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4.5 Ensemble forecast of ceiling, visibility and fog with NCEP Short-Range Ensemble Forecast System (SREF)

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Abstract

The NCEP SREF System is an ensemble forecast system composed of 21 ensemble members generated from multiple models (Eta, WRF, RSM), multiple physical schemes and breeding of initial conditions. The forecast domains cover the Continental US (CONUS), Alaska and Hawaii regions. The SREF System was implemented operationally in 2001 and has since then been upgraded every year. In 2002 it was extended to aviation weather including 14 aviation products. In this paper, the focus will be given on visibility, ceiling, flight condition restriction and fog ensemble forecasts from the SREF system. The SREF aviation products are routinely generated but still experimental and displayed on NCEP website as reference for local forecasters and NCEP Aviation Weather Center(AWC).

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1. Introduction

The NCEP SREF system began in 1996 and become operational in 2001 (Du and Tracton 2001). The SREF aviation products were developed in 2002 with FAA support (Zhou et al. 2004). Since 1996 the SREF system has gone through several upgrades, from its earlier version with 15 members of ETA model and regional spectral model (RSM) to the later version of 21 members with including NMM-WRF model of NCEP and ARW-WRF model of NCAR and more physical schemes (Du et al. 2006). Recently the SREF system was further enhanced with adding more WRF members, covering more regions from CONUS to Alaska and Hawaii, and increasing the running time from two cycles (09 and 21Z) per day to four cycles per day (00, 06, 12 and 18Z). The forecast output intervals was also increased from 3 hours to 1 hour as well. The increase in running cycles and output frequency are crucial to timely deliver the SREF aviation products to local forecasters. But until we wrote this paper, the upgrade of SREF aviation products has still not been finished following the recent upgrade. In this paper we will focus on ceiling, visibility, flight restriction condition and fog products generated from the SREF system with 2 running cycles/day and every 3 forecast hours outputs.

Ceiling, visibility, flight condition restriction condition and fog, or C&V products, are critical weathers that strongly affect the air traffic management at airports and considerably concerned by airport forecasters. However, the forecast skills of these four forecasts from single models are notoriously low due to special and sophisticated PBL cloud procedures

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involved in numerical weather prediction (NWP) models. The NCEP SREF system are composed of multiple models with multiple cloud parameterization schemes, in which the conditions favorable for low visibility, low ceiling and fog could be more effectively captured by the ensemble system near the surface. The SREF C&V forecasts have been running for several years but the comprehensive verifications for these four forecasts are still not conducted yet. In this paper we only present the system structure and primary assessments based on the limited evaluations by some local forecasters.

Table 1. SREF member's configurations

Models (members)	Physics	Micro-Physics	Res(km) & levels	PBL	Sfc Boundary Layer	Base IC & BC	Long wave	Short wave	LSM
Eta (3)	BMJ	Ferrier	32/60	MYJ	Janjic similarity	NDAS/GENS	GFDL	GFDL	NOAH
Eta (2)	BMJ-SAT	Ferrier	32/60	MYJ	Janjic similarity	NDAS/GENS	GFDL	GFDL	NOAH
Eta (3)	KF	Ferrier	32/60	MYJ	Janjic similarity	NDAS/GENS	GFDL	GFDL	NOAH
Eta (2)	KF-DET	Ferrier	32/60	MYJ	Janjic similarity	NDAS/GENS	GFDL	GFDL	NOAH
WRF NMM (3)	NCEP/BMJ	Ferrier	40/52	MYJ	Janjic similarity	GDAS/GENS	GFDL	GFDL	NOAH
WRF ARW (3)	NCAR/KF	Ferrier	45/36	YSU	MO similarity	GDAS/GENS	RRTM	Dudhia	NOAH
RSM (3)	SAS	Zhao-Carr	45/28	MRF	NCEP/GFS	GDAS/GENS	RRTM	NASA	NOAH
RSM (2)	RAS	Zhao-Carr	45/28	MRF	NCEP/GFS	GDAS/GENS	RRTM	NASA	NOAH

