DROUGHT AND FINE FUEL MOISTURE CODE EVALUATION: AN EARLY WARNING SYSTEM FOR FOREST/LAND FIRE USING REMOTE SENSING APPROACH

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Abstract. This study evaluated two parameters of fire danger rating system (FDRS) using remote sensing data i.e. drought code (DC) and fine fuel moisture code (FFMC) as an early warning program for forest/land fire in Indonesia. Using the reference DC and FFMC from observation data, we calculated the accuracy, bias, and error. The results showed that FFMC from satellite data had a fairly good correlation with FFMC observations (r=0.68, bias=7.6, and RMSE=15.7), while DC from satellite data had a better correlation with FFMC observations (r=0.88, bias=49.91, and RMSE=80.22). Both FFMC and DC from satellite and observation were comparable. Nevertheless, FFMC and DC satellite data showed an overestimation values than that observation data, particularly during dry season. This study also indicated that DC and FFMC could describe fire occurrence within a period of 3 months before fire occur, particularly for DC. These results demonstrated that remote sensing data can be used for monitoring and early warning fire in Indonesia.

Keywords: *Fire danger rating systes, Drought code, Fine fuel moisture code*

1 INTRODUCTION

Every year during the dry season, land and forest fires always occur in Indonesia that vary depending on the drought level. Characteristics of fire in Southeast Asia are strongly connected to the occurrence of peat soil and land management status (Miettinen *et al*., 2011). Therefore, there are high variation of fire activities annually depending on weather patterns and land cover/ management issues, which creating greatly complicates estimation of the effects of fires. The cause of fire activity is not only by natural conditions but also more due to human activities. Therefore, it is needed to have a greater engagement by research and policy with all stakeholders in thoroughly exploring the full range of land and fire management options and in conjunction with fire management (Murdiyarso and Lebel, 2007).

Early warning system is essential to anticipate the spread of fire. There are several methods to map fire hazard or risk with remote sensing data. The Fire Information System (FIS) of the Integrated Forest Fire Management (IFFM) project in East Kalimantan, Indonesia, was developed with the output data consisting of fire danger criteria and fire danger maps derived from the drought index (Fire Danger Rating System) combined with vegetation maps (Hoffman *et al*., 1999). Another method was also proposed to asses forest fire potential in Kalimantan island based on a fuel model map modified from the US-National Fire Danger Rating System (US-NFDRS), Normalized Difference Vegetation Index (NDVI), and weather data (Sudiana *et al*., 2003) . While Adiningsih *et al*. (2006) proposed a dynamical land/forest fire hazard maps using spatial biophysical parameter such as rainfall, vegetation condition, land cover, and land type in Kalimantan. Rainfall and NDVI have greater contribution than that land cover and land type. Vasilakos *et al*. (2007) also offered integrating methods and tools in fire danger rating namely Fire Ignition Index, which was based on three other indices i.e., Fire Weather Index, Fire Hazard Index, and Fire Risk Index.

A method which has been widely adopted among countries in the world is adapting components of the Canadian Forest

Fire Danger Rating System (FDRS), including the Canadian Forest FireWeather Index (FWI).

System, and the Canadian Forest Fire Behavior Prediction (FBP) System, to local vegetation, climate, and fire regime conditions (Field *et al*., 2004; De Groot *et al*, 2006). Indonesian Geophysic, Climatologi and Meteorology Agency (BMKG) as an authorized institution in information using weather data in Indonesia, has conducted operations FDRS since February 2002 (Guswanto and Heriyanto, 2009).

Considering the limited number of BMKG climatology stations, the use of other data spatially covering a larger area is needed. The development of remote sensing technology that allows obtaining systematic, spatial, and the latest data is reliable for monitoring activities. In addition, all inputs required in FDRS system have been developed using remote sensing data, for example rainfall (Dinku *et al*., 2011; National Weather Service, 2012), air temperature (Vancutsem *et al*., 2010) and relative humidity (Han *et al*., 2003; Khomarudin *et al*., 2005). Therefore, the possibility of the development of FDRS system based on remote sensing is possible to perform.

Indonesian National Institute of Aeronautics and Space (LAPAN) functions to perform the development and utilization of remote sensing field and the development of remote sensing data as a national remote sensing data bank (LAPAN, 2012). Since 2005, LAPAN has implemented the FDRS program (FDRS-LAPAN) using all input data derived from remote sensing. Though the model was the same as model performed by BMKG and all input were validated (Noviar *et al*., 2005). However, some parameters such as Drought Code (DC) showed less correlation with observation data from BMKG.

