456 ASSESSING AND COMPARING REAL-TIME NORTHEAST PACIFIC ATMOSPHERIC RIVER IWV AND IVT INTENSITIES PROVIDED BY MODEL (GFS) AND SATELLITE (SSM/I, SSMIS) USING DTC'S MET/MODE OBJECT ATTRIBUTES

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Introduction

Landfalling atmospheric river events are responsible for a significant part of the precipitation along the North American west coast and nearly all the extreme precipitation events (Neiman et al., 2008). The accurate forecast of atmospheric rivers depends on accurately forecasting the ambient low-level atmospheric water vapor field as well as the speed and direction of the low level wind field. In this developmental verification study we apply DTC's MET/MODE object analysis package (Davis et al., 2006) to the fields at three significantly different develop a set of complimentary metrics that provide a more complete diagnostic verification. In particular we explore MODE analysis object attributes for the full Northeast Pacific domain (~4400 km scale), a second domain that covers the Northeast Pacific out to a boundary about 1000 km from the coast, and a coastal strip domain about 150 km wide longitudinally that is located 150 km offshore to avoid side lobe contamination of the SSMIS data, but that nevertheless is used to define landfall events. None of the sets of MODE attributes found in any one of these domains was found to provide a complete verification, but together a fairly complete picture emerged.

Domain 1: Northeast Pacific

The NEP domain is big enough for IWV and IVT verification studies, although IWV objects reach global scale.

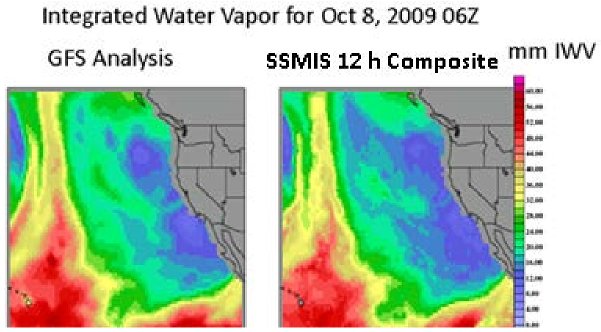
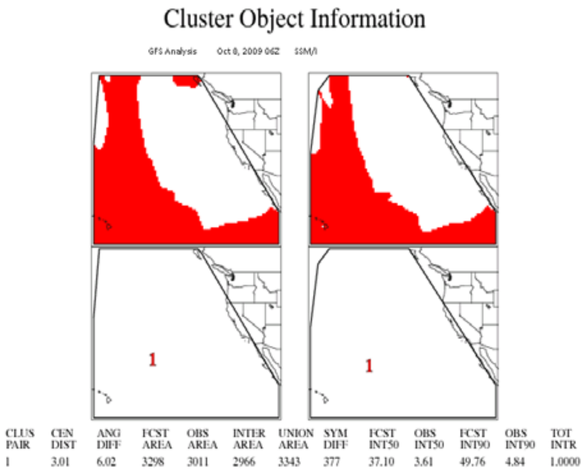


Figure 1: Integrated water vapor (IWV) for the GFS analysis (left) and the associated satellite observed 12 h SSMIS composite (right).

MODE object analysis was applied to the IWV data fields shown using a 25 mm IWV threshold to determine the clustered MODE objects shown in Figure 2. The GFS 6Z valid IWV output (left panel) was downscaled from a 1degree to a ½ degree latitude and longitude grid. while the right panel shows the morning 12 hour composite of SSMIS observed IWV at ½ degree resolution (upscaled from the originally ¼ degree data field). The fields are very similar to each other, but subtle differences are visible. MODE object attributes can be used to help quantify the multi-dimensional goodness of agreement.



