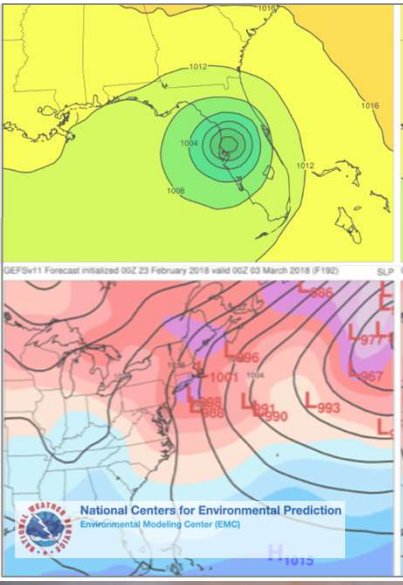
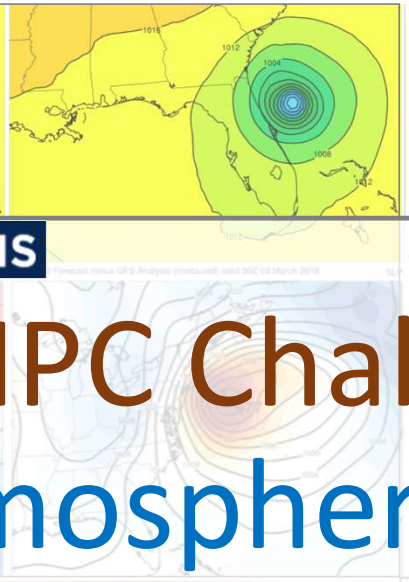


