Pixel level uncertainties

Overview + introduction

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The concept of pixel-level uncertainties

- Sensitivity to AOD varies largely with pixel conditions
  - AOD
  - Aerosol properties, surface brightness / bi-directionality
  - Geometry, cloud situation, …

Example nadir radiometer: Dominant uncertainty terms
bias corrected as much as we can do – random STD uncertainty

\[
\sigma_{AOD} = \sqrt{\left(\frac{\partial AOD}{\partial R_{TOA}} \sigma_{R_{TOA}}\right)^2 + \left(\frac{\partial AOD}{\partial Alb_{surf}} \sigma_{Alb_{surf}}\right)^2 + \left(\sigma_{ensemble}^{AOD}\right)^2 + \sigma^2(0)}
\]
Uncertainties and validation

Ex posteriori validation and pixel-level uncertainty prediction need to be consistent

Validation to reference data stratified for different conditions

Prediction of pixel-level uncertainties by error propagation

Validation of predicted uncertainties to reference data

Document untreated / unvalidated uncertainties quality flags / quality statements (e.g. near clouds)
Who needs pixel-level uncertainties?

Data assimilation
- No assimilation
- MODIS assimilation with fixed uncertainties
- AATSR assimilation with pixel-level uncertainties

Consistent data integration
- ATE_4, total
- ATS_4, total
- ATF_4, total
- ATO_4, total
Components of Level 2 Error Model
(requires lots of data to pull out)

- Can be as simple as RMSE as a function of AOD
  - AOD can be from AERONET (diagnostic) or own AOD (prognostic).
  - But, RMSE is symmetric nor does it address massive outliers which are often the problem

- Terms include:
  - Differential Signal to Noise: Lower boundary minus total, including view angle/optical path length.
  - Lower Boundary Condition:
    - Ocean: Wind/glint/whitecap, class 2 waters, sea ice
    - Land: Surface reflectance model, snow, view angle/BRDF/hotspot
  - Cloud mask
  - Microphysical: Fine coarse/partition, P(θ)/g, ω₀, AOD

- Biases are often folded into “random” error models. If they are known, why not correct for them?

- Radiance Calibration: Individual wavelengths propagate non-linear through retrievals and are not easy to incorporate.

- Verification of errors is also needed
New MISR V23 dark water uncertainties
see poster by M. Witek / JPL

- MISR’s aerosol retrieval algorithm calculates cost functions ($\chi^2_{abs}$) between observed and pre-simulated radiances for a range of AODs and a prescribed set of aerosol mixtures (74).
- The new approach in dark water retrievals considers the entire range of $\chi^2_{abs}$ for all mixtures and does not impose thresholds on $\chi^2_{abs}$ to determine the success or failure of a particular mixture.
- The uncertainty depends on the combination of:
  a) absolute values of $\chi^2_{abs}$ for each aerosol mixture,
  b) widths of $\chi^2_{abs}$ distributions,
  c) spread of $\chi^2_{abs}$ distributions among the ensemble of mixtures.

\[
\chi^2_{abs}(\tau) = \sum_{j=1}^{4} w_j \left[ \sum_{l=1}^{9} v(l, j) \frac{\rho_{\text{MISR}}(l, j) - \rho_{m}(l, j)}{\sigma^2_{\text{abs}}(l, j)} \right]^2
\]

\[
f(\tau) = \text{mean} \left( \frac{1}{\chi^2_{abs,m}(\tau)} \right)
\]

\[
\text{V22}: \tau = 0.174 \pm 0.003 \quad \text{V23}: \tau = 0.182 \pm 0.049
\]
MISR uncertainty evaluation

Uncertainty generally increases with the difference between MISR and Aeronet AOD (based on ~1300 collocations)

Retrieved uncertainty has characteristics similar to the standard deviation of the normal distribution: the 3-sigma rule (68-95-99.7) is followed closely.

Legend explanation:
• “Nearest retrieval” - MISR retrieval closest to the Aeronet location
• “Average retrievals (r<17.6 km)” - all MISR retrievals that are within 17.6 radius from the Aeronet location
MODIS Dark Target Retrievals in Cloud Vicinity

Varnai et al., 2015

Enhanced AOD near clouds

- MODIS has:
  1. Observations at 500 m
  2. Distance of every 500m pixel from a cloud

- To estimate cloud effect, retrievals were done as a function of distance to cloud

  1) \( \tau_0 \) : All pixels used in C6
  2) \( \tau_{20} \) : pixels with cloud pixel distance > 20 (1 km away from clouds)

Hypothesis:

If C6 AOD is elevated due to clouds then \( \tau_{20} - \tau_0 = \text{Negative} \)
Histograms of 865 nm reflectance pixels with good and bad AOD retrievals, shows that

- Reflectance histogram of **Clear-sky pixels** is **Gaussian**
- Reflectance histogram of **Cloudy region pixels** are **skewed**
- Filter cut-off will govern high / low bias in AOD

Per-pixel reflectance histograms suggests retrieval possibility using median reflectance values (work in progress)

\[ \Delta = \frac{AOD_{\text{ATSR}} - AOD_{\text{AERONET}}}{\sigma_{\text{ATSR}}} \]

-> talk K. Stebel
Questions

→ Can we achieve consistency validation <-> error propagation?

→ How can we treat non-Gaussian distributions?

→ How best validate pixel-level uncertainties?

→ How to treat propagation from lv2 to lv3 (correlations)?

→ How can we provide uncertainties for derived properties?

→ Goals / deliverables until AEROSAT 2018
  ➤ Overview / recommendation paper (-> talk A. Sayer)
Use of uncertainties in models

- Matching satellite – model on daily / hourly + colocation step needed (Schuttgens)
- Large uncertainties in monthly means due to sampling
- Satellite sampling in 1 degree box can provide histograms
- More validation data as reference needed
- How separate systematic and random uncertainties

Good discussion of basic principles

Use of linear regression and alternatives

- Uncertainties of metrics need to be considered
- Independent (trend) analysis need to be consistent
- Obvious analysis create higher confidence than those highly tuned

Uncertainties on different scales

- Be aware of limitations in error propagation and in validating propagated uncertainties

> conclusion: review / synthesis paper on characterizing uncertainties