RECENT RESEARCH IN THE AUTOMATED QUALITY CONTROL OF CLOUD MOTION VECTORS AT CIMSS/NESDIS

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ABSTRACT

Wind estimates derived via remote sensing of satellites are not direct measurements, and therefore require rigorous quality control. Historically this has been provided by human intervention, but with increasing sources and numbers of wind estimates, objective methods for quality control are both attractive and necessary. This presentation addresses the current methods applied operationally at the NESDIS and modifications developed at the Cooperative Institute for Meteorological Satellite Studies. These objective techniques provide for adjusting of the pressure altitude assigned to the vector and also yield a quality estimate of the accuracy. Recent results suggest increased accuracy and discrimination with the revised system which will be operational by the beginning of the year. Examples of these improvements are shown.

1. INTRODUCTION

Cloud motion vectors (CMV) from GOES infrared imagery are now routinely derived, 4 times daily over the full earth disc, 60N - 60S, 45-165W. Since February 1992, target selection, pressure height assignment, and tracking have been accomplished objectively (Merrill et al., 1991) and typically nearly 1000 vectors are generated at each time period. Anticipating that this volume would overwhelm the manpower available for traditional manual editing, an objective editor was developed at CIMSS (Hayden and Velden, 1991, Hayden, 1991) and introduced together with the objective generation system. Included was not only the facility of rejecting or flagging the CMV, but also the feature of reassigning the initial pressure altitude estimate, based on the amalgamation of the CMV with an NMC 6 or 12 hour forecast from the Aviation Model. The performance of the objective editor has been generally satisfactory. The rms vector error, as derived from collocated raw insondes, is reduced approximately 3 ms^{-1} in the editing process to a value in the neighbourhood of 7-8 ms^{-1}. This number is competitive with the accuracy estimated for the numerical forecast of the NMC. It is also competitive with the accuracy indicated for the METEOSAT and Himaware. It is not, however, as good as it needs to be to significantly improve weather forecasts.

In the revision of the editing procedures, six goals have been set. These are:

- Reduce the CMV vector rms error.
- Reduce the CMV speed bias error.
- Improve the quality flag associated with each CMV.
- Improve the pressure altitude assignment.
- Adapt to manual editing proclivities.
- Reduce the correlation of CMV error with forecast error.

The success in achieving these goals will be discussed below, following a description of changes made to the editing system.

2. REVISED AUTO-EDITOR

The basic tool of the objective editor remains the 3-dimensional recursive filter objective analysis developed at CIMSS. In the past year this system has undergone an extensive upgrade with attention to improving the quality control, especially the quality indicator which is appended to each datum following the analysis (Hayden and Purser, 1993). The basic flow of the editing procedure, as shown in Fig. 1, is unchanged except for the addition of the bias adjustment. This flow consists of:

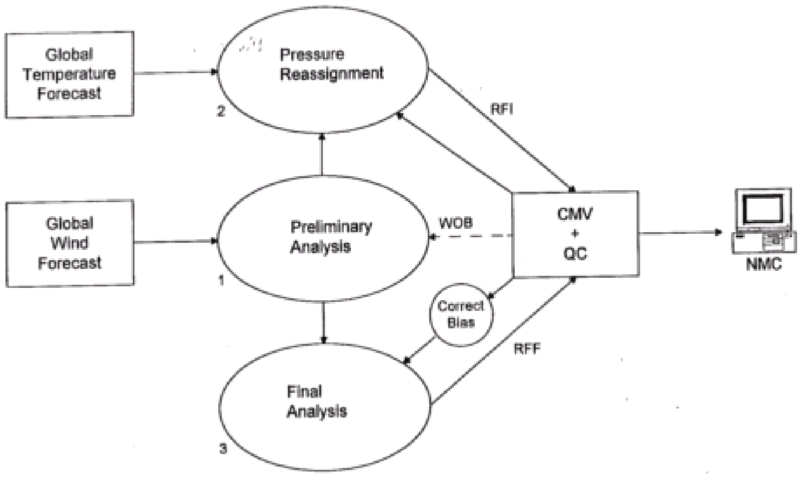

Fig. 1. The objective editing system.

Preliminary Analysis

A preliminary analysis is made using all the CMV which have passed the quality control measures of the CMV generation. The NMC Aviation forecast provides the background, and also pseudo observations over the full domain, 60S-60N; 45-165W. The grid increment is 2 deg. latitude/longitude. The pseudo observations are given half the weight of the CMV and further modified by latitude as described in Hayden (1991b). The result is 12 analyses of the u and v components distributed vertically from 925 to 150 hPa.

