Model Evaluation Tools – Tropical Cyclone (MET-TC)

Kathryn M. Newman
Introduction

- WHAT is MET-TC?
  - A set of tools to aid in TC forecast evaluation and verification
  - Developed to replicate (and add to) the functionality of the NHC verification software
  - Modular set of tools which utilize the MET software framework
    - Allows for additional capabilities and features to be added to future releases

- WHY use MET-TC?
  - Provides TC verification statistics consistent with operational centers
  - Easily parse and subset TC datasets
Compile & build

- Must use **METv4.1** for MET-TC
- MET-TC specific code and tools:
  - **bin/**: executables for each MET-TC module (tc_dland, tc_pairs, tc_stat)
  - **data/config/**: configuration files (TCPairsConfig_default, TCStatConfig_default)
  - **data/tc_data/**: static files used in MET-TC (aland.dat, wwpts_us.txt)
  - **doc/**: contains the MET-TC User’s Guide
  - **src/tools/tc_utils/**: source code for three MET-TC modules
  - **scripts/Rscripts/**: contains the R script (plot_tcmmpr.R) which provides graphics tools for MET-TC
Getting Started...

- The **best track analysis** is used primarily used as the observational dataset in MET-TC.
  - May use any reference dataset in ATCF format

- The input files must be in Automated Tropical Cyclone Forecasting System (ATCF) **format**.

- Model output must be run through an internal/external **vortex tracking algorithm**
Observations

- Observations are an important consideration for TC verification
  - Quality and quantity of observations available
    - Typically sparse or intermittent

- The best track analysis is used primarily used as the observational dataset in MET-TC.

All operational model aids and best track analysis can be found on the NHC ftp server: ftp://ftp.nhc.noaa.gov/atcf/archive/
Observations

- **Best track analysis**
  - Subjective assessment of TC’s center location and intensity (6 hr) using all observations available
  - Includes center position, maximum sfc winds, minimum center pressure, quadrant radii of 34/50/64 kt winds
  - Subjectively smoothed representation of storm’s location and intensity over its lifetime
Getting Started...

• Automated Tropical Cyclone Forecasting System (ATCF) format
  • First developed at Naval Oceanographic and Atmospheric Research Laboratory (NRL)
  • Currently used for National Hurricane Center (NHC) operations

• Must adhere to for MET-TC tools to properly parse the input data (first 17 columns must exist - missing values ok)
  • To ensure proper matching input data must contain:
    • BASIN, CY, YYYYMMDDHH and TAU fields

✓ MET-TC User’s Guide outlines these 17 columns and necessary fields
✓ For detailed information on ATCF format: http://www.nrlmry.navy.mil/atcf_web/docs/database/new/abdeck.txt
Getting Started...

- Model output must be run through an internal/external vortex tracking algorithm
- Any algorithm that obtains basic position, maximum wind, minimum sea level pressure information from model forecasts (in ATCF format) may be used
- Fully supported and freely available: GFDL Vortex Tracker

For more information (includes code and documentation):
Primary functions of the code are:

- Compute pair statistics from ATCF input files
- Filter pair statistics based on user specifications
- Compute summary statistics
**TC-dland**

- Aids in quickly parsing data for filter jobs:
  - Only verify over water
  - Threshold verification based on distance to land
  - Exclusion/inclusion of forecasts within a specified window of landfall

- **Input**: ASCII file containing Lon/Lat coordinates of all coastlines/islands considered to be a significant landmass. ([aland.dat](#))

- **Output**: gridded field representing distance to nearest coastline/island in NetCDF format
TC-dland

- **Usage:**
  
  ```
  tc_dland
  out_file
  [-grid_spec]
  [-noll]
  [-land file]
  [-log file]
  [-v level]
  ```

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>out_file</code></td>
<td>Indicates NetCDF output file containing the computed distances to land</td>
</tr>
<tr>
<td><code>-grid_spec</code></td>
<td>Overrides the default 1/10(^{th}) grid</td>
</tr>
<tr>
<td><code>-noll</code></td>
<td>Skips writing to reduce size of NetCDF file</td>
</tr>
<tr>
<td><code>-land file</code></td>
<td>Overwrites the default land data file</td>
</tr>
<tr>
<td><code>-log file</code></td>
<td>Outputs log messages to the specified file</td>
</tr>
<tr>
<td><code>-v level</code></td>
<td>Overrides the default level of verbosity (2)</td>
</tr>
</tbody>
</table>

- This exe only needs to be run once to establish the NetCDF file.
- If running over the AL/EP and desire NHC land/water determination: NetCDF file in build
TC-pairs

