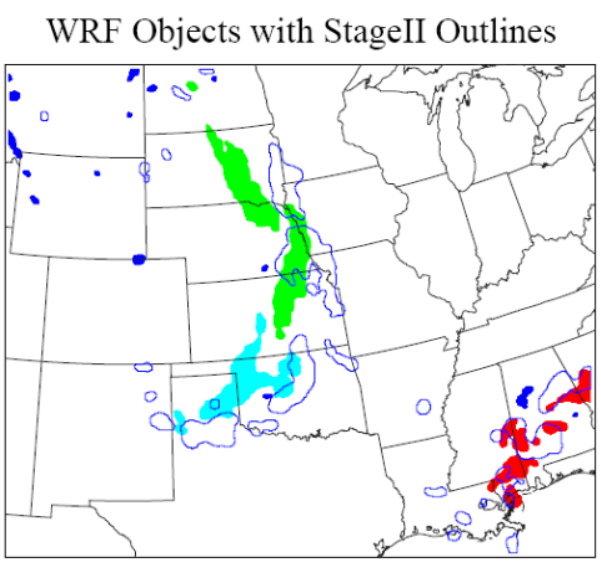
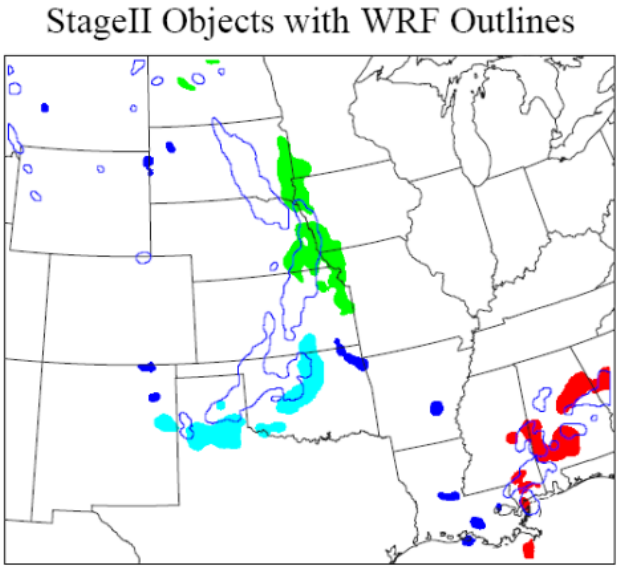
Introduction to MODE

Verifying with Objects

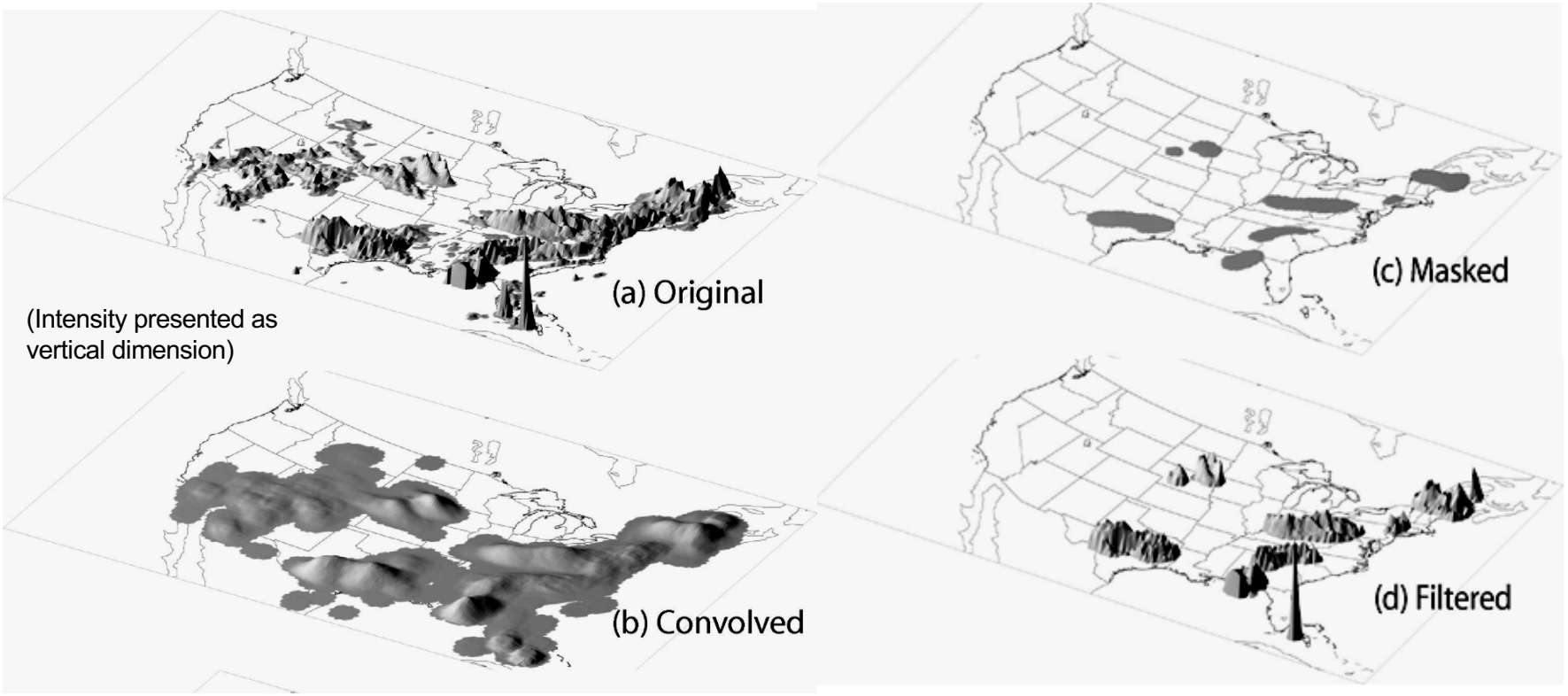




Presenter: Tara Jensen

MODE Object Identification

Source: Davis 2006

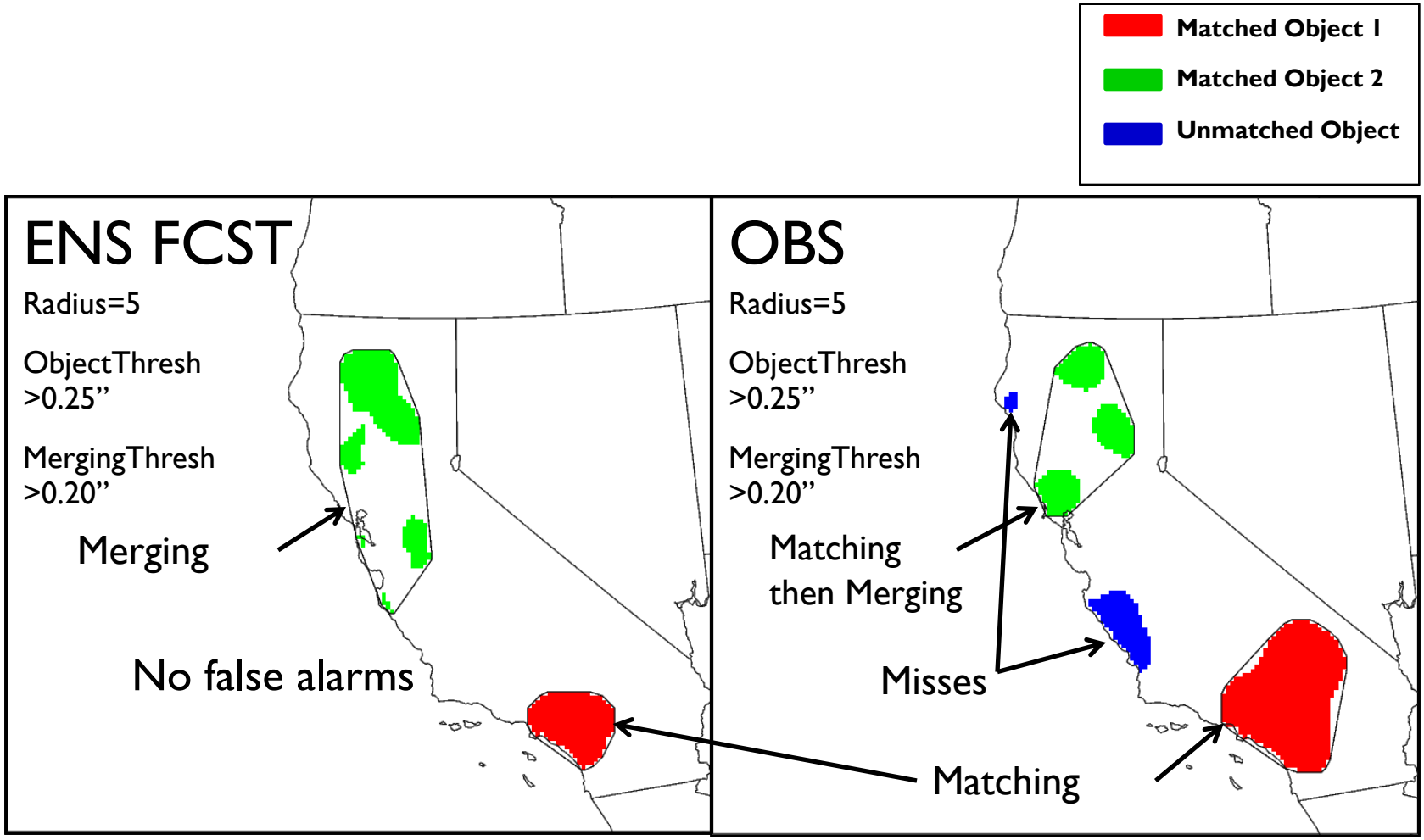


Smoothing radius
(in grid squares)

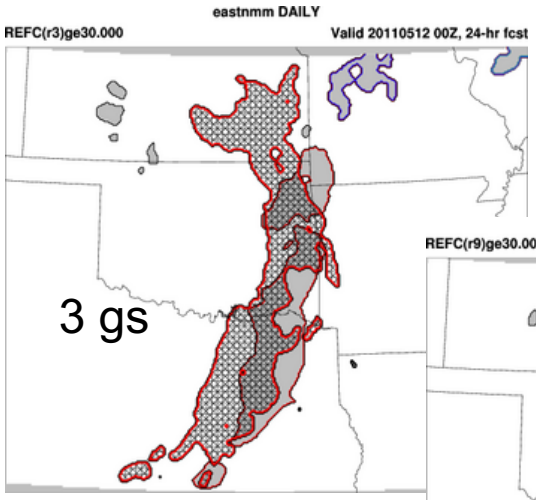
Accumulation threshold
(in mm)

*** User-defined parameters in configuration file**

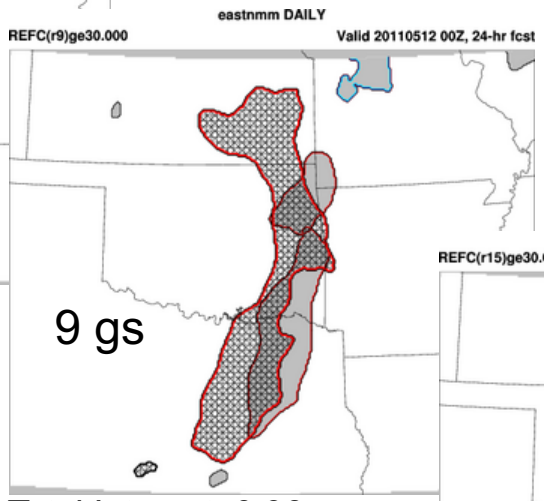
MODE Example



Example – REFC > 30 dBZ – Impact of smooting radius



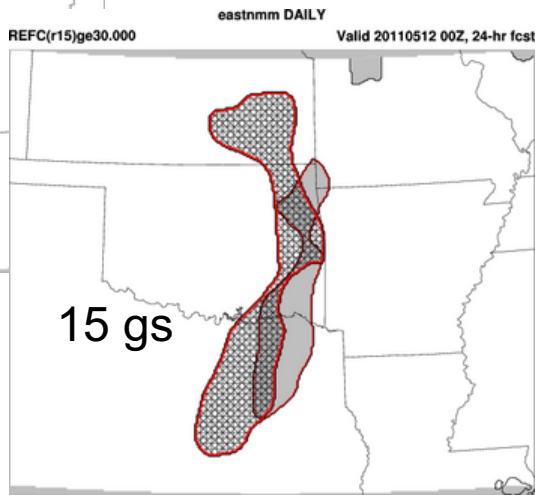
Total Interest: 0.96
Area Ratio: 0.57
Centroid Distance: 95km
P90 Intensity Ratio: 1.00



Total Interest: 0.96
Area Ratio: 0.57
Centroid Distance: 94km
P90 Intensity Ratio: 1.02

Convolution Radius Increases

Total Interest: 0.96
Area Ratio: 0.53
Centroid Distance: 92km
P90 Intensity Ratio: 1.04



MODE Input and Usage

- Input Files
  - Gridded forecast and observation files
    - GRIB1 output of Unified Post-Processor (or other)
    - GRIB2 from NCEP (or other)
    - NetCDF from PCP-Combine, wrf_interp, or CF-compliant

- Usage: mode
  - fcst_file
  - obs_file
  - config_file
  - [-config_merge merge_config_file]
  - [-outdir path]
  - [-log file]
  - [-v level]