Although the calibration and validation of components FDRS were performed such as Fine Fuel Moisture Code (FFMC), DC, Initial Spread Index (ISI), and Fire Weather Index (FWI) (Field *et al*., 2004; Dymond *et al*., 2004; Dymond *et al*., 2005; De Groot *et al*., 2006), nevertheless FDRS-LAPAN validation is still lacking and such validation should be carried out continuously. The objective of this study was to evaluate two parameters of FDRS using remote sensing data i.e., Drought Code (DC_s) and Fine Fuel Moisture Code (FFMC_s) as an early warning program for forest/land fire in Indonesia.

2 MATERIALS AND METHOD

2.1 Description of LAPAN FDRS programme

FFMC is a numerical ranking moisture content of fine fuel material. FFMC is used as an indicator of the potential level of ease ignition of fire, while DC is a numerical ranking moisture content in the organic layer of 10-20 cm below the soil surface. DC is used as an indicator of potential drought and the potential for smoke/haze. Both codes are under Fire Weather Index (FWI) system which are initiated as an operational program since June 2005 (Noviar *et al*., 2005; Khomarudin *et al*., 2005). The general structure FDRS is adapted from Canadian FDRS (De Groot *et al*., 2006).

Several weather parameters are needed to run FWI programme. DC require temperature and rain, while FFMC is more complex that need temperature, relative humidity, wind speed, and rain. All parameters were estimated from remote sensing data with the reference listed in Table 1. Once every inputs was obtained, FFMC and DC will compute using Canadian FDRS model which already calibrated for Indonesia and Malaysia (De Groot *et al*., 2006) and classified in to several classes (Table 2 and 3). The information spatial resolution was 2.5 km x 2.5 km after interpolated into a grid. This information was then uploaded to the website LAPAN daily (http://www.lapanrs. com).

2.2 Data sources

We used climate data from BMKG,

consisting of relative humidity (Rh), wind speed (W), air temperature (T), rainfall (R), DC, and FFMC prepared from climate data (DC_obs and FFMC_obs). There were 9 of 210 days data which were not available, therefore, it needed further processing by filling gap with averaging values (one day before and after). In addition, fire suppression field data were obtained from the Natural Resources Conservation Center,

Table 1. FDRS LAPAN data sources.

Input	Data sources	References
Temperature	NOAA-AVHRR	Khomarudin *et al*., 2005; Noviar *et al*., 2005
Relative humidity	NOAA-AVHRR	Khomarudin *et al*., 2005; Noviar *et al*., 2005
Wind speed	Bureau of Meteorology (BOM-Australia)	http://www.bom.gov.au/
Rainfall	Qmoprh, National Centers for Environmental Prediction (NCEP)	ftp://ftp.cpc.ncep.noaa.gov/precip/qmorph/30min_8km

Table 2. FFMC classes and its interpretation (De Groot et al., 2005).

Ignition potential	FFMC	Interpretation
Low	0-72	Low probability of fire
Moderate	73-77	Moderate probability of fire starts in areas of local dryness
High	78-82	Cured grass fuels becoming easily ignitable; high probability of fire starts
Extreme	>83	Cured grass fuels highly flammable; very high probability of fire starts

Table 3. DC clasess and its interpretation.

Smoke potential	DC	Interpretation	Drying days before drought
Low	<140	Typical wet-season conditions. More than 30 dry days until DC reaches threshold. Severe haze periods unlikely.	>30
moderate	140-260	Normal mid-dry-season conditions. Between 15 and 30 dry days until DC reaches threshold. Burning should be regulated and monitored as usual.	16-30
High	260-350	Normal dry-season peak conditions. Between 5 and 15 dry days until DC reaches threshold. All burning in peat lands should be restricted. Weather forecasts and seasonal rainfall assessments should be monitored closely for signs of an extended dry season.	6-15
Extreme	>350	Approaching disaster-level drought conditions. Fewer than 6 dry days until DC reaches threshold, at which point severe haze is highly likely. Complete burning restriction should be enforced.	<6

Central Kalimantan Province in 2011 (red flag on Figure 1). Hotspot Terra/Aqua MODIS acquired from Indofire Map Service (http://indofire.dephut.go.id/) were also used. These fires occurred in peatlands.

2.3 Study area

This study was conducted in the province of Central Kalimantan as one of the most fire prone areas in Indonesia. Figure 1 shows the located study with the hotspot and fire suppression in 2011.

