Spatial resolution issues for SMOS

1. General remarks

Unlike a radar where spatial resolution may be determined by time sampling or Doppler characteristics, in a radiometer the spatial resolution at ground level is entirely dictated by the angular resolution of the (copolar) antenna pattern.

A useful way of characterizing this angular resolution is to consider the 3 dB solid angle, i.e. the solid angle within which the directional (power) gain is larger than half the gain on axis. Accordingly, the pixel will be defined as the intersection of the cone including this solid angle with Earth's surface.

It is however good to remember that the gain integrated over this solid angle is about the half of the the total gain; most of the remaining half lies in the remaining part of the antenna main beam (since the main beam efficiency is assumed to be high)

2 The SMOS case

In the case of a 2D interferometric radiometer such as MIRAS on SMOS, several complications arise.

2.1 The beam width on axis

The antenna pattern to be considered is the "reconstructed" antenna pattern. Its size (i.e. angular widths) depends both on the antenna size (in practice, the length L of antenna arms) and the apodisation window applied to the measured visibilities. On the axis, the half power beam width ε_0 will be isotropic:

$$\varepsilon_0 = k \lambda / (2 L)$$

Where λ is the wavelength, and the factor k takes values ranging from 1 to 2, depending on the apodization window. The angular 3 dB beamwidth for SMOS on axis is expected to be close to 2°.

2.2 Horizontal antenna plane

The instantaneous field of view is **bidimensional**. As a consequence, the angular resolution is not isotropic and its characteristic sizes vary all over the field of view; so do the spatial resolutions.

The basic phenomenon is illustrated by Figure 1, which considers a nadir pointed antenna (horizontal antenna plane). Looking at nadir, the pixel is isotropic; the spatial resolution Ds is given by:

$$Ds = h \varepsilon_0$$

Where h is the satellite altitude.

Looking at a point P on the surface, away from nadir, the "**transverse**" angular half power beam width, **perpendicular** to the incidence plane is unchanged with respect to nadir; the spatial resolution becomes:

$$Dq = SP \varepsilon_0$$

Where SP is the length of the line between the satellite S and the target point P. If the Earth were a plane, one would have SP = h / cos (θ_z), where θ_z is the look angle (with respect to the vertical through the satellite).

Within the incidence plane, the "**radial**" beamwidth ε_p is larger, because the relevant size of the antenna is smaller: $\varepsilon_p = \varepsilon_0 / \cos(\theta_a)$, where θ_a is the look angle with respect to the antenna axis. On Figure 1, since the antenna plane is horizontal, $\theta_a = \theta_z = \theta$.

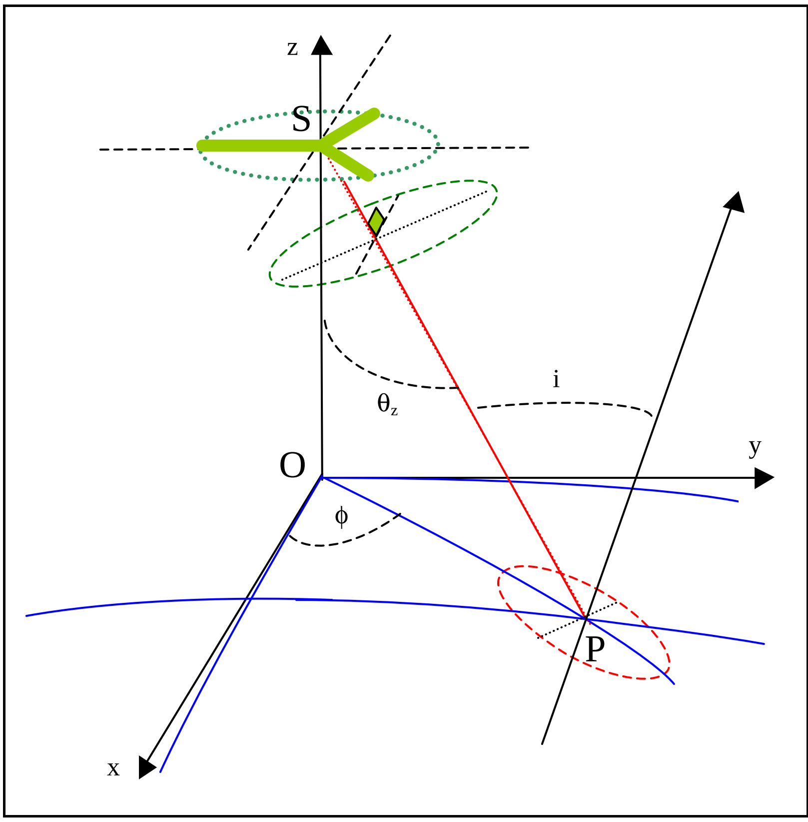

Figure 1

For an horizontal antenna plane, the pixel (limited by 3dB directional gain) is appromately an ellipse, with major axis within the elevation plane SOP

