RESEARCH LEADING TO FUTURE OPERATIONAL METHODS FOR WIND EXTRACTION

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ABSTRACT

The NESDIS will be implementing an automated procedure for producing satellite measured winds at high as well as low levels. The procedure will be applied to infrared window and water vapor imagery. The system will introduce CO_2 slicing for height assignment, but only for the infrared window vectors. To improve height assignment for the water vapor vectors an objective, assimilation technique is under development. The same procedure provides quality control which should ease the manpower intensive manual editing task, especially necessary with the far higher density of vectors produced automatically.

1. Introduction

There are three avenues which promise rapid improvement in the quality of Satellite Motion Winds (SMW) produced at the National Environmental Satellite and Information Data Services (NESDIS). These are: 1) improved target designation, especially in areas of multiple cloud layers; 2) improved pressure altitude assignment; and 3) improved quality control information for user discrimination. Unfortunately, better target discrimination is currently not a subject of active research at either NESDIS or the Cooperative Institute for Meteorological Satellite Studies where the SMW systems are developed. However, the latter two topics are. This paper reports on some recent research results.

Height assignment for the SMW has traditionally been accomplished by an histogram technique. After the selection of a target, a 20 x 20 template of pixels is extracted for pattern recognition in the subsequent imagery. These 400 samples are sorted in a histogram and the coldest 15 percent is assumed to represent cloud top temperature. That temperature, without emissivity correction, is matched to a forecast (at the SMW location) temperature profile to assign the cloud pressure. The histogram method is known to give poor results in the case of semi-transparent cloud, and recently the CO_2 slicing method has been introduced (Merrill et al., 1990) to the NESDIS processing of upper level SMW. The new procedure is clearly better, but for logistical reasons it cannot be used for water vapor tracers. More importantly, it will not be available with the next generation of GOES, since the requisite measurements are not included with the imaging instrument. Thus alternative procedures need to be developed. A similar slicing method can be used with the 6.7 micrometer band, which will be available with the next GOES. This method, in variant form, is already used by Eumetsat (Schmetz et al., 1987) for processing METEOSAT data. However, the accuracy achievable with the water vapor channel is not as precise as one would like, as discussed in a report prepared by Smith and Fry in a companion contribution to this volume. So, with the intent of improving the assignment of water vapor vectors, and also in preparation for the next series of GOES, a method of height assignment by assimilation is being studied.

Quality control of SMW has been successful at NESDIS, but at the expense of intensive manual editing. This involves the rejection of suspect vectors as well as occasional height reassignment, based on the subjective judgment of the analyst. Clearly the process should be at least partially automated, and it is rational to combine the height assignment by assimilation with such a quality control procedure. To this end an objective analysis procedure has been extended to offer an "expert system" (more properly a "novice system" at this stage of development) for accomplishing these tasks. This system is known as the SMW auto-editor, and it is described and evaluated here.

2. Method

Height reassignment by auto-editor

The basic flow of the auto editor is shown in Fig. 1. The objective analysis system, invoked twice in the system, is a 3 dimensional recursive filter, successive approximation (Hayden and Purser, 1988) which uses 12 vertical levels and a pseudo Mercator latitude-longitude grid. The National Meteorological (NMC) global forecast is used as a background field and also to provide pseudo observations. These "background" reports are initially given up to half the weight (adjusted by a latitude factor as shown in table 1) of the SMW observations, which, for the height reassignment application, are currently all given the same weight. No other data are used, though they obviously could be. Fatal flags given at the wind production stage are honored except that the reproducibility flag is rechecked and may be overruled as a function of the velocity (in the background field, VG) as shown in table 1. (In the wind production, any situation where the vector associated with image 1 to image 2 differs by more than 5 ms^{-1} from the vector of image 2 to image 3 is flagged.) All observations are carried through 5 iterations, though their weights change at each iteration as described in Hayden and Purser (1988).

