Preliminary assessment for sub-seasonal to seasonal precipitation model on four specific conditions over western Indonesia

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Abstract. Preliminary assessment of sub-seasonal to seasonal reforecast precipitation model (S2S) was conducted to analyze the model's performance over western Indonesia on four conditions. The ECMWF S2S model was compared to quality controlled daily precipitation data from 645 observation points over the region. The control and perturbed model for the first three time steps and the last three were utilized to obtain the best performance comparison. The analysis was conducted in monthly period, MJO events, NCS events, and when both of them were active during period of November-December-January-February (NDJF) from 1998 to 2017. The results show that the first three time steps perform much better than the last one with a slightly higher correlation coefficient from the control model with relatively similar RMSE in Natuna Islands. Spatial analysis indicates that both of the control and perturbed models can catch the variation brought by the wet season in the NDJF period, by the MJO, show a hint of NCS effect, and the combination when MJO and NCS were active at the same time. The models can depict the precipitation pattern pretty well with the tendency to overestimate low rainfall intensity and underestimate the high one. The models relatively overestimate the intensity in Sumatra for the whole period. Meanwhile, consistently good spatial performance is shown by the models over Java, both in NDJF periods or MJO events.

1. Introduction
The Madden-Julian Oscillation (MJO), as a dominant convective system over the tropics, propagates eastward with sub-seasonal period around 30-90 days [1]. This phenomenon is proven to trigger increasing precipitation over the tropics [2,3]. The MJO is daily monitored widely using MJO Real-time Multivariate Index (RMM) [4] calculated from Outgoing Longwave Radiation (OLR) as well as 850 hPa and 200 hPa zonal wind data around the tropics. This index is capable of capturing the evolution of MJO as it propagates along the equator [5]. Besides MJO, the tropics are also influenced by the Northerly Cold Surge (NCS) as it flows southward from the extratropics [6–8] with life cycle around one day to two weeks [9]. The NCS is marked by the increasing mean sea level pressure and wind speed as well as the decreasing surface temperature in the mid-latitude around boreal winter [8]. This phenomenon is believed to give a significant effect around the southern South China Sea (SCS) by strengthening the convergence in the lower level as well as increasing vorticity around Kalimantan [10].

The effect of MJO and NCS on the precipitation over western Indonesia is considered significant. Interaction of these phenomena even leads to extreme precipitation. The sooner that extreme
Utilization of S2S forecast on the prediction and simulation of MJO as well as extreme events shows relatively good result [11,13,14]. Among 11 S2S models with details shown in Table 1, European Centre for Medium-Range Weather Forecasts (ECMWF) offers the best performance in forecasting MJO up to four weeks before the events [11]. Comparison of ECMWF’s S2S model to JMA’s and CMA’s on forecasting summer sub-seasonal precipitation over eastern China and find that ECMWF performed superior result among the others with the best correlation achieved on the first five days lead time [15]. A similar result was obtained in the study of S2S models’ skill in predicting MJO. Models from the Bureau of Meteorology Australia (BoM), ECMWF, and United Kingdom Met Office (UKMO) showed relatively higher performance with prediction skill up to four to five weeks before the event [16].

Although some researches had been made to investigate the capability of the S2S forecast, research concerning assessment of the models over Indonesia is hard to be found. Therefore, the ability of the models needs to be investigated over the area. More detailed analysis is conducted on four specific conditions, i.e., monthly, during MJO active, NCS active, and both of MJO and NCS are active. The effect of MJO and NCS lead to extreme precipitation over western Indonesia.

Table 1. Main characteristics of the S2S model database [12]

| Model  | Time range | Resolution | Reforecast period | Ensemble size |
|--------|------------|------------|------------------|---------------|
| BoM    | 0 – 62     | ~2° × 2°, L17 | 1981 – 2013      | 33            |
| CMA    | 0 – 60     | ~1° × 1°, L40 | 1994 – 2014      | 4             |
| ECCC   | 0 – 32     | 0.45° × 0.45°, L40 | 1995 – 2012      | 21            |
| ECMWF  | 0 – 46     | up to 0.25° × 0.25°, L91 | Past 20 years | 51            |
| HMCR   | 0 – 61     | 1° × 1.4°, L28 | 1985 – 2010      | 20            |
| CNR-ISAC | 0 – 31     | 0.8° × 0.56°, L54 | 1981 – 2010      | 41            |
| JMA    | 0 – 33     | ~0.5° × 0.5°, L60 | 1981 – 2010      | 25            |
| KMA    | 0 – 60     | ~0.5° × 0.5°, L85 | 1996 – 2009      | 4             |
| CNRM   | 0 – 61     | ~0.7° × 0.7°, L91 | 1993 – 2014      | 51            |
| NCEP   | 0 – 44     | ~1° × 1°, L64 | 1999 – 2010      | 16            |
| UKMO   | 0 – 60     | ~0.5° × 0.8°, L85 | 1996 – 2009      | 4             |

