Applying a nonlinear transformation to the analysis of surface visibility and cloud ceiling height

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Real-Time and Unrestricted Mesoscale Analysis Systems

The Real Time Mesoscale Analysis (RTMA) and the UnRestricted Mesoscale Analysis (URMA) are 2D variational analysis systems that first went into operations at NOAA in 2006 and 2013, respectively. The systems provide gridded analyses of surface pressure, temperature and moisture at 2 meters above ground level, wind speed/direction and wind gust at 10 meters, significant wave height, ceiling height and visibility, and cloud cover for the contiguous United States (CONUS), Alaska, Hawaii, Puerto Rico, and Guam (Pondeca et al. 2011). In December of 2017, the rapid-update RTMA (RTMA-RU) system was added to the RTMA operational suite, refining the hourly-updated analysis to 15-minute-updated analysis for CONUS.

The three components of RTMA are a downscaling and first guess process leveraging short-term forecasts from the best-available convection-allowing model output (e.g., the High Resolution Rapid Refresh); an analysis process using the NOAA Grid-point Statistical Interpolation (GSI) system; and a post processing step to convert the guess and analysis into GRIB2 format, as well as estimate the analysis error using a Lanczos-based method (Pondeca et al. 2011). The system assimilates observations from a variety of platforms including surface observing systems, mesonets, buoys, geostationary satellite cloud products, scatterometer winds, and altimeter-derived significant wave heights. This paper focuses on efforts toward improving the ceiling and visibility analysis through a nonlinear transformation of the variables.

Objective

The objective is to improve ceiling and visibility analysis by employing a nonlinear transformation technique into RTMA. Analyzing ceiling and visibility is very challenging, mainly because the fields are highly discontinuous in space and time. While poor visibility and low cloud ceiling are typically rare events, they are critically important to general aviation, commercial transportation, and helicopter emergency rescue services.

There are two advantages from this new algorithm: 1) the transformed variables better adhere to a Gaussian distribution, therefore leading to a better analysis; 2) the errors associated with the linear approximation are eliminated. In the previous algorithm, a linear approximation was required to combine the penalties calculated in logarithmic space with those calculated in the state space. The new algorithm eliminates this step because all computations in the analysis process are computed with the transformed ceiling and visibility (Yang et al. 2018).

Nonlinear Transformation and parameter estimation

The general nonlinear transformation formula (Purser, personal communication) takes the following form:

$G(p;x) = [x^p - 1]/p$

Here, x is the variable to be transformed and p is a real constant. The transformation converts x, which is not a Gaussian variable, into the space of $G(p;)$. The transformed variable possesses a Gaussian distribution. Figure 1 shows the function family with several p values: when $p \rightarrow 0$, $G(p;x)$ is the natural logarithm function, whereas when p=1, it is a linear function.

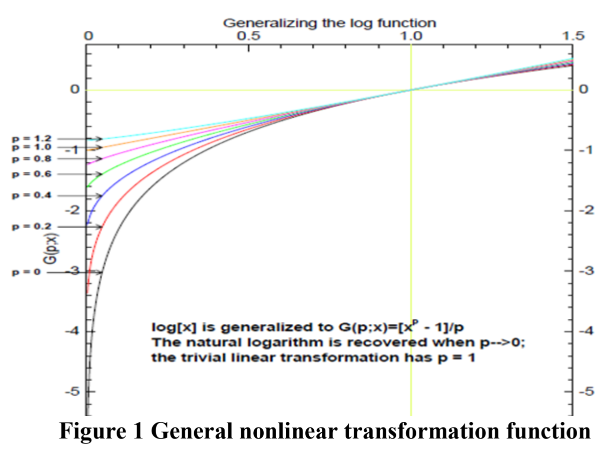

Figure 1 General nonlinear transformation function

The procedure to determine p was done empirically in the following way: given a value, p confined to a range [0-1], we apply $G(p;x)$ to both observations and the first guess, and compute the innovation. The median of the innovations is then used to divide the data into two groups, one with values less than the median (denoted as R1), the other with values equal to or larger than the median (denoted as R2). A histogram is computed for each group. The same computation is then repeated using the data set generated by $G(p;x)$ with a different p value. Here we defined the so-called optimal p when the following criterion was satisfied: if the histogram shapes of R1 and R2 change significantly with different p values, an optimal p exists between these two adjacent values. In practice, the resulting histogram of R1 is the one closest to Gaussian distribution among all other histograms (e.g., Fig. 4 of Yang et al. 2018). In this application, $p = 0.2$ for visibility and $p = 0.1$ for cloud ceiling.

We analyzed data sets of the innovations from multiple RTMA analyses to obtain a range of approximate error statistics. Single observation tests were also used to check and adjust these statistics. A real-time test run spanning several months was also leveraged to adjust the statistics based on the overall analysis fits to the observations.

Assessment and Examination of Results

The experiment run started March 2018 and continued for several months. The corresponding control run for the comparison was performed with the previous ceiling and visibility analysis algorithm used in the operations. The metrics for assessment focused on comparisons between the control and the experiment throughout examination of the overall analysis fits to observations, visual inspection of the 2D-fields, and multi-level contingency tables based on flight category definitions. A preliminary assessment shows the experimental runs produce a consistent reduction in RMSE but yield a slightly larger bias for visibility. The comparisons of 2D fields revealed that the experimental run represents the fine-scale structures of the ceiling and visibility field, particularly in areas with significant weather systems. The details are described in Carley et al. (2018). Table 1 lists the Hit Rate and False Alarm Rate computed from the observed and analyzed visibility, generated by the control and the experiment with RTMA-RU, over the CONUS for the period of 03/31 – 04/03, 2018. The Hit Rate indicates a system's ability to detect an event of interest, while False Alarm Rate describes the fraction of events that were forecast but did not occur. The table clearly demonstrates that the experiment improves the Hit Rate and reduces the False Alarm Rate in all four flight categories for visibility. Similar improvements are found for ceiling (not shown).

Table 1. Hit Rate and False Alarm Rate (x 100) computed from observed and analyzed visibility generated by the control and the experiment. False Alarm rate is annotated in brackets.

	LIFR Low Instrument Flight Rules Visibility < 1 mi.	IFR Instrument Flight Rules 1 mi <= Visibility < 3	MVFR Marginal Visual Flight Rules 3 mi <= Visibility <= 5	VFR Marginal Visual Flight Rules Visibility > 5
Control	48.84 [1.34]	50.28 [1.77]	49.96 [2.32]	98.39 [10.63]
Experiment	71.99 [0.48]	70.04 [1.44]	62.10 [2.00]	98.61 [5.55]

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