An Application of MODIS Surface Reflectance Product for Drought Assessment on Agriculture Area in Manukwari – West Papua – Indonesia

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Abstract. Drought is one of the natural disasters in Indonesia. Some regions in Indonesia are very vulnerable to drought, including West Papua. This research aimed to map the droughtiness level on the agriculture area in Manokwari - West Papua using MODIS Surface Reflectance and Moisture Adequacy Index (MAI) methods. A total of 20 MODIS surface reflectance image recording 2018 and ground check on agriculture area at some location were used for the analysis. Research shows that MODIS Surface Reflectance and MAI methods are entirely accurate in describing the level of drought in the agriculture area in Manokwari - West Papua.

Keywords: MODIS Surafce, drought assessment, natural disaster

1 INTRODUCTION

Drought is a condition of water availability less than the water needs to support life, agriculture, economic, and environmental activities [1]. Wilhite and Glantz classify the droughts into 4 categories: meteorological drought, agricultural drought, and socio-economic drought [2]. Subrahmanyam [3] classified 6 types of drought: meteorological, climatological, atmospheric, agricultural, hydrologic, and water management.

Drought has a significant impact on agriculture. Food and Agriculture Organization (FAO) documented that 83% of all damage and loss caused by drought was absorbed by agriculture which amounted to over USD 29 billion between 2005 and 2015 [4]. Indonesian National Disaster Management Organisation or Badan Nasional Penaggulangan Bencana (BNPB) reported several areas in West Papua to have a high risk of drought: Manokwari, Raja Ampat, Teluk Bintuni, Sorong Selatan, Teluk Wondama, Maybrat, and moderate drought threat: Sorong, Tambrauw, dan Fakfak [5].

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There are five methods and indicators used for drought monitoring and assessment, i.e., meteorology, soil moisture, hydrology, remote sensing, and modeling methods [6]. The meteorological method uses the soil water balance approach for drought analysis. The research conducted by Rahmat et al. [7] shows that the meteorological method provides the best initial assessment for drought monitoring and early warning [7]. Soil moisture method identifies drought using water availability in the root zone of the crop. Wambua [8] using this method to monitoring agricultural drought in Kenya. Hydrology method analyzes drought based on surface and sub-surface water using hydrological parameters such as streamflow, precipitation, and evapotranspiration. Bakanoğullari and Yeşilköy [9] using hydrology method to determine drought periods in Damlica Creek Watershed in Çatalca – Turkey. Remote sensing is an advanced method to identify the drought phenomenon. This method using vegetation index including normalized difference vegetation index (NDVI), enhanced vegetation index (EVI), vegetation condition index (VCI), vegetation drought response index (VegDRI), and vegetation health index (VHI) to identifier the drought. Thenkabail et al.[10] using remote sensing techniques to identifies and to monitor drought in Southwest Asia. Modeling method using a combination of meteorology, soil moisture, hydrology, and remote sensing methods for drought assessment. Aswathi et al. [11] combine meteorological and remote sensing methods to assess agricultural drought in Maharashtra – India.

MODIS Surface Reflectance product (MOD09) has been used by the International Water Management Institute (IWMI) for drought monitoring in South Asia since 2014 [12]. Then, Gulácsi and Kovács [13-14] have applied MODIS surface reflectance for drought monitoring in the agriculture area in Hungary. The same method also used for drought monitoring in China [15-16]. Other studies that deal with the utilization of the MODIS canal for vegetation drought monitoring have reported in Oklahoma [17]. Furthermore, the utilization of the MODIS canal for drought monitoring in Kenya have reported by Klisch and Atzberger [18]. Finally, Qu et al. [19] done an example of monitoring extreme agricultural drought in Africa. Furthermore, Amalo et al. [20] use NDWI (Normalized Difference Water Index (NDWI) for drought monitoring in West Java. Those research show that MODIS surface reflectance acceptable for assessing the drought condition at large scales and useful source of information to support drought management decision.

Some methods based on evapotranspiration for drought assessment including standardized evapotranspiration deficit index (SEDI)[21-22], evapotranspiration deficit index (ETDI)[6, 23], standardized precipitation evapotranspiration index (SPEI) [6, 24], aridity anomaly index (AAI)[6, 25], moisture adequacy index (MAI) [25-26], evaporative stress index (ESI) [27], and reconnaissance drought index (RDI) [28-29].

