Jet Propulsion Laboratory
California Institute of Technology

Cloud Information Content in EPIC's O_2 A- and B-band channels (680, 688, 764, 780 nm): Two Approaches, Same Conclusions

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Outline

- **Optimal estimation approach**
  - A.B. Davis, G. Merlin, C. Cornet, L. C.-Labonnote, J. Riédi, N. Ferlay, P. Dubuisson, Q. Min, Y. Yang, and A. Marshak. Cloud information content in EPIC/DSCOVR's oxygen A- and B-band channels: An optimal estimation approach. J. Quant. Spectrosc. Rad. Transf., 216, 6-16 (2018). https://doi.org/10.1016/j.jqsrt.2018.05.007
- **Physics-based approach**
  - A.B. Davis, N. Ferlay, Q. Libois, A. Marshak, Y. Yang, and Q. Min. Cloud information content in EPIC/DSCOVR's oxygen A- and B-band channels: A physics-based approach. J. Quant. Spectrosc. Rad. Transf. (2018, in press). https://doi.org/10.1016/j.jqsrt.2018.09.006
- **Conclusions/outlooks**

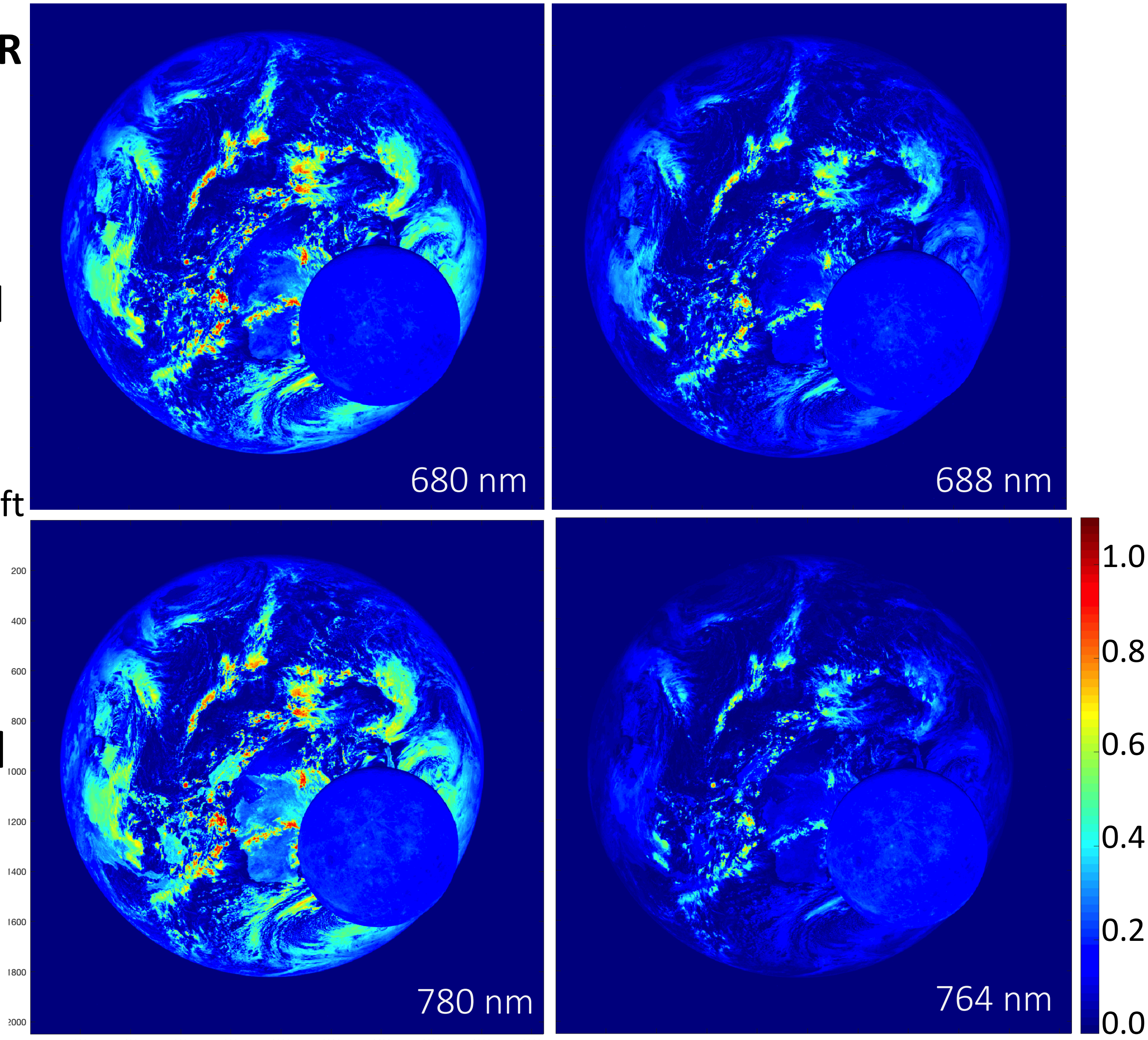
EPIC's A- and B-band channels … at 11/17 new Moon

