

Further Development of an Algorithm For Simulating Cloud Motion Vectors From Global Circulation Model Data

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1. Introduction

O'Handley et al (2001) described an algorithm for simulating cloud motion winds (CMWs) from numerical model data for use in OSSEs. Previously, the locations of CMWs for such studies were prescribed from the locations of observed CMWs at the model time, with only the velocity of the "simulated" CMWs being based on the model fields. Two main problems are associated with this approach. First, it often results in simulated CMWs in cloud-free areas of the model, though this depends on the accuracy of the simulation. Second, the slow bias inherent in observed CMWs is neglected. The algorithm described here overcomes both these limitations by (1) using the model's actual cloud fields to determine CMW locations, and (2) applying a consistent adjustment to simulate the slow bias.

1. Summary of Previous Results

Here we briefly describe our first attempt at algorithm development and the resulting CMWs; for more details, the reader is referred to O'Handley et al (2001). Data were obtained from a 30-day "nature run" of the ECMWF spectral model, which contains 31 levels and has a horizontal resolution of approximately 0.5° . Data were available every 6 hours from 0600 UTC 2/5/1993 to 0000 UTC 3/6/1993. Simulated CMWs were produced for each of the 5 satellites currently producing CMWs (GOES-W at 135 W,

GOES-E at 75W, METEOSAT-5 at 0, INSAT/METEOSAT-7 at 80 E, and GMS at 140 E). For each satellite, CMWs were produced in an area extending 60° from the subpoint. At each grid point within these regions, a satellite cloud view (SCV) profile was first determined using the maximum/random overlap assumption. The resulting SCV cloud fraction at each altitude represented the amount of cloud that would be visible to a geosynchronous satellite. Then, each profile was searched from the top down, looking for suitable tracers. A suitable tracer was defined as a level where the SCV was between .05 and .25. The first such level identified was designated as the CMW target for that location, and the model u and v wind components were assigned to that CMW.

Subsequently, a slow bias correction was applied as follows. For each simulated CMW, the SCV profile was examined for the presence of “cirrus” cloud above the target. If such cirrus was found, the height of the target cloud was adjusted upward. This approach assumes that the slow bias is caused by the presence of thin cirrus that contaminates the height estimate of the target cloud, making it appear too cold (high). Since winds generally increase upward in the troposphere, this effectively transfers a slower-moving cloud upward into an area where the true wind speed is higher, thus introducing a slow bias. Application of this algorithm did produce a slow bias in the simulated CMWs, with the magnitude of the bias increasing with wind speed. The magnitude of the bias appeared to be too large especially for higher wind speeds, though this could be adjusted by applying limits on the maximum adjustment depth.

Overall, the simulated CMWs exhibited the following problems: (1) there were too many vectors, which had to be thinned randomly to approach the numbers of observed CMWs in 1993, (2) the vertical distribution was faulty, with far too many vectors at low-levels, and (3) the spatial distribution did not capture the concentrated areas of CMWs generally found in observed data. Most of these shortcomings can be traced to the treatment of clouds in our SCV computation. The algorithm was originally developed for a different application, and treated “cirrus” and “opaque” clouds differently. Cirrus clouds were defined as clouds where the temperature was below 0° C and the liquid water content below .005 g/kg; all other clouds were considered to be opaque. Unfortunately, the SCV computation did not handle the “cirrus” clouds correctly, so our initial approach was to ignore them. This resulted in the skewed CMW distribution described earlier. This problem has been corrected in the latest version of the algorithm, resulting in more realistic simulations as described below.

1. Characteristics of Current Operational CMWs

We decided to tailor our algorithm to simulate current levels of CMW production. Therefore, the first requirement was to determine typical numbers and vertical distributions of CMWs being produced operationally. CMWs are produced from infrared (IR), visible and water vapor channel imagery. The technique we have developed is for the simulation of IR and possibly visible CMWs, as these CMWs are based on the observed cloud fields. The simulation of water vapor CMWs is left for future work.

Detailed information about GOES CMWs is available in real-time on the internet, in two forms: (1) as maps with the vectors plotted over satellite imagery, and (2) in ascii files containing the location, height, direction and speed of each vector. This has enabled us to carefully examine both the vertical and horizontal distribution of the GOES winds, and their relationships to cloud patterns. Unfortunately, similar information is not available for the other CMW producers. There are several web sites that provide summary data on a monthly basis (total observations and biases), and we have used these in an attempt to compare the CMW distributions for the other satellites with GOES CMWs. Based on the above, we have decided to tune our algorithm to the current GOES IR CMW distribution, and adjust the algorithm as needed for the other regions to produce the most realistic CMWs possible.

Figure 1a shows an example of GOES-E IR CMWs from 0000 UTC 6 September 2002. Note the abundance of high (red) CMWs, and the lack of midlevel (blue) tracers. The high-level CMWs are organized into distinct clumps associated with large scale cloud systems. Close-up views of these areas (Fig 1b) reveals that the high-level CMWs tend to be concentrated along the edges of the larger areas of cirrus cloud, in areas of obvious cloud inhomogeneity. Mid-level CMWs tend to be located adjacent to areas of higher-level CMWs, on the periphery of the large high-cloud systems. Low-level CMWs tend to occur in clumps primarily over the oceans, as evident in Figure 1a.

The vertical distribution of GOES-E CMWs for a recent date is shown in Figure 2a. A strongly bi-modal pattern is present, with the majority of CMWs concentrated in two layers: 150 to 350 mb, and 750 to 950 mb. This distribution is highlighted in Table I, which lists the total CMW in 3 layers (below 700 mb, 400-700 mb, and above 400 mb) for several recent cases. On average, about 60% of the GOES IR CMWs are at high levels, 10% in mid-levels, and 30% at low levels. In general, there appears to be a higher percentage of low-level vectors in the GOES-W data, most likely because of the

large oceanic regions covered. However, for some reason the GOES-W data files on the internet are incomplete, containing no southern hemisphere data. Based on these results, we have attempted to tailor our algorithm to produce, on average, the following vertical distribution of IR CMW for the GOES regions: 55-60% high, ~10% middle, and 30-35% low.

Table I further reveals that the average number of CMW for GOES-E is about 7500-8000. However, tabulations from the UKMet Office (available on-line) indicate that GOES-E IR wind totals might occasionally range as high as 12000-14000. Therefore, we have adjusted our algorithm to produce an average of about 10,000 IR CMWs for the GOES regions. End-users can simply randomly thin these winds to the desired density.

The monthly summary statistics for the other regions have been used to gain an idea of the relative number of CMWs in these regions. These statistics suggest that the two Meteosats produce about 2000-4000 CMWs each, approximately evenly distributed between high and low levels, while the Japanese GMS produces about 500. INSAT appears to produce few useable CMWs at this time. However, one of the Meteosats is currently situated over the Indian Ocean, so our simulations are based on the presence of two Meteosats.

1. CMW Simulation: Algorithm and Results

a. CMW target identification for GOES regions

Figure 3 shows the vertical distribution of simulated CMWs from our original algorithm (O’Handley et al, 2001), and serves as a basis for comparison with the modified algorithm described below. Note the lack of upper-level CMWs and excessive number of CMWs at mid and lower levels. The horizontal distribution (not shown) revealed the lack of any organized patterns similar to those seen in real CMWs (ref Fig 1). This computation was performed on a 1.5° grid, with CMW targets represented by a SCV cloud fraction range of .05 to .25, and no “cirrus” clouds.

The first step toward algorithm improvement was removing the distinction between cirrus and opaque clouds in the SCV computation. The ECMWF model makes no distinction between the cloud types, providing a single parameter (cloud fraction) at

each grid point to represent “clouds”. Examination of the model cloud fields revealed that higher level “cirrus” clouds tended to be organized into extensive sheets very similar in appearance to those in satellite imagery (this can be seen in Figure 8 below). Therefore, we are assuming that the model “knows” how to simulate the different cloud types. We ran the algorithm described above with the cirrus/opaque distinction removed, but obtained only minimal improvement. There was a slight increase in the number of upper-level CMWs, but the horizontal distribution was not improved (not shown). At this point, we tested many different cloud fraction ranges for tracer identification, but none proved completely satisfactory. The best was .3 to .6, but even this produced too many mid-level CMWs and the horizontal distribution remained unorganized (not shown). Another problem was noted in the higher level CMWs, which tended to organize in narrow bands that outlined the more extensive regions of high cloud. More detailed examination of the model cloud fields revealed that the cloud fraction in the interior of these regions often reached or exceeded .8, implying that we should use a higher cloud fraction. While this did improve the higher level CMWs, it worsened the lower level CMWs.