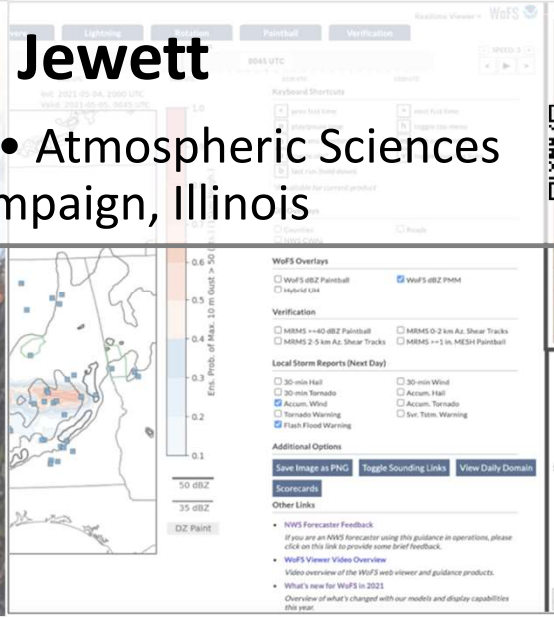



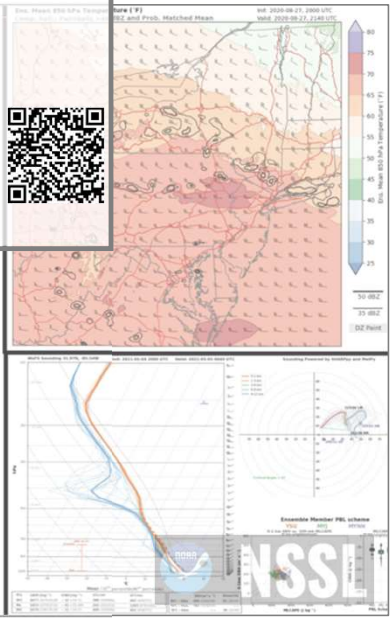

ILLINOIS

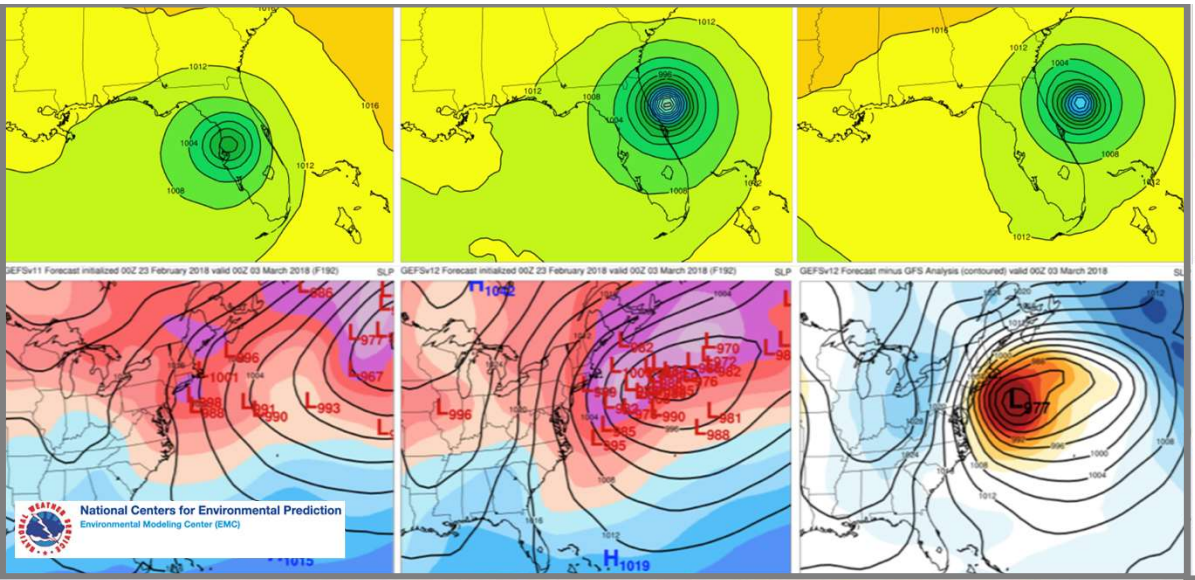
HPC Challenges in Atmospheric Sciences

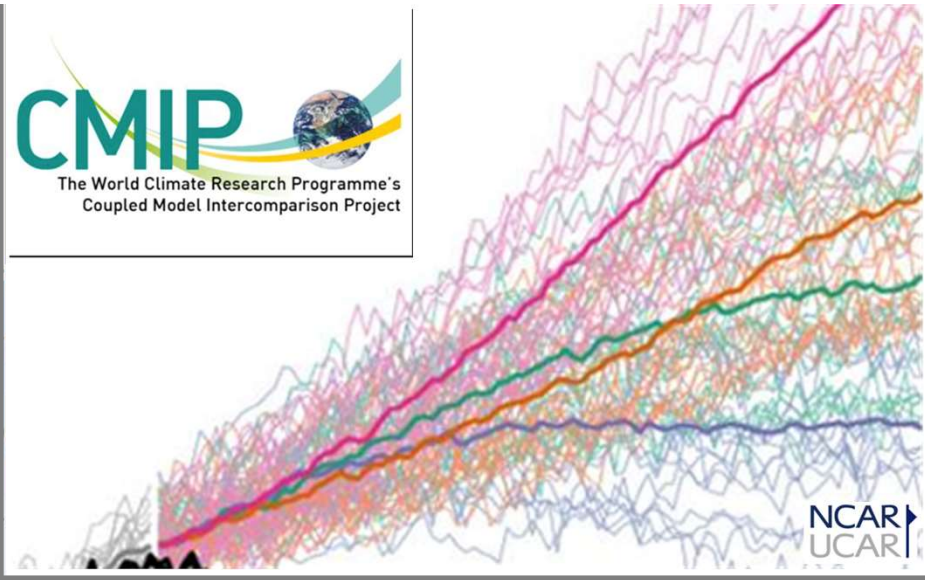
Brian Jewett

University of Illinois • Atmospheric Sciences
Urbana-Champaign, Illinois

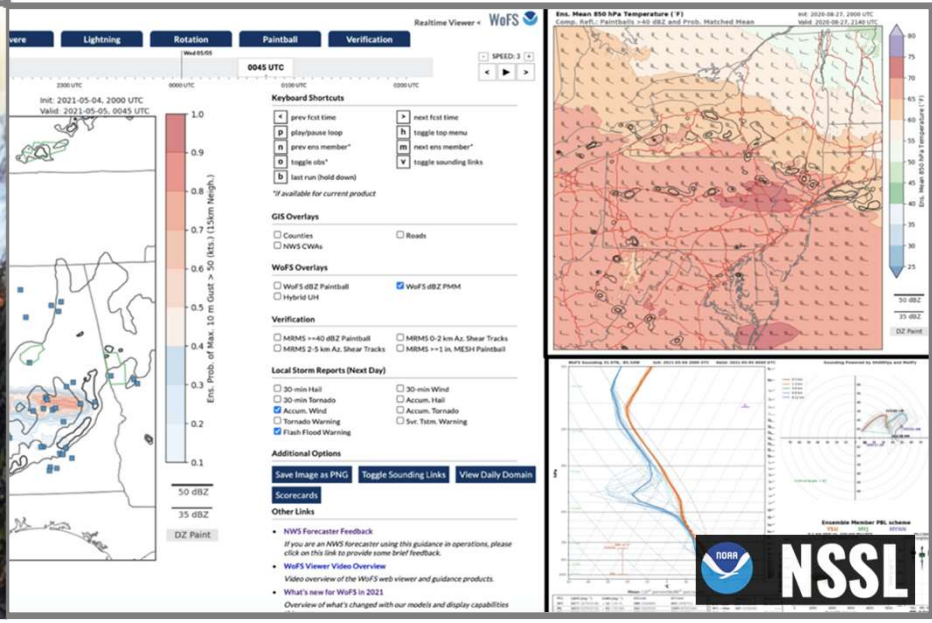


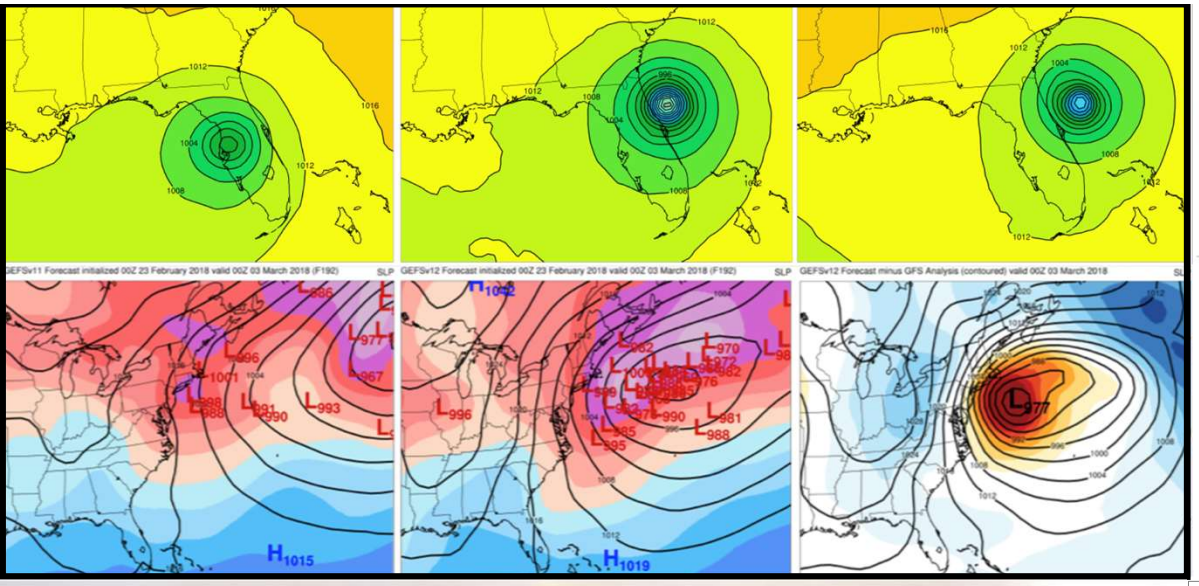


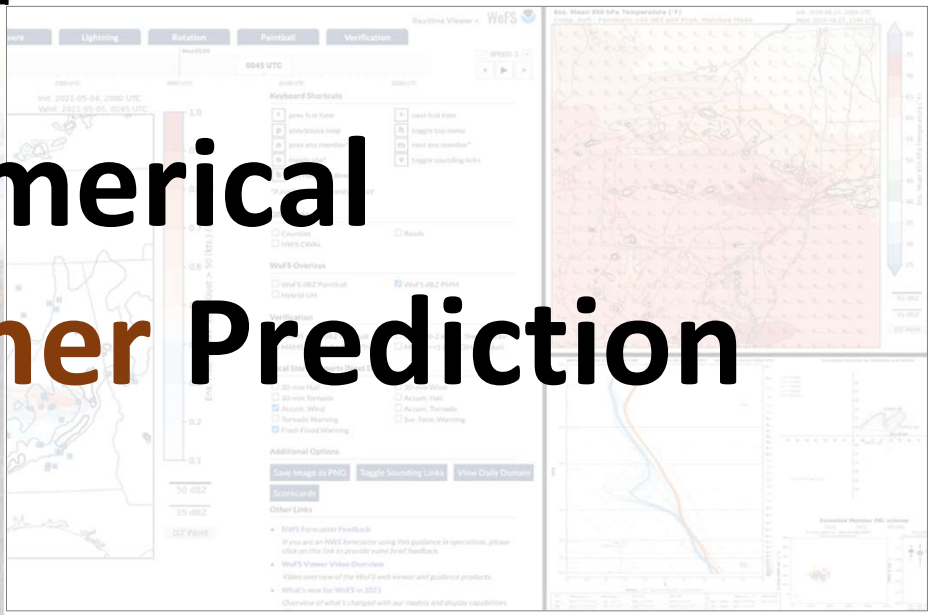

GEFSv11 Forecast initialized 00Z 23 February 2018 valid 00Z 03 March 2018 (F192) SLP
GEFSv12 Forecast initialized 00Z 23 February 2018 valid 00Z 03 March 2018 (F192) SLP
GEFSv12 Forecast minus GFS Analysis (contoured) valid 00Z 03 March 2018
National Centers for Environmental Prediction
Environmental Modeling Center (EMC)


CMIP
The World Climate Research Programme's
Coupled Model Intercomparison Project
NCAR
UCAR

