

Model Evaluation Tools (MET) tutorial

4 - 5 February, 2009



- **What?**

- Set of verification tools for evaluating forecasts via

- standard statistics
 - object-based methods
 - scale decompositions

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- **Why?**

- Make verifying easy.
 - Encourage verification.
 - Promote consistency across users.

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- **How?**

- A (unix like) package of software tools and scripts.
 - Community contributed methods, graphics, etc.

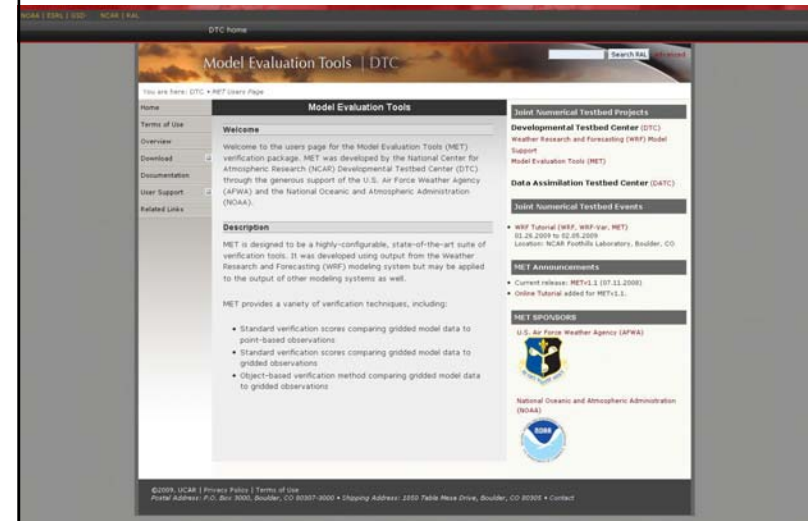
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Downloading MET

- MET distributed as a tarball to be downloaded and compiled locally.
 - METv1.1 released on July 11, 2008.
 - METv2.0 scheduled for February 2009.
 - METv2.0 BETA pre-installed on tutorial machines.
 - Register and download: www.dtcenter.org/met/users
- Language:
 - Written primarily in C++ with calls to a Fortran library
- Supported Platforms and Compilers:
 - Linux with GNU compilers
 - Linux with Portland Group (PGI) compilers
 - IBM machines with IBM compilers

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www.dtcenter.org/met/users



Dependencies

- **REQUIRED:**
 - GNU Make Utility
 - C++ and Fortran compilers (GNU, PGI, or IBM)
 - NetCDF version 3 Library
 - BUFRLIB Library
 - GNU Scientific Library (GSL)
 - F2C Library (f2c or g2c, for some compilers)
- **RECOMMENDED:**
 - WRF Post-Processor
 - COPYGB (included with WRF-Post)
 - R statistics and graphics package
 - *CWORDSH (not needed for v2.0)*

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Directory Structure

| File or Directory | Contents |
|----------------------------|--|
| README | Installation instructions and release notes. |
| Makefile_gnu (pgi, ibm) | Top-level Makefile to be configured prior to building MET. |
| lib/ | Source code for internal MET libraries. |
| src/ | Source code for the MET applications. |
| doc/ | MET User's Guide. |
| bin/ | Built MET executables. |
| scripts/ | Test scripts to be run after building MET. |
| data/ | Sample data used by the test scripts. |
| out/ | Output generated by the test scripts. |

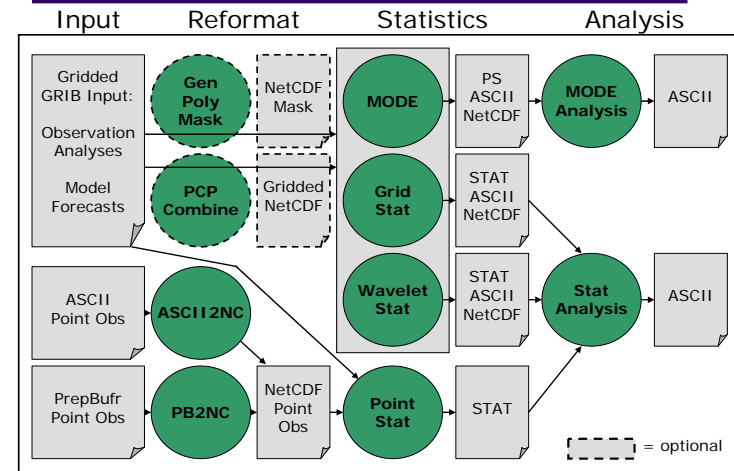
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Building MET

- Steps for building MET:
 1. Build the required libraries with the same family of compilers to be used with MET.
 - GNU, PGI, or IBM
 2. Select the appropriate Makefile.
 - GNU, PGI, or IBM
 3. Configure the Makefile.
 - C++ and Fortran compilers
 - Paths for NetCDF, BUFRLIB, GSL, and F2C libraries
 4. Execute the GNU Make utility to build all of the MET utilities.
 5. Run the test script and check for runtime errors.
 - Runs each of the MET tools at least once.
 - Uses sample data distributed with the tarball.

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MET v2.0 Flowchart



Graphics

- Limited graphics incorporated into MET.
- Several options for plotting MET statistical output - including R, NCL, IDL, GNUPlot, and many others.
- Users are encouraged to submit their own plotting and/or analysis scripts using any tool for posting to the MET website.

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R Statistics and Graphics

- The R Project for Statistical Computing (www.r-project.org)
 - Powerful statistical analysis and plotting tools.
 - Freely available and well supported for Linux/Windows/Mac.
- Sample R plotting and analysis scripts posted on the MET website.
- Recent praise for R in the technology section of the NY Times:
 - http://www.nytimes.com/2009/01/07/technology/business-computing/07program.html?_r=2

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Configuration Files

- Set of command line tools controlled using command line options and ASCII configuration files.
 - Well commented and documented in MET User's Guide.
 - Easy to modify.
 - Distributed with the tarball.
- Configuration files control things such as:
 - Fields/levels to be verified.
 - Thresholds to be applied.
 - Interpolation methods to be used.
 - Verification methods to be applied.
 - Regions over which to accumulate statistics.

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Data Formats and Types

Tressa L. Fowler

What you can do with MET
depends on
what type of data you have.

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The **format** (grid, point) of your
data determines your MET
tool(s).

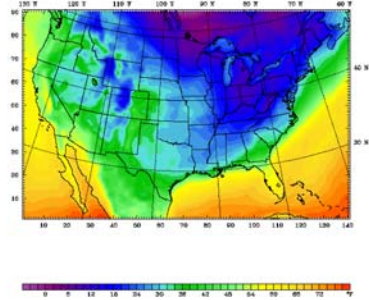
The **type** (continuous, binary) of
your data determines the
analyses to use within each
tool.

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Data Formats

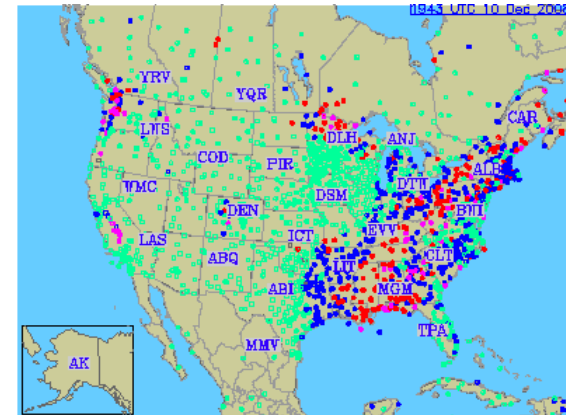
Gridded Forecasts (2D or 3D)

Dataset: GSI_RP2_reanalysis_tprc
 Post: 0000 UTC Sat 06 Dec 08
 Valid: 0600 UTC Sat 06 Dec 08 (G100 EDT Sat 06 Dec 08)
 Temperature
 at k-index = 30



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Point Observations (2D or 3D)



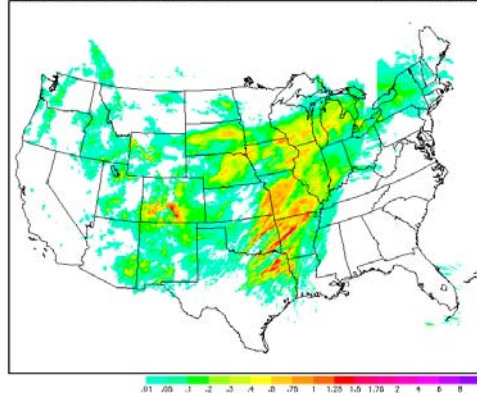
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Gridded Observations (2D or 3D)

Past 24-hour accumulated precip. (water equiv inches)

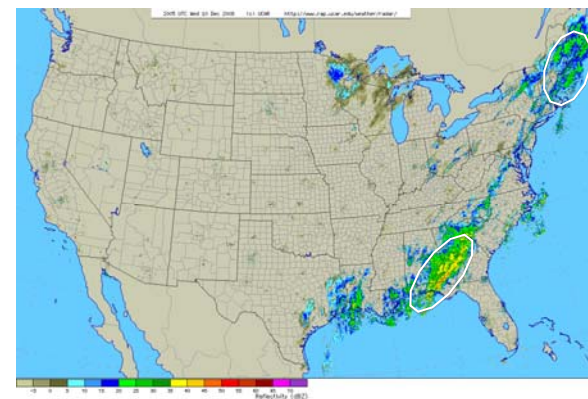
Analysis valid 1200 UTC Tue 09 Dec 2008

NGCEP "Stage IV" analysis



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Gridded data to transform into **Objects**



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| Data | MET Tool |
|---|-----------------------------------|
| Gridded Forecasts Gridded Observations | Grid stat Wavelet Stat MODE |
| Gridded Forecasts Point Observations | Point Stat |

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Data Types

Types of Forecasts

- Continuous
 - Wind speed
 - Temperature
- Categorical (includes Binary)
 - Rain / No Rain
 - Hurricane Category 1 - 5
- Probabilistic
 - Prob of freezing precip
- Ensembles

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Types of Observations

- Continuous
 - Wind speed
 - Temperature
- Categorical (includes binary)
 - Rain / No Rain
 - No tornado, F1, F2, F3, F4, F5

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| Data type | Analyses |
|--|---|
| Continuous forecasts Continuous observations | Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), Bias |
| Continuous forecasts, Categorical observations | Receiver Operating Characteristic (ROC) curve, Kolmogorov-Smirnov |
| Categorical forecasts, Categorical observations | Contingency table statistics and skill scores |
| Probabilistic forecasts, Categorical observations | Brier score, ranked probability score (RPS), reliability diagram |

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Introduction to Standard Verification

Tressa L. Fowler

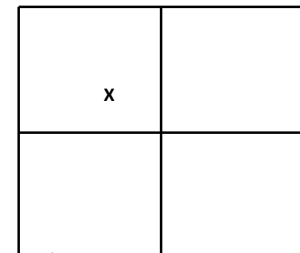
Basics

- Match up forecasts and observations at points.
- Calculate differences, sums, or counts over all the points.
- Summarize these things as statistics.

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Matching Points to Grids

- Observation points are unlikely to fall exactly on forecast grid points.
- Match in horizontal space via choice of methods:
 - Closest
 - Interpolate
 - Function of surrounding points, e.g.
 - Min of closest 4
 - Median of closest 25
- Match in vertical by interpolating between level above and below.



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Matching Grids to Grids

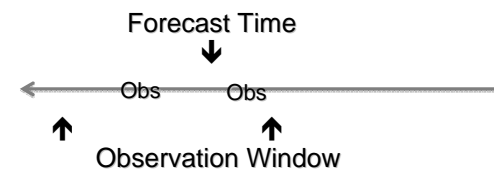
- Must use some converter to put forecasts and observations on the same grid.

– Example: copygb

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Time

- If your forecasts and observations are not at the same time, you may need to define a time window for your observations.



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Now you have a bunch of forecast / observation pairs

How well do they match?

| F | O | F | O |
|------|------|---|---|
| 0.32 | 0.03 | 1 | 1 |
| 0.51 | 0.0 | 0 | 0 |
| 0.42 | 0.48 | 0 | 1 |
| 0.08 | 0.14 | 1 | 0 |
| 0.20 | 0.23 | 0 | 1 |
| 0.75 | 0.33 | 1 | 1 |



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From those pairs, you can calculate a variety of statistics . . . like these

http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html

$$POD = \frac{hits}{hits + misses}$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (F_i - O_i)^2}$$

$$ETS = \frac{hits - hits_{random}}{hits + misses + false\ alarms - hits_{random}}$$

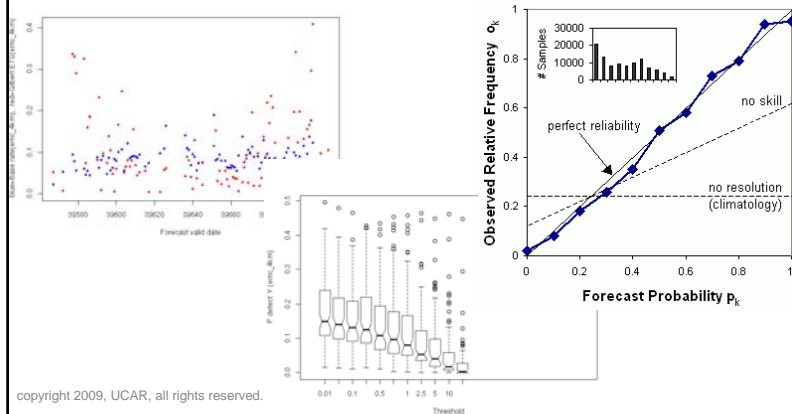
Correlation r

$$r = \frac{\sum (F - \bar{F})(O - \bar{O})}{\sqrt{\sum (F - \bar{F})^2} \sqrt{\sum (O - \bar{O})^2}}$$

| | Observed Event | Observed Non-event |
|--------------------|--------------------|------------------------------|
| Forecast Event | Count = 532 (Hits) | Count = 219 (False Alarm) |
| Forecast Non-event | Count = 393 (Miss) | Count = 1,627 (Correct No's) |

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Example Plots



References for information about verification

- http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html
- Wilks, D.S., 2006. Statistical Methods in the Atmospheric Sciences. 2nd Ed, Academic Press.
- Jolliffe, Stephenson (eds.), 2003. Forecast Verification: A Practitioner's Guide in Atmospheric Science. Wiley.

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File Formats and Pre-Processing

- Data Formats
- Pre-processing Tools
- Useful Links

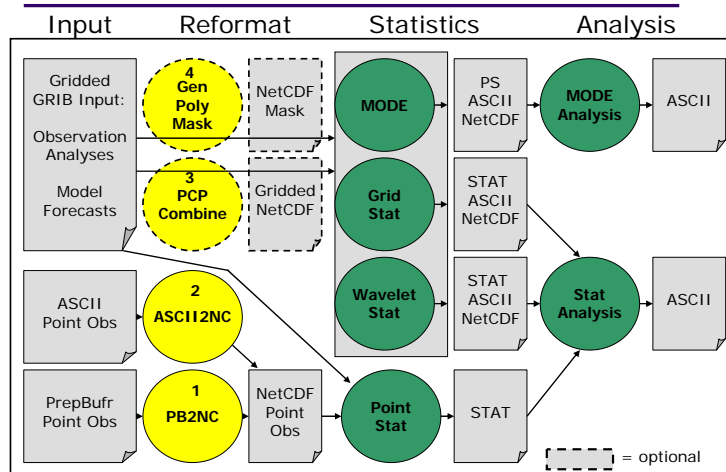
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Supported Data Formats

- **Forecasts**
 - **GRIB** – GRIdded Binary data format (*version 1)
 - **NetCDF** – network Common Data Format
- **Observations**
 - **PREPBUFR** – binary dataset prepared by NCEP from varied data sources.
 - **ASCII** – “Met_Point” format (10-cols x n-rows)
 - **gridded GRIB** – i.e. NEXRAD Level II or IV
 - **point NetCDF** – i.e. aircraft observations

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Pre-Processing / Reformatting



Data Reformating Tools

- **PB2NC and ASCII2NC**
 - Arrange observational data into the NetCDF point format expected by Point-Stat.
- **PCP_Combine (optional)**
 - Sum precipitation values across two or more time periods.
 - Subtract precipitation values to create values for finer subperiods.
 - Produces gridded NetCDF file that can be used as input grid for any Statistics tool.
- **Gen_Poly_Mask (optional)**
 - Used when more complex masking is needed.
 - Produces a NetCDF file of pre-defined mask.
 - May be used for masking in any Statistics tools.