Since adjustments to the cloud fraction range tended to produce improvements in one of the layers at the expense of the others, we decided to apply three separate cloud fraction ranges to identify tracers at the low, middle and high levels. This approach is consistent with the appearance of cloud systems on satellite imagery: upper-level cirrus clouds tend to consist of extensive stratiform sheets with large areas of relatively high cloud fraction. In contrast, the lower clouds tend to be scattered cumuliform clouds, with somewhat lower cloud fractions. Thus, to obtain organized areas of cloud at the different levels, we should require targets to have a higher cloud fraction at the higher levels, and lower fractions near the surface.

After extensive testing, it was found that the following cloud fractions produced reasonable cloud distributions: high (above 400 mb), .4-.8; mid (400-700 mb), .4-.8, low (below 700 mb), .2-.25. However, the resulting middle and especially higher level CMWs tended to form extensive solid areas of vectors with densities that exceeded those of observed CMWs. Thus, a random thinner was applied at these levels, with 40% of the original vectors being removed. This resulted in the best distribution of any of the tested methods. Table II shows the vertical distribution of the simulated CMWs for GOES-E and GOES-W, for three different days of the nature run. The vertical distribution averages out to 55% high, 10% mid, and 35% low-level vectors, with GOES-E producing slightly more high-level vectors and slightly fewer low-level vectors than

GOES-W. These numbers appear quite stable over time. Overall totals are about 10-15% higher than the observed total listed in Table I, but this could reflect seasonal differences (the simulated data is for the northern hemisphere winter, whereas the observed totals are for the summer). In any event, the end-user can simply thin the simulated CMWs to the desired density.

Figures 4,5 and 6 show the horizontal distribution of simulated CMWs plotted over the mean sea level pressure for the 3 days discussed above. High-level CMWs are red, mid-level blue, and low-level are gold. The high-level CMWs reveal organized patterns in the extratropical regions, generally near cyclones. This is especially evident at 1200 Feb 7 just off the west coast of North America, and at 1200 Mar 4 over eastern North America. In fact, at the latter time an extensive moisture plume is evident from the tropics (near 5N, 115W) northeastward to southeastern Canada. Other extensive areas of high CMWs are seen in the convective regions over South America and in the equatorial South Pacific. The mid-level CMWs tend to lie alongside the higher CMWs, as seen in the observed data. Overall, the mid and high-level simulated CMWs produce patterns that look quite realistic compared to true CMWs.

Unfortunately, the same cannot be said for the low-level CMWs. Figs 4,5 and 6 reveal that the low-level CMWs tend to be scattered throughout the areas that are not occupied by higher CMWs. In contrast, the observed low-level CMWs tend to form distinct clumps separated by extensive areas with no CMWs (Fig 1). We have tried many other cloud fraction ranges for the low clouds, but have not identified anything better than this. We get either widespread, scattered CMWs as shown in the figures, or more concentrated areas that tend to occur at higher latitudes. Also, the total number of low-level CMWs is very sensitive to the fraction range used.

Closer examination of the vertical distribution of the simulated CMWs (Fig 7) reveals a strongly bi-modal pattern very similar to the observed CMWs (Fig 2). However, the simulated low-level CMWs tend to concentrate at 800 mb whereas the observed CMWs are more evenly distributed in the 800-1000 mb layer (Fig 2). This is consistent for both GOES regions and all 3 times. Other studies of the model cloud fields (not shown) reveal that the CMW algorithm is responding to a pronounced cloud maximum at 800 mb. We could probably modify the algorithm to make the distribution of low-level CMWs more realistic compared to real CMWs, but the resulting CMWs might not be so representative of the true model conditions. Finally, the distribution of CMW speeds (Fig 7b) reveals a couple of problems compared to observations, primarily 1) too many

CMWs with speeds less than 5 m/s, and 2) a linear drop-off compared to the more logarithmic drop-off shown in Figure 2. It is not clear if this reflects disagreement between the model and atmosphere, or a shortcoming in our algorithm.

Detailed views of the northern hemisphere GOES-E CMWs for the March case are shown in Figure 8. Note that the plotted cloud fractions are the layer averages directly from the model; they are not the SCV cloud fractions. Thus, for the high CMWs, many of the vectors are in areas where the layer cloud fraction exceeds the 0.8 limit used to identify CMWs from the SCV fraction. Comparison with the observed CMWs in Figure 1 reveals that the simulated CMWs look quite reasonable.

a. **Slow Bias Algorithm**

In the earlier version of our algorithm we simulated the slow bias by assigning a cold bias to CMWs overlain by cirrus clouds, thus making the target cloud appear to be higher in the atmosphere. The assumption was that the presence of thin (perhaps subvisual) cirrus would contaminate the height estimate of the lower cloud. This did produce a slow bias, which exhibited some characteristics similar to the observations. However, it is generally believed that the slow bias is caused by other mechanisms, particularly non-representative cloud motions such as cloud development and dissipation, or layer effects. For example, for a relatively deep cloud, it is reasonable to assume that the entire cloud might tend to move with the mean velocity of the wind within the cloud layer, rather than the wind at cloud top. Since the wind speed increases upward throughout much of the troposphere, such a cloud would move slower than the wind speed at cloud top. And since cloud top is used to assign the CMW height (and thus serves as the basis for comparison to nearby radiosondes or model data), this could introduce an overall slow bias.

We have developed a new algorithm for simulating the slow bias, based on the above mechanism. After identifying a CMW based on the SCV cloud fraction, we determine the depth or thickness of that cloud. If the particular CMW target is limited to a single level, then the velocity assigned is the model velocity at that level. For deeper clouds, the wind velocity at the middle of the cloud layer is assigned to the CMW (whose height is based on the cloud top). Occasionally, deep cloud layers fill most or all of the model atmosphere. In such cases, we have limited the depth of the cloud layer to 300 mb for the purpose of computing the mean velocity.

This algorithm produces a slow bias quite similar to the original algorithm. Table III shows the average speed bias for the three nature run cases examined in this report. As before, we have tabulated the bias calculations against both the CMW speed (the way it is generally reported) and the true or radiosonde-equivalent speed. Both methods are similar for the lower wind speeds, with the bias increasing from 0 to -0.5 m/s for the 0-10 m/s range to about -3.5 m/s for the 20-30 m/s range. For higher speeds, the CMW-tabulation levels out between -3.5 to -4.0 m/s whereas the raob-tabulation steadily increases, reaching over -6 m/s for speeds above 40 m/s. It should be noted, however, that there are very few samples at wind speeds greater than 40 m/s. Overall, the slow bias for all the simulated winds is -1.48 m/s which is reasonably close to observed values.

The magnitude of the simulated slow bias varies with latitude, as does the observed slow bias. Values for the northern and southern hemispheres (poleward of 20°) are between -1.5 and -2.0 m/s, while equatorial values are close to -0.6 m/s (not shown). Again, this is reasonably consistent with observations. We have performed a cursory examination of the spatial patterns of the simulated slow bias. An example for March 4 is shown in Figure 9. Note that the largest slow bias values (reds and oranges) are concentrated within the organized regions of higher cloud in the mid-latitudes (compare with Fig 8), while the majority of the fast bias values (blues, purples) are in the equatorial zone. Several of the CMWs exhibit slow bias values that exceed 15 m/s. We don't know how realistic this is, since we are unaware of any studies that show the distribution of observed biases for individual observations. Another potential problem is that the algorithm produces either no bias or a slow bias for essentially every mid and high-level CMW within the synoptic-scale clusters in the mid-latitudes (such as over eastern North America in Figure 9).