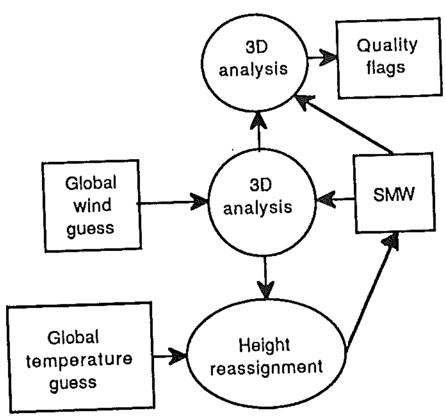


Fig. 1. The auto-editor system

Prior to the height reassignment, an analysis is performed using the available SMW at pressure altitudes assigned by the auto-wind processing. The resultant analysis provides a vertical profile of wind vectors at each observation which is compared to the observation, and a penalty, as a function of pressure, is calculated from:

$$((V(p)-SMW)/VV)^2 + ((T(p)-TC)/VT)^2 + ((P-PW)/VP)^2 \quad (1)$$

where TC and PW are the tracer temperature and pressure initially assigned. The denominators VV, VT, and VP are currently given the weights 2, 10 and 100, meaning that a vector discrepancy of 2 ms^{-1} has the same weight as a temperature discrepancy of 10 degrees or a pressure reassignment of 100 hPa. These choices are arbitrary, and were determined empirically. No claim of optimality is made. Equation (1) is evaluated with a vertical resolution of 25 hPa, and the SMW is reassigned at the pressure which gives the smallest value, if that value is more than 25 hPa different from the original assignment. Only two restrictions apply, the vector cannot be reassigned above the tropopause as determined from T(p), and the minimum value of (1) must be less than 100. In those cases the SMW is flagged.

PW is included in (1) to discriminate between multiple minima associated with the first term only. In effect, the minimum closest to the original height assignment is taken. The use of both TC and PW in (2) may seem somewhat redundant, insofar as the latter is usually derived from the former. However, by including the temperature we become more lenient in height reassignment when the lapse rate is smaller, and the TC-PW relationship is therefore less certain. Also, for CO_2 height assignment the two quantities may be derived independently.

Some experiments were conducted where the first term in (1) was replaced with separate terms for speed and direction. This did not appear to add additional discrimination.

Table 1. Special considerations applied during the auto-editing procedure.

o Flag removed when reproducibility check $< (3.* [v])^{1/2}$

o Background observation weight, latitude variation

LAT	FAC
>30N	1.
30N - 15S	[LAT]/60.+ .5
<15S	0.75

o Height assignment quality (5./BF)1/2 ; BF>5.

o Observation weight, vorticity adjustment
1.E-4 < VOR < 3.E-4 ; FAC= VOR*1.E4

o High velocity adjustment
[V] > [VG] ; [V] > 25 MS^{-1} ; P < 400 ; "IR"
QCMAX = QCMAX - .25

Quality control assignment

Following height reassignment, original weights are restored to the data (with one exception as explained below) and the objective analysis is repeated. One need not do this. New weights could be assigned based on the penalty function magnitude, or the observation weight at the end of the first analysis, or a combination of these. Experiments with such options have not proven fruitful. The magnitude of the penalty function is retained, however, normalized as shown in table 1, as an independent quality indicator. The exception noted above is a modification of the original weight, as shown in table 1, if the relative vorticity (in the background field) is sufficiently strong. It may be increased by as much as a factor of 3. This modification is intended to give greater credibility to observations in areas of high curvature or high horizontal shear.

The weight of each observation after the fifth iteration is used for wind editing. With one exception, any wind with a weight of less than .75 is flagged. The exception is for winds which are fast, high level, faster than the guess, and derived from the infrared window. As shown in table 1, for these SMW the rejection criterion is lowered to 0.50. The weight associated with unedited vectors is passed on as a quality indicator, but neither it nor the quality associated with the penalty function discussed earlier have proven to be very informative in terms of the absolute accuracy of the SMW.

3. Application

Height Reassignment

Fig. 2 represents an investigation of the height reassignment aspect of the editor applied to a single case study of April 24, 1990. The height assignment methods considered are: the histogram method (PWHI); the CO_2 method (PW58); and the auto-editor (APW). The methods are contrasted against each other.

The upper left panel contrasts the CO_2 with the auto-editor assignment for the full sample. Be aware that this panel includes points where the CO_2 assignment was not the final selection in the wind processing, and the auto-editor would begin from a different assignment. For example, the points where the PW58 are at 150 hPa are cases where that method has failed. The scatter at high pressures is caused by a constraint in the wind production algorithm which places the SMW at 900 hPa if histogram and CO_2 assignments (the latter including an infrared window estimate) are all greater than 600 hPa. This 900 hPa assignment has biased the APW assignment. But even including these aberrations, the mean difference is only 14 hPa, and major discrepancies are rare.

