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Comparison of ECMWF and Quikscat-Derived Surface Pressure Gradients

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COMPARISON OF ECMWF AND QuikSCAT-DERIVED SURFACE PRESSURE GRADIENTS

By

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ABSTRACT

A technique based solely on QuikSCAT data is developed for determining suspect differences between QSCAT and ECMWF pressure gradients. Pressure fields are computed from scatterometer winds using a variational method that applies a gradient wind conversion. Kinematic analysis of the satellite wind field is performed in order to determine which parameters are physically related to the suspect pressure gradients. It is discovered that the likelihood of these suspect occurrences has the greatest dependence on relative vorticity, total deformation, and the curvature Rossby number. A broad range of these values is tested and a single assessment criterion is derived based upon the value of several skill scores. Overall, the assessment criterion is able to correctly identify the majority of suspect pressure gradients; yet considerable over-flagging does occur in many instances. However, the over-flagging is not random: the false alarms are tightly clustered around the suspect areas, resulting in flagged regions that are too large. Identification of the location of suspect areas in pressure products should be useful to forecasters.
1. INTRODUCTION

Limited meteorological observations over the world’s oceans have long been a restricting factor in producing accurate weather forecasts (Atlas et al. 1985). In the past, the only surface data typically available were observations from ships and buoys. Unfortunately, these data are characterized by poor spatial coverage because most ships follow well-defined routes and the majority of buoys are located near coastal regions. At present, satellite data supplement conventional meteorological data over the oceans. One such source of data is the SeaWinds instrument aboard the QuikSCAT satellite. Launched in 1999, the SeaWinds scatterometer is a microwave radar that infers near surface wind vectors under most weather and cloud conditions over the earth's oceans. While scatterometer winds are useful for numerous research applications most operational meteorologists, particularly those in local weather offices, prefer surface pressure fields, and consider the pressure gradients to be the most important characteristic of the pressure field. The goal of this study was originally to provide quality assurance for scatterometer-derived surface pressure gradients. However, in situ observations are insufficient to test pressure gradients (Hilburn, personal communication, 2003). Consequently, the goal of this study is to determine under which conditions there are relatively large differences in ECMWF and QuikSCAT derived pressure gradients. With this information, QuikSCAT-derived pressure fields are more likely to be used by the operational community. Identification of these large differences is based solely on the QuikSCAT data.

Since it became operational, SeaWinds data has been used to determine accurate surface wind speed and direction (Bourassa et al. 2003). Numerous techniques have been developed for computing surface pressures from scatterometer winds. Endlich et al. (1981) were among the first to calculate surface pressures from scatterometer wind data. They obtained reasonable results however their method did not account for the atmospheric boundary layer. Brown and Zang (1994) were able to account for the boundary layer, yet their method suffered because the winds retrieved from their model were closer to gradient winds than geostrophic winds. Patoux and Brown (2002) were able to remove this weakness by applying a gradient wind adjustment. Another approach,
initially developed by Harlan and O’Brien (1986) and improved by Zierden et al. (2000) and Hilburn et al. (2003), used a variational method to blend vorticity from the scatterometer winds with geostrophic vorticity from an existing pressure analysis. The boundary layer was accounted for by simply assuming neutral stratification and barotropic conditions (i.e., 10 m winds were not adjusted to winds in the free atmosphere). These assumptions eliminate the need for upper air or temperature data, which could be highly inaccurate when the scatterometer observations differ greatly from the existing analysis. No more than a 2 hPa difference was found by Brown and Zeng (1994) when baroclinicity and stratification were included as opposed to when barotropic and neutral conditions were assumed.

Recently, Hilburn et al. (2003) further improved the variational method by applying a conversion (Endlich, 1981) from surface vorticity to geostrophic vorticity based on gradient winds. This method does not require any iteration when applying a gradient wind adjustment as in Patoux and Brown (2002). Validation of the pressure fields was achieved through comparison with in situ observations. Overall, they found the scatterometer-derived surface pressures to be a small improvement over the NCEP/NCAR reanalysis (which was used as the objective technique’s background field). The researchers noted that this improvement was understated due primarily to an under-sampling of storms over the region. They also pointed out instances where NCEP/NCAR reanalysis completely missed some storms and the QuikSCAT-derived pressures provided up to a 20 hPa improvement.

