1 (a) The point-by-point response to the reviews

2

3 - **Referee #2**

4 (1) Explain the abbreviations ICS, NCS and PCS in the abstract.

5 Sorry for my carelessness.

6 In abstract: "In general, the accuracy of the retrieval temperature of ICS

7 is improved. Especially, from 100 hPa to 0.01 hPa, the accuracy of ICS

8 can be improved by more than 11 %; (3) Statistical inversion comparison

9 experiments in four typical regions indicate that ICS in this paper is
10 significantly better than NCS and PCS in different regions and shows
11 latitudinal variations." (L 31-L 37)

This has been modified to "In general, the accuracy of the retrieval temperature of ICS (Improved Channel Selection) is improved; (3) Statistical inversion comparison experiments in four typical regions indicate that ICS in this paper is significantly better than NCS (NWP Channel Selection) and PCS (Primary Channel Selection) in different regions and shows latitudinal variations, which shows potential for future applications." (L 30-L 36)

19 Thanks.

20 (2) p. 21, L. 429: Include the following citation: Saunders, R., Hocking, J.,

- Turner, E., Rayer, P., Rundle, D., Brunel, P., Vidot, J., Roquet, P.,
- 22 Matricardi, M., Geer, A., Bormann, N., and Lupu, C.: An update on the

- 23 RTTOV fast radiative transfer model (currently at version 12), Geosci.
- 24 Model Dev., 11, 2717–2737, https://doi.org/10.5194/gmd-11-2717-2018,
- 25 2018.
- 26 Yes, you are right.
- This has been added. "...RTTOV can now simulate around 90 different
 satellite sensors measuring in the MW (microwave), IR (infrared) and
- 29 VIS (visible) regions of the spectrum (Saunders et al., 2018)" (L 420-L
- 30 423)
- ³¹ "Saunders, R., Hocking, J., Turner, E., Rayer, P., Rundle, D., Brunel, P.,
- Vidot, J., Roquet, P., Matricardi, M., Geer, A., Bormann, N., and Lupu,
- 33 C.: An update on the RTTOV fast radiative transfer model (currently at
- version 12), Geosci. Model Dev., 11, 2717-2737,
- 35 https://doi.org/10.5194/gmd-11-2717-2018, 2018." (L 1000-L 1004)
- 36 Thanks.
- 37 (3) p. 21, L. 429-430: The sentence "RTTOV is an evaluation of RTTOV
- v11, adding and upgrading many features" should be removed because
- explained is only the common procedure.
- 40 Yes, you are right.
- 41 The sentence "RTTOV is an evaluation of RTTOV v11, adding and
- 42 upgrading many features" has been removed. (L 419-L 420)
- 43 Thanks.
- 44 (4) Table 1 and table 2 should be removed or shifted to the appendix.

- 45 Yes, we agree with you.
- 46 The two tables have been shifted to the Appendix A. (L 846-L 854)
- 47 Thanks.
- 48 (5) p. 44, L. 747-748: Description of figure is too universal. Please
- 49 specify the behavior in more detail.
- 50 Sorry about this. We explain this as follows.
- 51 "In order to further compare the regional differences of inversion
- 52 accuracy, the temperature standard deviations of ICS in four typical
- regions are compared in Sect. 5.2." (L 722-L 724)
- 54 Thanks.
- (6) p. 3, L. 65: Atmospheric Infrared Sounder -> Atmospheric InfraRed
 Sounder.
- 57 Yes, we agree with you. This has been modified. (L 64)
- 58 Thanks.
- 59 (7) p. 14, L. 302: bright-> brightness.
- 60 Yes, you are right. This has been modified. (L 296; L 321; L 503; L 512)
- 61 Thanks.
- 62 (8) p. 16, L. 327: bright->brightness.
- Yes, you are right. This has been modified. (L 296; L 321; L 503; L 512)
- 64 Thanks.
- 65 (9) p 26, L. 495: add last access date.
- 66 Yes, we agree with you.

"The error covariance matrix of the background, Sa, is calculated using 67 5000 samples of the IFS-137 data provided by the ECMWF dataset. The 68 access date is April 26th, 2019 (download address: last 69 https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/, 2019)." 70 has been added to "The error covariance matrix of the background, S_a, is 71 calculated using 5000 samples of the IFS-137 data provided by the 72 ECMWF dataset (The detailed information will be introduced in Sect. 4). 73 The last access date is April 26th, 2019 (download address: 74 https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/, 2019)." 75 (L 477-L 482) 76

77 Thanks.

(10) p. 39, L. 656: Do not write and so on. Either specify the variables or
stop the sentence after cloud information.

80 Yes, you are right.

87 Thanks.

88 (11) p. 39, L. 664: add last access date.

- 89 Yes, we agree with you.
- 90 "Red parts represent precipitation. (from https://www.nwpsaf.eu/site/
- update-137-level-nwp-profile-dataset/, 2019)." has been added to "Red
- parts represent precipitation. The last access date is April 26th, 2019.
- 93 (from https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/,
- 94 2019)." (L 638-L 641)
- 95 Thanks.
- 96 (12) p. 40, L. 674: Do not write etc. Either specify the variables or stop
- 97 the sentence after wind speed.
- 98 Yes, you are right.
- ⁹⁹ "5000 profiles and their corresponding surface factors, including surface
- air pressure, surface temperature, 2 m temperature, 2 m specific humidity,
- 10 m wind speed, etc." has been modified to "5000 profiles and their
- 102 corresponding surface factors, including surface air pressure, surface
- temperature, 2 m temperature, 2 m specific humidity, 10 m wind speed."
- 104 (L 650)
- 105 Thanks.
- 106 (13) p. 51, l. 872: at 4.3 μm.
- 107 Yes, you are right.
- 108 "...and 4.3 μ m for the CO2 absorption bands;" has been modified to

- 109 "...and at 4.3 μ m for the CO2 absorption bands;" (L 833)
- 110

111 Thanks again for your careful review.

112

113

114 - **Referee #4**

(1) L1-3: I would like to suggest to streamline the title a bit, e.g., "A

channel selection method for hyperspectral atmospheric infrared sounders

based on layering". Perhaps the reference to the AIRS instrument can be

neglected in the title as the method will be applicable to other instruments,

119 too?

120 Yes, we agree with you.

121 The method will be applicable to other instruments. Your suggested title

122 "A channel selection method for hyperspectral atmospheric infrared

```
sounders based on layering" is more proper.
```

124 This has been modified. (L 1-L 3)

125 Thanks.

(2) L22-24: The statement "The distribution of the temperature weight

127 function is more continuous, more closely approximating that of the

- actual atmosphere" is unclear to me. Do you mean the coverage or
- sensitivity of the weighting functions is more evenly distributed over
- 130 height with this method?

131 Sorry about this.

132 The statement has been rewritten. "The coverage of the weighting

- functions is more evenly distributed over height with this method andcloser to the actual atmosphere" (L 22-L 24)
- 135 Thanks.
- (3) L28: The term "near space layer" is not commonly used, I think. I
- 137 would suggest to rephrase it by "stratosphere and mesosphere" here and
- in other places of the manuscript, for clarity.
- 139 Yes, you are right.
- "In the near space layer especially" has been modified to "In thestratosphere and mesosphere especially". (L 28)
- 142 "Near space (20–100 km)" has been modified to "Stratosphere and
 143 mesosphere". (L 542; L 696-L 697)
- "(the near space layer)" has been modified to "(the stratosphere and
 mesosphere)". (L 751-L752; L 825- L 826)
- 146 "The reason is that near space (20-100 km) is less affected by the ground
- 147 surface..."has been modified to "The reason is that stratosphere and
- 148 mesosphere are less affected by the ground surface..." (L 830-L 832)
- 149 Thanks.
- (4) L31-35: The acronyms ICS, NCS, and PCS need to be introduced inthe abstract
- 152 Sorry for my carelessness.
- 153 In abstract: "In general, the accuracy of the retrieval temperature of ICS
- is improved. Especially, from 100 hPa to 0.01 hPa, the accuracy of ICS

can be improved by more than 11 %; (3) Statistical inversion comparison
experiments in four typical regions indicate that ICS in this paper is
significantly better than NCS and PCS in different regions and shows
latitudinal variations." (L 31-L 37)

This has been modified to "In general, the accuracy of the retrieval temperature of ICS (Improved Channel Selection) is improved; (3) Statistical inversion comparison experiments in four typical regions indicate that ICS in this paper is significantly better than NCS (NWP Channel Selection) and PCS (Primary Channel Selection) in different regions and shows latitudinal variations" (L 31-L 36)

165 Thanks.

(5) L 50-55: The word "detection" is frequently used in the manuscript,
but considering that you are referring to temperature, I would recommend
to change this to "sounding", "observation", or "measurement" in most
instances.

170 Yes, you are right. This has been modified as follows.

"...satellite detection technology has developed rapidly" has been
modified to "...satellite observation technology has developed rapidly"
(L 40-L 41)

"From the perspective of vertical atmospheric detection, satellite
instruments are developing rapidly. In their infancy, the traditional
infrared detection instruments for detecting atmospheric temperature and

moisture profiles" has been modified to "From the perspective of
vertical atmospheric observation, satellite instruments are developing
rapidly. In their infancy, the traditional infrared measurement instruments
for detecting atmospheric temperature and moisture profiles ..." (L 47-L
50)

"... in terms of detection accuracy ... filter-based spectroscopic
detection instrument, therefore, ...To meet this challenge, ...for the
creation of high-spectral resolution atmospheric detection instruments ..."
has been modified to "... in terms of observation accuracy ... filter-based
spectroscopic measurement instrument, therefore, ...To meet this
challenge,... for the creation of high-spectral resolution atmospheric
measurement instruments..." (L 55-L 61)

"... such advanced detection technologies. ... techniques of
hyperspectral resolution atmospheric detection." has been modified to
"... such advanced sounding technologies. ... techniques of hyperspectral
resolution atmospheric observations." (L 72-L 75)

¹⁹³ "detection data" has been modified to "observation data" (L 80)

194 "...the general satellite detection instrument" has been modified to "...the

typical satellite instruments" (L 85)

196 "With the development of detection technology..."has been modified to

"With the development of measurement technology..." (L 88-L 89)

198 "temperature detection" has been modified to "temperature observation"

- 199 (L 391; L 530; L 547; L 701-L 702; L 777-L 778; L 835)
- 200 Thanks.
- 201 (6) L 61-62: Can you add a more recent reference regarding "today's
- needs" of NWP? Eyre et al. (1993) is more than 20 years old.
- 203 Sorry for my carelessness.
- Two recent references have been added to "(Eyre et al., 1993; Prunet et
- 205 al., 2010; Menzel et al., 2018)" (L 59)
- 206 "Menzel, W. P., Schmit, T. J., Zhang, P. and Li, J.: Satellite-based
- atmospheric infrared sounder development and applications, Bull. Amer.
- 208 Meteor. Soc., 99, 583–603, https://doi.org/10.1175/BAMS-D-16-0293.1,
- 209 2018." (L 974- L 977)
- ²¹⁰ "Prunet, P., Thépaut J. N., and Cass, V.: The information content of clear
- sky IASI radiances and their potential for numerical weather prediction,
- 212 Q. J. Roy. Meteor. Soc., 124, 211-241, https://doi.org/10.1002/
- 213 qj.49712454510, 2010." (L 978- L 981)
- 214 Thanks.
- (7) L 70-72: IASI became operational in 2007 and not in 2010.
- 216 Yes, you are right.
- This has been modified to "The United States and Europe, in 2010 and in
- 218 2007, also installed the CRIS (Cross-track Infrared Sounder) and the IASI
- 219 (Inter-Attractive Atmospheric Sounding Interferometer) on polar-orbiting
- 220 satellites". (L 68-L 71)

(8) L129-130 and L140-142: Which instruments are you referring to here?AIRS has more than 2000 channels.

Yes, you are right. AIRS has more than 2000 channels. We are sorry forthe confusion. This has been modified as follows.

"Kuai et al. (2010) analyzed both the Shannon information content and 226 degrees of freedom in channel selection when retrieving CO2 227 concentrations using thermal infrared remote sensing and indicated that 228 40 channels could contain 75% of the information from the total of 1016 229 channels." has been modified to "Kuai et al. (2010) analyzed both the 230 Shannon information content and degrees of freedom in channel selection 231 when retrieving CO2 concentrations using thermal infrared remote 232 sensing and indicated that 40 channels could contain 75% of the 233 information from the total channels." (L 125-L 129) 234

"Richardson et al. (2018) selected 75 from 853 channels using
information content analysis to retrieve the cloud optical depth, cloud
properties, and position." has been modified to "Richardson et al. (2018)
selected 75 from 853 channels based on the high spectral-resolution
oxygen A-band instrument on NASA's Orbiting Carbon Observatory-2
(OCO-2), using information content analysis to retrieve the cloud optical
depth, cloud properties, and position." (L 138-L 142)

242 Thanks.

- (9) L147: I would suggest to rephrase "weight function" by "weightingfunction" here and throughout the manuscript.
- 245 Yes, we agree with you.
- 246 "weight function" has been modified to "weighting function" throughout247 the manuscript.
- 248 Thanks.

(10) L 147-148: The statement "... use only the weight function to study
appropriate numerical methods, the use of which allows sensitive
channels to be selected." is unclear to me. Please rephrase.

252 Sorry for this.

"Today's main methods for channel selection (such as the data precision 253 matrix method (Menke, 1984), singular value decomposition method 254 (Prunet et al., 2010; Zhang et al., 2011; Wang et al., 2014), and the Jacobi 255 method (Aires et al., 1999; Rabier et al., 2010) use only the weight 256 function to study appropriate numerical methods, the use of which allows 257 sensitive channels to be selected." has been modified to "Today's main 258 methods for channel selection use only the weighting function to study 259 appropriate numerical methods, such as the data precision matrix method 260 (Menke, 1984), singular value decomposition method (Prunet et al., 2010; 261 Zhang et al., 2011; Wang et al., 2014), and the Jacobi method (Aires et al., 262 1999; Rabier et al., 2010). The use of the methods allows sensitive 263 channels to be selected." (L 143-L 149) 264

(11) L 155-161: The concept of information content itself does consider 266 all the height dependencies of the kernel matrix K (Rodgers, 2000 or Eq. 267 (1) in the present manuscript). Earlier work may have neglected the 268 height dependencies of K for simplicity and to ease the calculations. 269 These sentences should be rephrased so that they do not give the wrong 270 impression that the information content ignores the height dependencies 271 of the weighting functions in general. 272 Yes, you are right. 273 "Currently, information content is often employed in channel selection. 274 During retrieval, this method delivers the largest amount of information 275 for the selected channel combination (Rodgers, 1996; Du et al., 2008; He 276 et al., 2012; Richardson et al., 2018). Although this method has made 277 great breakthroughs in both theory and practice, however, it does not take 278 the sensitivity of different channels at different heights into consideration." 279 has been modified to "Currently, information content is often employed 280 in channel selection. During retrieval, this method delivers the largest 281 amount of information for the selected channel combination (Rodgers, 282 1996; Du et al., 2008; He et al., 2012; Richardson et al., 2018). This 283 method has made great breakthroughs in both theory and practice, and the 284 concept of information content itself does consider all the height 285 dependencies of the kernel matrix K (Rodgers, 2000). However, earlier 286

- works have neglected the height dependencies of K for simplicity." (L
- 288 155-L 163)
- 289 Thanks.
- (12) L 195-195: This is redundant and can be deleted.
- 291 . Yes, you are right.
- 292 The sentence "where S_a is the error covariance matrix of the background
- or the estimated value of the atmospheric profile, and \hat{S} represents the
- observation error covariance matrix of each hyperspectral detector
- channel."has been deleted. (L 195)
- 296 Thanks.
- (13) L 216-219: This sentence is unclear and should be rephrased.
- 298 Yes, you are right.
- ²⁹⁹ "Furthermore, under the maximum one p-value, the corresponding
- 300 channel combination is used as the optimum channel combination;
- therefore, the entire atmosphere must be calculated $M \cdot C_N^n$ times." has
- been modified to "Furthermore, there are M layers in the vertical
- direction of the atmosphere. Therefore, the entire atmosphere must be
- 304 calculated $\mathbf{M} \cdot \mathbf{C}_N^n$ times." (L 212-L 214)
- 305 Thanks.
- 306 (14) L 221-227: The "sequential absorption method" has been described
- elsewhere before, e.g., (Dudhia et al., 2002):
- 308 Dudhia, A., Jay, V. L., & Rodgers, C. D. (2002). Microwindow selection

- for high-spectral-resolution sounders. Applied Optics, 41(18), 3665-3673.
- 310 Yes, you are right. The corresponding references have been cited.
- 311 It has been modified to "Therefore, it is necessary to design an effective
- calculation scheme, and such a scheme, i.e., a channel selection method,
- using iteration is proposed, called the "sequential absorption method"
- 314 (Dudhia et al., 2002; Du et al., 2008)." (L 216-L 219)
- ³¹⁵ "Dudhia, A., Jay, V. L., and Rodgers, C. D.: Microwindow selection for
- high-spectral-resolution sounders, Appl. Opt. 41, 3665-3673,
- 317 https://doi.org/10.1364/AO.41.003665, 2002." (L 916-L 918)
- 318 Thanks.
- (15) L 231: The expression "\partial^2 $Omega / partial nu^2$ " has not
- been explained and the derivative looks wrong, maybe skip it here?
- 321 Yes, you are right.
- The expression " $s_{\varepsilon} \frac{\partial^2 \Omega}{\partial v^2}$ " has not been explained, which is an
- unimportant item and can be skipped.
- The sentence "A diagonal element, $s_{\varepsilon} \frac{\partial^2 \Omega}{\partial v^2}$, in the S_{ε} matrix is the error variance in the channel." has been deleted. (L 227)
- 326 Thanks.
- (16) L 262-263: The sentence "According to S_a, S_\epsilon...can be
- calculated" is unclear and should be rephrased.
- 329 Sorry about this.
- 330 "According to S_a , S_{ε} , K and Eq. (6), R, which is r corresponding to all

the selected channels, can be calculated." has been	modified to
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- "According to S_a , S_{ε} , K and Eq. (6), R can be calculated." (L 258) Thanks.
- (17) L 271-275: I would suggest to remove the phrase "... but it still
- satisfies the optimum value in a certain sense". The method cannot find
- the global optimum as it applies only a sequential search strategy. It is
- 337 good to point out this limitation, no need to oversell the results.
- 338 Yes, you are right.
- 339 The sentence "Of course, the combination selected by this method is not
- completely equivalent to the channel combination corresponding to the
- optimum value of C_N^n p, but it still satisfies the optimum value in a
- certain sense." has been removed. (L 265)
- 343 Thanks.
- (18) L 283-285: I did not understand how you are actually making use of
- the different channel selections for the different heights in the retrieval
- process. Does this mean the different channel sets are used to evaluate
- only certain heights in the retrieved profile?
- 348 Yes, you are right.
- This has been explained "In this way, different channel sets can be used
- to evaluate corresponding height in the retrieved profiles." (L 276-L 278)
- 351 Thanks.
- (19) L 330 and 344: I got confused about the notation, what is "\hat T'"

- referring to?
- 354 Sorry for my carelessness.
- 355 "where \overline{T} and $\overline{T_b}$ are the corresponding average values of the elements,
- respectively. T' and T_{b}' represent the corresponding anomalies of the
- elements, respectively." has been modified to "where \hat{T} stands for the
- retrieval atmospheric temperature. \overline{T} and $\overline{T_b}$ are the corresponding
- average values of the elements, respectively. \widehat{T}' and T_{b}' represent the
- corresponding anomalies of the elements, respectively." (L 326-L 329)
- 361 Thanks.
- (20) L 379-380: "after retrieval of observations has been complete several
 times" is unclear to me.
- 364 Sorry for the confusion.
- ³⁶⁵ "It should be noted that the least squares solution obtained here aims to
- 366 minimize the sum of the error variance for each element in the
- atmospheric state vector after retrieval of observations has been
- 368 completed several times." has been modified to "It should be noted that
- the least squares solution obtained here aims to minimize the sum of the
- 370 error variance for each element in the atmospheric state vector after
- retrieval for several times." (L 372-L 374)
- 372 Thanks.
- 373 (21) L 380-383: How do you deal with non-linearity inherent
- atmospheric radiactive transfer? Isn't that a major problem for multiple

- regression?
- Yes, you are right. We have explained this as follows.
- ³⁷⁷ "Because the statistical inversion method does not directly solve the
- radiation transfer equation, it has the advantages of fast calculation speed.
- In addition, the solution is stable, which makes it one of the highest
- 380 precision methods (Chedin et al., 1985)." (L 288-L 290)
- 381 This study is aimed to examine the effectiveness of a channel selection
- method for hyperspectral atmospheric infrared sounders based on
- layering. The most particular aspect of this work is that it takes the height
- dependencies of the kernel functions into account. Thus, considering the
- calculation speed, the statistical inversion method is used for our channel
- selection experiment.
- 387 Thanks.
- (22) L 387: Add a reference for the AIRS instrument, e.g. (Aumann et al.,
 2003).
- 390 Sorry for my carelessness. The references have been added.
- ³⁹¹ "...(Aumann et al., 2003; Hoffmann and Alexander, 2009)" (L 383-L
- 392 384)
- 393 Thanks.
- (23) L 395: The AIRS footprint size 13.5 km at nadir, please check.
- Yes, you are right. The AIRS footprint size 13.5 km at nadir.
- ³⁹⁶ "The spatial footprint of the infrared channels is 1.1° in diameter, which

- 397 corresponds to about 15×15 km at the nadir." has been modified to "The
- footprint size 13.5 km at nadir (Susskind et al., 2003)." (L 389)
- ³⁹⁹ "Susskind, J., Barnet, C. D. and Blaisdell, J. M.: Retrieval of atmospheric
- and surface parameters from AIRS/AMSU/HSB data in the presence of
- 401 clouds, IEEE Trans. Geosci. Remote Sensing, 41, 390-409,
- 402 https://doi.org/10.1109/TGRS.2002.808236, 2003." (L 1005- L 1008)
 403 Thanks.
- (24) L 396-398: 4.3 and 15 micron are used simultaneously for both,
- temperature and carbon dioxide retrievals, I think.
- 406 Yes, you are right.
- 407 "The spectral range includes 4.2 μm for important temperature
- 408 observation, 15 μ m for CO2, 6.3 μ m for water vapor, and 9.6 μ m for
- 409 ozone absorption bands." has been modified to "The spectral range
- 410 includes 4.3 μ m and 15.5 μ m for important temperature observation and
- 411 CO2, 6.3 μ m for water vapor, and 9.6 μ m for ozone absorption bands
- 412 (Menzel et al., 2018)." (L 389-L 392)
- 413 Thanks.
- 414 (25) L398: When you refer to "absolute accuracy", does this include
- noise as well? Noise should not be included as it counts as "precision".
- 416 Yes, you are right.
- 417 "The absolute accuracy of the measured radiation is better than 0.2 K ."
- 418 has been modified to "The root mean square error (RMSE) of the

- 419 measured radiation is better than 0.2 K (Susskind et al., 2003)". (L 392-L
- 420 394)
- 421 Thanks.
- 422 (26) L 399-401: "the four imaging channels of visible/near infrared are
- always filled" is unclear, please explain or remove.
- 424 Yes, you are right. The sentence has been removed. (L 394-L 395)
- 425 Thanks.
- 426 (27) L406-411: This paragraph can be deleted. Everything was already
- said in the introduction.
- 428 Yes, you are right. This paragraph has been deleted. (L 400)
- 429 Thanks.
- 430 (28) L412: Does the "root-mean square error" include both, accuracy and
- 431 prediction, in this study?
- 432 Root mean square error (RMSE) in this study can be described as
- 433 accuracy in this study.
- 434 Thanks.
- (29) L 416-417: Delete the sentence "Moreover, not all channels possess
- the same measurement error." This is obvious from the figure.
- 437 Yes, you are right. The sentence "Moreover, not all channels possess the
- same measurement error." has been deleted. (L 404)
- 439 Thanks.
- (30) L 415: Please provide a reference or a web link for the RMS errors

441 shown here.

442 Yes, you are right.

"There are a few with extremely large measurement errors, which reduce
the accuracy of prediction to some extent." has been modified to "There
are a few channels with extremely large measurement errors, which
reduce the accuracy of prediction to some extent. Among them, some
extremely large measurement errors reduce the accuracy of prediction to

- some extent. (Susskind et al., 2003)" (L 402-L 406)
- 449 Thanks.
- 450 (31) L 429: Introduce acronym and provide reference for RTTOV.
- 451 Yes, you are right.

"For the radiative transfer model and its weight function matrix, K, the 452 RTTOV v12 fast radiative transfer model is used. RTTOV is an evolution 453 of RTTOV v11, adding and upgrading many features." has been modified 454 to "For the radiative transfer model and its weighting function matrix, K, 455 the RTTOV (Radiative Transfer for TOVS) v12 fast radiative transfer 456 model is used. Although initially developed for the TOVS (TIROS 457 Operational Vertical Sounder) radiometers, RTTOV can now simulate 458 around 90 different satellite sensors measuring in the MW (microwave), 459 IR (infrared) and VIS (visible) regions of the spectrum (Saunders et al., 460 2018)." (L 417-L 423) 461

462 Thanks.

- (32) L 429-430: Delete sentence saying "RTTOV is an evolution of..." as
- this does not provide really useful information.
- 465 Yes, you are right. The sentence has been deleted. (L 423)
- 466 Thanks.
- 467 (33) L 431: What is ATOVS?
- 468 Sorry for my carelessness.
- 469 "ATOVS (Advanced TOVS)" has been added. (L 424)
- 470 Thanks.
- 471 (34) L 440-443: Table 1 is not needed at all in this manuscript, I think.
- 472 What is the reader supposed to do with it? Just provide the web link for
- 473 reference.
- 474 Yes, we agree with you.
- Table 1 and table 2 is not needed.
- The two tables have been shifted to the Appendix A. (L 846-L 854)
- 477 Thanks.
- (35) L 451-452: The phrase "The weight function matrix K ..." can be
- 479 deleted, as this is clear.
- 480 Yes, you are right. The sentence has been deleted. (L 437)
- 481 Thanks.
- (36) L 465: What is H(X0)? Is it needed for anything here?
- 483 Sorry for the confusion.
- 484 It has been explained "The RTTOV_K (the K mode), is used to calculate

the matrix H(X0) (Eq. (1)) for a given atmospheric profile characteristic."

486 (L 448-L 450)

487 Thanks.

(37) L 473-475: Which "products" are you referring to? Is there a
reference for the NWPSAF requirements?

- 490 Sorry for this. This has been modified and a reference for the NWPSAF491 has been added.
- 492 "NCS is short for NWP channel selection in this paper. The products were
- released by the NWPSAF 1DVar (one-dimensional variational analysis)
- scheme, in accordance with the requirements of the NWPSAF." has been
- 495 modified to "NCS is short for NWP channel selection in this paper. NCS
- 496 were released by the NWPSAF 1DVar (one-dimensional variational
- analysis) scheme, in accordance with the requirements of the NWPSAF
- 498 (Saunders et al., 2018)." (L 456-L 460)
- 499 Thanks.

