Assessment of the MTG IR Sounding Mission Spectral Calibration Algorithm

Part 2: Radiometric sensitivity to algorithm and instrument parameters

For the attention of: Rolf STUHLMANN (EUMETSAT)

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<td>Prepared by</td>
<td>Project Engineer Carsten STANDFUSS, Bernard TOURNIER</td>
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<td>Approved by</td>
<td>Project Manager Carsten STANDFUSS</td>
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<tr>
<td>Authorised by</td>
<td>General Manager Richard BRU</td>
<td>Signed on original</td>
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Assessment of the MTG IR Sounding Mission Spectral Calibration Algorithm

Part 2: Radiometric sensitivity to algorithm and instrument parameters

Summary
In preparation of the quantification of the MTG/IRS spectral calibration noise budget, this technical report establishes the link between the radiometric MTG/IRS spectral calibration algorithm performance with instrument parameters (radiometric resolution), geophysical parameters (atmospheric variability), and algorithm design parameters (calibration window selection).
## Distribution list

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<td>Rolf STUHLMANN</td>
</tr>
<tr>
<td>Richard BRU</td>
<td></td>
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<tr>
<td>Bernard TOURNIER</td>
<td></td>
</tr>
<tr>
<td>Carsten STANDFUSS</td>
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Assessment of the MTG IR Sounding Mission Spectral Calibration Algorithm

Part 2: Radiometric sensitivity to algorithm and instrument parameters

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Modification status

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<td>I</td>
<td></td>
<td>3.2</td>
<td>Insertion of Table 7</td>
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<td>3.2, ex 6.1</td>
<td>Preliminary spectral calibration noise budget allocation is removed. Consolidated budget allocations are discussed in part 3, section 6.1.</td>
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*I = Inserted  D = deleted  M = Modified
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1. Introduction

Part 1 of the study on the ‘Assessment of the MTG IR Sounding Mission Spectral Calibration Algorithm’ [RD 1] provides the theoretical basis for the IRS spectral calibration algorithm assessment. It describes the software system implementation and its link with instrumental and geophysical input parameters.

The present report on task 2 is addressed to the analysis of the sensitivity of the spectral calibration algorithm performance to instrument parameters (radiometric resolution), geophysical parameters (atmospheric variability), and algorithm design parameters (calibration window selection).

The overall assessment strategy is to obtain first performance estimations at low level of the spectral calibration sub-system, i.e. in terms of noise estimations generated by ISRF shift and shape knowledge errors for a given spatial sample in various spectral calibration windows. This facilitates the separation of error contributions from atmospheric variability, radiometric noise to the spectral calibration algorithm noise, and a subsequent allocation of instrument contributions to the spectral calibration noise budget. From the analysis of these performances at low level, detailed spectral calibration algorithm design hypotheses are derived (consolidated list of spectral calibration windows, choice of the correlation space).

First, the relationship between ISRF shift and shape knowledge errors and radiometric spectrum errors are established. This is required to translate algorithm and instrument dependent shift knowledge errors and instrument instability into radiometric errors to be linked with the spectral calibration noise allocation.

Second, the impact of radiometric noise on the spectral calibration algorithm noise is evaluated by estimating shift determination errors of uncalibrated spectra at various instrument states and a known atmospheric reference state. The impact of atmospheric variability on the spectral calibration algorithm noise is evaluated by estimating shift determination errors between uncalibrated spectra in selected atmospheric conditions and a globally unique calibrated reference spectrum.

The above quantifications are derived for the two instrument baseline concepts, DS (dispersive spectrometer) and FTS (Fourier Transform Spectrometer), and for pre-selected spectral calibration windows. Inter-comparison allows for linking individual windows with their performance in the spectral calibration algorithm. Taking account of constraints imposed by the instrument design (e.g., array separation), the spectral calibration window selection is consolidated by consideration of additional windows or of improved spectral resolution in already investigated windows.

Section 2 briefly recalls the characteristics of the instrument baseline concepts (DS and FTS), of the spectral calibration windows, and of the considered geophysical conditions. The relationship between spectral calibration algorithm errors (i.e., ISRF shift and shape knowledge errors) and the corresponding radiometric noise is established in section 3. The impact of radiometric noise and of atmospheric variability on the spectral calibration algorithm performance is investigated in sections 4 and 5, respectively. Preliminary conclusions on spectral calibration algorithm design parameters are drawn. Based on these conclusions, the selection of spectral calibration windows is consolidated in section 6, to be applied in part 3 [RD 2] of the study as described in section 7.
1.1. Acronyms

ccm  corner cube motion
DS  Dispersive Spectrometer
ESA  European Space Agency
EUMETSAT  European Organisation for the Exploitation of Meteorological Satellites
E/W  East-West
FIR  Finite Impulse Response
FWHM  Full Width at Half Maximum
FTS  Fourier Transform Spectrometer
IASI  Infrared Atmospheric Sounding Interferometer
IR  InfraRed
IRS  (MTG) InfraRed Sounder
ISRF  Instrument Spectral Response Function
ISRF-EM  ISRF Estimation Model
MRD  Mission Requirements Document
MTG  Meteosat Third Generation
NEdT  Noise equivalent brightness temperature difference
N/S  North-South
RD  Reference Document
rms  root mean square
SCS  Spectral Calibration Subsystem
SDE  Shift Determination Error
SEI  Shape Error Index
SSI  Spectral Sampling Interval
TBD  To be defined
WP  Work Package

1.2. References


2. Instrument, algorithm and geophysical parameters

This section recalls the instrument baseline parameters for the two possible concepts, the principal characteristics of pre-selected spectral calibration windows as well as of the considered atmospheric conditions. A more detailed description is given in [RD 1].

2.1. Instrument baseline concepts

It is reminded that the implementation of mission bands 5 and 6 is alternative.

2.1.1. DS baseline

Spectral and radiometric characteristics of the DS instrument baseline are summarised in Table 1.

<table>
<thead>
<tr>
<th>Mission Band</th>
<th>IRS-1</th>
<th>IRS-2</th>
<th>IRS-3</th>
<th>IRS-4</th>
<th>IRS-5</th>
<th>IRS-6</th>
<th>IRS-7</th>
<th>IRS-8</th>
<th>IRS-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavenumber range [cm⁻¹]</td>
<td>700-770</td>
<td>770-980</td>
<td>980-1070</td>
<td>1070-1210</td>
<td>1210-1600</td>
<td>1600-2000</td>
<td>2000-2250</td>
<td>2250-2400</td>
<td>2400-2500</td>
</tr>
<tr>
<td>Array band index</td>
<td>S2</td>
<td>S3</td>
<td>S4</td>
<td>S4'</td>
<td>S5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>req. spect. resolution [nm;cm⁻¹]</td>
<td>0.5</td>
<td>0.5</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>spect. resolution [nm;cm⁻¹]</td>
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<td>0.5</td>
<td>0.85</td>
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<td>0.85</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSI [nm]</td>
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<td>6.9</td>
<td>3.9</td>
<td>3.9</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
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<tr>
<td>spectral samples</td>
<td>189</td>
<td>404</td>
<td>221</td>
<td>277</td>
<td>745</td>
<td>781</td>
<td>467</td>
<td>156</td>
<td>59</td>
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<tr>
<td>equivalent SSI [cm⁻¹]</td>
<td>0.37</td>
<td>0.52</td>
<td>0.405</td>
<td>0.505</td>
<td>0.523</td>
<td>0.512</td>
<td>0.535</td>
<td>0.96</td>
<td>1.96</td>
</tr>
<tr>
<td>I° and last nominal 1b centroid</td>
<td>700.04</td>
<td>769.60</td>
<td>770.12</td>
<td>979.68</td>
<td>980.505</td>
<td>1069.605</td>
<td>1070.095</td>
<td>1209.475</td>
<td>1210.222</td>
</tr>
<tr>
<td>1st and last nominal 1b</td>
<td>700.28</td>
<td>770.12</td>
<td>979.68</td>
<td>980.505</td>
<td>1069.605</td>
<td>1209.475</td>
<td>1210.222</td>
<td>1600.512</td>
<td>2000.365</td>
</tr>
<tr>
<td>centroid [cm⁻¹]</td>
<td>769.98</td>
<td>979.68</td>
<td>1069.69</td>
<td>1209.60</td>
<td>1210.222</td>
<td>1599.334</td>
<td>1600.512</td>
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<tr>
<td>req. rad. resolution</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
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<tr>
<td>NEdT@280K [K]</td>
<td>0.25-0.45</td>
<td>0.08-0.25</td>
<td>0.05-0.09</td>
<td>0.04-0.07</td>
<td>0.09-0.17</td>
<td>0.10-0.25</td>
<td>0.12-0.22</td>
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<td>0.16-0.36</td>
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<td>K_FIR</td>
<td>1.22</td>
<td>1.22</td>
<td>1.20</td>
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<td>1.17</td>
<td>1.18</td>
<td>1.18</td>
<td>1.19</td>
<td>1.19</td>
</tr>
</tbody>
</table>

Table 1: Spectral and radiometric characteristics for the IRS/DS baseline. Radiometric performance as provided in [RD 3] is corrected by a factor 1/k'FIR provided in [RD 4]. Legend: *=at band centre.