2. Data and Methods

The S2S [12] re-forecast precipitation model from ECMWF with a real-time date of the whole 2018 was utilized in this research. Since the model was produced twice a week, one year of real-time date consists of 105 dates with 20 years of re-forecast. Thus 2100 dates for each time steps are utilized further in this research. Control and perturbed (member I) model with three earliest (24, 48, 72) and three latest (1056, 1080, 1104) time step were downloaded to provide a better comparison. Due to the accumulation properties of the precipitation forecast, time step 0 and 1032 need to be downloaded as well to calculate the daily precipitation for the three earliest and latest time steps. The data were downloaded for an area of 10.0°N 90.0°E 10.0°S 120.0°E to cover western Indonesia.

The model was verified based on the ground rainfall observation data by correlation coefficient and root mean square error (RMSE). 645 quality-controlled observation points over Sumatra, Java, and
Kalimantan, as shown in Figure 1, are used to verify the model to represent the model’s strength to the actual condition. The distribution parameters and spatial analysis were also conducted to study the model’s further performance on NDJF monthly basis, when MJO active, when NCS active, and when both of MJO and NCS are active. The MJO is identified by utilizing the RMM index [4], including amplitude, phase, RMM 1, and RMM 2. This index is widely used [5,8,10,17–20] as it can capture the evolution of MJO along the equator [5]. Active MJO days are identified by using the pentad average of the index, which follow these criteria: (i) RMM index is greater than or equal to 1 for more than one pentad consecutively; (ii) the phases passed should be in sequential order; (iii) The MJO needs to fulfill the first (i) and second (ii) criteria for more than six pentads (30 days) and does not stationer in one phase for more than four pentads (20 days) [21,22].

The NCS is identified using extracted ERA-Interim reanalysis data [23], so that mean sea level pressure gradient between Gushi (32°15’ N; 115°40’ E) and Hongkong (22°18’ N; 113°55’ E), as well as averaged meridional wind over 15° N along 110° E - 117.5° E, was obtained [9,17,24]. Active NCS days defined when averaged meridional wind exceeds or equal to 8 m s⁻¹ preceded by mean sea level pressure gradient with value higher or equal to 10 hPa during 72 hours before. ERA-Interim reanalysis was utilized instead of observation data since this data set shows similarity to observation data from some validation test. Four months time-series validation of MSLP gradient ERA-Interim reanalysis data from November 2000 to February 2001 to observation data shows 0.99 correlation coefficient with a p-value of 0.0, which means the correlation coefficient of 0.99 also works for the population with almost 100% confidence. Statistical tests to compare reanalysis data and observation of the MSLP gradient was conducted with a p-value of 0.80, represent that both data set do not differ significantly.

Figure 1. Study Area

3. Result and Discussion
Gamma distribution parameters, including shape, scale, and location (loc), of observed and S2S modelled precipitation, for both control and perturbed model, in the first and last three time steps are compared to analyze the similarity among those dataset as shown in
Figure 2. The shape parameter in gamma distribution for the observed precipitation dataset shows similar value in each observation points, ranging from 0 to 1 indicating that the mean is less or equal to the standard deviation almost in every observation point. This pattern is quite different from the shape parameters from S2S predicted precipitation dataset, both in the control and perturbed model, with the first or last three time step. The shape parameter on the control model has a relatively higher value than the perturbed model. In the first three time steps of the control model, the shape parameters vary at each observation point, with dominance in the range of 1.5 - 3.5. This range of shape parameter show that the mean of the data is greater than the standard deviation. However, some near 0 values can be seen at several points. Higher ranges are observed in the last three time steps of the control model. In this model, the shape parameter ranges from 1 - 4, with the dominant value of 4 over the Kalimantan and southern parts of Sumatra. The bigger the shape parameter is, the greater the mean from standard deviation for every observation points, and thus, bigger differences from the observation data.

Lower range of shape parameter values can be spot on the perturbed S2S model. In the first three time steps, the shape parameter values from 0 - 1, with lower values dominating the northern Kalimantan and Sumatra regions while higher values dominate the Java region. In the last three time step, the shape parameter values that dominate Java are generally similar to the initial time step. However, higher values were observed over the Kalimantan and Sumatra regions, ranging between 1 - 2. This condition indicates that the shape parameters of the S2S precipitation perturbed forecast model between the first and last three time steps do not differ significantly over Java.

