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Impacts of Spatial Fidelity Violations in the Forward Signal Model on DOAS-based Greenhouse Gas Retrievals: A Preliminary Analysis for OCO-2 (and Other Missions)

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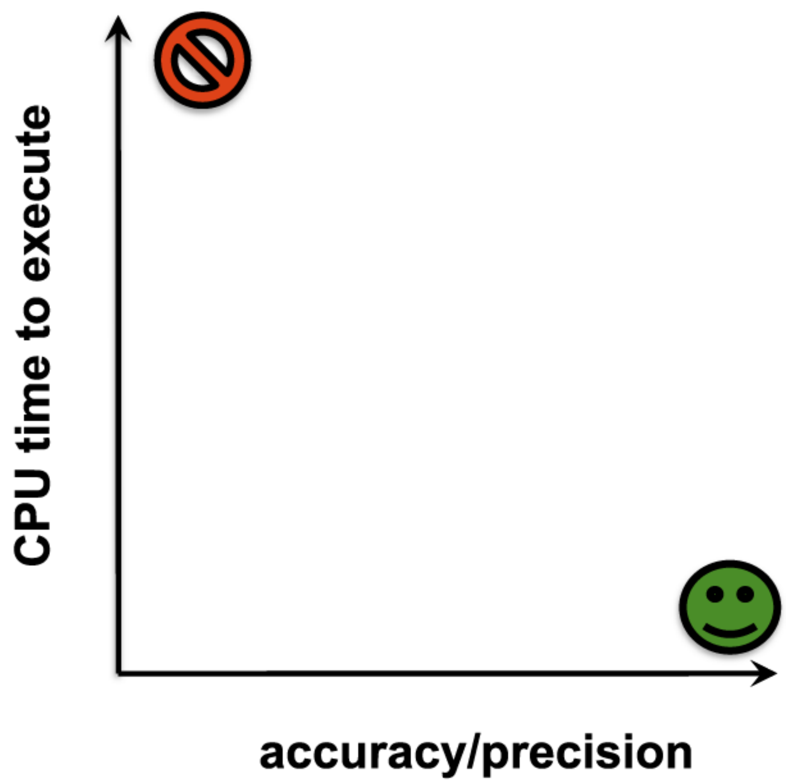
Computational Model Fidelity: The Implicit Dimension in Tradeoff Spaces