This research applied MODIS surface reflectance for mapping of droughts level on the agriculture area in West Papua. Visible electromagnetic band (band 1, band 3, and band 4), the near-infrared band (band 2, band 5, and band 7), and thermal infrared band (band 31 and band 32) were used for drought assessment.

2 MATERIAL AND METHODS

This research was conducted in Manokwari - West Papua – Indonesia.

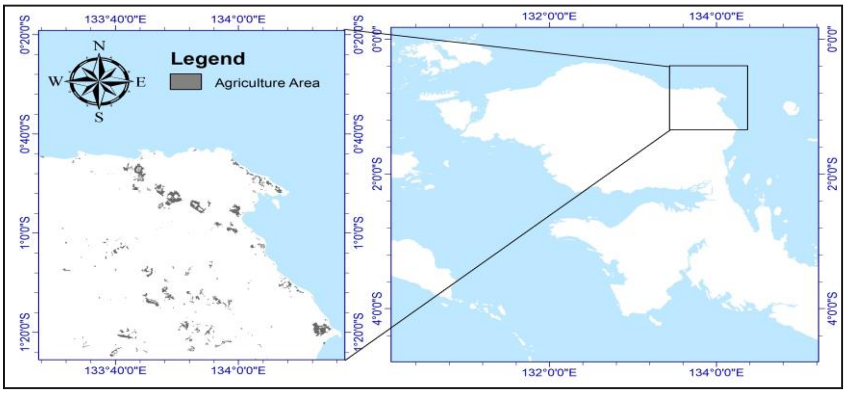

Fig. 1. Study area

Generally, the main stages of this research are as follows:

1. Data inventory
   The 20 scenes of MODIS surface reflectance (MOD09) recorded during the year 2018 are collected as the primary input for this study.
2. Evapotranspiration information extraction
   Actual evapotranspiration was generated from MODIS surface reflectance using equation (1) [30]:

$$ETa = \frac{ET_i\, 2N_e}{\pi \sin\left[\pi\, t/N_e\right]} \quad (1)$$

Where:
ETa is actual evapotranspiration (mm.day^{-1}),
ETi instantaneous evapotranspiration (mm.hr^{-1}),
Ne is evapotranspiration duration (hr), and
t is time interval between satellite image recording and sunrise (hr).

Instantaneous evapotranspiration is evapotranspiration at the image time and calculated following the equation (2) [31] :

$$ET_i = 3600 \frac{\lambda ET}{\lambda} \quad (2)$$

Where:
λET is latent heat flux (W.m^{-2}),
λ is latent heat of vaporization (J/kg).

The latent heat flux is the flux of heat from the earth's surface to the atmosphere that is associated with evapotranspiration or transpiration and calculated using the surface energy balance of equation (3) [32]:

$$\lambda ET = Rn - G - H \quad (3)$$

Where :
Rn is net radiation (W.m^{-2}),
G is soil heat flux (W.m^{-2}), and
H is sensible heat flux (W.m^{-2}).

Furthermore, the net radiation (*Rn)*, soil heat flux *(G)*, and sensible heat flux *(H)* are calculated using equation (4), (5) and (6) respectively [31]:

$$R_n = R_{S\downarrow} - \alpha R_{S\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1 - \varepsilon_0) R_{L\downarrow} \quad (4)$$

$$G = \frac{(T_s - 273.1)\left(0{,}0038\alpha + 0{,}0074\alpha^2\right)\left(1 - 0{,}98\, .NDVI^4\right) R_n}{\alpha} \quad (5)$$

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$$H = \frac{\rho . c_p . dT}{r_{ah}} \quad (6)$$

Where:

$R_{S\downarrow}$= incoming shortwave radiation ($W.m^{-2}$),

R_L = incoming longwave radiation ($W.m^{-2}$),

$R_{L\uparrow}$ = outgoing longwave radiation ($W.m^{-2}$),

ε_o = surface emissivity,

α = surface albedo,

Ts = land surface temperature (^oK),

NDVI= normalized difference vegetation index,

ρ = air density ($kg.m^{-3}$),

c_p = air specific heat (1004 $J.kg^{-1}.^oK^{-1}$),

dT = temperature difference between air temperature and land surface temperature (^oK), and

r_{ah} = aerodynamic resistance to heat transport ($s.m^{-1}$).