Unlike the shape parameter of the observed precipitation data, which is generally similar from one observation point to another, the scale parameter from the data has relatively high spatial variation, with a range between 0 - 60. This condition is different from the scale parameters of the S2S model, both control and perturbed, which actually look uniform from one observation point to another. In the S2S model, the scale parameter only ranges from 0 - 10, much less variable than the observed precipitation data.
Figure 2. Gamma distribution parameters (shape, scale, loc) of observed and S2S (perturbed and control) re-forecasted precipitation for periods of NDJF 1998 – 2017

The loc parameter at every observation points looks similar to each other, with a range of -0.2 - 0.0. This value is almost the same as the loc parameter in the S2S model with the first three time step. A slight difference is seen over West Kalimantan and Bengkulu, with a slightly lower range of values at -0.4 - (-0.2) at the last three time steps. The differences in these regions are increasingly significant in the S2S control model, both at the first and last three time steps. In the first three time step, the West Kalimantan and Bengkulu regions are dominated by loc parameters with a value reaching -1.0, far from the observation data. The observation point with a value of -1.0 is increasingly expanding at the last three time steps until the remaining observation points in the northern part of Sumatra, Banten, and West Java have loc parameters with a value of -0.2 - 0.0.

The number of rainy days fractions (rainfall greater than or equal to 1 mm/day) between the observation data and the S2S forecasts in the NDJF period of 1998 - 2017 can be seen in

Figure 3. From the figure, it can be seen that there is a large difference in the percentage of the number of rainy days between the observation data and the S2S model forecast, both control and perturbed models, at the first and last three time steps. The fraction of rainy days at each observation point varies between 13 - 81% in the observational data. The lowest fraction of rainy days is generally concentrated over North Sumatra. In contrast, a relatively high fraction of rainy days is observed at
several points over Bengkulu, West Java, East Java, and Kalimantan. This condition is quite different from the rainy day fraction of the S2S model. There is no significant spatial variation on the S2S models, both control and perturbed, at the first or last three steps. In the models, the rainy days' fraction ranges from 49 - 99%. This value is much higher than the observed value and indicates that the S2S model tends to predict non-rainy conditions as rain.

The histogram of observed precipitation data and the S2S model at six rain observation points (North Sumatra, Riau Islands, Bengkulu, West Java, East Java, and West Kalimantan) is shown in Figure 4. Those points were selected to represent the distribution of observation points in the study area. In Figure 4, the frequency of rainfall events with intensity between 0 - 5 mm / day in the observation data appears to be around 1000. A higher value is observed at observation points in North Sumatra and Riau Islands, where the frequency reaches 1200. This value is much higher than the S2S models' prediction, which is only around 500, except at points in the Riau Islands, which reached 1000. Even so, this value is still smaller than the observed value, which reaches 1200.

The opposite condition is seen in higher rain intensity. At rainfall intensity of 5 - 10 mm / day, 10 - 15 mm / day, 15 - 20 mm / day, and so on, the frequency of observed rainfall is much lower than the prediction of the S2S model, both control and perturbed models. This condition can be seen at the whole six observation points, thus supporting the analysis in

Figure 3, which states that the S2S model tends to provide rain forecasts rather than no rain.

![Figure 3](image)

Observed and S2S rainy days fractions forecast for perturbed and control model, both the first and last three time steps for periods of NDJF 1998 - 2017

The comparison between observed rainfall frequency with the S2S model is similar for the perturbed and control S2S models. The perturbed S2S model generally has higher rainfall frequency with an intensity of 0 - 5 mm / day. In contrast, in the rainfall above 5 mm/day, the frequency of the control S2S model appears to be more dominant. In comparing the first and last three time steps, the observed pattern is entirely random, so it cannot be concluded which time step is better in this condition.

The comparison of the scatter plot between observation data and the S2S model at six observation points mentioned above is shown in Figure 5. From this figure, the observed precipitation and the model
do not establish a linear relationship. Precipitation forecast models tend to underestimate high rainfall and overestimate low rainfall. In West and East Java, several data between the observation and the first three time steps of the S2S perturbed model show a linear pattern. However, there are far fewer data that fit this pattern, so that the linear relationship between the observation and the S2S model dataset cannot be determined.

Figure 4. Histograms for Observed and S2S precipitation forecast for control and perturbed models, both at the first and last three time steps for periods of NDJF 1998 - 2017

Figure 5. Scatter plot of observed and S2S precipitation forecast for control and perturbed models, both at the first and last three time steps for periods of NDJF 1998 - 2017
The correlation coefficient and RMSE of the S2S model are calculated using daily precipitation and pentad accumulation forecast, as shown in a boxplot in Figure 6. This figure shows that the first three time steps for both perturbed and control show better performance since they have a higher correlation coefficient than the last three time steps. At the first three time steps, the correlation coefficient between the daily precipitation data of the perturbed model has an average of 0.21, a maximum value of 0.48, and a minimum of -0.03, while in the control model, the correlation coefficient is slightly higher with an average of 0.25, a maximum value of 0.50, and minimum value of -0.03. The correlation value at the first three time steps is much higher when compared to the last three time steps with an average correlation of 0.03, a maximum value of 0.14, and minimum value of -0.07 in the perturbed daily precipitation model and an average correlation value of 0.04, a maximum value of 0.16, and minimum value of -0.07 in the daily control precipitation model.

