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The New Turbulence Nowcast from Schneider Electric

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1. INTRODUCTION

The *Glossary of Meteorology* defines a nowcast as "A short-term weather forecast, generally for the next few hours." Typically, weather forecasters start with a detailed analysis of the observations then extrapolate the trends that they see in the data. Extrapolation involves integrating multiple data sources which include radar and satellite imagery and numerical model forecasts. Short term extrapolation can be very good for an hour or two (Pinto et al., 2015). After that atmospheric processes unaccounted for in the analysis begin to dominate.

Proper flight planning takes into account the weather expected enroute. Nowcasts often do not play a role because the flight plan is generated one to two hours before embarking for a flight that may be in the air for hours afterward. But once the plane has taken off, the weather may change and the pilot needs to be informed of it. Nowcasts become invaluable tools. Because a flight crew can prepare its aircraft for rough turbulence in 30 minutes or less, nowcasts beyond one hour are relatively useless. Therefore, unlike the *Glossary of Meteorology* definition, aviation nowcasts should be no more than one hour.

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Note that a nowcast is not an analysis. An analysis is helpful to identify important features that could affect the flight, but, in order to make a good flight decision, a pilot needs to know where these features will be when the plane arrives at a feature's future location.

Too much nowcast information can hinder a pilot's comprehension. Weather is only one flight safety factor. The pilot still has to fly the aircraft. The pilot may not have time to thoroughly examine a detailed nowcast.

Current aviation nowcasting is a twofold endeavor. Onboard radar can detect precipitation ahead of the aircraft. The pilot can maneuver around the heaviest precipitation cores, if needed. However, maintaining flight safety is difficult because (1) onboard radars have detection inefficiencies, (2) the turbulence may not be located near the high reflectivity core, (3) radar is not a forecast tool, and (4) most radars are manually operated which distract pilots from their other duties

"Ride reports" are the second aspect of today's nowcasting system. Another aircraft may have previously flown in the airspace the pilot intends to fly, so it is helpful to know the weather that a previous pilot experienced. Obviously, the weather may change by the time one arrives at the ride report's location. If no one has flown through the interest airspace, then the pilot is out of luck.

With those considerations, Schneider Electric introduces its turbulence nowcast. It combines turbulence observations from any high quality source and short term numerical model forecasts. The nowcast is a one-stop-shop for short term turbulence. It displays turbulence in eddy dissipation rate (EDR) for convective and non-convective sources for the upcoming hour every 10 minutes. It is altitude-specific (surface to FL500) and available anywhere over the globe.

This paper describes how Schneider Electric creates the nowcast.

2. CREATING THE NOWCAST

a. Non-convective turbulence

The Schneider Electric INTTURB forecast (McCann and Lennartson, 2014) provides a first-guess of the non-convective turbulence sources. INTTURB integrates the four primary sources of turbulence, clear-air, mountain wave, boundary layer, and convection.

INTTURB computes the EDR turbulence individually for each source, clear-air (McCann et al., 2012), mountain wave (McCann, 2006), boundary layer (McCann, 2001), and convective (McCann, 1999). McCann and Lennartson found that adding individual turbulence outputs does not address the possible interaction of initiating mechanisms. For example, the conditions for mountain waves to break may not be favorable by themselves, or conditions for turbulent unbalanced flow gravity waves may not be favorable by themselves, but a mountain wave superimposed on an unbalanced flow gravity wave may have sufficient amplitude to initiate turbulence.

The nowcast uses the INTURB's non-convective output that verifies within the upcoming hour that the nowcast forecasts. Figure 1 shows an example of a non-convective first guess.

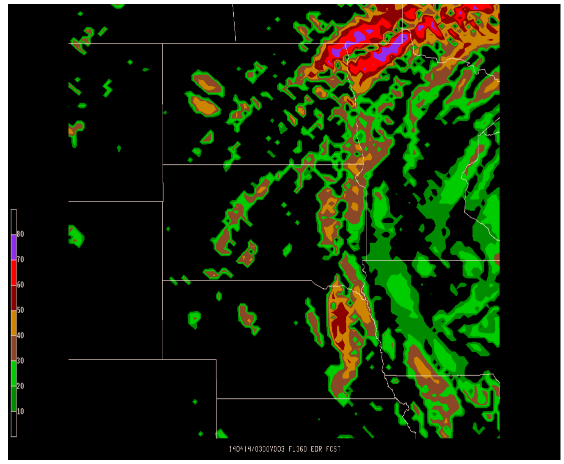

Figure 1. Three hour RAP model non-convective turbulence forecast at 36 000 feet (FL360) from 14 April 2014.

b. Convective turbulence

Because convection often forms in situations which are difficult for numerical models to resolve and because strong convection is easy to observe, the nowcast uses observations of convection for the convective first guess instead of model forecasts. The process begins by calculating the potential turbulence from convection. We preface this discussion by noting that with all the research into turbulence in thunderstorms, none has discovered a better convection/turbulence relationship than that determined with the 1947-1948 Thunderstorm Project data (Byers and Braham, 1949). They found a high correlation of turbulence intensity with storm draft velocity.

