A study comparison of two system model performance in estimated lifted index over Indonesia.

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Abstract. Lifted index (LI) is one of atmospheric stability indices that used for thunderstorm forecasting. Numerical weather Prediction Models are essential for accurate weather forecast these day. This study has completed the attempt to compare the two NWP models these are Weather Research Forecasting (WRF) model and Global Forecasting System (GFS) model in estimates LI at 20 locations over Indonesia and verified the result with observation. Taylor diagram was used to comparing the models skill with shown the value of standard deviation, coefficient correlation and Root mean square error (RMSE). This study using the dataset on 00.00 UTC and 12.00 UTC during mid-March to Mid-April 2017. From the sample of LI distributions, both models have a tendency to overestimated LI value in almost all region in Indonesia while the WRF models has the better ability to catch the LI pattern distribution with observation than GFS model has. The verification result shows how both WRF and GFS model have such a weak relationship with observation except Eltari meteorologi station that its coefficient correlation reach almost 0.6 with the low RMSE value. Mean while WRF model have a better performance than GFS model. This study suggest that estimated LI of WRF model can provide the good performance for Thunderstorm forecasting over Indonesia in the future. However unsufficient relation between output models and observation in the certain location need a further investigation.

Keywords: Lifted Index, WRF, GFS, Taylor diagram

1. Introduction
Thunderstorm (TS) activity is closely related to a cumulonimbus development where the form of the cloud is affected by the atmospheric stability. Atmospheric Stability is the resistance of the atmosphere to vertical motion [1]. In meteorology, there known as Stability indices that used to examine the atmospheric stability rate in a certain region and lifted Index is one of them. Galway of the U. S. Weather Bureau SEIJ3 desived the Lifted Index (LI), a modification of the Showalter Index [2] which is calculating the parcel temperature at 500 mb.

In now days, The atmospheric stability indices are used to predict TS [3] or severe TS [4]. While there is Numerical Weather Prediction (NWP) as the developed method for weather prediction. NWP is a very young discipline that developed essentially in the second half of the twentieth century with the continual benefit of advances in computing. The techniques implemented are used to solve equations describing the behaviour of the atmosphere, that is, to numerically compute future values of the atmosphere’s characteristic parameters from initial values that are known from meteorological
observations [5]. In order to supporting the upgraded weather prediction method, Atmospheric stability from NWP model is used in this study.

2. Numerical Weather Prediction (NWP) Model

There are two different NWP models that used in this study. Those are Global forecast System (GFS) model dan Weather research and forecasting (WRF) model. The Global Forecast System (GFS) is a weather forecast model produced by the National Centers for Environmental Prediction (NCEP). Dozens of atmospheric and land-soil variables are available through this dataset, from temperatures, winds, and precipitation to soil moisture and atmospheric ozone concentration [6]. The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications [7].

2.1 Global Forecast System (GFS) Model

Barry and Chorley[8] in their book said that The Global Forecast System (GFS) model (formerly known as the AVN/MRF for aviation/medium-range forecast) model has a spectral truncation of T170 (approximately 0.7 × 0.7- degree grid), 42 unequally spaced vertical level out to seven days. The truncation is increased to T62 with 28 level out to 15 days. 

GFS model is Global Spectral Model (GSM) with spherical harmonic basis function. Operational Dinamic core of this model is based on two time-level discreet semi-implicit semi-lagrarian with three dimentional interpolation. while three time-level Eularian is used in vertical. the physic parameterization in GFS incNde: Radiation, Boundary Layer, Gravity wave drag and mountain blocking, Shallow convection, Deep convection, and The Noah Land Surface Model (SM) [9].

2.2 Weather Research and Forecasting (WRF) Model

Skamarock et al., [10] explain that The Weather Research and Forecasting (WRF) model is a numerical weather prediction (NWP) and atmospheric simulation system designed for both research and operational applications. WRF is supported as a common tool for the university/research and operational communities to promote closer ties between them and to address the needs of both. The development of WRF has been a multi-agency effort to build a next-generation mesoscale forecast model and data assimilation system to advance the understanding and prediction of mesoscale weather and accelerate the transfer of research advances into operations.