In addition, the radial spatial resolution is increased by a factor 1 / cos (i), where i is the incidence angle, and therefore:

$$Dp = SP / (\cos(\theta_a)\cos(i)).$$

If the surface of the Earth were a plane, one would have (with $i = \theta$):

$$Dq = h\ \varepsilon_0\ / \cos(\theta)\ ; \qquad Dp = h\ \varepsilon_0\ / \cos^3(\theta)$$

Although of course the sphericity of the Earth must be taken into account, this helps to appreciate that the actual pixel will be significantly elongated when looking away from the vertical.

It cannot be very wrong to assimilate the surface limiting the half power solid angle to a cone with an elliptical cross section. Even then, the actual pixel on Earth surface will be the intersection of such an elliptical cone with a sphere, which is a complicated curve. Again, the result cannot be very different from an ellipse (this has been verified), and we shall assume here this to be true.

2.3 Tilted antenna plane

When the antenna axis is tilted with respect to the vertical, both look angles θ_a and θ_z become different. Similarly, the intersections with Earth's surface of the incidence plane and the plane defined by the line of sight and the antenna axis become different .The result is that the major axis of the ellipse becomes oriented somewhere between the directions of those intersections, and that the ellipse tends to become "shorter", (less elongated), and "thicker".

2.4 The multiangular retrieval

The basic retrieval scheme consists of combining views of the same area on the surface obtained for various incidence angles as the satellite moves along, as shown by Figure 2. Then it becomes clear that the pixel sizes and orientations for all those views are **not the same**.

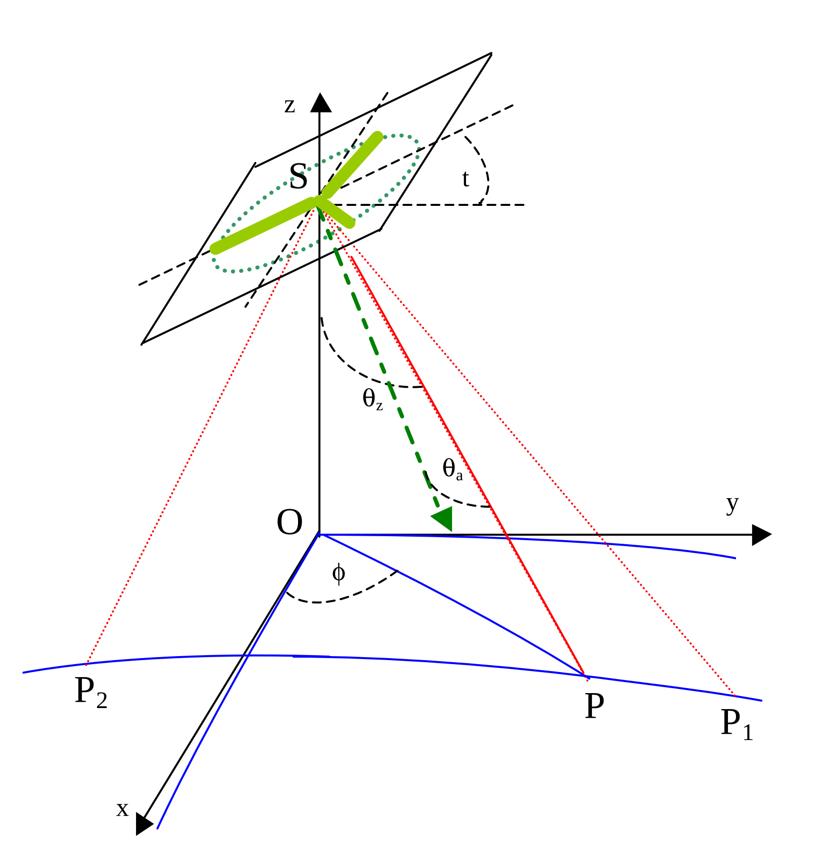

Figure 2

The multiangular processing is carried out combining data taken over the "data line" P_1 P_2, hence with various pixel shapes and sizes.

3 SMOS science requirements on land surface

3.1 The interplay between spatial resolution, accuracy and revisit time.

For a given set of (plausible) mission parameters including a tilted antenna plane, table 1 a, b, c presents schematic maps of the characteristics of the pixel over half a field of view.