2.1.2. FTS baseline

Spectral and radiometric characteristics of the FTS instrument baseline are summarised in Table 2.

<table>
<thead>
<tr>
<th>Mission Band</th>
<th>IRS-1</th>
<th>IRS-2</th>
<th>IRS-3</th>
<th>IRS-4</th>
<th>IRS-5</th>
<th>IRS-6</th>
<th>IRS-7</th>
<th>IRS-8</th>
<th>IRS-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavenumber range [cm⁻¹]</td>
<td>700-770</td>
<td>770-980</td>
<td>980-1070</td>
<td>1070-1210</td>
<td>1210-1600</td>
<td>1600-2000</td>
<td>2000-2250</td>
<td>2250-2400</td>
<td>2400-2500</td>
</tr>
<tr>
<td>Array band index</td>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A3'</td>
<td>A4</td>
<td>A4'</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>integration time [s]</td>
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<td>6.0</td>
<td>6.0</td>
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<tr>
<td>spect. resolution [cm⁻¹]</td>
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<td>0.62</td>
<td>0.49</td>
<td>0.84</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
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<tr>
<td>SSI [cm⁻¹]</td>
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<td>0.52</td>
<td>0.41</td>
<td>0.70</td>
<td>0.52</td>
<td>0.52</td>
<td>0.52</td>
<td>1.03</td>
<td>2.03</td>
</tr>
<tr>
<td>spectral samples</td>
<td>171</td>
<td>403</td>
<td>219</td>
<td>200</td>
<td>750</td>
<td>769</td>
<td>481</td>
<td>145</td>
<td>49</td>
</tr>
<tr>
<td>I° and last nominal 1b centroid</td>
<td>700.28</td>
<td>769.98</td>
<td>770.64</td>
<td>979.68</td>
<td>980.31</td>
<td>1069.69</td>
<td>1070.30</td>
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<tr>
<td>1st and last nominal 1b</td>
<td>700.28</td>
<td>769.98</td>
<td>770.64</td>
<td>979.68</td>
<td>980.31</td>
<td>1069.69</td>
<td>1070.30</td>
<td>1209.60</td>
<td>1210.04</td>
</tr>
<tr>
<td>centroid [cm⁻¹]</td>
<td>769.98</td>
<td>979.68</td>
<td>1069.69</td>
<td>1209.60</td>
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<td>req. rad. resolution</td>
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<td>0.2</td>
<td>0.2</td>
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<td>0.2</td>
</tr>
<tr>
<td>NEdT@280K [K]</td>
<td>0.25-0.85</td>
<td>0.31-0.49</td>
<td>0.22-0.45</td>
<td>0.19-0.46</td>
<td>0.28-1.43</td>
<td>0.29-1.43</td>
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<td>0.44-0.75</td>
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<td>K_FIR</td>
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<td>0.63</td>
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<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td>K_noise-apo</td>
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<td>1.08</td>
<td>1.04</td>
<td>1.04</td>
<td>1.08</td>
<td>1.08</td>
<td>1.08</td>
<td>1.08</td>
<td>1.08</td>
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</tbody>
</table>

Table 2: Spectral and radiometric characteristics for the IRS/FTS baseline. Radiometric performance as provided in [RD 3] is corrected by a factor 1/(k'FIR k'noise-apo) provided in [RD 4]. Legend: *=excluding self-apodisation.

Noveltis 2006
2.2. Candidate spectral calibration algorithms

Table 3 recalls the list of spectral calibration windows pre-selected in [RD 1].

<table>
<thead>
<tr>
<th>Window id</th>
<th>Wavenumber range (cm⁻¹)</th>
<th>IRS Band</th>
<th>Species</th>
<th>Absorption line spacing (cm⁻¹)</th>
<th>Spectral resolution required (cm⁻¹)</th>
<th>Spectral resolution IRS/FTS(cm⁻¹)</th>
<th>Spectral resolution IRS/DS(cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W02</td>
<td>720 - 750</td>
<td>IRS-1</td>
<td>CO₂</td>
<td>1.5</td>
<td>0.5</td>
<td>0.50</td>
<td>0.67</td>
</tr>
<tr>
<td>W02F</td>
<td>722 - 743</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W03</td>
<td>2040 - 2070</td>
<td>IRS-7</td>
<td>CO₂</td>
<td>1.55</td>
<td>0.625</td>
<td>0.62</td>
<td>0.94</td>
</tr>
<tr>
<td>W03F</td>
<td>2044 - 2066</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W04</td>
<td>2300 - 2350</td>
<td>IRS-8</td>
<td>CO₂</td>
<td>1.8</td>
<td>1.25</td>
<td>1.24</td>
<td>1.67</td>
</tr>
<tr>
<td>W04F</td>
<td>2303 - 2348</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W05</td>
<td>2345 - 2375</td>
<td>IRS-8</td>
<td>CO₂</td>
<td>1.35</td>
<td>1.25</td>
<td>1.24</td>
<td>1.67</td>
</tr>
<tr>
<td>W05F</td>
<td>2350 - 2370</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>W11</td>
<td>1125 - 1195</td>
<td>IRS-4</td>
<td>-</td>
<td></td>
<td>0.85</td>
<td>0.85</td>
<td>0.92</td>
</tr>
<tr>
<td>W12</td>
<td>1145 - 1195</td>
<td>IRS-4</td>
<td>-</td>
<td></td>
<td>0.85</td>
<td>0.85</td>
<td>0.92</td>
</tr>
<tr>
<td>W13</td>
<td>1350 - 1400</td>
<td>IRS-5</td>
<td>-</td>
<td></td>
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<td>0.62</td>
<td>0.93</td>
</tr>
<tr>
<td>W14</td>
<td>1500 - 1550</td>
<td>IRS-5</td>
<td>-</td>
<td></td>
<td>0.625</td>
<td>0.62</td>
<td>0.93</td>
</tr>
<tr>
<td>W15</td>
<td>1650 - 1700</td>
<td>IRS-6</td>
<td>-</td>
<td></td>
<td>0.625</td>
<td>0.62</td>
<td>0.93</td>
</tr>
<tr>
<td>W16</td>
<td>1800 - 1850</td>
<td>IRS-6</td>
<td>-</td>
<td></td>
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<td>0.62</td>
<td>0.93</td>
</tr>
<tr>
<td>W17</td>
<td>1880 - 1980</td>
<td>IRS-6</td>
<td>-</td>
<td></td>
<td>0.625</td>
<td>0.62</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Table 3: List of IRS candidate spectral calibration windows. Windows applied in the Fourier space are indicated by ‘F’ and are defined at slightly different spectral limits.

2.3. Geophysical conditions

Spectral calibration of MTG/IRS spectra is considered for four representative atmospheric regimes. Each regime is represented by a clear-sky and a cloudy spectrum. The atmospheric and surface conditions are characterised in Table 4.

The characterisation provides surface pressure \( p_{surf} \), surface temperature \( T_{surf} \), total water vapour content \( T_{WC} \), and a spectral surface emissivity classification \( I_{emm} \) (oce=ocean, des=desert, wsa=woody savannah). For cloudy components, the cloud layer is characterised by the cloud type \( C \) (Sc=stratocumulus, Ns=nimbostratus, Cb=cumulonimbus, Ci=cirrus), the total optical depth in the visible \( \tau \), cloud bottom and cloud top pressure \( p_{b} \) and \( p_{t} \), respectively and the cloud top temperature \( T_{ctop} \). Each clear-sky/cloud couple, is simulated at the reported, realistic satellite zenith angle \( \theta \) and is described in view of the general synoptic conditions.

<table>
<thead>
<tr>
<th>spectrum identifier</th>
<th>Psurf [hPa]</th>
<th>Tsurf [K]</th>
<th>TWC [kg/m²]</th>
<th>Iemm</th>
<th>Tctop [K]</th>
<th>C</th>
<th>( \tau )</th>
<th>pb [hPa]</th>
<th>pt [hPa]</th>
<th>( \theta )</th>
<th>Synoptic conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0511</td>
<td>1017.1</td>
<td>290.08</td>
<td>30.8</td>
<td>oce</td>
<td>284.14</td>
<td>Sc</td>
<td>10</td>
<td>950</td>
<td>900</td>
<td>47°</td>
<td>NE trade wind regime, temperate and moderately humid</td>
</tr>
<tr>
<td>0512</td>
<td>1017.1</td>
<td>290.08</td>
<td>31.2</td>
<td>oce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0721</td>
<td>965.89</td>
<td>305.18</td>
<td>52.2</td>
<td>wsa</td>
<td>242.11</td>
<td>Cb</td>
<td>40</td>
<td>800</td>
<td>300</td>
<td>22°</td>
<td>Central Africa, ITCZ deep-convection, hot and humid</td>
</tr>
<tr>
<td>0722</td>
<td>963.88</td>
<td>304.89</td>
<td>65.6</td>
<td>wsa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0931</td>
<td>979.54</td>
<td>271.53</td>
<td>6.78</td>
<td>oce</td>
<td>243.24</td>
<td>Ng</td>
<td>5</td>
<td>700</td>
<td>500</td>
<td>61°</td>
<td>South Atlantic depression system, cold and dry</td>
</tr>
<tr>
<td>0932</td>
<td>980.62</td>
<td>271.97</td>
<td>7.81</td>
<td>oce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1611</td>
<td>990.76</td>
<td>303.21</td>
<td>11.1</td>
<td>des</td>
<td>206.44</td>
<td>Ci</td>
<td>0.5</td>
<td>200</td>
<td>150</td>
<td>24°</td>
<td>West Sahara high-pressure belt, hot and dry</td>
</tr>
<tr>
<td>1614</td>
<td>990.76</td>
<td>303.21</td>
<td>11.1</td>
<td>des</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Surface, atmospheric and cloud parameters for selected high-resolution radiance spectra.
3. Radiometric impact of ISRF shift and shape errors

The instrument independent specification of the spectral calibration noise budget and its components has to be formulated as a spectral radiance error. The MTG Mission Requirements Document (MRD) [RD 5] specifies the spectral calibration noise budget to within 0.1K NEdT at reference temperature 280K.

