The EUMETSAT Network of Satellite Application Facilities

NWP SAF

Numerical Weather Prediction

Associate Scientist mission (AS09_01) report

Document NWPSAF-MO-VS-040

Version 1.0

November 2009

TELSEM: a Tool to Estimate Land Surface Emissivities at Microwave frequencies

F.Aires[1], C.Prigent[2], F.Bernardo[3], C.Jiménez[2], R.Saunders[4] and P.Brunel[5]

[1] LMD / IPSL and LERMA, CNRS, Paris, France
[2] LERMA, CNRS, Paris, France
[3] LMD / IPSL / CNRS, Paris, France
[4] Met Office, Exeter, UK
[5] Météo-France Lannion, France

Met Office ECMWF KNMI METEO FRANCE Toujours un temps d'avance

TELSEM: a Tool to Estimate Land Surface Emissivities at Microwave frequencies

F.Aires, C.Prigent, F.Bernardo, C.Jiménez, R.Saunders and P.Brunel

This documentation was developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), under the Cooperation Agreement dated 1 December, 2006, between EUMETSAT and the Met Office, UK, by one or more partners within the NWP SAF. The partners in the NWP SAF are the Met Office, ECMWF, KNMI and Météo France.

Change record			
Version	Date	Author / changed by	Remarks
1.0	Nov-2009	F. Aires	Version for distribution

Table of Contents

1. Introduction

1.1. Scope of the document

This document describes a microwave emissivity interpolator attached to RTTOV, along with the emissivity climatology to which it is anchored. It provides the necessary technical information for the user who wishes to use this tool.

1.2. Software version identification

The current version of the softwave is 1.0.

2. Description of the MW emissivity interpolator

2.1. Goal of the Emissivity interpolator

The goal of the emissivity interpolator is to provide a first-guess of the microwave emissivity for simulation purposes of MW satellite observations, for its use in inversion algorithms, and as a tool for variational assimilation.

The interpolator is originally designed for frequencies between 19 and 85 GHz. However, it can still be used for lower or higher frequencies. Tests have shown that it is beneficial down to 10 GHz or up to 190 GHz. For example, it has been shown very valuable at AMSU-B frequencies.

2.2. SSM/I MW emissivity dataset description

The interpolator is anchored to a monthly-mean climatology of emissivities calculated from SSM/I observations at SSM/I frequencies (19, 22, 37 and 85 GHz for vertical and horizontal polarizations, except for 22 GHz which is vertical only), with a spatial resolution of 0.25°x0.25° at the equator (equal area grid). This climatology has been computed by averaging 8 years of SSM/I monthly-mean emissivities (from 1993 to 2000, see references in annexe 1). This climatology is distributed with the emissivity interpolator. The ASCII files content is described in the following table:

Cell number	Number of the cell in the 0.25°×0.25° equal-area grid
Emis19V	Emissivity at 19 GHz for vertical polarization
Emis19H	Emissivity at 19 GHz for horizontal polarization
Emis22V	Emissivity at 22 GHz for vertical polarization
Emis37V	Emissivity at 37 GHz for vertical polarization
Emis37H	Emissivity at 37 GHz for horizontal polarization
Emis85V	Emissivity at 85 GHz for vertical polarization
Emis85H	Emissivity at 85 GHz for horizontal polarization
VAR Emis19V	Variance[1] of the emissivity at 19 GHz V used as uncertainty
VAR Emis19H	Variance of the emissivity at 19 GHz H used as uncertainty

[1] Please note that the original climatology files provide the variance of the emissivity uncertainties but that the interpolator converts right away, during the reading of this to the emissivity uncertainty standard-deviation.

VAR Emis22V	Variance of the emissivity at 22 GHz V used as uncertainty
VAR Emis37V	Variance of the emissivity at 37 GHz V used as uncertainty
VAR Emis37H	Variance of the emissivity at 37 GHz H used as uncertainty
VAR Emis85V	Variance of the emissivity at 85 GHz V used as uncertainty
VAR Emis85H	Variance of the emissivity at 85 GHz H used as uncertainty
Surface class	Surface class for the location: from 1 to 5 snow and ice free regions from highly vegetated to desert, from 6 to 9 various snow and ice types, and class 10 for pixels containing standing water.

