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Full waveform inversion schemes for 3D density structures

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NWO

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Questions?

find Nienke

The problem with density

We are developing new methods for seismic tomography that better constrain density variations in the Earth. While density variations drive convection in the Earth and serve to discriminate between thermal and compositional heterogeneities, classical seismological observables and gravity provide only weak constraints (figures 1, 2), with strong trade-offs (figure 3). Instead of simply scaling density to velocity, we attempt to address this issue using full waveform inversion schemes based on numerical wave propagation with adjoint techniques, <u>including any information that can help constrain 3D density structure</u> (diagram 1).

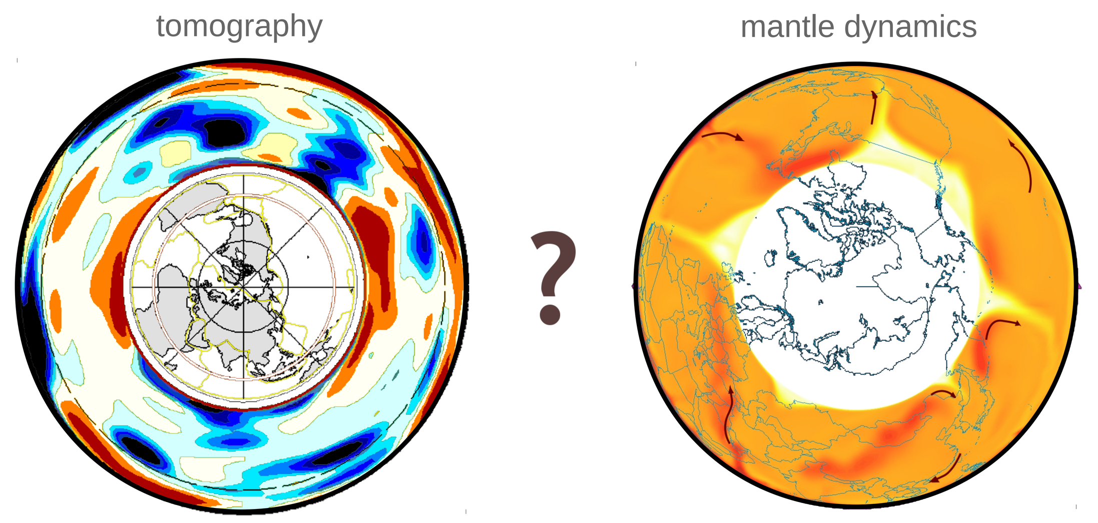


Figure 1: Linking seismic tomography and mantle dynamics is difficult because our seismic observables are mainly sensitive to wave speeds rather than density.

