Response to Anonymous Referee #1

We greatly appreciate the reviewer for providing constructive comments, which have helped us improve the paper quality significantly. We have addressed all of the comments carefully, as detailed below. The original comments are in black and our responses are in blue. Major changes made in the revised manuscript are in red color.

Major Comments:

Comment 1:

Section 3.1 and Figure 2 – The authors have not described how the errors were calculated. Furthermore, the justification of some of the coefficients needs to be further detailed and not simply justified by a previous citation. For example, line 185.

Response:

We have added a description of the traditional method for fire spot extraction in *Section 2.1*, which reads: “Furthermore, fire spots from open straw burning were extracted using the traditional method that does not integrate crop cycle information. Only the current year’s ChinaCropArea1 km data was extracted to Fire spots (MCD14ML). Then, fire spots occurring on agricultural land with growing crops were identified as open straw burning.”

We have also added a description of the calculation method for the error in ***Fig. 2***, which reads: “The error is calculated as the number of fire spots identified by the traditional method minus those extracted by the novel method.”

We have added a description of the justification of the coefficients selected in *Section*

2.2, which reads: "*α* is a correction factor used to adjust for *FRP* detection errors between MODIS and VIIRS, which is given a value of 2.5 following Vadrevu and Lasko (2018), indicating that the *FRP* VIIRS sum is 2.5 times of the *FRP* MODIS sum;" and "f_{FRP} is a correction factor that is used to adjust the underestimated emissions by fire spots, and Yang et al. (2020) determined an optimal value of 5 for f_{FRP} by calibrating the contributions of open straw burning to ground observation data in Northeast China using WRF-CMAQ

Comment 2:

Figure 3c – This is a very interesting plot and a unique way to show the fire activity. However, in Spring 2014, there was a very distinct cut-off with a yellow section at the start of the cut-off. This tells me that this could be a data artifact, and the authors should re-download the data to see if there was a disruption with the data download. The science quality MCD14ML data downloaded from the University of Maryland's FUOCO SFTP site is the more robust data and contains the "type" column which the authors should use to filter out any non-vegetation fire activity within the cropland area (see User Guide section 5.5 and others - https://modis-fire.umd.edu/files/MODIS_C6_C6.1_Fire_User_Guide_1.0.pdf).

Response:

We re-downloaded science quality MCD14ML data from the University of Maryland's FUOCO SFTP site, which are described in the revised manuscript as follows: "The MODIS fire product (MCD14ML, Collection 6.1) was selected from 1 January 2001 to

31 December 2020 for the whole region of Northeast China (Giglio et al., 2016, sftp://fuoco.geog.umd.edu)."

We then filtered out any non-vegetation fire activity within the cropland area, which is described in *Section 2.1* as follows: "The dataset, with a spatial resolution of about 1 km^2, includes essential variables, such as latitude, longitude, acquisition date and time (in UTC), satellite (Aqua or Terra), FRP, and fire type (presumably vegetation fire, active volcano, other static land source, and offshore), among others (https://modis-fire.umd.edu/files/MODIS_C6_C6.1_Fire_User_Guide_1.0.pdf). Non-vegetation fire activities (active volcano, other static land source, and offshore) were then filtered out from the selected dataset for subsequent analysis."

Subsequently, we re-analyzed the spatial and temporal distributions of fire spots, the emission inventory of GHGs, and the driving factors of open straw burning based on the corrected fire spot data in *Sections 3.1*, *3.2*, and *3.4*, respectively.

In **Fig. 3(c)**, the distinct yellow cut-off observed in Spring 2014 was not a data artifact caused by errors in the fire spot data, but rather caused by the expansion of the bean distribution data from Heilongjiang Province to the whole region of Northeast China. We have added a clarification in *Section 2.1*, which reads "Considering that Northeast China is a major bean-producing area, we also compiled bean distribution datasets (Li et al., 2021; Xuan et al., 2023). However, bean distribution in Jilin and Liaoning provinces was not recorded during 2001-2012 in this dataset. The dataset was extended to the whole region of Northeast China (Heilongjiang, Jilin, and Liaoning provinces) after 2013."