The VVSTORM[1] algorithm computes turbulence potential from updrafts, from downdrafts, and above overshooting tops. At every model grid point VVSTORM finds the most unstable parcel in the sounding. If the parcel is conditionally unstable, it lifts that parcel to its level of free convection (LFC). At each level above the LFC, the parcel is accelerated depending on the temperature difference between the lifted parcel temperature and the environmental temperature. Knowing the upward speed at the level, VVSTORM finds the new updraft speed after acceleration. Downdraft speeds are estimated from each grid point's WINDEX (McCann 1994). The downdraft is

[1] The VVSTORM algorithm referenced in McCann (1999) is now called VVTURB.

assumed to initiate at the freezing level then uniformly accelerate to the WINDEX value at the surface. The result is a grid of potential storm draft speeds at every level from the surface to FL500. Then the draft speeds are converted to EDR turbulence. In addition, VVSTORM computes potential turbulence above storm tops by examining the potential for vertically propagating gravity waves generated by the overshooting parcel to break.

The grand result is a grid set of EDR turbulence potential as shown in the example Figure 2. The grids resemble convective available potential energy (CAPE) grids but with the modifications outlined above and are at every 1000 foot level from the surface to FL500. The grids depict the potential turbulence if convection were to be located there.

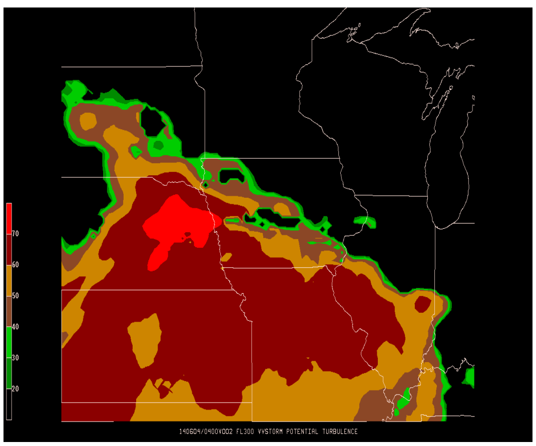

Figure 2. Two hour VVSTORM potential turbulence forecast at FL300 from the 0200UTC 4 June 2014 RAP numerical model forecast.

The turbulence potential grids are masked by current storm observations. There are several ways to observe storms remotely. Each has its strengths and weaknesses. Radar reflectivity locates storms very well, but the storms must be within the radar network's detection range. Therefore, radar networks have coverage holes and do not detect oceanic convection. Furthermore, reflectivity is not a reliable turbulence indicator. Geostationary satellites cover the Earth, and can be monitored continuously. Bedka et al. (2010) describe a method for detecting overshooting tops from such imagery. While they present some evidence to correlate their method with turbulence observations, they did not address operational issues such as availability, temporal frequency, and processing time.

Lightning density data are a third way to observe convection. Lightning forms within storms when the turbulent updraft flow separates precipitation of different charges. Therefore, the stronger the updraft, the more frequent these charge separations occur and the more frequent are lightning flashes. Since lightning forms in turbulent updrafts, it is an ideal observation platform to observe updraft locations. Today's lightning networks give global coverage and have no discernable holes. Processing lightning data is quick and easy. The downside is that the updraft/lightning relationship is only solid for total lightning, which is cloud-to-ground and in-cloud flashes together. Ground-based total lightning networks are expensive and so are only available over limited areas. Current broad-coverage lightning networks can detect many in-cloud flashes when their detection instruments are closely spaced, but these dense networks are available only in areas such as the United States and Europe. Over most of the remainder of the world, only cloud-to-ground flashed are detected. Lightning detection capabilities will increase dramatically when the United States launches its next geostationary satellite with a lightning mapper instrument in 2016. Europeans and Chinese will launch similar satellites in 2017. A lightning mapper observes the total lightning visually over its field of view. When these sensors are operational, there will be nearly global total lightning coverage.