The lower left panel contrasts the CO_2 with auto-editor assignments which were forced to begin from PW58 assignments (APWC). Note that the scatter at high pressures seen in the upper left panel has vanished. This would appear to cast doubt on the wisdom of the 900 hPa rule. The sample has also been diminished by 37 members where the penalty function has rejected the vector assigned to the PW58 level. It is apparent that the CO_2 slicing and the auto-editor assignment are quite compatible, and no bias exists.

It is well known that the histogram method frequently assigns a pressure which is too high because of the semi-transparency of many clouds. This is confirmed by the upper right panel which compares histogram assignments (PWHI) with auto-editor assignments begun from the histogram height (APWH). That the bias is for the most part removed by the auto editor is shown by the lower right panel which compares APWC and

APWH. Some of the bias is retained, but this is consistent with the philosophy that the auto-editor height assignment should give some weight to the original.

The lower right panel shows considerable scatter at high pressures, which indicates that the auto-editor assignment is correlated with the initial assignment. This implies small wind shear at low levels so that the second and third terms of (1) predominate. This result suggests that the denominator weighting of (1) should be pressure dependent.

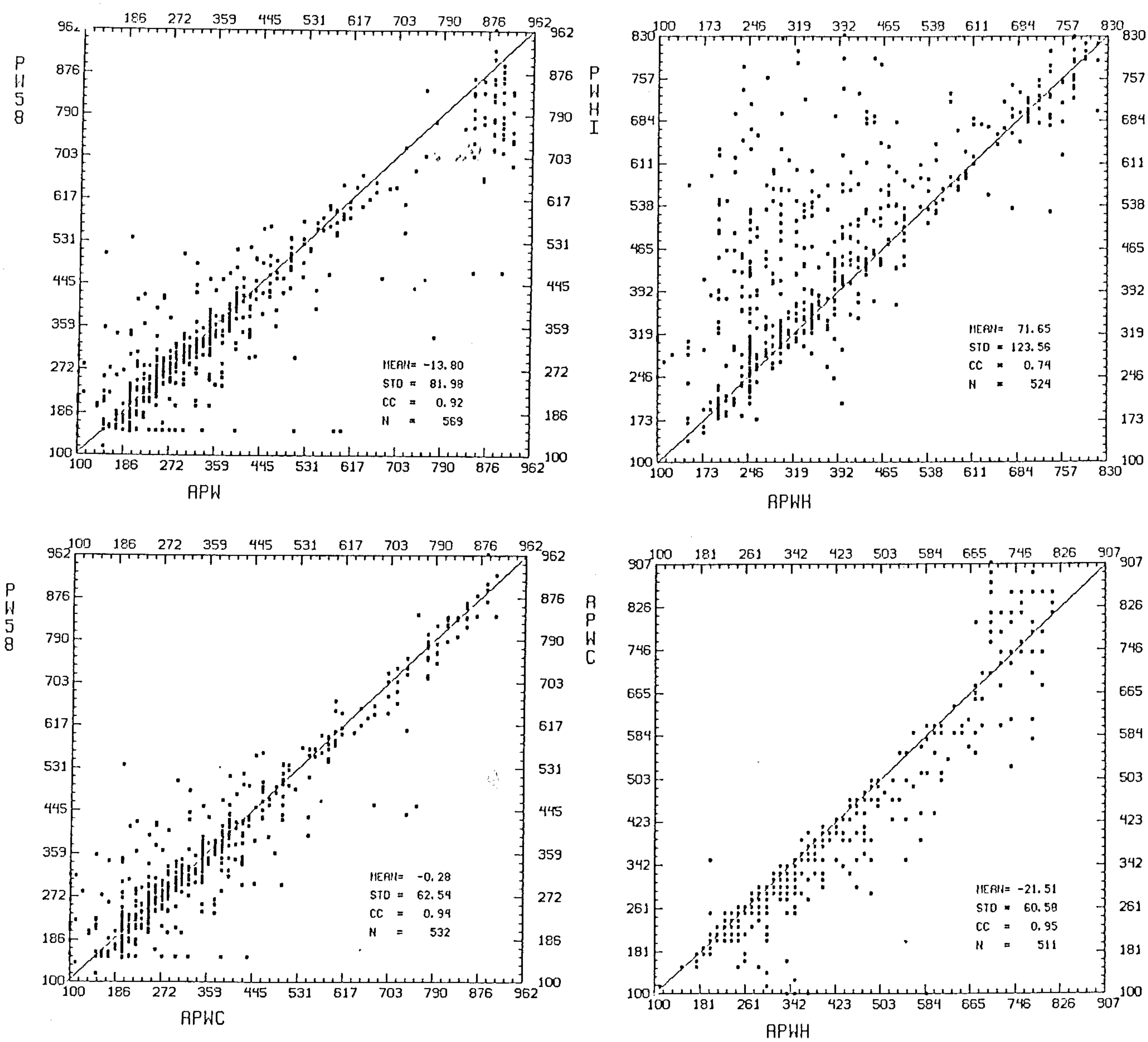
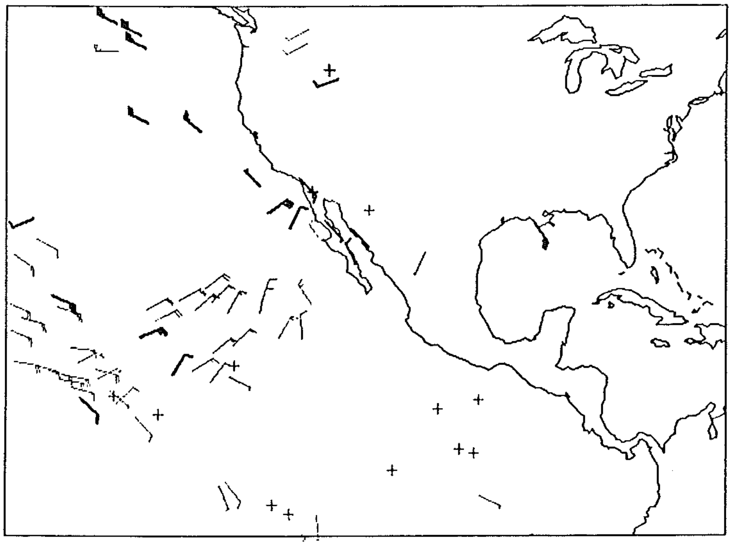


