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Frost Predictions in Dieng using the Outputs of Subseasonal to Seasonal (S2S) Model

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ABSTRACT

Dieng volcanic highland, where located in Wonosobo and Banjarnegara regencies, has a unique frost phenomenon that usually occurs in the dry season (July, August, and September). This phenomenon may attract tourism, but it has caused losses to farmers due to crop damage. Information regarding frost prediction is needed in order to minimize the negative impact of this extreme event. This study evaluates the potential use of the Subseasonal to Seasonal (S2S) forecast dataset for frost prediction, with a focus on two areas where frost usually occurs, i.e. the Arjuna Temple and Sikunir Hill. Daily minimum air temperature data used to predict frost events was from the outputs of the ECMWF model, which is one of the models contributed in the Subseasonal to Seasonal prediction project (S2S). The minimum air temperature observation data from the Banjarnegara station was used in conjunction with the Digital Elevation Model Nasional (DEMNAS) data to generate spatial data based on the lapse rate function. This spatial data was used as a reference to downscale the ECMWF S2S data using the bias correction approach. The results of this study indicated that the bias corrected data of the ECMWF S2S forecast was able to show the spatial pattern of minimum air temperature from observations, especially during frost events. The S2S prediction represented by the bias corrected ECMWF model has the potential for providing early warning of frost events in Dieng, with a lead time of more than one month before the event.

KEYWORDS
bias correction, crop damage, ECMWF, extreme events, lapse rate

INTRODUCTION

Climate related studies in Indonesia showed that extreme weather events are closely related to various natural disasters, such as drought (King et al., 2016; Surmaini et al., 2018; Taufik et al., 2020, 2017), floods (Lestari and Dasanto, 2019; Narulita and Ningrum, 2018), and frost (Pradana et al., 2018a, 2018b). The disasters influence many sectors in Indonesia specially the agricultural sector (Amalo et al., 2017; Kim et al., 2019; Kuswanto et al., 2019; Lesk et al., 2016; Mulyaqin, 2020), which indirectly affect national economic conditions (Boer and Surmaini, 2020; Chatzopoulos et al., 2020). Extreme weather events mostly influence by regional climate variability, which periodically occur (Newman et al., 2018; Veitch et al., 2019). Most researches in Indonesia discuss how climate variability impacts on agriculture in lowland area (e.g. Mulyaqin, 2020; Surmaini et al., 2018), but limited studies explained how agriculture in highland are influenced by extreme weather events such as frost (Pradana et al., 2018a).

In Dieng Plateau, Indonesia, there is a frost event, which called as 'upas dew'. This event occurs only in the dry season, which is around July-September. Upas dew occurs due to the combination of the highland topography and the advective frost. Advective frost is characterized by lower temperature below 273 K (0°C) (Kotikot et al., 2020) and usually occurs in highland affecting to agriculture problem (Kalma et al., 1992). The frost event affects agricultural activities causing vegetable damage. For instance, frost that sticks to two-month old potato plants will kill their cell function and damage plant tissue. Although the frost only lasts for about 2 hours (4:00 to 6:00 am), leaves exposed to the frost will dry out when the frost has melted. The dried leaves of the potato plant cause dryness of the potato stem leading to crop failure. In 2017, the total loss of potato farming due to frost reached IDR 15 million per hectare (Pradana et al., 2018a). This loss associated with a declined production of potato.

The effect of extreme cold on decreasing agricultural production has also been confirmed by studies in other countries. In Australia, frost cause physiolofical damage of wheat plant during growing season leading to a decline of wheat production (Barlow et al., 2015). A similar event also found in the kiwifruit crop in South Korea. The occurrence of frost during the spring of 2014 in Jeonnam Province caused an average decline of kiwifruit production by 10% (Kim et al., 2015). Based on the impacts on a crop failure, an early warning system of frost events may necessary. Here we use prediction of extreme weather event as a proxy for early warning system.

Predictions of extreme weather events can be obtained using the results of global climate model simulations (Nurdiansyah and Faqih, 2018), such as the subseasonal to seasonal (S2S) model. This model can fill the gap between medium-scale weather prediction (15 days) and seasonal scale (3 to 6 months) (Vitart and Robertson, 2018). The output of the S2S model has provide benefit to predict climate-related events in various fields including general health, energy, climate and extreme weather phenomena, water management, and agriculture (White et al., 2017). Also, the S2S model output is claimed to predict the characteristics of large-scale extreme weather events, such as (i) heatwaves, (ii) drought, (iii) tornadoes, and (iv) tropical cyclones, in the next few weeks (Vitart and Robertson, 2018).