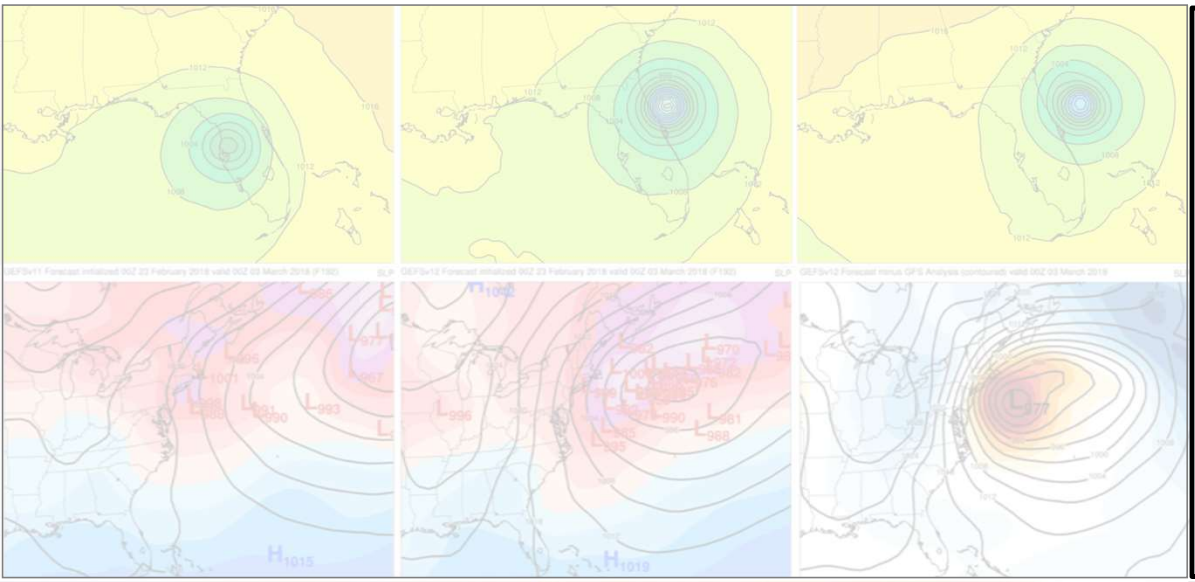

NCAR
UCAR

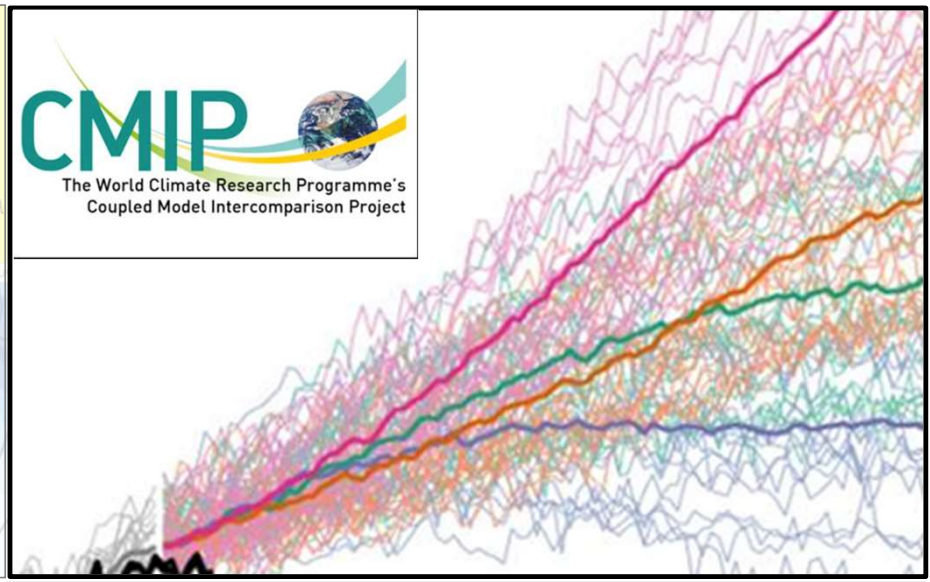

Realtime Viewer
WoFS
Lightning
Rotation
Paintball
Verification
0045 UTC
Init: 2021-05-04, 2000 UTC
Valid: 2021-05-05, 0045 UTC
Keyboard Shortcuts
GIS Overlays
WoFS Overlays
Verification
Local Storm Reports (Next Day)
Additional Options
Save Image as PNG
Toggle Sounding Links
View Daily Domain
Scorecards
Other Links
NWS Forecaster Feedback
WoFS Viewer Video Overview
What's new for WoFS in 2021
Ens. Mean 850 hPa Temperature (°F)
NSSL