2 SREF system configuration

The SREF system is built with four base models including ETA model, WRF-ARW, WRF-NMM and RSM models, running twice a day (09Z and 21Z) over CONUS, Alaska and Hawaii out to 87 forecast hours with output in every 3 hours. Perturbed initial conditions (IC, breeding method) as well as multiple convection schemes and cloud schemes with same lateral boundary condition (BC) and same land surface model (LSM) are used to generate a total of 21 ensemble members, including 10 ETA members, 3 WRF-ARW members, 3 WRF-NMM members and 5 RSM members. The detailed physical schemes initial/boundary conditions are described in Table 1, where BMJ refers to Betts-Miller-Janjic, SAT to saturated moisture profiles, KF to Kain-Fritsch, DET to full cloud detrainment, SAS to Simple Arakawa Shubert, RAS to Relaxed Arakawa Shubert, NDAS to NAM data assimilation system, NAM to North American Mesoscale Model of NCEP, GDAS to GFS data assimilation system of NCEP, GFS to global forecast system, GENS to GFS ensemble forecast system of NCEP, MYJ to Mellor-Yamada-Janjic PBL scheme, YSU to Yonsei University PBL scheme, MRF to Medium-Range Forecast system PBL scheme, MO to Monin-Obkhov similarity, GFDL to Geophysical Fluid Dynamics Lab, RRTM to rapid radiative transfer model, NOAH to NOAA, Oregon State University, Air Force and Hydrological Research Lab. Recently, the SREF system has been further enhanced by increasing more WRF members, but this new upgrade has not been implemented into operation yet. It should be noticed that all of cloud schemes were designed for the upper level clouds instead of the lower level clouds near the surface like fogs. However, the upper level clouds significantly affect the procedures within PBL and the atmospheric conditions near the ground. Using multiple models and schemes aims at improving the predictability of the ensemble system, or increasing the spread of the ensemble forecasts. We hope that this is also true for aviation weather, particularly for visibility and ceiling forecasts. The general framework of the SREF aviation products is similar to the SREF regular weather products as shown in Figure 1. For each running cycle, the model outputs (all of prognostic fields like temperature, humidity, winds, cloud, etc. at the surface and sigma-levels) are stored in a binary file for each individual member and every forecast output. Thereafter a unified WRF post is conducted for each individual member to generate diagnostic variables, which are interpolated to 40 standard-pressure levels plus the surface. The post-processed results are stored in native-grid GRIB covering North America, Canada, Alaska and Hawaii. The NCEP unified WRF post is designed in such a way that it can process all of NECP operational models and generate the similar products on same standard pressure levels and the surface from these models including regular weather variables, C&V products and other aviation weather products . The native-grid GRIB files for individual members are thereafter further processed by so-called "Pro-Gen", which, as requested by the SREF system, splits the native-grid products to CONUS 212-grid, Alaska 216-grid and Hawaii 243-grid respectively. After "Pro-gen", the vertical levels are not changed, still as same as those in the native-grid GRIB files. The detailed geographical definitions for these three grid GRIB formats can be found from the NCEP mesoscale model website www.emc.ncep.noaa.gov/mmb/namgrids/

The individual member's GRIB files for these three grids can be accessed and downloaded from NCEP NOMADS web site. The next step is processing individual members to generate ensemble products. The procedure is sending the 212, 216 and 243-grid individual GRIB files, respectively, to a unified Ensemble Product Generator to create ensemble mean, spread and probability products for requested regular and aviation variables on selected standard pressure levels and on the ground, such as C&V products. In current version of the SREF system, the mean, spread and probability for different grids (212,216 and 243) are stored in mean, spread and probability files, respectively, in the same grid format as the individual members. The last step is sending the ensemble product files via the AWIPS, or the Advanced Weather Interactive Processing System, to local forecasters in the Weather Forecast Offices (WFO) of National Weather Service (NWS) routinely. The local forecasters can further digest or re-analyze the ensemble data for their own purposes. At NCEP, the ensemble products are processed with GrADs, a meteorological graphics tool, to generate graphic plots and displayed on the NCEP SREF web site: www. emc.ncep.noaa.gov/ /mmb/SREF_avia/FCST/AVN/web_site/visb/ cnv_com_09z_prb1.htm.

This website is updated twice a day. The 21Z run plots are actually for the 21Z run in the previous day. Many users are strongly asking for zooming capability in the SREF web site. But the current computing resources distributed to the SREF system are still very limited, so zooming function is still not available as of now.

3. Methods

As is discussed, all of aviation products in NCEP SREF system are diagnosed in its post processor. Since the C&V products are cloud related, they are diagnosed from model cloud-related variables such as cloud amount, cloud base, and cloud liquid water content (LWC) near the ground output from each member from the SREF system. The advantage of diagnosis methods is that they are simple and fast. At current stage, diagnosis from post processors is still most efficient way for those C&V products in the SREF system.