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1. PB2NC Tool

- Stands for “PREPBUFR to NetCDF”
- **Functionality:**
 - Filters and reformats PREPBUFR point observations into intermediate NetCDF format.
 - Configuration file specifies:
 - Observation types, variables, locations, elevations, quality marks, and times to retain or derive for use in Point-Stat.
- **Data formats:**
 - Reads PREPBUFR using NCEP's BUFRLIB.
 - Writes point NetCDF as input to Point-Stat.

Note: v2.0 no longer requires CWORDSH to pre-process PREPBUFR files.

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PB2NC: Usage

Usage: pb2nc

prepbuf_file

netcdf_file

config_file

[-pbfile prepbuf_file]

[-valid_beg time]

[-valid_end time]

[-nmsg n]

[-dump path]

[-v level]

| | |
|--------------|---|
| prepbuf_file | Input obs file in PrepBuf format |
| netcdf_file | Output name for NetCDF file |
| config_file | PB2NC configuration file |
| -pbfile | Additional input PrepBuf files |
| -valid_beg | Beginning of valid time window [YYYYMMDD_[HH[MMSS]]] |
| -valid_end | End of valid time window [YYYYMMDD_[HH[MMSS]]] |
| -nmsg | Number of PrepBuf messages to process |
| -dump | Dump entire contents of PrepBuf file to file in path |
| -v | Level of logging |

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PB2NC: Run

- **METv2.0/bin/pb2nc **
**ndas.t00z.prepbuf.t12.20070401.nr **
**tutorial/out/pb2nc/tutorial_pb.nc **
**tutorial/config/PB2NCCConfig_tutorial **
-v 2

```
==> append : to filename to view the data source
BUFR
230ADPUPA  UPPER-AIR (RAOB, PIBAL, RECCO, DROPS) REPORTS
231AIRCAR  MDCRS ACARS AIRCRAFT REPORTS
232AIRCFT  232AIRCFT
AIREP/PIREP, AMDAR(ASDAR/ACARS), E-ADAS(AMDAR BUFR) ACF233SATWIND
SATELLITE-DERIVED WIND REPORTS
234PROFLR  WIND
PROFILER REPORTS
235VADWIND  VAD (NEXRAD) WIND
REPORTS
236SATEMP  TOVS SATELLITE DATA (SOUNDINGS,
RETRIEVALS, RADIANCES) 237ADPSFC  SURFACE LAND (SYNOPTIC, METAR)
REPORTS
238SFCSHP  SURFACE MARINE (SHIP, BUOY, C-MAN
PLATFORM) REPORTS
239SFCBOG  MEAN SEA-LEVEL PRESSURE BOGUS
REPORTS
240SPSSMI  SSM/I RETRIEVAL PRODUCTS (REPROCESSED
WIND SPEED, TPW) 241SYNDAT  SYNTHETIC TROPICAL CYCLONE BOGUS
REPORTS
242ERS1DA  ERS SCATTEROMETER DATA (REPROCESSED
WIND SPEED)
243GOESND  GOES SATELLITE DATA (SOUNDINGS,
RETRIEVALS, RADIANCES) 244OKSWND  QUIKSCAT SCATTEROMETER DATA
(REPROCESSED WIND SPEED)
245MSONET  MESONET SURFACE REPORTS
(COOPERATIVE NETWORKS)
246GPSIPW  GLOBAL POSITIONING
SATELLITE-INTEGRATED PRECIP. WATER
247TRASSDA  RADIO ACOUSTIC
SOUNDING SYSTEM (RASS) TEMP PROFILE RPTSM063000BYTCNT
...
```

Result of running linux “less”
command:

```
>less \
ndas.t00z.prepbuf.t12.2007
0401.nr
```

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PREPBUFR

- **BUFR** is the World Meteorological Organization (WMO) standard binary code for the representation and exchange of observational data.
 - <http://www.ncep.noaa.gov/sib/decoders/BUFRLIB/>
 - <http://www.ecmwf.int/products/data/software/>
- The **PREPBUFR** format is produced by NCEP for analyses and data assimilation. The system that produces this format:
 - Assembles observations dumped from a number of sources
 - Encodes
 - information about the observational error for each data type
 - background (first guess) interpolated to each data location
 - Performs both rudimentary multi-platform quality control and more complex platform-specific quality control
- **MET currently only supports PREPBUFR.** Let us know if you need to read in other BUFR format.

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PREPBUFR - Known Issues

- CWORDSH blocking
 - In v1.0 and v1.1 it was needed to structure to data properly for reading by the MET fortran code.
 - Need eliminated in v2.0.
- Compilation 64-bit OS
 - Will work if you compile using 32-bit flags.
 - Investigation of this problem in ongoing.

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2. ASCII2NC Tool

- Stands for “ASCII to NetCDF”
- **Functionality:**
 - Reformat ASCII point observations into intermediate NetCDF format.
 - One input ASCII format supported (10 columns):
 - No configuration file.
- **Data formats:**
 - Reads Met_Point ASCII.
 - Writes point NetCDF as input to Point-Stat.
 - **Future: support additional standard ASCII formats.**

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ASCII2NC: Usage

Usage: ascii2nc

ascii_file

netcdf_file

[-format ascii_format]

[-v level]

| | |
|-------------|---|
| ascii_file | Input obs file in ASCII format |
| netcdf_file | Output name for NetCDF file |
| -format | Override default MET_Point format (Future Option) |
| -v | Level of logging |

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MET_Point Format

| Msg | STID | ValidTime | Lat | Lon | Elev | GC | Lvl | Hgt | Ob |
|--------|-------|-----------------|-------|---------|--------|----|-------|------|---------|
| ADPUPA | 72365 | 20070331_120000 | 35.03 | -106.62 | 1618.0 | 7 | 837.0 | 1618 | 1618 |
| ADPUPA | 72365 | 20070331_120000 | 35.03 | -106.62 | 1618.0 | 11 | 837.0 | 1618 | 273.05 |
| ADPUPA | 72365 | 20070331_120000 | 35.03 | -106.62 | 1618.0 | 17 | 837.0 | 1618 | 271.85 |
| ADPUPA | 72365 | 20070331_120000 | 35.03 | -106.62 | 1618.0 | 52 | 837.0 | 1618 | 92 |
| ADPUPA | 72365 | 20070331_120000 | 35.03 | -106.62 | 1618.0 | 53 | 837.0 | 1618 | 0.00417 |
| ADPUPA | 72365 | 20070331_120000 | 35.03 | -106.62 | 1618.0 | 7 | 826.0 | 1724 | 1724 |
| ADPUPA | 72365 | 20070331_120000 | 35.03 | -106.62 | 1618.0 | 11 | 826.0 | 1724 | 274.55 |

* Use a value of "-9999" to indicate missing data

| Msg | Message type |
|------|---|
| STID | WMO Station ID |
| Lat | Latitude [North] |
| Lon | Longitude [East] |
| Elev | Elevation [m] (Note: currently not used by MET code so can be filled with -9999.) |
| GC | GRIB code for variable (i.e. AccPrecip = 61; MSLP = 2; Temp = 11, etc...) http://www.cpc.ncep.noaa.gov/products/wesley/opn_gribtable.html |
| Lvl | Pressure [mb] or Accumulation Interval [hr] |
| Hgt | Height above Mean Sea Level [m – MSL] (Note: currently not used by MET code so can be filled with -9999.) |
| Ob | Observed value |

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ASCII2NC: Run

- **METv2.0/bin/ascii2nc sample_obs.txt sample_ascii.nc -v 2**

```
netcdf sample_ascii {
dimensions:
    mxstr = 15 ;
    hdr_arr_len = 3 ;
    obs_arr_len = 5 ;
    nhdr = 5 ;
    nobs = UNLIMITED ; // (2140 currently)
variables:
    char hdr_typ(nhdr, mxstr) ;
        hdr_typ::long_name = "message type" ;
    char hdr_sid(nhdr, mxstr) ;
        hdr_sid::long_name = "station identification" ;
    char hdr_vld(nhdr, mxstr) ;
        hdr_vld::long_name = "valid time" ;
        hdr_vld::units = "YYYYMMDD_HHMMSS UTC" ;
    float hdr_arr(nhdr, hdr_arr_len) ;
        hdr_arr::long_name = "array of observation station header values" ;
        hdr_arr::fill_value = -9999.f ;
        hdr_arr::columns = "lat lon elev" ;
    float obs_arr(nobs, obs_arr_len) ;
        obs_arr::long_name = "array of observation values" ;
        obs_arr::fill_value = -9999.f ;
        obs_arr::columns = "hdr_id gc lvt hgt ob" ;
        obs_arr::hdr_id_long_name = "index of matching header data" ;
    ...
}
```

← Result of **ncdump -h**

Result of **ncdump -v obs_arr** →

```
obs_arr =
1, 7, 837, 1618, 1618,
1, 11, 837, 1618, 273.05,
1, 17, 837, 1618, 271.85,
1, 52, 837, 1618, 92,
1, 53, 837, 1618, 0.00417,
1, 7, 826, 1724, 1724,
1, 11, 826, 1724, 274.55,
1, 17, 826, 1724, 272.15,
1, 52, 826, 1724, 84,
1, 53, 826, 1724, 0.00432,
1, 7, 815.3, 1829, 1829,
1, 11, 815.3, 1829, 276.45,
1, 17, 815.3, 1829, 265.75,
1, 52, 815.3, 1829, 45,
1, 53, 815.3, 1829, 0.0027,
1, 7, 815, 1832, 1832,
1, 11, 815, 1832, 276.55,
1, 17, 815, 1832, 265.55,
1, 52, 815, 1832, 44,
1, 53, 815, 1832, 0.00266,
1, 7, 784.7, 2134, 2134,
1, 11, 784.7, 2134, 274.05,
1, 17, 784.7, 2134, 264.15,
1, 52, 784.7, 2134, 47,
```

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3. PCP-Combine Tool

- Stands for “Precip-Combine”
- **Functionality:**
 - Mathematically combines precipitation fields across multiple files.
 - Add precipitation over 2 files
 - 2 NMM output files to go from 3-hr to 6-hr accumulation.
 - Sum precipitation over more than 2 files
 - 12 ARW output files to go from 1-hr to 12 hr accumulation.
 - Subtract precipitation in 2 files
 - 2 Level II radar files).
 - Specify field name on the command line.
 - No configuration file.
- **Data formats:**
 - Reads GRIB format.
 - Writes gridded NetCDF as input to stats tools.

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PCP-Combine: Usage

Usage: **pcp_combine**

[-sum sum_args]
or [-add add_args]
or [-subtract sub_args]
[-gc code]
[-v level]

| | |
|------------------|--|
| -sum | Accumulates data over multiple files. <i>Sum_args</i>: (init_time, in_accum, valid_time, out_accum, out_file, -pcpdir path, -pcprx reg_exp) |
| -add | Accumulates data over two files. <i>Add_args</i>: (in_file1, Accum1, in_file2, Accum2, out_file). |
| -subtract | Subtracts data over two files. <i>Sub_args</i>: (in_file1, Accum1, in_file2, Accum2, out_file). |
| -gc | GRIB code for variable (<i>i.e.</i> AccPrecip = 61; MSLP = 2; Temp = 11, etc...). |
| -v | Level of logging |

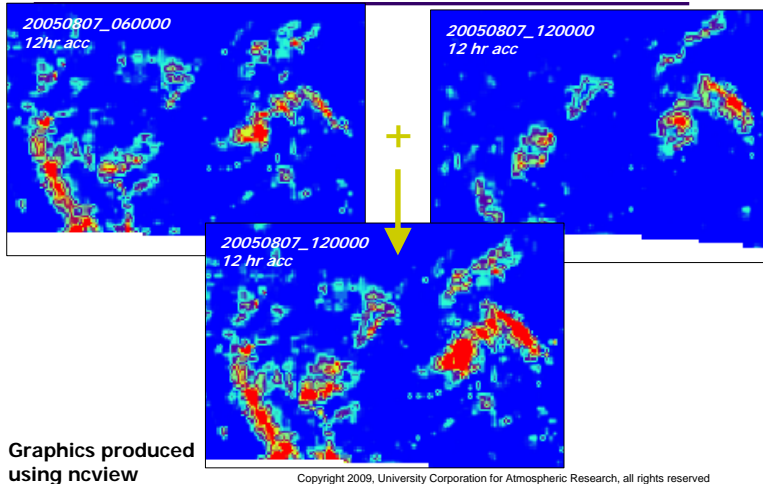
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PCP-Combine: Run

- **Two example command lines**
 - 1) Summing two 6-hourly accumulation forecast files into a single 12-hour accumulation forecast.
**METv2.0/bin/pcp_combine **
**-add 20050807_060000 6 20050807_120000 6 **
**sample_fcst.nc **
-pcpdir data/2005080700
 - 2) Summing 12 1-hourly accumulation observation files into a single 12-hour accumulated observation.
**METv2.0/bin/pcp_combine **
**-sum 00000000_000000 1 20050807_120000 12 **
**sample_obs.nc **
-pcpdir data/ST2ml

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PCP-Combine: Example #1



GRIB vs GRIB2

- **GRIB (or GRIB1):** WRF postprocessor (WPP) produces GRIB1 format using copyGB
 - Performs horizontal interpolation and destaggering (in the case of WRF-NMM) onto a defined grid.
 - Useful for both cores in creating an output grid not fixed by the model integration domain.
 - <http://www.dtcenter.org/wrf-nmm/users/downloads/>
- **GRIB2:** NCEP and other WMO organizations have historical data in GRIB1 but now use GRIB 2 as the standard for gridded binary data.
- **At least two GRIB2toGRIB1 converters available**
 - NCEP cnvgrib
 - <http://www.nco.ncep.noaa.gov/pmb/codes/GRIB2/>
 - UCAR/CISL Grib Converter
 - <http://dss.ucar.edu/libraries/grib/c.html>

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Data Inventory Tools

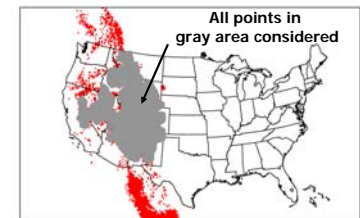
- **wgrib** – dumps GRIB1 headers and data.
 - <http://www.cpc.ncep.noaa.gov/products/wesley/wgrib.html>
- **wgrib2** – dumps GRIB2 headers and data.
 - <http://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/>
- **ncdump** - dumps NetCDF headers and data.
ncview – plots gridded NetCDF data.
 - <http://www.unidata.ucar.edu/software/netcdf/>
- **GrADS** – command line interface to produce plots.
 - <http://www.iges.org/grads/downloads.html>
- **NCL** – command line interface to produce plots.
 - <http://www.ncl.ucar.edu/>
- **IDV** – gui-driven visualization of many gridded and point datasets.
 - <http://www.unidata.ucar.edu/software/idv/>

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4. Gen Poly Mask Tool

- **Stands for “General Polyline Mask”**
- **Functionality:**
 - Pre-computes a lat/lon polyline to generate a 0/1 mask field to be applied to your data.
 - Applies this mask once – prior to running Point-Stat or Grid-Stat
 - No configuration file.
- **Data formats:**
 - Reads Ascii formatted polyline file.
 - Reads GRIB file.
 - Reads NetCDF files from PCP-Combine.
 - Writes gridded NetCDF file of 0/1 mask.

Example polyline mask
Coordinates generated from underlying points of Elevation > 5000 ft.