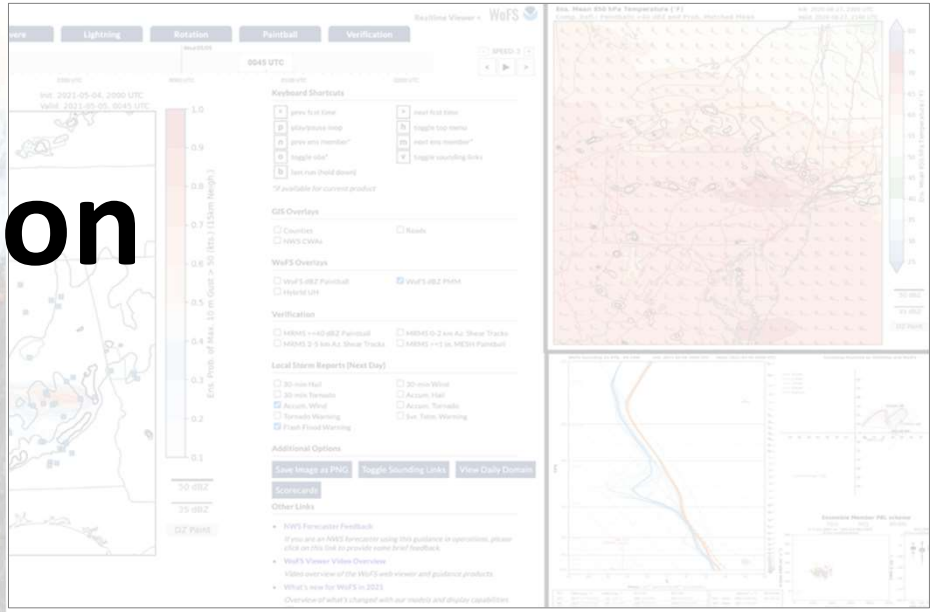


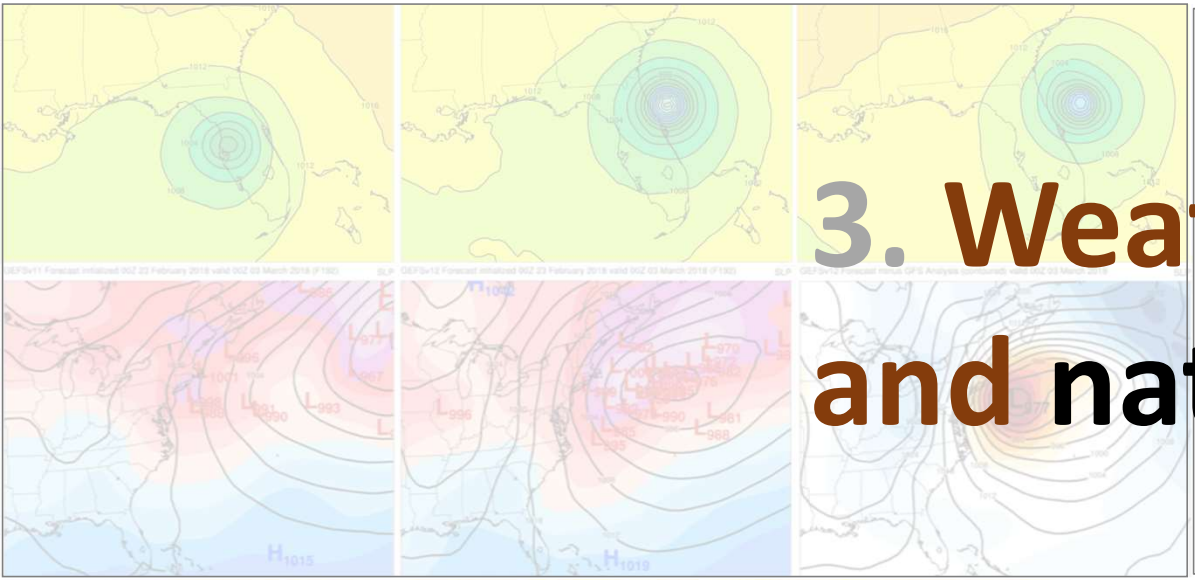
1. Numerical Weather Prediction

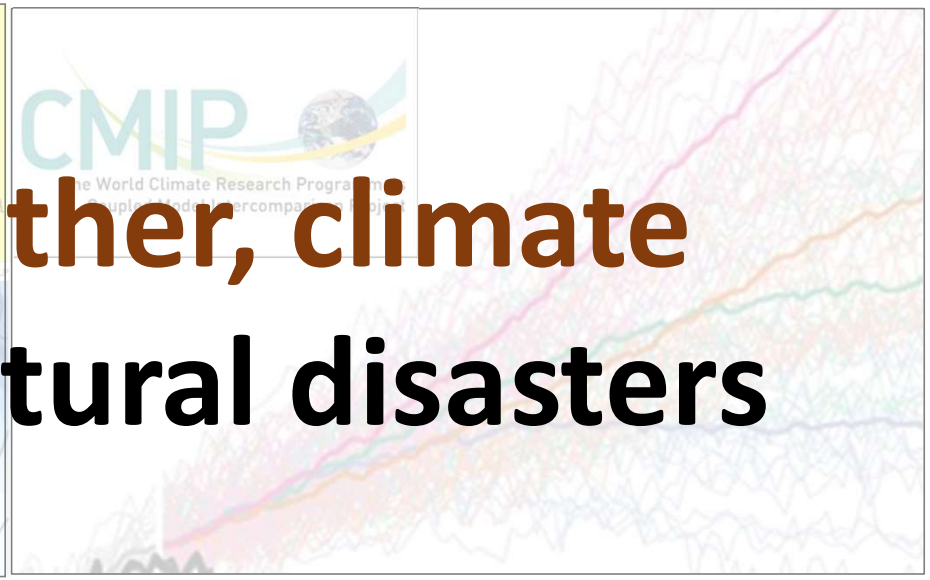




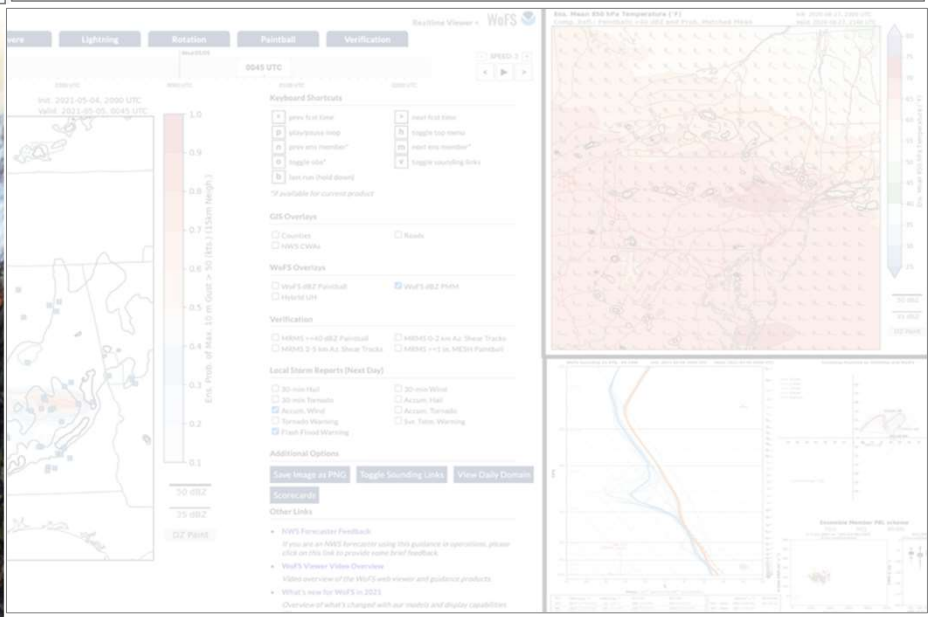
2. Climate Prediction



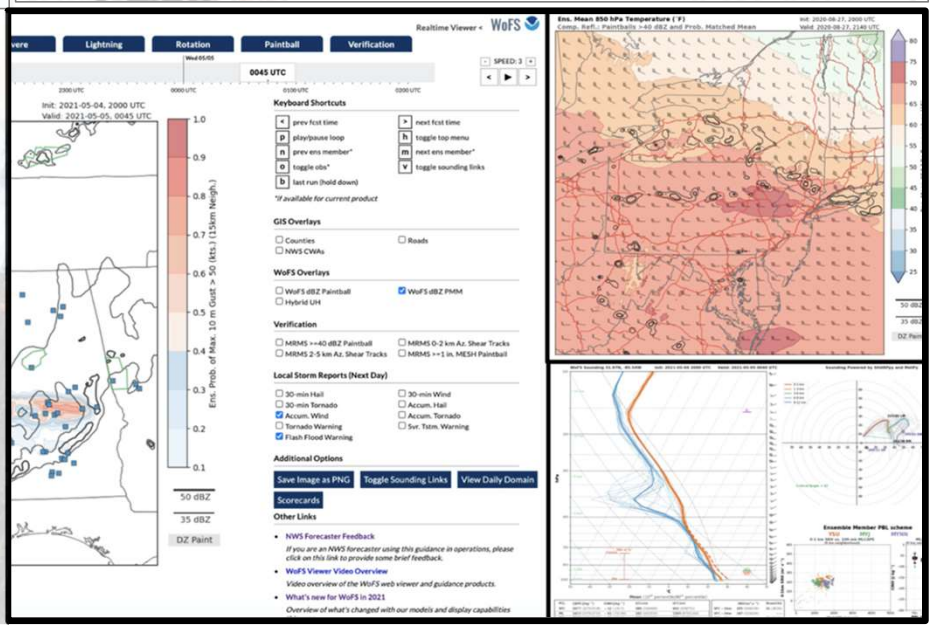


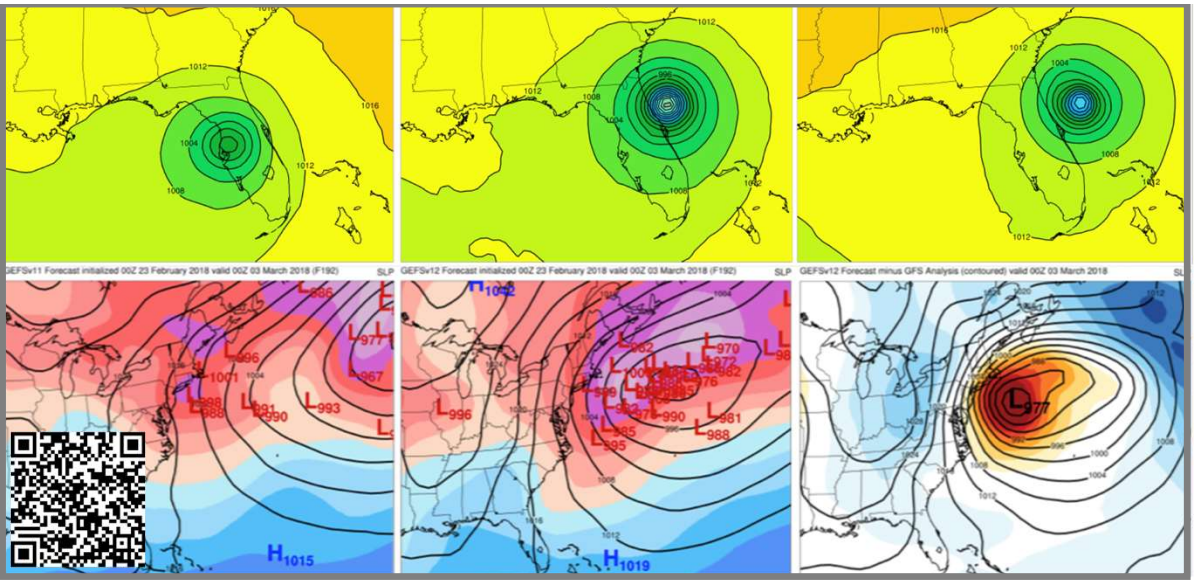


3. Weather, climate and natural disasters



4. Real-time weather-driven prediction & warnings





1. *NWP:* Numerical Weather Prediction

- NWP : an early application of HPC
- Growth of errors and related limitations in so-called *deterministic* forecasts were recognized early (Lorenz)
- Ensemble prediction of long-range global weather beat out higher-resolution single forecasts long ago
- Ensembles now important for short-range prediction too
- Cycling ensemble / data assimilation systems are front and center today

Challenges in (operational) NWP today (1/4)

- Making ***effective*** use of many-*many* core HPC nodes
  - we often default to leaving some cores *unused*
  - considerations: limitations on data bandwidth, and/or high communication-to-computation ratio in our codes
    - ✓This could also be an opportunity for more sophisticated physics!
- We often limit the output data from forecasts / simulations
  - saves disk space!
  - limits forecast usefulness!
  - make use of those unused cores?

