A Severe Weather Proxy Developed From the NOMADS Real Time Data Base of an Operational Model

Jordan Alpert*
NOAA/NWS/NCEP
Camp Springs, MD 20746

Jun Wang
SAIC,
Beltsville, MD 20705

1. Introduction

The highest resolution operational numerical weather prediction models are not able to resolve and predict with skill severe weather causing phenomena. The difficulties with NWP models predicting severe weather are many and include a lack of horizontal and vertical scale resolution of observations and models with sufficient detail and physical knowledge, for example, the details of the convection phenomena physics. This is in spite of great advances in our ability to integrate the fundamental equations of motion with sophisticated assimilation schemes that take advantage of the conventional and non-conventional stream of observations . Advances in modeling continue, for example, at the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) where improvements in model development show remarkable accuracy. The results of model runs serve many functions and foremost is the production of forecasts for watches of severe weather even though the individual agents that cause the severe weather are not resolved by the model.

Severe weather, as defined on the NCEP Storm Prediction Center (SPC) web page, is a tornado, damaging winds greater than 50 knots or hail of ¾ inches or larger. Although severe winds can result from a number of meteorological situations, these phenomena are the result of severe convection or thunderstorms from organized convection that include supercells, squall lines and multicell thunderstorm complexes. An array of indicators are used to determine the stable nature of the atmosphere and thus the potential for severe weather. Vertical profiles of weather elements such as temperature, dew point and wind are used to calculate an array of indicators, for example, the Lifted Index. This and more complex indicators such as Storm Relative Helicity and Convective Available Potential Energy are calculated from observed conventional and non-conventional soundings to analyze the severe weather potential at or near observation time. Model forecasts and initial conditions are used to assess the future potential for severe weather. A practical and important application of this are the Day 1-3 Convective Outlook and the Severe Weather Watch issued by the SPC.

We confine our attention to predictions beyond 12 hours where the model results are used to alert forecasters to the potential of severe weather. A challenge in reducing severe weather risk is to improve the utilization of model output signatures and indexes of severe weather and convection. It is well known that wind convergence patterns, often along frontal boundaries and in meso-scale complexes, areas of vorticity advection and vertical motions are regions where the potential for extreme convection events exist. These often occur at scales of motion that are barely resolvable by models and may have difficulty faithfully reproducing the convection details.

Utilizing improved software for displaying 3-dimensional animated displays, we have noticed qualitatively that the vertical extent of convergence patterns associated with severe weather at the surface, appears to grow and be advected vertically. While this phenomena can not be directly observed with our current observing network, qualitative results from NCEP Global Forecast System (GFS) operational model suggests that it is a model signature for sub-grid scale convective outbreaks (Alpert, 2003). We explore

*Corresponding author address: Jordan C. Alpert, NOAA/NWS/NCEP/Environmental Modeling Center, 5200 Auth Road, Rm. 204, Camp Springs, MD 20746; e-mail: jordan.alpert@noaa.gov