Config File

- https://dtcenter.org/met/users/support/online_tutorial/METv6.0/config/MODEConfig_default

```
//
// Run all permutations of radius and threshold
//
quilt = FALSE;

//
// Forecast and observation fields to be verifi
//
fcst = {
   field = {
      name  = "APCP";
      level = "A03";
   }

   raw_thresh        = NA;
   conv_radius       = 60.0/grid_res; // in gri
   conv_thresh       = >=5.0;
   vld_thresh        = 0.5;
   area_thresh       = NA;
   inten_perc_value  = 100;
   inten_perc_thresh = NA;
   merge_thresh      = >=1.25;
   merge_flag        = THRESH;
}
obs = fcst;
```

```
//
// Handle missing data
//
mask_missing_flag = NONE;

//
// Match objects between the forecast and observation fields
//
match_flag = MERGE_BOTH;

//
// Maximum centroid distance for objects to be compared
//
max_centroid_dist = 800.0/grid_res;

////////////////////////////////////////////////////////////////////////

//
// Verification masking regions
//
mask = {
   grid      = "";
   grid_flag = NONE; // Apply to NONE, FCST, OBS, or BOTH
   poly      = "";
   poly_flag = NONE; // Apply to NONE, FCST, OBS, or BOTH
}
```

Config File

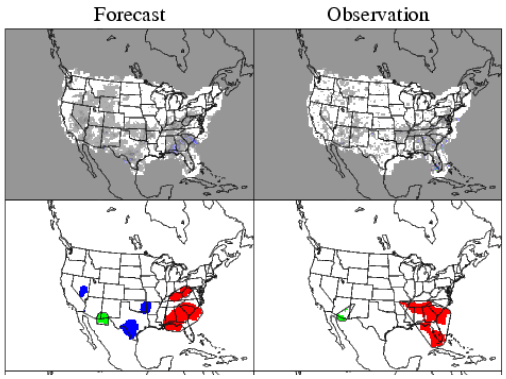
- https://dtcenter.org/met/users/support/online_tutorial/METv6.0/config/MODEConfig_default

```
//
// Fuzzy engine weights
//
weight = {
   centroid_dist    = 2.0;
   boundary_dist    = 4.0;
   convex_hull_dist = 0.0;
   angle_diff       = 1.0;
   aspect_diff      = 0.0;
   area_ratio       = 1.0;
   int_area_ratio   = 2.0;
   curvature_ratio  = 0.0;
   complexity_ratio = 0.0;
   inten_perc_ratio = 0.0;
   inten_perc_value = 50;
}
```

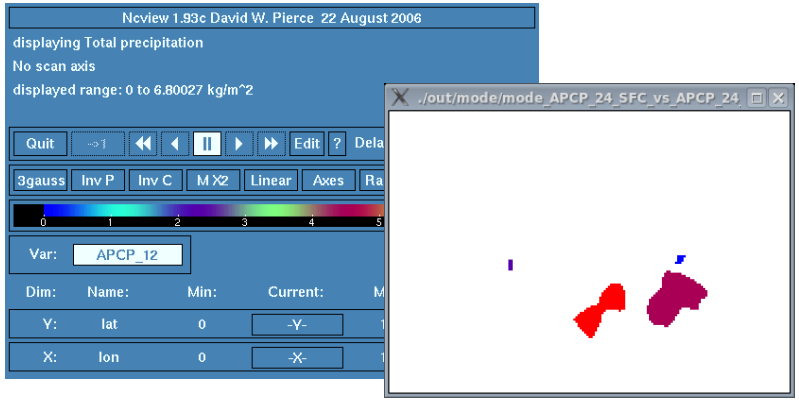
```
//
// Fuzzy engine interest functions
//
interest_function = {

   centroid_dist = (
      (             0.0, 1.0 )
      (  60.0/grid_res, 1.0 )
      ( 600.0/grid_res, 0.0 )
   );

   boundary_dist = (
      (             0.0, 1.0 )
      ( 400.0/grid_res, 0.0 )
   );

   convex_hull_dist = (
      (             0.0, 1.0 )
      ( 400.0/grid_res, 0.0 )
   );
```

MODE Output

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

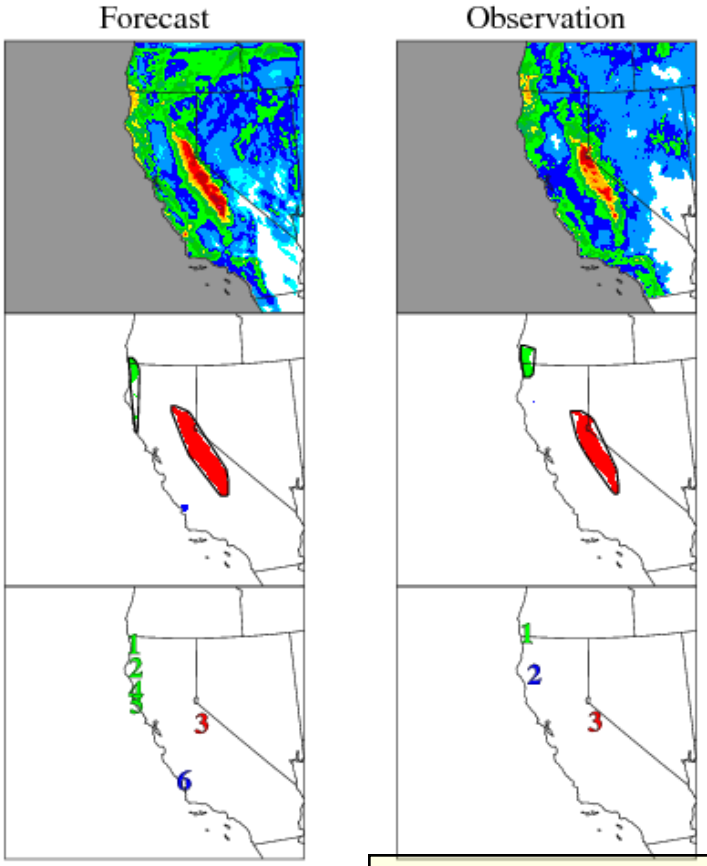


- ASCII Text
  - attributes of simple, paired objects and clusters
    - size, shape, position, separation, total interest
  - verification scores (CSI, bias, etc.) for “objectified” fields
- netCDF
  - gridded object fields
  - view with ncview



MODE: APCP_24_A24_ENS_MEAN at A24 vs APCP_24 at A2

object pictures



Fcst	Obs	Interest
3	3	1.0000
1	1	0.9360
2	2	0.6436
5	2	0.6372
4	2	0.5085
2	1	0.4060
1	2	0.3871
4	1	0.3545
3	1	0.3422
6	3	0.3265
1	3	0.3141
4	3	0.2813
3	2	0.2719
2	3	0.2704
5	1	0.2406
5	3	0.2266
6	1	0.2203
6	2	0.1936

Total Interest of object pairs

Pairs above dashed line have high enough Interest to be processed further

Field names model description

	Forecast	Observation
Model:	hmt-ens-d01	
Field:	APCP_24_A24_ENS_MEAN	
Level:	A24	A24
Units:	kg/m^2	kg/m^2
Initial:	20110216 12:00:00	20110216 12:00:00
Valid:	20110217 12:00:00	20110217 12:00:00
Accum:	24:00:00	24:00:00

Weight of object attributes

Centroid/Boundary:	2.00	4.00
Convex Hull/Angle:	0.00	1.00
Area/Intersection Area:	4.00	4.00
Complexity/Intensity:	0.00	2.00
Total Interest Thresh:	0.70	

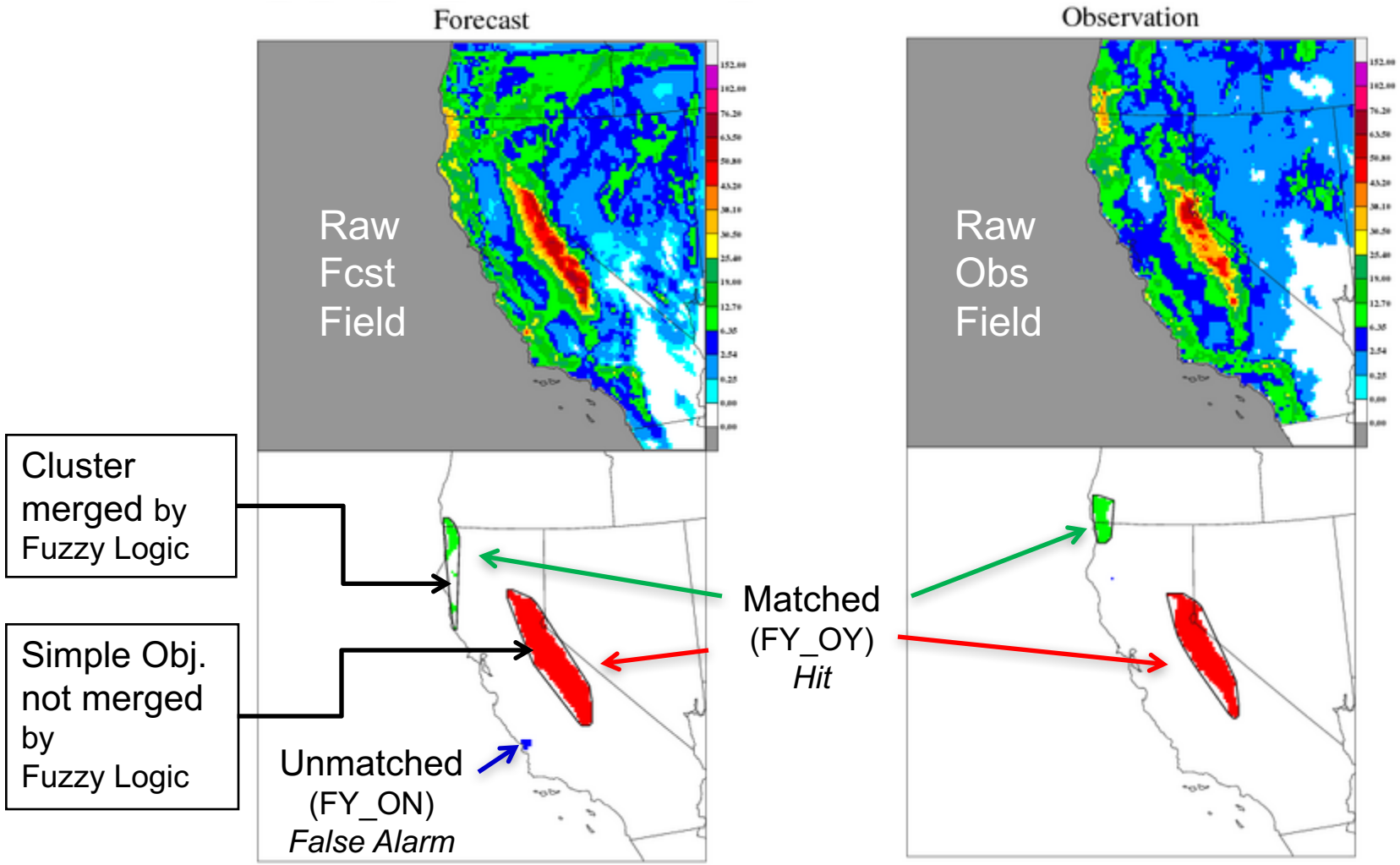
	Forecast	Observation
Mask M/G/P:	on/off/off	on/off/off
Raw Thresh:	>=0.00	>=0.00
Conv Radius:	2 gs	2 gs
Conv Thresh:	>=25.40	>=25.40
Area Thresh:	>=0 gs	>=0 gs
Inten Thresh:	p100>=0.00	p100>=0.00
Merge Thresh:	>=20.00	>=20.00
Merging:	thresh	thresh
Matching:	match/merge	
Simple/M/U:	6/5/1	3/2/1
Area:	696 gs	589 gs
Area M/U:	674/22	585/4
Cluster:	2	2
MMI:	0.6404	0.9360
MMI (F+O):	0.6436	

Definition of objects

- smoothing radius
- intensity threshold
- area threshold
- matching and/or merging
- # and area of objects
- **M**edian **M**ax. **I**nterest (**MMI**)

Page 2 and 3 of PostScript:

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

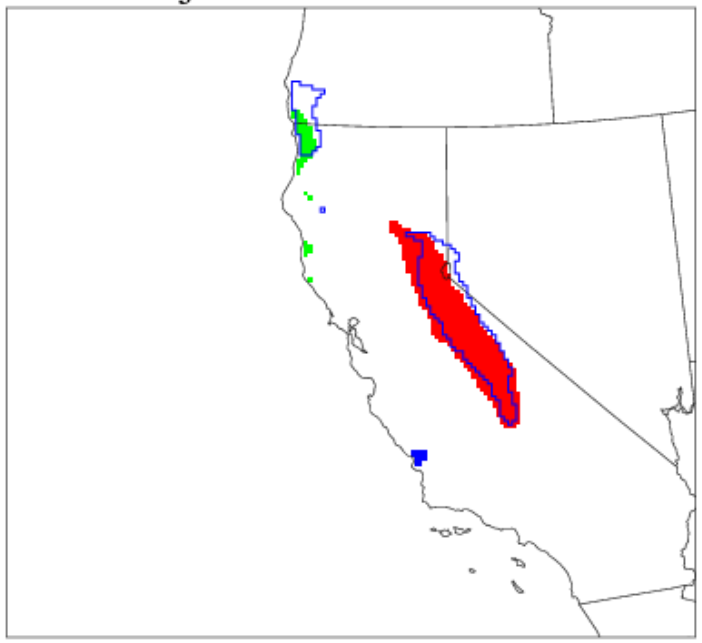


Page 4 of PostScript

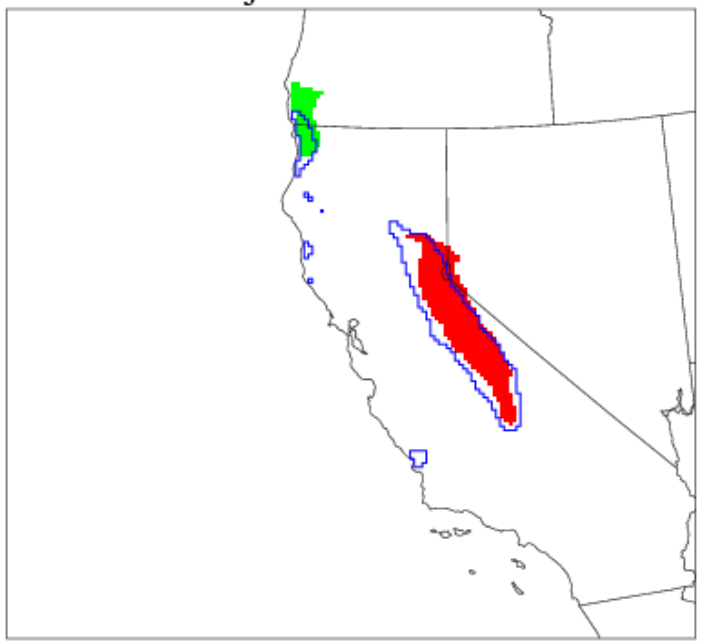
Objects overlapped
In two different views…

Which do you prefer?