Based on potency of S2S model to predict few weeks weather events ahead, likely it may benefit to a prediction of frost events in Dieng. Then the characteristic of frost such as the duration and the impacted area will be derived. This study aims to evaluate the potential output of the S2S model in predicting the timing of frosts in the Dieng plateau. In particular, the prediction analysis only focuses on one of the output variables of the S2S model that is most relevant to frost occurrence, namely the minimum temperature. The research findings are expected to be a reference in the development of an early warning system for upas dew.

RESEARCH METHODS

Data and Study Area

This study used three types of secondary data, namely: (i) spatial elevation data, (ii) daily minimum air temperature data, and (iii) S2S output model. All secondary data used in this study were available online provided by their agencies (Table 1). In addition, we also use frost information collected from the news and social media to identify the frost events. The online news media explored for this study are tempo.co, regional.kompas.com, tribunnews.com, news.detik.com, republika.co.id, and liputan6.com. While, frost information from social media is obtained from Instagram.

We choose the DEMNAS data to provide topography data in the study area because it has a high resolution. With this resolution, description on the surface shape and elevation of the study area is accurate. For daily air temperature, we used observation data from geophysical station at Banjarnegara (Table 1) as the station is the nearest to the research locations. For S2S model, we employed data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF), which publishes the model output twice a week. In this study, forecast data published in June 2018 were used (8 issued date), with each lead time of 46 days. Table 2 describes the eight issued date of the ECMWF data.

Table 1. Characteristic of the data used in the study.

No.	Type of Data	Source	Resolution
1	National Digital Elevation Model Data (DEMNAS) (grid 1408-41:44)	Indonesian Geospatial Information Agency (BIG)	8m x 8m
2	Daily observation data of minimum air temperature (Tmin) at Class III Geophysical Station Banjarnegara (June -August 2018)	Meteorology, Climatology, and Geophysics Agency (BMKG) (http://dataonline.bmkg.go.id/)	-
3	Data on spatial minimum air temperature (mn2t6) parameters of the S2S model.	European Centre for Medium-Range Weather Forecasts (ECMWF) (https://apps.ecmwf.int/datasets/data/s2s-realtime-instantaneous-accum-ecmf/levtype=sfc/type=cf/)	0.125° x 0.125°

Table 2. Length of forecast data for daily minimum air temperature from the output of the S2S model in June 2018.

No.	Issued Date	Lead Time
1	4 June 2018	5 June – 20 July 2018
2	7 June 2018	8 June – 23 July 2018
3	11 June 2018	12 June – 27 July 2018
4	14 June 2018	15 June – 30 July 2018
5	18 June 2018	19 June – 03 August 2018
6	21 June 2018	22 June – 06 August 2018
7	25 June 2018	26 June – 10 August 2018
8	28 June 2018	29 June – 13 August 2018

Geographically, the Dieng Plateau is located at 7.20-7.27 °S and 109.83-109.98 °E, which extends from Banjarnegara Regency to Wonosobo Regency in Central Java Province, Indonesia. This research focused on two locations that are often affected by the upas dew phenomenon, namely in the Arjuna Temple area (2061 m) and Sikunir Hill (2204 m).

Data Analysis

To identify frost event, we processed the data as follows: (i) data preparation, (ii) interpolation of daily minimum air temperature, (iii) bias correction of S2S model output data, and (iv) identification of frost events. Below are details of explanation for each stage of data analysis.

Data Preparation

The DEMNAS data consists of four separate raw data with reference coordinate type WGS84. From this data, four initial processing stages were carried out, namely (i) changing the data reference coordinates from WGS 1984 to UTM zone 49S, (ii) merging data (mosaic), (iii) changing the spatial resolution of the mosaic data to 50 m, and (iv)) changing the data format from *.tif to *.nc.

The output of the S2S model was in format *.grib with a spatial resolution of ~13km. Initial processing for this data model includes (i) changing the data format from *.grib to *.nc (same as the final DEMNAS data format), (ii) changing the spatial resolution from ~13km to 50m, and (iii) separation of data based on the issued date of the S2S model data. The technique used to change the size of the spatial resolution of the S2S model was a bilinear interpolation. The results of regridding the S2S model data are shown in Figure 1.

