An experimental 2D-Var retrieval using AMSR2

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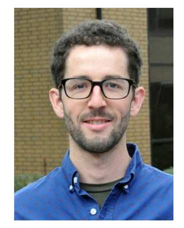

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1. Introduction

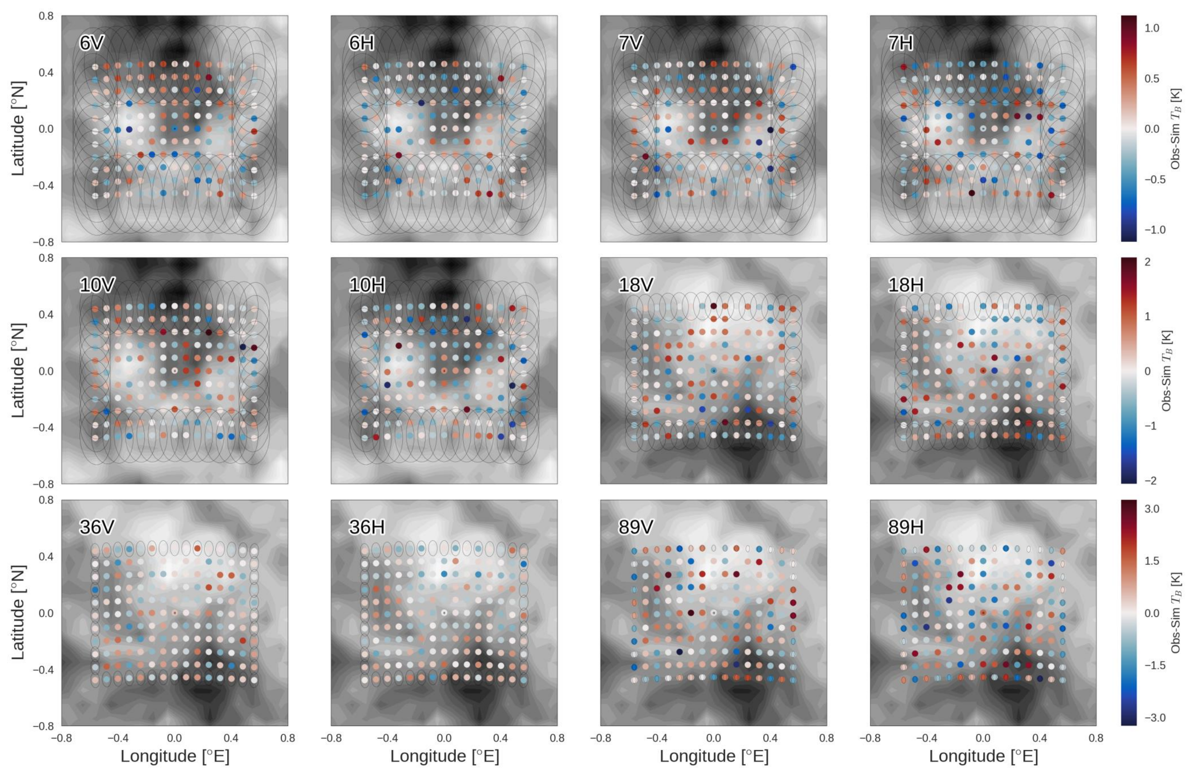
Overlapping passive microwave field of view (FOV) information is usually discarded in data assimilation systems and standalone retrievals. But at low frequencies this is very significant information loss and a concern for MetOp-SG sensors MWI and ICI with heavily overlapping scan strategies. In this study we build and test a two-dimensional variational (2D-Var) retrieval that accounts for overlapping beams and full antenna patterns in the forward model. It is applied to the Advanced Microwave Scanning Radiometer 2 (AMSR2) to retrieve surface parameters. The goal is to resolve patterns smaller than passive microwave FOVs by leveraging this overlapping information content.

