

# Response to Reviewer Comments

## **General Comment:**

The manuscript updates the Zeeman effect coefficients of Larsson (2019) in the 2024 RS-LBL model, which improves the accuracy of simulation at the bands near Zeeman splitting lines, and put forward a new channel configuration for near space temperature profiles. After comparing them with the channels of SSMIS through simulations, it is proved that a finer vertical resolution can be realized from the configuration, which will be served as a good reference for the future payload design and channel selection of near space microwave radiometers.

We have made substantial improvements to both the writing and the analysis in response to the reviewer's concerns. Detailed point-by-point responses are provided below.

## **Point 1:**

The first sentence at the first paragraph at page 2 “*Infrared hyperspectral instruments have now reached maturity, and the radiance data have been proven to improve NWP forecast accuracy (Aires et al., 2015; Eresmaa et al., 2017; McNally et al., 2006). However, microwave sensors have significantly fewer detection channels compared to infrared instruments due to technological limitations (Boukabara and 40 Garrett, 2011)*” seems there is logically confusion in the comparison between infrared sensors and microwave sensors, where the authors try to argue the importance of microwave sensors. But, since the infrared sensors “have now reached maturity, and the radiance data have been proven to improve NWP forecast accuracy”, why still need microwave sensor? The reasons seem not be clearly given.

## **Responses:**

We sincerely thank the reviewer for identifying this logical gap. In the revised manuscript, we rewrote this paragraph: “Infrared hyperspectral instruments have now reached maturity, and their radiance data have been proven to improve NWP forecast accuracy (Aires et al., 2015; Eresmaa et al., 2017; McNally et al., 2006). Nevertheless, infrared observations are inherently limited by their shorter wavelengths, which are strongly attenuated by clouds and precipitation, making it difficult to obtain valid measurements under cloudy conditions. Microwave sensors, operating at much longer wavelengths, can penetrate clouds and precipitation, enabling all-weather observations and reaching higher altitudes. Thus, microwave sensors are essential for filling the observational gaps left by infrared instruments, particularly in cloudy conditions and the upper atmosphere.”

This revision makes clear that infrared and microwave sensors are complementary rather than substitutive, with microwave sensors uniquely capable of all-weather and high-altitude observations.

## **Point 2:**

Through the manuscript tries to explain the Zeeman effect of O<sub>2</sub> on radiative transfer in the atmosphere, there seems no much special improvements or new contribution in Section 2 but summaries on the principle of Zeeman Splitting and progress in its absorption models. Furthermore, some references on oxygen absorption models are not fully covered, such as Liebe 1989,1992,and 1993.

**Responses:**

We appreciate the reviewer’s constructive comment. Section 2 primarily provides the methodological foundation for the subsequent analyses in Sections 3 and 4, rather than claiming original contributions. We supplemented the references to include Liebe (1981) and Liebe et al. (1992) in Section 2.1. The Liebe (1981) paper established the foundational MPM framework, including the treatment of the Zeeman effect for mesospheric O<sub>2</sub> lines, while Liebe et al. (1992) provided updated laboratory measurements of the 60-GHz oxygen band and refined line mixing parameters. Both are directly relevant to the oxygen absorption modeling discussed in our study.

**Point 3:**

There is no definition on ‘product matrix P’ in line 153, and transmittance matrix  $\Gamma$  should be defined by a 4\*4 matrix by considering the Zeeman effect, but 2\*2 matrix only, in considering the radiation of four Stokes parameters due to Zeeman effect. See reference: Wang K X, Wang Z Z, Wang W Y. Analysis of the remote sensing mechanism and influencing factors of microwave radiometers for the Earth's magnetic field. Chinese Journal of Geophysics, 2026, 69(2): 496-510.

**Response:**

We thank the reviewer for this important technical comment. About the definition of the cumulative product matrix **P**: In the revised manuscript, we provided a clearer definition. **P** is accumulated layer by layer starting from the top of the atmosphere as  $\mathbf{P}_{i-1} = \mathbf{P}_i \mathbf{E}_i$ , where  $\mathbf{E}_i = \exp(-\mathbf{G}\Delta z_i)$  is the exponential matrix for layer  $i$  based on the complex propagation matrix **G**, and  $\Delta z_i$  is the propagation path length. This definition follows the theoretical framework of Rosenkranz and Staelin (1988).