A higher correlation coefficient is observed from the comparison between the observed precipitation and the S2S model in pentad accumulation. The first three time steps' correlation coefficient is still higher than the last three in this condition. In the perturbed model, the correlation value reaches 0.65 at the first three time step, with an average of 0.33 and a minimum value of -0.09. At the last three time steps, the maximum correlation coefficient is only 0.31. Slightly higher than the perturbed model, the control model has a maximum correlation coefficient of 0.66 at the first three time steps and 0.30 at the last three. These conditions indicate that the control model’s correlation is generally higher than the perturbed models, both for daily and pentad accumulation precipitation. The first three time step being much higher than the last one.

The RMSE between daily observed and the S2S model precipitation shows similar values for the perturbed and control models, both at the first and last three time steps. In the perturbed model, the average of RMSE is at a value of 21.3 in the first three time steps and 21.4 at the last three time steps. The RMSE value is slightly lower in the control model, with an average of 19.8 for the first three time steps and 20.6 for the last three time steps. In this model, the maximum RMSE value reaches 44.2 at the first three time steps and 46.1 at the last three time steps, still lower than the perturbed model. The control model's RMSE value, which tends to be lower than the perturbed model in the pentad accumulation calculation, shows the same trend as the daily rainfall calculation. This condition is in line with the correlation coefficient, which is higher in the control than perturbed model so that statistically, it shows that the relationship between the observed precipitation and the control S2S model is slightly better than the perturbed S2S model.

Spatial mapping of correlation and RMSE values between daily precipitation data (above) and pentad accumulation (bottom) with control and perturbed S2S models at the first and last three time steps can be seen in Figure 7. The correlation coefficient in the image is represented by the color based on the color bar below the pictures, while the size of the circle at each point of observation represents RMSE.
value. Only observation points that correlate with a confidence level above 95% are shown in the figure. In other words, the mapped observation points have a correlation value that can represent the entire rainfall population at each point. Figure 7 shows more points in the first three than the last three time steps, both in daily precipitation (above) and pentad accumulation (bellow). It shows that more observation points have a correlation coefficient with confidence level above 95% at the first three time steps. Another thing that can be observed is that the correlation coefficient at the last three time step is much lower than the first three, as shown in the boxplot in Figure 6. Similar conditions are also seen in pentad accumulation. The first three time steps offer more observation points than the last three time steps, as well as a higher correlation value. The essential difference between the daily value and the accumulated pentad is found in the RMSE, where the RMSE for daily value is lower than the accumulated pentad. This condition is expected considering pentad accumulation is calculated by adding up the precipitation for five days.

Despite having a confidence level above 95%, the observed correlation values are generally not too high. The last three time steps show a small correlation coefficient with near-zero value, both for daily and pentad accumulation dataset. Detailed observation points with a correlation coefficient bigger than 0.4 (medium relationship category) with a confidence level above 95% can be seen in Figure 8. The figure shows the mapping of correlation coefficient and RMSE in daily and pentad accumulation for control and perturbed S2S model in the first three time step. Only the initial time step is displayed because, at the last three time steps, there are no observation points with a correlation value of more than or equal to 0.4, as shown in Figure 7.

The daily control S2S model shows a correlation value of more than 0.4 at some points distributed throughout the study area, such as Aceh, North Sumatra, Riau Islands, Bengkulu, West Kalimantan, Banten, West Java and East Java. In this model, the maximum correlation coefficient of 0.5 is seen in Riau Islands, especially in the Natuna Islands. In the daily perturbed S2S model, two observation points are plotted, those are in Aceh and Natuna Islands. Those points were also observed to have a correlation value of more than 0.4, respectively 0.41 and 0.48. This model’s correlation coefficient is slightly lower than the correlation coefficient in the daily control S2S model. The number of points that have a correlation coefficient of more than or equal to 0.4 is lower as well.