Schneider Electric creates lightning density grids every 10 minutes at a 0.1 degree latitude/longitude resolution. Figure 3 shows an example. Figure 4 shows the interest field after the Fig. 2 grid is masked with the Fig. 3 lightning.

Figure 4 is analysis of the turbulence at the observed time of the lightning. To be completely useful to aircraft in flight, Schneider Electric forecasts this grid to one hour ahead. Each grid point is moved by two different vectors, (1) the advecting vector which represents how individual cells will move, and (2) the propogating vector which represents how the storm body will develop. The advecting vector is the wind at the freezing level while the propagating vector is the advecting vector summed with a vector along the parcel's original level equivalent potential temperature (Θ_e) gradient with a magnitude proportional to the

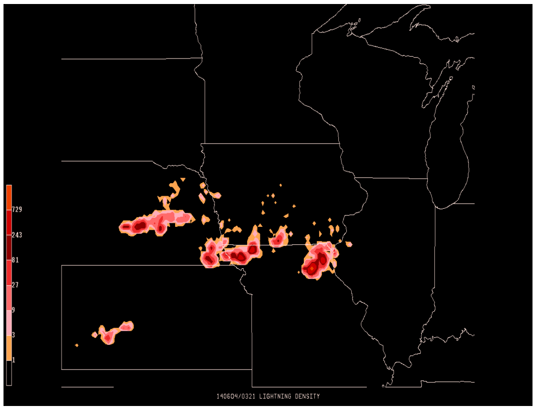

Figure 3. Flash density at 0321UTC 4 June 2014.

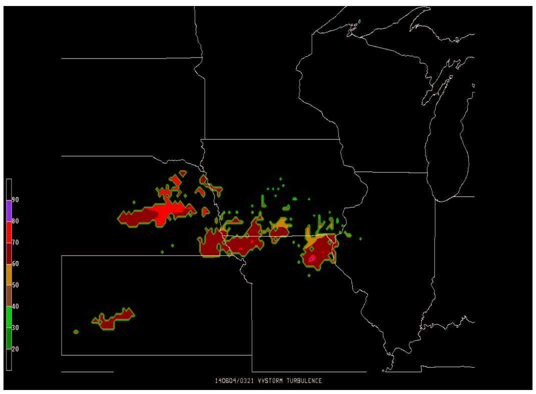

Figure 4. The turbulence potential in Fig. 2 after being masked by the lightning density in Fig. 3.

magnitude of the Θ_e gradient and the parcel's maximum potential updraft speed. The resulting grid is displayed in Figure 5.

The nowcast does not track the thunderstorms with which two observations are necessary. This allows the nowcast to respond to new storms quicker because it will forecast the storms as soon as they are observed. The nowcast depicts developing storms at their full potential. Furthermore, the nowcast will show storm intensification (weakening) if the storm moves into a more (less) potentially stable air mass.

The eastern Nebraska storms in Fig. 5 appear to move both northeastward and east-southeastward. In this case the advecting vector was from the southwest. One can infer from Fig. 2 that the Θ_e contours run west-northwest/east-southeast. Thus, the Θ_e gradient vector rotated the advecting vector to the right so that the propagating vector points to the southeast. New updrafts were forecast to develop as the storms propagate to the southeast. Indeed, this forecast scenario verified very well in the subsequent radar data (not shown).

The one hour forecast is not just the forecast one hour ahead but is a composite of all the turbulence expected in the upcoming hour. Schneider Electric chose to display the nowcast in this way in order to give users a single product to view. An alternative would be to create forecasts at, say, 10 minute intervals, but that would mean users would have to sort through 6 images versus the one composite image.

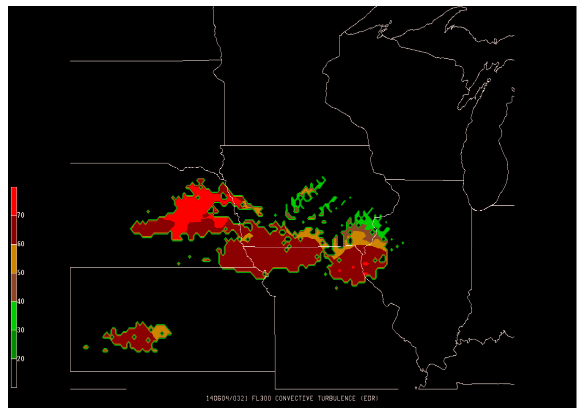

Figure 5. The Fig. 4 potential turbulence analysis forecast for one hour.

