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Short communication

Misuses of the terms Day of the Year and Julian Day in agricultural and environmental sciences

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ABSTRACT

The purpose of this short communication is to establish a discussion about the correct use of the terms Julian Day and Day of the Year. The Day of the Year is used for environmental modelling and calculating daily solar radiation and evapotranspiration. The concept of Julian Day is misused in the field of agricultural and environmental sciences. Specifically, the use of the term Julian Day might have been misleading or incorrect for the last ten years in the journal Agricultural Water Management. In this brief communication we intend to clarify the concept of Julian Day, and expose the most commonly used equations, so that the concept might be used with more rigor and precision in the future.

1. Introduction

The most common application of the parameters Julian Day (JD) and Day of the Year (DOY) in the fields of agriculture, irrigation, hydrology, ecology, biology, and environmental sciences is the estimation of solar radiation, day length and designation of the day. The term DOY is used broadly in agricultural water management, especially concerning the estimation of solar radiation and evapotranspiration, on which rely, among others, the calculation of crop water requirements, and subsequently irrigation scheduling.

In the areas 'Agricultural and Biological Sciences' and 'Environmental Science' (based on sciencedirect.com database), 1276 articles have been published since 2011, where the term "Julian Day" is used (Fig. 1).

A detailed paper review was carried out assessing the use of the terms JD, and DOY in this two areas. 153 articles were published in this two areas since January 2021 (https://www.sciencedirect.com/ accessed 20 January 2022), and their review revealed that the term was clearly correctly used 1 time, it was misused 128 times (83.6%), while in the remaining articles (15.6 3%) it was unclear if the use was correct or not. In the journal *Agricultural Water Management* (since the year 2011), the "Julian Day" concept appears 39 times and the term was incorrectly used in 34 articles (87.2%), while in the remaining 5 times it was not clear whether the use was correct or not. Summing up, there are evidences about the fact that the concept might be often misused. DOY and JD are different concepts and measure different magnitudes. Mixing JD and DOY creates confusion and should request more rigor. This Short Communication intends to highlight this common error. It is not an exhaustive critical review of the misuse of the term, it simply aims to contribute to offset it in future research.

A review of recent papers in environmental, agricultural and biological sciences reveals that many authors might be unaware that they are using the term JD instead of DOY. However, the misuse of the terms does not affect the results and conclusions of the papers. JD and DOY terms involve different concepts designed to measure distinctive time bases. The term JD is used to record astronomical periodic events. There are many solar position algorithms. The Meeus algorithm uses the JD term, and the Spencer and Cooper algorithm uses the DOY term.

(Cooper, 1969; Meeus, 1991; Spencer, 1971). Compared to the Meeus algorithms, the results indicate that the Spencer model for

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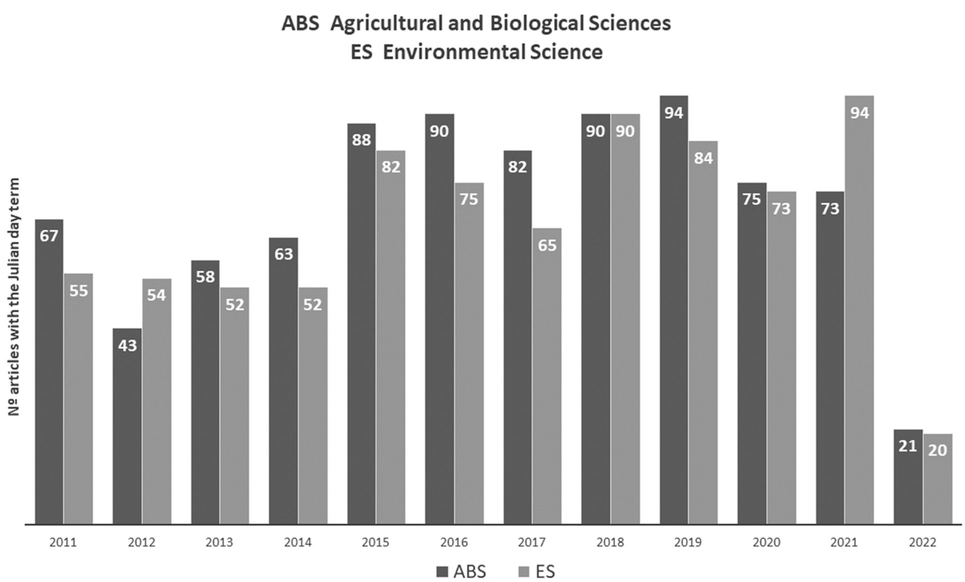

Fig. 1. Articles with the "Julian day" term since 2011 in 'Agricultural and Biological Sciences' and 'Environmental Science'.