- Produces pair statistics on independent model input or user-specified consensus forecasts
- Matches forecast with reference TC dataset (most commonly Best Track Analysis)
- Pair generation can be subset based on user-defined filtering criteria
- ASCII pair output allows for new or additional analyses to be completed without performing full verification process
**Tc_pairs**

- **Input**: NetCDF gridded distance file, forecast/reference in ATCF format
- **Output**: TCSTAT format
  - Header, column-based ASCII output
- **Usage**: `tc_pairs`  
  - `-adeck source`  
  - `-bdeck source`  
  - `-config file`  
  - `[-out base]`  
  - `[-log file]`  
  - `[-v level]`

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-adeck source</code></td>
<td>ATCF format file containing TC model forecast</td>
</tr>
<tr>
<td><code>-bdeck source</code></td>
<td>ATCF format file containing TC reference dataset</td>
</tr>
<tr>
<td><code>-config file</code></td>
<td>Name of configuration file to be used</td>
</tr>
<tr>
<td><code>[-out base]</code></td>
<td>Indicates path of output file base</td>
</tr>
<tr>
<td><code>[-log file]</code></td>
<td>Name of log file associated with pairs output</td>
</tr>
<tr>
<td><code>[-v level]</code></td>
<td>Indicates desired level of verbosity</td>
</tr>
</tbody>
</table>
**Tc_pairs**

- Configuration file determines filtering criteria

<table>
<thead>
<tr>
<th>MODEL</th>
<th>VALID_MASK</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORM_ID</td>
<td>CHECK_DUP</td>
</tr>
<tr>
<td>BASIN</td>
<td>INTERP_12</td>
</tr>
<tr>
<td>CYCLONE</td>
<td>CONSENSUS</td>
</tr>
<tr>
<td>STORM_NAME</td>
<td>LAG_TIME</td>
</tr>
<tr>
<td>INIT_BEG/INIT_END</td>
<td>BEST_BASELINE</td>
</tr>
<tr>
<td>INIT_INC/INIT_EXC</td>
<td>OPER_BASELINE</td>
</tr>
<tr>
<td>VALID_BEG/VALID_END</td>
<td>MATCH_POINTS</td>
</tr>
<tr>
<td>INIT_HR</td>
<td>DLAND_FILE</td>
</tr>
<tr>
<td>INIT_MASK</td>
<td>VERSION</td>
</tr>
</tbody>
</table>

- Take care not to over-subset!
- Can perform additional filters with tc_stat tool

```cpp
// Model initialization time windows to include or exclude
// init_beg = "";
// init_end = "";
// init_inc = [];
// init_exc = [];

// Valid model time window
// valid_beg = "";
// valid_end = "";

// Model initialization hours
// init_hour = [];

// lat/lon polylines defining masking regions
// init_mask = "";
// valid_mask = "";

// Specify if the code should check for duplicate ATCF lines
// check_dup = FALSE;

// Specify if special processing should be performed for interpolated models with
// 12-hour spacing.
// interp12 = TRUE;
```
### Tc_pairs

- Output in ASCII space delimited columns with header information

<table>
<thead>
<tr>
<th>Column Number</th>
<th>Header column Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VERSION</td>
<td>Version number</td>
</tr>
<tr>
<td>2</td>
<td>AMODEL</td>
<td>User provided text string designating model name</td>
</tr>
<tr>
<td>3</td>
<td>BMODEL</td>
<td>User provided text string designating model name</td>
</tr>
<tr>
<td>4</td>
<td>STORM_ID</td>
<td>BBCCYYY designation of storm</td>
</tr>
<tr>
<td>5</td>
<td>BASIN</td>
<td>Basin</td>
</tr>
<tr>
<td>6</td>
<td>CYCLONE</td>
<td>Cyclone number</td>
</tr>
<tr>
<td>7</td>
<td>STORM_NAME</td>
<td>Name of Storm</td>
</tr>
<tr>
<td>8</td>
<td>INIT</td>
<td>Initialization time of forecast</td>
</tr>
<tr>
<td>9</td>
<td>LEAD</td>
<td>Forecast lead time in HH format</td>
</tr>
<tr>
<td>10</td>
<td>VALID</td>
<td>Forecast valid time in YYYYMMDD_HH</td>
</tr>
<tr>
<td>11</td>
<td>INIT_MASK</td>
<td>Initialization time masking grid applied</td>
</tr>
<tr>
<td>12</td>
<td>VALID_MASK</td>
<td>Valid time masking grid applied</td>
</tr>
<tr>
<td>13</td>
<td>LINE_TYPE</td>
<td>Output line type (TCMPR currently only line type)</td>
</tr>
<tr>
<td>14</td>
<td>TOTAL</td>
<td>Total number of matched pairs</td>
</tr>
<tr>
<td>15</td>
<td>INDEX</td>
<td>Index associated with init time</td>
</tr>
<tr>
<td>16</td>
<td>LEVEL</td>
<td>Level of storm classification</td>
</tr>
<tr>
<td>17</td>
<td>WATCH_WARN</td>
<td>HU or TS watch or warning in effect</td>
</tr>
<tr>
<td>18</td>
<td>INITIALS</td>
<td>Forecaster initials</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Column</th>
<th>Header</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>46, 47</td>
<td>A/BNE_WIND_50</td>
<td>a/bedck 50-knot radius winds in NE quadrant</td>
</tr>
<tr>
<td>48, 49</td>
<td>A/BSE_WIND_50</td>
<td>a/bedck 50-knot radius winds in SE quadrant</td>
</tr>
</tbody>
</table>
TC Metrics