The core of the spectral calibration algorithm is the estimation of the ISRF shape and its centroid position (by means of an instrument model and observed instrument state parameters and spectra). Therefore, the relationship between ISRF shift and shape errors and the corresponding radiometric error links the algorithm and instrument contributions to the spectral calibration noise budget with the specification. It is quantified in this paragraph. We introduce the following parameters:

- The ISRF centroid knowledge error (or shift determination error $SDE$), defined as the difference between the determined centroid position (in wave number, wavelength or frequency) of an uncalibrated spectral sample and its true position,

$$SDE(\nu_0) = \delta\nu_M(\nu_0) - \delta\nu_t(\nu_0)$$

where $\delta\nu_M$ and $\delta\nu_t$ are the estimated and the true frequency shifts of a measured (uncalibrated) spectral sample with respect to the corresponding spectral sample of the calibrated reference spectrum at frequency $\nu_0$. In Fourier spectrometry, the relative shift determination error $SDE_r$ is more commonly used, due to the proportionality between spectral shift and wave number. It is defined by:

$$SDE_r(\nu_0) = SDE(\nu_0) / \nu_0$$

The radiometric error generated by a constant SDE decreases with a lower spectral resolution. In view of translating shift determination errors in radiometric errors, in particular for instruments with variable spectral resolution as MTG/IRS, it may be useful to express the shift determination error as fraction of spectral resolution, i.e., the full width at half maximum (FWHM) of the ISRF.

$$SDE_{sr}(\nu_0) = SDE(\nu_0) / \text{FWHM}(\nu_0)$$

- The ISRF shape error index ($SEI$), defined as the spectral integral of the absolute difference between modelled and true ISRF (centered to a common centroid) of a spectral sample,

$$SEI(\nu_0) = \int_{-\infty}^{\infty} |\text{ISRF}_M(\nu, \nu_0) - \text{ISRF}_t(\nu, \nu_0)| d\nu$$

where $\nu_0$ is the common ISRF centroid frequency, $\text{ISRF}$ and $\text{ISRF}_M$ are the actual and modelled spectral response functions, respectively, centred at $\nu_0$.

3.1. Shift knowledge errors

Shift knowledge errors are applied to both instrument concepts and translated in radiometric errors in different geophysical conditions.
In this section, radiometric noise induced by a spectral shift knowledge error is presented for a hot and humid clear-sky atmosphere, its variability with the atmospheric state is quantitatively discussed in section 3.3.

The radiometric error associated to a spectral shift is governed by the spectrum derivative in a given spectral sample. The derivative varies non-linearly with spectral shift according to the locally resolved spectroscopic signatures. Defining the radiometric noise associated to shift knowledge errors as the rms of the radiometric errors in all spectral samples of an IRS mission band, local non-linearity is averaged out. Thus we expect a linear relationship between radiometric noise and associated shift knowledge errors as far as the latter remains small against the spectral sampling interval. The factor of proportionality depends on the amplitude of resolved spectroscopic signatures, typical for each band. Therefore, we investigate the noise/shift relationship individually in each of the nine IRS mission bands and separately for the two baseline concepts. The objective is twofold:

- Identification of the most suitable shift parameter upon which system and instrument specifications shall be formulated, if possible independently of instrument concept and spectral resolution.

For the instrument baselines recalled in section 2.1, Figure 1, Figure 2 and Figure 3 present the radiometric noise associated to shift knowledge errors as function of the three shift parameters $SDE$ (absolute), $SDE_r$ (relative), $SDE_{sr}$ (fraction of spectral resolution), respectively. Each figure consists of noise estimations for three spectral shifts per concept and per mission band. Spectral shifts are simulated as follows:

- **DS**: In absence of an explicit instrument model at present, we simulate absolute spectral shift errors of 1.0, 0.5 and 0.1 m$^{-1}$ in all spectral samples and evaluate the radiometric noise as rms difference between shifted and unshifted spectra per spectral band by convolution with the ISRF of the DS baseline (thus of identical shape).
- **FTS**: ISRF are generated by the ISRF model (for details see [RD 1, section 3.1.2.3]) for three central instrument field angles 0.711, 1.423 and 2.845 mrad, corresponding to a shift by 3, 6 and 12 km in both dimensions at ground with respect to a spatial sample at zero central field angle. We evaluate the radiometric noise as rms difference between shifted and unshifted spectra per spectral band by convolution with the shifted and unshifted ISRF. This configuration generates spectrally constant relative shifts (0.25 $10^{-6}$, 1.0 $10^{-6}$, 4.0 $10^{-6}$, respectively). The impact of a slight shape difference between shifted and unshifted ISRF due to the field angle difference is negligible (below 100 µK NEdT@280K).

The expected linear relationship between shift and noise for a given instrument in a given band is confirmed.

In terms of absolute shift (Figure 1), it can be stated that the factor of proportionality varies by a factor up to 20 between bands of a given concept. FTS noise is up to two times stronger than DS noise. The same statements can be given in terms of relative shift (Figure 2). Both parameters prove unsuitable with regard to a concept independent formulation of spectral shift knowledge requirements. In terms of spectral shift as fraction of spectral resolution (Figure 3), the variation of the proportionality factor between bands is reduced, but still varies by a factor up to 8.
Figure 1: Radiometric noise (rms of individual spectral sample errors) as function of the absolute spectral shift determination error (SDE). Evaluation for the FTS and DS baseline concepts and the nine IRS mission bands.

Figure 2: Radiometric noise (rms of individual spectral sample errors) as function of the relative spectral shift determination error (SDE_r). Evaluation for the FTS and DS baseline concepts and the nine IRS mission bands.
Figure 3: Radiometric noise (rms of individual spectral sample errors) as function of the spectral shift determination error in fractions of spectral resolution (SDE_{sr}). Evaluation for the FTS and DS baseline concepts and the nine IRS mission bands.

Although the spectral shift as fraction of spectral resolution reduces the dependence of associated noise on the instrument parameters, the noise/shift relationship

\[ \text{NEdT}_{\text{shift,280K}}(B,C) [K] = a(B,C) \times SDE_{sr}(B) [%] \]  

in a spectral band \( B \) remains dependent on the concept \( C \).

Table 5 quantifies the slopes \( a(B,C) \), i.e. the radiometric noise associated with a spectral shift equal to one percent of spectral resolution, the slope ratio and spectral resolution ratio of the two concepts.

<table>
<thead>
<tr>
<th>( a(B,FTS) [K/%] )</th>
<th>( a(B,DS) [K/%] )</th>
<th>( a(B,FTS)/ a(B,DS) )</th>
<th>( \text{FWHM(DS)/FWHM(FTS)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.165</td>
<td>0.129</td>
<td>1.27</td>
<td>1.34</td>
</tr>
<tr>
<td>0.075</td>
<td>0.061</td>
<td>1.22</td>
<td>1.50</td>
</tr>
<tr>
<td>0.090</td>
<td>0.048</td>
<td>1.90</td>
<td>1.48</td>
</tr>
<tr>
<td>0.113</td>
<td>0.079</td>
<td>1.43</td>
<td>1.08</td>
</tr>
<tr>
<td>0.100</td>
<td>0.091</td>
<td>1.10</td>
<td>1.49</td>
</tr>
<tr>
<td>0.046</td>
<td>0.040</td>
<td>1.14</td>
<td>1.49</td>
</tr>
<tr>
<td>0.149</td>
<td>0.115</td>
<td>1.30</td>
<td>1.52</td>
</tr>
<tr>
<td>0.026</td>
<td>0.019</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>0.035</td>
<td>0.040</td>
<td>0.87</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Table 5: Proportionality factor between radiometric noise (in K NEdT@280K) and shift fraction of spectral resolution (in %) for FTS and DS baseline concepts, their ratio and the ratio of spectral resolution FWHM.
Except for band 9, FTS baseline noise for equivalent $SDE_{sr}$ is larger than DS baseline noise. This ‘excess’ noise is limited to below 50%, except in band 3. However, it cannot be explained by the higher spectral resolution since spectral resolution ratios in Table 5 are uncorrelated with the noise/shift sensitivity ratios over spectral bands. It is more likely that the higher noise level of FTS is explained by the cardinal sine shape of the spectral response that may amplify noise in spectral regions with correlated spectroscopic features. This would justify distinct specification levels for FTS and DS for requirements concerning spectral shift.