EPIC/DSCOVR
O_2 channels:

B-band
$\tau_{O2} \approx 0.3$

Reference on left
($\tau_{O2} = 0$)

A-band
$\tau_{O2} \approx 0.6$



2017-11-19

EPIC's A- and B-band channels … at 11/17 new Moon

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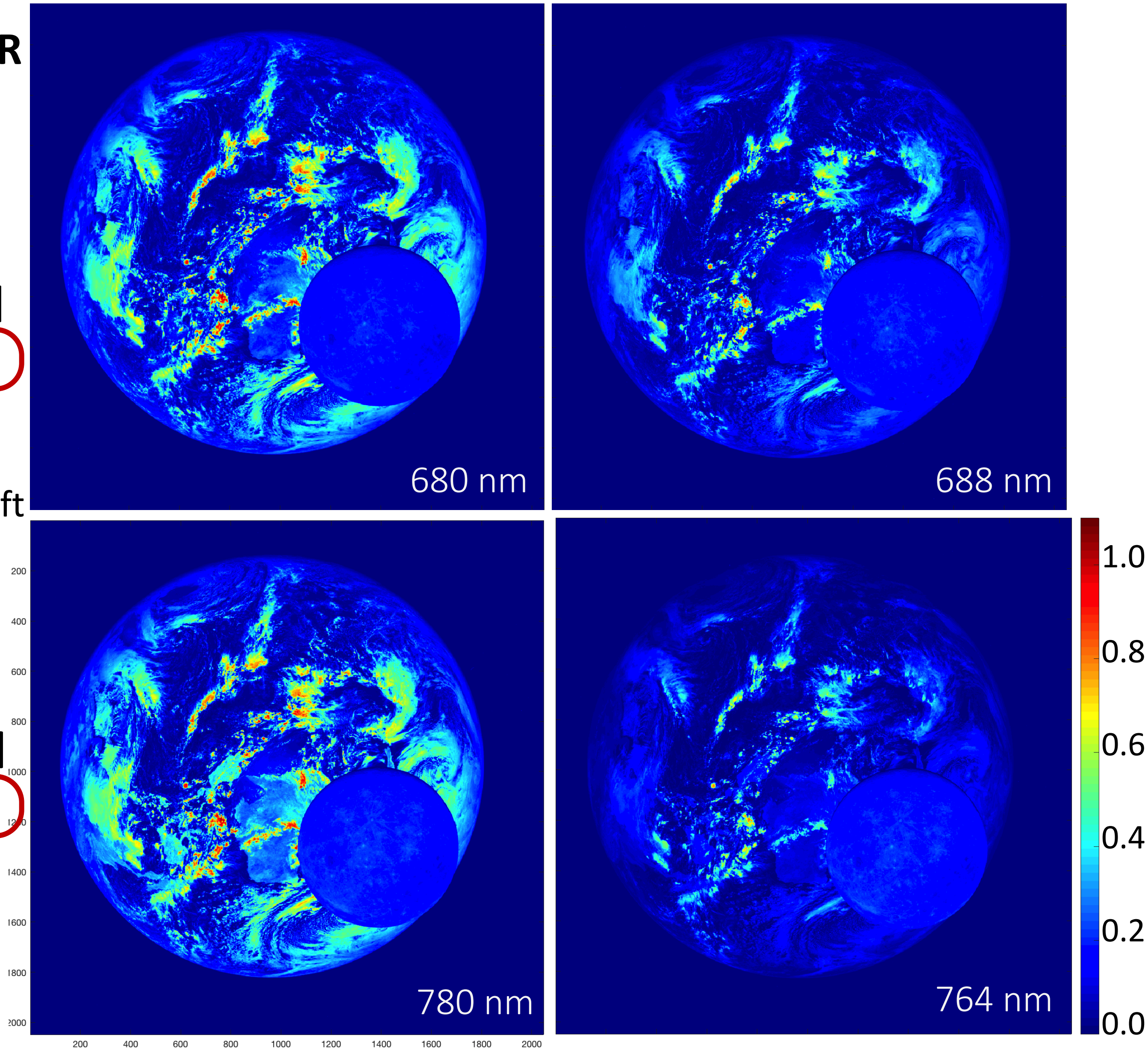
effective optical thicknesses