500 (38) L 492-495: At this point the reader does not know anything about the

- ⁵⁰¹ IFS-137 data set. It is introduced much later in the manuscript.
- 502 Yes, you are right. Because the main idea of this part is to introduce the
- channel selection experiment, we will introduce IFS-137 data set in Sect.
- 504 4.
- 505 It has been explained "The error covariance matrix of the background, S_a ,
- is calculated using 5000 samples of the IFS-137 data provided by the

- 507 ECMWF dataset (The detailed information will be introduced in Sect. 4).
- 508 The last access date is April 26th, 2019 (download address:
- 509 https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/, 2019)."
- 510 (L 476-L 482)
- 511 Thanks.
- 512 (39) L 500: What is causing the off-diagonal bands in the temperature
- 513 covariance matrix? For instance, why is the temperature at 100 hPa
- closely correlated with temperature at about 60-70 hPa?
- 515 Yes, you are right. We have noticed the off-diagonal bands in the
- temperature covariance matrix, especially from 50hPa to 200hPa. There
- should be some dynamic processes here. But this study is aimed to
- examine the effectiveness of a channel selection method. As the
- temperature covariance matrix is the same, so we do not introduce it
- 520 further here.
- 521 Thanks.
- 522 (40) L 516: The color bar unit is "K²", but shouldn't this be "K/K", as it
- refers to a change of brightness temperature with respect to atmospheric
- temperature, i.e., dBT/dT? (Same for Fig. 7)
- Sorry for this. This has been modified (Fig. 3: L 500; Fig.6: L 575-L 577)Thanks.
- (41) L 532-544: Wavenumbers are missing the unit "cm⁻¹". Replace "11
 micron" by "10 micron".

- 529 Yes, you are right.
- 530 The wavenumber unit " cm⁻¹" has been added. (L 518; L 520; L 524; L
- 531 527; L 534)
- 532 "11 μ m" has been replaced by "10 μ m "(L 517)
- 533 Thanks.
- (42) L 546: The term "high temperature zone" is used here and elsewhere
- in the manuscript, but what does it refer to? Please explain.
- Sorry for this. We have added our explanations "Because 4.2 μ m and 4.3
- μ m bands are sensitive to high temperature, the higher temperature is, the
- better observation can be obtained". (L 531-L 533)
- 539 "...in the high temperature zone." has been modified to "...to the higher
- 540 temperature." (L 546-L 547)
- 541 "...the channel combination of ICS is superior to that of PCS and NCS
- 542 for atmospheric temperature observation in the high temperature zone"
- has been modified to "...the channel combination of ICS is better than
- that of PCS and NCS for atmospheric temperature observation to the
- 545 higher temperature" (L 775-L 778; L 834-L 836)
- 546 Thanks.
- (43) L 575-576: "Moreover, the temperature profile of each layer can be
- retrieved." How can you retrieve a profile for a layer? Please clarify.
- 549 Sorry for this.
- 550 After 324 channels are selected for each layer, the temperature profile of

each layer can be retrieved based on statistical inversion (see at Sect. 4).

⁵⁵² "In this paper, the atmosphere is divided into 137 layers, and based on the

information content and iteration, 324 channels are selected for each layer.

554 Moreover, the temperature profile of each layer can be retrieved." has

been modified to "In this paper, the atmosphere is divided into 137 layers,

and based on the information content and iteration, 324 channels are

selected for each layer. Then, the temperature profile of each layer can be

- retrieved based on statistical inversion (see at Sect. 4)" (L 560-L 564)
- 559 Thanks.
- (44) L 569 and 583: Figs. 5 and 6 could be combined in a single figure toallow for a comparison.

562 Yes, we agree with you.

Figs.5 and Figs.6 has been combined in a single figure. (Figure 5: L556)

The following figure numbers (Fig. 7-13) have been modified (Fig. 6-12).Thanks.

- 567 (45) L 596-605: You are describing the PCS distribution as "scattered",
- but I would rather apply this word to the ICS distribution. The ICS
- distributions seems to jump or scatter
- 570 Thank you for your notice. Sorry for my carelessness.
- In Fig.6 "(a) PCS. (b) ICS." should be "(a) ICS. (b) PCS." Which has
- 572 been modified. (L 576-L 577)

- 573 Thanks.
- 574 (46) L 604-605: Sorry, but I don't know what you mean by "scenario in575 the real atmosphere" in this context?
- 576 Sorry for the confusion.
- ⁵⁷⁷ "(2) regardless of the number of iterations, the maximum value of the
- weighting function is stable near 300–400 hPa and 600–700 hPa, without
- scattering, which resembles more closely the scenario in real atmosphere."
- has been modified to "(2) regardless of the number of iterations, the
- maximum value of the weighting function is stable near 300–400 hPa and
- 582 600–700 hPa, without scattering, which is closer to the situation in real
- sa atmosphere." (L 585-L 588)
- 584 Thanks.
- 585 (47) L 615-619: Please provide a reference for the IFS-137 data set here.
- 586 Sorry for my carelessness.
- 587 The corresponding references have been added.
- ⁵⁸⁸ "...(Eresmaa and McNally, 2014; Brath et al., 2018)" (L 603)
- 589 "Brath, M., Fox, S., Eriksson, P., Harlow, R. C., Burgdorf, M., and
- 590 Buehler, S. A.: Retrieval of an ice water path over the ocean from ISMAR
- and MARSS millimeter and submillimeter brightness temperatures,
- 592 Atmos. Meas. Tech., 11, 611–632,
- 593 https://doi.org/10.5194/amt-11-611-2018, 2018." (L 891-L 895)
- ⁵⁹⁴ "Eresmaa, R. and McNally, A. P.: Diverse profile datasets from the

595 ECMWF 137-level short-range forecasts, Tech. rep., ECMWF, 2014."

⁵⁹⁶ "(L 919-L 921)

597 Thanks.

(48) L 620-623: Please replace the number of model grid points by

something more meaningful such as horizontal resolution of the data. The

list of the 137 individual pressure levels and Table 2 are not really needed,

601 I think.

602 Yes, we agree with you.

⁶⁰³ "There are two operational analyses each day (at 00z and 12z), and the

modeling grid contains 2,140,702 grid points. The pressure levels adopted

for IFS-137 are shown in Table 2." has been modified to "There are two

operational analyses each day (at 00z and 12z), and approximately 13 000

atmospheric profiles over the ocean. The pressure levels adopted for

IFS-137 are shown in Table A2 (see Table A2 in Appendix A)." (L 604- L

609 608)

610 Thanks.

(49) L 647-664: As you are not going to make any use of the IFS-91 data

set in this study, there is no need to introduce it and discuss the

differences with respect to the IFS-137 data set. Section 4.1 could be

shortened significantly, I think.

615 Yes, we agree with you.

⁶¹⁶ "The temporal distribution of the selected profiles is illustrated in Fig. 9.

617	Again, the lack of randomized selection results in large variations from
618	one month to the next in the case of the IFS-91 database (left panel). The
619	different distributions come mainly from variations in the ozone subset
620	(green parts of each column). Dominance of randomly-selected profiles in
621	the IFS-137 database leaves little room for monthly variation in the data
622	count (right panel). Moreover, the IFS-91 database also supports the
623	mode with input parameters, such as detection angle, 2 m temperature,
624	cloud information. Therefore, it is feasible to use the selected samples in
625	a statistical multiple regression experiment." has been modified to "The
626	temporal distribution of the selected profiles is illustrated in Fig. 8. The
627	coverage of the IFS-137 data set is more homogeneous than the IFS-91
628	data set. Moreover, the IFS-137 database supports the mode with input
629	parameters, such as detection angle, 2 m temperature, and cloud
630	information. Therefore, it is feasible to use the selected samples in a
631	statistical multiple regression experiment." (L 628-L 633)
632	Thanks.
633	(50) L 641: The axes labels in Fig. 8 are too small

- 634 Sorry for this.
- 635 It has been modified. (Fig. 7: L 622-L 626)
- 636 Thanks.
- (51) L 658: Fig. 9 is not really needed, as it was already pointed out
- in the text that the coverage of the IFS-137 data set is rather

- 639 homogeneous.
- 640 Because the introduction of IFS-137 data set has been shortened, in order
- to introduce IFS-137 data set briefly and visually, Fig.8 (previous Fig. 9)
- 642 can be remained.
- 643 Thanks.
- (52) L 674: Why does the RTTOV model need 10 m wind speeds forthe radiative transfer calculations?
- 646 According to RTTOV users' guide, the new physically-based model
- 647 (RTTOV) depends on wind speed and skin temperature as well as zenith
- angle. Some parameters are put into the RTTOV mode. 10 m wind speeds
- are used to calculate emissivity (details can be seen at RTTOV users'
- 650 guide).
- 651 Thanks.
- (53) L 744-746: Did you also look at the southern hemisphere polar
- regions? The sentence "These regions' profiles can represent the
- global typical atmospheric temperature profiles" makes no sense to
- ⁶⁵⁵ me because the regional means are different from the global mean.
- 656 Delete this.
- 657 Sorry for my carelessness.
- We haven't looked at the southern hemisphere polar regions. The sentence "The profiles of these regions can represent the global typical atmospheric temperature profiles." has been deleted. (L 720)
 - 30

(54) L 746-748: I got very concerned about the mean temperature

profiles shown in Fig. 11. If these are regional means of hundreds to

- thousands of profiles, how can they show wave oscillations and look
- that noisy? Shouldn't the mean profiles be rather smooth? Is this due
- to the original selection of the IFS-137 profiles focusing on cases

with strong temperature gradients?

668 Sorry for my careless.

669 The figure actually is the temperature standard deviation of ICS in four

typical regions (Figure 12). I put the wrong figure here. Wave oscillations
in this figure is due to the number of profiles in each region are not
hundreds to thousands of profiles. For example, in the arctic (80N -90 N),

- there are 45 samples. So in the figure, wave oscillation is obvious inarctic.
- 675 The average temperature profiles in these four regions have been676 modified (Fig.10). (L 727-L 731)

677 Thanks.

- (55) L 774-775 and 813: It is okay to say that ICS works "better"
- than NCS or PCS, but saying it is "greatly superior" or "impressive"
- is overselling the results, I think. Suggest to rephrase this and use

681 more moderate wording.

682 Yes, we agree with you.

"Generally, the retrieval temperature by ICS is greatly superior to that of
NCS and PCS." has been modified to "Generally, the retrieval
temperature by ICS is better than that of NCS and PCS." (L 750-L 751)

686 "According to Fig. 12, ICS takes channel sensitivity as a function of 687 height into consideration, so its retrieval result is impressive." has been 688 modified to "According to Fig. 11, ICS takes channel sensitivity as a 689 function of height into consideration, so its retrieval result is better." (L

690 786-L 788)

691 Other similar problems have been modified.

"...the channel combination of PCS is superior to that of NCS for
atmospheric temperature observation in the high temperature zone." has
been modified to "...the channel combination of PCS is better than that of
NCS for atmospheric temperature observation to the higher temperature."

696 (L 546-L 547)

697 "...the ICS method is superior to that of PCS." has been modified to "the
698 ICS method is better than that of PCS." (L 567-L 568)

699 "...the channel combination of ICS is superior to that of PCS and NCS

for atmospheric temperature observation in the high temperature zone"

has been modified to "...the channel combination of ICS is better than

that of PCS and NCS for atmospheric temperature observation to the

703 higher temperature" (L 775-L 778; L 834-L 836)

"...ICS is superior to PCS." has been modified to "...ICS is better than

- 705 PCS." (L 821-L 822)
- ⁷⁰⁶ "Moreover, ICS takes channel sensitivity as a function of height into
- consideration, so its retrieval result is impressive." has been modified to
- ⁷⁰⁸ "Moreover, ICS takes channel sensitivity as a function of height into
- consideration, so its retrieval result is improved." (L 703-L 704)
- 710 Thanks.
- (56) L 819-834: Tables 4 to 7 are largely redundant and can be
- removed from the paper, I think.
- 713 Yes, we agree with you.
- Tables 4 to 7 have been removed from the paper. And the correspondingindication has been modified. (L 795)
- In abstract "Especially, from 100 hPa to 0.01 hPa, the accuracy of ICS 716 can be improved by more than 11 %; (3) Statistical inversion comparison 717 experiments in four typical regions indicate that ICS in this paper is 718 significantly better than NCS (NWP Channel Selection) and PCS 719 (Primary Channel Selection) in different regions and shows latitudinal 720 variations. Especially, from 100 hPa to 0.01 hPa, the accuracy of ICS can 721 be improved by 7% to 13%, which means the ICS method selected in this 722 paper is feasible and shows great promise for applications." has been 723 modified to "(3) Statistical inversion comparison experiments in four 724 typical regions indicate that ICS in this paper is significantly better than 725 NCS (NWP Channel Selection) and PCS (Primary Channel Selection) in 726

- 727 different regions and shows latitudinal variations, which shows potential
- for future applications." (L 32-L 36)
- 729 Thanks.
- (57) L 849 and 882: Suggest to simply delete the headings for Sects.
- 6.1 and 6.2, as they appear in the wrong order. The conclusions
- r32 should follow the discussion.
- 733 Yes, you are right.
- The headings and the correct order have been modified. (L 796-L 840)
- 735 Thanks.
- 736 Technical Corrections
- 737 (58) L30: remove "evidently"
- 738 Yes, you are right.
- "row "evidently" has been deleted. (L 30)
- 740 Thanks.
- (59) L 38-39: suggest to rephrase "... is feasible and shows great
- promise for application" as "... shows potential for future
- 743 applications"
- Yes, we agree with you.
- ⁷⁴⁵ "(3) Statistical inversion comparison experiments in four typical regions
- race indicate that ICS in this paper is significantly better than NCS (NWP
- 747 Channel Selection) and PCS (Primary Channel Selection) in different
- regions and shows latitudinal variations. Especially, from 100 hPa to 0.01

hPa, the accuracy of ICS can be improved by 7% to 13%, which means
the ICS method selected in this paper is feasible and shows great promise
for applications." has been modified to "(3) Statistical inversion
comparison experiments in four typical regions indicate that ICS in this
paper is significantly better than NCS (NWP Channel Selection) and PCS
(Primary Channel Selection) in different regions and shows latitudinal
variations, which shows potential for future applications." (L 32-L 36)

"...Especially, from 100 hPa to 0.01 hPa, the accuracy of ICS can be
improved by 7% to 13%, which means the ICS method selected in this
paper is feasible and shows great promise for applications." has been
modified to "..., which shows potential for future applications." (L 839-L

760 840)

761 Thanks.

762 (60) L44: _the_ Earth's

Yes, you are right

"...observe Earth's atmosphere..." has been modified to "...observe the

- 765 Earth's atmosphere..." (L41)
- 766 Thanks.

(61) L 67-68: suggest to rephrase "AIRS has 2378 spectral channels
with subpoint at 13 km and a detection height from the ground of up
to 65 km" as "AIRS has 2378 spectral channels providing sensitivity

from the ground to up to about 65 km of altitude"

- Yes, you are right. This has been modified. (L 66-L 68)
- 772 Thanks.
- (62) L 73: change "attaches" to "devotes" (or similar)
- Yes, you are right. This has been modified. (L 72)

(63) L 76: change "detection" to "observations" (or similar)

Yes, you are right. This has been modified. (L 75)

- The similar problems have been modified.
- 779 "...satellite detection technology has developed rapidly" has been
- modified to "...satellite observation technology has developed rapidly"
- 781 (L 40-L 41)

"From the perspective of vertical atmospheric detection, satellite 782 instruments are developing rapidly. In their infancy, the traditional 783 infrared detection instruments for detecting atmospheric temperature and 784 moisture profiles ..." has been modified to "From the perspective of 785 vertical atmospheric observation, satellite instruments are developing 786 rapidly. In their infancy, the traditional infrared measurement instruments 787 for detecting atmospheric temperature and moisture profiles ..." (L 47-L 788 50) 789

"… in terms of detection accuracy … filter-based spectroscopic
detection instrument, therefore, …To meet this challenge, …for the
creation of high-spectral resolution atmospheric detection instruments …"

has been modified to "... in terms of observation accuracy ... filter-based
spectroscopic measurement instrument, therefore, ...To meet this
challenge,... for the creation of high-spectral resolution atmospheric
measurement instruments..." (L 55-L 61)

- ⁷⁹⁷ "... such advanced detection technologies. ... techniques of hyperspectral
- resolution atmospheric detection." has been modified to "... such
- 799 advanced sounding technologies. ... techniques of hyperspectral
- resolution atmospheric observations." (L 72-L 75)
- ⁸⁰¹ "detection data" has been modified to "observation data" (L 80)
- 802 "...the general satellite detection instrument" has been modified to "...the
- typical satellite instruments" (L 85)
- "With the development of detection technology..." has been modified to
- *With the development of measurement technology..." (L 88-L 89)
- ⁸⁰⁶ "temperature detection" has been modified to "temperature observation"
- 807 (L 391; L 530; L 547; L 701-L 702; L 777-L 778; L 835)
- 808 Thanks.
- (64) L 80: change "atmospheric detectors" to "instruments"
- 810 Yes, you are right. This has been modified. (L 79)
- 811 Thanks.
- 812 (65) L 83: delete "intense"
- Yes, you are right. This has been deleted. (L 82)
- 814 Thanks.

- (66) L 86: change "general satellite detection instrument" to "typical
- 816 satellite instruments"
- Yes, you are right. This has been modified. (L 85)
- 818 Thanks.
- (67) L 89: change "the center frequency, bandwidth" to "center
- s20 frequency and bandwidth"
- Yes, you are right. This has been modified. (L 88)
- 822 Thanks.
- 823 (68) L 96: there is _often_ a close correlation between _the
- 824 channels_
- Yes, you are right. This has been modified. (L 94-L 95)
- 826 Thanks.
- 827 (69) L 106: demands of _simulating_ all the channels
- Yes, you are right. This has been modified. (L 105)
- 829 Thanks.
- 830 (70) L 107: to _properly_ select
- Yes, you are right. This has been modified. (L 106-L 107)
- 832 Thanks.
- 833 (71) L 151: ignoring _some_ factors
- Yes, you are right. This has been modified. (L 151)
- 835 Thanks.
- (72) L 183: change "\hat S" to "S_\epsilon"

- 837 Sorry for my careless.
- 838 " \hat{S} " has been modified to " S_{ϵ} ". (L 185)
- 839 Thanks.
- 840 (73) L 186: delete "by hyperspectral data"
- 841 Yes, you are right. This has been deleted. (L 188)
- 842 Thanks.
- (74) L 187-188: delete "which comes from the selected channel in
- ⁸⁴⁴ hyperspectral data with respect to ..." or rephrase to clarify
- 845 Sorry for this. It has been deleted. (L 188)
- 846 Thanks.
- (75) L 209-210: rephrase to "... combination making the information
 content..."
- ⁸⁴⁹ "This combination make the information content, H, or the ARI defined
- in this paper as large as possible, in order to maintain the highest possible
- accuracy in the retrieval results." has been modified to "This combination
- makes the information content, H, or the ARI defined in this paper as
- large as possible, in order to maintain the highest possible accuracy in the
- retrieval results." (L 205-L 208)

855 Thanks.

- 856 (76) L 235: change "single" to "scalar"
- Yes, you are right. This has been modified. (L 230)
- 858 Thanks.

- 859 (77) L 242: rephrase to "Since S_a and S_nepsilon are ..."
- 860 Yes, you are right.
- ⁸⁶¹ "Since S_a is a positive definite symmetric matrix..." has been modified
- to "Since S_a and S_{ε} are positive definite symmetric matrixes..." (L 237)
- 863 Thanks.
- (78) L 248: change "pre-observation error" to "a priori uncertainty"
- Yes, you are right. This has been modified. (L 243)
- 866 Thanks.
- 867 (79) L 275: delete "its"
- 868 Yes, you are right. This has been deleted. (L 266)
- 869 Thanks.
- 870 (80) L 288: method_s for_ the ... profile_s_
- 871 Yes, you are right.
- ⁸⁷² "The inversion method of the atmospheric temperature profile..." has
- 873 been modified to "The inversion methods for the atmospheric
- temperature profiles..." (L 281)
- 875 Thanks.
- 876 (81) L 297: _numerically_ stable
- Yes, you are right. This has been added. (L 290)
- 878 Thanks.
- (82) L 302: change "bright temperature" to "brightness temperature"
- (here and throughout the manuscript)

- 881 Sorry for my careless. Those have been modified. (L 296; L 321; L 503; L
- 882 512)
- 883 Thanks.
- 884 (83) L 303: expanded _as_
- 885 Yes, you are right. This has been modified. (L 297)
- 886 Thanks.
- (84) L 367: Taking a derivative of Eq. (21) with respect to G,...
- 888 Yes, you are right.
- ⁸⁸⁹ "Equation (21) takes a derivative with respect to G..." has been modified
- to "Taking a derivative of Eq. (21) with respect to G..." (L 362)
- 891 Thanks.
- (85) L 387: delete "instrument suite" and change to "is _primarily_
- 893 designed"
- 894 Yes, you are right.
- 895 "The Atmospheric Infrared Sounder (AIRS) instrument suite is designed
- to..." has been modified to "The Atmospheric Infrared Sounder (AIRS) is
- primarily designed to..." (L 381)
- 898 Thanks.
- 899 (86) L 415: few _channels_
- 900 Yes, you are right. This has been modified. (L 402-L 403)
- 901 Thanks.
- 902 (87) L 428: rephrase to "For the calculation of radiative transfer and

- ⁹⁰³ the weighting function matrix, K, the RTTOV..."
- 904 Yes, you are right. This has been modified. (L 417-L418)
- 905 Thanks.
- 906 (88) L 434: rephrase to "and _trace_ gas concentration_s_"
- 907 Yes, you are right. This has been modified. (L 427)
- 908 Thanks.
- 909 (89) L 439 and 440: delete "v12"
- 910 Yes, we agree with you. Those have been deleted. (L 431-L 432 and L
- 911 433)
- 912 Thanks.
- 913 (90) L 459 and 461: change "characteristic" to "variable"
- Yes, you are right. This has been modified. (L 443 and L 445)
- 915 Thanks.
- 916 (91) L 460: delete "radiation"
- 917 Yes, you are right. This has been deleted. (L 444)
- 918 Thanks.
- 919 (92) L 481: selection ____ in
- 920 Yes, you are right. This has been modified. (L 466)
- 921 Thanks.
- 922 (93) L 491: rephrase to "...of the AIRS channels"
- 923 Yes, you are right. This has been modified. (L 476)
- 924 Thanks.

- 925 (94) L 510: change "But due to" to "However,"
- 926 Yes, we agree with you.
- 927 "Therefore, when we select channels, the results differ because of the
- 928 different observation angles. But due to the selection principle and
- method are exactly the same and our key is the selection method; we do
- not discuss, therefore, the variation in observation angle when making a
- selection." has been modified to "The goal of this section is focusing on
- the selection methods of selecting channels; therefore the biases produced
- from different observation angles can be ignored." (L 495-L 497)
- 934 Thanks.
- 935 (95) L 518: delete "of ICS"
- 936 Yes, you are right. This has been deleted. (L 502)
- 937 Thanks.
- 938 (96) L 563: change to "retrieval of temperature"
- 939 Yes, you are right. This has been modified. (L 550)
- 940 Thanks.
- 941 (97) L 611: was used _for the statistical inversion experiments_.
- 942 Yes, you are right. This has been added. (L 594-L 595)
- 943 Thanks.
- 944 (98) L 675: mode_l_. Then, the _simulated AIRS spectra are_
- 945 obtained
- 946 Yes, you are right. This has been modified. (L 651)

- 947 Thanks.
- 948 (99) L 696: delete "obviously"
- 949 Yes, you are right. This has been deleted. (L 671)
- 950 Thanks.
- 951 (100) L 704 and 719: _at_ different height_s_
- Yes, you are right. Those have been modified. (L 679 and L 694)
- 953 Thanks.
- 954 (101) L 729: change "impressive" to "improved"
- 955 Yes, you are right.
- This has been modified to "...its retrieval result is improved". (L 704)
- 957 Thanks.
- 958 (102) L 740: change "weather conditions" to "atmospheric
- conditions" (also elsewhere in the manuscript)
- 960 Yes, you are right. Those have been modified. (L 715 and L 722)
- 961 Thanks.
- 962 (103) L 743: change "and divides it" to "have been divided"
- 963 Yes, we agree with you.
- 964 "...the atmospheric profile is from the IFS-137 database introduced in
- 965 Sect. 4, and divides it into four regions..." has been modified to "...this
- 966 paper has divided the atmospheric profile from the IFS-137 database
- 967 introduced in Sect. 4 into four regions..." (L 716-L 720)
- 968 Thanks.

- 969 (104) L 777: replace "optimized to" by "improved by"
- 970 Yes, you are right. This has been modified. (L 753)
- 971 Thanks.
- 972 (105) L 785: (_d_) Arctic
- 973 Sorry for my carelessness. This has been modified. (L 761)
- 974 Thanks.
- 975 (106) L 892: _is_ proposed
- 976 Yes, you are right. This has been modified. (L 806)
- 977
- 978 Thanks again for your careful review.
- 979
- 980

981	(b) The list of all relevant changes made in the manuscript
982	ChannelA channel selection method for
983	hyperspectral atmospheric infrared sounder-
984	using AIRS datasounders based on layering
985	Shujie Chang ^{1, 2,3} , Zheng Sheng ^{1,2} , Huadong Du ^{1,2} , Wei Ge ^{1,2} and
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996	
997	Abstract. Because a satellite channel's ability to resolve
998	hyperspectral data varies with height, an improved channel selection
999	method is proposed based on information content. An effective
1000	channel selection scheme for a hyperspectral atmospheric infrared
1001	sounder using AIRS data based on layering is proposed. The results
1002	are as follows: (1) Using the improved method, the atmospheric

1003	retrievable index is more stable, the value reaching 0.54. The							
1004	distributioncoverage of the temperature weight functionweighting							
1005	functions is more continuous, more closely approximating that							
1006	ofevenly distributed over height with this method and closer to the							
1007	actual atmosphere; (2) Statistical inversion comparison experiments							
1008	show that the accuracy of the retrieval temperature, using the							
1009	improved channel selection method in this paper, is consistent with							
1010	that of 1Dvar channel selection. In the near space layerstratosphere							
1011	and mesosphere especially, from 10 hPa to 0.02 hPa, the accuracy of							
1012	the retrieval temperature of our improved channel selection method							
1013	is evidently-improved by about 1 K. In general, the accuracy of the							
1014	retrieval temperature of ICS (Improved Channel Selection) is							
1015	improved. Especially, from 100 hPa to 0.01 hPa, the accuracy of ICS							
1016	can be improved by more than 11 %; (3) Statistical inversion							
1017	comparison experiments in four typical regions indicate that ICS in							
1018	this paper is significantly better than NCS (NWP Channel Selection)							
1019	and PCS (Primary Channel Selection) in different regions and shows							
1020	latitudinal variations. Especially, from 100 hPa to 0.01 hPa, the							
1021	accuracy of ICS can be improved by 7% to 13%,, which means the							
1022	ICS method selected in this paper is feasible and shows great							
1023	promisepotential for future applications.							