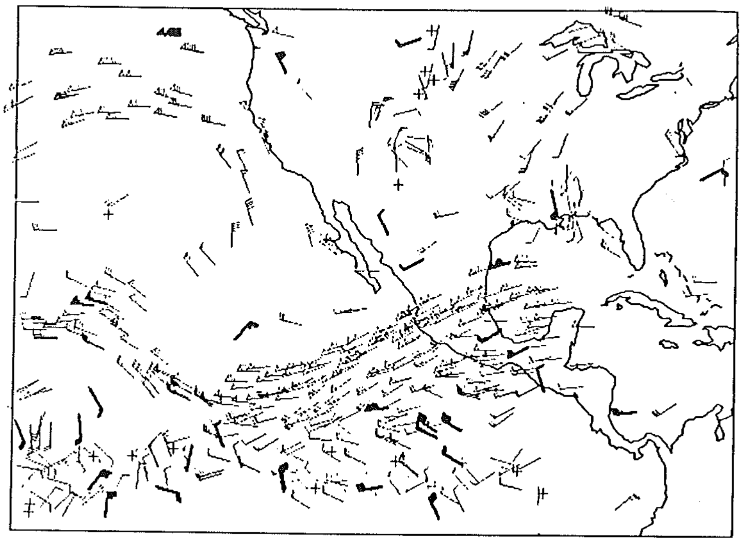
Fig. 2. Scatter diagrams of pressure altitude assignment. Upper left; CO_2 heights (PW58) vs. auto-editor heights (APW); upper right; IR histogram heights (PWHI) vs. auto-editor heights (APWH) which used the PWHI as a first estimate. lower left; PW58 vs. auto-editor heights (APWC) which used PW58 as a first estimate; lower right: APWC vs. APWI.

As a general comment, Fig. 2 suggests that the height reassignment aspect of the auto-editor performs quite well. Changes to the original assignments are generally modest, but larger for the less reliable method.

Rejections

Fig. 3 shows the SMW coverage for the traditional high, middle, and low level designations, and indicates by boldface the vectors which were flagged by the auto-editor. (Those failing the redundancy check are not shown.) The percentage of rejections is quite small at high levels, somewhat greater at middle and low levels. What may be somewhat surprising is that those which are flagged are often not obviously rogues. This is probably the result of the arbitrary 0.75 gate for acceptance/rejection. More disturbing is some apparent coherence in those rejected. Note in particular the low level vectors off the west coast or the midlevel vectors near the Great Lakes. One must suspect some residual height misassignment. However, if the height is not being properly assigned, the SMW should be rejected.