Minimum Air Temperature Data Spatialization

In this study, frost event was identified based on daily minimum air temperature. However, our observed data from geophysical station (608 m) were not representative for weather condition in Arjuna Temple (2061 m) and Sikunir Hill (2204 m). Assuming that the pattern of minimum air temperature at geophysical station was similar to that of both study areas, the minimum air temperature will be spatially interpolated based on altitude information. Therefore, based on this interpolation the daily minimum air temperature at Arjuna Temple and Sikunir Hill will be obtained.

The interpolation of air temperature data was performed based on lapse rate equation. The lapse rate is a condition of decreasing temperature in respond to an increased elevation. Lapse rate calculations can be obtained using Equations (1) and (2).

$$\gamma = -\frac{\partial T}{\partial Z} \qquad (1)$$

$$T_2 = T_1 + (h_2 - h_1) * (-\gamma) \qquad (2)$$

where γ is the dry adiabatic lapse rate (°C km^{-1}), ∂T is the change in air temperature (°C), and ∂Z is the change in elevation (m). Equation (2) is a translation of Equation (1), where T_1 and T_2 are the daily minimum air temperatures at locations 1 and 2 (°C), while h_1 and h_2 are the elevation data from locations 1 and 2.

In this study, T_2 is the minimum temperature value calculated for each DEM data pixel. T_1 is the daily time series data of the minimum temperature at the geophysical station, h_1 is the elevation for the location

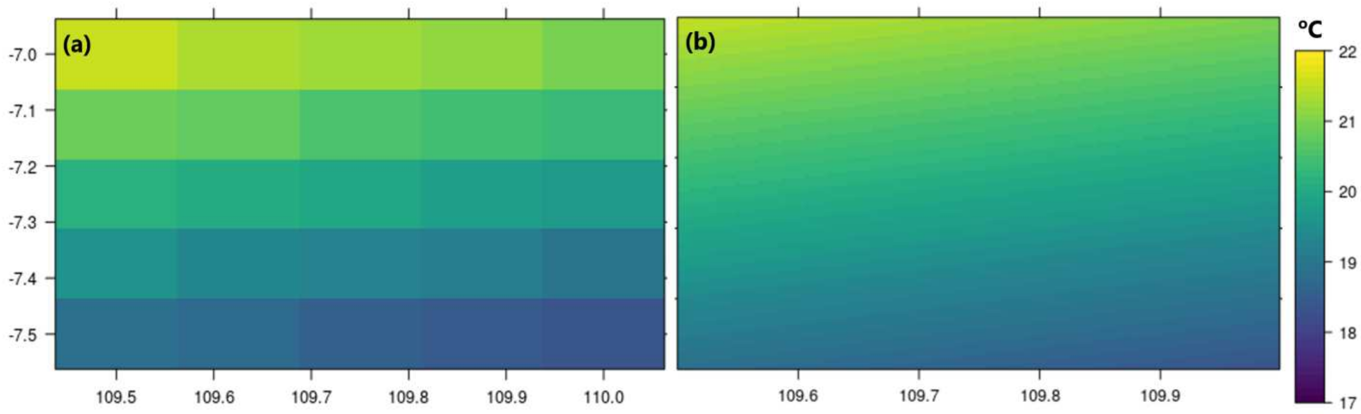


Figure 1. Minimum air temperature (°C) data of the S2S model dated 6 July 2018, on the 1st issued (output): (a) before regridding, and (b) after regridding.

of the geophysical station, which is 608 m, and h_2 is elevation data based on DEMNAS data. The dry adiabatic lapse rate (DALR) constant used in this study was 9.76 °C km^{-1}. The output of this stage was grid data of daily minimum air temperature for the Dieng area.

Bias Correction of S2S Model Output Data

The climate model output data usually have a bias value against the observed data. Bias correction is performed to eliminate the bias value. The spatially minimum temperature obtained from interpolation processes was used as a reference to calculate bias value of the S2S model output data. In this study, bias correction was done based on the delta (Δμ) method, which is mathematically written in Equation (3) (Graham et al., 2007).

$$X_{cor,i} = X_{mp,i} + \mu_{ob} - \mu_{mb} \quad (3)$$

where $X_{cor,i}$ is the value of bias correction, $X_{mp,i}$ is the model value (S2S), μ_{ob} is the mean value of the time-series of the observation data, and μ_{mb} is the mean value of the time-series data model (S2S).