Obviously, the sizes will increase as one moves along the x-axis, away from the subsatellite track. Therefore, requirements (based on scientific needs) will limit the maximum distance from the track up to which data can be accepted on land surface, in other words the **swath**; ultimately the limit set upon the swath will determine the **time sampling interval** of the mission.

However, one cannot specify the useful swath by only taking into account the maximum acceptable ground resolution within the field of view (FOV). First, the FOV is further limited by **alias-free boundaries**; a (plausible) example of the alias-free zone is illustrated by table (1d). Secondly, in order to achieve the required retrieval **accuracy** (over soil moisture), it is necessary to use, for any abscissa x, a set of data along the y axis which covers an **adequate range of incidence angles** and a **sufficient number of independent data** within the alias free zone. In other words the useful swath is also a function of the way the number of independant samples and angle range vary with abscissa x. Considering the former requirement, it is necessary to have about 150-200 km (that is 3 – 4 locations along y for the rough 50 km grid depicted by table 1) to be able to perform an adequate retrieval; this gives another constraint on the swath limits

Consequently, the swath, and therefore the time sampling interval, will be a function of a combination of requirements in which the spatial resolution requirement will play a major role.

Table 1

(a)	0	50	100	150	200	250	300	350	400	450
800	77	77	78	79	81	84	87	91	95	100
750	70	70	71	72	74	76	79	83	87	92
700	63	63	64	65	67	69	72	76	80	85
650	57	57	58	59	61	63	66	69	73	78
600	51	52	52	54	55	57	60	64	68	72
550	47	47	47	49	50	52	55	58	62	67
500	42	42	43	44	46	48	51	54	58	62
450	38	39	39	40	42	44	47	50	54	58
400	35	35	36	37	39	41	43	46	50	54
350	32	32	33	34	36	38	40	43	47	51
300	29	30	31	32	33	35	38	41	45	49
250	31	29	29	30	31	33	36	39	43	47
200	26	27	28	28	30	32	34	38	41	46
150	26	26	26	27	29	31	33	37	40	45
100	25	25	26	26	28	30	33	36	40	45
50	25	26	26	27	28	30	33	36	40	45
0	26	26	27	28	29	31	34	37	41	46
-50	27	27	28	29	30	32	35	39	43	47
-100	28	29	29	30	32	34	37	41	45	50
-150	31	31	31	33	34	37	40	43	48	53
-200	33	34	34	36	38	40	43	47	52	57

(b)	0	50	100	150	200	250	300	350	400	450
800	39	39	39	40	40	40	41	42	43	43
750	38	38	38	38	39	39	40	40	41	42
700	36	36	36	37	37	38	38	39	40	41
650	35	35	35	35	36	36	37	38	39	40
600	34	34	34	34	35	35	36	37	37	38
550	32	32	32	33	33	34	35	35	36	37
500	31	31	31	32	32	33	34	34	35	36
450	30	30	30	31	31	32	33	33	34	35
400	29	29	29	30	30	31	32	32	33	35
350	28	28	28	29	29	30	31	32	33	34
300	28	27	27	28	28	29	30	31	32	33
250	30	26	27	27	28	29	29	30	31	32
200	26	25	26	27	27	28	29	30	31	32
150	25	25	26	26	27	28	29	29	30	32
100	25	25	26	26	27	27	28	29	30	31
50	25	25	25	26	26	27	28	29	30	31
0	25	25	25	26	26	27	28	29	30	31
-50	25	25	25	25	26	27	28	29	30	31
-100	25	25	25	26	26	27	28	29	30	31
-150	25	25	25	26	27	27	28	29	30	31
-200	26	26	26	26	27	28	29	30	31	32

(c)	0	50	100	150	200	250	300	350	400	450
800	90	86	82	78	74	71	67	64	61	57
750	90	86	82	77	73	69	66	62	59	55
700	90	85	81	76	72	68	64	60	57	53
650	90	85	80	75	71	66	62	58	54	51
600	90	85	79	74	69	64	60	56	52	48
550	90	84	78	73	67	62	57	53	49	45
500	90	84	77	71	65	59	54	50	45	42
450	90	83	76	69	62	56	51	46	42	38
400	90	82	74	67	59	53	47	42	37	34
350	-90	82	73	64	55	48	42	37	32	29
300	90	86	72	60	50	42	36	31	27	23
250	90	84	69	55	44	35	28	24	20	17
200	0	69	63	48	34	25	19	16	13	11
150	-90	72	60	35	19	12	9	7	5	4
100	-90	88	87	4	-3	-3	-3	-3	-3	-3
50	90	-80	-62	-37	-24	-18	-15	-13	-11	-10
0	90	-78	-64	-49	-37	-30	-25	-21	-19	-17
-50	90	-79	-67	-56	-46	-39	-33	-29	-27	-23
-100	90	-80	-70	-61	-53	-46	-40	-35	-32	-29
-150	90	-81	-73	-65	-57	-51	-46	-41	-37	-34
-200	90	-82	-75	-68	-61	-55	-50	-46	-42	-38