A file (correlations.txt) is also distributed to provide the 7×7 correlation matrices of the SSM/I emissivity uncertainties.

2.3. Interpolation scheme description

See annexe 3.

2.4. Different configurations for the interpolator

Four configurations have been considered for the emissivity interpolator to facilitate and optimize its use, depending on the various applications that can utilize the interpolator. These 4 configurations are:

- **IND_SING**: when the location and frequency are specified, the interpolator uses an INDividual atlas-pixel (i.e. nearest location in the equal-are grid), and estimates a SINGle frequency emissivity.
  → *emis_interp_ind_sing*(lat, lon, theta, freq, atlas, ev, eh, stdv, stdh, verb)

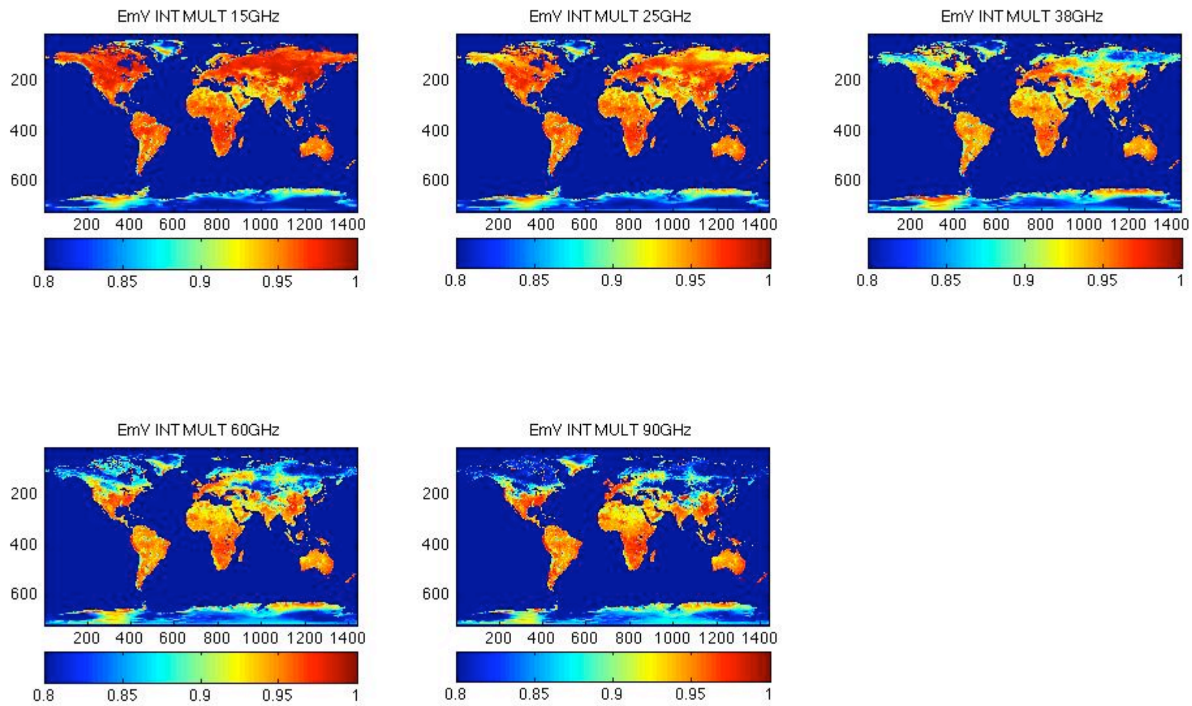
- **INT_SING**: In this configuration again, only one frequency is considered but the interpolator INTegrates multiple atlas pixels taking into account the resolution that is specified. If the spatial resolution is higher than the 0.25° x0.25° spatial resolution of the initial dataset, the pixels that fall into the new spatial grids are averaged. If the spatial resolution is lower than the 0.25°x0.25° initial spatial resolution, the nearest pixel is considered.
  → *emis_interp_int_sing*(lat, lon, resol, theta, freq, atlas, ev, eh, stdv, stdh, verb)