- **Track Error**: great-circle distance between the forecast location and the actual location of the storm center (nmi)
- **Along-track Error**: indicator of whether a forecasting system is moving a storm too slowly/quickly
- **Cross-track Error**: indicates displacement to the right/left of the observed track
- **Intensity Error**: Difference between forecast and actual intensity (kts)

Graphics courtesy of NCAR TCMT
Tc_stat

- Provides summary statistics and filtering jobs on TCST output
  - **Filter job:**
    - Stratifies pair output by various conditions and thresholds
  - **Summary job:**
    - Produces summary statistics on specific column of interest
- **Input:** TCST output from tc_pairs
- **Output:** TCST output file for either filter or summary job
**Tc_stat**

- **Usage:**
  - `tc_stat` 
  - `-lookin source` 
  - `[ -out file ]` 
  - `[ -log file ]` 
  - `[ -v level ]` 
  - `[ -config file ]` 
  - `[ JOB COMMAND LINE ]`

- **Options Table**:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-lookin source</code></td>
<td>Location of TCST files generated from tc_pairs</td>
</tr>
<tr>
<td>-out file</td>
<td>Desired name of output file</td>
</tr>
<tr>
<td>-log file</td>
<td>Name of log file associated with tc_stat output</td>
</tr>
<tr>
<td>-v level</td>
<td>Verbosity level</td>
</tr>
<tr>
<td>-config file</td>
<td>Configuration file to be used</td>
</tr>
<tr>
<td>Job command line</td>
<td>specify joblist on command line</td>
</tr>
</tbody>
</table>

- **Note:** Configuration file options will be applied to every job, unless an individual job specifies a configuration option – joblist options will override.
Tc_stat

- Configuration file will filter TCST output from tc_pairs to desired subset over which statistics will be computed.

```c
// Stratify by the ADECK and BDECK distances to land.
water_only = FALSE;

// Specify whether only those track points for which rapid intensification occurred in the BDECK track between the current time and 24-hours prior should be retained.
rapid_inten = FALSE;
rapid_inten_thresh = >=30.0;

// Specify whether only those track points occurring near landfall should be retained, and define the landfall retention window as a number of seconds offset from the landfall time.
landfall = FALSE;
landfall_beg = -86400;
landfall_end = 0;

// Specify whether only those track points common to both the ADECK and BDECK tracks should be retained. May modify using the "match_points" job command option.
match_points = TRUE;

// Specify whether only those cases common to all models in the dataset should be retained.
event_equal = TRUE;
```

<table>
<thead>
<tr>
<th>AMODEL/BMODEL</th>
<th>INIT_MASK/VALID_MASK</th>
<th>LANDFALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORM_ID</td>
<td>LINE_TYPE</td>
<td>LANDFALL_BEG (END)</td>
</tr>
<tr>
<td>BASIN</td>
<td>TRACK_WATCH_WARN</td>
<td>MATCH_POINTS</td>
</tr>
<tr>
<td>CYCLONE</td>
<td>COLUMN_THREH_NAME (VAL)</td>
<td>EVENT_EQUAL</td>
</tr>
<tr>
<td>STORM_NAME</td>
<td>COLUMN_STR_NAME (VAL)</td>
<td>OUT_INIT_MASK</td>
</tr>
<tr>
<td>INIT_BEG/INIT_END</td>
<td>COLUMN_STR_NAME (VAL)</td>
<td>OUT_VALID_MASK</td>
</tr>
<tr>
<td>INIT_INC/INIT_EXC</td>
<td>INIT_THRESH_NAME (VAL)</td>
<td>JOBS [ ]</td>
</tr>
<tr>
<td>VALID_BEG/VALID_END</td>
<td>INIT_STR_NAME (VAL)</td>
<td>VERSION</td>
</tr>
<tr>
<td>VALID_INC/VALID_EXC</td>
<td>WATER_ONLY</td>
<td></td>
</tr>
<tr>
<td>INIT_HR/VALID_HR/LEAD</td>
<td>RAPID_INTEN (THRESH)</td>
<td></td>
</tr>
</tbody>
</table>
Tc_stat