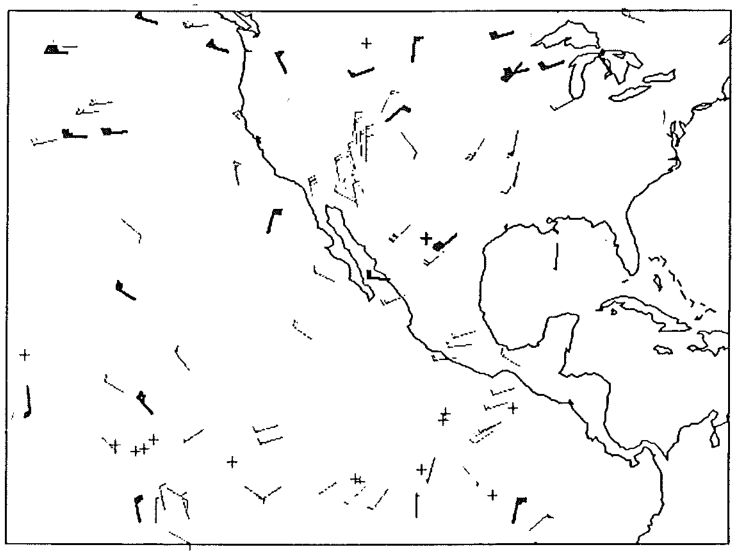


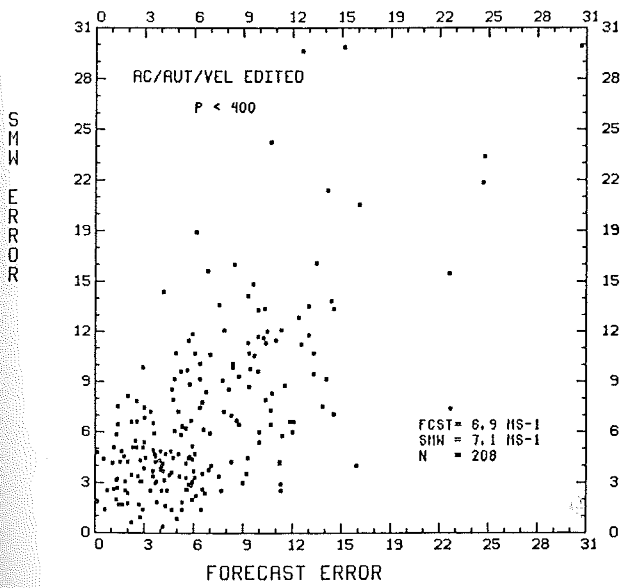
Fig. 3. SMW coverage for April 24, 1990, 1200 UT. The three panels represent low, middle, and high level vectors. Vectors flagged by the auto-editor are shown as boldface.

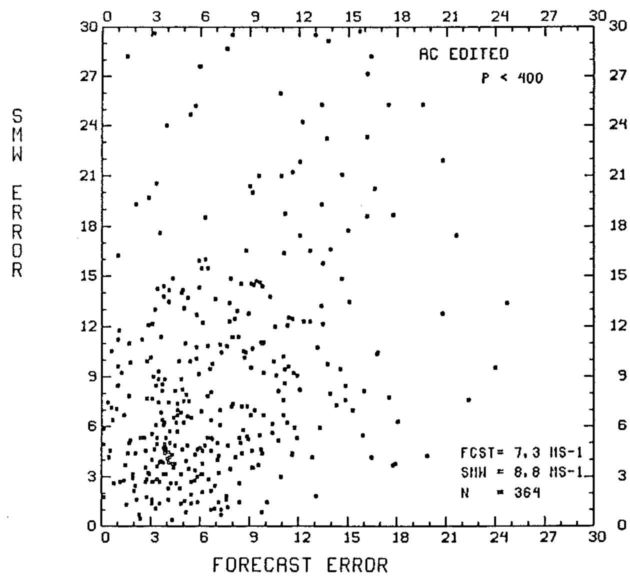
Accuracy

The accuracy of SMW exposed to the auto-editor has been evaluated in the traditional manner, by comparison with collocated rawinsondes. For the results presented here, four time periods from the case study of April 24-25, 1991 are included. In these collocations, a 200 km window is used. There is virtually no time discrepancy. Statistics are given in Table 2. Comparisons between the NMC forecast and the rawinsonde are also presented.

