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A novel method for vicarious re-characterisation of the MVIRI VIS spectral response to facilitate climate monitoring

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Aim (2/14)

Fidelity and uncertainty in climate data records from Earth Observations (FIDUCEO) brings insights from metrology to the observation of Earth's climate from space.

FIDUCEO will create a new fundamental climate data record (CDR) from more than 30 years of Meteosat First Generation (MFG) MVIRI visible (VIS) band observations that include traceable state-of-the-art information on measurement uncertainty.

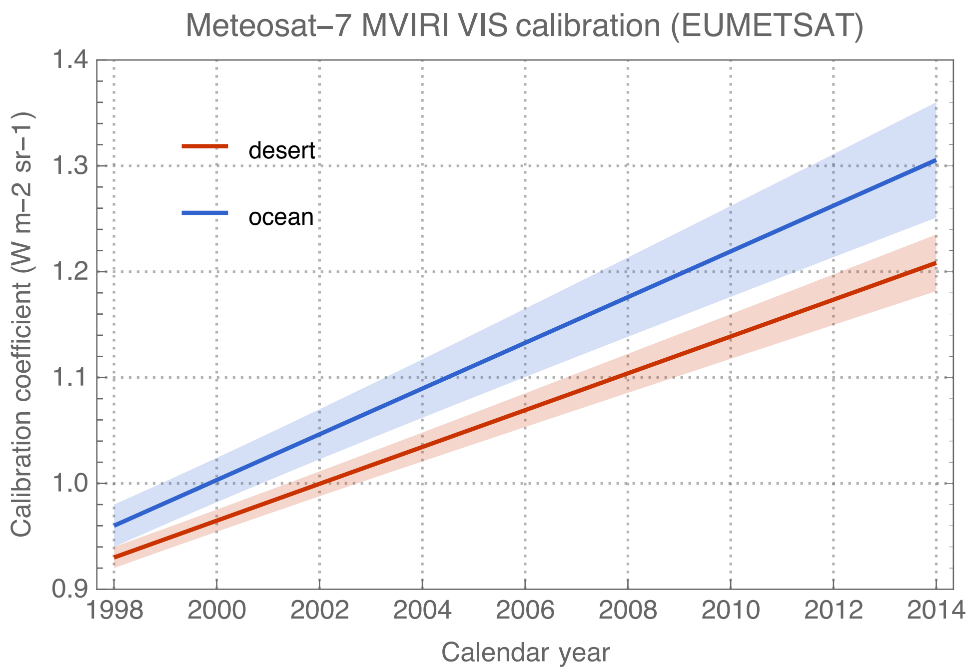
Overview (3/14)

1. What are the fundamental problems and how does vicarious re-characterisation solves them?
2. How do we …?
3. What are our results and how do they improve calibration?

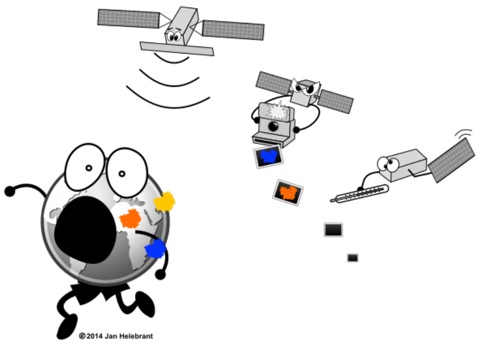
What are the fundamental problems? (4/14)

Past efforts to create CDRs from MFG MVIRI VIS band observations revealed temporal inconsistencies ⇒ **The existing sensor spectral response characterisations are inaccurate**

The calibration coefficients derived from ocean targets increases faster than that derived from desert sites ⇒ **The spectral response of the sensor degrades faster in the blue than in the red**



