Nowcasting near-ground winter precipitation for aviation: a simple approach based on radar observation and NWP model outputs

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1. **Why simple?**

Severe winter precipitation over airport terminal maneuvering areas causes non-trivial economic and societal damages. Heavy snowfalls often cause flight cancelation and delay, and icing and freezing conditions near ground raise safety issues of affecting land-in and-off operation of the flight. In addition, such events result in extra costs associated with snow clearing tasks over runways, taxiways, aircraft surfaces, chemical usage for anti/de-icing, and staffing. To cope with these situations, pilots and ground/traffic controllers have been guided mainly with i) current weather information (snow, freezing rain, ice pellets, or drizzle) based on point measurements of aviation routine weather reports (METARs) and pilot weather reports (PIREPs) as well as ii) current temperature of pavement surface observed from the runway surface condition sensors specially installed at the airport (Prentice and Streu 2010).

Although numerical modeling of atmospheric variables has greatly improved, forecasting the wintry ground conditions is still challenging because various factors (e.g., profiles of temperature and humidity, existence of supercooled liquid water) can affect the final forms of precipitation on the ground and their solid-liquid transition processes. For better understanding of these factors, numerous research efforts have focused on

i. Improving and testing numerical model of winter precipitation (e.g., Liu et al. 2011), and
ii. Exploring identification of winter precipitation using radar reflectivity (Ikeda et al. 2009) and dual polarimetric radar (Bellon and Zawadzki 2007; Schuur et al. 2012).

In parallel, for practical airport operations, the combination of several observations and numerical model outputs has been applied to diagnosing and forecasting winter conditions in terms of

- *Snow equivalent rate*: the Weather Support Deicing Decision making system (WSDDM, Rasmussen et al. 2001) developed by the National Center for Atmospheric Research (NCAR) and the U. S. Federal Aviation Administration (FAA) utilizes snow gauge rate at the ground and radar reflectivity aloft. It provides an integrated display of real-time nowcasting based on such as Tracking Radar Echoes by Correlation (TREC) or Dynamic and Adaptive Radar Tracking of Storms (DARTS; Ruzanski and Chandrasekar 2012) valid for up to 1 hour.
- *In-flight icing conditions (supercooled liquid water)*: the Current Icing Potential (CIP, Bernstein et al. 2005) algorithm developed by NCAR and FAA integrates satellite, radar, surface, lightning, and PIREPs and diagnoses in-flight icing potentials using Fuzzy Logic approach.
- *Icing scenarios and intensity*: the Advanced Diagnosis and Warning system for aircraft Icing Environments (ADWICE, Tafferner et al. 2003), designed by the Deutsches Zentrum für Luft- und Raumfahrt (DLR) in Oberpfaffenhofen, Germany and further developed operationally by the German Meteorological Service (DWD), utilizes model atmospheric profiles together with current weather reports, and radar reflectivity, observation of cloud amounts, and estimation of the cloud base height.

However, these operational products still demand further research on specific/various observations that contain their own uncertainties to be better understood and on fusion strategies to deal in regionally different data availability, data quality, and observation representativeness due to the different temporal and spatial resolutions.

As a recent assessment to these issues, the meteorological decision support system for aviation (MEDUSA) is developed by DLR and HYDS within the EC's People Programme, Industry-Academia Partnerships and Pathways. To augment safety and efficiency of air transportation, its winter weather algorithms targeted at the ground level are based on the concept of fusion. One is a Fuzzy Logic approach using high-resolution model (COSMO-DE) and ADWICE outputs as well as various observations collected from the DLR polarimetric radar POLDIRAD, microwave rain radar (MRR), Particle Size Velocity optical disidrometer (PARSIVEL), and Aircraft Meteorological Data Relay (AMDAR) soundings over the Munich Airport area (Gerz et al. 2012). This extended-ADWICE algorithm will eventually provide nowcast of 3-D icing conditions in high-resolutions and still under development.

