Adapting the AAPP microwave tests for EPS-SG: part 2 – surface tests

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Version	Date	Author / changed by	Remarks
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1. INTRODUCTION

NWP SAF document NWPSAF-MO-TR-040 discusses the adaption of several AAPP microwave tests for use with the MicroWave Sounder (MWS) on EPS-SG.

In this document we consider in more detail the test that is intended to characterise the land or sea surface.

It should be noted that these tests make use only of the observations, and do not use a model background. They can therefore be useful for detecting inconsistencies between the data and the model.

2. SURFACE TEST IMPLEMENTED IN AAPP V8

This section is largely based on the earlier document NWPSAF-MO-TR-040, and is included for completeness.

The surface test implemented in AAPP version 8 (and earlier releases) makes use of three channels, at 23.8 GHz (channel 1), 31.4 GHz (channel 2) and 50.3 GHz (channel 3). These channels are common to AMSU, ATMS and MWS. The test works by looking for the surface type that minimises a cost function

$$J = (T_1 - \overline{T}_1\,,\quad T_2 - \overline{T}_2\,,\quad T_3 - \overline{T}_3)\,\mathbf{C}^{-1}\begin{pmatrix} T_1 - \overline{T}_1 \\ T_2 - \overline{T}_2 \\ T_3 - \overline{T}_3 \end{pmatrix} \qquad (1)$$

where **C** is a 3x3 covariance matrix, T_i is the brightness temperature for channel i and the overbar denotes a mean brightness temperature. Values of **C**, $\overline{T}_1$, $\overline{T}_2$ and $\overline{T}_3$ are provided for 5 different fixed zenith angles (sec(z) = 1.0,1.25,1.5,1.75,2.0), and they are interpolated for each observation. Matrices are provided for 8 surface types, and a ninth (desert) is deduced afterwards from a test of channel 1 BT. The types are shown in Table 1. The principles for distinguishing the various types, based on emissivity characteristics (including variation with frequency) are given in Grody (1988).

Table 1: Microwave surface types in AAPP

Type number	Description
1	Bare young ice (i.e. new ice, no snow)
2	Dry land (i.e. dry with or without significant vegetation)
3	Dry snow (i.e. snow with water less than 2%, over land)
4	Multi-year ice (i.e. old ice with snow [assumed dry] cover)
5	Sea (i.e. open water, no islands, ice-free, WS=0 to 14m/s)
6	Wet forest (i.e. established forest with wet canopy)
7	Wet land (i.e. non-forested land with a wet surface)
8	Wet snow (i.e. snow with water content > 2%, over land or ice)

9	Desert

The value of the cost function, after surface type identification, gives an indication of cloud liquid water. As stated in English (1997): *In simple terms, AMSU-A channel 1 is sensitive to total water vapour, channel 2 cloud liquid water and channel 3 absorber temperature. Because the covariance due to water vapour and temperature variations is large in channels 1 and 3, changes in the atmospheric profile have little impact on the cost, **J**. However, the introduction of liquid water, which increases channel 2 out of proportion, leads to a very rapid rise in cost. This test is sensitive enough to the presence of cloud liquid water to detect cloud amounts below 100 gm^{-2}*.

Note that matrix **C** is symmetric and its terms are all positive. $\mathbf{C}^{-1}$ is also symmetric but can have negative off-diagonal terms.

It is not known exactly what database was used to establish this test. The AAPP Scientific Description states: “Mean brightness temperatures and BT covariance matrices have been calculated (with a radiative transfer model) for the 20 AMSU channels for different surface types, with no cloud liquid water.” Moreover, the document also says, “the coefficients are not well developed and its results are currently not very meaningful.”

It is likely that the FASTEM land/sea-ice component was used. This is configurable via 5 input parameters to represent different surface types for MW emissivities (the “Grody parameters”). This code is still available in the current FASTEM (part of RTTOV), but it is considered to be deprecated (J. Hocking, pers. comm.).

Different centres would be expected to have different uses for the AAPP surface test output. At the Met Office, it is used (i) to improve the profile surface type and to set “mismatch” flags if the AAPP surface type differs from the model type, and (ii) to set an appropriate emissivity over sea ice (B. Candy, pers. comm). The Met Office requirement is for the AAPP test to distinguish between (i) sea, (ii) multi-year ice and (iii) other surfaces.

Figure 1 shows the AMSU surface type for NOAA-18 and NOAA-19 observations for the 00Z cycle on 16th March 2021. We can see that sea areas are correctly identified as type 5. Land areas are mostly classified as dry land (type 2) or wet land (type 7); it is not obvious whether there is any skill in distinguishing them. The main areas of wet forest (type 6) are over polar sea-ice – which is not realistic! There are some areas classified as multi-year ice (type 4) in the Arctic, but also some areas in central Asia which are more likely to be desert. Almost no areas are actually classified as desert, though note that this was a night-time scene over the African deserts, where the land surface is cold.