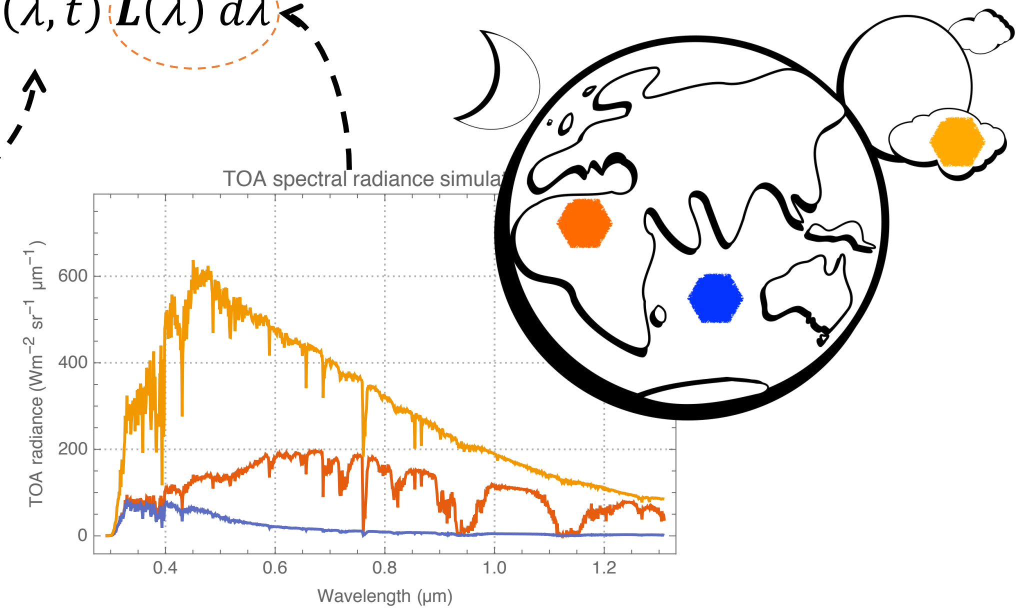
What is vicarious re-characterisation? (5/14)



$$\overline{K}(t) = \int_{\lambda} \zeta(\lambda, t)\, \boldsymbol{L}(\lambda)\, d\lambda$$

Earth counts, space counts, uncertainties, … (EUMETSAT)

Sensor spectral response, uncertainty, covariance, … (FastOpt)



Simulated TOA spectral radiance, uncertainties, … over pseudo-invariant calibration sites (PICS): convective clouds, bright desert and open ocean (Rayference)

FastOpt
Fast Optimisation and Sensitivities

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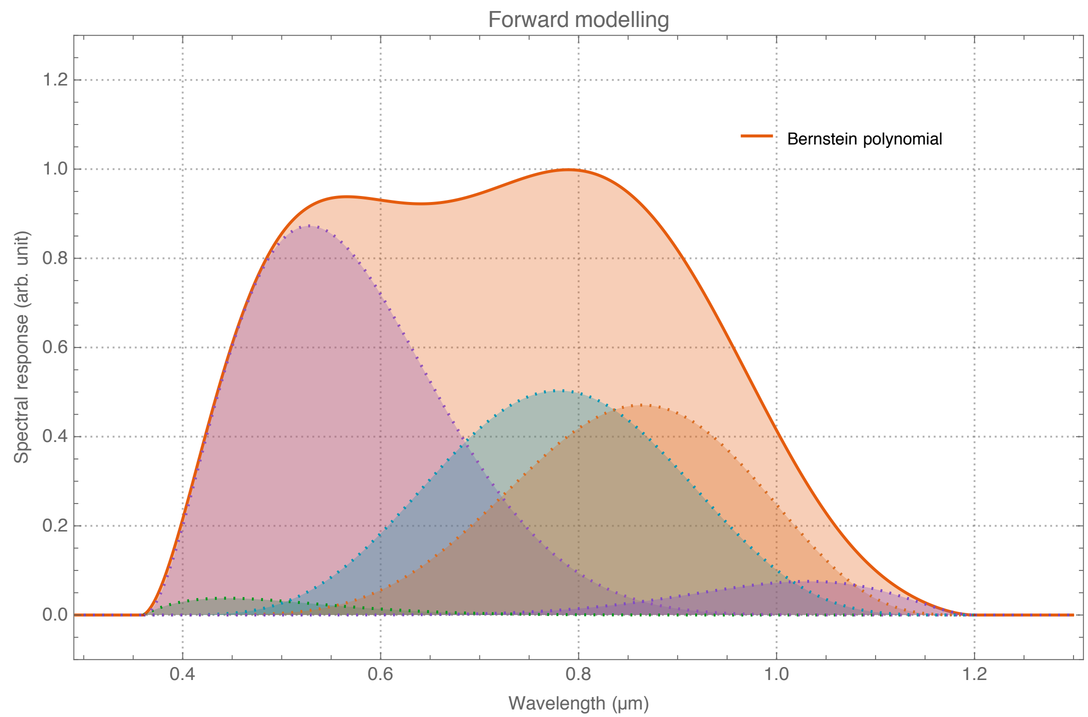
How do we model a spectral response? (6/14)

