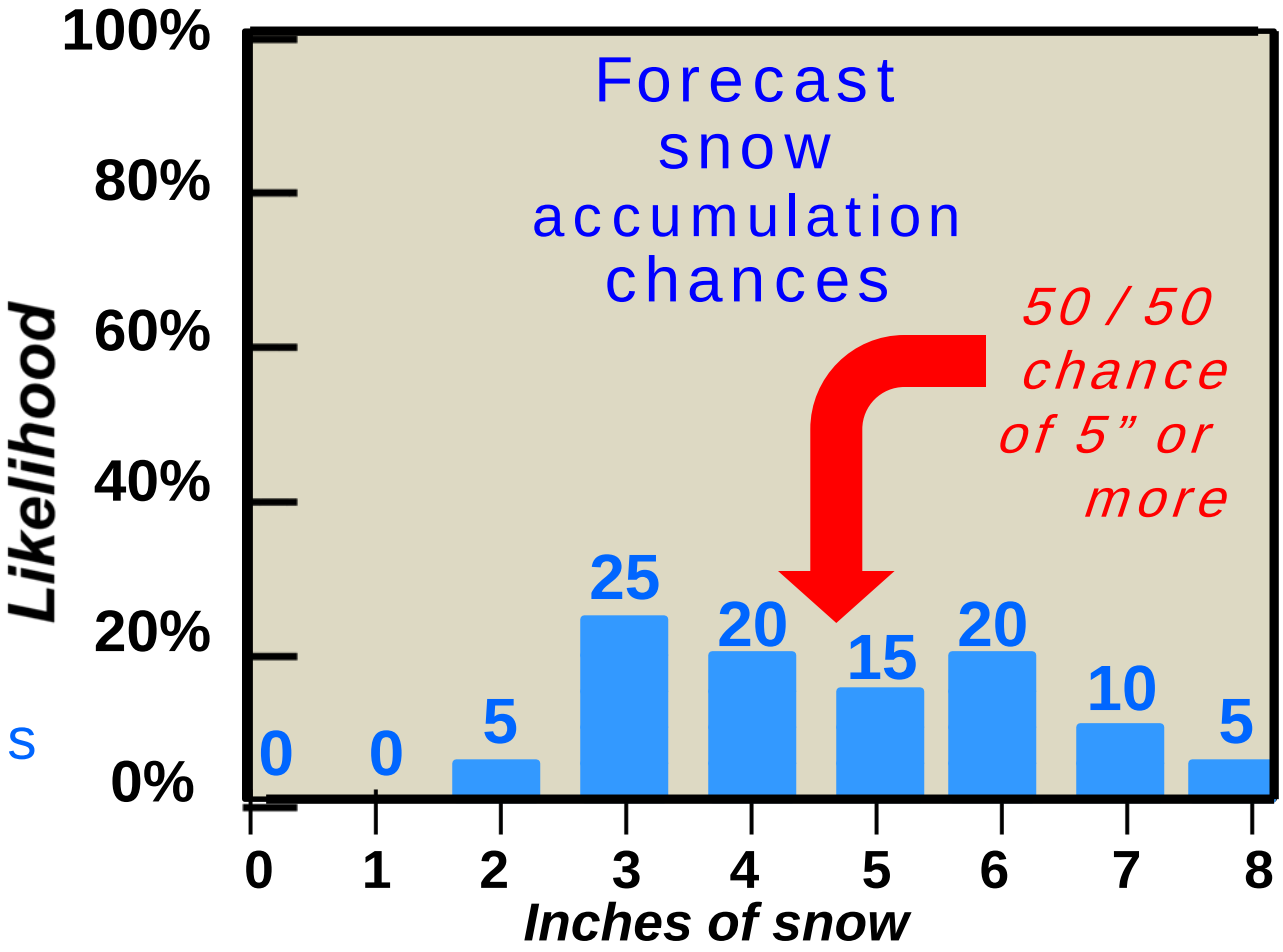


Example: Run model 100 times with slightly different "settings"

How do ensembles forecasts help?

Old way – one "deterministic" forecast

New way – run an "ensemble" of forecasts – get information about range of possible outcomes