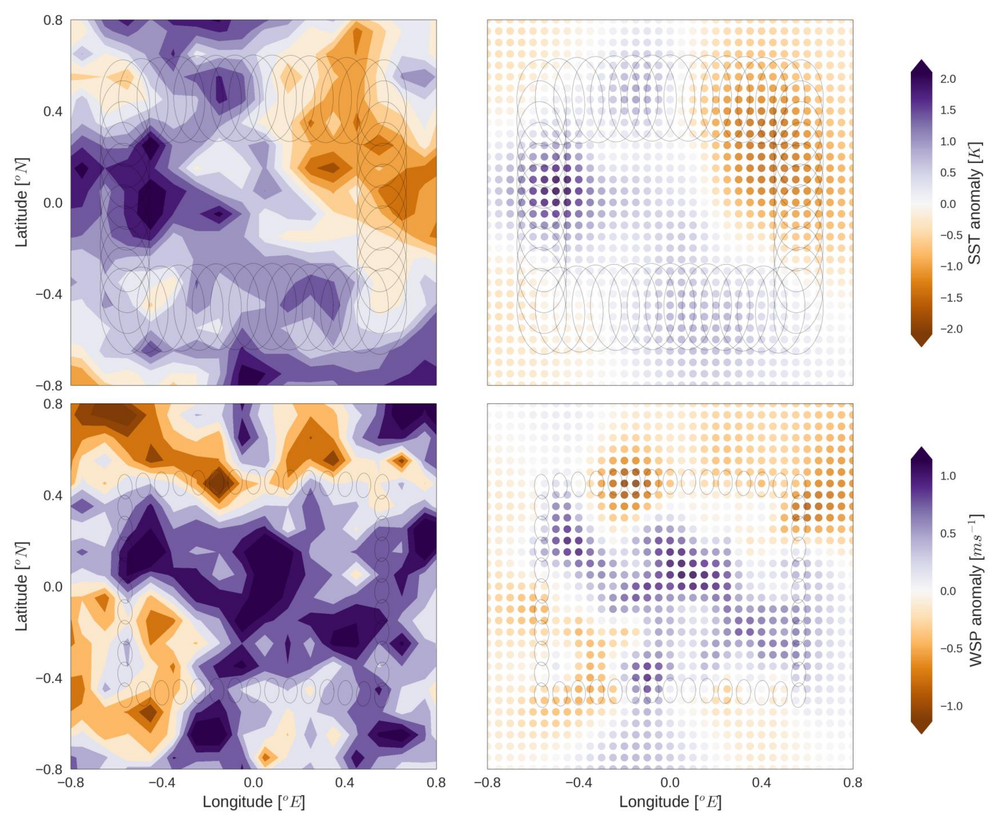
3. Synthetic scene results

To ensure posterior errors and averaging kernels are *exactly correct*, background fields are constructed to have exact spatial decorrelations and standard deviations from a flat prior. The measurement vector is created by running the forward model and then noise is added equivalent to published NEDT.

	2D-Var (.05°)	2D-Var (.1°)	1D-Var mimic (0.1°)
$RMSE_{SST}$ [K]	0.36	0.35	0.94
$RMSE_{WSP}$ [ms^{-1}]	0.41	0.31	0.69
r_{SST}	0.73	0.89	0.65
r_{WSP}	0.79	0.81	0.59

- Larger spatial structures in SST, WSP are resolved
- Retrieved SST is a smoother field due to FOV size
- Grid spacing of 0.05°
- Posterior errors are dominated by smoothing error
- 2D-Var outperforms a 1D-Var-type retrieval that lacks antenna patterns and spatial correlations





Right: Background SST and WSP anomalies (left panels) versus retrieved (right panels)
Left: O-B for synthetic scene after 2D-Var convergence

