Indonesian Geomagnetic Maps for Epoch 2015.0 to cover of Indonesian Regions

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Abstract. In compliance with the resolutions of IAGA (International Association of Geomagnetism and Aeronomy), Since 1960’s, every five years BMKG or Meteorology, Climatology and Geophysics Agency of Indonesia made geomagnetic field maps based on actual measurements in 53 repeat stations. It’s the map for more accurate result of Geomagnetic maps Epoch 2015.0, the number of repeat stations has been increased to 68 locations. Analysis data was conducted by spatial analyses using collocated co-kriging and kriging with external drift to map the observation data in five components, such as Declination (D), Inclination (I), Vertical (Z), Horizontal (H), and Total Geomagnetic Field (F). The data reduction used one permanent observatory i.e., Kupang Geophysical Observatory, as a reference standard. The results of this Geomagnetic Maps, that the contour lines of Indonesian geomagnetic declination in range -1 to 4.5 degree, Inclination component are -5 to -37 degree, Vertical component are -4000 to -28000 nT, Horizontal component are 36000 to 42000 nT, and Total Geomagnetic Field are 39000 to 46000 nT. In conclusion, Indonesian Geomagnetic Maps for Epoch 2015.0 can be used to compute geomagnetic data around Indonesian regions until next 5 years.

Keywords: BMKG, Epoch 2015.0, geomagnetic map, Indonesian

1. Introduction
The Indonesia is country archipelago with more than 17,504 islands and rich in mineral resources that spread from Sabang to Merauke. This condition makes the geomagnetic data very important to use, because navigation, mineral exploration, Geology map and defense map are using geomagnetic data in any case. Accurate geomagnetic map is important in many fields ranging from navigation, mineral exploration to defense. The accuracy of such map, in mineral exploration, is about 0.1° in declination and about 50 nT in total intensity [1]. Since the Earth’s magnetic field is dynamic, geomagnetic maps need to be revised on regular basis. This process requires direct observation of the geomagnetic field in a number of repeat stations.
In Indonesia, the above activities are carried out by BMKG (Badan Meteorologi Klimatologi dan Geofisika or/Meteorology, Climatology and Geophysics Agency of Indonesia). BMKG conducted limited survey in 1960-1962 and in 1970-1974. In compliance with IAGA (International Association of Geomagnetism and Aeronomy) resolutions number 23/1963 and 9/1995, BMKG conducted more extended survey every five years since 1985 until 2010 in 53 repeat stations at Epoch 2015.0, BMKG add 15 new repeat stations to increase quality and accuracy of geomagnetic map epoch 2015.0 (see Table 1).

| TABLE 1. History of Indonesia repeat stations expansion |
|--------------------------------------------------------|
| 1960-1962 | 1970-1974 | 1985 | 1990 | 1995 | 2000-2001 | 2005 | 2010 | 2015 |
| Sumatra    | 4         | 10    | 15   | 15   | 13        | 12   | 12   | 17   |
| Java and Bali | 7     | 7    | 8    | 8    | 8         | 9    | 8    | 9    |
| Kalimantan | 3         | 4     | 8    | 9    | 9         | 10   | 10   | 11   |
| Sulawesi   | 0         | 4     | 9    | 7    | 7         | 8    | 8    | 11   |
| Nusa Tenggara | 1   | 1     | 5    | 6    | 6         | 5    | 5    | 5    |
| Maluku     | 0         | 5     | 10   | 6    | 6         | 7    | 7    | 6    |
| Irian Jaya | 0         | 0     | 10   | 6    | 6         | 7    | 7    | 6    |

During this time, geomagnetic data from BMKG is rarely used as a reference for analysis especially in the exploration and other research using geomagnetic method by Indonesian researchers. The researchers generally using IGRF (International Geomagnetic Reference Field) which arose from the results of the World Magnetic Survey (WMS) that is produced by IAGA [2]. In principle, IGRF is the Earth’s magnetic field model based on spherical harmonics. IGRF, in turn, could be used to create geomagnetic map. The first IGRF version was ratified by IAGA in 1971 and since then it has been revised ten times. The IGRF benefitted from excellent coverage and quality of satellite data provided by Ørsted and CHAMP and is now truncated at degree of 13 [3].

Comparative study between IGRF data and observation data in Trelew, Argentina in 1990-2000 show that there was a big discrepancy that could not covered by IGRF model [4]. Another research conducted in China, which used 29 observation stations in 1960-1990 reported that a sizable discrepancy between observation data and IGRF [5]. In the previous research, it is investigated that there is difference between the geomagnetic maps of BMKG model and IGRF. The difference varies in each epoch from 1985 to 2010 with difference between 300 to 200 nT for the total intensity component and -3.5 to 0.5 degrees for declination component [6].

2. Data and methods

This study uses BMKG geomagnetic data of 2015 and the IGRF-12 model. The BMKG data were derived from about 68 stations all over Indonesia (see Figure 1). Most of the stations are located in airports and other accessible sites that are relatively free from geomagnetic disturbance.

For determination of epoch value in measurement location, first shall do is data correction by using daily geomagnetic variation that recorded in Kupang geomagnetic observatory. After it, the data reduced to the 2015.0 epoch at each measurement location. This correction value calls as term C1 calculated for every datum from direct measurements reduced to Kupang geomagnetic observatory. Mathematically, is described by

\[ C_1 = C_e - C_t \]  \hspace{1cm} (1)

Where \( C_1 \) is data of each geomagnetic component in geomagnetic station for epoch year \((C_e)\) reduced by data value of the same component of measurement location \((C_t)\). The data values of 2015.0 epoch for geomagnetic station were determined from the average data of January until December 2015.
Since the measuring stations were spread unevenly in the archipelago, the data (coordinates and geomagnetic values) could not be used for extrapolation processes. Therefore secondary data derived from IGRF-12, in the form of coordinates and value patterns or trends, were used to complement the BMKG data. To obtain data in locations outside BMKG measuring stations the approaches namely Collocated Cokriging and Kriging with External Drift were used.

