Evaluation of “non-standard” variables

Barbara Brown (bgb@ucar.edu)
National Center for Atmospheric Research (NCAR)
Boulder, Colorado, USA

Verification Methods Tutorial
Berlin, Germany

JWGFVR

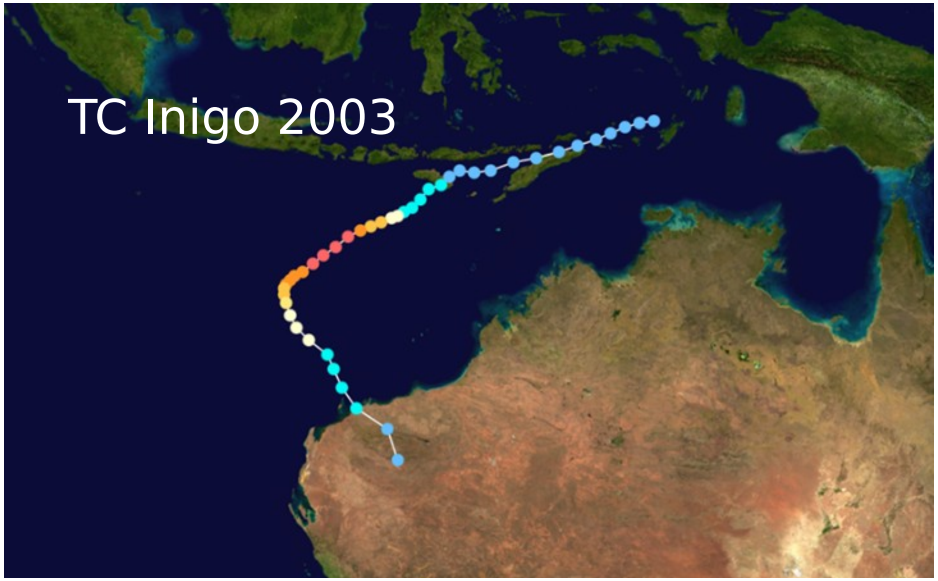
NCAR

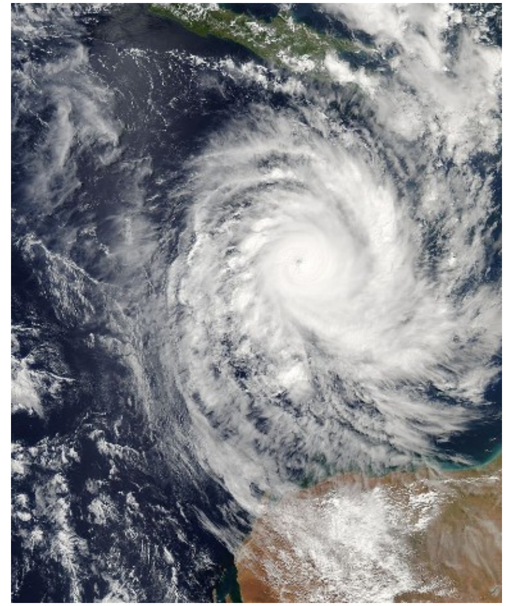
What makes variables "non-standard"

- Not focused on commonly measured weather variables (e.g., T, Td, Wind speed, u, v, etc.)
- ???
- Perhaps…
  - Not observed well or require special observations
  - Forecasts of things that are difficult to measure
  - Predictions directly serve specific users
    - Particular events are forecasted for particular decision-making situations (e.g., C&V for determining if planes can land)
    - The stakes can be high! (i.e., the decisions can have major safety and/or economic impacts)

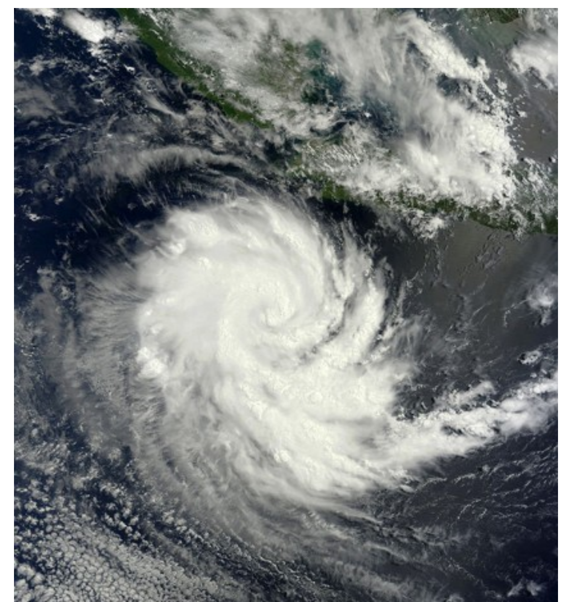
Topics

- Tropical cyclones
- Wildfires and fire weather
- Sea ice
- Aviation
- Resources





TROPICAL CYCLONE FORECAST VERIFICATION



What makes TC forecast verification "special"?

- *High impact* ***weather*** **and** *High impact weather* ***Forecasts***
  - TC **weather** impacts affect large populations and have major economic impacts
  - TC weather **forecasts** impact disaster management decisions
- *TC forecasts are given intense attention by the media and public – in the public "eye", so to speak*
- ***Observations*** are generally inferred and limited

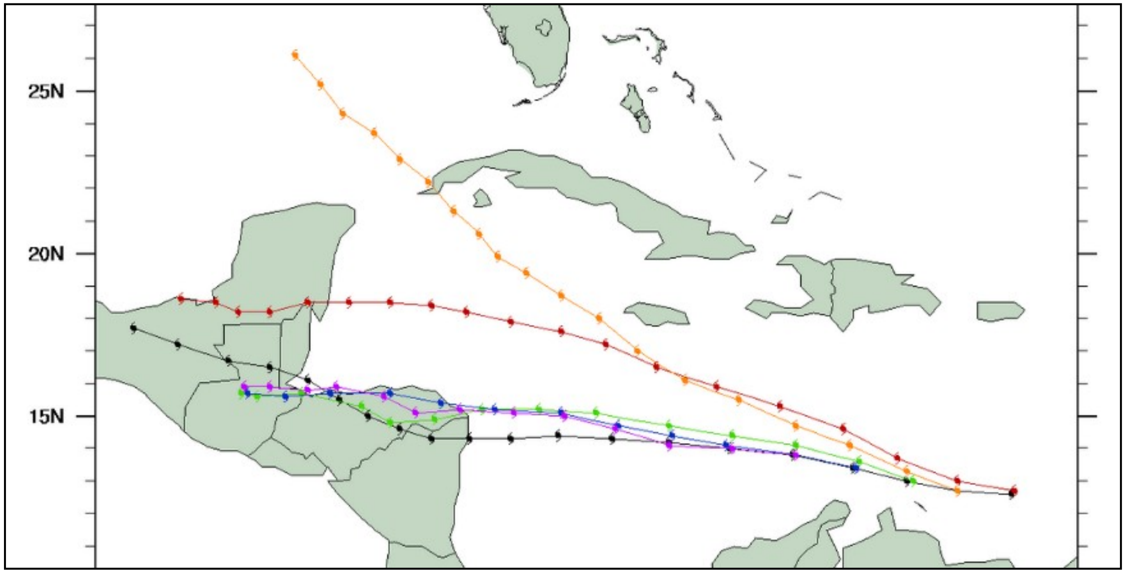
What is ***not*** *different?*

- Information is needed by Managers, Forecasters, Model developers and End users
- Basic verification methods are applicable, in general (i.e., continuous, categorical, probabilistic)

What attributes of TC forecasts?

Deterministic

- TC track
  - Overall error
  - Cross-track error
  - Along-track error
  - Landfall timing and location



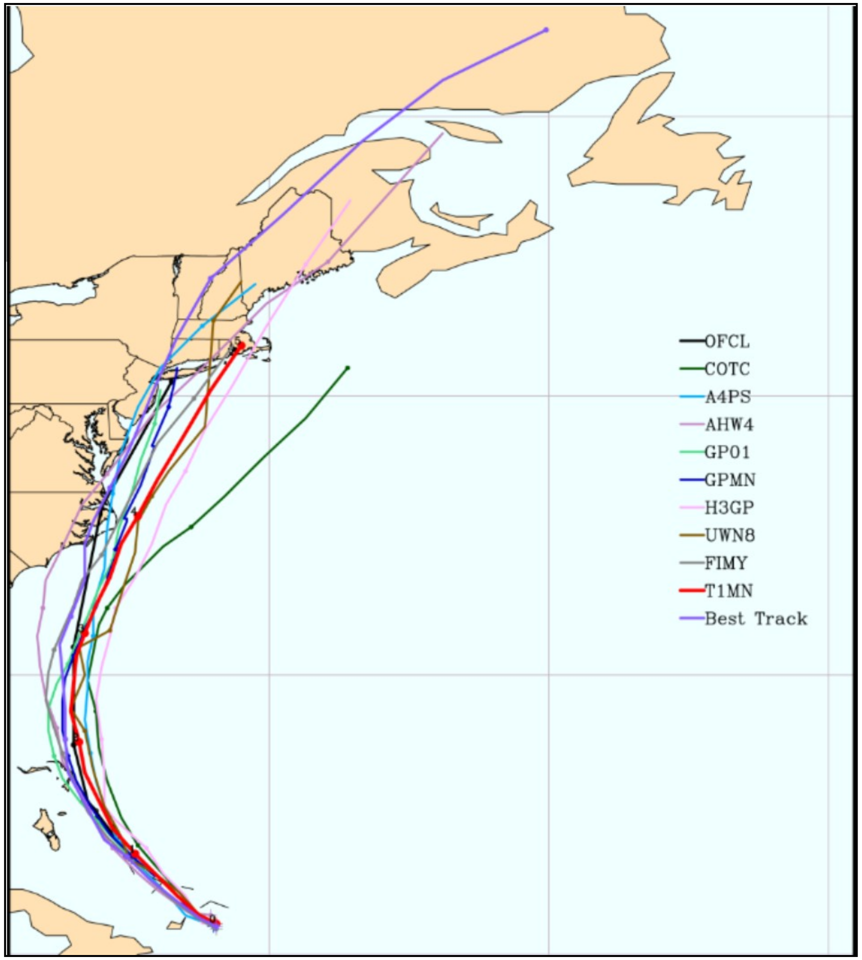
- Intensity
  - maximum wind
  - central pressure
  - temporal trend (rapid intensification)

- Wind field
- Size / radii
- Precipitation
- Temporal consistency
- Storm surge
- Waves

What Attributes of TC forecasts?