1025 **1 Introduction**

Since the successful launch of the first meteorological satellite, 1026 TIROS in the 1960s, satellite detection observation technology has 1027 developed rapidly. Meteorological satellites observe the Earth's 1028 atmosphere from space and are able to record data from regions 1029 which are otherwise difficult to observe. Satellite data greatly enrich 1030 the content and range of meteorological observations, and 1031 consequently, atmospheric exploration technology and 1032 meteorological observations have taken us to a new stage in our 1033 understanding of weather systems and related phenomena (Fang, 1034 2014). From the perspective of vertical atmospheric 1035 detection observation, satellite instruments are developing rapidly. In 1036 their infancy, the traditional infrared detection measurement 1037 instruments for detecting atmospheric temperature and moisture 1038 profiles, such as TOVS (Smith et al., 1991) or HIRS in ATOVS 1039 (Chahine, 1972; Li et al., 2000; Liu, 2007), usually employed filter 1040 spectrometry. Even though such instruments have played an 1041 important role in improving weather prediction, it is difficult to 1042 continue to build upon improvements in terms of 1043 detection observation accuracy and vertical resolution due to the 1044 limitation of low spectral resolution. By using this kind of 1045 filter-based spectroscopic detectionmeasurement instrument, 1046

1047	therefore, it is difficult to meet today's needs in numerical weather						
1048	prediction (Eyre et al., 1993): Prunet et al., 2010; Menzel et al.,						
1049	2018). To meet this challenge, a series of plans for the creation of						
1050	high-spectral resolution atmospheric detectionmeasurement						
1051	instruments has been executed in the United States and in Europe in						
1052	recent years: One example is the AIRS (Atmospheric						
1053	InfraredInfraRed Sounder) on the Earth Observation System,						
1054	"Aqua", launched on May 4, 2002 from the United States. AIRS has						
1055	2378 spectral channels with subpoint at 13 km and a detection						
1056	heightproviding sensitivity from the ground of to up to about 65 km						
1057	of altitude (Aumann et al., 2003; Hoffmann and Alexander, 2009;						
1058	Gong et al., 2011). The United States and Europe, in 2010 and in						
1059	2007, also installed the CRIS (Cross-track Infrared Sounder) and the						
1060	IASI (Inter-Attractive Atmospheric Sounding Interferometer) on						
1061	polar-orbiting satellites.						
1062	China also attachesdevotes great importance to the development						
1063	of such advanced detectionsounding technologies. In the early 1990s,						
1064	the National Satellite Meteorological Center began to investigate the						
1065	principles and techniques of hyperspectral resolution atmospheric						

1066 detection.<u>observations.</u> China's development of interferometric

1067 atmospheric vertical detectors eventually led to the launch of

¹⁰⁶⁸ Fengyun No. 3, on May 27, 2008, and Fengyun No. 4 on December

1069	11, 2016, both of which were equipped with infrared atmospheric							
1070	detectors.instruments. How best to use the hyperspectral resolution							
1071	detection observation data obtained from these instruments, to obtain							
1072	reliable atmospheric temperature and humidity profiles, is an active							
1073	area of intense study in atmospheric inversion theory.							
1074	Due to technical limitations, only a limited number of channels							
1075	could at first be built into the generaltypical satellite detection							
1076	instrument.instruments. In this case, channel selection generally							
1077	involved controlling the channel weightweighting function by							
1078	utilizing the spectral response characteristics of the channel (such as							
1079	the center frequency; and bandwidth). With the development of							
1080	detectionmeasurement technology, increasing numbers of							
1081	hyperspectral detectors were carried on meteorological satellites.							
1082	Due to the large number of channels and data supported by such							
1083	instruments today (such as AIRS with 2378 channels and IASI with							
1084	8461 channels), it has proven extremely cumbersome to store,							
1085	transmit, and process such data. Moreover, there is often a close							
1086	correlation between eachthe channel, causing an ill-posedness of the							
1087	inversion, potentially compromising accuracy of the retrieval							
1088	product based on hyperspectral resolution data.							
1089	However, hyperspectral detectors have many channels and							
1090	provide real-time mode prediction systems with vast quantities of							

data, which can significantly improve prediction accuracy. But, if all 1091 the channels are used to retrieve data, the retrieval time considerably 1092 increases. Even more problematic are the glut of information 1093 produced, and the unsuitability of the calculations for real-time 1094 forecasting. Concurrently, the computer processing power must be 1095 large enough to meet the demands of simulating all the channels 1096 simultaneously within the forecast time. It is important to properly 1097 select a group of channels that can provide as much information as 1098 possible from the thousands of channels' observations to improve the 1099 calculation efficiency and retrieval quality. 1100

Many researchers have studied the channel selection algorithm. 1101 Menke (1984) first chose channels using a data precision matrix 1102 method. Aires et al. (1999) made the selection using the Jacobian 1103 matrix, which has been widely used since then (Aires et al., 2002; 1104 Rabier et al., 2010). Rodgers (2000) indicated that there are two 1105 useful quantities in measuring the information provided by the 1106 observation data: Shannon information content and degrees of 1107 freedom. The concept of information capacity then became widely 1108 used in satellite channel selection. In 2007, Xu (2007) compared the 1109 Shannon information content with the relative entropy, analyzing the 1110 information loss and information redundancy. In 2008, Du et al. 1111 (2008) introduced the concept of the atmospheric retrievable index 1112

(ARI) as a criterion for channel selection, and in 2010, Wakita et al. 1113 (2010) produced a scheme for calculating the information content of 1114 the various atmospheric parameters in remote sensing using 1115 Bayesian estimation theory. Kuai et al. (2010) analyzed both the 1116 Shannon information content and degrees of freedom in channel 1117 selection when retrieving CO₂ concentrations using thermal infrared 1118 remote sensing and indicated that 40 channels could contain 75% of 1119 the information from the total of 1016-channels. Cyril et al. (2003) 1120 proposed the optimal sensitivity profile method based on the 1121 sensitivity of different atmospheric components. Lupu et al. (2012) 1122 used degrees of freedom for signals (DFS) to estimate the amount of 1123 information contained in observations in the context of observing 1124 system experiments. In addition, the singular value decomposition 1125 method has also been widely used for channel selection (Prunet et al., 1126 2010; Zhang et al., 2011; Wang et al., 2014). In 2017, Chang et al. 1127 (2017) selected a new set of Infrared Atmospheric Sounding 1128 Interferometer (IASI) channels using the channel score index (CSI). 1129 Richardson et al. (2018) selected 75 from 853 channels based on the 1130 high spectral-resolution oxygen A-band instrument on NASA's 1131 Orbiting Carbon Observatory-2 (OCO-2), using information content 1132 analysis to retrieve the cloud optical depth, cloud properties, and 1133 position. 1134

1135	Today's main methods for channel selection (use only the							
1136	weighting function to study appropriate numerical methods, such as							
1137	the data precision matrix method (Menke, 1984), singular value							
1138	decomposition method (Prunet et al., 2010; Zhang et al., 2011; Wang							
1139	et al., 2014), and the Jacobi method (Aires et al., 1999; Rabier et al.,							
1140	2010)). The use only of the weight function to study appropriate							
1141	numerical methods, the use of which allows sensitive channels to be							
1142	selected. The above-mentioned studies also take into account the							
1143	sensitivity of each channel to atmospheric parameters during channel							
1144	selection, while ignoring <u>some</u> factors that impact retrieval results.							
1145	The accuracy of retrieval results depends not only on the channel							
1146	weightweighting function but also on the channel noise, background							
1147	field, and the retrieval algorithm.							
1148	Currently, information content is often employed in channel							

selection. During retrieval, this method delivers the largest amount 1149 of information for the selected channel combination (Rodgers, 1996; 1150 Du et al., 2008; He et al., 2012; Richardson et al., 2018). Although-1151 this This method has made great breakthroughs in both theory and 1152 practice, however, it does not take and the sensitivity concept of 1153 different channels at different heights into consideration.information 1154 content itself does consider all the height dependencies of the kernel 1155 matrix K (Rodgers, 2000). However, earlier works have neglected 1156

1157	the height dependencies of K for simplicity. This paper uses the
1158	atmospheric retrievable index (ARI) as the index, which is based on
1159	information content (Du et al., 2008; Richardson et al. 2018).
1160	Channel selection is made at different heights, and an effective
1161	channel selection scheme is proposed which fully considers various
1162	factors, including the influence of different channels on the retrieval
1163	results at different heights. This ensures the best accuracy of the
1164	retrieval product when using the selected channel. In addition,
1165	statistical inversion comparison experiments are used to verify the
1166	effectiveness of the method.

1168 2 Channel selection indicator and scheme and method

2.1 Channel selection indicator

According to the concept of information content, the information
content contained in a selected channel of a hyperspectral instrument
can be described as H (Rodgers, 1996; Rabier et al., 2010). The final
expression of H is:

$$\mathbf{H} = -\frac{1}{2}\ln\left|\hat{S}S_a^{-1}\right|$$

1176
$$= -\frac{1}{2} ln |(S_a - S_a K^T (K S_a K^T + S_{\varepsilon})^{-1} K S_a) S_a^{-1}|, \qquad (1)$$

where S_a is the error covariance matrix of the background or the 1178 estimated value of atmospheric profile, \hat{S}_{ε} represents the 1179 observation error covariance matrix of each hyperspectral detector 1180 channel, $\hat{S} = (S_a - S_a K^T (K S_a K^T + S_{\varepsilon})^{-1} K S_a)$ denotes the 1181 covariance matrix after retrieval by hyperspectral data, K is the 1182 weightweighting function matrix, which comes from the selected 1183 channel in the hyperspectral data with respect to a specific-1184 atmospheric profile parameter. 1185

In order to describe the accuracy of the retrieval results visually and quantitatively, the atmospheric retrievable index (ARI), p, (Du et al., 2008) is defined as follows:

1189

1190
$$p = 1 - \exp(\frac{1}{2n} ln |\hat{S}S_a^{-1}|),$$
 (2)

1191

where S_{a} is the error covariance matrix of the background or the 1192 estimated value of the atmospheric profile, and \hat{S} represents the 1193 observation error covariance matrix of each hyperspectral detector-1194 channel. Assuming that before and after retrieval, the ratio of the 1195 root mean square error of each element in the atmospheric state 1196 vector is 1-p, then $|\hat{S}S_a^{-1}| = (1-p)^{2n}$ is derived. By inverting the 1197 equation, the ARI that is p can be obtained in Eq. (2), which 1198 indicates the relative portion of the error that is eliminated by 1199

retrieval. In fact, before and after retrieval, the ratio of the root mean
square error of each element cannot be 1-p. Therefore, p defined by
Eq. (1) is actually an overall evaluation of the retrieval result.

1204 **2.2 Channel selection scheme**

The principle of channel selection is to find the optimum channel combination after numbering the channels. This combination will makemakes the information content, H, or the ARI defined in this paper as large as possible, in order to maintain the highest possible accuracy in the retrieval results.

Let there be M layers in the vertical direction of the atmosphere 1210 and N satellite channels. Selecting n from N channels, there will be 1211 C_N^n combinations in each layer, leading C_N^n calculations to get C_N^n 1212 kinds of p results. Furthermore, under there are M layers in the 1213 maximum one p-value, vertical direction of the corresponding 1214 channel combination is used as the optimum channel combination; 1215 therefore atmosphere. Therefore, the entire atmosphere must be 1216 calculated $\mathbf{M} \cdot \mathbf{C}_{\mathbf{M}}^{n} \mathbf{C}_{\mathbf{N}}^{n}$ times. However, the calculation $\mathbf{M} \cdot \mathbf{C}_{\mathbf{N}}^{n}$ times 1217 will be particularly large, which makes this approach impractical in 1218 calculating p for all possible combinations. Therefore, it is necessary 1219 to design an effective calculation scheme, and such a scheme, i.e., a 1220 channel selection method, using iteration is proposed, called the 1221

"sequential absorption method": <u>(Dudhia et al., 2002; Du et al.,</u>
<u>2008</u>). The method's main function is to select ("absorb") channels
one by one, taking the channel with the maximum value of p.
Through n iterations, n channels can be selected as the final channel
combination. The steps are as follows:

1227 (1) The expression of information content in a single channel:

First, we use only one channel for retrieval. A row vector, k, in the weightweighting function matrix, K, is a weightweighting function corresponding to the channel. A diagonal element, $s_{\varepsilon} \frac{\partial^2 \Omega}{\partial v^2}$, in the S_{ε} matrix is the error variance in the channel. After observation in this channel, the error covariance matrix is:

1233
$$\hat{S} = S_a - S_a k^T (s_{\varepsilon} + k S_a k^T)^{-1} k S_a.$$
(3)

1234 It should be noted that $(s_{\varepsilon} + kS_ak^T)$ is a singlescalar value in Eq. 1235 (3), so Eq. (3) can be converted to:

1236
$$\hat{S} = \left(I - \frac{S_a k^T k}{\left(s_{\varepsilon} + k S_a k^T\right)}\right) S_a = \left(I - \frac{\left(k S_a\right)^T k}{\left(s_{\varepsilon} + k\left(k S_a\right)^T\right)}\right) S_a.$$
(4)

1237 Substituting Eq. (4) into Eq. (2) gives:

1238
$$p = 1 - \exp(\frac{1}{2n} ln(\left|I - \frac{(kS_a)^T k}{(s_{\varepsilon} + k(kS_a)^T)}\right|)).$$
 (5)

- 1241 Since S_a is and S_{ε} are positive definite symmetric
- 1242 matrix matrix matrix it can be decomposed into $S_a = (S_a^{1/2})^T (S_a^{1/2})$ and

1243
$$S_{\varepsilon} = (S_{\varepsilon}^{1/2})^T (S_{\varepsilon}^{1/2}).$$

1245 Define
$$R = S_{\varepsilon}^{1/2} K S_a^{1/2}$$
. (6)

1246

The matrix R can then be regarded as a weightweighting function matrix, normalized by the observed error and pre-observation error.a priori uncertainty. A row vector of R, $r = s_{\varepsilon}^{-1/2} k S_{a}^{1/2}$, represents the normalized weightweighting function matrix of a single channel.

1252

1253
$$p = 1 - \exp(\frac{1}{2n}ln\left(\left|I - \frac{rr^{T}}{1 + r^{T}r}\right|\right)).$$
 (7)

1254

For arbitrary row vectors, a and b, using the matrix property det(I + a^T b) = 1 + b a^T , the new expression for p is:

1257

$$p = 1 - \exp\left(\frac{1}{2n}ln\left(1 - \frac{r^{T}r}{1 + r^{T}r}\right)\right)$$
$$= 1 - \exp\left(\frac{1}{2n}ln\left(\frac{1}{1 + r^{T}r}\right)\right)$$

1258

1259 =
$$1 - \exp\left(-\frac{1}{2n}ln(1+r^Tr)\right).$$
 (8)

- 1261 (3) Iteration in a single layer:
- ¹²⁶² First, the iteration in a single layer requires the calculation of R.

1263	According to $S_{\overline{a}}, S_{\overline{e}}S_{a}$, K and Eq. (6), R, which is r								
1264	corresponding to all the selected channels, can be calculated. Second,								
1265	using Eq. (8), p of each candidate channel can be calculated.								
1266	Moreover, the channel corresponding to maximum p is the selected								
1267	channel for this iteration. After a channel has been selected,								
1268	according to Eq. (3) we can use \hat{S} to get S_a for the next iteration.								
1269	Finally, channels which are not selected during this iteration are used								
1270	as the candidate channels for the next iteration.								
1271	When selecting n from N channels, it is necessary to calculate								
1272	(N-n/2)n \approx Nn p values, which is much smaller than C_N^n . Of course,								
1273	the combination selected by this method is not completely-								
1274	equivalent to the channel combination corresponding to the optimum								
1275	value of C_N^{n} p, but it still satisfies the optimum value in a certain-								
1276	sense. In addition to its In addition to high computational efficiency								
1277	by using this method, another advantage is that all channels can be								
1278	recorded in the order in which they are selected. In the actual								
1279	application, if n' channels are needed, and $n' < n$, we will not								
1280	need to select the channel again, but record the selected channel								
1281	only.								
1282	(4) Iteration for different altitudes:								

Because satellite channel sensitivity varies with height, repeating
the iterative process of step (3), selects the optimum channels at

1285different heights. Assuming there are M layers in the atmosphere and1286selecting n from N channels, it is necessary to calculate M· (N –1287n/2)n \approx M· Nn p values, a much smaller number than M· C_N^n . In1288this way, different channel sets can be used to evaluate1289corresponding height in the retrieved profiles.

1290

1291 **2.3 Statistical inversion method**

The inversion method of methods for the atmospheric temperature 1292 profile profiles can be summarized in two categories: statistical 1293 inversion and physical inversion. Statistical inversion is essentially a 1294 linear regression model which uses a large number of satellite 1295 measurements and atmospheric parameters to match samples and 1296 calculate their correlation coefficient. Then, based on the correlation 1297 coefficient, the required parameters of the independent 1298 measurements obtained by the satellite are retrieved. Because the 1299 method does not directly solve the radiation transfer equation, it has 1300 the advantages of fast calculation speed. In addition, the solution is 1301 numerically stable, which makes it one of the highest precision 1302 methods (Chedin et al., 1985). Therefore, the statistical inversion 1303 method will be used for our channel selection experiment and a 1304 regression equation will be established. 1305

According to an empirical orthogonal function, the atmospheric

1307	temperature (or humidity), T, and the brightbrightness temperature,							
1308	T_b , are expanded thus as:							
1309								
1310	$\mathbf{T}=T^*\cdot A,$	(9)						
1311								
1312	$T_b = T_b^* \cdot A,$	(10)						
1313								
1314	where T^* and T_b^* are the eigenvectors of the covariance matrix	x of						
1315	temperature (or humidity) and brightness temperature, respectiv	vely.						
1316	A and B stand for the corresponding expansion coefficient vector	ors of						
1317	temperature (humidity) and brightness temperature.							
1318	Using the least squares method and the orthogonal property, the							
1319	coefficient conversion matrix, V, is introduced:							
1320								
1321	$\mathbf{A}=\mathbf{V}\cdot \mathbf{B},$	(11)						
1322								
1323	where $V = AB^T (BB^T)^{-1}$.	(12)						
1324								
1325	Using the orthogonality, we get:							
1326								
1327	$\mathbf{B} = (T_b^*)^T T_b,$	(13)						
1328								

1329
$$A = (T^*)^T T.$$
 (14)

For convenience, the anomalies of the state vector (atmospheric temperature), T, and the observation vector ($\frac{\text{bright}brightness}{\text{brightness}}$ temperature), T_b , are taken:

1334

1335
$$\widehat{T} = \overline{T} + \widehat{T}' = \overline{T} + GT_{b}' = \overline{T} + G(T_{b} - \overline{T_{b}}),$$
 (15)

1336

where \widehat{T} stands for the retrieval atmospheric temperature. \overline{T} and $\overline{T_{b}}T_{b}$ are the corresponding average values of the elements, respectively. $\underline{T}'=\widehat{T}'$ and T_{b}' represent the corresponding anomalies of the elements, respectively.

Assuming there are k sets of observations, a sample anomalymatrix with k vectors can be constructed:

1343

1344
$$T' = (t'_1, t'_2, \cdots, t'_k),$$
 (16)

1345

1346
$$T_{b}' = (t_{b1}', t_{b2}', \cdots, t_{bk}').$$
 (17)

1347

1348 Define the inversion error matrix as:

1350
$$\delta = \overline{T} - \widehat{T} = \widehat{T}' - T' .$$
(18)

1352 The retrieval error covariance matrix is:

1353

1351

$$S_{\delta} = \frac{1}{k - n - 1} \delta \delta^{T}$$

$$= \frac{1}{k - n - 1} (T' - GT_{b}') (T' - GT_{b}')^{T}$$

$$= \frac{k - 1}{k - n - 1} (S_{e} - G^{T}S_{xy} - S_{xy}G^{T} + GS_{y}G^{T}), \qquad (19)$$

$$= 1356$$

1358

1359
$$S_{e} = \frac{1}{k-1} T' T'^{T}$$
,
1360 $S_{y} = \frac{1}{k-1} T_{b}' T_{b}'^{T}$,
1361 $S_{xy} = \frac{1}{k-1} T' T_{b}'^{T}$. (20)

1362

 S_e stands for the sample covariance matrix of T, S_y denotes the sample covariance matrix of T_b , and S_{xy} represents the covariance matrix of T and T_b . The elements on the diagonal of the error covariance matrix, S_δ , represent the retrieval error variance of T. The matrix G that minimizes the overall error variance is the least squares coefficient matrix of the regression equation (15), which meets the criteria:

1371	$\delta^2 = \operatorname{tr}(S_{\delta}) = \min.$	(21)					
1372							
1373	Equation (21) takes Taking a derivative of Eq. (21) with respect to						
1374	G, $\frac{\partial}{\partial G}$ tr(S _{δ}) = 0 = (-2S _{xy} + 2GS _y), which means that:						
1375							
1376	$G = S_{xy}S_y^{-1}.$	(22)					
1377							
1378	Substituting Eq. (22) into Eq. (15) finally gives the lea	st squares					
1379	solution as:						
1380							
1381	$\widehat{T} = \overline{T} + S_{xy}S_y^{-1}(T_b - \overline{T_b}).$	(23)					
1382							
1383	It should be noted that the least squares solution obtain	ned here					
1384	aims to minimize the sum of the error variance for each e	element in					
1385	the atmospheric state vector after retrieval of observations has been-						
1386	completed <u>for</u> several times. At present, statistical multiple regression						
1387	is widely used in the retrieval of atmospheric profiles based on						
1388	atmospheric remote sensing data. As long as there are en	ough data,					
1389	S_{xy} and S_y can be determined.						
1390							
1391	3. Channel selection experiment						

3.1 Data and model

1393	The Atmospheric Infrared Sounder (AIRS) instrument suite is_						
1394	primarily designed to measure the Earth's atmospheric water vapor						
1395	and temperature profiles on a global scale- (Aumann et al., 2003;						
1396	Hoffmann and Alexander, 2009). AIRS is a continuously operating						
1397	cross-track scanning sounder, consisting of a telescope that feeds an						
1398	echelle spectrometer. The AIRS infrared spectrometer acquires 2378						
1399	spectral samples at a resolution $\lambda/\Delta\lambda$, ranging from 1086 to 1570, in						
1400	three bands: 3.74 μm to 4.61 $\mu m,$ 6.20 μm to 8.22 $\mu m,$ and 8.8 μm to						
1401	15.4 μm. The spatial footprint of the infrared channels is 1.1° in						
1402	diameter, which corresponds to about 15×15 size 13.5 km at the						
1403	nadir. (Susskind et al., 2003). The spectral range includes 4.23 μm						
1405							
1404	and 15.5 μ m for important temperature detection, 15 μ m						
1404	and 15.5 μ m for important temperature detection, 15 μ m						
1404 1405	and 15.5 μ m for important temperature detection, 15 μ m- for <u>observation and</u> CO ₂ , 6.3 μ m for water vapor, and 9.6 μ m for						
1404 1405 1406	and 15.5 μ m for important temperature detection, 15 μ m- forobservation and CO ₂ , 6.3 μ m for water vapor, and 9.6 μ m for ozone absorption bands- <u>(Menzel et al., 2018)</u> . The absolute-						
1404 1405 1406 1407	and 15.5 μ m for important temperature detection, 15 μ m- forobservation and CO ₂ , 6.3 μ m for water vapor, and 9.6 μ m for ozone absorption bands- <u>(Menzel et al., 2018)</u> . The absolute- accuracyroot mean square error (RMSE) of the measured radiation is						
1404 1405 1406 1407 1408	and 15.5 μ m for important temperature detection, 15 μ m for observation and CO ₂ , 6.3 μ m for water vapor, and 9.6 μ m for ozone absorption bands- (Menzel et al., 2018). The absolute- accuracyroot mean square error (RMSE) of the measured radiation is better than 0.2 K- (Susskind et al., 2003). Moreover, global						
1404 1405 1406 1407 1408 1409	and 15.5 μ m for important temperature detection, 15 μ m forobservation and CO ₂ , 6.3 μ m for water vapor, and 9.6 μ m for ozone absorption bands- <u>(Menzel et al., 2018)</u> . The absolute accuracyroot mean square error (RMSE) of the measured radiation is better than 0.2 K- <u>(Susskind et al., 2003)</u> . Moreover, global atmospheric profiles can be detected every day, and the four imaging						
1404 1405 1406 1407 1408 1409 1410	and 15.5 μ m for important temperature detection, 15 μ m. forobservation and CO ₂ , 6.3 μ m for water vapor, and 9.6 μ m for ozone absorption bands- <u>(Menzel et al., 2018)</u> . The absolute- accuracyroot mean square error (RMSE) of the measured radiation is better than 0.2 K- <u>(Susskind et al., 2003)</u> . Moreover, global atmospheric profiles can be detected every day , and the four imaging channels of visible/near infrared are always filled. Due to						
1404 1405 1406 1407 1408 1409 1410 1411	and 15.5 μ m for important temperature detection, 15 μ m forobservation and CO ₂ , 6.3 μ m for water vapor, and 9.6 μ m for ozone absorption bands <u>- (Menzel et al., 2018)</u> . The absolute- accuracyroot mean square error (RMSE) of the measured radiation is better than 0.2 K <u>- (Susskind et al., 2003)</u> . Moreover, global atmospheric profiles can be detected every day , and the four imaging channels of visible/near infrared are always filled. Due to radiometer noise and faults, there are currently only 2047 effective						
1404 1405 1406 1407 1408 1409 1410 1411 1412	and 15.5 μ m for important temperature detection, 15 μ m forobservation and CO ₂ , 6.3 μ m for water vapor, and 9.6 μ m for ozone absorption bands- <u>(Menzel et al., 2018)</u> . The absolute accuracyroot mean square error (RMSE) of the measured radiation is better than 0.2 K- <u>(Susskind et al., 2003)</u> . Moreover, global atmospheric profiles can be detected every day, and the four imaging channels of visible/near infrared are always filled. Due to radiometer noise and faults, there are currently only 2047 effective channels. However, compared with previous infrared detectors,						

1415 Li et al., 2005).

AIRS provides real-time mode prediction systems with vastquantities of data, which greatly improves prediction accuracy.
However, if all the channels are used to retrieve data, the retrievaltime becomes greatly extended. Even more problematic are the hugeamounts of information and calculations not being suitable forreal-time forecasting.-

The root mean square error of an AIRS infrared channel is shown 1422 in Fig. 1, with black spots, indicating that not all the instrument 1423 channels possess a measurement error of less than 0.2 K. There are a 1424 few channels with extremely large measurement errors, which 1425 reduce the accuracy of prediction to some extent. Moreover, not all-1426 channels possess the same Among them, some extremely large 1427 measurement error.errors reduce the accuracy of prediction to some 1428 extent (Susskind et al., 2003). At present, more than 300 channels 1429 have not been used because their errors exceed 1 K. If data from 1430 these channels were to be used for retrieval, the accuracy of the 1431 retrieval could be reduced. Therefore, it is necessary to select a 1432 group of channels to improve the calculation efficiency and retrieval 1433 quality. In this paper we study channel selection for temperature 1434 profile retrieval by AIRS. 1435

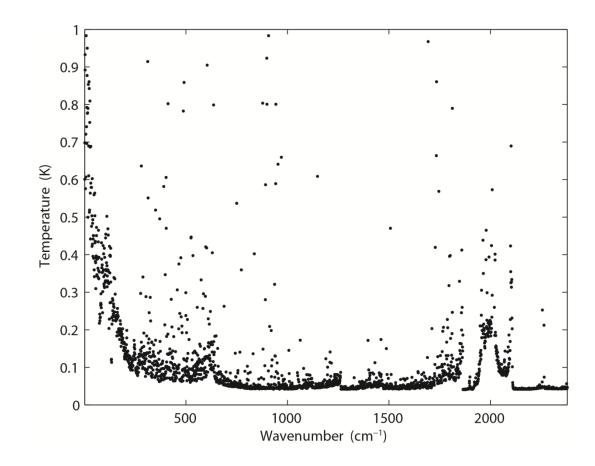
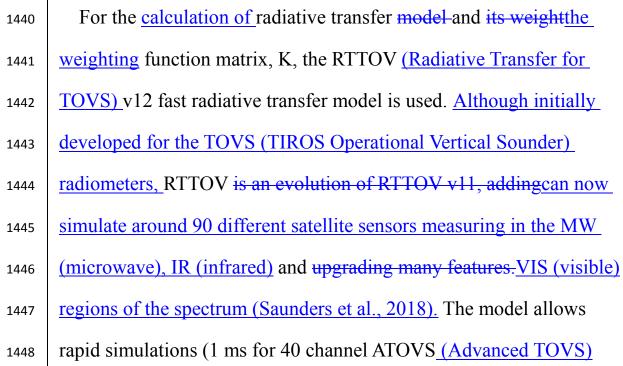


Figure 1. Root mean square error of AIRS infrared channel (blackspots).



on a desktop PC) of radiances for satellite visible, infrared, or 1449 microwave nadir scanning radiometers given atmospheric profiles of 1450 temperature and variabletrace gas concentration concentrations, and 1451 cloud and surface properties. The only mandatory gas included as a 1452 variable for RTTOV v12 is water vapor. Optionally, ozone, carbon 1453 dioxide, nitrous oxide, methane, carbon monoxide, and sulfur 1454 dioxide can be included, with all other constituents assumed to be 1455 constant. RTTOV-v12 can accept input profiles on any defined set of 1456 pressure levels. The majority of RTTOV v12-coefficient files are 1457 based on the 54 levels shown in (see Table 1, A1 in Appendix A), 1458 ranking from 1050 hPa to 0.01 hPa, though coefficients for some 1459 hyperspectral sounders are also available on 101 levels. 1460

1461

1462

1463

1464

1466

Table 1. Pressure levels adopted for RTTOV v12 54 pressure level
coefficients and profile limits within which the transmittance
calculations are valid. Note that the gas units here are ppmv.
(From https://www.nwpsaf.eu/site/software/rttov/, RTTOV Users-
guide, 2019).