As mentioned above, the noise/shift sensitivity variation over spectral bands is governed by the resolved spectroscopic signatures. Figure 3 and Table 5 indicate that a band independent specification of spectral shift knowledge errors at a constant radiometric noise level is driven by bands 1 and 7. Band 8 is characterised by the lowest noise at a given $SDE_{sr}$, more than 6 times smaller than in band 1. Regarding the alternative implementation of water vapour bands 5 and 6, it is interesting to notice that band 5 is two times more sensitive to spectral shift knowledge errors. Visual inspection of the corresponding error spectra (not shown) reveals a higher error level in the spectral domain 1200 – 1400 cm$^{-1}$ (band 5) than in the ‘corresponding’ spectral domain 1800 – 2000 cm$^{-1}$ in band 6.

In view of facilitating the extrapolation of radiometric noise due to shift determination errors over different mission bands (see section 4), we provide in Table 6 additionally the slope factors $b$ between radiometric noise and the relative spectral shift.

\[
NEdT_{\text{shift},280K}(B,C) [K] = b(B,C) SDE_{r}(B)
\]

Table 6: Proportionality factor between noise and relative shift for FTS and DS baseline concepts.

<table>
<thead>
<tr>
<th>B</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b(B,\text{FTS}) [K/10^{-5}]$</td>
<td>0.24</td>
<td>0.10</td>
<td>0.18</td>
<td>0.15</td>
<td>0.22</td>
<td>0.13</td>
<td>0.51</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>$b(B,\text{DS}) [K/10^{-5}]$</td>
<td>0.14</td>
<td>0.06</td>
<td>0.07</td>
<td>0.10</td>
<td>0.14</td>
<td>0.08</td>
<td>0.26</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

### 3.2. Shape knowledge errors

The investigation of shape knowledge errors, expressed by the shape error index SEI considers the following configurations:

**DS:** In absence of an explicit instrument model, a simulation of ISRF shape variation as function of instrument state parameters is not possible. Therefore, we define synthetic shape variations using the DS baseline ISRF available in each band at lower and upper wavelength limits and at centre wavelength [RD 3]. We simulate three hypothetical DS instruments with constant ISRF over each spectral band, (i) at lower wavelength limit, (ii) at centre wavelength, (iii) at upper wavelength limit. We calculate the shape error indices (constant within each band) for instruments (ii) and (iii) with respect to the reference instrument (i), and evaluate the radiometric noise as rms difference per spectral band between convolved spectra of instruments (ii) or (iii) and (i) (without any spectral shift).

**FTS:** ISRF are generated by the ISRF model described in [RD 1].

(1) To evaluate the impact of field angle induced shape variations, ISRF are generated for three central instrument field angles 29.2, 58.3 and 87.5 mrad, corresponding to an (unrealistically strong) shift of the interferometer axis by one third, two third and the total of the maximum field angle of the instrument. Shape error indices and related radiometric noise are evaluated with respect to the ISRF at zero field angle.
(2) A deviation of the corner cube motion is simulated by introducing offset, linear and parabolic perturbations in the corner cube motion law. The corresponding ISRF is estimated at maximum field angle, shape error index and associated radiometric noise are evaluated with respect to the ISRF at maximum field angle for an unperturbed linear corner cube motion.

(3) We consider microvibrations of the corner cube with amplitude 100 nm at two frequencies, 5.8 and 2.9 Hz. Again, the ISRF is estimated at maximum field angle, shape error index and associated radiometric noise are evaluated with respect to the ISRF at maximum field angle without microvibrations.

![ISRF shape variation: Demonstration for FTS/IRS band 9](image1)

**Figure 4:** IRS/FTS ISRF in band 9 in five configurations.

![ISRF shape variation: Demonstration for FTS/IRS band 9](image2)

**Figure 5:** Four configurations of band 9 IRS/FTS ISRF deviation from the reference ISRF at field angle 87.5 mrad without instrument perturbation (red curve in Figure 4). Unsigned relative deviations (normalised by the maximum value of the reference ISRF) are shown.
Since the shape error index does not depend on the distance of shape variations from the ISRF barycentre, it cannot be expected to find a global relationship between SEI and the associated radiometric noise. This is demonstrated for FTS by the different impact on the ISRF shape depending on the perturbation type. For the example of mission band IRS-9, Figure 4 presents the ISRF at zero and maximum field angle without any instrument perturbation, the ISRF at maximum field angle in the two vibration modes and the corner cube motion (ccm) deviation described above.

To visually enhance the ISRF differences, relative ISRF deviations with respect to the unperturbed case at maximum field angle are shown in Figure 5. Field angle dependent self-apodisation and ccm deviations generate quasi-symmetric perturbations with respect to the ISRF centroid. In contrary, micro-vibrations generate quasi-anti-symmetric perturbations with strong maxima (“ghosts”) at about $\pm 700$ and $\pm 1400$ m$^{-1}$ around ISRF centroid for the investigated frequencies 2.9 and 5.8 Hz, respectively.

In view of establishing thumb rules for radiometric noise as function of SEI it is expected that symmetric and anti-symmetric contributions to the SEI must be considered separately. The former generate unbiased noise independent of the local derivative of the spectrum, the latter generate noise proportional to the spectral gradient at the scale of the ghost wave number position.

Again we present radiometric noise in this section for a hot and humid clear-sky atmosphere, the variability with the atmospheric state is quantified in section 3.3.

Table 7 summarises the radiometric error for SEI=0.1 per mission band for DS synthetic shape variations and FTS symmetric shape variations.

<table>
<thead>
<tr>
<th>IRS-</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTS [K/0.1]</td>
<td>0.14</td>
<td>0.03</td>
<td>0.05</td>
<td>0.08</td>
<td>0.05</td>
<td>0.02</td>
<td>0.11</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>DS [K/0.1]</td>
<td>0.42</td>
<td>0.19</td>
<td>0.21</td>
<td>0.23</td>
<td>0.25</td>
<td>0.10</td>
<td>0.36</td>
<td>0.02</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 7: Radiometric error (NEdT@280K in K) for SEI=0.1 per mission band for DS synthetic shape variations and FTS symmetric shape variations.

In the most sensitive band, IRS-1, the sensitivity of radiometric errors to the shape error index NEdT@280K/SEI are:

- 0.42 K/0.1 for DS,
- 0.14 K/0.1 for FTS symmetric shape variations.

As for spectral shift knowledge errors, it is stated that radiometric noise sensitivity to SEI is lower in band 6 than in band 5.
Finally, it is demonstrated that SEI is not suitable to control asymmetric shape variations (represented by triangles pointing upward at the example of FTS micro-vibrations) globally. First, the radiometric noise level is much higher than for symmetric shape variations at comparable SEI. Secondly, there is no clear relation between noise at different vibration frequencies and SEI. In certain bands a lower SEI may cause a higher noise. It appears more suitable to introduce instead a specification on forbidden frequencies, because the relation between the spectral ghost position and the vibration frequency depends only on the corner cube speed. For the current concept these forbidden frequencies would be lower than about 20 Hz. The alternative is to formulate an SEI specification for a known spectrum of vibration frequencies, as attempted in the frame of IASI in [RD 6].

Figure 6: Radiometric noise per IRS mission band as function of the shape error index for the above-described instrument configurations. (1) Squares (FTSf, 3 estimations): FTS in unperturbed instrument conditions at various field angles. (2) Triangles upward (FTSv, 2 estimations): FTS, impact of micro-vibrations. (3) Triangles downward (FTSc, 1 estimation): FTS, impact of corner cube motion deviations. (4) Open circles (DS, 2 estimations): Synthetic DS-ISRF perturbation.
3.3. Atmospheric variability

Obviously, the radiometric noise induced by unknown spectral shift or shape errors depends on the atmospheric conditions. The related radiometric errors have been evaluated for four clear-sky spectra recalled in section 2.3: (1) hot and humid, (2) hot and dry, (3) temperate and moderately humid and (4) cold and dry. The shift and shape knowledge error noise ratio with respect to case (1), to which results in sections 3.1 and 3.2 refer, are presented for the three other atmospheres and the two concepts in Figure 8 and Figure 9, respectively.

Atmospheric variability has a comparable impact on shift knowledge error noise for the two concepts. The noise ratios are governed by the amplification or the smoothing of the spectral signature. Lower surface and low-level temperature explains ratios below one for the cold and the temperate atmosphere. The hot and dry case (at temperatures similar to the hot and humid case) shows variable noise ratios. In bands without strong water vapour absorption, the water vapour continuum signature is weakened due to the relative absence of humidity, leading to a ratio below one. In contrary, in the strong water vapour absorption bands 5 and 6, the humidity deficit causes a reduced atmospheric opacity so that the observed signal originates from lower and therefore hotter vertical levels. This explains a ratio above one. The much higher ratio in band 6 than in band 5 indicates that the earlier stated lower radiometric sensitivity to shift and shape errors in band 6 is partly cancelled for a dry and hot atmosphere.
3.4. Preliminary conclusions

This section summarises the relevant findings of the radiometric sensitivity analysis to spectral shift and ISRF shape knowledge errors. The results will be applied for the consolidation of the IRS spectral calibration noise budget and the quantification of related instrument stability requirements.
3.4.1. Radiometric shift knowledge error noise

Radiometric shift knowledge error noise, as rms over mission bands, increases linearly with the spectral shift knowledge error.