The other approach is combining only surface data (i.e., radar reflectivity, temperature from both NWP model and surface station), which is presented here. Our goal is to perform winter precipitation nowcasting in a simple framework using limited data sources and to assess its performance. Hence, the warning output would not be able to differentiate solid precipitation on the ground in detail. However, such a simple process allows us to address the problem and to better understand what can be expected with limited information, as well as to establish a baseline for the evaluation of the improvement achieved when extra observations or methodologies are added to the system. Besides, the warning output in terms of potential snow areas (PSA) can be generated in real-time and at low-cost, which can be practical for small airports. The performance of the algorithm is illustrated for a selected case over Munich airport together with some additional observations used in the framework of extended-ADWICE.

2. Data sources

We construct the algorithm with real-time hourly operational data, i.e., regional model surface outputs, radar reflectivity composite at low-level, and surface observations. Because of different grid spacing of each data source, we set the user-changeable common grid spacing with the radar grid of 0.01° × 0.01° in longitude and latitude for this study.

- *Digital elevation Model (DEM)*

ASTER GDEM2 (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) is freely accessible on-line[1]. It provides terrain heights as well as its quality matrices with a horizontal grid spacing of 1 arc-second, both in longitude and in latitude. This high-resolution data is re-mapped to the common grid (Fig. 1a).

- *Radar*

Radar reflectivity mosaics at low-level are available every 5 minutes from the DWD operational radar network composed of 17 Doppler radars at the C-band (5640 MHz) covering Germany (Helmert et al. 2011). The composite is made with the resolution of 1 km in range and 1 degree in azimuth after checking some spurious features such as positive and negative spokes and circles, speckles due to ground clutter and anomalous propagation over each reflectivity scan.

- *COSMO-DE*

COSMO (Consortium for Small Scale Modelling) at DWD, named COSMO-DE, has been used operationally covering central Europe including Germany, some parts of the neighboring countries, and most of the Alps. It has horizontal grid spacing of 2.8 km and features with i) the enhancement of cloud microphysics parameterization by adding a graupel class and the adaption for describing evaporation of rain and stratiform precipitation processes as well as ii) the ability of simulating convective processes by assimilating surface precipitation rate estimated from the radar composite with the latent heat nudging technique (Baldauf et al. 2011 and references therein). Although it provides variables at 50 model layers, we use mainly the 2-m level outputs. The cycle of 21 hours forecasts is rapidly updated every 3 hours and we consider 1 hour as a spin-up time (i.e., for the valid time of the 0000 UTC, we use the 2100 COSMO-DE run with a lead time of 3 hours).

- *SYNOP*

Surface observation data at 2 m height is provided hourly with up to 90 different parameters. In this study, we use standard variables of pressure (in hPa), temperature (in °C), dew-point temperature (in °C), snow depth (cm), and the current weather reports described in the code of WMO[2] for the validation and forecast verification of the potential areas of winter precipitation.

3. Detection of Potential Snow Areas

It is well known that the temperature variation below and above melting layer affects the type of precipitation on the ground (Schuur et al. 2012 and more references therein). However, our challenge is to use data available only near surface; mainly model temperature (T) at 2 m and near-surface radar reflectivity (Z) composite. Hence, the definition of Potential Snow Areas (PSA) here is rather the condition prone to have any solid precipitation (e.g., freezing rain/crystals/ice pellets/sleets). And, we detect the PSA based on temperature and reflectivity thresholds considering some aspects in data quality and fusion.