Collocated Cokriging or CC is a simplified cokriging that is used when a target variable (like our BMKG data) is sparsely sampled, compared to a densely sampled auxiliary variable (like IGRF data). In its strict sense, collocated cokriging makes use of the auxiliary variable only at the current point where the target variable is to be estimated [7]. Mathematically, CC is described by

$$Z_{cc}(x_0) = \sum_i \lambda_i Z_1(x_i) + \mu Z_2(x_0)$$

(2)

where $Z_{cc}(x_0)$ is the result of CC calculation at a particular position $x_0$, $Z_1(x_i)$ is the primary or BMKG data at the $i$th station, $\lambda_i$ is the weight of $Z_1(x_i)$, $Z_2(x_0)$ is the secondary or IGRF data calculated for position $x_0$ and $\mu$ is the weight for $Z_2(x_0)$.

Kriging with External Drift or KED is a kriging with a trend model that is used if auxiliary information (like IGRF data) is available at all grid nodes and correlated with target variable (in this case BMKG data) [8, 9]. Mathematically, KED is described by

$$Z_{KED}(x_0) = \sum_i \lambda_i Z_1(x_i) + a \sum_i \lambda_i Z_2(x_i) + a Z_2(x_0)$$

(3)

where $Z_{KED}(x_0)$ is the result of KED calculation at a particular position $x_0$, $Z_1(x_i)$ is the primary or BMKG data at the $i$th station, $Z_2(x_i)$ is the secondary or IGRF data at the $i$th BMKG station, $\lambda_i$ is the weight of $Z_1(x_i)$ and $Z_2(x_i)$ and $a$ is the slope of secondary data at $x_0$.

The results from CC and KED were then compared. The one with smaller error variation and the best cross-plot validation were adopted as BMKG geomagnetic map. In each location repeat station shall do measurement absolute geomagnetic component such as component declination (D), component inclination (I) and component geomagnetic field total (F). That measurement shall do in the same time measurement. Thus, value of component geomagnetic horizontal (H) and component geomagnetic vertical can calculate from the formula. Mathematically, is described by:

$$H = F \cdot \cos I$$

(4)

$$Z = F \cdot \sin I$$

(5)
All of data measurement in location repeat station after reduced with data from station geomagnetic Tondano and reduced again to data in measurement epoch 2010.0 then we set a final data of epoch for each location measurement repeat. Value data of each location for each component geomagnetic plotted in as a map and illustration like a contour for determine a changes data, and that can call as isomagnetic map

3. Results and discussions
This Figure 2a show typical BMKG map for declination component produces in this study. It shows that the contour lines of Indonesian geomagnetic declination component in range -1 to 4.5 degree. For validation accuracy this declination component map, we compare with respective declination component map derived fully from IGRF model as shown at Figure 2b. There is rather similar between the geomagnetic declination component in the two maps for 2015 epoch. This discrepancy has interval about 16 to 20 minutes (see Figure 2c).

![Typical geomagnetic maps produced in this study showing the Declination component for epoch 2015.0. The BMKG contour in degree (a) IGRF contour in degree (b) and discrepancy between BMKG and IGRF map in minute (c).](image)

Inclination component have interval contour lines are -5 to -37 degree as shown at Figure 3a. If this component is compare with respective inclination component map derived fully from IGRF model as shown at Figure 3b. There is rather similar discrepancy about 20 to 25 minutes (see Figure 3c).

Figure 4a show typical BMKG map for Total Intensity component have interval contour lines are 39000 to 46000 nT. If this component is compare with respective Total intensity component map derived fully from IGRF model as shown at Figure 4b. There is rather similar discrepancy about 30 to 140 nT (see Figure 4c).

Horizontal component after derived from equation 4, have interval contour lines are 36000 to 42000 nT. Vertical component after derived from equation 5, have interval contour lines are -4000 to -28000 nT. This might be due to the limited number of magnetic observatories in Indonesia used by IGRF, which is only two stations: Tuntungan and Tondano, North Sulawesi [3]. The second factor is tectonic structure in Indonesian Region hasn’t been cover by IGRF model. This second conclusion is supported
by a research of Pétrélis which shown that the movement mechanism of tectonic crustal has a significant contribution for geomagnetic field [10].

![Images of geomagnetic maps](a) (b) (c)

**Figure 3.** Typical geomagnetic maps produced in this study showing the Inclination component for epoch 2015.0. The BMKG contour in degree (a) IGRF contour in degree (b) and discrepancy between BMKG and IGRF map in minute (c).

![Images of geomagnetic maps](a) (b) (c)

**Figure 4.** Typical geomagnetic maps produced in this study showing the Total Intensity component for epoch 2015.0. The BMKG contour in nT (a) IGRF contour in nT (b) and discrepancy between BMKG and IGRF map in nT (c).

4. **Concluding remarks**

We have shown that BMKG geomagnetic maps of 2015.0 have good result. The contour lines of Indonesian geomagnetic declination in range -1 to 4.5 degree, Inclination component are -5 to -37 degree, Vertical component are -4000 to -28000 nT, Horizontal component are 36000 to 42000 nT, and Total Geomagnetic Field are 39000 to 46000 nT. In conclusion, Indonesian Geomagnetic Maps
for Epoch 2015.0 can be used to compute geomagnetic data around Indonesian regions until next 5 years.

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