Ensemble

- Track distribution
- Strike probability
- Intensity distribution
  - mean / median
  - spread
  - 90th percentile
- Prob (wind > threshold)
- Prob (precip > threshold
- Storm surge
- Landfall timing



What verification methods are appropriate?

Since we are evaluating a variety of variables and attributes…

A variety of methods are used

- Categorical
  - Rapid intensification / weakening
- Continuous
  - Intensity, track location, wind, size, winds, precipitation, …
- Probabilistic / ensemble
  - Track and intensity, location ellipses, exceedance probabilities, precipitation, winds, size, strike probability, …

- Spatial
  - Wind structure, precipitation, …

What about observations?

Many hurricane observations are inferred…

As usual there is no such thing as “truth” – but maybe more so for tropical cyclones than other phenomena

Track and intensity

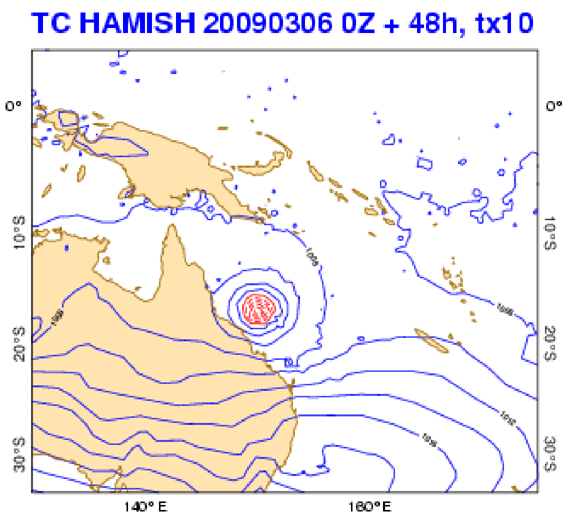
- Identified in “*Best track*” - Subjective analysis
  - Track: Latitude, longitude
  - Intensity: Minimum sea level pressure, maximum 1-min surface wind speed
- Best track is an analysis of all of the latest information about a storm in post-analysis
  - Uses satellite and reconnaissance information
  - Smoothed version of the track
  - Intensity often subjectively inferred from flight level winds or satellite information (Dvorak technique)

Precipitation and wind fields

Over oceans limited to satellite based information + data from reconnaissance

Forecast characteristics

- Forecast types
  - *Human-generated* tracks and intensity
  - *NWP Models:* Cyclone tracks are analyzed from gridded model output using a "tracker" algorithm
  - *Statistical models*: Especially useful for predicting intensity
- Model interpolation
  - Needed to adjust "late" models with current track information
- Reference forecasts
  - Statistical forecast or climate/persistence



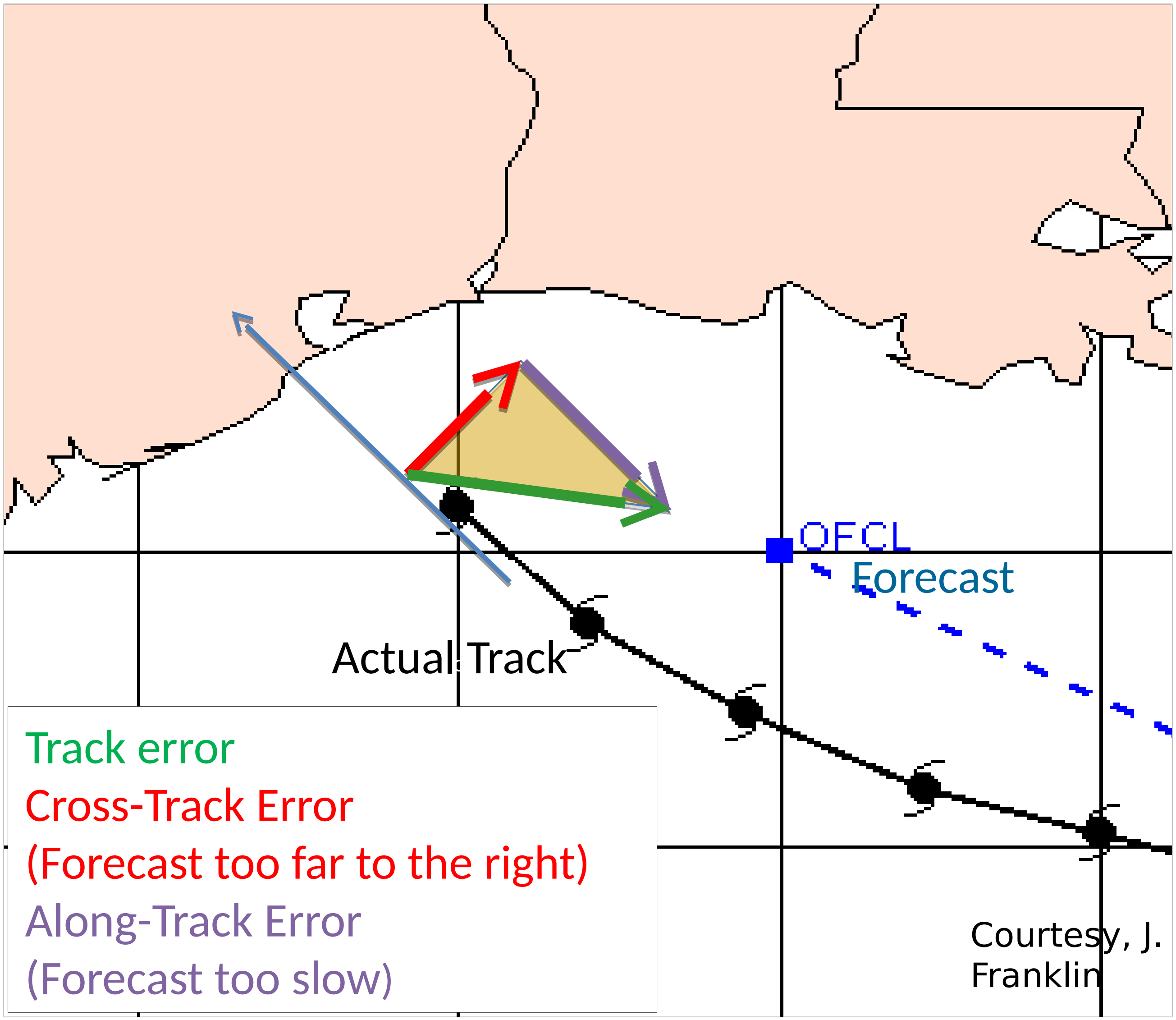
Quality of deterministic TC Track forecasts

Example questions:

- What are the track errors (along-track, cross-track)?
- What are the intensity errors?
- Are temporal intensity trends correctly predicted?
- What is the error in timing of landfall?
- What is the error in forecast maximum wind (rain)?
  - Multi-day total precipitation
- Is the spatial distribution of wind (rain) correct?

Others?

