Application of Consecutive Dry Days (CDD) Multi-Model Ensemble (MME) Prediction to Support Agricultural Sector in South Sulawesi Rice Production Centers

A M Setiawan ¹, Y Koesmaryono³, A Faqih² and D Gunawan²

¹ Center for Climate Change Information, Indonesia Agency for Meteorology Climatology and Geophysics (BMKG), Jakarta, Indonesia
² Applied Climatology, Department of Geophysics and Meteorology, Bogor Agricultural University (IPB), Bogor, Indonesia

E-mail: amsari_setiawan@apps.ipb.ac.id

Abstract. Sufficient water availability during the vegetative, reproductive, and early ripening phases of the rice plants is essential. Information on drought, such as Consecutive Dry Days (CDD) predictions in this period, became very crucial and had an important role in maintaining rice production stability. The aim of this study is to investigate the performance of CDD Multi-Model Ensemble prediction, which is applied to South Sulawesi rice production centers. CDD observation was calculated using high resolution gridded precipitation blending data, obtained from BMKG precipitation network stations and the daily-improved Climate Hazards group InfraRed Precipitation with Stations (CHIRPS) version 2.0. The North American Multi-Model Ensemble (NMME) monthly precipitation hindcast data during 1982 – 2010 periods from each nine individual global climate models were used to develop seasonal CDD predictions. World Meteorological Organization (WMO) Standard Verification for Long Range Forecast (SVS-LRF) method applied to describe this CDD prediction performance on four different seasons. Investigation of model performance during strong El Niño event in 1997 also conducted in order to get general skill overview regarding extreme climate event. Best performance of CDD prediction generally occurred during JJA and DJF period. MME CDD prediction shows better performance compared to individual model performance for almost all season. Spatial coherence between prediction and observation over rice production centers during 1997 El Niño confirms the skill of CDD predictions. The application of this prediction on agricultural sector will be very useful in order to support rice production sustainability and food security. Further analysis result can be found on full paper.

1. Introduction
Meteorological drought information can be used by government and policies makers as general guidance to anticipate its impact on sensitive sector (i.e. agriculture). This drought condition usually can be considered as thread for food security issue if occurred during longer time period and located on rice production centers. Warm phase of El Niño Southern Oscillation (ENSO) or El Niño usually can lead to drought occurrence over Indonesia [1–6], include South Sulawesi region. As one of national rice production centers, this region also can be affected by El Niño, such as drought which occurred in large coverage areas [4, 7]. The weak and moderate El Niño intensity can have an impact on reduced rice yields. On the average, this reduction can reach up to 40%. Moreover, the most drought-prone areas are located in South Sulawesi, especially for August–October season [7].
Based on the National Central Statistics Agency (BPS) data in 2016, South Sulawesi was on the first position of national food production center province in eastern Indonesia and outside Java. Bone, Wajo, Pinrang, Sidrap and Maros districts are listed as the top five regions that provide the largest contribution to rice production in South Sulawesi [8]. However, this area has a high level of drought susceptibility, especially during the dry growing season from March to October [7]. Sufficient water availability during the vegetative, reproductive and early ripening phases of rice plant is very important. The role of drought information and Consecutive Dry Days (CDD) [9] prediction in this period is very important to maintain the stability of rice production. Water requirements during the planting period to active tillering stage (10 to 30 days after planting) and panicle initiation to flowering (50 to 90 days after planting) are at an important to critical and very important level [10,11].

Utilization of North American Multi Model Ensemble (NMME) for global rainfall and Standardized Precipitation Index (SPI) prediction was investigated previously. It shows significant reliability especially in ENSO-affected areas, but has experienced a sharp performance reduction for lead times more than one month [12]. Nevertheless, this dynamical climate model generally shows good performance in order to generate monthly rainfall prediction in South Sulawesi [13].