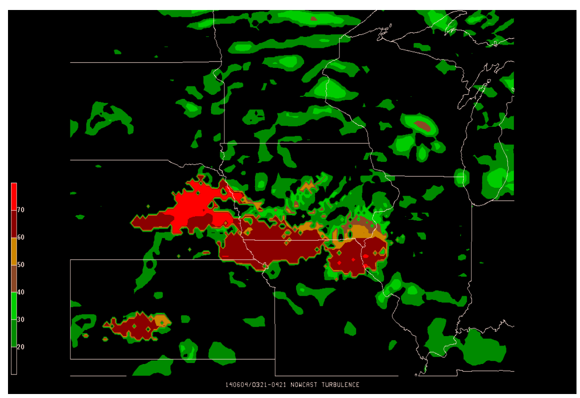

Figure 6. Same as Fig. 5 except with the non-convective turbulence added.

Figure 6 shows the complete turbulence first guess by adding the non-convective and the convective turbulence. Figure 7 shows a successful prototype nowcast that would have been available to an Allegiant MD88 aircraft 10 minutes prior to encountering severe turbulence at FL330 as it was cruising northward. The aircraft was forced an emergency diversion to St. Petersburg, Florida. Just a slight deviation to the left would have avoided the turbulence. Figure 8 shows a similar nowcast 30 minutes prior to a severe turbulence encounter at FL120 by an EasyJet A319 as it was approaching Naples, Italy. This aircraft diverted to Rome, Italy. Had the aircraft viewed this nowcast, it could have requested a different route to avoid the forecast turbulence.

c. Adjusting the first guess

Once the first guess is in place, Schneider Electric adjusts it with high quality turbulence observations. One source is the set of *in situ* EDR observations collected on aircraft with software onboard that automatically calculates and transmits the turbulence (Sharman et al., 2014). These are available with a frequency as high as one per minute.

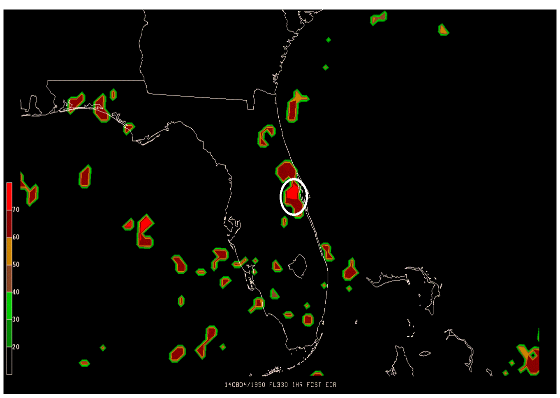

Figure 7. A 1950UTC 4 August 2014 FL330 prototype nowcast that would have been available to an Allegiant Air MD88 that encountered severe turbulence at 2000UTC. The turbulence was caused by the storm circled in white.

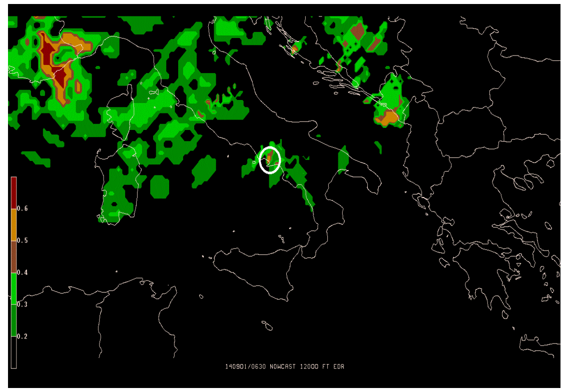

Figure 8. A similar nowcast as Fig. 7 for 0630UTC 1 September 2014 FL120 that would have been available to an EasyJet A319 that encountered severe turbulence at 0700UTC.

Since the EDRs in Schneider Electric turbulence forecasts are calibrated to the EDR observations, the observations may directly modify the first guess grids. Schneider Electric assimilates these observations with a three-dimensional statistical interpolation technique. Horizontally, we use an elliptical area of influence oriented along the wind direction with eccentricity proportional to the wind speed. The elliptical area of influence is equal to a 200 km circular radius. Vertically, observations influence grid points within 3000 feet. The assimilation volume resembles a football as shown horizontally in Figure 9.

The nowcast assimilates only EDR observations within one hour of the nowcast time. Figure 10 shows the resulting nowcast after ingesting all the EDR observations including the Fig. 9 0.75 EDR into the Fig. 1 first guess.