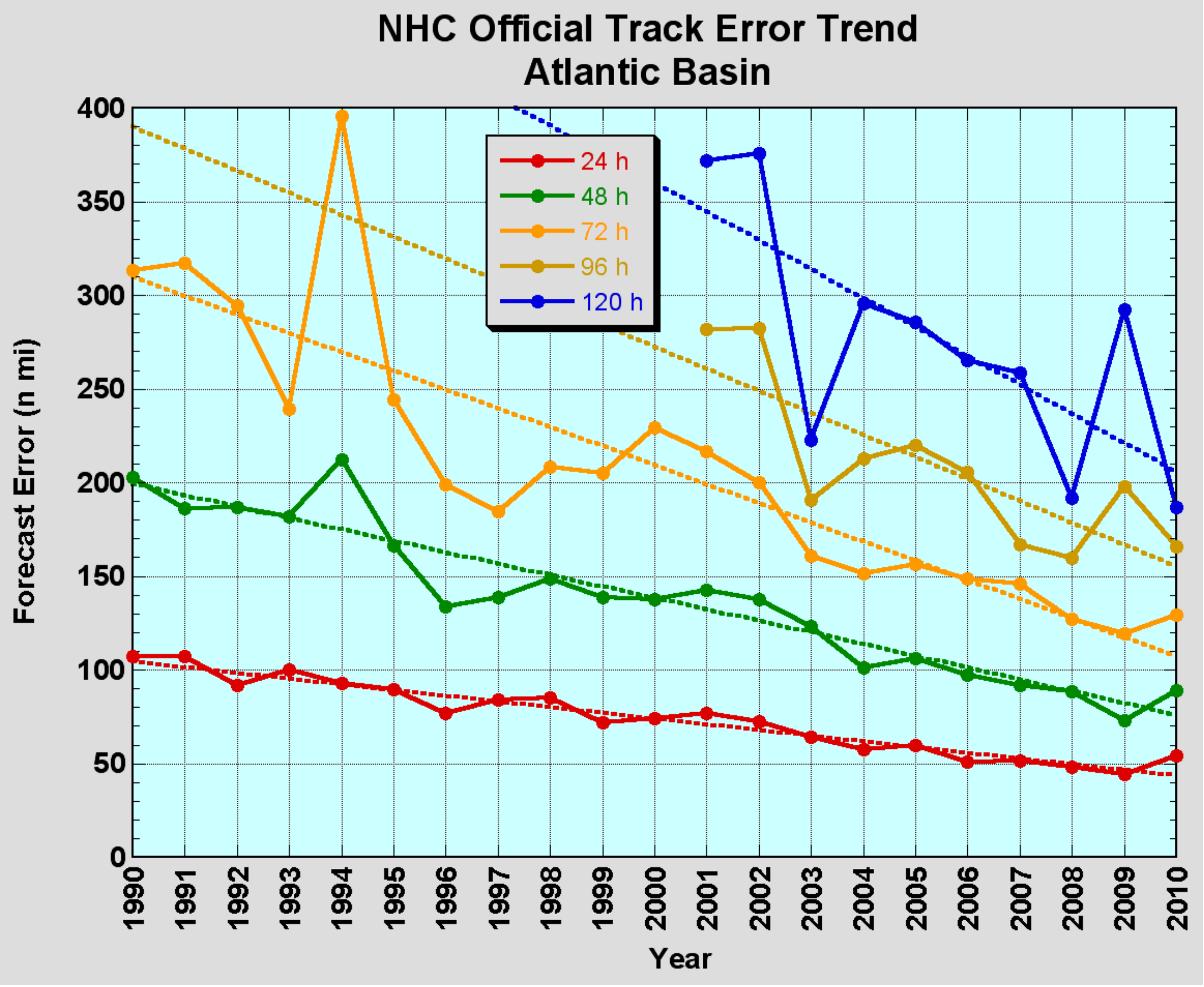
Total, Along-, and Cross-Track Errors



Cross-track measures error in **direction** of movement

Along-track measures error in **speed** of movement

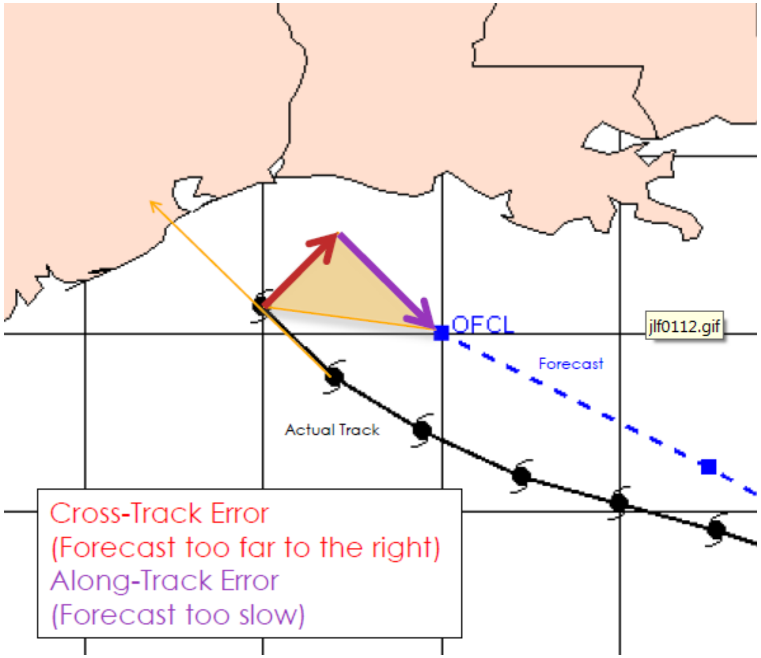
Track error summary

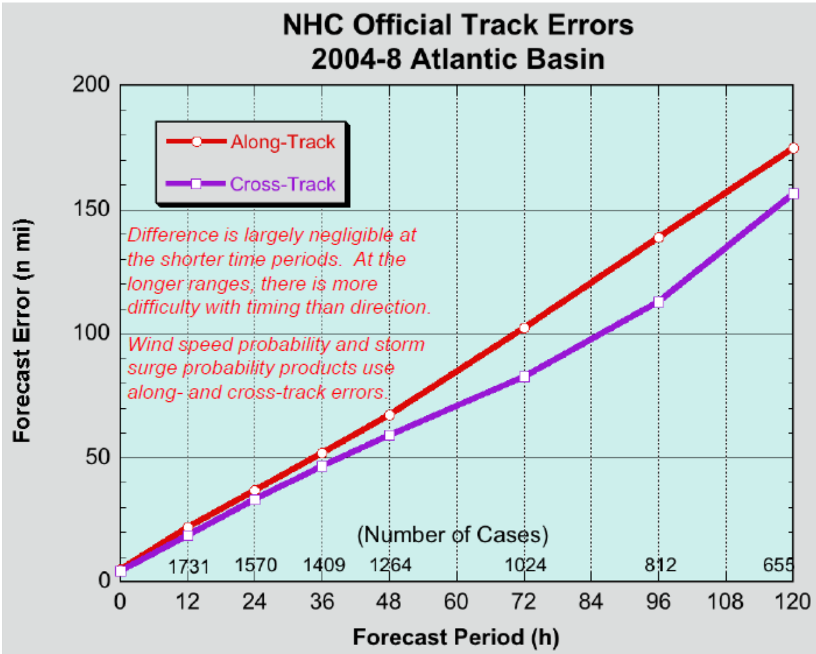


Track error is typically summarized as Average error (always positive)

Verification methods for deterministic TC forecasts

- Example: Along-track and cross-track errors

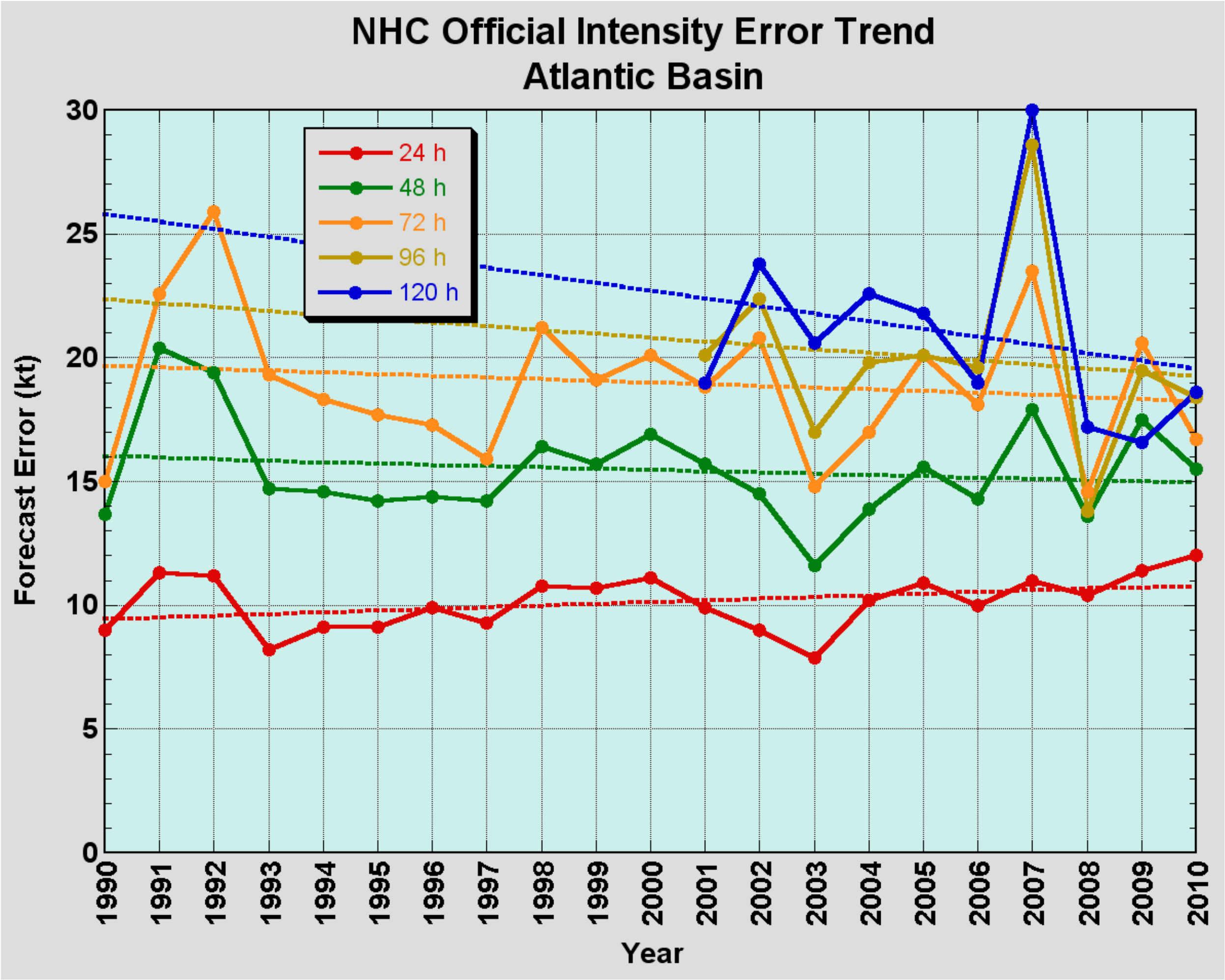




- “Along-track” measures errors in “**Speed**”
- “Cross-track” measures errors in “**Direction**”