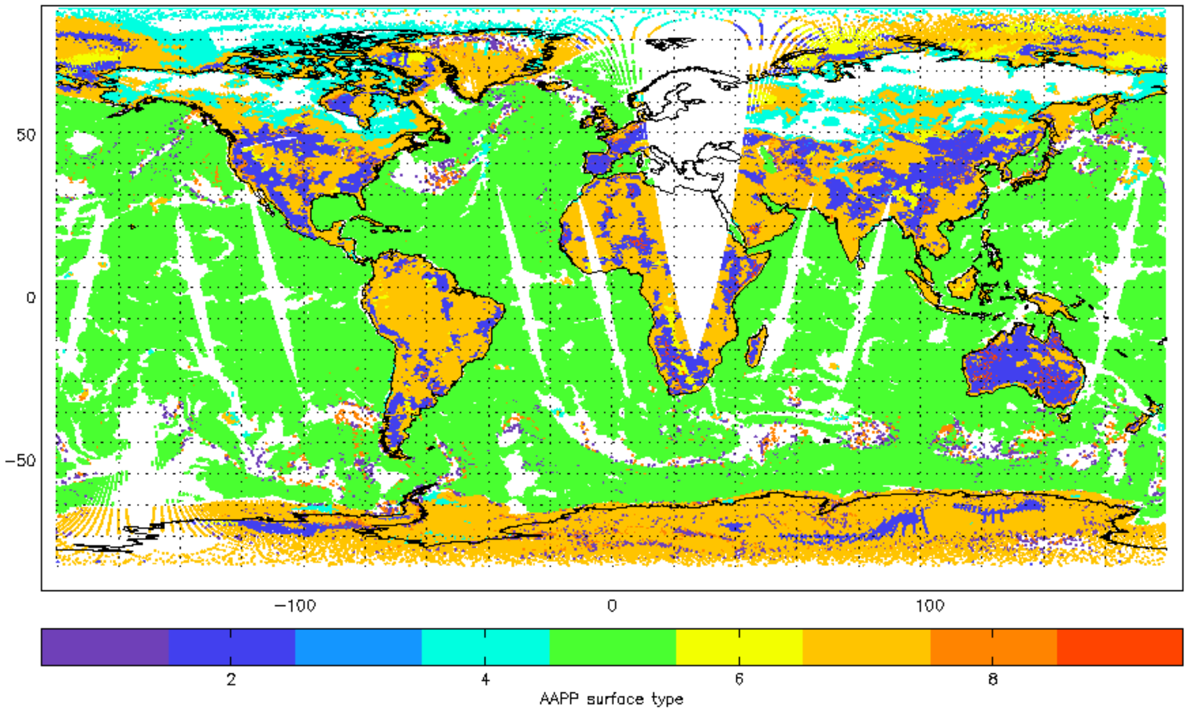

Figure 1: AMSU surface type from AAPP for samples with surface cost < 10K

The test would need improvement, and coefficients would need to be re-generated, if it is to be useful for MWS on EPS-SG. In the next section we discuss use of the TELSEM atlas in performing this task.

3. THE TELSEM ATLAS

RTTOV has an option to use emissivity values from the TELSEM version 2 atlas (Prigent and Aires, 2015). This atlas comprises monthly files from which it is possible to derive surface emissivity at different microwave frequencies. It is also possible to extract the surface category – there are 18 surface categories provided, covering land and sea-ice, as shown in Figure 2.

Surface type	Class nb for each type	Class1 in TELSEM²	Class2 in TELSEM²	Broad characteristics
Sea-ice	1	10	11	Sea-ice marging
	2	10	12	New sea-ice
	3	10	13	New sea-ice
	4	9	14	Multi-year sea-ice
	5	8	15	Multi-year sea-ice
	6	7	16	Multi-year sea-ice
Snow and continental ice	1	TELSEM class	17	Snow (small grain)
	2	TELSEM class	18	Snow (medium grain)
	3	TELSEM class	19	Snow (large grain)
	4	TELSEM class	20	Continental ice
	5	TELSEM class	21	Continental ice
	6	TELSEM class	22	Continental Ice
Continents (snow and ice-free)	1	1	1	Tropical forest
	2	2	2	Dense vegetation
	3	3	3	Bushes
	4	4	4	Grassland
	5	5	5	Deserts
	6	10	10	Water surfaces

Figure 2: TELSEM surface types. The table is from Prigent and Aires, 2016

The resolution of the atlas is 0.25° in latitude and longitude. Interpolation software is provided, to allow emissivity to be estimated at any point.

For AAPP use, it is clearly necessary to reduce the number of categories, which will be discussed in subsequent sections.

4. MWS SIMULATION

The NWP SAF Radiance Simulator (RadSim) was used to simulate MWS brightness temperatures for channels 1, 2 and 3 (23.8, 31.4 and 50.3 GHz respectively).

To generate the statistics from which the means and covariances can be derived, a rectangular (720 x 360) half-degree lat/lon grid was used – repeated 5 times for the 5 zenith angles. RTTOV was configured to use the TELSEM atlas.

Atmospheric state was taken from Met Office UM model fields. Two different sets of fields were used covering different seasons and times of day

- 20210316T0000Z
- 20220807T1200Z

This allows simulated brightness temperatures to be generated. The analysis could be extended later, if needed, to cover other seasons and times.

The TELSEM categories were extracted from the database, for the appropriate month. These should be consistent with the simulated BTs. The outputs were then combined and analysed according to the scheme illustrated in Figure 3.

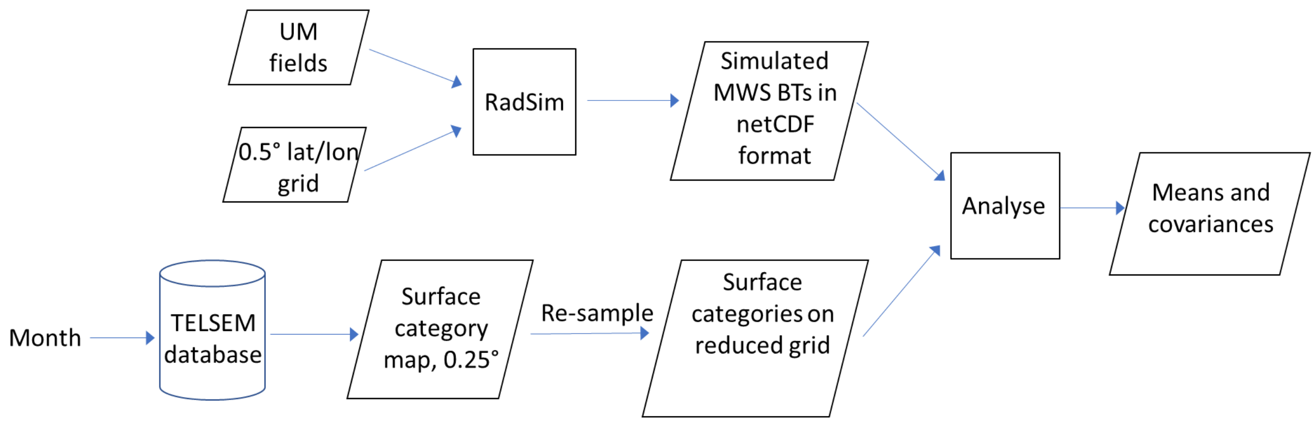

Figure 3: Processing scheme used in this study

The 'analyse' step in Figure 3 is as follows:

1. For each observation, identify the surface category (discussed in subsequent sections) and the zenith angle category.
2. For each surface category i and zenith angle category j, compute the sum of the BTs and also the sum of $\mathbf{B}_{ij}\ \mathbf{B}_{ij}^T$ (where $\mathbf{B}_{ij}$ is a 3-element column vector of brightness temperatures for the 3 channels). The sums are stored in a file which can be added to in subsequent runs.
3. For each category, compute the mean BT: $\mathbf{m}_{ij} = \Sigma(\mathbf{B}_{ij})/n_{ij}$ and covariance $\mathbf{C}_{ij} = \Sigma(\mathbf{B}_{ij}\ \mathbf{B}_{ij}^T)/n_{ij} - \mathbf{mm}^T$, where n_{ij} is the number of observations in categories i and j.

The March and August runs were combined together before computing means and covariances.

Having computed the means and covariances, it is then possible to access the degree to which the different surface categories can be identified in the simulated BTs, by computing the cost function (eq. 1) for each category and identifying the category that minimises the cost function.

