The impact of land cover changes on temperature parameters in new capital of Indonesia (IKN)

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Abstract. North Penajam Paser Regency and Kutai Kartanegara Regency which are located in East Kalimantan Province are two locations that are planned as the New Capital of Indonesia (IKN). This has become one of the factors changing land cover from vegetation land to urban land, so that it can contribute to temperature changes. In this work, we analyze impacts of land use change on temperature in the new capital city. The change will simulate land cover changes using the Weather Research and Forecasting (WRF) model with two scenarios of land cover change from vegetation land to 547% and 1,222% urban land. Scenarios I and II will increase the temperature to 1.17 and 1.77 °C, respectively. This could mean that the addition of more urban areas results in an increase in temperature. The quantitative values of this connection will be beneficial for urban planners to manage the development of new capitals without having a significant impact on climate change.

1. Introduction
Changes in land cover also change solar heat radiation, surface temperature, and heat storage in urban areas [1]. Urbanization has also been a major factor in land use and land cover changes in human history [2]. Urbanization causes an increase in the amount of accumulated rainfall [3]. Balk et al. [4], explains that the projected percentage increase in urbanization in Asia between 2010 and 2030 is 40-60% and the increase in Asian urbanization population is the highest in the world with a total of 800 million to 1 billion inhabitants. The projected rate of population growth in Indonesia is also projected by the Central Statistics Agency (BPS) to continue to increase where by 2035 there were 305.6 million from 238.5 million in 2010 [5]. North Penajam Paser Regency and Kutai Kartanegara Regency which are located in East Kalimantan Province are two locations planned as the National Capital of Indonesia (IKN). The relocation of the national capital will make land use activities high, whether in the form of building construction, vegetation cover, or daily human activities. The high level of these activities leads to changes in land cover that have the greatest impact on urban temperatures [6]. Planning in developing cities must determine ways to conserve biodiversity when the city develops and does not damage natural habitats[7].
This research will study how the impact of land cover changes on temperature in IKN using the Weather Research and Forecasting - Advanced Research WRF (WRF-ARW) model. WRF-ARW is an advanced generation model of meso-scale weather simulation systems used for operational simulations and atmospheric research needs. The WRF-ARW model is part of the WRF modeling system that includes physical settings, numeric / dynamic options, and data initialization [8].

Research conducted by Lim et al. [9], investigating the sensitivity of surface climate change to land cover types in the northern hemisphere with surface temperatures analyzed, that the temperature of barren land and urban areas will be higher than most other land types. Research on land cover changes conducted by Tursilowati et al. [10], in the city of Jakarta, using Weather Research and Forecasting (WRF) Version 3, which modified pasture land use into urban areas and expanded the Urban Heat Island (UHI) area by around 43 km2 (5%). Furthermore, adding more vegetation, will reduce the temperature in areas with high temperatures. Quantitatively with the addition of 440, 95, and 48% of vegetation (grasslands) in urban areas, the UHI area (306 K) was reduced respectively 88, 54, and 48%. In general, the addition of vegetation in this study will reduce the temperature in areas that have high temperatures. In research conducted by Wang et al. [11], analyzed that changing agricultural land to urban land in the cities of Beijing and Tianjin using WRF 3.3 resulted in a significant increase in temperature and a decrease in humidity.

2. Data and methods

2.1 Observational data

![Location Map of New Capital of Indonesia (IKN)](image)

Air temperature data is obtained from three meteorological stations operated by Agency for Meteorology, Climatology and Geophysics. Locations of observation data are Meteorological Station of Sepinggan Balikpapan (01°16' S, 116°53' E), Automatic Agroclimate and Weather Station (AAWS) of Penajam Paser Utara (01°21' S, 116°39' E), and Automatic Weather Station (AWS) APT Pranoto Samarinda (00°29' S, 117°09' E). The data taken from 1 to 11 June 2019 are used for equalizing the time period of model runs.

2.2 WRF configuration

Weather Research and Forecasting - Advanced Research WRF (WRF-ARW) is a next-generation meso-scale numerical weather prediction model designed for the needs of both operational and research predictions. The basic equation used in WRF-ARW is a non-hydrostatic compressible equation, but WRF-
ARW also provides hydrostatic options for research under ideal conditions. WRF-ARW is suitable for applications in areas ranging from meter scale to thousands of kilometers [12]. In this study, the WRF simulations were executed with three domains with horizontal resolutions of 9, 3, and 1 km for domains 1, 2, and 3, respectively (Figure. 2). Domain 3 covers the whole administrative boundary of Ibu Kota Negara (IKN). The physics schemes used in numerical experiments are listed in Table 1.