Forecast Objects with Observation Outlines

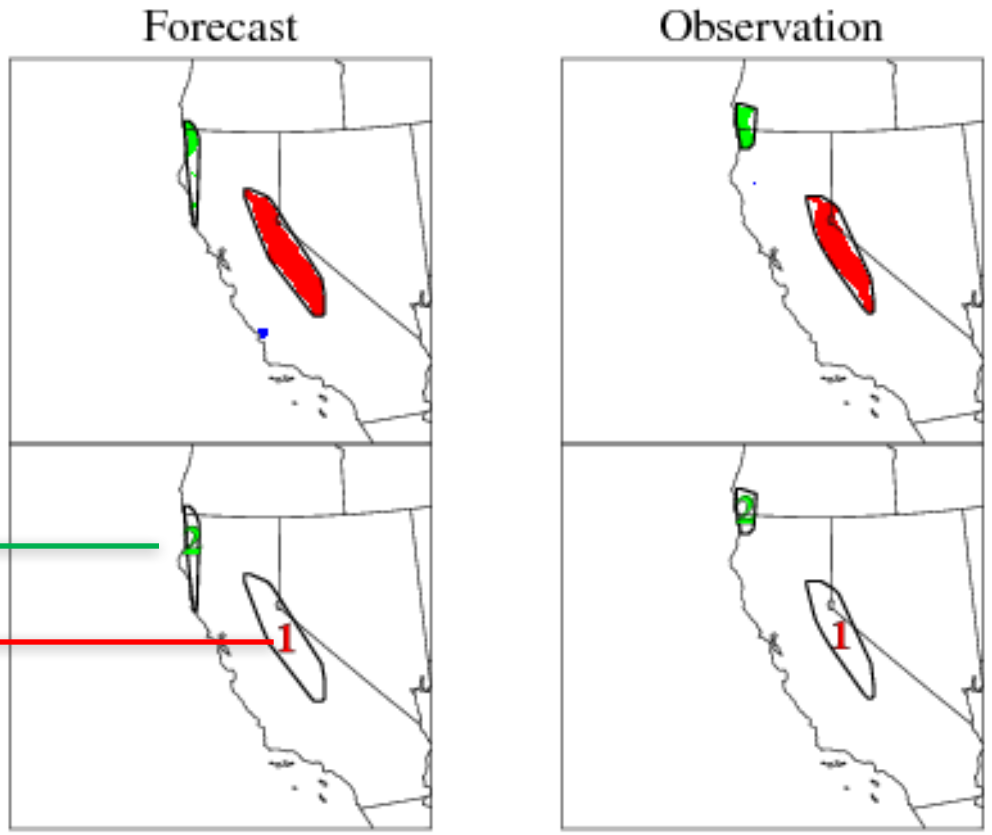


Observation Objects with Forecast Outlines



Page 5 of PostScript - Summary information for clusters in the domain

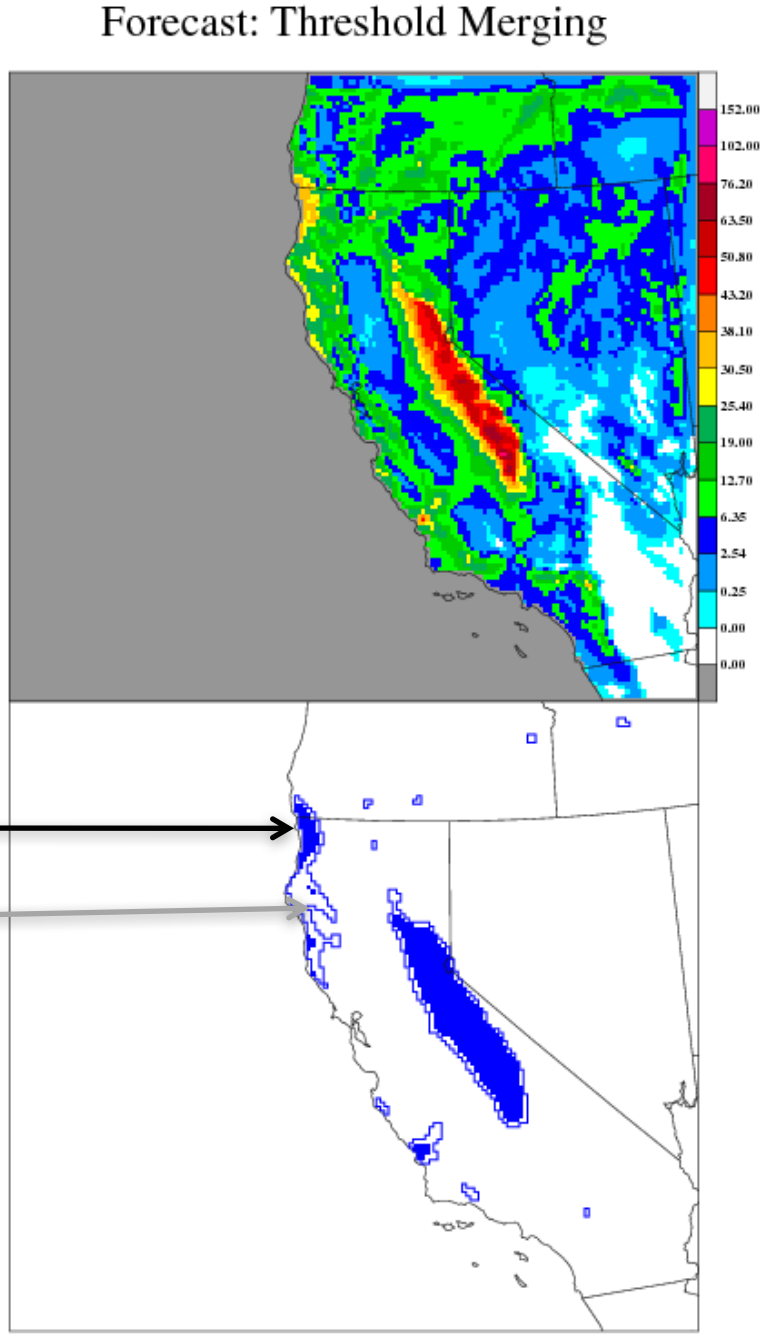
Cluster Object Information



CLUS PAIR	CEN DIST	ANG DIFF	FCST AREA	OBS AREA	INTER AREA	UNION AREA	SYM DIFF	FCST INT50	OBS INT50	FCST INT90	OBS INT90	TOT INTR
1	1.51	3.65	579	466	418	627	209	39.89	34.95	56.20	49.70	1.0000
2	11.94	2.59	95	119	53	161	108	27.56	27.40	34.28	36.42	0.9909

Page 6 & 7 of PostScript

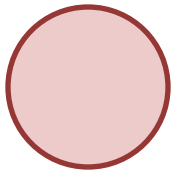
Raw Field and Double Thresholding For Merging Process



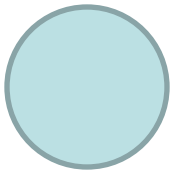
Convolution Threshold (>=25.4mm)

Double Thresholding Value (>=22.5mm)

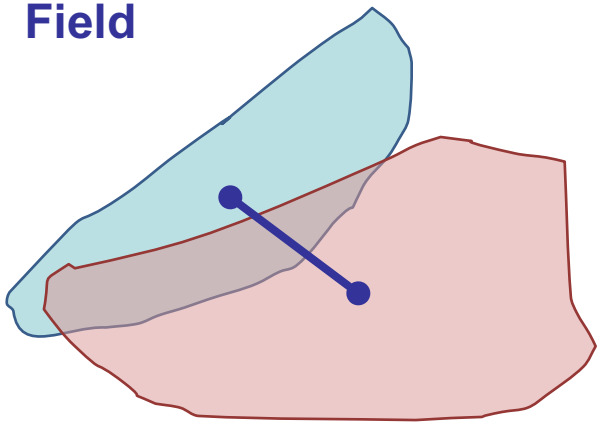
Use of Pair Attributes defined by MODE



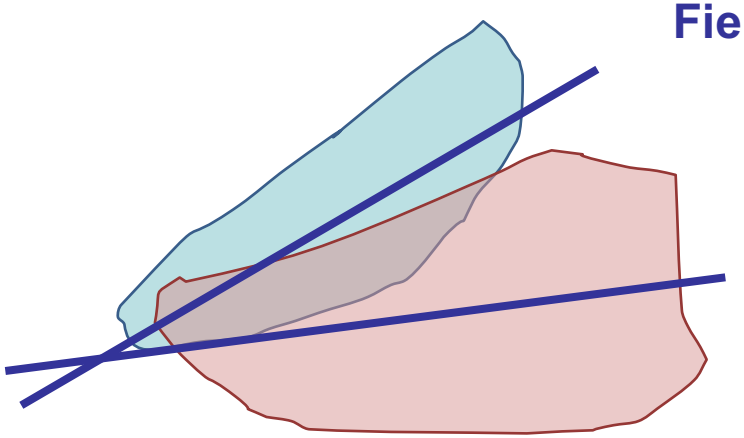
Forecast Field



Observed Field

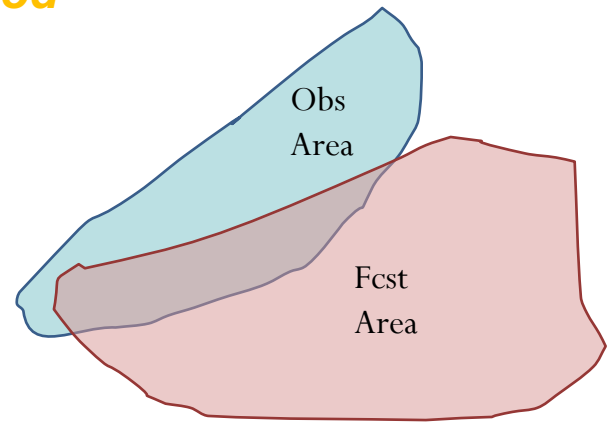


Centroid Distance: Provides a quantitative sense of spatial displacement of forecast.
Small is good



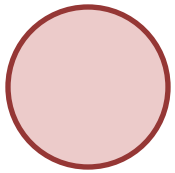
Axis Angle: For non-circular objects – gives measure of orientation errors.
Small is good

$$\text{Area Ratio} = \frac{\text{Fcst Area}}{\text{Obs Area}}$$

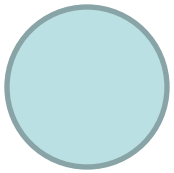


Area Ratio: Provides an objective measure of whether there is an over- or under-prediction of areal extent of forecast.
Close to 1 is good

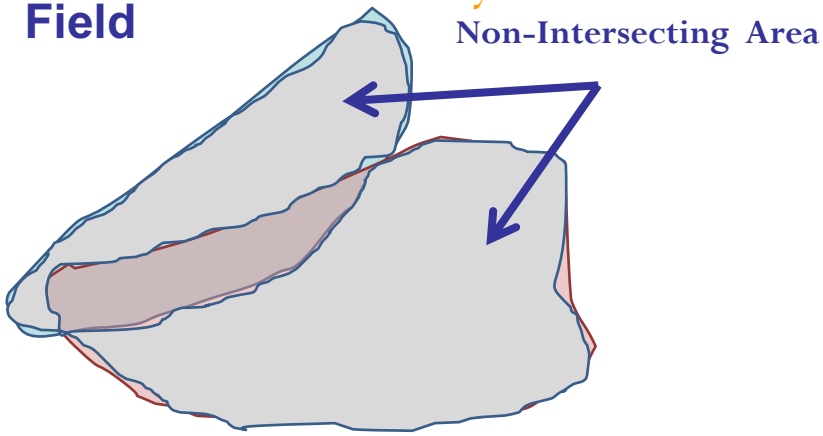
Use of Pair Attributes defined by MODE



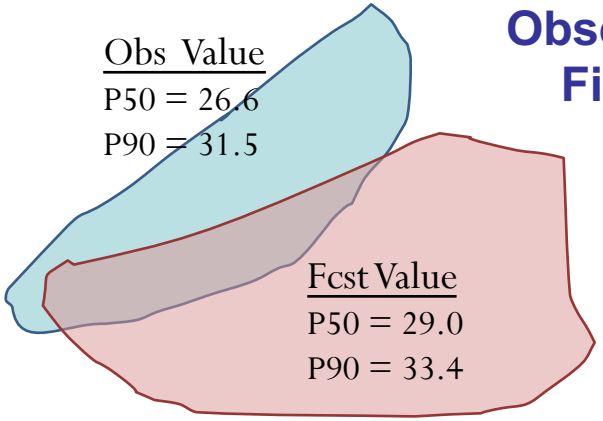
Forecast Field



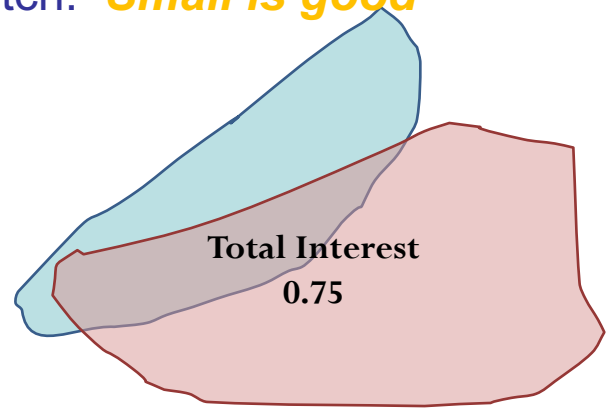
Observed Field



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

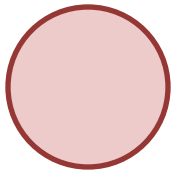


P50 | P90 Int: Provides objective measures of Median (50th percentile) and near-Peak (90th percentile) intensities found in objects. ***Ratio close To 1 is good***