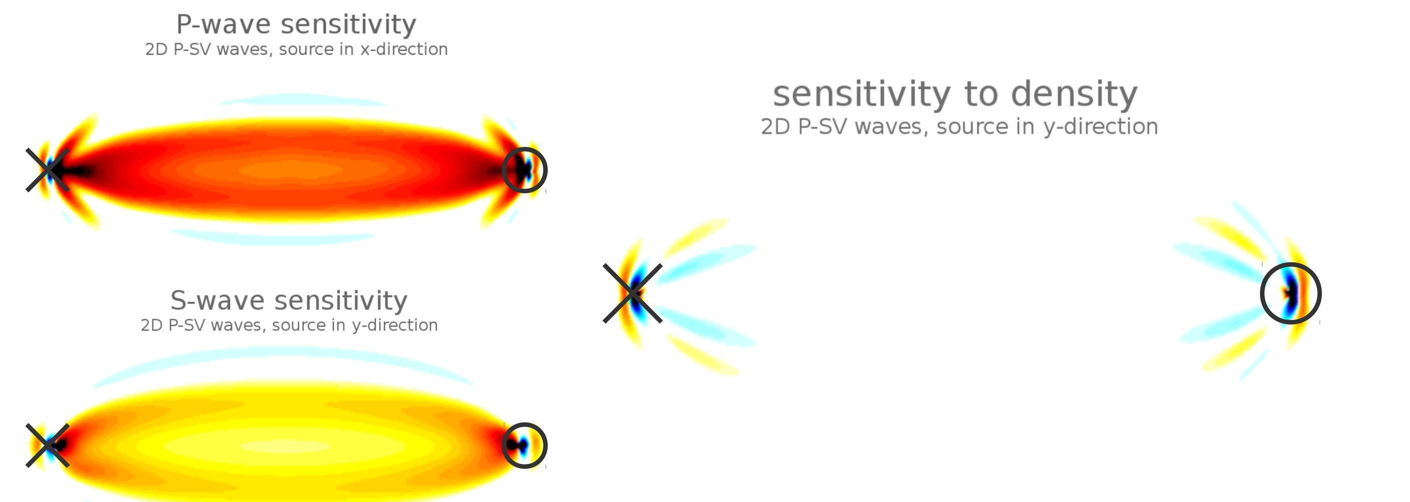
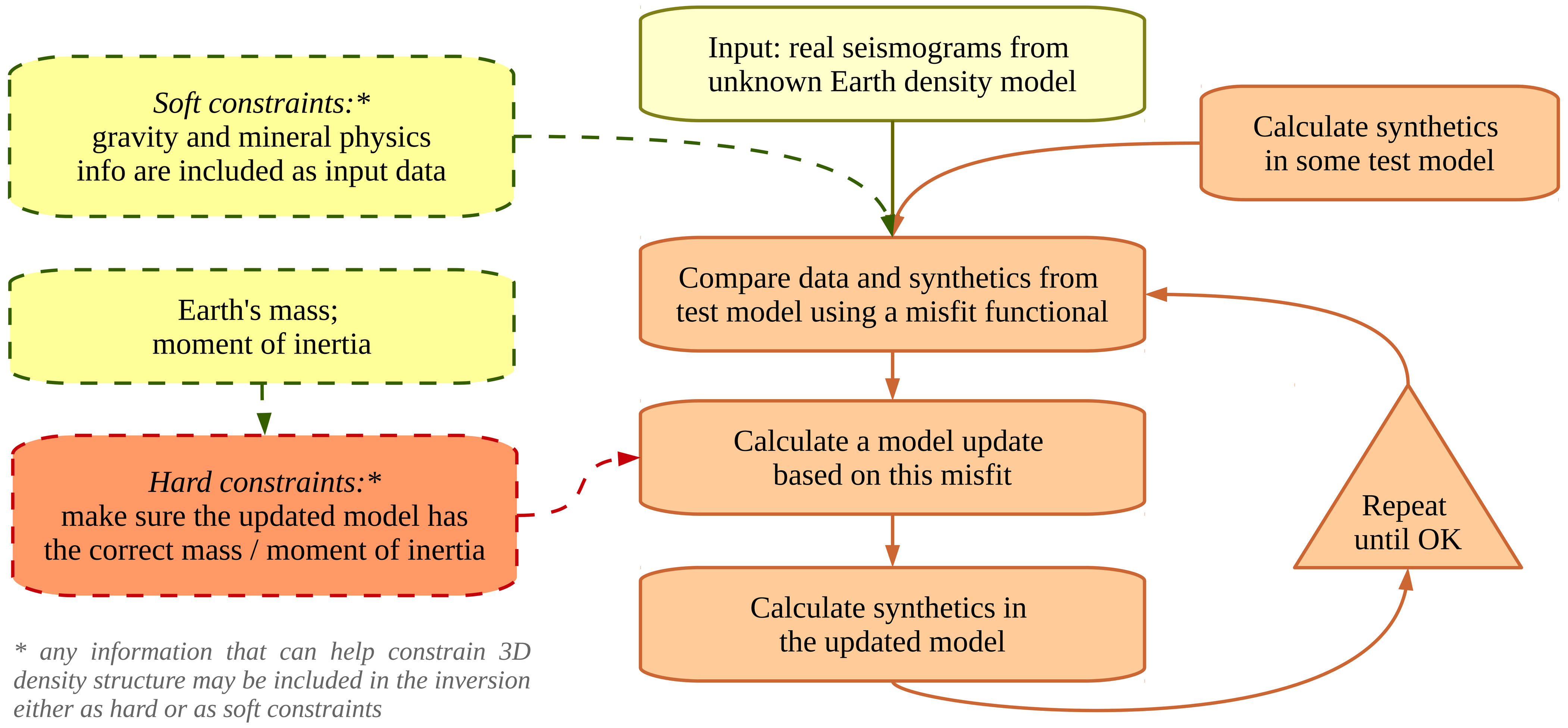


Figure 2: Travel times of seismic waves are sensitive to changes in P and S velocity (left), but hardly to density variations (right). Shown here are travel time sensitivity kernels which show the region in which an anomaly would alter the seismic travel time from source × to receiver ○. The darker the colour, the more the travel time would be altered. Reds mean delays, blues mean early arrivals.

1. Density inversion how-to



** any information that can help constrain 3D density structure may be included in the inversion either as hard or as soft constraints*

Diagram 1: The schematics of seismic inversion. Extra information, meant to better constrain 3D density variation, can be incorporated in different ways – as soft constraints (i.e. minimising an augmented misfit functional that includes all the data) or as hard constraints (i.e. adjustment of the model after updating it so that it definitely fits those constraints).