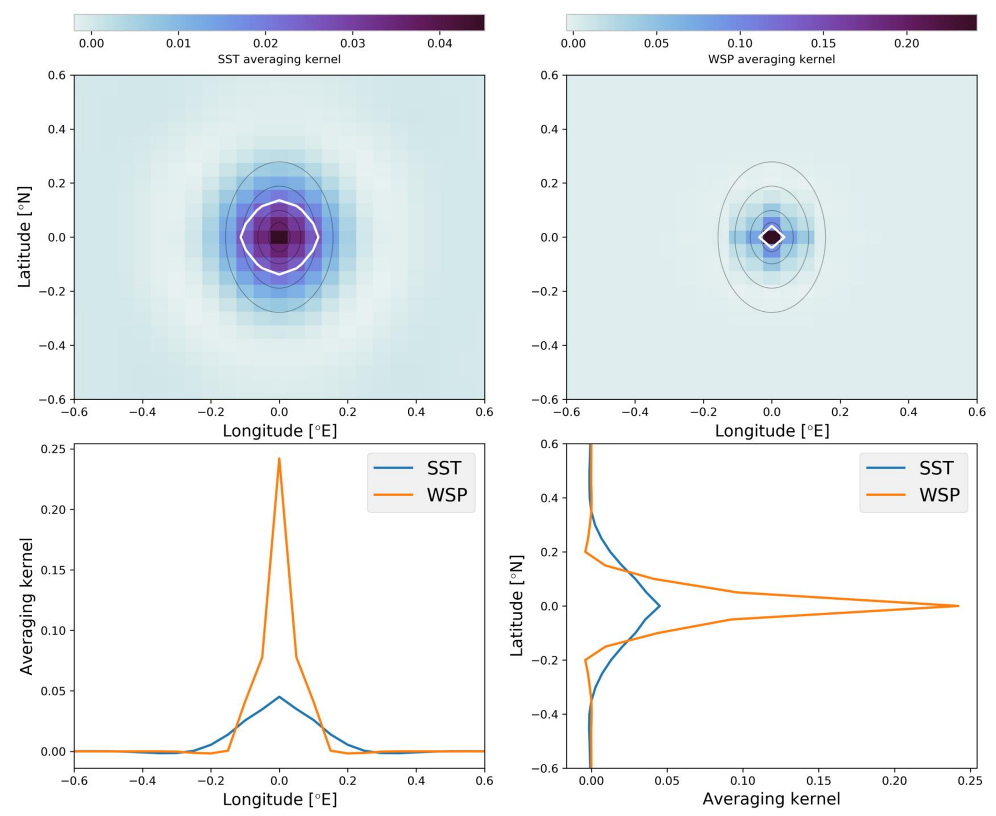
4. Achieved resolution

From synthetic scene, we judge achieved spatial resolution by the HPBW of the averaging kernel. This "measurement response" is compared to FOVs of co-located AMSR2 channels

Achieved spatial resolutions:

- ~30km for SST (about 10GHz FOV)
- ~10km for WSP (about 36GHz FOV)

All points within area of dense observations show that sum of measurement response is 1.0, indicating retrieval is fully constrained by measurements



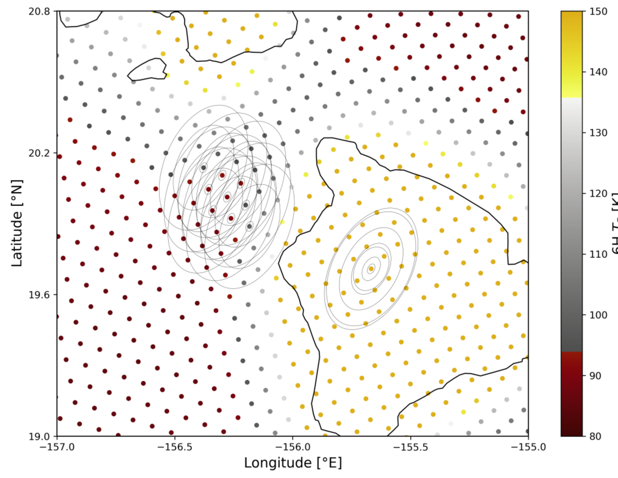
Measurement response for a retrieval point near middle of the grid. Black lines indicate AMSR2 FOVs (at HPBW), white line is HPBW of averaging kernel.

2. Forward model and method

The forward model and variational solver are contained in Atmospheric Radiative Transfer Simulator (ARTS) v2.3 using FASTEM-6.
The AMSR2 sensor geometry is from JAXA L1R data and all channels are used at their native resolution.

Antenna patterns are modelled as a 2D Gaussian in angular space with measurements sampled by a grid of "pencil beam" calculations.

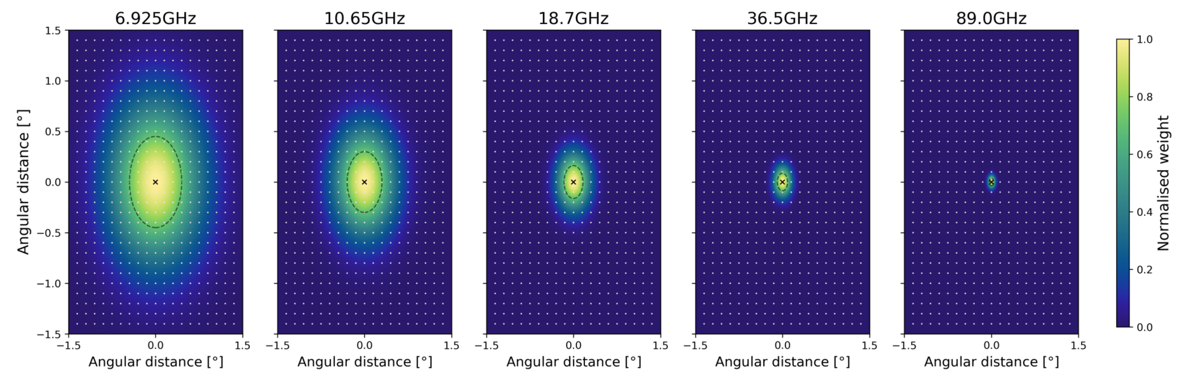
The 2D-Var solver returns grids of SST and wind speed (WSP). Observation error is a diagonal matrix of sensor noise, while state vector error is non-diagonal with a defined decorrelation length.