The CDD studies generally have been carried out and focused on analyzing the past CDD characteristics, include its conditions over several areas [14–16]. Another study was also conducted to determine the annual trends of previous CDD and their projections in the future [17]. Monthly to seasonal timescale CDD predictions are generally assessed using a statistical approach [18,19]. The aim of this study is to investigate performance of CDD Multi Model Ensemble seasonal prediction from dynamical climate model output, which applied to South Sulawesi rice production centers.

2. Data and Methodology

2.1. Data
CDD observation was calculated using high resolution gridded precipitation blending data, obtained from BMKG precipitation network stations and the daily-improved Climate Hazards group InfraRed Precipitation with Stations (CHIRPS) version 2.0 [20]. Each CDD data previously calculated by using (i) quality controlled daily observational precipitation data from 23 weather stations of various record lengths within 1967-2015 periods, and (ii) 0.05° x 0.05° blended gauge-satellite of daily and monthly precipitation estimates of the Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) dataset. This gridded dataset was obtained from Climate Hazards Group/ The Department of Geography, University of California Santa Barbara (ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/).

The North American Multi-Model Ensemble (NMME) monthly precipitation hindcast data during 1982 – 2010 periods from each nine individual global climate models were used to develop seasonal CDD predictions. This seasonal CDD prediction includes March – April – May (MAM), June – July – August (JJA), and September – October – November (SON) seasons. All initial-time coverage with all lead time and ensemble mean [21] of each NMME member are used to generate CDD prediction over South Sulawesi region. Table 1 provides a brief description of the models are used in this study.
2.2. Methodology

Daily precipitation from observation used to calculate maximum number of consecutive days with daily precipitation amount < 1 mm (CDD) [9]. CDD values were also calculated from CHIRPS daily precipitation, for each grid in the study area with a 0.05 x 0.05 o horizontal resolution. Geostatistical approach then applied for those CDD data to generate high resolution gridded CDD data [20].

The Multi-Model Ensemble (MME) was built using the simple composite method [5,30] of each NMME member. Simple downscaling method was performed for seasonal CDD prediction at 0.05 o x 0.05 o spatial resolution of from each seasonal precipitation forecast NMME member data with a spatial resolution of 1 o x 1 o. Statistical downscaling is performed using a regression equation at each observation grid point for the entire model member and MME. Furthermore, the CDD prediction is built based on the regression equation between seasonal rainfall average against CDD value for each season.

World Meteorological Organization (WMO) Standard Verification for Long Range Forecast (SVS-LRF) method [31] was applied to describe this CDD prediction performance on four different seasons. The SVS consists of four parts including diagnostic measures, key parameters, verification data sets, and details of forecast systems. The first Mean Square Skill Score (MSSS) decomposition as SVS-LRF component, which provide valuable information on phase errors through forecast/observation correlation was used in this deterministic forecast verification. Product moment correlation r fx, for CDD anomaly forecast (f) and observed CDD anomaly (x), is given by the formula [31]:

\[ r_{fx} = \frac{\sum(f-i)(x-\bar{x})}{\sqrt{\sum(f-i)^2}(x-\bar{x})^2}} \]  

\[ (1) \]
Investigation of model performance during strong El Niño event in 1997 also conducted in order to get general skill overview regarding extreme climate event. In order to generate and verify CDD prediction, only 1982 – 2010 observational data period used in this study.

In general, Bone and Wajo districts are located in the eastern part of South Sulawesi. Pinrang and Maros districts are on the west side, while Sidrap Regency is generally located in the central part of South Sulawesi (Figure 1). Assessment of model prediction performance is carried out using the Standardized Verification System (SVS) for long-range forecasts (LRF) for all time periods, MAM, JJA and SON.

![Figure 1](image.png)

**Figure 1.** Location of five selected rice production center in South Sulawesi. Shaded color indicate elevation in above mean sea level.

### 3. Result and Discussion

#### 3.1. Consecutive Dry Days Forecast over South Sulawesi

Each individual model shows an irregular bias pattern over South Sulawesi region. Overall bias in general has a very small value (order $10^{-14}$) compared to the CDD prediction and observation value (days), so it is not shown in the discussion. This condition indicates that the average of seasonal CDD prediction is relatively similar to seasonal CDD observation.