Our discussions with colleagues in the operational community indicate that widespread use of scatterometer-derived pressures has been hampered largely because of questionable accuracy under specific synoptic conditions. In order to identify the conditions for which suspect differences occur, kinematic analysis of the QuikSCAT wind field is performed and horizontal pressure gradients are computed from both the QuikSCAT wind field and the ECMWF operational data. The magnitude of the pressure gradient differences \( |\nabla P_Q - \nabla P_M| \) are calculated and used to determine when the gradients of surface-derived pressure fields are operationally useful. The scatterometer data and comparison derived pressure fields are described in section 2. In sections 3 and 4, the methodology and quality assessment are outlined. Section 5 presents our results and validation and
section 6 gives our conclusions. Overall, these techniques are able to consistently locate nearly 80% of the suspect QuikSCAT pressure differences; however, considerable over-flagging does occur in many instances.
2. DATA

The data utilized in this study include SeaWinds on QuikSCAT surface equivalent neutral wind vectors (calibrated to a height of 10 m), NCEP/NCAR reanalysis surface pressures, and ECMWF operational surface pressures. QuikSCAT is a sun-synchronous satellite with an orbital period of approximately 100 minutes. The SeaWinds scatterometer uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 GHz and records data over a continuous, 1,800 km-wide swath, making approximately 400,000 vector wind measurements and covering 90% of the Earth's ice-free oceans every day (Fig. 1). Individual footprints are binned into 25x25 km cells with as many as 76 cells across the satellite swath. A “geophysical model function” is applied to convert the backscatter cross-section to near surface (equivalent neutral) wind speed and direction. For this study, the winds were determined using the Ku-2001 model function. This model function was created by Remote Sensing Systems Inc., and is currently the most accurate under most meteorological conditions (Bourassa et al. 2003). The function is considerably more accurate than previous model functions near nadir and near the edge of the satellite swath, and overall, has been shown to remove approximately 40% of the QSCAT-1 uncertainties (Bourassa et al. 2003).

NCEP/NCAR reanalysis (NCEPR) pressures are available on a 2.5° global grid at 6-hour intervals and serve as the background pressure field for computing surface pressures from the scatterometer winds (Fig. 2). ECMWF operational pressures are available on a 1° global grid at 6-hour intervals and are used as the comparison data in this study because of their superior resolution and accuracy (Patoux et al. 2002). In order to obtain pressure fields that are temporally consistent with the QuikSCAT overpasses, linear interpolation is used (Hilburn et al. 2003). Note that NWP products have regional biases with regards to wind vectors (Smith et al. 2001), which must contribute to biases in vorticity. The spatial scale over which these biases change is very large, resulting in very low biases in vorticity related to this problem.
Figure 1. Illustration of SeaWinds (22 hour) daily coverage. Top image is the ascending node and bottom is the descending node (courtesy of Paul Chang – NOAA/NESDIS: http://manati.wwb.noaa.gov/quiKscat).
Figure 2. Computing surface pressure fields from scatterometer winds: top image displays QSCAT surface wind vectors (color indicates speed in knots) and bottom image displays surface pressures (hPa) from ECMWF operational (dotted lines) and QSCAT-derived (solid lines).
3. PRESSURE METHODOLOGY

The computation of surface pressures from QuikSCAT winds is achieved by applying a variational method adapted from Harlan and O’Brien (1986) and improved by Zierden et al. (2000) and Hilburn et al. (2003). This method minimizes a cost function

\[
F(p_{ij}, \zeta_{ij}, \lambda_{ij}) = \sum_i \sum_j \left[ \lambda_{ij} H_{ij} + \frac{K_{\xi}}{2} M_{ij}^2 + \frac{K_E}{2} G_{ij} \right].
\]  

where \(p_{ij}\) and \(\zeta_{ij}\) are the solution pressure and the solution geostrophic vorticity fields, respectively. \(\lambda_{ij}\) are the Lagrange multipliers and \(f_j\) and \(\beta_j\) are the Coriolis and beta parameters, respectively. Following Sasaki (1970), \(H_{ij}\) is the strong constraint and has the form

\[
H_{ij} = \frac{1}{\rho f_j} \left( \nabla^2 p_{ij} - \frac{\beta_j}{f_j} \frac{\partial p_{ij}}{\partial y} \right) - \zeta_{ij},
\]