The (unknown) spectral response is modelled by a **Bernstein polynomial**.



The polynomials vanish at the bounds of the response interval and are positive in-between.

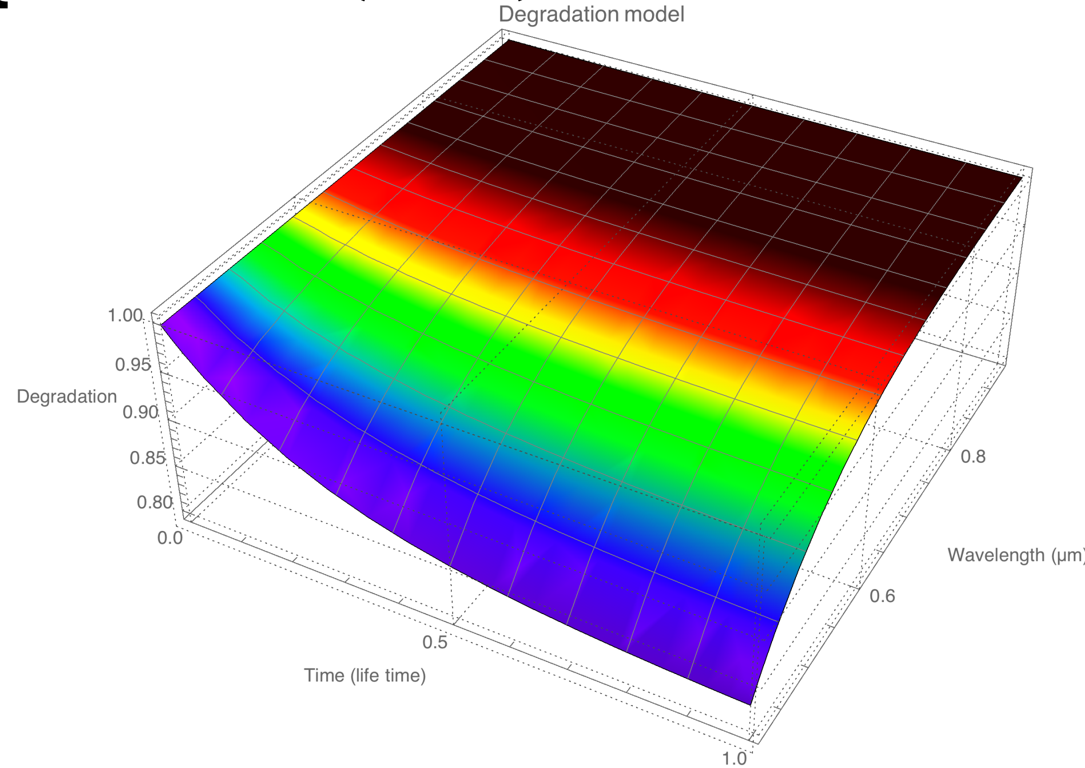
The polynomial is determined by a few linear coefficients.

$$\zeta(\lambda, \boldsymbol{x}) = \sum_{i=1}^{n-1} x_i B_{n,i}^{[x_n, x_{n+1}]}(\lambda)$$

How do we model a degrading spectral response? (7/14)

The **spectral degradation** is modelled by an empirical function of time and wavelength.