The overall CDD prediction model built from the NMME output shows a strong correlation across the South Sulawesi region (Figure 2). The high correlation is mainly located in the southern and western
parts of the study area. Lower correlation values are shown on the east coast of the central part of the study area. The interaction between global scale climate anomalies, such as ENSO events, and local topographic conditions in the South Sulawesi region is suspected as one of the possible physical and dynamical atmospheric – ocean explanation regarding highly spatial model performance variability [5,6].

![Figure 2](image)

**Figure 2.** Anomaly Correlation Coefficient (ACC) of Consecutive Dry Days (CDD) forecast with 1 – 3 month lead time from CanCM3 (a), CanCM4 (b), CCSM3 (c), CCSM4 (d), CFSv2 (e), CM2p1 (f), CM2p5A (g), CM2p5B (h), GEOSS2S (i), and MME (j) for all season and time period (1982 – 2010)

### 3.2. Consecutive Dry Days Forecast over Rice Production Center

Seasonal CDD forecast verification was applied to five rice production districts in South Sulawesi. Bone, Wajo, Pinrang, Sidrap, and Maros districts are listed as the five most contributed regions for rice
production in South Sulawesi, especially lowland and upland rice [32]. Generally, all models show outstanding performance in predicting seasonal CDD. This condition is indicated by the relatively high value of the correlation coefficient in the rice production center areas. Relatively lower correlation coefficient values are in Wajo and Sidrap for the CanCM3, CanCM4, and CFSv2 models (Figure 3).

![Figure 3](image)

**Figure 3.** Anomaly Correlation Coefficient (ACC) of Consecutive Dry Days (CDD) forecast for all time period in rice production center from CanCM3 (a), CanCM4 (b), CCSM3 (c), CCSM4 (d), CFSv2 (e), CM2p1 (f), CM2p5A (g), CM2p5B (h), GEOSS2S (i), and MME (j).

The best performance of all models indicated by the high correlation coefficient value of the CDD anomaly is in the Maros region (western part of South Sulawesi). In contrast, almost all models show relatively lower performance when used to make predictions in the Wajo district (eastern part of South Sulawesi). However, all models show relatively good performance when applied to the largest rice production center in South Sulawesi, namely Bone district (eastern part of South Sulawesi).

MME generally shows a higher correlation value than other models. CanCM3, CanCM4 and CFSv2 show lower correlation values than other models in the center and north. Best performance of CDD prediction generally occurred during JJA and DJF period. MME CDD prediction shows better performance compared to individual model performance for almost all season. These results are consistent with previous studies that investigated the performance of MME in predicting the monthly precipitation in the same area [13].

Spatial coherence between prediction and observation over rice production centers during 1997 El Niño confirms the skill of CDD predictions (Figure 4). Southern Wajo in the DJF period is predicted to have CDD for 20 to 30 days, longer than other rice production center areas which are predicted to experience CDD for 10 to 20 days. The increase in CDD in 1997 is predicted to begin in the JJA period and reach its highest value in the SON period. Generally, these rice production centers are predicted to experience CDD for 20 to 30 days in the JJA period and 35 to 55 days in the SON period in 1997.
Figure 4. Results of seasonal MME CDD forecast during 1997 for MAM (a), JJA (b), SON (c), compared with CDD observation during corresponding period (d to f) in South Sulawesi rice production center. Shaded color denoted CDD in days unit.