The highest sensitivity is observed in band 7. For shift knowledge errors expressed as fraction of the spectral resolution and as relative shift knowledge error, SDE_{sr} and SDE_{r}, respectively, we derive for a hot and humid atmosphere the following sensitivities in terms of radiometric noise \( \sigma_{\text{shift}} \) in NEdT@280K:

\[
\begin{align*}
\sigma_{\text{shift}}/\text{SDE}_{sr} &= 0.15 \text{ K/\%} \quad \text{and} \quad \sigma_{\text{shift}}/\text{SDE}_{r} = 0.5 \text{ K}/10^{-5} \quad \text{for the FTS baseline} \\
\sigma_{\text{shift}}/\text{SDE}_{sr} &= 0.12 \text{ K/\%} \quad \text{and} \quad \sigma_{\text{shift}}/\text{SDE}_{r} = 0.25 \text{ K}/10^{-5} \quad \text{for the DS baseline}
\end{align*}
\]

Sensitivities in other bands are smaller, in particular in bands 6, 8 and 9.

If referred to a temperate and moderately humid atmosphere, a correction factor of about 0.8 applies to the above values.

3.4.2. Radiometric shape knowledge error noise

For quasi-symmetric ISRF shape variations, radiometric shape knowledge error noise, as rms over mission bands, increases linearly with the shape error index SEI.

The highest sensitivity is observed in band 1. We derive for a hot and humid atmosphere the following sensitivities in terms of radiometric noise \( \sigma_{\text{shape}} \) in NEdT@280K:

\[
\begin{align*}
\sigma_{\text{shape}}/\text{SEI} &= 0.14 \text{ K}/0.1 \quad \text{for the FTS baseline} \\
\sigma_{\text{shape}}/\text{SEI} &= 0.42 \text{ K}/0.1 \quad \text{for the DS baseline}
\end{align*}
\]

Remarks on variations with spectral bands and with the atmosphere type apply as for shift knowledge errors.

The shift error index is unsuitable for a global control of asymmetric ISRF shape variations like ghosts. Further investigations should be based on an explicit instrument design.

3.4.3. Co-alignment of detector arrays

Extrapolation of the spectral calibration function and thus reduction of the number spectral calibration windows requires a good co-alignment of the different focal planes of the instrument.

In case of a mis-alignment, a single-window approach does not account for a shift between spectral domains covered by different focal planes. This shift has to be limited to a negligible noise level, e.g., 0.025K NEdT@280K. A single-window spectral calibration algorithm design requires an inter-array co-alignment, expressed as relative shift knowledge error, of

\[
\begin{align*}
\text{below } 5 \times 10^{-7} & \quad \text{for FTS,} \\
\text{below } 1 \times 10^{-6} & \quad \text{for DS.}
\end{align*}
\]

The definite spectral calibration algorithm design will be defined in trade-off with the instrument performance analysis with respect to those requirements. For instance, the necessity to apply the spectral calibration algorithm individually to each detector array must be considered as a realistic option, while worst case with regard to the system requirements.
4. Shift determination errors for a known atmosphere

The impact of radiometric noise on the spectral shift determination of an individual measured spectrum is estimated in various spectral calibration windows by application of the spectral shift determination algorithm with and without consideration of radiometric noise. Applied to spectra without noise, the resulting shift determination knowledge errors may be interpreted as the algorithmic performance (intrinsic algorithm noise) as function of the spectral calibration window. Subsequently applied to noisy spectra, the impact of radiometric noise on the shift determination performance is estimated. In this section, all shift determination exercises are carried out on spectra corresponding to the reference atmosphere. This excludes any noise due to atmospheric variability (investigated in section 5) and represents shift determination errors in case of perfectly known atmospheric conditions.

Sections 4.1 and 4.2 present the results separately for the DS and the FTS baseline, respectively, in comparable configurations of radiometric noise and initial shifts between measured spectra and the reference spectrum.

Shift determination errors are presented as relative errors ($SDE_r$) and as fraction of the spectral resolution ($SDE_{sr}$) of the mission band where the respective spectral calibration window is situated. Using the shift/noise conversion factors in Table 5 and Table 6, the radiometric noise corresponding to the shift determination errors can be estimated for a single spectrum. In terms of $SDE_{sr}$, the drawback is that the noise estimation is only valid in the mission band of the spectral calibration window. The propagation of shift determination errors and the associated noise over the entire spectrum is not directly described by $SDE_{sr}$. Therefore, performances in different windows are not directly comparable at first glance.

In this context, we recall briefly the assumed spectral shift dependency for the two instrument concepts (detailed in [RD 1, section 3.2.1]). For a given DS spatial sample, the shift (in wavelength) $\delta \lambda$ is the sum of an offset $A$ and a distortion $D$ of the detector array in the spectral dimension:

$$\delta \lambda = A + (D-1) \lambda_0$$

In wave number ($\nu$), this yields:

$$\delta \nu = v_0 (1/(A v_0 + D) - 1)$$

For FTS, the field angle ($\alpha$) dependent spectral shift is given by

$$\delta \nu = v_0 (\cos \alpha - 1)$$

Except for the offset dependent component for DS, the relative shift $\delta \nu / v_0$ is constant over the spectrum. By consequence, shift determination performances in different spectral calibration windows can be better compared if expressed as relative shift determination errors $SDE_r$.

4.1. SDE estimation for the DS baseline

The SDE estimation in reference atmospheric conditions is carried out for eight combinations of radiometric noise and initial shifts. As initial shift between the uncalibrated and the reference spectrum we simulate spectrally constant absolute values of 0 and 1 cm$^{-1}$, represented by open and filled symbols, respectively, in all figures of this section.
Figure 10: Relative shift determination errors in reference atmospheric conditions per spectral calibration window for the DS baseline. Level 1a spectra are considered at initial absolute shifts 0 and 1 cm\(^{-1}\) (legend key for shift: n-y) with respect to the reference spectrum and at four noise levels, no noise, nominal noise, half and twice the nominal noise (legend key for noise: 0-1/2-2). For the definition of spectral calibration windows see Table 3.

Figure 11: Shift determination errors as fraction of spectral resolution, otherwise as in Figure 10.

In terms of noise, we consider the nominal radiometric noise of the DS baseline at typical brightness temperature (c.f., Table 1) at four levels, 0%, 50%, 100% and 200%, represented by black, red, green, and blue symbols, respectively, in all figures of this section.
Figure 10 and Figure 11 present the shift determination errors in terms of $SDE_r$ and $SDE_{nr}$ in these eight noise/initial shift combinations for the fifteen pre-selected spectral calibration windows (windows 2F to 5F in the Fourier correlation space, windows 2 to 5 and 11 to 17 in the spectral calibration space). For the interpretation of relative shift determination errors, we identify in Table 6 band IRS-7 as the most critical one with a sensitivity of 0.26K (NEdT@280K) per $10^{-5}$. Thus, a relative shift determination error of $4 \times 10^{-6}$ corresponds to 0.1K radiometric noise (the current specification for the overall spectral calibration noise).

### 4.1.1. Intrinsic algorithm noise

The intrinsic algorithm noise corresponds to the shift determination performance without radiometric noise. If the first guess of the correlation procedure is the right one, i.e., if no initial shift is applied, the performance is at the level of the numerical precision and related noise is negligible, except for windows 2F, 4F, 5F. In the more realistic case that the initial shift is not known as first guess, relative $SDE$ is of magnitude $10^{-6}$ in windows 4F, 5F, 4, and 5. As expected, spectroscopic line structures are insufficiently resolved in these windows, so even intrinsic algorithm noise becomes significant. The intrinsic algorithm noise in all other windows is of magnitude $10^{-8}$, the related radiometric noise does not exceed 1 mK and remains strictly negligible.

### 4.1.2. Initial shift knowledge

If radiometric noise is introduced, the impact of the initial shift knowledge, represented by the distance between open and full symbols of the same colour, is reduced. In average, the $SDE_r$ ratio between these cases is about two third, but dispersion is strong. Hence, the algorithm tends to become independent of the initial shift knowledge, and it is concluded that the correlation performance does not primarily depend on the procedure’s initialisation and iteration parameters.

### 4.1.3. Impact of radiometric noise

As expected, radiometric noise at the three considered levels predominates over algorithm noise. Exceeding 1K in some configurations; the noise level becomes unacceptable in windows 4 and 5 in both correlation spaces. In all other windows, relative $SDE$ are confined to the range $10^{-7}$ to $10^{-5}$ for all noise levels. Excluding windows 4 and 5, the average $SDE$, is quite exactly $10^{-6}$, $2 \times 10^{-6}$, $4 \times 10^{-6}$ for 50, 100 and 200% nominal noise, respectively. This suggests a roughly linear impact of radiometric noise on the shift determination performance.