![Figure 2. Plot the nesting of three regions 1, 2 and 3.](image)

| Parameter                  | Domain 1  | Domain 2  | Domain 3  |
|---------------------------|-----------|-----------|-----------|
| Meridional Grid Dimension | 162       | 148       | 136       |
| Zonal Grid Dimension      | 243       | 229       | 217       |
| Grid Resolution           | 27 km     | 9 km      | 3 km      |
| Terrain Resolution        | 10 min    | 10 min    | 5 min     |
| mp_physics                | WRFS 6-class | WRFS 6-class | WRFS 6-class |
| cu_physics                | Tiedtke   | Tiedtke   | Tiedtke   |
| bl_pbl_physics            | YSU       | YSU       | YSU       |
| sf_surface_physics        | Noah      | Noah      | Noah      |
| sf_sfclay_physics         | MM5       | MM5       | MM5       |
| ra_lw_physics             | RRTMG     | RRTMG     | RRTMG     |
| ra_sw_physics             | RRTMG     | RRTMG     | RRTMG     |
| sf_urban_physics          | BEP       | BEP       | BEP       |

2.3 NCEP FNL data
National Centers for Environmental Prediction (NCEP) Final (FNL) Operational Global Analysis data providing the values of surface pressure, sea surface temperature, temperature, u- and v- winds, sea level pressure, geopotential height, soil values, ice cover, relative humidity, vertical motion, vorticity and ozone
(UCAR, 2010). The NCEP FNL (Final) Operational Global Analysis data with 0.25° x 0.25° resolution (http://rda.ucar.edu/datasets/ds083.3/). The product that Global Forecast System (GFS) offers the near-real time analysis that runs four times a day at NCEP. The analyses are available at 26 mandatory (and other pressure) levels from 1000 mb to 10 mb, belonging the surface boundary layer and some sigma layers. The time period that this study taken is from 1 to 11 June 2019, with the benchmark of FNL data (fnl_190601_00_00–fnl_190611_00_00) in six hour time steps.

2.4 Landuse modification

![Figure 3. Unmodification or original landuse.](image)

Figure 3. Unmodification or original landuse.

In the model running process, hypothetical modification of land use is applied in accordance with the following two scenarios: (S1) no modification (fig. 3), (S2) modification by added 547% of urban, and (S3) modification by added 1,222% of urban (fig. 4). Modification of LU from vegetation to urban using the Python program.

![Figure 4. Land use modification by altering a fraction of vegetation area into urban area: (Scenario I) 547% and (Scenario II) 1,222%.](image)

Figure 4. Land use modification by altering a fraction of vegetation area into urban area: (Scenario I) 547% and (Scenario II) 1,222%.
3. Results and discussion

3.1 Validation of the urban physical parameterization schemes

Validation of the urban physical parameterization schemes uses 4 parameters of BULK, SLUCM, BEP and BEM parameterization schemes. Table 2 is the result value from the calculation of BIAS, MAE and RMSE surface temperature variables between the output of the model and the observation data of Stamet Sepinggan, AWS APT Pranoto and AAWS Penajam Paser Utara 1 – 11 June 2019. Yellow colored values are the best results.

Table 2. Comparison of parameterization schemes in WRF and observation stations around of IKN.

| Station     | Verification | BULK   | SLUCM | BEP   | BEM   |
|-------------|--------------|--------|-------|-------|-------|
| SEPINGGAN   | BIAS         | -0.06  | -0.10 | -0.11 | -0.14 |
|             | MAE          | 0.93   | 0.93  | 1.11  | 1.07  |
|             | CORR         | 0.86   | 0.87  | 0.75  | 0.83  |
|             | BIAS         | -0.41  | -0.41 | -0.44 | -0.54 |
| AAWS        | MAE          | 0.97   | 1.02  | 1.04  | 1.00  |
|             | CORR         | 0.82   | 0.81  | 0.80  | 0.81  |
|             | BIAS         | -0.11  | -0.06 | -0.07 | 0.08  |
| AWS         | MAE          | 1.12   | 1.33  | 1.15  | 1.11  |
|             | CORR         | 0.78   | 0.64  | 0.80  | 0.78  |

From Table 2 that all schemes show their ability to properly simulate surface temperature values. The model tends to show a cooler value or underestimate of surface temperature observation data in almost all observation points indicated with a negative BIAS value and only the BEM model at AWS APT Pranoto Smarinda shows a warmer value or overestimate of surface temperature observation data shown with a positive BIAS value. The best BIAS value is shown in the BULK scheme at the AWS APT Pranoto Smarinda with a value of -0.057.