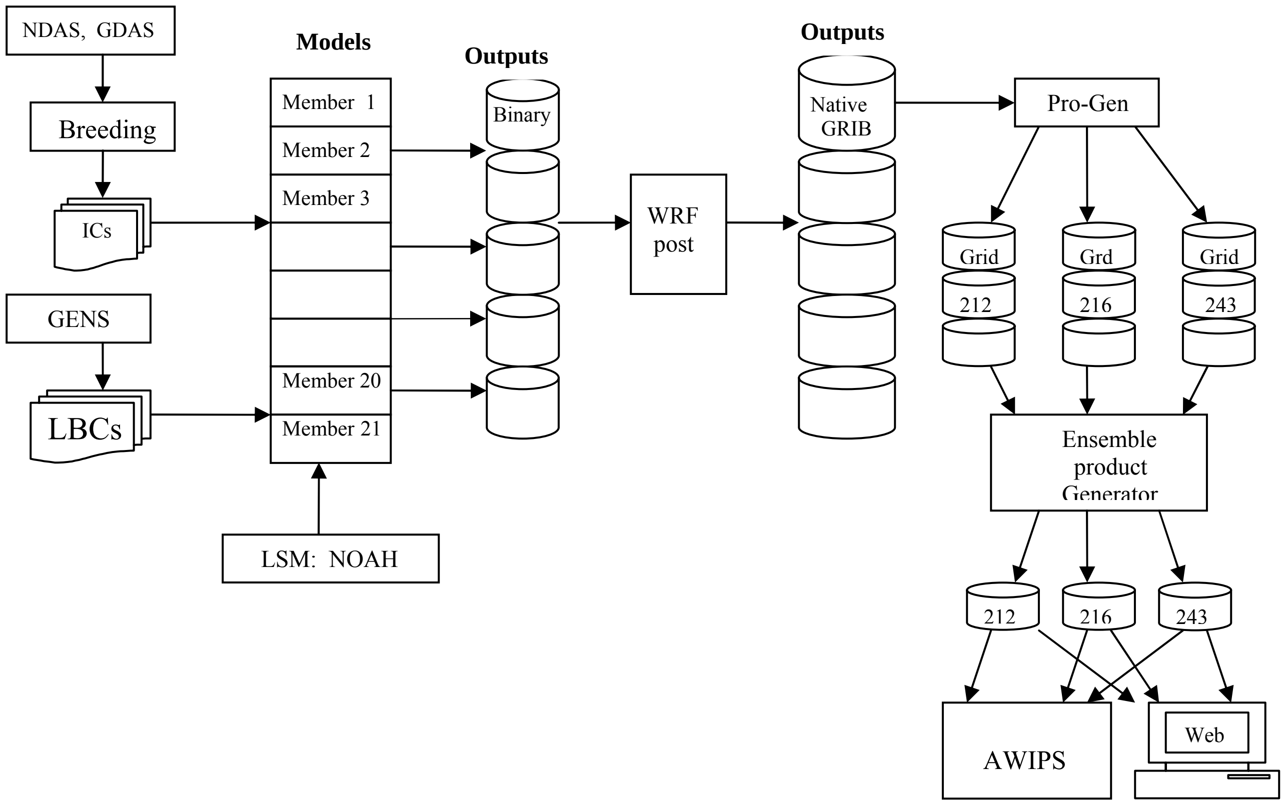

Figure 1. NCEP SREF System Configuration

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3.1. *Ceiling*

Ceiling height, or ceiling, is low cloud base height information, and is, according to Federal Meteorological Handbook No.1 (FMH-1,1995), defined as the height of lowest cloud layer aloft reported as broken or overcast. At a grid point in a SREF member, if it is cloud-free, the cloud base is set to a very large value (e.g. 50,000 feet). Therefore, clear and scattered members are not involved in the ceiling mean computation. The ensemble probabilities are computed based on a set of ceiling height thresholds: less than 500, 1000, 2000, 3000, and 4000 feet. The probability at a grid point for a specific threshold, c_i, is computed as following

$$P(ceiling < c_i) = \frac{n_i}{N} \times 100\%, \qquad (1)$$

where n_i is the number of members with ceiling $< c_i$ at this grid point; N is the total ensemble members (or 21). The ensemble mean at a grid point is an arithmetic average value of all members with equal weight while the spread is their standard deviation. However, the ceiling mean and spread in the SREF system are calculated on "*conditional*" base, which excludes those cloud-free members from the mean and spread computations. Such "conditional" mean and spread can avoid a conceptual contradiction in such a situation at a grid point when there are only a few cloud-free members, for instance, 4 members without ceiling but all other have low ceiling of 2000 feet. In this case the regular mean value is (2000 ×17 + 50,000 ×4) ÷ 21 which gives rise to 11143 feet. This value shows almost no ceiling at this point, providing misleading ensemble information at this point. But if with conditional mean, the value will be 2000 feet which is more representative for the most ensemble members.