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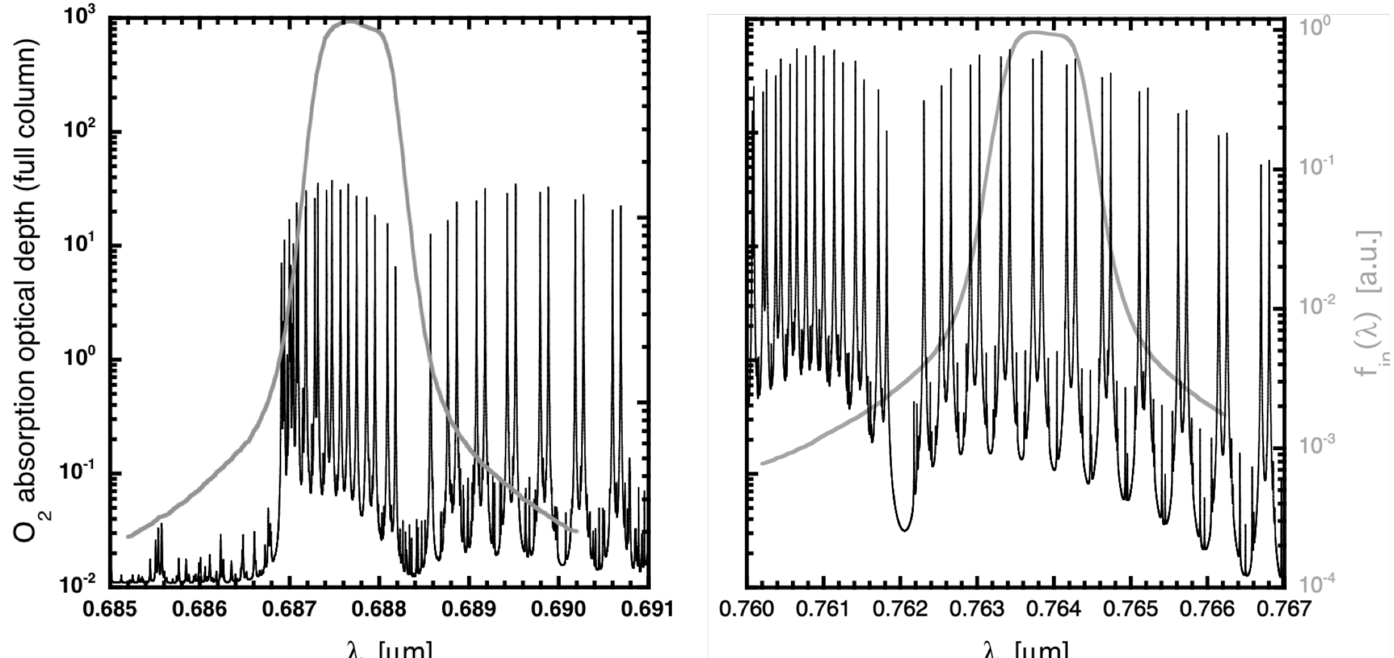

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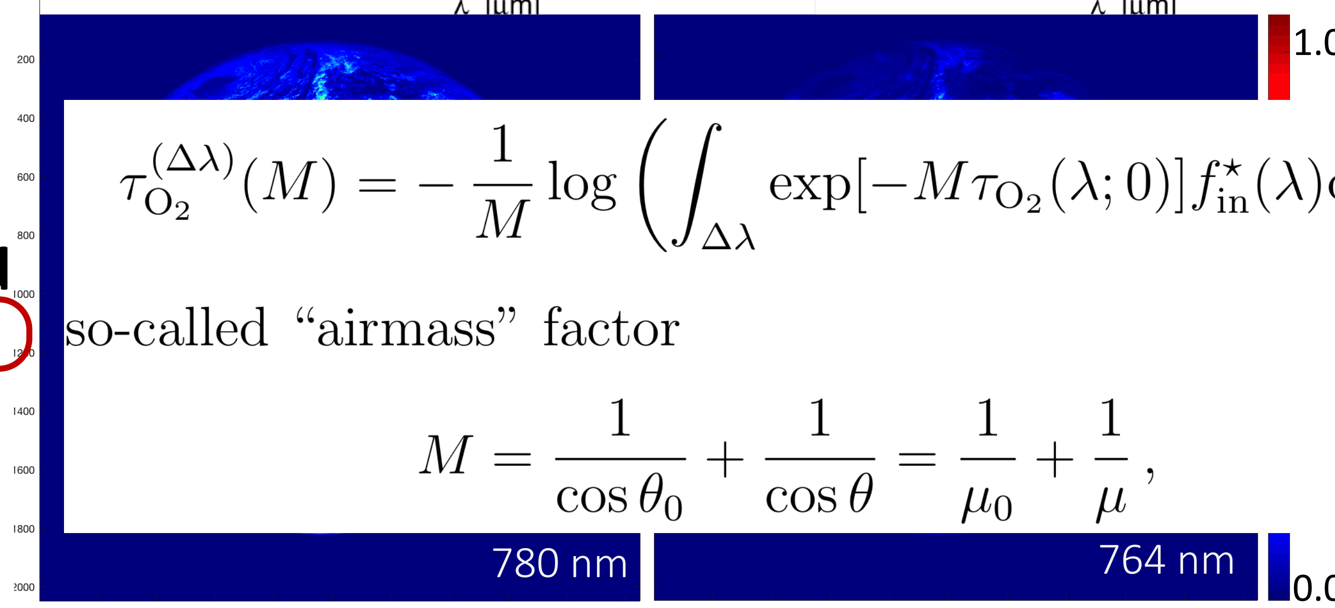

$$\tau_{O_2}^{(\Delta\lambda)}(M) = -\frac{1}{M}\log\left(\int_{\Delta\lambda}\exp[-M\tau_{O_2}(\lambda;0)]f_{in}^{\star}(\lambda)d\lambda\right)$$

so-called "airmass" factor

$$M = \frac{1}{\cos\theta_0} + \frac{1}{\cos\theta} = \frac{1}{\mu_0} + \frac{1}{\mu},$$

