Pixel-level uncertainties in aerosol remote sensing: techniques and their applicability

Andrew Sayer, GESTAR-USRA/NASA GSFC
andrew.sayer@nasa.gov

with input from a whole bunch of you

- Definitions: uncertainty, diagnostic vs. prognostic uncertainty estimates
- Three examples of techniques
- Where are we now?
- Questions for group discussion

- Definitions: uncertainty, diagnostic vs. prognostic uncertainty estimates
- Three examples of techniques
- Where are we now?
- Questions for group discussion

Uncertainty

- Error = (retrieval – truth)
  - But note that we don't know the truth everywhere (anywhere?)
- Uncertainty: distribution of errors
  - How confident am I (quantitatively) in what I am reporting?
  - I suggest the most useful metric for many applications is to provide a one-standard-deviation confidence interval

Prognostic estimate

Image courtesy pixabay.com

- I think that cow weighs 3,000 kg.
- Given that, how much does it weigh?

$$\Delta AOD = f(retrieved\ state)$$

Diagnostic estimate

Image courtesy pixabay.com

- That cow weighs 3,000 kg.
- Given that, how much do I think it weighs?

$$\Delta AOD = \pm(a + b \times AOD_{AERONET})$$

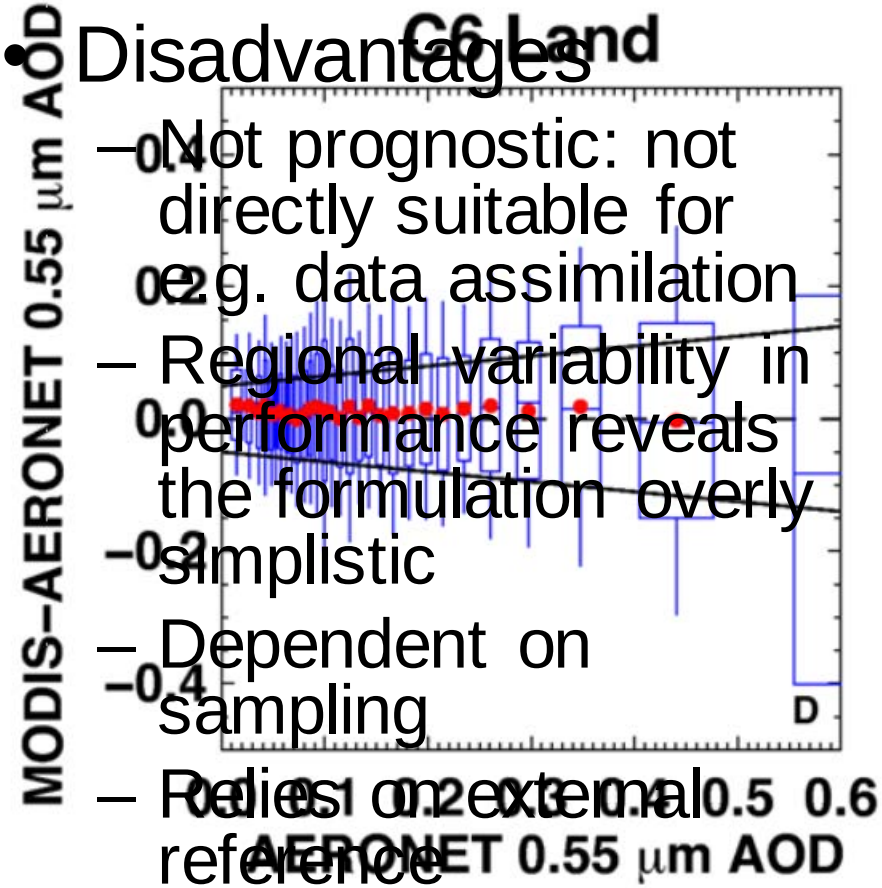
- Definitions: uncertainty, diagnostic vs. prognostic uncertainty estimates
- Three examples of techniques
- Where are we now?
- Questions for group discussion

Diagnostic: MODIS Dark Target

$$\Delta AOD = \pm(0.05 + 0.15 \times AOD_{AERONET})$$

- Advantages
  - Easy to communicate and understand
  - Easy to assess compliance via AERONET comparison

- Disadvantages
  - Not prognostic: not directly suitable for e.g. data assimilation
  - Regional variability in performance reveals the formulation overly simplistic
  - Dependent on sampling
  - Relies on external reference