- TC_stat output similar to TC_pairs for filter job (TCSTAT)
- Summary job output
  - "-column" option produces summary statistics for the specified column
  - "-by" option can be used to search each unique entry in selected column

<table>
<thead>
<tr>
<th>Column number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SUMMARY: (job type)</td>
</tr>
<tr>
<td>2</td>
<td>Column (dependent parameter)</td>
</tr>
<tr>
<td>3</td>
<td>Case (storm + valid time)</td>
</tr>
<tr>
<td>4</td>
<td>Total</td>
</tr>
<tr>
<td>5</td>
<td>Valid</td>
</tr>
<tr>
<td>6-8</td>
<td>Mean including normal upper and lower confidence limits</td>
</tr>
<tr>
<td>9</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>10</td>
<td>Minimum value</td>
</tr>
<tr>
<td>11-15</td>
<td>Percentiles (10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th})</td>
</tr>
<tr>
<td>16</td>
<td>Maximum Value</td>
</tr>
<tr>
<td>17</td>
<td>Sum</td>
</tr>
<tr>
<td>18-19</td>
<td>Independence time</td>
</tr>
<tr>
<td>20-23</td>
<td>Frequency of superior performance</td>
</tr>
</tbody>
</table>
Graphics tools

- Graphical capabilities are included in the MET-TC release
  - `plot_tcmpr.R`

- **Input:** TCSTAT tc_pairs output

- **Output:** R graphics, tc_stat logs/filter job TCSTAT (optional)

- **Usage:** `Rscript plot_tcmpr.R -lookin`
  - `-filter` (specify filter job)
  - `-config` (run filter job w/ configuration file)
    - Default Rscript configuration file included in release
Spatial Forecast Verification methods overview

Eric Gilleland (EricG@ucar.edu)
Research Application Laboratory
National Center for Atmospheric Research

SpatialVx: R package for performing spatial verification (in the works)

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

WRF/MET Tutorial, 23 – 24 January 2014
NCAR, Boulder, Colorado

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Spatial Prediction Comparison Test

\[ D = D_1 - D_2 \]

Loss Differential Field

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Spatial Prediction Comparison Test


\[ S = \frac{\bar{D}}{\sqrt{\text{var}(D)}} \]
Spatial Prediction Comparison Test

Accounting for Location Errors and Reducing Effects of Small Scale Errors

Above Figure from Beth Ebert

Fig. 1 and Table 2 from Ahijevych *et al.* (2009, *WAF*, 24, 1485 – 1497)
Spatial Prediction Comparison Test
Accounting for Location Errors and Reducing Effects of Small Scale Errors

Above Figure from Johan Lindström

Copyright 2014 NCAR
Spatial Prediction Comparison Test
Accounting for Location Errors and Reducing Effects of Small-Scale Errors
Spatial Prediction Comparison Test
Accounting for Location Errors and Reducing Effects of Small Scale Errors

Loss at each point =

Distance from original location of each point to warped location

Loss at each point between observation value and warped value

Spatial Prediction Comparison Test
Accounting for Location Errors and Reducing Effects of Small Scale Errors

\[ \bar{D} \quad S \]
Methods Overview

Fig. 2 from G. et al. (2010, BAMS, 91 (10), 1365 – 1373)
Filter Methods: Smoothing

The fuzzy logic approach compares smoothed indicator fields:

- a new contingency table where
  - hits = sum of the minima between the two fields at each (smoothed) grid point.

Fuzzy Logic: Hit Rate

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Filter Methods: Smoothing Fractions Skill Score (FSS)

\[ FSS = 1 - \frac{\sum_{s=1}^{n} (\hat{p}_s - p_s)^2}{\sum_{s=1}^{n} \hat{p}_s^2 + \sum_{s=1}^{n} p_s^2} \]

\( p_s, \hat{p}_s \) are the fraction of events in a neighborhood centered on point \( s \).

Filter Methods: Scale separation
Filter Methods: Scale separation

Intensity-Scale

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Filter Methods: Scale separation

Wavelets
Displacement Methods: Binary Image Metrics

- Perfect score (zero) only when verification and forecast are identical: $M(A,B)=0$ only if $A=B$.