Courtesy James Franklin, NHC

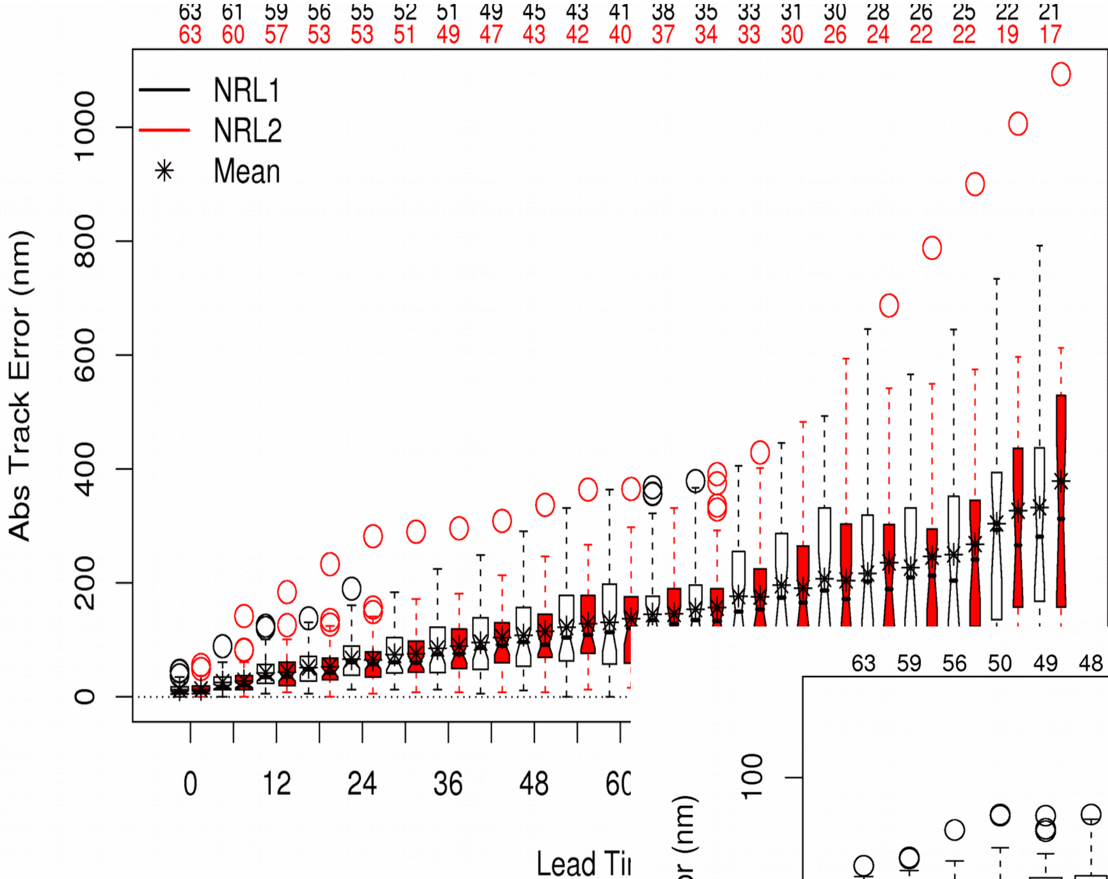
Intensity error



Intensity error is typically summarized as

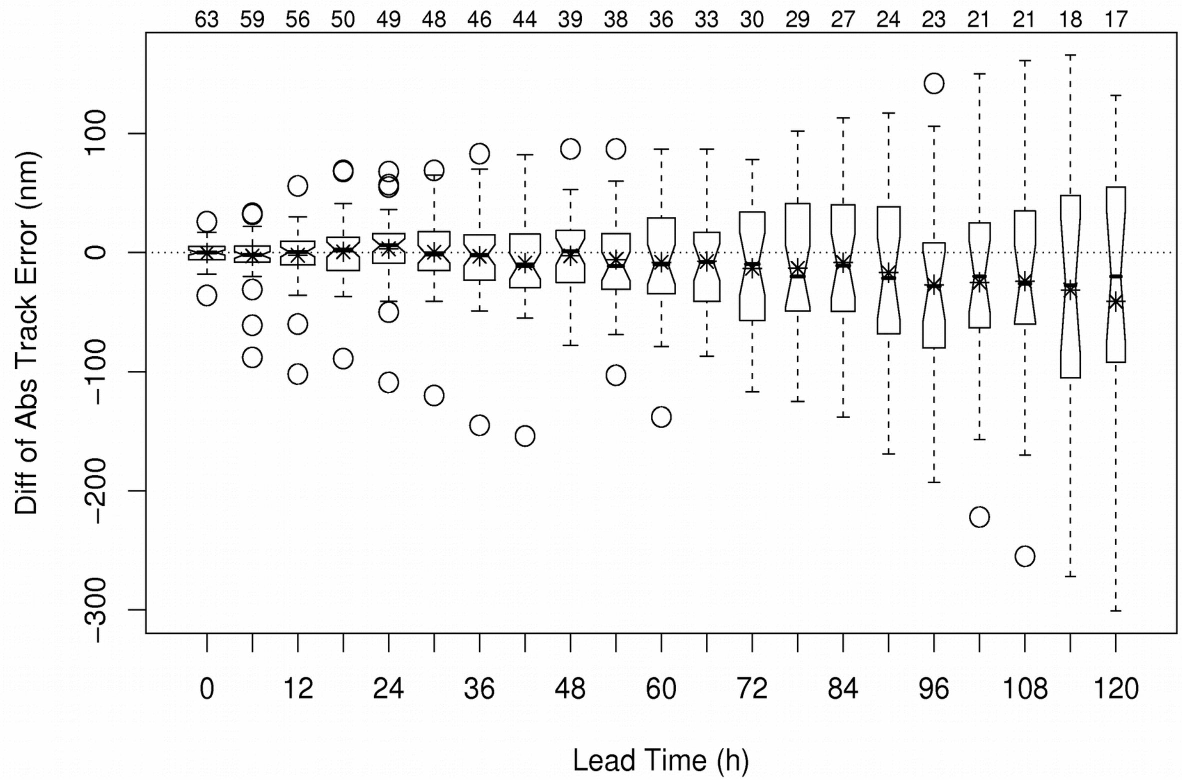
(1) mean error (bias) or

(2) mean absolute error (always positive)



Alternative:

Examine distributions of errors



And differences in errors

Paired comparisons: Track and intensity
% improvement and p-value

FSI	0.0	-5.1	-9.1	-11.5	-15.0	-19.8	-16.3	-28.0	-33.4	-47.6
rack	0%	-15%	-17%	-16%	-17%	[illegible]	[illegible]	[illegible]	[illegible]	23%
and water)	-	0.999	0.999	0.999	0.999	[illegible]	[illegible]	[illegible]	[illegible]	.987
HMI	0.0	-3.0	-5.0	-5.4	-9.9	-14.2	-7.2	-11.4	-6.4	-15.5
rack	0%	-8%	-9%	-7%	-10%	-12%	-5%	-7%	-4%	-7%
and water)	-	0.979	0.977	0.927	0.989	0.927	0.551	0.661	0.508	0.836
HMI	0.0	-0.8	1.4	3.1	3.6	3.2	2.1	0.4	-0.7	-2.6
ensity	0%	-9%	10%	18%	20%	17%	11%	2%	-4%	-14%
and water)	-	0.992	0.995	0.999	0.999	0.999	0.893	0.210	0.338	0.805

Target forecasts significantly improve on standard of comparison for intensity forecasts

Paired comparisons: Track and intensity
% improvement and p-value

FSI	0.0	-5.1	-9.1	-11.5	-15.0	-19.8	-16.3	-28.0	-33.4	-47.6
rack	0%	-15%	-17%	-16%	-17%	-18%	-12%	-19%	-19%	-23%
and water)	-	0.999	0.999	0.999	0.999	0.990	0.929	0.950	0.971	0.98
				-5.4	-9.9	-14.2	-7.2	-11.4	-8.4	-15.5
				-7%	-10%	-12%	-5%	-7%	-4%	-7%
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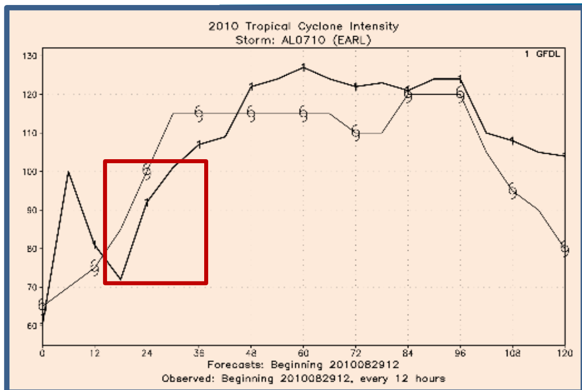
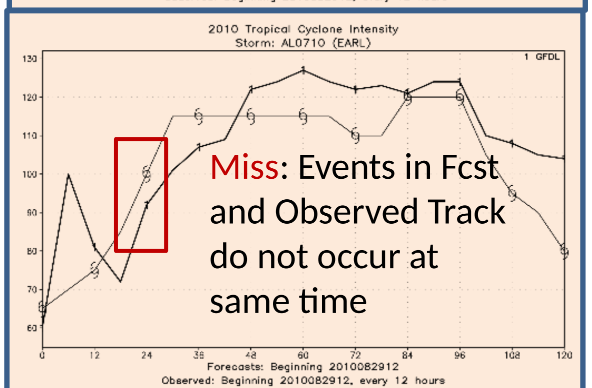
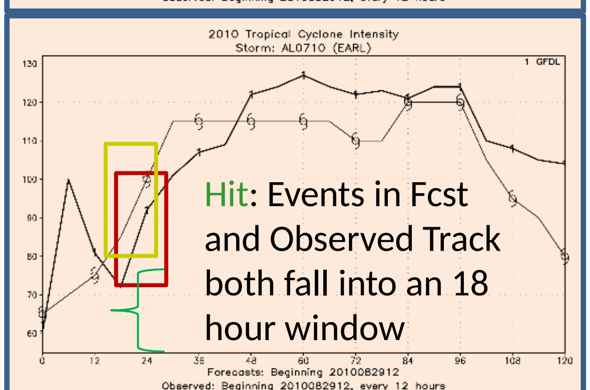
Target forecasts significantly *reduce performance* relative to standard of comparison for track forecasts and some intensity forecasts

Rapid intensification and weakening (RI/RW)