2017-11-19

Statistical (optimal estimation) approach

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errors

sensor ↓ model ↓

Cloud information content in EPIC/DSCOVR's oxygen A- and B-band channels: An optimal estimation approach

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not shown here: $\mathbf{S_y} = \mathbf{S_\varepsilon} + \mathbf{S_b}$

Bayes' theorem:

observations ↓

PDF of total cost function =

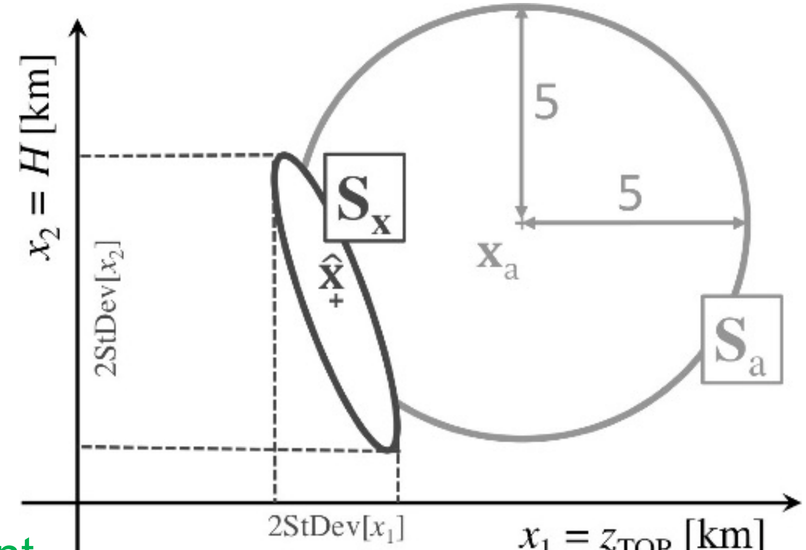
PDF of forward model prediction error on **y**

x PDF of prior uncertainty on state vector **x**

likelihood of y, given **x** — *prior* uncertainty on **x**

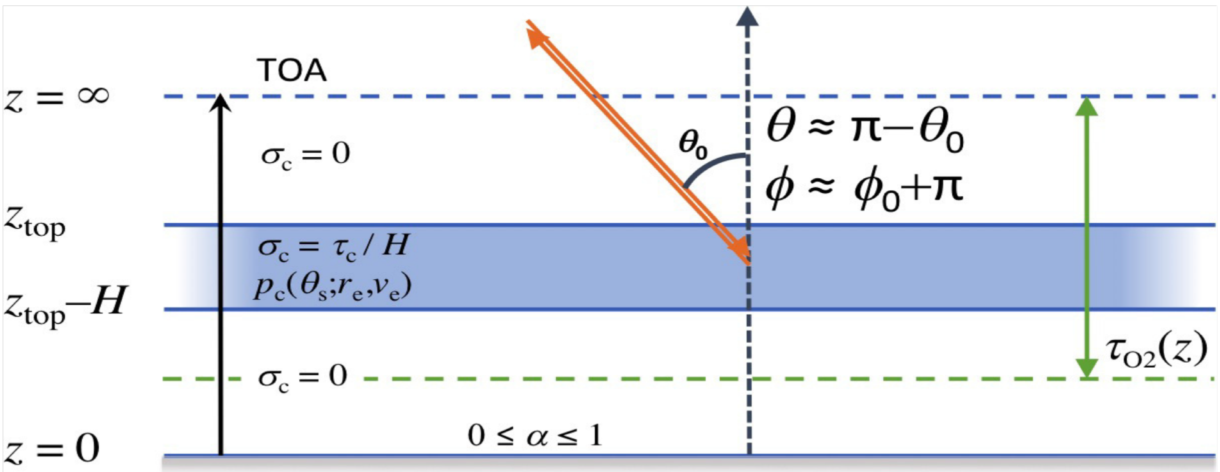
$$p(\mathbf{x}|\mathbf{y}) = p(\mathbf{y}|\mathbf{x})\, p(\mathbf{x}) \,/\, p(\mathbf{y})$$

posterior uncertainty on **x**, given **y** — unimportant



(Partial) Shannon information content / gain

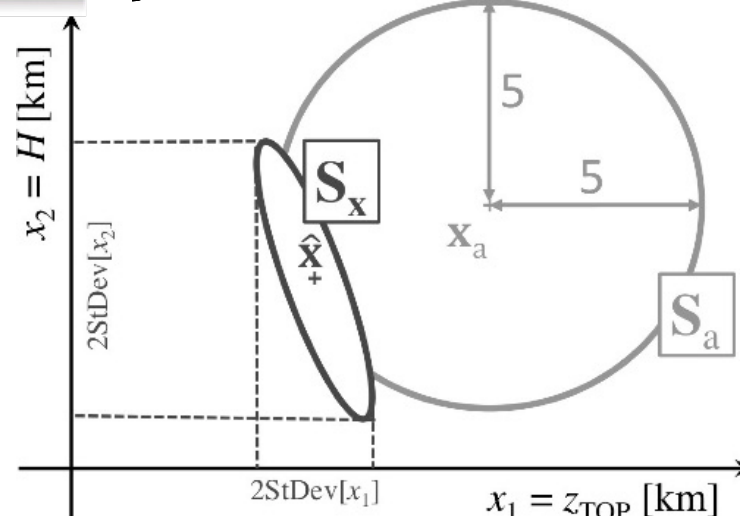
Information Content (IC) gain or Degrees-Of-Freedom (DOF) per cloud property = ratio of the areas of S_a and $S_\mathbf{x}$, projected onto one of the state/**x**-space axes