- *Temperature*

We set an initial temperature thresholds of below 2°C as a favorable to have solid precipitation on the ground, which will be checked with surface stations. Because of this simple constrain in temperature, the algorithm is critical to the quality of the model temperature input. Although the model is designed to capture small-scale atmospheric variations, temperature outputs show some departures from our truth provided by station measurements plotted as the black circles in Figs. 1b and 1c at different times. Hence, the interpolation of temperature to the common grid is taken into account merging the station

[1] http://GDEM.ersdac.jspacesystems.or.jp/
[2] http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/LatestVERSION/WMO306_vI2_BUFRCREX_CodeFlag_en.pdf

temperature at the analysis time with the spatial variability (or the structure) from the model as well as the adjustment of model temperature with respect to terrain heights assuming environment lapse rate. We statistically cross-validate the modified output applying leave-one-out. As shown in the red circles of Figs. 1b and 1c, the modified interpolation reduces the mean absolute error within 1°C. This approach can perform better in the environment restricted to have coarse resolution model outputs and mountainous terrains [e.g., Barcelona winter cases analyzed in Gerz et al. (2012)]. Furthermore, this temperature merging between model and station is applied to run the PSA nowcasting assuming that the initial frozen station temperature persists in the near future.

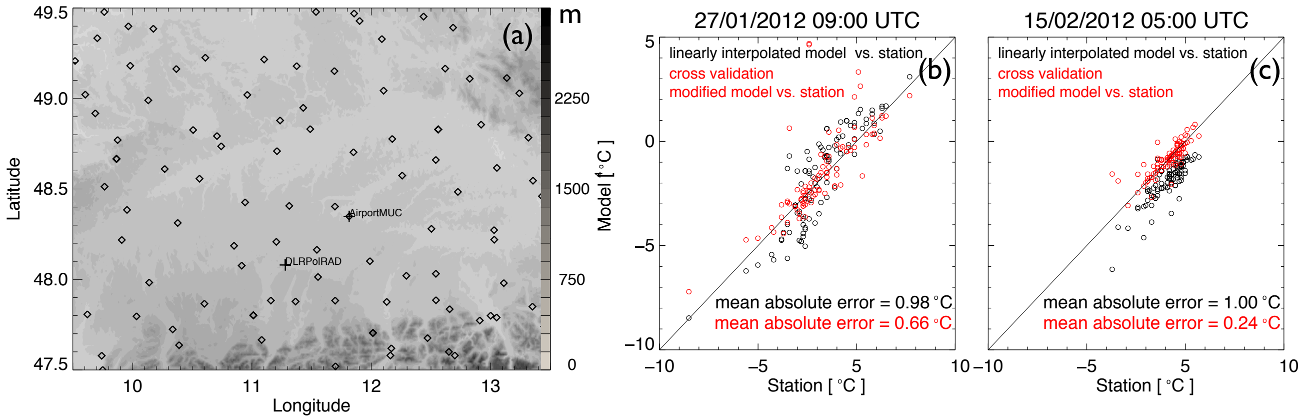

Fig. 1: (a) Orography over the analysis domain around Munich airport. Available surface stations are plotted in black diamonds. (b) Temperature comparison between model and station before correction in black circle after in red circle on 09:00 UTC, 27 Jan 2012. Station location is selected where the absolute difference in height between from terrain is less than 50 m (c) Similar as (c) for 05:00UTC, 15 Feb 2012.

- *Radar reflectivity*

The use of high reflectivity value as a threshold for the detection of winter solid precipitation is not as useful as for heavy rainfall estimation, yielding the significantly reduced area detected by radar. Hence, we allow the area of reflectivity larger than 0 dBZ as a favorable conditions to have solid precipitation.

- *Validation challenges*

For the validation of the detected PSA, we first categorize SYNOP reports as “snow, crystal like snow, ice pellet, snow grain, freezing rain/drizzle” at the time of observation not during the preceding hour and excluded for missing/no observation/no weather. Then, we define all of these as the SYNOP winter precipitation and plot it with the diamond symbol in Fig. 2 left. Also, more symbols are plotted considering its computability with other data sources; for example, because of some height differences between stations and common grids (often in the valley area near the Alps), we perform the analysis over the stations where their absolute height differences less than 50 meters (the red cross). Besides, the observations are excluded over the area with poor radar coverage due to beam blockage by hilly terrain (the blue cross). All these constrain cause the validation points over the domain to be only a few. Although station snow depth is available seen as red open circle in Fig. 2 left, the observation of solid weather report does not always coincide with those of snow depth. Hence, proper utilization of the ground information in terms of snow accumulation is not straightforward.