Using a flexible definition of Rapid Intensification / Rapid Weakening events

Standard Definition: NHC Definition 30m/s in 24 hours

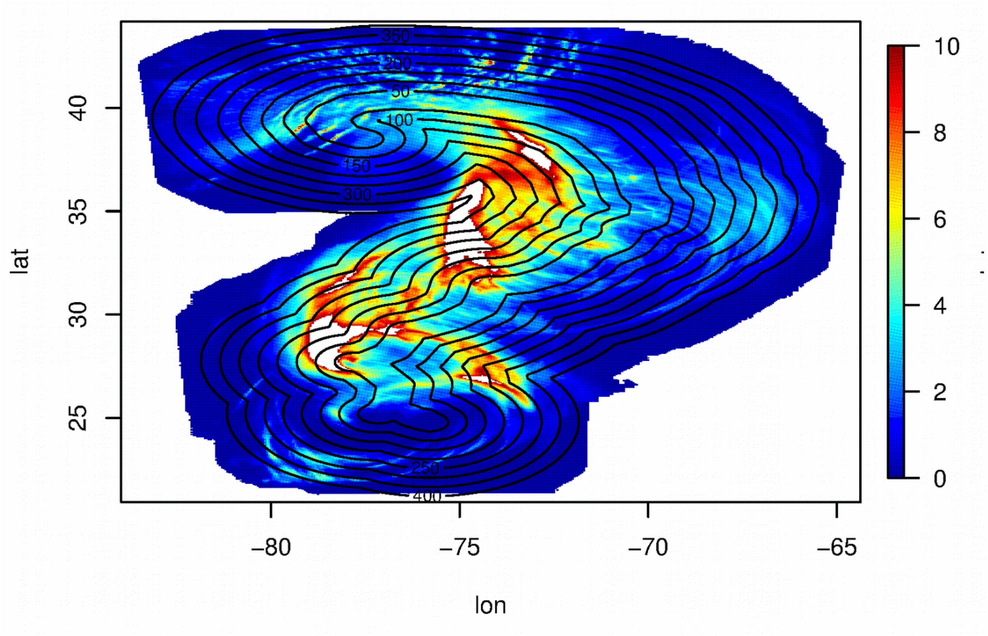
Stricter Definition: 30m/s in 12 hours

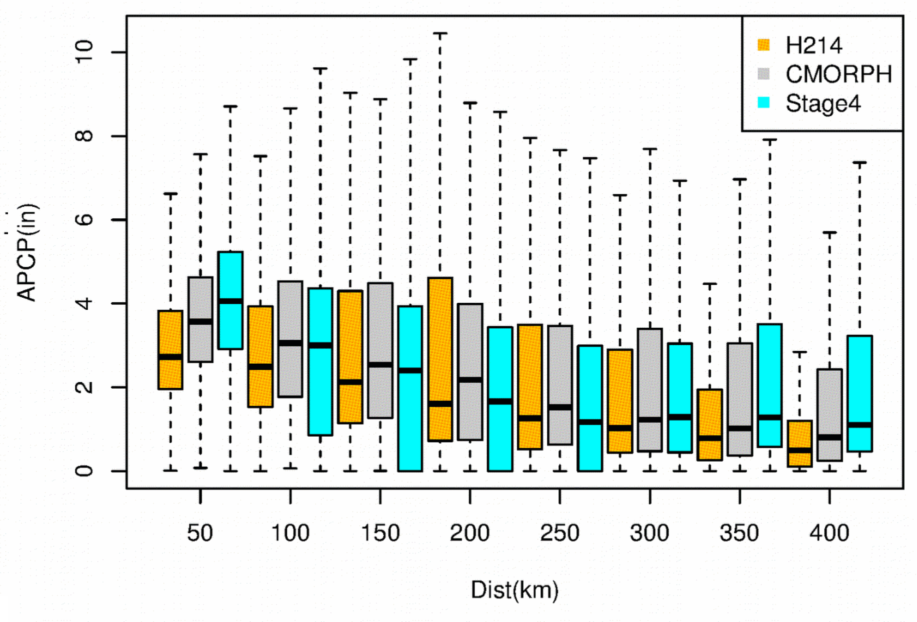
"Fuzzy" Definition: Adjustable window to give credit even if there is a timing error

Categorical statistics for RI/RW events can then be calculated: *POD, FAR, CSI, etc.*

Evaluating features: TC precipitation evaluation

Storm-following masking with range rings





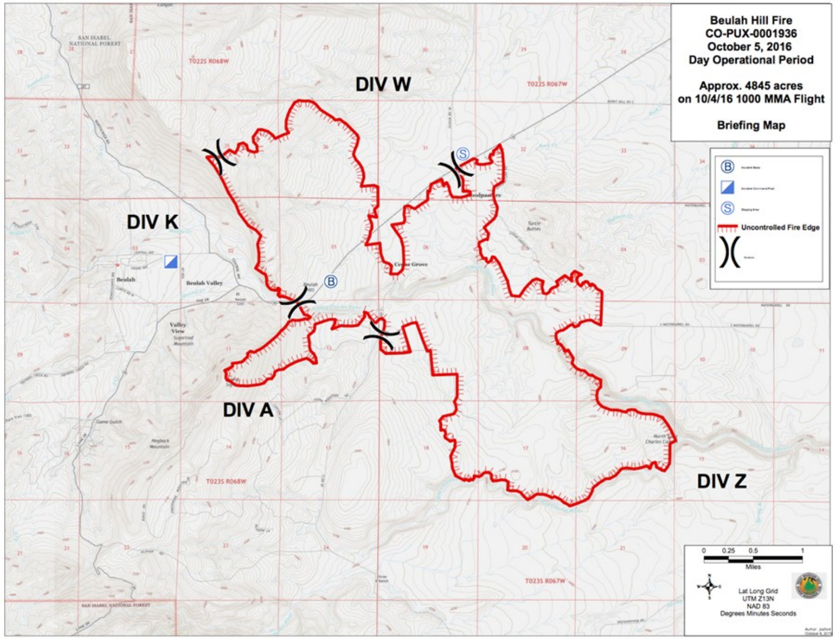
Shifted forecast precipitation to account for track error, with range rings around the best track

Accumulated storm precipitation distributions for Model, Satellite, and Radar by range ring

WILDFIRES AND FIRE WEATHER

Fire weather verification

- Wildfire conditions and associated weather can be predicted by humans, spread simulators, or coupled weather-fire models
- Variables of interest:
  - Fire perimeter
  - Fire rate-of-spread
  - Underlying wind and other weather variables
  - Significant fire behavior (flame length, pyrocumulus, etc.)

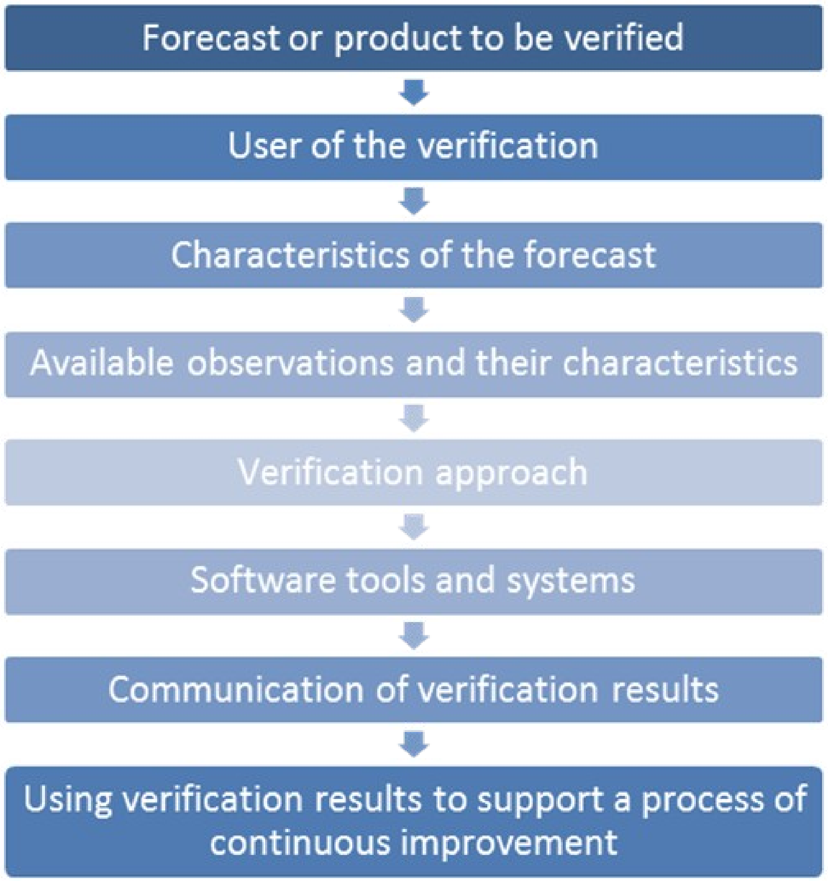


Many complications with evaluation of these variables

Meeting the users' needs

Australia BOM process

- Focus on process to identify and document stakeholders' goals
- Different users have different needs
  - Management (Which model/simulator is best?)
  - Fire behavior analysts (How accurate are fire predictions?)
  - Simulator / Model developers (quantify uncertainty in weather inputs to identify simulator improvements needed)

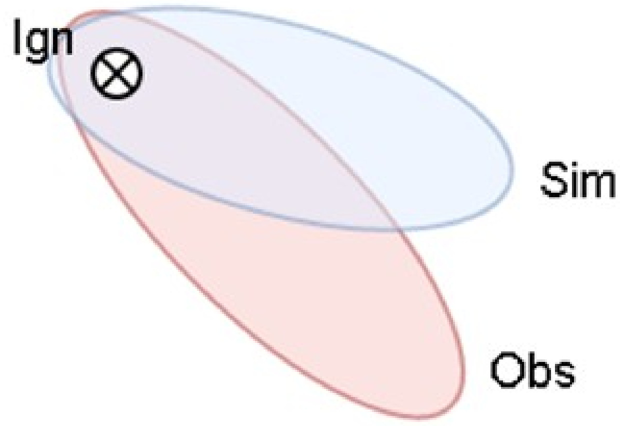


Observation issues

- Fire perimeter
  - Observed from the air?
  - Satellite?
  - Obs are infrequent at best…
- Only rare observations of significant phenomena (flame height, heat release, pyrocumulus, etc.)
- Weather observations very limited…
  - Poor coverage in complex terrain

Verification approaches

- Spatial methods
  – MODE? CRA?
- Contingency table statistics (TS, Bias)
- Area measures



Issue: What about the impact of fire suppression efforts?