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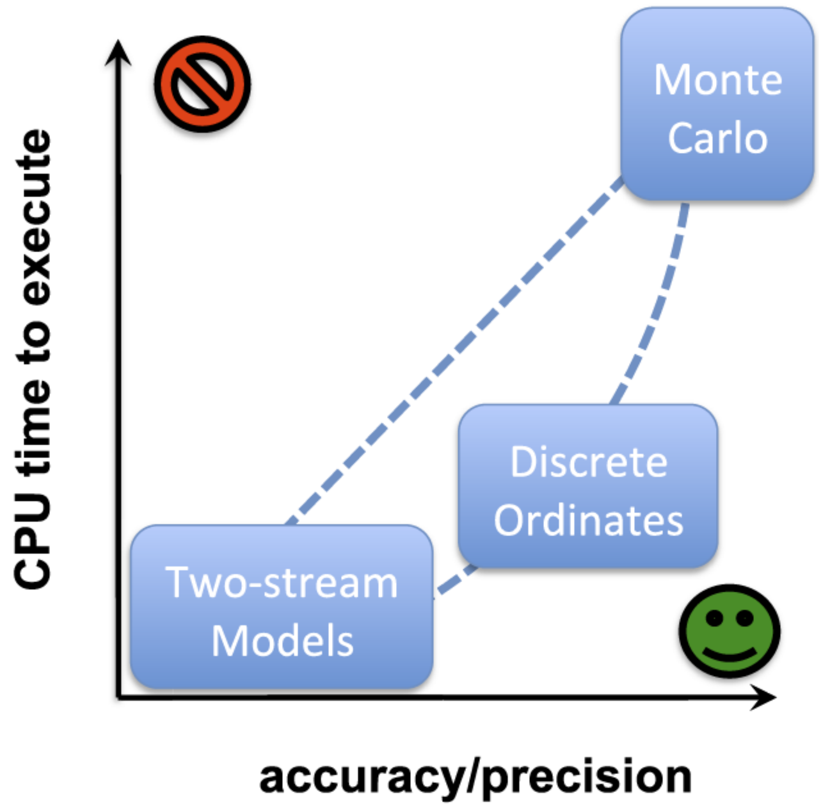
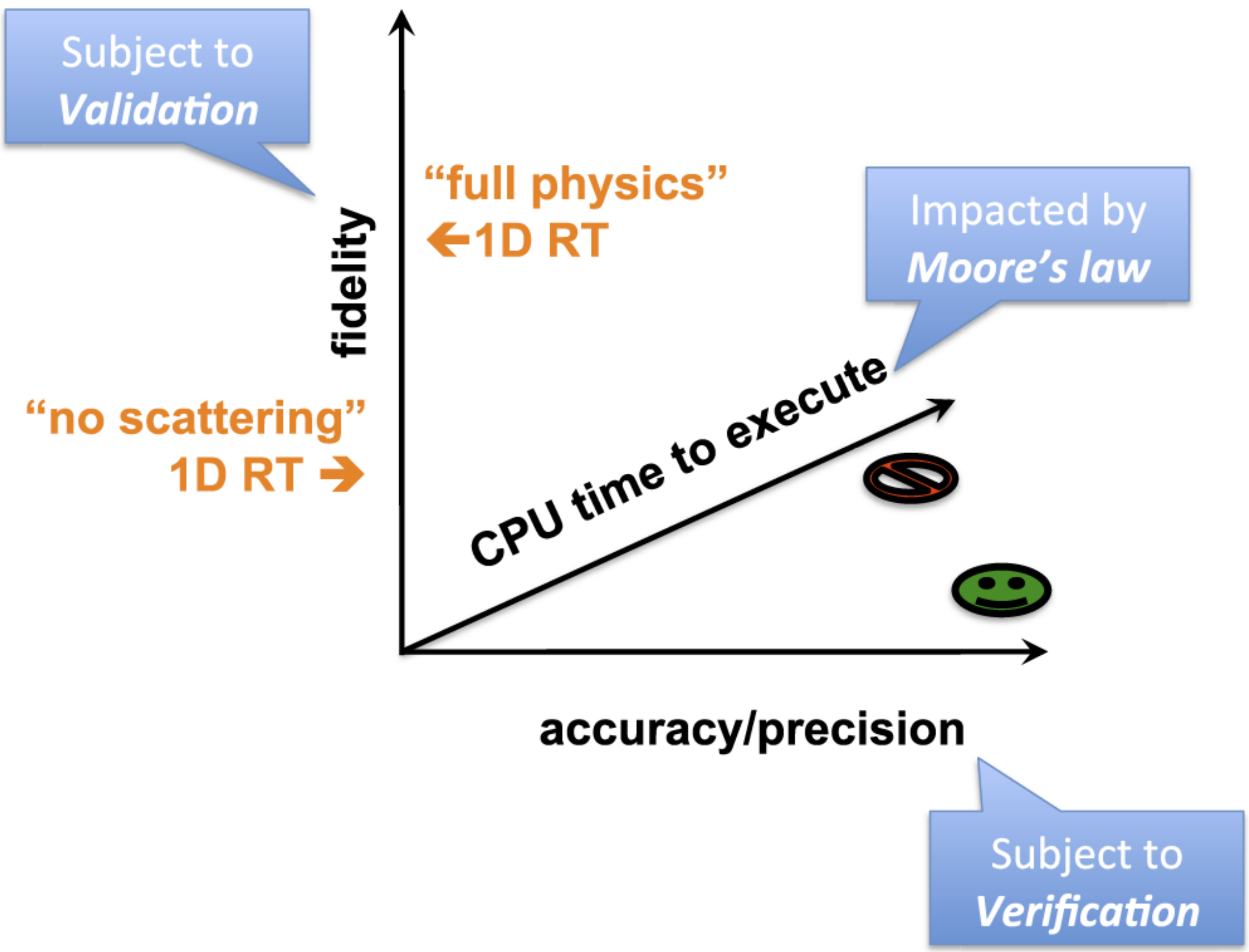
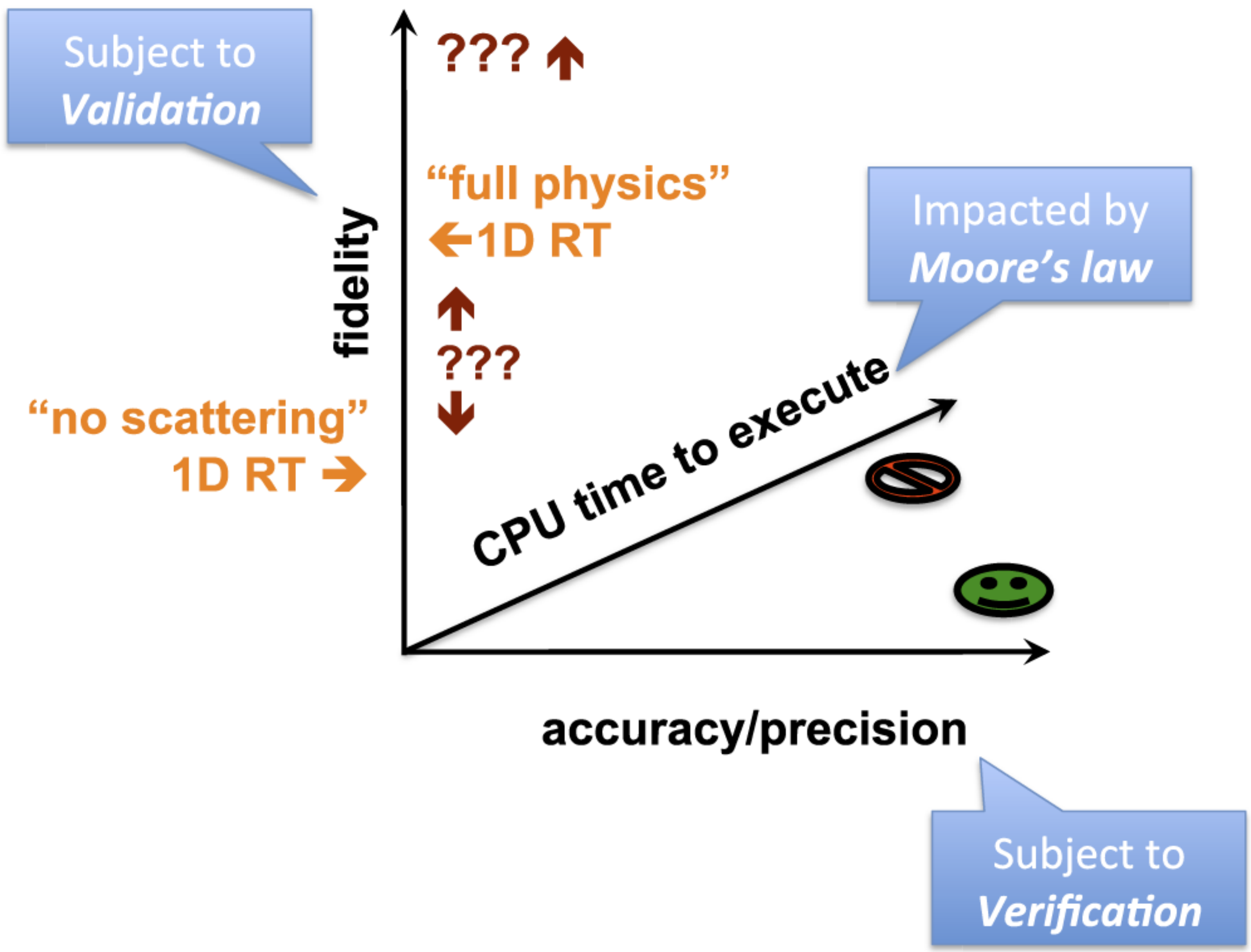