For this assessment, the sample locations and viewing geometry were taken from approximately 12 hours of ATMS data. Both NOAA-20 and Suomi NPP were used, in order to give a good distribution of viewing angles. AAPP "level 1d" files were used, retaining all 96 spots across scan, but thinning to 1 scan in 3. Note that the date and time of the ATMS observations is irrelevant as they are merely to provide a good geographical spread of sample locations and angles. The reference matrices for the 5 zenith angles were interpolated for each observation – as in the operational version of AAPP.

5. RESULTS FOR 8 CATEGORIES

As noted previously, a scheme such as the one described above cannot expect to identify all 18 TELSEM categories. As a first attempt at reducing the number of categories, they were merged so as to give 8 categories similar to those implemented in AAPP v8.

Table 2: Translation of TELSEM categories to eight categories based on those in AAPP v8

AAPP category number	TELSEM Class2	Characteristic
1	11, 12, 13	New sea-ice
2	3, 4	Bushes; grassland
3	17, 18, 19	Snow
4	20, 21, 22, 14, 15, 16	Continental ice; multi-year sea-ice
5	-	Ocean
6	1, 2	Tropical forest; dense vegetation
7	10	Water surfaces over land
8	5	Desert

Note that there is no TELSEM category for “wet snow” – hence there are only 8 categories, not the 9 shown in Table 1.

Maps of the 8 classes corresponding to the TELSEM atlas are shown in Figure 4 for March and Figure 5 for August. Note the rather large extent of northern hemisphere snow in March (category 3), and the Antarctic sea-ice in August (category 4).

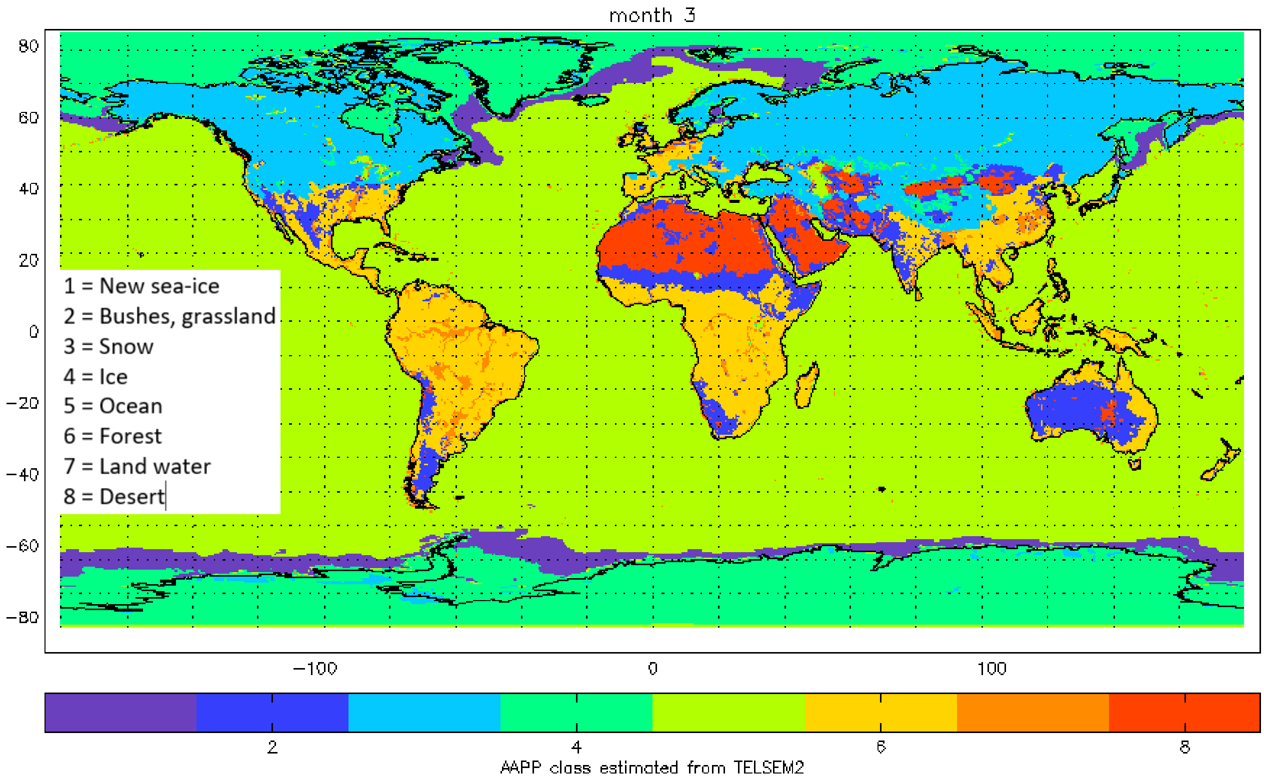

Figure 4: TELSEM categories for March converted to 8 AAPP classes. Note that data poleward of 87.5°N have been excluded as the TELSEM atlas appears to be missing these points