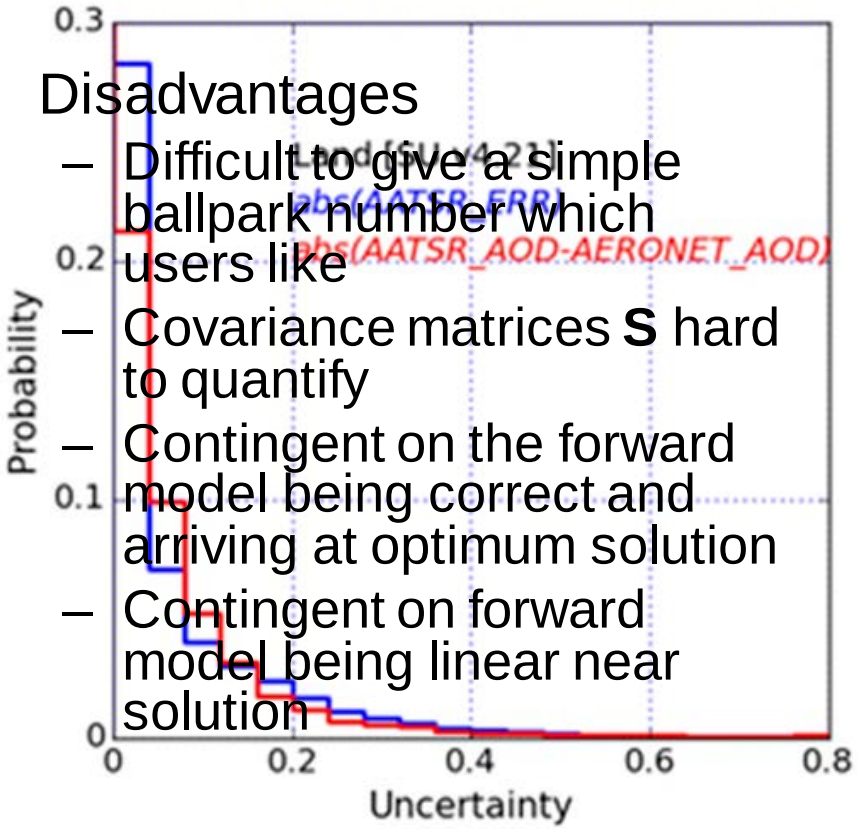
Levy *et al.*, AMT (2013)

Prognostic: Optimal Estimation

$$\hat{\mathbf{S}} = \left(\hat{\mathbf{K}}^T \mathbf{S}_\epsilon^{-1} \hat{\mathbf{K}} + \mathbf{S}_a^{-1} \right)^{-1}$$

- Advantages
  - A true dynamic pixel-level uncertainty estimate
  - Uncertainties can be validated by comparing to actual error distributions
  - You can provide an uncertainty estimate even when you don't have a validation data set

- Disadvantages
  - Difficult to give a simple ballpark number which users like
  - Covariance matrices **S** hard to quantify
  - Contingent on the forward model being correct and arriving at optimum solution
  - Contingent on forward model being linear near solution



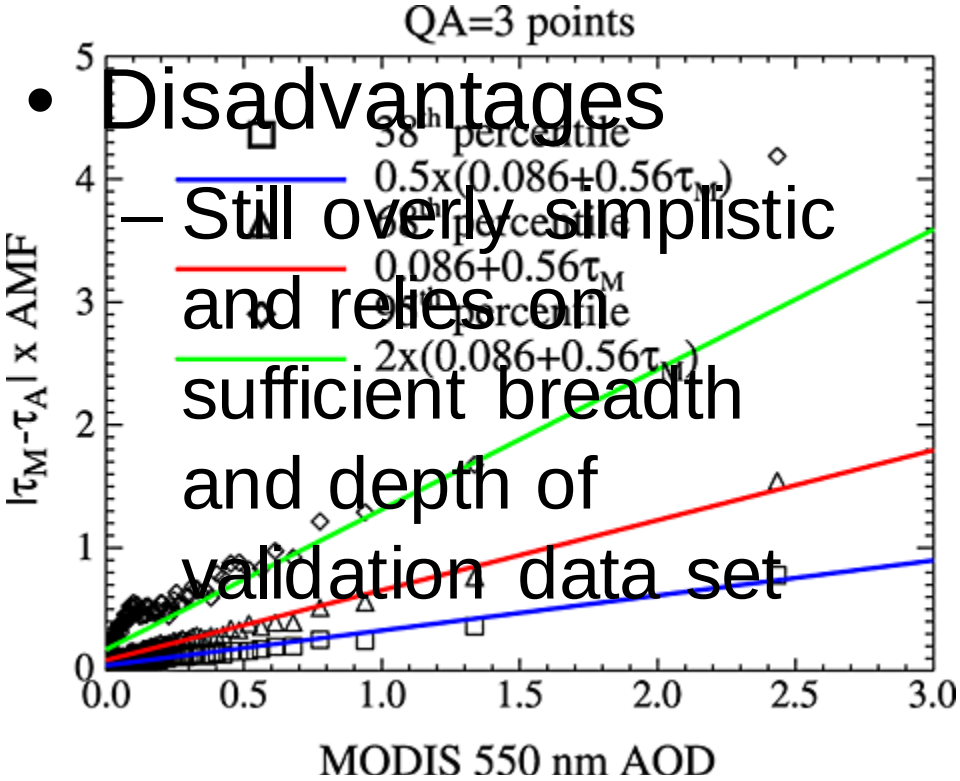
Popp *et al.*, Remote Sensing (2016)

