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Wideband correlated-k distributions: a pseudo-monochromatic approach

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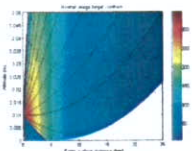
Contents

The Problem

- We need to characterize a 2D plane or 3D space
- Line of sight transmission models typically give propagation results at a single coordinate (1D)
  - Run the model at every point on a tight grid
    - Slow!
  - Run the model on a coarser grid and interpolate
    - Inaccurate: Beer's Law

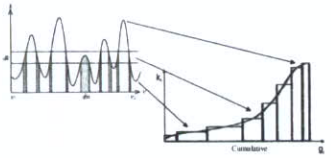


Requirements

- Accuracy
  - Radiance results within 5% of full MODTRAN 4 calculations
  - Capable of multiple scattering
  - No need for spectral information (wideband)
- Speed
  - At least 100 lines of sight per second (excluding initialization)
  - No major slowdown in 2 stream MS

A correlated-k refresher

- Transformation to Correlated-K space



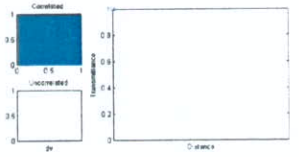
- Monotonic function need much fewer points to be represented accurately

$$T = \sum_i \exp\left(-k_i(g)\cdot s\right)\Delta g_i$$

Wideband correlated-ks

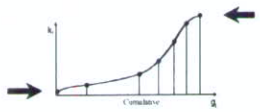
- Variation between minimum and maximum absorption is much larger for wide bands

- Spectra from all species are binned together
  - Does the correlation still hold?



Wideband correlated-ks

- We potentially need thousands of K bins to correctly represent the variation



-or-

- We need a better integration scheme

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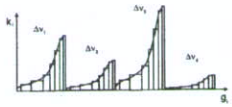
Wideband Correlated-Ks

- Converting MODTRAN4™ CK extinctions to wideband CK

1) Sort



2) $\Delta g_n = \frac{\Delta g_i}{\sum_i \Delta g_i}$

3) Interpolate

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Wideband Correlated-Ks

- Correlating to spectral variations
  - The spectral variations need to be incorporated in the CK distribution
  - The distribution needs to remain smooth and monotonic

$$R_t(\nu_t) = \sum_n F(\nu_t) T(k_n) \Delta g_n$$

$$= \sum_n T(k_n) \{ F(\nu_t) \Delta g_n \}$$

$$= \sum_n T(k_n) \Delta g_n^f$$

$$\Delta g_n^f = F(\nu_t) \Delta g_n$$

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Wideband Correlated-Ks

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  - The spectral variations need to be incorporated in the CK distribution
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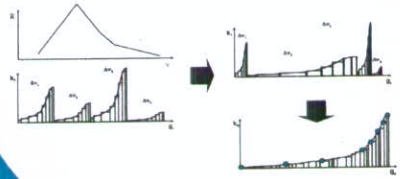

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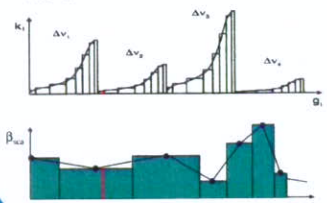
Wideband Correlated-Ks

- Every thing else is binned around the CK points
- $P(\theta)$, β_{sca}, P_n



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The SMART library

The wideband CK method is part of

SMART

for ultiresolution

tmospheric

adiative

ransmission

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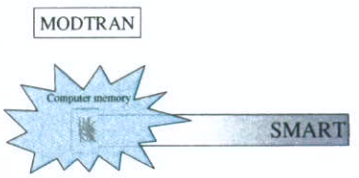
The SMART library

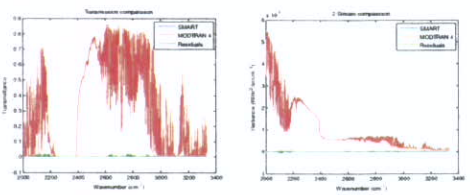
- SMART features
  - Spectral and wideband CK transmittance & radiance
  - MODTRAN molecular extinctions (CK)
    - Seamless integration of MOD4v3r1
  - MODTRAN and DRDC aerosol models
  - DRDC accurate refracted path calculation
  - 2-stream (flux) and DISORT (N-stream) MS calculations
  - Lambert and sea surface (DRDC analytical model) BRDF. Others to come.
  - Optimized by using advanced C++ programming methods
    - Intuitive like C++, fast like Fortran/C

The SMART library

- No source modifications to MODTRAN source is necessary
  - Works with the official MODTRAN4 executable



Results – Spectral (3.0 to 5.0 µm)



(45° slant path from ground to space in a maritime environment, sun at 57° from zenith)

Results - 0.4 to 0.7 µm

- Accuracy

	Single	2 Str MS	16 Str DISORT
R (% from MOD4)	0.41%	0.44%	0.18%
T (% from MOD4)	0.32%		

- Speed

	W-CK (17 ck)	W-CK (2 Str)	W-CK (16 Str)	MOD4 (5 cm^{-1})	MOD4 (2 Str)	MOD4 (16 Str)
Time (s)	0.00078 s	0.00125 s	0.166 s	0.83 s	2.86 s	3061 s
Ratio to W-CK	-	-	-	1064	2288	18439

(45° slant path from ground to space in a maritime environment, sun at 57° from zenith)

Results - 3.0 to 5.0 µm

- Accuracy

	Single	2 Str MS	16 Str DISORT
R (% from MOD4)	2.3%	1.5%	1.8%
T (% from MOD4)	3.0%		

- Speed

	W-CK (17 ck)	W-CK (2 Str)	W-CK (16 Str)	MOD4 (1 cm^{-1})	MOD4 (2 Str)	MOD4 (16 Str)
Time (s)	0.00124 s	0.00234	0.19 s	1.05 s	3.08 s	1586
Ratio to W-CK	-	-	-	847	1316	8347

(45° slant path from ground to space in a maritime environment, sun at 57° from zenith)

Results - 8.0 to 12.0 µm

- Accuracy

	Single	2 Str MS	16 Str DISORT
R (% from MOD4)	0.61%	0.75%	0.87%
T (% from MOD4)	10.2%		

- Speed

	W-CK (17 ck)	W-CK (2 Str)	W-CK (16 Str)	MOD4 (1 cm^{-1})	MOD4 (2 Str)	MOD4 (16 Str)
Time (s)	0.00031 s	0.00078	0.020 s	0.41 s	1.03 s	63.7 s
Ratio to W-CK	-	-	-	1323	1321	3185

(45° slant path from ground to space in a maritime environment, sun at 57° from zenith)

Results – 10.0 to 12.0 µm

- Accuracy

	Single	2 Str MS	16 Str DISORT
R (% from MOD4)	0.77%	0.82%	0.72%
T (% from MOD4)	1.25%		

O_3 Band?

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Conclusion

- Accurate and fast RT is possible with the wideband CK method
- Divergence from MODTRAN 4 in radiance and transmittance are well below 5% for most visible and IR bands
  - Solutions exist for special cases
- The method can compute radiance and transmittance for ~1000 lines of sight per second
- The SMART library is under validation
  - Should be available within a year
  - Has been selected for use in multiple international EO-TDA applications

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