Table 1
Formulations.

Parameter	Formulation	Reference
E_o	$Eo=\left(\frac{1}{R_{AU}}\right)^2$	(Annear and Wells, 2007; Grena, 2012; Jean Meeus, 1991; NOAA Global Monitoring Laboratory ESRL, n.d.; Reda and Andreas, 2004) Me
	$R_{AU}=\frac{1.000001018(1-(E_{c0})^2)}{1+E_{c0}cos(q)}$	
	$E_{co}=0.016708634-T(0.000042037+0.0000001267\cdot T)$	
	$T=\frac{JD-2451545.0}{36525.0}$	
	$q=c+M$	
	$c=sin(M)(1.914602-0.004817T-0.000014T^2)+sin(2M)(0.019993-0.000101T)+sin(3M)0.000289$	
	$M=357.52911+35999.05029T-0.0001537T^2$	
	$E_o=1.00011+0.034221cos\left(2\pi\frac{DOY-1}{365}\right)$ $+0.00128sin\left(2\pi\frac{DOY-1}{365}\right)$ $+0.000719\cos2\left(2\pi\frac{DOY-1}{365}\right)$ $+0.000077sin2\left(2\pi\frac{DOY-1}{365}\right)$	(Spencer, 1971) Sp
	$E_o=\left(1+0.033cos\frac{360DOY}{365}\right)$	(Duffie et al., 2003) Co
δ	$\delta=\arcsin(sin(\varepsilon p)\quad sin(L))$	(Annear and Wells, 2007; Grena, 2012; Meeus, 1991; NOAA Global Monitoring Laboratory ESRL, n.d.; Reda and Andreas, 2004) Me
	$\varepsilon p=\varepsilon o+0.00256cos(125.04-1934.136T)$	
	$T=\frac{JD-2451545.0}{36525.0}$	
	$\varepsilon o=23.0+\frac{1}{60}(26+\left(\frac{21.448-T(46.815+T(0.00059-0.001813T))}{60}\right)$	
	$L=\quad\theta_{TLO}-0.00569-0.00478sin(125.04-1934.136T)$	
	$\theta_{TLO}=c+\theta_{LO}$	
	$c=sin(M)(1.914602-0.004817T-0.000014T^2)$ $+sin(2M)(0.019993-0.000101T)$ $+sin(3M)\quad0.000289$	
	$M=357.52911+35999.05029T-0.0001537T^2$	
	$\theta_{LO}=280.46646+T(36000.76983+T0.0003032)$	
	$\delta=\frac{180}{\pi}(0.006918-0.399912\,cos\left(2\pi\frac{DOY-1}{365}\right)$ $+0.070257\,sin\left(2\pi\frac{DOY-1}{365}\right)$ $-0.006758\,\cos2\left(2\pi\frac{DOY-1}{365}\right)$ $+0.000907\,\sin2\left(2\pi\frac{DOY-1}{365}\right)$ $-0.002697\,\cos3\left(2\pi\frac{DOY-1}{365}\right)$ $+0.001418\,sin3\left(2\pi\frac{DOY-1}{365}\right))$	(Spencer, 1971) Sp
	$\delta=23.45sin\left[\frac{360(DOY+284)}{365}\right]$	(Cooper, 1969; Duffie et al., 2003) Co
H_o	$H_0=\frac{24\times3600}{\pi10^6}TSIEo(cos(\Phi)\quad cos(\delta)\quad sin(\omega_s)$ $+\left(\frac{\pi}{180}\right)sin(\Phi)\quad sin(\delta)\quad\omega_s)\ \text{Mj}\ \text{m}^{-2}$	
N	$N=\frac{2}{15}\omega_s$	
	$\omega_s=arccos(-tan(\Phi)tan(\delta))$	