Level	Pressure	Tmax	Tmin	Qmax	Qmin	Q ₂ max	Q₂min	Q ₂ Ref
Number	hPa	¥	¥	ppmv*	ppmv*	ppmv*	ppmv*	ppmv*
4	0.01	245.95	143.66	5.24	0.91	1.404	0.014	0.296
£	0.01	252.13	154.19	6.03	1.08	1.410	0.069	0.321
÷	0.03	263.71	168.42	7.42	1.35	1.496	0.108	0.361
4	0.03	280.12	180.18	8.10	1.58	1.670	0.171	0.527
				68				

5	0.13	299.05	194.48	8.44	1.80	2.064	0.228	0.769
6	0.23	318.64	206.21	8.59	1.99	2.365	0.355	1.074
¥	0.41	336.24	205.66	8.58	2.49	2.718	0.553	1.471
÷	0.67	342.08	197.17	8.34	3.01	3.565	0.731	1.991
Ð	1.08	340.84	189.50	8.07	3.30	5.333	0.716	2.787
10	1.67	334.68	179.27	7.89	3.20	7.314	0.643	3.756
11	2.50	322.5	17627	7.75	2.92	9.191	0.504	4.864
12	3.65	312.51	175.04	7.69	2.83	10.447	0.745	5.953
13	5.19	303.89	173.07	7.58	2.70	12.336	1.586	6.763
14	7.22	295.48	168.38	7.53	2.54	12.936	1.879	7.109
15	9.84	293.33	166.30	7.36	2.46	12.744	1.322	7.060
16	13.17	287.05	16347	7.20	2.42	11.960	0.719	6.574
17	17.33	283.36	161.49	6.96	2.20	11.105	0.428	5.687
18	22.46	280.93	161.47	6.75	1.71	9.796	0.278	4.705
19	28.69	282.67	162.09	6.46	1.52	8.736	0.164	3.870
20	36.17	27993	162.49	6.14	1.31	7.374	0.107	3.111
21	45.04	27315	164.66	5.90	1.36	6.799	0.055	2.478
22	55.44	265.93	166.19	6.21	1.30	5.710	0.048	1.907
23	67.51	264.7	167.42	9.17	1.16	4.786	0.043	1.440
24	81.37	261.95	159.98	17.89	0.36	4.390	0.038	1.020
25	97.15	262.43	163.95	20.30	0.01	3.619	0.016	0.733
26	114.94	259.57	168.59	33.56	0.01	2.977	0.016	0.604
27	134.83	259.26	169.71	102.24	0.01	2.665	0.016	0.489
28	156.88	260.13	169.42	285.00	0.01	2.351	0.013	0.388
29	181.14	262.27	17063	714.60	0.01	1.973	0.010	0.284
30	207.61	264.45	174.11	1464.00	0.01	1.481	0.013	0.196
31	236.28	270.09	177.12	2475.60	0.01	1.075	0.016	0.145
32	267.10	277.93	181.98	4381.20	0.01	0.774	0.015	0.110
33	300.00	285.18	184.76	6631.20	0.01	0.628	0.015	0.086
34	334.86	293.68	187.69	9450.00	1.29	0.550	0.016	0.073

35	371.55	300.12	190.34	12432.00	1.52	0.447	0.015	0.063
36	409.89	302.63	194.40	15468.00	2.12	0.361	0.015	0.057
37	449.67	304.43	198.46	18564.00	2.36	0.284	0.015	0.054
38	490.85	307.2	201.53	21684.00	2.91	0.247	0.015	0.052
39	532.56	31217	202.74	24696.00	3.67	0.199	0.015	0.050
40	572.15	31556	201.61	27480.00	3.81	0.191	0.012	0.050
41	618.07	318.26	189.95	30288.00	6.82	0.171	0.010	0.049
42	661.00	321.71	189.95	32796.00	6.07	0.128	0.009	0.048
43	703.59	327.95	189.95	55328.00	6.73	0.124	0.009	0.047
44	745.48	333.77	189.95	37692.00	8.71	0.117	0.009	0.046
45	786.33	336.46	189.95	39984.00	8.26	0.115	0.008	0.045
46	825.75	338.54	189.95	42192.00	7.87	0.113	0.008	0.043
47	863.40	342.55	189.95	44220.00	7.53	0.111	0.007	0.041
48	898.93	346.23	189.95	46272.00	7.23	0.108	0.006	0.040
49	931.99	34924	189.95	47736.00	6.97	0.102	0.006	0.038
50	962.26	349.92	189.95	51264.00	6.75	0.099	0.006	0.034
51	989.45	350.09	189.95	49716.00	6.57	0.099	0.006	0.030
52	1013.29	360.09	189.95	47208.00	6.41	0.094	0.006	0.028
53	1033.54	350.09	189.95	47806.00	6.29	0.094	0.006	0.027
54	1050.00	350.09	189.95	47640.00	6.19	0.094	0.006	0.027

1468The weight function matrix, K (Jacobian matrix), in this paper is1469the weight function matrix of the atmospheric characteristics. In1469order to correspond to the selected profiles, the atmosphere is1470divided into 137 layers, each of which contains corresponding1471atmospheric characteristics, such as temperature, pressure, and the1473humidity distribution. Each element in the weightweighting function1474matrix can be written as $\partial yi/\partial xj$. The subscript i is used to identify

the satellite channel, and the subscript j is used to identify the 1475 atmospheric characteristics.variable. Therefore, $\partial yi/\partial xj$ indicates the 1476 variation in radiation brightness temperature in a given satellite 1477 channel, when a given atmospheric characteristic variable in a given 1478 layer changes. We are thus able to establish which layer of the 1479 satellite channel is particularly sensitive to which atmospheric 1480 characteristic (temperature, various gas contents) in the vertical 1481 atmosphere. The RTTOV K (the K mode), is used to calculate the 1482 matrix H(X0) (Eq. (1)) for a given atmospheric profile characteristic. 1483 1484

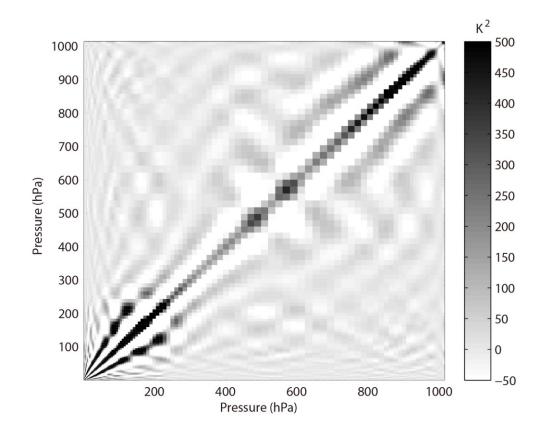
1485**3.2 Channel selection comparison experiment and results**

In order to verify the effectiveness of the method, three sets of 1486 comparison experiments were conducted. First, 324 channels used 1487 by the EUMETSAT Satellite Application Facility on Numerical 1488 Weather Prediction (NWP SAF) were selected. NCS is short for 1489 NWP channel selection in this paper. The products NCS were 1490 released by the NWPSAF 1DVar (one-dimensional variational 1491 analysis) scheme, in accordance with the requirements of the 1492 NWPSAF- (Saunders et al., 2018). Second, 324 channels were 1493 selected using the information capacity method. This method was 1494 adopted by Du et al. (2008) without the consideration of layering. 1495 PCS is short for primary channel selection in this paper. 1496

Third, 324×M channels were selected using the information
capacity method for the M layer atmosphere. ICS is short for
improved channel selectioninselection in this paper. In order to
verify the retrieval effectiveness after channel selection, statistical
inversion comparison experiments were performed using 5000
temperature profiles provided by the ECMWF dataset, which will be
introduced in Sect. 4.

The observation error covariance matrix, S_{ε} , in the experiment is 1504 provided by NWP SAF 1Dvar. In general, it can be converted to a 1505 diagonal matrix, the elements of which are the observation error 1506 standard deviation of each hyperspectral detector channel, which is 1507 the square of the root mean square error for each channel. The root 1508 mean square error of anthe AIRS infrared channel channels is shown 1509 in Fig. 1. The error covariance matrix of the background, S_a , is 1510 calculated using 5000 samples of the IFS-137 data provided by the 1511 ECMWF dataset (The detailed information will be introduced in 1512 Sect. 4). The last access date is April 26th, 2019 (download address: 1513 https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/, 1514 2019). The covariance matrix of temperature is shown in Fig. 2, the. 1515 The results are consistent with the previous study by Du et al. 1516 (2008).1517

1518

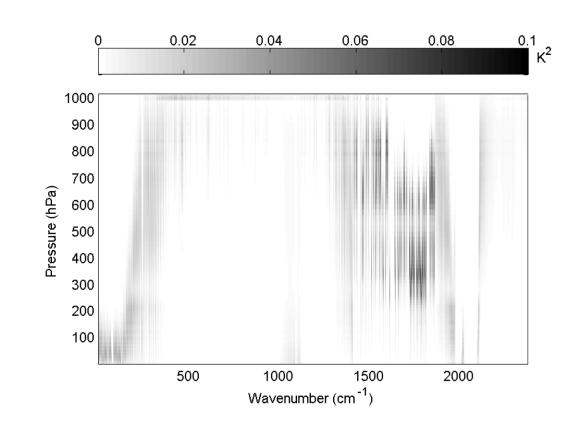


1520 **Figure 2.** Error covariance matrix of temperature (shaded).

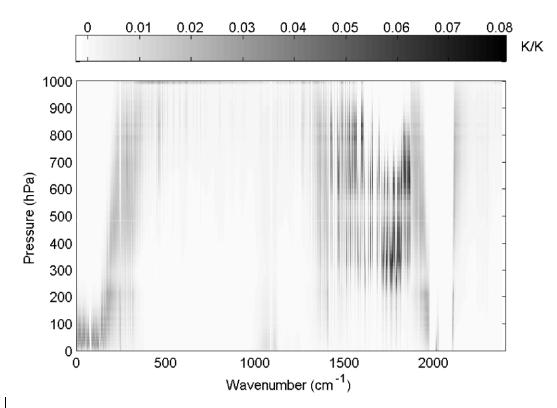
1519

The reference atmospheric profiles are from the IFS-137 database, 1522 and the temperature weightweighting function matrix is calculated 1523 using the RTTOV K mode, as shown in Fig. 3; the results are 1524 consistent with those of the previous study by Du et al. (2008). For 1525 the air-based passive atmospheric remote sensing studied in this 1526 paper, when the same channel detects the atmosphere from different 1527 observation angles, the value of the weightweighting function matrix 1528 K changes due to the limb effect. Therefore, when we select The goal 1529 of this section is focusing on the selection methods of selecting 1530 channels, the results differ because of; therefore the biases produced 1531

1532 <u>from different observation angles. But due to the selection principle-</u>
1533 and method are exactly the same and our key is the selection method;
1534 we do not discuss, therefore, the variation in observation angle when1535 making a selection can be ignored.



1539



1540 **Figure 3.** Temperature <u>weightweighting</u> function matrix (shaded).

1541

In order to verify the effectiveness of ICS, the distribution of 324 channels, without considering layering, in the AIRS brightbrightness temperature spectrum is indicated in Fig. 4. The background brightness temperature is the simulated AIRS observation brightness temperature, which is from the atmospheric profile in RTTOV put into the model. Figure 4(a) shows the 324 channels selected by PCS, while Fig. 4(b) shows the 324 channels selected by NCS.

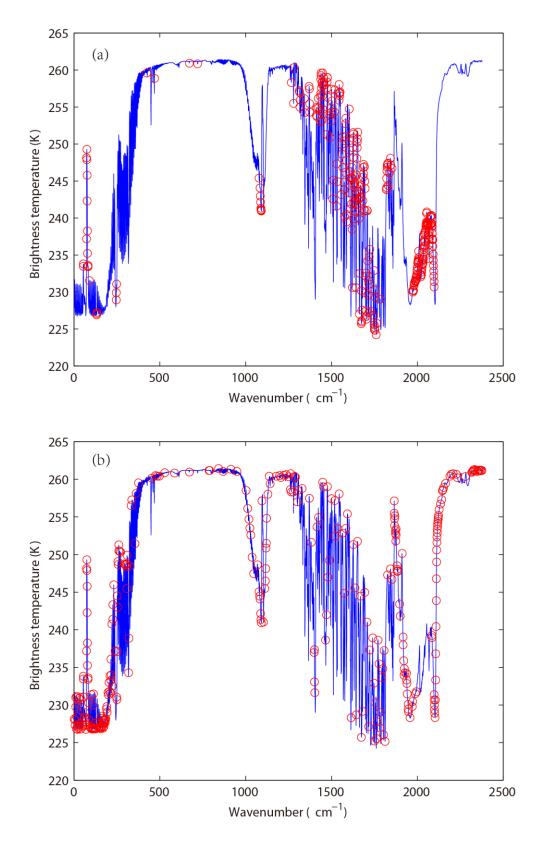


Figure 4. The distribution of different channel selection methods
without considering layering in the AIRS <u>brightbrightness</u>

1553	temperature spectrum (blue line). (a) 324 channels selected by PCS
1554	(red circles). (b) 324 channels selected by NCS (red circles).
1555	Without considering layering, the main differences between the
1556	324 channels selected by PCS and NCS are as follows: (1) When the
1557	wavenumber approaches 1000, the wavelength is $\frac{1110}{10} \mu\text{m} (1/1000)$
1558	\underline{cm}^{-1}). Near this band, fewer channels are selected by PCS because
1559	the retrieval of ground temperature is considered by NCS; (2) When
1560	the wavenumber is near 1200, the wavelength is 9 μ m (1/1200 <u>cm⁻¹</u>).
1561	Near this band, no channels are selected by PCS because the
1562	retrieval of O_3 is not considered in this paper; (3) When the
1563	wavenumber approaches 1500, the wavelength is 6.7 μ m (1/1500_
1564	<u>cm⁻¹</u>). As is known, the spectral range from 6 μ m to 7 μ m
1565	corresponds to water vapor absorption bands, but fewer channels are
1566	selected by NCS; (4) When the wavenumber is close to 2000, it
1567	derives a wavelength of 5 μ m (1/2000 <u>cm⁻¹</u>), which includes 4.2 μ m
1568	for N_2O and 4.3 μm for CO_2 absorption bands. As is shown in Fig. 4,
1569	fewer channels are selected by PCS in those bands. PCS is favorable
1570	for atmospheric temperature detection observation in the high
1571	temperature zone. Because 4.2 µm and 4.3 µm bands are sensitive to
1572	high temperature, the higher temperature is, the better observation
1573	can be obtained; (5) In the near infrared area, the wavenumber
1574	exceeds 2200, deriving a wavelength of less than 4 μ m (1/2000 cm ⁻¹).

A small number of channels is selected by NCS, but no channels areselected by PCS.

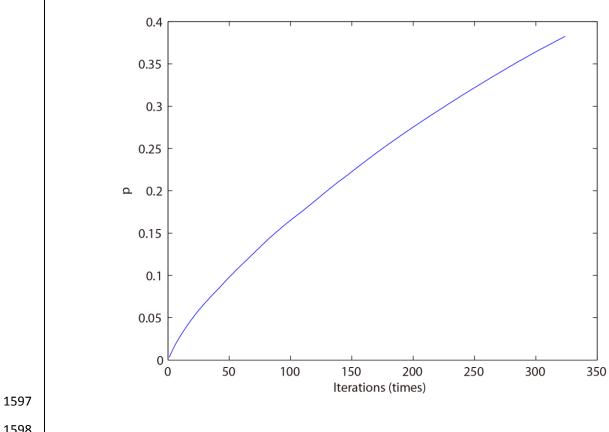
Above all, the information content used in this paper only takes 1577 the temperature profile retrieval into consideration, so the channel 1578 combination of PCS is inferior to that of NCS for the retrieval of 1579 surface temperature and the O_3 profile. The advantages of the 1580 channel selection method based on information content in this paper 1581 are mainly reflected in: (1) Near space (20-100 km)Stratosphere and 1582 mesosphere is less affected by the ground surface, so the retrieval 1583 result of PCS is better than that of NCS. (2) Due to the method 1584 selected in this paper there are more channels at 4.2 µm for N₂O and 1585 4.3 μ m for CO₂ absorption bands; the channel combination of PCS is 1586 superior tobetter than that of NCS for atmospheric temperature 1587 detection in observation to the highhigher temperature zone. 1588 By comparing channel selection without considering layering, 1589 we note the general advantages and disadvantages of PCS and NCS 1590 for the retrieval of atmospheretemperature and can improve the 1591 channel selection scheme. First, the retrieval of the temperature 1592

relationship between the number of iterations and the ARI is shown in Fig. 5.

profile for 324 channels selected by PCS is obtained. The

1596

1593



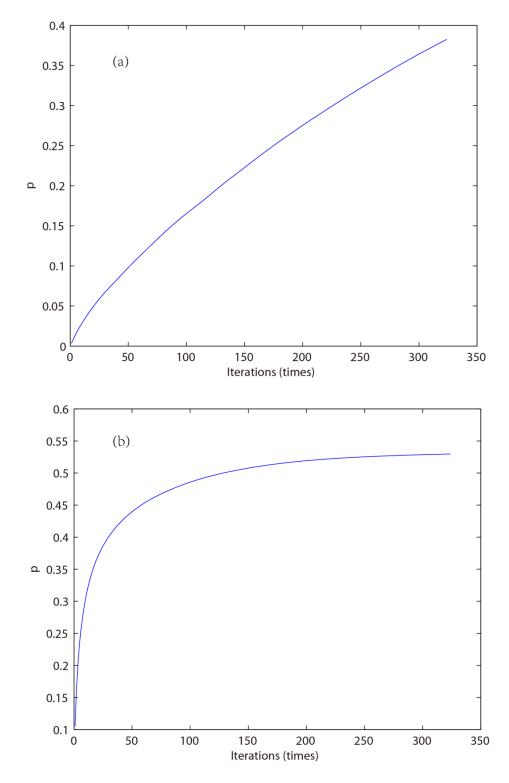
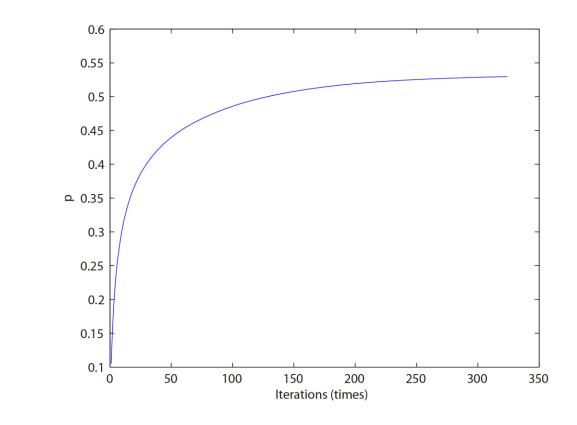


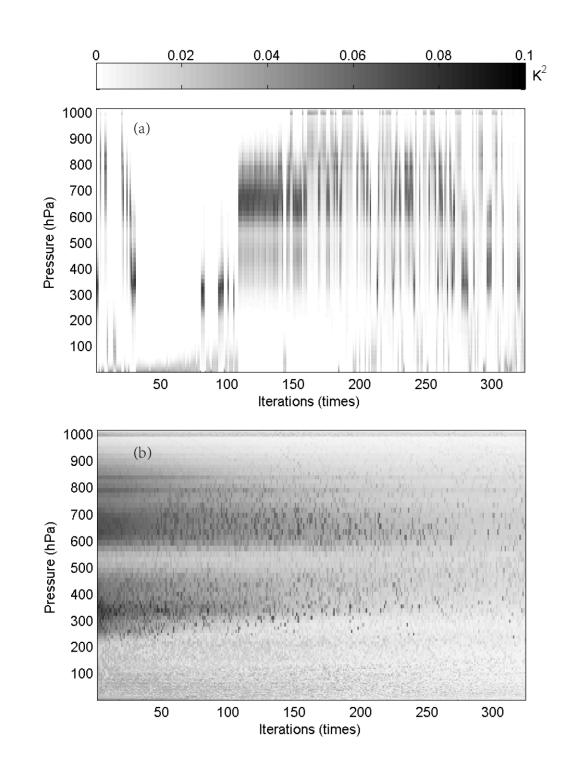
Figure 5. The relationship between the number of iterations and ARIfor. (a) PCS. (b) ICS.

1602	The ARI for PCS tends to be 0.38 and is not convergent, so the
1603	PCS method needs to be improved. In this paper, the atmosphere is
1604	divided into 137 layers, and based on the information content and
1605	iteration, 324 channels are selected for each layer. Moreover <u>Then</u> ,
1606	the temperature profile of each layer can be retrieved. <u>based on</u>
1607	statistical inversion (see at Sect. 4). The relationship between the
1608	number of iterations and the ARI for ICS is shown in Fig. 6.5b.
1609	When the number of iterations approaches 100, the ARI of ICS tends
1610	to be stable, reachingand reach to 0.54. Thus, in terms of the ARI
1611	and convergence, the ICS method is superior to better than that of
1612	PCS.



1615 Figure 6. The relationship between the number of iterations and the 1616 ARI for ICS.

1618	Furthermore, because an iterative method is used to select					
1619	channels, the order of each selected channel is determined by the					
1620	contribution from the ARI. The weightweighting function matrix of					
1621	the top 324 selected channels, according to channel order, is shown					
1622	in Fig. <u>76</u> .					



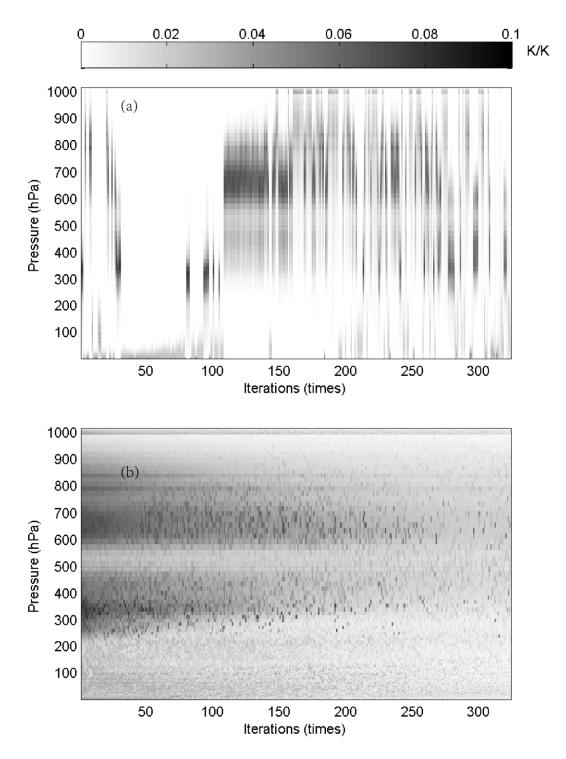


Figure 76. The relationship between the number of iterations and the
weightweighting function of the top 324 selected channels (shaded).
(a) PCS.ICS. (b) ICSPCS.