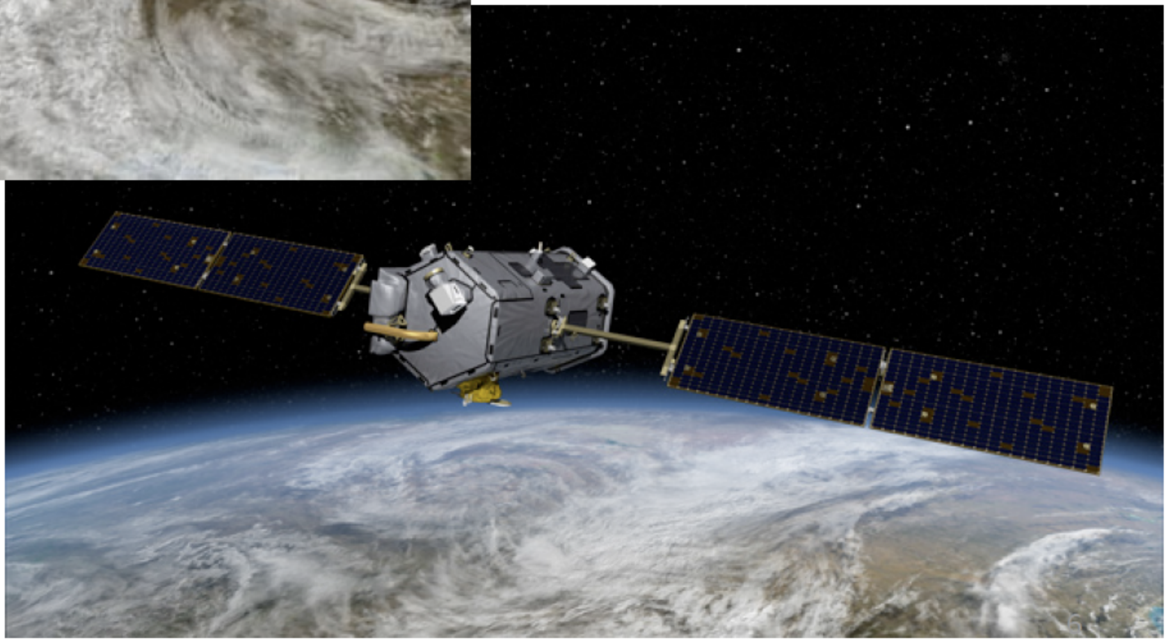
Computational Model Fidelity: The Implicit Dimension in Tradeoff Spaces



Computational Model Fidelity: The Implicit Dimension in Tradeoff Spaces



The problem …



… the problem solvers:

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JPL/Caltech

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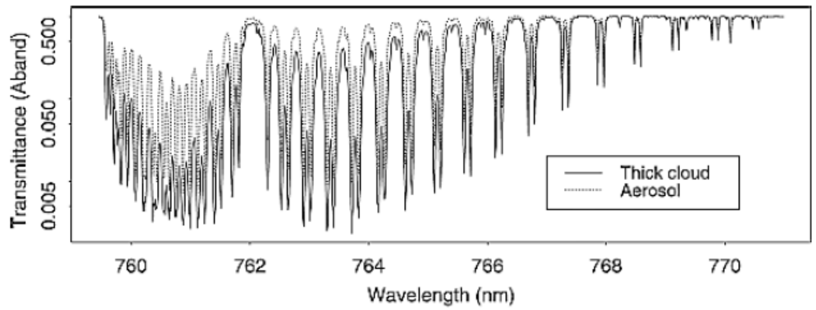
Differential optical absorption spectroscopy (DOAS) at *high* spectral resolution



From: Min Q.-L., L. C. Harrison, P. Kiedron, J. Berndt, and E. Joseph, 2004: A high-resolution oxygen A-band and water vapor band spectrometer, *J. Geophys. Res.*, **109**, D02202, doi:10.1029/2003JD003540.

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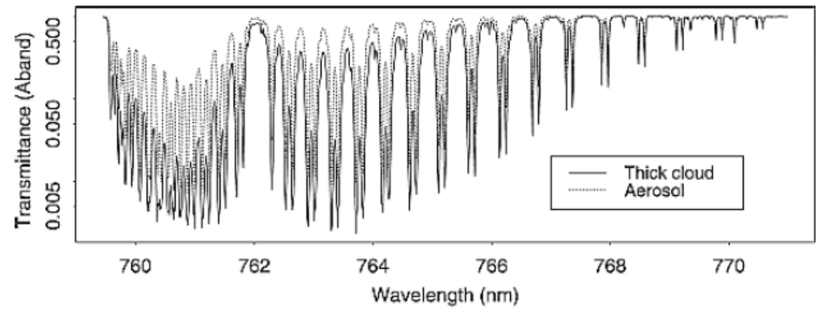

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x-section **density** **pathlength**

$$I(\nu)/I_0 = \exp[-\sigma_\nu \; n \; L]$$

known/not:

x-section	density	pathlength	
?	√	√	estimating molecular cross-sections in the laboratory
√	?	√	monitoring amounts of chemical effluent in situ
√	√	?	scattering/reflection diagnostics of media permeated with gas

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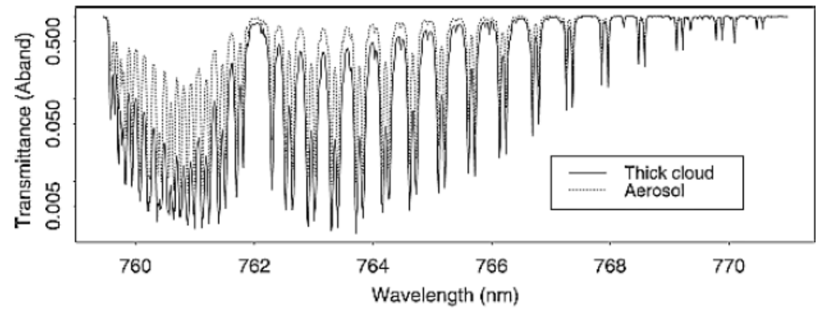

