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

Anthony B. Davis (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Ca, USA)

Guillaume Merlin, Céline Cornet, Laurent C.-Labonnote, Philippe Dubuisson, Jérôme Riédi, and Nicolas Ferlay (Laboratoire d'Optique Atmosphérique, Lille, France)

Quentin Libois (CNRM, U. de Toulouse, Météo-France, CNRS)

Qilong Min (Atmospheric Science Research Center, State University of New York at Albany, NY, USA)

Yuekui Yang and Alexander Marshak (NASA – Goddard Space Flight Center, Greenbelt, USA)

DSCOVR Science Team Meeting, NASA-GSFC, Greenbelt, Md, Sept 17–18, 2018

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

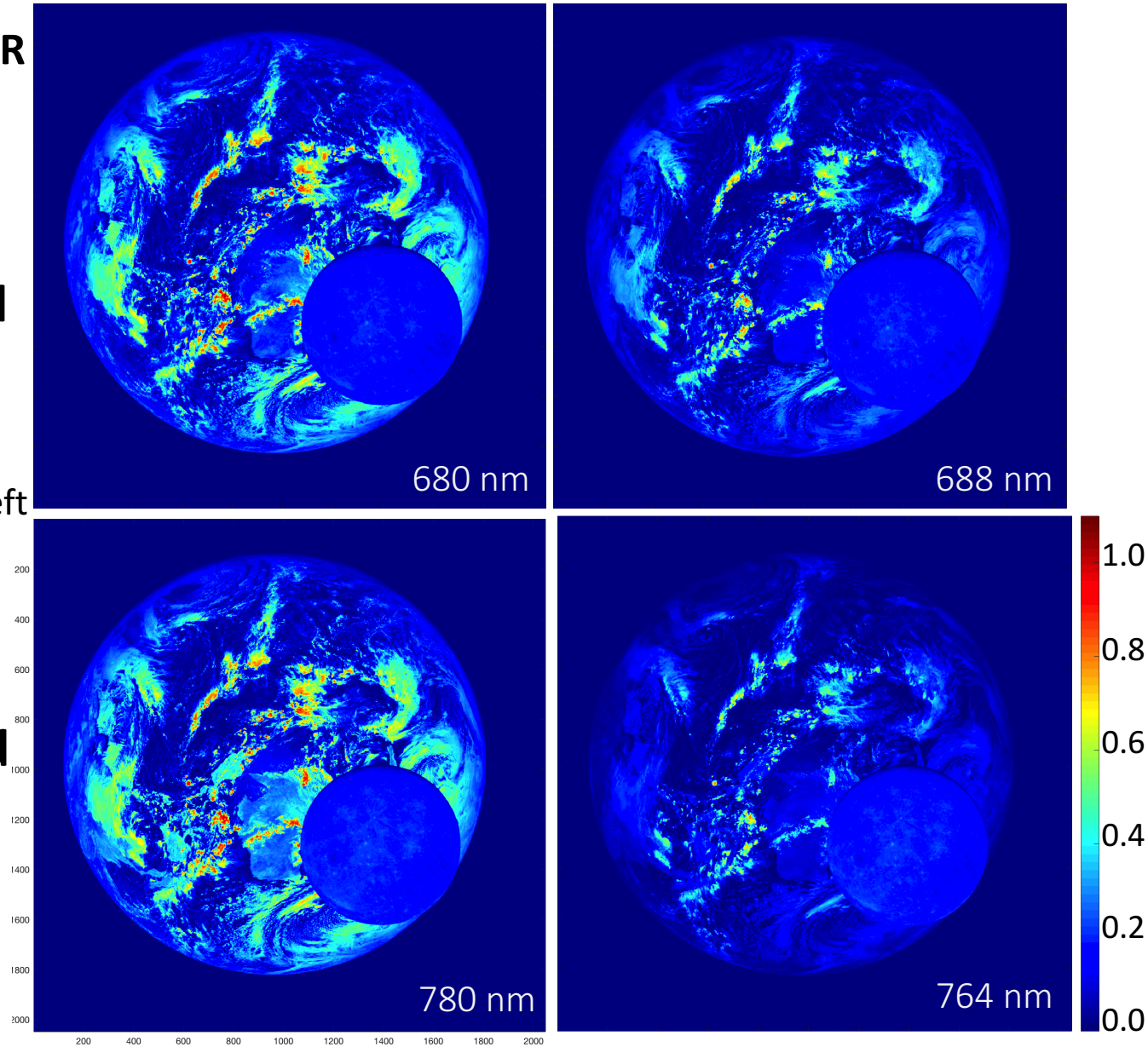
EPIC/DSCOVR
O_2 channels:

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

EPIC/DSCOVR

O_2 channels:

effective optical thicknesses

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Reference on left

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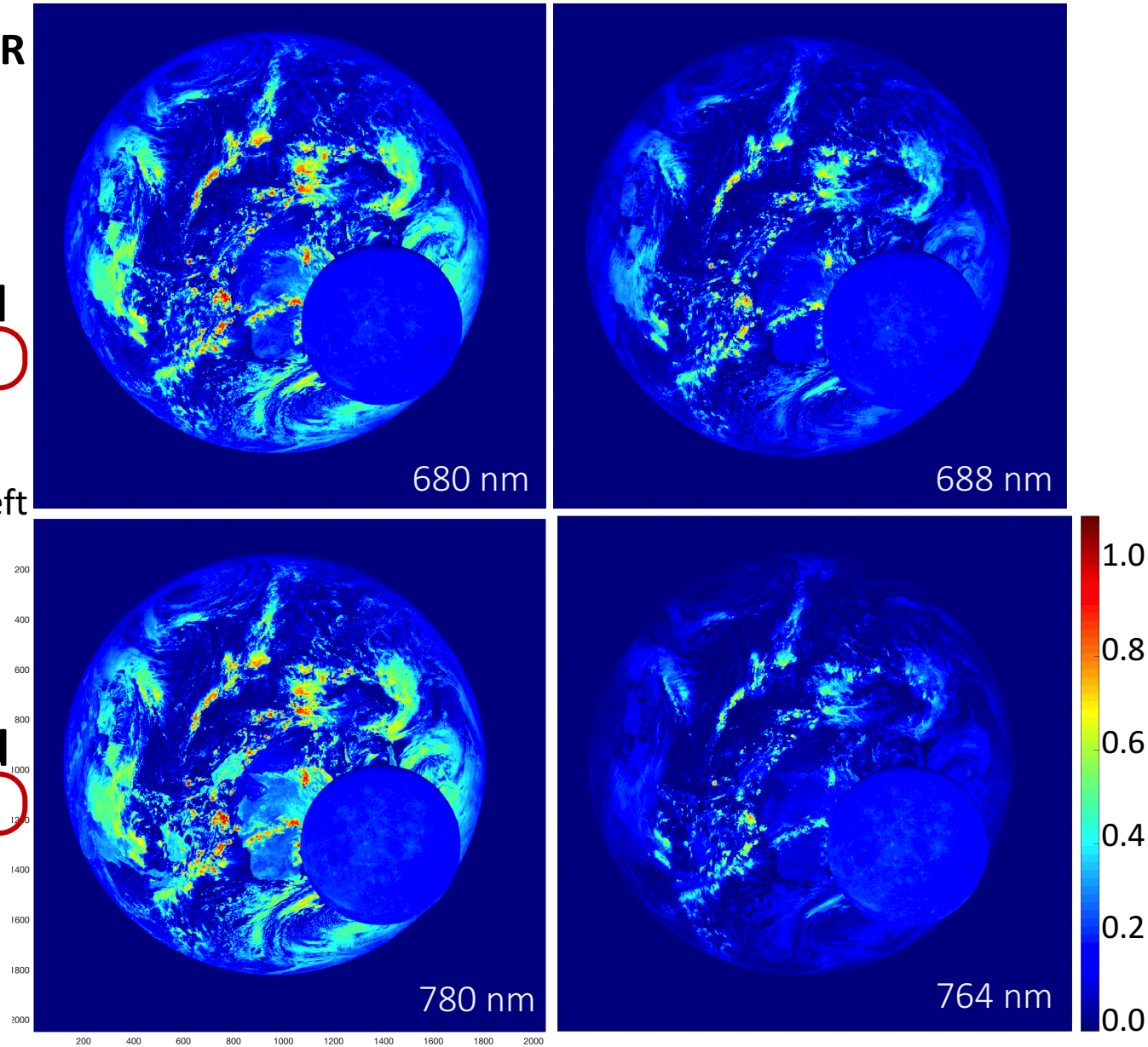
$\tau_{O2} \approx 0.6$