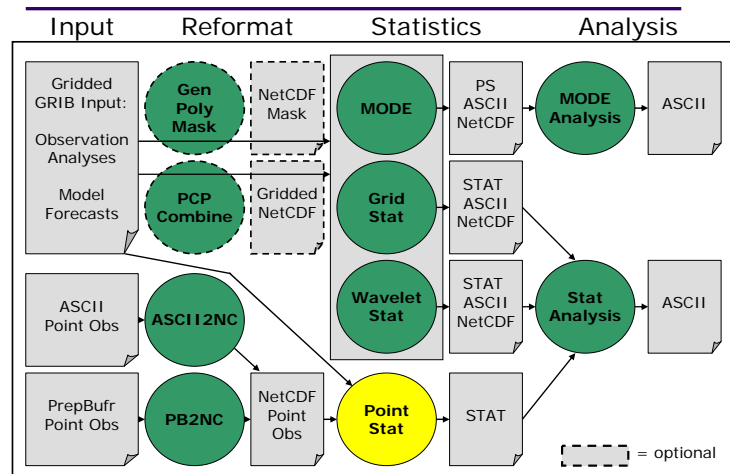


Example polyline file:
data/poly/CONUS.poly

```
CONUS
35.81352 -122.33439
36.01565 -121.51420
35.35092 -121.27343
34.68935 -121.03940
34.03100 -120.81184
34.21258 -120.01634
33.55392 -119.80508
...
```

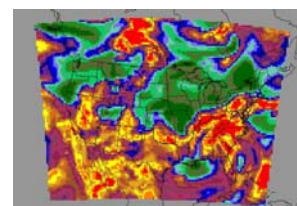
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Point-Stat Tool

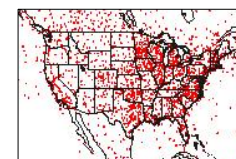


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Point-Stat: Overview



- Compare **gridded forecasts to point observations**.
- Accumulate matched pairs over a defined area at a *single* point in time.
- Verify one or more variables/levels.
- Analysis tool provided to aggregate through time.



- Verification methods:
 - Continuous statistics for raw fields.
 - Categorical counts and statistics for thresholded fields.
 - Parametric and non-parametric confidence intervals for statistics.
 - Compute partial sums for raw fields and/or the raw matched pair values.
 - Probabilistic methods.

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Point-Stat: Input/Output

- Input Files
 - Gridded forecast file
 - GRIB output of WRF Post-Processor (or other)
 - NetCDF output of PCP-Combine
 - Point observation file
 - NetCDF output of PB2NC
 - NetCDF output of ASCII2NC
 - ASCII configuration file
- Output Files
 - ASCII statistics file with all output lines (end with ".stat")
 - Optional ASCII files sorted by line type with a header row (ends with "_TYPE.txt")

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Point-Stat: Usage

Usage: point_stat

fcst_file

obs_file

config_file

[-climo climo_file]

[-ncfile netcdf_file]

[-valid_beg time]

[-valid_end time]

[-outdir path]

[-v level]

| | |
|-------------|--|
| fcst_file | Forecast file in GRIB or NetCDF |
| obs_file | Point observation file in NetCDF (PB2NC or ASCII2NC) |
| config_file | ASCII configuration file |
| -climo | Climatological file for computing anomaly partial sums |
| -ncfile | Additional point observation files in NetCDF |
| -valid_beg | Beginning of valid time window for matching |
| -valid_end | End of valid time window for matching |
| -outdir | Output directory to be used |
| -v | Level of logging |

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Point-Stat: Configuration

- 25 configurable parameters – only set a few:
 - Temperature at the surface (2-meter).
 - `fcst_field[] = ["TMP/Z2"];`
 - Temperature below freezing.
 - `fcst_thresh[] = ["le273"];`
 - Match to observations at the surface.
 - `message_type[] = ["ADPSFC"];`
 - Look at all the points in my domain.
 - `mask_grid[] = ["FULL"];`
 - Match observation to the nearest forecast value.
 - `interp_width[] = [1];`
 - Generate all possible statistic types.
 - `output_flag[] = [2, 2, 2, 2, 2, 2, 2, 2];`

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Point-Stat: Run

- METv2.0/bin/point_stat \
sample_fcst.grb sample_pb.nc \
PointStatConfig_TMPZ2 -outdir out -v 2

```
Forecast File: sample_fcst.grb
Climatology File: none
Configuration File: PointStatConfig_TMPZ2
Observation File: sample_pb.nc
-----
Reading records for TMP/Z2.
For TMP/Z2 found 1 forecast levels and 0 climatology levels.
-----
Searching 179772 observations from 44076 PrepBufr messages.
-----
Processing TMP/Z2 versus TMP/Z2, for observation type ADPSFC, over region FULL, for interpolation method
UM_MEAN(1), using 11370 pairs.
Computing Categorical Statistics.
Computing Continuous Statistics.
Computing Scalar Partial Sums.
-----
Output file: out/point_stat_360000L_20070331_120000V.stat
Output file: out/point_stat_360000L_20070331_120000V_fho.txt
Output file: out/point_stat_360000L_20070331_120000V_ctc.txt
Output file: out/point_stat_360000L_20070331_120000V_cts.txt
Output file: out/point_stat_360000L_20070331_120000V_cnt.txt
Output file: out/point_stat_360000L_20070331_120000V_sl1l2.txt
Output file: out/point_stat_360000L_20070331_120000V_sal1l2.txt
Output file: out/point_stat_360000L_20070331_120000V_vl1l2.txt
Output file: out/point_stat_360000L_20070331_120000V_val1l2.txt
Output file: out/point_stat_360000L_20070331_120000V_mpr.txt
```

Point-Stat: ASCII Output Types

- Statistics line types: 9 possible
 - Categorical - apply threshold
 - Contingency table counts (**FHO**, **CTC**)
 - Contingency table statistics (**CTS**)
 - Continuous - raw fields
 - Continuous statistics (**CNT**)
 - Partial Sums (**SL1L2**, **SAL1L2**, **VL1L2**, **VAL1L2**)
 - Matched Pairs
 - Raw matched pairs – a lot of data! (**MPR**)
 - Additional line type(s) for probabilistic methods
- 21 header columns common to all line types
- Remaining columns specific to each line type

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Point-Stat: Sample Output

- **STAT** file output for sample run:
 - 1 line each for **FHO**, **CTC**, **CTS**, **CNT**, and **SL1L2**
 - 11,370 lines for **MPR**!
- 6 additional **TXT** files with lines sorted by type

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Point-Stat: CTC Output Line

| | |
|-----------------------|-----------------|
| VERSION | V2.0 |
| MODEL | WRF |
| FCST_LEAD | 360000 |
| FCST_VALID_BEG | 20070331_120000 |
| FCST_VALID_END | 20070331_120000 |
| OBS_LEAD | 000000 |
| OBS_VALID_BEG | 20070331_103000 |
| OBS_VALID_END | 20070331_133000 |
| FCST_VAR | TMP |
| FCST_LEV | Z2 |
| OBS_VAR | TMP |
| OBS_LEV | Z2 |
| OBTYPE | ADPSFC |

| | |
|--------------------|----------|
| VX_MASK | FULL |
| INTERP_MTHD | UW_MEAN |
| INTERP_PNTS | 1 |
| FCST_THRESH | <273.000 |
| OBS_THRESH | <273.000 |
| COV_THRESH | NA |
| ALPHA | NA |
| LINE_TYPE | CTC |
| TOTAL | 11370 |
| FY_OY | 1635 |
| FY_ON | 380 |
| FN_OY | 438 |
| FN_ON | 8917 |

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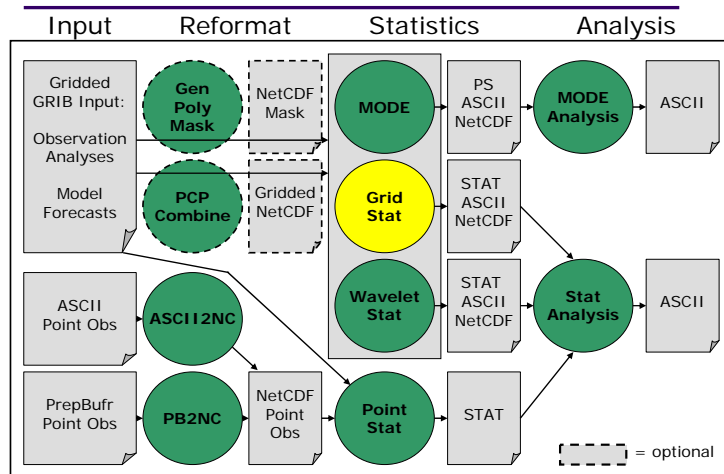
Point-Stat: Matched Pairs

- **Matched Pair (MPR) line type contains raw matched pairs.**
 - Data overload!

| TOTAL | INDEX | OBS_LAT | OBS_LON | OBS_LVL | OBS_ELV | FCST | OBS | CLIMC |
|-------|-------|----------|------------|------------|-----------|-----------|-----------|-------|
| 11370 | 1 | 43.93000 | -60.01000 | 1010.79999 | 4.01053 | 271.87788 | 271.54999 | NA |
| 11370 | 2 | 46.43000 | -71.93000 | 1016.09998 | 102.04903 | 268.50255 | 269.45001 | NA |
| 11370 | 3 | 44.23000 | -78.36000 | 1004.50000 | 191.44466 | 272.94013 | 272.35001 | NA |
| 11370 | 4 | 51.67000 | -124.40000 | 916.50000 | 872.82202 | 263.69020 | 264.95001 | NA |
| 11370 | 5 | 58.61000 | -117.16000 | 973.90002 | 337.50449 | 272.37757 | 270.95001 | NA |
| 11370 | 6 | 52.18000 | -122.04000 | 906.50000 | 938.08594 | 271.37738 | 264.35001 | NA |
| 11370 | 7 | 50.68000 | -127.36000 | 1020.20001 | 22.03931 | 275.44020 | 275.04999 | NA |
| 11370 | 8 | 50.45000 | -100.59000 | 949.09998 | 562.38477 | 272.18978 | 271.75000 | NA |
| 11370 | 9 | 57.13000 | -61.47000 | 899.70001 | 834.87476 | 258.06464 | 254.64999 | NA |
| 11370 | 10 | 47.56000 | -59.16000 | 1000.90002 | 40.06803 | 272.06486 | 269.54999 | NA |
| 11370 | 11 | 47.41000 | -72.79000 | 1006.90002 | 169.37592 | 266.37724 | 265.95001 | NA |
| 11370 | 12 | 45.76000 | -62.68000 | 1014.00000 | 1.99518 | 268.94018 | 268.64999 | NA |
| 11370 | 13 | 49.24000 | -65.33000 | 1014.90002 | 28.96468 | 264.25276 | 267.25000 | NA |
| 11370 | 14 | 43.29000 | -79.79000 | 1017.79999 | 77.03765 | 273.56474 | 275.85001 | NA |
| 11370 | 15 | 48.78000 | -123.04000 | 1015.70001 | 23.93772 | 278.12724 | 280.25000 | NA |

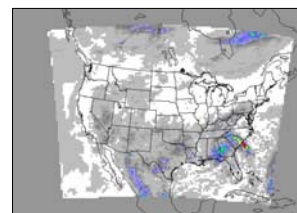
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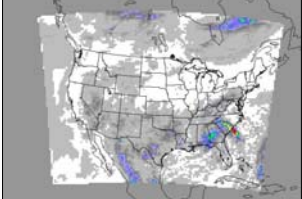
Grid-Stat Tool



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Grid-Stat: Overview



- 
- Compare **gridded forecasts** to **gridded observations** on the same grid.
 - Accumulate matched pairs over a defined area at a *single* point in time.
 - Verify one or more variables/levels.
 - Analysis tool provided to aggregate through time.
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Grid-Stat: Input/Output

- Input Files
 - Gridded forecast and observation files
 - GRIB output of WRF Post-Processor (or other)
 - NetCDF output of PCP-Combine
 - ASCII configuration file
- Output Files
 - ASCII statistics file with all output lines (end with ".stat")
 - Optional ASCII files sorted by line type with a header row (ends with "_TYPE.txt")
 - Optional NetCDF matched pairs file

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Grid-Stat: Usage

Usage: point_stat

fcst_file

obs_file

config_file

[-outdir path]

[-v level]

| | |
|-------------|------------------------------------|
| fcst_file | Forecast file in GRIB or NetCDF |
| obs_file | Observation file in GRIB or NetCDF |
| config_file | ASCII configuration file |
| -outdir | Output directory to be used |
| -v | Level of logging |

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Grid-Stat: Configuration

- 24 configurable parameters – only set a few:
 - Precipitation accumulated over 24 hours.
 - **fcst_field[]** = ["APCP/A24"];
 - Any rain and moderate rain.
 - **fcst_thresh[]** = ["gt0.00, gt20.00"]; (mm)
 - Look at all the points and only the eastern United States.
 - **mask_grid[]** = ["FULL"];
 - **mask_poly[]** = ["EAST.poly"];
 - Compute neighborhood statistics with two sizes.
 - **nbr_width[]** = [3, 5];
 - Generate all possible statistic types.
 - **output_flag[]** = [2, 2, 2, 2, 2, 2, 2, 2];

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Grid-Stat: Run

- METv2.0/bin/grid_stat \

sample_fcst.grb sample_obs.nc \

GridStatConfig_APCP24 -outdir out -v 2

```
Forecast File: sample_fcst.grb
Observation File: sample_obs.nc
Configuration File: GridStatConfig_APCP24
-----
Processing APCP/A24 versus APCP/A24, for interpolation method UM_MEAN(1), over region FULL, using 6412 pairs.
Computing Categorical Statistics.
Computing Continuous Statistics.
Processing APCP/A24 versus APCP/A24, for interpolation method UM_MEAN(1), over region EAST, using 2586 pairs.
Computing Categorical Statistics.
Computing Continuous Statistics.
Processing APCP/A24 versus APCP/A24, for interpolation method NBRHD(9), raw thresholds of >0.000 and >0.000,
over region EAST, using 5829 pairs.
... MORE NEIGHBORHOOD COMPUTATIONS ...
-----
Output file: out/grid_stat_240000L_20050808_000000V.stat
Output file: out/grid_stat_240000L_20050808_000000V_fho.txt
Output file: out/grid_stat_240000L_20050808_000000V_ctc.txt
Output file: out/grid_stat_240000L_20050808_000000V_ots.txt
Output file: out/grid_stat_240000L_20050808_000000V_cnt.txt
Output file: out/grid_stat_240000L_20050808_000000V_all12.txt
Output file: out/grid_stat_240000L_20050808_000000V_nbrctc.txt
Output file: out/grid_stat_240000L_20050808_000000V_nbrcts.txt
Output file: out/grid_stat_240000L_20050808_000000V_nbrcnt.txt
Output file: out/grid_stat_240000L_20050808_000000V_pairs.nc
```

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Grid-Stat: ASCII Output Types

- Statistics line types: 8 possible
 - Same as Point-Stat
 - FHO**, **CTC**, **CTS**, **CNT**, and **SL1L2**
 - Omitted for Grid-Stat
 - SAL1L2**, **VL1L2**, or **VAL1L2**
- Neighborhood – define neighborhood, apply threshold
 - Neighborhood continuous statistics (**NBRCNT**)
 - Neighborhood contingency table counts (**NBRCTC**)
 - Neighborhood contingency table statistics (**NBRCTS**)
- Additional line type(s) for probabilistic methods
- 21 header columns common to all line types
- Remaining columns specific to each line type

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Grid-Stat: Sample Output

- STAT** file output for sample run:
 - 2 lines each for **CNT** and **SL1L2**
 - = 2 verification regions (FULL and EAST)
 - 4 lines each for **FHO**, **CTC**, and **CTS**
 - = 2 regions * 2 thresholds
 - 8 lines each for **NBRCNT**, **NBRCTC**, **NBRCTS**
 - = 2 regions * 2 thresholds * 2 neighborhood sizes
- 8 additional **TXT** files with lines sorted by type
- NetCDF** file containing matched pairs