- Symmetry ensures that answer does not depend on order of comparison: $M(A,B)=M(B,A)$

- Triangle inequality ensures that results are not overly sensitive: $M(A,B)$ much lower than $M(A,C)$, then $M(B,C)$ is appropriately large.

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Examples of some binary image measures and metrics

- Hausdorff Metric
- Baddeley’s Δ Metric
- Pratt’s Figure of Merit (FOM)
- Forecast Quality Index (FQI, also incorporates intensity information)
- Minimum separation distance
Displacement Methods: Baddeley’s Δ Metric

From G. (2011, WAF, 26, 409 - 415)
Geometric Indices

Fig. 3. The connectivity index ($C_{\text{index}}$) for three patterns.

Fig. 7. The perimeter and $S_{\text{index}}$ of 3 patterns that consist of 8 pixels with a $P_{\min} = 12$: (a) $P = 22$, (b) $P = 16$, and (c) $P = 12$.

Fig. 9. The $A_{\text{index}}$ for three example patterns: (a) $A_{\text{index}} = 0.61$, (b) $A_{\text{index}} = 0.44$, and (c) $A_{\text{index}} = 0.21$.

AghaKouchak et al. (2011, J. Hyrdometeorology, 12, 274-285)
Displacement Methods: Field deformation

Reduction in RMSE is over 50% after applying the (space-time) warp.
Displacement Methods: Feature-based

UKobs6

UKfcst6

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Final Remarks

- R software package: `SpatialVx` (not yet ready for prime time)
- Spatial Forecast Verification Inter-Comparison Project (ICP)
  
  http://www.ral.ucar.edu/projects/icp

- ICP web page
  - List of references relevant to spatial forecast verification, as well as the ICP special collection in *WAF*. 
    - See, e.g., review papers:
      - Ahijevych *et al.* (2009),
      - G. *et al.* (2010, 2010 *BAMS*),
      - Brown *et al.* (2012),
  - ICP test cases available (geometric, perturbed and real)
  - Sign up to receive emails about the ICP

- ICP2 to begin soon, and to be called the Mesoscale Verification Intercomparison over Complex Terrain (MesoVICT) Project
  - New test cases
  - Includes: ensembles (forecast and observation), realistic meteorological cases over multiple time points, complex terrain, more variables

  Note describing project plans:

Defining Objects in MODE
What are Objects?

Raw Field

Object Field

Objects are Regions of Interest
Four Step Process for Resolving Objects

Step #1
Start with the raw data field.
In this case, a precipitation field.
Four Step Process for Resolving Objects

Step #2

Apply convolution operator.

This is basically a smoothing operation.
Convolution Radius

Radius of Influence

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Convolution operates on the raw data field $f(x, y)$ using a filter function $\phi(x, y)$. MODE uses a simple “circular” filter, so this operation amounts to taking a weighted average of the raw field values in some neighborhood of the point $(x, y)$.

$$C(x, y) = \sum_{(x', y') \in G} f(x', y') \phi(x - x', x - y')$$
Just Threshold Raw Data?

(a) Raw Field

(b) Thresholded Raw Field

(c) Convolved Field

(d) Thresholded Convolved Field
Four Step Process for Resolving Objects

Step #3
Threshold the smoothed field.
This produces an on/off mask field.
Masking

Masking uses the convolved field $C(x, y)$ and the threshold $T$ to produce the masked field $M(x, y)$. This is set to 1 if the convolved field exceeds the threshold $T$, otherwise it’s set to 0. That’s why it’s called a “mask.”

\[
M(x, y) = \begin{cases} 
1 & \text{if } C(x, y) \geq T \\
0 & \text{otherwise}
\end{cases}
\]
Four Step Process for Resolving Objects

Step #4

Restore raw data inside objects.

This gives us our objects for this field.
Note the Effect of Changing the Object-Definition Parameters
Matching & Merging

Merging: Associating objects in the same field.

Matching: Associating objects in different fields.

MODE does this using a Fuzzy-Logic engine.
Example of Matching & Merging

Fct Raw

Obs Raw

Fct Obj

Obs Obj
Fuzzy Logic Intro

Attributes
Interest Maps
Confidence Maps
Weights
Total Interest
Object Attributes

**Single:**
- Area
- Centroid
- Axis Angle
- Median Intensity
- Complexity
- Aspect Ratio
- Curvature

**Pair:**
- Centroid Distance
- Angle Difference
- Median Intensity Ratio
- Intersection Area
- Convex Hull Distance
- Boundary Distance
- Area Ratio

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Example Single Attributes

Centroid

Axis

Convex Hull
The Trouble with Least Squares
Three Approaches to Calculating the Axis in 2D

- Maximize second moments
- Principal Components
- Total Least Squares
Example Pair Attributes

Forecast Object

Observation Object

Union

Intersection

Symmetric Difference
Interest Maps

Map attributes to interest values.