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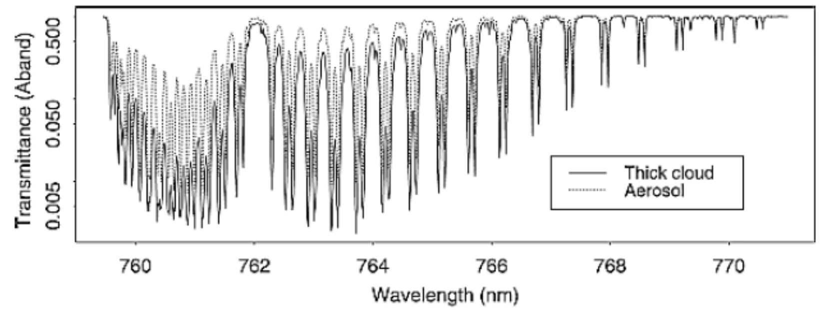
OCO-2's fundamental DOAS problem

Differential optical absorption spectroscopy (DOAS) at *high* spectral resolution



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x-section / density / pathlength

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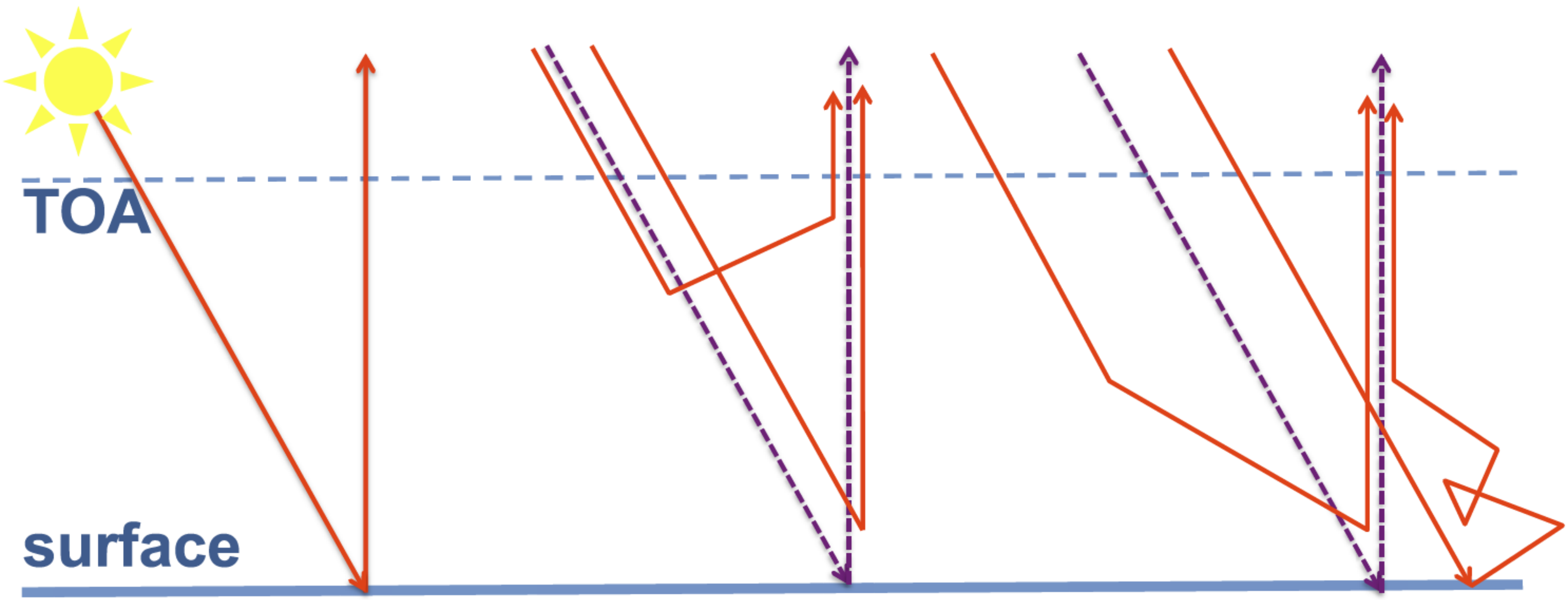
$$I(\nu) = I(k_\nu) = I_0 \int_0^\infty p(L) \; \exp[-k_\nu L] \, \mathrm{d}L \; (\text{equivalence "theorem"}) \Rightarrow \langle L^q \rangle = \frac{(-1)^q}{I_0} \left(\frac{\mathrm{d}^q I}{\mathrm{d}k_\nu^q} \right)_{k_\nu = 0}$$

L ➔ ct: **time-domain Green function**

Cartoon for DOAS in the presence of multiple scattering/reflections



General strategy:

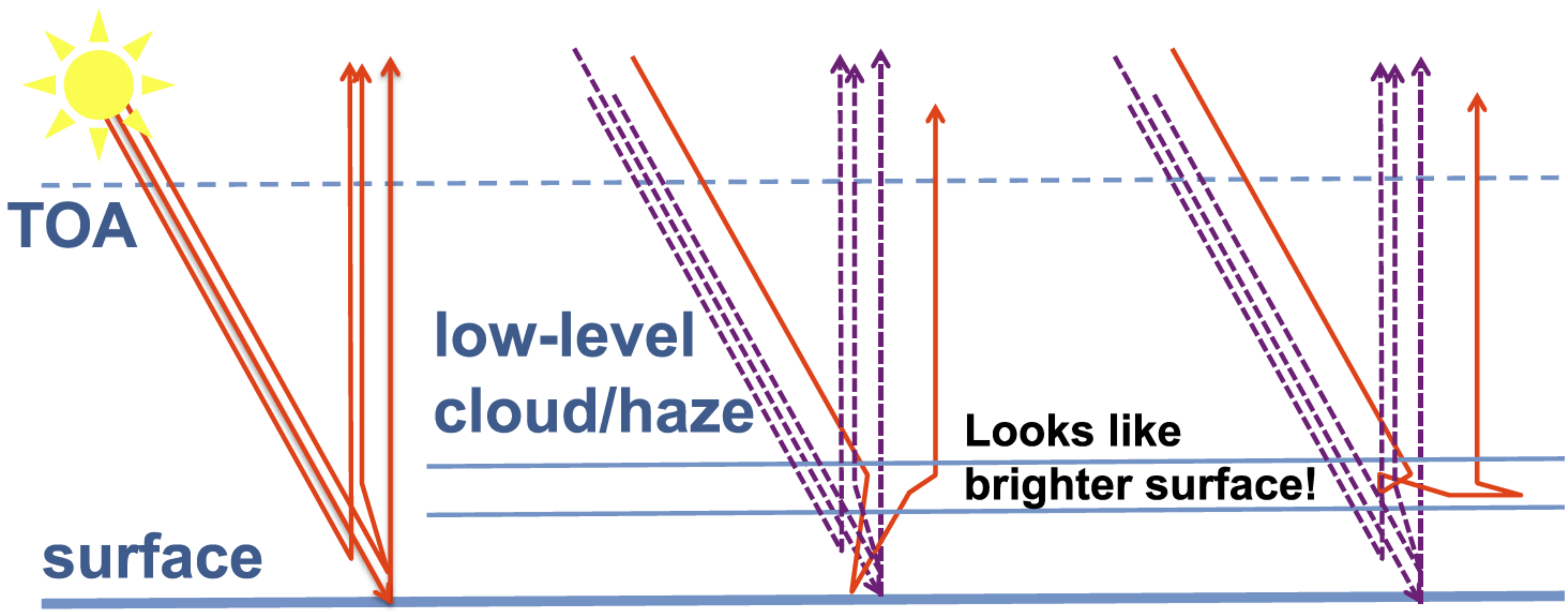
Use simple models for time-domain Green function $I(ct)$, or $I(k_\nu)$, to gain insights and 1st-order quantification of main effects.

Tasks/Goals

1) Understand OCO-2 cloud screening process in sufficient detail to make recommendations for an improved (but still simple) algorithm that will catch low-level clouds with moderate optical depths in preprocessing stage.
2) Evaluate the impact of 3D RT effects of cloud edges on OCO-2 X_{CO2} retrievals in neighboring cloud-free pixels; explore the options of further screening or correcting this cloud adjacency effect; make recommendations, if necessary, about extending the cloud mask to their zone of "radiative influence" and/or about the exploration of mitigation strategies.
3) Evaluate the impact of spatial variability of aerosol and surface on CO_2 retrievals under the large viewing angles used in target mode; perform a cost/benefit analysis of implementing multi-angle (and possibly multi-pixel) algorithms; make recommendations about how to best use these validation exercises.

Task #1: Low/moderately opaque cloud screening problem

Planned preprocessing: Use simple RT (w/o scattering) ➔ retrieve $\{\alpha, P_{\text{surf}}\}$.
If **(1)** P_{surf} notably ≠ from ECMWF reanalysis,
and **(2)** χ^2 is large due to poor fit,
then flag pixel as cloudy and preclude from further ("full-physics") processing.

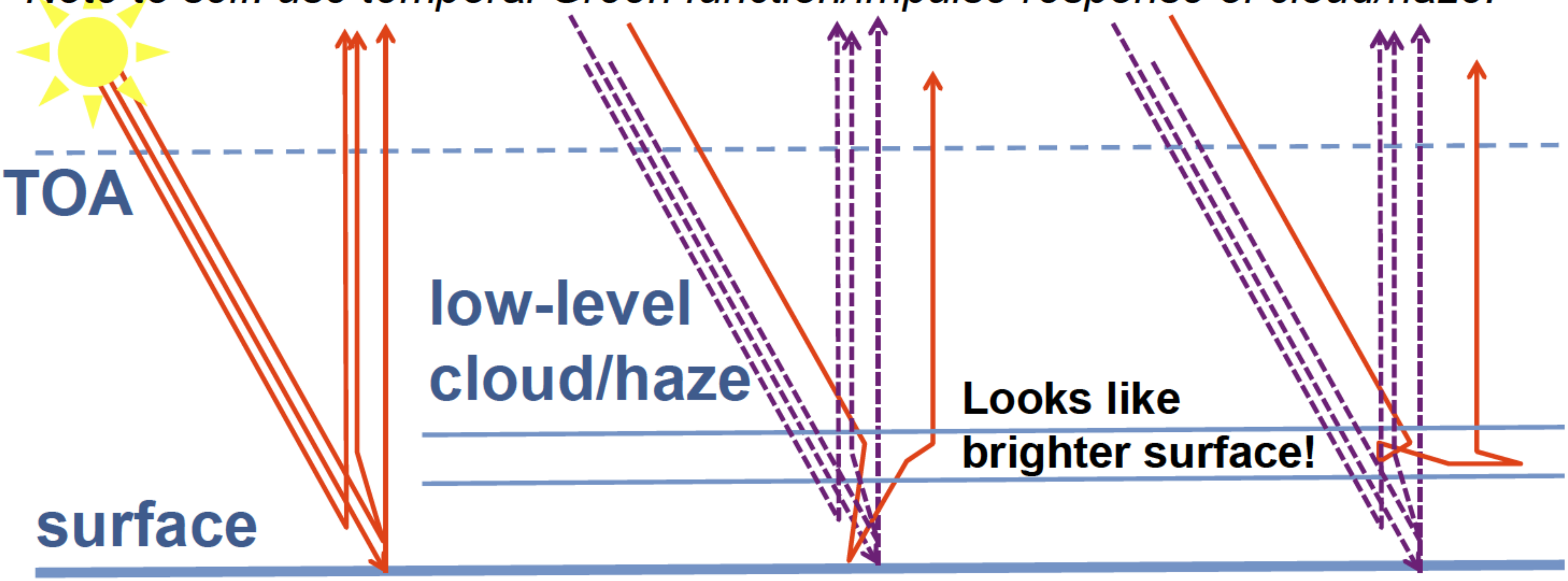


In-cloud (multiple) scattering mimics effect of height!