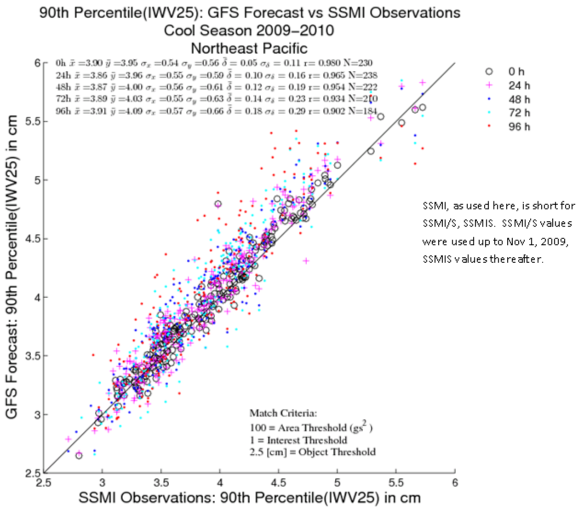
CLUS PAIR	CEN DIST	ANG DIFF	FCST AREA	OBS AREA	INTER AREA	UNION AREA	SYM DIFF	FCST INT50	OBS INT50	FCST INT90	OBS INT90	TOT INTR
1	3.01	6.02	3298	3011	2966	3343	377	37.10	3.61	49.76	4.84	1.0000

Figure 2: The right clustered GFS IWV clustered object 1 has been matched with the SSMIS IWV clustered object 1 in the right panel. Selected object-pair attributes found for the match are tabulated at the bottom of the figure.

In Figure 2 the matched and ‘clustered’ MODE objects for the GFS analysis IWV field (left panel) and the SSMIS IWV field (right panel) are shown. Clustered here means that, within each data field, user adjustable criteria have been applied to objectively group relate and group smaller objects into larger (and less numerous) ‘clustered’ objects. This alleviates, but doesn’t completely eliminate, the appearance of large errors due to slight intensity differences in one field leading to a different selection of objects than those found in the other field. The objects in each field above were grouped into a single cluster object labeled cluster object 1. The centroid (geometric center) distance for the two objects (in grid spaces) is one measure of the agreement in location and shape. The ratio of the size of the analysis area to the observed area is a measure of the agreement in object size, while the ratio of the union area (area in common) to the observed area indicates the degree of overlap. The symmetric difference, on the other hand, measures the amount of non-overlap. MODE determines the frequency distribution of the pixel intensities (i.e., IWV values) within each of the matched objects. The median values (INT50) and the 90th percentile (INT90) values are tabulated at the bottom of the Figure 2. The ratio of GFS to SSMIS percentile values is an indicator of the agreement in IWV throughout the objects, and relates to the goodness of calibration for both the model and the sensors. Due to the dimensions contained in the input data sets, the GFS values are shown in mm IWV, while the SSMIS values are in cm.

Selected Statistical Summary of NEP Domain IWV Object Attributes for the 2009-2010 Cool Season

1. Intensity

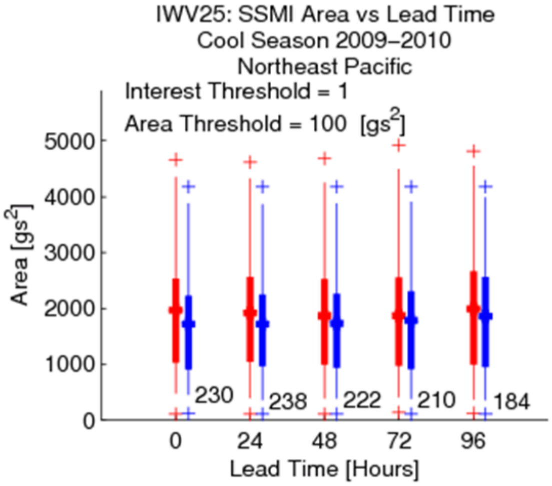


SSMI, as used here, is short for SSMI/S, SSMIS. SSMI/S values were used up to Nov 1, 2009, SSMIS values thereafter.

Figure 3

Figure 3 compares forecast versus observed 90th percentile pixel values of IWV within the matched objects. A few objects during the season contained values reaching 5.7 cm. In the statistical table at the top of the panel x represents SSMI and y GFS 90^{th} percentile values. δ represents y-x. Thus the 90^{th} percentile values of the GFS analysis IWV pixel values averaged 0.05 cm higher than the mean for the satellite values, but the standard deviation of this difference was 0.11 cm, suggesting this value is not statistically different from 0. Although this difference increased to 0.18 cm by 96 h lead time, the difference standard deviation of 0.29 cm, again suggests the bias is not be significant. The correlation coefficient is high for all lead times. However, while 230 matching objects were found at analysis time, only 184 were found by 96 hours forecast lead time, reflecting poorer agreement in shape, size, and location of the objects, resulting in fewer matches.