### 4.1.4. Performance by window

After exclusion of windows 4 and 5, performance differences over spectral calibration windows are not striking. A slightly outstanding performance may be noticed in windows 11, 12 and 17 where relative $SDE$ at nominal noise remain below $10^{-6}$. A relatively high sensitivity to radiometric noise is observed in windows 2F, 2, 14, 15, and 16. At least for windows 2F and 2, this can be explained by the high nominal noise level with respect to the noise in other calibration windows. In general, windows associated with higher brightness temperatures are less sensitive to radiometric noise, and vice versa. Comparing the performance with respect to the correlation space in the remaining windows 2 and 3, no significant difference is noticeable.
4.2. SDE estimation for the FTS baseline

For the FTS baseline, the SDE estimation in reference atmospheric conditions is carried out in noise/shift configurations comparable to those applied to the DS baseline. We consider 0%, 50%, 100% and 200% of the FTS baseline noise at typical brightness temperature (c.f., Table 2).

Initial shifts are considered for detectors in the centre and at one corner of the array at nominal minimum and maximum central field angles, i.e., 0 and 87.5 mrad. These detectors are considered for two positions of the interferometer axis:

1. The nominal interferometer axis position in the detector array centre generates relative shifts $7 \times 10^{-8}$ and $3.819 \times 10^{-3}$ for the centre and corner detector, respectively. Presented as first guess to the initialisation of the correlation windows, the shift determination performance is supposed to be equivalent for both detector positions.

2. The interferometer axis is shifted from its nominal position by 1.42 mrad in the direction opposite to the considered corner detector. This corresponds to a 6 km shift in both ground dimensions, the relative shift becomes $1.08 \times 10^{-6}$ and $3.944 \times 10^{-3}$ for the centre and corner detector, respectively, leading to unknown initial relative shifts of $1.01 \times 10^{-6}$ and $1.25 \times 10^{-4}$. This difference of two magnitudes is typical for the FTS baseline concept. Its possible impact on the shift determination performance is investigated by comparison between the results for the two extreme detector positions.

In analogy to Figure 10, Figure 12 and Figure 13 present the relative shift determination errors $SDE_r$ for the FTS central and corner detectors, respectively. For completeness, Figure 14 and Figure 15 present the same results as fraction of spectral resolution $SDE_{sr}$. For the interpretation of relative shift determination errors, we identify in Table 6 band IRS-7 as the most critical one with a sensitivity of 0.51K (NEdT@280K) per $10^{-5}$. Thus, a relative shift determination error of $2 \times 10^{-6}$ corresponds to 0.1K radiometric noise (current specification for overall spectral calibration noise).

4.2.1. Intrinsic algorithm noise

Intrinsic algorithm noise for a known initial shift (open circles) is unacceptable in windows 4F and 5F, elevated in window 2F, and negligible in all other windows. As expected, it is equivalent for the two detectors. For unknown initial relative shifts (full circles), the performance depends strongly on the detector position. For the central detector, relative shift determination errors of magnitude $10^{-8}$ to $10^{-9}$ are observed (except for windows 4F, 5F, 5). This performance is comparable to that observed for the DS baseline and the related radiometric algorithm noise is negligible. For the corner detector, relative SDE are above $10^{-6}$ in most cases, the average value over all windows except 4, 5, 4F and 5F is $2.7 \times 10^{-6}$. Thus the algorithm noise is of the order of the specification for the overall spectral calibration noise.

This gives first indications on the full spectral calibration algorithm design. In order to reduce algorithm noise of the spectral shift determination, there are three possible methods: (1) Exclusion of measurements at large field angle for the determination of the interferometer axis position, (2) Field angle dependent initialisation of the shift determination procedure, (3) Iterative interferometer axis position determination, first over detectors at small field angle, then using the shift corresponding to the first guess interferometer axis position as input information for the spectral shift determination in detectors at large field angles. While method (3) appears as the most precise, it adds complexity to the algorithm. For instance, we conclude that elevated algorithm noise at large field angles is not a critical issue per se in view of the instrument concept choice.
Figure 12: Relative shift determination errors in reference atmospheric conditions per spectral calibration window for the FTS baseline (detector at central field angle 0). Level 1a spectra are considered at unknown initial relative shifts 0 and 1.01 $10^{-6}$ (legend key for shift: n-y) with respect to the reference spectrum and at four noise levels, no noise, nominal noise, half and twice the nominal noise (legend key for noise: 0-1-1/2-2). For the definition of spectral calibration windows see Table 3.

Figure 13: As Figure 12, but for a detector at central field angle 87.5 mrad. Unknown initial relative shifts are 0 and 1.25 $10^{-4}$ for shift legend n-y, respectively.
Figure 14: Shift determination errors as fraction of spectral resolution, otherwise as in Figure 12.

Figure 15: Shift determination errors as fraction of spectral resolution, otherwise as in Figure 13.
4.2.2. Initial shift knowledge

At small field angle, radiometric noise predominates the algorithm noise. As for the DS baseline, shift determination performances tend to become independent of the initial shift if radiometric noise is included. At high field angle, radiometric and algorithm noise are of the same magnitude. Thus the shift determination performance remains dependent on the initial shift.

4.2.3. Impact of radiometric noise

Excluding windows 4 and 5 in both correlation spaces, and the case of strong initial shifts at large field angle (i.e. full symbols in Figure 13) to become independent of algorithm noise, a relatively homogeneous performance over the remaining windows can be noticed. The average SDE_r is roughly $10^{-6}$, $2 \times 10^{-6}$ and $6 \times 10^{-6}$ for 50, 100 and 200% nominal noise, respectively. The linear impact of radiometric noise on the shift determination performance as stated for the DS baseline cannot be fully confirmed.

4.2.4. Performance by window

The average shift determination performance at nominal radiometric noise is close to $2 \times 10^{-6}$ corresponding to 0.1K NEdT@280K radiometric noise. Strong performance variations between windows cannot be clearly identified, except that ‘cold’ windows (e.g., 14 and 15) tend to be more sensitive to radiometric noise than ‘warm’ windows.

Again we state similar performances in the two correlation spaces in the windows 2 and 3.
4.3. Preliminary conclusions

This section summarises the relevant findings of the shift determination exercise for single measurements in perfectly known atmospheric conditions in various spectral calibration windows.

4.3.1. Intrinsic algorithm noise

Intrinsic shift determination algorithm noise is found negligible, except for measurements at large field angle of the FTS concept. The major conclusion is that due to the large field angles, the FTS spectral shift determination algorithm might become dependent on the detector position in the array. This is no a priori reservation against the FTS concept, but a possible impact on the complexity of the algorithm design should be kept in mind.

4.3.2. Spectral calibration windows

For both concepts, the performance in calibration windows 4 and 5 is poor in both correlation spaces. A relatively homogeneous performance is observed in all other pre-selected windows. A performance difference in windows 2 and 3 with respect to the correlation space is not observed.

4.3.3. Shift determination performance for single measurements

As thumb rule, we state relative SDE of $2 \times 10^{-6}$ at nominal radiometric noise for both concepts. This corresponds to a radiometric noise of 0.05K and 0.1K NEdT@280K for DS and FTS, respectively, in the most sensitive band IRS-7. These estimations apply under the following conditions: (1) Each spectrum is calibrated individually, (2) the spectral calibration function is perfectly known, i.e., spectral shifts can be extrapolated from a calibration window all over the spectrum, or multiple-window shift determination is applied, (3) the atmospheric state is perfectly known.
5. Impact of atmospheric variability

The impact of atmospheric variability on the spectral shift determination is evaluated in various spectral calibration windows. The shift determination process is applied to uncalibrated spectra in selected atmospheric conditions and a reference spectrum in atmospheric reference conditions. The selection of atmospheric conditions (c.f. section 2.3) comprises four clear-sky atmospheres (including the reference atmosphere) and four cloudy atmospheres, represented by open and full symbols, respectively, in all figures of this paragraph.

Since the four clear-sky/cloudy atmosphere couples represent different atmospheric regimes, the overall variation of the shift determination performance in each spectral calibration window can be interpreted as the impact of atmospheric variability in case of a unique, globally applied reference spectrum. Each individual SDE provides the impact of the deviation of the investigated atmospheric state from the reference state. The following subsections present the impact of atmospheric variations on the shift determination as relative shift determination errors $SDE_r$.

In order to separate this atmospheric noise from the impact of radiometric noise on the shift determination and to identify the dominating component for the overall SDE, all shift determination experiments in this paragraph are carried out twice, without radiometric noise and with the nominal radiometric noise for the two instrument baselines.

Some general characteristics of atmospheric noise should be kept in mind:

- Opposite to radiometric noise, atmospheric noise is not necessarily reduced by the accumulation of a large number of measurements, i.e. by extending the spectral calibration period. This is because atmospheric variations tend to increase with increasing geographical coverage. Atmospheric noise can be considered as constant only for a spectral calibration period of the order of the MTG/IRS repeat cycle of 30 minutes, or beyond.