2.4 Data Analyses

The correlation between insitu and estimation FFMC and DC was calculated as well as bias and RMSE with the following equations.

$$\text{Bias} = \frac{1}{n}\sum_{i=1}^{n}\left(x_{dgi} - x_{obi}\right) \qquad (1)$$

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{dgi} - x_{obi}\right)^2} \qquad (2)$$

$$r = \frac{\mathrm{Cov}(x_{dgi}, x_{obi})}{s_{x_{dg}} s_{x_{ob}}} = \frac{\sum_{i=1}^{n}(x_{dgi}-\bar{x}_{dg})(x_{obi}-\bar{x}_{ob})}{\sqrt{\sum_{i=1}^{n}(x_{dgi}-\bar{x}_{dg})^2 \sum_{i=1}^{n}(x_{obi}-\bar{x}_{ob})^2}} \qquad (3)$$

where, *dg*=FFMC and DC estimation, *ob*=observation data.

Moreover, time series analyses before and after the fire were also performed to obtain an understanding of the development extent of FFMC and DC in describing the fire phenomenon.

3 RESULTS AND DISCUSSION

The results showed that FFMC_s had good agreement with FFMC_Obs (r = 0.68), while DC_LAPAN had very good correlation with DC_Obs (r = 0.88). Meanwhile, the bias and RMSE between FFMC_obs and FFMC_s relatively small of 7.67 and 15.4 points, respectively. This was also nearly similar to the DC bias (Table 4). However, the relationship between FFMC_s and DC_s tended to be over estimate compared with FFMC_Obs and DC_obs particularly in the

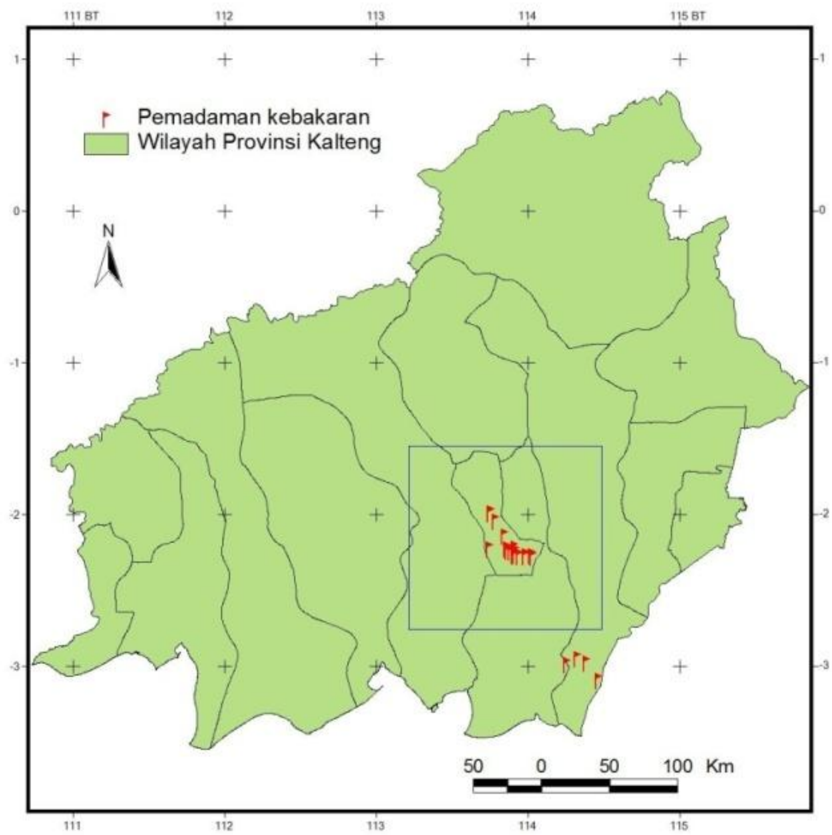

Figure 1 Hotspot and fire suppression data in Central Kalimantan 2011.

dry season. Though, its distribution values were comparable (Figure 2 and 3).

DC seemed to be a very good parameter as an early warning of the possibility of a very large fire smoke impacts at least 3 months before the peak of fire activity (Figure 4). Although FFMC revealed patterns of change increase, but the series appeared very insignificant to mark the possibility of big fire event. These results indicated that the FFMC_s and DC_s were reliable and robust for the use as an early warning of forest fires and land. The remote sensing data is also superior in terms of a wider scope of monitoring and data can be obtained in near-real time.