\(M_{ij}\) is the data misfit term and has the form

\[
M_{ij} = \zeta_{ij} - \left( \zeta_{ij}^* \right)_{g}.
\]

\(K_{\xi}\) and \(K_E\) are the Gaussian precision modulii, and their ratio determines the relative amounts of smoothing to data misfit. The background geostrophic vorticity is computed from the following formula

\[
\left( \zeta_{ij}^* \right)_{g} = \frac{1}{\rho f_j} \left( \nabla^2 p_{ij} - \frac{\beta_j}{f_j} \frac{\partial p_{ij}}{\partial y} \right).
\]
\( (\zeta^s)_{ij} \) is the geostrophic vorticity data term and assumes the background value \( (\zeta^B_{ij})_{ij} \) outside the swath and the satellite value \( (\zeta^S_{ij})_{ij} \) inside the swath. Calculations involving satellite winds are done on the observational grid, which has an approximate spacing of 25 km. Following Renka (1982), the satellite and background vorticity are transferred onto a regular 0.25° earth-aligned grid just prior to minimizing the cost function.

In order to obtain geostrophic winds from satellite winds, the following method is used. A boundary layer adjustment converts the 10 m equivalent neutral scatterometer winds (Verschell et al. 1999) to gradient winds at the top of the boundary layer. This adjustment requires an 18° anticyclonic rotation of the wind direction and a multiplication of the wind speed by 1.5 (Brown and Zeng 1994). The gradient winds \( (V) \) are then adjusted to geostrophic values \( (V_g) \) by applying the following form of the gradient wind equation

\[
V_g = V \left(1 + \frac{V}{jR} \right) = V(1 + Ro)
\] (5)

where \( Ro \) is the Rossby number. The Rossby number field requires a small amount of smoothing to produce a meaningful gradient wind adjustment and as in Patoux and Brown (2002), but does not require any iteration because it is calculated directly from the scatterometer winds. A 225-km low-pass binomial filter (Jähne 1991) is applied to the satellite vorticity and a 325-km low-pass binomial filter is applied to the Rossby number field.

A regularization term \( (G_{ij}) \) is included in the original cost function in order to blend the scatterometer vorticity with the background vorticity. The absence of such a term would yield a solution of \( \lambda = 0 \) and the satellite vorticity would be inserted directly into the field. Zierden et al. (2000) and Harlan and O’Brien (1986) found that minimization of the geostrophic kinetic energy could be successfully used as a regularization term:

\[
G_{ij} = \frac{1}{2 \rho^2 f_j^2} \nabla p_{ij} \cdot \nabla p_{ij}
\] (6)
In order to minimize the cost function, one must solve

$$\frac{\partial F}{\partial \lambda_{ij}} = H_{ij} = 0 , \quad (7)$$

$$\frac{\partial F}{\partial \zeta_{ij}} = K \cdot M_{ij} - \lambda_{ij} = 0 , \text{ and} \quad (8)$$

$$\frac{\partial F}{\partial p_{ij}} = \frac{1}{pf_j} \left[ \nabla^2 \lambda_{ij} + \left( \frac{\beta_{ij}}{\rho_{ij}} \right) \nabla \lambda_{ij} + \frac{K_E}{(2pf_j)^2} \nabla^2 p_{ij} \right] = 0 \quad (9)$$