4. Conclusion
MME CDD prediction shows better performance compared to individual model performance for almost all season. Spatial coherence between prediction and observation over rice production centers during 1997 El Niño confirms the skill of CDD predictions, especially on JJA and SON period. The application of this prediction on agricultural sector will be very useful in order to support rice production sustainability and food security. Policy makers in this sectors and farmers should take the advantages of this CDD information and predictions, especially when the extreme climatic conditions occur, in order to avoid the greater potential losses due to crop failures.
References

[1] Nicholls N 1981 Air-sea interaction and the possibility of long-range weather prediction in the Indonesian archipelago Mon. Weather Rev. 109 2435–43

[2] D’Arrigo R, Allan R, Wilson R, Palmer J, Sakulich J, Smerdon J E dan Ngkoimani L O 2008 Pacific and Indian Ocean climate signals in a tree-ring record of Java monsoon drought Int. J. Climatol. 1901 1889–901

[3] Quinn W H, Zopf D O, Short K S dan Kuo Yang R T W 1978 Historical trends and statistics of the Southern Oscillation, El Nino, and Indonesian droughts (Peru). Fish. Bull. 76 663–78

[4] Setiawan A M 2011 Determination of Reference ENSO Index for Indonesian Region Based on Correlation Analysis of Spatial and Temporal Pattern with Standardized Precipitation Index (SPI) (Bandung: Institut Teknologi Bandung (ITB))

[5] Setiawan A M, Lee W-S dan Rhee J 2017 Spatio-temporal characteristics of Indonesian drought related to El Niño events and its predictability using the multi-model ensemble Int. J. Climatol. 37 4700–19

[6] Supari, Tangang F, Salimun E, Aldrian E, Sopaheluwakan A dan Juneng L 2018 ENSO modulation of seasonal rainfall and extremes in Indonesia Clim. Dyn. 51 2559–2580

[7] Surmaini E, Hadi T W, Subagyro K dan Puspito N T 2015 Early detection of drought impact on rice paddies in Indonesia by means of Niño 3.4 index Theor. Appl. Climatol. 121 669–84

[8] [BPS] Badan Pusat Statistik 2016 Data Hasil Laporan Statistik Pertanian Tanaman Pangan Nasional Tab. Din. Stat. Pertan. Tanam. Pangan Indomes.

[9] Tank A M G K, Zwiers F W dan Zhang X 2009 Guidelines on Analysis of Extremes in a Changing Climate in Support of Informed Decisions for Adaptation ed A M G K Tank, F W Zwiers dan X Zhang (Geneva, Switzerland: World Meteorological Organization)

[10] Vergara B S 1976 Physiological and morphological adaptability of rice varieties to climate Proceedings of The Symposium on Climate and Rice vol 91 (Los Banos, Philippines: The International Rice Research Institute) hal 399–404

[11] Subagyro K, Dariah A, Surmaini E dan Kurnia U 2005 Pengelolaan Air pada Tanah Sawah Lahan Sawah dan Teknologi Pengelolaannya (Bogor: Badan Penelitian dan Pengembangan Pertanian) hal 193–226

[12] Mo K C dan Lyon B 2015 Global Meteorological Drought Prediction Using the North American Multi-Model Ensemble J. Hydrometeorol. 16 1409–24

[13] Setiawan A M, Koesmaryono Y, Faqih A dan Gunawan D 2017 North American Multi Model Ensemble (NMME) Performance of Monthly Precipitation Forecast over South Sulawesi, Indonesia IOP Conference Series: Earth and Environmental Science vol 58 hal 12–35

[14] Xiao M, Zhang Q dan Singh V P 2017 Spatiotemporal variations of extreme precipitation regimes during 1961–2010 and possible teleconnections with climate indices across China Int. J. Climatol. 37 468–79

[15] Duan Y, Ma Z dan Yang Q 2017 Characteristics of consecutive dry days variations in China Theor. Appl. Climatol. 130 701–9

[16] Supari, Tangang F, Juneng L dan Aldrian E 2017 Observed changes in extreme temperature and precipitation over Indonesia Int. J. Climatol. 37 1979–97

[17] Anandhi A, Hutchinson S, Harrington J, Rahmani V, Kirkham M B dan Rice C W 2016 Changes in spatial and temporal trends in wet, dry, warm and cold spell length or duration indices in Kansas, USA Int. J. Climatol. 36 4085–101

[18] Asong Z E, Khaliq M N dan Wheater H S 2016 Multisite multivariate modeling of daily precipitation and temperature in the Canadian Prairie Provinces using generalized linear models Clim. Dyn. 47 2901–21