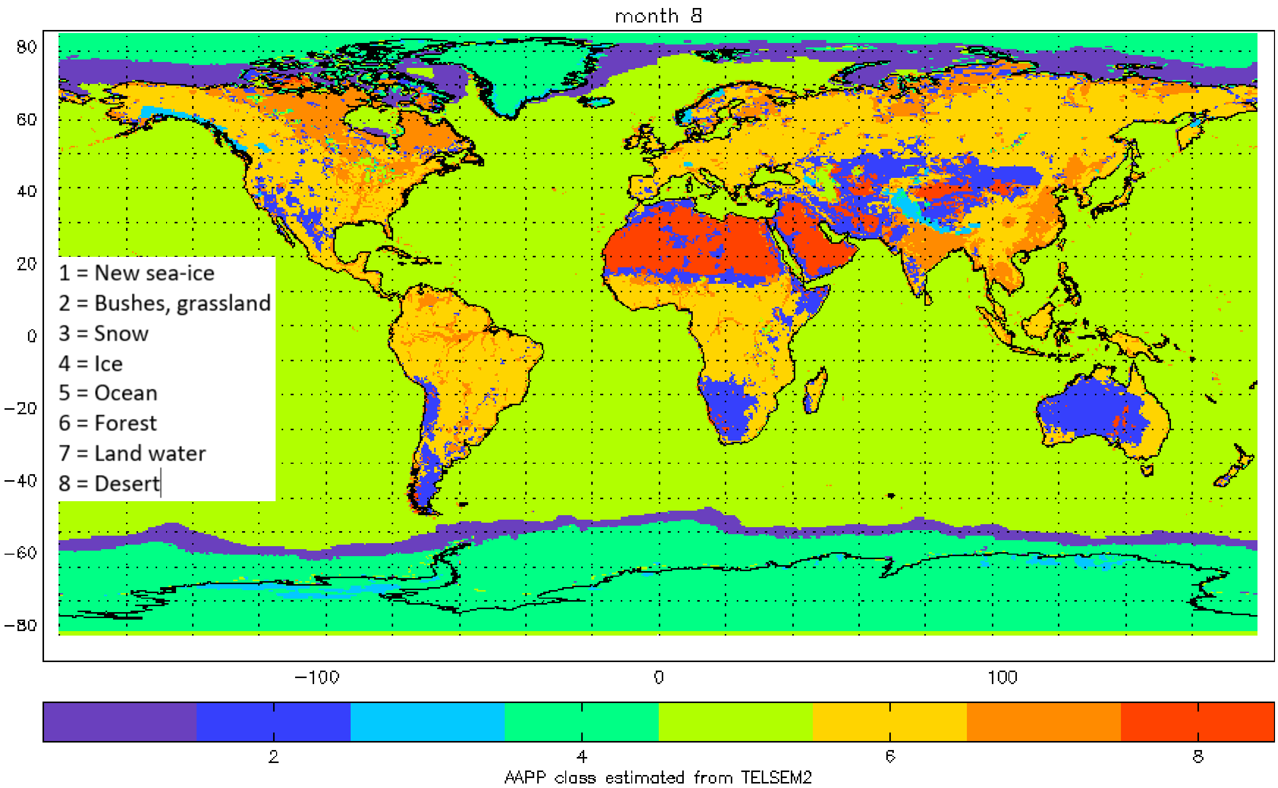

Figure 5: TELSEM categories for August converted to 8 AAPP classes

The retrieved surface types are shown in Figure 6 and Figure 7 for March and August respectively.

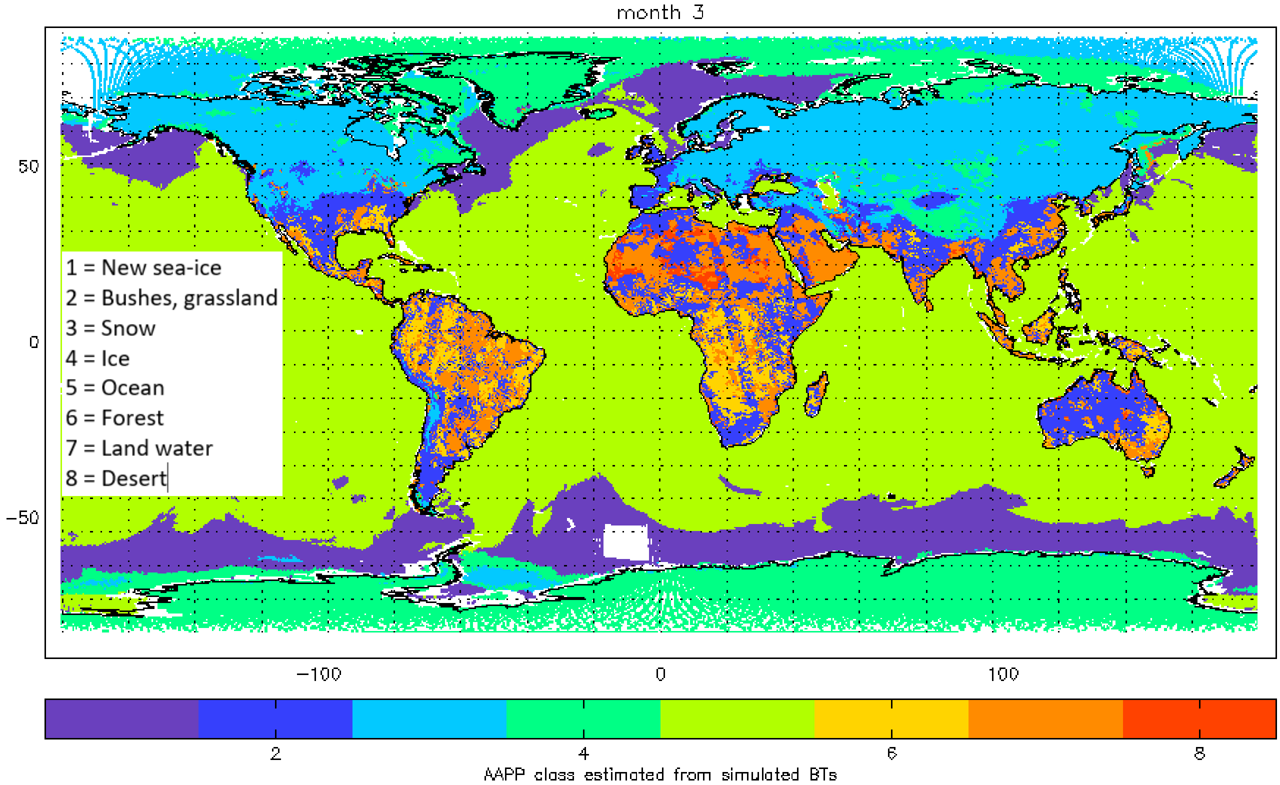

Figure 6: Retrieved surface category for 00Z on 16 March 2021 using simulated MWS BTs from ATMS sample locations. Note that the gap in the south Atlantic is because the time period used was a little less than 12 hours.