As illustrated in Fig. 76, in the first 100 iterations, the distribution 1629 of the temperature weightweighting function for PCS is relatively 1630 scattered; it does not reflect continuity between the adjacent layers 1631 of the atmosphere. Besides, the ICS result is better than that of PCS, 1632 showing that: (1) the distribution of the temperature 1633 weightweighting function is more continuous and reflects the 1634 continuity between adjacent layers of the atmosphere; (2) regardless 1635 of the number of iterations, the maximum value of the 1636 weightweighting function is stable near 300–400 hPa and 600–700 1637 hPa, without scattering, which resembles more closely is closer to the 1638 scenariosituation in real atmosphere. 1639

1640

1641 **4. Statistical multiple regression experiment**

1642 **4.1 Temperature profile database**

A new database including a representative collection of 25,000
atmospheric profiles from the European Centre for Medium-range
Weather Forecasts (ECMWF) was used-<u>for the statistical inversion</u>
experiments. The profiles were given in a 137-level vertical grid
extending from the surface up to 0.01 hPa. The database was divided
into five subsets focusing on diverse sampling characteristics such as
temperature, specific humidity, ozone mixing ratio, cloud

1650	condensates, and precipitation. In contrast with earlier releases of the					
1651	ECMWF diverse profile database, the 137-level database places					
1652	greater emphasis on preserving the statistical properties of sampled					
1653	distributions produced by the Integrated Forecasting System (IFS).					
1654	(Eresmaa and McNally, 2014; Brath et al., 2018). IFS-137 spans the					
1655	period from September 1, 2013 to August 31, 2014. There are two					
1656	operational analyses each day (at 00z and 12z), and <u>approximately</u>					
1657	13 000 atmospheric profiles over the modeling grid contains					
	<u>15 000 atmospheric promes over</u> the modering grid contains					
1658	2,140,702 grid points.ocean. The pressure levels adopted for					

Table 2. Pressure levels adopted for IFS-137-137 pressure levels (in-

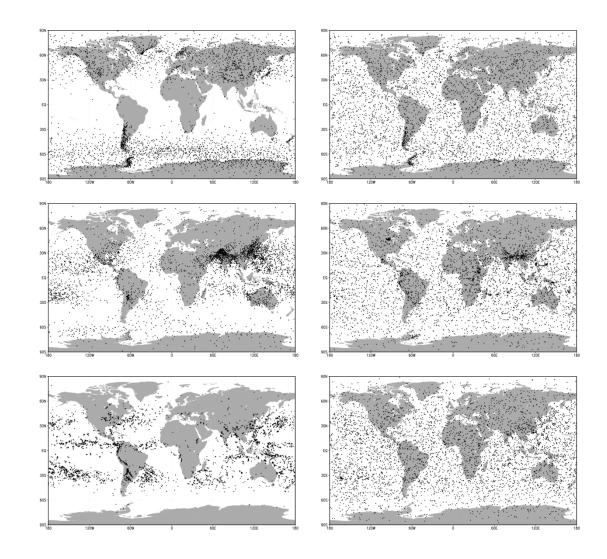
hPa).

Level	pressure	Level	pressure	Level	pressure	Level	pressure	Level	pressure
number	hPa	number	hPa	number	hPa	number	hPa	number	hPa
4	0.02	31	12.856 1	61	106.4153	} 91	424.019	121	934.7666
£	0.031	32	14.2377	4 62	112.0681	92	441.5395	122	943.1399
÷	0.0467	33	15.7162	e 63	117.9714	⊧ 93	459.6321	123	950.9082
4	0.0683	34	17.2945	64	124.1337	<u>4</u>	478.3096	124	958.1037
5	0.0975	35	18.9752	e 65	130.5637	<mark>≅ 95</mark>	497.5845	125	964.7584
€	0.1361	36	20.76 1	- 66	137.2703	9 6	517.4198	126	970.9046
¥	0.1861	37	22.6543	} 67	144.262 4	⊧ 97	537.7195	127	976.5737
용	0.2499	38	24.6577	<u> </u>	151.5493	98 98	558.343	128	981.7968
Ð	0.3299	39	26.7735	6 9	159.1403	99	579.1926	129	986.6036
10	0.4288	40	29.003 9	→ 70	167.045	i 100	600.1668	130	991.023
11	0.5496	41	31.3512	₽ 74	175.273 1	- 101	621.1624	131	995.0824
12	0.6952	42	33.8174	⊧ 72	183.834 4	+ 102	642.0764	132	998.8081
13	0.869	43	36.4047	73	192.738 9	103	662.8084	133	1002.225
14	1.0742	44	39.1149	74	201.9969	104	683.262	13 4	1005.356
15	1.3143	45	41.9493	75	211.618 €	105	703.3467	135	1008.224
16	1.5928	46	44 <u>.9082</u>	76	221.614 6	106	722.9795	136	1010.849

17	1.9134	47	47.9915	77	231.9954	107	742.0855	137	1013.25
18	2.2797	48	51.199	78	242.7719	108	760.5996		
19	2.6954	49	54.5299	79	253.9549	109	778.4661		
20	3.1642	50	57.9834	80	265.5556	110	795.6396		
21	3.6898	51	61.5607	81	277.5852	111	812.0847		
22	4 <u>.2759</u>	52	65.2695	82	290.0548	112	827.7756		
23	4.9262	53	69.1187	83	302.9762	113	842.6959		
24	5.6441	54	73.1187	84	316.3607	114	856.8376		
25	6.4334	55	77.281	85	330.2202	115	870.2004		
26	7.2974	56	81.6182	86	344.5663	116	882.791		
27	8.2397	57	86.145	87	359.4111	117	894.6222		
28	9.2634	58	90.8774	88	374.7666	118	905.7116		
29	10.372	59	95.828	89	390.645	119	916.0815		
30	11.5685	60	101.0047	90	407.0583	120	925.7571		
<u>,</u>									

The locations of selected profiles of temperature, specific 1663 humidity, and cloud condensate subsets of the IFS-91 and IFS-137 1664 databases are plotted on the map in Fig. 87. In the IFS-91 database, 1665 the sampling is fully determined by the selection algorithm, which 1666 makes the geographical distributions very inhomogeneous. Selected 1667 profiles represent those regions where gradients of the sampled 1668 variable are the strongest: in the case of temperature, mid- and 1669 high-latitudes dominate, while humidity and cloud condensate 1670 subsets concentrate at low latitudes. However, the IFS-137 database 1671 shows a much more homogeneous spatial distribution in all the 1672 sampling subsets, which is a consequence of the randomized 1673 selection. 1674

1675





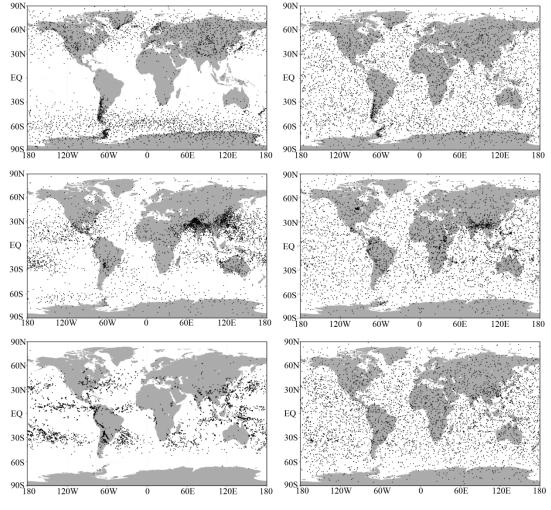


Figure 8.7. Locations of selected profiles in the temperature (top),
specific humidity (middle), and cloud condensate (bottom), sampled
subsets of the IFS-91 (left) and IFS-137 (right) databases (from
<u>https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/</u>,
2019).
The temporal distribution of the selected profiles is illustrated in Fig.
9. Again, the lack of randomized selection results in large variations-

1686	from one month to the next in the case <u>8</u> . The coverage of the IFS-91-
1687	database (left panel). The different distributions come mainly from-
1688	variations in the ozone subset (green parts of each column).
1689	Dominance of randomly-selected profiles in the IFS-137 database
1690	leaves little room for monthly variation in the data count (right-
1691	panel).set is more homogeneous than the IFS-91 data set. Moreover,
1692	the IFS-91137 database also supports the mode with input
1692 1693	the IFS-91137 database also supports the mode with input parameters, such as detection angle, 2 m temperature, <u>and</u> cloud

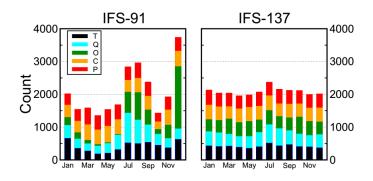


Figure 9.8. Distribution of profiles within the calendar months in
IFS-91 (left) and IFS-137 (right) databases. Different subsets are
shown in different colors.Black parts stand for temperature. Blue
parts represent specific humidity. Green parts indicate ozone subset.
Orange parts stand for cloud condensate. Red parts represent
precipitation. <u>(from-</u>)

1702 <u>https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/Th</u>

1703 <u>e last access date is April 26th, 2019.</u> (from

1704 <u>https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/</u>,
1705 2019).

- 1706
- 1707 **4.2 Experimental scheme**

1708 In order to verify the retrieval effectiveness of ICS, 5000

temperature profiles provided by the IFS-137 were used for

1710 statistical inversion comparison experiments. The steps are as

1711 follows:

(1) 5000 profiles and their corresponding surface factors,

including surface air pressure, surface temperature, 2 m temperature,

2 m specific humidity, 10 m wind speed, etc. are put into the RTTOV
mode. Then, the <u>simulated</u> AIRS observation brightness temperature-

1716 isspectra are obtained.

1717 (2) The retrieval of temperature is carried out in accordance with

Eq. (23). The 5000 profiles are divided into two groups. The first

group of 2500 profiles is used to obtain the regression coefficient,

and the second group of 2500 is used to test the result.

(3) Verification of the results. The test is carried out based on thestandard deviation between the retrieval value and the true value.

1723

1724 **4.3 Results and Discussion**

¹⁷²⁵ For the statistical inversion comparison experiments, the standard

deviation of temperature retrieval is shown in Fig. 10.9. First, 1726 because PCS does not take channel sensitivity as a function of height 1727 into consideration, the retrieval result of PCS is inferior to that of 1728 ICS. Second, by comparing the results of ICS and NCS we found 1729 that below 100 hPa, since the method used in this paper considers 1730 near ground to be less of an influencing factor, the channel 1731 combination of ICS is slightly inferior to that of NCS, but the 1732 difference is small. 1733

From 100 hPa to10 hPa, the retrieval temperature of ICS in this 1734 paper is consistent with that of NCS, slightly better than the channel 1735 selected for NCS. From 10 hPa to 0.02 hPa, near the space layer, the 1736 retrieval temperature of ICS is obviously better than that of NCS. In 1737 terms of the standard deviation, the channel combination of ICS is 1738 slightly better than that of PCS from 100 hPa to 10 hPa. From 10 1739 hPa to 0.02 hPa, the standard deviation of ICS is lower than that of 1740 NCS at about 1 K, meaning that the retrieval result of ICS is better 1741 than that of NCS. 1742

In order to further illustrate the effectiveness of ICS, the mean improvement value of the ICS and its percentages compared with the PCS and NCS in<u>at</u> different <u>heightheights</u> are shown in Table <u>31</u>. Because PCS does not take channel sensitivity as a function of height into consideration, the retrieval result of PCS is inferior to

that of ICS. In general, the accuracy of the retrieval temperature of 1748 ICS is improved. Especially, from 100 hPa to 0.01 hPa, the mean 1749 value of ICS is evidently improved by more than 0.5 K which means 1750 the accuracy can be improved by more than 11%. By comparing the 1751 results of ICS and NCS we found that below 100 hPa, since the 1752 method used in this paper considers near ground to be less of an 1753 influencing factor, the channel combination of ICS is slightly 1754 inferior to that of NCS, but the difference is small. From 100 hPa to 1755 0.01 hPa, the mean value of ICS is improved by more than 0.36 K 1756 which means the accuracy can be improved by more than 9.6%. 1757

1758

Table 31. The mean improvement value of the ICS and its
percentages compared with the PCS and NCS inat different
heightheights.

Pressure	Improved mean value /Percentage compared with PCS	Improved value /Percentage compared with NCS	
hPa	K/%	K/%	
surface-100hPa	0.24/10.77%	-0.04/-3.27%	
100hPa-10hPa	0.15/5.08%	0.06/2.4%	
10hPa-1hPa	0.04/0.64%	0.17/2.99%	
1hPa-0.01hPa	0.52/11.92%	0.36/9.57%	

1762

1763

1764 <u>km)Stratosphere and mesosphere</u> is less affected by the ground

surface, so the retrieval result of PCS is better than that of NCS. (2)

This is because, as shown in Fig. 4: (1) Near space (20–100–

Due to the method selected in this paper, there are more channels at
4.2 μm for N₂O and 4.3 μm for CO₂ absorption bands, and the
channel combination of PCS is superior to that of NCS for
atmospheric temperature detectionobservation in the high
temperature zone. Moreover, ICS takes channel sensitivity as a
function of height into consideration, so its retrieval result is
impressiveimproved.

1773

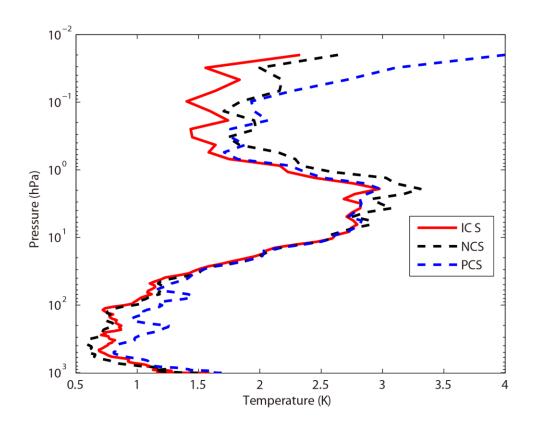
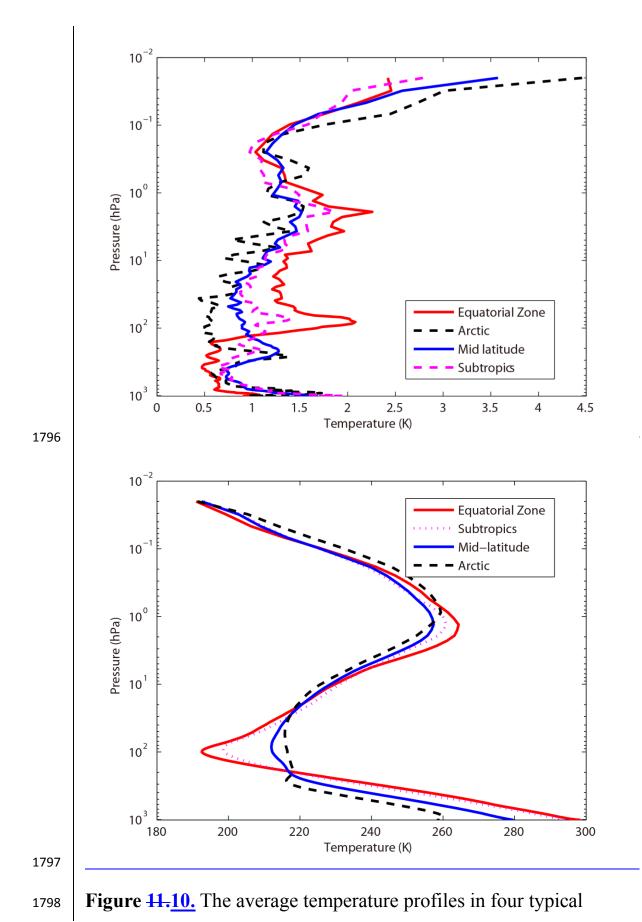
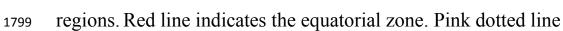


Figure 10.9. The temperature profile standard deviation of statistical
inversion comparison experiments. Red line indicates the result of
ICS. Black dotted line stands for the result of NCS. Blue dotted line
represents the result of PCS.

5 Statistical inversion comparison experiments in four typical 1780 regions 1781 The accuracy of the retrieval temperature varies from place to place 1782 and changes with weatheratmospheric conditions. Therefore, in 1783 order to further compare the inversion accuracy under different 1784 atmospheric conditions, this paper has divided the atmospheric 1785 profile is from the IFS-137 database introduced in Sect. 4, and 1786 divides it4 into four regions: equatorial zone, subtropical region, 1787 mid-latitude region and Arctic. These regions' profiles can represent 1788 the global typical atmospheric temperature profiles. The average 1789 temperature profiles in these four regions are shown in Fig. <u>11.10</u>. 1790 The retrieval temperature varies from place to place and changes 1791 with weather atmospheric conditions. In order to further compare the 1792 regional differences of inversion accuracy, the temperature standard 1793 deviations of ICS in four typical regions are compared in Sect. 5.2. 1794

1795





stands for the subtropics. Blue dotted line represents the mid-latituderegion. Black dotted line stands for the Arctic.

1802

1803

1804 5.1 Experimental scheme

In order to further illustrate the different accuracy of the retrieval temperature using our improved channel selection method under different atmospheric conditions, the profiles in four typical regions were used for statistical inversion comparison experiments. The experimental steps are as follows:

(1) 2500 profiles in Sect. 4 are used to work out the regressioncoefficient.

(2) The atmospheric profiles of the four typical regions: equatorialzone, subtropical region, mid-latitude region and Arctic are used for

1814 statistical inversion comparison experiments and test the result.(3)

1815 Verification of the results. The test is carried out based on the

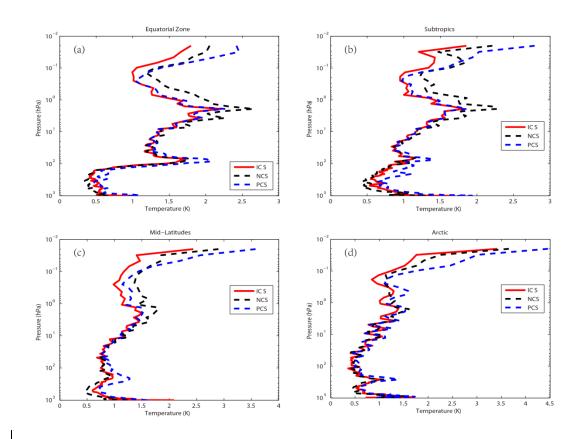
1816 standard deviation between the retrieval value and the true value.

1817

1818 **5.2 Results and Discussion**

Using statistical inversion comparison experiments in four typical regions, the standard deviation of temperature retrieval is shown in Fig. 1211. Generally, the retrieval temperature by ICS is greatly superior tobetter than that of NCS and PCS. In particular, above 1
hPa (the near space layerstratosphere and mesosphere), the standard
deviation of atmospheric temperature can be optimized toimproved
by 1 K with PCS and NCS. Thus, ICS shows a great improvement.
The results were consistent with Sect. 4.



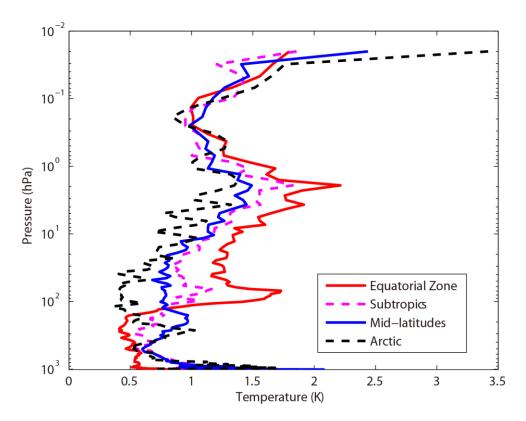


1828

Figure 1211. The temperature profile standard deviation of
statistical inversion comparison experiments in four typical regions.
Red line indicates the result of ICS. Black dotted line stands for the
result of NCS. Blue dotted line represents the result of PCS. (a)
Equatorial zone. (b) Subtropics. (c) Mid-latitudes. (bd) Arctic.

In order to further compare the regional differences of inversion accuracy, the temperature standard deviation of ICS in four typical regions are compared in Fig. 1312.

1838



1839

Figure 13.12. The temperature standard deviation of ICS in four
typical regions. Red line indicates the result of equatorial zone. Pink
dotted line represents the result of Subtropics. Blue line represents
the result of Mid-latitudes. Black dotted line stands for the result of
Arctic.

1845

As can be seen from Fig. 13, the The temperature standard
deviations of the ICS in the four typical regions are large- (Fig. 12).

Below100 hPa, due to the high temperature in the equatorial zone, 1848 the channel combination of ICS is superior tobetter than that of PCS 1849 and NCS for atmospheric temperature detection in observation to the 1850 highligher temperature-zone. The standard deviation is 0.5K. Due to 1851 the method selected in this paper there are more channels at $4.2 \,\mu m$ 1852 for N_2O and 4.3 µm for CO_2 absorption bands which has been 1853 previously described in Sect. 3. Near the tropopause, the standard 1854 deviation of the equatorial zone increases sharply. It is also due to 1855 the sharp drops in temperature. However, the standard deviation of 1856 the Arctic is still around 0.5K. From 100hPa to 1hPa, the standard 1857 deviation of ICS is 0.5 K to 2K. With the increase of latitude, the 1858 effectiveness considerably increases. According to Fig. 1211, ICS 1859 takes channel sensitivity as a function of height into consideration, 1860 so its retrieval result is impressivebetter. 1861

In order to further illustrate the effectiveness of ICS, the mean
improvement value of the ICS and its percentages compared with the
PCS and NCS in different height of four typical regions are shown in
Table 4 to Table 7.-

1866

Table 4. The mean improvement value of the ICS and its
percentages compared with the PCS and NCS in different height in
equatorial zone.

Pressure	Improved mean value /Percentage compared with PCS	Improved value /Percentage compared with- NCS		
hPa	K/%	K/%		
surface-100hPa	0.18/12.25%	-0.06/-5.61%		
100hPa-10hPa	0.13/4.23%	0.04/1.28%		
10hPa-1hPa	0.03/0.09%	0.24/6.24%		
1hPa-0.01hPa	0.24/7.41%	0.33/11.22%		

1871 **Table 5.** The mean improvement value of the ICS and its

1872 percentages compared with the PCS and NCS in different height in-

1873 subtropics.

Pressure	Improved mean value /Percentage compared with PCS	Improved value /Percentage compared with NCS
hPa	K/%	<u>K/%</u>
surface-100hPa	0.26/12.49%	-0.08/-5.94%
100hPa-10hPa	0.08/3.55%	0.02/1.28%
10hPa-1hPa	0.02/0.56%	0.2/5.94%
1hPa-0.01hPa	0.25/7.73%	0.34/12.51%

1874

1875 **Table 6.** The mean improvement value of the ICS and its

1876

6 percentages compared with the PCS and NCS in different height in

1877 mid-latitudes.

Pressure	Improved mean value /Percentage compared with PCS	Improved value /Percentage compared with- NCS
hPa	<u>K/%</u>	<u>K/%</u>
surface-100hPa	0.18/9.23%	-0.13/-7.41%
100hPa=10hPa	0.06/3.68%	0.03/1.84%
10hPa-1hPa	0.03/1.03%	0.18/6.01%
1hPa-0.01hPa	0.36/10.64%	0.36/12.71%

1879 Table 7. The mean improvement value of the ICS and its 1880 percentages compared with the PCS and NCS in different height in-

1881

Arctic.

1878

Pressure	Improved mean value /Percentage compared with PCS	Improved value /Percentage compared with NCS
hPa	K/%	K/%
surface-100hPa	0.12/6.52%	-0.05/-3.47%
100hPa-10hPa	0.08/6.59%	0.02/1.97%
10hPa-1hPa	0.09/3.64%	0.06/2.5%
1hPa-0.01hPa	0.49/13.72%	0.18/6.47%

1882

Although the improvements of ICS in the four typical regions are 1883 different, in general, the accuracy of the retrieval temperature of ICS 1884 is improved. Because PCS does not take channel sensitivity as a 1885 function of height into consideration, the retrieval result of PCS is 1886 inferior to that of ICS. In general, the accuracy of the retrieval 1887 temperature of ICS is improved. Especially, from 100 hPa to 0.01 1888 hPa, the accuracy of ICS can be improved by 7% to 13%. By 1889 comparing the results of ICS and NCS we found that below 100 hPa, 1890 since the method used in this paper considers near ground to be less 1891 of an influencing factor, the channel combination of ICS is slightly 1892 inferior to that of NCS, but the difference is small. From 100 hPa to 1893 0.01 hPa, the accuracy of ICS can be improved by 7% to 13%. 1894

6.7 Conclusions and discussion

6.1 Conclusions

An improved channel selection method is proposed, based on-information content in this paper. A robust channel selection scheme-and method are proposed, and a series of channel selection-comparison experiments are conducted. The results are as follows:(1) Since ICS takes channel sensitivity as a function of height into-consideration, the ARI of PCS only tends to be 0.38 and is not-convergent. However, as the 100th-iteration is approached, the ARI ofICS tends to be stable, reaching 0.54, while the distribution of the-temperature-weight function is more continuous and closer to that ofthe actual atmosphere. Thus, in terms of the ARI, convergence, andthe distribution of the temperature weight function, ICS is superior-to PCS.

(2) Statistical inversion comparison experiments show that the
retrieval temperature of ICS in this paper is consistent with that of
NCS.-In particular, from 10 hPa to 0.02 hPa (the near space layer),
the retrieval temperature of ICS is obviously better than that of NCSat about 1 K. In general, the accuracy of the retrieval temperature of
ICS is improved. Especially, from 100 hPa to 0.01 hPa, the accuracyof ICS can be improved by more than 11%. The reason is that near-

1917	space (20-100 km) is less affected by the ground surface, so the
1918	retrieval result of ICS is better than that of NCS. Additionally, due to-
1919	the method selected in this paper there are more channels at 4.2 µm
1920	for the N_2O and 4.3 μm for the CO_2 absorption bands; the channel-
1921	combination of ICS is superior to that of NCS for atmospheric-
1922	temperature detection in the high temperature zone.
1923	(3) Statistical inversion comparison experiments in four typical
1924	regions indicate that ICS in this paper is significantly better than
1925	NCS and PCS in different regions and shows latitudinal variations.
1926	Especially, from 100 hPa to 0.01 hPa, the accuracy of ICS can be-
1927	improved by 7% to 13%, which means the ICS method selected in
1928	this paper is feasible and shows great promise for applications.

1

1930 **6.2 Discussion**

In recent years, the atmospheric layer in the altitude range of about 1931 20-100 km has been named "the near space layer" by aeronautical 1932 and astronautical communities. It is between the space-based 1933 satellite platform and the aerospace vehicle platform, which is the 1934 transition zone between aviation and aerospace. Its unique resource 1935 has attracted a lot of attention from many countries. Research and 1936 exploration, therefore, on and of the near space layer are of great 1937 importance. A new channel selection scheme and method for 1938

hyperspectral atmospheric infrared sounder AIRS data based on layering areis proposed. The retrieval results of ICS concerning the near space atmosphere are particularly good. Thus, ICS aims to provide a new and an effective channel selection method for the study of the near space atmosphere using the hyperspectral atmospheric infrared sounder.

An improved channel selection method is proposed, based on 1945 information content in this paper. A robust channel selection scheme 1946 and method are proposed, and a series of channel selection 1947 comparison experiments are conducted. The results are as follows: 1948 (1) Since ICS takes channel sensitivity as a function of height into 1949 consideration, the ARI of PCS only tends to be 0.38 and is not 1950 convergent. However, as the 100th iteration is approached, the ARI of 1951 ICS tends to be stable, reaching 0.54, while the distribution of the 1952 temperature weighting function is more continuous and closer to that 1953 of the actual atmosphere. Thus, in terms of the ARI, convergence, 1954 and the distribution of the temperature weighting function, ICS is 1955 better than PCS. 1956 (2) Statistical inversion comparison experiments show that the 1957 retrieval temperature of ICS in this paper is consistent with that of 1958 NCS. In particular, from 10 hPa to 0.02 hPa (the stratosphere and 1959 mesosphere), the retrieval temperature of ICS is obviously better 1960

1961	than that of NCS at about 1 K. In general, the accuracy of the
1962	retrieval temperature of ICS is improved. Especially, from 100 hPa
1963	to 0.01 hPa, the accuracy of ICS can be improved by more than 11%.
1964	The reason is that stratosphere and mesosphere are less affected by
1965	the ground surface, so the retrieval result of ICS is better than that of
1966	NCS. Additionally, due to the method selected in this paper there are
1967	more channels at 4.2 μ m for the N ₂ O and at 4.3 μ m for the CO ₂
1968	absorption bands; the channel combination of ICS is better than that
1969	of NCS for atmospheric temperature observation to the higher
1970	temperature.
1971	(3) Statistical inversion comparison experiments in four typical
1972	regions indicate that ICS in this paper is significantly better than
1973	NCS and PCS in different regions and shows latitudinal variations,
1974	which shows potential for future applications.
1975	
1976	Data availability. The data used in this paper are available from the
1977	corresponding author upon request.
1978	
1979	Appendices
1980	Appendix A
1981	Table A1. Pressure levels adopted for RTTOV v12 54 pressure level
1982	coefficients and profile limits within which the transmittance
	105

1983 <u>calculations are valid. Note that the gas units here are ppmv.</u>

1984 (From https://www.nwpsaf.eu/site/software/rttov/, RTTOV Users

1985

guide, 2019).