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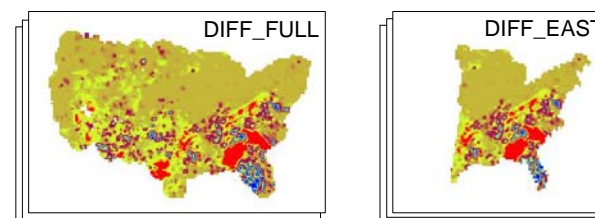
Grid-Stat: CTC Output Line

| | | | |
|-----------------------|-----------------|--------------------|----------|
| VERSION | V2.0 | VX_MASK | EAST |
| MODEL | WRF | INTERP_MTHD | UW_MEAN |
| FCST_LEAD | 240000 | INTERP_PNTS | 1 |
| FCST_VALID_BEG | 20050808_000000 | FCST_THRESH | >=20.000 |
| FCST_VALID_END | 20050808_000000 | OBS_THRESH | >=20.000 |
| OBS_LEAD | 000000 | COV_THRESH | NA |
| OBS_VALID_BEG | 20050808_000000 | ALPHA | NA |
| OBS_VALID_END | 20050808_000000 | LINE_TYPE | CTC |
| FCST_VAR | APCP | TOTAL | 2586 |
| FCST_LEV | A24 | FY_OY | 5 |
| OBS_VAR | APCP | FY_ON | 104 |
| OBS_LEV | A24 | FN_OY | 70 |
| OBTYPE | MC_PCP | FN_ON | 2407 |

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Grid-Stat: NetCDF Matched Pairs

- Forecast, observation, and difference fields for each combination of...
 - Variable, level, masking region, and interpolation method (smoothing)
- Sample output contains 6 variables:
 - FCST, OBS, and DIFF for **FULL** and **EAST**



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Variations

- **Grid-Stat** and **Point-Stat** may be used to compare two *different* variables.
 - Not strictly verification.
 - Leave observation blank to use forecast setting.
 - Selecting variable/levels:
 - `fcst_field[] = ["61/A24"];`
 - `obs_field[] = [];`
 - Selecting thresholds:
 - `fcst_thresh[] = ["gt0.0 ge20.0"];`
 - `obs_thresh[] = [];`

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Stat Analysis Tool

- Filtering
- Summarizing
- Aggregating

of Grid Stat, Point Stat,
& Wavelet output

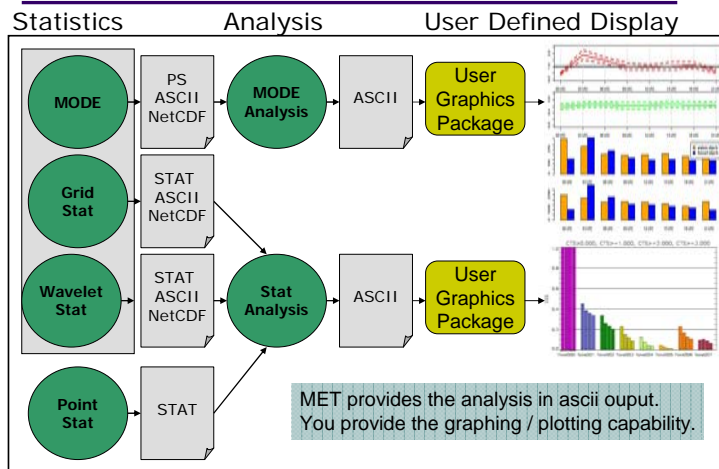
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What can Stat Analysis do for you?

- ✓ **Q:** If I wanted the overall statistics for all the gridded observations compared to the forecasts for hours 0 through 24 together, can MET do this?
A: Yes – using Stat Analysis Tool on Grid-Stat output
- ✓ **Q:** Can I compute long-term statistics at individual sites (eg, mean absolute error or RMS error for daily forecasts for a month).?
A: Yes – using Stat Analysis Tool on Point-Stat output
- ✓ **Q:** Can I aggregate my contingency table statistics over multiple runs?
A: Yes – using Stat Analysis Tool on any output
- ❑ **Q:** Can I aggregate statistics for a large number of individual stations in one simultaneous run?
A: No – but you could get the aggregate statistics for each individual station and run Stat Analysis Tool n-times.

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Stat Analysis Tool



Stat Analysis Jobs

- **Filtering**
 - **stat_job_filter** - filters out lines from one or more stat files based on user-specified filtering options.
- **Summarizing**
 - **stat_job_summary** - produces summary information from a single column of data including:
 - mean, standard deviation, min, max, and the 10th, 25th, 50th, 75th, and 90th percentiles.
- **Customized tool for AFWA**
 - **stat_job_go_index** - computes the GO Index, a performance Statric used primarily by the United States Air Force.

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Stat Analysis Jobs

• Aggregation

- **stat_job_aggr** - aggregates stat data across multiple time steps or masking regions to sum contingency table data or partial sums across multiple lines of data.
- **stat_job_aggr_cts** - aggregates contingency table to produce aggregated contingency table statistics.
- **stat_job_aggr_cnt** - computes as many continuous statistics from aggregated partial sums as possible.
- **stat_job_aggr_mpr** - aggregates the matched pair output of Point-Stat and recomputes the requested stat line type.

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PB2NC: Usage

Usage: stat_analysis

-lookin path
-out filename
[-v level]
[-config config_file]
or command line options with associated arguments
[stat_job_filter]
[stat_job_summary]
[stat_job_aggr]
[stat_job_cts]
[stat_job_aggr_cnt]
[stat_job_aggr_mpr]
[stat_job_go_index]

| | |
|--------------------------|-------------------------------------|
| -lookin | Directory where *.stat files reside |
| -out | Output name for NetCDF file |
| -v | Level of logging |
| -config | StatAnalysisConfig file |
| stat_job_filter | See previous 2 slides |
| stat_job_summary | See previous 2 slides |
| stat_job_aggr | See previous 2 slides |
| stat_job_cts | See previous 2 slides |
| stat_job_aggr_cnt | See previous 2 slides |
| stat_job_aggr_mpr | See previous 2 slides |
| stat_job_go_index | See previous 2 slides |

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Point-Stat: Configuration

- 22 configurable parameters – only set a few:
 - Apply NAM G212 mask
 - **vx_mask[] = ["G212"];**
 - Using only the Temperature variable
 - **var[] = ["TMP"];**
 - Filter on CTC lines that have been thresholded var[]>278
 - **line_type[] = ["CTC"];**
 - **fcst_thres[] = [">278"];**
 - Dump the filtered stat data to a file AND sum contingency table count (CTC) lines of data for pressure levels between 850 and 750
 - **joblist[] = ["-job stat_job_filter -dump_row out/filter_job.stat", "-job stat_job_aggr -dump_row out/aggr_ctc_job.stat -level P850-750"];**

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Stat Analysis Tool: Run stat_job_aggr

"-job stat_job_aggr -dump_row out/aggr_ctc_job.stat -level P850-750"

Point Stat Output (i.e. point_stat_out.stat)

```
V2.0   WRF   ... ADPUPA G212 ... TMP
P850-750 ... >278.00 CTC
= 401      192      174      11
24
UW_MEAN      1
```

```
V2.0   WRF   ... ADPSFC G212 ... TMP
P850-750 ... >278.00 CTC
= 167      25      119      23
0
UW_MEAN      1
```

(NOTE: header modified to show only pertinent info)

| OBS | | | | |
|------------------|---|-----|-----|-----|
| F C S T | | Y | N | |
| | Y | 192 | 11 | 203 |
| | N | 24 | 174 | 198 |
| | | 216 | 185 | 401 |

| OBS | | | | |
|------------------|---|----|-----|-----|
| F C S T | | Y | N | |
| | Y | 25 | 23 | 48 |
| | N | 0 | 119 | 119 |
| | | 25 | 142 | 167 |

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Stat Analysis Tool: Run `stat_job_aggr`

Stat Analysis Output (i.e. `stat_analysis.out`)

```
FILTER: -job vsdb_job_filter
-vx_mask G212 -line_type CTC
-fcst_thresh >278.000 -var TMP
-dump_row out/filter_job.vfdb
```

```
COL_NAME: TOTAL
FY_OY      FY_ON
FN_OY      FN_ON
INTERP_MTHD INTERP_PNTS
CTC:        568      217
34          24       293
-9999      -9999
```

```
JOB_COMMAND: -job vsdb_job_aggr
-vx_mask G212 -line_type CTC
-fcst_thresh >278.000 -var TMP
-level P850-750 -dump_row
out/aggr_ctc_job.vfdb
```

| OBS | | | | |
|------------------|---|-----|-----|-----|
| | | Y | N | |
| F C S T | Y | 217 | 34 | 251 |
| | N | 24 | 293 | 317 |
| | | 241 | 327 | 568 |

Identifying JOB_COMMAND Line comes after data

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Stat Analysis Tool: Run `stat_job_summary`

"`-job stat_job_summary -line_type CNT -alpha = 0.50 -var TMP \`
`-dump_row ./out/job_summary_RMSE.vfdb -column RMSE"`

(`stat_analysis.out` cont.)

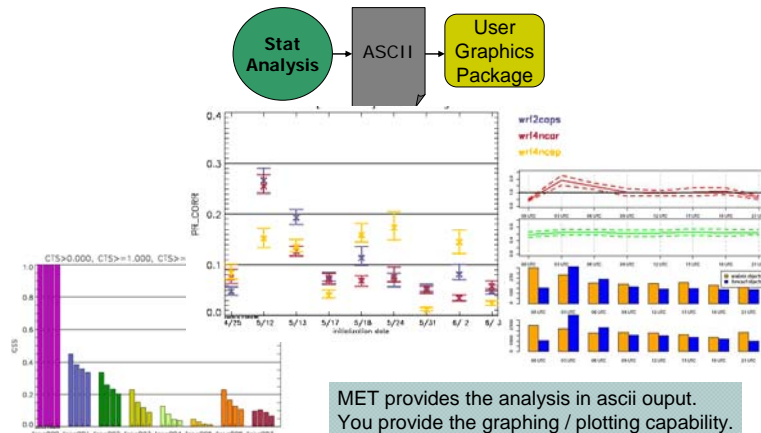
| Column Number | Description |
|---------------|---|
| 1 | Summary (job type) |
| 2 | Total |
| 3-7 | Mean* Includes normal and bootstrap upper and lower confidence limits |
| 8-10 | Standard deviation** Includes bootstrap upper and lower confidence limits |
| 11 | Minimum value |
| 12 | 10 th percentile |
| 13 | 25 th percentile |
| 14 | Median (50 th percentile) |
| 15 | 75 th percentile |
| 16 | 90 th percentile |
| 17 | Maximum value |

```
COL_NAME: TOTAL MEAN
MEAN_NCL MEAN_NCU MEAN_BCL
MEAN_BCU STDEV STDEV_BCL
STDEV_BCU MIN P10
P25 P50 P75
P90 MAX
SUMMARY: 4 1.98438
1.33219 2.63656 1.58837
2.29289 0.40986 0.04574
0.55950 1.41291 1.59671
1.87241 2.07130 2.18328
2.18328 2.30251
JOB_COMMAND: -job
vsdb_job_summary -line_type
CNT ...
```

Identifying JOB_COMMAND Line comes after data

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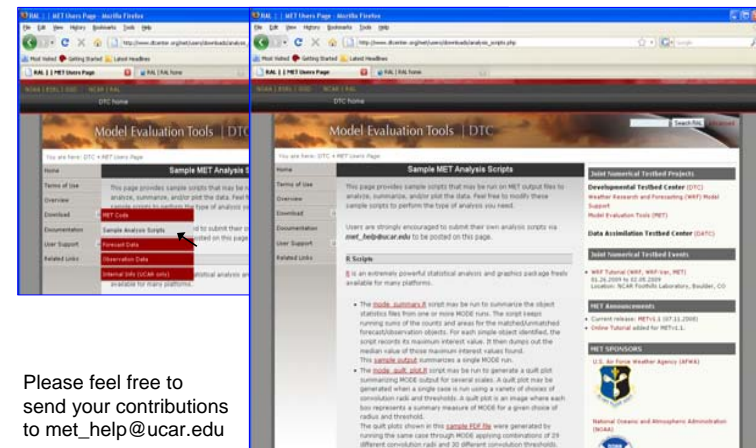
Use your favorite plotting software



MET provides the analysis in ascii ouput.
 You provide the graphing / plotting capability.

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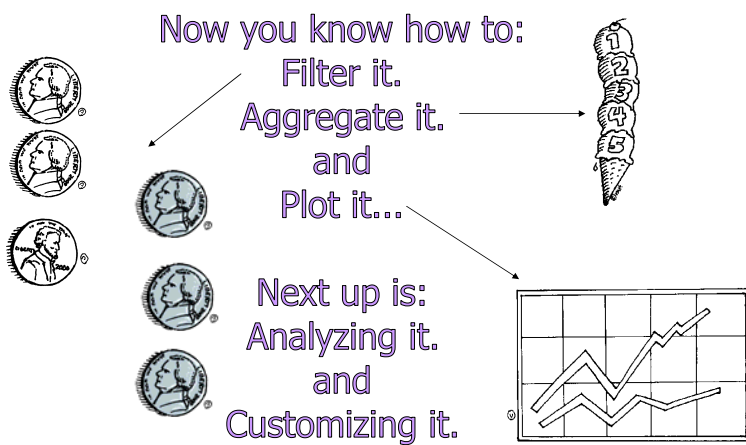
User Contributed Plotting Scripts



Please feel free to
 send your contributions
 to met_help@ucar.edu

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Thanks - Any Questions?



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Interpretation of Output – Grid and Point Stat

Tressa L. Fowler

Point and Grid Stat Output Lines

- CTC - Contingency Table Counts
- CTS - Contingency Table Statistics
- CNT - Continuous Statistics
- *FHO - Forecast, Hit, Observation Rates*
- *SL1L2 - Scalar L1L2 Partial Sums*
- *SAL1L2 - Scalar Anomaly L1L2 Partial Sums when climatological data is supplied*
- *VL1L2 - Vector L1L2 Partial Sums*
- *VAL1L2 - Vector Anomaly L1L2 Partial Sums when climatological data is supplied*
- MPR - Matched Pair data

Available in the newest release MET 2.0, line types for probability forecasts.

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Point and Grid stat output example

Header Line:

- TOTAL BASER BASER_NCL BASER_NCU BASER_BCL BASER_BCU FMEAN FMEAN_NCL FMEAN_NCU FMEAN_BCL FMEAN_BCU ACC ACC_NCL ACC_NCU ACC_BCL ACC_BCU FBIAS FBIAS_BCL FBIAS_BCU PODY PODY_NCL PODY_NCU PODY_BCL PODY_BCU PODN PODN_NCL PODN_NCU PODN_BCL PODN_BCU POFD POFD_NCL POFD_NCU POFD_BCL POFD_BCU FAR FAR_NCL FAR_NCU FAR_BCL FAR_BCU CSI CSI_NCL CSI_NCU CSI_BCL CSI_BCU GSS GSS_BCL GSS_BCU HK HK_NCL HK_NCU HK_BCL HK_BCU HSS HSS_BCL HSS_BCU ODDS ODDS_NCL ODDS_NCU ODDS_BCL ODDS_BCU

Data Line:

- CTS 5 1.00000 0.56552 1.00000 NA NA 0.40000 0.11762 0.76928 NA NA 0.40000 NA NA 0.40000 0.11762 0.76928 NA NA NA NA NA NA NA NA NA NA NA NA 0.00000 0.00000 0.43448 NA NA 0.40000 0.11762 0.76928 NA NA 0.00000 NA NA NA NA NA NA 0.00000 NA NA NA NA NA NA NA NA

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See Appendix C of MET documentation for equations and details

- TOTAL – Count of total pairs included in the stats for this line
- BASER – base rate (e.g. sample climatological rate of event)
- FMEAN – mean of forecast values
- ACC - accuracy
- FBIAS – frequency bias
- PODY – probability of detection (events)
- PODN – probability of detection (non-events)
- POFD – probability of false detection
- FAR – False Alarm Ratio
- CSI – Critical success index
- GSS – Gilbert Skill Score
- HK - Hanssen-Kuipers Discriminant
- HSS - Heidke Skill Score
- ODDS – Odds Ratio
- Etc., etc., etc. . .