$\mathbf{x}^T = (z_{top}, H)$

$\mathbf{y}^T = (I_{abs,\lambda}/I_{ref,\lambda},$
λ = A-,B-bands)

Total information content/gain = Ratios of ellipses areas |**S**|, i.e., of products of minor and major axes of the prior-to-posterior PDFs

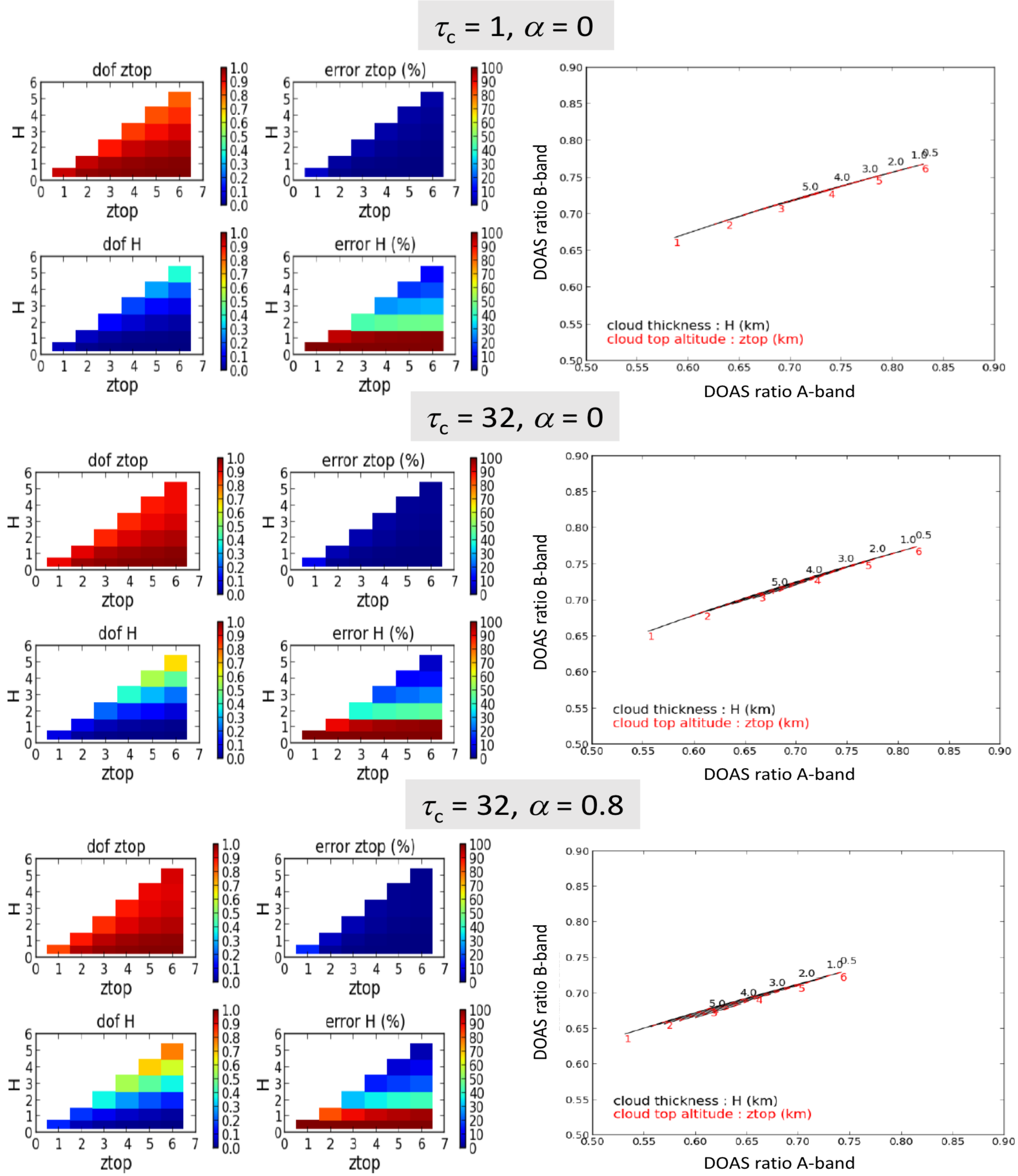


Posterior uncertainty of the retrieved cloud properties

$0 \leq \mathrm{pDOF}_i \leq 1$, for $i = 1,2$ (z_{top}, H) and $\sigma_{pi} = \sigma_{ai}(1 - \mathrm{DOF}_i)^{1/2}$ for the standard deviations.

