Forecasting the Ferocious: 
*The Predictive Science Behind NWS Forecasts for Tornadoes and Floods*

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Forecasting the Ferocious: The How, What, Where and Why of Tornadoes

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Storm Prediction Center (SPC)
Severe Weather Forecasts Used Nationwide
Weather Prediction Center
Precipitation Forecasts Used Nationwide
The forecast process =

CONCEPTUAL MODELS + DIAGNOSIS + EXPERIENCE

+ TREND

• CONCEPTUAL MODELS help simplify the atmosphere

• DIAGNOSIS requires analysis and attention to detail

• EXPERIENCE comes with time, dedication, climatology

• TREND – Bringing it all together and using extrapolation, ingredients evaluation and modification, numerical model guidance, including statistical techniques to enhance model output.
CONCEPTUAL MODELS
Severe convective weather is a product of thunderstorms...
...or, more accurately, “sustained deep moist convection”
The forecast task reduces to:

(1) ASSESS THE POTENTIAL FOR THUNDERSTORMS

(2) DETERMINE WHETHER STORMS WILL BECOME SEVERE OR NOT
CONCEPTUAL MODELS

Storms **require** a combination of three Ingredients

- **INSTABILITY**
- **LIFT**
- **MOISTURE**

*Instability*: tendency for air parcels to move up or down when displaced from rest; determined by rate of temperature change with height

*Lift*: mechanism(s) to initiate, maintain or augment vertical air motions (updrafts)

*Moisture*: Fuel in the form of the latent heat of condensation \((2.5 \times 10^6 \text{ J/kg})\)
CONCEPTUAL MODELS

Sustained convection requires another ingredient:

• VERTICAL SHEAR

The change in wind speed or direction with height...

10 km
8 km
6 km
4 km
2 km

2–10 km Shear
DIAGNOSIS

Combining surface observations/analysis with upper air data and conceptual models
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Combining surface observations/analysis with upper air data and conceptual models
Most flood events have antecedent conditions too
EXPERIENCE

Climatology of Hazards

U.S. Daily Average Relative Weather Risk Based on NOAA/NWS Data, 2008-2012

- Flash Floods
- Heat Waves
- Severe Thunderstorms and Tornadoes
- Tropical Cyclones and Hurricanes
- Wildfires
- Snow/Ice Storms and Blizzards

NOAA/NWS/SPC

G. Cermak
The daily probability of a tornado within 25 miles of a point (20 years of data).
EXPERIENCE

Pattern recognition and past events

GFS Ensemble Mean – 48h Forecast

November 10, 2002
Service Assessment

Veterans Day Weekend Tornado
Outbreak of November 9-11, 2002

Tornadoes: 83 (1 F4, 2 F3 in AL)
States: 13
Fatalities: 36 (11 AL)
EXPERIENCE

Other significant U.S. tornado outbreaks...

April 3-4, 1974 Super Outbreak
EXPERIENCE
Historical flash floods

May 1889

July 2016
Large scale weather systems:
Air masses, highs, lows

Cold fronts, rain bands,
lake-effect snow

Thunderstorm cells

Flood Tor?
Bringing it all together: Forecast Funnel
Bringing it all together: Scale Interaction
Bringing it all together: Models

Forecast valid at 00Z (10 hours)
Bringing it all together: Ensembles

91-member spaghetti plot (left)
ECMWF ensemble 1” QPF (right)
SREF plume chart (bottom)
Bringing it all together: Anomalies

Ingredients-based approach

- PW and flux anomalies
- Anomaly persistence
- Warm-rain processes
- Model trends

Lend confidence in forecast of occurrence of rare events

Standard deviations from climatology
Bringing it all together: Products

Thunderstorm, Fire Weather, Severe Weather OUTLOOKS

Detailed Mesoscale DISCUSSIONS

TOR/FLOOD WATCHES

WARN

SPC/WPC Products

Local NWS Products (WFO)
Severe Weather/Flood Watches
Tornado and Severe Thunderstorm

Monitor Conditions in Your Area. Watch!

Environment Becoming More “Favorable”

Issued Based on Forecasts & Observations
Severe Weather Watches

Severe Thunderstorm Watches per year

Tornado Watches per year
Severe Weather/Flood Warnings
Tornado and Severe Thunderstorm

Take Cover Now! (Put your plan into ACTION)

Danger is Immediate / Certainty is High

Issued Based on Observations (radar/reports)
Severe Weather **Warnings**

Gridded Tornado Warnings Yearly Mean (2002-2011)
More info on weather watches

http://www.youtube.com/watch?v=x3V3HZBs1Y4
Increasingly Heavy Rainfall

17-years daily average 1” rainfall coverage over U.S by month

2015-16 daily average coverage by month
Increasingly Heavy Rainfall

17-years daily average 1” rainfall coverage over U.S by month

- Every one of the past 12 months has been above normal
- 6 of the past 12 months set new records for 1” coverage!
Increasingly Heavy Rainfall

Six Separate Billion Dollar Flooding Disasters in FY16

$17.5 Billion in losses  124 Fatalities

South Carolina Floods Oct 2015
Midwest Holiday Storm Dec 2015
TX/Louisiana Flood March 2016
Houston Flash Flood April 2016
WV Flash Flood June 2016
Louisiana Flood Aug 2016

Observed Rainfall

25 Fatalities  50 Fatalities  5 Fatalities  8 Fatalities  23 Fatalities  13 Fatalities

Source: NCEI
Tornado Variability in Recent Decades
60-years of Annual (E)F1 and Stronger U.S. Tornado Counts

![Graph showing tornado counts from 1954 to 2014 with std deviations and notable years highlighted.]

- 1973
- 2011
- 1987
- 2008
- 2012, 2014

+1STD
-1STD
Predictions Have Steadily Improved

- Gap between Day 1, 2, 3 threat scores is narrowing
- Upward trend began in 1970s with LFM NWP
- Abrupt jump in 1990s with modernization/WSR-88D
- Day 3 scores today as good as Day 1 scores in 1994
What’s Next?

Climate Forecast System (CFS)

V2 Became operational in March 2011

Global model: coupled ocean–sea ice–land–atmosphere

1979-2011 CFS-reanalysis was used to calibrate and initialize the CFSv2 but CDASv2 is used to init operational CFSv2 runs

T126 horizontal resolution (~100km) & 64 vertical sigma-pressure hybrid layers

16 CFSv2 operational runs per day

Forecasts to at least 45 days!
What’s Next?

Evaluating a large ensemble of forecasts depicting the ingredients for severe thunderstorms over a limited domain.

Forecast consistency provides insight into regime predictability.

R2O efforts are ongoing to extend predictions beyond 7 days.
What’s Next?

CFS Day 11 Forecast for 24h Average Supercell Composite

SPC 20 UTC Day 1 Outlook issued Saturday, Dec. 21, 2013
More information and links...
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