Confidence Intervals for some measures are included with the following suffixes:
_NCL = Normal Confidence Lower
_NCU = Normal Confidence Upper
_BCL = Bootstrap Confidence Lower
_BCU = Bootstrap Confidence Upper

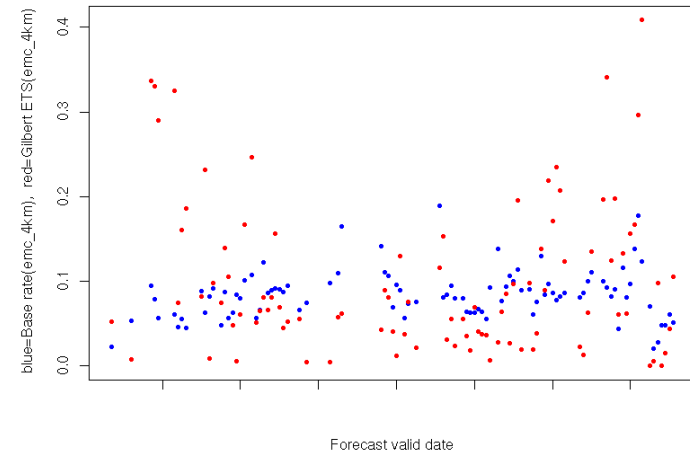
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Example of Appendix C info

- **Accuracy** - for a 2x2 contingency table is defined as $\frac{n_{11} + n_{00}}{T}$
- That is, it is the proportion of forecasts that were either hits or correct rejections – the fraction that were correct.
- Accuracy ranges from 0 to 1; a perfect forecast would have an accuracy value of 1.
- Accuracy should be used with caution, especially for rare events, because it can be strongly influenced by large values of n_{00} .

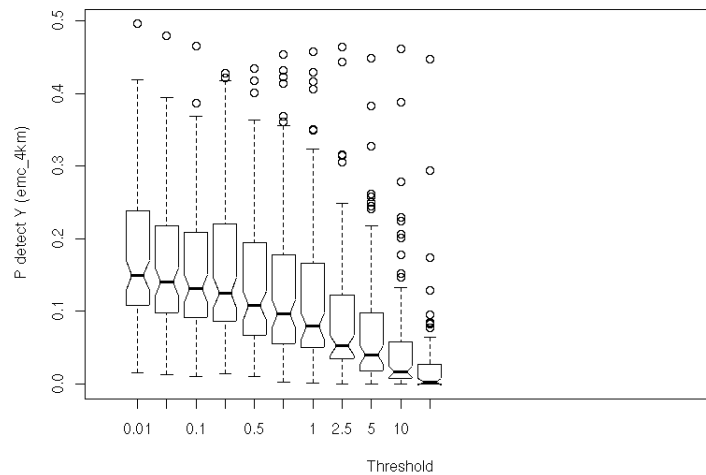
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Example Scatter Plot



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Example Box Plot



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Customizing Point-Stat and Grid-Stat Output

We'll restrict this discussion to an explanation of masking and interpolation.

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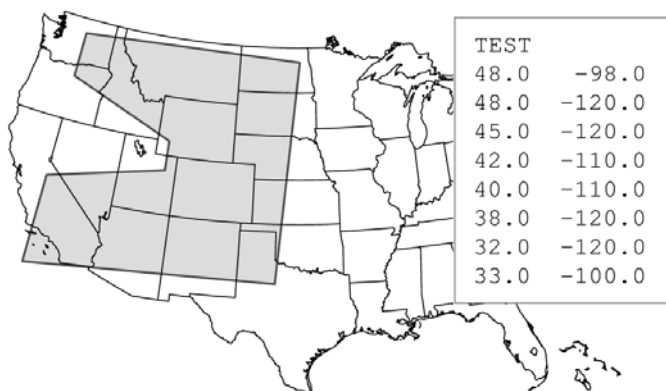
Masking Methods

| | Polyline | Grid | Stations | On/Off Bit Map |
|------------|----------|------|----------|----------------|
| Point Stat | ✓ | ✓ | ✓ | ✓ |
| Grid Stat | ✓ | ✓ | N/A | ✓ |

Masking by stations doesn't apply to Grid Stat.

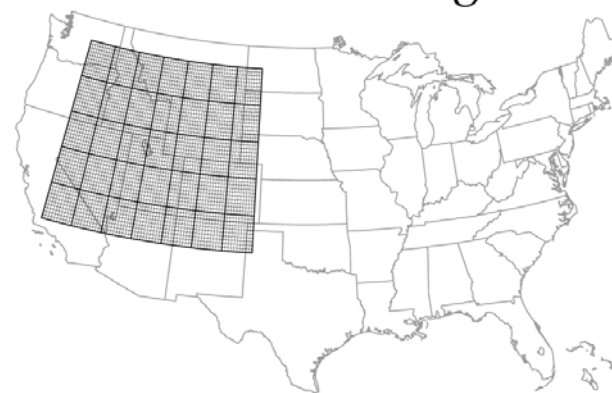
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Polyline Masking



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Grid Masking



NCEP grids link: www.nco.ncep.noaa.gov/pmb/docs/on388/tableb.html

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Station Masking



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Data Threshold Mask



Topography > 5000 feet

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Interpolation Methods

| | Min | Max | Median | UW Mean | DW Mean | Nearest Nbr | Least Squares |
|---------------|-----|-----|--------|------------|------------|----------------|------------------|
| Point Stat | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Grid Stat | ✓ | ✓ | ✓ | ✓ | N/A | N/A | N/A |

For Grid Stat, these are smoothing methods.

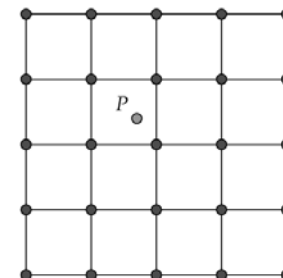
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Interpolation

Need to Choose:

(1) Method

(2) Width



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Min, Max, Median

Takes minimum, maximum or median of values in interpolation square.

Median separates the upper half of data values from the lower half. This is different from the mean, which is an average.

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Nearest Neighbor

Essentially, no interpolation is performed.

Value at interpolation point is simply the data value at the closest grid point.

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Unweighted Mean Distance-Weighted Mean

Unweighted Mean is the average.

Distance-Weighted Mean is an average weighted according to distance from nearby grid points.

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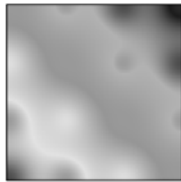
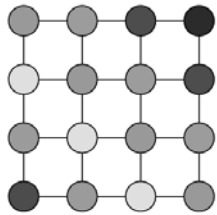
Least Squares

Performs a local Least-Squares linear fit in interpolation square.

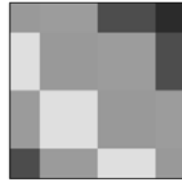
$$z = Ax + By + C$$

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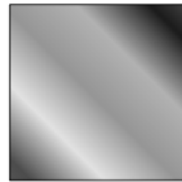
Interpolation Examples



DW Mean



Nearest Neighbor



Least Squares

Giving meaning to your forecast verification results

What is the answer to life, the universe and everything?

42.

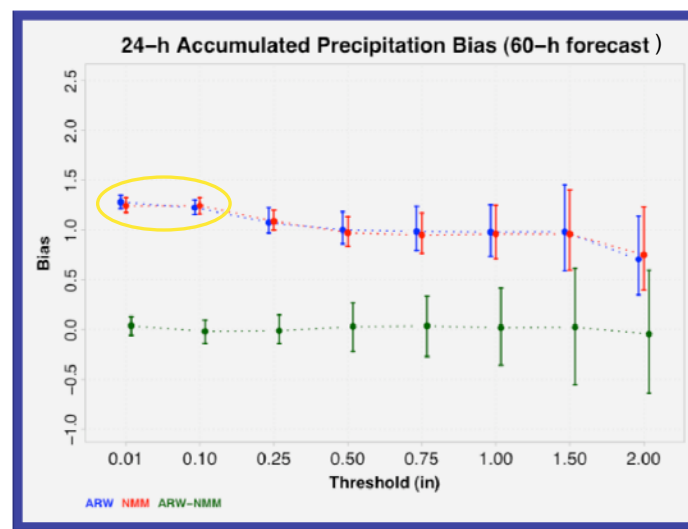
Eric Gilleland

Research Applications Laboratory,

National Center for Atmospheric Research

Boulder, Colorado

Email: [EricG @ ucar.edu](mailto:EricG@ucar.edu)



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Accounting for Uncertainty

- Observational
- Model
 - Model parameters
 - Physics
 - Verification scores
- Sampling
 - Verification statistic is a realization of a random process.
 - What if the experiment were re-run under identical conditions?

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Hypothesis Testing and Confidence Intervals

- Hypothesis testing
 - Given a null hypothesis (e.g., no bias), is there enough evidence to reject it?
 - One- or two-sided, but test is against a single null hypothesis.
- Confidence intervals
 - Related to hypothesis tests, but more useful.
 - How confident are we that the true value of the statistic (e.g., bias) is different from a particular value?
 - Interpretation for most *frequentist* intervals is a bit awkward.

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Hypothesis Testing and Confidence Intervals

"If we re-run the experiment 100 times, and create 100 $(1-\alpha)100\%$ CI's, then we expect the true value of the parameter to fall inside $(1-\alpha)100$ of the intervals."



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Hypothesis Testing and Confidence Intervals

Example: The difference in bias between two models is 0.01.

Hypothesis test: Is this different from zero?

Confidence interval: Does zero fall within the interval? Does 0.5 fall within the interval?

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Confidence Intervals (CI's)

- Parametric
 - Assume the observed sample is a realization from a known *population* distribution with possibly unknown parameters (e.g., normal).
 - Normal approximation CI's are most common.
 - Quick and easy.
- Nonparametric
 - Assume the distribution of the observed sample is representative of the *population* distribution.
 - Bootstrap CI's are most common.
 - Can be computationally intensive, but easy enough.

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Normal Approximation CI's

$$\hat{\theta} \pm z_{\alpha/2} se(\theta)$$

Is a $(1-\alpha)100\%$ Normal CI for Θ , where Θ is the statistic of interest (e.g., the forecast mean), $se(\Theta)$ is the standard error for the statistic, and z_v is the v -th quantile of the standard normal distribution.

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Normal Approximation CI's

Example: Let X_1, \dots, X_n be independent and identically distributed (iid) sample from a normal distribution with variance σ_X^2 .

Then, $\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i$ is an estimate of the mean of the sample. And a $(1-\alpha)100\%$ CI is given by

$$\bar{X} \pm z_{\alpha/2} \frac{\sigma_X}{\sqrt{n}}$$

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Normal Approximation CI's

- Numerous verification statistics can take this approximation in some form or another. In other cases (e.g., forecast/observation variance, linear correlation), different parametric CI's can be used that still rely on the underlying sample's being iid normal.
- Contingency table verification scores such as probability of detection (POD) and false alarm ratio (FAR) also have normal approximation CI's (for large enough sample sizes).

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Normal Approximation CI's

- Check the validity of the independence assumption.
- Check the validity of the normal distribution (e.g., qq-plots, automatic tests exist too).

(cf. Gilleland, 2008)

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Bootstrap CI's

IID Bootstrap Algorithm

1. Resample *with replacement* from the sample, X_1, \dots, X_n .
2. Calculate the verification statistic(s) of interest from the resample in step 1.
3. Repeat steps 1 and 2 many times, say B times, to obtain a sample of the verification statistic(s).
4. Estimate $(1-\alpha)100\%$ CI's from the sample in step 3.

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Bootstrap CI's

IID Bootstrap Algorithm: **Types of CI's**

1. Percentile Method CI's*
2. Bias-corrected and adjusted (BCa)*
3. ABC
4. Basic bootstrap CI's
5. Normal approximation
6. Bootstrap-t

*1 and 2 are available in MET

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Bootstrap CI's

Block Bootstrap Algorithm

- Block bootstrapping is one way to obtain bootstrap CI's for dependent samples.
- Same as IID Bootstrap, but resample blocks of contiguous data points.
- Use percentile method for CI's.
- Block sizes should be substantially larger than the correlation length, but substantially smaller than the sample size. Usually, one takes the greatest integer below the square root of the sample size.

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Bootstrap CI's

Block Bootstrap Algorithm: Blocks

Non-overlapping (NBB)

$$Y_1 = \{X_1, \dots, X_l\}, \dots, Y_k = \{X_{(k-1)l+1}, \dots, X_{kl}\}, \dots, Y_b = \{X_{(b-1)l+1}, \dots, X_n\}$$

Moving (MBB)

$$Y_i = \{X_i, \dots, X_{i+l-1}\}$$

Circular (CBB)

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Bootstrap CI's

Parametric Bootstrap Algorithm:

- Same as IID Bootstrap algorithm, but first model the dependence in the data, then in step 1, take random samples from the model instead of the data.
- Generally preferable to block bootstrap.
- Stronger assumptions about the sample than block bootstrap.
- Use percentile method for CI's.

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Bootstrap CI's

Configurable parameters for the bootstrap in MET. For example, usually it is appropriate to take resamples of size n , where n is the size of the original sample. However, there are cases where it is better to take samples of size, $m < n$ (e.g., if the population distribution is heavy-tailed; see Gilleland, 2008).

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Practical Considerations

- Point-stat is quicker than Grid-stat, so bootstrap is quicker with Point-stat.
- May be prohibitively computationally inefficient to bootstrap over an entire field (i.e., over several thousand points), but can also bootstrap the statistics for each field over time. Measures the (between-field) uncertainty of the estimates over time, rather than the within field uncertainty.
- Normal approximation intervals are quick, and generally accurate. Check the normality assumption!
- Check whether the samples (for either type of interval) are independent or not.

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Thank you. Questions?

For more information, see:

Developmental Testbed Center, 2008. Model Evaluation Tools Version 1.1 (METv1.1) User's Guide. Available at: <http://www.dtcenter.org/met/>

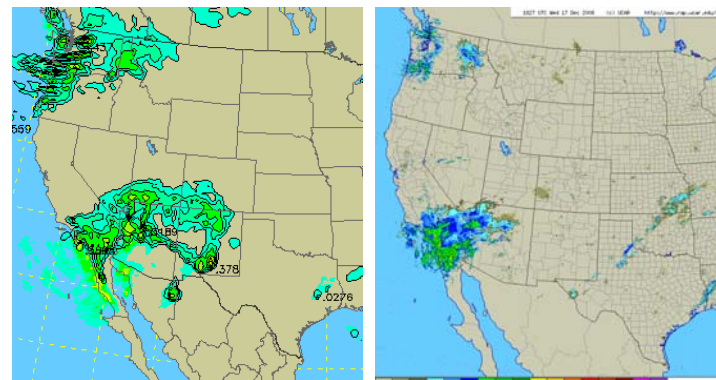
Gilleland E, 2008. Confidence intervals for forecast verification. *Submitted* as an NCAR Technical Note. Available at: <http://www.ral.ucar.edu/~ericg/Gilleland2008.pdf>

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Why Use Objects?

Tressa L. Fowler

Typical situation



Forecast

Observation

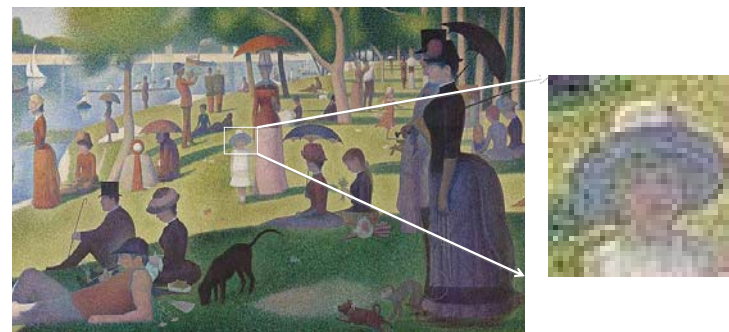
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Traditional verification matches up points,
then sums them up.

Many forecasts are more than the sums of
their parts.

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Pixels or Pictures?



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Object verification
is more like what
humans
do.