Eq. (9) has a solution of the form

$$\lambda_{ij} = \left( \frac{K_E}{4pf_j} \right) (p_{ij} - p_{oi}) , \quad (10)$$

where $p_{oi}$ is the homogeneous solution. $p_{oi}$ satisfies

$$\left( \frac{K_E}{4pf_j} \right) \nabla^2 p_{oi} = 0 , \quad (11)$$

and $\lambda = 0$ on the boundaries implies $p_{oi} = p_{ij}$. Substituting (10) into (8) gives

$$\zeta_{ij} = \zeta^*_{ij} + \left( \frac{K}{2pf_j} \right) (p_{ij} - p_{oi}) , \quad (12)$$

where $K = K_E/2K$. Inserting (12) into (7) gives
\[ \nabla^2 p_y = \left( \frac{\beta_j}{f_j} \right) \frac{\partial p_y}{\partial y} - \left( \frac{K}{2} \right) (p_y - p_{0y}) = \rho f_j \zeta^* y \]  

Equation (13) is solved by applying successive overrelaxation of Neumann boundary conditions. Second-order finite difference representations of derivatives and an optimal relaxation parameter of 1.8 (e.g., Press et al. 1992) are used. A value of \( K = 5.0 \times 10^{-12} \) m\(^{-2}\) is used in order to retain important physical features in the SeaWinds geostrophic vorticity field while simultaneously producing a smooth pressure field.

Comparison of the QuikSCAT-derived pressures to in situ observations found that the random error in the QuikSCAT pressures was estimated at 8 hPa. The density of in situ pressure observations was insufficient to examine the quality of pressure gradients. It is speculated that the pressure gradients, determined with the above method, are much more accurate than would be expected from the propagation of a 8 hPa random error. Such random errors in observations 25km apart leads to a random error in the pressure gradient of 0.45 hPa/km, which is inconsistent with the smoothness of the scatterometer-derived pressure fields. It is likely that most of their errors are due to a bias that can be applied over a wide area relative to the scatterometer grid spacing. Such errors are believed to come from the Neumann (matching slope) boundary conditions on the QuikSCAT-derived pressure fields.
4. QUALITY ASSESSMENT TECHNIQUES

Operational meteorologists are more interested in the accuracy of pressure gradients than in the accuracy of pressure fields. Therefore knowledge of regions where pressure is suspect (from either QuikSCAT or a numerical weather model) would be useful to forecasters. Knowledge of which data to trust, and which data to consider more carefully, would help forecasters. The temporal difference between QuikSCAT overpasses and ECMWF operational pressures (computed for 00, 06, 12, and 18UTC) varies from zero to three hours. In areas of active weather there is often substantial advection; therefore, differences between the QSCAT and operational surface pressure fields would often be present even for perfect fields. In this comparison, temporal differences were limited to ± 1 hour of each other.

Two-dimensional pressure gradients are computed for both the QuikSCAT and ECMWF pressure fields as follows:

\[
\nabla P_Q = \frac{\partial P_Q}{\partial x} i + \frac{\partial P_Q}{\partial y} j
\]

(14)

\[
\nabla P_M = \frac{\partial P_M}{\partial x} i + \frac{\partial P_M}{\partial y} j
\]

(15)

where subscripts \(Q\) and \(M\) denote QuikSCAT and ECMWF respectively. Next, the magnitude of the vector differences (16) are computed:

\[
|DPG| = \left( \left( \frac{\partial P_Q}{\partial x} - \frac{\partial P_M}{\partial x} \right)^2 + \left( \frac{\partial P_Q}{\partial y} - \frac{\partial P_M}{\partial y} \right)^2 \right)^{1/2}
\]