- **IND_MULT**: The nearest atlas-pixel is used here to interpolate at MULTiple frequencies.
  → *emis_interp_ind_mult*(lat, lon, theta, freq, n_chan, atlas, ev, eh, std, verb)

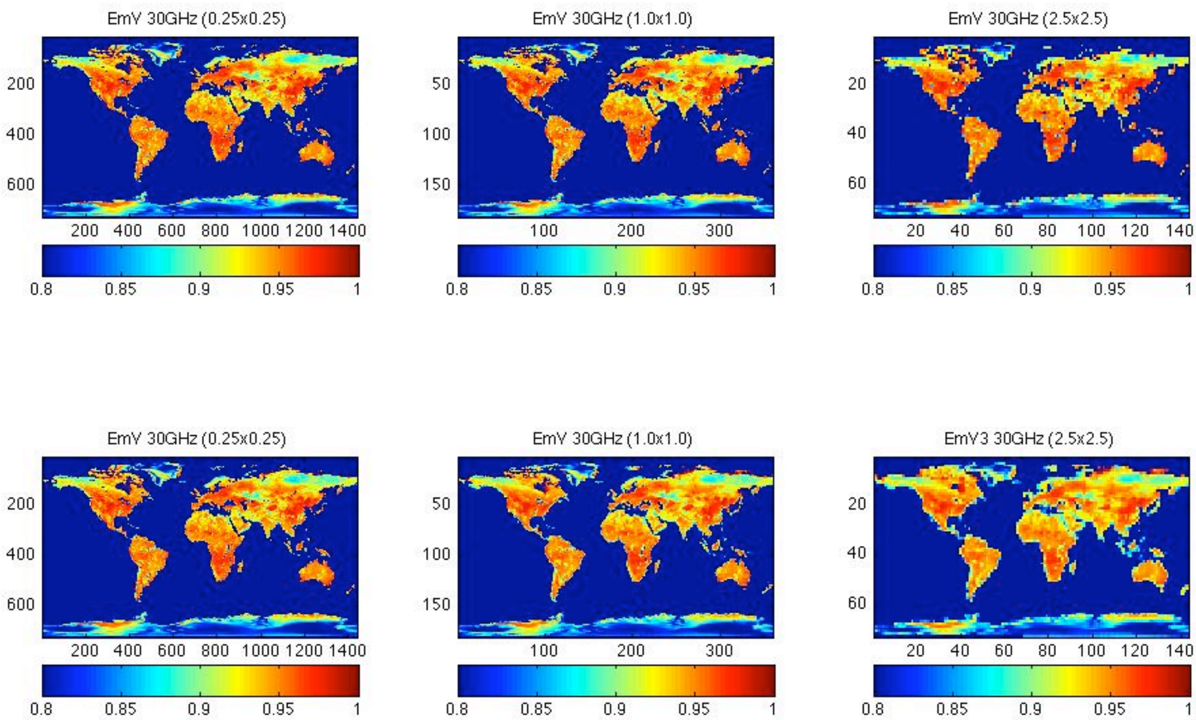
- **INT_MULT**: The INTegration of the atlas-pixels is used to interpolate MULTiple frequencies.
  → *emis_interp_int_sing*(lat, lon, resol, theta, freq, atlas, ev, eh, std, verb)

2.5. Examples of interpolated emissivities

In the following figures, the INT_MULT interpolator configuration is used to estimate the emissivities at 15, 25, 38, 60 and 90 GHz at vertical polarization.



The next figures give examples of emissivity estimates for 30 GHz at vertical polarization for horizontal resolutions, from left to right, of 0.25°×0.25°, 1.0°×1.0° and 2.5°×2.5°; top 3 maps are for the IND configuration (nearest atlas-pixels), and bottom 3 maps are for the INT configuration (i.e., integration of the atlas pixels).