2. Object Area



Legend

Median = Thick Bar, Mean = Thin Bar

Percentile Ranges: 2.5—97.5 = Thin line, 25—75 = Thick line

Figure 4

In Figure 4 the paired box plots show that the number of hits (matchable objects) decreased with lead time (230 matches at 00h lead, 184 hits at 96h). Some objects had areas approaching 5000 grid squares (1/2°x1/2° lat, lon). A positive area bias of GFS (red) over SSMIS (blue) is evident. This observed bias is discussed in more detail further on.

3. Object Overlap Ratio

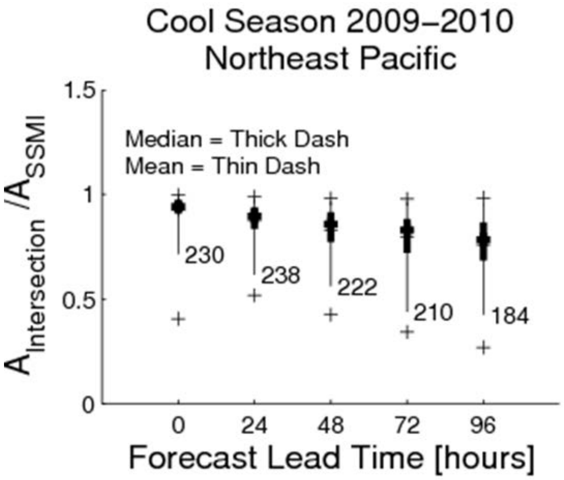
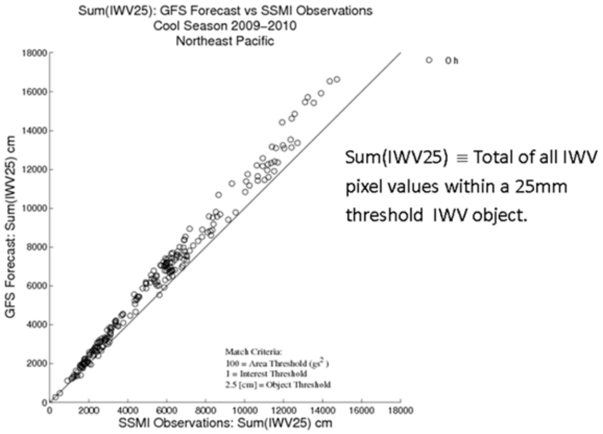


Figure 5

In Figure 5 the overlaps that are less than one indicate that the GFS object is smaller than the SSMI and/or that the objects are offset. However, the ratio of object areas also has to be consulted, since a GFS object that is much bigger than SSMI could completely overlap the SSMI object, even though the match would be poor. The increasing spread in the 50% and 95% boxplot bars, as well as the decreasing median values, track the deterioration of fit for the GFS forecast objects with lead time.

Example Result: Sensitivity of Object Area to Data Resolution and Grid Matching Operations



Sum(IWV25) ≡ Total of all IWV pixel values within a 25mm threshold IWV object.

Figure 6

In Figure 6, for the 2009-2010 cool season, the sum of all the IWV pixel values within each object of each matched pair are plotted. The SSMI satellite observations are on the x axis and the GFS analysis values are on the y axis.

A positive bias for the analysis totals that increases as the total IWV gets larger is apparent in Figure 6. However, the scatter plots of the matching-object median and 90th percentile IWV values shown in Figure 7 suggest this bias isn't due to intensity (i.e., calibration) bias.

Rather, as shown in Figure 8, the bias is due to differences in the SSMI and GFS object areas. The GFS object areas are, albeit with a lot of scatter, about 12% larger than the SSMI's. The bias appears to change non-linearly with size at small values. These findings are consistent with the GFS object boundaries typically extending a grid cell or so further out from center than the SSMI boundaries. The most likely cause of this discrepancy is the grid matching process that was applied to the original data fields: The original 1 degree GFS data was downscaled and the originally ¼ degree SSMI data was upscaled to create a grid match at ½ degree of latitude and longitude.

