Constraining the deconvolution of oversampled satellite microwave observations to enhance the spatial resolution of rain estimates

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To obtain higher spatial resolution from a vertically-profiling precipitation radar with a given aperture size, one can consider a judicious use of spatial oversampling (which may require frequency diversity to achieve in hardware, but does not require any increase in real aperture). Deconvolution alone cannot be guaranteed to produce physically meaningful results, as noisy in the input measurements can produce numerical outputs that have unrealistic values in significant portions of the domain. Two different constraints can be placed on the deconvolution: a variational constraint, adding an a priori first guess to the minimization problem; and a reformulation of the problem to force the measurements in neighboring resolution elements to have the same correlations as those resulting from empirical high-resolution analyses. This approach has been successfully tested on oversampled passive observations, and is adapted to the case of reflectivity-factor measurements by radar. The success, i.e. a sufficiently low error in the results of this guided disaggregation, will enable the design of a future satellite radar that could achieve up to five-times better resolution than today's, with straightforward changes in the system design and, most significantly for a spaceborne system, no added mass or volume or unmanageable complexity.

The aproach has been succesfulling implemented and tested for the observations of conically-scanning multi-channel microwave radiometers. One of the significant advantages offered by such radiometers (over cross-track scanners) is their ability to have a large overlap between the footprints of a) consecutive beams in a scan, and b) consecutive scans. This overlapped sampling opens up the possibility of extracting, from the oversampled radiances, higher-resolution estimates of the finer-scale radiances. The approaches that have been developed to date to obtain these finer-scale estimates rely on a deconvolution of the oversampled radiances. However the numerical solution of the deconvolution, especially when the observations are noisy, may produce physical unrealistic values (which cancel each other during the convolution to produce values that are consistent with the observed coarse-resolution radiances). No effective method has been demonstrated to date to enforce physical consistency in the deconvolution process. To do so, one would need to enforce consistency relations between the high-resolution radiances in the various channels –and these relations are nonlinear as well as statistical in nature, expressing the fact that the processes of absorption/emission and out-of-beam-scattering should produce values in the different channels which are between some statistically constrained bounds.

We developed an approach to enforce these constraints using two basic new ideas:
1) Instead of looking for unknown high-resolution radiance fields t that convolve to produce coarse-resolution fields A •t which are close to the observations T, the first idea is to look instead for the top vertical principal components t’ of the t. In effect, using principal components forces the high-resolution solution to have the empirical joint behavior between different channels that is observed in physical reality, and considering only the top principal components as the unknowns forces the information that is extracted from the observations to be applied to the physically significant properties of the column (embodied by the most variable principal components) instead of trying to make inferences about principal components which are known to be globally essentially invariable (or, at least, with a variability that is smaller than the variance of the measurement noise).
2) Instead of merely solving the deconvolution equations without assuming any a-priori knowledge about

the physical nature of the high-resolution solution, the second idea is to start with an a-priori estimate that is derived from our observations, in particular the high-resolution portion of the observations (in the higher-frequency channels). In addition to imposing a physically reasonable a priori assumption, this also in effect regularizes the deconvolution process, so that even if we do not have as many observations as we have unknowns, we are guaranteed to have more equations than unknowns (since each a-priori first guess imposes an equation, and there are as many of those as there are unknowns).

The success in the passive case strongly supports the applicability of the same approach to radar measurements. In the case of radar, vertical principal components of reflectivity factors are sought, instead of the high-resolution reflectivity factors themselves, column per column. The initial first guess is obtained by interpolating the observed radar reflectivities, then the results of the minimization are used as the first guess for the subsequent iteration until the magnitude of the "innovation" falls below the measurement uncertainty. The approach does not depend on the means by which the overlapped coarse-resolution radar observations are obtained, and its success will pave the way for very efficient future design that do not require prohibitively large apertures to resolve convective-scale cloud features.

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