Subsequently, we increased the resolution of the frequency distribution of burning dates for various straws from 10 days to 1 day to mitigate this error (**Fig. 3**), and modified the results for the frequency distribution of burning dates for bean straw in *Section 3.1*, as follows: “During **Period I** (2003-2012), the spring and autumn burning dates of bean straw in Heilongjiang Province were concentrated from mid-March to late April (DOY range of 70 to 120) and from early October to mid-November (DOY range of 270 to 320), respectively (**Fig. 3(c)**). During 2013-2020, the spring burning dates of bean straw in Northeast China were concentrated between early February and late April (DOY range of 30 to 120), while the autumn burning dates remained consistent with those during Period I in Heilongjiang Province (**Fig. 3(c)**).”

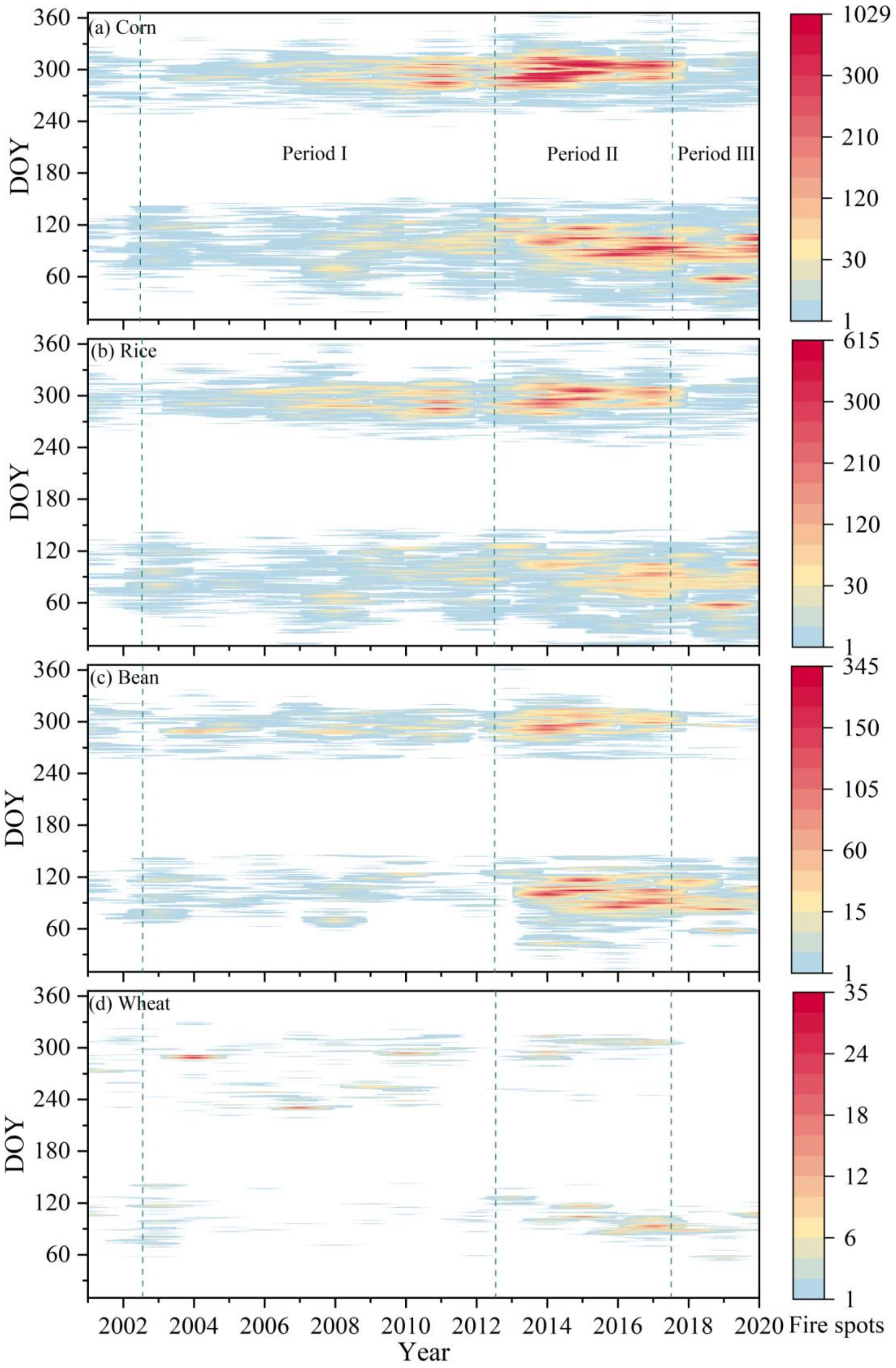

Fig. 3 The daily frequency distribution of fire spots from various straws burning: (a), (b), (c), and (d) represent corn, rice, bean, and wheat straw, respectively. Note: The x-axis is Year; the y-axis is DOY; and the daily number of fire spots for straw burning ranges from 1 to 1,029 for

corn, 1 to 615 for rice, 1 to 345 for beans, and 1 to 35 for wheat.

Comment 3:

2001 - 2003 data: The authors should consider only analyzing data from 2003 (or 2004 for a full year) onwards since both Aqua and Terra satellites were available. The lower number of fires in 2001 – 2003 is due to the Terra-only time period. All the statistics (especially the ones related to fire counts) and the trend analysis will be skewed because the first few years have significantly fewer fires purely based on the Terra-only period. Also, there was a 2-week window in August 2020 where MODIS Aqua failed, and therefore, you will be missing ~ 2 weeks' worth of fire counts within that peak burning time period (Section 8.4 - /https://modis-fire.umd.edu/files/MODIS_C61_BA_User_Guide_1.1.pdf). The authors need to add this as a limitation to the text.