(16)

where DPG is the Difference between the Pressure Gradients (Pa m\(^{-1}\)).
Kinematic analysis of the QuikSCAT wind field is also performed in order to determine whether or not a useful relationship exists between differences in QuikSCAT and ECMWF pressure gradients and kinematic components of the wind field. Surface vorticity (relative), divergence, stretching deformation, shearing deformation, total deformation, Rossby Number, and the 5-point Jacobian are computed directly from the swath winds using the following equations (Bluestein 1992):

\[
\text{Vorticity, } \zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \tag{17}
\]

\[
\text{Divergence} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \tag{18}
\]

\[
\text{Stretching Deformation} = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \tag{19}
\]

\[
\text{Shearing Deformation} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \tag{20}
\]

\[
\text{Rossby Number} = \frac{1}{fV^2} \left[ \left( u^2 \frac{\partial v}{\partial x} - v^2 \frac{\partial u}{\partial y} \right) - uv \left( \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \right) \right] \tag{21}
\]

\[
\text{Jacobian} = \begin{vmatrix}
\frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\
\frac{\partial v}{\partial x} & \frac{\partial v}{\partial y}
\end{vmatrix} \tag{22}
\]

\( u \) and \( v \) are the zonal and meridional wind components, respectively. The vorticity and divergence terms are rotationally invariant, however the deformation terms are not (i.e., the values depend on the orientation of the coordinate system). This presents a problem because the orientation of the satellite swath is different from that of a regular earth-
aligned grid. In order to overcome this discrepancy, the sum of the squares of each deformation term is computed because this combined term is rotationally invariant:

\[
\text{Total Deformation} = \sqrt{\text{StretchingDef}^2 + \text{ShearingDef}^2}.
\] (23)

Six separate synoptic cases are used to develop these techniques. Each case contains several thousand QSCAT grid cells. These cases include a broad range of synoptic conditions including midlatitude and highlatitude cyclones and anticyclones, fronts, and tropical cyclones (Table 1). The kinematic parameters listed above as well as pressures are computed for each case.

**Table 1.** Locations and dates for the six sets of QuikSCAT data used for technique development.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Date(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf of Mexico</td>
<td>20 to 30°N</td>
<td>265 to 280°E</td>
<td>Aug 1, 2, 3 of 2001</td>
</tr>
<tr>
<td>Northeast Atlantic</td>
<td>40 to 60°N</td>
<td>320 to 350°E</td>
<td>Jan 20, 21 of 2001 &amp; Feb 10 of 2001</td>
</tr>
<tr>
<td>Northwest Atlantic</td>
<td>35 to 55°N</td>
<td>280 to 310°E</td>
<td>Mar 21, 22, 25, 26 of 2001</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>20 to 30°N</td>
<td>265 to 280°E</td>
<td>Mar 21, 22 of 2001</td>
</tr>
<tr>
<td>Northeast Pacific</td>
<td>40 to 60°N</td>
<td>180 to 220°E</td>
<td>Feb 3, 10 of 2002; Feb 5, 6 of 2003; Mar 10 &amp; Jan 16 of 2000</td>
</tr>
<tr>
<td>South Pacific</td>
<td>2 to 25°N</td>
<td>150 to 180°E</td>
<td>Feb 8, 9 of 2003</td>
</tr>
</tbody>
</table>

It is often assumed that under the majority of synoptic conditions the divergence and deformation terms are small compared to the vorticity term (Holton 1992), and where this assumption is not true large errors in the scatterometer pressure field could be expected. In reality, it is difficult to verify this assumption using QuikSCAT data because
significant sub-25 km variability is convolved into the satellite-derived wind data (Bourassa et al. 2003). An alternate approach involves determining when and where the wind field is most ageostrophic, which presents problems for both QuikSCAT-derived pressures and coarse resolution numerical weather models. These conditions can be found by computing a curvature Rossby Number for each grid cell in the satellite swath. According to geostrophic wind theory, smaller values of the curvature Rossby Number correspond to flow that is nearly in geostrophic balance while larger Rossby numbers are indicative of flow that is more ageostrophic (Stull 2000). When the wind field is more ageostrophic, larger amounts of divergence/convergence and deformation typically result. These increases could substantially decrease the accuracy of the QuikSCAT-derived pressures because the variational method relies upon blended vorticity values and not divergence and deformation. In contrast, weather models are often over smoothed and misplacement of features, in addition to, poorer resolution are more noticeable for these conditions.