Example: Centroid Distance

All interest maps can be changed in the config file.
Interest Maps

Centroid Distance

Intersection Area

Area Ratio

2-variable Interest Map $I(x,y)$
Confidence Maps and Sensitivity
Weights

Express relative importance of different attributes in matching and merging.

All weights can be changed in the config file.
Total Interest
Calculated from weights, attributes, and interest maps.

\[ T(\alpha) = \sum_{i} w_i C_i(\alpha) I_i(\alpha_i) \]

\[ \frac{\sum_{i} w_i C_i(\alpha)}{\sum_{i} w_i C_i(\alpha)} \]
MODE also has an alternative merging method that can be used, if desired. It’s called **Double Thresholding**.

Two thresholds are set. If objects are separate at the higher threshold, but run together at the lower threshold, this can be used to help with the overall object merging.
MODE Output

Attributes file
Netcdf Objects file
Contingency Table Counts & Stats
PostScript Graphics file
Why use PostScript?

Library available
Easier to program
PDF not yet dominant
No external libraries needed
Conversion available

ps2pdf -dPDFSETTINGS=/prepress
Appalachia Example

Vector Centroid Differences

Observed Object over Appalachain Mountains
Interpreting MODE Output

Verifying with Objects

Presenter: Tara Jensen
MODE Output

- **PostScript**
  - object pictures, definitions
  - matching/merging strategy
  - total interest for each object pair

- **ASCII Text**
  - attributes of simple, paired objects and clusters
    - size, shape, position, separation, total interest
  - verification scores (CSI, bias, etc.) for “objectified” fields

- **netCDF**
  - gridded object fields
  - view with ncview
**Definition of objects**
- smoothing radius
- intensity threshold
- area threshold
- matching and/or merging
- # and area of objects
- Median Max. Interest (MMI)

**Weight of object attributes**
- Centroid/Boundary: 2.00 4.00
- Convex Hull/Area: 0.00 1.00
- Area/Intersection Area: 4.00 4.00
- Complexity/Intensity: 0.00 2.00
- Total Interest Thresh: 0.79

**Field names model description**
- Model: hml-ens-d01
- Field: APCP_24_A24_ENS_MEAN
- Level: A24
- Units: kg/m²
- Initial: 20110216 12:00:00
- Valid: 20110217 12:00:00
- Accum: 24:00:00

**Object pictures**

**Total Interest of object pairs**
Pairs above dashed line have high enough Interest to be processed further.
Page 2 and 3 of PostScript:

- Band shows which Simple Objects are merged (aka Cluster)
- Colors show matching between Fcst and Obs.

Cluster merged by Fuzzy Logic

Simple Obj. not merged by Fuzzy Logic

Unmatched (FY_ON)
False Alarm

Matched (FY_OY)
Hit
Objects overlapped
In two different views...

Which do you prefer?
Summary information for clusters in the domain
Raw Field and Double Thresholding For Merging Process

Convolution Radius (>=25.4mm)

Double Thresholding Value (>=22.5mm)
Use of Pair Attributes defined by MODE

**Centroid Distance:** Provides a quantitative sense of spatial displacement of forecast. *Small is good*

**Axis Angle:** For non-circular objects – gives measure of orientation errors. *Small is good*

**Area Ratio:** Provides an objective measure of whether there is an over- or under-prediction of areal extent of forecast. *Close to 1 is good*
**Use of Pair Attributes defined by MODE**

**Symmetric Difference:** May be a good summary statistic for how well Forecast and Observed objects match. *Small is good*

**Total Interest:** Summary statistic derived from fuzzy logic engine with user-defined Interest Maps for all these attributes plus some others. *Close to 1 is good*

**P50 | P90 Int:** Provides objective measures of Median (50\(^{th}\) percentile) and near-Peak (90\(^{th}\) percentile) intensities found in objects. *Ratio close To 1 is good*

Forecast Field

---

**Symmetric Difference:** Non-Intersecting Area

---

Observed Field

---

<table>
<thead>
<tr>
<th>Field Type</th>
<th>P50</th>
<th>P90</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fcst Value</strong></td>
<td>29.0</td>
<td>33.4</td>
</tr>
<tr>
<td><strong>Obs Value</strong></td>
<td>26.6</td>
<td>31.5</td>
</tr>
</tbody>
</table>