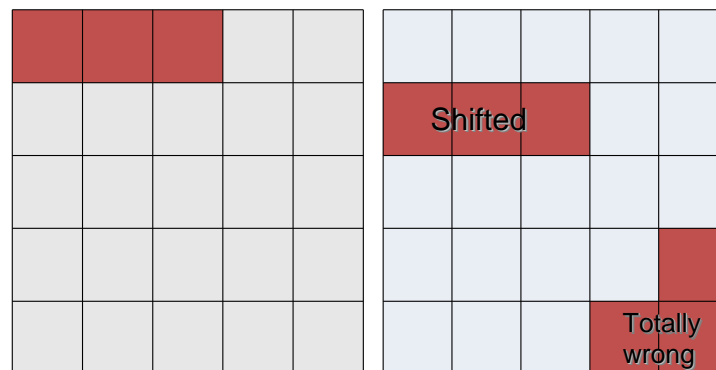
Objects recognize
the spatial relationship
between points.

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Simple example

Observed

Forecast



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REAL - observed



Forecast 1 –
Distorted view of reality

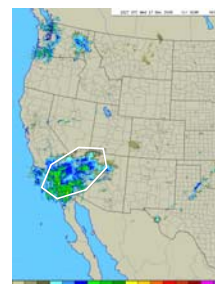


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Forecast 2 –
Another distorted
view of reality



REAL - observed



Forecast 1 –
Distorted view of reality



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Forecast 2 –
Another distorted
view of reality



This is not really a new idea . . .

Analytic cubists "analyzed" natural forms and reduced the forms into basic geometric parts on the two-dimensional picture plane.

Analytic cubism was developed between 1908 and 1912 . . .

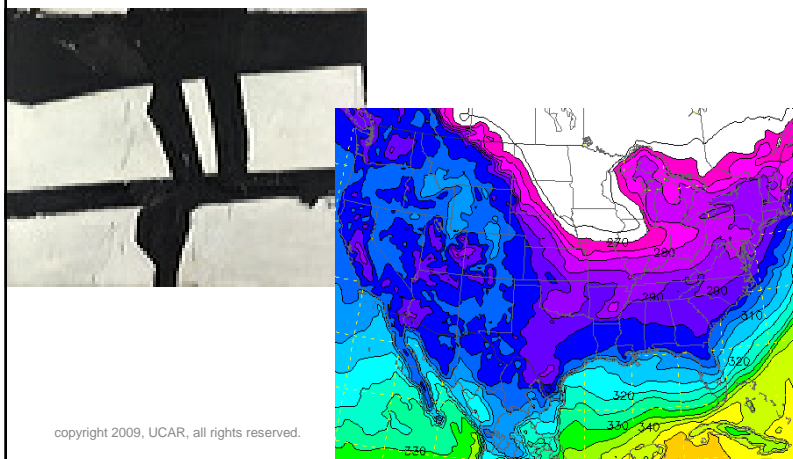
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Comparing objects can tell you things about your forecast like . . .

| This: | Instead of this: |
|-------------------------|------------------|
| 30% Too Big | POD = 0.35 |
| Shifted west 1 km | FAR = 0.7235 |
| Rotated 15° | CSI = 0.1587 |
| Peak Rain 1/2" too much | |

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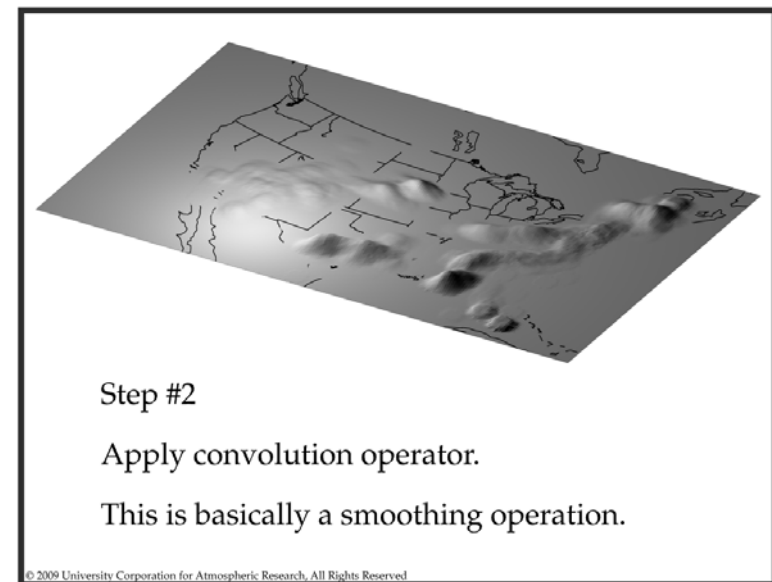
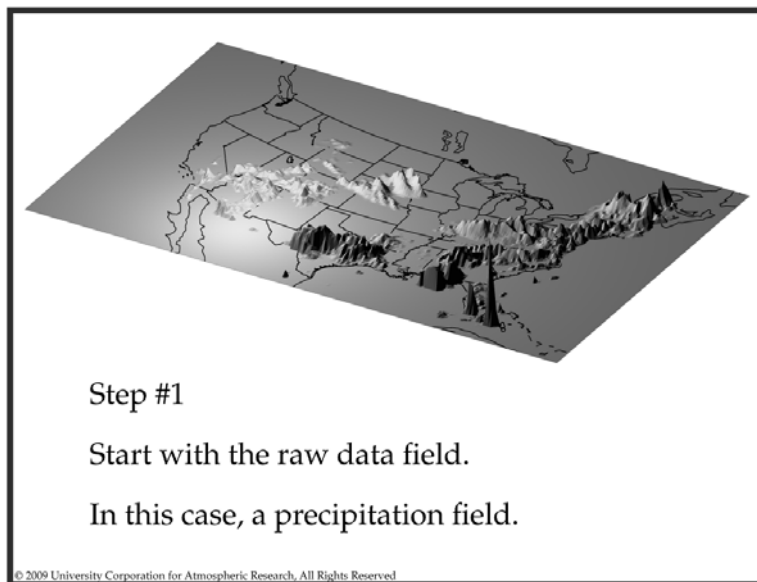
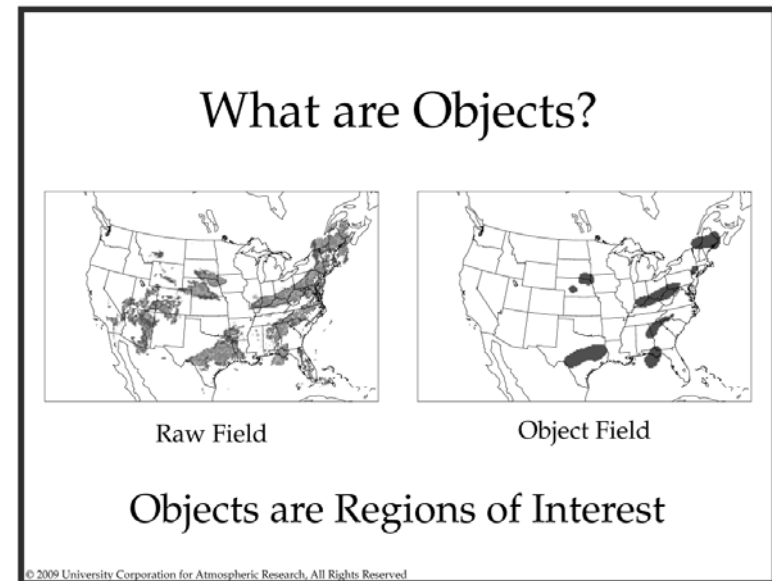
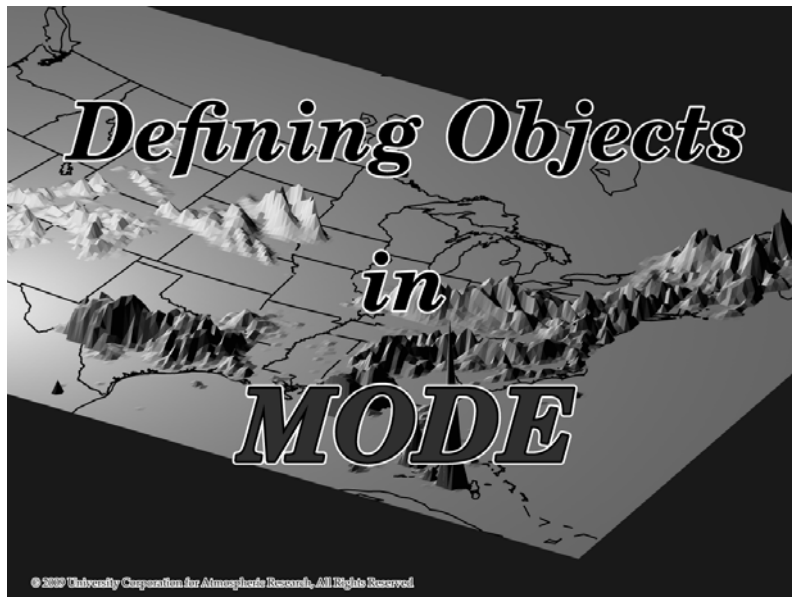
Verifying with objects doesn't always make sense . . .



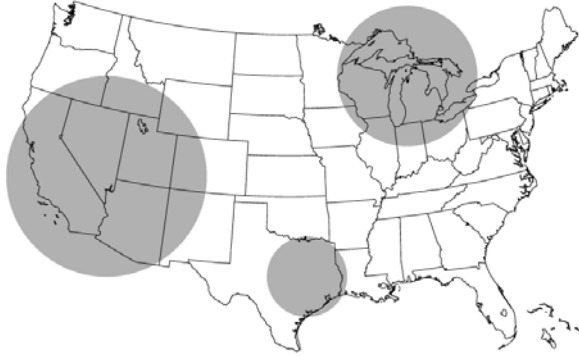
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- In MET, object based verification is done using the MODE (Method for Object-Based Diagnostic Evaluation) tool.
 - Define objects
 - Compute attributes (e.g. area, centroid, axis angle, intensity)
 - Merge objects (e.g. thunderstorm cells merge into line)
 - Match forecast and observed objects
 - Compare attributes between matches
 - Output summary statistics

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Convolution Radius



Radius of Influence

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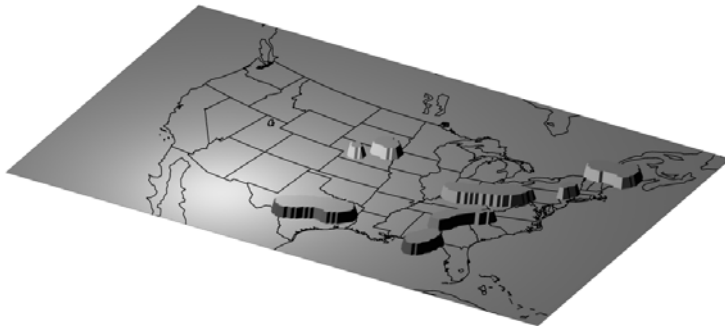
Convolution

Requires raw field $f(x, y)$ and

filter function $\phi(x, y)$

$$C(x, y) = \sum_{(\hat{x}, \hat{y}) \in G} \phi(\hat{x}, \hat{y}) f(x - \hat{x}, y - \hat{y})$$

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Step #3

Threshold the smoothed field.

This produces an on/off mask field.

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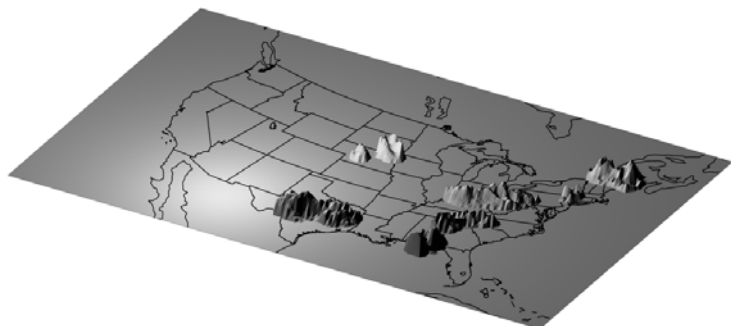
Masking

Uses convolved field $C(x, y)$

and threshold T

$$M(x, y) = \begin{cases} 1 & \text{if } C(x, y) \geq T \\ 0 & \text{else} \end{cases}$$

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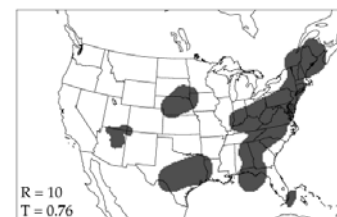
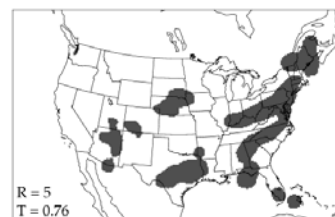
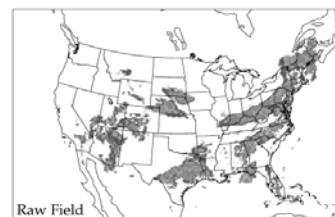
Step #4

Restore original data to object interiors.

This gives us our objects.

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Changing Object-Definition Parameters



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Matching & Merging

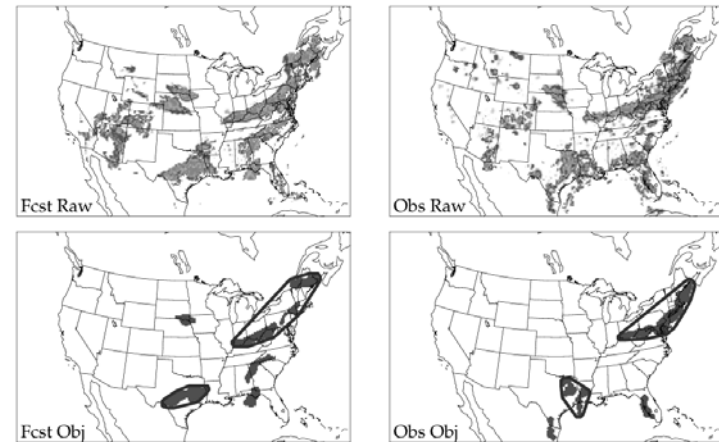
Merging: Associating objects in the same field.

Matching: Associating objects in different fields.

MODE does this using a Fuzzy-Logic engine.

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Example of Matching & Merging



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Object Attributes

Single:

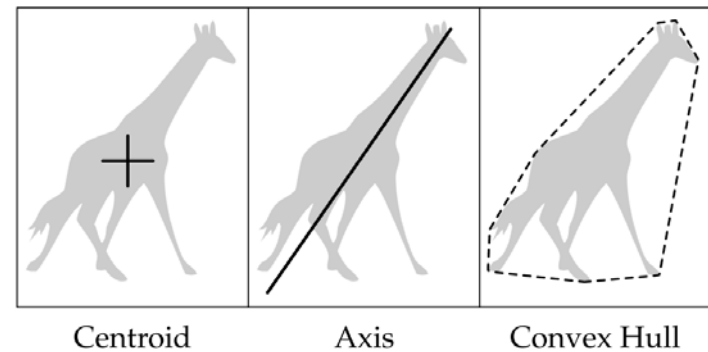
- Area
- Centroid
- Axis Angle
- Median Intensity
- Complexity
- Aspect Ratio
- Curvature

Pair:

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

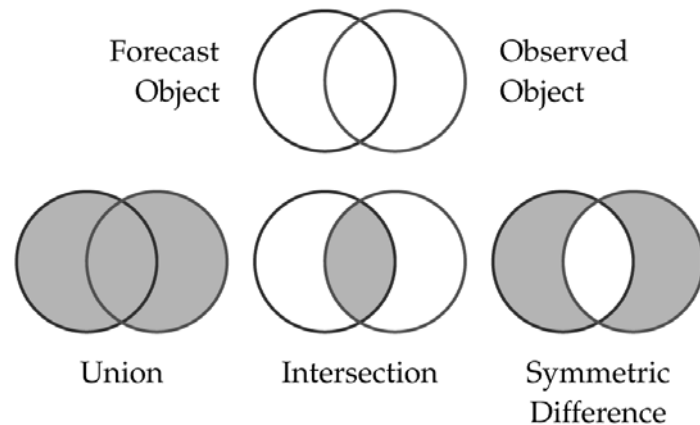
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Example Single Attributes



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Example Pair Attributes

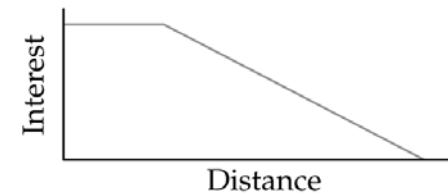


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Interest Maps

Map attributes to interest values.