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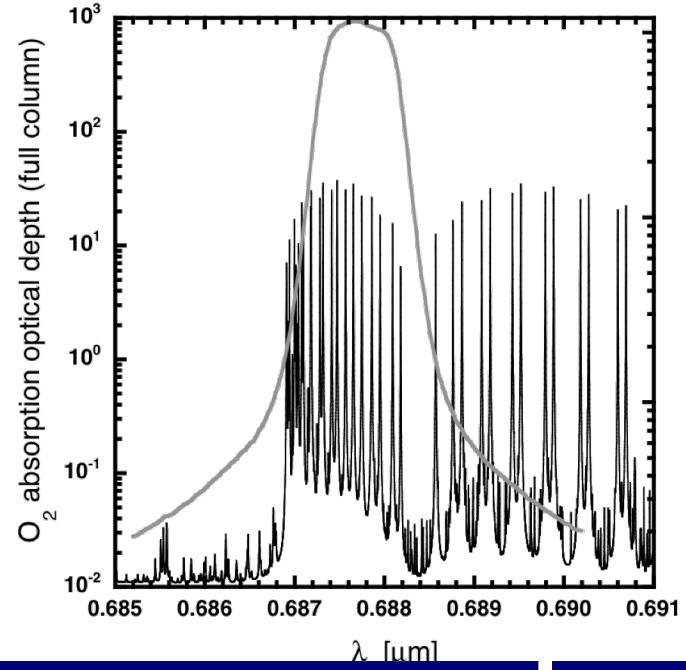