Height Reassignment

A pressure reassignment of each CMV is considered using the result of the preliminary analysis. This consists of minimizing a penalty function B which is calculated from values interpolated in the preliminary analysis to a vertical resolution of 25 hPa. The function is given below, where subscript m refers to the CMV measurement and subscripts i,j,k are the 3 dimensions of the analysis. Temperature is obtained by interpolation in the NMC temperature forecast (the same one used in the CMV processing to obtain pressure altitude).

$$B_{m,k} = \left(\frac{P_m - P_{i,j,k}}{F_p}\right)^2 + \left(\frac{T_m - T_{i,j,k}}{F_t}\right)^2 + \left(\frac{V_m - V_{i,j,k}}{F_v}\right)^2 + \left(\frac{dd_m - dd_{i,j,k}}{F_{dd}}\right)^2 + \left(\frac{s_m - s_{i,j,k}}{F_s}\right)^2 \quad (1)$$

P = *pressure*, T = *temperature*, V = *velocity*, dd = *direction*, s = *speed*
F = 100 10 2 1000 1000

A question sometimes asked concerns the redundancy of including both pressure and temperature in the penalty function. There is, of course, some redundancy, but temperature is included to reflect that the radiative pressure altitude assignment is likely to be highly reliable in an atmosphere with large lapse rate (and vice versa). This attribute cannot be captured by considering only pressure. On the other hand, to not include pressure could result in some absurd reassignments.

The normalizing functions given above are unchanged from those currently applied. Many experiments have shown that these choices are quasi optimal. Some success has been achieved by including *dd* (i.e. reducing F_{dd}) while increasing F_v but the improvement has not been consistent.

One of the concerns of those monitoring the CMV has been the absence of a hard constraint on the magnitude of the pressure reassignment $\boldsymbol{P_m - P_{i,j,k}}$. In response to this, the revised procedure has introduced hard constraints on all of the numerators in (1).

$$\begin{aligned}
&(V_m - V_{i,j,k}) < M_v F_v S && ; \quad M_v = 7. \\
&(T_m - T_{i,j,k}) < M_t F_t && ; \quad M_t = 2. \\
&(P_m - P_{i,j,k}) < M_p F_p && ; \quad M_p = 1.5 \\
&(dd_m - dd_{i,j,k}) < M_{dd} F_{dd} / S && ; \quad M_{dd} = 2. \\
&(s_m - s_{i,j,k}) < M_s F_s S && ; \quad M_s = 7. \\
&S = s/30 && ; \quad 0.5 < S < 2.
\end{aligned} \quad (2)$$

Thus the constraint on pressure reassignment is 150 hPa. (In practice with the current editing procedure this was very rarely exceeded). Note that the constraints dealing with speed and direction are speed-dependent. Looser speed (vector) constraints apply to faster winds. Looser direction constraints apply to slower winds. Finally, a constraint is applied to the magnitude of the penalty function.

$$B_{\max} = 0.75 S (M_v)^2 \quad (3)$$

A CMV is rejected if the minimum B exceeds this value and the minimum occurs at the maximum pressure displacement. Otherwise, a quality estimate of the reassignment is returned:

$$RFI = (1. - (B / B_{\max}))^{1/2} \geq 0.1 \quad (4)$$

This indicator is currently not used, though the option exists for applying it as a weight in the final analysis.

Bias Adjustment

The revised editor contains an adjustment for the well-documented slow bias error of CMV. The quarterly statistical summaries of the ECMWF routinely show this feature, with respect to both wind measurements and coincident speeds of the ECMWF forecast. For the GOES, the bias can reach -5 ms-1 at higher wind speeds. The bias signal is also present in comparisons with the NMC aviation forecasts which are used in the derivation and quality control of the GOES CMV. Taking advantage of this, the revised editing procedure now increments each CMV with 5 percent of the speed of the forecast, interpolated to the reassigned level, provided the forecast wind speed is greater than 10 ms^{-1}. There has been some mild protest from users regarding this manipulation, but it is philosophically no different from the bias corrections routinely applied to satellite temperature retrievals, or even the radiation corrections applied to radiosondes. If it helps, it seems reasonable to invoke it, and the correction is reversible if desired. The magnitude of the correction was estimated from verifications taken during the summer of 1993, and there has been no attempt to optimize it.