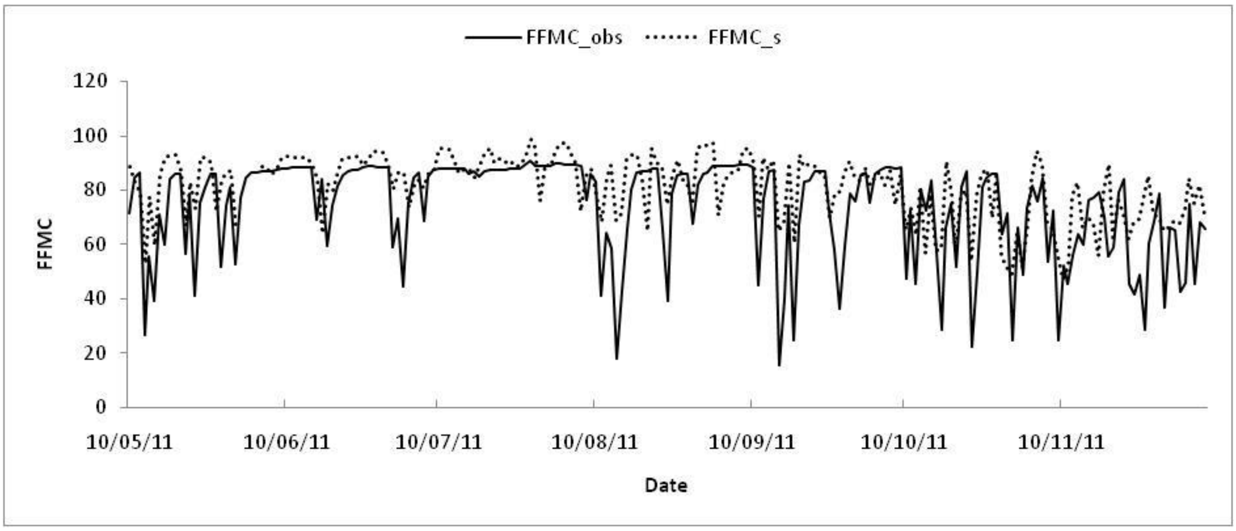

Figure 2. Distribution value of FFMC_obs and FFMC_s (May-November 2011)

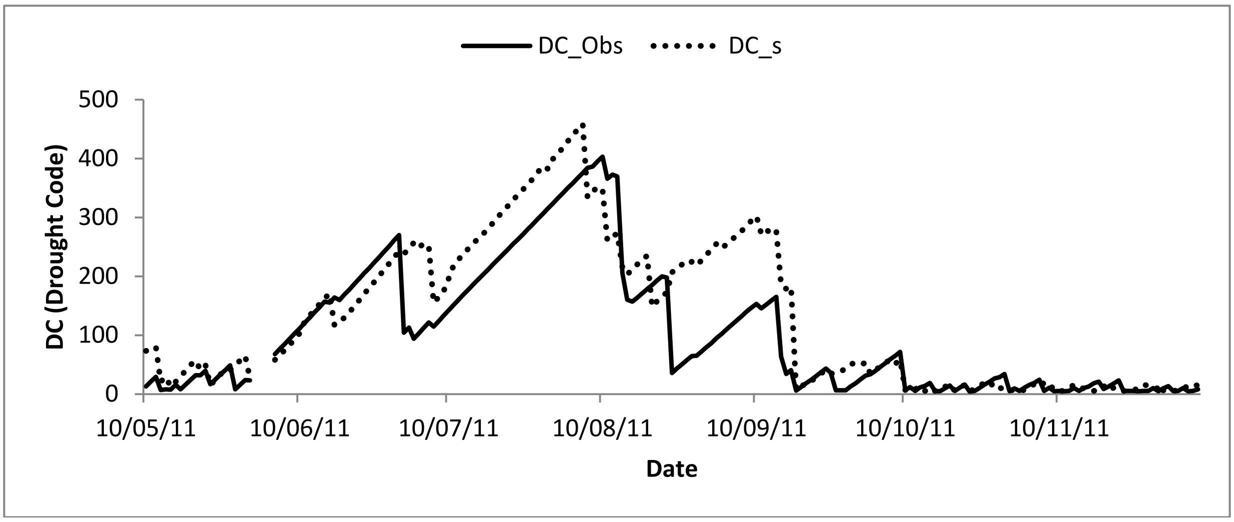

Figure 3. Distribution value of DC_obs and DC_s (May-November 2011).