It is difficult to compare these bias values with observations because the observed CMWs have all been quality controlled by the time we receive them. In contrast, at this stage our simulated CMWs probably represent the CMWs before such corrections have been applied. Recent studies of the slow bias of GOES IR CMWs, for example, have shown values that are closer to -1 m/s and that do not vary much with wind speed (ref). During the quality control (QC) process, GOES CMWs are adjusted so that they show better agreement with analyzed wind fields, and similar adjustments are applied at the other wind production centers. On the other hand, studies have shown that the bias values for non QC'd CMWs can be as large as -6 m/s at higher wind speeds.

a. Other Satellites

As noted earlier, we do not have detailed information on the total number and distribution of CMWs from non-GOES satellites. Therefore, we have attempted to produce CMWs for these areas using the rough numbers available from several sources, i.e. 2000-4000 CMWs for the Meteosat regions and 500 for the Japanese GMS satellite. The vertical distribution for Meteosat has been assumed to be similar to that obtained from the GOES regions, but it appears that the Japanese satellite produces about twice as many low as high-level CMWs. For the non-GOES regions we ran our algorithm on a 1° grid. For the March 4 case, this yielded 2808 CMWs for the Meteosat-5 region and 2291 CMWs for Meteosat-7 (over the Indian Ocean). These numbers appear to be acceptable at this point. For the Japanese region, in addition to the 1° grid we had to apply a much stronger random thinner to get a reasonable number of vectors. For the mid and upper levels we thinned out 80% of the CMWs, for the low levels 50% was sufficient. This resulted in 580 CMWs for the region, with a 2:1 ratio of low-level to upper-level.

Figure 10 shows the distribution of all simulated CMWs for 1200 March 4. The CMWs in the non-GOES regions exhibit the same spatial patterns as the GOES regions, albeit at lower density. And the same problem exists for the low level CMWs, namely the relatively scattered nature of the CMWs versus the clustering typically seen in observations. Slow bias calculations (not shown) are consistent with earlier results for the GOES regions.

1. Conclusions

TABLE I: Vertical distribution of observed GOES CMWs (IR) for selected cases

CASE	HIGH ($P < 400$)	MED (400-700)	LOW ($P > 700$)	TOTAL
0000 Sep 9 2002 GOES-E	4922 (64%)	555 (7%)	2130 (28%)	7607
0000 Sep 9 2002 GOES-W	2734(64%)	266 (6%)	1298 (30%)	4298*

0000 Jul 25 2002 GOES-E	4452 (55%)	627 (8%)	2969 (37%)	8048
1800 Aug 22 2002 GOES-E	4929 (62%)	571 (7%)	2456 (31%)	7956
1200 Jun 21 2002 GOES-E	3814 (50%)	754 (10%)	3041 (40%)	7609
Totals	20851 (59%)	2773 (8%)	11894 (33%)	35518

TABLE II: Vertical distribution of simulated GOES CMWs for selected times.

CASE	HIGH (P<400)	MED (400-700)	LOW (P>700)	TOTAL
1200 Feb 7 GOES-E	5538 (59%)	888 (9%)	2952 (32%)	9378
1200 Feb 7 GOES-W	4951 (54%)	1078 (12%)	3104 (34%)	9133
0000 Feb 15 GOES-E	5504 (58%)	1054 (11%)	2932 (31%)	9490
0000 Feb 15 GOES-W	4328 (50%)	911 (11%)	3422 (39%)	8661
1200 Mar 4 GOES-E	4890 (58%)	829 (10%)	2762 (32%)	8481
1200 Mar 4 GOES-W	4649 (52%)	1247 (14%)	2965 (34%)	8861
Total GOES-E	5311 (58%)	924 (10%)	2882 (31%)	9117
Total GOES-W	4643 (52%)	1079 (12%)	3164 (36%)	8886

Total	9954 (55%)	2003 (11%)	6046 (34%)	18003
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TABLE III: Speed bias (m/s) for all simulated CMW listed in TABLE II.

	BIAS VS CMW SPEED		BIAS VS RAOB SPEED	
Wind Speed	BIAS	Pct of Winds	BIAS	Pct of Winds
0 – 10	-0.52	49	-0.02	45
10-20	-1.73	32	-1.65	31
20-30	-3.50	14	-3.25	14
30-40	-3.97	4	-5.02	8
40-50	-3.85	1	-6.50	2
TOTAL	-1.48		-1.48	

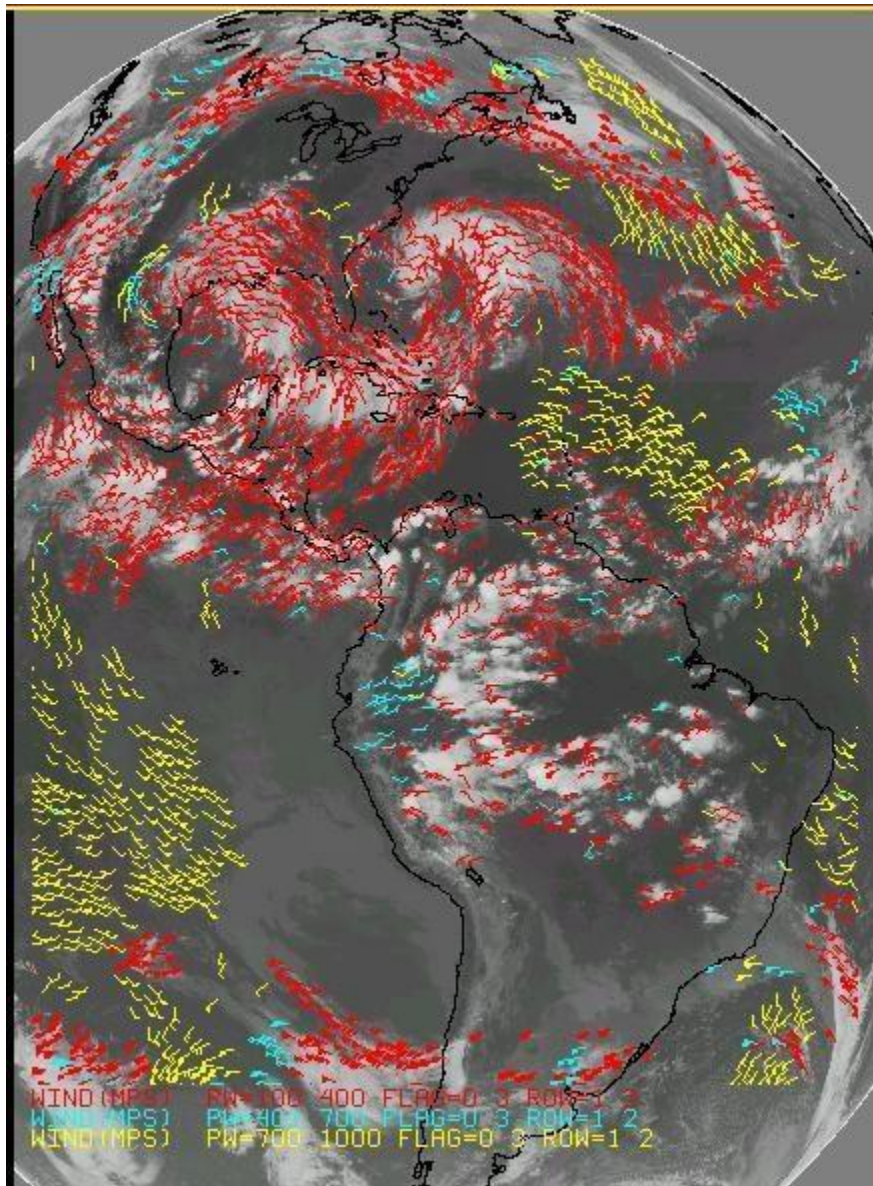


Figure 1a: GOES-E IR picture and superimposed CMWs for 0000 UTC September 8, 2002. High CMWS are in red, middle-level in blue, low in yellow.