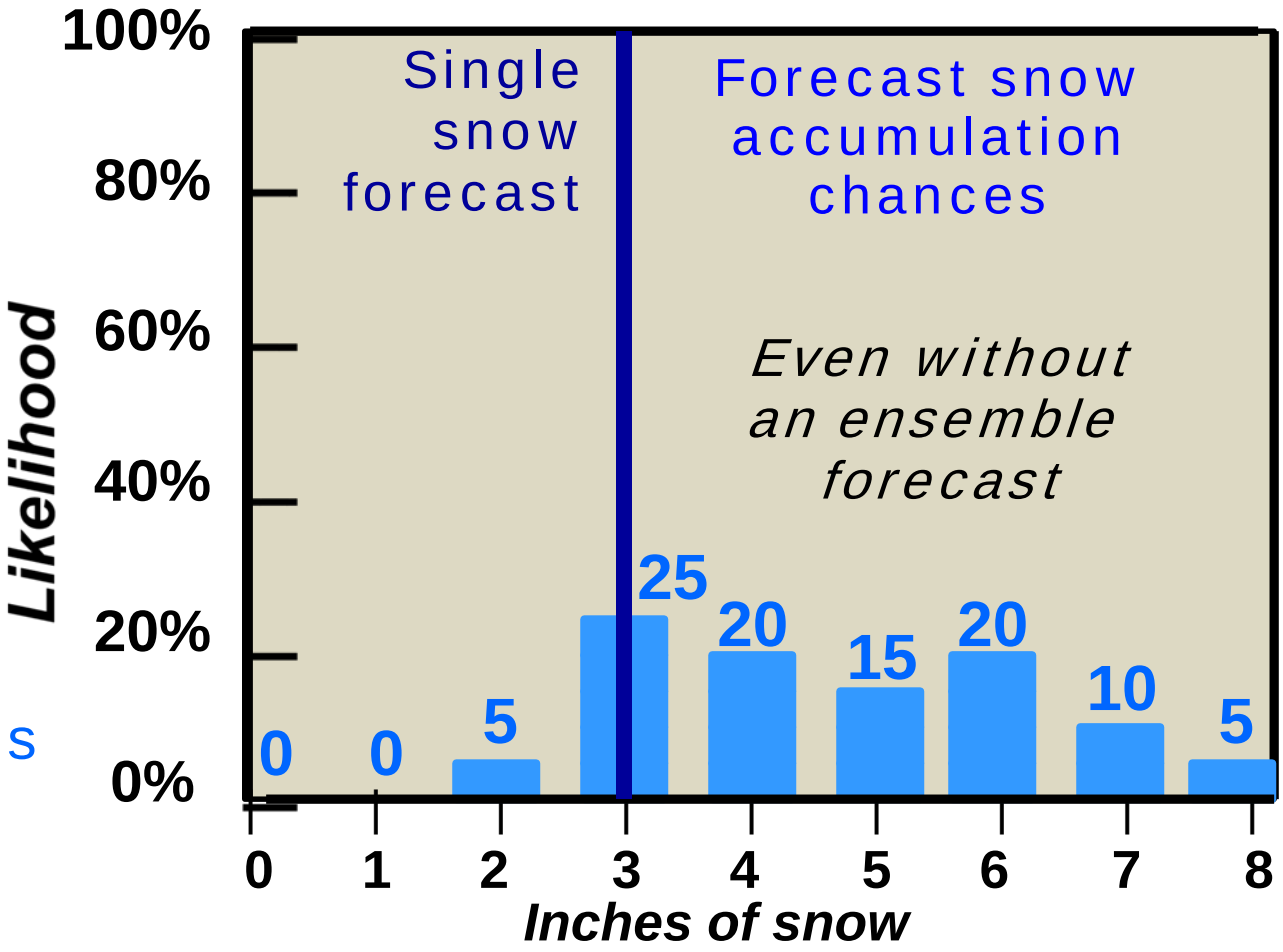


Example: Run model 100 times with slightly different "settings"

How do ensembles forecasts help?

Old way – one "deterministic" forecast

New way – run an "ensemble" of forecasts – get information about range of possible outcomes

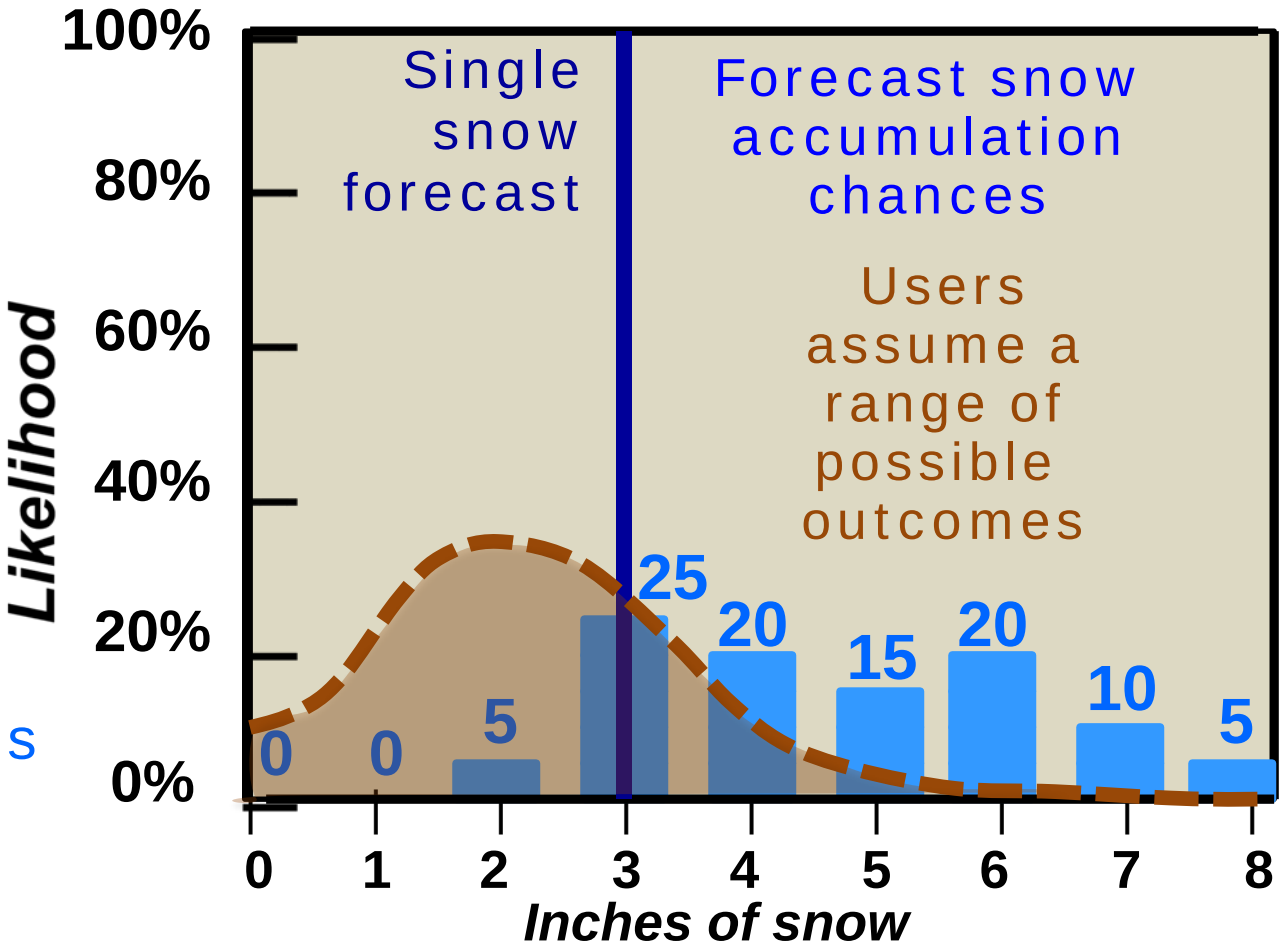


you still get the deterministic forecast

How do ensembles forecasts help?