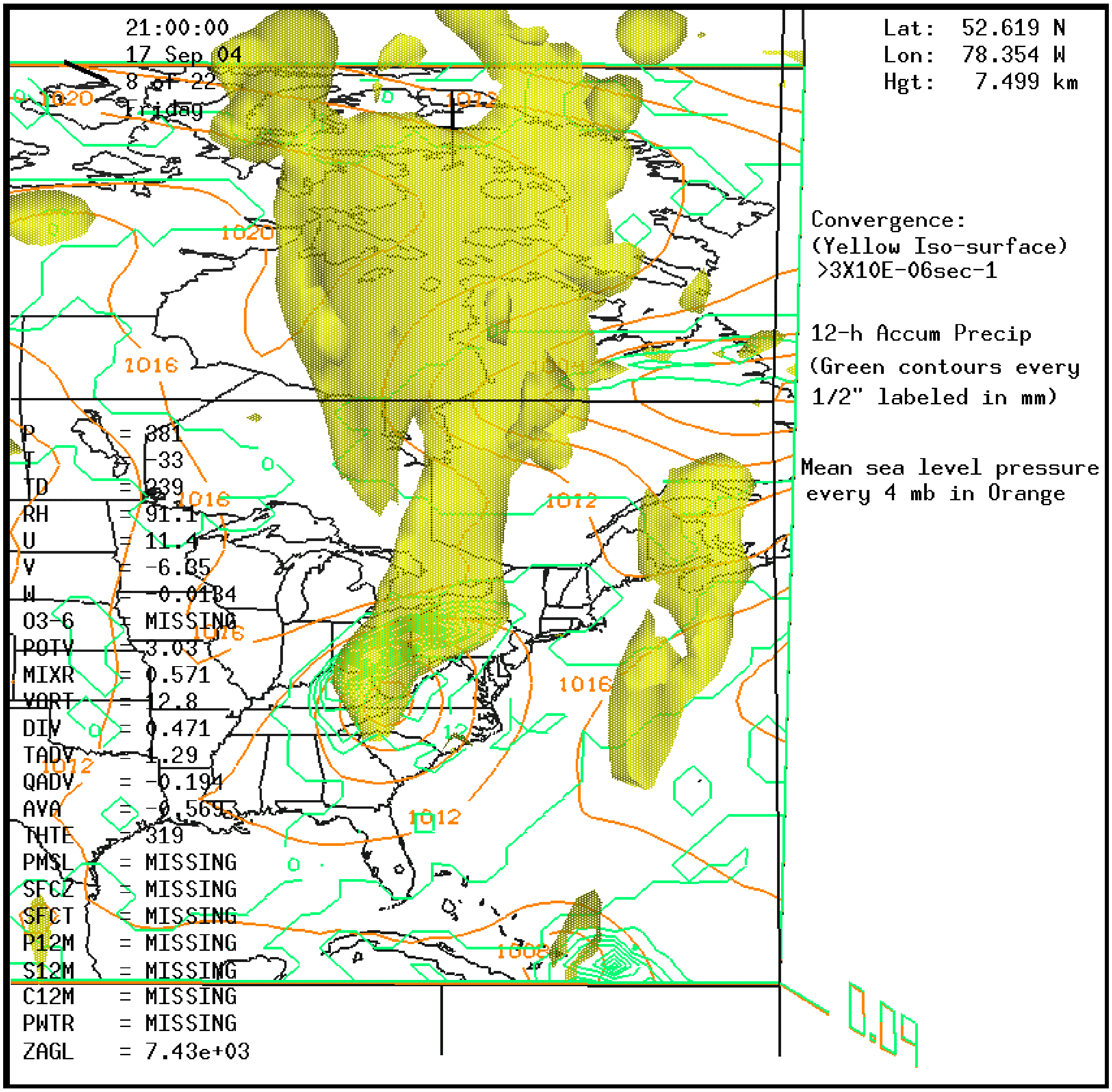

Fig 1. Rendering of the 21-hr NCEP operational GFS forecast of Convergence >3X10-5s-1 as a Yellow iso-surface, 12-h accumulated precipitation in green with contours every 1/2" and labeled in mm and Mean sea level pressure in Orange shown every 4 mb, from initial conditions of 00Z 17SEP2004. The top of the convergence iso-surface extends to 7.4km at 52.6N, 78.8W. The rendering was done with Vis5D.

the extent that these convergence iso-surfaces are proxies for severe weather and compare their locations to other severe weather indicators such as Lifted Index. We will verify these results with the NCEP SPC Severe Weather Watches which we note are also themselves forecasts. Convergence calculated from the motion fields from the GFS model will be used. The model data is obtained using NCEP Real Time NOMADS Open-DAP server, also known as DODS, to provide access to archive and real time records. We will also use model calculations to compare for example, a model forecasts of a known severe weather index, such as Lifted Index. The results of the development of our model proxy for sub-grid scale severe weather indicator will be shown.

The data for this study was obtained through queries to the NCEP real-time NOMADS server. The acronym stands for the NOAA Operational Model Archive Distributed System and provides a framework for NCEP real time operational model data sets to be distributed in a server-client relationship.