Final Analysis

A final analysis is performed with the reassigned CMV. This provides a data quality estimate for each vector. The flag is a combination of the quality of the analysis QW_m in the environment of each CMV and the fit of the datum to the analysis T_m (Explanations of these quantities , both of which vary between 0 and 1, can be found in Hayden and Purser (1993)). Thus:

$$XFF = (QWJ_m r \quad (5)$$

If the value of *RFF* is less than a defined minimum, the CMV is not passed to the user. The minimum is nominally 0.5, but reduced to 0.45 if the CMV velocity is greater than that of the forecast, greater than 25 ms^{-1}, and the location is above 400 hPa (a modification of the current "high velocity adjustment" reported in Hayden (1991).

3. RESULTS

The success of the revisions to the objective editing process will be considered from the aspect of the 6 goals presented in the Introduction.

Vector Error Reduction

Table 1 contains statistical comparisons of the current and revised objective editor where the same CMV have been processed for a period of 10 days in November and December 1993. The column labeled "Pass" represents statistics for the sample which survived the objective editing. It is seen that with the revised system, the error has been slightly reduced, from 6.8 to 6.6 ms"*. This is a small improvement but enough to bring the statistic below the error of the NMC forecast. A similar result was previously reported with a summer sample (Hayden et al., 1993)

Table 1. Comparisons of CMV with collocated rawinsondes. Statistics are presented for the current and revised objective editor. FRMS are comparisons with NMC forecast, VRMS are comparisons with CMV. Units are ms^{-1}. Samples include vectors with quality flag (RFF) greater than number indicated. Units are xlOO. "Pass" indicates passed by objective editor.

RFF	Pass	30	40	50	60	70	80	90
CURRENT OPERATIONS								
FRMS	6.8	6.9	6.9	6.8	6.8	6.7	6.7	6.6
VRMS	6.9	7.4	7.3	7.0	7.0	6.9	6.8	6.5
SPD	23	22	22	22	22	22	23	23
BIAS	-1.8	-1.9	-1.8	-1.8	-1.8	-1.8	-1.8	-1.7
SAMPLE	351	420	,,414	396	386	353	315	235
REVISED EDITOR WITH BIAS CORRECTION								
FRMS	6.8	6.8	6.7	6.4	6.2	5.8		
VRMS	6.6	6.8	6.5	6.1	5.8	5.4		
SPD	23	23	22	22	21	19		
BIAS	-0.7	-0.6	-0.8	-0.9	-1.0	-0.7		
SAMPLE	302	320	311	288	211	81		

Bias Reduction

The bias correction has been successful in reducing the full sample bias by about 50 percent, from -1.8 to -0.7 ms^{-1}. Although the table gives results for vectors at all levels, the same trend is seen for the high level (< 400 hPa), where the bias is reduced from -1.9 to -0.7 ms^{-1} for samples of 236 and 200. Again, a similar result was reported for a summer sample (loc. cit.).

Improved Quality Flag

Table 1 indicates that there has been a considerable betterment in the discriminating capability of the CMV quality flag, *RFF*. Within the "pass" sample *(RFF>70)* VRMS in the current system shows only a modest improvement from 6.9 to 6.5 ms^{-1}. In the revised system *(RFF* >.40) VRMS improves from 6.5 to 5.4 ms^{-1}, and the improvement over the FRMS is better defined. There is some decrease in the mean speed as the quality improves which is a little puzzling and needs more study. In general, however, the quality flag should now be useful to the user.

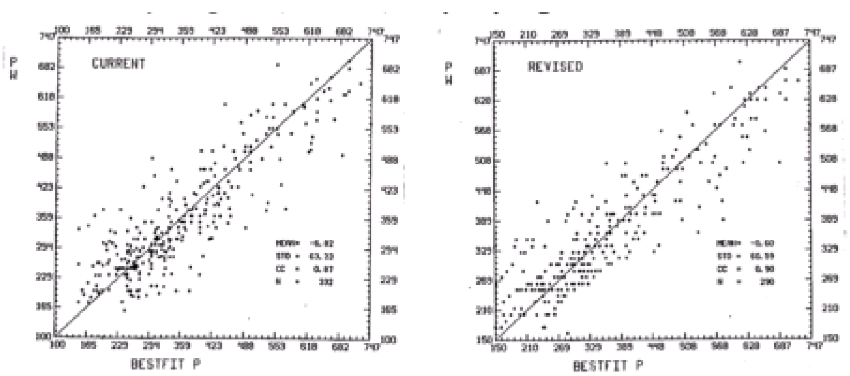

Fig. 2. Scatter plots of reassigned pressure altitude vs. level-of-best fit to rawinsonde. Current and revised editor results are shown Units are hPa.