Task #1: Low/moderately opaque cloud screening problem

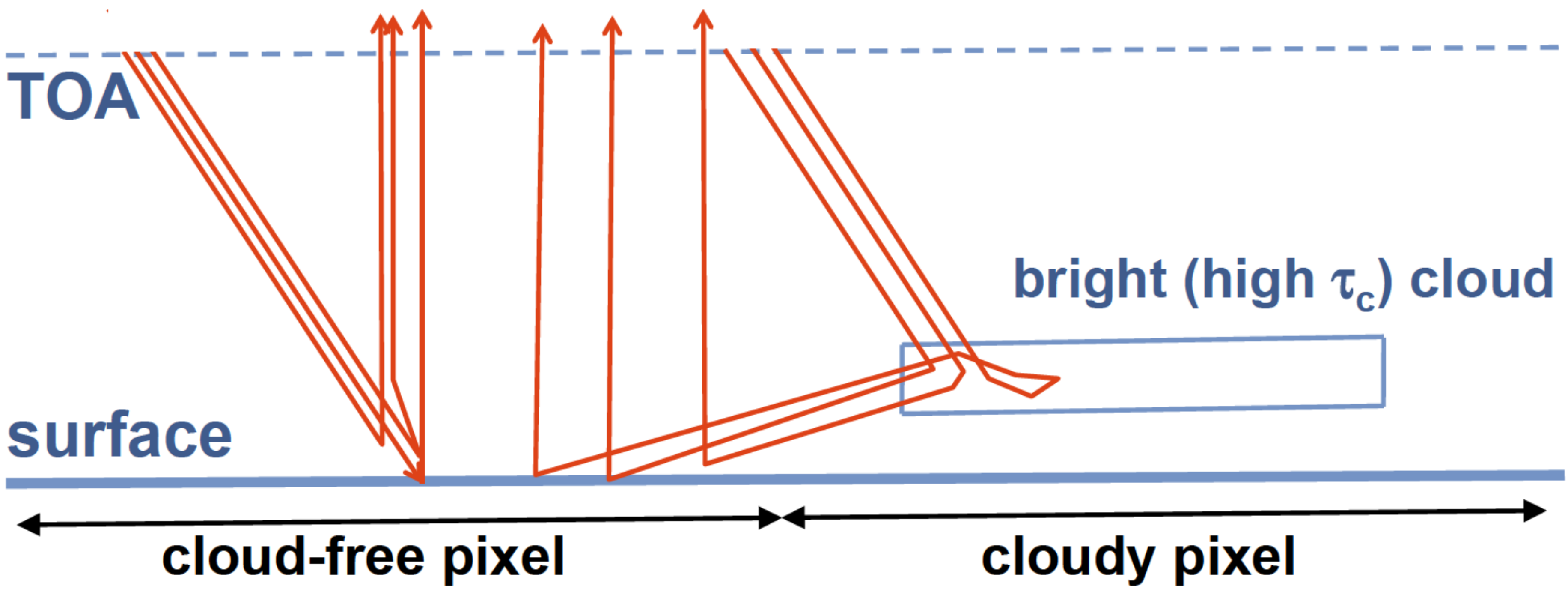
Possible remedy: If passed with albedo α too high, use *still* simple RT (w/ scattering layer) ➔ retrieve $\{\tau_c, P_{layer}\}$, given P_{surf} from ECMWF and α from climatology. If $\{\tau_c, P_{layer}\}$ in problem zone, and χ^2 is reasonable, then eliminate from further consideration.

Note to self: use temporal Green function/impulse response of cloud/haze.



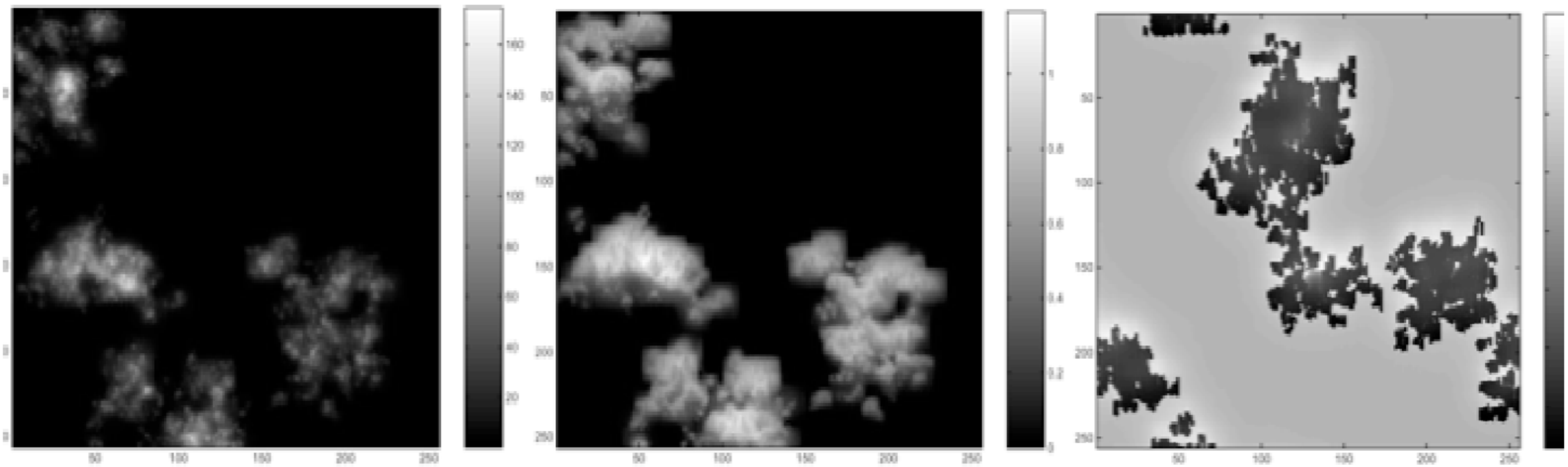
In-cloud (multiple) scattering mimics effect of height!

Task #2: Cloud adjacency problem



Considering clear pixels near cloudy ones, surface albedo α and X_{CO2} will be biased high (due to extended paths) on sunny side of cloudy pixel; see schematic. On shady side of cloud, α will seem low and X_{CO2} will again seem high.