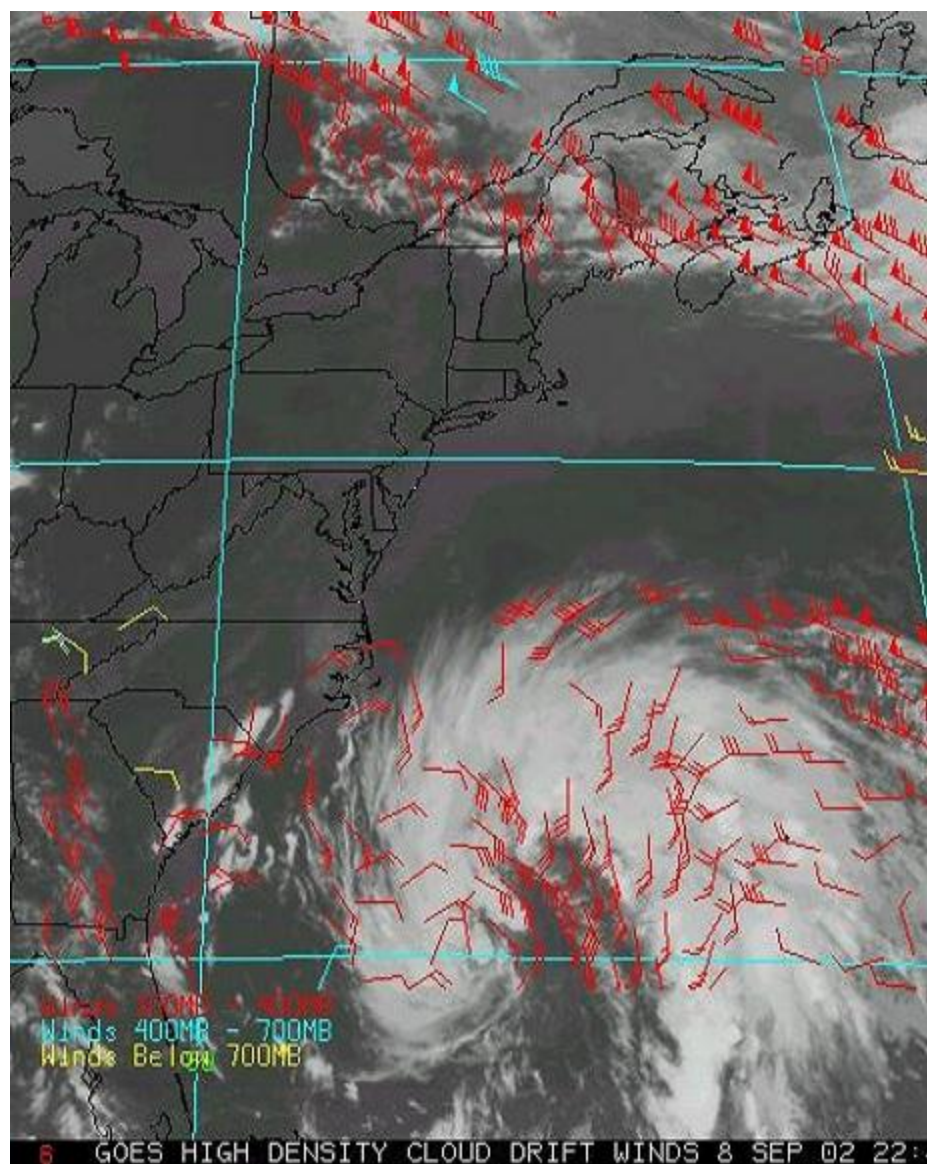


Figure 1b: Close-up view from Figure 1a.

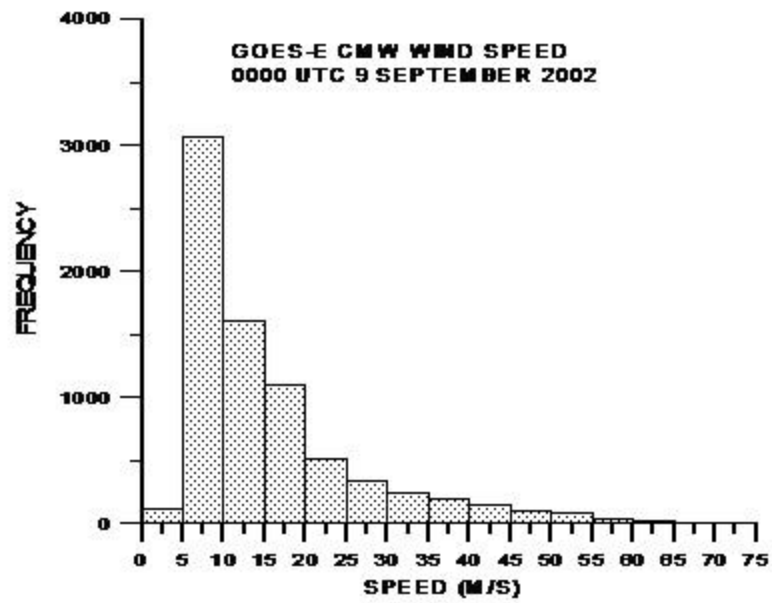
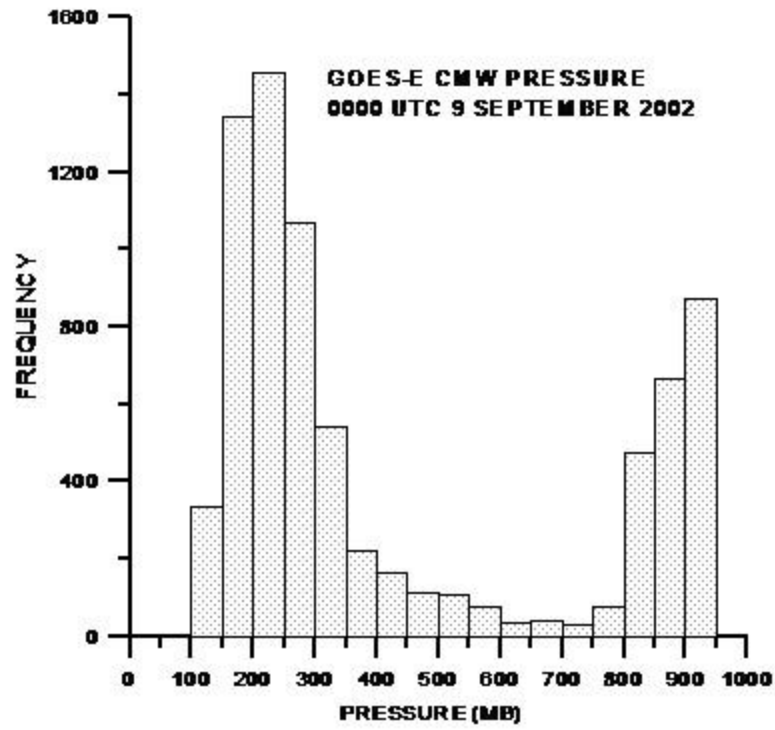


Figure 2: GOES-E observed CMWs for 0000 UTC Sep 9, 2002. (a) distribution of CMWs by pressure (b) distribution of CMWs by wind speed.