- An efficient way to reduce atmospheric noise is to reduce the possible deviations of the observed atmospheric state from the reference state by improving the a-priori knowledge on the atmospheric conditions. In practice, this means that shift determination are carried out on a set of representative reference spectra. Either a-priori knowledge on the atmospheric state is injected (a simple scene identification from the built-in imager or static geographical criteria may be suitable) and the corresponding reference spectrum is used for shift determination. Or, without explicit a-priori information, shift determinations are applied to a couple of reference spectra and the best fitting estimation is retained.

- Another way to reduce atmospheric noise is to exclude certain spectra types, by simple scene identification, that are known to be unsuitable for shift determination. This concerns mainly spectra at low radiometry level without strong spectral signatures. This kind of scene filtering, however, must be compatible with the spectral calibration period, i.e., it must be ensured that a sufficient number of unfiltered measurements is accumulated in any possible Earth scan position.

Attempting to put minimum constraints on the ground segment, we will investigate in this paragraph the atmospheric noise in case of a unique, globally used reference spectrum.
5.1. SDE estimation for the DS baseline

**Figure 16:** Relative shift determination errors in eight atmospheric conditions per spectral calibration window for the DS baseline. No radiometric noise is considered. Legend key for atmospheric conditions: (1) Identification number (see Table 4); (2) Surface Temperature $T +0/0/-$ hot/temperate/cold; (3) Humidity $H +0/-$ humid/moderately humid/dry; (4) Cloudiness $C 0/0/0/0/-$ clear-sky/high opaque/high thin/low opaque. For the definition of spectral calibration windows see Table 3.

**Figure 17:** As Figure 16, but with nominal radiometric noise at typical brightness temperature.
Figure 16 and Figure 17 present relative shift determination errors for the DS baseline without radiometric noise and including nominal radiometric noise, respectively, in eight atmospheric conditions. Results obtained for the reference atmosphere without noise are identical to those obtained in Figure 10 and there interpreted as intrinsic algorithm noise.

The impact of the low cloud occurrence in otherwise unchanged atmospheric conditions is represented by the SDE difference for atmospheres 0511 and 0512. As expected due to their weighting functions close to zero in the lower troposphere all over the window, we identify in Figure 16 windows 4, 5, 14, 15, and, to a smaller extent, 13 and 16 as those windows that are insensitive to low cloud occurrence.

The impact of thin cirrus can be evaluated by the SDE difference for atmospheres 1611 and 1612. As expected, thin cirrus has no significant impact on the shift determination procedure by conserving the resolved spectral signatures (Figure 16). SDE differences in Figure 17 are clearly due to the randomly added radiometric noise.

A general tendency to poor shift determination performances can be observed for cold scenes (atmospheres 0722, 0932, and, to a slightly lower extent, 0931). This finding can be explained either by the generally decreasing amplitudes of spectral signatures with decreasing temperature and small vertical temperature gradients (in high latitudes), or with the masking of spectral signatures from mid or low tropospheric altitude levels (in case of high opaque clouds). The first effect explains a particularly bad performance for high-latitude atmospheres 0931 and 0932 in windows 14 and 15, the second effect the bad performance for the tropical atmosphere 0722 in windows 11, 12, and 17. Despite the different physical effects, a scene filtering of cold scenes including both relevant types of atmospheric conditions is suggested by the generally lower performances in all calibration windows. The scene filtering could be obtained by a simple threshold test on the collocated TIR observations from the IRS built-in imager.

With regard to variations with spectral windows, we state again an unsatisfactory performance in windows 4 and 5 in the two correlation spaces. Including radiometric noise, relative SDE are generally between $10^{-4}$ and $10^{-5}$, corresponding to radiometric noise far beyond the overall spectral calibration noise allocation. For the remaining windows and for the atmosphere types after scene filtering (i.e., 0721, 1611, 1612), it is important to note by comparison of Figure 16 with Figure 17 that there is only a slight impact of radiometric noise on shift determination errors. This means that a reduction of nominal radiometric noise has only a small impact on the spectral calibration noise budget, under the condition that a unique reference spectrum is used.

On the other hand, we also verify in Figure 17 that good atmospheric a-priori knowledge is not driving the overall shift determination performance. Indeed, the performance for the (known) reference atmosphere (open circles) is not systematically superior to the performance for other atmospheric states. Hence, the impact of radiometric noise and of atmospheric variability is of the same magnitude. A clear separation between the two components in general terms is not possible and has to be investigated individually for each window.

The combined impact of radiometric noise and atmospheric variability constitutes the overall algorithmic shift determination error. The relative shift determination errors, approximately averaged over the five relevant atmospheres, are provided in Table 8. These values can be interpreted as the typical overall shift determination error of individual measurements.
Table 8: Relative shift determination errors as multiples of $10^{-6}$, corresponding to the overall noise in the shift determination of a single IRS/DS spectrum by means of correlation maximisation with a unique, globally applied reference spectrum.

The overall shift determination noise is of the order $10^{-6}$ (corresponding to 0.025K NEdT@280K in band 7) in windows 11/12 (remind that these windows are alternative since only distinguished by their width) and 17. In all other windows, it is below $6 \times 10^{-6}$. These performances appear encouraging in view of the full spectral calibration exercise because many options for noise reduction are left open (reduction of radiometric noise by accumulation of measurements, reduction of atmospheric noise by use of several reference spectra).

Furthermore, a slight tendency towards a better performance in the spectral correlation space as compared to the Fourier correlation space can be noticed in windows 2 and 3. Finally, in view of the alternative implementation of band 5 or 6, we note a tendency to higher performance in windows situated in band 6 (15, 16, 17) than in those of band 5 (13, 14).

5.2. SDE estimation for the FTS baseline

For the FTS concept, SDE estimation results are shown for the detectors in the centre and the corner of the array consistently with section 4. Figure 18 and Figure 20 present relative shift determination errors for the FTS centre detector without radiometric noise and including nominal radiometric noise, respectively, in eight atmospheric conditions. Figure 19 and Figure 21 do so for the FTS corner detector. In order to exclude undesired and corrigeble algorithm parameterisation effects, results are shown for zero initial shift. Therefore, performance estimates in Figure 18 / Figure 19 should be equivalent except for random effects within the correlation procedure. Equivalence of performance estimates in Figure 20 / Figure 21 is further affected by random effects in the radiometric noise attribution. In spite of some strong individual shift determination error differences, the expected overall equivalence is confirmed.

There is no substantial difference in the shift determination performance between DS and FTS baseline:

- The impact of cloud occurrence as discussed for DS is qualitatively confirmed. In particular, filtering of cold scenes is suggested.
- Exclusion of windows 4 and 5 is recommended in both correlation spaces.
- In the investigated configuration of a unique reference spectrum, the impact of atmospheric variation and of radiometric noise on the shift determination error is of the same magnitude.

The relative shift determination errors, approximately averaged over the five unfiltered atmospheres, are provided in Table 9.

Table 9: Relative shift determination errors as multiples of $10^{-6}$, corresponding to the overall noise in the shift determination of a single IRS/FTS spectrum by means of correlation maximisation with a unique, globally applied reference spectrum.

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Figure 18: Relative shift determination errors in eight atmospheric conditions per spectral calibration window for the FTS baseline (detector at central field angle 0). No radiometric noise is considered. Legend key for atmospheric conditions: (1) Identification number (see Table 4); (2) Surface Temperature T+/0/- hot/temperate/cold; (3) Humidity H+/0/- humid/moderately humid/dry; (4) Cloudiness C 0/ho/ht/lo clear-sky/high opaque/high thin/low opaque. For the definition of spectral calibration windows see Table 3.

Figure 19: As Figure 18, but for a detector at central field angle 87.5 mrad.
Figure 20: As Figure 18, but with nominal radiometric noise at typical brightness temperature.

Figure 21: As Figure 19, but with nominal radiometric noise at typical brightness temperature.

Using the radiometric sensitivity factor 0.5K/10⁻⁵ (Table 6, worst case sensitivity for band IRS-7, in NEdT@280K), the overall radiometric performance varies between 0.04 and 0.25 K depending on the windows. Values of 0.10 K or below are observed in windows 2, 3, 11, 13, 16, 17, again encouraging in view of the full spectral calibration exercise.
As for DS, the tendency towards a better performance in the spectral correlation space as compared to the Fourier correlation space can be noticed in windows 2 and 3. Also, a better performance in band 6 windows than in band 5 windows is confirmed.

5.3. Preliminary conclusions

This section summarises the results of the shift determination exercise in various spectral calibration windows for single measurements in variable atmospheric conditions.

5.3.1. Instrument concept

The impact of atmospheric variability on the shift determination of individual measurements is qualitatively identical for both instrument concepts.

5.3.2. Reference spectrum

The overall shift determination performance of individual measurements is encouraging in numerous windows. This let us envisage the use of a unique, globally applicable reference spectrum for the shift determination of measured spectra. However, filtering of cold scenes, by means of a simple threshold scene identification, is suggested.

