Extended Optimal Estimation Techniques for SST retrieval

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Extended optimal estimation techniques for sea surface temperature from the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI)

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ABSTRACT

Sea surface temperature (SST) can be estimated from day and night observations of the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) by optimal estimation (OE). We show that exploiting the 8.7 μm channel, in addition to the "traditional" wavelengths of 10.8 and 12.0 μm, improves OE SST retrieval statistics in validation. However, the main benefit is an improvement in the sensitivity of the SST estimate to variability in true SST.

In a fair, single-pixel comparison, the 3-channel OE gives better results than the SST estimation technique presently operational within the Ocean and Sea Ice Satellite Application Facility. This operational technique is to use SST retrieval coefficients, followed by a bias-correction step informed by radiative transfer simulation. However, the operational technique has an additional "atmospheric correction smoothing", which improves its noise performance, and hitherto had no analogue within the OE framework. Here, we propose an analogue to atmospheric correction smoothing, based on the expectation that atmospheric total column water vapour has a longer spatial correlation length scale than SST features. The approach extends the obser-

Point of comparison: NLSST

- "Non linear sea surface temperature"

$$\hat{x} = (a + bS)y_{11\mu m} + (c + dS + ex_c)\left(y_{11\mu m} - y_{12\mu m}\right) + f + gS$$
$$S = \sec\theta - 1$$

- Noise in SST

$$\varepsilon\sqrt{(a + bS + c + dS + ex_c)^2 + (c + dS + ex_c)^2}$$

- Sensitivity to true SST

$$\frac{\partial \hat{x}}{\partial x} = (a + bS)\frac{\partial y_{11um}}{\partial x} + (c + dS + ex_c)\left(\frac{\partial y_{11um}}{\partial x} - \frac{\partial y_{12um}}{\partial x}\right)$$

Point of comparison: simulated bias correction

- Le Borgne et al. (2011) extension to NLSST
- "NL2011"

Uncorr SST = NLSST($\mathbf{y}$)

Sim bias correction = NLSST($\mathbf{y}_{sim}$) – SST_{sim}

Corr SST = NLSST($\mathbf{y}$) – (NLSST($\mathbf{y}_{sim}$) – SST_{sim})

= SST_{sim} + NLSST($\mathbf{y} - \mathbf{y}_{sim}$)

Equivalent to Petrenko et al. (2011), Incremental Regression, to within an offset

- Sensitivity is also unchanged by simulated bias correction

Point of comparison: atmospheric correction smoothing

- Atmospheric state assumed to vary less in space than pixel resolution
- So "atmospheric correction" term may be averaged over a wider area to reduce noise

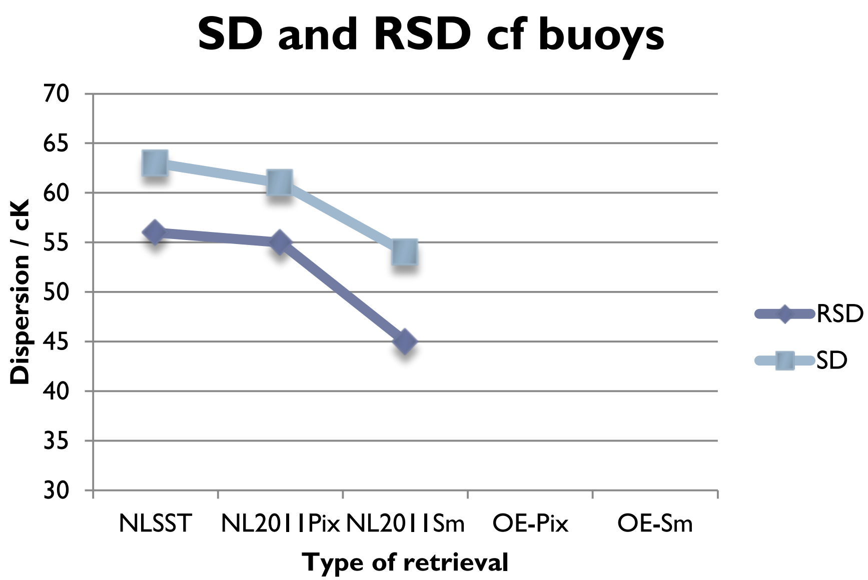
$$\hat{x} = (a + bS)y_{11\mu m} + (c + dS + ex_c)\left(\overline{y_{11\mu m}} - \overline{y_{12um}}\right) + f + gS$$