As for the dimensionality of the transmittance matrix, we understand the reviewer’s concern. The  $2 \times 2$  formulation used in this study follows the theoretical framework of Lenoir (1967, 1968) and Rosenkranz and Staelin (1988), where the radiative transfer is expressed in terms of a  $2 \times 2$  brightness temperature coherence matrix. In this formulation, the  $2 \times 2$  brightness temperature matrix **T<sub>B</sub>** is a Hermitian matrix whose diagonal elements correspond to the brightness temperatures for a specific polarization basis (linear or circular), and the off-diagonal elements describe the coherence between polarization components. The four Stokes parameters (I, Q, U, V) can be fully recovered from the  $2 \times 2$  brightness temperature matrix via Eqs. (8) and

$$(9) \text{ in the manuscript: } I = T_{B_{VV}} + T_{B_{HH}}, Q = T_{B_{VV}} - T_{B_{HH}}, U = 2 \operatorname{Re}(T_{B_{VH}}), V = -2 \operatorname{Im}(T_{B_{VH}})$$

Thus, the  $2 \times 2$  formulation is physically equivalent to the  $4 \times 4$  Stokes vector approach and is sufficient for the nadir-viewing geometry considered in this study.

**Point 4:**

About “Microwave LBL Model Simulations” at Section3, there is no introduction on the input parameters or profiles used as backgrounds.

**Response:**

We thank the reviewer for this reminder. In the revised manuscript, we added a description of the input parameters and profiles at the beginning of Section 3.1: “The simulations use the 84-layer ECMWF profile

dataset developed by Peter Rayer (Met Office) as input, with geomagnetic field parameters obtained from the International Geomagnetic Reference Field (IGRF-13) (Alken et al., 2021).”

**Point 5:**

There is no unit given for the parameters in formula (12) at line 295.

**Response:**

Thanks! In the revised manuscript, we added the units for all parameters in Eq. (12):

$$NEDT = (T_r + T_a) / \sqrt{BW \cdot t}$$

where  $NEDT$  denotes the channel noise equivalent delta temperature (unit: K),  $BW$  represents the channel bandwidth (unit: MHz),  $T_r$  is the receiver equivalent noise temperature (unit: K),  $T_a$  is the antenna temperature (unit: K), and  $t$  is the integration time (unit: s).

**Point 6:**

It is suggested that the authors give clearer introductions on how to set integration time for SSMIS and HMAS, whether through the hardware design or averaging by the software, since there is not more time for integration time during a scan with the satellite flying.

**Response:**

In the revised manuscript, we added a clearer explanation of the integration time settings for both instruments. For SSMIS: “The integration time for the SSMIS channel 19-23 is 25.2 ms, and for channel 24 is 12.6 ms, which are fixed hardware parameters determined by the radiometer design (Swadley et al., 2008).”

For HMAS: “To reduce channel noise, the integration time is extended to approximately 44.3 ms. This can be achieved through software averaging (i.e., accumulating and averaging observations from the same channel over multiple scan cycles), which is within the allowable range of satellite scan periods.”

We would also like to clarify that regarding the feasibility of the HMAS integration time setting. The HMAS is designed with a higher spectral resolution compared to SSMIS, which enables finer frequency sampling within the same spectral region. This higher spectral resolution provides greater flexibility in the scanning strategy, allowing the instrument to dwell longer over the same geographic region during a single scan cycle. Additionally, we plan to configure HMAS as a cross-track scanning instrument, which inherently allows for a longer integration time per field of view compared to the conical scanning configuration used by SSMIS. The cross-track scan geometry provides more time for each individual observation point, further supporting the extended integration time required for HMAS to achieve the desired noise performance.

*We sincerely thank the reviewer for these detailed and constructive comments, which have substantially improved the quality and clarity of our manuscript.*