Old way – one "deterministic" forecast

New way – run an "ensemble" of forecasts – get information about range of possible outcomes



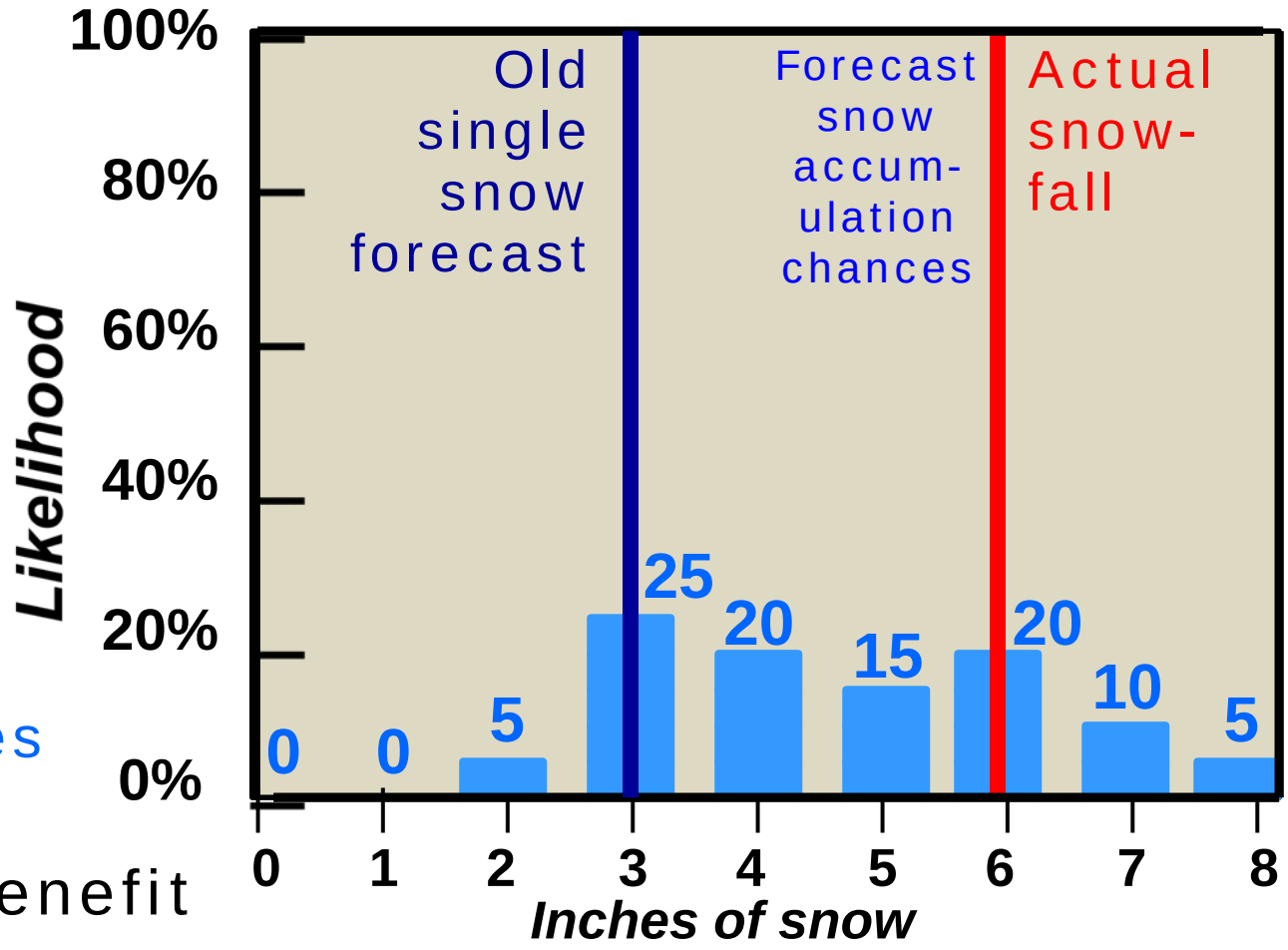
Forecast users will make their own assumptions about the range of possible outcomes

How do ensembles forecasts help?

Old way – one "deterministic" forecast

New way – run an "ensemble" of forecasts – get information about range of possible outcomes

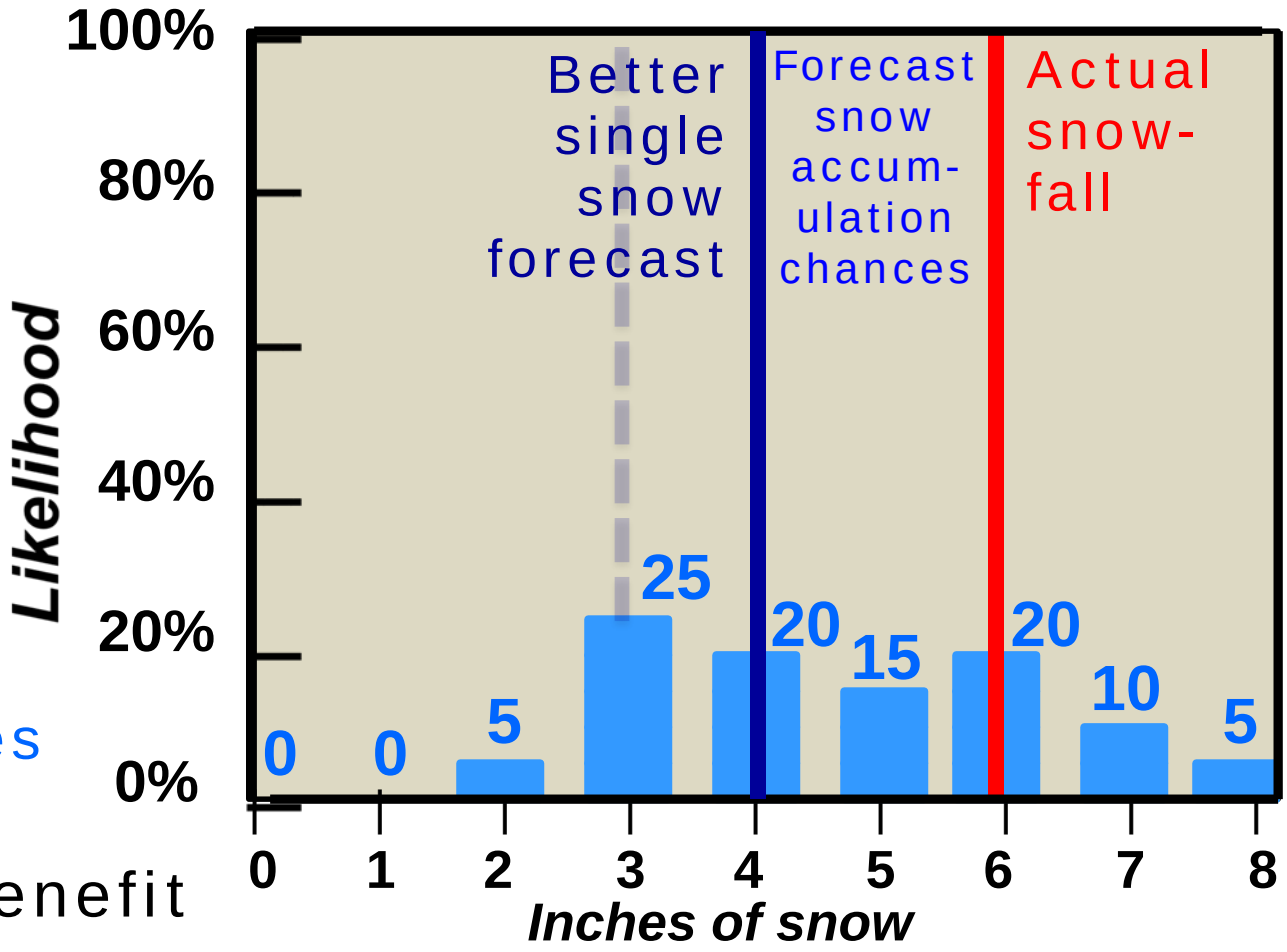
One more key benefit from ensembles:



How do ensembles forecasts help?