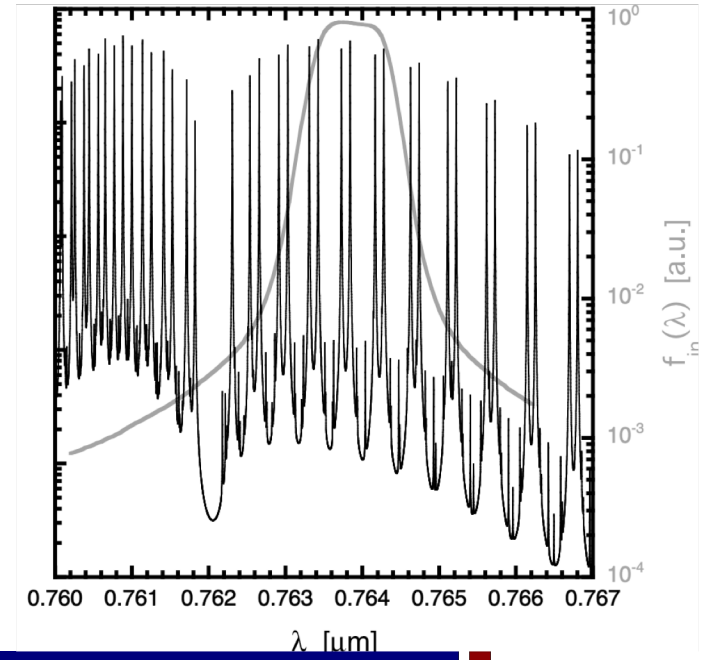

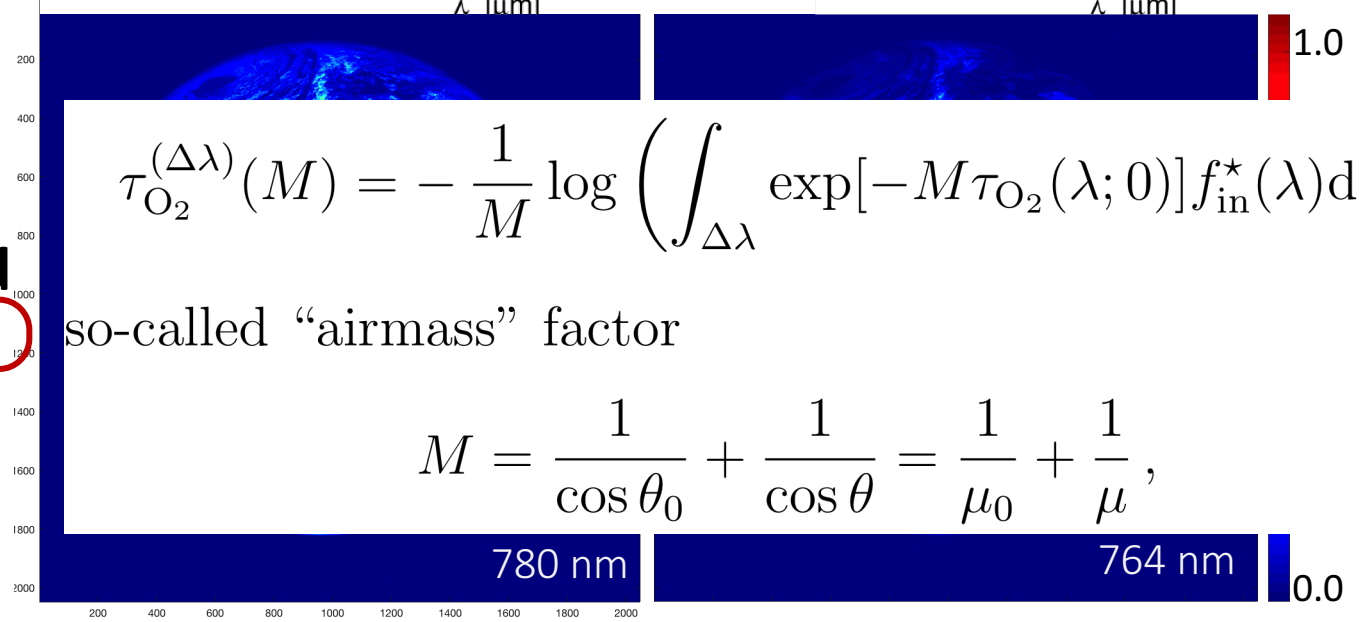

$$\tau_{O_2}^{(\Delta\lambda)}(M) = -\frac{1}{M}\log\left(\int_{\Delta\lambda} \exp[-M\tau_{O_2}(\lambda;0)]f_{in}^{\star}(\lambda)d\lambda\right)$$

so-called "airmass" factor

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

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

Anthony B. Davis[a,*], Guillaume Merlin[b], Céline Cornet[b], Laurent C. Labonnote[b], Jérôme Riédi[b], Nicolas Ferlay[b], Philippe Dubuisson[b], Qilong Min[c], Yuekui Yang[d], Alexander Marshak[d]

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

Bayes' theorem:

observations ↓

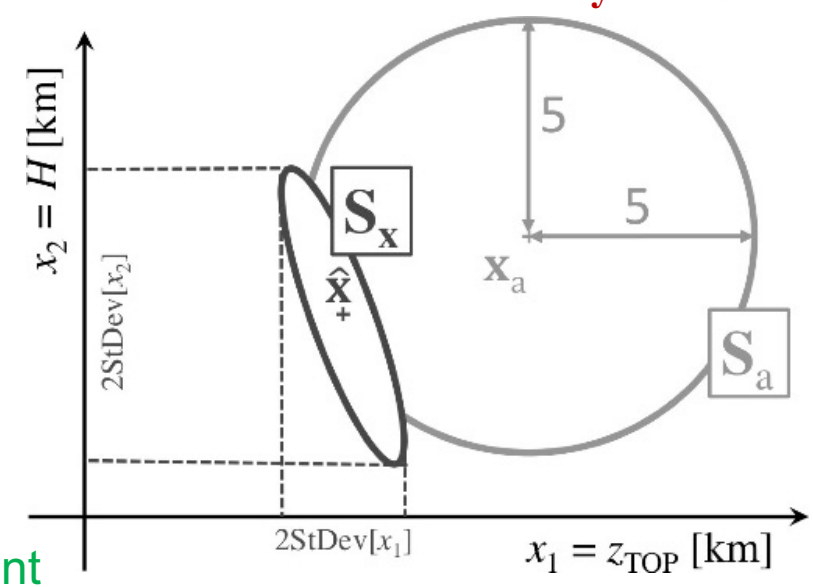
PDF of total cost function =

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

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

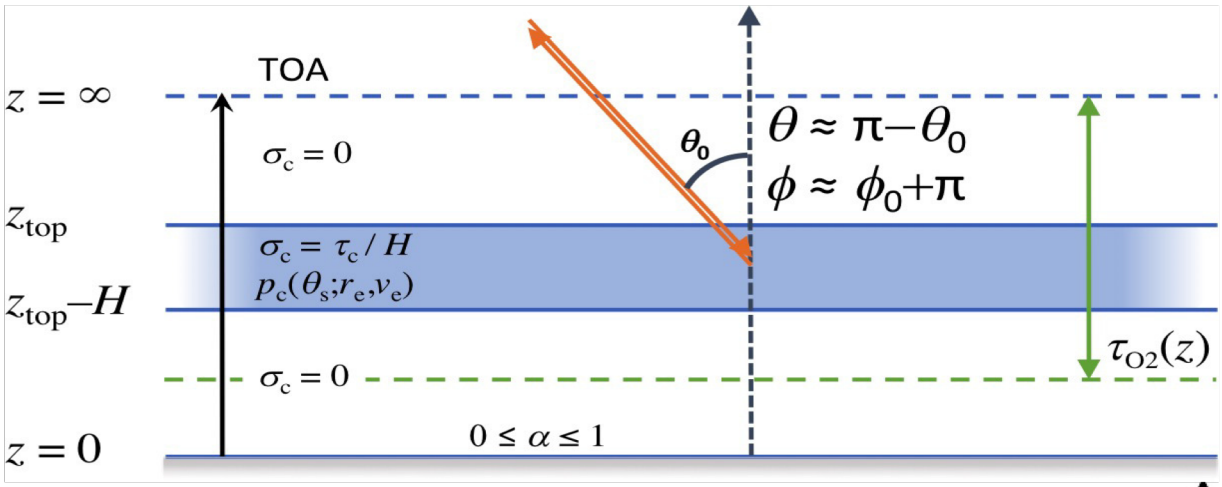
likelihood of y, given **x** *prior* uncertainty on **x**

$$\underbrace{p(\mathbf{x}|\mathbf{y})}_{\textit{posterior}\text{ uncertainty on }\mathbf{x}\text{, given }\mathbf{y}} = \overbrace{p(\mathbf{y}|\mathbf{x})}^{\text{likelihood of y, given }\mathbf{x}}\ \overbrace{p(\mathbf{x})}^{\textit{prior}\text{ uncertainty on }\mathbf{x}}\ \underbrace{/\ p(\mathbf{y})}_{\text{unimportant}}$$



(Partial) Shannon information content / gain

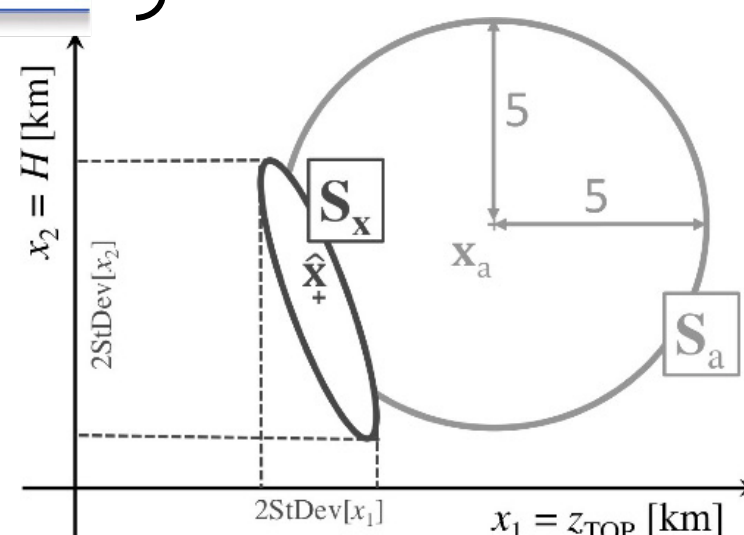
Information Content (IC) gain or Degrees-Of-Freedom (DOF) per cloud property = ratio of the areas of S_a and $S_{\mathbf{x}}$, projected onto one of the state/**x**-space axes