Table 4. Statistic parameter values.

Value	FFMC	DC
Bias	7.7	30.8
RMSE	15.4	66.6
R	0.655271	0.88

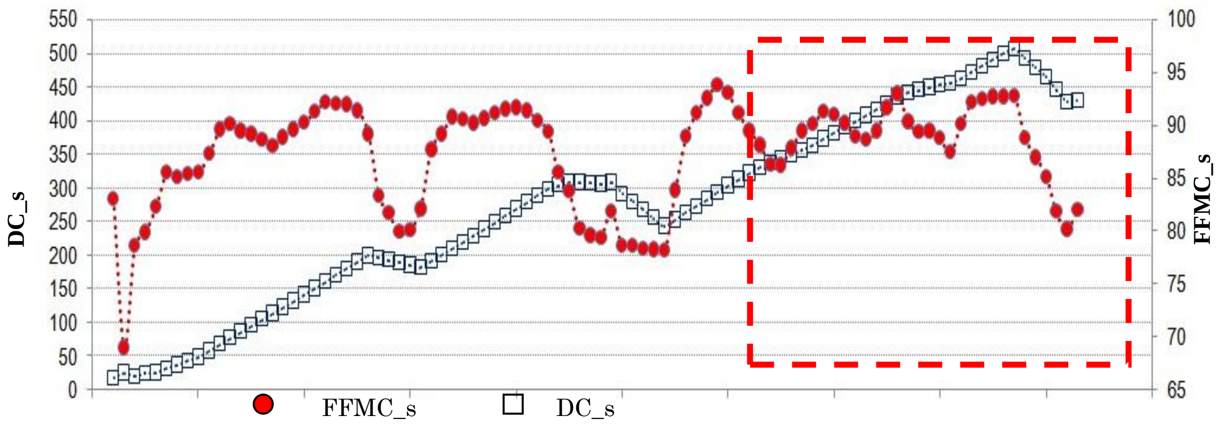

Figure 4. FFMC_s and DC_s value growth in the period ahead of fire. Red box shows the peak of fire accidence with the values of FFMC and DC that have been classified as extreme (see Table 2 and 3).

The development of remote sensing technology with new sensor capabilities, multiscale, and multitemporal enable us to obtain the new data in estimating some parameters of weather, for example rainfall. In addition, as the major contribution of fire event, rainfall also affects the water content in the organic fuel peat (Syaufina *et al.*, 2011) which is often experienced in Palangkaraya. The latest research conducted by the International Research Institute with Central Kalimantan Peatlands Project (CKPP) in Central Kalimantan furthermore discovered that the input parameters of FDRS such as temperature, relative humidity, and wind speed had no major effect on the analysis of the fire behavior in that region. Conversely, rainfall anomalies in particular had an enormous correlation (Ceccato *et al.*, 2010). Additionally, NINO4 index (an indicator of sea surface temperature anomalies) can be used as a predictor of the severity of fire (Someshwar *et al.*, 2012).

The analyses of time series at the fire location showed that DC_s could be used as an early warning smoke possibility of a serious incident due to fire particularly in peatland region. While FFMC_s could be used as an indication of the potential to start fires in large numbers. Field *et al.* (2004) noted that DC was capable to estimate the moisture content to a depth of 10-20 cm, including the organic content in peatland (Lee *et al.*, 2002) as the case in this study. DC was also used as an indicator of drought in a long time and ignition as well (McAlpine, 1990). Peatlands in the tropics is one of the organic carbon pools that highly related to global climate change (Page *et al.*, 2002) in which damage to peat can release large amounts of carbon into the atmosphere. Fires in peatlands is a major contribution in smoke catastrophic fires in Indonesia as well (Page *et al.*, 2002). At the 1997 fires were estimated at about 94% of the total ingredients sourced emissions from fires in peatland fires (Levine *et al.*, 1999). Although the previous results of validation DC_s by Noviar *et al* (2005) found no better correlation between DC_S and DC_obs, but we found that DC_s can be a very good tool to describe an event of fire.

4 CONCLUSION

FFMC and DC from satellite data can be used as an early warning program for forest/land fire in Indonesia. FFMC satellite data indicated a good correlation with observation data (r=0.68, bias=7.6, and RMSE=15.7 points), while DC satellite data showed better relationship with obervation data (r=0.88, bias=49.91, and RMSE=80.22 points) than that FFMC. Both parameters were suitable to be used as a tool to detect possible developments in a fire incident.

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