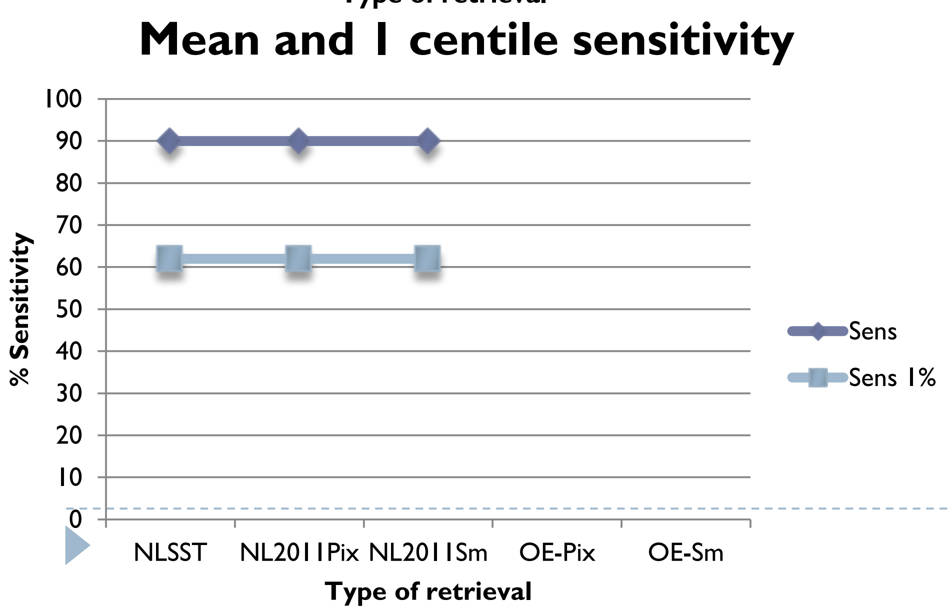
- So NLSST noise reduces to

$$\varepsilon\sqrt{(a + bS)^2 + \frac{2}{n}(c + dS + ex_c)^2}$$

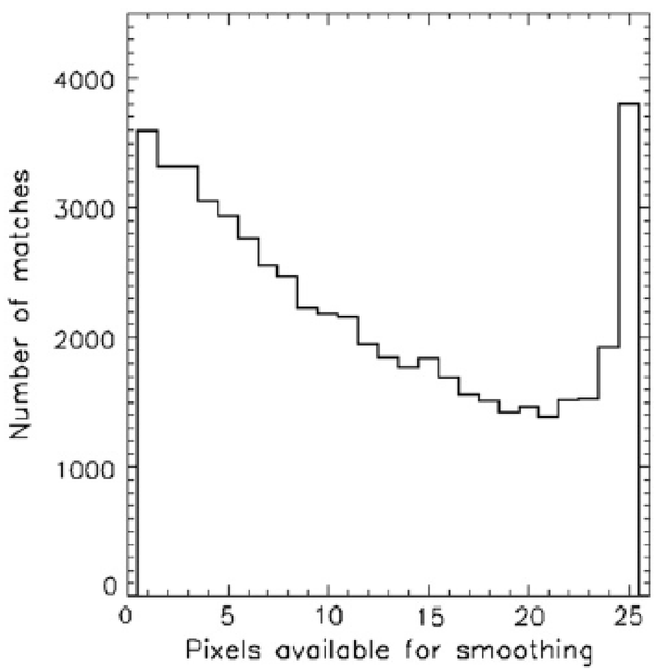
- The SST sensitivity is not systematically changed/improved

Results for dispersion and sensitivity





Over 54000 SEVIRI-buoy matches in CMS MD



Optimal estimation

- OE SST = SST_{sim} + GAIN($\mathbf{y}$ – $\mathbf{y}_{sim}$)

- Looks a bit like Inc Regression

- But GAIN is a matrix calculated dynamically using a forward model **F** and its derivative **K** = δ**F**/δ**x**

$$\mathbf{x}_a + \left(\mathbf{K}^{\mathrm{T}}\mathbf{S}_{\varepsilon}{}^{-1}\mathbf{K} + \mathbf{S}_a{}^{-1}\right)^{-1}\mathbf{K}^{\mathrm{T}}\mathbf{S}_{\varepsilon}{}^{-1}\left(\mathbf{y}_o - \mathbf{F}(\mathbf{x}_a)\right)$$

- We can obtain different properties by choosing different $\boldsymbol{S}_a$

Optimal estimation

$$\mathbf{x}_a + \left(\mathbf{K}^T \mathbf{S}_\varepsilon^{-1} \mathbf{K} + \mathbf{S}_a^{-1}\right)^{-1} \mathbf{K}^T \mathbf{S}_\varepsilon^{-1} \left(\mathbf{y}_o - \mathbf{F}(\mathbf{x}_a)\right)$$