Coeffier [5] through his book teel us tha WRF is nonhydrostatic dynamical core is based on the Euler equations, but it can be easily be simplified to accommodate the hydrostatic relation and to operate with primitive equations. The WRF model uses a split-explicit time integration method; this consists of splitting the system of equations into several separate parts which are then integrated with different time steps, adapted to each, so as to ensure the overall stability of the process.

WRF can produce simulations based on actual atmospheric conditions (i.e., from observations and analyses) or idealized conditions. WRF offers operational forecasting a flexible and computationally-efficient platform, while reflecting recent advances in physics, numerics, and data assimilation contributed by developers from the expansive research community. WRF is currently in operational use at NCEP and other national meteorological centers as well as in real-time forecasting configurations at laboratories, universities, and private companies[7].

3. Method

Dataset on this study is the LI data during March, 12th – April, 16th in 2017 from both WRF and GFS model, and also LI data from radiosonde observation on 20 locations which spreads through over Indonesia region.
Table 1. The Research Locations

| Station Name                                         | Symbol | Letak Geografis     |
|------------------------------------------------------|--------|---------------------|
| Blangbintang Meteorology Station (Banda aceh)        | BB     | 5.5222N 95.4167E    |
| Kualanamu Meteorology Station (Medan)                | KL     | 3.5952N 98.8616E    |
| Ranai Meteorology Station                            | RN     | 3.95N 108.3833E     |
| Tabing Meteorology Station (Papang)                  | TB     | 0.9166S 100.35E     |
| Pangkalpinang Meteorology Station                    | PP     | 2.163S 106.1379E    |
| Padangkemiling Meteorology Station                   | PK     | 3.8833S 102.333E    |
| Supadio Meteorology Station                          | SP     | 0.15S 109.6E        |
| Syamsudin Noor Meteorology Station                   | SN     | 3.43S 114.75E       |
| Cengkareng Meteorology Station                       | CK     | 6.116S 106.65E      |
| Cilacap Meteorology Station                          | CL     | 7.73S 109.016E      |
| Juanda Meteorology Station                           | JD     | 7.366S 112.767E     |
| Dr. Sam Ratulangi Meteorology Station                | SR     | 1.533N 124.917E     |
| Mutiara P. Meteorology Station                       | MP     | 0.683S 119.733E     |
| S. Hasanuddin Meteorology Station                    | HS     | 5.066S 119.55E      |
| El Tari Kupang Meteorology Station                   | EL     | 10.166S 123.667E    |
| Jefman Meteorology Station                           | JM     | 0.933S 131116E      |
| Mokmer (Biak) Meteorology Station                    | MM     | 1.183S 136.116E     |
| Pattimura Meteorology Station                        | PT     | 3.75S 128.083E      |
| Saumlaki Meteorology Station                         | SL     | 7.983S 131.3E       |
| Mopah Meteorology Station                            | MO     | 8.467S 140.383E     |

Comparison between the two NWP models is done using the taylor diagram method. This diagram is described that can concisely summarize the degree of correspondence between simulated and observed fields. On this diagram the correlation coefficient and the root-mean-square (RMS) difference between the two fields, along with the ratio of the standard deviations of the two patterns, are all indicated by a single point on a two-dimensional (2-D) plot [11]. The similarity between two patterns is quantified in terms of their correlation, their centered root-mean-square difference and the amplitude of their variations (represented by their standard deviations) [12].

The Coefficient correlation formula defined as,  
\[ r = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{n\Sigma x^2 - (\Sigma x)^2} \cdot n\Sigma y^2 - (\Sigma y)^2} \]

When, x: estimated LI NWP, y: LI observation from radiosonde.