2.6. Interpolation of the uncertainties

Let $EM_{SSMI}(6)$ be the 6-channels SSM/I emissivities from the atlas (19V, 37V, 85V, 19H, 37H and 85H). The goal of the emissivity interpolator is to estimate a new emissivities $EM_{NEW}(f)$ at frequency f. The first half of EM_{NEW} is for vertical and the second half for horizontal polarizations. How is the new uncertainty covariance matrices computed?

In order to estimate the emissivities at new frequencies (and scanning angle and polarization), the interpolator uses a (f×6) matrix, FIM, such that:

$$(EmV; EmH) = FIM \bullet EM_{SSMI}$$

From the SSMI atlas, we have the 6×6 correlation matrix:

$$COR_{SSMI}(6,6)$$

for the uncertainties on the 6 SSMI channels and the associated vector of uncertainty standard deviation is defined by:

$$STD_{SSMI}(6)$$

The covariance matrix of the new emissivity uncertainties can be estimated using:

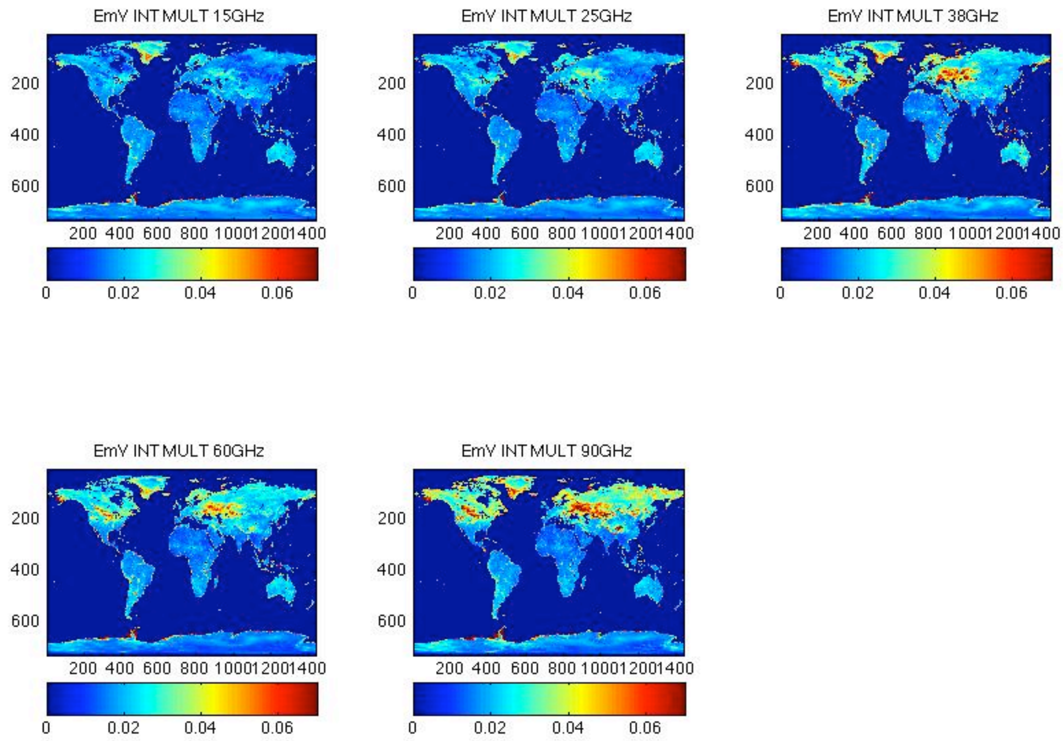
$$COV_{SSMI} = STD'_{SSMI} \bullet COR_{SSMI} \bullet STD_{SSMI}$$

The covariance matrix of the new emissivity uncertainties can be estimated using:

$$COV_{NEW} = FIM' \bullet COV_{SSMI} \bullet FIM = FIM' \bullet STD'_{SSMI} \bullet COR_{SSMI} \bullet STD_{SSMI} \bullet FIM$$

In order to better explain this process, an example of such computations is given in Annexe 2.

The following figure gives the uncertainty estimates for interpolation at 15, 25, 38, 60 and 90 GHz.