---

Total Interest: 0.75

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Symmetric Diff: May be a good summary statistic for how well Forecast and Observed objects match. **Small is good**

Symmetric Difference: Non-Intersecting Area

**Forecast Field**

**Observed Field**

**P50 | P90 Int:** Provides objective measures of Median (50\(^{th}\) percentile) and near-Peak (90\(^{th}\) percentile) intensities found in objects. **Ratio close To 1 is good**

**Obs Value**
- P50 = 26.6
- P90 = 31.5

**Fcst Value**
- P50 = 29.0
- P90 = 33.4

**Total Interest:** Summary statistic derived from fuzzy logic engine with user-defined Interest Maps for all these attributes plus some others. **Close to 1 is good**

**Angle_diff & Sym_diff**
- less so

**Total Int.**
- higher

0.90

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Summary Score for Forecast
Median of the Max. Interest (MMI*)

Interest Matrix

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.90</td>
<td>0.65</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>0.80</td>
</tr>
<tr>
<td>3</td>
<td>0.40</td>
<td>0.55</td>
</tr>
</tbody>
</table>

* MMI = median { 0.90, 0.80, 0.90, 0.80, 0.55 } = 0.80

* Davis et al., 2009: The Method for Object-based Diagnostic Evaluation (MODE) Applied to WRF Forecasts from the 2005 SPC Spring Program. Weather and Forecasting
Summary Score for Forecast
Median of the Max. Interest (MMI*)

Interest Matrix

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</tr>
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<td>2</td>
<td>0.50</td>
<td>0.80</td>
</tr>
<tr>
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<td>0.40</td>
<td>0.55</td>
</tr>
</tbody>
</table>

* Davis et al., 2009: The Method for Object-based Diagnostic Evaluation (MODE) Applied to WRF Forecasts from the 2005 SPC Spring Program, Weather and Forecasting

\[
MMI = \text{median} \{ 0.90, 0.80, 0.90, 0.80, 0.55 \} = 0.80
\]
Median of the Max. Interest (MMI) Quilt Plot

MMI as a function of convolution radius (grid squares) and threshold (mm) for 24-h forecast of 1-h rainfall
- Each pixel is a MODE run.
- This graphic is not in MET, but R code on MET website.

(b) ARW4: 1 June, 2005
Scoring MODE Object Forecasts

use total interest threshold to separate matched objects, or “hits” from false alarms and misses

Traditional Categorical Statistics

critical success index (CSI) = \[
\frac{\text{Hit}}{\text{Hit} + \text{Miss} + \text{False Alarm}}
\]

bias = \[
\frac{\text{Hit} + \text{False Alarm}}{\text{Hit} + \text{Miss}}
\]
sometimes area-weighted
MODE Output

• **PostScript**
  – object pictures, definitions
  – matching/merging strategy
  – total interest for each object pair

• **ASCII Text**
  – attributes of simple, paired objects and clusters
    • size, shape, position, separation, total interest
  – verification scores on smoothed and thresholded fields (objects)

• **netCDF**
  – gridded object fields
  – view with ncview
Object Attribute file (*.obj)
- Header with fields names and object definition info
- Object ID and Category
- Simple Object Attributes such as Simple Obj. Centroid info, Length, Width, Area, etc…
- Matched Pair/Composite information including Centroid Distance, Angle Difference, Symmetric Difference, etc…

Contingency Table Stat file (*.cts)
- Header with fields names and object definition info
- Contingency Table counts such as number of hits, false alarms, misses and correct negs (in FY|FN_OY|ON notation)
- Contingency Table statistics such as BASER, FBIAS, GSS, CSI, PODY, FAR etc…
How netCDF could be used

Display actual intensities inside objects (in this case Reflectivity)

Employ a different plotting approach to show matched clusters

Plots generated using NCL
MODE Analysis Tool

- mode_analysis
MODE_Analysis Usage

Usage: mode_analysis
-lookin path
-summary or -bycase
[-column name]
[-dump_row filename]
[-out filename]
[-log filename]
[-v level]
[-help]
[MODE FILE LIST]
[-config config_file]
or [MODE LINE OPTIONS]

MODE LINE OPTIONS

Object Toggles

-fcst versus -obs
Selects lines pertaining to forecast objects or observation objects

-single versus -pair
Selects single object lines or pair lines

-simple versus -cluster
Selects simple object lines or cluster

-matched versus -unmatched
Selects matched simple object lines or unmatched simple object lines.