Also true for research simulations!

Challenges in NWP today (2/4)

- Big computations requires big computers … right?
  - Longer integrations (e.g. supporting longer hurricane forecasts)
  - More integrations: increased use of ensembles in more ways –
    - ✓ensembles from varied model physical parameterizations
    - ✓ensembles from perturbed / diverse observational data
  - Particularly true as we move to high-resolution *global* forecasting
  - A major effort now is *seasonal-to-subseasonal (S2S) prediction*
- Move to use of GPUs
  - Requires reconsideration of computation algorithms
  - Progress has been slow, and sometimes proprietary (discussion)

Challenges in NWP today (3/4)

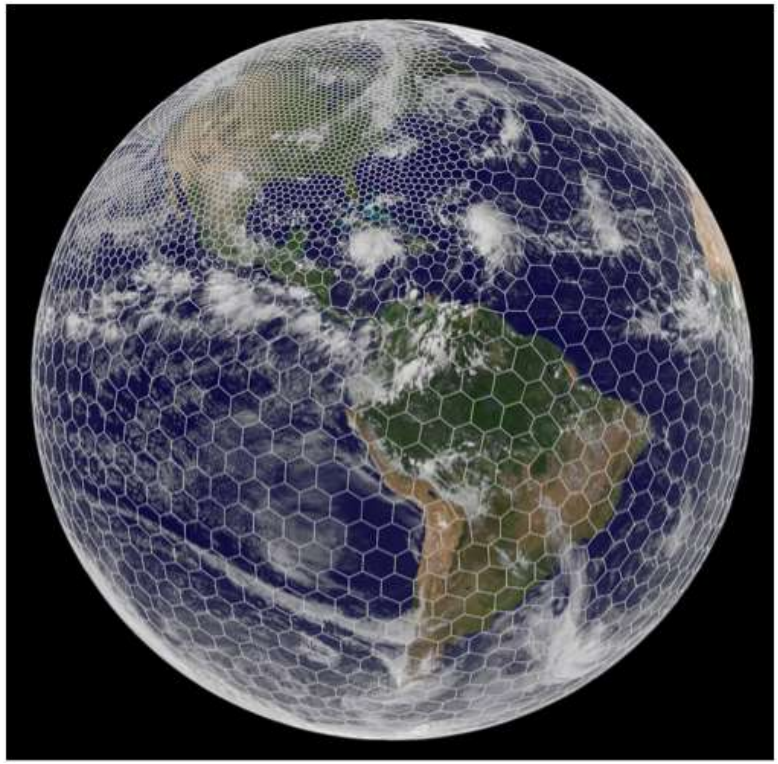
- Speeding up long model simulations with machine learning
  - Key model *physics* are often occurring at small scales – scales below that *resolvable by the model*
  - This is treated with physics *parameterizations,* which for e.g. clouds/precipitation & radiation are computationally expensive
  - Machine learning being explored to *learn* the essence of model physics, and then replace the costly functions currently in use.
- New paradigm: moving away from local grid refinement?
  - Global refinement cleaner – less noise – and arguably better

Challenges in NWP today (4/4)

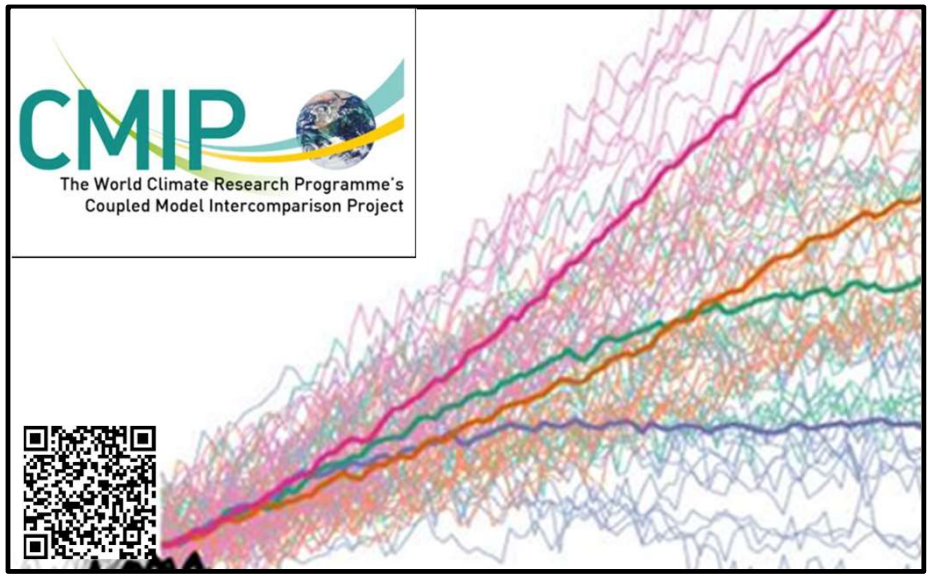
- High resolution global + local forecasting
  - **Not**: using global model to drive local mesh refinement *nests*, e.g. nested grids over the continental US (CONUS), or other areas
    - ✓e.g. *WRF Weather & Forecasting* model
  - The global model is the local model!
  - Requires new (or at least modified..) tools
    - ✓irregular grid • subsetting capabilities
    - ✓visualization • efficient I/O

github.com/MPAS-Dev

MPAS
Model for Prediction Across Scales

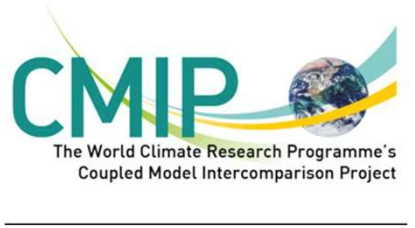


- Predictions of a warming climate and warnings from scientists to the public were occurring decades ago
- The reality is occurring in our lifetimes
- Separating natural variability from human-caused *anthropogenic* warming is one of the current challenges
- Distinguishing climate from weather is another challenge
- Global climate forecasts have been available for a long time
- Downscaling climate forecasts to understand future weather is ongoing
- Ensembles are a must! Data sets are large!



2. Climate Prediction

A few words about climate



- Long-term climate model forecasts have long been available as part of the CMIP project
- Data sets are freely available, and widely used
- Being able to interrogate and work with such data sets is a skill that undergraduate data science / meteorology / other students need – today
- Large data sets are the norm!