In contrast to daily precipitation, the calculation of correlation and RMSE using pentad accumulation results in a higher correlation value. The number of points with a correlation coefficient of more than or equal to 0.4 is much higher in this calculation. However, the number of points with a correlation coefficient of more than or equal to 0.4 in the control model is still observed bigger than the perturbed model. In the utilization of this accumulation method, the correlation coefficient reaches 0.66 in the control S2S model and 0.65 in the perturbed S2S model. The high correlation value is found in the Riau region in both models. Not only in the Riau region, correlation coefficient higher than the daily calculations can also be found in Aceh, North Sumatra, West Kalimantan, Central Kalimantan, and Central Java. The lower correlation coefficient is generally found in Java, where only some observed points are observed to have a correlation coefficient of more than 0.5.
Figure 7. Spatial Mapping of S2S Models Correlation (shaded) and RMSE (circle size) to daily (above) and pentad accumulation (bellow) observed precipitation in for periods of NDJF 1998 - 2017 with confidence level above 95%

Figure 8. Spatial Mapping of S2S Models Correlation (shaded) and RMSE (circle size) to daily and pentad accumulation observed precipitation for the first three time steps in for periods of NDJF 1998 - 2017 with correlation coefficient $\geq 0.4$ and confidence level above 95%

The long-term daily average of observed and S2S precipitation forecast for the first three time steps for the periods of November, December, January, and February, with the average number of days, is shown at the top right of each map, is shown in

Figure 9. There is no significant difference in the precipitation forecast by the control and perturbed S2S models. Both models provide similar precipitation pattern, with values tending to be lower in the control model. This lower value can be seen in Aceh, North Sumatra, East Java, the north coast of
western Java, and East Java. However, it can also be seen that the S2S perturbed model precipitation forecast is lower in the December period for the coastal areas of West Kalimantan. The model with a lower forecast value is generally more similar to the observed precipitation, showing the tendency of overestimating from the S2S model.

Although accurate quantitative precipitation forecasts cannot be achieved yet, the spatial patterns shown by the S2S forecast for the November period can provide an overview of the actual precipitation in several regions, such as Riau, Jambi, South Sumatra, Bengkulu, West Kalimantan, and the southern coast of Java. In December, the S2S model precipitation forecasts tend to underestimate for the Kalimantan and West Sumatra regions. However, they tend to overestimate for Aceh, North Sumatra, Bengkulu, Lampung, and the northern coast of Java. The tendency of S2S models to underestimate the precipitation is also evident in the Kalimantan region in January. They tend to overestimate in Aceh, North Sumatra, and Bengkulu during this period. The model’s character to overestimate was still visible in February, such as in Aceh, North Sumatra, Bengkulu, and Kalimantan. The perturbed S2S model, which in the previous period predicted a higher precipitation value than the control S2S model, shifted to provide lower precipitation for the Kalimantan region in this period, especially in the coastal area, thus providing a better picture of the spatial distribution of the precipitation. In this period, better forecasts are spotted over Riau Islands, where the forecast of control and perturbed models show quite similar value to the observed precipitation over the region.

![Figure 9. Long term mean of observation and S2S model (control and perturbed) precipitation forecast for the first three time steps for November, December, January, and February 1998 - 2017](image)

Although the S2S model can predict the spatial pattern of high precipitation over the north coast of Central and East Java in the January and February periods, rainfall above 20 mm / day in the western and central part of Java is to be captured by the model. In that period, the predicted precipitation is only 17 mm / day in the East Java region. It shows that the spatial mapping consistent with the histogram plot, which shows model’s tendency to underestimate high precipitation intensity and overestimate the low.

Comparison of the average daily observed precipitation with the S2S model when MJO is active is shown in Figure 10. As in the NDJF period, the S2S model seems unable to correctly display the spatial variations in each observation point. However, there is a similar pattern between the observed
precipitation and the model forecast over a specific area. When the MJO is active, the S2S model precipitation forecast seems to recognize the wet and dry phases brought by the MJO. It can be seen from the significant dominance of the forecast when the MJO was active in phases 1-4 and 5-8.

When MJO was active in phase 1, high rainfall intensity dominated Kalimantan, while northern Sumatra and the north coast of Java were dominated by low rainfall intensity. This pattern cannot be seen in the S2S precipitation forecast, which predicts high rainfall intensity over Bengkulu. Nevertheless, the model captures patterns of low rainfall intensity at several points in East Java as well as over Banten, Lampung, and Bangka Belitung. Similar conditions can also be found when MJO is active in phase 2. The S2S models still underestimate the precipitation in Kalimantan and Java, and tend to overestimate over Bengkulu. However, it appears that several points over Sumatra can be predicted better by the perturbed S2S model and the East Java region, particularly Banyuwangi, which consistently has a similar pattern to the observed results.