3.2 Visibility

Surface visibility range, or visibility, is computed from the WRF post, where the visibility is expressed with a relatively simple equation

$$Visibility(km) = \frac{-\ln(0.02)}{\beta}, \qquad (2)$$

where β is an extinction coefficient, which is computed from the LWC at lowest model level above the ground using the relationship suggested by Stoelinga and Warner (1999). The mean value of visibility is also defined as "conditional". The effects of haze and sand storms are not considered in the visibility computation since there are no such parameters in the ETA, WRF or RSM models. As described by Stoelinga and Warner, the β value is determined by all of hydrometeors such as rain, snow, drizzle, fog, etc. One of advantages for current NCEP operational models is that the hydrometeor types can be identified and partitioned at each grid near the surface in the WRF post. In the SREF system, the unit of visibility is converted from km to mile in compliance with the aviation weather convention. The visibility thresholds are set as less than 0.5, 1, 3, and 5 miles, based on which the ensemble probabilities at all of grid points near the surface can be computed with a similar method as Equation (1).

Table 2. Flight restriction condition

Category	Ceiling (ft)		Visibility (miles)		Sky type
LIFR	< 500	AND/OR	<1	AND	Broken or Overcast
IFR	500 ~ 1000	AND/OR	1 ~ 3	AND	Broken or Overcast
MVFR	1000 ~ 3000	AND/OR	3 ~ 5	AND	Broken or Overcast
VFR	> 3000	AND	> 5	OR	Clear or Scattered

3.3 Flight restriction condition

The flight restriction condition, or flight categories, include Low Instrument Flight Rule (LIFR), Instrument Flight Rule (IFR), Marginal Visual Flight Rule (MVFR), and Visual Flight Rule (VFR) as defined in the National Aviation Weather Initiatives (FCM-P34-1999). These four flight categories are combinations of effects of ceiling, visibility and cloud amount, see Table 2. The WRF post first find the occurrence of each category at all of grids near the surface (1 for LIFR, 2 for IFR, 3 for MVFR and 4 for VFR) for all of individual members. In the Ensemble Product Generator, the probabilities for each category are computed by checking and counting the occurrence conditions in all ensemble members.

$$P(f_i) = \frac{n_i}{N} \times 100\%, \qquad (3)$$

where n_i is the number of members with flight category f_i at this grid point; N is the total ensemble members. There is no mean or spread for flight category in the SREF system.

3.4 Fog

Fog ensemble product was new added recently to the SREF system. One of reasons for adding fog is that it significantly reduces the surface visibility at airports when it happens. Although fogs have been extensively studied with surface *in situ* observations or numerical simulations, the progress in operational forecast at NCEP or other weather centers is very slow due to its complexity and low predictability of current operation models. As of now, fog is still not a guidance from NCEP operational forecast but diagnosed by local forecasters with other indictor variables like humidity and wind speed near the surface. Because such local diagnosis of fog is strongly relied on the experience of local forecasters, a central guidance for fog from NCEP is inevitably required. It has been well recognized that a major huddle to fog forecasting in current NWP model is in physical schemes which are usually designed for clouds at higher levels or precipitations instead of fogs near the ground. In addition, the vertical resolution near the surface in regular NWP model, such as ETA, WRF and RSM, is about 30 ~ 40 meters, which is too coarse for fog prediction since many ground fogs are of 30 ~ 40 meters in depth. In other words, there is a 30~40 meter uncertain vacancy between the lowest cloud base and the ground for fog in current models. Therefore modeled LWC at lowest levels is not reliable to represent real fog. At current stage, only fog occurrence instead of its intensity (or LWC) could be predicted by diagnosing the fog conditions through cloud base and cloud top information from each individual member as following thresholds:

$$\text{Cloud base} < 30\ m,\ \text{AND} \quad \text{Cloud top} < 400\ m. \qquad (4)$$

In (4) "*AND*" means that only both cloud base and cloud top conditions satisfied simultaneously at a grid point can fog occur. The threshold "*30 m*" for cloud base reflects the lowest sigma level height above the ground and threshold "*400 m*" for cloud top considers the maximum depth of marine fog over waters. Since only fog occurrence but no intensity is diagnosed, only fog occurrence ensemble probability is computed in the SREF system. The procedure is, the occurrence of fog at all of grid points are detected in each individual member, 0 for non-fog, 1 for fog. Then the fog occurrence probabilities are calculated based on the statistics of fog occurrence members.