(d)	0	50	100	150	200	250	300	350	400	450
800	0	0	0	0	0	####	####	####	####	####
750	0	0	0	0	0	0	0	####	####	####
700	0	0	0	0	0	0	0	0	0	####
650	0	0	0	0	0	0	0	0	0	0
600	0	0	0	0	0	0	0	0	0	0
550	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0
450	0	0	0	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0	0	0	0
350	0	0	0	0	0	0	0	0	0	####
300	0	0	0	0	0	0	0	0	0	####
250	0	0	0	0	0	0	0	0	####	####
200	0	0	0	0	0	0	0	0	####	####
150	0	0	0	0	0	0	0	0	####	####
100	0	0	0	0	0	0	0	0	####	####
50	0	0	0	0	0	0	0	0	####	####
0	0	0	0	0	0	0	0	0	####	####
-50	0	0	0	0	0	0	0	0	0	####
-100	0	0	0	0	0	0	0	####	####	####
-150	0	0	0	0	0	####	####	####	####	####
-200	0	0	0	####	####	####	####	####	####	####

Table 1: the right side of the field of view is gridded over a 450 x 1000 km with a 50 km resolution; abscissas along y are with respect to the subsatellite point. Assumed flight altitude, arm length and tilting angle are 670 km, 4.80 m and 30°. Shown are the (a) radial and (b) transverse spatial resolutions (km); table (1c) depicts the inclination angle β° of the approximately elliptical pixel with respect to the x-axis. Table (1d) shows the alias free area, assuming the spacing ratio is 0.82 and a 0° steering angle.

Figures for a particular abscissa x have been shaded over the alias-free zone, in order to make comparisons easier.

3.2 Defining a spatial resolution criterium

Then, the main question is: how to apply a spatial resolution requirement in such geometry? Possible (not exhaustive) choices consist, having selected a threshold **Ds (the threshold value being considered for SMOS is near 50 km)**, of stipulating that:

- the **maximum** length of the **major** axis along the data line is smaller than Ds ;
- the **maximum average** pixel resolution along the data line is smaller than Ds. Here "average" might mean: arithmetic mean between lengths of major and minor axes, or geometrical mean (i.e. radius of the equivalent circle), or mean of the spatial resolutions projected on the x and y-axes.
- the **minimum** length of the **major** axis along the data line is smaller than Ds . The rationale for this possible choice is that at least some information on this scale is provided by the data; therefore a sophisticated processing, using available oversampled data, gives hope of retrieving features down to this scale.

Depending on the choice of the spatial resolution criterium, the revisit time will be substantially different. In addition, the way mission parameters should be optimized also depends on this choice.

In any case, one should be aware that the variation of actual pixel size and orientation will have to be considered in the retrieval processing.

3.3 Defining an improved resolution zone

Having selected a threshold value for the spatial resolution and defined rules in order to use it enables to carry out the optimisation process on the mission parameters.

However, it is well known that in any case the spatial resolution performances of SMOS will fall short of performances wished for by many scientists, particularly in the hydrological community.

Keeping this in mind and coming back to table 1, it is seen that the spatial resolution in the central area of the FOV is significantly better than on its edges. Therefore the question arises whether, for some purposes, it would be worthwhile identifying a "restricted" swath where the spatial resolution would be better than for example 30 or 35 km, and setting a requirement on the minimum value of the corresponding swath width (this amounts to a requirement on the revisit time, which is bound to be larger than for the "full" usable swath).

In case there is a strong scientific interest for such a requirement, it may have consequences on the optimisation of mission parameters, and particularly the flight altitude.

3.4 Conclusions

It would be useful that the SMOS SAG considers the spatial resolution issues, and gives some recommendations to the project team about:

- How the spatial resolution requirement ought to be applied (see § 3.2) ;
- The possible scientific interest of having a restricted zone with improved (i.e. smaller) spatial resolution and degraded revisit time (see § 3.3), with indications on the values of both space resolution and revisit time which would make such an option worthwhile.