Table 2. Coefficient Correlation relationship rate [13]

| Interval     | Relationship |
|--------------|--------------|
| 0.00 – 0.199 | Very weak    |
| 0.20 – 0.399 | Weak         |
| 0.40 – 0.599 | Moderate     |
| 0.60 – 0.799 | Strong       |
| 0.8 - 1.00   | Very strong  |

And, RMSE formula defined as [14],  
\[ RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i)^2}{n}} \]

Which, \( x_i \) = LI estimated value from NWP product, \( y_i \) = LI value from observation radiosonde, \( n \) = amount of data.
4. Result and Comments

4.1. Comparison Lifted Index estimated WRF and GFS model

Randomly choosen day during dataset has used in mapping distribution LI, that is at March 17th, 2017. From the LI distribution map over Indonesia shows that LI Prediction output WRF model tend to quite resembles the LI observation pattern more than GFS model. While GFS model show pattern that goes off from LI observation pattern. However the LI distribution of WRF model has the Underestimate value on most of Indonesia region meanwhile GFS model shows the Overestimate value on the most of Indonesia region.

Based on the scale NWP model is devided into 4 type, which are global scale model, mesoscale, local and all scale model. This study has examined the two of them, these are WRF model as the mesoscale model and GFS model as the Global scale model. WRF model were designed to simulate and predict the weather in the smaller region than GFS with the higher resolution. This theory support the result of why WRF model generally can predict LI in Indonesia.

Comparison between two NWP models (figure 2. a, b, c, d) has shown almost random result in predict LI at 00.00 and 12.00 UTC over Indonesia region. Verification result tell that at 00.00 UTC 65% of research locations shows that WRF model won over GFS model with the lowest RMSE while the coefficient correlation tells opposite. More than half (55%) of research location found that GFS model has the better relationship with observation than WRF has.

Verification that has done at 12 UTC (figure 2, a &b) show that generally WRF model has the better performance to predict LI in indonesia. This is indicated by 60% of indonesian region show that WRF has better relationship with observation than GFS, even though the RMSE value just reach 35% of Indonesia region that showed WRF model has the lower error than GFS model.

After all, the result showed how generally WRF still won over GFS with the better perfomance to predict LI over indonesia.

4.2. Verification Lifted Index WRF and GFS model

Verification has done for WRF and GFS model on 20 research locations over Indonesia at 00.00 and 12.00 UTC shows that the two models performance are quite good in predicting LI value though still there the poor result in some locations. The Error prediction that shown from RSME value told how both models have the quite good result which is within 1 to 2 in general (figure a & c). Significant differences in the different region has shown by coefficient correlation value which is known as the parameter to see how the similarity between two patterns (observation and NWP model).
Figure 2, b) shows that both NWP models can reach the maximal performance in LI estimation in Eltari meteorology Station while the poorest performance is found in Kualanamu meteorology station. Coefficient correlation were found close to zero (0) for GFS model in Kualanamu meteorology station while WRF model show inverse (downhill) linear relationship. This inverse relationship has also found in mopah, Patimura, Cilacap, Cengkareng, dan Blang Bintang meteorology station.

Eventhough not really significant, the verification result at 12 UTC shows how generally the error at 12 UTC prediction has increased from prediction at 00 UTC. This is because the unsufficient of water vapor in atmosphere at the time. Known as a tropic region, Indonesia got the biggest impact of sun radiation and convection process that affect the prediction result. The only significant change are found at Syamsuddin Noor and Ranai meteorology station, moreover the error increased 2 times higher.

The figure 3 Showed diagram Tylor for Eltari meteorology station with A as Observation, B as WRF model, and C as GFS models. While the error show the quite good result, coefficient correlation shows opposite. Both model at both time prediction tells that most of region have a weak relation with
observation (value < ±4). The maximum relation was only obtained by Eltari meteorology station (figure 3) which its value within 4 to 6 that indicate a moderate uphill linear relationship.