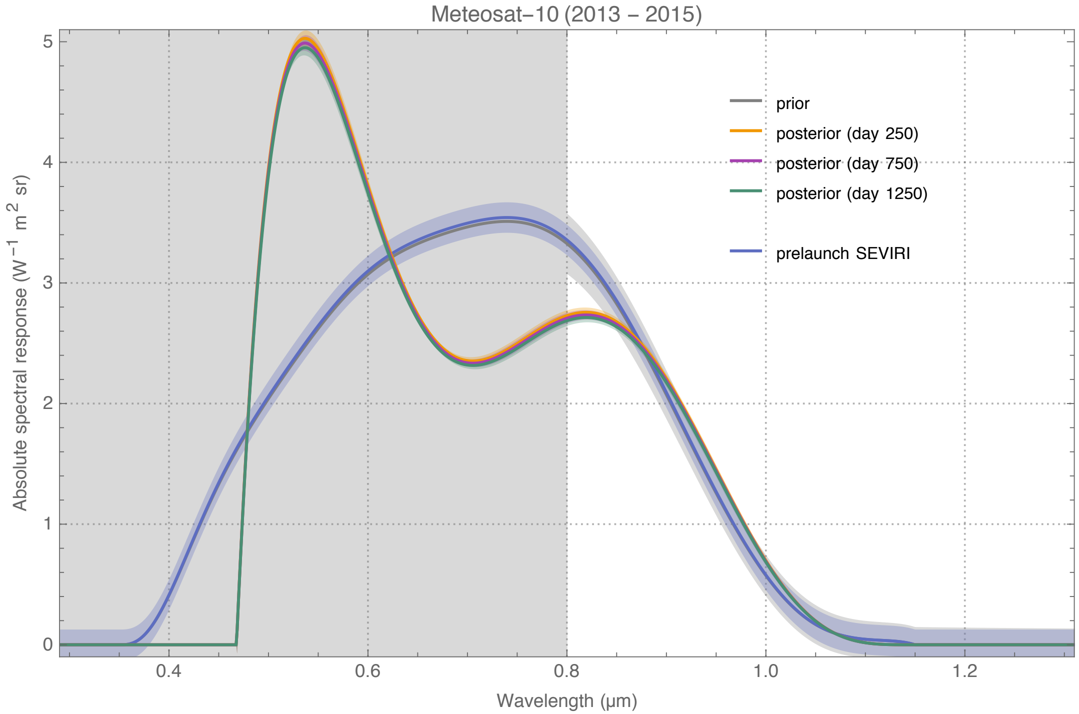
The model is inspired by the measured degradation of MODIS (Aqua) and VIIRS.



$$\zeta(\lambda, t, \boldsymbol{x}) = D(\lambda, t, x_{n+2}, \dots) \sum_{i=1}^{n-1} x_i B_{n,i}^{[x_n, x_{n+1}]}(\lambda)$$

How do we model systematic effects? (8/14)

Even small **mutual biases** between different target types due to systematic radiative transfer simulation or match-up selection effects may distort the retrieved spectral response function dramatically.



$$\zeta(\lambda, t, \boldsymbol{x}) = (1 + x_0)\, D(\lambda, t, x_{n+2}, \dots) \sum_{i=1}^{n-1} x_i B_{n,i}^{[x_n, x_{n+1}]}(\lambda)$$

How do we estimate our model parameters? (9/14)

We use a **Bayesian** approach to inverse problem theory.

$$\boldsymbol{K}(\boldsymbol{t},\boldsymbol{x}) = \int_\lambda \zeta(\lambda,\boldsymbol{t},\boldsymbol{x})\,\boldsymbol{L}(\lambda)\,d\lambda$$

$$2J(\boldsymbol{x}) = (\boldsymbol{K}(\bar{\boldsymbol{t}},\boldsymbol{x}) - \overline{\boldsymbol{K}})^{\mathrm{T}} C_{\boldsymbol{K}}^{-1} (\boldsymbol{K}(\bar{\boldsymbol{t}},\boldsymbol{x}) - \overline{\boldsymbol{K}}) + (\boldsymbol{x} - \overline{\boldsymbol{x}})^{\mathrm{T}} \bar{C}_{\boldsymbol{x}}^{-1} (\boldsymbol{x} - \overline{\boldsymbol{x}})$$

We compute a daily **maximum posterior probability** estimate (mean and error covariance matrix) of the absolute sensor spectral response.