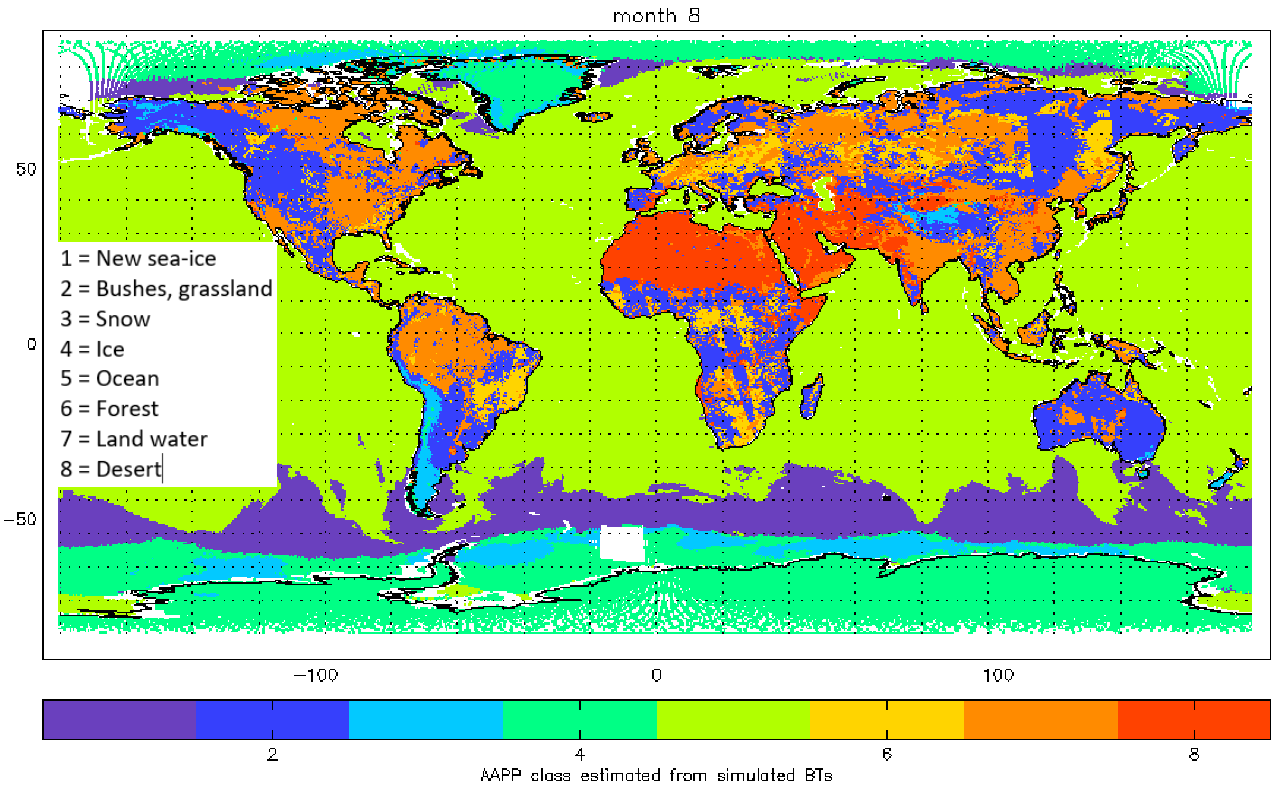

Figure 7: Retrieved surface category for 12Z on 7 August 2022 using simulated MWS BTs from ATMS sample locations

We can make the following observations:

- The distinction between "new ice" and "ocean" appears to be weak. There is far too much "new ice" shown in the retrieved categories. If this was used to identify sea areas as part of a quality control system, a lot of data would be rejected.
- The land categories are rather mixed up.
- There is reasonable skill in the sea-ice.
- The "desert" category exists mainly over Africa, and is only detectable in the microwave radiances in the daytime, once the land surface has heated up

6. RESULTS FOR 6 CATEGORIES

To attempt to improve these aspects, the number of categories was reduced to 6 by merging new sea-ice with ocean, and merging water surfaces over land with dense vegetation. See Table 3, Figure 8 and Figure 9.

Table 3: Translation of TELSEM categories to six categories

category number	TELSEM Class2	Characteristic
1	None, 11, 12, 13	Ocean and new sea-ice
2	20, 21, 22, 14, 15, 16	Multi-year ice
3	1, 2, 10	Wet land and forest
4	3, 4	Dry land
5	17, 18, 19	Snow
6	5	Desert