The impact of these kinematic terms on pressure gradient differences was examined in a sensitivity study using the data cases listed in Table 1. It is found that divergence is very noisy and has little influence on pressure gradient differences relative to this noise. It is determined that QuikSCAT/ECMWF pressure differences have the greatest dependence on the Rossby Number. The most egregious differences seem to correspond to larger Rossby numbers, while smaller Rossby Numbers are indicative of smaller pressure gradient differences. It is obvious from these results that certain values of Rossby Number, vorticity, and deformation more accurately correspond to pressure errors in specific synoptic situations. An objective of this study is to determine one universal criteria that can be applied to all synoptic situations with reasonable accuracy. We found statistics (skill scores) regarding suspect pressure gradients to have non-negligible sensitivity to the Rossby Number, total deformation, and relative vorticity. Examination of $\left|\text{DPG}\right|$ frequency plots suggests that Rossby Number, Jacobian, total deformation, and relative vorticity values can be linearly related and used to develop a condition for identifying suspect pressure gradients:

$$Ro > Ro_T - c_1 TD + c_2 \zeta$$

(24)
where $Ro$ is the Rossby Number, $Ro_T$ is the Rossby Number threshold, $TD$ is the total deformation, $\zeta$ is the relative vorticity, and $c_1$ and $c_2$ are the deformation and vorticity coefficients (with units of seconds), respectively.

In order to pinpoint which specific values of $c_1$ and $c_2$ perform best when applied to a wide variety of meteorological scenarios, skill scores are computed for a range of Rossby Number thresholds, vorticity coefficients, and deformation coefficients. The most useful skill scores for these purposes include the POD (Probability of Detection), FAR (False Alarm Ratio), and CSI (Critical Success Index) skill scores (Wiley 2003 and Stanski 1989).

$$POD = \frac{H}{H + M}$$  \hspace{1cm} (25)

$$FAR = \frac{F}{H + F}$$  \hspace{1cm} (26)

$$CSI = \frac{H}{H + F + M}$$  \hspace{1cm} (27)

where $H$ is the number of correctly identified suspect differences (hits), $M$ is the number of missed differences (misses), and $F$ is the number of false alarms. The POD score measures the technique’s ability to correctly flag significant pressure gradient differences and the FAR score relates to the fraction of false alarms. POD scores allow one to easily discern how many of the suspect regions are correctly identified and FAR scores reveal how many areas are flagged when they should not be. The CSI score is considered to be the most important statistical parameter in this study because it combines both the POD and FAR scores by testing how well the flagging criteria can separate hits from misses and false alarms. For the POD and CSI scores values of 1 are perfect and for FAR scores values of 0 are perfect.
Contour plots are generated in an effort to narrow down the most useful flagging criteria. Before these plots are created, it is necessary to remove the centers of closed lows and well-defined frontal regions because of the inherent problems of translation during the short time between QSCAT overpasses and synoptic hours. The areas removed were small in most instances (no more than 0.5° latitude around the center of a low and only one or two grid cells in width for well-defined fronts). This is done on a swath by swath basis using a combination of satellite wind vector and surface pressure plots, as well as, ECMWF surface pressure plots. It should be pointed out that several cases did not require this sort of quality control procedure and were used in their original form. It should also be noted that removal of these areas would not be necessary if a verification technique (such as the Ebert & McBride (2000) method) were applied. The statistical contour plots that are produced are able to examine a large range of Rossby Number thresholds, relative vorticity, and total deformation coefficients on the same plot (Figs. 2 and 3). This range is narrowed down once the best skill scores are identified. The values that produce the best skill scores are then used to flag suspect regions from the data in Table 1. The following four conditions were tested over a range of values

\[ Ro > R_{\text{RoT}} - c_1 TD + c_2 \zeta \]  
(28)

\[ (c_3 \ast f \ast Ro) > R_{\text{RoT}} - c_4 TD + c_5 \zeta \]  
(29)

\[ c_6 J > R_{\text{RoT}} - c_7 TD + c_8 \zeta \]  
(30)

\[ (c_9 \ast f \ast J) > R_{\text{RoT}} - c_{10} TD + c_{11} \zeta \]  
(31)