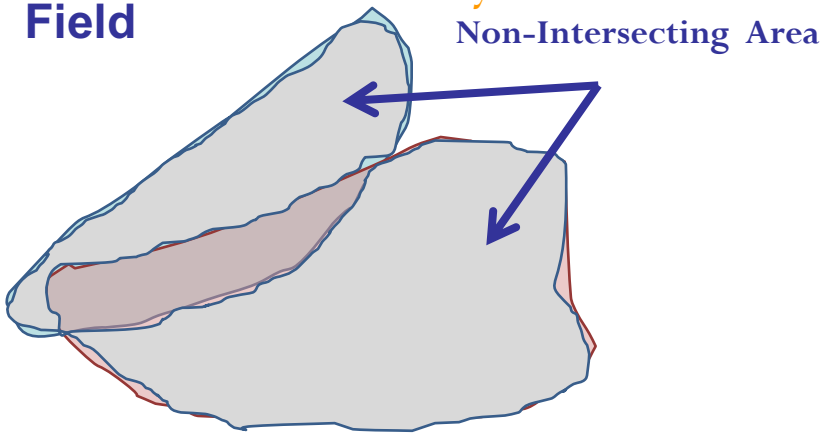
Total Interest: Summary statistic derived from fuzzy logic engine with user-defined Interest Maps for all these attributes plus some others. ***Close to 1 is good***

Use of Pair Attributes defined by MODE

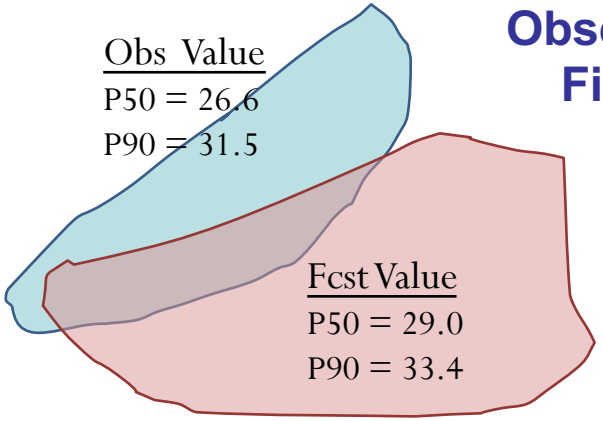


Forecast Field

Observed Field

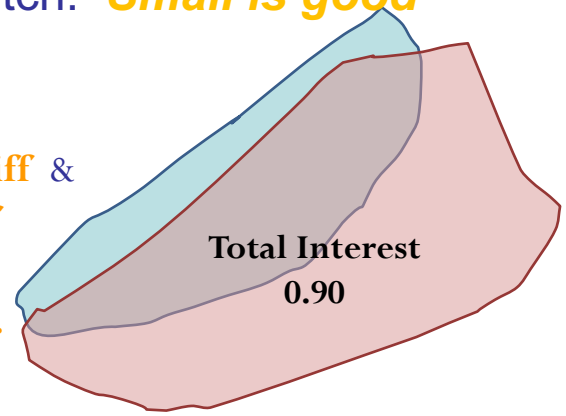


Symmetric Diff: May be a good summary statistic for how well Forecast and Observed objects match. ***Small is good***



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

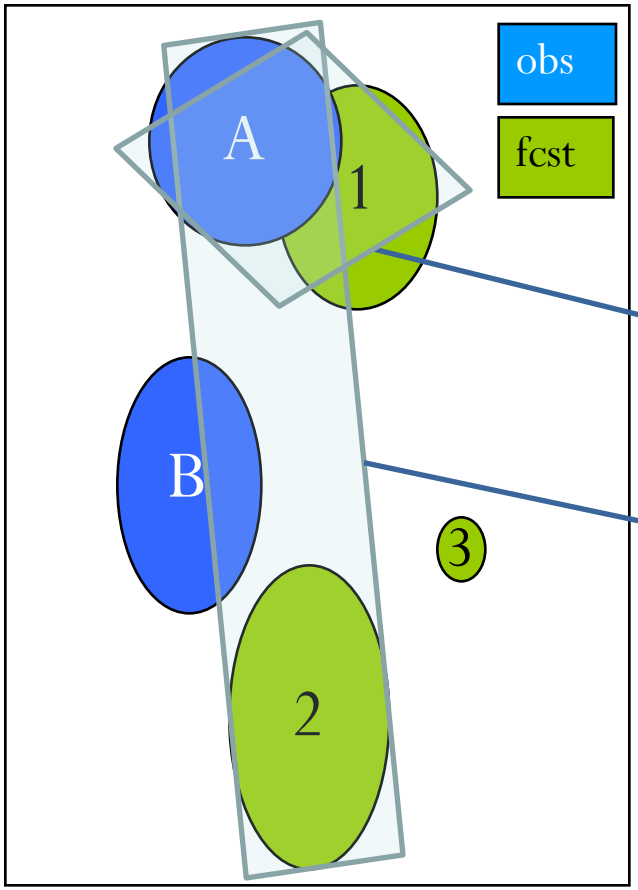
Angle_diff & **Sym_diff** less so **Total Int.** higher



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***

Summary Score for Forecast

Median of the Max. Interest (MMI*)



Interest Matrix

observed

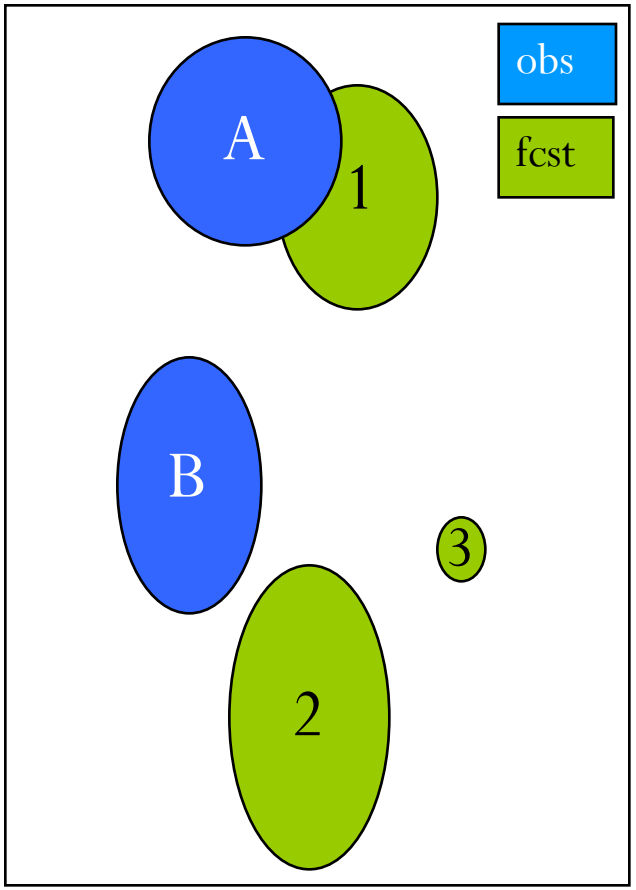
forecast	A	B
1	0.90	0.65
2	0.50	0.80
3	0.40	0.55

$$\text{MMI} = \underset{\text{maximum interest}}{\text{median}} \{ 0.90, 0.80, 0.90, 0.80, 0.55 \} = 0.80$$

* 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

observed

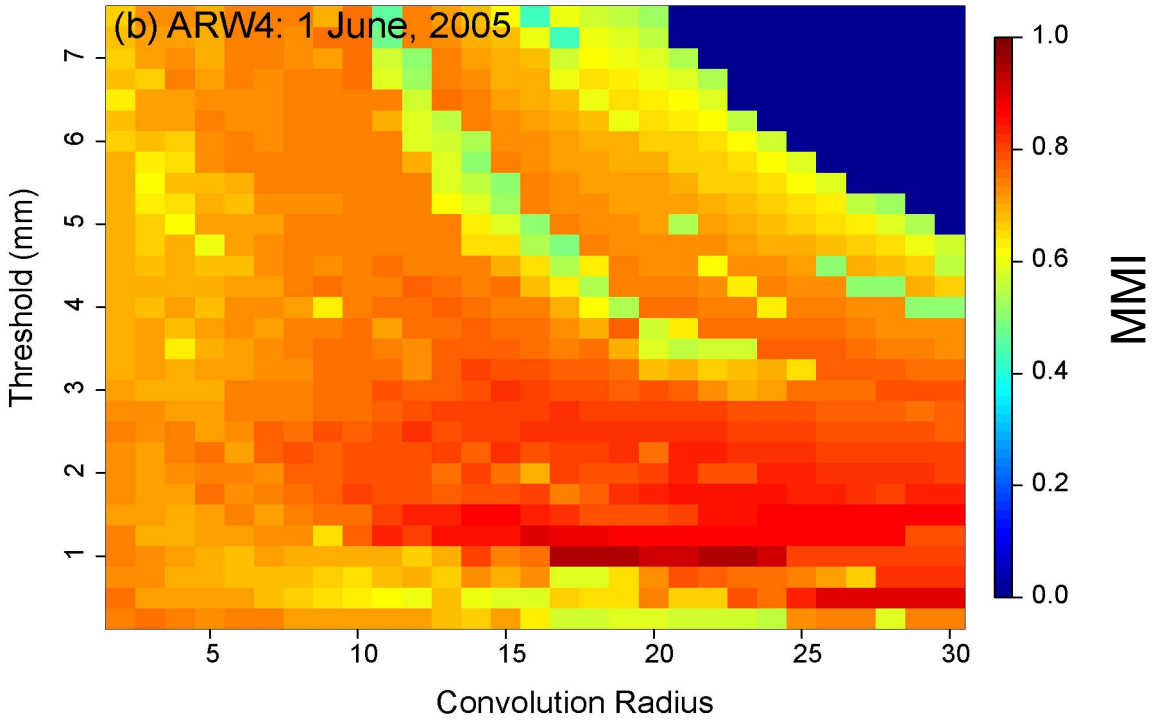
forecast	A	B
1	0.90	0.65
2	0.50	0.80
3	0.40	0.55

maximum interest

$$\text{MMI} = \text{median}\ \{\ 0.90, 0.80, 0.90, 0.80, 0.55\ \} = 0.80$$

* 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

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.

Scoring MODE Object Forecasts

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

Traditional Categorical Statistics

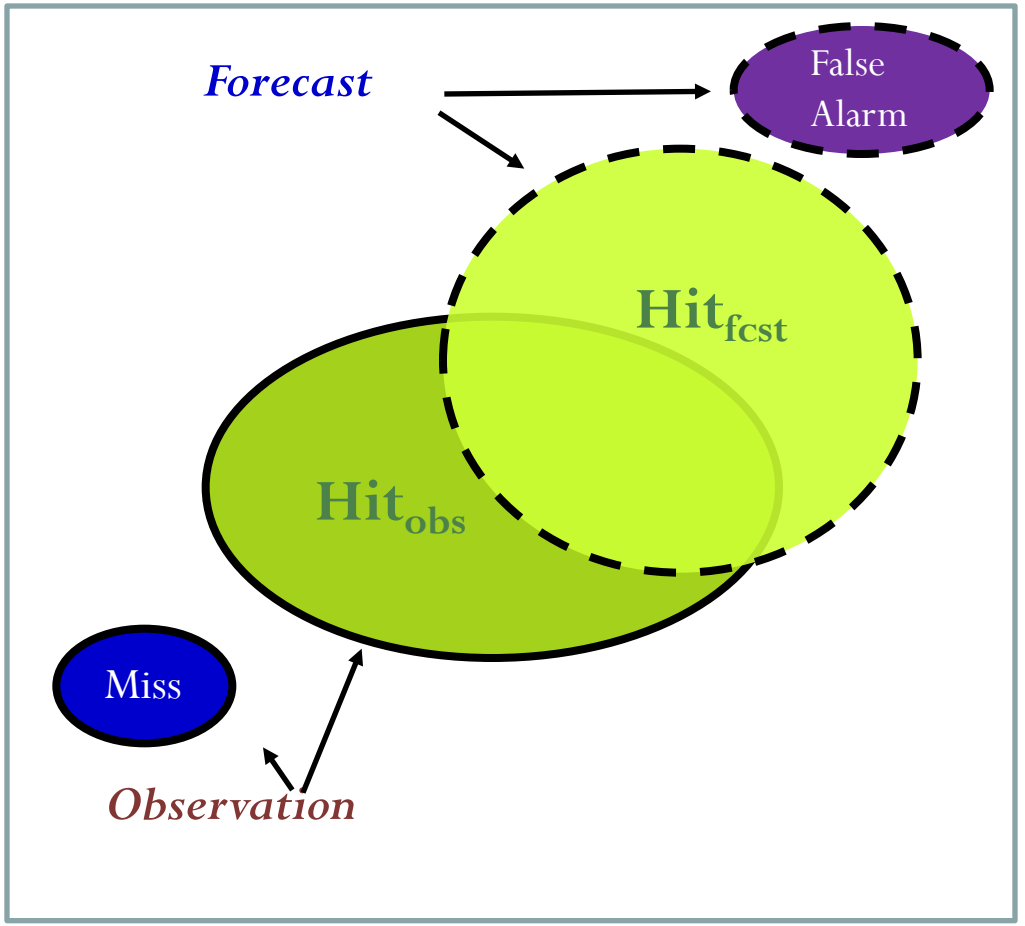
critical success index (CSI) =

$$\frac{\text{Hit}}{\text{Hit} + \text{Miss} + \text{False Alarm}}$$

bias =

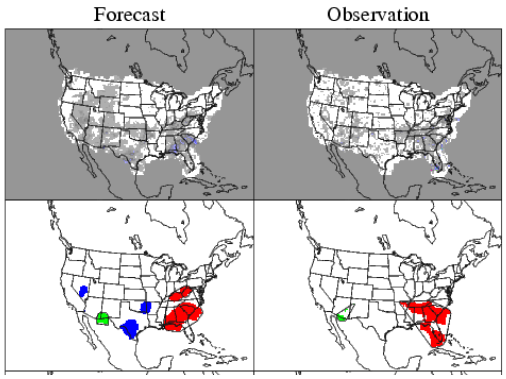
$$\frac{\text{Hit} + \text{False Alarm}}{\text{Hit} + \text{Miss}}$$