Level	Pressure	Tmax	<u>Tmin</u>	Qmax	Qmin	Q ₂ max	<u>Q₂min</u>	Q ₂ Ref
Number	hPa	<u>K</u>	K	ppmv*	ppmv*	ppmv*	ppmv*	ppmv*
<u>1</u>	0.01	245.95	143.66	<u>5.24</u>	<u>0.91</u>	1.404	0.014	0.296
2	0.01	252.13	154.19	6.03	1.08	<u>1.410</u>	0.069	0.321
<u>3</u>	0.03	263.71	168.42	7.42	1.35	1.496	0.108	0.361
4	0.03	280.12	180.18	<u>8.10</u>	1.58	1.670	<u>0.171</u>	0.527
<u>5</u>	0.13	299.05	194.48	8.44	1.80	2.064	0.228	0.769
<u>6</u>	0.23	318.64	206.21	<u>8.59</u>	1.99	2.365	0.355	1.074
<u>7</u>	0.41	336.24	205.66	8.58	2.49	2.718	0.553	1.471
8	0.67	342.08	197.17	8.34	3.01	3.565	0.731	1.991
<u>9</u>	1.08	340.84	189.50	8.07	<u>3.30</u>	5.333	0.716	2.787
<u>10</u>	<u>1.67</u>	334.68	179.27	7.89	<u>3.20</u>	7.314	0.643	3.756
<u>11</u>	2.50	322.5	<u>17627</u>	7.75	2.92	<u>9.191</u>	0.504	4.864
<u>12</u>	3.65	312.51	175.04	7.69	2.83	10.447	0.745	5.953
<u>13</u>	<u>5.19</u>	303.89	173.07	7.58	<u>2.70</u>	12.336	1.586	<u>6.763</u>
14	7.22	295.48	168.38	7.53	2.54	12.936	1.879	7.109
<u>15</u>	9.84	293.33	166.30	7.36	2.46	12.744	1.322	7.060
<u>16</u>	<u>13.17</u>	287.05	16347	7.20	<u>2.42</u>	<u>11.960</u>	<u>0.719</u>	<u>6.574</u>
<u>17</u>	17.33	283.36	161.49	6.96	2.20	<u>11.105</u>	0.428	5.687
<u>18</u>	22.46	<u>280.93</u>	<u>161.47</u>	<u>6.75</u>	<u>1.71</u>	9.796	0.278	<u>4.705</u>
<u>19</u>	28.69	282.67	162.09	6.46	1.52	8.736	0.164	3.870
<u>20</u>	<u>36.17</u>	27993	162.49	<u>6.14</u>	<u>1.31</u>	7.374	<u>0.107</u>	3.111
<u>21</u>	45.04	27315	164.66	5.90	<u>1.36</u>	6.799	0.055	2.478
22	55.44	265.93	166.19	6.21	1.30	5.710	0.048	1.907
<u>23</u>	67.51	264.7	<u>167.42</u>	<u>9.17</u>	<u>1.16</u>	4.786	0.043	<u>1.440</u>
24	81.37	261.95	159.98	17.89	0.36	4.390	0.038	1.020

25	97.15	262.43	163.95	20.30	0.01	3.619	0.016	0.733
<u>26</u>	<u>114.94</u>	259.57	168.59	<u>33.56</u>	0.01	2.977	0.016	0.604
27	134.83	259.26	169.71	102.24	0.01	2.665	0.016	0.489
28	156.88	260.13	169.42	285.00	0.01	2.351	0.013	0.388
<u>29</u>	<u>181.14</u>	262.27	17063	714.60	<u>0.01</u>	1.973	0.010	0.284
<u>30</u>	207.61	264.45	174.11	1464.00	0.01	1.481	0.013	0.196
<u>31</u>	236.28	270.09	<u>177.12</u>	2475.60	0.01	1.075	0.016	0.145
<u>32</u>	267.10	277.93	181.98	4381.20	0.01	0.774	0.015	0.110
<u>33</u>	300.00	285.18	184.76	6631.20	0.01	0.628	0.015	0.086
34	334.86	293.68	187.69	9450.00	1.29	0.550	0.016	0.073
<u>35</u>	371.55	300.12	190.34	12432.00	<u>1.52</u>	0.447	0.015	0.063
<u>36</u>	409.89	302.63	194.40	15468.00	<u>2.12</u>	0.361	<u>0.015</u>	0.057
<u>37</u>	449.67	304.43	198.46	18564.00	2.36	0.284	0.015	0.054
<u>38</u>	490.&5	307.2	<u>201.53</u>	21684.00	<u>2.91</u>	0.247	<u>0.015</u>	0.052
<u>39</u>	532.56	<u>31217</u>	202.74	24696.00	3.67	0.199	0.015	0.050
<u>40</u>	572.15	<u>31556</u>	201.61	27480.00	<u>3.81</u>	0.191	0.012	0.050
<u>41</u>	<u>618.07</u>	<u>318.26</u>	<u>189.95</u>	30288.00	6.82	<u>0.171</u>	0.010	0.049
<u>42</u>	661.00	<u>321.71</u>	<u>189.95</u>	<u>32796.00</u>	<u>6.07</u>	<u>0.128</u>	0.009	0.048
<u>43</u>	703.59	<u>327.95</u>	<u>189.95</u>	<u>55328.00</u>	<u>6.73</u>	<u>0.124</u>	0.009	0.047
<u>44</u>	745.48	<u>333.77</u>	<u>189.95</u>	<u>37692.00</u>	8.71	<u>0.117</u>	0.009	0.046
<u>45</u>	786.33	<u>336.46</u>	<u>189.95</u>	<u>39984.00</u>	<u>8.26</u>	<u>0.115</u>	0.008	0.045
<u>46</u>	825.75	338.54	<u>189.95</u>	42192.00	<u>7.87</u>	<u>0.113</u>	0.008	0.043
<u>47</u>	863.40	<u>342.55</u>	<u>189.95</u>	44220.00	7.53	<u>0.111</u>	0.007	0.041
<u>48</u>	898.93	346.23	189.95	46272.00	7.23	0.108	0.006	0.040
<u>49</u>	<u>931.99</u>	34924	<u>189.95</u>	47736.00	<u>6.97</u>	0.102	0.006	0.038
<u>50</u>	962.26	349.92	189.95	51264.00	6.75	0.099	0.006	0.034
<u>51</u>	<u>989.45</u>	350.09	<u>189.95</u>	<u>49716.00</u>	<u>6.57</u>	0.099	0.006	0.030
52	1013.29	360.09	189.95	47208.00	6.41	0.094	0.006	0.028
<u>53</u>	<u>1033.54</u>	350.09	<u>189.95</u>	47806.00	6.29	0.094	0.006	0.027
<u>54</u>	<u>1050.00</u>	350.09	<u>189.95</u>	47640.00	<u>6.19</u>	0.094	0.006	0.027

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Table A2. Pressure levels adopted for IFS-137 137 pressure levels

1988

<u>(in hPa).</u> Level pressure pressure pressure Level Level Level pressure Level pressure number hPa number hPa number hPa number hPa number hPa 12.8561 106.4153 424.019 934.7666 0.02 31 61 91 121 1 2 0.031 32 14.2377 62 112.0681 92 441.5395 122 943.1399 3 0.0467 33 15.7162 63 117.9714 459.6321 123 950.9082 93 4 0.0683 17.2945 124.1337 478.3096 958.1037 <u>34</u> <u>64</u> <u>94</u> 124 0.0975 18.9752 130.5637 497.5845 125 964.7584 5 35 65 95 6 0.1361 36 20.761 66 137.2703 96 517.4198 126 970.9046 7 0.1861 37 22.6543 67 144.2624 97 537.7195 127 976.5737 8 0.2499 38 24.6577 68 151.5493 98 558.343 128 981.7968 9 0.3299 39 26.7735 69 159.1403 99 579.1926 129 986.6036 10 0.4288 40 29.0039 70 167.045 100 600.1668 130 991.023 31.3512 101 621.1624 995.0824 11 0.5496 41 71 175.2731 131 998.8081 12 0.6952 42 33.8174 72 183.8344 102 642.0764 132 13 0.869 43 36.4047 <u>73</u> 192.7389 103 662.8084 133 1002.225 14 1.0742 44 39.1149 74 201.9969 104 683.262 134 1005.356 15 1.3143 45 41.9493 75 211.6186 105 703.3467 135 1008.224 1.5928 44.9082 106 722.9795 1010.849 16 46 76 221.6146 136 17 1.9134 47 47.9915 77 231.9954 107 742.0855 137 1013.25 18 2.2797 48 51.199 78 242.7719 108 760.5996 19 2.6954 49 54.5299 109 778.4661 79 253.9549 57.9834 795.6396 20 3.1642 50 80 265.5556 110 812.0847 21 3.6898 51 61.5607 81 277.5852 111 22 4.2759 52 65.2695 82 290.0548 112 827.7756 23 4.9262 53 69.1187 83 302.9762 113 842.6959 24 5.6441 54 73.1187 316.3607 114 856.8376 84 25 6.4334 55 77.281 85 330.2202 115 870.2004 26 7.2974 56 81.6182 86 344.5663 116 882.791 27 57 8.2397 86.145 87 359.4111 117 894.6222 28 9.2634 58 90.8774 88 374.7666 118 905.7116 29 10.372 59 95.828 89 390.645 119 916.0815 30 11.5685 60 101.0047 90 407.0583 120 925.7571

1989 Author contributions. ZS contributed the central idea. SC, ZS and

1986

HD conceived the method, developed the retrieval algorithm and discussed the results. SC analyzed the data, prepared the figures and wrote the paper. WG contributed to refining the ideas, carrying out additional analyses. All co-authors reviewed the paper.

1994

1995 *Competing interests*. The authors declare that they have no conflict 1996 of interest.

1997

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2166	(c) The marked-up manuscript version
2167	
2168	A channel selection method for hyperspectral
2169	atmospheric infrared sounders based on
2170	layering
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2182	
2183	Abstract. Because a satellite channel's ability to resolve
2184	hyperspectral data varies with height, an improved channel selection
2185	method is proposed based on information content. An effective
2186	channel selection scheme for a hyperspectral atmospheric infrared
2187	sounder using AIRS data based on layering is proposed. The results

are as follows: (1) Using the improved method, the atmospheric 2188 retrievable index is more stable, the value reaching 0.54. The 2189 coverage of the weighting functions is more evenly distributed over 2190 height with this method and closer to the actual atmosphere; (2) 2191 Statistical inversion comparison experiments show that the accuracy 2192 of the retrieval temperature, using the improved channel selection 2193 method in this paper, is consistent with that of 1Dvar channel 2194 selection. In the stratosphere and mesosphere especially, from 10 hPa 2195 to 0.02 hPa, the accuracy of the retrieval temperature of our 2196 improved channel selection method is improved by about 1 K. In 2197 general, the accuracy of the retrieval temperature of ICS (Improved 2198 Channel Selection) is improved; (3) Statistical inversion comparison 2199 experiments in four typical regions indicate that ICS in this paper is 2200 significantly better than NCS (NWP Channel Selection) and PCS 2201 (Primary Channel Selection) in different regions and shows 2202 latitudinal variations, which shows potential for future applications. 2203 2204

2205 **1 Introduction**

Since the successful launch of the first meteorological satellite,
TIROS in the 1960s, satellite observation technology has developed
rapidly. Meteorological satellites observe the Earth's atmosphere
from space and are able to record data from regions which are

otherwise difficult to observe. Satellite data greatly enrich the 2210 content and range of meteorological observations, and consequently, 2211 atmospheric exploration technology and meteorological observations 2212 have taken us to a new stage in our understanding of weather 2213 systems and related phenomena (Fang, 2014). From the perspective 2214 of vertical atmospheric observation, satellite instruments are 2215 developing rapidly. In their infancy, the traditional infrared 2216 measurement instruments for detecting atmospheric temperature and 2217 moisture profiles, such as TOVS (Smith et al., 1991) or HIRS in 2218 ATOVS (Chahine, 1972; Li et al., 2000; Liu, 2007), usually 2219 employed filter spectrometry. Even though such instruments have 2220 played an important role in improving weather prediction, it is 2221 difficult to continue to build upon improvements in terms of 2222 observation accuracy and vertical resolution due to the limitation of 2223 low spectral resolution. By using this kind of filter-based 2224 spectroscopic measurement instrument, therefore, it is difficult to 2225 meet today's needs in numerical weather prediction (Eyre et al., 2226 1993; Prunet et al., 2010; Menzel et al., 2018). To meet this 2227 challenge, a series of plans for the creation of high-spectral 2228 resolution atmospheric measurement instruments has been executed 2229 in the United States and in Europe in recent years: One example is 2230 the AIRS (Atmospheric InfraRed Sounder) on the Earth Observation 2231

System, "Aqua", launched on May 4, 2002 from the United States. 2232 AIRS has 2378 spectral channels providing sensitivity from the 2233 ground to up to about 65 km of altitude (Aumann et al., 2003; 2234 Hoffmann and Alexander, 2009; Gong et al., 2011). The United 2235 States and Europe, in 2010 and in 2007, also installed the CRIS 2236 (Cross-track Infrared Sounder) and the IASI (Inter-Attractive 2237 Atmospheric Sounding Interferometer) on polar-orbiting satellites. 2238 China also devotes great importance to the development of such 2239 advanced sounding technologies. In the early 1990s, the National 2240 Satellite Meteorological Center began to investigate the principles 2241 and techniques of hyperspectral resolution atmospheric observations. 2242 China's development of interferometric atmospheric vertical 2243 detectors eventually led to the launch of Fengyun No. 3, on May 27, 2244 2008, and Fengyun No. 4 on December 11, 2016, both of which 2245 were equipped with infrared atmospheric instruments. How best to 2246 use the hyperspectral resolution observation data obtained from 2247 these instruments, to obtain reliable atmospheric temperature and 2248 humidity profiles, is an active area of study in atmospheric inversion 2249 theory. 2250

Due to technical limitations, only a limited number of channels could at first be built into the typical satellite instruments. In this case, channel selection generally involved controlling the channel

weighting function by utilizing the spectral response characteristics 2254 of the channel (such as center frequency and bandwidth). With the 2255 development of measurement technology, increasing numbers of 2256 hyperspectral detectors were carried on meteorological satellites. 2257 Due to the large number of channels and data supported by such 2258 instruments today (such as AIRS with 2378 channels and IASI with 2259 8461 channels), it has proven extremely cumbersome to store, 2260 transmit, and process such data. Moreover, there is often a close 2261 correlation between the channel, causing an ill-posedness of the 2262 inversion, potentially compromising accuracy of the retrieval 2263 product based on hyperspectral resolution data. 2264

However, hyperspectral detectors have many channels and 2265 provide real-time mode prediction systems with vast quantities of 2266 data, which can significantly improve prediction accuracy. But, if all 2267 the channels are used to retrieve data, the retrieval time considerably 2268 increases. Even more problematic are the glut of information 2269 produced, and the unsuitability of the calculations for real-time 2270 forecasting. Concurrently, the computer processing power must be 2271 large enough to meet the demands of simulating all the channels 2272 simultaneously within the forecast time. It is important to properly 2273 select a group of channels that can provide as much information as 2274 possible from the thousands of channels' observations to improve the 2275

2276 calculation efficiency and retrieval quality.

Many researchers have studied the channel selection algorithm. 2277 Menke (1984) first chose channels using a data precision matrix 2278 method. Aires et al. (1999) made the selection using the Jacobian 2279 matrix, which has been widely used since then (Aires et al., 2002; 2280 Rabier et al., 2010). Rodgers (2000) indicated that there are two 2281 useful quantities in measuring the information provided by the 2282 observation data: Shannon information content and degrees of 2283 freedom. The concept of information capacity then became widely 2284 used in satellite channel selection. In 2007, Xu (2007) compared the 2285 Shannon information content with the relative entropy, analyzing the 2286 information loss and information redundancy. In 2008, Du et al. 2287 (2008) introduced the concept of the atmospheric retrievable index 2288 (ARI) as a criterion for channel selection, and in 2010, Wakita et al. 2289 (2010) produced a scheme for calculating the information content of 2290 the various atmospheric parameters in remote sensing using 2291 Bayesian estimation theory. Kuai et al. (2010) analyzed both the 2292 Shannon information content and degrees of freedom in channel 2293 selection when retrieving CO₂ concentrations using thermal infrared 2294 remote sensing and indicated that 40 channels could contain 75% of 2295 the information from the total channels. Cyril et al. (2003) proposed 2296 the optimal sensitivity profile method based on the sensitivity of 2297

different atmospheric components. Lupu et al. (2012) used degrees 2298 of freedom for signals (DFS) to estimate the amount of information 2299 contained in observations in the context of observing system 2300 experiments. In addition, the singular value decomposition method 2301 has also been widely used for channel selection (Prunet et al., 2010; 2302 Zhang et al., 2011; Wang et al., 2014). In 2017, Chang et al. (2017) 2303 selected a new set of Infrared Atmospheric Sounding Interferometer 2304 (IASI) channels using the channel score index (CSI). Richardson et 2305 al. (2018) selected 75 from 853 channels based on the high 2306 spectral-resolution oxygen A-band instrument on NASA's Orbiting 2307 Carbon Observatory-2 (OCO-2), using information content analysis 2308 to retrieve the cloud optical depth, cloud properties, and position. 2309 Today's main methods for channel selection use only the 2310 weighting function to study appropriate numerical methods, such as 2311 the data precision matrix method (Menke, 1984), singular value 2312 decomposition method (Prunet et al., 2010; Zhang et al., 2011; Wang 2313 et al., 2014), and the Jacobi method (Aires et al., 1999; Rabier et al., 2314 2010). The use of the methods allows sensitive channels to be 2315 selected. The above-mentioned studies also take into account the 2316 sensitivity of each channel to atmospheric parameters during channel 2317 selection, while ignoring some factors that impact retrieval results. 2318 The accuracy of retrieval results depends not only on the channel 2319

weighting function but also on the channel noise, background field,and the retrieval algorithm.

Currently, information content is often employed in channel 2322 selection. During retrieval, this method delivers the largest amount 2323 of information for the selected channel combination (Rodgers, 1996; 2324 Du et al., 2008; He et al., 2012; Richardson et al., 2018). This 2325 method has made great breakthroughs in both theory and practice, 2326 and the concept of information content itself does consider all the 2327 height dependencies of the kernel matrix K (Rodgers, 2000). 2328 However, earlier works have neglected the height dependencies of K 2329 for simplicity. This paper uses the atmospheric retrievable index 2330 (ARI) as the index, which is based on information content (Du et al., 2331 2008; Richardson et al. 2018). Channel selection is made at different 2332 heights, and an effective channel selection scheme is proposed 2333 which fully considers various factors, including the influence of 2334 different channels on the retrieval results at different heights. This 2335 ensures the best accuracy of the retrieval product when using the 2336 selected channel. In addition, statistical inversion comparison 2337 experiments are used to verify the effectiveness of the method. 2338 2339

2340 2 Channel selection indicator, scheme and method

2341 **2.1 Channel selection indicator**

According to the concept of information content, the information
content contained in a selected channel of a hyperspectral instrument
can be described as H (Rodgers, 1996; Rabier et al., 2010). The final
expression of H is:

2346

$$\mathbf{H} = -\frac{1}{2}\ln\left|\hat{S}S_a^{-1}\right|$$

2347

2348
$$= -\frac{1}{2} ln |(S_a - S_a K^T (K S_a K^T + S_{\varepsilon})^{-1} K S_a) S_a^{-1}|, \qquad (1)$$
2349

where S_a is the error covariance matrix of the background or the 2350 estimated value of atmospheric profile, S_{ε} represents the 2351 observation error covariance matrix of each hyperspectral detector 2352 channel, $\hat{S} = (S_a - S_a K^T (K S_a K^T + S_{\varepsilon})^{-1} K S_a)$ denotes the 2353 covariance matrix after retrieval, K is the weighting function matrix. 2354 In order to describe the accuracy of the retrieval results visually 2355 and quantitatively, the atmospheric retrievable index (ARI), p, (Du et 2356 al., 2008) is defined as follows: 2357

2358

2359
$$p = 1 - \exp(\frac{1}{2n} ln |\hat{S}S_a^{-1}|),$$
 (2)

2360

Assuming that before and after retrieval, the ratio of the root mean square error of each element in the atmospheric state vector is 1-p,

then $|\hat{S}S_a^{-1}| = (1-p)^{2n}$ is derived. By inverting the equation, the 2363 ARI that is p can be obtained in Eq. (2), which indicates the relative 2364 portion of the error that is eliminated by retrieval. In fact, before and 2365 after retrieval, the ratio of the root mean square error of each element 2366 cannot be 1-p. Therefore, p defined by Eq. (1) is actually an overall 2367 evaluation of the retrieval result. 2368

2369

2370

2.2 Channel selection scheme

The principle of channel selection is to find the optimum channel 2371 combination after numbering the channels. This combination makes 2372 the information content, H, or the ARI defined in this paper as large 2373 as possible, in order to maintain the highest possible accuracy in the 2374 retrieval results. 2375

Let there be M layers in the vertical direction of the atmosphere 2376 and N satellite channels. Selecting n from N channels, there will be 2377 C_N^n combinations in each layer, leading C_N^n calculations to get C_N^n 2378 kinds of p results. Furthermore, there are M layers in the vertical 2379 direction of the atmosphere. Therefore, the entire atmosphere must 2380 be calculated $\mathbf{M} \cdot \mathbf{C}_{\mathbf{N}}^{n}$ times. However, the calculation $\mathbf{M} \cdot \mathbf{C}_{\mathbf{N}}^{n}$ times 2381 will be particularly large, which makes this approach impractical in 2382 calculating p for all possible combinations. Therefore, it is necessary 2383 to design an effective calculation scheme, and such a scheme, i.e., a 2384

channel selection method, using iteration is proposed, called the
"sequential absorption method" (Dudhia et al., 2002; Du et al., 2008).
The method's main function is to select ("absorb") channels one by
one, taking the channel with the maximum value of p. Through n
iterations, n channels can be selected as the final channel
combination. The steps are as follows:

(1) The expression of information content in a single channel:

First, we use only one channel for retrieval. A row vector, k, in the weighting function matrix, K, is a weighting function corresponding to the channel. After observation in this channel, the error covariance matrix is:

2396
$$\hat{S} = S_a - S_a k^T (s_{\varepsilon} + k S_a k^T)^{-1} k S_a.$$
 (3)

It should be noted that $(s_{\varepsilon} + kS_ak^T)$ is a scalar value in Eq. (3), so Eq. (3) can be converted to:

2399
$$\hat{S} = \left(I - \frac{S_a k^T k}{\left(s_{\varepsilon} + k S_a k^T\right)}\right) S_a = \left(I - \frac{\left(k S_a\right)^T k}{\left(s_{\varepsilon} + k\left(k S_a\right)^T\right)}\right) S_a.$$
(4)

2400 Substituting Eq. (4) into Eq. (2) gives:

2401
$$p = 1 - \exp(\frac{1}{2n} ln(\left|I - \frac{(kS_a)^T k}{(s_{\varepsilon} + k(kS_a)^T)}\right|)).$$
 (5)

2402

Since S_a and S_{ε} are positive definite symmetric matrixes, it can be decomposed into $S_a = (S_a^{1/2})^T (S_a^{1/2})$ and $S_{\varepsilon} = (S_{\varepsilon}^{1/2})^T (S_{\varepsilon}^{1/2})$.

2407 Define
$$R = S_{\varepsilon}^{1/2} K S_{a}^{1/2}$$
. (6)

2408

The matrix R can then be regarded as a weighting function matrix, normalized by the observed error and a priori uncertainty. A row vector of R, $r = s_{\varepsilon}^{-1/2} k S_a^{1/2}$, represents the normalized weighting function matrix of a single channel. Substituting r into Eq. (5) gives: 2413

2414
$$p = 1 - \exp(\frac{1}{2n} ln\left(\left|I - \frac{rr^T}{1 + r^T r}\right|\right)).$$
 (7)

2415

For arbitrary row vectors, a and b, using the matrix property $det(I + a^Tb) = 1 + ba^T$, the new expression for p is:

2418

$$p = 1 - \exp\left(\frac{1}{2n}\ln\left(1 - \frac{r^{T}r}{1 + r^{T}r}\right)\right)$$

$$= 1 - \exp\left(\frac{1}{2n}\ln\left(\frac{1}{1 + r^{T}r}\right)\right)$$

2420 =
$$1 - \exp\left(-\frac{1}{2n}ln(1+r^Tr)\right)$$
. (8)

2421

2422 (3) Iteration in a single layer:

First, the iteration in a single layer requires the calculation of R.

2424 According to S_a , S_ϵ , K and Eq. (6), R can be calculated. Second,

using Eq. (8), p of each candidate channel can be calculated.

2426 Moreover, the channel corresponding to maximum p is the selected 2427 channel for this iteration. After a channel has been selected,

according to Eq. (3) we can use \hat{S} to get S_a for the next iteration.

Finally, channels which are not selected during this iteration are used

as the candidate channels for the next iteration.

2431 When selecting n from N channels, it is necessary to calculate

2432 (N-n/2)n \approx Nn p values, which is much smaller than C_N^n . In addition

to high computational efficiency by using this method, another

advantage is that all channels can be recorded in the order in which

they are selected. In the actual application, if n' channels are

needed, and n' < n, we will not need to select the channel again,

²⁴³⁷ but record the selected channel only.

2438 (4) Iteration for different altitudes:

2439 Because satellite channel sensitivity varies with height, repeating

the iterative process of step (3), selects the optimum channels at

different heights. Assuming there are M layers in the atmosphere and

selecting n from N channels, it is necessary to calculate $M \cdot (N -$

2443 n/2)n \approx M · Nn p values, a much smaller number than M · C_Nⁿ. In

this way, different channel sets can be used to evaluate

corresponding height in the retrieved profiles.