Task #2: Cloud adjacency problem

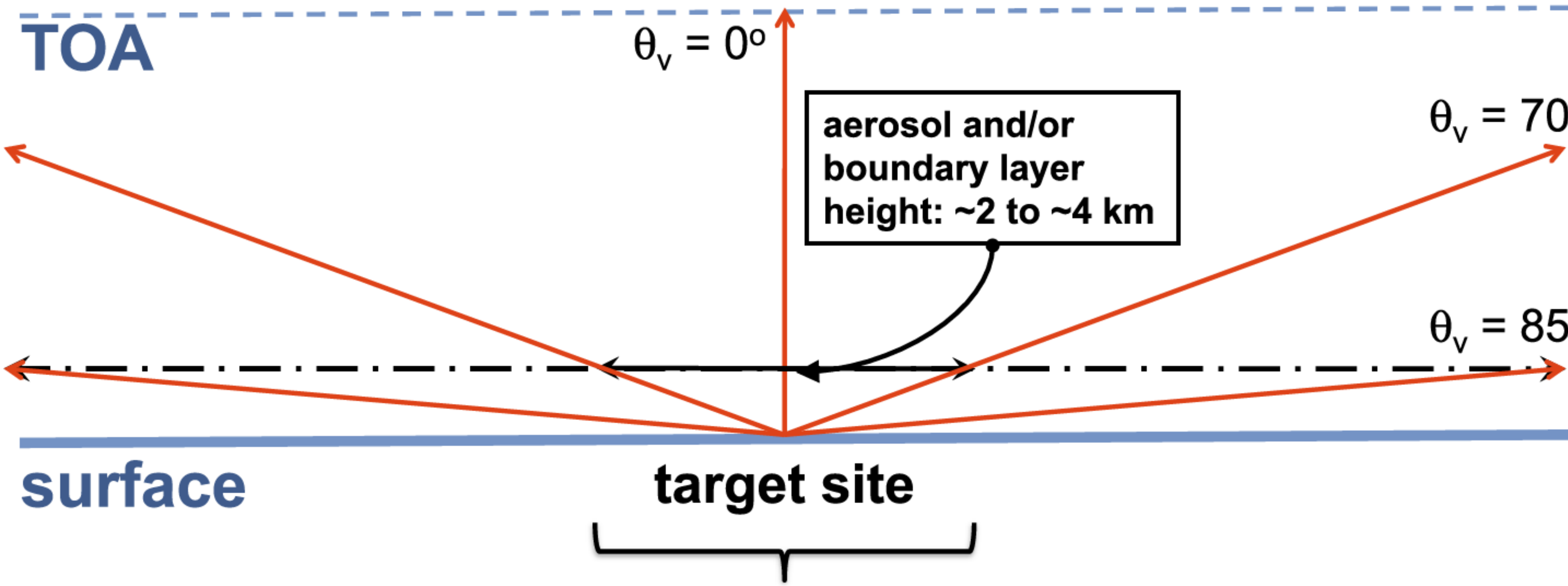


Possible remedy:

Use simple or realistic (stochastic or LES-based) cloud models to drive a 3D vector RT model. Confirm sign and quantify magnitude of anticipated biases.

Define extended cloud mask to eliminate apparently clear pixels near clouds from further consideration.

Task #3: Aerosol and/or surface spatial variability in target mode

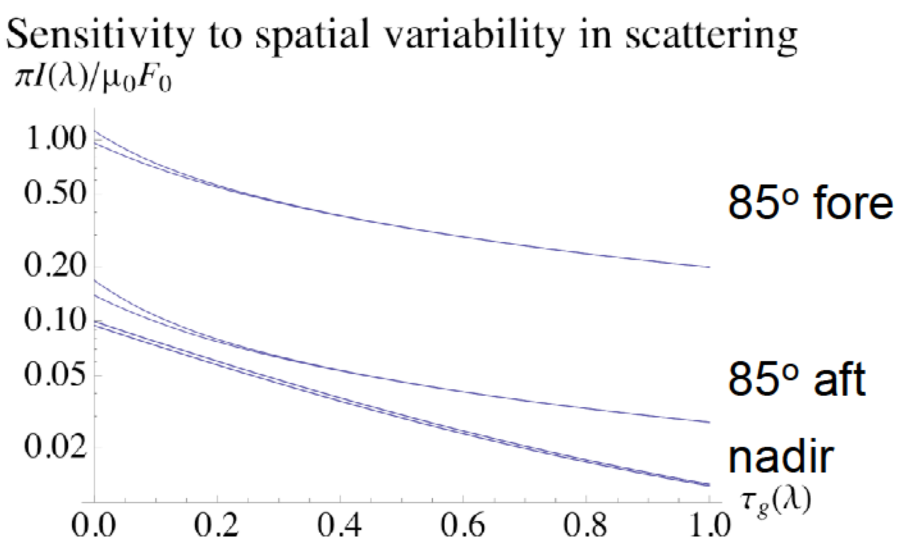


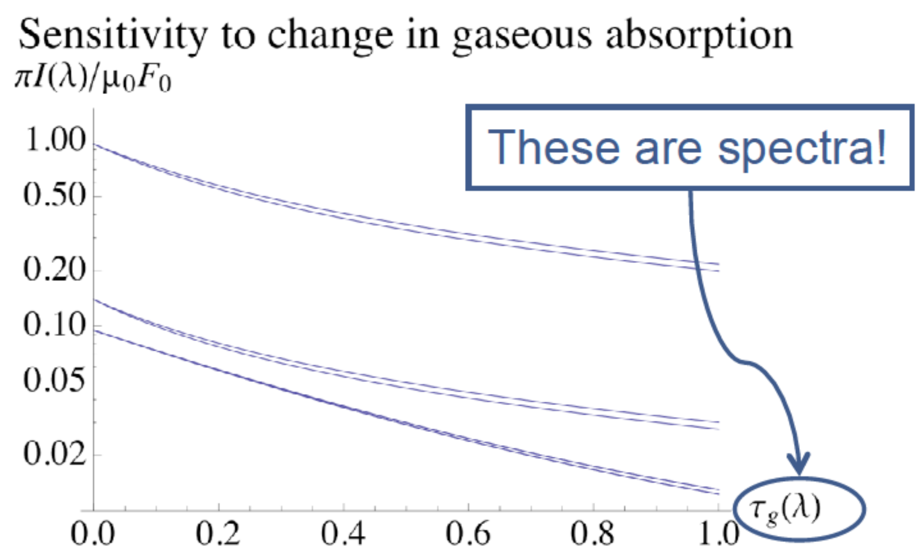
~50 to ~100 km @ 85°
~10 to ~120 km @ 70°

Can aerosols and/or surface be considered uniform over these scales?