There was no significant change in the S2S precipitation forecast for the Kalimantan region when MJO was active in phases 3 and 4, clarify the tendency of the S2S model to underestimate precipitation in that area. The S2S model forecast for North Sumatra and Bengkulu also consistently overestimate the rainfall intensity. Although the S2S models do not predict the intensity accurately, the models begin to show a pattern of increasing precipitation in Java when MJO is active in phase 3, as seen in the observation data. This increase in rainfall intensity forecasts can be observed more clearly in the perturbed S2S model, consistent until the MJO was active in phase 4. It can be seen that the prediction of high rainfall intensity in the S2S model, which was previously centered on the Central and East Java regions, began to expand to the west, as also spotted in the observation data. Over Bengkulu, although the models tend to overestimate the precipitation on the northern and southern coastal region, the models' precipitation forecast still represent the observed rainfall intensity at several observation points on the central coast of Bengkulu.
Figure 10. Long term mean of observation and S2S model (control and perturbed) precipitation forecast for the first three time steps for each MJO phase in the periods of NDJF 1998 - 2017.
The effect of MJO phase 5 on the western part of Indonesia, which generally reduces rainfall, can be seen in the S2S model forecast. The model seems to show a significant decrease in precipitation in most of the study areas. The S2S model appears to reveal patterns and ranges of rain in several regions in this condition, such as Riau Island, West Java, parts of East Java and West Kalimantan. At the observation points in Jambi and South Sumatra, the precipitation pattern seen in the S2S model, especially the control model, also provides a reasonably spatially representative picture. The spatial patterns in the area can also be described quite well when MJO was active in phase 6, as were parts of Bengkulu and West Java. However, the precipitation in the West Kalimantan region, which reached its minimum point when the MJO was active in phase 6, could not be captured by the S2S model perfectly. The model appears to overestimate in the region, as well as in the North Sumatra region, while in several observation points in Java, the model tends to underestimate. The lack of ability of the S2S models to predict precipitation over West Kalimantan and North Sumatra was also seen when the MJO was active in phases 7 and 8. However, this model’s ability in the Riau Islands looks quite good, although a little bit tendency to overestimate. The precipitation pattern shown in the Java region can also be said to be similar to the observation data, although high rainfall at several points cannot be captured.

Three days before to three days after the active NCS reaches 15°N, there is no significant difference in precipitation pattern over the study area as displayed by Figure 11. In the observation data, the increase in precipitation began to be seen at D + 1 and consistent up to D + 3 around Riau Islands and West Kalimantan. The increase in precipitation in the region can also be seen in the S2S model since D + 1, with the maximum precipitation being achieved at D + 3. However, the increase in precipitation in Kalimantan on D + 1 and D + 2 was not very significant and tended to be expected, so that the NCS flow pattern could not be clearly observed in the model. Increased precipitation is also seen in the Java region from D - 2 to D + 2 and Lampung on D day to D + 2. The increase in precipitation over Java region is in accordance with the increase in observed precipitation, but in a narrower period at D - 1 to D + 1. In contrast, the rise in precipitation forecasts in Lampung is less suitable when compared to the observation data, which tends to be constant in that period.
Figure 11. Long term mean of observation and S2S model (control and perturbed) precipitation forecast for the first three time steps three days before up to three days after active NCS reach 15°N in the periods of NDJF 1998 - 2017

Long term mean of precipitation one day up to three days after active NCS reaches 15°N on every MJO phase are accumulated to analyze the performance of S2S models to forecast the effect of the interaction between MJO and NCS on the precipitation over the study area, as shown in Figure 12. The increasing precipitation around Karimata Strait in the interaction between NCS and MJO phase 1 is hard to be seen on S2S models, both on the perturbed and control model. The high rainfall intensity due to the presence of NCS on MJO phase 1 is strongly noticed in the observation data. The models seem unable to predict the high rainfall intensity around Karimata strait in the interaction between NCS and MJO phase 1 and in MJO phase 2, 3, and 4. The models do not show a better ability over Sumatra as well. Almost in every phase of interaction, S2S models always overestimate the rainfall intensity over the region. However, better performance of the model can be noticed over Java. High rainfall intensity in East Java can be predicted by the perturbed model, even with a lower value or the tendency to underestimate the intensity. This performance over Java is also noticed almost in every phase of the interaction.
Figure 12. Accumulated long term mean precipitation from observation and S2S model forecast one to three days after NCS reach 15°N in every MJO phase for periods of NDJF 1998 – 2017

The S2S models tend to predict the effect of MJO better than NCS. In the interaction between NCS and MJO phase 5 and 6, where the dry phase of the MJO dominate, the S2S can estimate the precipitation better. Precipitation in Bengkulu is predicted to be higher, while decreasing precipitation dominates the rest of the study area, as been proven in the observation data. Although they show better performance in those phases, the models are still unable to predict the intensity correctly, where they underestimate some high rainfall intensity and overestimating the lower intensity. The capability of S2S models to
predict the precipitation pattern is well visible in the interaction between NCS and MJO phase 7. The increasing precipitation over West Kalimantan and Java are noticeable from the models, especially the perturbed. The S2S perturbed model also show relatively better performance over Sumatra, where the increased precipitation over the area can be captured by the model better in the interaction between NCS and MJO phase 8.