Response:

We have added the limitations of MCD14ML in *Section 2.1*, which reads: "To clarify, the MCD14ML underestimated fire spots in 2001 and 2002 because only the Terra satellite was operational before 3 July 2002. Therefore, data for the years of 2003 to 2020 were used for developing annual emission inventories, with relevant results for 2001 and 2002 as reference only. Also, a failure of the Aqua satellite on 16 August 2020 led to the loss of fire spot data for about two weeks (https://modis-fire.umd.edu/files/MODIS_C61_BA_User_Guide_1.1.pdf). However, as August is a crop-growing period in Northeast China, this failure would not lead to an underestimation of fire spots from open straw burning."

Comment 4:

Figure 5 and text - All trend analysis will be skewed because of 2001 – 2003 data. Trends should just be considered from 2004 onward since Aqua data was only available from July 2003.

Response:

We have revised **Fig. 5** and the accompanying text to analyze only the results for 2003-2020, which reads: "During **Period I** (2003 - 2012), average annual CO_2-eq emission was at 4.20 Tg, and the cumulative CO_2-eq emission amounted to 42.0 Tg. During **Period II** (2013 - 2017), average annual CO_2-eq emission increased substantially to 26.1 Tg, and the cumulative emission during this period amounted to 130 Tg, which accounted for 59.9% of the total emissions over the two decades. During **Period III** (2018 - 2020), average annual CO_2-eq emissions decreased significantly to 14.3 Tg, and the cumulative emission during this period amounted to 42.8 Tg (**Fig. 5(a)**). ...... The combustion of corn and rice straw were identified as the primary contributors to CO_2-eq emissions, accounting for 51.1% and 30.8%, respectively, of the total emissions (**Fig. 5(b)**). Specifically, corn straw burning released 99.6, 9.06, and 2.42 Tg, while rice straw burning released 61.8, 3.78, and 1.27 Tg of CO_2, CO_2-eq for CH_4, and CO_2-eq for N_2O, respectively."

