We consider a geosynchronous Ku band system, and the defocusing effects due to the temporal and spatial variability of the atmospheric water vapor. Due to the very slow formation of the spatial chirp, the temporal change of the local water vapor content may be significant, thus preventing a correct image focusing and the formation of a coherent image. Using ground based radar data, we estimate and model the spatial - temporal correlation function of the water vapor delay. Then, for a given spatial scale, we estimate the maximum time within which the temporal evolution of the water vapor should be carried out, to be able to track its temporal evolution without irremediable coherence loss. This requisite constrains both the EIRP and the apparent velocity of the satellite.

We evaluate the possibilities of real time ground motion analyses, as a function of the spatial and temporal resolution and the EIRP. We show that with *1000W* transmitted power and a *2.6m* diameter antenna, $\sigma_0 = -15dB$, we can get $SNR = 10dB$ for a ground cell of $350m^2$, in *7.63* hours or of $500x500\ m^2$, in a time of 5 minutes. This is enough to be able to compensate for the time variations of the Atmospheric Phase Screen (APS), that could otherwise defocus the signal. The minimal PRF is about 3Hz and therefore reflections can be averaged over 300msec time. If a scatterer moves for more than $\lambda/4$ in this time, the average reflected amplitude decreases further, the faster and the wider the motion. Slower motion of the scatterers entails smaller reduction of the amplitudes.

If the imaged object is always in view of the observing satellite, the azimuth chirp has a duration that can be approximated as 7.63 hours, if the time intervals corresponding to the minima of the relative velocity are neglected. This extreme time length makes it very unlikely that the imaged objects stay still during the entire duration of the chirp and therefore an analysis should be made of the effects of their motion. The result is that the total energy E_{tot} of the reflection is spread approximately along the azimuth line as $E(y)$ and therefore over a space interval say $2y_0$ wide.

$$E(y) = \frac{1}{\pi y_0} \frac{E_{tot}}{1 + (y / y_0)^2}$$

$$y_0 = \frac{4\pi}{\lambda} \frac{R\sigma_x^{\ 2}}{v\tau_0}$$

Here, R is the satellite to target distance, v the satellite velocity, σ_x is the standard deviation of the position $x(t)$ of the scatterer with time, and τ_0 is the time constant of the motion correlation i.e.:

$$E[(x(t)x(t+\tau)] = \sigma_x^{\ 2} e^{-\tau/\tau_0}$$

The approximate diameter of the reflection spread $2y_0$ could be much larger than the footprint of the satellite antenna. In other words, if the data are recorded with a sufficiently high PRF, then the backscatter of the moving parts expands over a much wider area than that of the fixed parts.

Two kinds of solutions are possible to solve the problem of the clutter; the satellite apparent velocity can be Fast (F) or Slow (S). In the case F, the PRF is large and much of the clutter appears “frozen”. Thus, the spill over of the scattered energy outside the resolution cell is avoided, more or less similarly to what happens for airborne SAR or for LEO SAR systems. In the case S, the PRF is reduced as much as possible and the clutter is averaged before imaging either by pre-summing several returns of the pulses or by using a very long time chirp.

Typical of the two modes of design are the proposals of JPL [1] (F) and this one (S) [3]. In the first case a very large satellite in L band (*65 KW* power, membrane antenna *50x50m*) is injected in a 60 degrees inclination orbit illuminating the earth along a meridian say from Canada to South Argentina. The satellite velocity is large (up to *3200 m/sec*), and the PRF proposed is about 200 Hz. The dwell time on the target is several minutes, still much longer than the second or so of the usual satellites. Therefore, the transmitting power has to be large. In the case of the S design, the long dwell time and the smaller area to be imaged allow a much lower power and a much smaller antenna. In the two cases the values for y_0 are in a ratio of about 10000, taking into account the

different band (L in one case and Ku in the other) and the different satellite apparent velocities. This entails that in the S case, the attenuation of some clutter could be up to 40dB greater.
On the other hand, the effect of the atmosphere for the S system in the long dwell time is to create a space and time varying differential phase shift, the Atmospheric Phase Screen (APS). Actually, given the short time needed to achieve a 1km azimuth resolution, the geosynchronous system could be considered as a tool for measuring short term APS.
Measurements were carried out of the effects of the water vapor in a mountainous environment, using a ground based radar in the band Ku [2]. The additional path delay in millimeters was measured over a distance of .4km and its variogram and power spectrum are shown in Fig 1. The time axis, covers a few days; the vertical axis (left) is in millimeters squared.