Old way – one "deterministic" forecast

New way – run an "ensemble" of forecasts – get information about range of possible outcomes



One more key benefit from ensembles:
"ensemble data assimilation"
improves the deterministic forecast

Need ensembles the most for the most challenging forecast situations

More information on ensembles

Types of ensembles:

1) Ensembles of opportunity

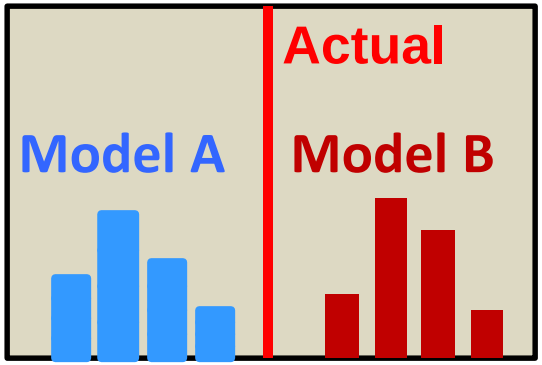
-- Time-lagged ensemble (HRRR-TLE)

-- Multi-model ensembles (SSEO)

ADS: computationally inexpensive

DISADS: model clustering, members not independent

Example of model clustering



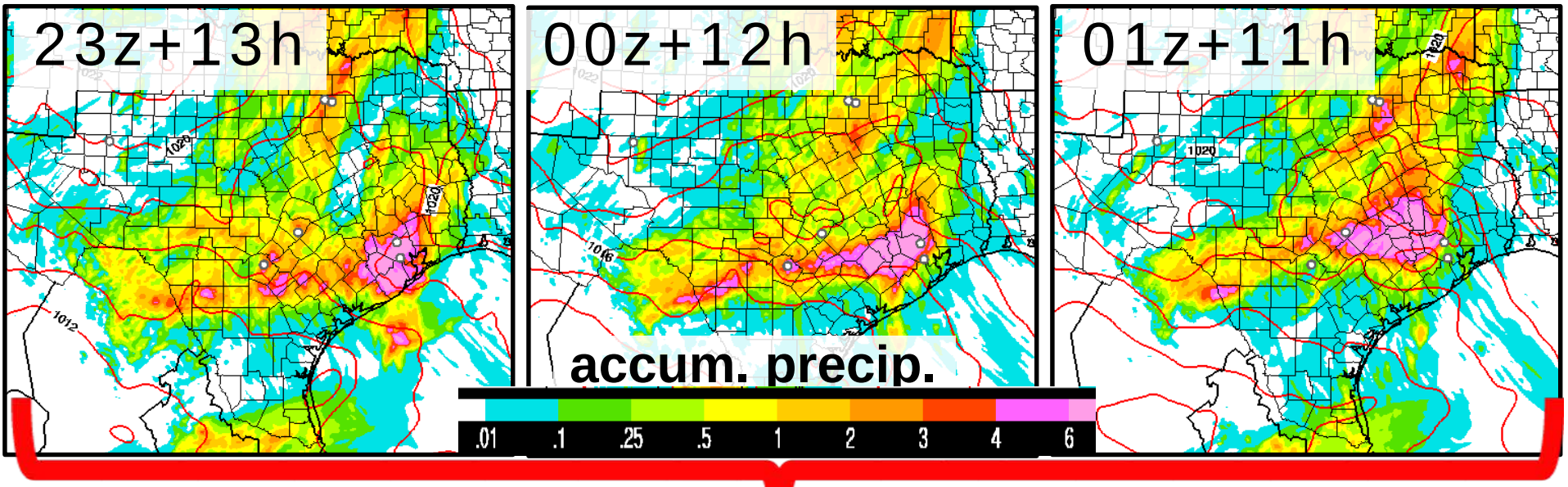
2) "Designed" ensembles

-- Perturbed members of single ensemble system (Global Ensemble Forecast System, HRRR-Ensemble)

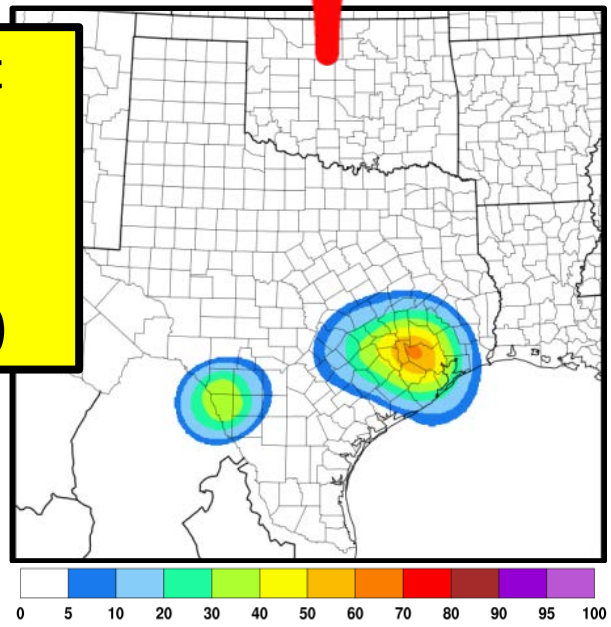
ADS: More useful spread, ensemble assimilation