Errors expressed here in %: $100\ \sigma_i / x_i$

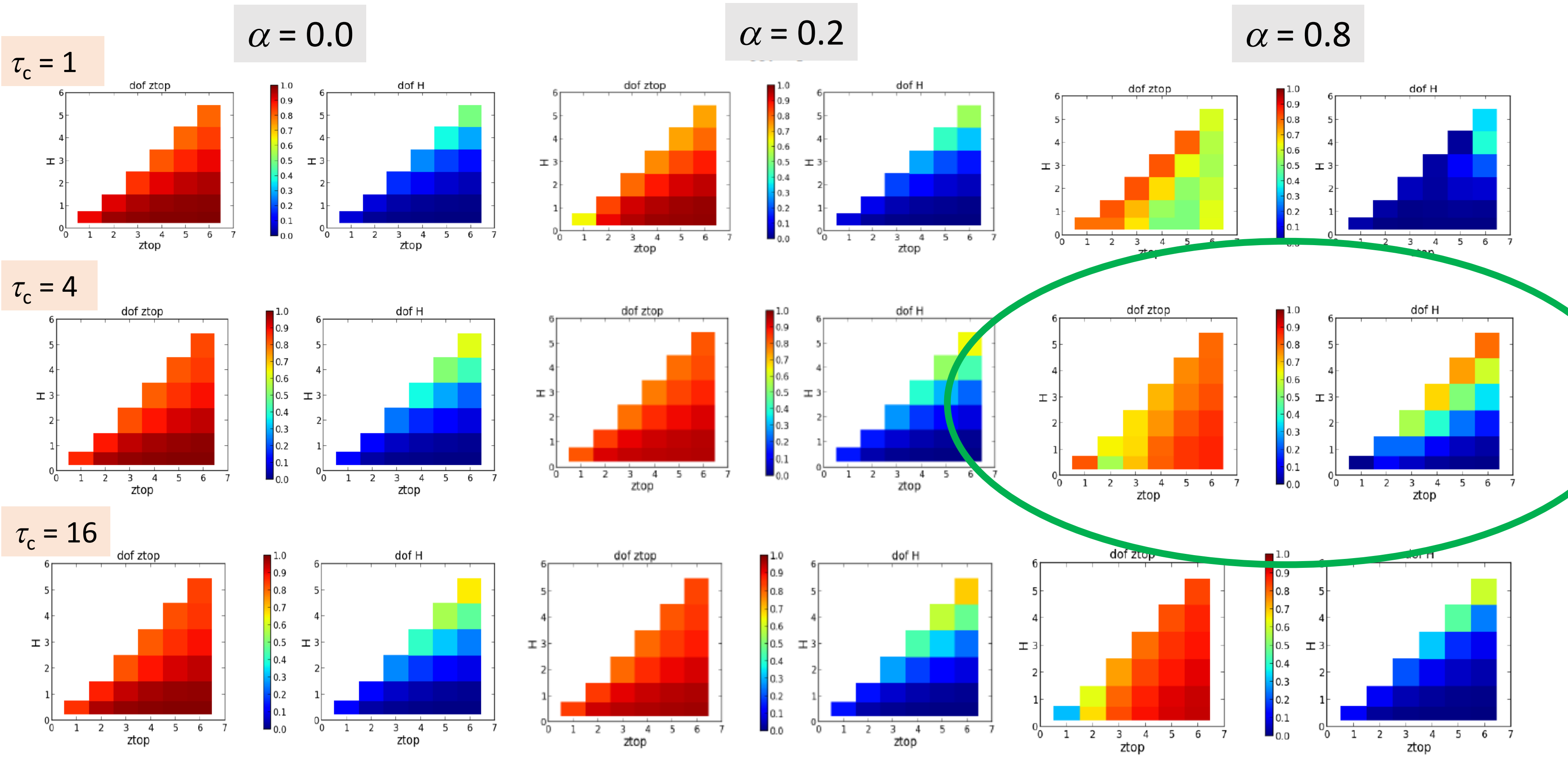
"Nakajima-King" plots of DOAS ratios



DOAS: Differential Optical Absorption Spectroscopy

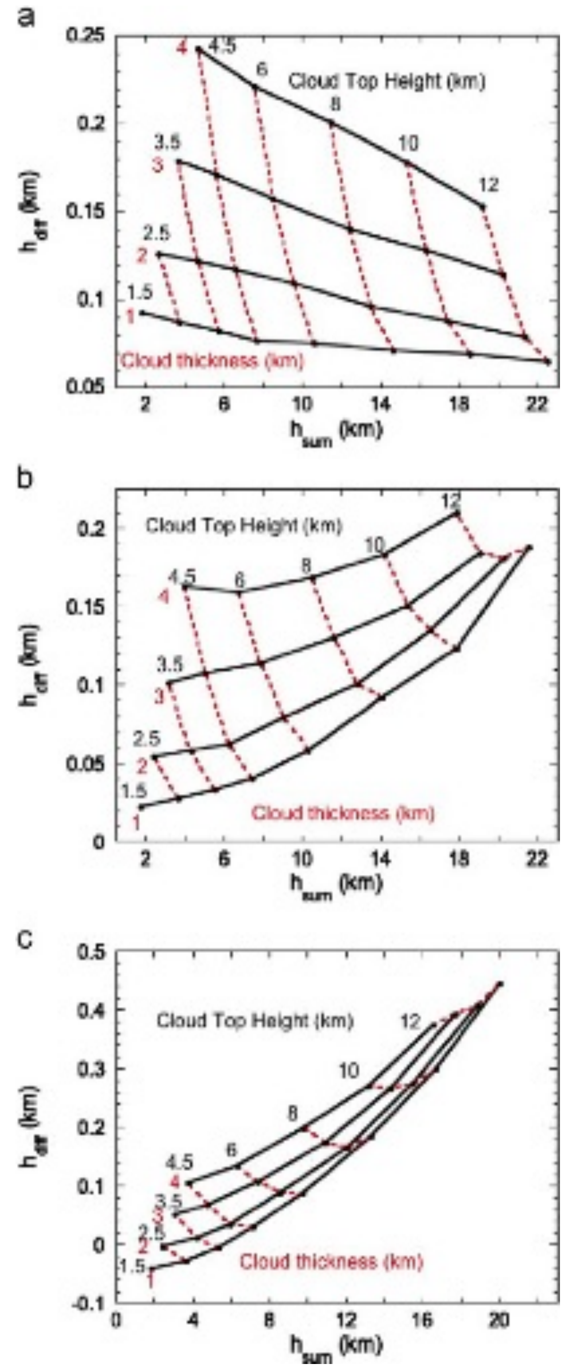
A sweet spot for z_{top} and *H* retrieval?

→ moderately opaque clouds over bright surfaces …



… a possible application to arctic clouds?

Conflict with Yang et al. (2013)?



cloud optical thickness (COT) τ_c = 30

→ not really …

τ_c = 10

ECH: “effective” cloud height

$h_{diff,sum} = CEH_A \pm CEH_B$

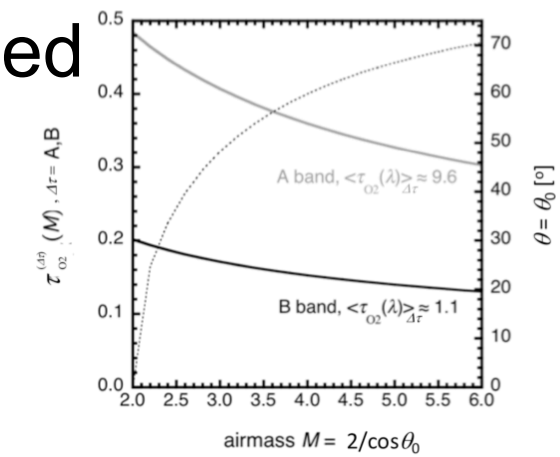
τ_c = 5

Factoring in sensor error,
uncertainty on h_{diff} is ~ vertical axes
uncertainty on h_{sum} is << horizontal axes

Physical modeling approach

Assumptions:

- plane-parallel geometry (1D RT is OK)