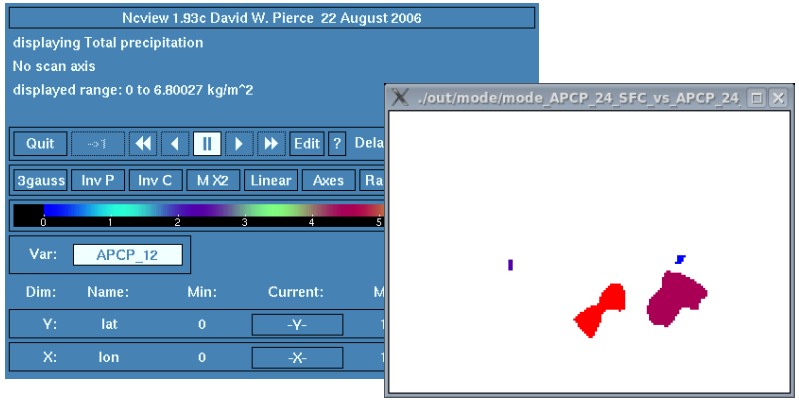
sometimes *area-weighted*



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





ASCII Output

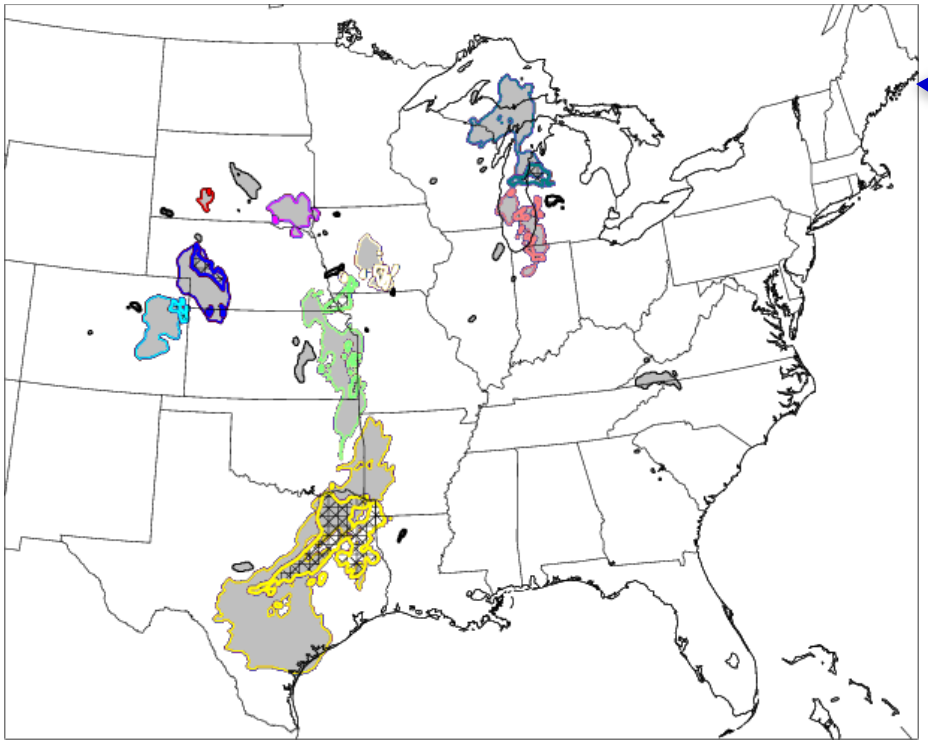
Object Attribute file
(*.obj)

- 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…

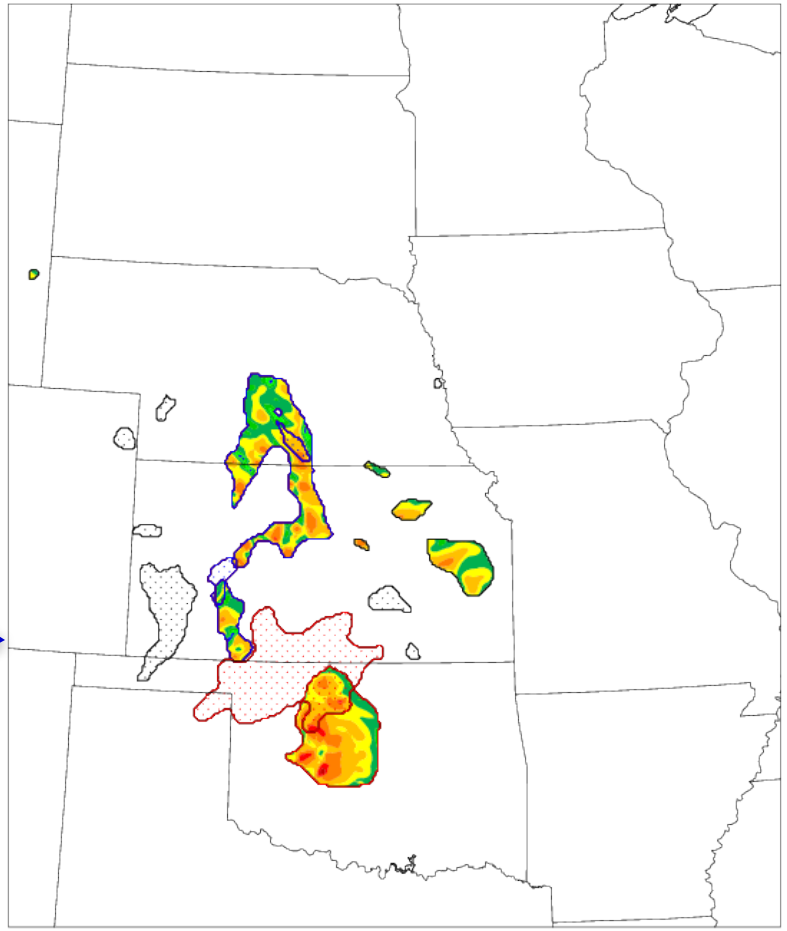
Contingency Table Stat file
(*.cts)

- 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



Employ a different plotting approach to show matched clusters

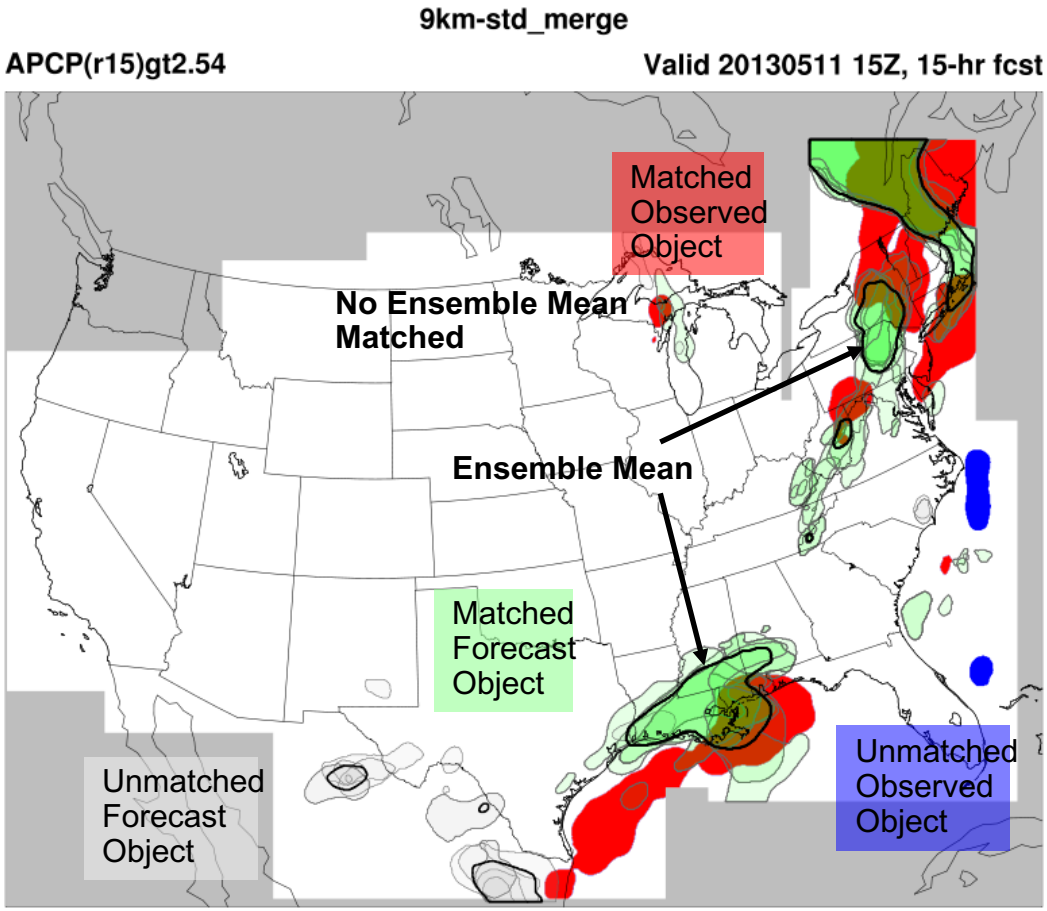


Display actual intensities inside objects (in this case Reflectivity)