From Ebert presentation Monday

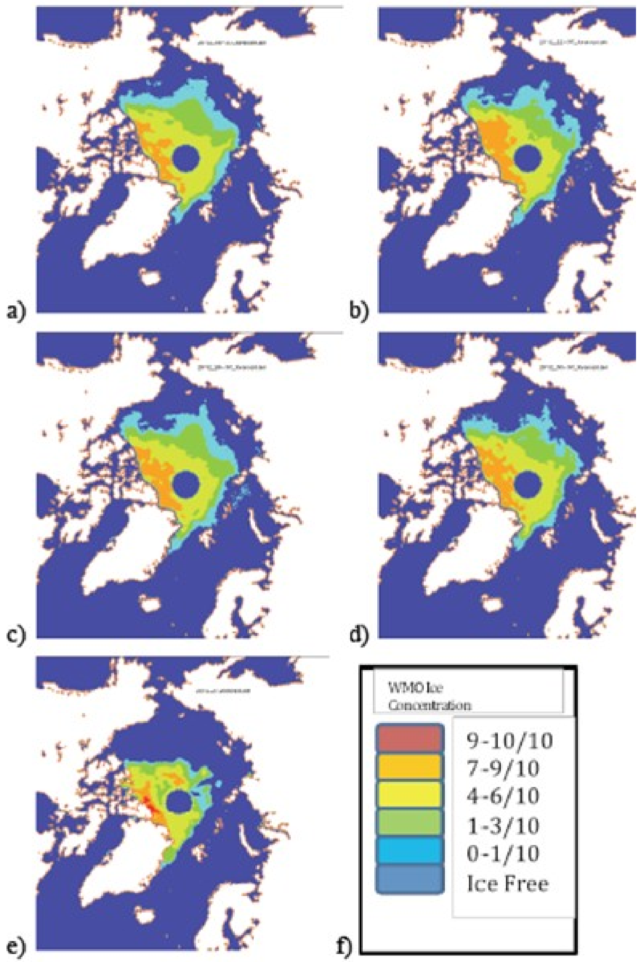
SEA ICE

The Challenges

- Arctic sea ice is changing dramatically and quickly
- Climate, seasonal, and other models depend on good estimates of sea ice extent – and other characteristics
- Many users interested in impacts of changes in ice (shipping, mining, etc.)
- Observations are limited…
  - Mainly satellite-based
  - Ice extent is best observed; other properties (thickness, concentration) more limited

Possible verification methods

- Spatial
  - MODE
  - CRA
  - Image warping
- Distance metrics:
  - Baddeley, Hausdorff (see methods in R package)
  - See references by Gilleland and others at https://ral.ucar.edu/projects/icp/



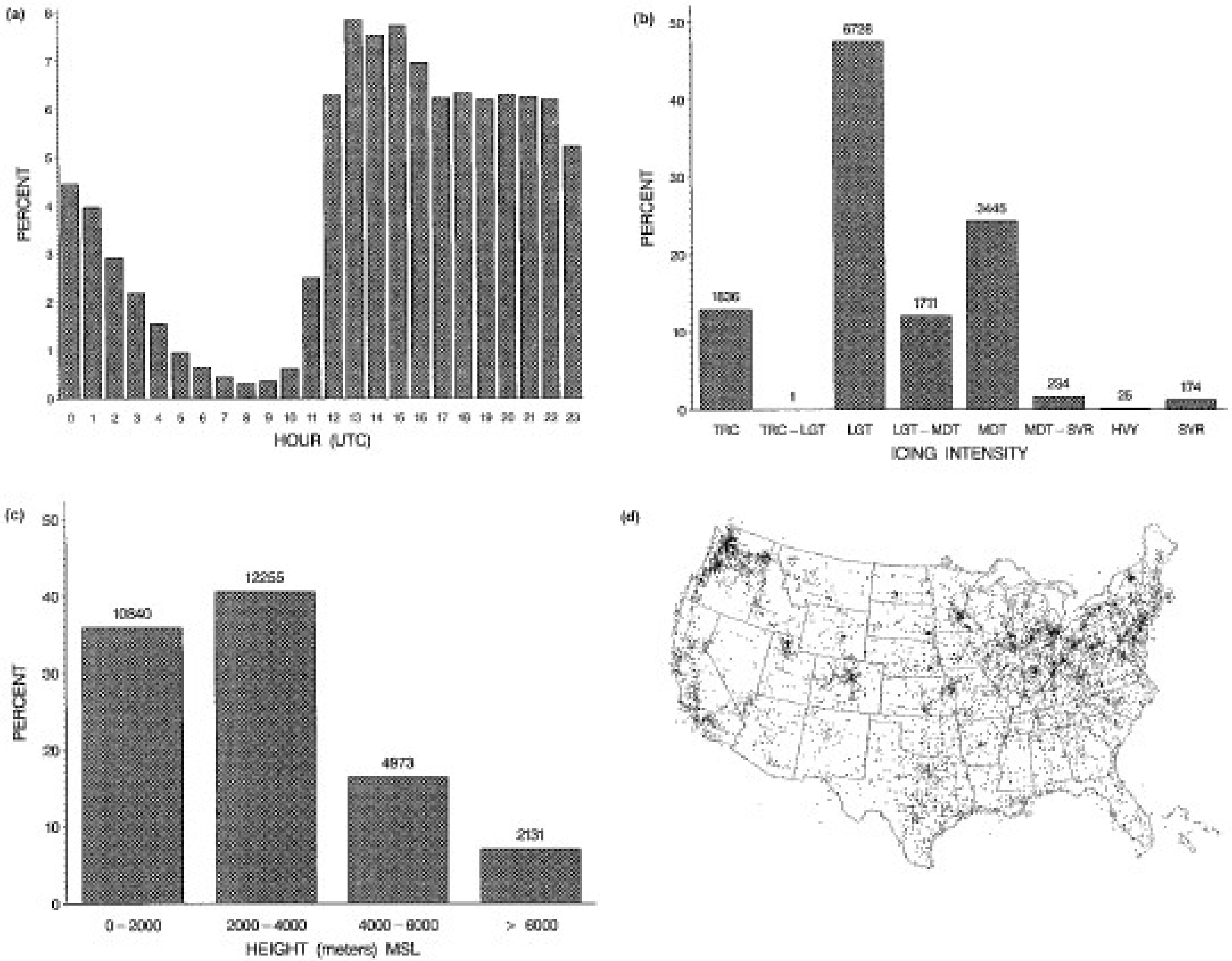
From Arbetter 2012

AVIATION WEATHER

Issues

- Main issue: Observations!!
  - Limited in space and time
  - Biased in space and time, and by event (e.g., around airports, on flight routes; where weather is good!)

Example: Icing PIREPs



Notable biases in location, time, intensity

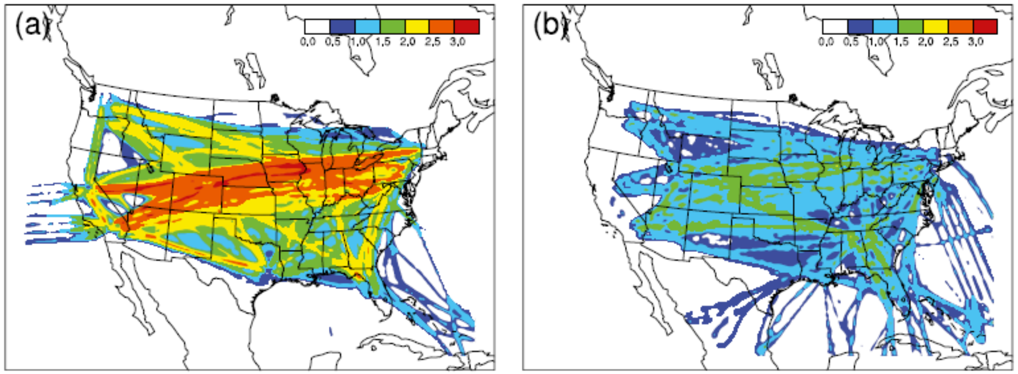
Potentially systematic in areas near airports?

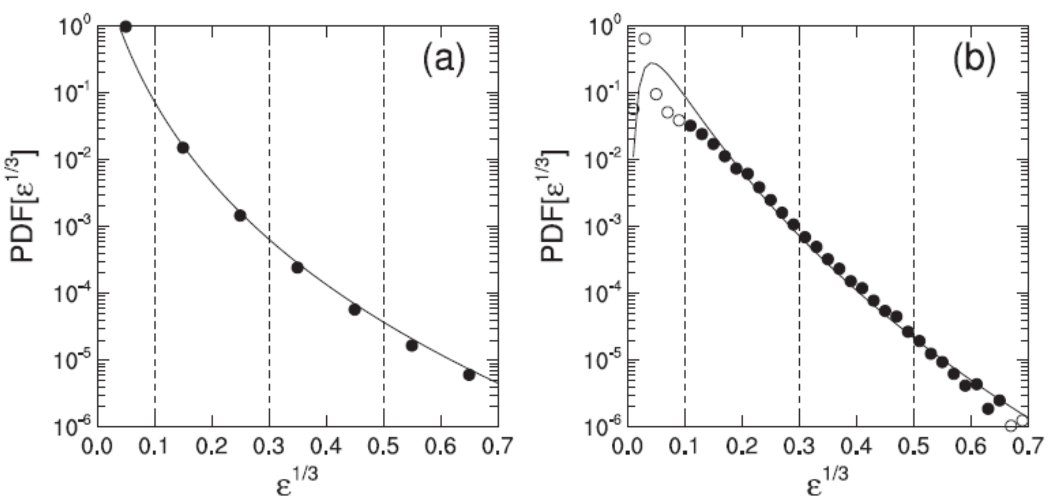
From Brown et al. 1997 (Weather and Forecasting)