3. Weather, climate and natural disasters

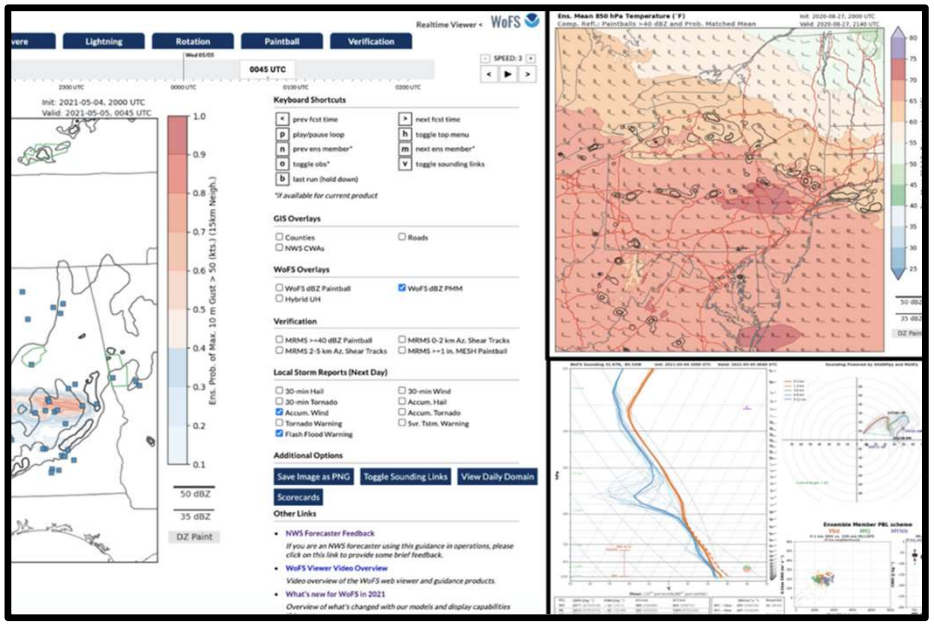
- Will our future climate contain more disasters?
  - What kind?
  - Can we prepare now?
  - What kinds of consequences are there?
  - How can we predict this?
- Work underway to address
  - drought
  - flooding
  - severe storms
  - hurricanes
  - wildfires
  - … in future climates.

4. Real-time *event-driven* prediction & warnings

Some types of events have immediate consequences for life and property.

These require time-critical simulations, which therefore depend on available HPC resources (and government / infrastructure planning).

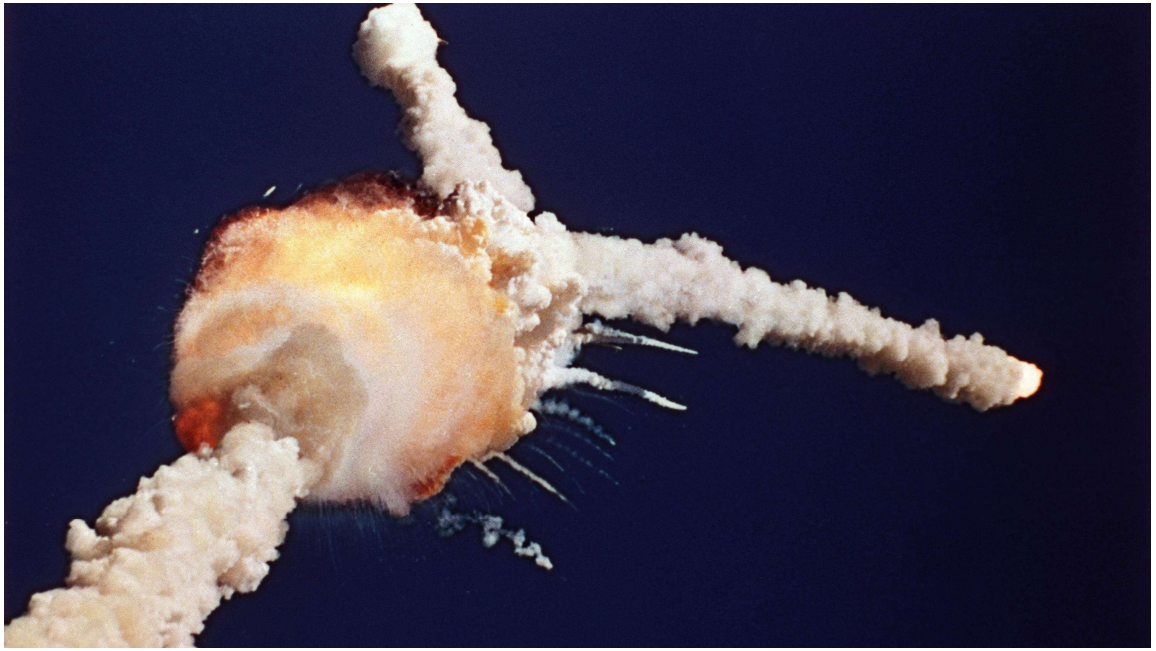
Let's look at a few candidates for critical simulations >



1986 Challenger shuttle explosion

- 73s in flight, at 46000 ft (14 km)
- O-ring failure, due to record cold
- Flaw known at least 9 years before
- 36˚F (2˚C) at launch; 53˚F prior record

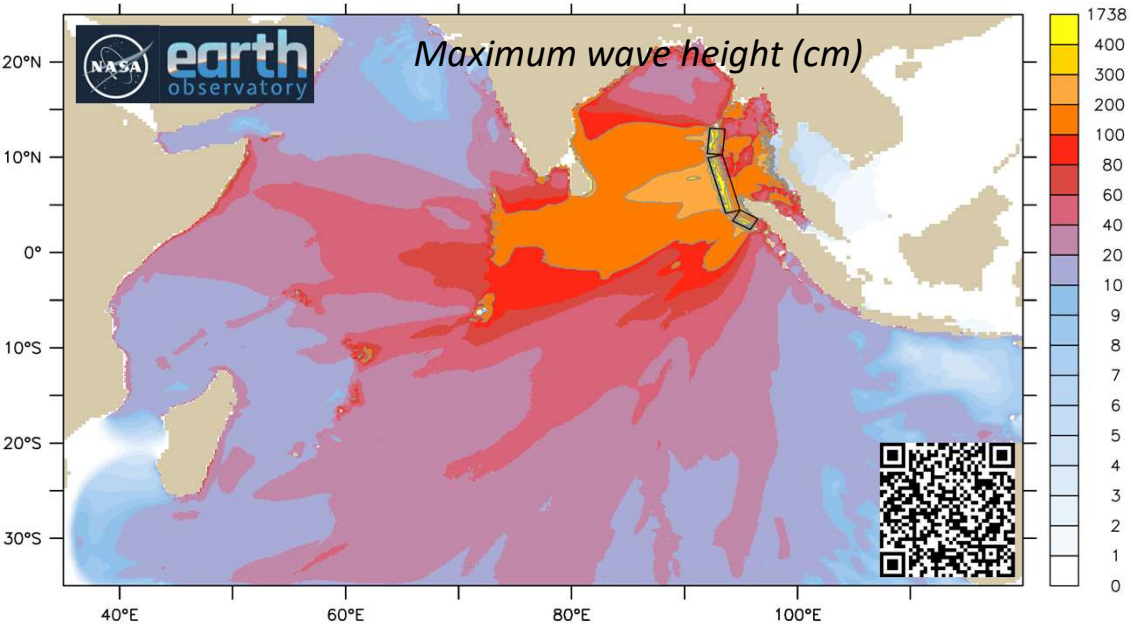
Real-time *event-driven* prediction & warnings