2. A Model Severe Weather Proxy

It is well known that convergence patterns occur regularly along fronts and cyclones and usually can be observed somewhere or sometime in most model 5-day forecasts. However, most regions of convergence from cyclones and frontal passages result in weather consisting of large scale rain or convective events with no severe weather. NWP model renderings using 3-dimensional animated display software, Vis5D (Hibbard et al, 1994) or D3D (Szoke et al, 2001) indicate that such convergence patterns appear as iso-surfaces and can be associated with particular cyclones and fronts. When predicted values of convergence larger than ~$3X10^{-5}sec^{-1}$ are found and these values persist above 500 mb we have found serve weather to occur (Alpert, 2003). Vis5D files of NCEP NWP models can be found on the authors web site:
http://wwwt.emc.noaa.gov/gmb/wd23ja/index1.html

The average front or cyclone system progresses with an associated "dome" of convergence. Typical of an area where a Watch box was issued is that of 17SEP2004 at 2100-h. The iso-surface of convergence is shown in Fig 1 for the 21-h forecast from the operational GFS. The surface cyclone at this time has a central pressure of less than 1000mb and the 12-h accumulated precipitation maximum to the north and west of the cyclone center is 5 inches. This convergence pattern not only grew with time but increased its volume with height. Values of convergence greater than $3X10^{-5}sec^{-1}$ were found from the surface to 7.5 km. In the next 3-h the cyclone system will move slowly east northeast and a number of severe weather watch boxes were issued in this region. The convergence area associated with this cyclone is well defined. One of the goals of this study is to find the right criteria in terms of the vertical extent of the pattern and what convergence values, if any, are a good indicator of severe weather.

The convergence patterns are typically seen to grow in vertical extent in proportion to increased precipitation, winds, decreased surface pressure and other indicators of cyclone intensification. The NWP model may advect the convergence patterns upward when the conditions are favorable in the absence of resolving the actual meso-scale phenomena. Whether this actually happens in the real atmosphere remains to be confirmed. Qualitatively we find two convergence criteria that may indicate severe weather: 1) the amplitude exceed a given value and 2) if the dome of convergence penetrates to middle or upper tropospheric levels.

3. The Verification

While these "domes" of convergence are seen to grow in horizontal and vertical extent, the precise criteria for mapping a critical convergence amount and height to severe weather needs to be known quantitatively to be useful as an indicator. We hypothesize that convergence patters are connected to surface systems and with sufficient vertical extent are the NWP models signature for severe weather at unresolvable model scales. To quantify this indicator we will calculate the magnitude of model forecast convergence from GFS model output winds at every 3-h on a 1x1 degree grid in an area over the eastern US (100 to 70W and 30 to 50N) and note regions that the vertical extent of the convergence exceeds various levels such as 700mb, 500mb and higher. To more objectively locate the patterns, and verify them with areas of severe weather, we need to locate GFS predicted areas of convergence, measure the vertical extent and investigate the best criteria for severe weather. To test how well these criteria are successful in predicting severe weather, we only recored the closest distance from the convergence or lifted index region which may be made up of many grid points that exceed one of the criteria. Each convergence region usually has a number of values which exceed a particular criteria and we will consider each group as a single area in scoring shown in Fig. 4 and Table 2. Later on we will show the total numbers which can give an indication of the false alarm rate.