The resulting error between observational data and model output results is also very good where it is shown from the MAE values in all four models at all points with values ranging from 0.93 - 1.33. The smallest MAE error value is shown in the BULK scheme at the Sepinggan Balikpapan Meteorological Station observation. The resulting correlation between the observation data and the model output is also very good, which is shown by the CORR value of the four models at all points with values ranging from 0.75 - 0.87.

Table 2 above, the best configuration scheme of the four schemes (BULK, SLUCM, BEP, and BEM) is the BULK scheme. The BULK scheme is the best scheme in simulating the state of surface temperature at 3 points in the area near the prospective National Capital City (IKN). The BULK scheme shows the best BIAS and CORR values and shows the smallest MAE error values of the four schemes.
3.2 Impact of landuse changes on temperature

Figure 5. Temperature (ºC) from WRF runs with input, (a) LU origin – S1, (b) +547% urban – S2 and (c) +1,222% urban – S3.

The panels in Fig. 5 are from WRF runs at 1 – 11 June 2019 and show at 06 UTC. The original LU (no modification) is shown in fig 5a. Fig. 5b (S2) shows the addition of approximately 1-2ºC in the IKN area with the addition of 547% urban, while Fig. 5c (S3) Indicates the increase of roughly 2-3ºC in the IKN area with the addition of 1,222% urban. Changes in air temperature also occur in the area around IKN but not significant. Therefore, this could conclude that UHI occurs in the central city.

Table 3. Temperature distribution from the result of running the WRF model on 4 observation points (IKN area, Sepinggan Meteorogical Station, AAWS of Penajam Paser Utara and AWS of APT Pranoto Samarinda.

| Pukul       | IKN Area | Sepinggan Meteorogical Station | AAWS of Penajam Paser Utara | AWS of APT Pranoto Samarinda |
|-------------|----------|--------------------------------|-----------------------------|-------------------------------|
|             | S1       | S2                               | S3                           | S1                           | S2 | S3 | S1 | S2 | S3 |
| 08 WITA/00 UTC | 26.00    | 26.83                            | 27.22                        | 26.22                        | 26.27 | 26.22 | 25.89 | 25.90 | 25.91 | 25.86 | 25.90 | 25.88 |
| 14 WITA/06 UTC | 26.51    | 27.68                            | 28.27                        | 26.07                        | 26.10 | 26.01 | 26.73 | 26.83 | 26.75 | 27.59 | 27.86 | 27.64 |
| 20 WITA/12 UTC | 23.33    | 24.46                            | 25.07                        | 24.42                        | 24.37 | 24.41 | 23.75 | 23.65 | 23.74 | 24.19 | 24.14 | 24.16 |
| 02 WITA/18 UTC | 22.53    | 23.17                            | 23.56                        | 23.51                        | 23.42 | 23.46 | 22.78 | 22.75 | 22.73 | 22.75 | 22.76 | 22.71 |

Table 3 shows the spread of temperature changes that occurred at 4 observation points (IKN area, Sepinggan Meteorogical Station, AAWS of Penajam Paser Utara and AWS of APT Pranoto Samarinda). In the IKN area there was an increase in air temperature of approximately 0.83-1.77ºC. The maximum temperature change occurred at 06 UTC with the addition of 1.77ºC in S3. At Sepinggan Meteorological Station there was an increase in air temperature of approximately 0.01-0.05 ºC at 00 UTC and a reduction in temperature of approximately 0.01-0.09 ºC at 06-18 UTC. At the point of AAWS Penajam Paser Utara and AWS APT Pranoto Samarinda, there was an increase in temperature at 00-06 UTC and a temperature reduction occurred at 12-18 UTC.
Generally, in the IKN area there will definitely be an increase in temperature in every time, while in the other three Sepinggan Meteorological Stations, AAWS Penajam Paser Utara and AWS APT Pranoto Samarinda, the temperature increase will only occur in the morning until noon. Reduction in temperature at 3 points occurs in the afternoon - early morning.