Procedures to extract actual evapotranspiration information from MODIS are showing in figure 2. Furthermore, the potential evapotranspiration is generated by using climate data analysis.

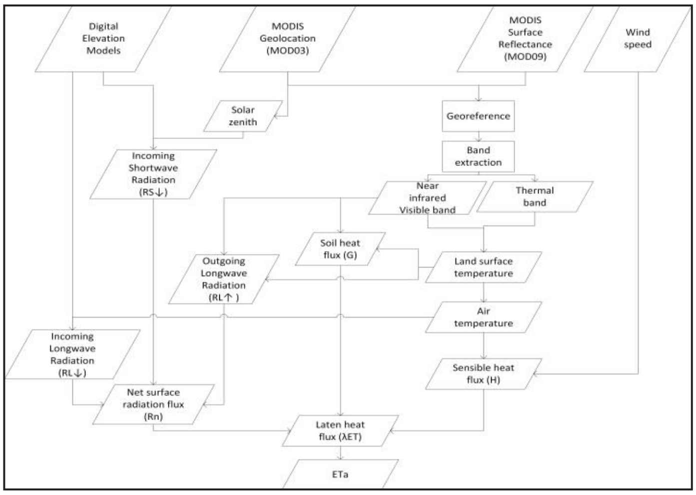

Fig. 2. Procedures to generate evapotranspiration information from MODIS surface reflectance

3. Generating droughtiness information
   The droughts information was analysis using Moisture Adequacy Index (MAI) following the equation (7) as following [33-35]:

$$MAI = \frac{ETa}{ETp} \quad (7)$$

Where:
MAI= moisture adequacy index,
Eta = actual evapotranspiration (mm/day), and
ETp = potential evapotranspiration (mm/day).

Table 1. Drought class.

MAI	Drought class
0,76 – 1,00	No drought
0,51 – 0,75	Mild drought
0,26 – 0,50	Moderate drought
0 – 0,25	Severe drought

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Source: [34-35]

According to Sarma [33], MAI is a relatively the best indicator than other methods for assessing the degree of adequacy of rainfall and soil moisture to meet the potential water requirement of crops [33-35].

4. Ground check
The calculated droughts based on the MAI method are then compared to the existing field condition. A ground check is conducted in some agriculture areas in Manokwari regions, including the district of Prafi, Masni, and West Manokwari.

3 RESULTS AND DISCUSSION

In 2018 agricultural areas in Manokwari were not in drought based on MODIS surface reflectance and MAI methods. The distribution of actual evapotranspiration and the level of droughts are presented in figure 3 to figure 10. The ground checkpoints at some locations are showing in figure 11.

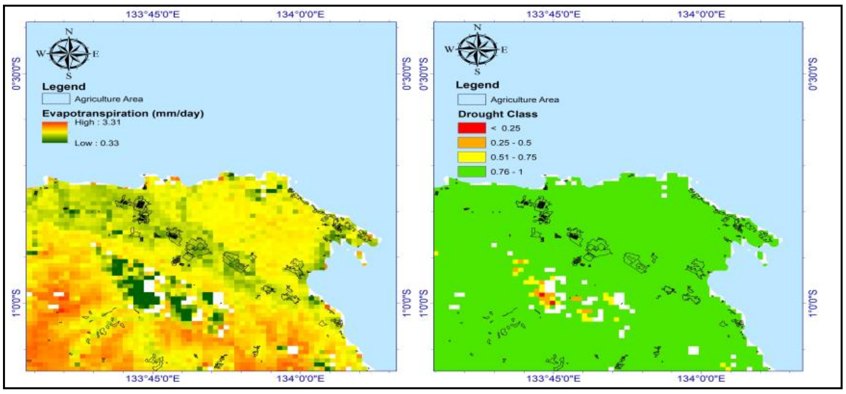

Fig. 3. Actual evapotranspiration and droughts on agriculture area on 7 January 2018