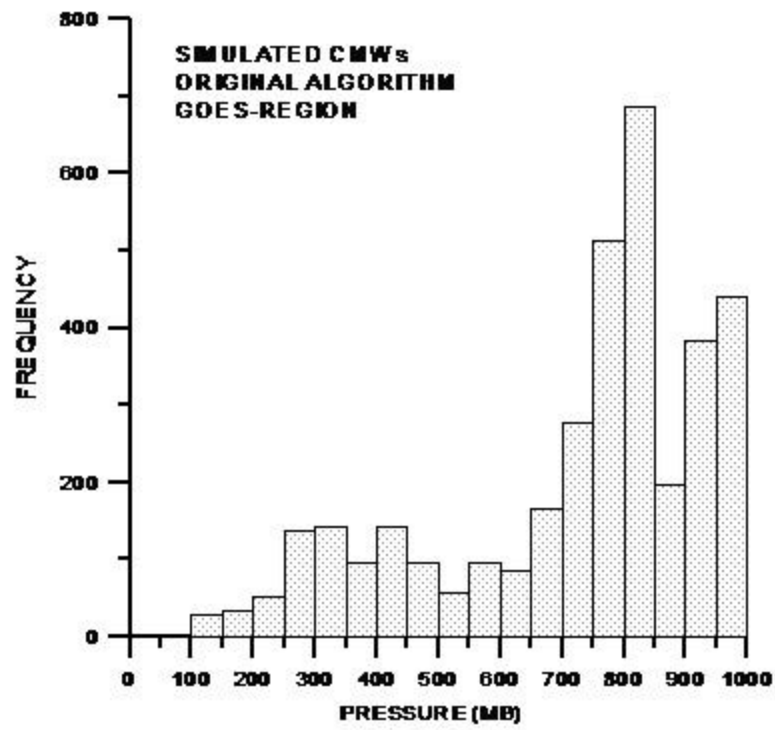
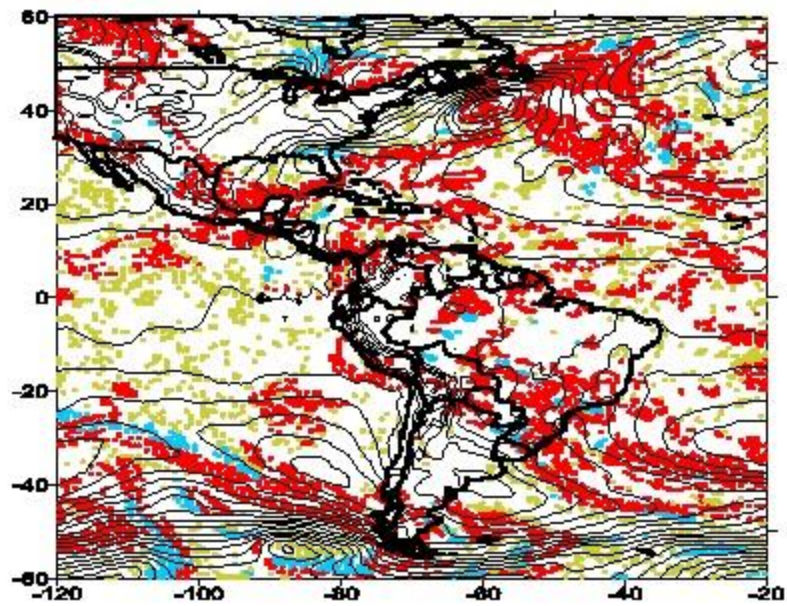


Figure 3: Vertical distribution of simulated CMWs for the GOES-E region using our original algorithm.

**FEB 07 1200 UTC GOES-E
SIMULATED CMW AND MODEL SLP**



**FEB 07 1200 UTC GOES-W
SIMULATED CMW AND MODEL SLP**

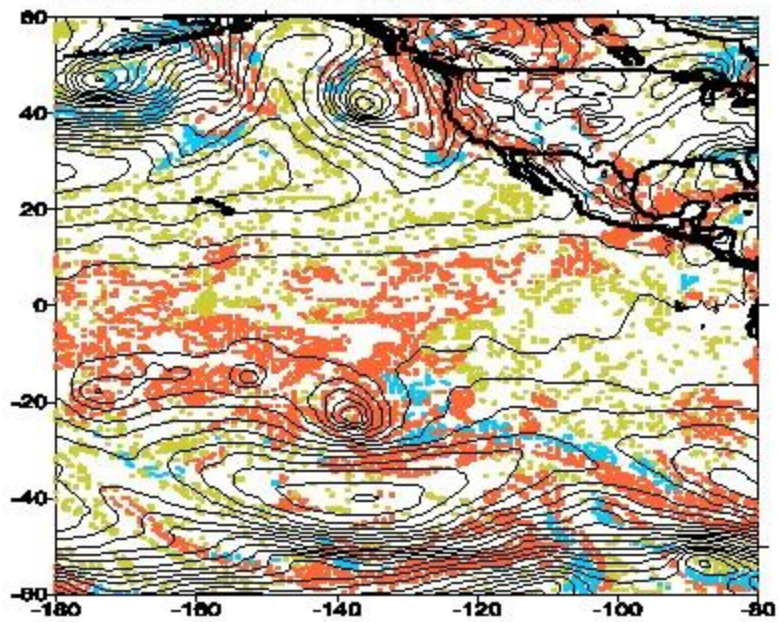
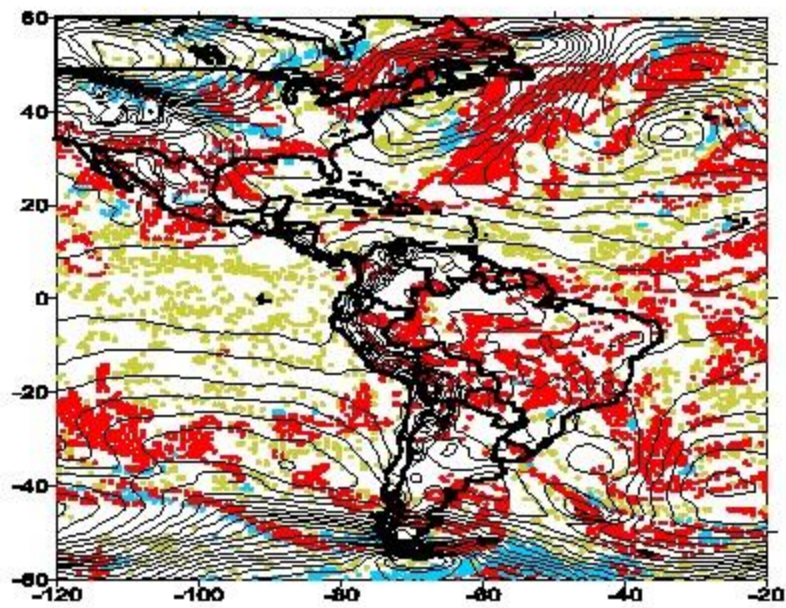


Figure 4: Mode sea level pressure (mb) and simulated CMWs for 1200 UTC Feb 7. High: red, middle: blue, low: gold. Pressure interval 2.5 mb.

**FEB 15 0000 UTC GOES-E
SIMULATED CMW AND MODEL SLP**



**FEB 15 0000 UTC GOES-W
SIMULATED CMW AND MODEL SLP**

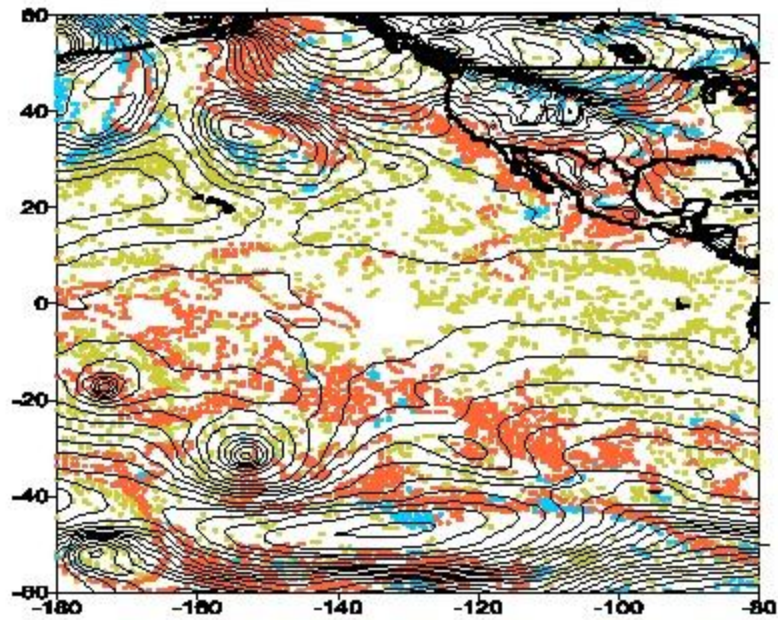
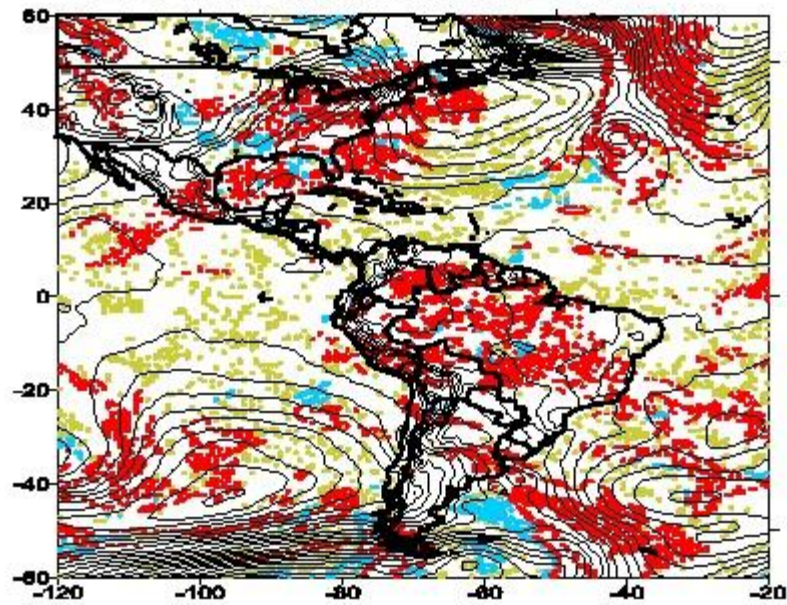


Figure 5: Mode sea level pressure (mb) and simulated CMWs for 0000 UTC Feb 15. High: red, middle: blue, low: gold. Pressure interval 2.5 mb.