Plots generated using NCL

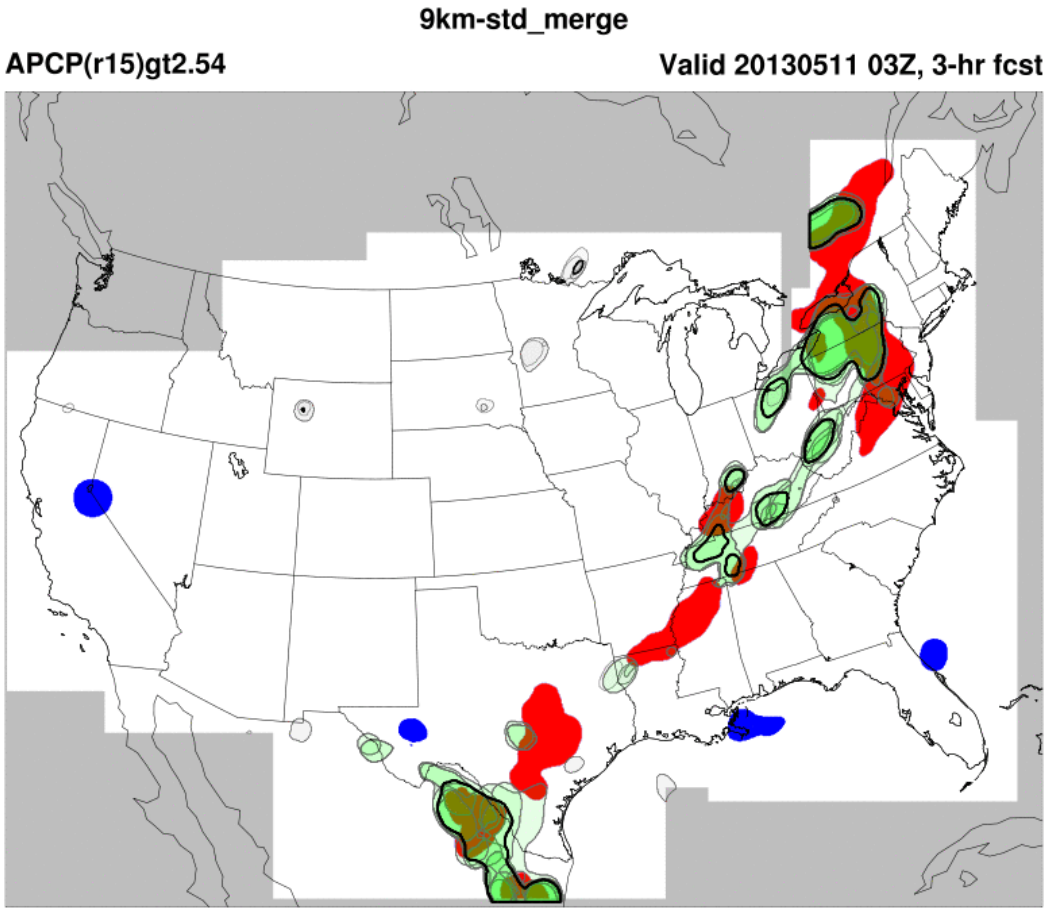
Example May 11, 2013

DTC SREF Tests – ARW Members



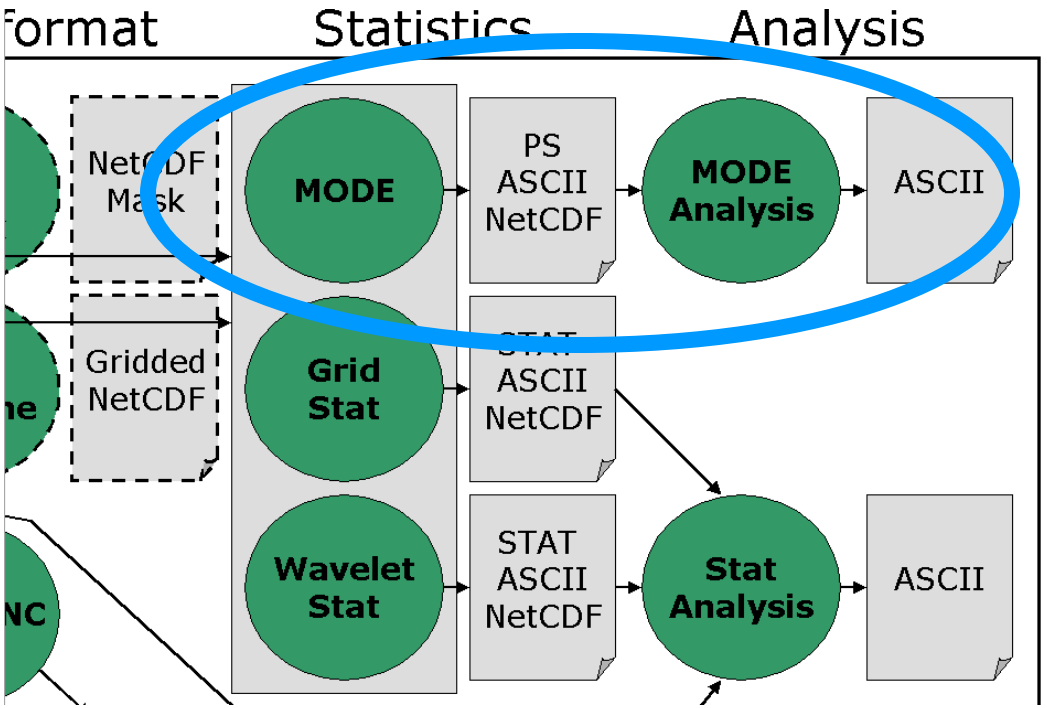
Developmental Testbed Center

Spread increases With Time



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…

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
```

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

Output

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

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

MODE Analysis Tool -*bycase* Example

Command Line

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

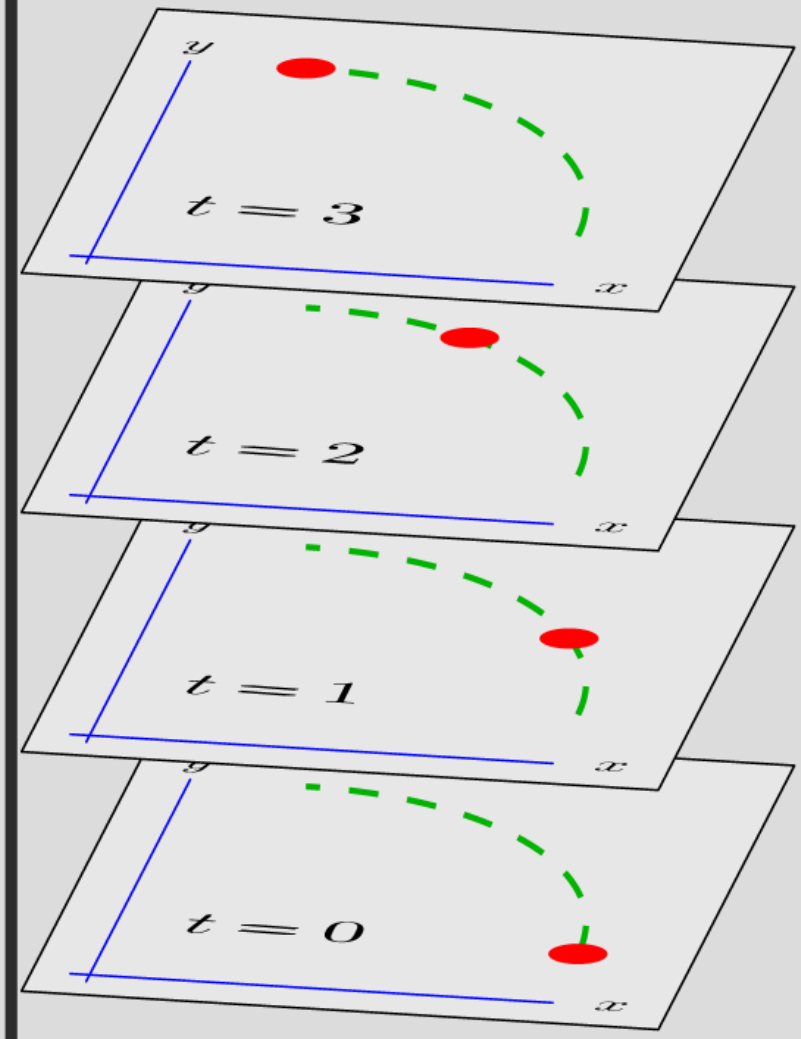
Output

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

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

Provides tallied information for all Simple Objects for each case in directory

Introduction to MODE-TD



Time Slices

Stacked Vertically

Moving 2D Object

Sweeps Out

3D Spacetime Object

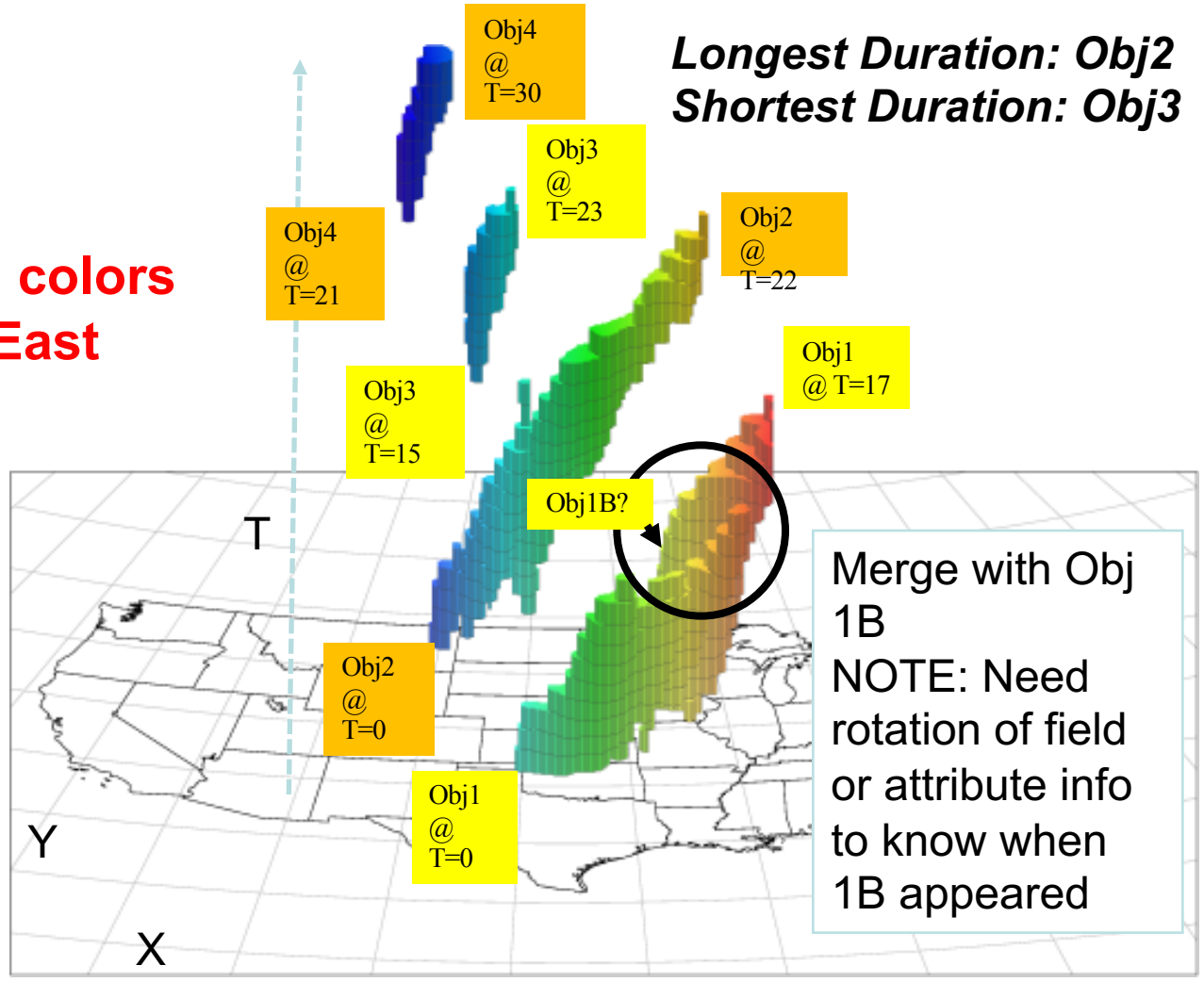
Interpretation

Cool colors – Warm colors
West – East

X-Y shows geographical location of objects

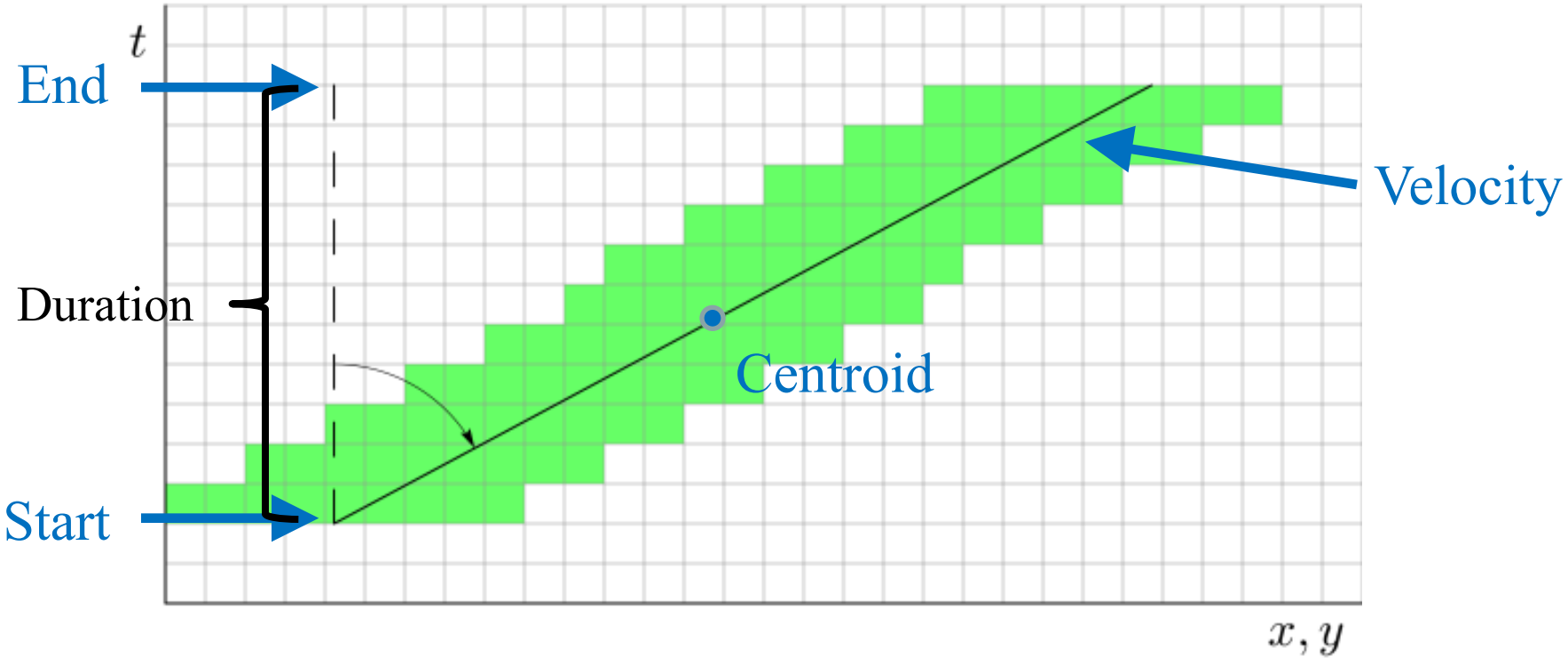
T shows timeline

Objects anchored to map are at time T=0



Longest Duration: Obj2
Shortest Duration: Obj3

Attributes (Think of object as 2D slice)



MODE-TD Input/Output

- Input Files
  - Gridded forecast and observation files
    - GRIB1 output of Unified Post-Processor (or other)
    - GRIB2 from NCEP (or other)
    - NetCDF from PCP-Combine, wrf_interp, or CF-compliant

- Output:
  - Single attributes for 2D simple objects (_2d.txt)
  - Single attributes for 3D composite objects (_3d_sc.txt)
  - Pair attributes for 3D simple objects (_3d_ss.txt)
  - Pair attributes for 3D composite objects (_3d_pc.txt)
  - Pair attributes for 3D simple objects (_3d_ps.txt)
  - Object NetCDF file (_obj.nc)

MODE-TD Usage

- Usage: mtd

  -fcst file_1 ... file_n | file_list

  -obs file_1 ... file_n | file_list

  -config config_file

  [-outdir path]

  [-log file]

  [-v level]

```
mtd -fcst fcst_files/*.grb \
-obs obs_files/*.grb \
-config MTDConfig_default \
-outdir out_dir/mtd \
```