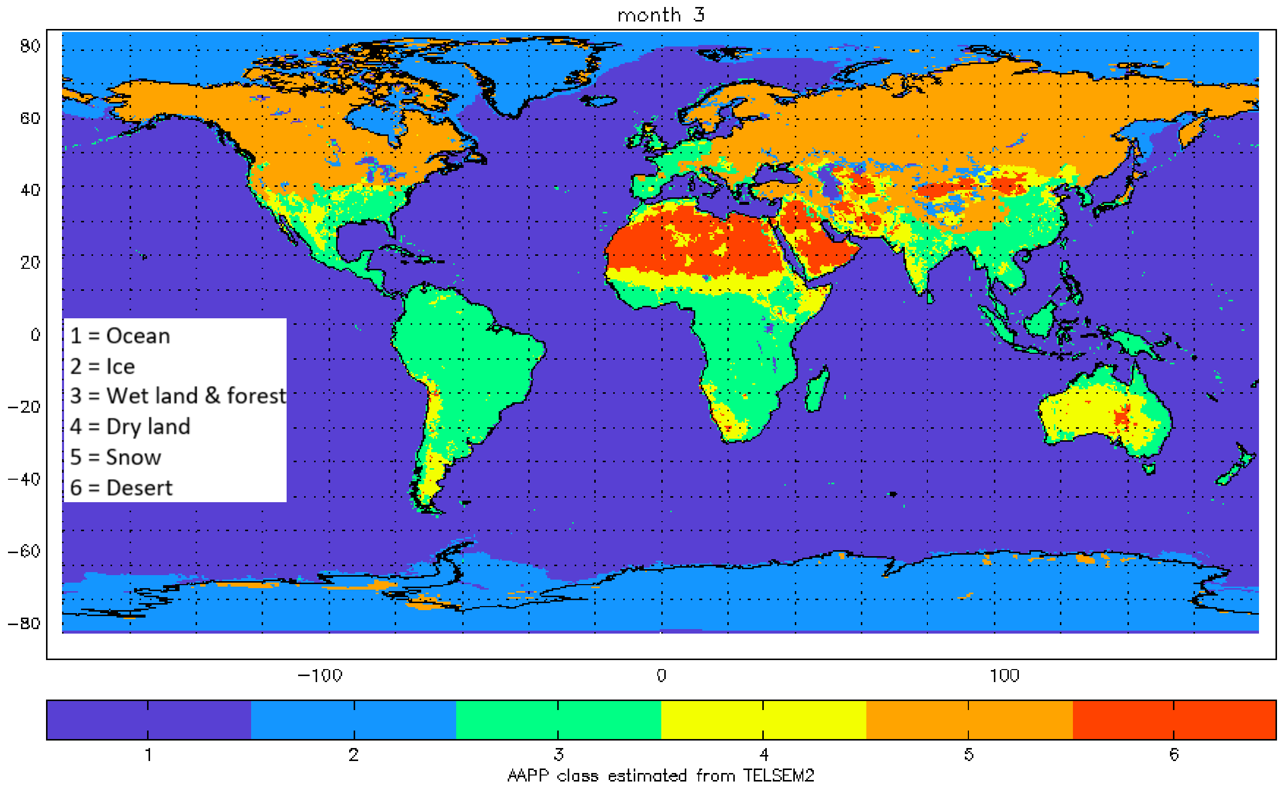

Figure 8: TELSEM categories for March converted to 6 AAPP classes

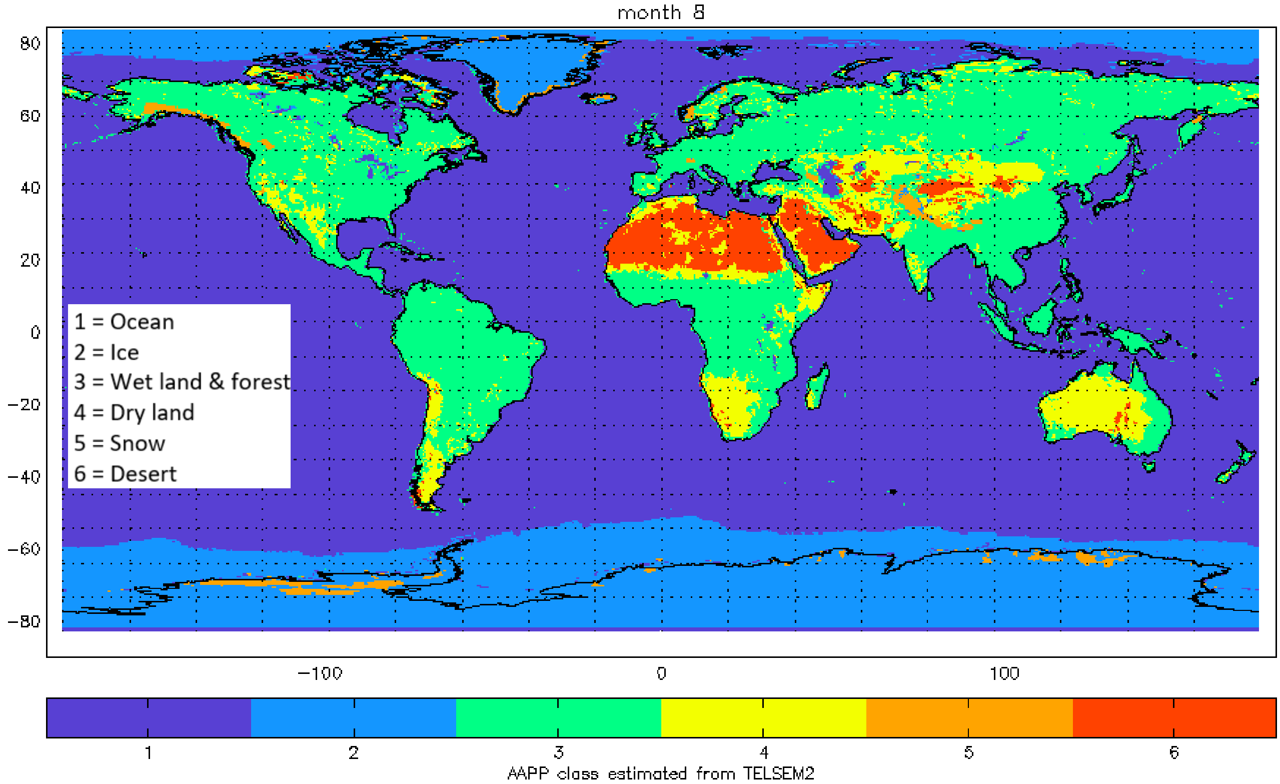

Figure 9: TELSEM categories for August converted to 6 AAPP classes

The corresponding retrievals are shown in Figure 10 and Figure 11.

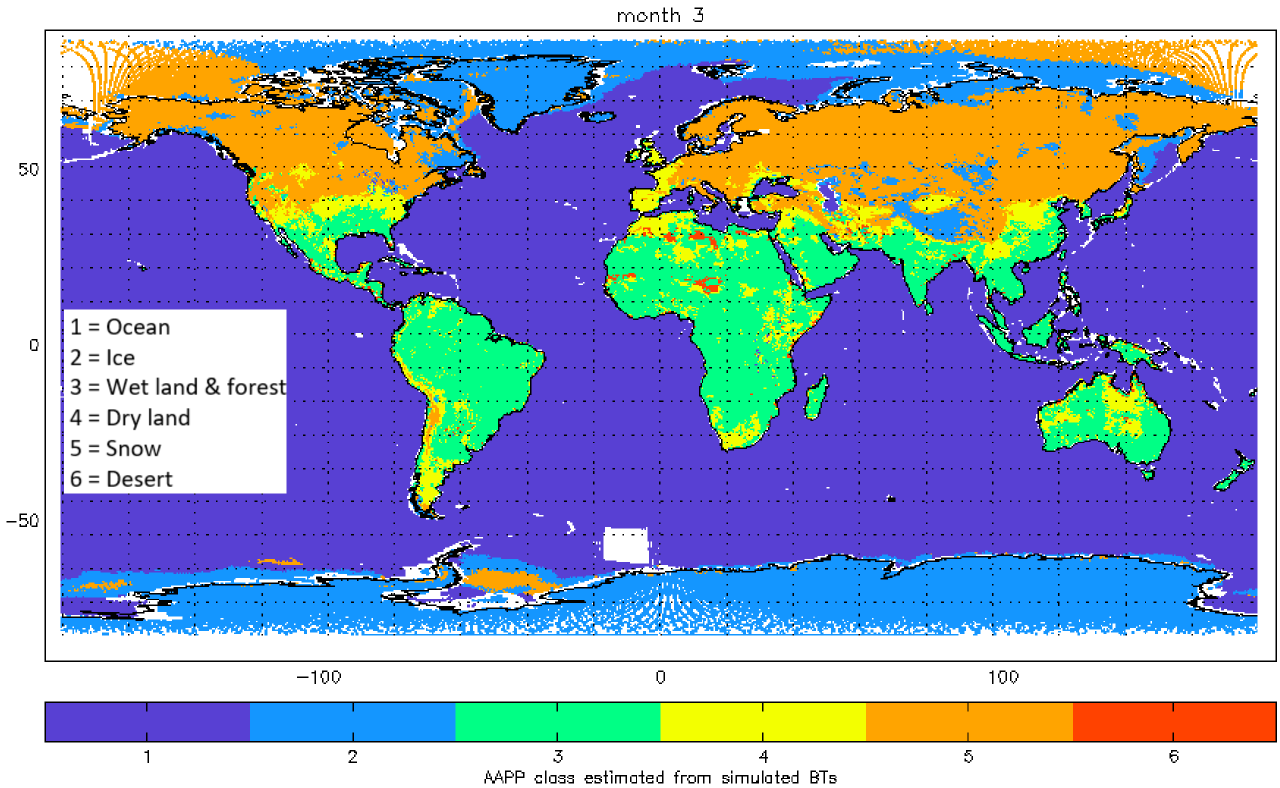

Figure 10: Retrieved surface category (1 to 6) for 00Z on 16 March 2021 using simulated MWS BTs from ATMS sample locations