Frost Event Identification and Evaluation

Based on the minimum air temperature data, the temperature limit that is considered to cause frost formation was 2°C. There are three categories of frost occurrence based on minimum air temperature, namely light frost (0 to 2°C), medium frost (-2 to 0°C), and heavy frost (lower than -2°C) (Moeletsi et al., 2016).

Evaluation of the output ability of the S2S model to predict frost events was identified from the time-series plot of observed and model data at two locations. Here the observed data was the interpolated data based on DEMNAS and lapse rate method. We evaluated all issued data (Table 2) producing 8 time-series plots.

RESULTS AND DISCUSSIONS

Characteristics of the Study Area

Dieng Plateau is a volcanic mountain complex located in Wonosobo and Banjarnegara Regencies. The area is mountainous region, where the area with a steep slope by more than 30% (Nugraha et al., 2015). There are four volcanic mountains surrounding Dieng, namely: (i) Prau, (ii) Binem, (iii) Kendil, and (iv) Pangonan. The Dieng Plateau is located at an altitude of 1500-2500 m (Figure 2). Based on data from geophysical station, the average temperature ranges from 19.3 to 20.6 °C and relative humidity of 86.6%. In the night, loss of energy through longwave radiation emission combined with a movement of cold air from downhill have caused a rapid cooling of the Earth surface. Based on the Schmidt-Ferguson climate classification, the Dieng Plateau has a type A (wet climate). The type of rain in this area is monsoonal, with average annual rainfall in the Dieng region reaching 2,270-4,835 mm/year (Pradana et al., 2018a).

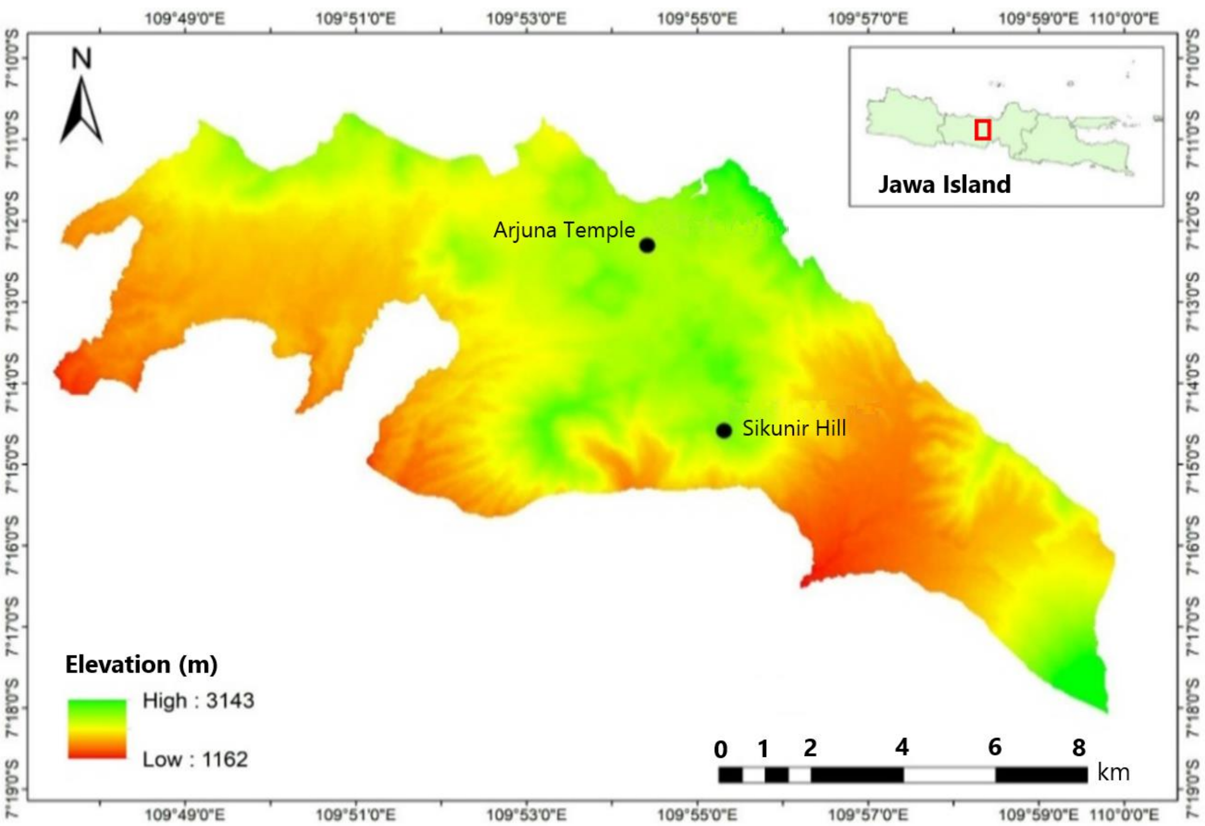


Figure 2. Research study area based on altitude data.