where \( f \) is the Coriolis Parameter, \( Ro \) is the Rossby Number, \( R_{\text{RoT}} \) is the Rossby Number threshold, \( J \) is the Jacobian, \( TD \) is the total deformation, and \( \zeta \) is the relative vorticity. \( c_6 \) has units of \( s^2 \), \( c_9 \) has units of \( s^3 \), and the remaining coefficients have units of seconds. The most successful condition is (29) with \( R_{\text{RoT}} = 0.75 \), \( c_3 = 10000s \), \( c_4 = 5700s \), and \( c_5 = -2500s \). When tested on the initial data set (Table 1), skill scores for the flagging criteria above were as follows: \( POD = 0.685 \), \( FAR = 0.849 \), and \( CSI = 0.141 \).
Figure 3: Top image is the POD (Probability of Detection) skill score plot and bottom image is the FAR (False Alarm Ratio) skill score plot. For both plots, coefficients for total deformation and relative vorticity are plotted on the vertical and horizontal axes, respectively.
Figure 4: As for Fig. 3 but for the CSI (Critical Success Index) skill score plot.
5. VALIDATION

An independent data set is used to measure the effectiveness of the assessment technique (Table 2). These data are divided into two subsets based upon synoptic characteristics and latitude. Subset one is comprised of tropical cyclones and lower latitude weather systems. Subset two is comprised of extra-tropical cyclones, fronts, and higher latitude weather systems. Skill scores are computed for each subset, as well as, all of the data (Table 3). Results for the entire set of data are more favorable than for the training data set.

Table 2. Locations and dates for the eight sets of QuikSCAT data used for validation.

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<td>Gulf of Mexico</td>
<td>20 to 30°N</td>
<td>265 to 280°E</td>
<td>Sept 25 of 2002</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>20 to 30°N</td>
<td>265 to 280°E</td>
<td>Feb 15, 16 of 2003</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>20 to 30°N</td>
<td>265 to 280°E</td>
<td>Oct 11 to 14 of 2003</td>
</tr>
<tr>
<td>Northeast Atlantic</td>
<td>25 to 35°N</td>
<td>280 to 295°E</td>
<td>Sept 13 of 2000</td>
</tr>
<tr>
<td>Northeast Pacific</td>
<td>40 to 60°N</td>
<td>180 to 220°E</td>
<td>Jan 14, 15 of 2001</td>
</tr>
<tr>
<td>Northeast Pacific</td>
<td>40 to 60°N</td>
<td>180 to 220°E</td>
<td>Feb 1, 2 of 2002</td>
</tr>
<tr>
<td>South Pacific</td>
<td>40 to 60°S</td>
<td>150 to 170°E</td>
<td>Aug 9, 10, 11 of 2002</td>
</tr>
</tbody>
</table>

Table 3. Skill scores for the eight data sets and two subsets.

<table>
<thead>
<tr>
<th>Skill Score</th>
<th>Subset 1</th>
<th>Subset 2</th>
<th>All Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>POD</td>
<td>0.990</td>
<td>0.736</td>
<td>0.795</td>
</tr>
<tr>
<td>FAR</td>
<td>0.914</td>
<td>0.827</td>
<td>0.866</td>
</tr>
<tr>
<td>CSI</td>
<td>0.086</td>
<td>0.163</td>
<td>0.130</td>
</tr>
<tr>
<td>% of Suspect Points</td>
<td>3.9%</td>
<td>6.5%</td>
<td>5.6%</td>
</tr>
</tbody>
</table>
The following series of figures provide examples of QuikSCAT-derived surface pressure fields and winds, typical differences with respect to the ECMWF analyses, and the flagging technique that has been developed in this study:

**Figure 5:** Upper left image displays QSCAT surface wind vectors (color indicates speed in knots); upper right image displays surface pressures (hPa) from ECMWF operational (dotted lines) and QSCAT-derived (solid lines). Lower left image shows the same surface pressures, with color indicating the magnitudes of the difference between the QSCAT and ECMWF pressure gradients (Pa/m). Lower right image displays the area(s) flagged as having suspect pressure gradient differences.
**Figure 6:** As for Fig. 5. Note the large differences in pressure gradient associated with a small difference in location of the low pressure system.
Figure 7: As for Fig. 5. Note the significant pressure gradients associated with this extratropical cyclone and how the flagging technique is able to identify the largest discrepancies in the pressure gradients.
Figure 8: As for Fig. 5. Note the flagging of the large directional differences in the largest cluster of flags despite good similarity in magnitude of the pressure gradient. Reversed pressure gradient directions are flagged in the lower left cluster.
These examples reveal some of the limitations of the ECMWF operational pressures. The global product has a 1° grid resolution compared to a 0.25° QSCAT grid resolution. Thus, substantial discrepancies can result due to shifts in position of strong gradients, and the coarser resolution product can significantly underestimate the central pressure in closed lows. This can be seen in Fig. 5 and to some extent, in Fig. 6. The speed at which weather systems move can also complicate matters when comparing QSCAT pressures with model pressures. Higher latitude cyclones are known to move at speeds in excess of 50 to 60 km/hr, thus even if one limits the QSCAT overpass to ± one hour of the model output time, significant translational differences can still result (Fig. 7). These complications appear to make a significant contribution to the large false alarm rate. The false alarms related to misplaced systems could be greatly reduced through application of an analysis that repositions features (Ebert and McBride 2000) so that they are well matched in position. For forecast applications it is useful to flag these areas because they are often associated with miss-position of a key meteorological feature. For example, if the NWP position of a Nor’easter is off by half a grid cell there could be very large errors in precipitation forecasts.
6. CONCLUSIONS

Analytical techniques have been developed to provide a higher degree of quality assurance for QuikSCAT and ECMWF pressure gradients. These QuikSCAT pressure fields rely upon a variational method first developed by Harlan and O’Brien (1986) and further improved upon by Zierden et al. (2000) and Hilburn et al. (2003) that blends geostrophic vorticity values and applies a gradient wind conversion. It has been found that highly ageostrophic conditions tend to produce the largest discrepancies between QuikSCAT and ECMWF pressure gradients. Thus, a curvature Rossby number is used as the primary diagnostic parameter when creating more useful assessment criteria. Relative vorticity and total deformation values are also found to add additional accuracy to the assessment criteria.

A broad range of Rossby number, vorticity, and total deformation values are tested on an initial data set in order to determine which specific values give the best skill scores. Although it has not been possible to derive assessment criteria that give very high POD and CSI scores, as well as, low FAR scores (as is desired), the values obtained (Equation 29) do provide clear evidence that this technique is useful under most synoptic conditions. The assessment criteria are applied to an independent data set and produce more favorable skill scores however, high FAR score values are still present. The high false alarm rate can be partially attributed to the translational differences between the QSCAT and ECMWF pressures, and it is important to note that the vast majority of false alarms are clustered around areas that should be flagged rather than in random locations. Also, the application of the Ebert and McBride (2000) statistical technique as well as the use of a test based on percentage error near areas of large vorticity could substantially improve the FAR and CSI skill scores.

It might also be possible to derive multiple assessment criteria that could perform better under specific synoptic conditions; however, the main goal of this study is to identify a single test that performs reasonably well under most conditions. This degree of versatility and simplicity should prove useful for the operational forecasting community.
REFERENCES


Jeffrey P. Taylor was born on May 28, 1979 and raised in Pine Bluff, AR. Jeffrey graduated from Pine Bluff High School in 1997 and afterwards, attended the University of Hawaii at Hilo, located in Hilo, HI. He completed his Bachelor’s Degree in Marine Science in 2001. Upon graduating, he accepted a commission in the NOAA Officer Corps and after three months of intensive training was stationed on the NOAA Ship Gordon Gunter in Pascagoula, MS. While at sea, Jeffrey became increasingly interested in meteorology and forecasting and decided to return to graduate school and study meteorology. He was awarded a research assistantship with Dr. Mark Bourassa and began his graduate studies in the fall of 2003. In the fall of 2005, he accepted a forecasting position with a private weather company in Norman, OK.