To verify the location and occurrence of severe weather for the purpose of this report, we will use the SPC Severe Weather Watch or Warning. The Watch means that severe weather has potential, usually over a period of a few hours, and although it is a manually prepared prediction itself, it is manually made from non-conventional and conventional observations such as radar and soundings. A Warning box is issued when severe weather is known to have occurred but their occurrence is less frequent than are Watches. We will use a Watch or Warning to indicate the presence of severe weather for testing our hypothesis and consider it to be the verification for severe weather. A Watch or Waring consists of a text file indicating the location of the area for severe weather. Fig 2 shows an example of a Watch from September 17, 2004 issued near 2100 hours GMT showing 3 different areas. The text gives the latitude and longitude pairs of the Watch box outline. Note also that the box is valid for

---

```
(File: 2004091721.sevmkc)
WWUS60 KWNS 172103^M
SEVSPC^M
FILE CREATED 17-SEP-04 AT 21:00:00 UTC^M
SEVR 040917 1715 WT0833 0000^M
03902.07624        03450.07515        03450.07732
03902.07850;^M
^M
SEVR 040917 1950 WT0834 0000^M
03859.07839        03944.07840        03944.07613
03859.07614;^M
^M
SEVR 040917 2035 WT0835 0000^M
03400.07849 03722.07832 03722.07715 03400.07735;
```

Fig 2. Text file of a Severe Weather Watch issued by the SPC on September 17, 2004 at 21:00 hours.

---

varying amounts of time, for example, through 3 hours (0000 GMT). Typical watches cover an area of a few degrees square or 25,000 sq miles. The location of the first watch box is 39.02N, 76.24W. These values will be used as the verification area, any forecast pattern meeting the convergence criteria will be considered a success if it is forecast within this watch box. Fig 3 shows this watch box outlined in black.

The model predictions of 2-dimensional quantities such as lifted index will also be compared with the model predictions of convergence. The lifted index (AWS manual, 1961) used is called the best lifted index calculated from a number of atmospheric layers and the lowest (negative values less than -4 are considered indicators of potential severe thunderstorms) value reported.

4. Accessing the Data Using NOMADS

The NOMADS real time server was used to obtain the wind fields to calculate the convergence. One could have downloaded the GFS model run history, unpacked the GRIB files and read the global wind fields necessary for calculating the convergence at the proper points. As NOMADS is a OPEN-DAP/DODS server we may obtain the wind values needed by making queries to the server. An example is found in the text line near the top of Fig 3 and reprinted below:

url=http://nomad2.ncep.noaa.gov:9090/dods/gfs/archive/gfs20040917/gfs_00z.ascii?ugrd10m[7:7][110:140][235:300]
myvurl=http://nomad2.ncep.noaa.gov:9090/dods/gfs/archive/gfs20040917/gfs_00z.ascii?vgrd10m[7:7][110:140][235:300]

The top URL is a query to the real time NOMADS DODS server to obtain the u-component of the wind while the following line will obtain the v-component. The address of the URL is is first part of the query:
http://nomad2.ncep.noaa.gov:9090/dods/gfs/archive/gfs20040917/
which is the location of the data files for 20040917 and the file for the 00Z run is gfs_00z. This location is found in the metadata description located on the NOMADS server .info metadata section:

http://nomad2.ncep.noaa.gov:9090/dods/gfs/archive/gfs20040917/gfs_00z.info

along with pressure level, variable unit, projection, and other information in ascii digital form. The queries, url= and myvurl= each obtain either the wind variable ugrd10m or vgrd10m which are 2-dimensional variables as they are at 10m at different forecast times. Other levels are obtained from using the variables ugrd or vgrd which are 3-dimenisional and forecast time. For the 10m case shown above, constraints to time and space are done with values in square brackets: [7:7] indicates the seventh forecast time or 21z, and [110:140][235:300] are the grid points used in the eastern US domain chosen to encompass an area where severe weather often occurs. 110 is 110 degrees north of the south pole and 235 represents 235 degrees east of 0 meridian. The region under consideration is a 30