The variability of the daily minimum air temperature at the study area may be indicated by the time-series of minimum temperature at geophysical station at Banjarnegara (Figure 3). Based on data in 2018, the average minimum temperature in July-August is lower than in other months (red box mark, Figure 3). During these two months, the minimum temperature value ranges from 15 to 21 °C. Previous works showed that the temperature can drop to freezing point during dry season at dawn (Ngabekti et al., 2007; Susilowati et al., 2018).

We validated the temperature model based on lapse rate approach with observed data (red box, Figure 3a and 3b) for dry season only in July-August 2018. The reason why we only used both July-August because we focused only to frost events during dry season. Figure 3b points out that there is a similar pattern between both temperature. The temperature model showed a consistently lower estimate from the observation data in a range of 0.4C°. The difference in these values is probably influenced by the use of the lapse rate constant values. Based on this estimate we assumed that the temperature model based on lapse rate may represent the temperature variation in altitude.

Spatial Daily Minimum Air Temperature

Based on lapse rate approach, the spatial daily minimum air temperature was generated. Figure 4 presents sample of the spatial data for 6 July 2018 (Figure 4a) and 27 July 2018 (Figure 4b). Both figures indicate that minimum temperature at geophysical station was around 15°C. This value was higher than that of the study area in Arjuna Temple and Sikunir Hill (<5°C).

Spatially, location with temperature below 0 °C was wider on 27 July compare to temperature at 6 July. Overall, minimum temperature at Arjuna Temple was higher than Sikunir Hill. For instance, at 6 July 2018 the temperature at Arjuna was 1.8°C, whereas in Sikunir Hill was 0.4°C. A similar pattern was observed on 27 July 2018, when the temperature in Arjuna Temple and Sikunir Hill was 0.8°C and -0.6°C, respectively.