Other Options (each option followed by value)
-model, -fcst|obs_thr , -fcst_var , etc...
-area_min|max, -intersection_area_min|max , etc...
-centroid_x_min|max , -centroid_y_min|max,
-axis_ang_min|max, -int10_min|max,
-centroid_dist_min|max, -angle_diff_min|max, etc...

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MODE Analysis Tool

-**summary** Example

**Command Line**

```
mode_analysis -summary \
-lookin mode_output/wrf4ncep/40km/ge03.\ 
-fcst -cluster \
-area_min 100 \ 
-column centroid_lat -column centroid_lon \ 
-column area \ 
-column axis_ang \ 
-column length
```

**Output**

Total mode lines read = 393
Total mode lines kept = 17

<table>
<thead>
<tr>
<th>Field</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>StdDev</th>
<th>P10</th>
<th>P25</th>
<th>P50</th>
<th>P75</th>
<th>P90</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>centroid_lat</td>
<td>17</td>
<td>31.97</td>
<td>46.24</td>
<td>38.65</td>
<td>3.81</td>
<td>33.89</td>
<td>36.13</td>
<td>38.54</td>
<td>40.12</td>
<td>43.99</td>
<td>657.00</td>
</tr>
<tr>
<td>centroid_lon</td>
<td>17</td>
<td>-103.89</td>
<td>-85.20</td>
<td>-96.32</td>
<td>5.91</td>
<td>-103.15</td>
<td>-102.65</td>
<td>-96.26</td>
<td>-93.95</td>
<td>-86.78</td>
<td>-1637.49</td>
</tr>
<tr>
<td>area</td>
<td>17</td>
<td>180.00</td>
<td>8393.00</td>
<td>2955.06</td>
<td>2246.49</td>
<td>624.80</td>
<td>1206.00</td>
<td>2662.00</td>
<td>3958.00</td>
<td>5732.20</td>
<td>50236.00</td>
</tr>
<tr>
<td>axis_ang</td>
<td>17</td>
<td>-88.63</td>
<td>85.66</td>
<td>12.62</td>
<td>64.35</td>
<td>-70.77</td>
<td>-63.86</td>
<td>35.04</td>
<td>74.37</td>
<td>79.24</td>
<td>214.60</td>
</tr>
<tr>
<td>length</td>
<td>17</td>
<td>25.25</td>
<td>234.76</td>
<td>124.41</td>
<td>60.99</td>
<td>48.85</td>
<td>65.37</td>
<td>116.67</td>
<td>169.37</td>
<td>204.57</td>
<td>2114.90</td>
</tr>
</tbody>
</table>

Provides summary statistics for Forecast Clusters with minimum area of 100 grid-sq for the specified MODE output columns.
# MODE Analysis Tool

## -bycase Example

### Command Line

```
mode_analysis -bycase -lookin mode_output/wrf4ncep/40km/ge03. -single -simple
```

### Output

Total mode lines read = 393  
Total mode lines kept = 141

<table>
<thead>
<tr>
<th>Fcst Valid Time</th>
<th>Area Matched</th>
<th>Area Unmatched</th>
<th># Fcst Matched</th>
<th># Fcst Unmatched</th>
<th># Obs Matched</th>
<th># Obs Unmatched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr 26, 2005 00:00:00</td>
<td>3210</td>
<td>1046</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>May 13, 2005 00:00:00</td>
<td>8892</td>
<td>9320</td>
<td>2</td>
<td>19</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>May 14, 2005 00:00:00</td>
<td>16994</td>
<td>4534</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>May 18, 2005 00:00:00</td>
<td>6057</td>
<td>852</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>May 19, 2005 00:00:00</td>
<td>1777</td>
<td>1624</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>May 25, 2005 00:00:00</td>
<td>8583</td>
<td>928</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Jun 1, 2005 00:00:00</td>
<td>12456</td>
<td>2657</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Jun 3, 2005 00:00:00</td>
<td>7561</td>
<td>102</td>
<td>11</td>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Jun 4, 2005 00:00:00</td>
<td>11464</td>
<td>5715</td>
<td>6</td>
<td>12</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Provides tallied information for all Simple Objects for each case in directory
Diurnal Cycle of the Number of Storms

Time of the Day (UTC)

# of simple objects

observation

model
Examples on the Web of MODE-based Evaluation

Reports, Powerpoints, Config Files demonstrating use of MODE in DTC Evaluations

http://www.dtcenter.org/eval
  – GFS/NAM Precip Forecast Comparison
  – Hazardous Weather Testbed (2009-2012)
  – Hydrometeorology Testbed (2010-2012)

Scripts for Calculation of MMI and Quilt Plots


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