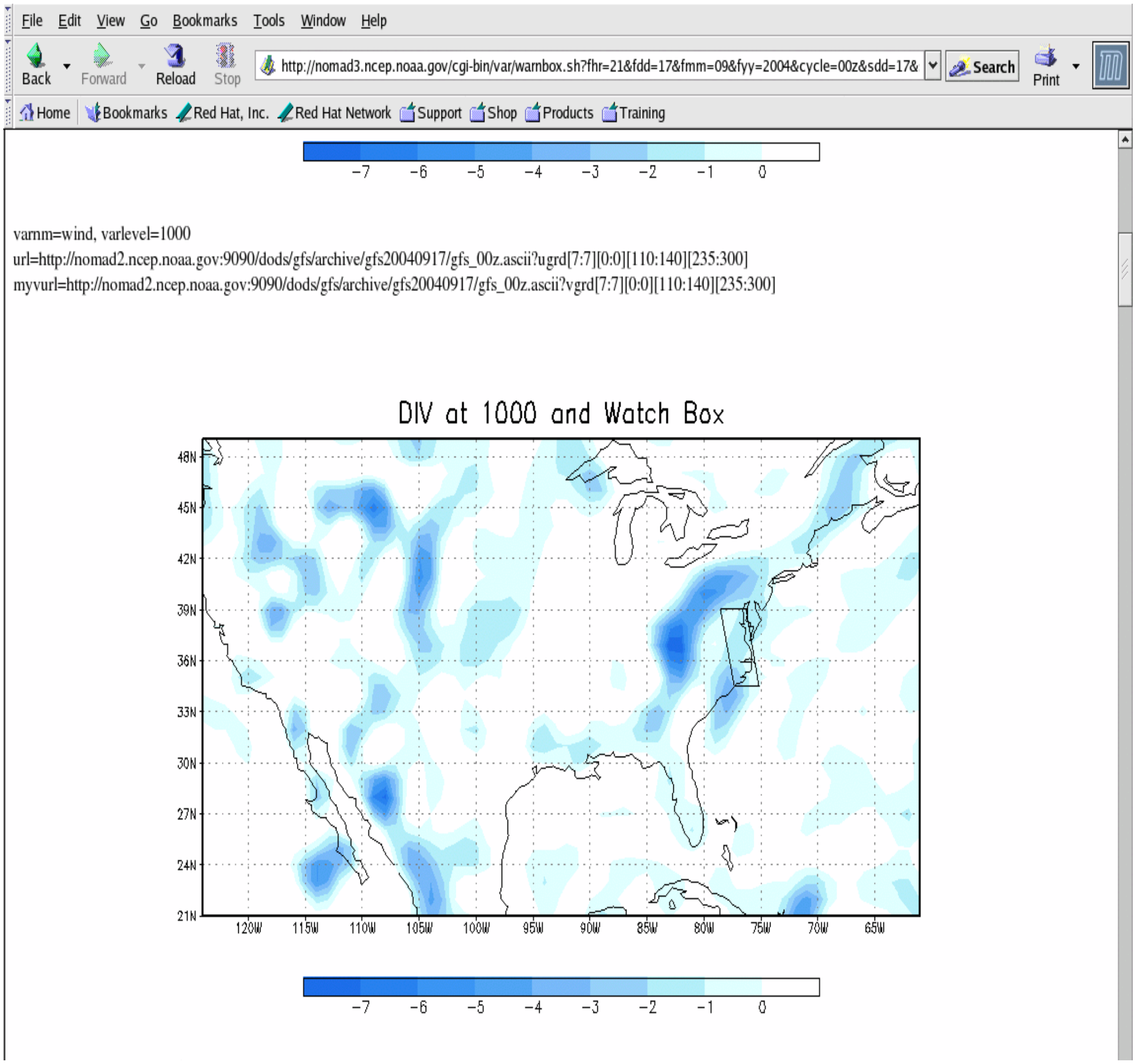

Fig 3. The watch box for 17SEP2004 21Z (located at the east coast of the middle Atlantic states) and the convergence pattern (X10-5sec-1) at 1000 mb calculated from the 00Z cycle of the 17SEP2004 21-h forecast of the operational GFS.

by 20 (600 grid point) area but for the purposes of making the plot in Fig 3 we use the 65X30 (CONUS) point area or 1950 grid points. The convergence is calculated using finite difference in the standard way including the proper map factors. These queries are repeated for all levels to test if the criteria for the convergence is met. The convergence patterns shown in Fig 3 compare with that shown in Fig 1 as they are both calculated form the same data. The convergence pattern shown near the watch box, along the middle Atlantic states , is moved slowly eastward which is the reason for the watch box to be valid over the next 3 hours.