- Choose $\boldsymbol{S}_a$ to match the error covariance of prior information
  - Maximum a posteriori probability (MAP) solution
  - Usually regarded as the "optimum" solution
  - Minimizes the error variance of the solution
  - But solution is a balance between prior and observations
  - If prior is biased, some of this bias remains
  - Sensitivity to true SST not equal to 1 (dependency on prior)

Optimal estimation

$$\mathbf{x}_a + \left(\mathbf{K}^{\mathrm{T}}\mathbf{S}_\varepsilon{}^{-1}\mathbf{K} + \mathbf{S}_a{}^{-1}\right)^{-1}\mathbf{K}^{\mathrm{T}}\mathbf{S}_\varepsilon{}^{-1}(\mathbf{y}_o - \mathbf{F}(\mathbf{x}_a))$$

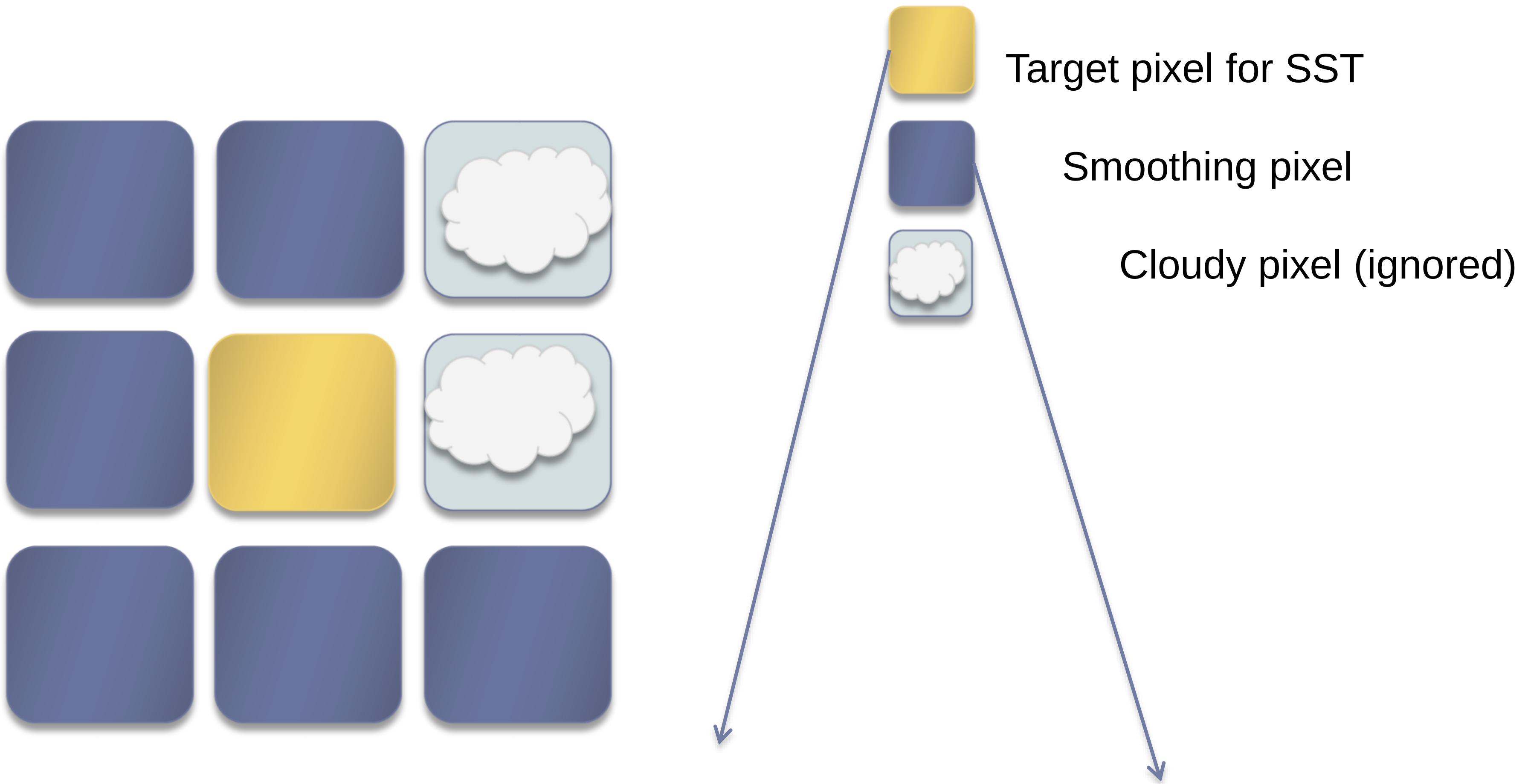
- Choose $\boldsymbol{S}_a$ to be infinity
  - Maximum likelihood (ML) solution
  - Prior effectively doubles as a linearization point
  - Solution is insensitive to prior (if within valid linear range)
  - Sensitivity to true SST = 1 (no dependency on prior)
  - Only a good solution if there is enough information in obs