**MAR 04 1200 UTC GOES-E
SIMULATED CMW AND MODEL SLP**



**MAR 04 1200 UTC GOES-W
SIMULATED CMW AND MODEL SLP**

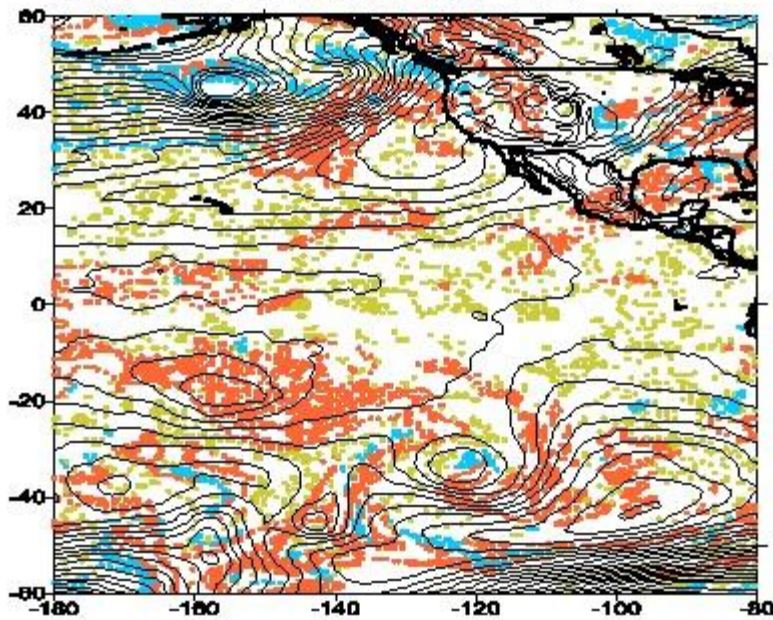


Figure 6: Mode sea level pressure (mb) and simulated CMWs for 1200 UTC Mar 4. High: red, middle: blue, low: gold. Pressure interval 2.5 mb.

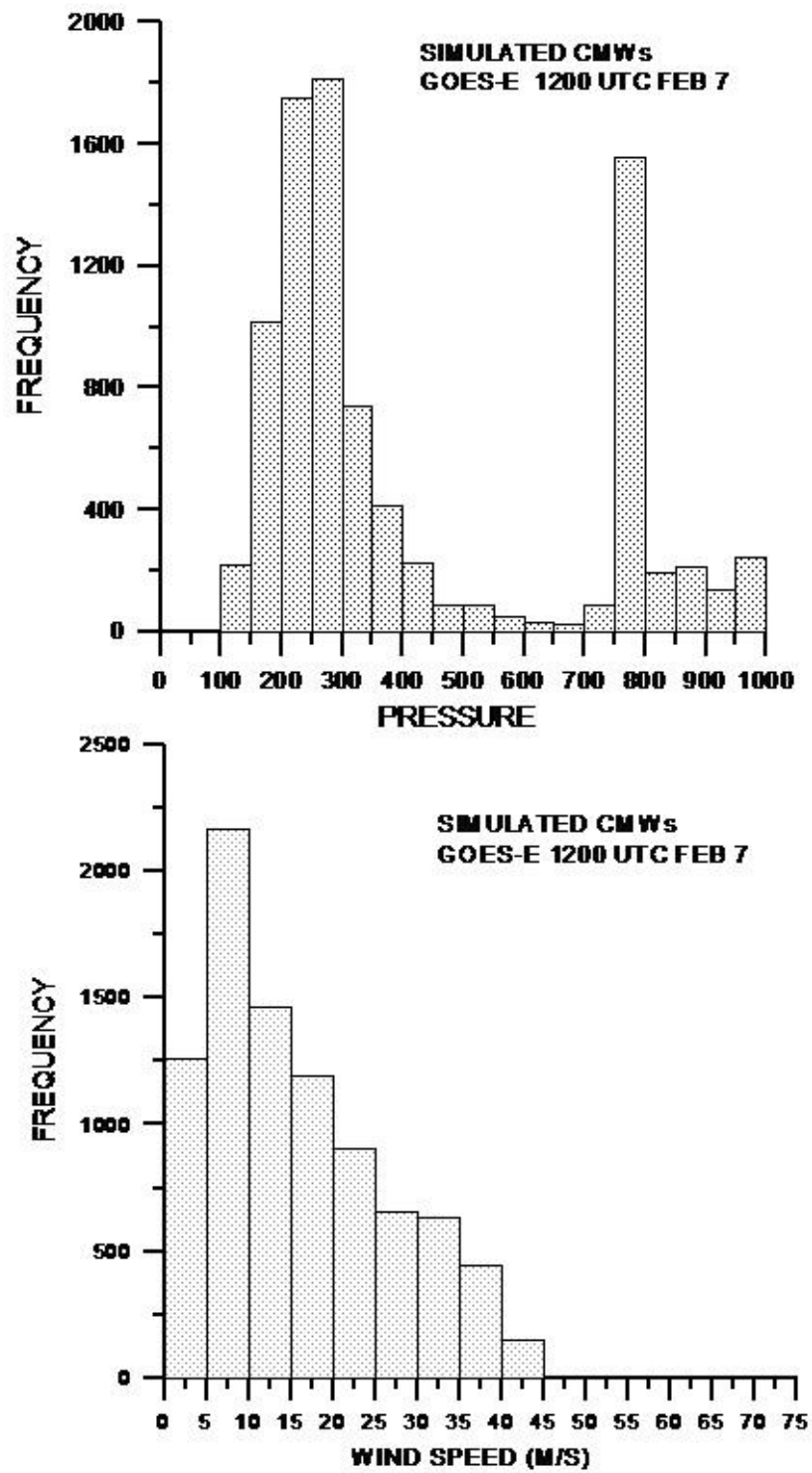


Figure 7: Distribution of GOES-E simulated CMWs by pressure for 1200 UTC Feb 7.