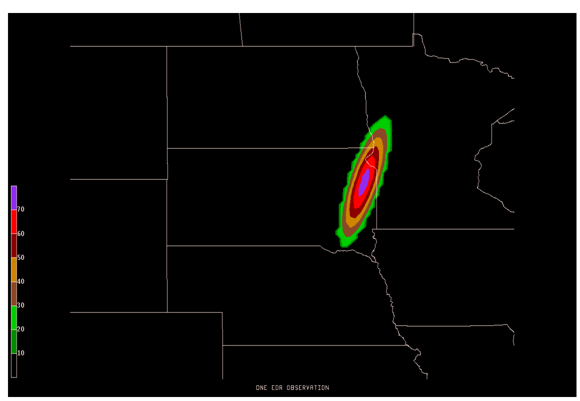

Figure 9. An assimilation of a 0.75 EDR observation if all first guess grid points were zero.

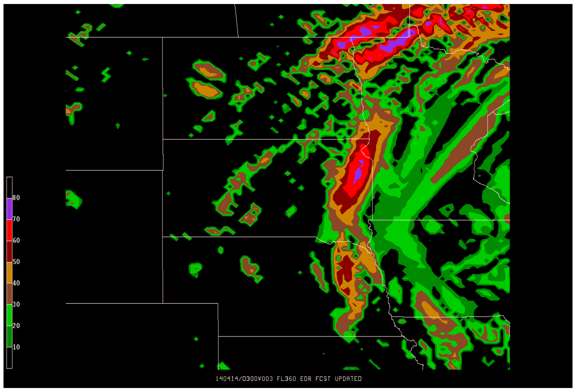

Figure 10. The resulting nowcast after adjusting the Fig. 1 first guess for all the EDR observations available one hour prior including the 0.75 EDR observation over eastern South Dakota.

The nowcast assimilates voice pilot reports similarly as *in situ* EDR observations but with much more quality control. Each pilot report is first assigned an EDR based on its reported subjective intensity.

Light	0.15
Light-Moderate	0.25
Moderate	0.35
Moderate-Severe	0.45
Severe	0.55
Extreme	0.75

Then the EDR is adjusted for aircraft type. Tipps et al. (2000) describe a simple aircraft turbulence response factor (*A*) that accounts for how much turbulence an aircraft will subjectively feel. With this, the EDR necessary for an aircraft type to experience a particular turbulence intensity may be estimated. Schneider Electric's turbulence forecasts assume its EDR forecasts are standard for a Boeing 737-800. The formula to adjust the EDR is

$$EDR = EDR_{PIREP}\left(\frac{A_{B738}}{A_{acft}}\right)^{1/3}$$

where

$$A = \frac{V\ S}{M}.$$

In *A*, *V* is the typical cruise velocity, *S* is wing surface area, and *M* is the aircraft maximum take-off mass. Some of the nearly 700 aircraft types in the database are

B738	.3650
A345	.2858
GLF5	.6443
C172	.9186

For example, a moderate turbulence report from a C172 will adjust downward from 0.35 EDR to 0.26 EDR.

To account for the questionable pilot report locations, only pilot reports with adjusted EDR/first guess errors greater than 0.1 EDR of all grid points within 150 km and 3000 feet vertically are assimilated.

Assimilating aircraft turbulence observations is like a pilot asking for ride reports, only all reports are incorporated in the nowcast. The pilot has the ride report's location and impact within the nowcast displayed before him/her.

3. SUMMARY

Schneider Electric has developed a turbulence nowcast that is issued globally every 10 minutes at all flight levels from the surface to FL500. The nowcast displays recent turbulence observations such as *in situ* EDR reports and voice pilot reports. Where there are no reports, the nowcast uses the upcoming hour INTTURB non-convective turbulence forecast and the one hour forecast convective turbulence from the convection as observed by lightning density data.

The nowcast is unique from other nowcast products because it is a one-stop-shop for all turbulence sources. Users are not forced to mentally integrate data from several data services.

The nowcast is modular so will accommodate future observation platforms/techniques with satellite or radar data. A promising candidate is the NCAR Turbulence Detection Algorithm (Willams et al, 2006) although only available over the United States.

The nowcast is compatible with display software including tablets for cockpit users. Schneider Electric anticipates the nowcast to be integrated with flight following software, including its own Flight Watch® program. The nowcast will be invaluable to flights without onboard radar. Even those with radar have to mentally estimate where storms are heading to efficiently avoid them. Furthermore, radar may not see the most turbulent storm portions, and, of course, radar does not detect non-convective turbulence.

ACKNOWLEDGEMENTS

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