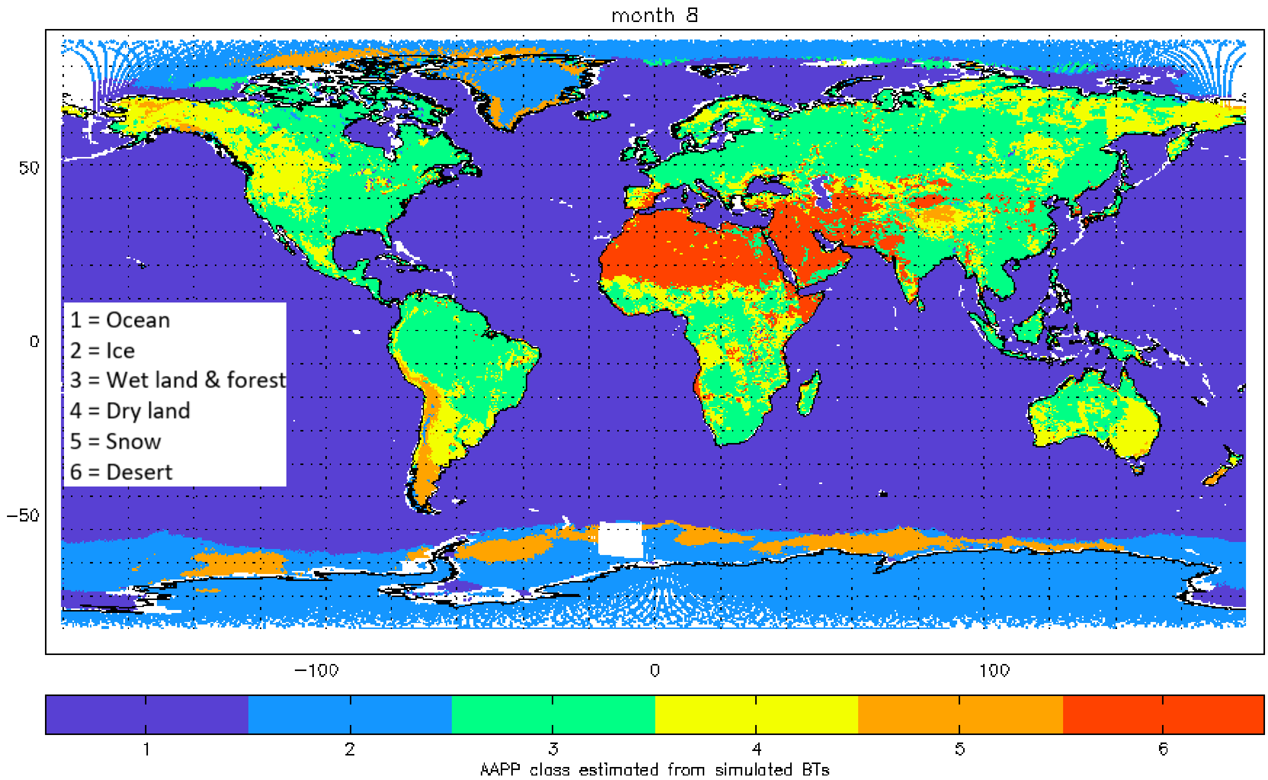

Figure 11: Retrieved surface category (1 to 6) for 12Z on 7 August 2022 using simulated MWS BTs from ATMS sample locations

With six categories, the retrieval is somewhat improved. The ocean, sea-ice and snow categories are broadly correct. The desert is reasonable during the day. There is rather limited skill in distinguishing between dry land and vegetated land, but that is of secondary importance as far as AAPP users are concerned (infrared techniques work better in that regard).

The cost function (defined in equ. (1)) corresponding to Figure 11, is shown in Figure 12. In AAPP, the cost function is normalised by dividing by the square of the number of channels, and a threshold for cloud is specified as 5.5 in the normalised cost function. Nearly all points in Figure 12 would therefore be classified as cloud-free – which is as expected since no clouds were included in the RTTOV simulation.

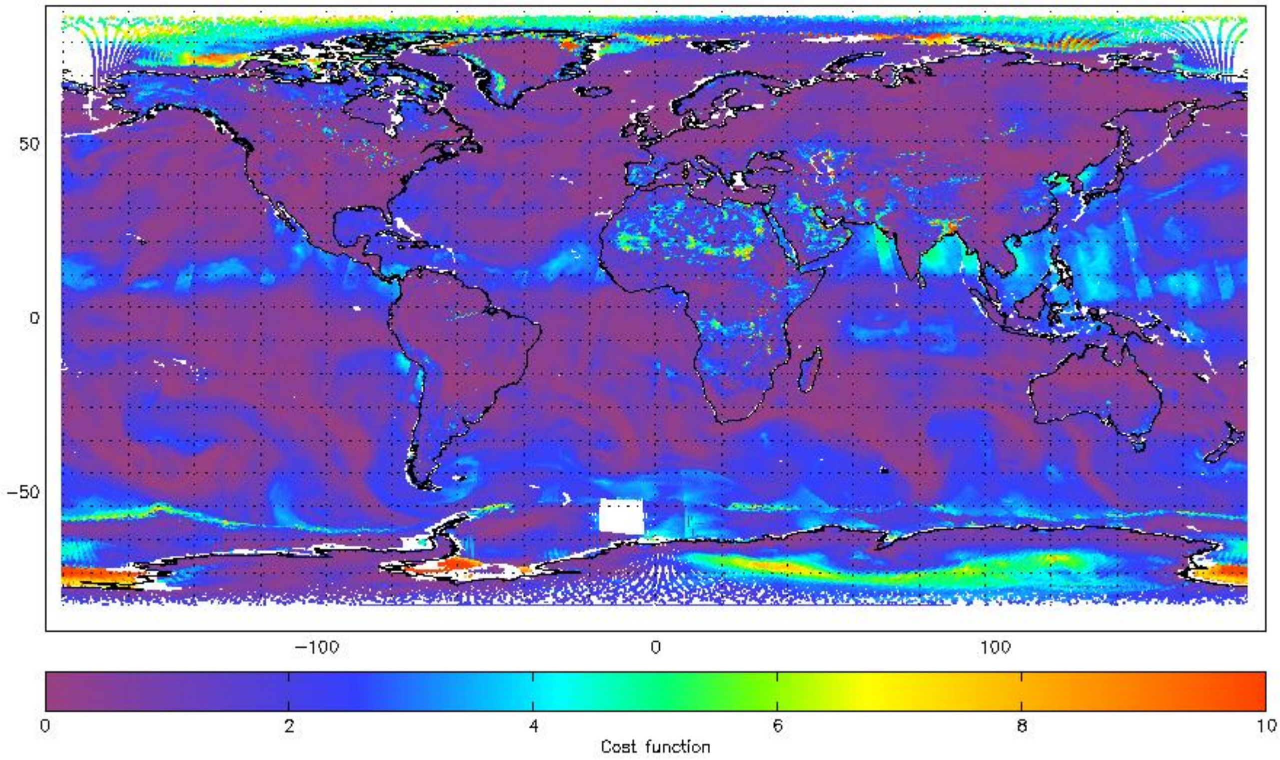

Figure 12: Cost function (un-normalised) corresponding to Figure 11. AAPP subsequently normalises the cost by dividing by the square of the number of channels

7. CONCLUSIONS

A six-category standalone surface test has been devised for use with MWS. It is proposed to implement this test in AAPP version 9, in the module that will accommodate EPS-SG. Mean BTs and covariances are shown in the Appendix.