4. Conclusion

Performance of the S2S control and perturbed precipitation forecast over western Indonesia varies on the location and corresponding condition. Gamma distribution parameters on the perturbed model show higher similarity to the observation dataset than the control model, especially on the shape and location parameters, indicating that the comparison of the mean and standard deviation of the dataset resembles the observation dataset better. The perturbed model offers better similarity to the categorical precipitation frequency from the observation dataset as well. The perturbed model offers higher frequency than the control model in the rainfall intensity ranges from 0 - 5 mm/day, although it still far below the actual observed frequency. Conversely, the models, both perturbed and control, predict the frequency far above the observation at higher rainfall intensity, indicating that they tend to overestimate the precipitation forecast. This statement is reinforced by comparing rainfall event fraction, which exhibits vast differences between the observed and S2S models prediction, both for perturbed and control models.

Statistical verification using the correlation coefficient and RMSE denotes slightly better performance from the S2S control model on daily and pentad accumulated precipitation. A correlation coefficient of 0.5 represents the best performance of the S2S control model precipitation forecast for daily precipitation with RMSE around 20 over Natuna Islands. The S2S perturbed forecast also performs the best in that region with a correlation coefficient of 0.48. Those two values of correlation coefficient are achieved in the first three time steps of the forecast, while the last three time steps show less correlation coefficient. In the term of pentad accumulated precipitation, a higher correlation coefficient is achieved for an observation point in Riau. The control model shows a slightly better value at 0.66 while the perturbed show 0.65, with RMSE around 40.

Spatial analysis of the S2S models' precipitation forecast compared to ground observation data show relatively good performance. The perturbed and control model seems like complementing each other wherein some condition the perturbed model perform better while in other condition, the control model does. Both models can catch the variation brought by the wet season in the NDJF period, by the MJO, and show a hint of NCS effect. Even though the models tend to overestimate low rainfall intensity and underestimate the high one, they can depict the precipitation pattern pretty well. In November, December, January, and February, the models tend to overestimate the intensity in Sumatra but show quite reliable performance in Kalimantan and Java. In the MJO event, the models can also catch the variation between the wet and dry effect of the MJO phases with the tendency of overestimating in Sumatera for the whole phases. When MJO was active in phase 1-4, S2S precipitation forecast in Kalimantan tend to underestimate and cannot catch high rainfall intensity in some observation points, but when MJO was active in phase 5-7, the models being more overestimate on low rainfall intensity. Meanwhile, consistently good spatial performance is shown by the models over Java, both in NDJF periods or MJO events.

Similar performance is shown in the active NCS periods. The models can hint at an increase in precipitation due to NCS around Karimata Strait. However, the models still tend to overestimate rainfall intensity over Sumatra and hardly show high rainfall intensity in Kalimantan and Java. This condition is also noticed in the interaction between NCS and MJO, when both of MJO and NCS are active. The models apparently show the predicted precipitation as reflected by the combination of MJO and NCS effect. They still overestimate in Sumatra, and some high and low rainfall intensity in Kalimantan and Java cannot be predicted correctly.
Acknowledgments

Data in this study is supported by the European Centre for Medium-Range Weather Forecasts (ECMWF) for Sub-seasonal to Seasonal model precipitation dataset and Agency for Meteorology Climatology and Geophysics for the ground observation precipitation dataset. Appreciation is delivered to the Center of Education and Training of Agency Meteorology, Climatology, and Geophysics (Pusdiklat BMKG) for the scholarships at Applied Climatology, IPB University.