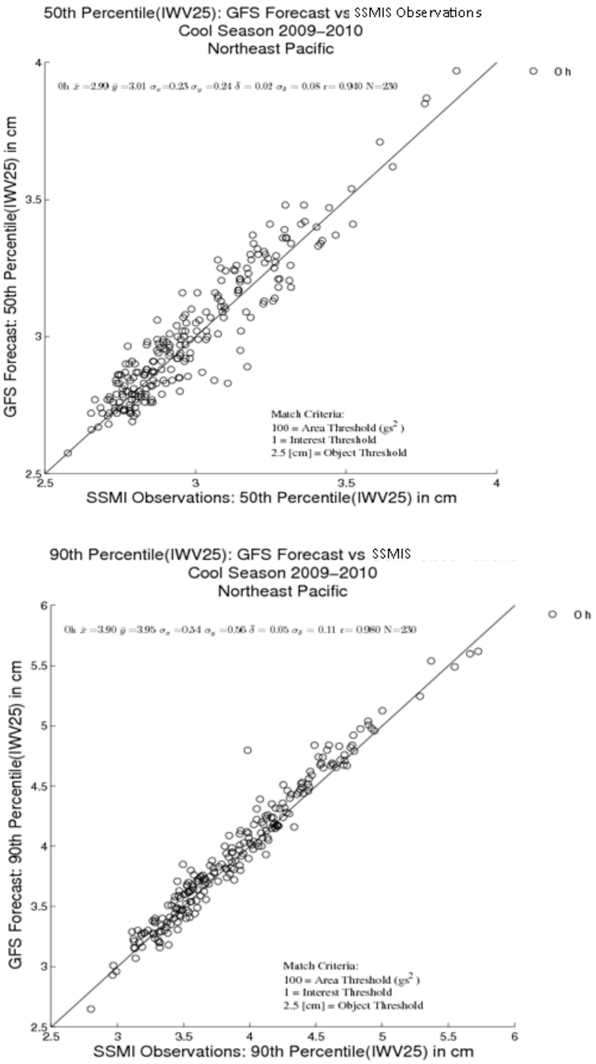


Figure 7

Figure 7 is like Figure 6 but for the median (top panel) and 90th percentile (bottom panel) within-object IWV pixel values.

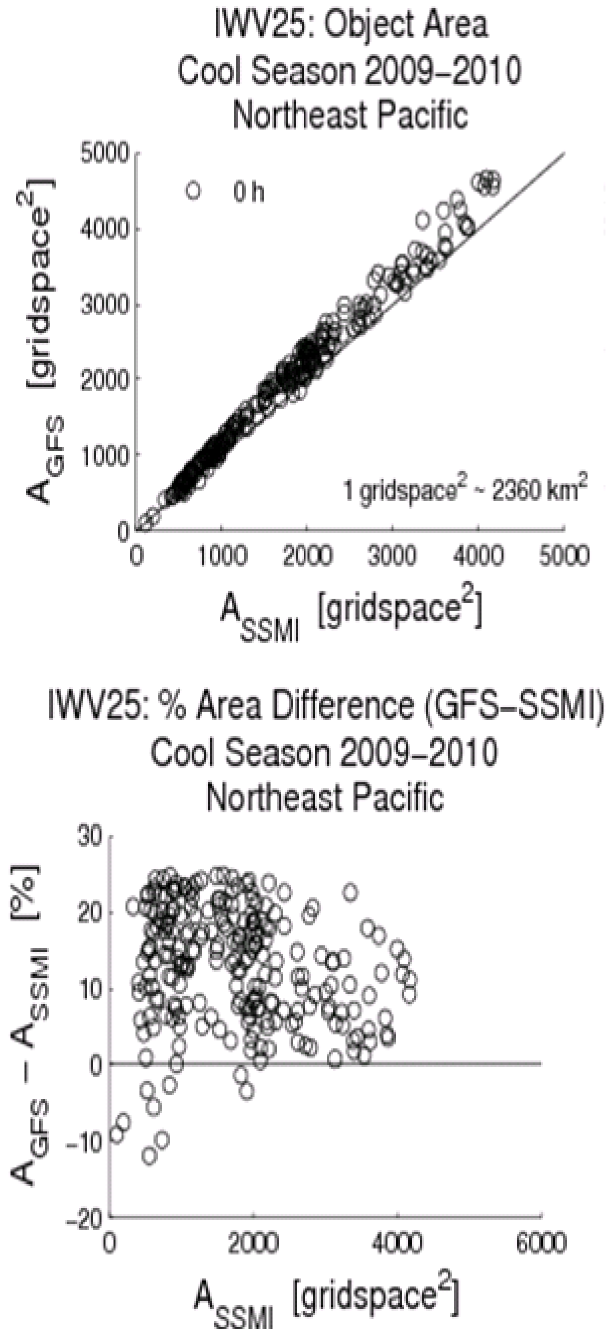


Figure 8

In Figure 8 - Top panel, the object areas for the GFS analysis are plotted against the paired-partner SSMI object areas. Bottom panel – The matched-object differences in area are plotted, with positive values indicating A_{GFS} is positively biased relative to A_{SSMI}.