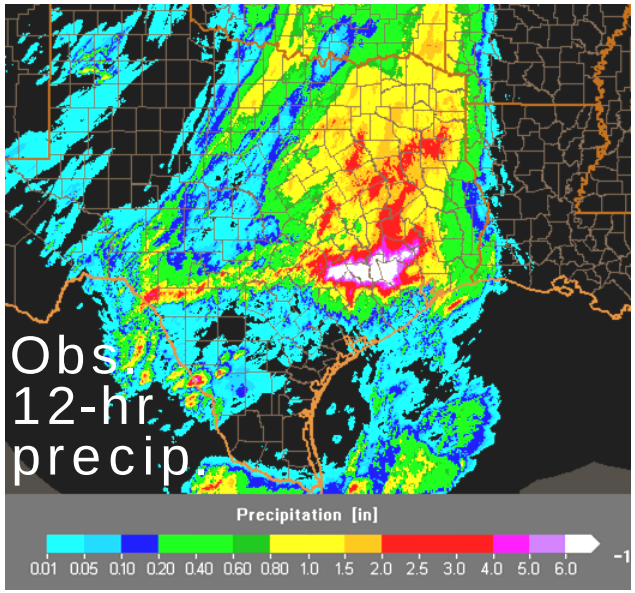
DISADS: computationally expensive

HRRR-TLE example: 18 April 2016



HRRR-TLE forecast probability of 6hr QPF exceeding 100 year average return interval (ARI)

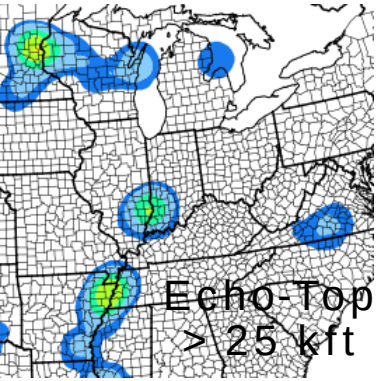


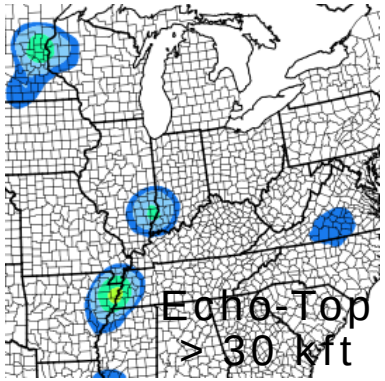


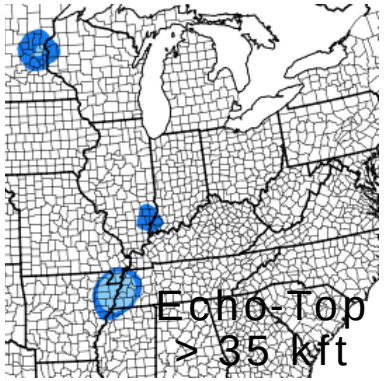
HRRR Time-Lagged Ensemble (HRRR-TLE): GSD real-time product generation

Real-Time Web Graphics (and grids via LDM/FTP)

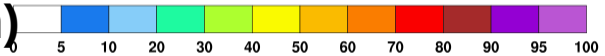
http://rapidrefresh.noaa.gov/hrrrtle

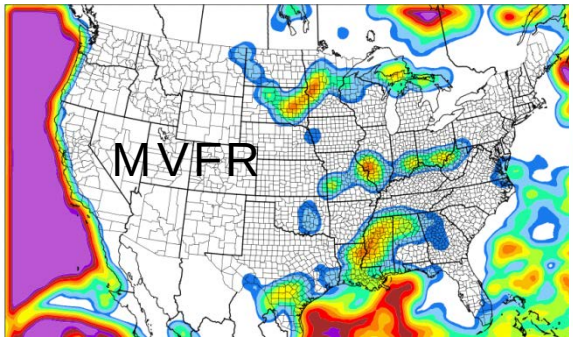


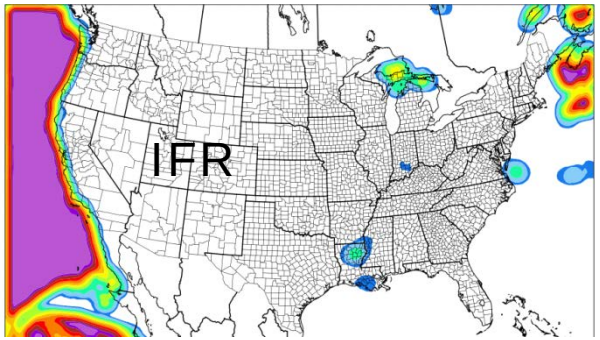




Probability of condition)







	All times	Loop	Wed 09	Wed 10	Wed 11	Wed 12	Wed 13	Wed 14	Wed 15	Wed 16	Wed 17	Wed 18	Wed 19	Wed 20	Wed 21
			Forecast												
			00	01	02	03	04	05	06	07	08	09	10	11	12
all fields			00	01	02	03	04	05	06	07	08	09	10	11	12
0.50" / 1 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12
1.00" / 1 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12
2.00" / 1 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12
0.50" / 3 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12
1.00" / 3 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12
2.00" / 3 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12
3.00" / 3 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12
0.50" / 6 hr precip	✓	✓							06	07	08	09	10	11	12
1.00" / 6 hr precip	✓	✓							06	07	08	09	10	11	12
2.00" / 6 hr precip	✓	✓							06	07	08	09	10	11	12
3.00" / 6 hr precip	✓	✓							06	07	08	09	10	11	12
6.00" / 6 hr precip	✓	✓							06	07	08	09	10	11	12
6 hr precip > 100-yr recurrence	✓	✓							06	07	08	09	10	11	12
0.50" / 3 hr runoff	✓	✓				03	04	05	06	07	08	09	10	11	12
1.00" / 3 hr runoff	✓	✓				03	04	05	06	07	08	09	10	11	12
2.00" / 3 hr runoff	✓	✓				03	04	05	06	07	08	09	10	11	12
3.00" / 3 hr runoff	✓	✓				03	04	05	06	07	08	09	10	11	12
0.50" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12
1.00" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12
2.00" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12
1.00" / 6 hr snowfall	✓	✓							06	07	08	09	10	11	12
3.00" / 6 hr snowfall	✓	✓							06	07	08	09	10	11	12
6.00" / 6 hr snowfall	✓	✓							06	07	08	09	10	11	12
Thunderstorm	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Wind > 50 kt in last 4 hr	✓	✓							06	07	08	09	10	11	12
Hail > 1" in last 4 hr	✓	✓							06	07	08	09	10	11	12
Tornado in last 4 hr	✓	✓					04	05	06	07	08	09	10	11	12
Visibility < 5 mi	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Visibility < 3 mi	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Visibility < 1 mi	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Ceiling < 3000 ft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Ceiling < 1000 ft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Ceiling < 500 ft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
IFR conditions	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Echo Tops > 25 kft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Echo Tops > 30 kft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Echo Tops > 35 kft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
Echo Tops > 40 kft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
VIP >= 1	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
VIP >= 2	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
VIP >= 3	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
VIP >= 4	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12
VIP >= 5	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12