- optical thick clouds (asymptotic/diffusion theory)
- dark surface (water)
- "effective" O_2 optical depth for each band ↓
- exponential pressure profile, as needed



… i.e., it's OK to use $\tau_{O_2}^{(\Delta\lambda)}(M)$ here

$$-\log r_\lambda(\boldsymbol{\Omega};\boldsymbol{\Omega}_0,\tau_c) \approx (1/\mu_0+1/\mu)\tau_{O_2}(\lambda;z_{top}) + (\mu+\mu_0)\left[\tau_{O_2}(\lambda;z)\right]_{z_{top}-H}^{z_{top}} \times (1+C(\tau_c,g,\mu_0))$$

↑ DOAS ratio

… and here

a pre-asymptotic correction term

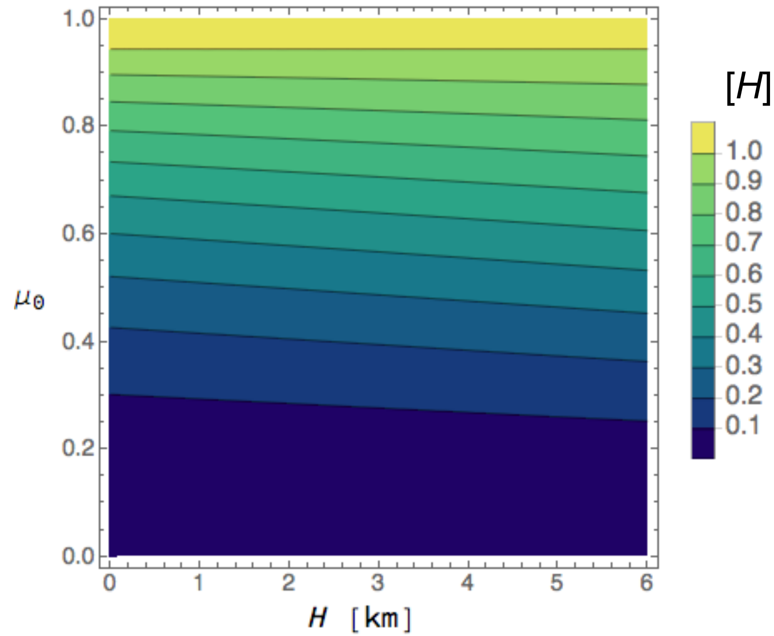
Physical insights …

retrieval bias from ignoring in-cloud path length

$$z_{\rm top}^{\rm (app)} \approx z_{\rm top} \overbrace{- H_{\rm mol} \log\left[1 + \mu_0\mu\left(e^{H/H_{\rm mol}} - 1\right) \times (1 + C(\tau_{\rm c}, g, \mu_0))\right]}$$