LI is the index who describe the humidity or moist air in the upper level which is calculated the difference of environment temperature and parcel temperature. Eltari Meteorology station is the region where the place are surrounded by oceans. These fact made this region to have more than enough supply air mass as the determinant factor of humidity in the region. this come to be an advantage for this region to be predict TS or any other convective clouds that form in this location.

The reason of why Lifted Index have such a poor coefficient correlation between NWP models and observation probably because the LI formula itself that doesn’t quite suitable with how numerical weather prediction work, let alone the fact that Indonesia is on the tropic region. The LI formula has known to calculate the difference between temperature of environment and temperature of parcel that raised from level 850 mb. the NWP model required more complex calculation as closer to surface (ground) because the closer a place to the surface means there are more kinetic process happened. The models apparently can’t catch all the kinetic process through the equations that turn out into the more biases in prediction.

5. Conclusions
Comparison and verification Lifted index between has done in 20 research locations over Indonesia region. This is show that from the LI distribution map show that WRF model can follow the observation pattern better than GFS even though the value mostly underestimate, while GFS model shows how GFS model pattern goes off from observation pattern with the mostly overestimate value.

To wrap it in general by the verification result, WRF model has won over WRF model in which NWP model that predict LI better. With the result at 00.00 UTC 65% of research locations shows that WRF model won over GFS model with the lowest RMSE while the coefficient correlation tell us opposite. More than half (55%) of research location found that GFS model has the better relationship with observation than WRF has. At 12 UTC, 60% of Indonesia region show that WRF model has better relationship with observation than WRF.

The RMSE value shows the quite good result which is generally less than 2 for both time predictions, but the coefficient correlation shows opposite. Both model at both time predictions indicate that most of region have a weak relation with observation, except Eltari meteorology station which its value within 4 to 6 that indicate a moderate uphill linear relationship.

From All those, LI product GFS model generally more recommended to be used at the weather or TS prediction purpose than WRF in Indonesia.

References
[1] M. Jenskin, “Unit 7: Atmospheric Stability and Instability Document Actions,” 2008.
[2] AWS, “the Use of the Skew T, Log P Diagram in Analysis and Forecasting,” p. 164, 1995.
[3] D. Vujovic, M. Paskota, N. Todorovic, and V. Vuckovic, “Evaluation of the stability indices for the thunderstorm forecasting in the region of Belgrade, Serbia,” Atmos. Res., vol. 161–162, pp. 143–152, 2015.
[4] H. Huntrieser, H. H. Schiesser, W. Schmid, and A. Waldvogel, “Comparison of Traditional and Newly Developed Thunderstorm Indices for Switzerland,” Weather forecasting, vol. 12, no. 1979, pp. 108–125, 1997.
[5] J. Coiffier, Fundamentals of Numerical Weather Prediction. Cambridge University Press, 2012.
[6] NOAA, “Global Forecast System (GFS),” 2003. [Online]. Available: https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs.
[7] NCAR, “Weather Research Forecasting Model,” 2017. 
[8] Barry and R. Chorley, Atmosphere, Weather & Climate. Routledge, 2009.
[9] NCEP, “The Global Forecast System (GFS) - Global Spectral Model (GSM).” [Online]. Available: http://www.emc.ncep.noaa.gov/GFS/doc.php.
[10] W. C. Skamarock et al., “A Description of the Advanced Research WRF Version 3,” Tech. Rep., no. June, p. 113, 2008.
[11] K. E. Taylor, “Summarizing multiple aspects of model performance in a single diagram,” J. Geophys. Res., vol. 106, no. D7, pp. 7183–7192, 2001.
[12] K. E. Taylor, “Taylor Diagram Primer,” Work. Pap., no. January, pp. 1–4, 2005.
[13] Sugiyono, Statistik Untuk Penelitian. Bandung: Alfa Beta, 2004.
[14] D. S. Wilks, Statistical methods in the atmospheric sciences, 3rd Editio., vol. 100, no. 3. USA: Academic Press, Elsevier, 2011.