QPF

Winter

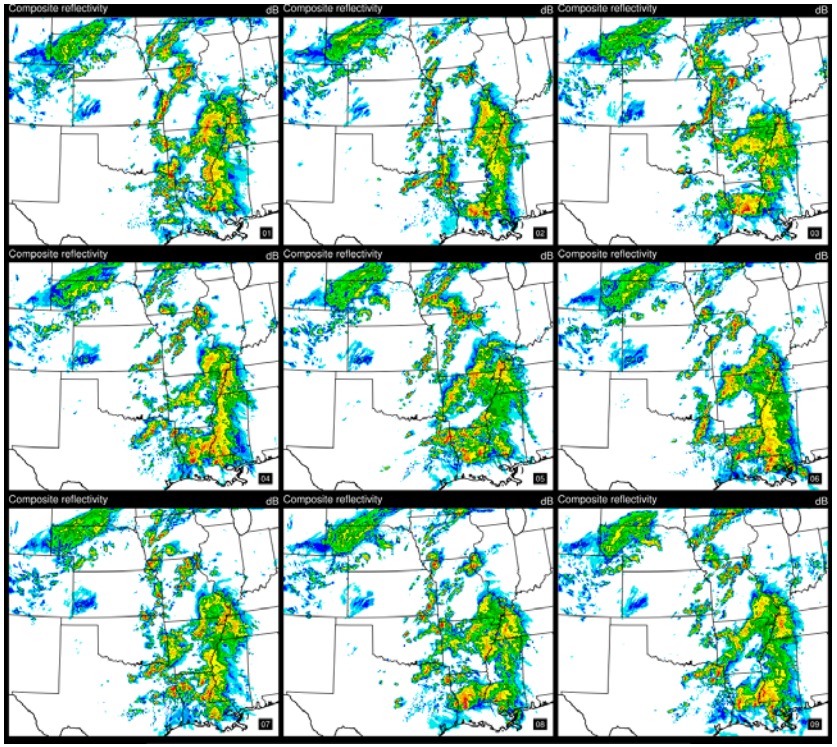
Severe

Aviation

HRRR Ensemble (HRRRE)

Web Graphics (real-time HRRRE to resume Nov. 2016)
http://rapidrefresh.noaa.gov/HRRRE

- **Single core (ARW)**
- **Ensemble DA (GSI-EnKF)**
- **RAP mean + perturbations**



Planned Fall 2016 Refinements

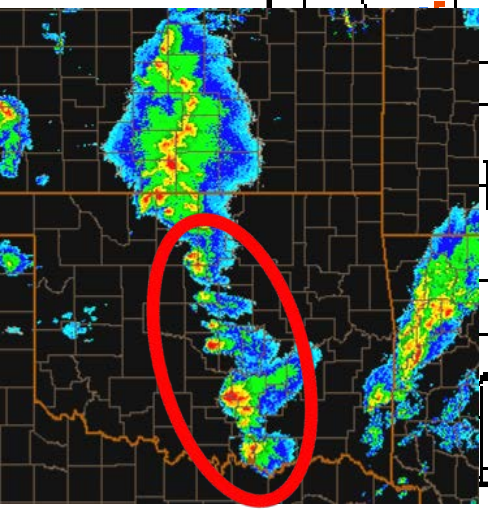
- Add radar reflectivity data assimilation
- Stochastic physics
- Apply HRRR-TLE statistical processing
- Include lagged members?

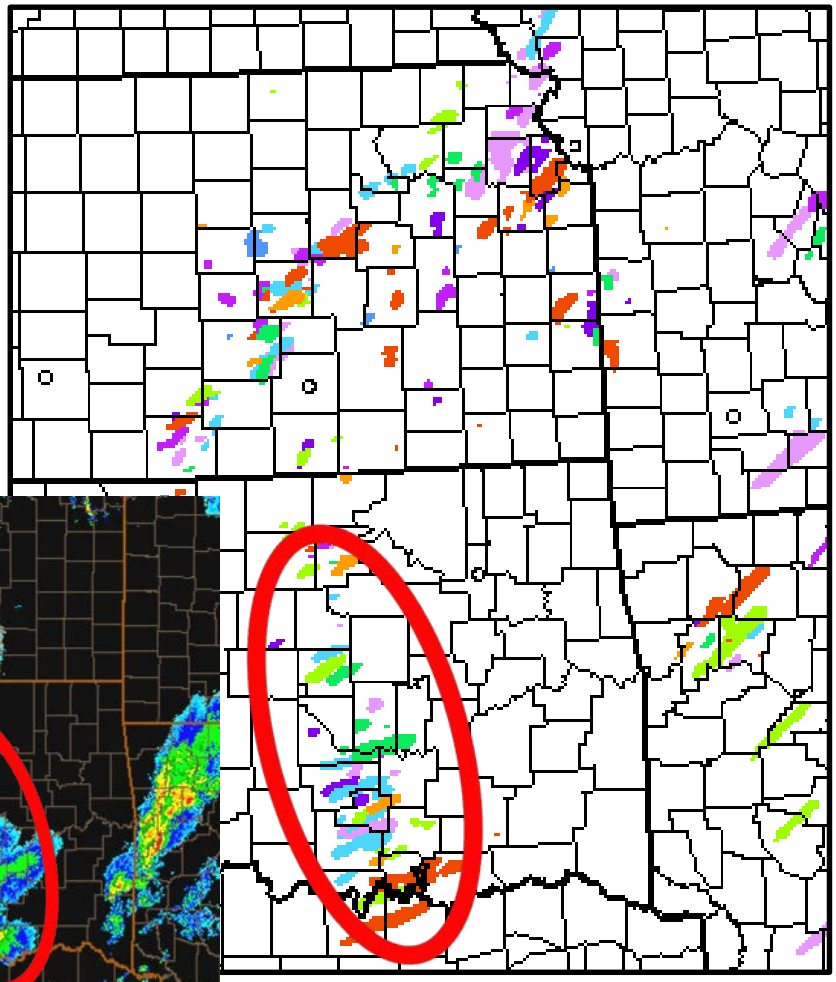
Assimilation	Forecast
20 members	00z - Three mem to 30 hr
1 hr cycling	03z - Three mem to 27 hr
21 fcsts / day	12z - Six mem to 18 hr
Start 21z day zero	15z - Eighteen mem to 15 hr
End 18z day one	18z - Eighteen mem to 12 hr