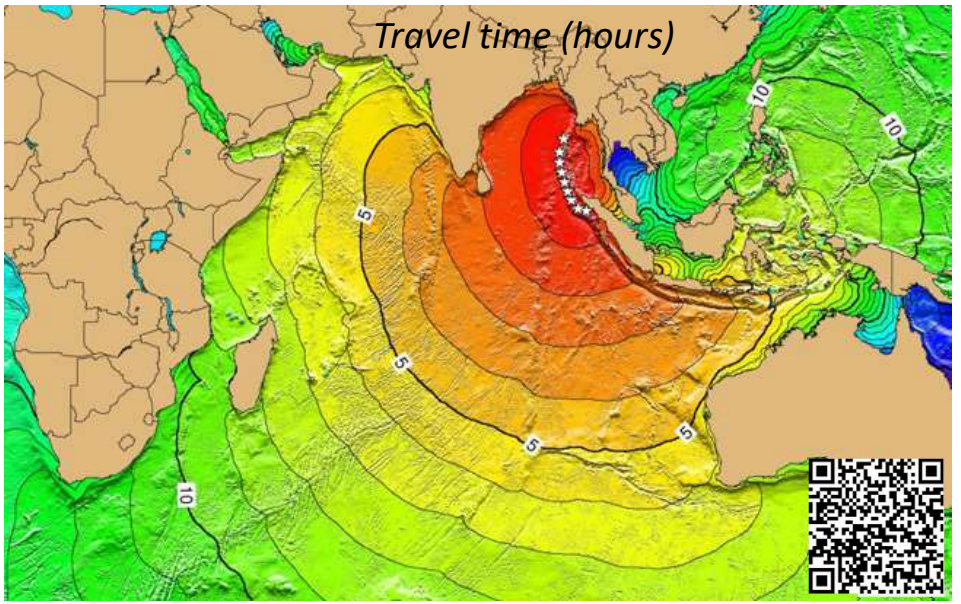


2004 Indian Ocean Tsunami

- Waves to 30m; inland up to 2 km
- Sumatra coast: 10+ m waves; minutes
- Somalia: 5000 km, 5-9m, 300 dead
- Tip of S. Africa: 1.5m, 16 hours

Real-time *event-driven* prediction & warnings





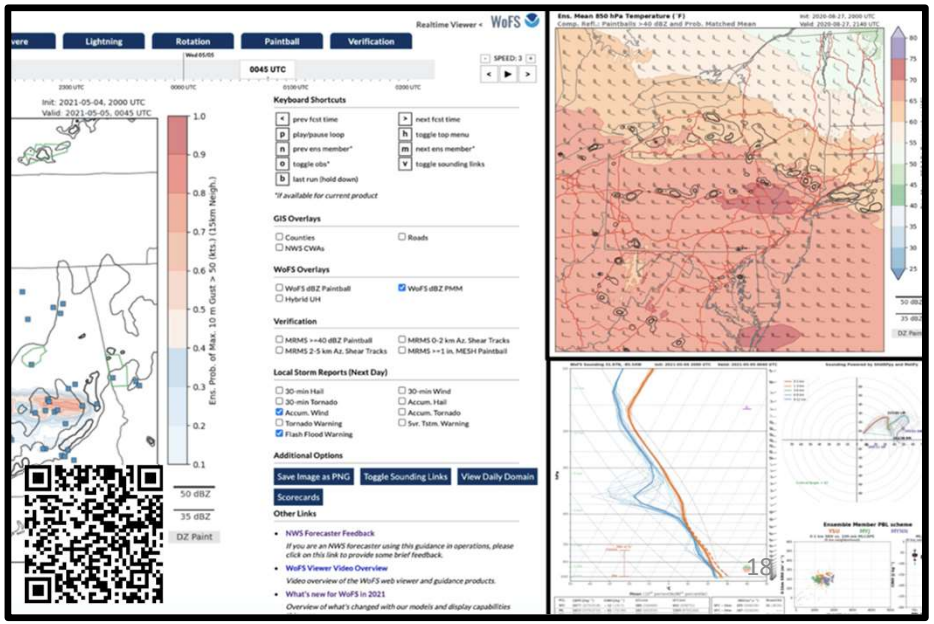
Real-time *weather-driven* prediction & warnings

And a **weather** example -

- Sometimes anticipated
- High-societal impact
- **HPC-constrained**
- On-demand Prediction …

with public safety implications.

Warn on Forecast – a public severe weather warning system based on NWP • NOAA/NSSL National Severe Storms Lab.



Ideally most tornadoes look like this …

it isn't moving towards me. See? This is safe…

- in **open country**, **daylight**.
- We have a lot of this –

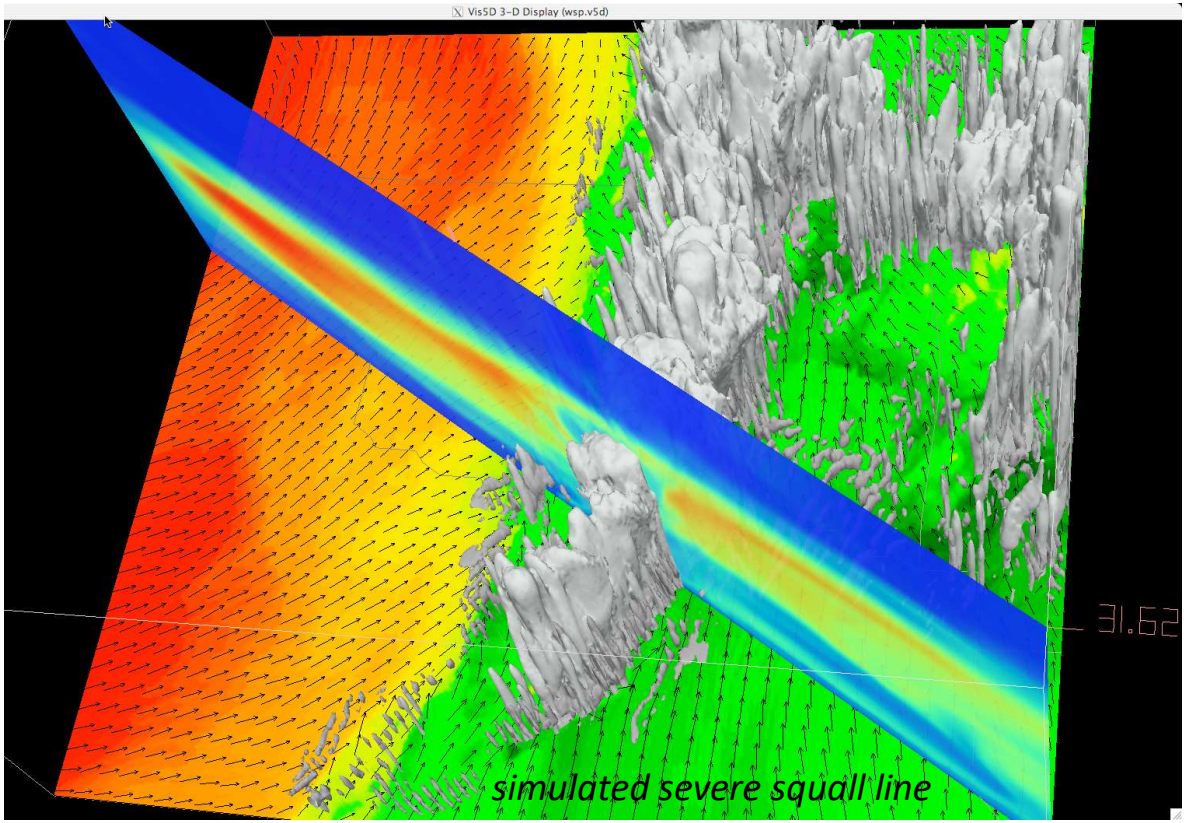
  (tornadoes)

  (also, open country)

  … in the States.
- We need to warn the public (and many others..) about severe storms & tornadoes.