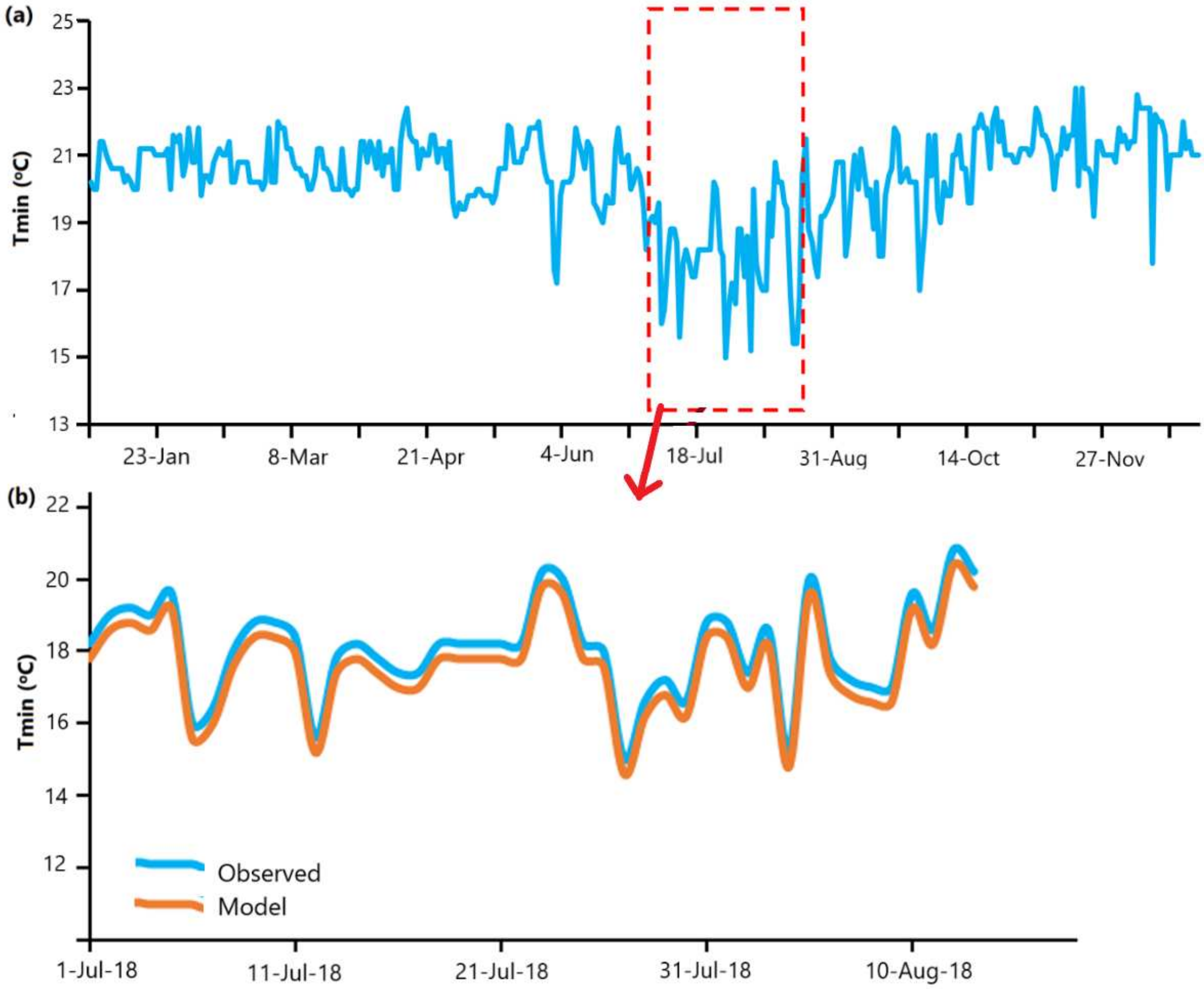


Figure 3. The daily minimum air temperature at study area: (a) observed data from geophysical station of Class III Banjarnegara in 2018, and (b) comparison of observed (geophysical station) and model (lapse rate approach) data in July-August 2018.

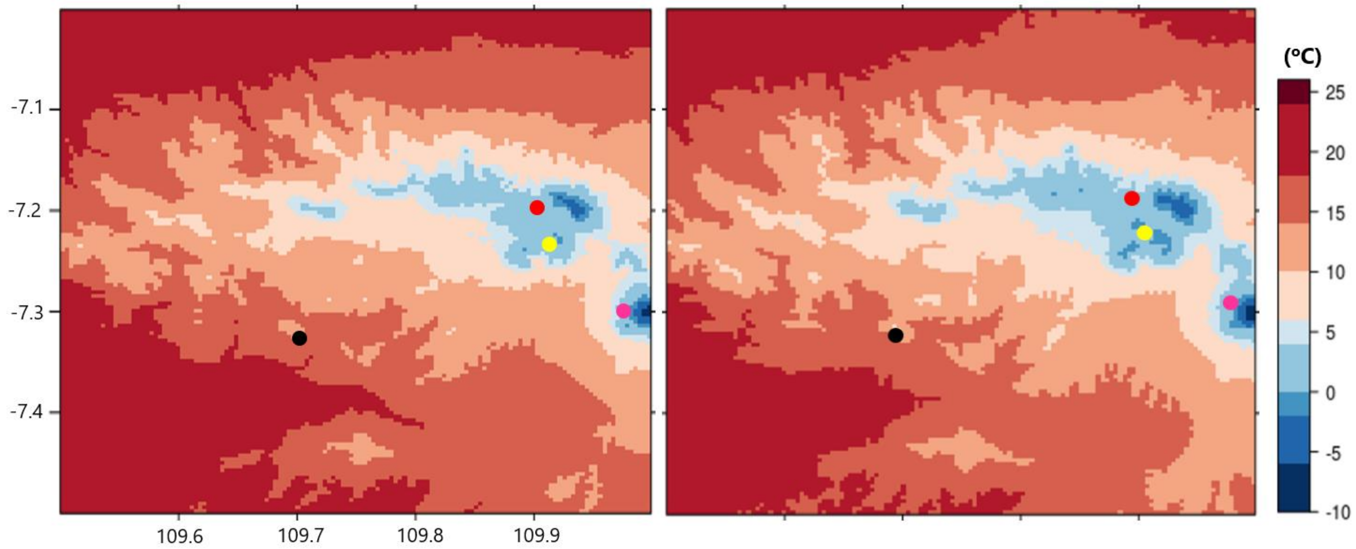


Figure 4. The spatial daily minimum air temperature (°C) for: (a) 6 July 2018 and (b) 27 July 2018 based on lapse rate approach. Location of the study area is marked with red dot (Arjuna Temple) and yellow dot (Sikunir Hill), while the black dot indicates the geophysical station at Banjarnegara. The purple dot represents the Mount Sumbing. The Mount Sumbing area is not exposed to frost. Frost often occurs in valleys that have a concave or flat shape.