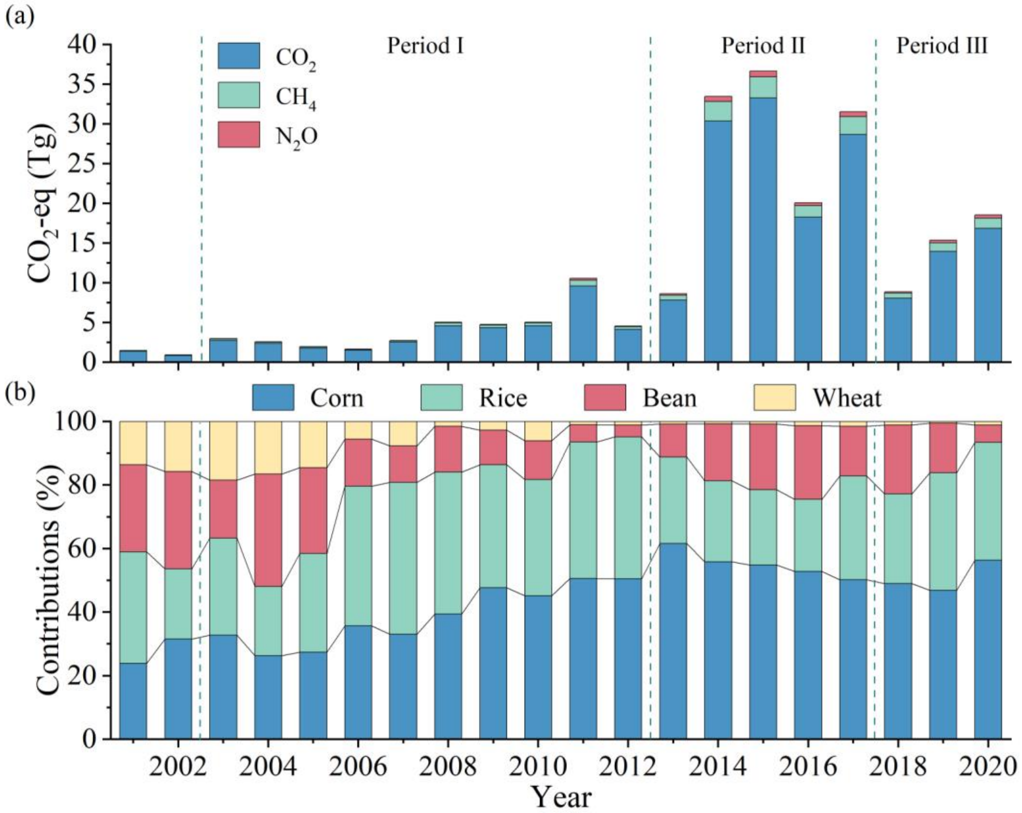

Fig. 5 (a) Regional total annual CO_2-eq emissions and (b) percentage contributions from open burning of individual crop straw type.

Comment 5:

Limitations and caveats: The authors need to add a section outlining the above-mentioned limitations and including the limitations of mapping crop residue burning using current remote sensing technology.

Response:

We have added a more formal section to outline the limitations regarding this novel method and remote sensing techniques in *Section 3.3*, which reads: "Although this study effectively improved the accuracy of emission inventory for open straw burning through the novel method that integrates crop cycle information into extraction and classification of fire spots and the modified FRP algorithm, certain limitations still exist. The uncertainty in this study stems mainly from the inherent limitations of satellite fire detection systems. The MODIS fire spot product, although widely used, is limited by its temporal resolution and tends to miss transient or small-scale fires. In addition, straw burning during non-satellite transit periods, on cloudy days, at night, and under heavy haze further exacerbates the underestimation of fire incidence, leading to potential gaps in emission inventories.

Additionally, the novel method that integrates crop cycle information into extraction and classification of fire spots presents a promising advancement. However, its applicability is constrained to regions where comprehensive and detailed crop data are available. In countries or regions lacking such agricultural information, this method may face challenges, thereby limiting its broader applicability. These factors underscore the need for continued refinement of satellite detection technologies and the expansion of agricultural data collection efforts to reduce uncertainties and enhance the robustness of emission inventories on regional to global scales."

Comment 6:

Validation or product intercomparison: The authors need to include a more formal section on validating their results and comparing them against other products. Are there other remote sensing sensors or on-the-ground station data that the authors can use to include a more high-resolution comparison?