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

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

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

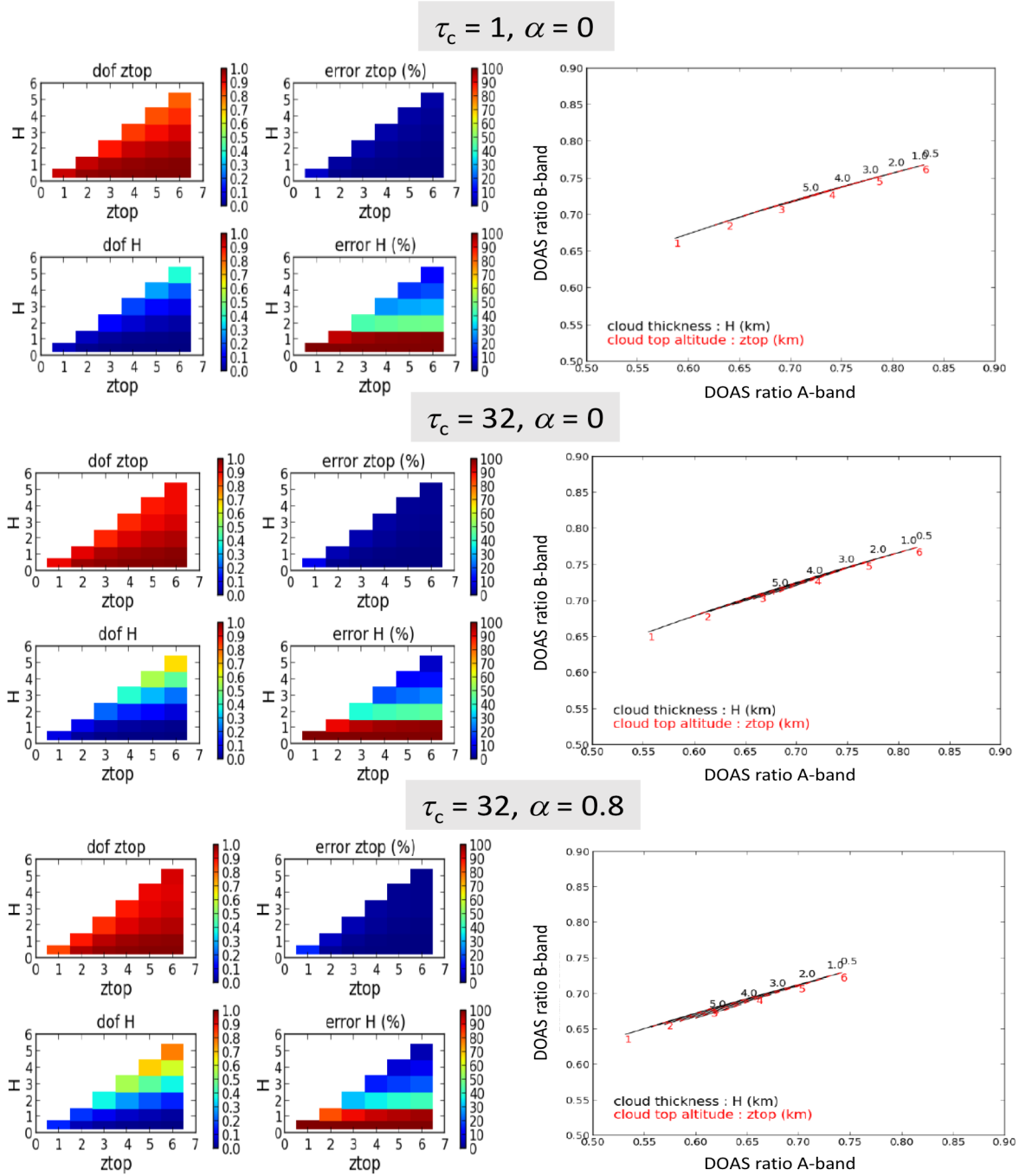


Posterior uncertainty of the retrieved cloud properties

$0 \leq \mathrm{pDOF}_i \leq 1$, 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 σ_i/x_i