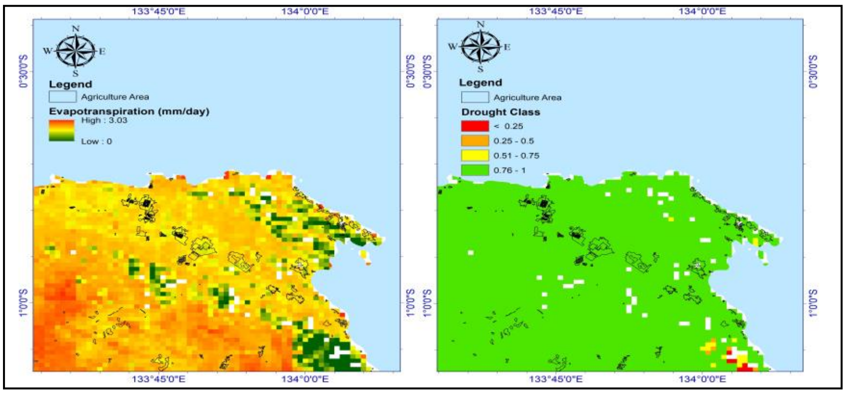

Fig. 4. Actual evapotranspiration and droughts on agriculture area on 15 February 2018

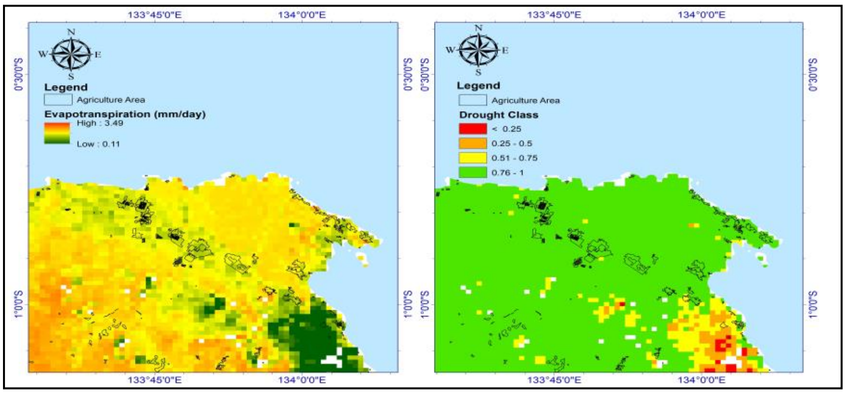

Fig. 5. Actual evapotranspiration and droughts on agriculture area on 17 March 2018

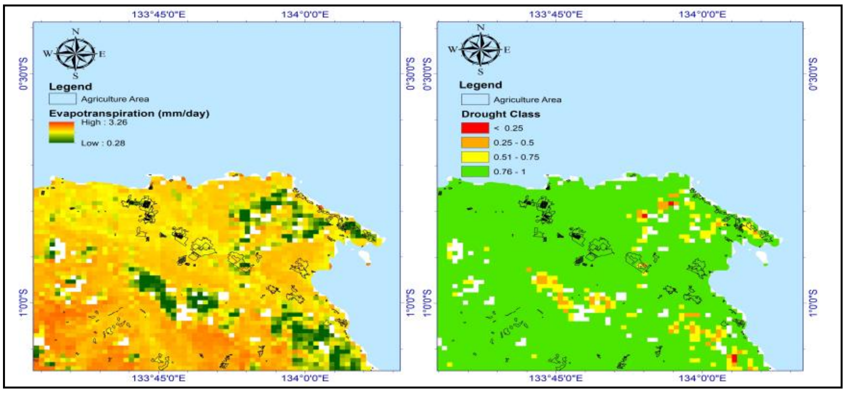

Fig. 6. Actual evapotranspiration and droughts on agriculture area on 11 April 2018