Fig 2 (a-d) show examples of ceiling, visibility, flight category and fog forecasts on CONUS, Alaska and Hawaii.

4. Verification

In each upgrade of the SREF system, various service centers at NCEP will conduct verifications over several months testing periods. But such verifications do not include the aviation products since they are still not operational. In fact a comprehensive and objective verification of the SREF C&V forecasts at NCEP is still difficult due to: (1) C&V observational data sets are still not available in the context of ensemble verification procedure, and (2) the ensemble verification systems built at NCEP are for regular weather not for aviation products. Thus much more efforts are waiting for NCEP to establish such a system to objectively verify the C&V ensemble products. At current stage we encourage outside users and local forecasters to voluntarily evaluate the SREF C&V forecasts on local scales. At current stage we encourage outside users and local forecasters to voluntarily evaluate the SREF C&V forecasts on local scales. The recent collaborations between NCEP and the forecasters at Alaska and Now York offices are such good examples in which the SREF aviation data files in GRIB1 format are

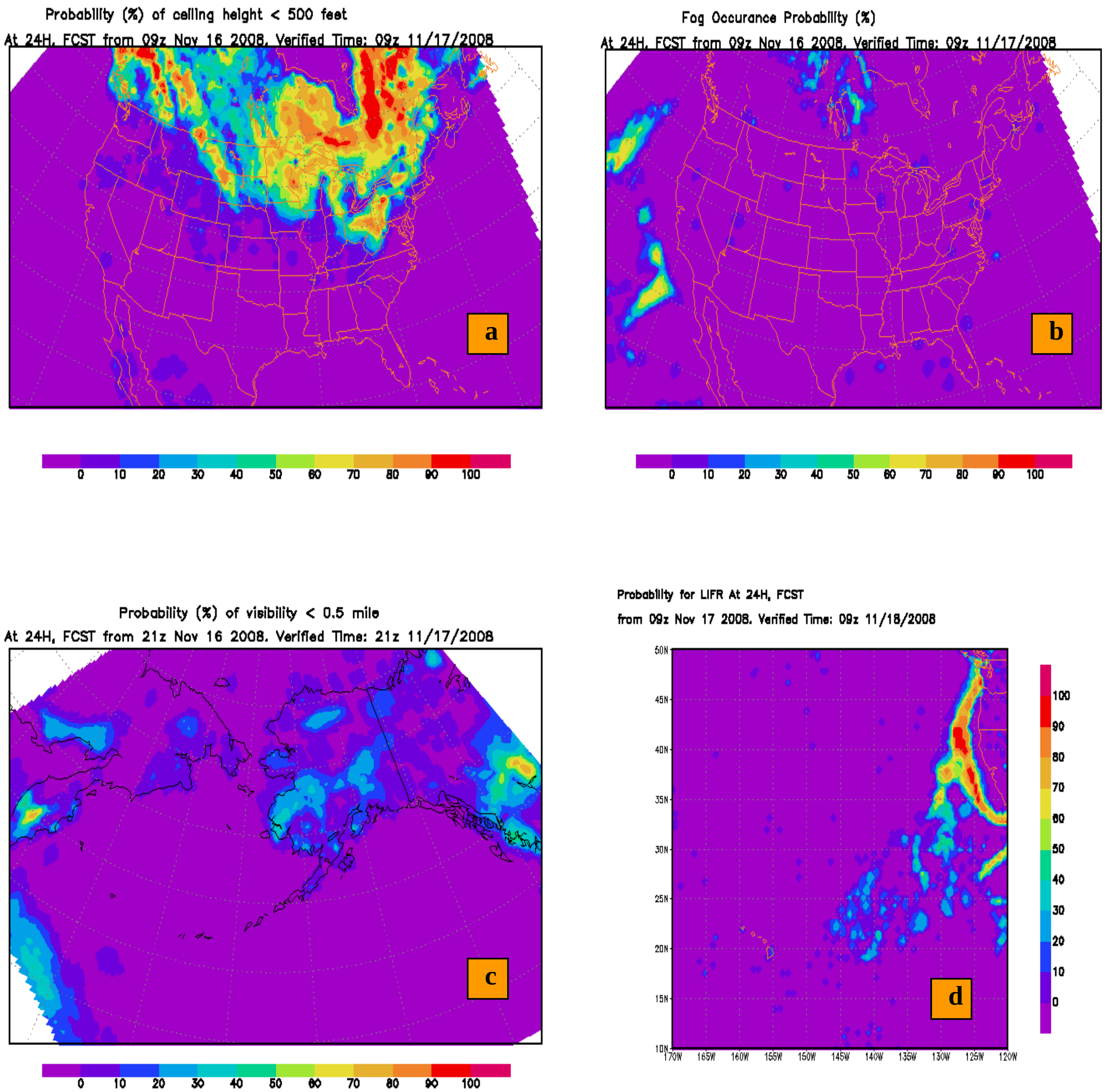

Figure 2. The examples of SREF C&V products, a: 24 hour forecast of ceiling probability < 500 feet over CONUS issued at 09Z Nov 16 2008; b: 24 hour forecast of fog occurrence probability over CONUS issued at 09Z Nov 16 2008; c: 24 hour forecast of visibility probability < 0.5 mile over Alaska issued at 21Z Nov 16 2008; and d: 24 hour forecast of LIFR probability over Hawaii issued at 09Z Nov 17 2008.

provided to the local forecasters through the NCEP FTP site, while the forecasters at Alaska and NY offices downloaded the data and verify the C&V products with their local observations in real time. The subjective assessment during May of 2008 by Alaska office showed that the SREF visibility forecast is not too bad but ceiling height is overdone, especially for areas over waters. The reason may be that the individual members could not correctly pick up lower level moisture (Alaska IC4D Report May 2008, Scott 2008). The objective verification by the New York office in August of 2008 indicated that the mean values of either ceiling or visibility have low skill and the SREF flight restriction category were found to be over-casted over eastern coast area, but the probability with certain thresholds, 20~30% for ceiling and 10% for visibility or MVFR/IFR, have skills comparable to GFS MOS forecasts (Justin Arnott of Binghamton WFO, New York, personal communications). The evaluations by the local forecasters have shown us a strong signal that the SREF C&V products are promising for providing direct C&V guidance from NCEP (instead of current MOS-based guidance) in the future, but such central forecasts require further improvements and upgrades.