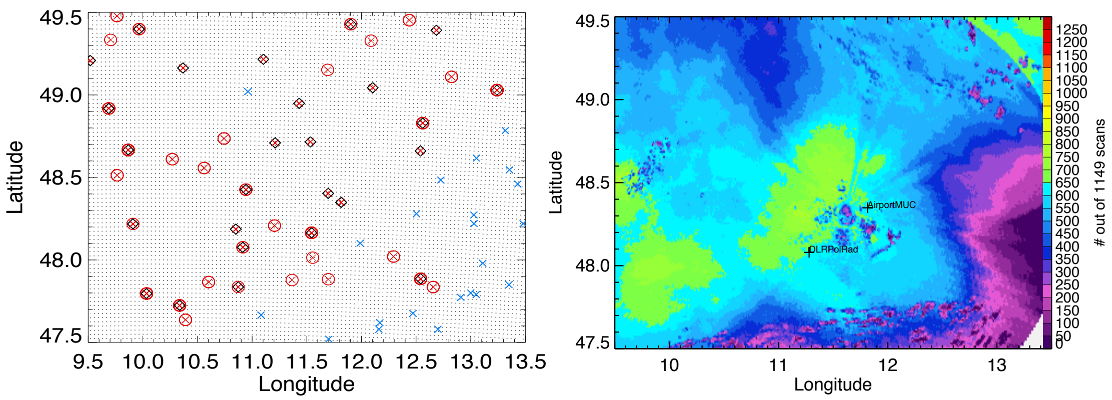

Fig. 2: (Left) Available SYNOP weather stations selected based on i) weather reports excluding no observation/no significant weather reported/missing (◇), ii) the absolute height differences less than 50 m between stations and terrain (×), and iii) free of the radar blockage marked as blue cross (X). The point of snow depth report (○) is plotted as well. (Right) The blocked area is determined by computing the frequency reflectivity scans (1149 scans on 29 Nov 2010, and 27 Jan, 14 Feb, 15 Feb 2012) exceeding 0 dBZ.

4. An example case of PSA analysis and nowcast

To illustrate the performance of the Potential Snow Areas algorithm, we have chosen the snow/freezing rain event of 27 Jan 2012. As shown in Fig. 3, observation from the Micro Rain Radar and SYNOP/METAR report over the Munich airport (left and right respectively) show snow conditions around 09:00 UTC (small Doppler velocity) transformed into freezing rain one hour later (increasing fall velocity and reflectivity). This is supported by the icing scenarios near surface diagnosed by ADWICE algorithm that indicates the freezing conditions started around 10:00 UTC.