References

[1] Zhang C 2005 Madden Julian Oscillation Impacts Rev. Geophys. 43 4
[2] Hidayat R 2016 Modulation of Indonesian Rainfall Variability by the Madden-julian Oscillation Procedia Environ. Sci. 33 167–77
[3] Pramuwardani I, Hartono,; Sunarto; and Sopaheluwakan A 2018 The Influence of Madden-Julian Oscillation on Local Scale Phenomena over Indonesia during The Western North Pacific and Australian Monsoon Phase Forum Geogr. 31 156–69
[4] Wheeler M C and Hendon H H 2004 An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction Mon. Weather Rev. 132 1917–32
[5] Jeong J H, Ho C H, Kim B M and Kwon W T 2005 Influence of the Madden-Julian Oscillation on wintertime surface air temperature and cold surges in east Asia J. Geophys. Res. D Atmos. 110 1–7
[6] Chang C P and Lau K M W 1979 Northeasterly cold surges and near-equatorial disturbances over the winter MONEX area during December 1974. Part I: Synoptic Aspects Mon. Weather Rev. 108 298–312
[7] Chang C P and Lau K M W 1980 Northeasterly Cold Surge and Near-Equatorial Disturbances over the Winter MONEX Area During December 1974. Part II Planetary Scale Aspect Mon. Weather Rev. 108 298–312
[8] Wang L, Kodera K and Chen W 2012 Observed triggering of tropical convection by a cold surge: Implications for MJO initiation Q. J. R. Meteorol. Soc. 138 1740–50
[9] Chang C P, Harr P A and Chen H J 2005 Synoptic Disturbances over the Equatorial South China Sea and Western Maritime Continent during Boreal Winter Mon. Weather Rev. 133 489–503
[10] Lim S Y, Marzin C, Xavier P, Chang C P and Timbal B 2017 Impacts of boreal winter monsoon cold surges and the interaction with MJO on southeast Asia rainfall J. Clim. 30 4267–81
[11] Vitart F and Robertson A W 2018 The sub-seasonal to seasonal prediction project (S2S) and the prediction of extreme events npj Clim. Atmos. Sci. 1 1–7
[12] Vitart F, Ardilouze C, Bonet A, Brookshaw A, Chen M, Codorean C, Déqué M, Ferranti L, Fucile E, Fuentes M, Hendon H, Hodgson J, Kang H S, Kumar A, Lin H, Liu G, Liu X, Malguzzi P, Mallas I, Manoussakis M, Mastrangelo D, MacLachlan C, McLean P, Minami A, Mladek R, Nakazawa T, Najm S, Nie Y, Rixen M, Robertson A W, Ruti P, Sun C, Takaya Y, Tolstykh M, Venuti F, Waliser D, Woolnough S, Wu T, Won D J, Xiao H, Zaripov R and Zhang L 2017 The subseasonal to seasonal (S2S) prediction project database Bull. Am. Meteorol. Soc. 98 163–73
[13] Vitart F 2009 Impact of the Madden Julian Oscillation on tropical storms and risk of landfall in the ECMWF forecast system Geophys. Res. Lett. 36 1–6
[14] Vitart F and Molteni F 2010 Simulation of the Madden-Julian oscillation and its teleconnections in the ECMWF forecast system Q. J. R. Meteorol. Soc. 136 842–55
[15] He H, Yao S, Huang A and Gong K 2020 Evaluation and Error Correction of the ECMWF Subseasonal Precipitation Forecast over Eastern China during Summer Adv. Meteorol. 2020
[16] Lim Y, Son S W and Kim D 2018 MJO prediction skill of the subseasonal-to-seasonal prediction models J. Clim. 31 4075–94
[17] Fauzi R R and Hidayat R 2018 Role of cold surge and MJO on rainfall enhancement over Indonesia during east asian winter monsoon IOP Conf. Ser. Earth Environ. Sci. 149 0–10
[18] Hidayat R and Kizu S 2010 Influence of the Madden-Julian Oscillation on Indonesian rainfall
variability in austral summer *Int. J. Climatol.* **30** 1816–25

[19] Ling J, Zhang C and Bechtold P 2013 Large-scale distinctions between MJO and non-MJO convective initiation over the tropical Indian Ocean *J. Atmos. Sci.* **70** 2696–712

[20] Zhang C and Ling J 2017 Barrier effect of the Indo-Pacific Maritime Continent on the MJO: Perspectives from tracking MJO precipitation *J. Clim.* **30** 3439–59

[21] Becker E J, Berbery E H and Higgins R W 2011 Modulation of cold-season U.S. Daily precipitation by the Madden-Julian oscillation *J. Clim.* **24** 5157–66

[22] L’Heureux M L and Higgins R W 2008 Boreal winter links between the Madden-Julian oscillation and the arctic oscillation *J. Clim.* **21** 3040–50

[23] Dee D P, Uppala S M, Simmons A J, Berrisford P, Poli P, Kobayashi S, Andrae U, Balmaseda M A, Balsamo G, Bauer P, Bechtold P, Beljaars A C M, van de Berg L, Bidlot J, Bormann N, Delsol C, Dragani R, Fuentes M, Geer A J, Haimberger L, Healy S B, Hersbach H, Hölm E V., Isaksen L, Källberg P, Köhler M, Matricardi M, Menally A P, Monge-Sanz B M, Morcrette J J, Park B K, Peubey C, de Rosnay P, Tavolato C, Thépaut J N and Vitart F 2011 The ERA-Interim reanalysis: Configuration and performance of the data assimilation system *Q. J. R. Meteorol. Soc.* **137** 553–97

[24] Aldrian E and Utama G S A 2010 Identifikasi dan Karakteristik Seruak Dingin (Cold Surge) tahun 1995-2003 *J. Sains Dirgant.*