2.7. List of inputs/outputs for the interpolator

Real Latitude: [-90; 90]

Real Longitude: [0; 360]

Real Theta [0; 60°] *! Incidence angle*

Real freq[19; 85] *!(in GHz) Freq to interpolate. It is possible to use lower/higher freq.*

! -----For individual freq interpolations

Real ev, eh, stdv, stdh *! Interpolated emissivities with uncertainties (emis are between 0-1)*

!----- For multiple freq interpolations

Real resol *! Horizontal resolution for the user*

Integer n_chan=5 *!Number of channel to interpolate*

Real ev(5), eh(5), std(2*5,2*5) *!Interpolated emissivities with uncertainties*

Real freq2(5) *!Frequencies for the interpolation*

2.8. Implementation of the interpolator

2.8.1. Installation

The atlas (12 monthly-mean emissivity files and the correlations file) can be copied in any location. The library needs to be compiled with

```
g95 -c mod_mwatlas.f90
```

The compilation of the Fortran code, *test*, that will ask for the library needs to be compiled with:

```
g95 -o test mod_mwatlas.o test.o
```

A make file is provided (make, make clean, make test). The user needs to edit the makefile code to for their local compiler and flags.

The make test launches a ndiff command to verify that the computation done by the interpolator is similar to a test_reference case (see makefile). To this purpose, the user needs to check that the "ndiff" command is installed in its machines (this is similar to the usual "diff" command but with the possibility to introduce a threshold).

The compilation has been tested using Nag, g95, gFortran et Ifort compilers on Linux and Mac machines (64bytes).

2.8.2. Structure of the library

At the hart of the library is the structure Atlas_emis_mw that represents the microwave emissivity atlas. This structure is composed by:

TYPE atlas_emis_mw		
Type	**Array name**	**Contents**
INTEGER	Ndat	Number of lines in the atlas
INTEGER	Nchan	Number of channels in the atlas
CHARACTER(len=22)	Name	Name of the atlas (including version number)
INTEGER	Month	Month of the atlas
REAL	Dlat	Resolution of the atlas (equal-area)
INTEGER, POINTER	ncells(:)	Number of cells per lat band
INTEGER, POINTER	Firstcell(:)	The first cell number of lat band
REAL	lat1, lat2, lon1, lon2	Limits of the spatial domain (flagged if global)
REAL, POINTER	emis(ndat,nchan)	Emissivities
REAL, POINTER	correl(10,nchan,nchan)	Correlations or uncertainties for each surface class
REAL, POINTER	emis_err(ndat,nchan)	Emissivity uncertainties (std)
INTEGER, POINTER	class(ndat)	Surface class (1-10)
INTEGER, POINTER	Cellnum(ndat)	Cell number of each pixel in the atlas
INTEGER	correspondance(660066)	"Correspondance" vector indicating

		that for the i^{th} element, the j so that EMIS(j,...) is the emissivity of cell number i.

The codes are in a library « mod_mwatlas.f90 ».

- SUBROUTINE **rttov_readmw_atlas**(dir,month,atlas,error_status,lat1,lat2,lon1,lon2)
  These routines read the emissivity atlas, including the emissivities, the associated standard deviations for uncertainties and the correlation matrices for uncertainties for each surface type (see files in section 2.2). The user can specify a zone (lat1, lat2, lon1 and lon2) to download only a limited amount of the atlas.

- SUBROUTINE **equare**(DLAT,NCELLS,FIRSTCELL)
  This routine computes the number of cells and the first cell number for each latitude band. This procedure is for equal-area grids such as for the SSM/I microwave atlas provided in this package. As an example, for a 0.25°x0.25° equal-area grid, there are 720 latitude bands, NCELLS(720) gives the numbers of pixels for each band, and FIRSTCELL(720) gives the cell number of the first pixel in a latitude band.

- FUNCTION **calc_cellnum**(lat,lon,atlas)
  This routine computes the cell number from the lat and lon. This procedure uses the NCELLS included in the atlas, and computed once and for all by routine EQUARE during the atlas reading (rttov_readmw_atlas).