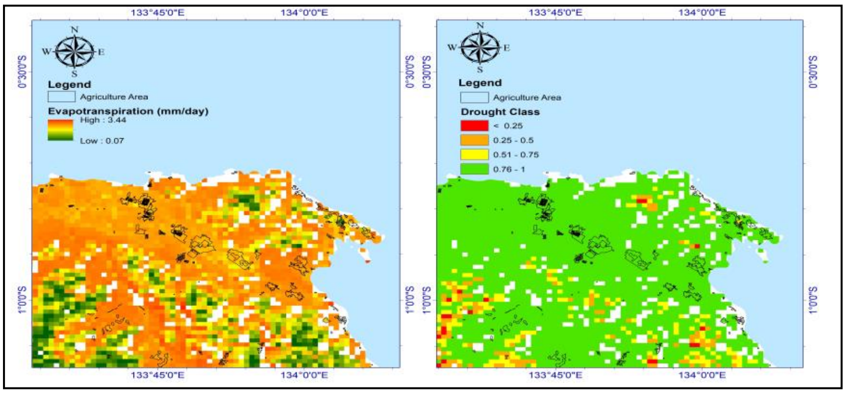

Fig. 7. Actual evapotranspiration and droughts on agriculture area on 11 May 2018

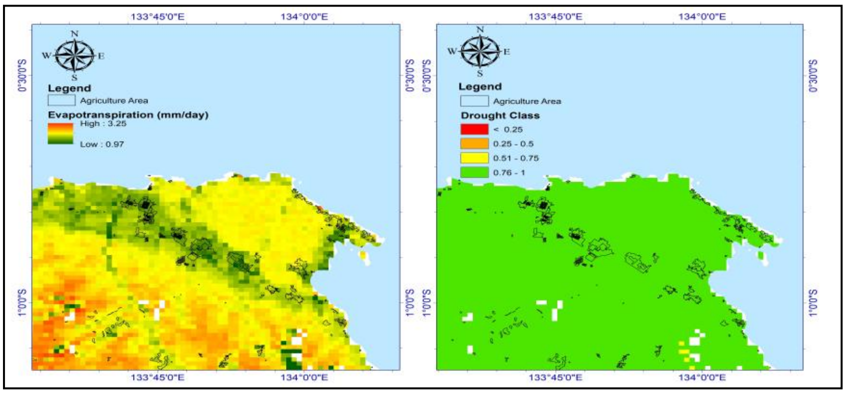

Fig. 8. Actual evapotranspiration and droughts on agriculture area on 9 June 2018

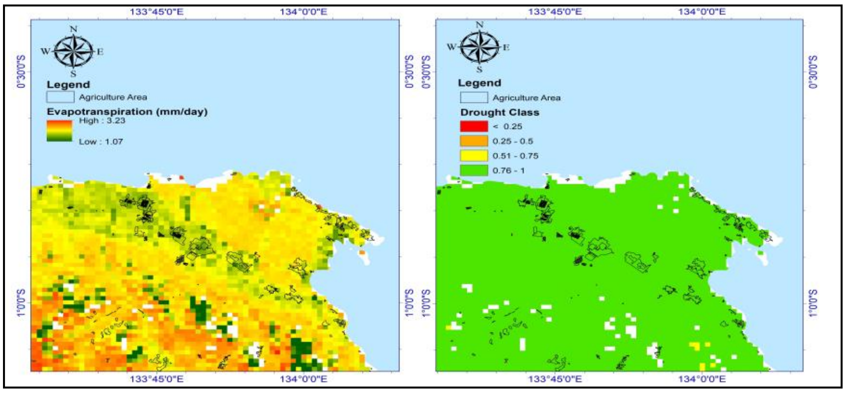

Fig. 9. Actual evapotranspiration and droughts on agriculture area on 16 July 2018

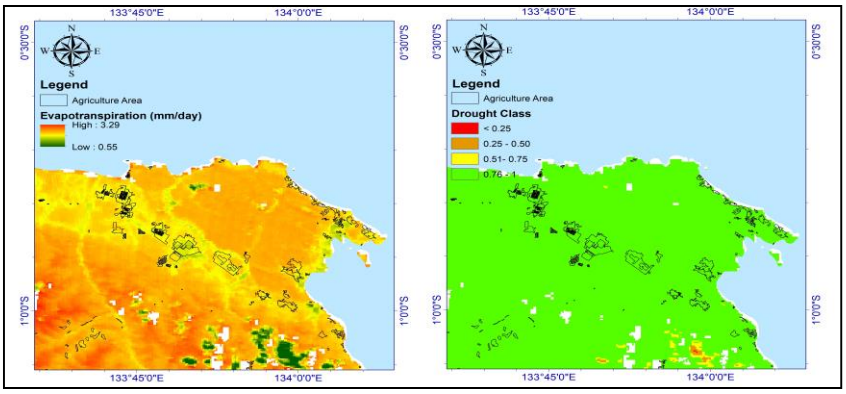

Fig. 10. Actual evapotranspiration and droughts on agriculture area on 18 August 2018