[19] Anderson B T, Gianotti D dan Salvucci G 2015 Characterizing the Potential Predictability of Seasonal, Station-Based Heavy Precipitation Accumulations and Extreme Dry Spell Durations J. Hydrometeorol. 16 843–56
[20] Setiawan A M, Koesmaryono Y dan Faqih A 2018 Development of High Resolution Precipitation Extreme Dataset Using Spatial Interpolation Methods and Geostatistics in South Sulawesi Indonesia Int. J. Sci. Basic Appl. Res. 42 27–46

[21] Ishizaki Y, Nakaegawa T dan Takayabu I 2012 Validation of precipitation over Japan during 1985–2004 simulated by three regional climate models and two multi-model ensemble means Clim. Dyn. 39 185–206

[22] Merryfield W J, Lee W-S, Boer G J, Kharin V V., Scinocca J F, Flato G M, Ajayamohan R S, Fyfe J C, Tang Y dan Polavarapu S 2013 The Canadian Seasonal to Interannual Prediction System. Part I: Models and Initialization Mon. Weather Rev. 141 2910–45

[23] Collins W D, Bitz C M, Blackmon M L, Bonan G B, Bretherton C S, Carton J A, Chang P, Doney S C, Hack J J, Henderson T B, Kiehl J T, Large W G, McKenna D S, Santer B D dan Smith R D 2006 The Community Climate System Model Version 3 (CCSM3) J. Clim. 19 2122–43

[24] Gent P R, Danabasoglu G, Donner L J, Holland M M, Hunke E C, Jayne S R, Lawrence D M, Neale R B, Rasch P J, Vertenstein M, Worley P H, Yang Z L dan Zhang M 2011 The community climate system model version 4 J. Clim. 24 4973–91

[25] Saha S, Moorthi S, Wu X, Wang J, Nadiga S, Tripp P, Behringer D, Hou Y-T, Chuang H, Iredell M, Ek M, Meng J, Yang R, Mendez M P, van den Dool H, Zhang Q, Wang W, Chen M dan Becker E 2014 The NCEP Climate Forecast System Version 2 J. Clim. 27 2185–208

[26] Delworth T 2006 GFDL ‘s CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics J. Clim. 19 643–74

[27] Vecchi G A, Delworth T, Gudgel R, Kapnick S, Rosati A, Wittenberg A T, Zeng F, Anderson W, Balaji V, Dixon K, Jia L, Kim H S, Krishnamurthy L, Msadek R, Stern W F, Underwood S D, Villarini G, Yang X dan Zhang S 2014 On the seasonal forecasting of regional tropical cyclone activity J. Clim. 27 7994–8016

[28] Jia L, Vecchi G A, Yang X, Gudgel R G, Delworth T L, Stern W F, Paffendorf K, Underwood S D dan Zeng F 2016 The roles of radiative forcing, sea surface temperatures, and atmospheric and land initial conditions in U.S. summer warming episodes J. Clim. 29 4121–35

[29] Borovikov A, Cullather R, Kovach R, Marshak J, Vernieres G, Vikhliaev Y, Zhao B dan Li Z 2017 GEOS-5 seasonal forecast system Clim. Dyn.

[30] Jeong H-I, Lee D Y, Ashok K, Ahn J-B, Lee J-Y, Luo J-J, Schemm J-K E, Hendon H H, Braganza K dan Ham Y-G 2012 Assessment of the APCC coupled MME suite in predicting the distinctive climate impacts of two flavors of ENSO during boreal winter Clim. Dyn. 39 475–93

[31] World Meteorological Organization 2010 Standardized Verification System (SVS) for Long-Range Forecasts (LRF) Manual on the Global Data Processing and Forecasting System WMO-No. 485 vol I-Global (Geneva: World Meteorological Organization) hal II.8.1-II.8.17

[32] [BPS] Badan Pusat Statistik 2016 Data Produksi Tanaman Pangan Sulawesi Selatan Tab. Din. Stat. Provinsi Sulawesi Selatan