$$\frac{\partial J}{\partial \boldsymbol{x}}(\overline{\overline{\boldsymbol{x}}}) = 0$$

$$\frac{\partial^2 J}{\partial \boldsymbol{x}^2}(\overline{\overline{\boldsymbol{x}}}) = \bar{\bar{C}}_{\boldsymbol{x}}^{-1}$$

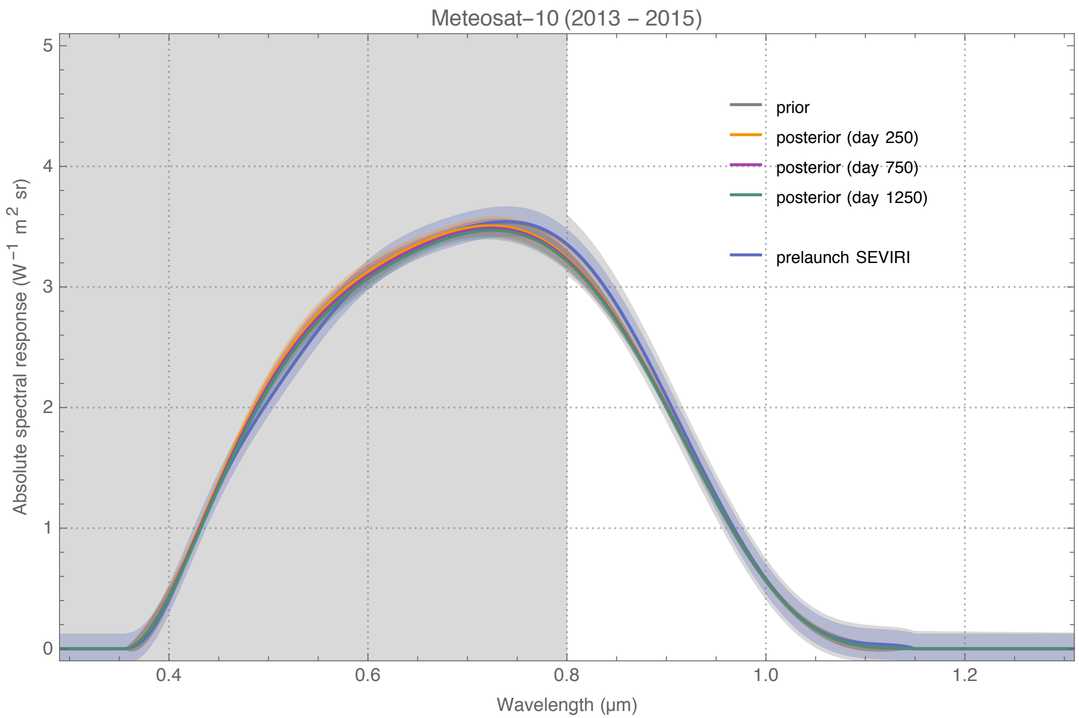
We use advanced **algorithmic differentiation** techniques to compute Jacobian and Hessian matrices.

$$C_\zeta(\lambda,t) = D_{\boldsymbol{x}}\zeta(\lambda,t,\overline{\overline{\boldsymbol{x}}})\;\bar{\bar{C}}_{\boldsymbol{x}}\;D_{\boldsymbol{x}}^{\mathrm{T}}\zeta(\lambda,t,\overline{\overline{\boldsymbol{x}}})$$

How do we validate our method? (10/14)

The method was validated with different realistic scenarios of synthetic data representing different sensor response and ageing behaviours.

Ultimately, the method was applied to real data acquired by the SEVIRI HRVIS band on-board Meteosat-8 and -10 and results were compared to the actual SEVIRI spectral response.