We may consider areas were the convergence severe weather indicator predicts severe weather where there is no watch box as shown in these figures. The verification will calculate the distance from all forecast points to the watch box. How accurate a severe

Divergence and lifted index for severe weather forecast

date	C1 (div<3e-6 reach 6 levels)	C2 (div<3e-6 reach 5 levels)	C3 (div<5e-6 reach 6 levels)	C4 (div<5e-6 reach 5 levels)	C5 (div<1e-5 reach 6 levels)	C6 (div<1e-5 reach 5 levels)
2004091419	box 1 256 66	box 1 distance=0 distance=0 distance=0 distance=0	Box1 256 66	Box1 0 0 0 0	box 1 256	box 1 distance=0 distance=0
2004091420	box 1 256 66	box 1 distance=0 distance=0 distance=0 distance=0	Box1 256 66	Box1: 0 0 0 0	box 1 256	box 1 distance=0 distance=0
2004091500	box 1 556 box 3 520 587	box 1 657 box 3 distance=0	Box1: Box3: 520 587	Box1: 657 Box3: 0	box 1 box 3	box 1 box 3
2004091502	box 1 515 box 3 915 box 4	box 1 311 328 box 3 781 box 4	Box1: Box3: Box4:	Box1:311 Box3: Box4:	box 1 box 3 box 4	box 1 box 3 box 4

Fig 4. Excerpt of table showing convergence criteria and distance from the watch box in km. Distance=0 means the convergence point was within the watch box.

weather forecast is depends on this distance, although the usefulness to a forecaster is subjective. Large distance errors in the location of the severe weather indicate a high false alarm rate. We acknowledge that our criteria of counting all layers in a column that exceed the amplitude criteria, over estimates the extent of the convergence domes. These may not be completely connected between the surface and upper layers. However, we are most interested in testing if this 3-dimensional criteria has merit therefore refinements can come later.

5. Results

There are 6 criteria chosen, C1-C6, according to amplitude and the number of vertical levels between the surface and 500mb that exceed the convergence

Criteria	Convergence Amplitude ($10^{-6}s^{-1}$)	Number of Vertical levels between the surface and 500 mb
C1	> 3.0	6
C2	> 3.0	5
C3	> 5.0	6
C4	> 5.0	5
C5	>10.0	6
C6	>10.0	5

Table 1: Criteria for selecting convergence as a proxy for model severe weather. The number of vertical levels between the surface and 500 mb which exceed the convergence amplitude criteria.

amplitude as shown in Table 1. The vertical levels used are the surface (10m wind), 1000, 925, 850, 700, 500. Thus, if the criteria is 6 vertical levels then all the vertical levels must exceed the convergence amplitude in Table 1. In addition we include 3 criteria for severe weather from the lifted index values, C7-C9, respectively, less than -3, -4, and -5. Fig 4 shows an excerpt from the calculation of all the divergence criteria. For example, the first watch box on 14SEP2004 at 19Z had 2 grid points satisfying the criteria, C1, for severe weather 66 km and 256 km away. The second column, C2 shows 4 grid points satisfying the convergence criteria under column, C2 in Table 1, inside the watch box. The C2 values are considered "hits" for the convergence severe weather indicator. For this verification we found 47 watch boxes were issued by SPC between 14SEP2004 and 26OCT2004. However, we categorize each region exceeding the criteria of Table 1 as a single region to be verified. Each convergence region may consist of a number of grid points that exceed a respective criteria in which case the closest grid point is used for the distance to the watch box. This is done because there may be cyclone systems entering our domain which have nothing to do with the severe weather predicted at the SPC watch box. There is the possibility that there are more than one watch box in the domain, as shown for example in Fig 2, which may be associated with separate systems. When this is so, meaning that the distance of the convergence region is larger than 1000 km from the watch box, we label the result N/A. Therefore, for this first verification we will attempt to isolate each convergence region and compare with one watch box. For comparison, the same is done for the lifted index whenever its criteria is met.