Frost incident in the Dieng Region

The Arjuna Temple is a large plain area located in the upstream of Tulis river basin. The topography is flat and surrounded by several mountains, which is suitable for frost formation. Other factors that influence frost formation are minimum air temperature, wind speed, solar radiation, elevation, and the shape of the surface area (Lindkvist et al., 2000). The study area was covered by grass formation. Areas with low vegetation density are more likely to experience this phenomenon than areas with high vegetation density (Pradana et al., 2018a). Arjuna Temple and Sikunir Hill have a high exposure to the frost phenomenon due to the following reasons. At night, areas with flat and open topography are cool faster due to the air movement from the downhill of the mountain to the valleys. Secondly, the air pressure during the dry season increases, which reduces the potency of strong wind movements. This causes the movement of cold air from the downhill to move faster into the study area.

We identified frost events based on the news and social media. Based on Tribunjateng.com, on 6 July 2018 frost events appeared in several areas in Dieng, such as in Arjuna Temple and Sikunir Hill with temperatures plummeted to -5°C. There is a possibility that the minimum temperature value from the media coverage may be lower than the value obtained from the results of spatialization due to the calculation process of the lapse rate function. Another online news, Kompas.com, reported a similar frost event on 27 July 2018 in Dieng area. Several media online also listed frost occurences in periode of July-August, as shown in Figure 5. The media online consisted of daily news (namely tempo.co, regional.kompas.com, tribun-news.com, news.detik.com, republika.co.id, and liputan6.com) and social media based on Instagram.

Identification of Frost Events Based on the Output Model S2S

The output of predicted data from the S2S model in June 2018 comprised of eight issued dates (Table 2). The predicted data of each issued date has a lead time of up to 46 days ahead. Assuming that interpolated temperature data in Arjuna Temple and Sikunir Hill as observed data, we compared the observed data with the results of S2S model for the period 1 July 2018 to 13 August 2018 (Figure 6). The daily minimum air temperature value from the S2S model output in the Arjuna Temple area on the 5th issued date was relatively close to the observed data (Figure 6a).