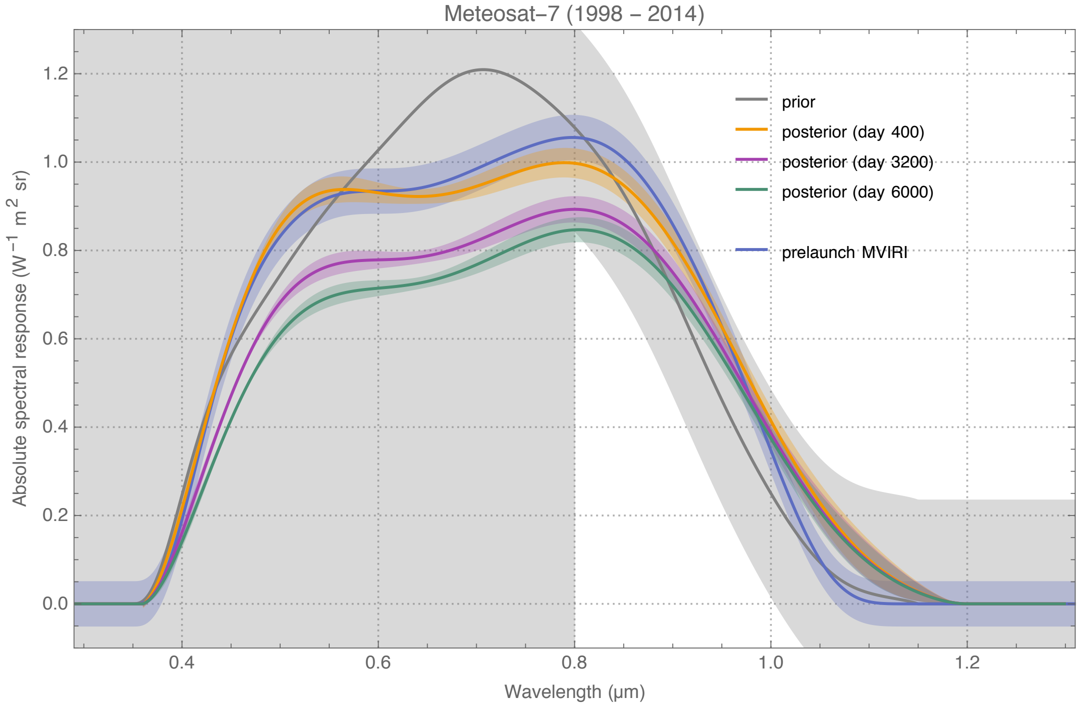


What are our results? (11/14)

The re-characterisation method yields an absolute sensor spectral response function that is very similar to the MVIRI prelaunch characterisation in the blue, but markedly different in the red and beyond.

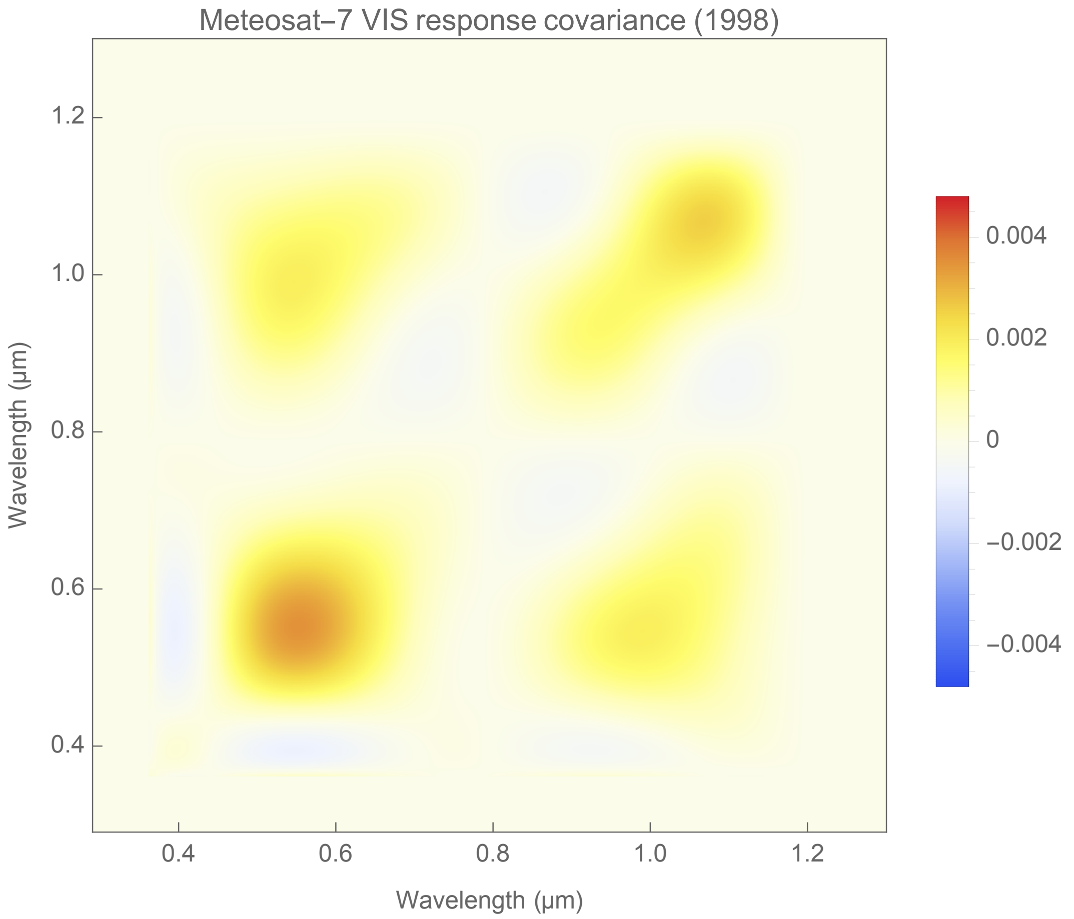
The re-characterised sensor spectral response function degrades stronger in the blue than in the red, and faster at the beginning than later in the end.