```
bin/mtd \
-fcst data/sample_fcst/2005080700/wrfprs_ruc13_03.tm00_G212 \
data/sample_fcst/2005080700/wrfprs_ruc13_06.tm00_G212 \
data/sample_fcst/2005080700/wrfprs_ruc13_09.tm00_G212 \
data/sample_fcst/2005080700/wrfprs_ruc13_12.tm00_G212 \
data/sample_fcst/2005080700/wrfprs_ruc13_15.tm00_G212 \
data/sample_fcst/2005080700/wrfprs_ruc13_18.tm00_G212 \
data/sample_fcst/2005080700/wrfprs_ruc13_21.tm00_G212 \
data/sample_fcst/2005080700/wrfprs_ruc13_24.tm00_G212 \
-obs data/tutorial/sample_obs/ST2ml_3h/sample_obs_2005080703V_03A.nc \
data/tutorial/sample_obs/ST2ml_3h/sample_obs_2005080706V_03A.nc \
data/tutorial/sample_obs/ST2ml_3h/sample_obs_2005080709V_03A.nc \
data/tutorial/sample_obs/ST2ml_3h/sample_obs_2005080712V_03A.nc \
data/tutorial/sample_obs/ST2ml_3h/sample_obs_2005080715V_03A.nc \
data/tutorial/sample_obs/ST2ml_3h/sample_obs_2005080718V_03A.nc \
data/tutorial/sample_obs/ST2ml_3h/sample_obs_2005080721V_03A.nc \
data/tutorial/sample_obs/ST2ml_3h/sample_obs_2005080724V_03A.nc \
-outdir tutorial/out/mtd \
-config tutorial/config/MTDConfig_tutorial \
-v 2
```

Examples

MODE – Time Represented by Animation

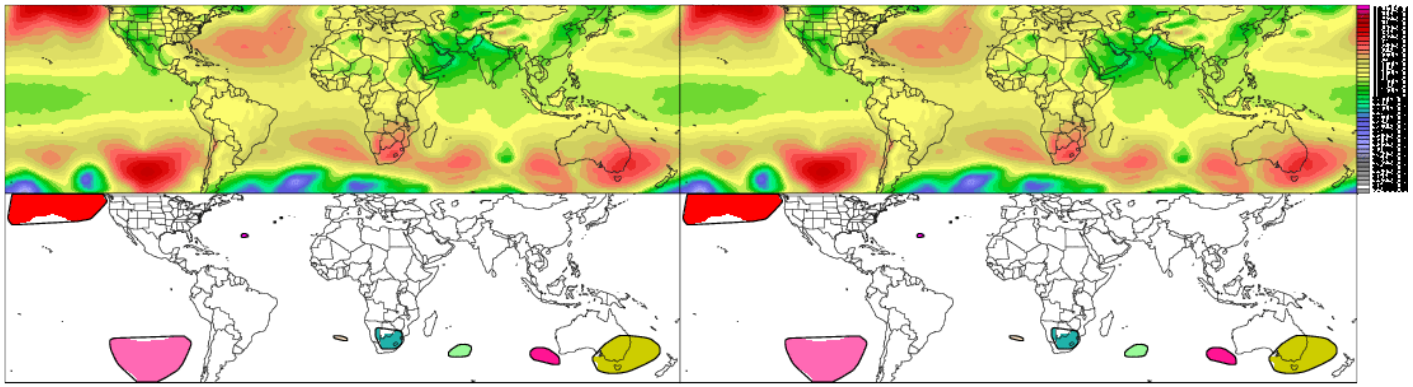
GFS vs Analysis

f000 to f240 every 6 hours

Objects >= 1025mb

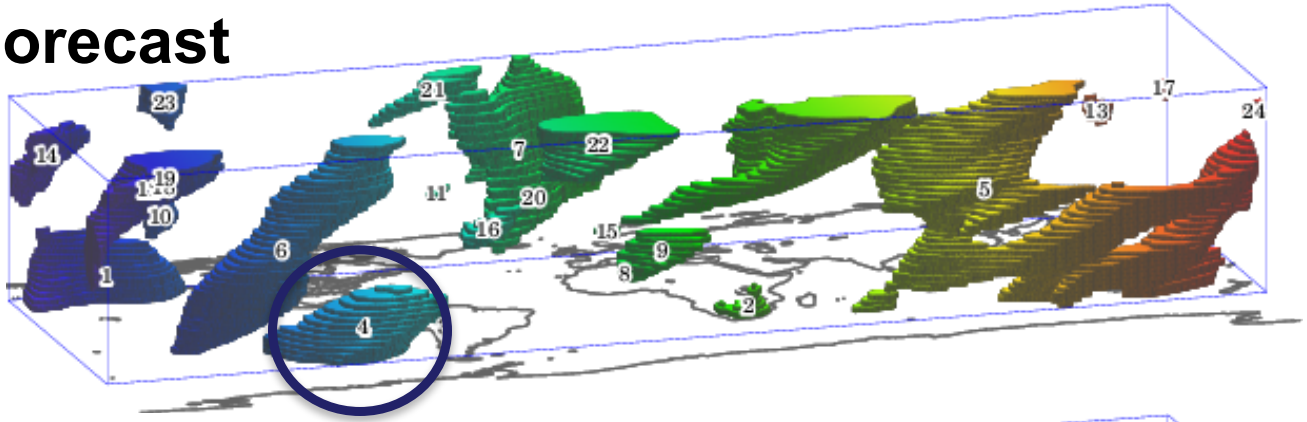
High Pressure Regions

Forecast **Analysis**

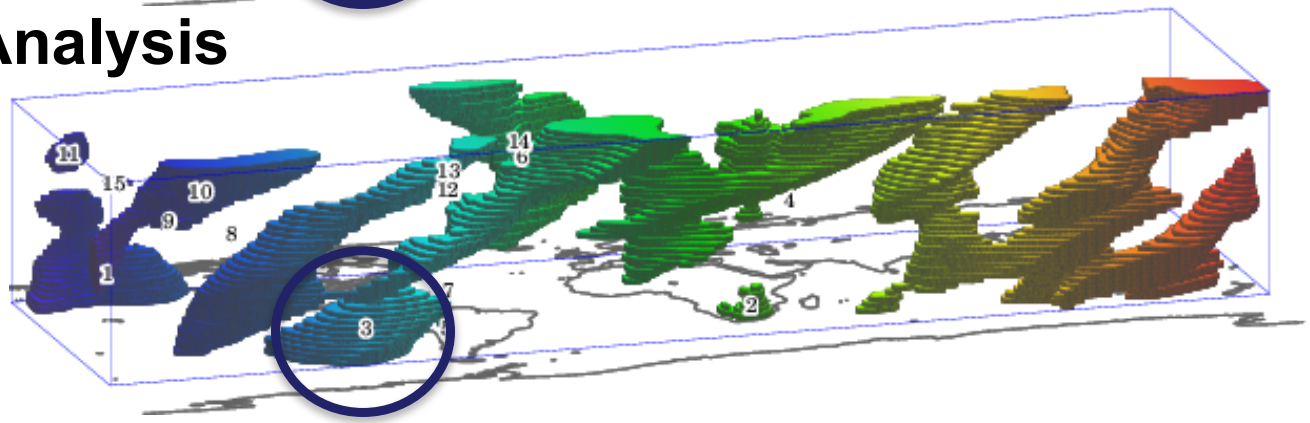


MODE Time-Domain

Forecast

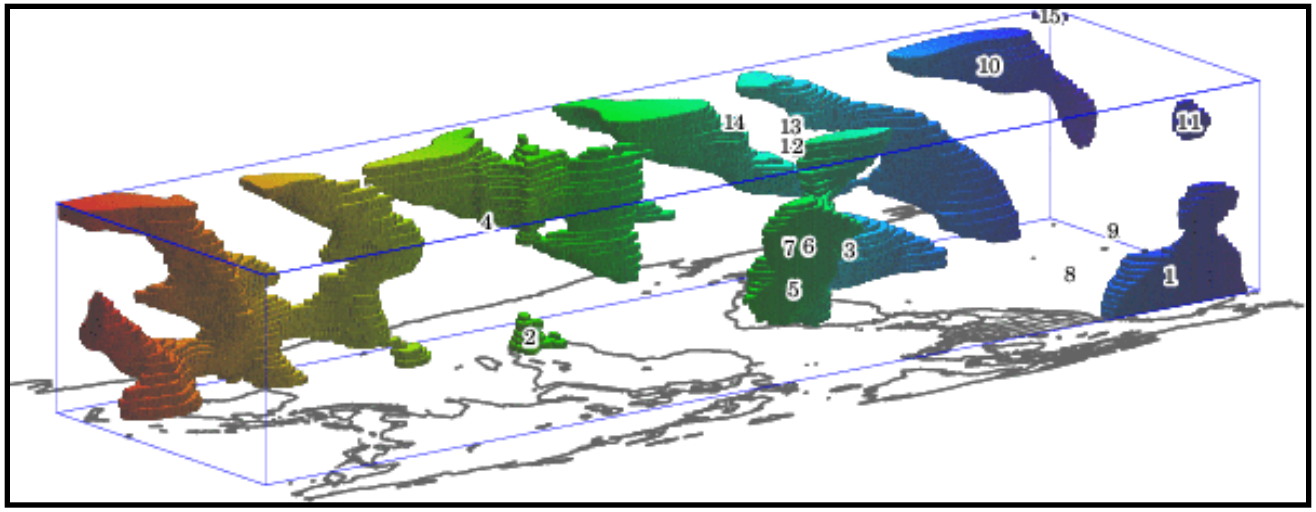