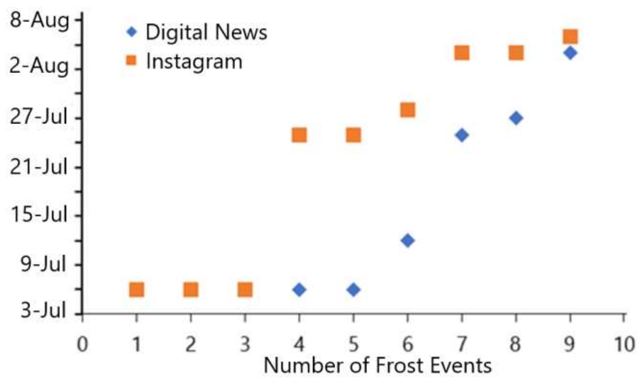
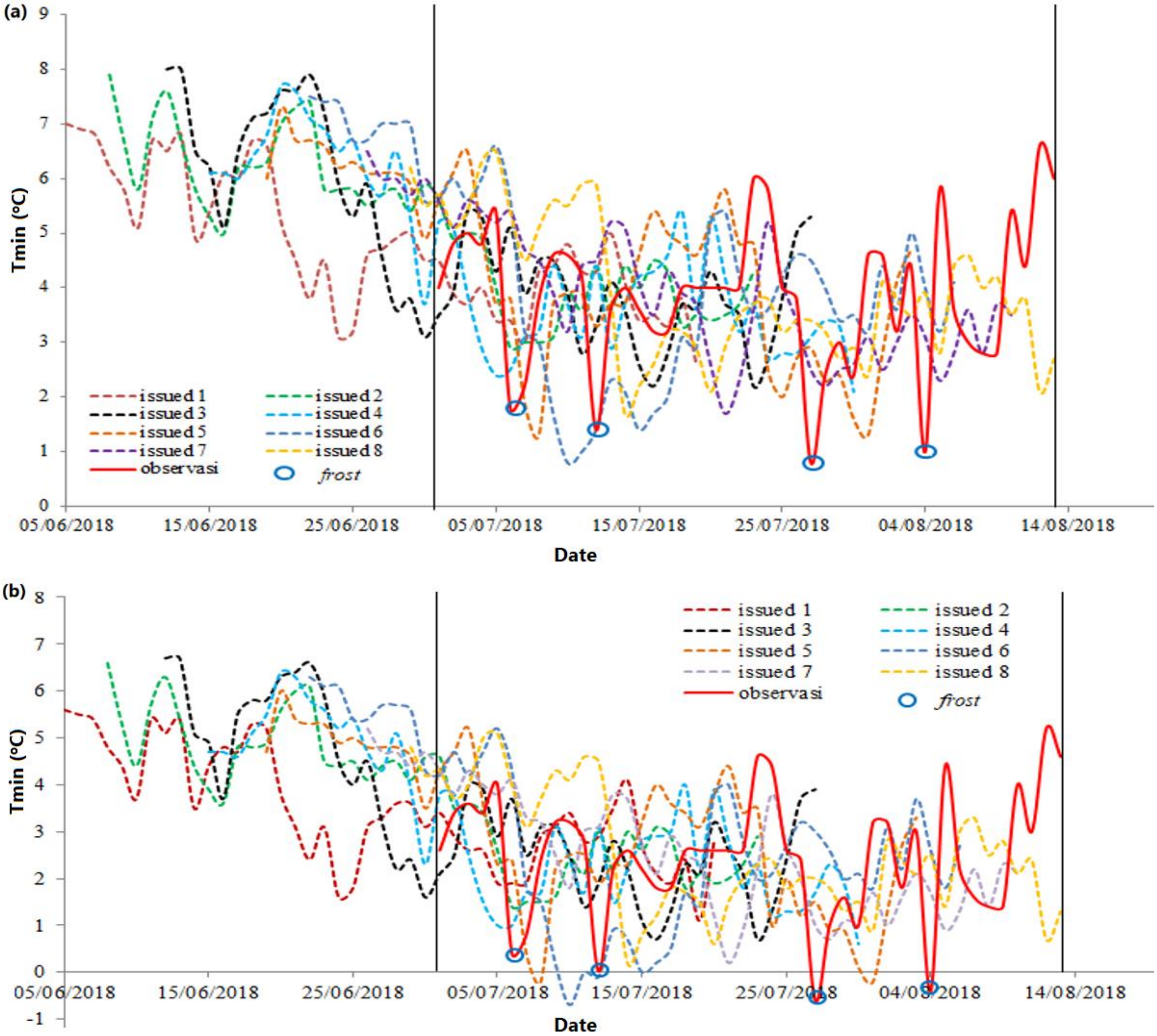


Figure 5. Number of frost events reported from media online in periode of July-August 2018. Two types of data are available based on digital news (blue rhomb) and Instagram (orange square)



Gambar 6. Time series of daily minimum temperature based on bias correction of S2S model (dash lines) for each issued date and the observed data from lapse rate approach (line) located at: (a) the Arjuna Temple area (2061 m) and (b) the Sikunir Hill area (2204 m). Frost events were indicated by hollow blue circle.

On other hand, for Sikunir Hill, the 7th issued date likely followed the pattern of the observed data. Several days had experienced with frost events on the study area at 6 July, 12 July, 27 July, and 4 August 2018. Based on temperature data, it clearly showed that frost events might occur even the temperature was not negative values or below 0°C. This indicated that some frosts in the Dieng region are tipically as light frost.

CONCLUSIONS

The use of S2S output model was promising to provide daily minimum temperature data. Here we applied the model to predict frost occurrence in Dieng Plateau. We combined observed based data with lapse rate approach to estimate the minimum temperature at various elevations. The use of lapse rate approach was useful to deal with the limited observational data. Our result indicated that the predicted data of daily minimum air temperature from the S2S model can produce a similar pattern of dropped temperature with the observation data when a frost events occured in Dieng. Further, the utilization of the S2S output model is promising by providing a potential early warning of frost events to farmers with a lead time up to 46 days.

Further analysis is needed by considering the ensemble member and multi-model ensemble S2S in producing predictions based on probabilistic calculations. The frost phenomenon that occurs in Dieng is also influenced by other factors such as topography, land slope, elevation, and various meteorological factors such as relative humidity, dew point, wind speed, and solar radiation. So, for further research, it can discuss the relationship between these various factors, and it is necessary to build a more accurate prediction model.

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