2446

2447 **2.3 Statistical inversion method**

The inversion methods for the atmospheric temperature profiles can 2448 be summarized in two categories: statistical inversion and physical 2449 inversion. Statistical inversion is essentially a linear regression 2450 model which uses a large number of satellite measurements and 2451 atmospheric parameters to match samples and calculate their 2452 correlation coefficient. Then, based on the correlation coefficient, the 2453 required parameters of the independent measurements obtained by 2454 the satellite are retrieved. Because the method does not directly solve 2455 the radiation transfer equation, it has the advantages of fast 2456 calculation speed. In addition, the solution is numerically stable, 2457 which makes it one of the highest precision methods (Chedin et al., 2458 1985). Therefore, the statistical inversion method will be used for 2459 our channel selection experiment and a regression equation will be 2460 established. 2461

According to an empirical orthogonal function, the atmospheric temperature (or humidity), T, and the brightness temperature, T_b , are expanded as:

2465

 $T = T^* \cdot A, \tag{9}$

2467

 $T_b = T_b^* \cdot A, \tag{10}$

2470	where T^* and T_b^* are the eigenvectors of the covariance matrix of
2471	temperature (or humidity) and brightness temperature, respectively.
2472	A and B stand for the corresponding expansion coefficient vectors of
2473	temperature (humidity) and brightness temperature.
2474	Using the least squares method and the orthogonal property, the
2475	coefficient conversion matrix, V, is introduced:
2476	
2477	$\mathbf{A} = \mathbf{V} \cdot \mathbf{B},\tag{11}$
2478	
2479	where $V = AB^T (BB^T)^{-1}$. (12)
2480	
2481	Using the orthogonality, we get:
2482	
2483	$\mathbf{B} = (T_b^*)^T T_b, \tag{13}$
2484	
2485	$\mathbf{A} = (T^*)^T T. \tag{14}$
2486	
2487	For convenience, the anomalies of the state vector (atmospheric
2488	temperature), T, and the observation vector (brightness temperature),
2489	T_b , are taken:
2490	

2491
$$\widehat{T} = \overline{T} + \widehat{T}' = \overline{T} + GT_{b}' = \overline{T} + G(T_{b} - \overline{T_{b}}),$$
 (15)

where \hat{T} stands for the retrieval atmospheric temperature. \overline{T} and $\overline{T_{b}}$ are the corresponding average values of the elements, respectively. \hat{T}' and $\overline{T_{b}'}$ represent the corresponding anomalies of the elements, respectively. Assuming there are k sets of observations, a sample anomaly

2498 matrix with k vectors can be constructed:

2499

2500
$$T' = (t'_1, t'_2, \cdots, t'_k),$$
 (16)

2501

2502
$$T_{b}' = (t_{b1}', t_{b2}', \cdots, t_{bk}').$$
 (17)

2503

2505

2506
$$\delta = \overline{T} - \widehat{T} = \widehat{T}' - T' .$$
(18)

2507

2508 The retrieval error covariance matrix is:

2509

$$S_{\delta} = \frac{1}{k - n - 1} \delta \delta^{T}$$

$$= \frac{1}{k - n - 1} (T' - GT_{b}') (T' - GT_{b}')^{T}$$

$$= \frac{k - 1}{k - n - 1} (S_{e} - G^{T}S_{xy} - S_{xy}G^{T} + GS_{y}G^{T}), \qquad (19)$$

2513 where

2514

2515
$$S_e = \frac{1}{k-1}T'T''$$
,
2516 $S_y = \frac{1}{k-1}T_b'T_b''$,

2517
$$S_{xy} = \frac{1}{k-1}T'T_{b}'^{T}$$
 (20)

2518

S_e stands for the sample covariance matrix of T, S_y denotes the sample covariance matrix of T_b , and S_{xy} represents the covariance matrix of T and T_b . The elements on the diagonal of the error covariance matrix, S_{δ}, represent the retrieval error variance of T. The matrix G that minimizes the overall error variance is the least squares coefficient matrix of the regression equation (15), which meets the criteria:

2526

2527
$$\delta^2 = tr(S_{\delta}) = min.$$
 (21)

2528

Taking a derivative of Eq. (21) with respect to G, $\frac{\partial}{\partial G} tr(S_{\delta}) = 0 =$ (-2S_{xy} + 2GS_y), which means that:

2532
$$G = S_{xy}S_y^{-1}$$
. (22)

Substituting Eq. (22) into Eq. (15) finally gives the least squaressolution as:

2536

2537
$$\widehat{T} = \overline{T} + S_{xy}S_{y}^{-1}(T_{b} - \overline{T_{b}}).$$
(23)

2538

It should be noted that the least squares solution obtained here aims to minimize the sum of the error variance for each element in the atmospheric state vector after retrieval for several times. At present, statistical multiple regression is widely used in the retrieval of atmospheric profiles based on atmospheric remote sensing data. As long as there are enough data, S_{xy} and S_y can be determined.

2546 **3. Channel selection experiment**

2547 **3.1 Data and model**

2548 The Atmospheric Infrared Sounder (AIRS) is primarily designed to

measure the Earth's atmospheric water vapor and temperature

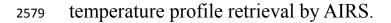
profiles on a global scale (Aumann et al., 2003; Hoffmann and

Alexander, 2009). AIRS is a continuously operating cross-track

- scanning sounder, consisting of a telescope that feeds an echelle
- spectrometer. The AIRS infrared spectrometer acquires 2378 spectral
- samples at a resolution $\lambda/\Delta\lambda$, ranging from 1086 to 1570, in three
- bands: $3.74 \ \mu m$ to $4.61 \ \mu m$, $6.20 \ \mu m$ to $8.22 \ \mu m$, and $8.8 \ \mu m$ to $15.4 \ \mu m$

µm. The footprint size 13.5 km at nadir (Susskind et al., 2003). The 2556 spectral range includes 4.3 µm and 15.5 µm for important 2557 temperature observation and CO_2 , 6.3 µm for water vapor, and 9.6 2558 µm for ozone absorption bands (Menzel et al., 2018). The root mean 2559 square error (RMSE) of the measured radiation is better than 0.2 K 2560 (Susskind et al., 2003). Moreover, global atmospheric profiles can be 2561 detected every day. Due to radiometer noise and faults, there are 2562 currently only 2047 effective channels. However, compared with 2563 previous infrared detectors, AIRS boasts a significant improvement 2564 in both the number of channels and spectral resolution (Aumann, 2565 1994; Huang et al., 2005; Li et al., 2005). 2566 The root mean square error of an AIRS infrared channel is shown 2567 in Fig. 1, with black spots, indicating that not all the instrument 2568 channels possess a measurement error of less than 0.2 K. There are a 2569 few channels with extremely large measurement errors, which 2570 reduce the accuracy of prediction to some extent. Among them, 2571 some extremely large measurement errors reduce the accuracy of 2572 prediction to some extent (Susskind et al., 2003). At present, more 2573 than 300 channels have not been used because their errors exceed 1 2574 K. If data from these channels were to be used for retrieval, the 2575 accuracy of the retrieval could be reduced. Therefore, it is necessary 2576 to select a group of channels to improve the calculation efficiency 2577

and retrieval quality. In this paper we study channel selection for



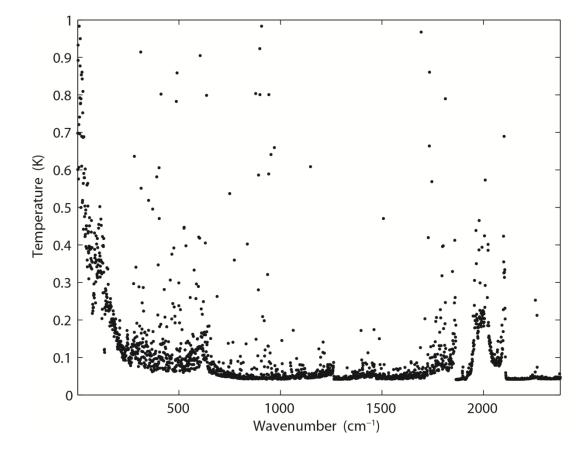


Figure 1. Root mean square error of AIRS infrared channel (blackspots).

2583

2580

For the calculation of radiative transfer and the weighting function

2585 matrix, K, the RTTOV (Radiative Transfer for TOVS) v12 fast

radiative transfer model is used. Although initially developed for the

2587 TOVS (TIROS Operational Vertical Sounder) radiometers, RTTOV

can now simulate around 90 different satellite sensors measuring in

the MW (microwave), IR (infrared) and VIS (visible) regions of the

spectrum (Saunders et al., 2018). The model allows rapid

simulations (1 ms for 40 channel ATOVS (Advanced TOVS) on a 2591 desktop PC) of radiances for satellite visible, infrared, or microwave 2592 nadir scanning radiometers given atmospheric profiles of 2593 temperature and trace gas concentrations, and cloud and surface 2594 properties. The only mandatory gas included as a variable for 2595 RTTOV v12 is water vapor. Optionally, ozone, carbon dioxide, 2596 nitrous oxide, methane, carbon monoxide, and sulfur dioxide can be 2597 included, with all other constituents assumed to be constant. RTTOV 2598 can accept input profiles on any defined set of pressure levels. The 2599 majority of RTTOV coefficient files are based on the 54 levels (see 2600 Table A1 in Appendix A), ranking from 1050 hPa to 0.01 hPa, 2601 though coefficients for some hyperspectral sounders are also 2602 available on 101 levels. 2603

In order to correspond to the selected profiles, the atmosphere is 2604 divided into 137 layers, each of which contains corresponding 2605 atmospheric characteristics, such as temperature, pressure, and the 2606 humidity distribution. Each element in the weighting function matrix 2607 can be written as $\partial yi/\partial xj$. The subscript i is used to identify the 2608 satellite channel, and the subscript j is used to identify the 2609 atmospheric variable. Therefore, $\partial yi/\partial xj$ indicates the variation in 2610 brightness temperature in a given satellite channel, when a given 2611 atmospheric variable in a given layer changes. We are thus able to 2612

2613 establish which layer of the satellite channel is particularly sensitive

to which atmospheric characteristic (temperature, various gas

contents) in the vertical atmosphere. The RTTOV_K (the K mode),

is used to calculate the matrix H(X0) (Eq. (1)) for a given

2617 atmospheric profile characteristic.

2618

2621

3.2 Channel selection comparison experiment and results

In order to verify the effectiveness of the method, three sets of

comparison experiments were conducted. First, 324 channels used

2622 by the EUMETSAT Satellite Application Facility on Numerical

2623 Weather Prediction (NWP SAF) were selected. NCS is short for

NWP channel selection in this paper. NCS were released by the

2625 NWPSAF 1DVar (one-dimensional variational analysis) scheme, in

accordance with the requirements of the NWPSAF (Saunders et al.,

2627 2018). Second, 324 channels were selected using the information

capacity method. This method was adopted by Du et al. (2008)

without the consideration of layering. PCS is short for primary

channel selection in this paper.

Third, 324×M channels were selected using the information capacity method for the M layer atmosphere. ICS is short for improved channel selection in this paper. In order to verify the

²⁶³⁴ retrieval effectiveness after channel selection, statistical inversion

comparison experiments were performed using 5000 temperature
profiles provided by the ECMWF dataset, which will be introduced
in Sect. 4.

The observation error covariance matrix, S_{ε} , in the experiment is 2638 provided by NWP SAF 1Dvar. In general, it can be converted to a 2639 diagonal matrix, the elements of which are the observation error 2640 standard deviation of each hyperspectral detector channel, which is 2641 the square of the root mean square error for each channel. The root 2642 mean square error of the AIRS channels is shown in Fig. 1. The error 2643 covariance matrix of the background, S_a , is calculated using 5000 2644 samples of the IFS-137 data provided by the ECMWF dataset (The 2645 detailed information will be introduced in Sect. 4). The last access 2646 date is April 26th, 2019 (download address: 2647 https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/, 2648 2019). The covariance matrix of temperature is shown in Fig. 2. The 2649

results are consistent with the previous study by Du et al. (2008).

2651

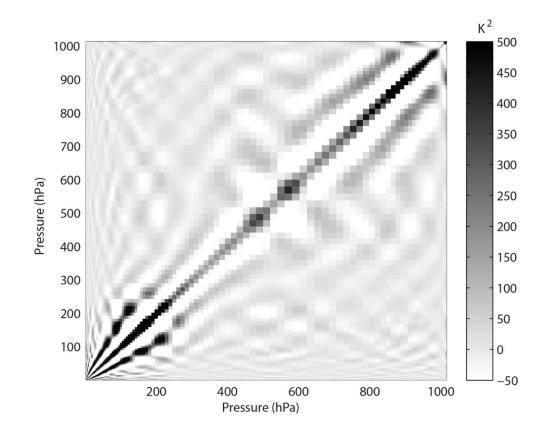


Figure 2. Error covariance matrix of temperature (shaded).

2652

The reference atmospheric profiles are from the IFS-137 database, 2655 and the temperature weighting function matrix is calculated using 2656 the RTTOV K mode, as shown in Fig. 3; the results are consistent 2657 with those of the previous study by Du et al. (2008). For the 2658 air-based passive atmospheric remote sensing studied in this paper, 2659 when the same channel detects the atmosphere from different 2660 observation angles, the value of the weighting function matrix K 2661 changes due to the limb effect. The goal of this section is focusing 2662 on the selection methods of selecting channels; therefore the biases 2663 produced from different observation angles can be ignored. 2664

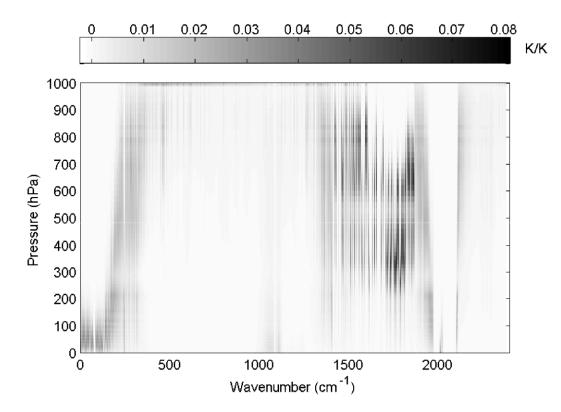


Figure 3. Temperature weighting function matrix (shaded).

In order to verify the effectiveness, the distribution of 324
channels, without considering layering, in the AIRS brightness
temperature spectrum is indicated in Fig. 4. The background
brightness temperature is the simulated AIRS observation brightness
temperature, which is from the atmospheric profile in RTTOV put
into the model. Figure 4(a) shows the 324 channels selected by PCS,
while Fig. 4(b) shows the 324 channels selected by NCS.

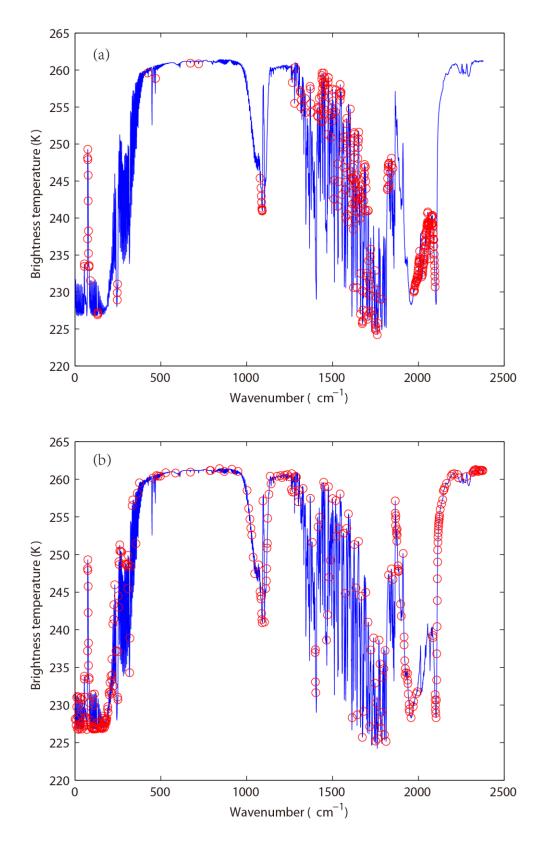


Figure 4. The distribution of different channel selection methodswithout considering layering in the AIRS brightness temperature

spectrum (blue line). (a) 324 channels selected by PCS (red circles).

2681 (b) 324 channels selected by NCS (red circles).

Without considering layering, the main differences between the 2682 324 channels selected by PCS and NCS are as follows: (1) When the 2683 wavenumber approaches 1000, the wavelength is $10 \,\mu m (1/1000)$ 2684 cm⁻¹). Near this band, fewer channels are selected by PCS because 2685 the retrieval of ground temperature is considered by NCS; (2) When 2686 the wavenumber is near 1200, the wavelength is 9 μ m (1/1200 cm⁻¹). 2687 Near this band, no channels are selected by PCS because the 2688 retrieval of O_3 is not considered in this paper; (3) When the 2689 wavenumber approaches 1500, the wavelength is 6.7 μ m (1/1500 2690 cm^{-1}). As is known, the spectral range from 6 μ m to 7 μ m 2691 corresponds to water vapor absorption bands, but fewer channels are 2692 selected by NCS; (4) When the wavenumber is close to 2000, it 2693 derives a wavelength of 5 μ m (1/2000 cm⁻¹), which includes 4.2 μ m 2694 for N_2O and 4.3 µm for CO_2 absorption bands. As is shown in Fig. 4, 2695 fewer channels are selected by PCS in those bands. PCS is favorable 2696 for atmospheric temperature observation in the high temperature 2697 zone. Because 4.2 μ m and 4.3 μ m bands are sensitive to high 2698 temperature, the higher temperature is, the better observation can be 2699 obtained; (5) In the near infrared area, the wavenumber exceeds 2700 2200, deriving a wavelength of less than 4 μ m (1/2000 cm⁻¹). A 2701

small number of channels is selected by NCS, but no channels areselected by PCS.

Above all, the information content used in this paper only takes 2704 the temperature profile retrieval into consideration, so the channel 2705 combination of PCS is inferior to that of NCS for the retrieval of 2706 surface temperature and the O_3 profile. The advantages of the 2707 channel selection method based on information content in this paper 2708 are mainly reflected in: (1) Stratosphere and mesosphere is less 2709 affected by the ground surface, so the retrieval result of PCS is better 2710 than that of NCS. (2) Due to the method selected in this paper there 2711 are more channels at 4.2 μ m for N₂O and 4.3 μ m for CO₂ absorption 2712 bands; the channel combination of PCS is better than that of NCS for 2713 atmospheric temperature observation to the higher temperature. 2714

By comparing channel selection without considering layering, we note the general advantages and disadvantages of PCS and NCS for the retrieval of temperature and can improve the channel selection scheme. First, the retrieval of the temperature profile for 324 channels selected by PCS is obtained. The relationship between the number of iterations and the ARI is shown in Fig. 5.

2721

2722

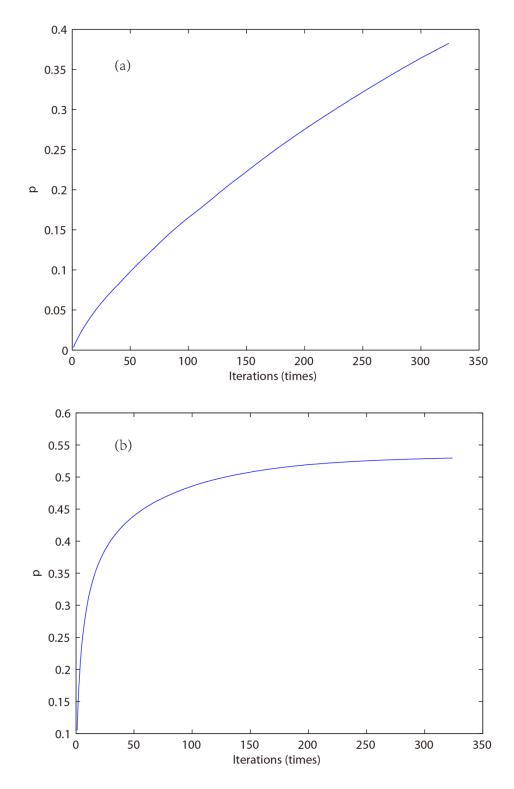


Figure 5. The relationship between the number of iterations and ARI.

2724 (a) PCS. (b) ICS.

The ARI for PCS tends to be 0.38 and is not convergent, so the 2726 PCS method needs to be improved. In this paper, the atmosphere is 2727 divided into 137 layers, and based on the information content and 2728 iteration, 324 channels are selected for each layer. Then, the 2729 temperature profile of each layer can be retrieved based on statistical 2730 inversion (see at Sect. 4). The relationship between the number of 2731 iterations and the ARI for ICS is shown in Fig. 5b. When the number 2732 of iterations approaches 100, the ARI of ICS tends to be stable, and 2733 reach to 0.54. Thus, in terms of the ARI and convergence, the ICS 2734 method is better than that of PCS. 2735 Furthermore, because an iterative method is used to select 2736 channels, the order of each selected channel is determined by the 2737 contribution from the ARI. The weighting function matrix of the top 2738 324 selected channels, according to channel order, is shown in Fig. 2739 6. 2740

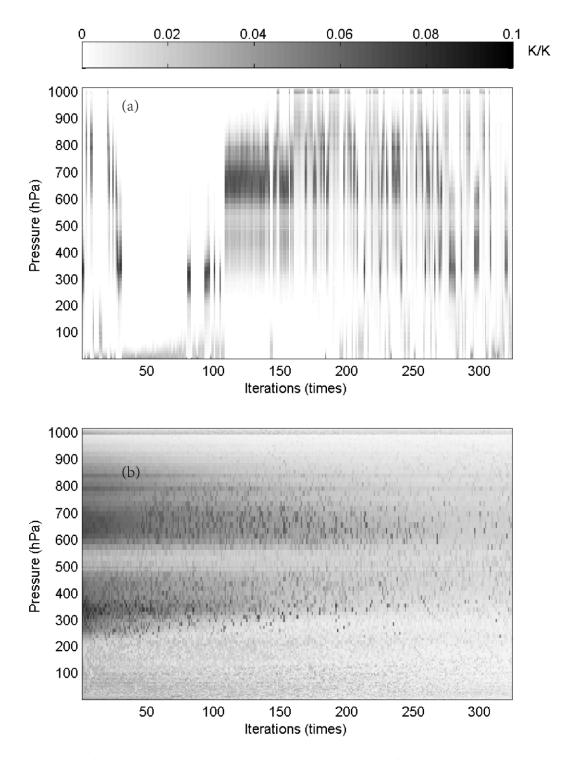


Figure 6. The relationship between the number of iterations and the
weighting function of the top 324 selected channels (shaded). (a)
ICS. (b) PCS.

2746	As illustrated in Fig. 6, in the first 100 iterations, the distribution
2747	of the temperature weighting function for PCS is relatively scattered;
2748	it does not reflect continuity between the adjacent layers of the
2749	atmosphere. Besides, the ICS result is better than that of PCS,
2750	showing that: (1) the distribution of the temperature weighting
2751	function is more continuous and reflects the continuity between
2752	adjacent layers of the atmosphere; (2) regardless of the number of
2753	iterations, the maximum value of the weighting function is stable
2754	near 300–400 hPa and 600–700 hPa, without scattering, which is
2755	closer to the situation in real atmosphere.

2756

2757 **4. Statistical multiple regression experiment**

2758 **4.1 Temperature profile database**

A new database including a representative collection of 25,000

atmospheric profiles from the European Centre for Medium-range

2761 Weather Forecasts (ECMWF) was used for the statistical inversion

experiments. The profiles were given in a 137-level vertical grid

extending from the surface up to 0.01 hPa. The database was divided

into five subsets focusing on diverse sampling characteristics such as

temperature, specific humidity, ozone mixing ratio, cloud

condensates, and precipitation. In contrast with earlier releases of the

2767	ECMWF diverse profile database, the 137-level database places
2768	greater emphasis on preserving the statistical properties of sampled
2769	distributions produced by the Integrated Forecasting System (IFS)
2770	(Eresmaa and McNally, 2014; Brath et al., 2018). IFS-137 spans the
2771	period from September 1, 2013 to August 31, 2014. There are two
2772	operational analyses each day (at 00z and 12z), and approximately
2773	13 000 atmospheric profiles over the ocean. The pressure levels
2774	adopted for IFS-137 are shown in Table A2 (see Table A2 in
2775	Appendix A).
2776	The locations of selected profiles of temperature, specific
2777	humidity, and cloud condensate subsets of the IFS-91 and IFS-137
2778	databases are plotted on the map in Fig. 7. In the IFS-91 database,
2778 2779	databases are plotted on the map in Fig. 7. In the IFS-91 database, the sampling is fully determined by the selection algorithm, which
2779	the sampling is fully determined by the selection algorithm, which
2779 2780	the sampling is fully determined by the selection algorithm, which makes the geographical distributions very inhomogeneous. Selected
2779 2780 2781	the sampling is fully determined by the selection algorithm, which makes the geographical distributions very inhomogeneous. Selected profiles represent those regions where gradients of the sampled
2779 2780 2781 2782	the sampling is fully determined by the selection algorithm, which makes the geographical distributions very inhomogeneous. Selected profiles represent those regions where gradients of the sampled variable are the strongest: in the case of temperature, mid- and
2779 2780 2781 2782 2783	the sampling is fully determined by the selection algorithm, which makes the geographical distributions very inhomogeneous. Selected profiles represent those regions where gradients of the sampled variable are the strongest: in the case of temperature, mid- and high-latitudes dominate, while humidity and cloud condensate

2787 selection.

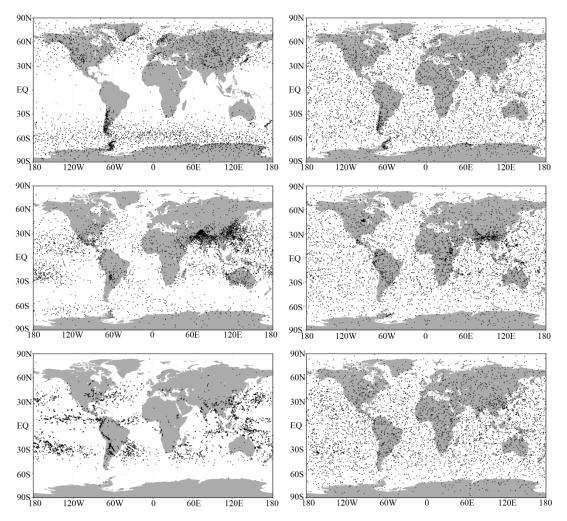


Figure 7. Locations of selected profiles in the temperature (top),

specific humidity (middle), and cloud condensate (bottom), sampled

- subsets of the IFS-91 (left) and IFS-137 (right) databases (from
- 2792 <u>https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/</u>,
- 2793 2019).

- ²⁷⁹⁵ The temporal distribution of the selected profiles is illustrated in Fig.
- 8. The coverage of the IFS-137 data set is more homogeneous than

the IFS-91 data set. Moreover, the IFS-137 database supports the
mode with input parameters, such as detection angle, 2 m
temperature, and cloud information. Therefore, it is feasible to use
the selected samples in a statistical multiple regression experiment.