Prognostic: MODIS Deep Blue

$$\Delta AOD = \pm \frac{(a + b \times AOD_{MODIS})}{\frac{1}{\mu_0} + \frac{1}{\mu}}$$

- Advantages
  - (Fairly) easy to communicate and understand
  - More specific and useful than diagnostic approaches
  - Coefficients e.g. *a*, *b* can be computed using validation data

- Disadvantages
  - Still overly simplistic and relies on sufficient breadth and depth of validation data set



Sayer *et al.*, JGR (2013)

- Definitions: uncertainty, diagnostic vs. prognostic uncertainty estimates
- Three examples of techniques
- Where are we now?
- Questions for group discussion

Proposed paper outline

- Definition of terms
  - Uncertainty, error, prognostic, diagnostic
  - Also link in with what other disciplines are doing
- Some specific examples
  - Tables/lists (see following slides) with references
  - I'm not interested in what your uncertainty estimate is, so much as how you come up with it
- Validating uncertainties
  - Examples from CCI work, perhaps include some new analysis as well?
- Recommendations and path forward
- Who's interested, what target journal, how to finance publication charges?

Who's doing prognostic uncertainty estimates?

Formal error propagation	Other error propagation	Empirical
ATSR (ORAC , FMI)	ATSR Swansea	MODIS Deep Blue
GRASP (POLDER, etc)	IASI (IMARS, LMD, UMB)	MISR dark-water (V23 onwards)
CALIPSO		MISR research algorithm (in development)
CATS		
GOMOS		
MODIS above-cloud (cloud team)		
MODIS above-cloud (Deep Blue)		

Note: AERONET version 3 inversion products will also fall within here

Who's doing (solely) diagnostic uncertainty estimates?

- MODIS Dark Target land
- MODIS Dark Target ocean
- SOAR (AVHRR/SeaWiFS/VIIRS ocean)
- Deep Blue (AVHRR, SeaWiFS)
- MISR (up to V22)
- OMI OMAERUV (full-column and above-cloud)
- MAIAC MODIS
- Bremen Aerosol Retrieval (BAER MERIS/SeaWiFS)
- NOAA, GACP AVHRR

Who do I not know about?

- OMI OMAERO
- Stratospheric data products
- Unknown unknowns???

- Definitions: uncertainty, diagnostic vs. prognostic uncertainty estimates
- Three examples of techniques
- Where are we now?
- Towards some recommendations
- Questions for group discussion

- Do we all mean the same thing when we talk about our data set's uncertainty estimates?
  - If not, can we settle on a common metric, e.g. 1-σ confidence interval?
- What's the right balance between specificity and user ease-of-understanding for uncertainty estimates?
- Should/how can those doing diagnostic uncertainty estimates change to also provide pixel-level prognostic uncertainty estimates?
- When assessing products, should we use some common metric for more valid intercomparison of different data sets?
  - e.g. 'GCOS compliance fraction'?
- Can we increase emphasis on, and standardise, validating uncertainty estimates?
- We tend to assume uncertainties can be represented as Gaussian envelopes; what about extreme outliers?
- When do uncertainties in ground truth data become non-negligible for our validation, and how do we best account for them?
  - AERONET radiometric uncertainties
  - Sampling differences
- How do we quantify and validate uncertainties in AE, SSA, fine fraction, etc?
  - These often can't be *validated*, only *compared*, due to lack of ground truth
- How do we propagate uncertainties from level 2 to level 3?