Model Hi Cloud Cover and Simulated High-Level CMWs 1200 UTC 4 March

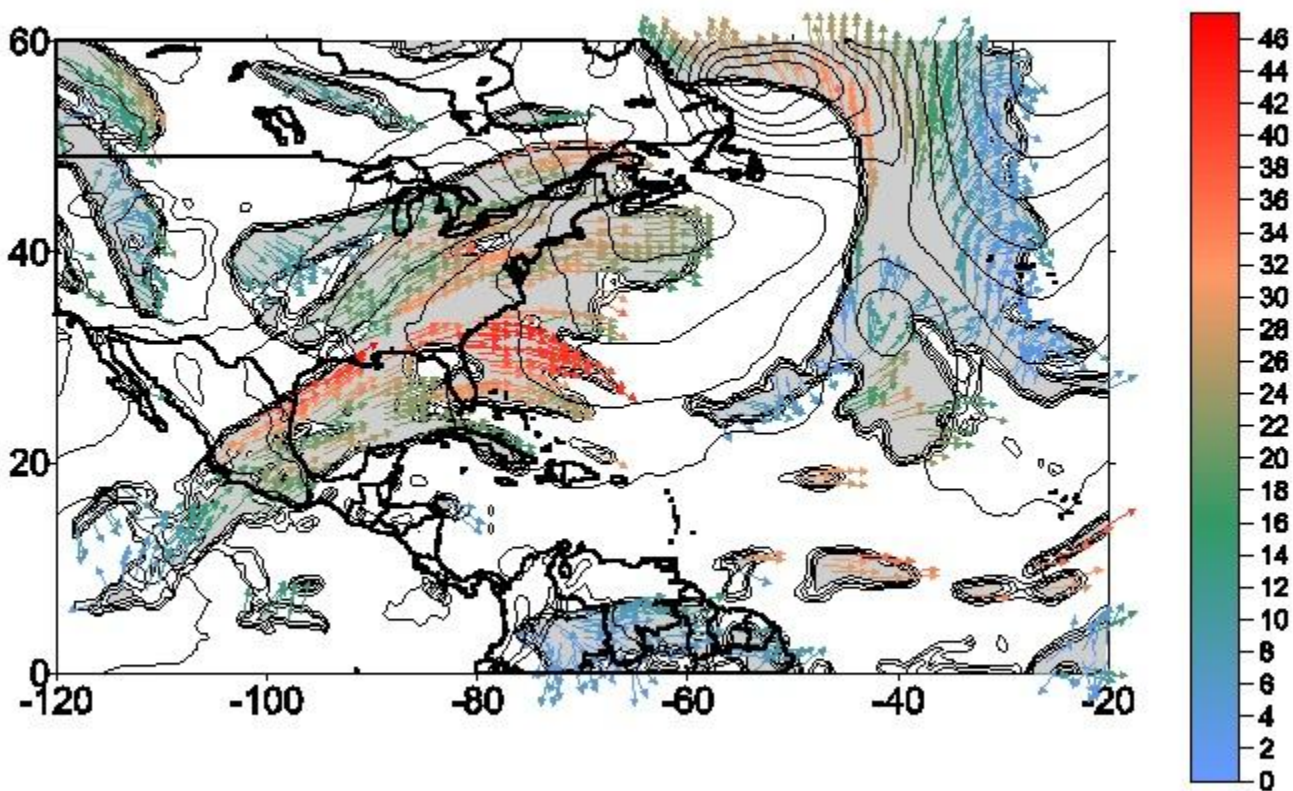


Figure 8a: Model high cloud cover, sea-level pressure and simulated hi-level CMWs for 1200 UTC March 4. Contour interval 2.5 mb (pressure) and 0.2 (cloud fraction). Shading represents cloud fraction greater than 0.8. CMW vectors are all the same length, with color indicating wind speed.

Model Mid Cloud Cover and Simulated Mid-Level CMWs
1200 UTC 4 March

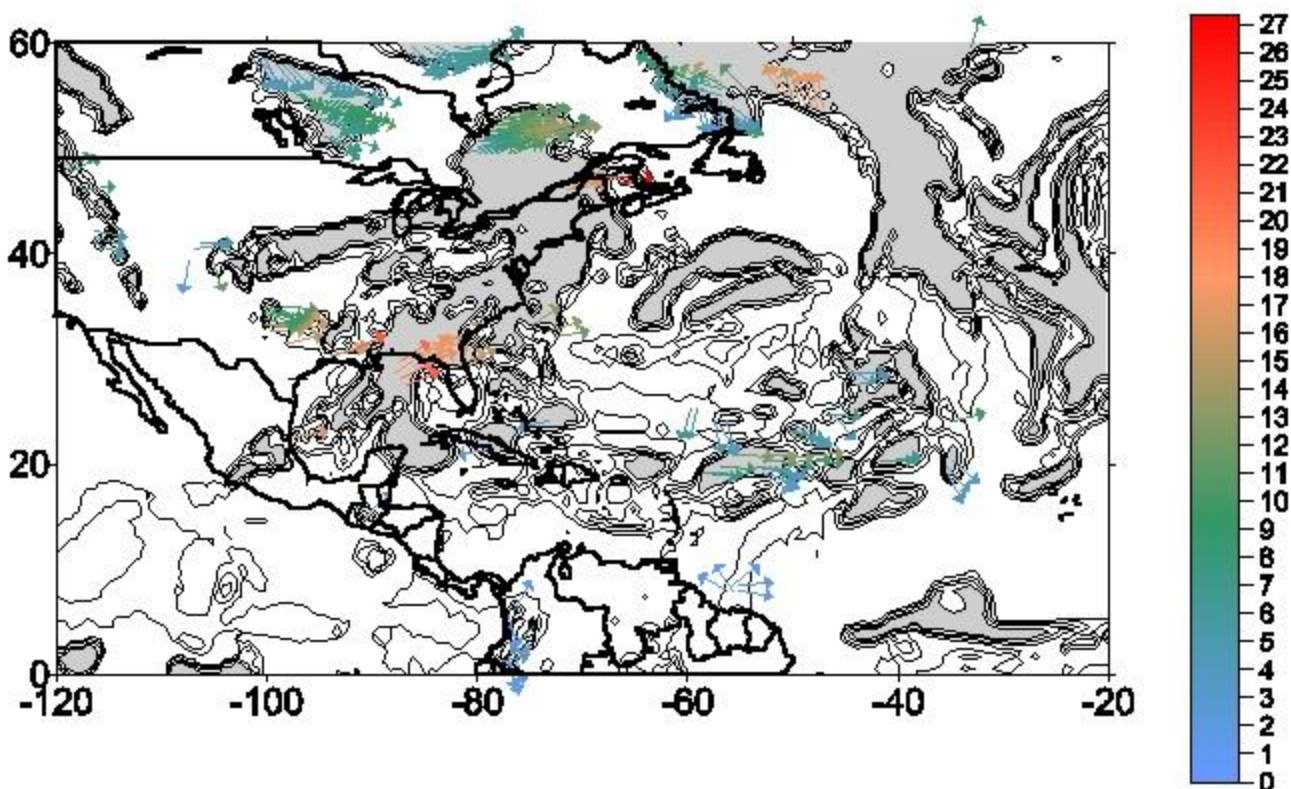


Figure 8b: As in Fig 8a, except for mid-levels. Sea-level pressure omitted for clarity.