EDR (turbulence) example: Automated observations

Spatial biases and *highly* skewed distribution

- Difficult to tune forecasts to predict “positive” events
- Turbulence forecasts may not be representative of areas where planes don’t fly

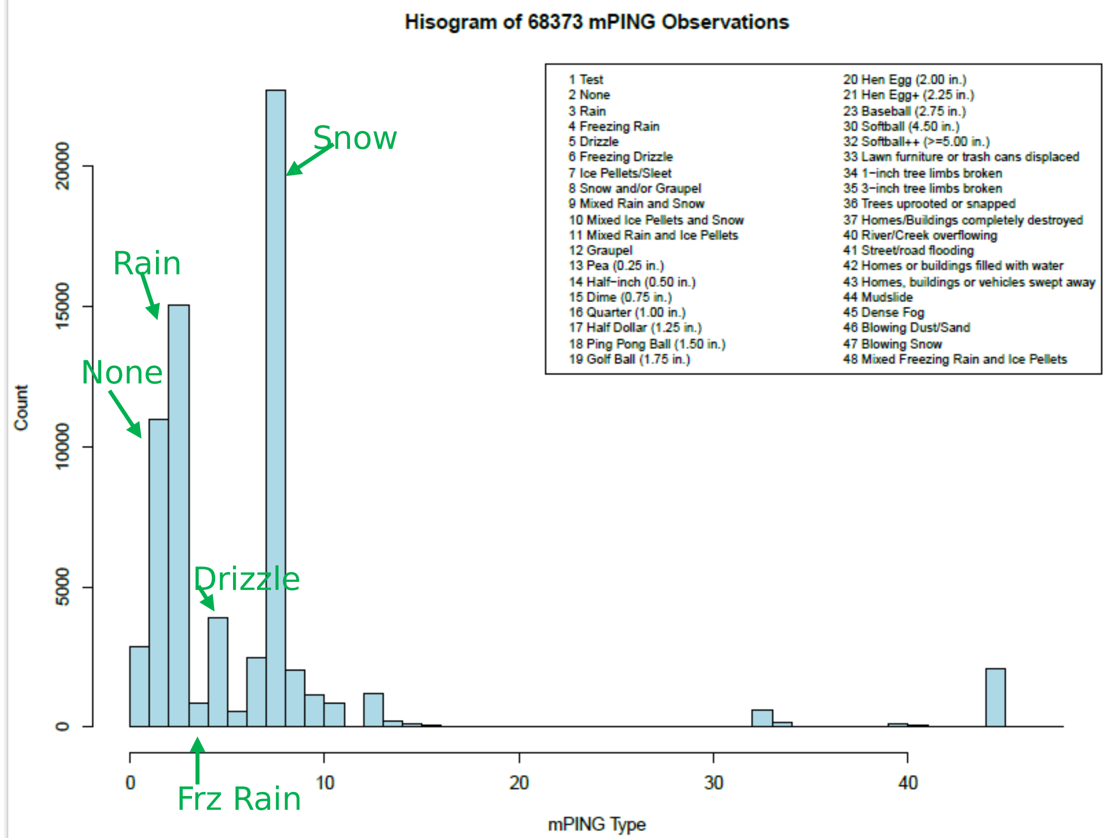




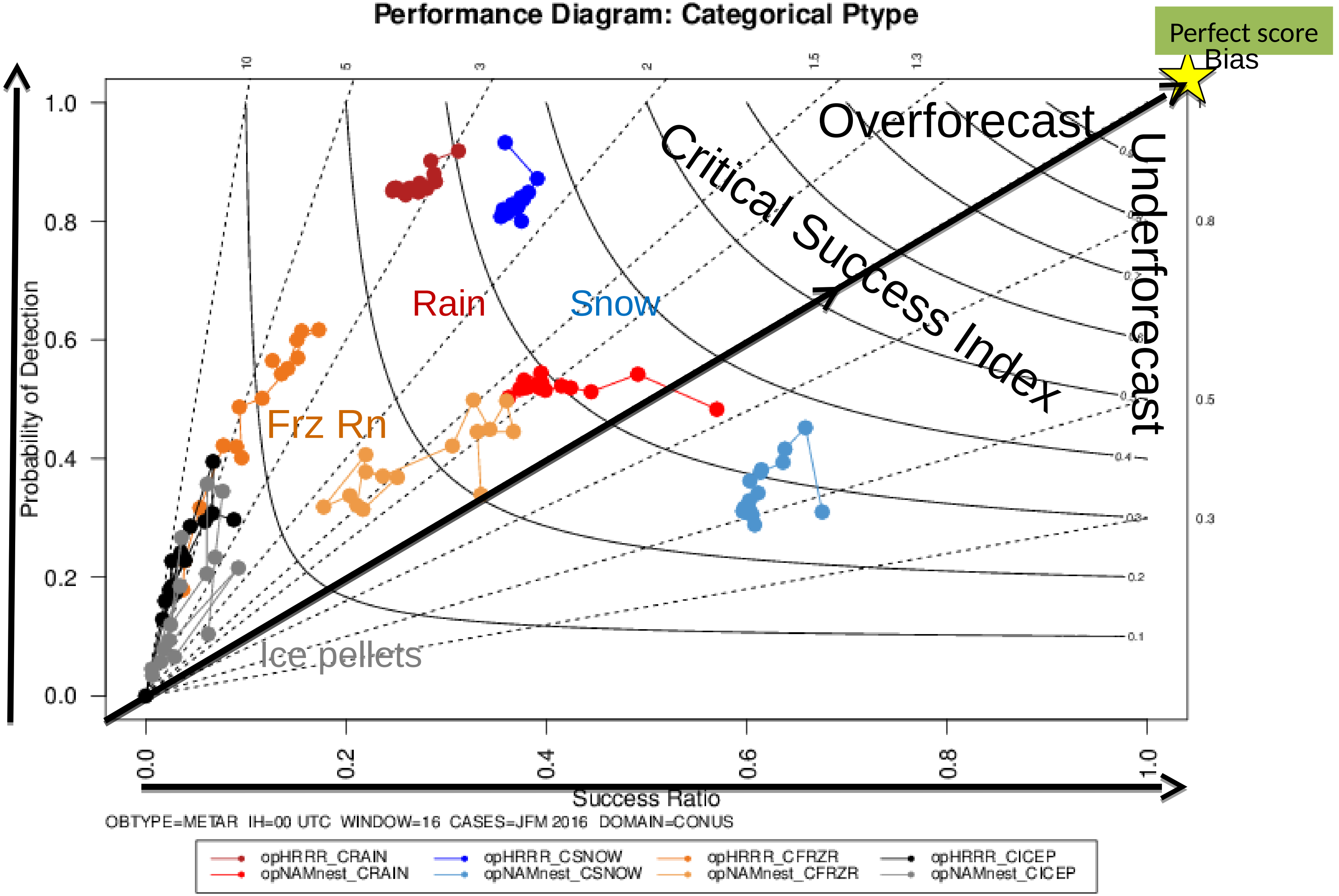
From Sharman et al. 2014 (*J. Appl. Climate and Weather*)

TAIWIN: Terminal Area Icing Weather Information for NextGen (TAIWIN)

- Goal: Improve NWP forecasts of precip type (especially freezing rain/drizzle) to predict super-cooled liquid
- First step: Identify appropriate observations
  - METARs
  - Radar/Satellite
  - Crowd-sourced (MPING)



Courtesy J. Wolff



Credit: J. Wolff, NCAR

Observation implications…

- Observation characteristics often *limit the kinds of verification* that can be done
  - ***Ex***: In-flight icing, turbulence; gridded C&V
- Observation characteristics can *bias the verification results*
- Improvement of aviation weather observations would greatly help improve development and evaluation of aviation weather forecasts

SUMMARY

Summary

- Standard verification methods apply to most variables

  But:

  – Focus is needed on what aspects users care about
    - Good news: Typically easier to understand who the users are

  – Care needed to understand implications of observation biases
    - May limit what verification approaches are reasonable to apply

- Observation issues – availability, uncertainty – are even more important than for more standard variables!

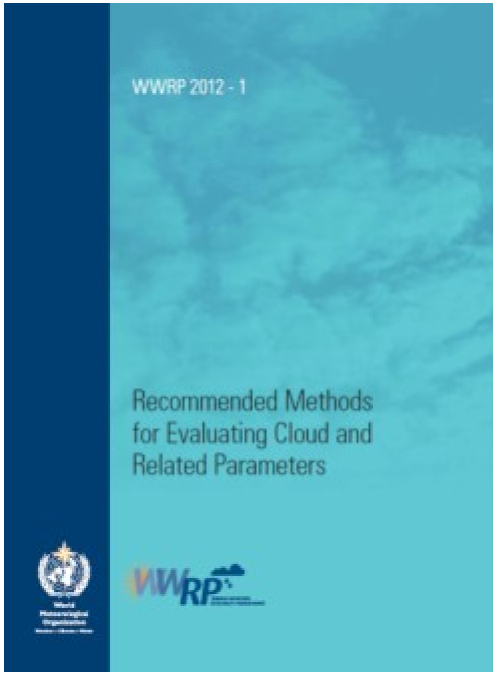
RESOURCES

WMO Working Group on Forecast Verification Research

Many resources on the WMO website:

https://www.wmo.int/pages/prog/arep/wwrp/new/Forecast_Verification.html

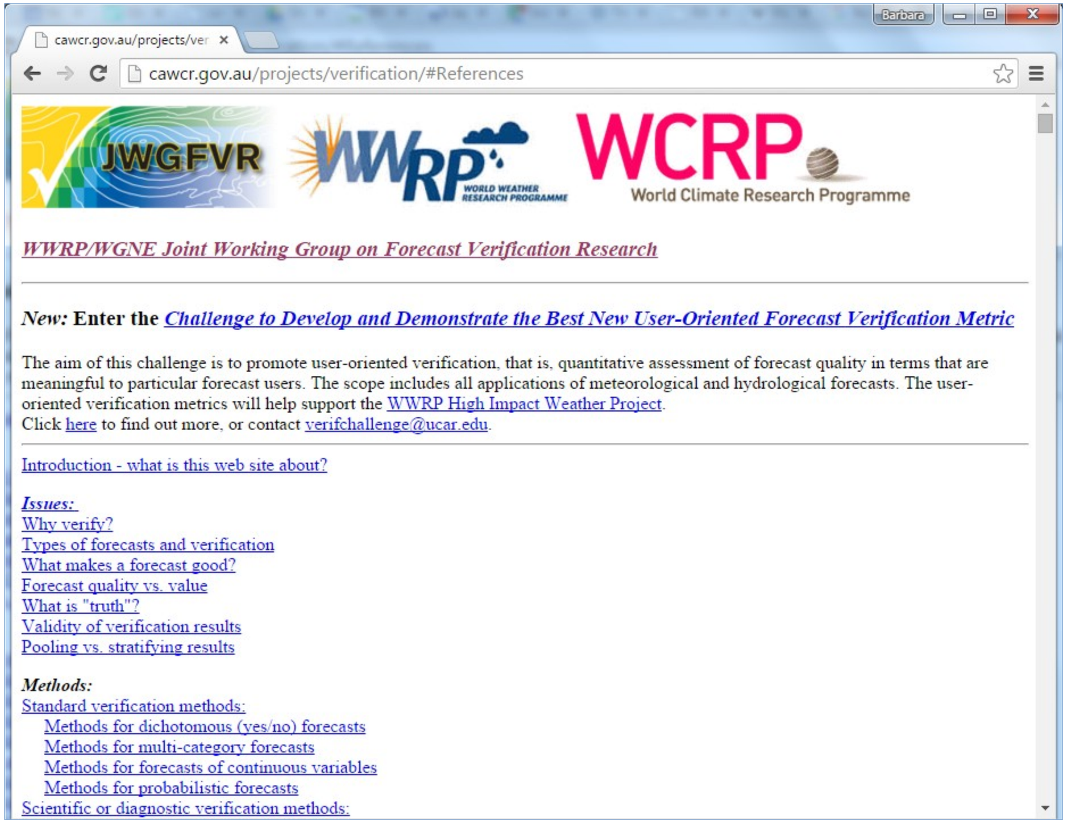
- Guidance documents
- Links to past tutorials
- Information about upcoming meetings, etc.



Resources: Verification methods and FAQ

- Website maintained by WMO verification working group (JWGFVR)
- Includes
  - Issues
  - Methods (brief definitions)
  - FAQs
  - Links and references
- Verification discussion group:

http://mail.rap.ucar.edu/mailman/listinfo/vx-discuss



http://www.cawcr.gov.au/projects/verification/

Resources: Overview papers

- Casati et al. 2008: *Forecast verification: current status and future directions*.

  Meteorological Applications, **15**: 3-18.

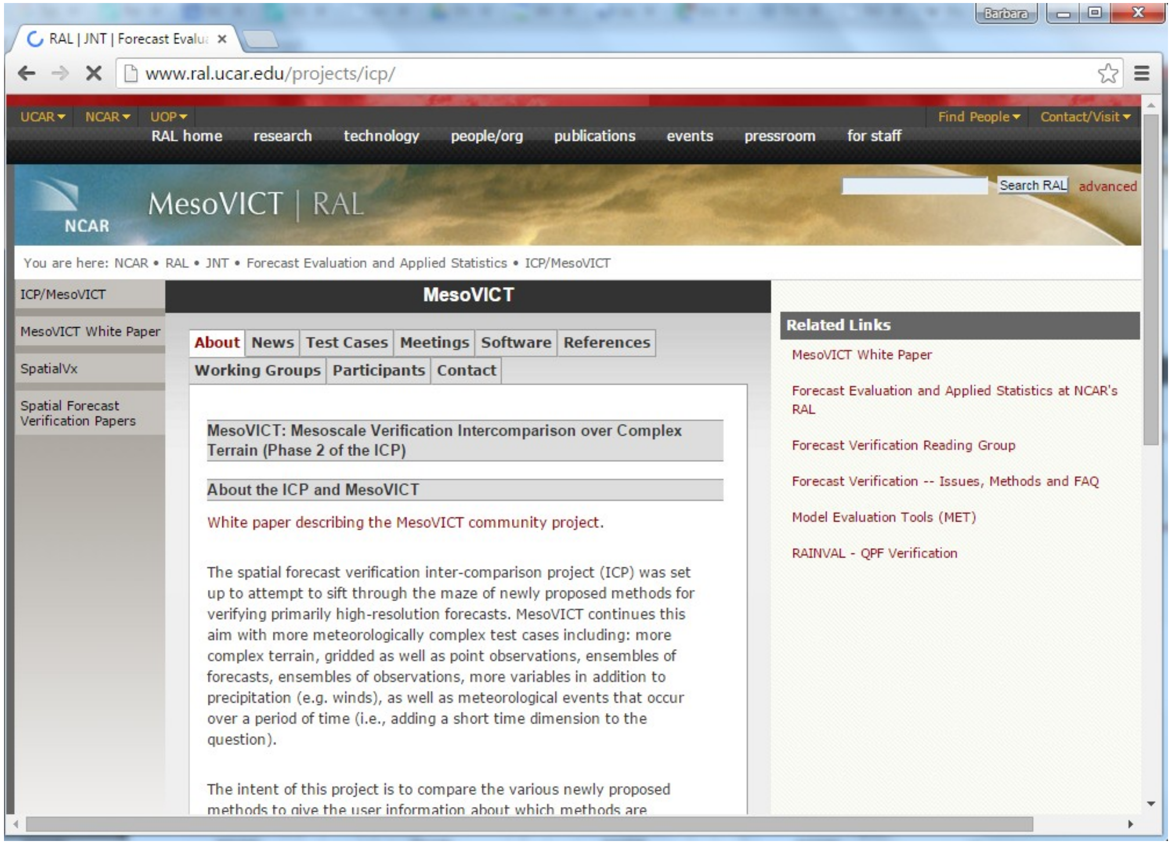
- Ebert et al. 2013: *Progress and challenges in forecast verification*

  Meteorological Applications, **20**, 130-139.

Information about spatial methods

MesoVICT website:

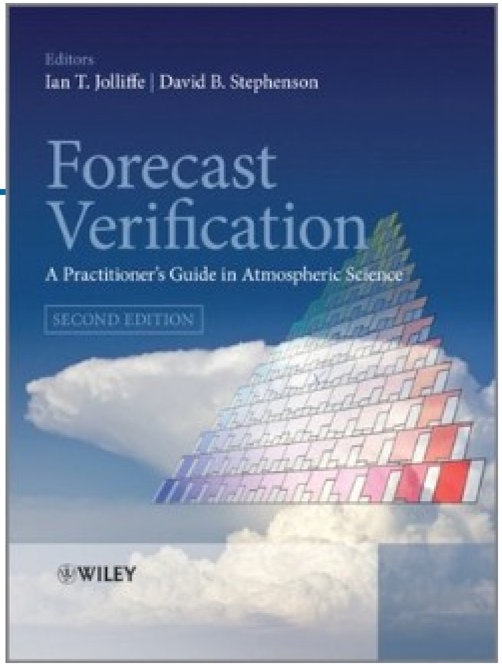
- Includes references and some software
- New results will be provided as available

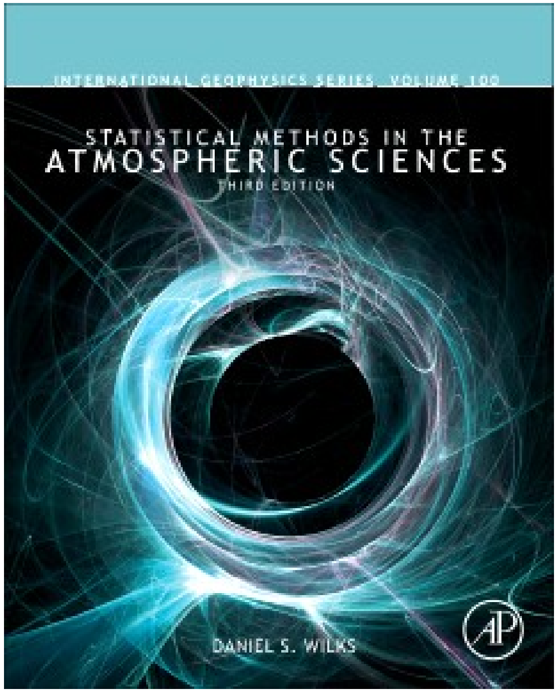


http://www.ral.ucar.edu/projects/icp/

Resources - Books

- Jolliffe and Stephenson (2012): *Forecast Verification: a practitioner's guide*, Wiley & Sons, 240 pp.
- Stanski, Burrows, Wilson (1989) *Survey of Common Verification Methods in Meteorology* (available at http://www.cawcr.gov.au/projects/verification/)
- Wilks (2011): *Statistical Methods in Atmospheric Science*, Academic press. (*Updated chapter on Forecast Verification*)





Software: R verification packages

- R is a flexible, open source statistical computing package
  - Available from https://www.r-project.org/
  - Works on all platforms
- "Verification" and "SpatialVx" packages are available from the contributed packages list on the "CRAN" website: http://cran.repo.bppt.go.id/ in Indonesia

- "Verification" package
  - Includes all standard verification metrics for
    - Contingency tables
    - Continuous variables
    - Probability forecasts
    - Ensemble forecasts
  - Many graphical tools (e.g., attribute diagrams)
- "SpatialVx" package
  - Includes many of the new spatial verification methods
  - New methods added as available

Software: Model Evaluation Tools (MET)

- MET is a freely available software package
- Supported to the community and well-documented
- Highly configurable and flexible
- Tutorials (on-line and in person) are available

- Includes
  - Traditional methods (contingency table, continuous, probabilistic)
  - Ensemble approaches
  - Spatial methods
  - Package for Tropical Cyclones (MET-TC)

MET is available at: www.dtcenter.org/met/users