Response:

We have added a more formal section to validate the results and compare them with other products in *Section 3.3*, which reads: “Our estimated total CO_2 emissions from 2012 to 2020 with MODIS (161 Tg) or with VIIRS (165 Tg) were much lower than that (~ 523 Tg) estimated by Liu et al. (2022), the latter was based on a modified FRP algorithm and fire spot products by VIIRS, which has limitations in its traditional straw extraction methods in accurately identifying fire spots during certain times of the year. Our estimated CO_2 emission from 2002 to 2020 in Northeast China (196 Tg) was slightly lower than that (195 Tg) estimated by Global Fire Emissions Database Version 4.1 (GFED4.1s) by van der Werf et al. (2017), and slightly higher than that (181 Tg) estimated from the Fire Inventory from NCAR version 2.5 (FINNv2.5) by Wiedinmyer et al. (2023), which addresses the underestimation of open biomass burning in China by the older version FINNv1.5 (Stavrakou et al., 2016; Yang et al., 2020) (**Fig. 6**). However, our estimated total CO_2 emission from 2012 to 2020 was significantly higher than that (35.6 Tg) estimated by VIIRS-based Fire Emission Inventory version 0 (VFEIv0) by Ferrada et al. (2022), which relies on the traditional FRP algorithm (**Fig. 6**). Furthermore, Northeast China surpassed East China (27.1 Tg) as the highest emitter from open straw burning in China since 2014, with CO_2 emissions reaching 30.4 Tg (Zhang et al. 2020).”

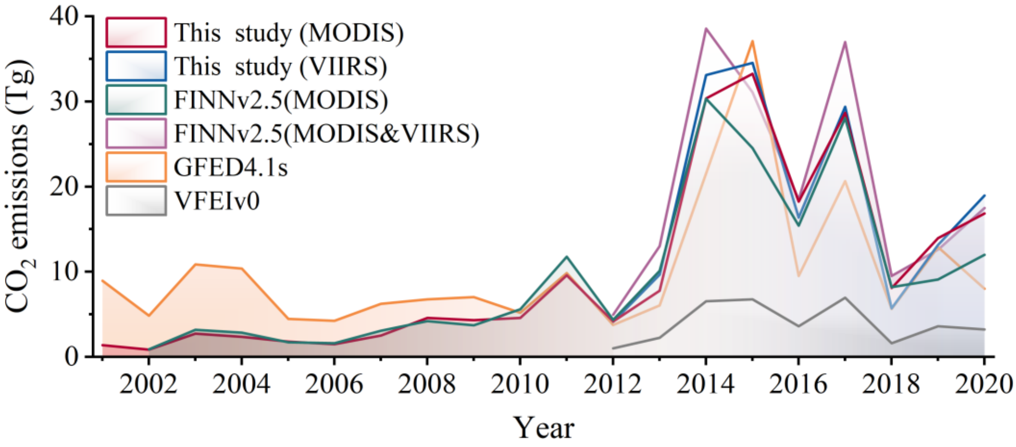

Fig. 6 Annual total emissions of CO_2 from open straw burning (agricultural waste burning) in Northeast China from this study with MODIS (red, 2001-2020) and VIIRS (blue, 2012-2020), the Fire Inventory from NCAR version 2.5 (FINNv2.5) with MODIS-only (green, 2002-2020), FINNv2.5 with MODIS and VIIRS (purple, 2012-2020), Global Fire Emissions Database Version 4.1 (GFED4.1s) (orange, 2001-2020), and VIIRS-based Fire Emission Inventory version 0 (VFEIv0) (grey, 2012-2020).

Minor Comments:

Comment 7:

Line 36: change "elevated" to "evaluated"; Line 61: change "remains to be prevalent" to "remains prevalent"; Line 132: change to "China"; Line 422: change to "Period".

Response:

We have corrected these grammatical and spelling errors and thoroughly checked the manuscript.

Comment 8:

Figure 3 (and others) - Make a note in the caption that the y-axis is different for each crop or that the scales are different.

Response:

We have added notes in the caption, which reads: "**Fig. 3** The daily frequency distribution of fire spots from various straws burning: (a), (b), (c), and (d) represent corn, rice, bean, and wheat straw, respectively. Note: The x-axis is Year; the y-axis is DOY; and the daily number of fire spots for straw burning ranges from 1 to 1,029 for corn, 1 to 615 for rice, 1 to 345 for beans, and 1 to 35 for wheat."