Model Low Cloud Cover and Simulated Low-Level CMWs
1200 UTC 4 March

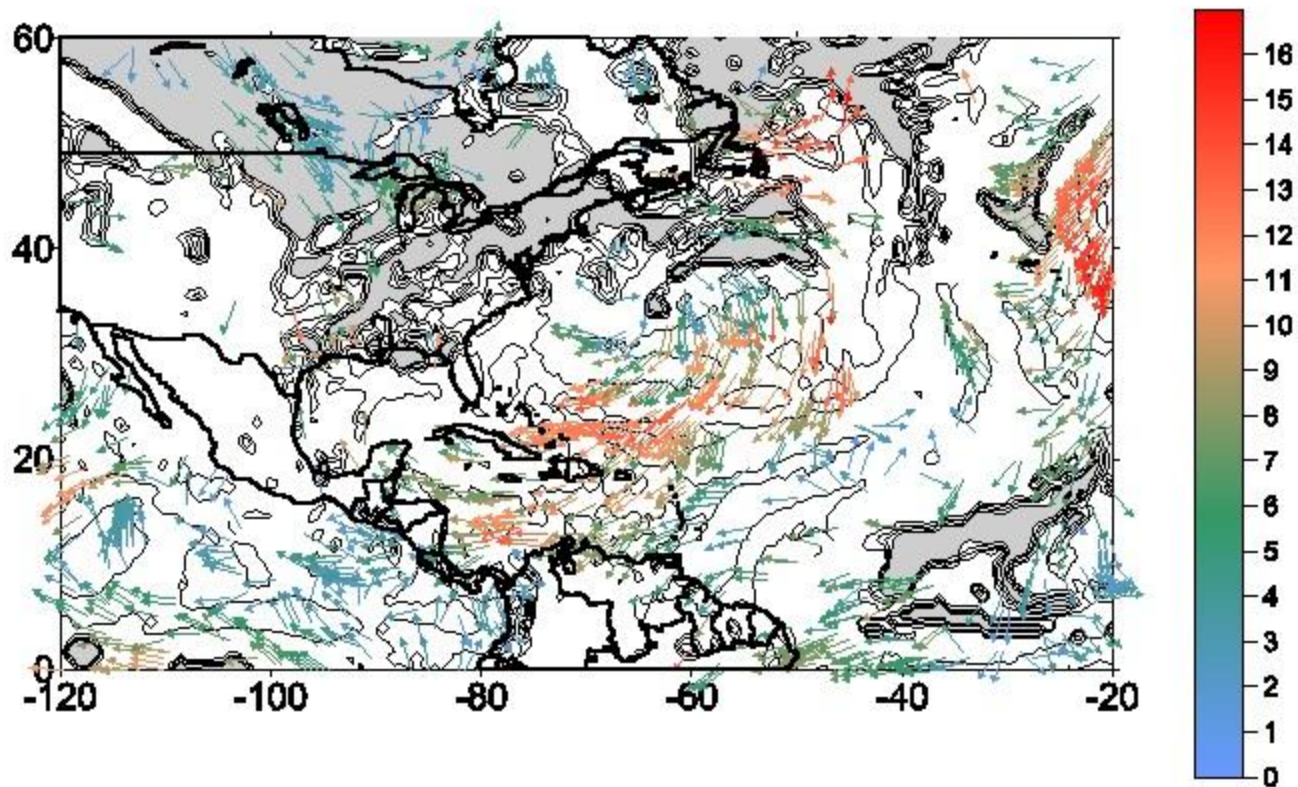


Figure 8c: As in Fig 8b, except for low-levels.

BIAS VALUES FOR SIMULATED CMWs
1200 UTC 4 March

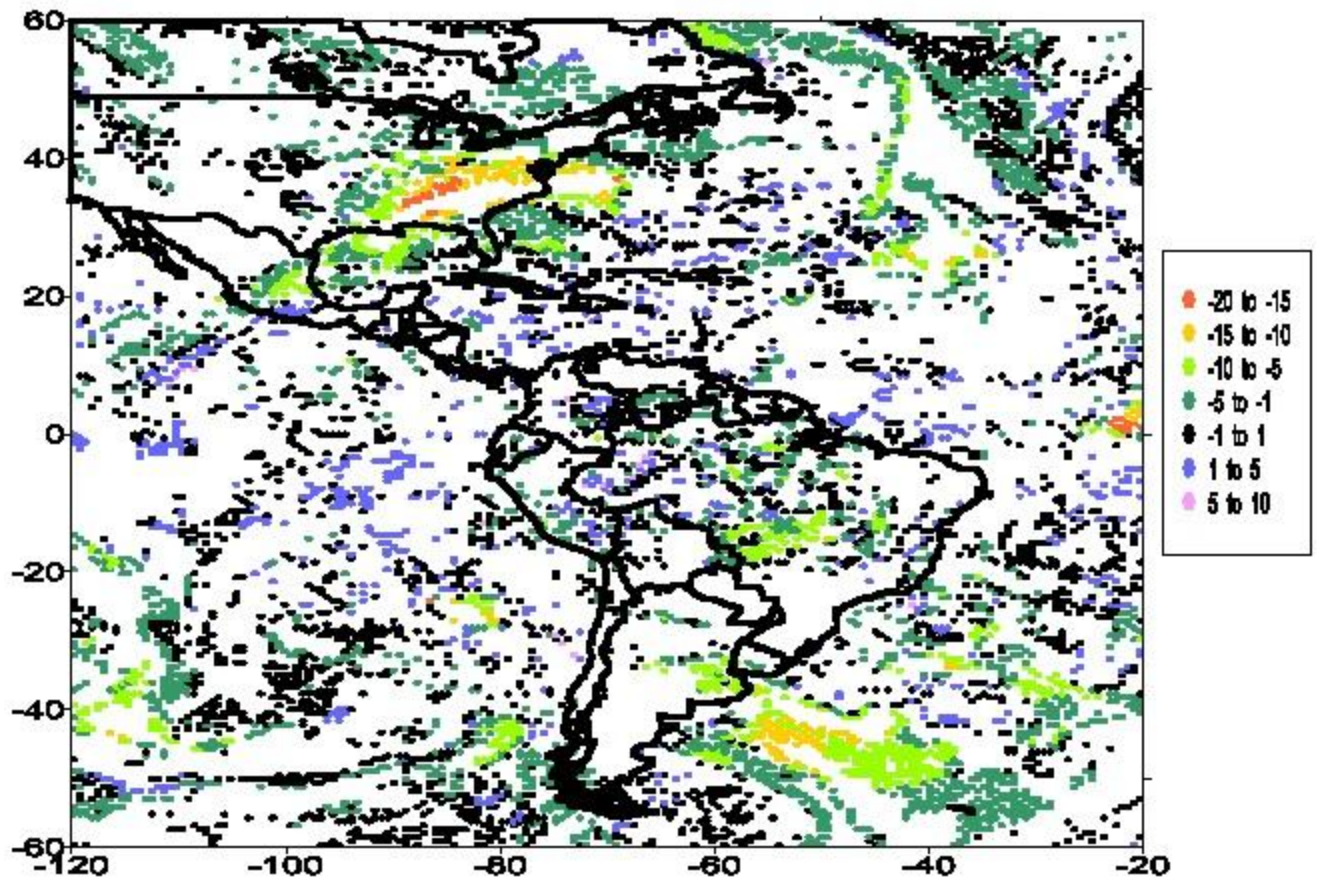


Figure 9: Bias values for all CMWs for the GOES-E region, 1200 UTC March 4. Bias values (m/s) color-coded according to the key at the right edge of the figure.

**MARCH 4 1200 UTC
ALL SIMULATED CMWs**

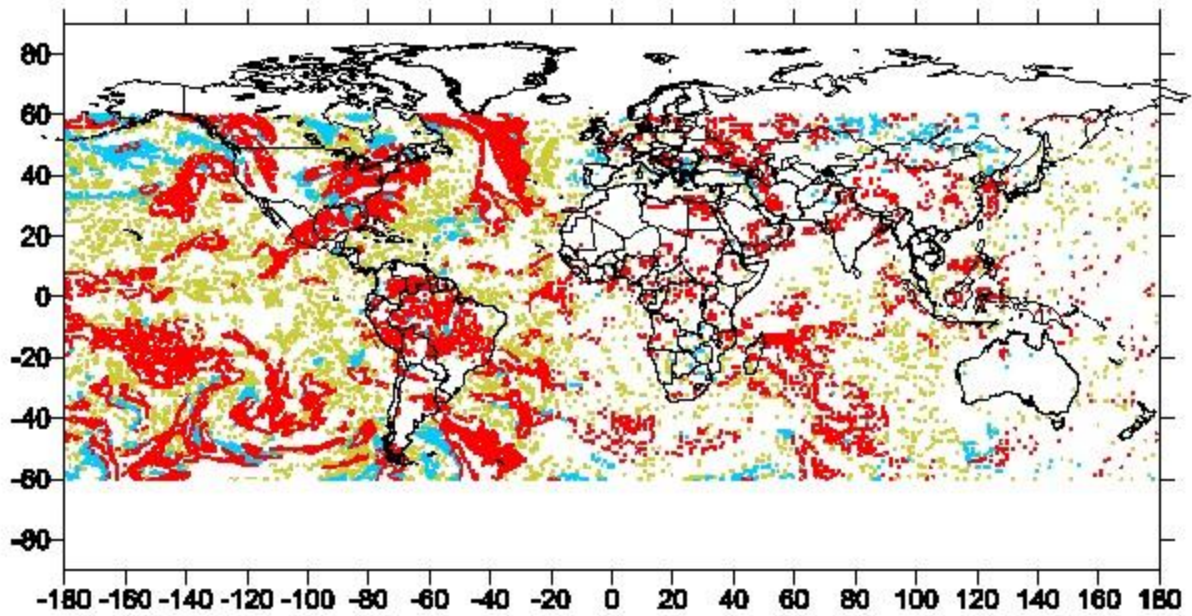


Figure 10: Distribution of all CMWs for 1200 UTC March 4.