Task #3: Aerosol and/or surface spatial variability in target mode

Aerosol density variations





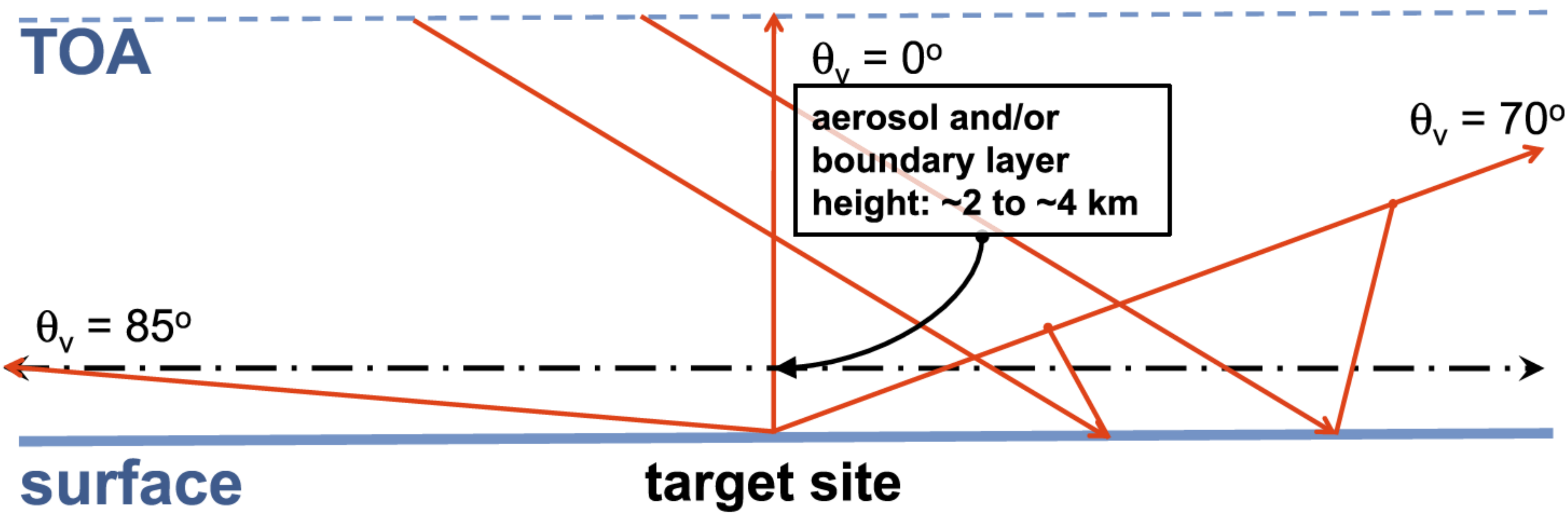
Aerosols fluctuate as in a typical turbulent PBL: Gamma PDF, power-law (spatial) wave-number spectrum

Gas: 100% ➔ 90% (typical of H_2O)
CO_2: much less

Simplified RT: 1 reflection or 1 scatter
(SZA 60°, AOD 0.25, sfc albedo 0.15)

Task #3: Aerosol and/or surface spatial variability in target mode

Surface albedo variations



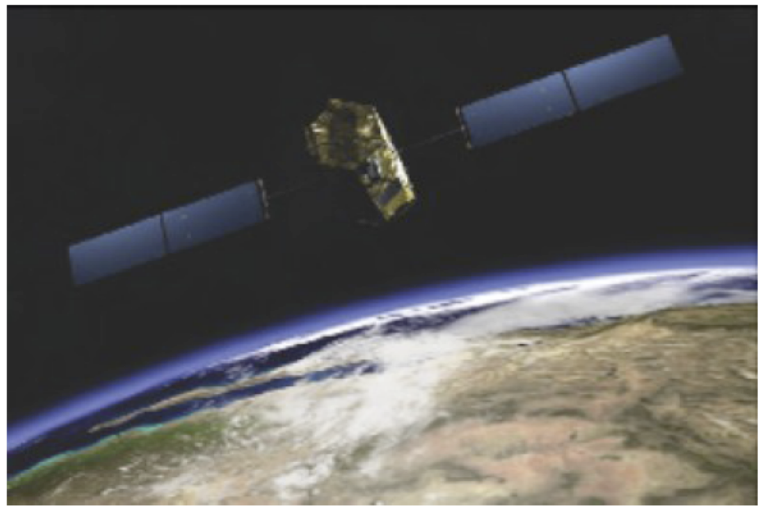
Spectroscopic will depend on **forward and backward/adjoint spatial Green functions** of the scattering atmosphere (aerosols and, in O_2 A-band, Rayleigh) convolved with spatial distribution of surface albedo.

Note to self: use MTFs rather than PSFs!

Summary & Outlook

- Success in three aspects of OCO-2 mission is threatened by unaccounted spatial variability effects, all involving atmospheric scattering:
    1. Low/moderately opaque clouds can escape the prescreening by mimicking a brighter surface.
    2. Prescreening does not account for long-range radiative impact (adjacency effect) of nearby clouds. Need for extended cloud masking?
    3. Oblique looks in target mode are highly exposed to surface adjacency and aerosol variability effects.
- We'll be covering all three bases!

Thank you! *Questions?*



Acknowledgment:

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