5.3.3. Spectral calibration windows

Among the investigated spectral calibration windows, we exclude the CO₂ windows 4 and 5 because of an insufficient spectral resolution in band IRS-8. Shift determination performance in the Fourier space does not prove superior to the performance in the radiance space in corresponding windows. Therefore, we abandon windows 2F and 3F. Finally, with regard to the alternative windows 11 and 12 that are only distinguished by their width, a slightly higher performance is observed in window 11, i.e. for the broader window, so we abandon window 12.

Applying the noise/shift sensitivity factors of Table 6, the radiometric error due to shift determination errors of individual measurements including the impact of radiometric noise and atmospheric variability are provided in Table 10. It is given for the mission band of the respective calibration window, as well as extrapolated to the radiometrically most sensitive band IRS-7.

<table>
<thead>
<tr>
<th>window</th>
<th>2</th>
<th>3</th>
<th>11</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>mission band</td>
<td>IRS-1</td>
<td>IRS-7</td>
<td>IRS-4</td>
<td>IRS-5</td>
<td>IRS-5</td>
<td>IRS-6</td>
<td>IRS-6</td>
<td>IRS-6</td>
</tr>
<tr>
<td>NEdT@280K [K] in mission band (DS)</td>
<td>0.04</td>
<td>0.05</td>
<td>0.01</td>
<td>0.04</td>
<td>0.08</td>
<td>0.02</td>
<td>0.02</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>extrapolated to IRS-7 (DS)</td>
<td>0.08</td>
<td>0.05</td>
<td>0.03</td>
<td>0.08</td>
<td>0.16</td>
<td>0.08</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>NEdT@280K in mission band [K] (FTS)</td>
<td>0.02</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
<td>0.11</td>
<td>0.05</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>extrapolated to IRS-7 (FTS)</td>
<td>0.05</td>
<td>0.04</td>
<td>0.10</td>
<td>0.10</td>
<td>0.25</td>
<td>0.20</td>
<td>0.05</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Table 10: Radiometric error corresponding to shift determination errors for individual MTG/IRS spectra reported in Table 8 and Table 9.

Individual shift determination performances reported in Table 10 are generally within the overall spectral calibration noise allocation of 0.1 K NEdT@280K. Since accumulation of measurements will further reduce the algorithmic contribution to the spectral calibration noise budget, it can be anticipated that a large part of the budget can be allocated to the component related to instrument instability.

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6. Consolidation of spectral calibration windows

In spite of the encouraging shift determination performance in numerous spectral calibration windows, the proposed spectral calibration algorithms are not yet linked to the instrument concepts in case that co-alignment between different focal planes is not feasible with the required accuracy. In this case, spectra observed in each focal plane have to be calibrated separately. It is recalled that array separations are identical for both concept baselines.

For the FTS concept, we assume the spectral calibration function depending only on the average cosine of the field angle, while for the DS concept, it depends on a spectral offset due to relative motion of the detector array along the spectral dimension and on a distortion factor due a spread or compression of the detector array along the spectral dimension.

To ensure the feasibility of the spectral calibration in the worst case, at least one calibration window for FTS and at least two calibration windows for DS must be available. Referring to the array band indices defined in Table 1 and Table 2, we state for:

- **Array S2/A1** Mission bands IRS-1, IRS-2
  The only investigated spectral calibration window is W02 in IRS-1. We define an additional window W21 in IRS-2 between 790 and 860 cm\(^{-1}\) in order to investigate its shift determination performance as complementary window to W02 for the DS concept. For FTS, this window might be of interest in case of removal of IRS-1. However, it is expected that the low atmospheric opacity in W21 causes a relatively unstable shift determination performance.

- **Array S3/A2** Mission bands IRS-3, IRS-4
  Window W11 in IRS-4 has been selected for both concepts. We define an additional window W22 in IRS-3 between 1020 and 1070 cm\(^{-1}\) in order to investigate its shift determination capability as complementary window to W11 for the DS concept. Situated in the ozone absorption band, this window appears not particularly suitable for spectral shift determinations since spectral signatures are strongly variable with the atmospheric state.

- **Array S4/A3** Mission band IRS-5
  Windows W13 and W14 are selected. A definition of additional windows is not required.

- **Array S4’/A3’** Mission band IRS-6
  Windows W15, W16 and W17 are selected. A definition of additional windows is not required.

- **Array S5/A4** Mission bands IRS-7, IRS-8, IRS-9
  Window W03 in IRS-7 is selected. Since there is little hope for finding another suitable spectral calibration window, we investigate the already investigated windows W04 and W05 in IRS-8 at enhanced spectral resolution. We consider a hypothetical mission band IRS-8’ that differs from IRS-8 only in on-board processing issues, causing a higher data transfer rate but no modifications of the instrument. For DS, spectral filtering is applied to a couple (instead of a triple) of elementary spectral detectors. This leads to a spectral sampling and a spectral resolution both enhanced by a factor 1.5 in comparison to IRS-8, which come close to the values in IRS-7. Thus we consider IRS-8’ at the spectral resolution of IRS-7, that is, expressed in terms of wavenumber at the band centre, 0.95 cm\(^{-1}\). For FTS, we consider IRS-8’ with an interferogram decimation equivalent to that applied in IRS-7. The spectral resolution in IRS-8’ is then enhanced by a factor 2 to 0.62 cm\(^{-1}\).
The characteristics of the additional calibration windows are summarised in Table 11.

<table>
<thead>
<tr>
<th>Window id</th>
<th>Wavenumber range (cm(^{-1}))</th>
<th>IRS Band</th>
<th>Species</th>
<th>Absorption line spacing (cm(^{-1}))</th>
<th>Spectral resolution required (cm(^{-1}))</th>
<th>Spectral resolution IRS/FTS(cm(^{-1}))</th>
<th>Spectral resolution IRS/DS(cm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>W04' W04F'</td>
<td>2300 - 2350 2303 - 2348</td>
<td>IRS-8'</td>
<td>CO(_2)</td>
<td>1.8</td>
<td>1.25</td>
<td>0.62</td>
<td>0.95</td>
</tr>
<tr>
<td>W05' W05F'</td>
<td>2350 - 2370</td>
<td>IRS-8'</td>
<td>CO(_2)</td>
<td>1.35</td>
<td>1.25</td>
<td>0.62</td>
<td>0.95</td>
</tr>
<tr>
<td>W21</td>
<td>790 - 860</td>
<td>IRS-2</td>
<td>-</td>
<td>-</td>
<td>0.625</td>
<td>0.62</td>
<td>0.94</td>
</tr>
<tr>
<td>W22</td>
<td>1020 - 1070</td>
<td>IRS-3</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>0.49</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Table 11: Additional spectral calibration windows for consolidation of the window selection.

In analogy to sections 5.1 and 5.2, Figure 22 and Figure 23 present relative shift determination errors without radiometric noise and including nominal radiometric noise for DS and FTS (for zero central field angle), respectively, in eight atmospheric conditions.

The performance in window W21 is roughly 5 \(10^{-6}\) in all instrument configurations after elimination of cold scenes. As expected, the overall performance is lower than in initially selected windows. However, its exploitation for the DS array S2 calibration in combination with W02 is not excluded, according to a noise/shift sensitivity of 0.06 K/10\(^{-5}\) in IRS-2. An exploitation of W21 for FTS array A1 calibration does not appear beneficial.

Exceeding 10\(^{-5}\) in numerous cases, the performance in window W22 is unacceptable for DS. It is not of interest for FTS due to the higher performances in the adjacent window W11.

The theoretical capacity of windows 4' and 5' in both correlation spaces is demonstrated for DS by a very homogenous and high-level performance if radiometric noise is not included. Unfortunately, inclusion of radiometric noise generates shift determination errors of the order of 10\(^{-5}\), which appears unacceptable for a common exploitation with W03 for the calibration of array S5. The same behaviour can be observed for FTS, though the overall performance is better due to higher spectral resolution. Nevertheless, the implementation of IRS-8' for FTS is not justified, because higher shift determination performances in the adjacent window W03 have been found.
Figure 22: Relative shift determination errors in eight atmospheric conditions per spectral calibration window for the DS baseline. No radiometric noise is considered. Legend key for atmospheric conditions: see section 5. Left: without radiometric noise, right: with nominal radiometric noise.

Figure 23: Relative shift determination errors in eight atmospheric conditions per spectral calibration window for the FTS baseline (detector at central field angle 0). No radiometric noise is considered. Legend key for atmospheric conditions: see section 5. Left: without radiometric noise, right: with nominal radiometric noise.
7. Outlook

In part 3 of the assessment of the IRS spectral calibration algorithm, we will investigate the overall spectral calibration noise upon the consolidated algorithm and instrument design hypotheses outlined in this report.

Full spectral calibration experiments will be carried out with the objective to consolidate the spectral calibration noise budget and to derive allocations for its (algorithm and instrument) components. A major issue is to explicitly quantify the algorithmic shift determination noise by relating individual shift determinations to the instrument state parameters derived from the analysis of accumulated individual measurements. This requires the application of various spatio-temporal selection scenarios of individual measurements in different atmospheric conditions, and of various configurations of the assessed spectral calibration windows. The latter includes in particular an optimised window choice in case of good focal plane co-alignment and a worst-case configuration in case of necessity for an individual spectral calibration per focal plane.