Example: Centroid Distance



All interest maps can be changed in the config file.

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Weights

Express relative importance
of different attributes in
matching and merging.

All weights can be changed
in the config file.

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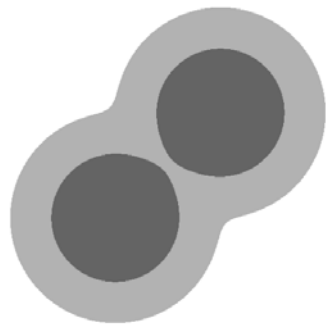
Total Interest

Calculated from weights, attributes,
and interest maps.

$$T(\alpha) = \frac{\sum_i w_i C_i(\alpha) I_i(\alpha)}{\sum_i w_i C_i(\alpha)}$$

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Alternative Merging Method



Double
Thresholding

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Verifying WRF with Objects

Running MODE and MODE
analysis tool

Running MODE - Input

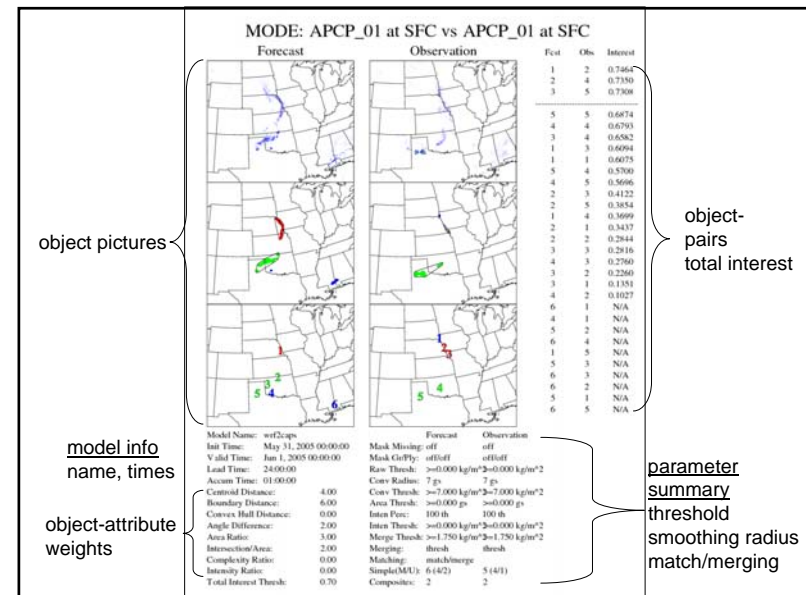
- 2 gridded fields, same grid, possibly different variables
 - forecast (fcst_file) and observation (obs_file)

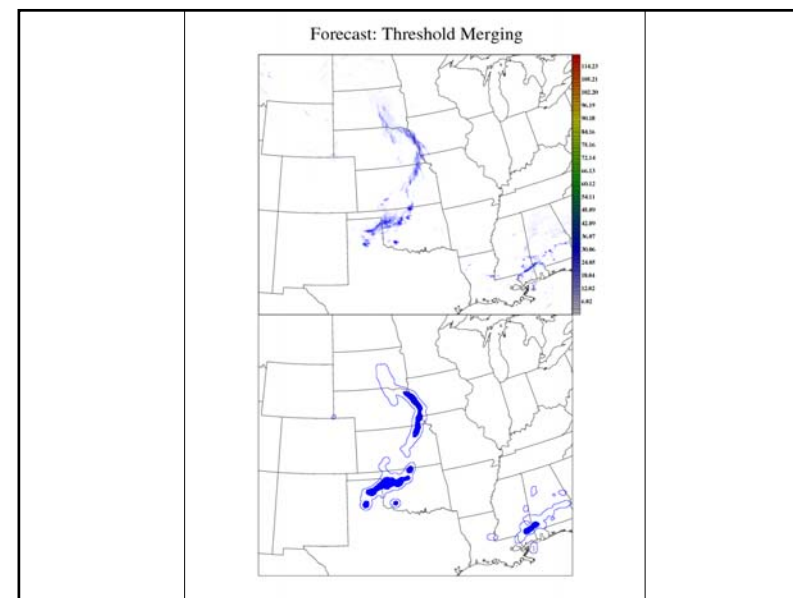
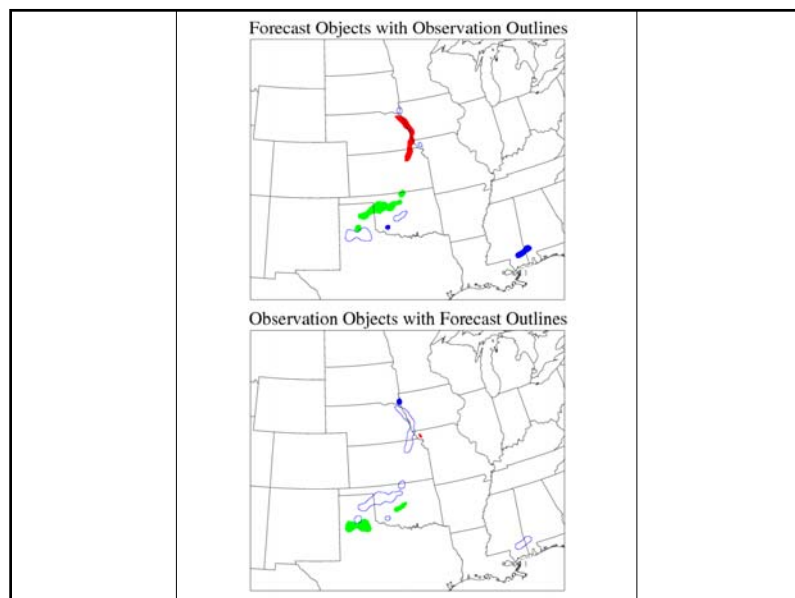


- configuration settings (config_file)
- syntax
 - >mode fcst_file obs_file config_file

Running MODE - Output

- PostScript
 - object pictures
 - parameter summary
 - total interest for each object pair





Running MODE - Output

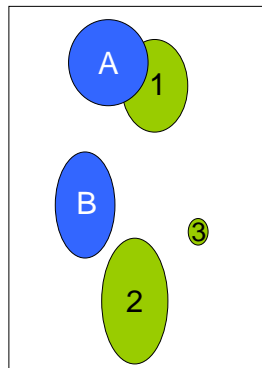
- PostScript
 - object pictures
 - parameter summary
 - total interest for each object pair
- ASCII
 - object sizes, shapes, positions
 - stats for simple, paired objects and clusters
 - standard contingency table stats based on objects
- netCDF
 - gridded object fields

Interpretation of MODE output

- How well do objects match?
 - median of the maximum interest (MMI)*
- What % of objects are matched?
- Displacement of matched objects
- mode_analysis tool

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

Median of the Max. Interest (MMI)

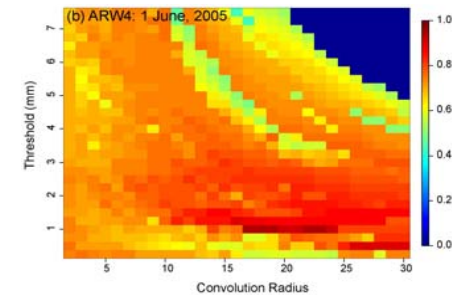


Interest Matrix
observed

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

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

What % of Objects are Matched?

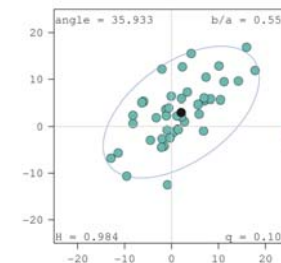
- Hit rate, Threat Score, Heidke Skill Score
- Other standard contingency table scores

| | Forecasted object | Unforecasted object |
|-------------------|-------------------|---------------------|
| Observed object | Matched | Missed |
| Unobserved object | False alarm | Correct null |

MODE Analysis

- displacement of forecast clusters from matched observed clusters

Composite Object Centroid Differences
over the Appalachian Mountains



MODE Analysis Tool SUMMARY Example

Command Line

```
mode_analysis -summary
-mask_file ttt -config config/mode_test_config \
-dump_lines out -lookin /dl/score/mode_files \
-fcst -composite -area_min 3000 \
-centroid_x_min 600
-centroid_x_max 1100 \
-column centroid_x \
-column centroid_y \
-column centroid_lat \
-column centroid_lon \
-column area \
-column axis_ang \
-column length
```

Output

Total mode lines read = 73,330
Total mode lines kept = 539

| Field | Min | Max | Mean | StdDev | P10 | P25 | P50 | P75 | P90 |
|--------------|---------|----------|----------|---------|---------|---------|---------|----------|----------|
| centroid_x | 600.23 | 914.61 | 779.36 | 97.98 | 626.36 | 687.96 | 804.30 | 866.75 | 894.24 |
| centroid_y | 55.22 | 560.08 | 325.55 | 113.08 | 189.48 | 240.58 | 333.51 | 421.06 | 496.82 |
| centroid_lat | 22.00 | 40.14 | 32.08 | 4.06 | 26.83 | 28.66 | 32.00 | 35.15 | 37.87 |
| centroid_lon | -107.03 | -95.01 | -100.18 | 3.75 | -106.03 | -103.67 | -99.23 | -96.84 | -95.79 |
| area | 3210.00 | 85486.00 | 12680.96 | 9931.67 | 4935.00 | 6256.00 | 9445.00 | 16106.00 | 23678.00 |
| axis_ang | -88.84 | 89.90 | 13.54 | 44.82 | -55.80 | -16.36 | 17.28 | 48.23 | 71.27 |
| length | 100.57 | 494.54 | 200.08 | 82.11 | 112.44 | 133.62 | 179.96 | 249.06 | 315.33 |

MODE Analysis Tool By Case Example

Command Line

```
mode_analysis -bycase
-dump_lines out
-mask_file ttt -config config/mode_test_config
-fcst_valid_min 20070702 -fcst_valid_max 20070702_12
-area_min 3000
-centroid_x_min 600 -centroid_x_max 1100
/dl/score/mode_files/ncwf2_vs_ncwdp/* /dl/score/mode_files/rcpf_vs_ncwdp/*
```

Output

| Fcst Valid Time | Area Matched | Area Unmatched | # Fcst Matched | # Fcst Unmatched | # Obs Matched | # Obs Unmatched |
|----------------------|--------------|----------------|----------------|------------------|---------------|-----------------|
| Jul 2, 2007 00:00:00 | 12392 | 20786 | 0 | 1 | 1 | 1 |
| Jul 2, 2007 01:00:00 | 8706 | 11038 | 0 | 0 | 1 | 2 |
| Jul 2, 2007 02:00:00 | 7507 | 18696 | 0 | 0 | 1 | 3 |
| Jul 2, 2007 03:00:00 | 19401 | 32268 | 2 | 3 | 1 | 2 |
| Jul 2, 2007 04:00:00 | 0 | 14551 | 0 | 2 | 0 | 1 |
| Jul 2, 2007 05:00:00 | 15315 | 29730 | 1 | 2 | 1 | 2 |
| Jul 2, 2007 06:00:00 | 4730 | 8182 | 0 | 0 | 1 | 2 |
| Jul 2, 2007 07:00:00 | 3733 | 13285 | 0 | 1 | 1 | 2 |
| Jul 2, 2007 08:00:00 | 6994 | 6994 | 0 | 0 | 1 | 1 |
| Jul 2, 2007 09:00:00 | 15981 | 15981 | 0 | 0 | 2 | 2 |
| Jul 2, 2007 10:00:00 | 51501 | 53427 | 2 | 2 | 4 | 4 |
| Jul 2, 2007 11:00:00 | 15779 | 21089 | 1 | 1 | 1 | 2 |
| Jul 2, 2007 12:00:00 | 31339 | 40665 | 1 | 2 | 2 | 2 |

Thurs AM Lecture Wrap-Up

- Confidence intervals
- Verifying WRF with objects
 - matching and merging
- Running MODE
 - MODE analysis
- Questions?

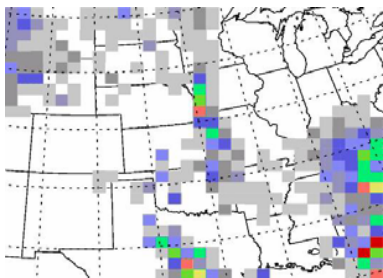


Filter Methods

- Smoothing (e.g., FSS, Upscaling)
 - Neighborhood or “fuzzy” (Ebert 2008)
 - At what resolution does the model have skill?
 - Credit a forecast for being partially correct.
- Band-pass (e.g., Fourier, Wavelets)
 - How well does a model reproduce the spatial structure of the verification field?
 - Examine performance at different scales separately.

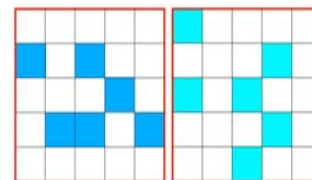
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Filter Methods



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Filter Methods



Fraction = 6/25 = 0.24

Fraction = 6/25 = 0.24

Numerator is Fractions
Brier Score (FBS)

$$FSS = 1 - \frac{\frac{1}{N} \sum_{i=1}^N (P_{fcst} - P_{obs})^2}{\frac{1}{N} \sum_{i=1}^N P_{fcst}^2 + \frac{1}{N} \sum_{i=1}^N P_{obs}^2}$$

Roberts and Lean (2008)

Fractions Skill Score (FSS)

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Filter Methods

Slide from E Ebert. See Ebert (2008) for full references.

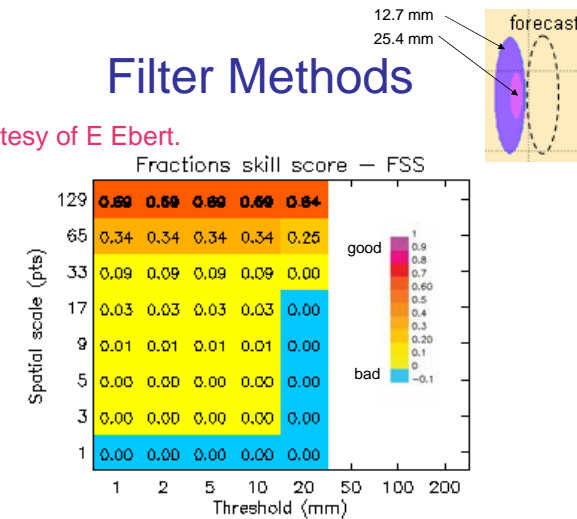
| Fuzzy method | Matching strategy* | Decision model for useful forecast |
|---|--------------------|---|
| Upscaling (Zepeda-Arce et al. 2000; Weygandt et al. 2004) | NO-NF | Resembles obs when averaged to coarser scales |
| Minimum coverage (Damrath 2004) | NO-NF | Predicts event over minimum fraction of region |
| Fuzzy logic (Damrath 2004), joint probability (Ebert 2002) | NO-NF | More correct than incorrect |
| Fractions skill score (Roberts and Lean 2007) | NO-NF | Similar frequency of forecast and observed events |
| Area-related RMSE (Rezacova et al. 2006) | NO-NF | Similar intensity distribution as observed |
| Practically perfect hindcast (Brooks et al. 1998) | NO-NF | Resembles a forecast based on perfect knowledge of observations |
| Pragmatic (Theis et al. 2005) | SO-NF | Can distinguish events and non-events |
| CSRR (Germann and Zawadzki 2004) | SO-NF | High probability of matching observed value |
| Multi-event contingency table (Atger 2001) | SO-NF | Predicts at least one event close to observed event |

*NO-NF = neighborhood observation-neighborhood forecast,
SO-NF = single observation-neighborhood forecast

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Filter Methods

Fig. courtesy of E Ebert.



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Filter Methods

- In MET, Neighborhood methods are in grid-Stat tool. See MET documentation for specific filters.
- Can be cumbersome (many numbers for one filter).
- Choose filter that addresses the verification question of interest.
- See Ebert (2008) for a good summary and comparison of these techniques (and references).