Domain 2: 1000 km from Shore: Integrated Vapor Transport (IVT)

To restrict attention to landfalling objects a smaller, more focused domain, as illustrated in Figure 9, is tempting. Problems inherent with this focus for IWV and IVT objects are discussed below. Figure 9 shows MODE analysis of GFS IVT forecasts versus analysis fields for a particular time.

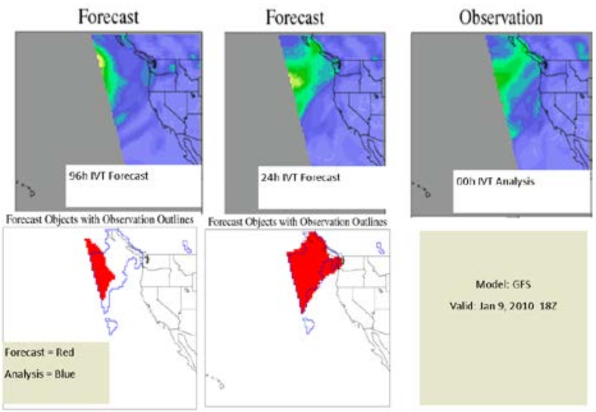


Figure 9

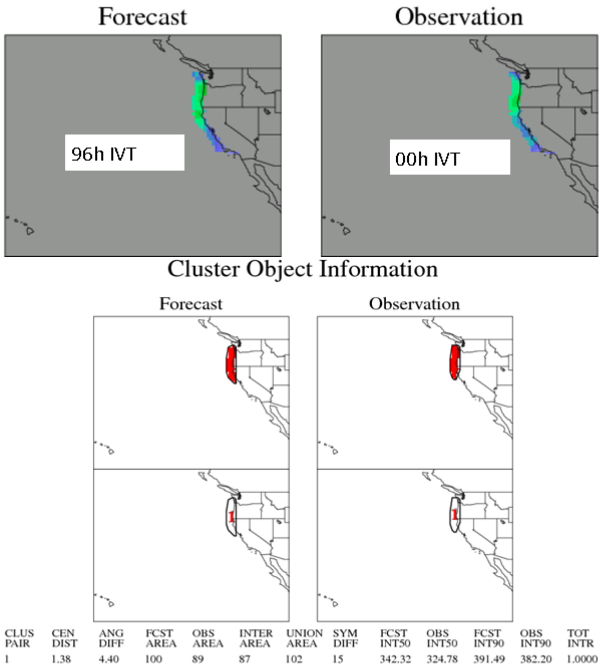
In Figure 9 the Integrated Vapor Transport (IVT) fields are shown for the GFS 96 and 24 hour forecast, as well as for the GFS analysis, which here serves as the 'observation' (appropriate wind observations were not available to convert the SSMI observed IWV into a water vapor horizontal flux). For each lead time the solid red forecast objects may be easily compared with the blue outlined analysis objects. For this particular case it is clear that the 96 h forecast severely lags the analysis, whereas the 24 h forecast compares rather well. This is visually clear but difficult to quantify with currently available MODE object attributes, so that a seasonal bias for each lead time must currently be done via case by case inspection. The centroid distance comes close to being the desired measure but is not quite what is needed. Better might be an attribute expressing the shortest distance from the object to a specified line (here, say, the coast line). This important need represents an opportunity for further development.

In fact, all the IVT or IWV MODE attributes in this domain are significantly distorted for significantly sized objects due to object truncation by the domain's prescribed western boundary. However, these attributes are not completely devoid of physical meaning. The signed centroid distance, for example, certainly conveys information about the leading or lagging of the forecast, as long as the truncation is not so severe as to prevent the algorithmic matching of the forecast with the observation object. Similarly, comparisons of the area and total intensity attributes can be used to create statements such as “the forecast put too much (or too little) water vapor into the domain relative to the observation at this particular time.”