DOY day of year. JD Julian day. E_o eccentricity correction factor earth's orbit. δ solar declination. H_o extraterrestrial radiation. *TSI* 1361 W/m^2. Φ latitude. ω_s sunset hour angle N daylight hours. εp corrected obliquity of the ecliptic. L apparent longitude of the sun. εo obliquity of the ecliptic. T Julian century. θ_{TLO} longitude of the sun. q actual anomaly of the sun (degrees). c center of the sun. M geometric mean anomaly of the sun. θ_{LO} geometric mean longitude of the sun. $R_{AU}=R/R_{mean.}$ R_{mean} 1 AU (astronomical unit); *R* is the actual distance earth-sun

Table 2
Abbreviations.

Parameter	Definition
c	center of the sun, degrees
Dfr	the decimal day for the day and fraction of the day
DOY	Day of the Year
E_o	eccentricity correction factor earth's orbit
H_o	daily extraterrestrial radiation MJ/m^2
INT	largest integer less than or equal to the value
JD	Julian Day
L	apparent longitude of the sun, degrees
M	geometric mean anomaly of the sun, degrees
Mo	Gregorian calendar month
N	daylight hours
q	actual anomaly of the sun, degrees
R_{AU}	$R/R_{mean.}$ relative distance sun-earth (astronomical unit)
R	actual distance earth-sun
R_{mean}	mean distance earth-sun
T	Julian century
TSI	1361 W/m^2
Yr	Gregorian calendar year
ω_s	sunset hour angle, degrees
εo	obliquity of the ecliptic, degrees
εp	corrected obliquity of the ecliptic, degrees
δ	solar declination, degrees
Φ	latitude, degrees
θ_{TLO}	longitude of the sun, degrees
θ_{LO}	geometric mean longitude of the sun, degrees

calculating solar declination and eccentricity resulted in better estimates than the Cooper model. DOY is the number of a certain Day of the Year, counting from a fixed day, normally January 1. Thus, January 31 is DOY 31 and December 30 is DOY 364 or 365, depending if it is a leap day or not. JD is a completely different way of measuring the day number. According to Resolution B1 (23rd International Astronomical Union General Assembly), JD is the number assigned to a day in a continuous count starting at UTC noon on 1 January 4713 BCE (IERS, n.d.). One can add decimals with the fraction of a day since the preceding noon. JD is another date format, and involves different day numbering system making easier to calculate the number of days between two dates. The JD term is widely used, but should be used appropriately. On Sciencedirect.com, the term "Julian Day" appears 1820 times in the subject Agricultural and Biological Sciences, and 1590 times in the subject Environmental Science (Accessed 20 January 2022). In many of them the use of the term is incorrect.

2. Julian Day

The term JD is a very precise and used number that commonly requires seven digits or more. The decimal point highlights that JD begins at noon and the day has 24 h. Some researchers are unaware of the accepted definition, and use JD to designate the DOY (McCarthy, 1998; Stone, 1983; Wilimovsky, 1990). For astronomical purposes, a continuous count of days is needed. JD zero is about 7000 years ago, starting at UTC noon on 1 January 4731 BCE. The JD of any instant is the number for the preceding noon plus the fraction of day since the instant. The formulation for computing the JD is (Annear and Wells, 2007; Grena, 2012; Meeus, 1991; NOAA Global Monitoring Laboratory ESRL (n.d.); Reda and Andreas, 2004):

$$JD = INT(365.25 \quad (Yr + 4716.0)) + INT(30.6001 \quad (Mo + 1)) + Dfr + B - 1524.5 \tag{1}$$

$$B = 2 - A + INT(0.25\ A)\ \textit{In the Julian calendar take B equal to zero} \tag{2}$$

$$A = INT(0.01 \quad Yr) \tag{3}$$

Where INT indicates the largest integer less than or equal to the value, Yr and Mo are the Gregorian calendar year and month, respectively. If Mo > 2, then Yr and Mo are unchanged, but if Mo = January 1 or February 2, then Yr is replaced by Year- 1 and Mo by Month + 12; Dfr is the decimal day for the day and fraction of the day. A Julian date begins at 12 h. January 1, 2000 (12 h) equals Julian date 2451545.0, and Julian centuries T are defined as:

$$T = \frac{JD - 2451545.0}{36525.0} \tag{4}$$

3. Extraterrestrial solar radiation and maximum duration of sunshine

The estimation of extraterrestrial solar radiation, H_o, and maximum possible sunshine duration or daylight hours, N, is based on the Day of the Year (solar declination and the effect of the earth-sun distance) and the latitude. As mentioned, DOY, H_o and N are often used to derive solar radiation and evapotranspiration (Allen et al., 1998). The solar declination, δ, and the eccentricity correction factor of the earth's orbit, E_o, rely on JD and DOY (Table 1). DOY is used in the estimation of H_o and N in the Duffie and Beckman/Cooper (Duffie et al., 2003) or Spencer expressions (Spencer, 1971) (noted by Co and Sp, respectively). And JD is used in the procedure to calculate solar declination and solar position described in The Astronomical Algorithm (Meeus, 1991). The procedure is also used in the calculations in the NOAA sunrise/sunset and solar position calculators (hereafter noted by Me) (Annear and Wells, 2007; Grena, 2012; Meeus, 1991; NOAA Global Monitoring Laboratory ESRL, n.d.; Reda and Andreas, 2004) see Table 1.

In order to assess the accuracy of the Sp and Co approximations H_o and N were calculated with the NOAA solar position calculator (Me) and the two approximations (Sp and Co) by calculating the values for all days of the year 2019, and latitude values of 65 °N to 0 °, an interval of 5°. The accuracy assessment focused on the daily pairwise comparison between Me and the approximated values. Several statistical indicators were used to assess the similarity, namely the regression coefficient *b* of a linear regression forced to the origin, the root mean square percentage error, *RMSE%*, the mean bias percentage error, *MBE%*, and the mean absolute percentage error, *MAPE*. The Co formulas are frequently used in the literature, despite being less accurate (especially for high latitudes), while the Sp formula represents the solar declination and eccentricity with truncated Fourier series, providing more accurate approximations. The Me model, based on the formulations from Astronomical Algorithms by Jean Meus, requires more complex computation and parameter calculation than the previous approximations. The more complex models for estimating solar position resulted in more accurate estimates (Annear and Wells, 2007; Grena, 2012; Meeus, 1991; NOAA Global Monitoring Laboratory ESRL, n.d.; Reda and Andreas, 2004) (Table 2).

Fig. 2 shows that the maximum errors for calculating H_o between Me and Sp are 1.14 RMSE%; −0.03 MBE% and 2.12 MAPE%; and Me and Co are 2.27 RMSE%; −1.72 MBE% and 4.53 MAPE%. Further, the b term remains constant (practically equal to one) for Sp for all latitude, while it decreases with latitude for Co model. The errors increase at higher latitudes. Fig. 3. shows that the maximum errors for calculating N between Me and Sp are 0.67 RMSE%; 0.01 MBE% and 0.83 MAPE%; and Me and Co are 1.48 RMSE%; −1.14 MBE% and 1.70 MAPE%. A similar pattern than in Fig. 2. was observed for the b terms in the N values.

4. Conclusion

The use of the terms DOY and JD was assessed in published papers within the subjects 'Agricultural and Biological Sciences' and 'Agricultural and Biological Sciences', and a clear misuse of the terms was detected, although it did not affect the results presented. An accurate and rigorous use of the terms should be desirable.

The Spencer formulation is a simplified computational tool that provides similar results to the NOAA/Meeus expression and more