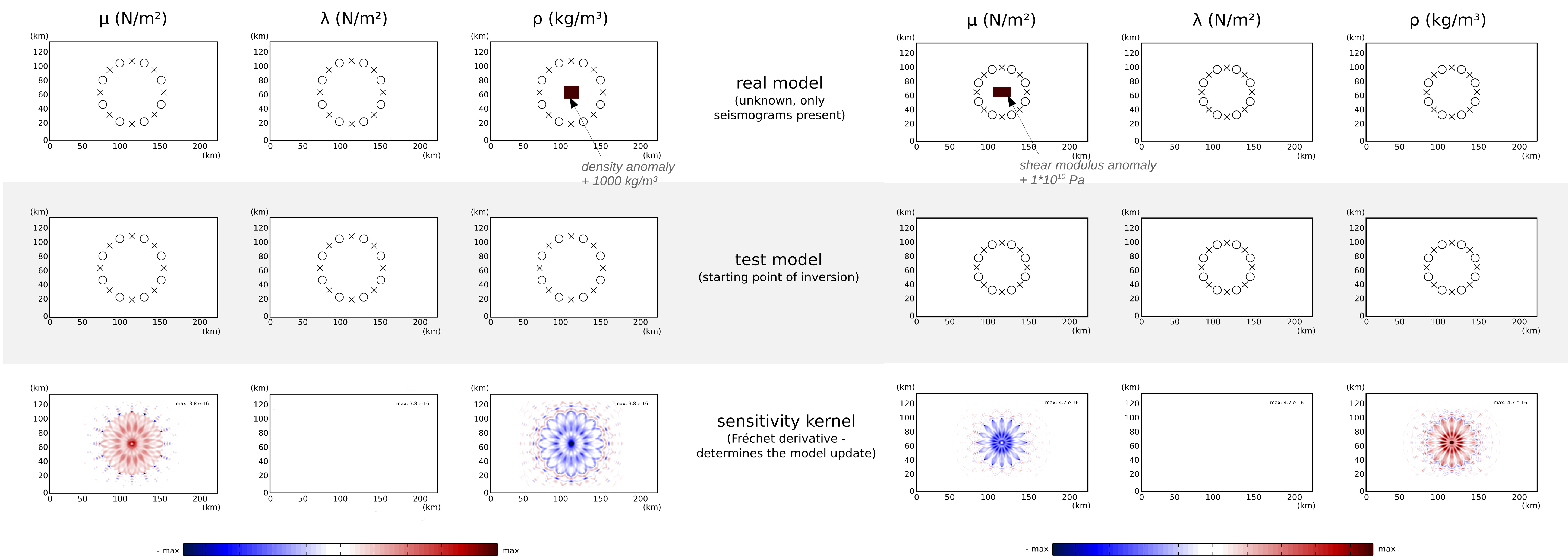


Figure 3: A comparison between inversions with a shear modulus μ or a density ρ anomaly illustrates the problem of trade-offs between these two parameters. On the left, only a density anomaly is introduced in the real model (top row), while on the right only a μ anomaly is introduced. The starting test model (middle row) is homogeneous in both cases, and seismograms are calculated for all the receivers using numerical wave propagation. The sensitivity kernels (bottom row) are calculated using the adjoint method with a L_2 misfit between real and test seismograms. The model update is simply a scaled version of these kernels. While we see that the strongest update is indeed suggested in the region where the anomaly lies, we also see that in both cases the first inversion update affects *both* parameters while only one of them has an anomaly (see also figure 4 for an example of the signature of a positive density anomaly on the wavefield of a single source).

Videos of wave propagation and the adjoint method:

2. Current state of affairs

We have developed a 2D wave propagation code for efficient calculation and assessment of synthetic inversions. With this code we calculate pure travel time sensitivity kernels (figure 2) and waveform sensitivity kernels (figure 3).* An illustration of P-SV wave propagation is shown in figure 4. We are currently incorporating gravitational constraints into our inversions, as depicted in diagram 1.

** videos of these calculations can be watched online: www.geo.uu.nl/~blom or use the QR-code.*

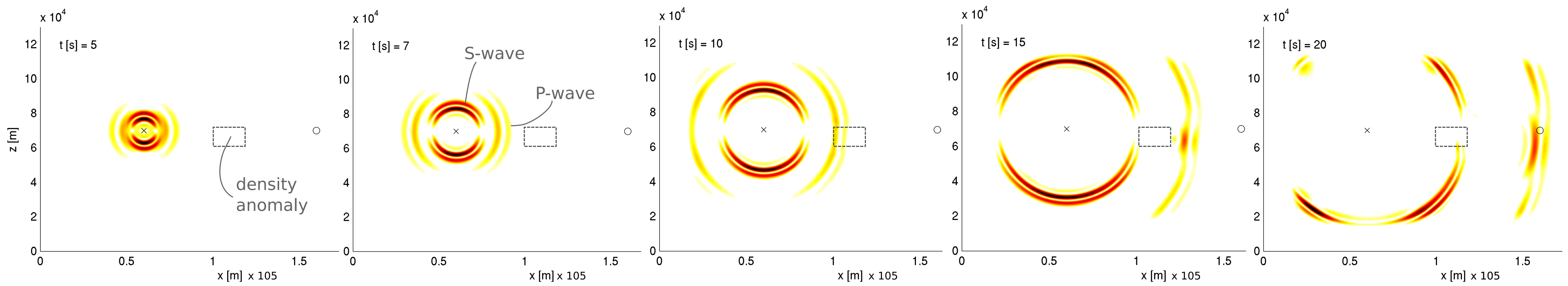


Figure 4: P-SV wave propagation past a positive density anomaly between a single source and receiver. In ρ-μ-λ parametrisation, the density signal is scattered forward, resulting in a seismogram which is so similar to one produced from a negative shear modulus anomaly, that there is a strong trade-off between these parameters (see figure 3).