Improvement in Altitude Assignment

The method of determining the quality of the pressure (re)assignment is to compare the pressure assignment with the level of best fit indicated by the collocated rawinsonde. That is the pressure level where the CMV best agrees with the wind indicated in the interpolated rawinsonde profile. The better the agreement between assigned and best fit pressure, the better the assignment technique. Scatter plots and statistics shown in Fig. 2 indicate a small improvement with the revised editor, and other samples corroborate this trend. The standard deviation should be considered in the light of professed accuracy for the CO_2 height assignment (about 50 hPa, Nieman et al., 1992). The value of 60 hPa seems a bit high, but error in the determination of the LBF should be taken into consideration.

Emulation of Manual Editing

During the 20 months that the objective editing has been in place, manual editing has continued as part of the NESDIS operation. It is now apparent that the time for phasing out the manual step is at hand, both because of manpower limitations (especially with anticipated increases in the number of CMV; higher frequency, water vapour-derived vectors) and because we have some confidence in the objective procedure. Also, it has been difficult to demonstrate, statistically, that the product is improved by this final step, although clearly the occasional poor vector is detected, and many of the manual deletions are made in tropical, convective regions which are not represented in collocation statistics. The revised editor appears to more closely resemble the manually edited product as can be seen in Fig. 3. Much of the convective chaos over South America has been eliminated, and the tropics generally are less confused. Sample sizes are smaller with the revised editor, as they must be if they are to replace the manual editing which routinely removes 20 percent of the vectors passed by the current objective editor.

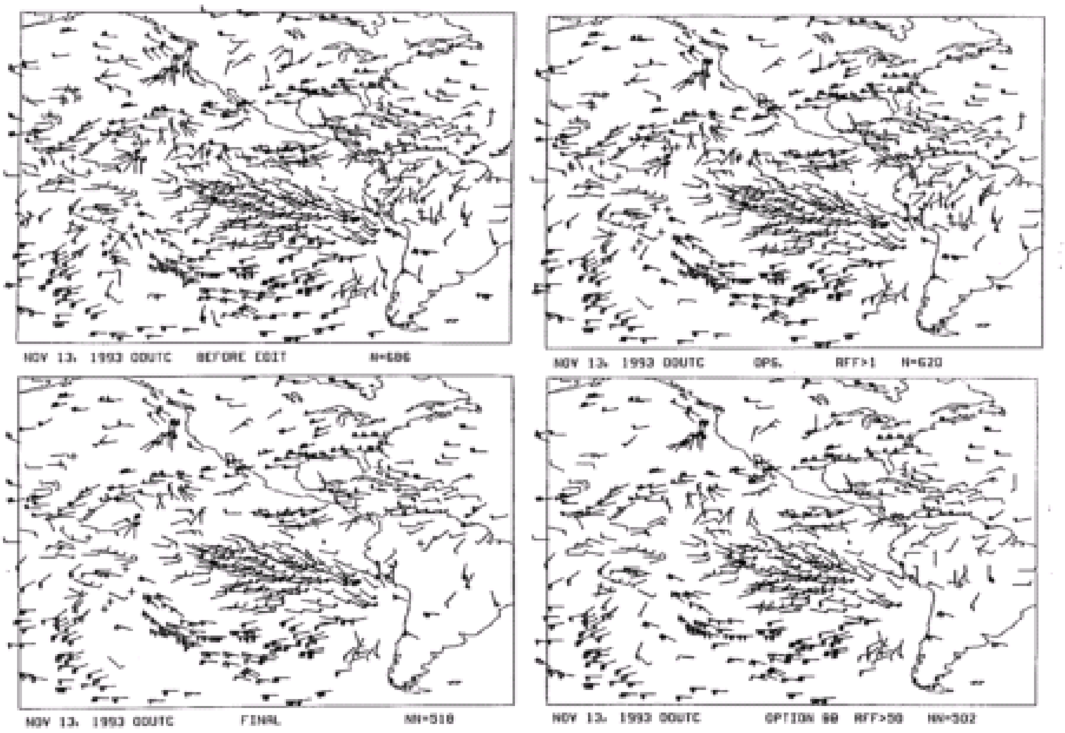

Fig 3: An example of unedited CMV (upper left); CMV passed by the current objective editor (upper right); CMV after objective and manual editing (lower left); and CMV after objective editing with the revised system.