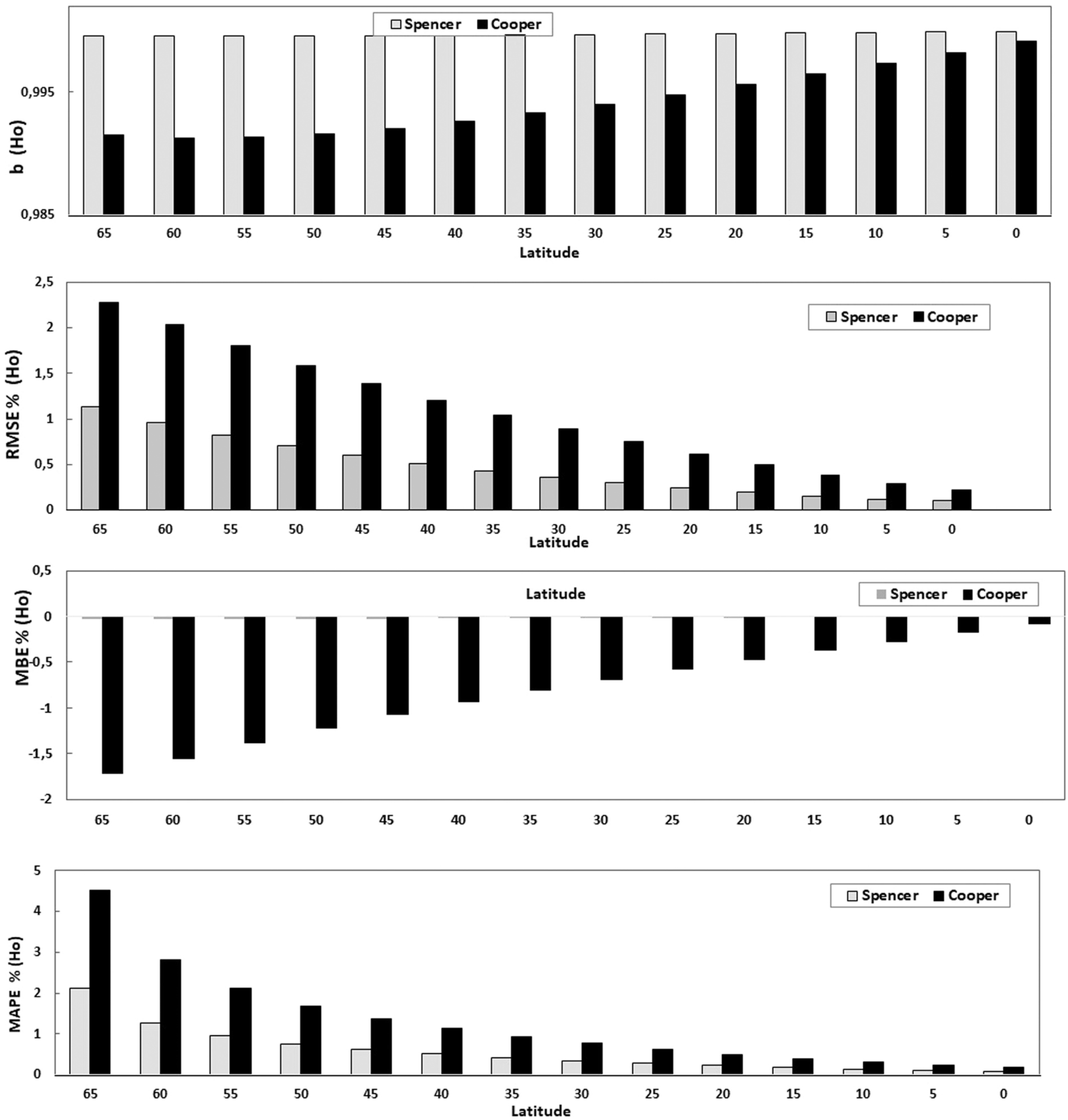

Fig. 2. b, RMSE%; MBE% and MAPE per latitude of H_o estimates based on the Spencer and Cooper formulas against NOAA targets.