Top: Observed AMSR2 TBs near Hawaii at 6H channel. FOVs at various channels are given to show overlap.

Bottom: Antenna response for AMSR2 channels in angular space with a line representing HPBW. Typical "pencil beam" sampling of measurements shown in white dots.

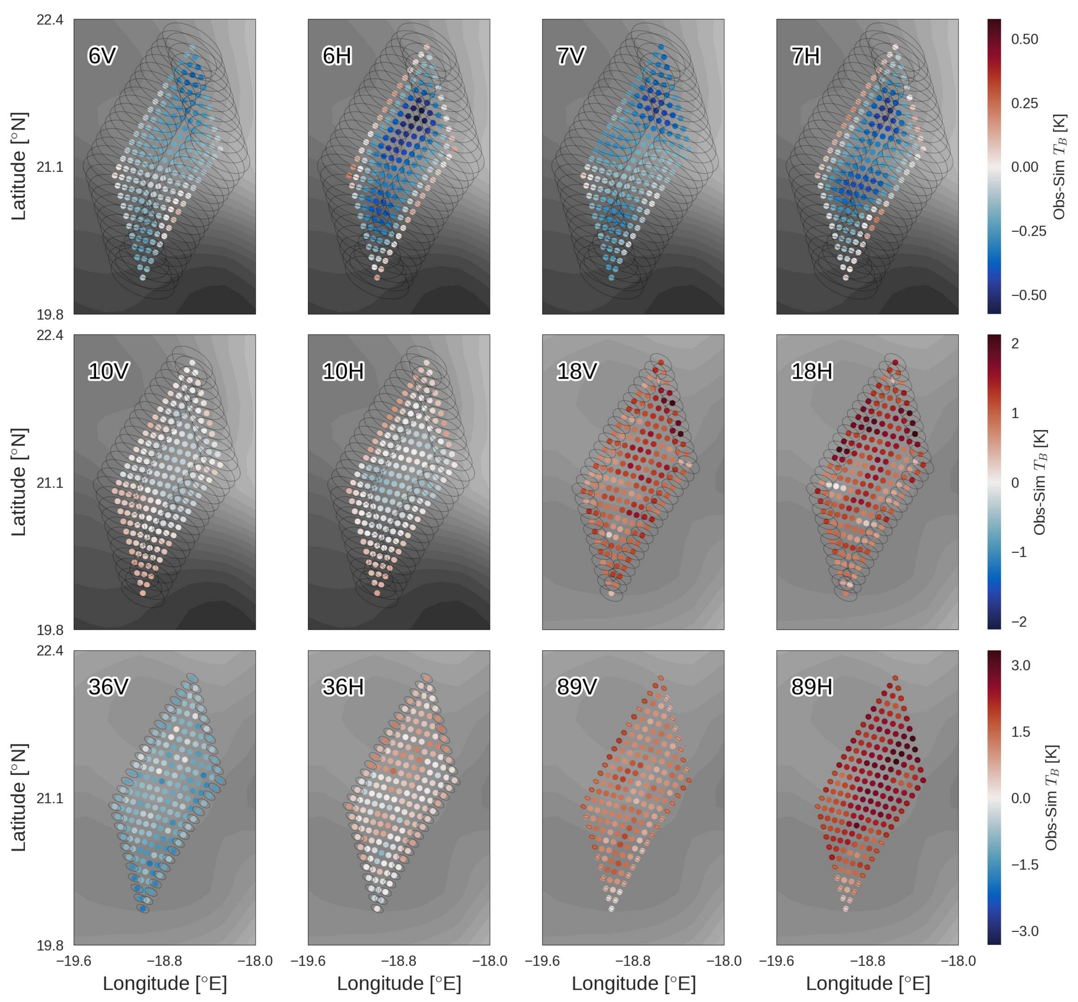
Centre Frequency [GHz]	6.925	7.3	10.65	18.7	23.8	36.5	89.0
Polarisations	V, H	V, H	V, H	V, H	V, H	V, H	V, H
Bandwidth [MHz]	350	350	100	200	400	1000	3000
NEDT [K]	0.34	0.43	0.70	0.70	0.60	0.70	1.20
Angular beam width [°]	1.80	1.80	1.20	0.65	0.75	0.35	0.15
IFOV width [km]	35	34	24	14	15	7	3
IFOV height [km]	62	58	42	22	26	12	5