There are (at least) two areas where monitors continue to be concerned. One is that at high latitudes, the pressure reassignment sometimes results in placement above the tropopause. The revised editor has tightened the tropopause check, which is a lapse rate (above 300 hPa) of less that .5 C/25 hPa, but this has not cured the problem. Apparently, the NMC temperature forecast is fallible, and a better tropopause definition is needed. A second concern is a perceived proclivity of the objective reassignment to erroneously reduce the altitude of cirrus tracers in the tropics. If this is actually occurring, it is not obvious from statistical evaluation as shown in Table 2. The table is for vectors above 700 liPa only, and shows no bias in the reassignment. Also, the standard deviation of the reassignment is in line with the extra tropics. What seems more surprising from Table 2 is that the average assignment of the Southern Hemisphere's mid latitudes is so low, 100 hPa lower than the Northern Hemisphere's.

Table 2. Statistical analysis of altitude reassignment in the revised objective editing. Only CMV above 700 hPa are included. Pressure units are hPa.

latitude	mean dP	sigma dP	meanP	sample
60-3 ON	28	107	352	139
30-10N	-11	59	315	211
10N-10S	-6	53	318	230
10-30S	2	57	320	245
30-60S	-16	74	446	175

Reduced Correlation

Although it is desirable for the errors of data to be uncorrelated with errors of forecast, correlation is inevitable in the system described here. In general, the system seeks to blend the forecast with the data, and the pressure reassignment necessarily increases the correspondence of the two. Highest quality indicators will be given where the data and forecast agree best, and if both disagree with the rawinsonde, the error correlation is necessarily high. It is tempting to ascribe a measure of the error correlation to error in the rawinsonde, but subjective evaluation suggests that only a small part can be accounted in this way. It is also tempting to believe that large errors and therefore large error correlation are most probable where there is strong vertical shear measured by the rawinsonde. However, in the collocated samples, very weak correlation exists between CMV error and vertical shear as measured by the rawinsonde. Thus we are left with the fact that high correlation (about 0.7) is an unavoidable feature of the objective editing system. Clearly it would be improved by including other data (even a different forecast) in the system, but that is not current practice.

4. SUMMARY

This paper has defined and presented results of a revised objective editing procedure to be applied to the CMV generated from GOES-7. Most of the goals sought for in the revision have been achieved. Most significantly, the slow-bias appears to be alleviated and the quality flag associated with each CMV can now discriminate the more accurate vectors. The system shows sufficient skill to persuade NESDIS operations to give up the practice of manual editing of the CMV.

More work needs to be done. Using other data in the objective assimilation is an attractive approach (although it is preferable that data user accomplish this by doing his own altitude reassignment within his assimilation system.) The puzzling lower altitude of the southern hemisphere vectors needs study; a better tropopause definition should be adopted. The insistence of the monitors to place all low level vectors (determined to be >650 hPa) over the oceans at 900 hPa seems arbitrary.

This can be investigated with the objective editing system. Finally, CMV which are accurate, but which are rejected because of a large discrepancy with the forecast need to be studied. The best hope for overcoming this last, serious deficiency is to provide a greater density of CMV (for better neighbor acceptance) and to find something in the CMV production itself which can be used as a quality indicator in the objective editing. To date we have found nothing.

5. REFERENCES

Hayden, CM., and R. J. Purser, 1993: Recursive Filter Objective Analysis of Meteorological Fields; Applications to NESDIS Operational Processing. Submitted to *J. Appl. Meteor.*

Hayden, C. M. and C. S. Velden, 1991: Quality control and assimilation experiments with satellite derived wind estimates. *Preprint Volume of 9th Conference on Numerical Weather Prediction* Oct. 14-18, Denver, CO, Amer. Meteor. Soc., 19-23.

Hayden, CM., 1991: Research leading to future operational methods for wind extraction. Workshop on wind extraction from operational meteorological satellite data, 17-19 September 1991. EUMP 10, ISBN 92-9110-007-2, 161-169.

Hayden, C. M.,, S. J. Nieman, and T. J. Schmit, 1993: Ongoing development of satellite-derived winds at NESDIS/CIMSS. To be included in Proceedings of ECMWF/EUMETSAT Seminar on Developments in the Use of Satellite Data in Numerical Weather Prediction. 6-10 September, 1993.

Merrill, R. T., W P. Menzel, W. Baker, J. Lynch, and E. Legg, 1991, A report on the recent demonstration of NOAA's upgraded capability to derive cloud motion satellite winds. *Bull. Amer. Meteor. Soc.*, 72,372-376.

Nieman, S, J. Schmetz and P. Menzel, 1992: A comparison of several techniques to assign heights to cloud tracers. *J. Appl. Meteor.* , **32,** 1559-1608.