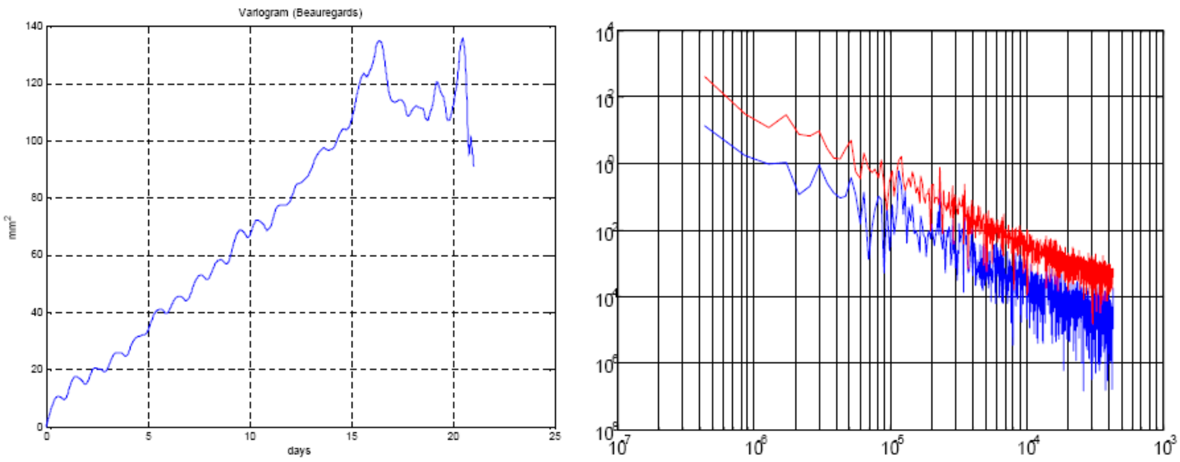

Figure 1 left: The variogram of the water vapor over a 400m distance. The horizontal scale is in days, and the maximum is about 150 mm^2. right: The power spectra (400 and 1000m distance; abscissae: sec^{-1})

Conclusions

A small communication satellite operating in the Ku band could act as a geosynchronous SAR with the capability of observing an area with a radius of about 50 km. twice a day, with 20m resolution. The very slow azimuth chirp and a PRF of say 2Hz would allow the suppression of clutter from many objects in motion, clutter that would otherwise appear defocused all over the image, in the case of faster moving satellites. Anyway, the geosynchronous SAR would only allow the imaging of scatterers persisting for about 8 hours; all others would be either defocused if their motion is very slow, or suppressed.

References

[1] S. N. Madsen, W. Edelstein, L. D. DiDomenico, J. LaBreque, A geosynchronous Synthetic Aperture Radar; for tectonic mapping, disaster management and measurements of vegetation and soil moisture., Proc. IGARSS 2001, pp. 447 – 449.
[2] Monti Guarnieri A., Rocca F., D'Aria D., Bernardini G. and Ricci P., Subsidences estimation from ground based SAR: techniques and experimental results ESA Fringe 2007 Symposium, Frascati
[3] C. Prati, F. Rocca, D. Giancola, A. Monti Guarnieri, Passive Geosynchronous SAR System Reusing Backscattered Digital Audio Broadcasting Signals, IEEE Transactions on Geoscience and Remote Sensing, Vol. 36, n.6, Nov 1998, pp. 1973-1976.