Table 2. Mean vector error between collocated rawinsonde and SMW (NMC forecast) for April 24-25, 1990. Values are given for unedited set, auto-edited set, and manually edited (after auto-edit) set. Units are ms^{-1}.

	Unedited		Auto		Edited Manual	
Level	Error	Sample	Error	Sample	Error	Sample
Low	6.1 (3.7)	51	4.8 (4.0)	59	4.0 (3.3)	40
Mid	8.3 (4.9)	167	5.2 (4.6)	129	4.2 (4.0)	82
High	8.8 (7.3)	364	7.2 (7.1)	341	7.1 (6.9)	208





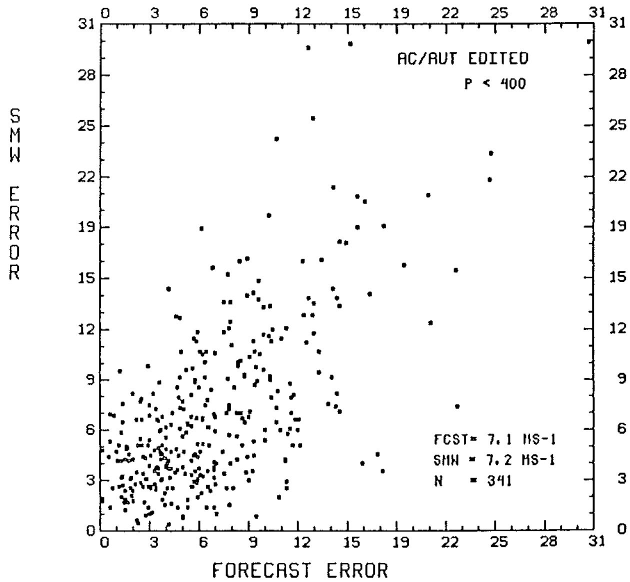


Fig. 4. Scatter diagram of SMW error vs. NMC forecast error for high level vectors derived April 24-25, 1990. Upper left: unedited; upper right: auto-edited; lower right; auto- and manual edited. Units are ms^{-1}.

The result in Table 2 for high level SMW is also shown as a scatter diagram in Fig. 4. Several conclusions can be drawn.

The auto-editing is successful in all cases in reducing the error of the SMW as compared to rawinsondes. The final result does not, however, "beat" the forecast. We have found this to be a general result. Edited SMW have an accuracy, as compared to rawinsondes, approximately equivalent to the guess.

Manual editing after the auto-editing has only a small effect. Some improvement is noted at midlevels.. Interestingly the converse is not true. During the fall, 1991 we have run the auto-editor on data sets which have been manually edited and consistently the accuracy is markedly improved.

Fig. 4 shows that the error of the SMW is correlated with the error of the forecast. This result is unavoidable as long as the forecast plays any role in the editing scheme. We have been careful to keep the dependence on the forecast fairly loose (which has hurt the accuracy statistics at mid levels). The dependence could be further decreased by the inclusion of more data, either additional SMW or other observations.

Fig. 4 presents some very large errors. The worst of these is caused by a bad radiosonde report (included to show that such things do happen), but the others are just poor SMW which were not identified by the auto editor (or in most cases by the manual editor).

The statistics presented in Table 1 have not made use of the penalty function flag. If this is done, with a cutoff of 0.75 similar to the weight flag, the statistics are improved but at the cost of increased correlation with the guess. The improvement is not felt to outweight the cost, so currently the auto-editor does not use the penalty function flag.

A recurring deficiency in the SMW provided by NESDIS is the "slow bias". At high windspeeds the SMW are consistantly an underestimate. Somewhat surprisingly, the problem is not cured by the auto-editor, despite the fact that the forecast does not show a bias. This result is probably caused by the use of the SMW in the analysis preceding the height reassignment. It is a problem requiring further attention.

4. Summary

The principal impact of the auto-editor is in the reassignment of SMW pressure altitude. The number of vectors rejected at the quality control stage is relatively modest, and most of those seem to represent a poor altitude assignment. This is an expected result. There is no question that animated imagery reveals motion in the atmosphere, but it is difficult to determine what that motion represents. By reassigning an altitude based on assimilation with other data we are avoiding that problem. It doesn't matter if the motion represents a tracer or some deep layer. We are assigning each vector to a level where it is representative. If it is nowhere representative, it is rejected.

Nothing is free. By using assimilation we are giving up independence. Some of the SMW we reassign we should not. Some which we reject, based on consistency, we should keep. In the mean the auto-editor works. It does as