- SUBROUTINE **calc_cellnum_mult**(lat,lon,resol,atlas,cell_num_mult,nb_cell)
  This routine is similar to function CALC_CELLNUM but it computes the list of cell numbers from the latitude, longitude and resolution (desired spatial resolution of the outputs). Gives for each cell of the new grid the cell numbers of the pixels in the initial grid to be averaged. This routine uses the NCELLS and FIRSTCELLS included in the atlas.

- SUBROUTINE **interp_freq2**(emiss19,emiss37,emiss85,f,emiss,an,bn,cn)
  This routine computes the linear interpolation of emissivity given the frequency and the atlas values for that cell number.

- SUBROUTINE **emis_interp**(lat,lon,theta,freq,classe,ev,eh,emiss_interp_v,emiss_interp_h)
  This routine performs the interpolation of emissivity in angle and frequency.

- SUBROUTINE **emis_interp_ind_sing**(lat,lon,theta,freq,atlas,ev,eh,stdv,stdh,verb)
  Interpolates emissivity for:
  IND: individual atlas-pixel
  SING: singular channel

- SUBROUTINE **emis_interp_int_sing**(lat,lon,resol,theta,freq,atlas,ev,eh,stdv,stdh,verb)
  Interpolates emissivity for:
  INT: integrate atlas-pixel
  SING: singular channel

- SUBROUTINE **emis_interp_ind_mult**(lat,lon,theta,freq,n_chan,atlas,ev,eh,std,verb)
  Interpolates emissivity for:
  IND: individual cell number atlas-pixel
  MULT: multiple channel

- SUBROUTINE **emis_interp_int_mult**(lat,lon,resol,theta,freq,atlas,ev,eh,std,verb)
  Interpolates emissivity for:
  INT: integrate atlas-pixel

MULT: multiple channel

2.8.3. Execution step

Please, see example in file test.f90

Annexe 1: References

- Prigent, C., E. Jaumouille, F. Chevallier, and F. Aires, A parameterization of the microwave land surface emissivity between 19 and 100 GHz, anchored to satellite-derived estimates, IEEE TGRS, 46, 344-352, 2008.
- Prigent, C., F. Aires, and W. B. Rossow, Land surface microwave emissivities over the globe for a decade, Bul. Amer. Meteorol. Soc., doi:10.1175/BAMS-87-11-1573, 1573-1584, 2006.
- Prigent, C., Microwave emissivity in arid reagions, what can we learn from satellite observations?, Chap. 4.5 in "Thermal Microwave Radiation - Applications for Remote Sensing", Matzler, C., P.W. Rosenkranz, A. Battaglia, and J.P. Wigneron (eds.), IEE Electromagnetic Waves Series 52, London, UK, 2006.
- Prigent, C., Passive microwave emissivity in vegetated reagions as directly calculated from satellite observations, Chap. 4.6, in "Thermal Microwave Radiation - Applications for Remote Sensing", Matzler, C., P.W. Rosenkranz, A. Battaglia, and J.P. Wigneron (eds.), IEE Electromagnetic Waves Series 52, London, UK, 2006.
- Prigent, C., J. Munier, B. Thomas, and G. Ruffié, Microwave signatures over carbonate sedimentary platforms in arid areas: Potential geological applications of passive microwave observations?, Geophys. Res. Let., 32, L23405, doi:10.1029/2005GL024691, 2005.
- Karbou, F., and C. Prigent, Calculation of microwave land surface emissivity from satellite observations: validity of the specular approximation over snow-free surfaces? IEEE Geoscience Remote Sensing Letters, 2, 311-314, 2005.
- Prigent, C., F. Chevallier, F. Karbou, P. Bauer and G. Kelly, AMSU-A land surface emissivity estimation for numerical weather prediction assimilation schemes, Journal of Applied Meteorology, 44, 416-426, 2005.
- Karbou, F., C. Prigent, L. Eymard, and J. Pardo, Microwave land emissivity calculations using AMSU measurements, IEEE TGRSE, 43, 5, 948- 959, 2005.
- Aires, F., C. Prigent, W. B. Rossow, M. Rothstein, A new neural network approach including first-guess for retrieval of atmospheric water vapor, cloud liquid water path,surface temperature and emissivities over land from satellite microwave observations, Journal of Geophysical Research, 106, 14 887-14 907, 2001.
- Prigent, C., J.P. Wigneron, W. B. Rossow, J. R. Pardo-Carrion, Frequency and angular variations of land surface microwave emissivities: Can we estimate SSM/T and AMSU emissivities from SSM/I emissivities?, IEEE Transactions on Geoscience and Remote Sensing, 38, 2373-2386, 2000.
- Prigent, C., W. B. Rossow, E.Matthews, Global maps of microwave land surface emissivities: Potential for land surface characterization, Radio Science, 33, 745-751, 1998.
- Prigent C., W. B. Rossow, E. Matthews, Microwave land surface emissivities estimated from SSM/I observations, Journal of Geophysical Research, 102, 21867-21890, 1997.

