Sensitivity analyses

Input variability
TOA radiance, VNIR/SWIR

Plot below shows relationship between at sensor radiance and view angle (lambertian surface at bottom of atmosphere)
TOA radiance, VNIR/SWIR

Plot below shows quantitatively the relationship between optical thickness and at-sensor radiance.
Sensitivity analysis

A sensitivity analysis in its basic form is to vary one parameter that is part of a problem while keeping all others constant.

- The results then show the sensitivity of the results to that single parameter.
- Extremely useful for finding the strong and weak links in the image chain.
- Also useful for determining where it is best to put one’s efforts.
- For example, consider Beer’s Law in logarithmic form:

\[
\ln(E) = \ln(E_0) - m\delta
\]

- Differentiating by parts gives:

\[
\frac{\Delta E}{E} = \frac{\Delta E_0}{E_0} - m\Delta \delta - \delta \Delta m \quad \rightarrow \quad \frac{\Delta \delta}{\delta} = 0.01 = \left( \frac{\Delta E_0}{m \delta E_0} - \frac{\Delta E}{m \delta E} - \frac{\Delta m}{m} \right)
\]

- If the desire is to know the optical depth to better than 1%, then we must know airmass to better than 1% (time to better than a few seconds early in the day).
- Incident irradiance and the measurement must be known to better accuracy at low optical depths.
In the case of radiative transfer in the atmosphere, it is difficult to assess theoretically the sensitivity. Rely instead on the brute force approach.

Here are results of over thirty runs of a radiative transfer code to examine sensitivity to optical depth:

- Wavelength = 835 nm
- Result here shows percent change in at-sensor radiance due to a change in aerosol optical depth of 0.02

- Effect is larger at larger optical depths
- Effect is larger at larger view angles
Some sensors will view a test site at large off-nadir angles

- Uncertainties larger due to longer atmospheric path
  - More sensitivity to atmospheric uncertainties
  - Phase functions are different
  - Larger impact from surface/ground interaction
- Surface BRDF plays a bigger role
  - Direct solar term
  - BRDF of the ground interacting with the atmosphere
- Radiative transfer code can be used to evaluate this through a sensitivity study
Sensitivity study example

- Two wavelengths were used - 479 and 835 nm
  - Molecular optical depth at 479 - 0.160
  - Molecular optical depth at 835 - 0.0168
- Aerosol models used the index of refraction for both wavelengths were
  - Desert(1.53, 0.008)(1.53, 0.012)
  - Clean maritime(1.44, 0.000)(1.39, 0.000)
  - Clean continental(1.53, 0.005)(1.52, 0.010)
  - Average continental(1.54, 0.032)(1.53, 0.035)
  - Urban(1.62, 0.188)(1.61, 0.182)
- Each model assumed to follow a Junge Power Law to simplify the study (values -2.5, 2.75, 3.0, 3.25, 3.5)
- Examined view angles of 45, 55, 65, and 75 degrees from nadir
- Relative azimuth angle between sun & sensor are 0, 90, and 180 degrees
- Solar zenith angles of 20, 50, and 70 degrees
- Surface reflectance was varied from 0.1 to 0.7 at 0.1 intervals
  - Lambertian
  - Non-lambertian model based on Hapke
Effects due to scattering optical depth

- Above results show percent change in at-sensor radiance due to a change in aerosol optical depth of 0.02
- Wavelength is 835 nm giving much greater dependence upon aerosol scattering relative to molecular
- Sensitivity to aerosol optical depth uncertainty is strongly dependent on aerosol type
- View angle effect is as expected, but surprisingly small for aerosols with low absorption properties
Size distribution effects

- % Differences are for a change in Junge parameter of 0.25
- 835 nm case with aerosol optical depth of 0.08
- Results shown above are similar to those obtained for the near-nadir case
  - Somewhat larger sensitivity to change in size distribution
  - Effect larger in general for smaller particles (large Junge parameter)
  - Minimal effect with change in reflectance
% Differences are for a change in Junge parameter of 0.25

- Desert model with surface reflectance of 0.3 and wavelength of 835 nm

Results show

- Higher sensitivity to size distribution at larger solar zenith angles, especially greater than 50 degrees
- Larger effect at larger optical depths
- Higher sensitivity at larger view angles
- Uncertainties due to assuming a lambertian surface are larger at higher reflectance and larger scattering optical depths
- Uncertainties are greater than 2% for the high sun case and low aerosol loading
  - Get larger errors for larger solar zenith angles
  - 2% uncertainty is already large enough to require accounting for this effect
  - Much larger effect than for the near-nadir case
- Still need to examine the accuracy requirements on the BRDF
An important result is that there are conditions for which the uncertainty in predicted radiance is relatively insensitive to atmospheric uncertainty:

- Low optical depth cases with solar zenith angles less than 50 degrees
- Larger particles (small Junge parameter) for small solar zenith angles
- Low absorption aerosols (desertic, clean continental, clean maritime)
- For absorbing aerosols, lower reflectance surfaces have less sensitivity to changes in atmospheric conditions

In all cases, it is important to know the surface bi-directional reflectance properties if the goal is the same 3-5% uncertainty of the near-nadir case:

- Need to account correctly for the surface-atmosphere interaction
- Need to know the reflectance of the surface for the direct-reflected direction to better than 2%
View angle conclusions

Can use the results to determine another set of requirements for test sites

- Based on these results, a good site for off-nadir calibration requires
  - “Clean” aerosols with larger sizes
  - High reflectance
  - Near-lambertian BRDF
  - Low-latitude or summer campaigns to ensure small solar zenith angle
- Fortunately, these are similar requirements needed for the near-nadir case, thus the same sites are suitable