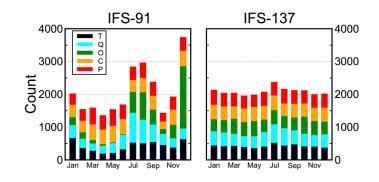


Figure 8. Distribution of profiles within the calendar months in 2801 IFS-91 (left) and IFS-137 (right) databases. Different subsets are 2802 shown in different colors. Black parts stand for temperature. Blue 2803 parts represent specific humidity. Green parts indicate ozone subset. 2804 Orange parts stand for cloud condensate. Red parts represent 2805 precipitation. The last access date is April 26th, 2019. (from 2806 https://www.nwpsaf.eu/site/update-137-level-nwp-profile-dataset/, 2807 2019). 2808

2809

2810 4.2 Experimental scheme

- In order to verify the retrieval effectiveness of ICS, 5000
- temperature profiles provided by the IFS-137 were used for
- statistical inversion comparison experiments. The steps are as

2814 follows:

(1) 5000 profiles and their corresponding surface factors, 2815

including surface air pressure, surface temperature, 2 m temperature, 2816

2 m specific humidity, 10 m wind speed. are put into the RTTOV 2817

mode. Then, the simulated AIRS spectra are obtained. 2818

(2) The retrieval of temperature is carried out in accordance with 2819

Eq. (23). The 5000 profiles are divided into two groups. The first 2820

group of 2500 profiles is used to obtain the regression coefficient, 2821

and the second group of 2500 is used to test the result. 2822

(3) Verification of the results. The test is carried out based on the 2823 standard deviation between the retrieval value and the true value. 2824

2825

2826

4.3 Results and Discussion

For the statistical inversion comparison experiments, the standard 2827 deviation of temperature retrieval is shown in Fig. 9. First, because 2828 PCS does not take channel sensitivity as a function of height into 2829 consideration, the retrieval result of PCS is inferior to that of ICS. 2830 Second, by comparing the results of ICS and NCS we found that 2831 below 100 hPa, since the method used in this paper considers near 2832 ground to be less of an influencing factor, the channel combination 2833 of ICS is slightly inferior to that of NCS, but the difference is small. 2834

From 100 hPa to10 hPa, the retrieval temperature of ICS in this 2835 paper is consistent with that of NCS, slightly better than the channel 2836

selected for NCS. From 10 hPa to 0.02 hPa, near the space layer, the
retrieval temperature of ICS is better than that of NCS. In terms of
the standard deviation, the channel combination of ICS is slightly
better than that of PCS from 100 hPa to 10 hPa. From 10 hPa to 0.02
hPa, the standard deviation of ICS is lower than that of NCS at about
1 K, meaning that the retrieval result of ICS is better than that of
NCS.

In order to further illustrate the effectiveness of ICS, the mean 2844 improvement value of the ICS and its percentages compared with the 2845 PCS and NCS at different heights are shown in Table 1. Because 2846 PCS does not take channel sensitivity as a function of height into 2847 consideration, the retrieval result of PCS is inferior to that of ICS. In 2848 general, the accuracy of the retrieval temperature of ICS is improved. 2849 Especially, from 100 hPa to 0.01 hPa, the mean value of ICS is 2850 evidently improved by more than 0.5 K which means the accuracy 2851 can be improved by more than 11%. By comparing the results of ICS 2852 and NCS we found that below 100 hPa, since the method used in this 2853 paper considers near ground to be less of an influencing factor, the 2854 channel combination of ICS is slightly inferior to that of NCS, but 2855 the difference is small. From 100 hPa to 0.01 hPa, the mean value of 2856 ICS is improved by more than 0.36 K which means the accuracy can 2857 be improved by more than 9.6%. 2858

Table 1. The mean improvement value of the ICS and its 2860

	Pressure	Improved mean value /Percentage compared with PCS	Improved value /Percentage compared with NCS		
	hPa	K/%	K/%		
	surface-100hPa	0.24/10.77%	-0.04/-3.27%		
	100hPa-10hPa	0.15/5.08%	0.06/2.4%		
	10hPa-1hPa	0.04/0.64%	0.17/2.99%		
	1hPa-0.01hPa	0.52/11.92%	0.36/9.57%		
2					
3	This is becau	use, as shown in Fig. 4: (1)	Stratosphere and		

percentages compared with the PCS and NCS at different heights. 2861

2863 ecause, as s W 4. (1) Stratosphere and

mesosphere is less affected by the ground surface, so the retrieval 2864

result of PCS is better than that of NCS. (2) Due to the method 2865

selected in this paper, there are more channels at 4.2 μ m for N₂O and 2866

 $4.3 \ \mu m$ for CO₂ absorption bands, and the channel combination of 2867

PCS is superior to that of NCS for atmospheric temperature 2868

observation in the high temperature zone. Moreover, ICS takes 2869

channel sensitivity as a function of height into consideration, so its 2870

retrieval result is improved. 2871

2872

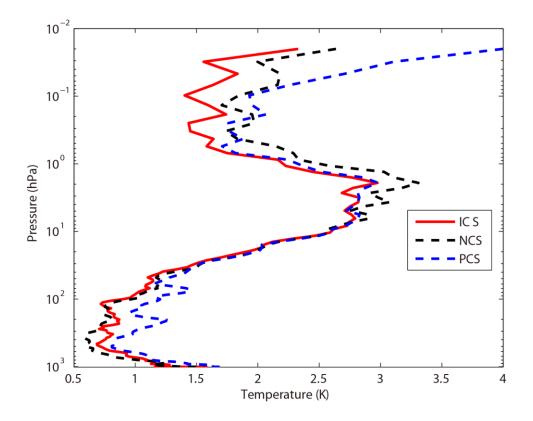




Figure 9. The temperature profile standard deviation of statistical
inversion comparison experiments. Red line indicates the result of
ICS. Black dotted line stands for the result of NCS. Blue dotted line
represents the result of PCS.

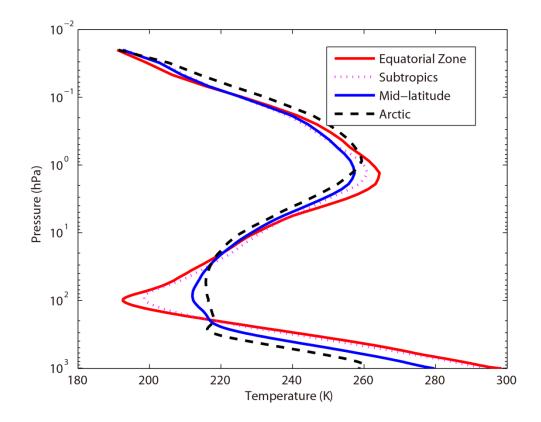
2879 5 Statistical inversion comparison experiments in four typical

2880 regions

The accuracy of the retrieval temperature varies from place to place and changes with atmospheric conditions. Therefore, in order to further compare the inversion accuracy under different atmospheric conditions, this paper has divided the atmospheric profile from the

2885 IFS-137 database introduced in Sect. 4 into four regions: equatorial

zone, subtropical region, mid-latitude region and Arctic. The average
temperature profiles in these four regions are shown in Fig. 10. The
retrieval temperature varies from place to place and changes with
atmospheric conditions. In order to further compare the regional
differences of inversion accuracy, the temperature standard
deviations of ICS in four typical regions are compared in Sect. 5.2.



2893

Figure 10. The average temperature profiles in four typical regions.
Red line indicates the equatorial zone. Pink dotted line stands for the
subtropics. Blue dotted line represents the mid-latitude region. Black
dotted line stands for the Arctic.

2900 **5.1 Experimental scheme**

In order to further illustrate the different accuracy of the retrieval temperature using our improved channel selection method under different atmospheric conditions, the profiles in four typical regions were used for statistical inversion comparison experiments. The experimental steps are as follows:

(1) 2500 profiles in Sect. 4 are used to work out the regressioncoefficient.

(2) The atmospheric profiles of the four typical regions: equatorial
zone, subtropical region, mid-latitude region and Arctic are used for
statistical inversion comparison experiments and test the result.(3)
Verification of the results. The test is carried out based on the

standard deviation between the retrieval value and the true value.

2913

2914 5.2 Results and Discussion

Using statistical inversion comparison experiments in four typical regions, the standard deviation of temperature retrieval is shown in Fig. 11. Generally, the retrieval temperature by ICS is better than that of NCS and PCS. In particular, above 1 hPa (the stratosphere and mesosphere), the standard deviation of atmospheric temperature can be improved by 1 K with PCS and NCS. Thus, ICS shows a



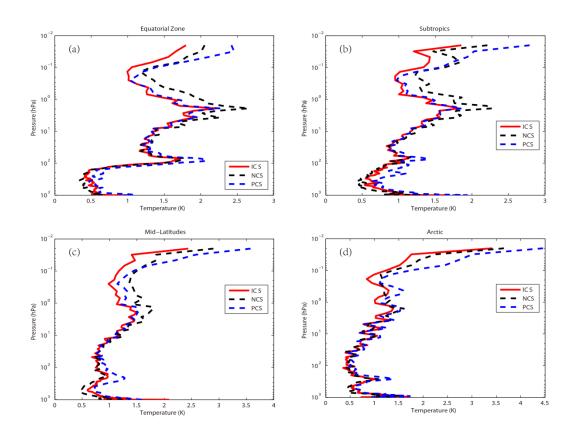
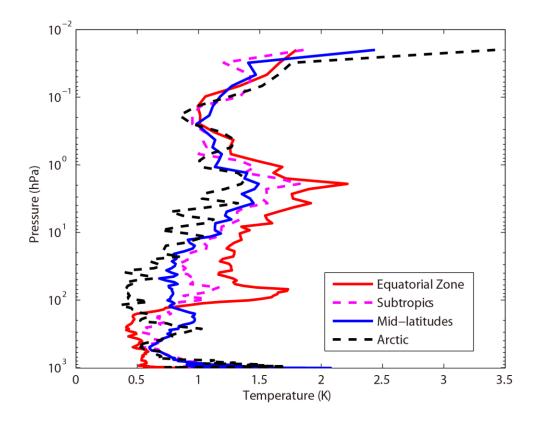


Figure 11. The temperature profile standard deviation of statistical inversion comparison experiments in four typical regions. Red line indicates the result of ICS. Black dotted line stands for the result of NCS. Blue dotted line represents the result of PCS. (a) Equatorial zone. (b) Subtropics. (c) Mid-latitudes. (d) Arctic.

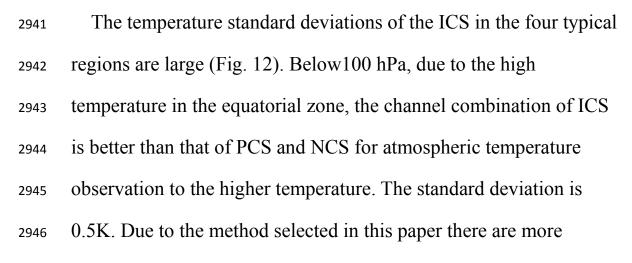
2923

In order to further compare the regional differences of inversion accuracy, the temperature standard deviation of ICS in four typical regions are compared in Fig. 12.



2934

Figure 12. The temperature standard deviation of ICS in four typical regions. Red line indicates the result of equatorial zone. Pink dotted line represents the result of Subtropics. Blue line represents the result of Mid-latitudes. Black dotted line stands for the result of Arctic.



channels at 4.2 μ m for N₂O and 4.3 μ m for CO₂ absorption bands 2947 which has been previously described in Sect. 3. Near the tropopause, 2948 the standard deviation of the equatorial zone increases sharply. It is 2949 also due to the sharp drops in temperature. However, the standard 2950 deviation of the Arctic is still around 0.5K. From 100hPa to 1hPa, 2951 the standard deviation of ICS is 0.5 K to 2K. With the increase of 2952 latitude, the effectiveness considerably increases. According to Fig. 2953 11, ICS takes channel sensitivity as a function of height into 2954 consideration, so its retrieval result is better. 2955

Although the improvements of ICS in the four typical regions are different, in general, the accuracy of the retrieval temperature of ICS is improved. Because PCS does not take channel sensitivity as a function of height into consideration, the retrieval result of PCS is inferior to that of ICS. In general, the accuracy of the retrieval temperature of ICS is improved.

2962

2963 7 Conclusions

In recent years, the atmospheric layer in the altitude range of about 20–100 km has been named "the near space layer" by aeronautical and astronautical communities. It is between the space-based satellite platform and the aerospace vehicle platform, which is the transition zone between aviation and aerospace. Its unique resource

has attracted a lot of attention from many countries. Research and 2969 exploration, therefore, on and of the near space layer are of great 2970 importance. A new channel selection scheme and method for 2971 hyperspectral atmospheric infrared sounder AIRS data based on 2972 layering is proposed. The retrieval results of ICS concerning the near 2973 space atmosphere are particularly good. Thus, ICS aims to provide a 2974 new and an effective channel selection method for the study of the 2975 near space atmosphere using the hyperspectral atmospheric infrared 2976 sounder. 2977

An improved channel selection method is proposed, based on 2978 information content in this paper. A robust channel selection scheme 2979 and method are proposed, and a series of channel selection 2980 comparison experiments are conducted. The results are as follows: 2981 (1) Since ICS takes channel sensitivity as a function of height into 2982 consideration, the ARI of PCS only tends to be 0.38 and is not 2983 convergent. However, as the 100th iteration is approached, the ARI of 2984 ICS tends to be stable, reaching 0.54, while the distribution of the 2985 temperature weighting function is more continuous and closer to that 2986 of the actual atmosphere. Thus, in terms of the ARI, convergence, 2987 and the distribution of the temperature weighting function, ICS is 2988 better than PCS. 2989

(2) Statistical inversion comparison experiments show that the

retrieval temperature of ICS in this paper is consistent with that of 2991 NCS. In particular, from 10 hPa to 0.02 hPa (the stratosphere and 2992 mesosphere), the retrieval temperature of ICS is obviously better 2993 than that of NCS at about 1 K. In general, the accuracy of the 2994 retrieval temperature of ICS is improved. Especially, from 100 hPa 2995 to 0.01 hPa, the accuracy of ICS can be improved by more than 11%. 2996 The reason is that stratosphere and mesosphere are less affected by 2997 the ground surface, so the retrieval result of ICS is better than that of 2998 NCS. Additionally, due to the method selected in this paper there are 2999 more channels at 4.2 μ m for the N₂O and at 4.3 μ m for the CO₂ 3000 absorption bands; the channel combination of ICS is better than that 3001 of NCS for atmospheric temperature observation to the higher 3002 temperature. 3003

3004 (3) Statistical inversion comparison experiments in four typical
regions indicate that ICS in this paper is significantly better than
3006 NCS and PCS in different regions and shows latitudinal variations,
3007 which shows potential for future applications.

3008

3009 *Data availability*. The data used in this paper are available from the 3010 corresponding author upon request.

3011

3012 *Appendices*

3013 Appendix A

Table A1. Pressure levels adopted for RTTOV v12 54 pressure level

- 3015 coefficients and profile limits within which the transmittance
- 3016 calculations are valid. Note that the gas units here are ppmv.
- 3017 (From <u>https://www.nwpsaf.eu/site/software/rttov/</u>, RTTOV Users
- 3018 guide, 2019).

1 0.01 245.95 143.66 5.24 0.91 1.404 0.014 0.2 2 0.01 252.13 154.19 6.03 1.08 1.410 0.069 0.3 3 0.03 263.71 168.42 7.42 1.35 1.496 0.108 0.3 4 0.03 280.12 180.18 8.10 1.58 1.670 0.171 0.3 5 0.13 299.05 194.48 8.44 1.80 2.064 0.228 0.3 6 0.23 318.64 206.21 8.59 1.99 2.365 0.355 1.0 7 0.41 336.24 205.66 8.58 2.49 2.718 0.553 1.4 8 0.67 342.08 197.17 8.34 3.01 3.565 0.731 1.9 9 1.08 340.84 189.50 8.07 3.30 5.333 0.716 2.3 10 1.67 334.68 179.27 7.89 3.20 7.314 0.643 3.3	Level	Pressure	Tmax	Tmin	Qmax	Qmin	Q ₂ max	Q ₂ min	Q ₂ Ref
2 0.01 252.13 154.19 6.03 1.08 1.410 0.069 0.3 3 0.03 263.71 168.42 7.42 1.35 1.496 0.108 0.3 4 0.03 280.12 180.18 8.10 1.58 1.670 0.171 0.8 5 0.13 299.05 194.48 8.44 1.80 2.064 0.228 0.7 6 0.23 318.64 206.21 8.59 1.99 2.365 0.355 1.6 7 0.41 336.24 205.66 8.58 2.49 2.718 0.553 1.4 8 0.67 342.08 197.17 8.34 3.01 3.565 0.731 1.5 9 1.08 340.84 189.50 8.07 3.30 5.333 0.716 2.7 10 1.67 334.68 179.27 7.89 3.20 7.314 0.643 3.7	umber	hPa	к	к	ppmv*	ppmv*	ppmv*	ppmv*	ppmv*
3 0.03 263.71 168.42 7.42 1.35 1.496 0.108 0.3 4 0.03 280.12 180.18 8.10 1.58 1.670 0.171 0.5 5 0.13 299.05 194.48 8.44 1.80 2.064 0.228 0.3 6 0.23 318.64 206.21 8.59 1.99 2.365 0.355 1.6 7 0.41 336.24 205.66 8.58 2.49 2.718 0.553 1.4 8 0.67 342.08 197.17 8.34 3.01 3.565 0.731 1.5 9 1.08 340.84 189.50 8.07 3.30 5.333 0.716 2.7 10 1.67 334.68 179.27 7.89 3.20 7.314 0.643 3.3	1	0.01	245.95	143.66	5.24	0.91	1.404	0.014	0.296
4 0.03 280.12 180.18 8.10 1.58 1.670 0.171 0.5 5 0.13 299.05 194.48 8.44 1.80 2.064 0.228 0.7 6 0.23 318.64 206.21 8.59 1.99 2.365 0.355 1.0 7 0.41 336.24 205.66 8.58 2.49 2.718 0.553 1.4 8 0.67 342.08 197.17 8.34 3.01 3.565 0.731 1.9 9 1.08 340.84 189.50 8.07 3.30 5.333 0.716 2.7 10 1.67 334.68 179.27 7.89 3.20 7.314 0.643 3.7	2	0.01	252.13	154.19	6.03	1.08	1.410	0.069	0.321
5 0.13 299.05 194.48 8.44 1.80 2.064 0.228 0.7 6 0.23 318.64 206.21 8.59 1.99 2.365 0.355 1.0 7 0.41 336.24 205.66 8.58 2.49 2.718 0.553 1.4 8 0.67 342.08 197.17 8.34 3.01 3.565 0.731 1.9 9 1.08 340.84 189.50 8.07 3.30 5.333 0.716 2.7 10 1.67 334.68 179.27 7.89 3.20 7.314 0.643 3.7	3	0.03	263.71	168.42	7.42	1.35	1.496	0.108	0.361
60.23318.64206.218.591.992.3650.3551.070.41336.24205.668.582.492.7180.5531.480.67342.08197.178.343.013.5650.7311.991.08340.84189.508.073.305.3330.7162.7101.67334.68179.277.893.207.3140.6433.7	4	0.03	280.12	180.18	8.10	1.58	1.670	0.171	0.527
7 0.41 336.24 205.66 8.58 2.49 2.718 0.553 1.4 8 0.67 342.08 197.17 8.34 3.01 3.565 0.731 1.9 9 1.08 340.84 189.50 8.07 3.30 5.333 0.716 2.7 10 1.67 334.68 179.27 7.89 3.20 7.314 0.643 3.7	5	0.13	299.05	194.48	8.44	1.80	2.064	0.228	0.769
8 0.67 342.08 197.17 8.34 3.01 3.565 0.731 1.9 9 1.08 340.84 189.50 8.07 3.30 5.333 0.716 2.7 10 1.67 334.68 179.27 7.89 3.20 7.314 0.643 3.7	6	0.23	318.64	206.21	8.59	1.99	2.365	0.355	1.074
91.08340.84189.508.073.305.3330.7162.7101.67334.68179.277.893.207.3140.6433.7	7	0.41	336.24	205.66	8.58	2.49	2.718	0.553	1.471
10 1.67 334.68 179.27 7.89 3.20 7.314 0.643 3.7	8	0.67	342.08	197.17	8.34	3.01	3.565	0.731	1.991
	9	1.08	340.84	189.50	8.07	3.30	5.333	0.716	2.787
11 2.50 322.5 17627 7.75 2.92 9.191 0.504 4.8	10	1.67	334.68	179.27	7.89	3.20	7.314	0.643	3.756
	11	2.50	322.5	17627	7.75	2.92	9.191	0.504	4.864
12 3.65 312.51 175.04 7.69 2.83 10.447 0.745 5.9	12	3.65	312.51	175.04	7.69	2.83	10.447	0.745	5.953
13 5.19 303.89 173.07 7.58 2.70 12.336 1.586 6.7	13	5.19	303.89	173.07	7.58	2.70	12.336	1.586	6.763
14 7.22 295.48 168.38 7.53 2.54 12.936 1.879 7.5	14	7.22	295.48	168.38	7.53	2.54	12.936	1.879	7.109
15 9.84 293.33 166.30 7.36 2.46 12.744 1.322 7.0	15	9.84	293.33	166.30	7.36	2.46	12.744	1.322	7.060
16 13.17 287.05 16347 7.20 2.42 11.960 0.719 6.5	16	13.17	287.05	16347	7.20	2.42	11.960	0.719	6.574
17 17.33 283.36 161.49 6.96 2.20 11.105 0.428 5.6	17	17.33	283.36	161.49	6.96	2.20	11.105	0.428	5.687
18 22.46 280.93 161.47 6.75 1.71 9.796 0.278 4.7	18	22.46	280.93	161.47	6.75	1.71	9.796	0.278	4.705
19 28.69 282.67 162.09 6.46 1.52 8.736 0.164 3.8	19	28.69	282.67	162.09	6.46	1.52	8.736	0.164	3.870
20 36.17 27993 162.49 6.14 1.31 7.374 0.107 3.4	20	36.17	27993	162.49	6.14	1.31	7.374	0.107	3.111

21	45.04	27315	164.66	5.90	1.36	6.799	0.055	2.478
22	55.44	265.93	166.19	6.21	1.30	5.710	0.048	1.907
23	67.51	264.7	167.42	9.17	1.16	4.786	0.043	1.440
24	81.37	261.95	159.98	17.89	0.36	4.390	0.038	1.020
25	97.15	262.43	163.95	20.30	0.01	3.619	0.016	0.733
26	114.94	259.57	168.59	33.56	0.01	2.977	0.016	0.604
27	134.83	259.26	169.71	102.24	0.01	2.665	0.016	0.489
28	156.88	260.13	169.42	285.00	0.01	2.351	0.013	0.388
29	181.14	262.27	17063	714.60	0.01	1.973	0.010	0.284
30	207.61	264.45	174.11	1464.00	0.01	1.481	0.013	0.196
31	236.28	270.09	177.12	2475.60	0.01	1.075	0.016	0.145
32	267.10	277.93	181.98	4381.20	0.01	0.774	0.015	0.110
33	300.00	285.18	184.76	6631.20	0.01	0.628	0.015	0.086
34	334.86	293.68	187.69	9450.00	1.29	0.550	0.016	0.073
35	371.55	300.12	190.34	12432.00	1.52	0.447	0.015	0.063
36	409.89	302.63	194.40	15468.00	2.12	0.361	0.015	0.057
37	449.67	304.43	198.46	18564.00	2.36	0.284	0.015	0.054
38	490.&5	307.2	201.53	21684.00	2.91	0.247	0.015	0.052
39	532.56	31217	202.74	24696.00	3.67	0.199	0.015	0.050
40	572.15	31556	201.61	27480.00	3.81	0.191	0.012	0.050
41	618.07	318.26	189.95	30288.00	6.82	0.171	0.010	0.049
42	661.00	321.71	189.95	32796.00	6.07	0.128	0.009	0.048
43	703.59	327.95	189.95	55328.00	6.73	0.124	0.009	0.047
44	745.48	333.77	189.95	37692.00	8.71	0.117	0.009	0.046
45	786.33	336.46	189.95	39984.00	8.26	0.115	0.008	0.045
46	825.75	338.54	189.95	42192.00	7.87	0.113	0.008	0.043
47	863.40	342.55	189.95	44220.00	7.53	0.111	0.007	0.041
48	898.93	346.23	189.95	46272.00	7.23	0.108	0.006	0.040
49	931.99	34924	189.95	47736.00	6.97	0.102	0.006	0.038
50	962.26	349.92	189.95	51264.00	6.75	0.099	0.006	0.034

51	989.45	350.09	189.95	49716.00	6.57	0.099	0.006	0.030
52	1013.29	360.09	189.95	47208.00	6.41	0.094	0.006	0.028
53	1033.54	350.09	189.95	47806.00	6.29	0.094	0.006	0.027
54	1050.00	350.09	189.95	47640.00	6.19	0.094	0.006	0.027

Table A2. Pressure levels adopted for IFS-137 137 pressure levels

3021 (in hPa).

Level	pressure								
number	hPa								
1	0.02	31	12.8561	61	106.4153	91	424.019	121	934.766
2	0.031	32	14.2377	62	112.0681	92	441.5395	122	943.139
3	0.0467	33	15.7162	63	117.9714	93	459.6321	123	950.908
4	0.0683	34	17.2945	64	124.1337	94	478.3096	124	958.103
5	0.0975	35	18.9752	65	130.5637	95	497.5845	125	964.758
6	0.1361	36	20.761	66	137.2703	96	517.4198	126	970.904
7	0.1861	37	22.6543	67	144.2624	97	537.7195	127	976.573
8	0.2499	38	24.6577	68	151.5493	98	558.343	128	981.796
9	0.3299	39	26.7735	69	159.1403	99	579.1926	129	986.603
10	0.4288	40	29.0039	70	167.045	5 100	600.1668	130	991.02
11	0.5496	41	31.3512	71	175.2731	101	621.1624	131	995.082
12	0.6952	42	33.8174	72	183.8344	102	642.0764	132	998.808
13	0.869	43	36.4047	73	192.7389	103	662.8084	133	1002.22
14	1.0742	44	39.1149	74	201.9969	104	683.262	134	1005.35
15	1.3143	45	41.9493	75	211.6186	6 105	703.3467	135	1008.22
16	1.5928	46	44.9082	76	221.6146	5 106	722.9795	136	1010.84
17	1.9134	47	47.9915	77	231.9954	107	742.0855	137	1013.2
18	2.2797	48	51.199	78	242.7719	108	760.5996		
19	2.6954	49	54.5299	79	253.9549	109	778.4661		
20	3.1642	50	57.9834	80	265.5556	5 110	795.6396		
21	3.6898	51	61.5607	81	277.5852	2 111	812.0847		
22	4.2759	52	65.2695	82	290.0548	8 112	827.7756		
23	4.9262	53	69.1187	83	302.9762	2 113	842.6959		
24	5.6441	54	73.1187	84	316.3607	' 114	856.8376		
25	6.4334	55	77.281	85	330.2202	2 115	870.2004		
26	7.2974	56	81.6182	86	344.5663	3 116	882.791		
27	8.2397	57	86.145	87	359.4111	117	894.6222		
28	9.2634	58	90.8774	88	374.7666	5 118	905.7116		
29	10.372	59	95.828	89	390.645	5 119	916.0815		

Author contributions. ZS contributed the central idea. SC, ZS and HD conceived the method, developed the retrieval algorithm and

discussed the results. SC analyzed the data, prepared the figures and wrote the paper. WG contributed to refining the ideas, carrying out additional analyses. All co-authors reviewed the paper.

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3028 *Competing interests*. The authors declare that they have no conflict 3029 of interest.

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