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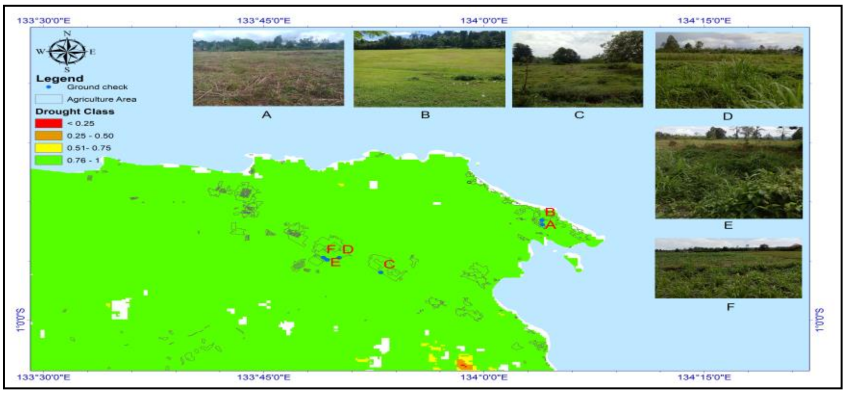

Fig. 11. Ground check on agriculture area on 18 August 2018

Generally, MODIS surface reflectance and moisture adequacy index (MAI) methods can assess the drought at reasonable accuracy compared to the ground check data. Besides climate data shows that at Manokwari it gets rain throughout the year of 2018 (Figure 12). Therefore MODIS surface reflectance and MAI methods can be used for drought assessment and monitoring on agriculture area in Manokwari – West Papua.

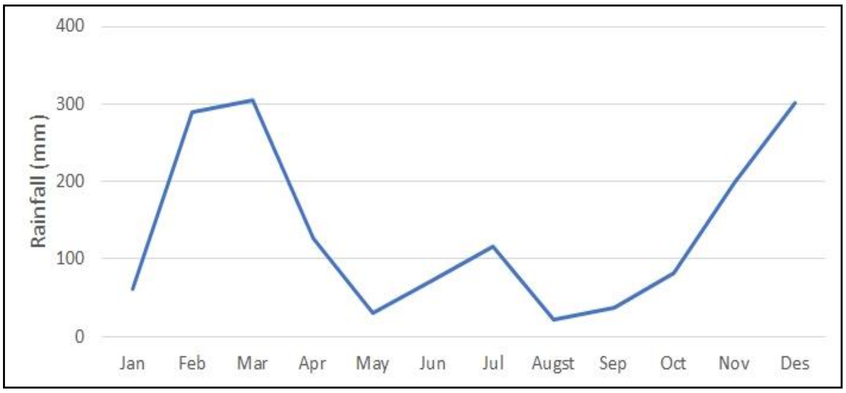

Fig. 12. Monthly rainfall in the study area in 2018.

Some studies show that MAI is a good indicator for assessing water balance and drought levels in the agriculture area. Gautam et al. combine meteorological data, geographic information system (GIS), and MAI to assess water deficit and agricultural drought in Uttarakhand – India [36], Arjun et al. using MAI to assess water deficit in Jalgaon District – India [37], and Gautam et al. using MAI to demarcating the periods of water deficit and water surplus in Uttarakhand – India [38]. Besides, the previous research shows that evapotranspiration generated from MODIS surface reflectance has an accuracy of 76,9% - 85% compared with climate data analysis [39-40]. Evapotranspiration is a parameter used in MAI.

4 CONCLUSIONS

Compared vi a vis a ground check and existing climate data, the MODIS surface reflectance (MOD09) and the moisture adequacy index (MAI) methods show more accurate to asses the drought level in Manokwari – West Papua. Therefore, this tool is potentially used for drought monitoring in the agriculture area.

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