There may be benefits to carrying out a similar analysis using post-launch observed BTs rather than simulated – provided that effective cloud-clearing is available.

8. REFERENCES

English S.J., R. J. Renshaw, P. C. Dibben, and J. R. Eyre, 1997: "The AAPP module for identifying precipitation, ice cloud, liquid water, and surface type on the AMSU-A grid". *Proceedings of the Ninth International TOVS Study Conference,* J. R. Eyre, Ed., ECMWF, 119–130 http://library.ssec.wisc.edu/research_Resources/publications/pdfs/ITSC9/english01_ITSC9_1997.pdf

N. C. Grody, "Surface identification using satellite microwave radiometers" in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 26, no. 6, pp. 850-859, Nov. 1988.

Catherine Prigent and Filipe Aires, 2016: "Tool to Estimate Land Surface Emissivity at Microwaves and Millimeter waves", EUMETSAT Project EUM/CO/14/4600001473/CJA, available from https://nwp-saf.eumetsat.int/site/software/rttov/download/ (included in TELSEM download).

9. APPENDIX – MEAN AND COVARIANCE TABLES FOR MWS

```
  AmeanBT =
! Surface 1
    172.2773     159.1212     222.3246
    176.1041     158.9730     228.6729
    187.5106     168.8058     237.4759
    199.1255     179.9392     244.6851
    209.0610     189.8634     249.8916
! Surface 2
    212.6208     212.0501     222.1425
    205.3085     204.4546     221.0775
    204.9024     202.7020     221.8196
    205.5846     202.0665     222.8645
    206.5107     201.8338     223.9334
! Surface 3
    271.9104     269.4530     273.8154
    272.9976     269.6643     273.6113
    273.7021     269.8256     273.1757
    274.4722     270.2219     272.7511
    275.1930     270.6958     272.2836
! Surface 4
    277.1412     275.7126     275.9280
    276.7378     274.7915     274.9898
    275.5508     272.9698     273.4575
    274.9624     271.7766     272.3121
    274.7267     271.0152     271.4140
! Surface 5
    240.4295     237.0165     239.6501
    238.0909     232.1580     238.3965
    236.8806     229.3316     238.1806
    236.3975     227.5217     238.4265
    236.2766     226.3215     238.8519
! Surface 6
    283.4961     282.0514     282.7207
    283.1535     281.0606     281.7412
```

```
    281.6212    278.6832    279.8548
    280.8539    277.1559    278.4293
    280.6029    276.2811    277.3721
  Acov =
! Surface 1
    572.7359    331.3117    193.5178
    331.3108    284.2204    114.6667
    193.5161    114.6702     77.4203

    723.8991    394.4729    228.0416
    394.4720    309.8286    117.2430
    228.0381    117.2395     85.3178

    764.4414    401.4511    236.9489
    401.4546    288.8710    109.8010
    236.9559    109.7992     90.6207

    760.3864    394.5778    240.1043
    394.5778    263.9452    107.1194
    240.1061    107.1177     97.1071

    742.9573    388.8227    242.4440
    388.8245    248.0406    109.7385
    242.4440    109.7350    103.4850

! Surface 2
    865.9026    852.0393    584.0352
    852.0393    849.1563    600.5607
    584.0352    600.5607    505.3091

    957.8180    883.4231    571.1099
    883.4231    827.6511    536.8618
    571.1099    536.8618    435.6057

    937.1466    850.7619    548.7581
    850.7619    790.5874    505.8399
    548.7581    505.8399    417.6859

    905.3373    816.4185    531.2586
    816.4185    758.0861    484.2149
    531.2586    484.2149    405.3534

    880.1515    792.0907    517.0356
    792.0907    737.6231    468.9370
    517.0356    468.9370    393.8088

! Surface 3
    677.9994    727.1792    367.2439
    727.1792    798.4813    395.8819
    367.2439    395.8819    208.1688

    633.4822    700.0149    318.2056
    700.0149    796.7484    352.1977
    318.2056    352.1977    169.6163

    518.6329    578.9856    241.2693
    578.9856    673.0345    268.2259
    241.2693    268.2259    122.0426
```

```
      418.7396    469.3496    183.3384
      469.3496    553.2678    202.5348
      183.3384    202.5348     90.4195

      343.1251    386.2328    144.3139
      386.2328    459.7285    158.2054
      144.3139    158.2054     71.6888

  ! Surface 4
      216.7694    218.3131    176.7972
      218.3131    221.5473    178.4317
      176.7972    178.4317    148.8197

      219.3762    221.3307    170.8387
      221.3307    225.7368    172.5833
      170.8387    172.5833    139.4114

      216.8966    218.0800    162.8190
      218.0800    222.0403    163.8111
      162.8190    163.8111    128.4772

      213.5354    213.9895    155.5059
      213.9895    217.8300    155.4934
      155.5059    155.4934    119.0975

      210.3403    211.1320    148.9119
      211.1320    215.0100    148.8125
      148.9119    148.8125    111.1047

  ! Surface 5
      357.5314    376.8039    265.7387
      376.8039    409.8458    296.0162
      265.7387    296.0162    230.6145

      384.4513    404.5731    260.6769
      404.5731    444.7213    294.9822
      260.6769    294.9822    212.8816

      385.4705    411.0099    248.2015
      411.0099    462.4702    284.6516
      248.2015    284.6516    191.5368

      378.6977    410.3182    233.3786
      410.3182    471.5127    270.6679
      233.3786    270.6679    171.8042

      369.5492    406.9485    218.8254
      406.9485    476.6099    255.7111
      218.8254    255.7111    153.7717

  ! Surface 6
      350.0343    358.7999    285.8337
      358.7999    369.3788    293.4213
      285.8337    293.4213    235.7079

      340.0107    351.3412    265.8422
      351.3412    365.0915    274.9252
      265.8422    274.9252    210.3610
```

```
323.4083    334.3326    238.8365
334.3326    348.1589    247.0750
238.8365    247.0750    178.6523

313.0638    325.0145    219.8418
325.0145    340.1192    228.1414
219.8418    228.1414    156.5159

303.8927    317.4441    203.5820
317.4441    334.9548    212.3494
203.5820    212.3494    138.6153
```