Analysis



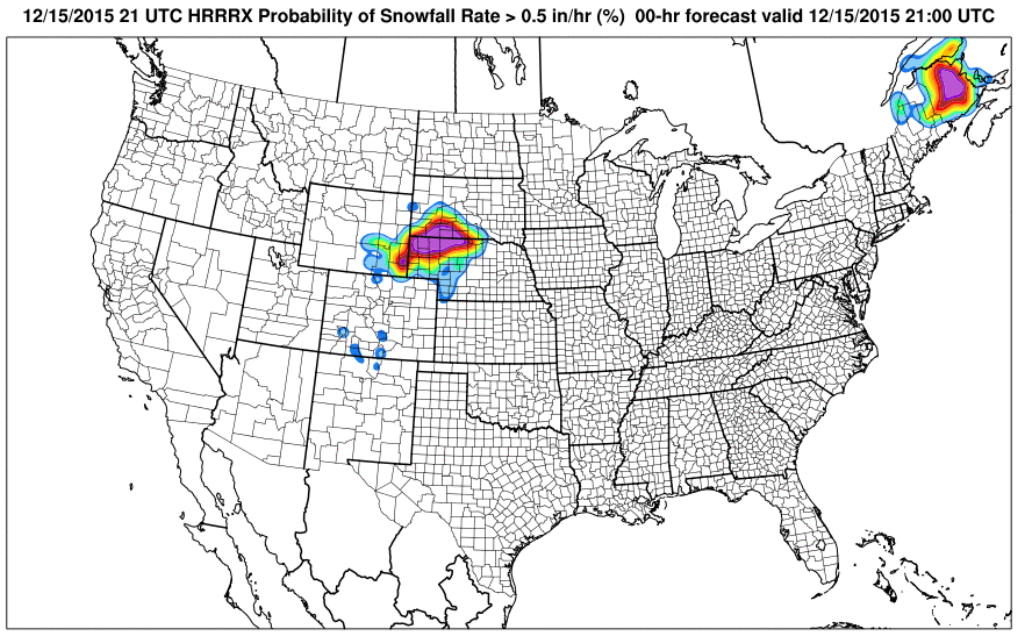
MODE Time-Domain

f000 – f240	Max Inten	Volume	Centroid(x,y,t)	Velocity
Fcst Object 4	103927	111493	336, 57, 4.19	2.85
Analysis Object 3	103914	113692	335, 59, 4.27	2.79

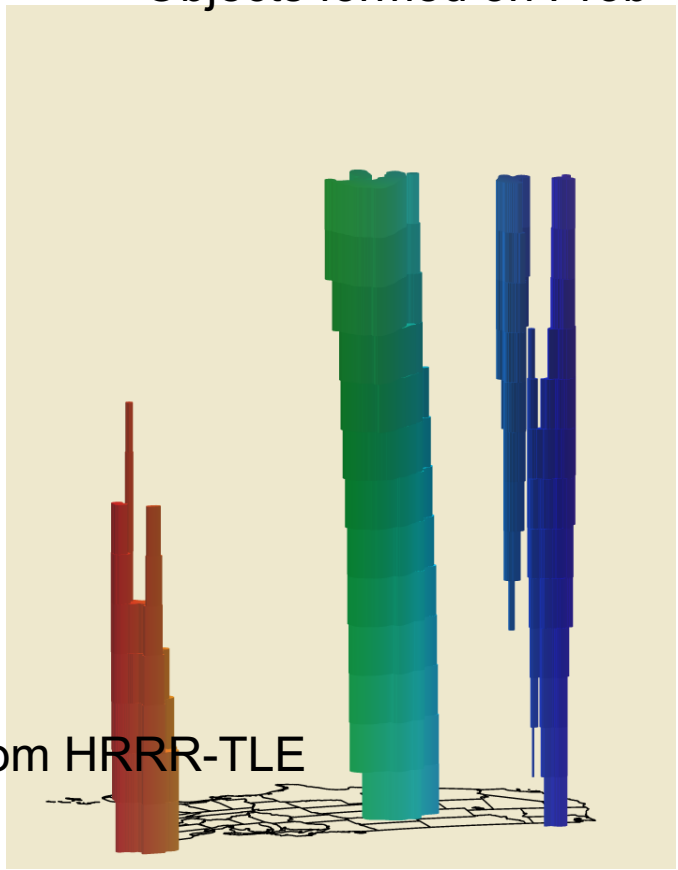


MTD on probability fields

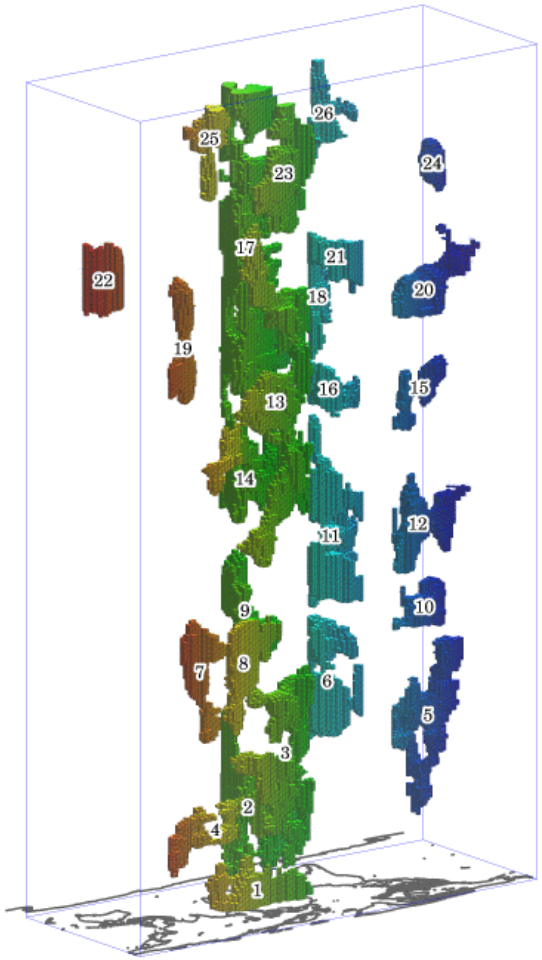
Objects formed on Prob > 0%



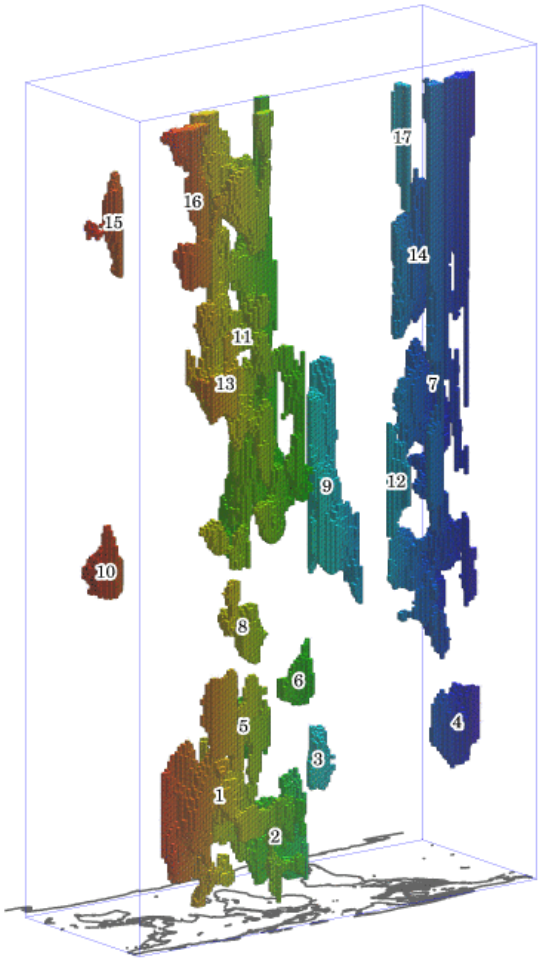
Probability of Snowfall Rate > 0.5” per hour from HRRR-TLE



MODE-TD applied to drought index for NSF EaSM project



Simulation



Analysis

Comparison Between Methods

2D MODE ERRORS

- Location
- Intensity
- Shape
- Size
- Orientation

MTD ERRORS

- Timing
- Velocity
- Duration
- Buildup and Decay

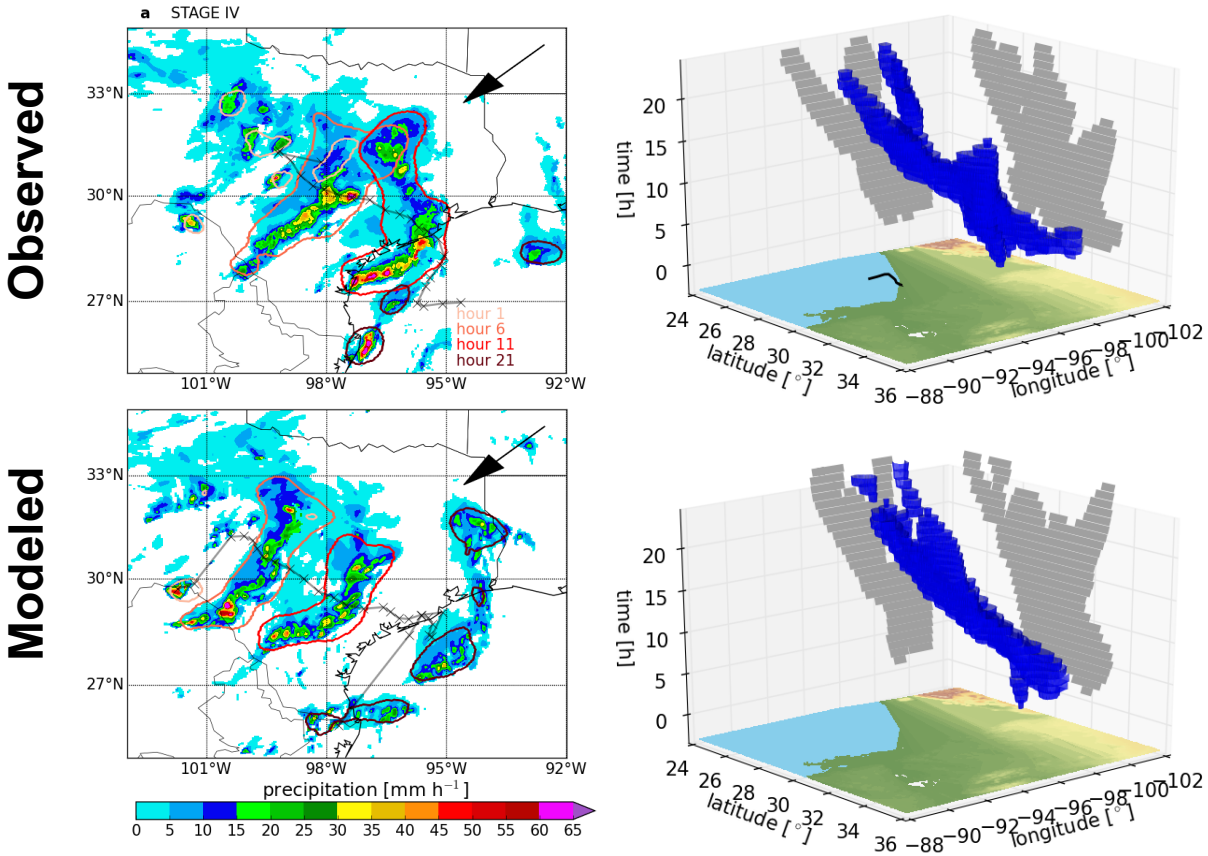
2D MODE Output

- NetCDF with 2D objects
- Text with 2D object attributes
- Postscript file with Objects

3D MODE Output

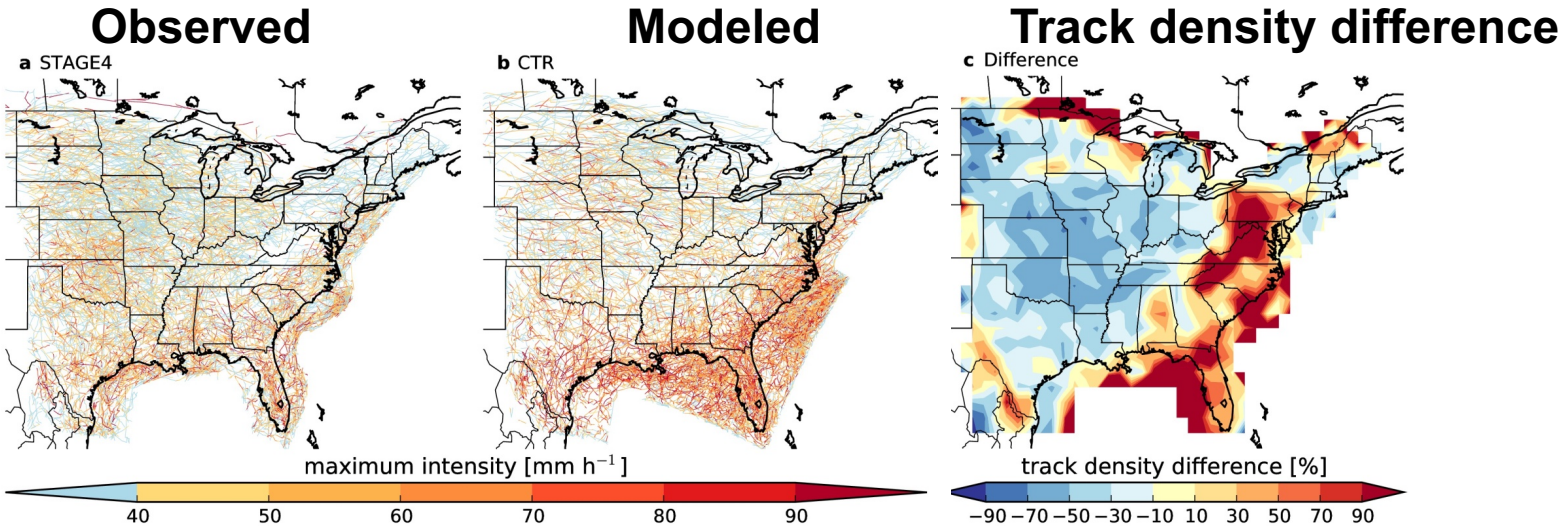
- NetCDF with 2D and 3D objects
- Text with 3D object attributes
- Text with 2D object attributes

MCS in Texas during March 2007



Slide Courtesy of Andreas Prein, NCAR/MMM

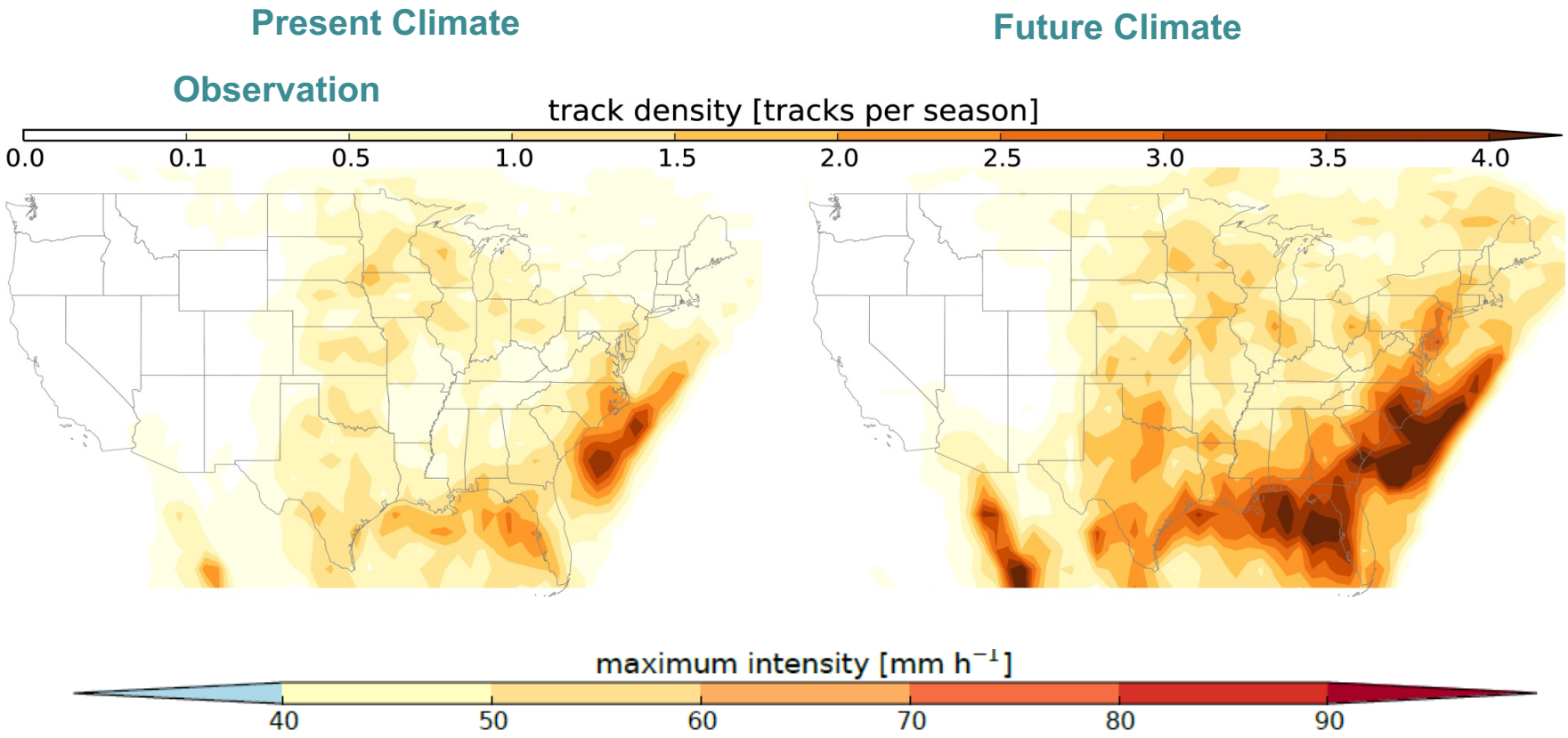
JJA Storm tracks



- Realistic representation of storm tracks
- Underestimation of storms in Central U.S. by up to -70 %

Slide Courtesy of Andreas Prein, NCAR/MMM

Storm Tracks



- Storms systems increase in intensity and frequency

Slide Courtesy of Andreas Prein, NCAR/MMM