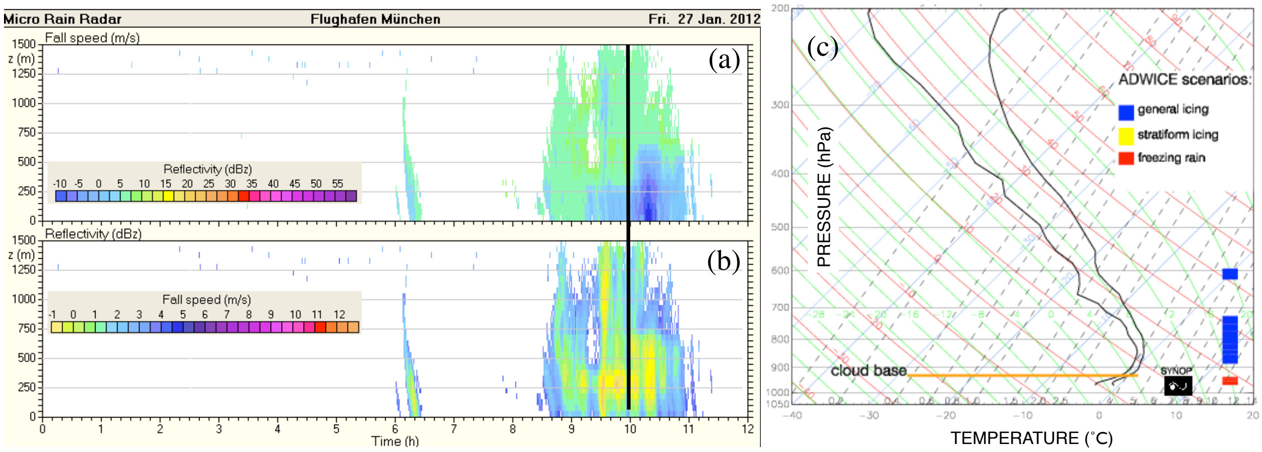

Fig. 3: A selected case on Jan 27 2012. MRR time series of (a) Doppler fall velocity in m/s and (b) reflectivity in dBZ at the MUC airport between 00 and 12 UTC. Sounding (COSMO) at MUC airport and ADWICE diagnoses at 10:00 UTC (c).

Based on the threshold of temperature colder than 2°C and radar reflectivity larger than 0 dBZ, Fig. 4 shows the preliminary results of the detected Potential Snow Areas with the yellow contour. The left column of "verification" indicates the analysis time 09:00 UTC and 10:00 UTC 27 Jan 2012 (top and bottom respectively). The right column is PSA nowcasts for the lead time + 01 hour. The model temperature is mostly below 2°C over the domain at both times indicated with the grey contour. Here, we generate the PSA nowcasts by combining the sources below:

- Hourly forecasted model temperature. Up to the lead time of 3 hours, it is merged with the station temperature of the initial time of nowcasting and then converges to the model temperature later in time.
- Hourly selected radar reflectivity nowcasts corresponding to the model output time. Here, the radar nowcasting output is generated every 15 minutes based on the algorithm of Berenguer et al. (2005); that is, first the motion field of precipitation is estimated and then used to extrapolate the precipitation fields with a semi-Lagrangian advection technique.