Prior information is needed in the NIR to supplement the matchup data.



What are our results? (12/14)

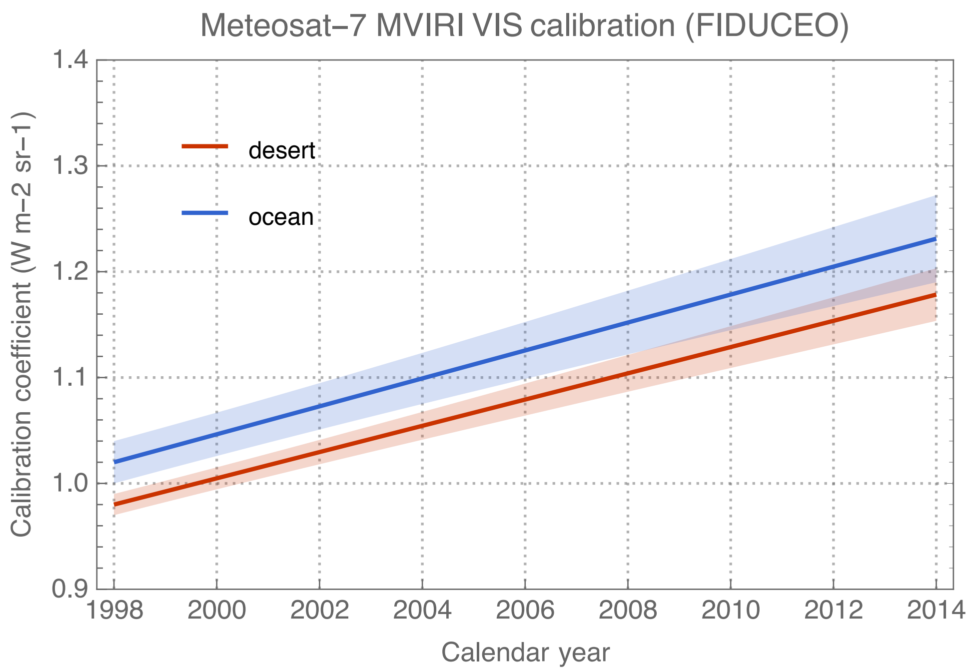
The spectral error covariance of the MVIRI spectral response function is fully characterised.



How do our results improve calibration? (13/14)

When using the (relative) spectral response function obtained from our re-characterisation method, the calibration coefficients derived from ocean targets and desert sites increase at the same rate ⇒

The chromatic sensor degradation is captured correctly



Conclusions

1. We established a novel method for the vicarious re-characterisation (including fully traceable uncertainty estimates) of the MVIRI VIS spectral response.
2. For Meteosat-7 our method captures the chromatic sensor degradation correctly and improves the calibration and its error characterisation significantly.

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