One of the greatest analysis needs in this domain (and the larger domains for that matter) is a set of attributes that could describe when and where landfall is occurring. If such attributes could be developed this would be a boon that would lead to another need: attributes that track particular objects in time. Some such attributes are well along in the development stage at DTC, but remain to be vetted and incorporated into MODE (Randy Bullock, NCAR RAL, private communication).

However, the use of strip domains as exampled in the next section partially alleviates this problem at the expense of requiring multiple passes of MODE.

Domain 3: Latitudinal Strip 150 km from Shore: IVT



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	1.38	4.40	100	89	87	102	15	342.32	324.78	391.49	382.20	1.0000

Figure 10

Although it is somewhat counterintuitive, MODE attributes can be made relevant to atmospheric river landfall studies by restricting the domain to a latitudinal coastal strip. By doing this we make every object becomes, by definition, a landfall event. Further, by minimizing the longitudinal information, the latitudinal location of the objects can be measured. Given frequent model or observational output, the intensity of the events can be located and tracked in time as well as latitude so that Hovmuller diagrams may be constructed. Overlaid with data fields from observations, time leads and lags and latitudinal biases can be determined. The following examples compare GFS forecasts to GFS analyses because grid-matched vector wind observations over the NEP were not available. The 12 h GFS outputs were found to be too widely spaced to create easily interpretable Hovmuller diagrams.

Applying the definition of landfall as the presence of an object within the strip provided the 2009-2010 cool season statistical summary plots shown in Figure 11.

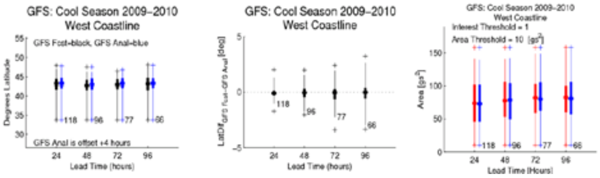


Figure 11

Physical and statistical characteristics gleaned from the three panels of Figure 11for the 2009-2010 Cool Season 2.5 cm IWV landfall events include:

1. ~50% of matched landfall object centroids were between 43° and 45° latitude.
2. Hits (matches) decreased from 118 to 66 betweemn24h and 96h lead time.
3. There is little if any centroid bias in latitudinal location but, as expected, the uncertainty (i.e., magnitude of the difference) increases with lead time.
4. 50% of the 25 cm m/s threshold IVT objects cover 930 to 1830 km of coastline (i.e., 1 latitudinal gs = 55 km, and the strip is 3 gs wide). The remaining 50% cover more.
5. At least one matched pair covered the whole domain (2750 km of coastline)

Note that additional studies can incorporate multiple strips for longitudinal event tracking.

Discussion

MODE object analysis can be usefully applied to provide useful verification metrics relative to the forecast of landfalling atmospheric river events. These metrics in many cases can be obtained in near real time as the

MODE analysis package can be inserted into the model-output post-processing stream. The technique is equally useful in retrospective analysis which extends the number and type of observational data fields that can be used for the model verification. In this developmental study verification was performed using GFS analysis and GFS forecasts from 24 to 96 h lead times, coupled with SSMIS satellite observations of IWV. The data fields analyzed were the precursors of AR events: integrated water vapor (IWV) and integrated vapor transport (IVT). Precipitation fields were not analyzed, but may be incorporated in further studies.

A clear result of this study is that no single domain size accomplished all the verification goals using MODE analysis. Consequently, this presentation focused on a large, medium, and coastal strip domain and described particular strengths and weaknesses for each. The general conclusion is that a comprehensive verification via object analysis of atmospheric river events will need to invoke attributes gleaned from all three.

Three Basic References

Atmospheric Rivers: Neiman, P. J., et al., 2008, J. Hydrometeorology, Vol. 9, pg. 22.

MODE:
www.dtcenter.org/met/users/support/online_tutorial/METv2.0/mode/index.php

Object-Based Verification of Precipitation Forecasts: Davis, C., B. Brown, and R. Bullock, 2006, Monthly Weather Rev., Vol. 134, pg. 1772.