- In practice, for SST, can choose $\boldsymbol{S}_a$ to be large wrt SST

Introducing atmospheric correction smoothing to OE

- OE formulation we have discussed so far retrieves SST and TCWV for a given pixel
- To take advantage of smoothly varying TCWV, retrieve the mean TCWV across the clear pixels in a box centred on the pixel
- Same box etc as previously shown for atmospheric correction smoothing of NLSST algorithms

Observations used for smooth-atmosphere OE



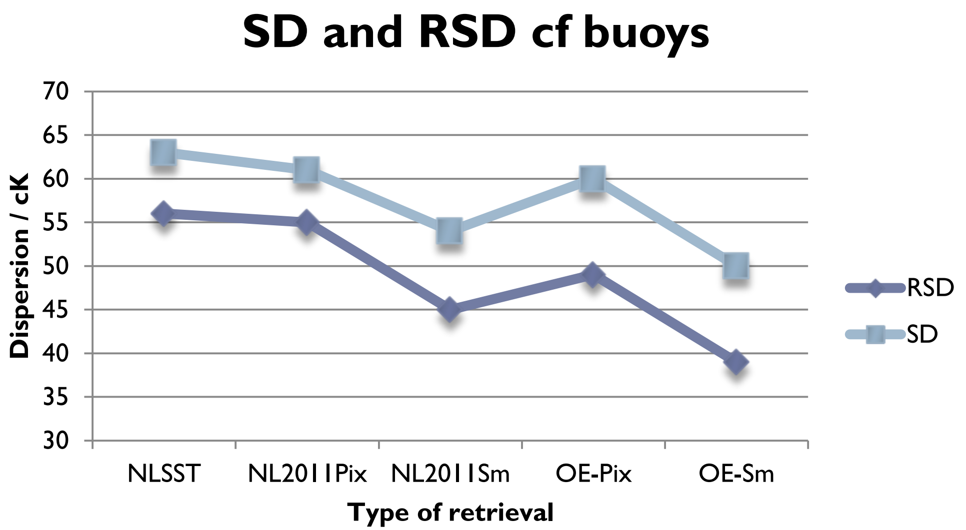
$$\mathbf{y}^{\mathrm{T}} = \left[y_{8.7\mu m},\ y_{11\mu m},\ y_{12\mu m},\ \overline{y_{8.7\mu m}},\ \overline{y_{11\mu m}},\ \overline{y_{12\mu m}} \right]$$

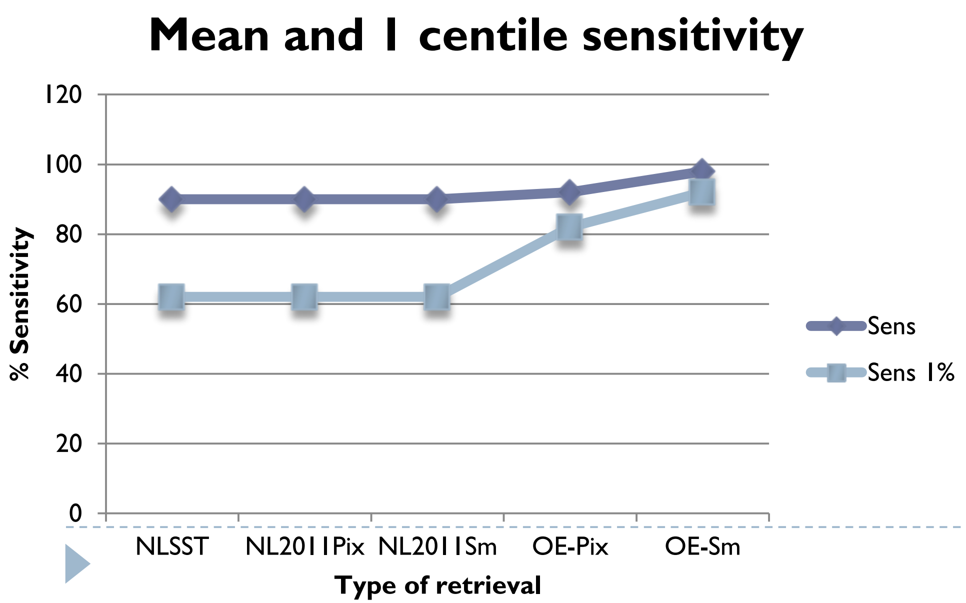
Dependence of observations on target pixel SST and box TCWV