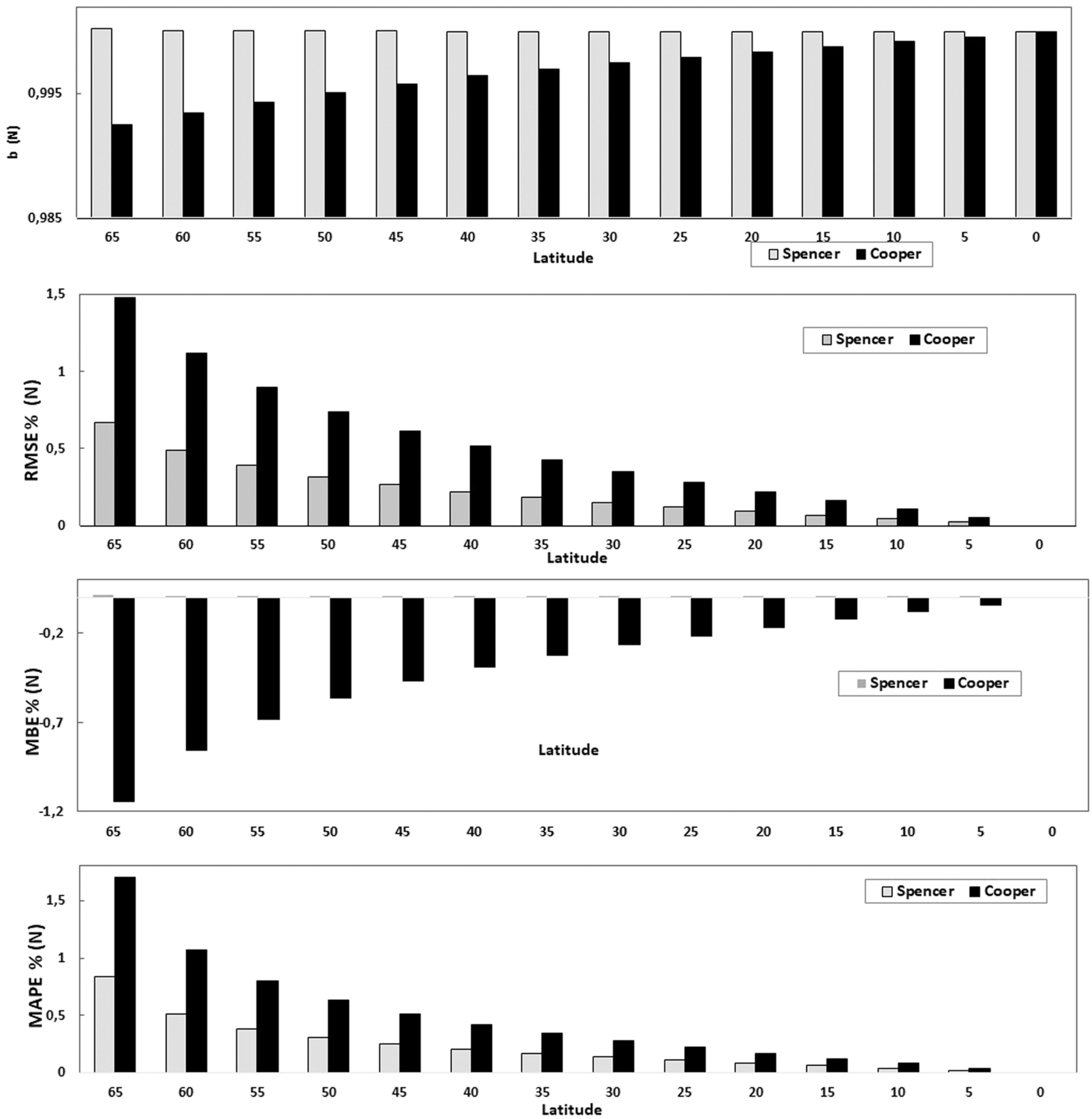

Fig. 3. b, RMSE%; MBE% and MAPE per latitude of N estimates based on the Spencer and Cooper formulas against NOAA targets.

accurate results than the Cooper method. The Spencer formulation does not require a heavier computation and data preparation than the Cooper method. The Spencer formulation introduced is simple and accessible. Further, the use of the Cooper formulations (Cooper, 1969; Duffie et al., 2003) should be omitted, because they are imprecise.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Update

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Corrigendum

Corrigendum to "Misuses of the terms Day of the Year and Julian Day in agricultural and environmental sciences" [Agric. Water Manag. 267 (2022) 107613]

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The authors regret that due to an oversight in the above article (https://doi.org/10.1016/j.agwat.2022.107613) we, the authors, omitted to cite a post "Arietta, AZA. (2020, Jan 27). "Julian Date vs Day of the Year" Published: https://www.azandisresearch.com/2020/01/27/julian-date-vs-day-of-the-year/.

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