Storm modeling was historically for understanding

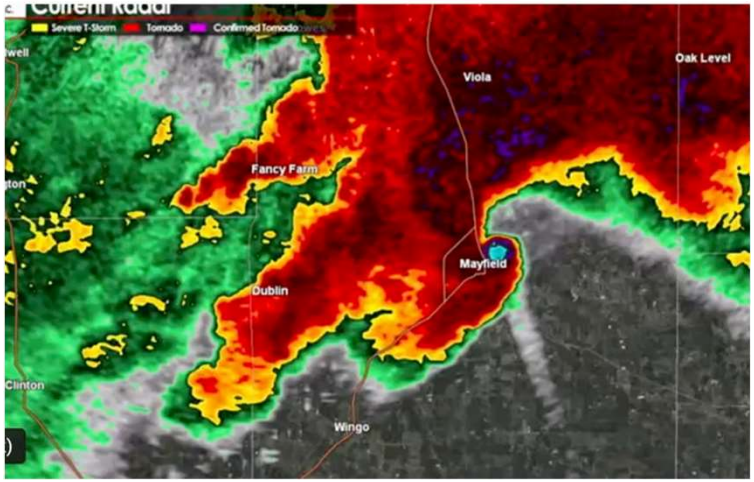
- "Grow a storm" in a box
- See if it appears sufficiently "real enough" for use
- If so,
  - change the temperature, moisture, and wind
  - document the changes
- This type work continues today w/higher resolution, ensembles of tornado simulations (K. Gray)

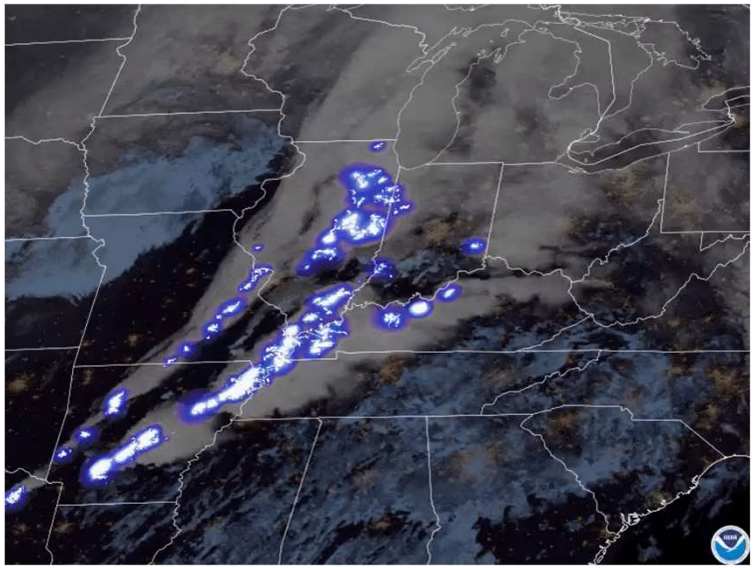


simulated severe squall line

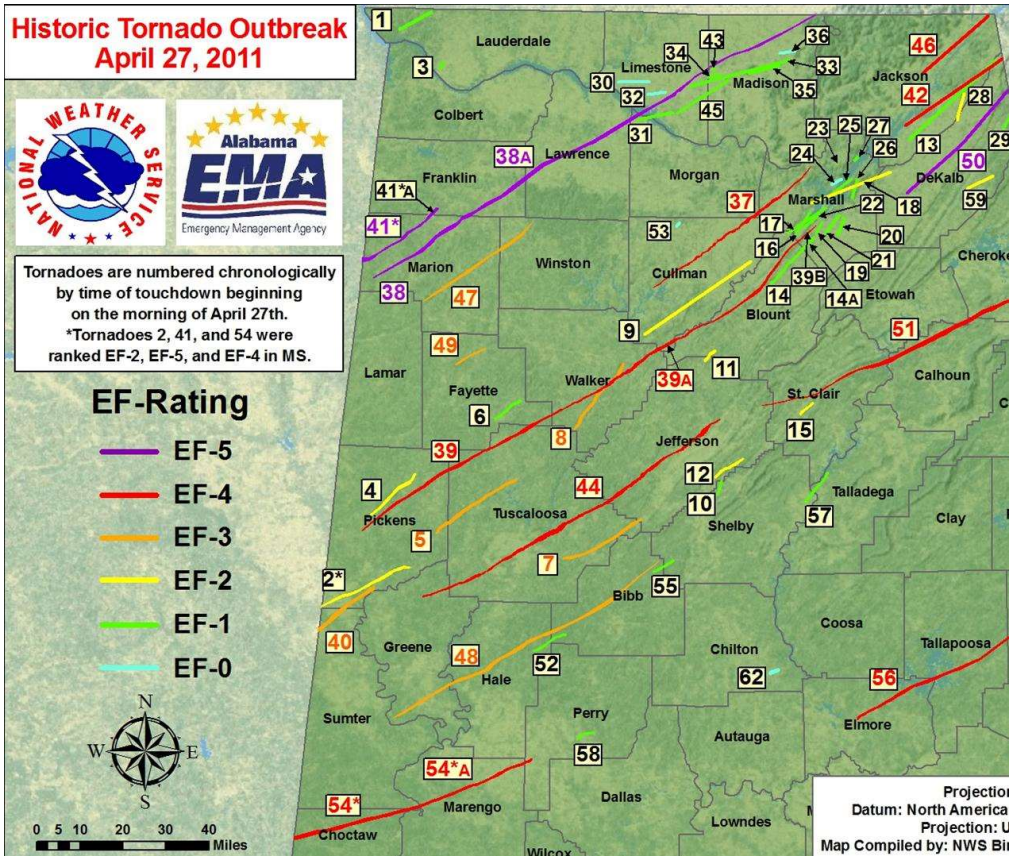
December 10, 2021 outbreak

- After dark, violent tornadoes - historic
  - Longest-tracked tornado on record - KY
    - ✓166 miles *(U.S. record for December)*
  - Deadliest December outbreak
    - ✓93 fatalities *(previously: 38 in 1953)*





A prediction / warning “opportunity”

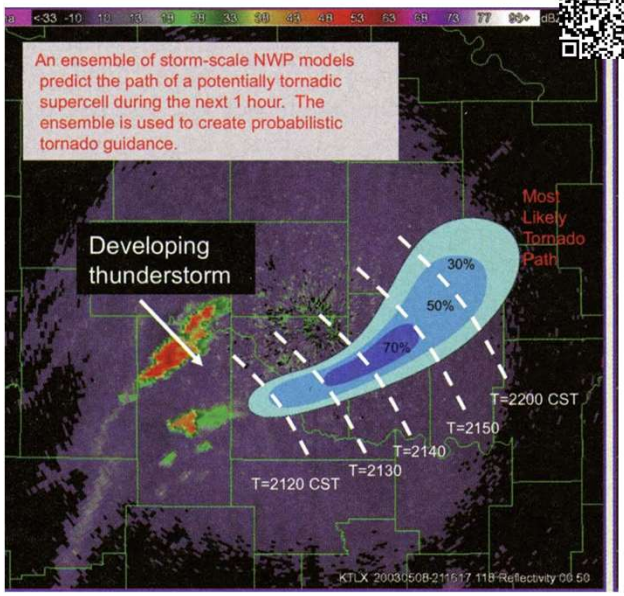


- April 27, 2011 (62 AL tornadoes)
  - 71 miles, 1:17, 22 dead
  - 72 miles, 1:25, 7 dead
  - 81 miles, 1:31, 65 dead
  - 116 miles, 2:10, 13 dead

Devastating tornadoes often move in straight lines!

Multiple paths to reduce casualties

- Change nature of severe storm/tornado warnings
- Move people out of the way!
- Make warnings w/numerical prediction –
  - Warn on Forecast (WoF)
  - Method is an analysis/forecast cycle broadly known as *data assimilation*
  - WoF is ~operational now
    - ✓run in the cloud
    - ✓forecasts on request!



Warn on Forecast (NOAA/NSL)

NOAA/NSSL Warn on Forecast home page >

- The computational configuration
  https://wof.nssl.noaa.gov/configuration.php