Method

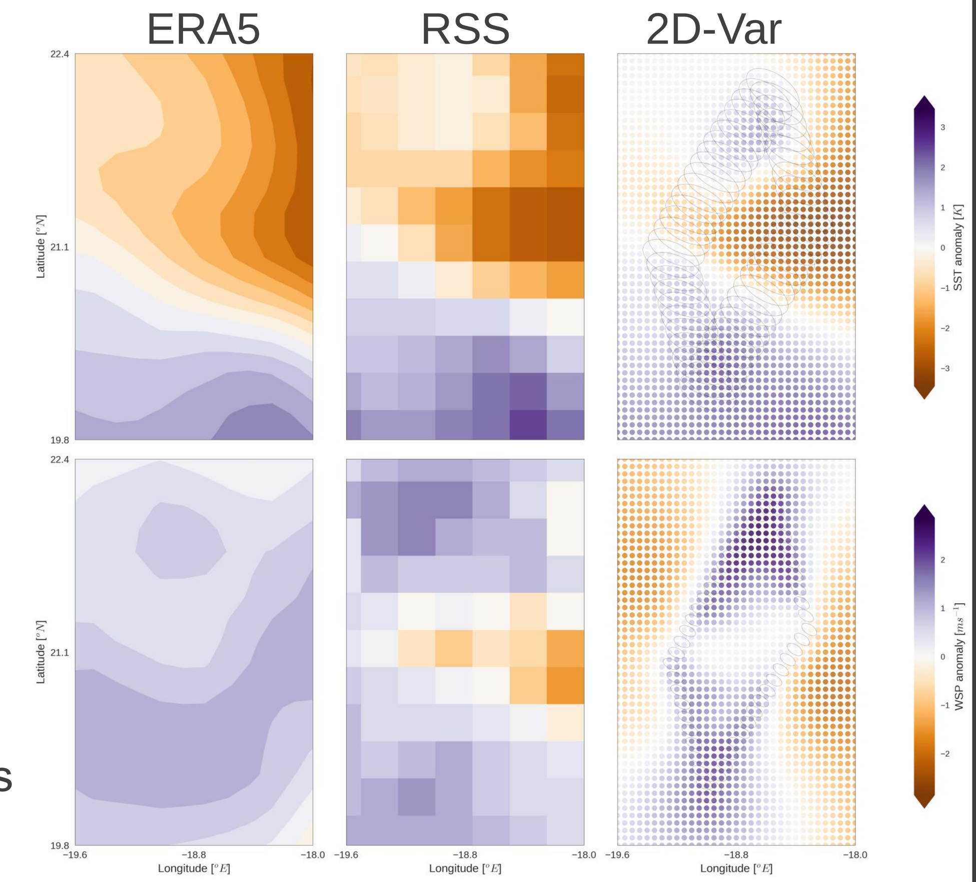
- Test 2D-Var on synthetic scene to determine optimal grid spacing and achievable resolution
- Assess achieved spatial resolution via averaging kernel rows
- Attempt 2D-Var retrievals with observed data from AMSR2

5. Observed scene from AMSR2



A test scene near Canary Islands

- Clear-sky, strong SST gradient
- ERA5 used for a priori but with large assumed errors
- Excellent fit to AMSR2 T_B despite some FASTEM-6 and calibration biases
- 2D-Var resolves stronger and tighter gradients in SST and WSP
- Note no sensitivity outside 'observation area' shown by FOVs
- Good agreement with RSS despite different methodologies
- T_B fits show remarkably low noise, less than NEDT



Left: O-B AMSR2 T_Bs after 2D-Var convergence. FOVs are shown for pixels on edge of observation area.

Right: SST and WSP anomalies from mean, shown for ERA5, RSS 0.25° product, and 2D-Var retrieval.

Summary

- 2D-Var permits greatest use of total information content from microwave sensors—targets are retrieved at the highest possible spatial resolution, driven by the channels' sensitivities
- Spatial oversampling can mitigate need for larger antennas in the push for higher spatial resolution of future sensors
- All AMSR2 channels can be simulated within near NEDT values for observed clear-sky ocean scenes
- This method could be applied to imagers or sounders and expanded to 3D-Var to retrieve cloud fields, temperature, and humidity

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