The simulation result for the impacts of land use changes as we described, proposed in the numerical experiments of the Indonesian capital city relocation plan. Nevertheless, the points below have to be considered as the limitations when interpreting our modelling results in the numerical experiments.

When interpreting modelling results, which are: The parameterization configuration used is Tropical Parameterization with the BULK configuration as the sf_urban_physics setting, because the configuration settings are the best configuration compared to 3 other configurations; the effects of future urban warning on health issues and the thermal comfort residents of growing cities in future studies are investigated to know the impact of temperature change in this area; and the benefits of this research are expected to be a consideration for the government of the Republic of Indonesia in carrying out the development and development of IKN that has been planned but has no significant impact on climate change.

4. Conclusions
To conclude, this study researched the impacts of land use changes proposed in the Indonesian capital city relocation master plan using numerical experiments with WRF modelling. The following are the main findings. It is found that the land use changes in IKN are respectively increase the average air temperature in the urban areas at S2 and S3 by up to 2 and 3°C. Further, LU modification added by 547% urban (S2) will increase in air temperature of approximately 0.64-1.17ºC while, in the (S3) modification added by 1,222% urban will increase in air temperature of approximately 1.03-1.77ºC.

The results of this study can still be improved by modifying the other land use form, so that the model’s results can be studied further for a better and more advanced city planning. The future work is to expected to analyze the other climate variables (i.e. albedo, accumulated total precipitation cumulus, planetary boundary layer height, latent heat flux, etc).

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References

[1] Tan KC, San Lim H, MatJafri MZ, Abdullah K. 2010 Landsat Data to Evaluate Urban Expansion and Determine Land Use/Land Cover Changes in Penang Island, Malaysia. Environmental Earth Sciences. Vol. 60(7):1509-21.

[2] Weng Q. 2001 A Remote Sensing? GIS Evaluation of Urban Expansion and its Impact on Surface Temperature in the Zhujiang Delta, China. International journal of remote sensing. Vol. 22(10):1999-2014.

[3] Wan H, Zhong Z. 2014 Ensemble Simulations to Investigate the Impact of Large-Scale Urbanization on Precipitation in the Lower Reaches of Yangtze River Valley, China. Quarterly Journal of the Royal Meteorological Society. Vol. 140(678):258-66.

[4] Balk D, McGranahan G, Anderson B. UNFPA; 2008 Urbanization And Ecosystems: Current Patterns and Future Implications. The new global frontier: Urbanization, poverty and environment in the 21st century. p. 183-202.

[5] BPS. BPS; 2013 Proyeksi Penduduk Indonesia 2010-2035. Jakarta. p. 468.

[6] Chapman S, Thatcher M, Salazar A, Watson JE, McAlpine CA. 2018 The Effect of Urban Density and Vegetation Cover on the Heat Island of a Subtropical City. Journal of Applied Meteorology and Climatology. Vol. 57(11):2531-50.

[7] McKinney ML. 2002 Urbanization, Biodiversity, and Conservation-the Impacts of Urbanization on Native Species are Poorly Studied, but Educating a Highly Urbanized Human Population about These Impacts can Greatly Improve Species Conservation in all Ecosystems. Bioscience. Vol. 52(10):883-90.

[8] Skamarock WC, Klemp JB, Dudhia J, Gill DO, Barker DM, Wang W, et al. National Center For Atmospheric Research Boulder Co Mesoscale and Microscale …; 2005 A Description of the Advanced Research WRF version 2.

[9] Lim YK, Cai M, Kalmay E, Zhou L. 2005 Observational Evidence of Sensitivity of Surface Climate Changes to Land Types and Urbanization. Geophysical Research Letters. Vol. 32(22).

[10] Tursilowati L, Sumantyo JTS, Kuze H, Adninginsih ES. 2012 Relationship Between Urban Heat Island Phenomenon and Land Use/Land Cover Changes in Jakarta-Indonesia. Journal of Emerging Trends in Engineering and Applied Sciences. Vol. 3(4):645-53.

[11] Wang M, Zhang X, Yan X. 2013 Modeling the Climatic Effects of Urbanization in the Beijing–Tianjin–Hebei Metropolitan Area. Theoretical and applied climatology. Vol. 113(3-4):377-85.

[12] Skamarock WC, Klemp JB, Dudhia J, Gill DO, Barker DM, Wang W, et al. 2008 A Description of the Advanced Research WRF Version 3.