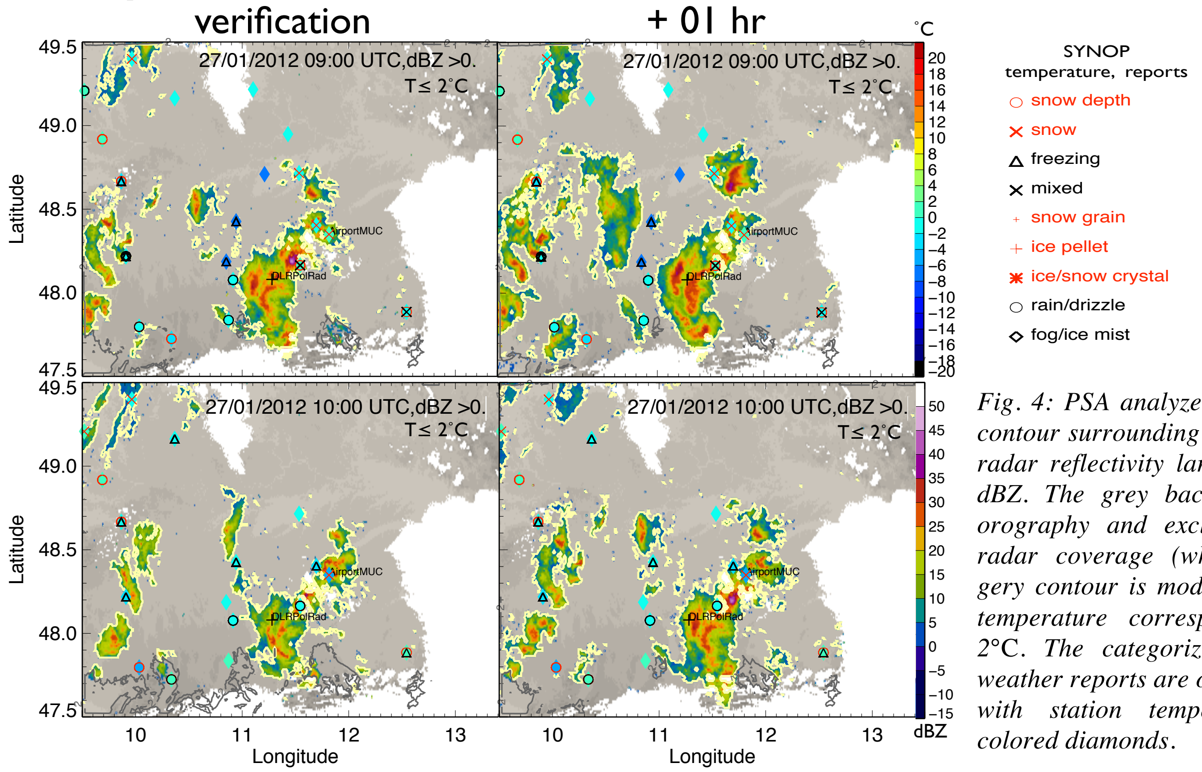

Fig. 4: PSA analyzed in yellow contour surrounding the area of radar reflectivity larger then 0 dBZ. The grey background is orography and excluded poor radar coverage (white). Dark gery contour is modified model temperature corresponding to 2°C. The categorized SYNOP weather reports are over-plotted with station temperature in colored diamonds.

Figure 4 shows that the reflectivity nowcasts for 09:00 UTC capture well some structures of strong radar precipitation echoes at the center of the domain. On the other hand, the nowcasted field valid at 10:00 UTC does not reproduce the decay of the storms seen in the verification.

The analysis PSA informs that there is a possibility to have winter precipitation affecting the area of the Munich airport (airportMUC in Fig. 4). However, the skill scores (probability of detection POD, false alarm ratio FAR, and critical success index CSI) computed at these analysis times (shaded as grey bar in Fig. 5a) are rather low because of:

i) Relatively small areas of localized precipitation echoes. Later in time, at 23:00 UTC (not shown in this paper), the CSI results in a high value (close to 0.8) when the radar precipitation echoes are widely spread over the domain. Depending on the type of events, the radar echo coverage can change. This may affect hits and misses of the stations reporting winter precipitation.

ii) Inability of separating rain/drizzle from winter precipitation. Certainly, we can see some stations with rain reported within the detected PSA (e.g., nearby the location of DLR polarimetric radar, DLRPolRad in Fig. 4). If the station report as rain is correct, it is difficult to separate rain from snow based on the precipitation echoes. Then the question is whether setting a single threshold to surface temperature is enough to isolate areas affected by winter precipitation from rain. Figure 5b shows the occurrence of the SYNOP reports for the categories “freezing rain or drizzle”, “snow grain”, “mixed precipitation”, “crystals”, “ice pellets”, “fog or ice mist”, “rain or drizzle”, and “snow” during 27 January 2012 as a function of temperature (as a function of wet-bulb temperature in grey). We can see that rain/drizzle happens below 2°C as well (i.e., below the threshold used to detect winter precipitation in the PSA algorithm). To overcome this limitation, we will need to add extra information for such a separation to be more efficient.

Meanwhile, compared with the CSI value at the analysis times, higher values have been obtained for the 1-hour nowscasts at 09:00 UTC (from 0.35 to 0.55), but smaller at 10:00 UTC (about from 0.35 to 0.30). One reason can be the failure of the location of storm growth and decay when performing the radar nowcasting (see the upper left portion of the domain in the bottom panels of Fig. 4).