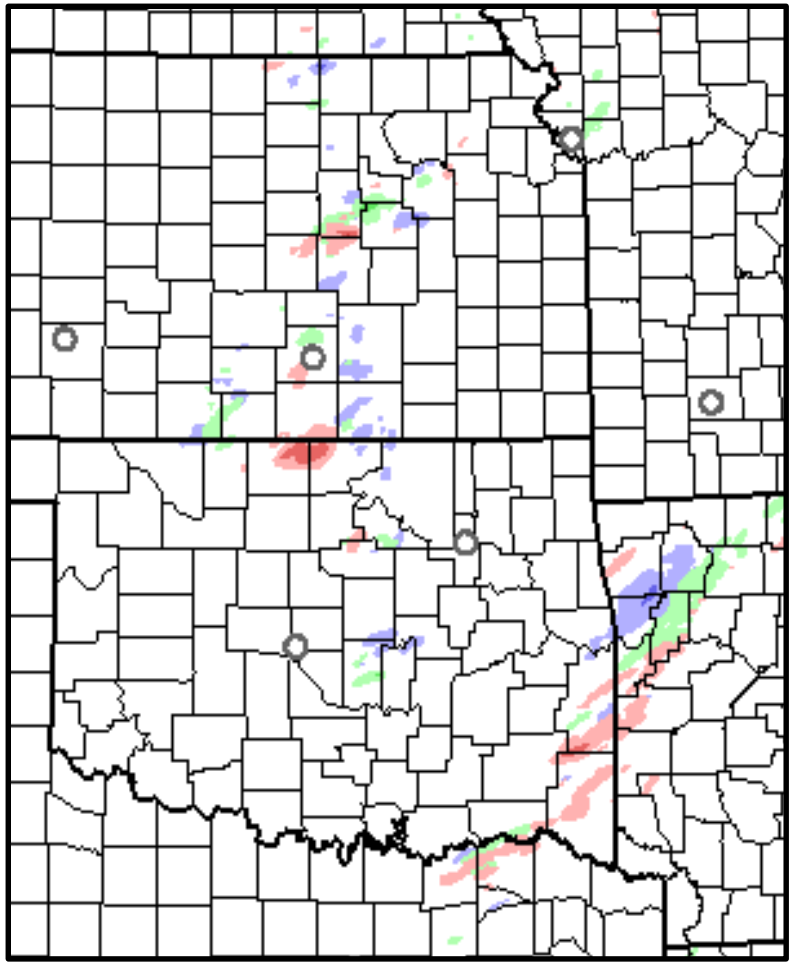
Proof-of-concept Real-time demonstration

Comparison: HRRR-TLE and HRRRE

Updraft Helicity > 25 m^2/s^2 from Different members



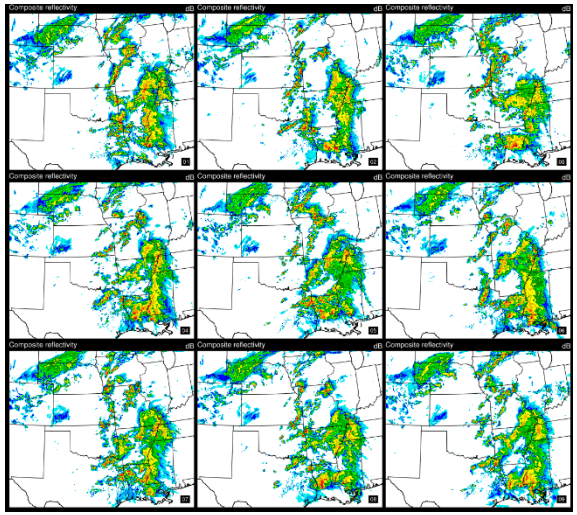




HRRR-Ensemble
15z + 7 hr forecast

Time-Lagged Ensemble
15z-17z initializations

A challenge of ensembles:
Displaying output / conveying information



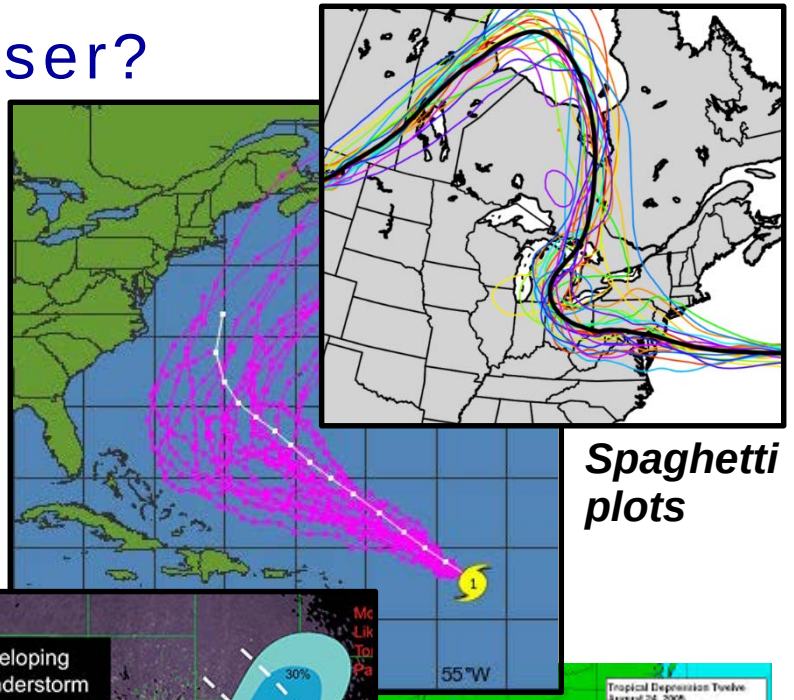
Postage stamp plots

Who is the user?