$$\approx -\mu_0\mu H \times (1 + C(\tau_{\rm c}, g, \mu_0))$$

Normalized CTH bias $\left(z_{\rm top} - z_{\rm top}^{\rm (app)}\right)/H$ from (19) for EPIC ($\mu_0 = \mu$), and $H_{\rm mol} = 8$ km.

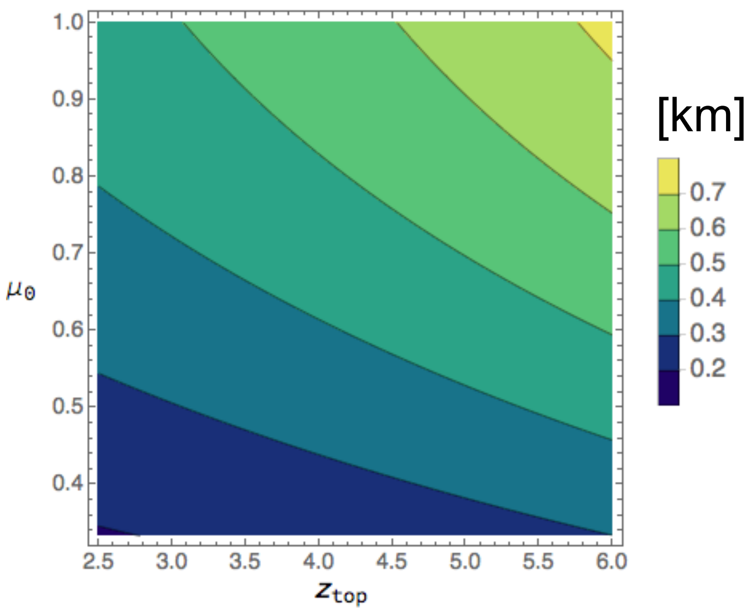


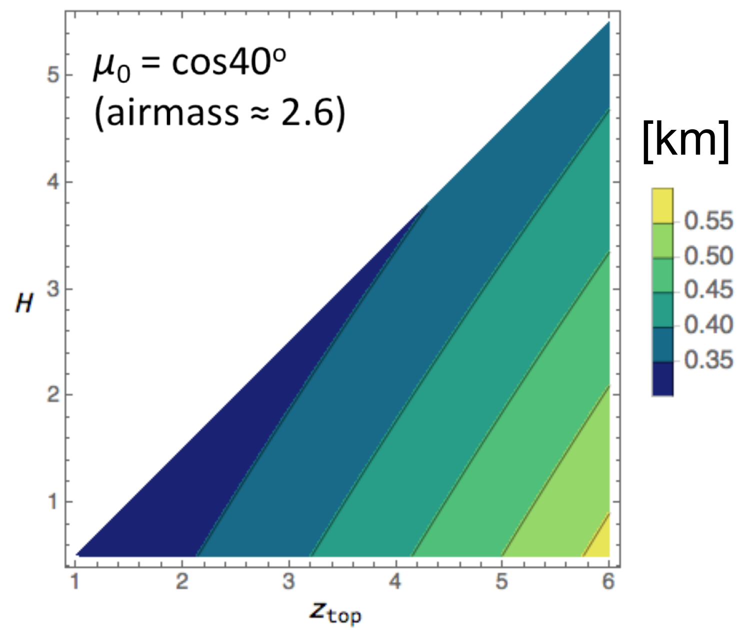
Physical insights …

random retrieval uncertainty resulting from sensor error, assuming 1.5% on DOAS ratio

$$\Delta z_{\text{top}}^{(\text{app})} \approx \frac{0.015\, H_{\text{mol}}}{\tau_{O_2}^{(\Delta\lambda)}} \times \frac{e^{z_{\text{top}}/H_{\text{mol}}}}{2\mu_0 \left(\mu_0^{-2} + e^{H/H_{\text{mol}}} - 1\right)}$$

$H = 2$ km





Summary/outlook

- **Optimal estimation approach**
  - computational (exact) 1D RT model
  - Rodgers' [2000] statistical formalism
- **Physics-based approach**
  - analytical (but approximate) 1D RT model
  - physical insights about biases and sensitivities
- **Both approaches …**
  - use derivatives of signals w.r.t. cloud properties (a.k.a. Jacobians)
  - account for sensor noise level
  - lead to the conclusion that, under most circumstances, only the cloud top height can be reliably retrieved