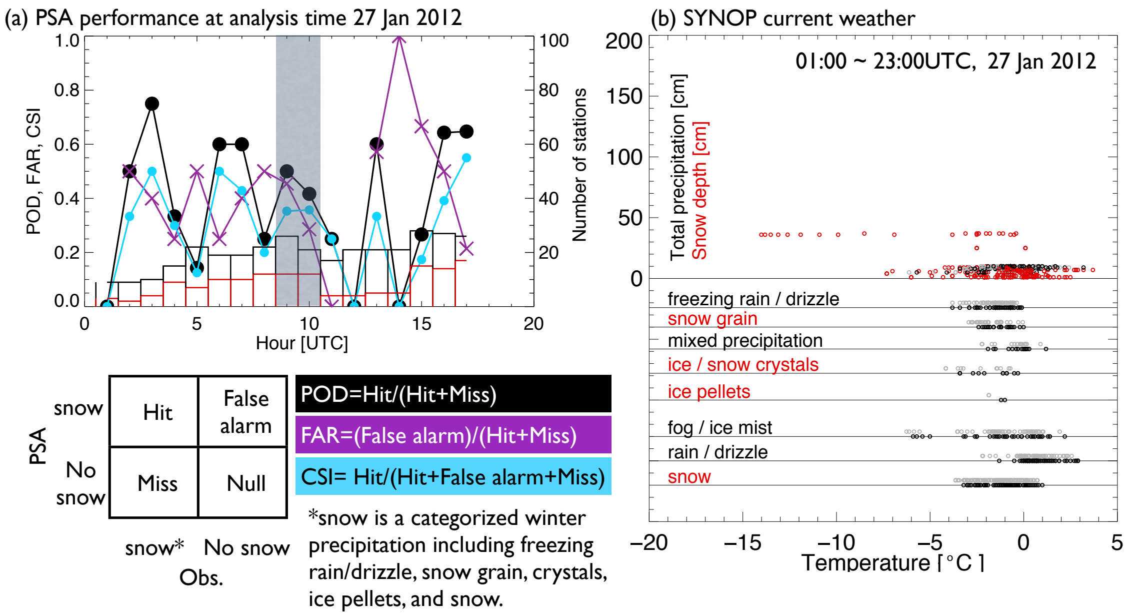

Fig. 5: (a) Skill scores of PSA performance at the analysis time. Black bar represents number of SYNOP stations available over the domain at the analysis time, whereas Red one represents those assigned to categorized winter precipitation. (b) Occurrence of SYNOP current weather conditions in terms of the customized categories (text descriptions above the lines) with respect to temperature (in black dots) and estimated wet-bulb temperature (in grey dots). Similarly, snow depth (red circles) and total precipitation (black circles) are also plotted in centimeter.

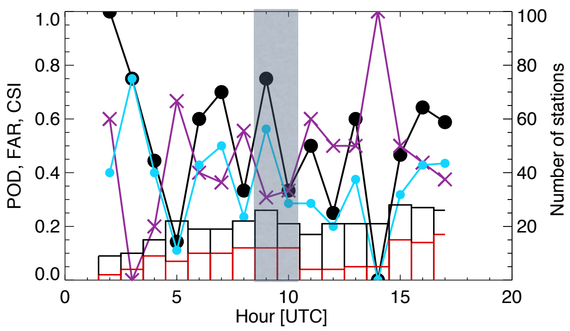

Fig. 6: Skill scores similar as Fig. 5a but for PSA at lead-time of 1hour.

5. Summary and future works

We have introduced a simple algorithm to provide ground level warnings for winter precipitation, in terms of Potential Snow Areas in real-time over the radar grid. Although the algorithm only utilizes temperature from NWP model and surface stations as well as reflectivity from radar composite, the case presented here shows some skills at detecting on winter precipitating areas. However, it does face several challenges regarding threshold sensitivity, radar coverage, and radar nowcasting skills. Also, we will need extra sources to separate among snow/ice/freezing rains/rain. The future work will analyze more cases for the performance PSA by taking into account the information above the ground (e.g., model temperature above the surface level). Also, the PSA algorithm will be implemented into the real-time operational precipitation nowcasting system (WICAST) of HYDS.

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