The objective verification for the SREF fog forecast has never been done yet but some subjective evaluations with NESDIS LowCloud/Fog satellite detection images were performed in March 2007 over CONUS (Zhou et al. 2007), showing a general agreement in fog event patterns between the fog ensemble probability and the satellite images on lands and waters.

5. Future work

As with gradual upgrade of the NCEP SREF system, its aviation weather products, particularly the C&V products, will be upgraded as well. Since the performance of C&V products are strongly relied on the cloud schemes but NCEP could yet not employ C&V related cloud schemes in the near future, the best way to improve the C&V forecasts in the SREF system is improving the diagnostic methods in the post processor. Therefore our future work will focus on the new methods to more effectively detect ceiling, visibility and fog. For example, current ceiling diagnosis is based on model cloud base and total cloud amount. The new method has been suggested to be with cloud amount at various levels instead of only with total cloud. The fog diagnostic algorithm also needs improvement. The current fog algorithm only detects fog occurrence without considering turbulence. It has been well known that turbulence intensity plays critical roles in fog evolution. However, the turbulence intensity threshold for fog has long been a mystery. Recently Zhou and Ferrier (2008) found such threshold through an asymptotic analysis method. Although this analysis is for radiation fog, it can be easily extended to other types of fogs. We will develop a new algorithm to diagnose fog based on their work in the WRF post.

The second focus of our future work is on objective verification for SREF C&V products with surface and satellite data. The former is based on models (grid) against station observations (g2o), the later on grid against analysis data (g2g). Recently EMC of NCEP has dedicated significant efforts to development of these two tools, with which the SREF C&V products can be conducted with either station data or satellite data.

6. Summary

The SREF ceiling, visibility, flight restriction category and fog ensemble products have been developed and run for several years but they are still in experimental stage. Since these four C&V variables are closely related to model's cloud schemes usually not designed for low cloud/fog near the surface, they are diagnosed from model post processors based on which their ensemble products are generated. Due to lack of observational data at NCEP, as of now comprehensive verifications for these C&V ensemble products have not been done but some subjective and limited objective evaluations were conducted by local forecasters, showing their promising usage as guidance in the future. We plan to further dedicate our efforts to improvements of these products by employing new diagnostic methods and conducting objective verifications.

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