Annexe 2: Example for uncertainty calculations

How are the uncertainty covariance matrices computed? The emissivities for new frequencies are first computed:

Frequency	15 GHz	25 GHz	38 GHz	60 GHz	90 GHz
Emis V	0.9603142	0.9595809	0.9588379	0.9618543	0.9659674
Emis H	0.9590667	0.9586814	0.9583531	0.9613068	0.9653345

From the SSMI atlas, we have the 6x6 covariance matrix Cov_{SSMI} and the correlation matrix Cor_{SSMI} for the uncertainties on the 6 SSM/I channels (19, 37 and 85 GHz for both V and H polarizations).

Em19V	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Em37V		0.0005	0.0004	0.0005	0.0005	0.0005
Em87V			0.0004	0.0004	0.0005	0.0005
Em19H				0.0005	0.0005	0.0005
Em37H					0.0010	0.0009
Em87H						0.0010

And the associated correlation matrix:

Em19V	**1.00**	0.96	0.96	0.94	0.72	0.73
Em37V		**1.00**	0.95	0.95	0.71	0.72
Em87V			**1.00**	0.96	0.79	0.79
Em19H				**1.00**	0.76	0.78
Em37H					**1.00**	0.93
Em87H						**1.00**

The "interpolation" matrix FIM is given by:

1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.6799	**0.3201**	0.0000	0.0000	0.0000	0.0000
0.0000	**0.9794**	**0.0206**	0.0000	0.0000	0.0000
0.0000	**0.5258**	**0.4742**	0.0000	0.0000	0.0000
0.0000	0.0000	**1.0000**	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	**1.0000**	0.0000	0.0000
0.0000	0.0000	0.0000	**0.6799**	**0.3201**	0.0000
0.0000	0.0000	0.0000	0.0000	**0.9794**	**0.0206**
0.0000	0.0000	0.0000	0.0000	**0.5258**	**0.4742**
0.0000	0.0000	0.0000	0.0000	0.0000	**1.0000**

And the new covariance matrix is estimated by:

Cov=10^{-4}.

Em15V	4	4	4	4	4	4	4	4	4	4
Em25V		4	4	4	4	4	4	5	5	5
Em38V			5	5	4	5	5	5	5	5
Em60V				4	4	4	4	5	5	5
Em90V					4	4	4	5	5	5
Em15H						5	5	5	5	5
Em25H							5	7	7	7
Em38H								10	10	9
Em60H									10	10
Em90H										10

That corresponds to a correlation matrix:

Em15V	**1.00**	0.995	0.960	0.972	0.960	0.940	0.904	0.721	0.737	0.730
Em25V		**1.00**	0.983	0.987	0.965	0.952	0.913	0.724	0.741	0.733
Em38V			**1.00**	0.991	0.951	0.951	0.908	0.713	0.729	0.721
Em60V				**1.00**	0.984	0.966	0.936	0.755	0.771	0.760
Em90V					**1.00**	0.960	0.947	0.791	0.804	0.790
Em15H						**1.00**	0.959	0.761	0.783	0.780
Em25H							**1.00**	0.913	0.919	0.780
Em38H								**1.00**	0.919	0.932
Em60H									**1.00**	0.980
Em90H										**1.00**