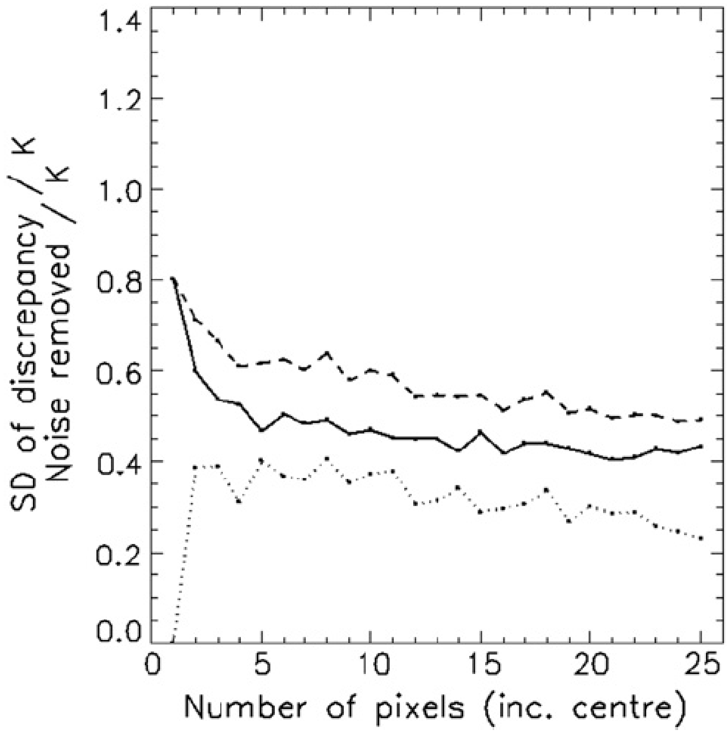
$$
\mathbf{K}^{\mathrm{T}} = \begin{bmatrix}
\frac{\partial y_{8.7\mu m}}{\partial x} & \frac{\partial y_{11\mu m}}{\partial x} & \frac{\partial y_{12\mu m}}{\partial x} & 0 & 0 & 0 \\
\frac{\partial y_{8.7\mu m}}{\partial \overline{w}} & \frac{\partial y_{11\mu m}}{\partial \overline{w}} & \frac{\partial y_{12\mu m}}{\partial \overline{w}} & \frac{\partial \overline{y_{8.7\mu m}}}{\partial \overline{w}} & \frac{\partial \overline{y_{11\mu m}}}{\partial \overline{w}} & \frac{\partial \overline{y_{12\mu m}}}{\partial \overline{w}}
\end{bmatrix}
$$

$$
\mathbf{S}_{\varepsilon} = \begin{bmatrix}
\varepsilon_{8.7\mu m}^{2} + \varepsilon_{RT}^{2} & 0 & 0 & 0 & 0 & 0 \\
0 & \varepsilon_{11\mu m}^{2} + \varepsilon_{RT}^{2} & 0 & 0 & 0 & 0 \\
0 & 0 & \varepsilon_{12\mu m}^{2} + \varepsilon_{RT}^{2} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{\varepsilon_{8.7\mu m}^{2}}{n} + \varepsilon_{RT}^{2} & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{\varepsilon_{11\mu m}^{2}}{n} + \varepsilon_{RT}^{2} & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{\varepsilon_{12\mu m}^{2}}{n} + \varepsilon_{RT}^{2}
\end{bmatrix}
$$

Results for dispersion and sensitivity







OE smoothing removes more noise than trad. atm. corr. smoothing, while increasing sensitivity

Conclusions & future work

- By adding surrounding observations to observation vector, can extend OE to reduce noise
- Assumption is that TCWV in target pixel equals the mean of the TCWV in the clear pixels surrounding
- Result is a reduction in noise with increase in sensitivity
- This algorithm will be used for MSG SEVIRI reprocessing

- Need to apply to dual view AATSR / SLSTR
- Haven't investigated optimum box size for TCWV average
- Need to extend to deal better with aerosol