In Table 2 we show totals for each convergence region valid when a watch box is present. The values are divided up into number of "hits" meaning the convergence criteria was met and located inside the watch box, or that the closest convergence criteria was within <100 km, 100-200 km, 200-300, or greater than 300 km but less than 1000 km for each criteria in Table 1. The criteria with the most hits is C2, (>3X10^{-6}s^{-1} convergence and with all five vertical levels). The criteria C4, >5X10^{-6}s^{-1} convergence and with all five vertical levels) gives similar results. The number of severe weather regions that were between 300 and 1000 km, a poor forecast, were fewer than in C2. Both of these criteria, C2 and C4, did a better job of predicting severe weather than any of the lifted index indicators. If we add the totals for hits, and those with distance errors of less than 200 km, the convergence criteria, C2 and C4, still show an improvement. Criteria that require the convergence to extend to all vertical levels and higher than 500mb, C1, C3, and C5 show little predictive capability.

	Criteria				
(km)	C1	C2	C3	C4	C5
Hits	0	27	0	25	0
<100	4	0	3	0	2
100-200	5	0	3	0	1
200-300	14	0	11	0	7
>300	13	12	11	6	13
N/A	11	8	19	16	24

	Criteria			
(km)	C6	C7	C8	C9
Hits	13	17	7	2
<100	0	3	3	0
100-200	0	9	13	9
200-300	0	6	7	4
>300	6	6	12	13
N/A	28	6	5	19

Table 2. The total number of hits or distance from the watch box for each convergence region exceeding the criteria in Table 2 during the valid times for all watch boxes.

When the convergence criteria is large as in C5 and C6, it appears that this criteria is too strict, as the number of hits is significantly reduced. We found the lifted index for all criteria has a large number of false alarms, that is, distance errors at 200 km and greater than 300km predicting severe weather through out most of the domain grid points.

6. Summary

We have shown that model forecasts of convergence that exceed a certain amplitude criteria (3-5X$10^{-6}s^{-1}$ and extend vertically to the middle troposphere are a good indication of severe weather as measured by the SPC weather watch box. These quantitative results confirm that the convergence patterns as shown in 3-dimensional renderings could be used as a proxy for model indications of severe weather. We note that a more complete statistical analysis needs to be done on these results. A much larger number of runs should be made to generate a larger sample to obtain more definitive statistical results.

The data for this study was obtained from queries to the NOMADS OPEN-DAP server which archived, unpacked and arranged NCEP operational runs from the global model fields.

7. References

Alpert, J.C., G.K. Rutledge, R. Stouffer, B. Doty, S. Hankin and B. Domenico, 2002: The plan to a ccess real-time NWP operational model data sets using NOMADS, AMS 18th Conf IIPS, Orlando FL, J4.16, 73-74.

Alpert, J.C., and J. Wang, 2004: The real time NOMADS project: Access to operational model data and value added products, AMS 20th Conf on IIPS. Seattle, WA, P1.25

Alpert, J. C., 2003: 3-Dimensional animated displays for sifting out medium range weather events and severe weather using NCEP model ensembles. 19th Conf on IIPS 15.2, AMS.

AWS Manual No. 105-124 Volume I, 1961: Use of the Skew T, Log P Diagram in Analysis and Forecasting, AWSM 105-124, vol I Air Weather Service HQ, Scott Air Fore Base, Ill 106pp.

Hibbard, W. L., B. Paul, D. Santek, C Dyer, A. Battaiola, and M-F. Voidrot-Martinez, 1994: Interactive Visualization of Earth and Space Science Computations, Computer, **27** 65-72.

Szoke, E. J., U. H. Grote, P. C. Kucera, P. T. McCaslin, P. A. McDonald, and W.F. Roberts, 2001: D3D: A Potential 3D Visualization Tool for the National Weather Service, Intl. Conf. IIPS, Albuquerque, NM. Amer. Meteor. Soc., 10-14.