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Band-pass Methods

- Fourier

$$Z(\mathbf{x}) = \sum_{k=1}^n Z_k \exp(i\omega_k^T \mathbf{x})$$

- Wavelets

$$Z(\mathbf{x}) = \sum_{j,k} c_{j,k} \varphi_k(2^{j-1} \mathbf{x}) + \sum_{j,k} d_{j,k} \psi_k(2^{j-1} \mathbf{x})$$

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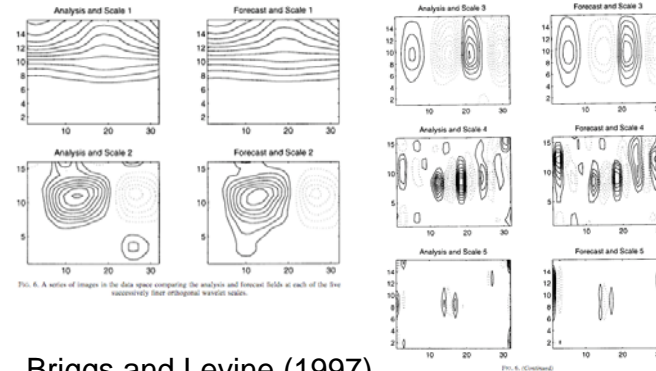
Band-pass Methods

- Fourier
 - Skamarock (2004), MWR **132**:3019-3032
 - Harris *et al.* (2001), J Hydrometeorol. **2**:406-418
 - Tustison *et al.* (2001), JGR **106**(D11):11775-11784
 - *and many more...*
- Wavelet
 - Briggs and Levine (1997), MWR **125**:1329-1341
 - Casati *et al.* (2004). [In MET Wavelet tool]

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Band-pass Methods

Wavelets



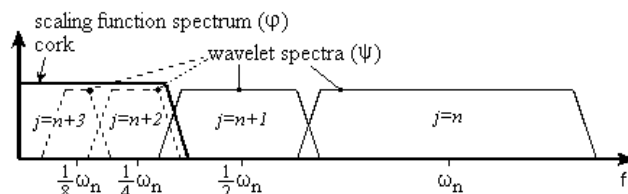
Briggs and Levine (1997)

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Band-pass Methods

Wavelets

$$Z(\mathbf{x}) = \sum_{j,k} c_{j,k} \varphi_k(2^{j-1} \mathbf{x}) + \sum_{j,k} d_{j,k} \psi_k(2^{j-1} \mathbf{x})$$



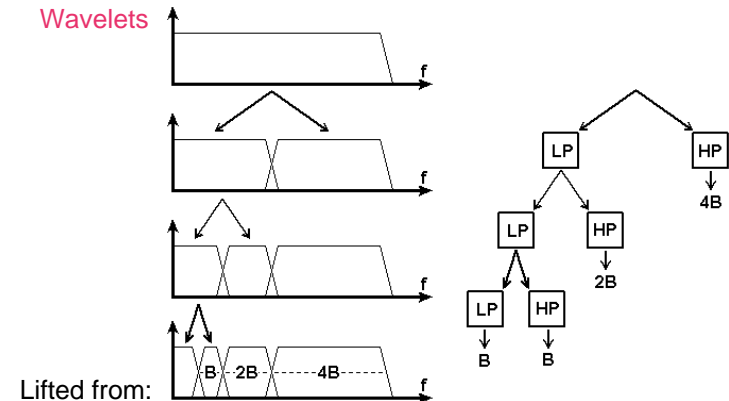
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<http://pagesperso-orange.fr/polyvalens/clemens/wavelets/>

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Band-pass Methods

Wavelets



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<http://pagesperso-orange.fr/polyvalens/clemens/wavelets/>

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Band-pass Methods

Wavelets: Practical considerations

- Applicable only on square grids of size, 2^n .
- If grid does not meet this, then must alter the grid in some way. For example,
 - Pad with zeros,
 - Cut the domain down.
- Several choices for wavelets. Haar Wavelets are a good choice for precipitation (because of their discrete nature), but other choices might be better for other fields.

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Quick Contingency Table Review

| | obs > threshold | obs < threshold | |
|----------------------|---|-------------------------|---------------|
| forecast > threshold | a hits | b false alarms | a + b |
| forecast < threshold | c misses | d correct rejections | c + d |
| | a + c copyright 2009, UCAR, all rights reserved. | b + d | n = a + b + c |

Band-pass Methods

Intensity Scale (IS) (Casati *et al.*, 2004)

1. Create binary fields for a threshold, and calculate MSE (denote, $MSE(t)$).
2. Apply wavelet decomposition to binary fields.
3. Calculate MSE for each threshold (t) and scale (j) (denote, $MSE(t,j)$), and find $MSE\%(t,j) = MSE(t,j)/MSE(t)$.
4. Find $MSE(t)_{random} = FBI \cdot Br \cdot (1 - Br) + Br \cdot (1 - FBI \cdot Br)$, where $FBI = (a+b)/(a+c)$ is the frequency bias index and $Br = (a+c)/n$ is the sample climatology from the contingency table.
5. Calculate $SS(t,j) = 1 - MSE(t,j) \cdot (n+1)/MSE(t)_{random}$.

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Band-pass Methods

In addition to MSE and SS, the energy squared (denote $En2$) is calculated. That is,

$$En2(X) = \sum_{i=1}^n X_i^2$$

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Band-pass Methods

Also find the relative difference in En2 between the forecast and verification fields. That is,

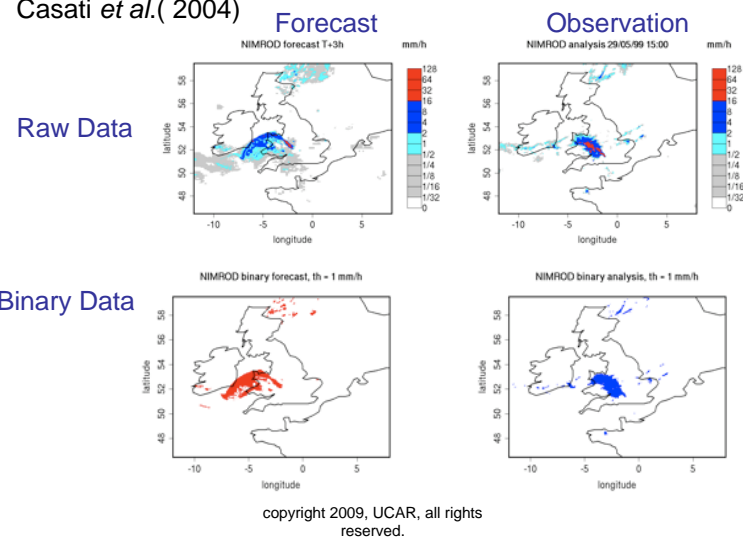
$$[\text{En2}(\text{F}) - \text{En2}(\text{O})] / [\text{En2}(\text{F}) + \text{En2}(\text{O})]$$

Similar to MSE, let $\text{En2}(\text{X}, \text{t})$ be the energy for the raw binary field X (where X is either the verification or forecast field), and $\text{En2}(\text{X}, \text{t}, \text{j})$ is the same, but taken only at scale j . Then

$$\text{En2}\%(\text{X}, \text{t}, \text{j}) = \text{En2}(\text{X}, \text{t}, \text{j}) / \text{En2}(\text{X}, \text{t}).$$

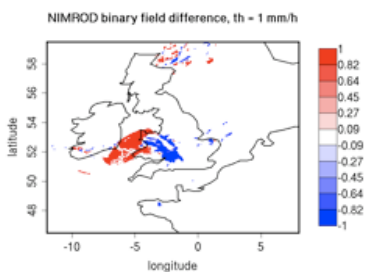
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Casati *et al.* (2004)

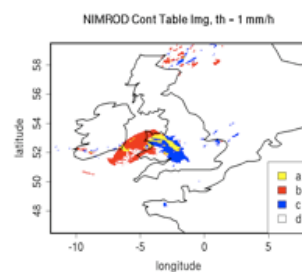


Casati *et al.* (2004)

Binary Difference Field



Contingency Table Contributions



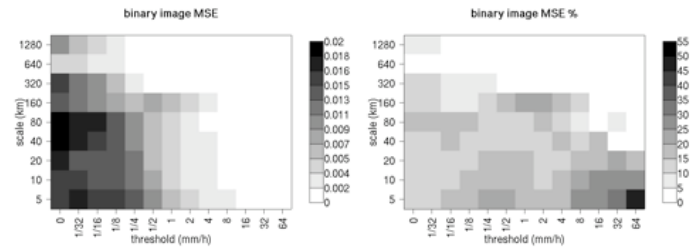
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Casati *et al.* (2004)



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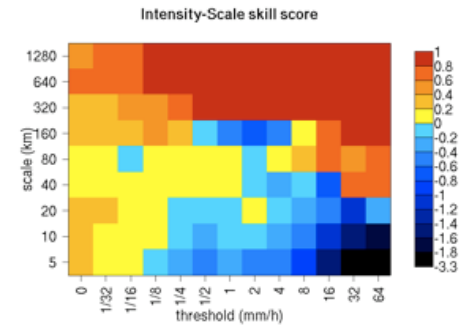
Casati *et al.*(2004)



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Casati *et al.*(2004)

Intensity Skill Score (ISS) is the Heidke Skill Score (HSS), but calculated at each threshold and wave number.



HSS is an accuracy score corrected for random chance.

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Thank you...Questions?

References

- Casati B, G Ross, and DB Stephenson, 2004. A new intensity-scale approach for the verification of spatial precipitation forecasts. *Meteorol. Appl.* **11**:141--154.
- Ebert EE, 2008. Fuzzy verification of high resolution gridded forecasts: A review and proposed framework. *Meteorol. Appl.*, **15**:51--64. DOI: 10.1002/met.25.

See also, <http://www.ral.ucar.edu/projects/icp>



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Customizing and Understanding Wavelet Stats

Tressa L. Fowler

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Options for Handling Missing data

- Points with valid forecasts. 
- Points with valid observations. 
- Points with both valid forecasts and observations. $F \cap O$
- All points. $F \cup O$

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Thresholds

| Forecast | | Threshold | Event |
|----------|---|-----------|-------|
| 0.05 | < | 0.2 | 0 |
| 0.17 | < | 0.2 | 0 |
| 0.45 | > | 0.2 | 1 |
| 2.15 | > | 0.2 | 1 |
| 0.05 | < | 1 | 0 |
| 0.17 | < | 1 | 0 |
| 0.45 | < | 1 | 0 |
| 2.15 | > | 1 | 1 |

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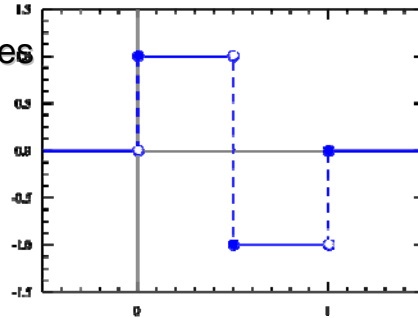
Tiles – Grid must be $2^n \times 2^n$

- Cut down – user selected subset (square)
- Tiles – automated selection of subset(s)
- Pad with zeros – not recommended unless adds very small number of points.

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Wavelets

- Haar
- Centered Haar
- Daubechies
- Centered Daubechies
- B spline
- Centered B spline



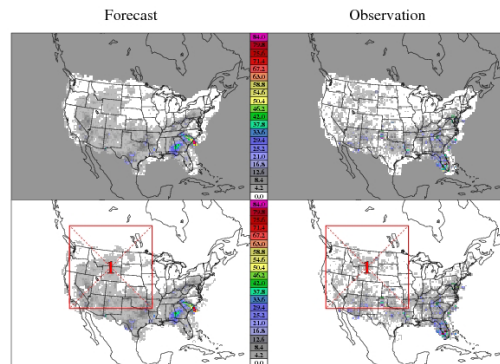
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Output

- Text files
 - Options
 - Statistics
 - Can be read into stat analysis tool.
- Postscript files
 - Graphics
 - Options
 - Statistics

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Wavelet-Stat: APCP at A24



Model Name: WRF

Init Time: Aug 7, 2005 00:00:00
Valid Time: Aug 8, 2005 00:00:00
Lead Time: 24:00:00
Accum Time: 24:00:00

Tile Method: User-Defined
Tile Count: 1
Tile Dim: 64 x 64
Tile Corner: (45, 45)

Mask Missing: Fcat/Obs
Wavelet(k): Haar (2)

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Wavelet-Stat: APCP at A24, Tile 1, >1.000, Binary

Difference (F-O)



Frequency Bias: 1.61235
Bias Rate: 0.14233
Mean-Squared Error (%): 0.19214 (100.00)

Intensity Skill Score: 0.37311
Fcat Energy Squared (%): 0.22909 (100.00)
Obs Energy Squared (%): 0.14233 (100.00)

Wavelet-Stat: APCP at A24, Tile 1, >1.000, Scale 1

Difference (F-O)

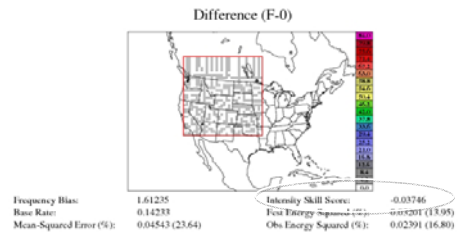


Frequency Bias: 1.61235
Bias Rate: 0.14233
Mean-Squared Error (%): 0.08575 (44.63)

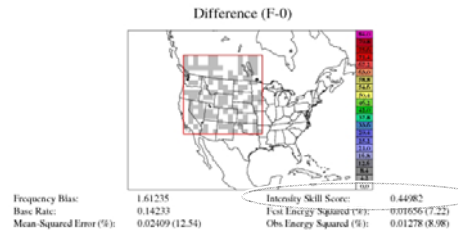
Intensity Skill Score: 0.95852
Fcat Energy Squared (%): 0.24402 (17.87)
Obs Energy Squared (%): 0.05170 (36.32)

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Wavelet-Stat: APCP at A24, Tile 1, >1,000, Scale 2

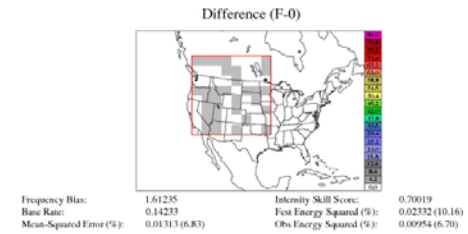


Wavelet-Stat: APCP at A24, Tile 1, >1,000, Scale 3

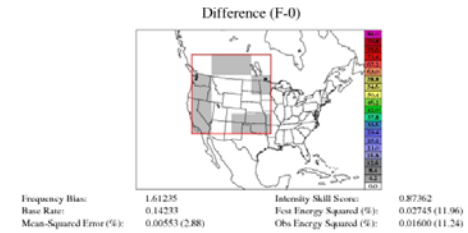


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Wavelet-Stat: APCP at A24, Tile 1, >1,000, Scale 4

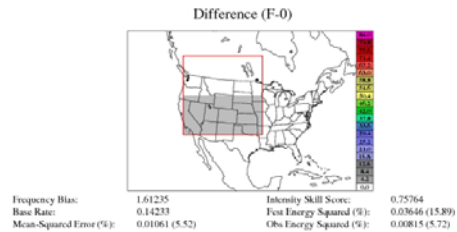


Wavelet-Stat: APCP at A24, Tile 1, >1,000, Scale 5

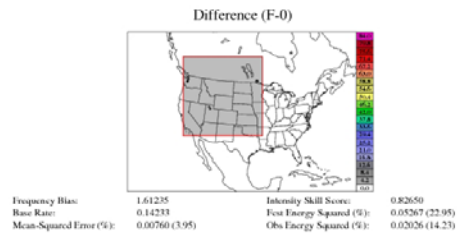


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Wavelet-Stat: APCP at A24, Tile 1, >1,000, Scale 6



Wavelet-Stat: APCP at A24, Tile 1, >1,000, Scale 7



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Summary

- Wavelet tool provides a flexible method for decomposing spatial fields into different scales.
- Once decomposed, verification measures at each *physical* scale can be examined and compared.

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