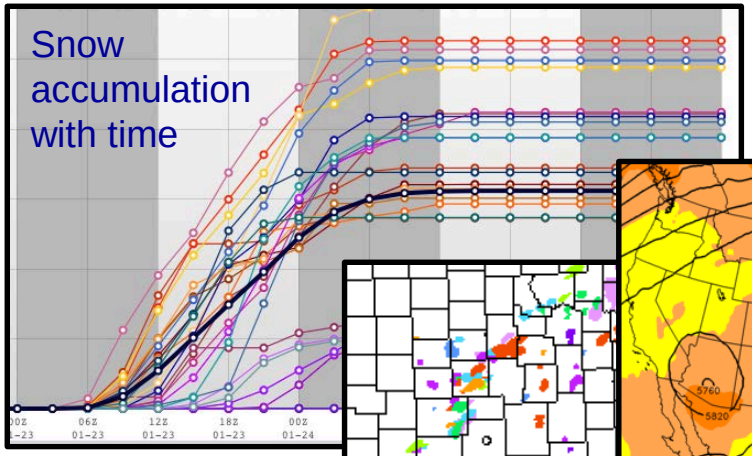
Need more creative display methods

Extract hazard specific information

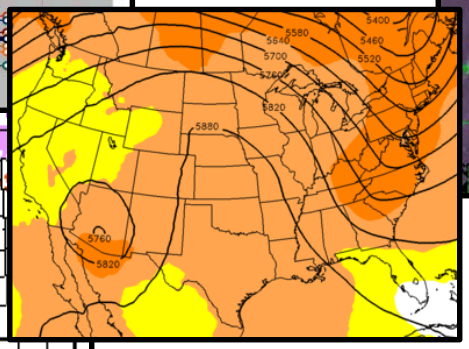
Simplify display, only most critical information



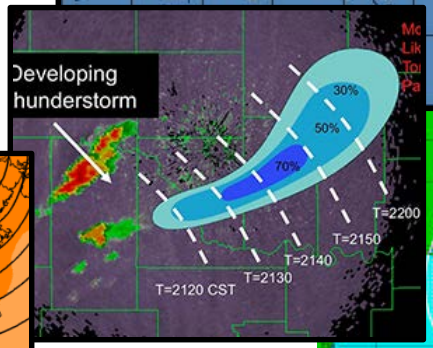
Spaghetti plots

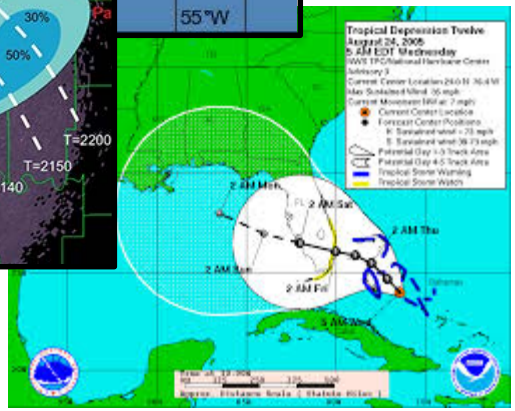


Plume diagrams



Mean and spread





Probability regions

Paintball plots

Feed ensemble information into decision support systems?

Rapid Refresh and HRRR
NOAA hourly updated models

13km Rapid Refresh (RAP)

Version 3 -- NCEP implement 23 Aug 2016

Version 4 – GSD

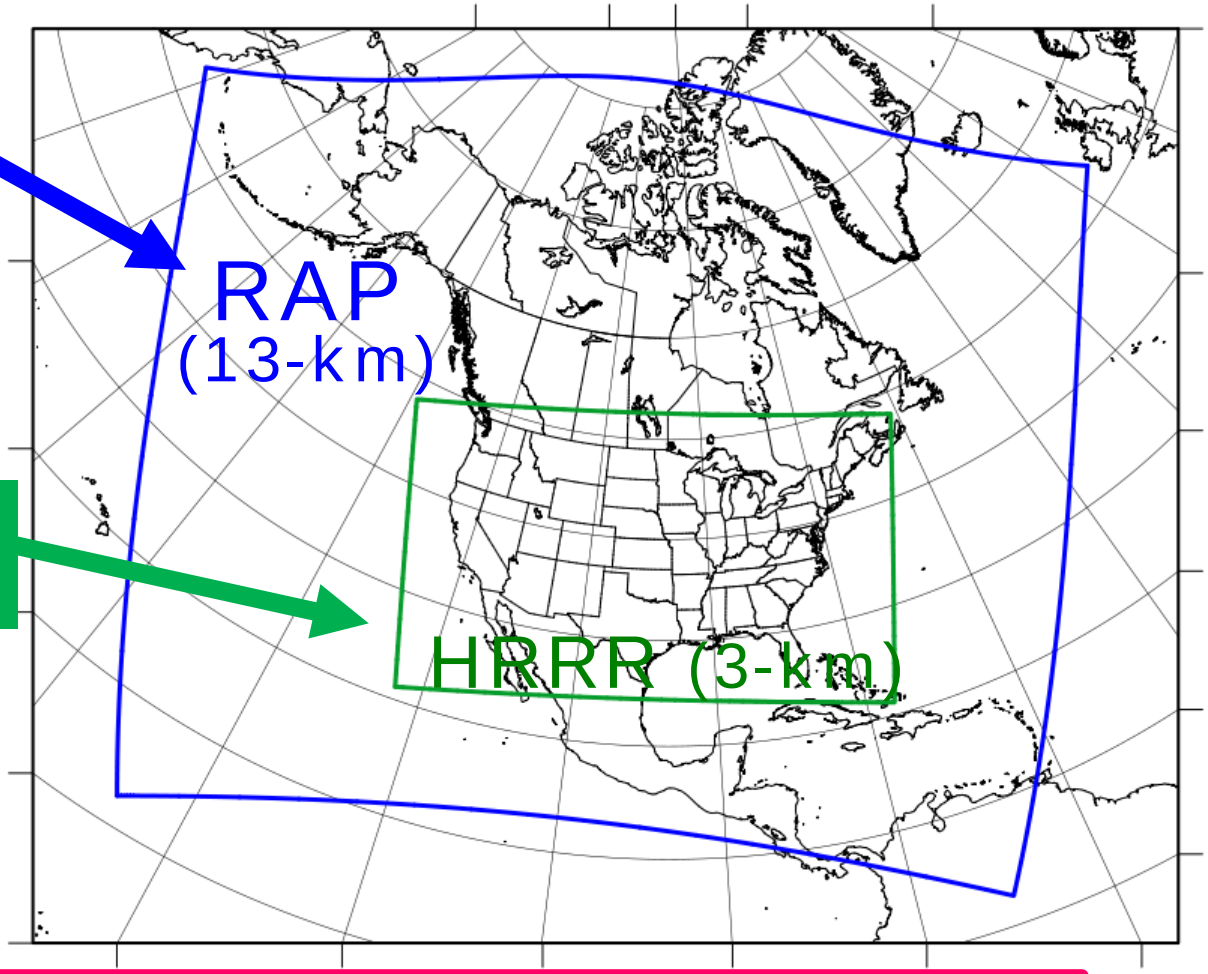
Planned NCEP – Early 2018

3km High Resolution Rapid Refresh (HRRR)

Version 2 – NCEP implement 23 Aug 2016

Version 3 – GSD

Planned NCEP – Early 2018



HRRR v3 ➔ plan HRRR-E (Ensemble)