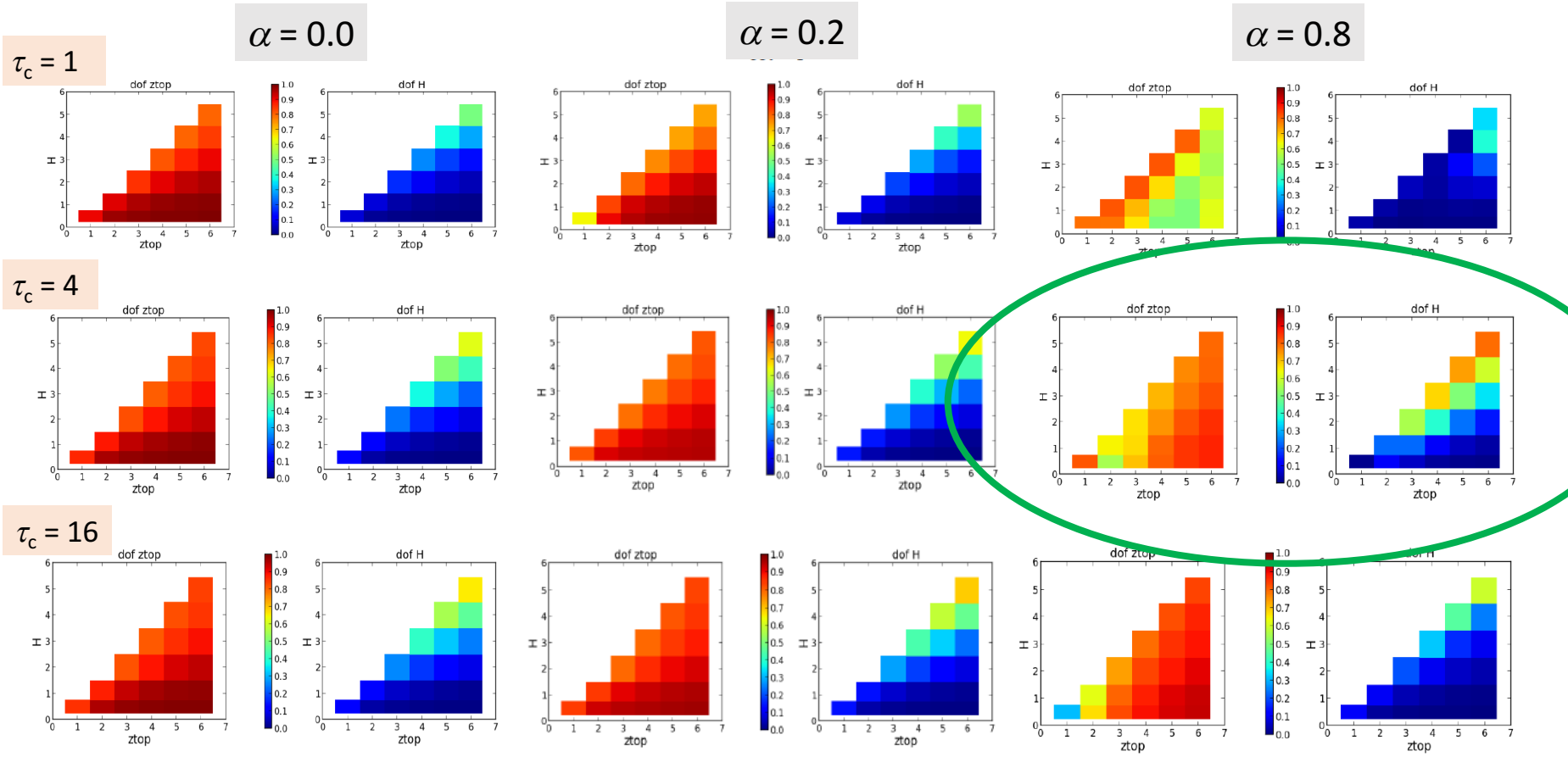
"Nakajima-King" plots of DOAS ratios



DOAS: Differential Optical Absorption Spectroscopy

A sweet spot for z_{top} <u>and</u> H retrieval?

→ moderately opaque clouds over bright surfaces …



… a possible application to arctic clouds?

Conflict with Yang et al. (2013)?

cloud optical thickness (COT) $\tau_c = 30$

→ not really …

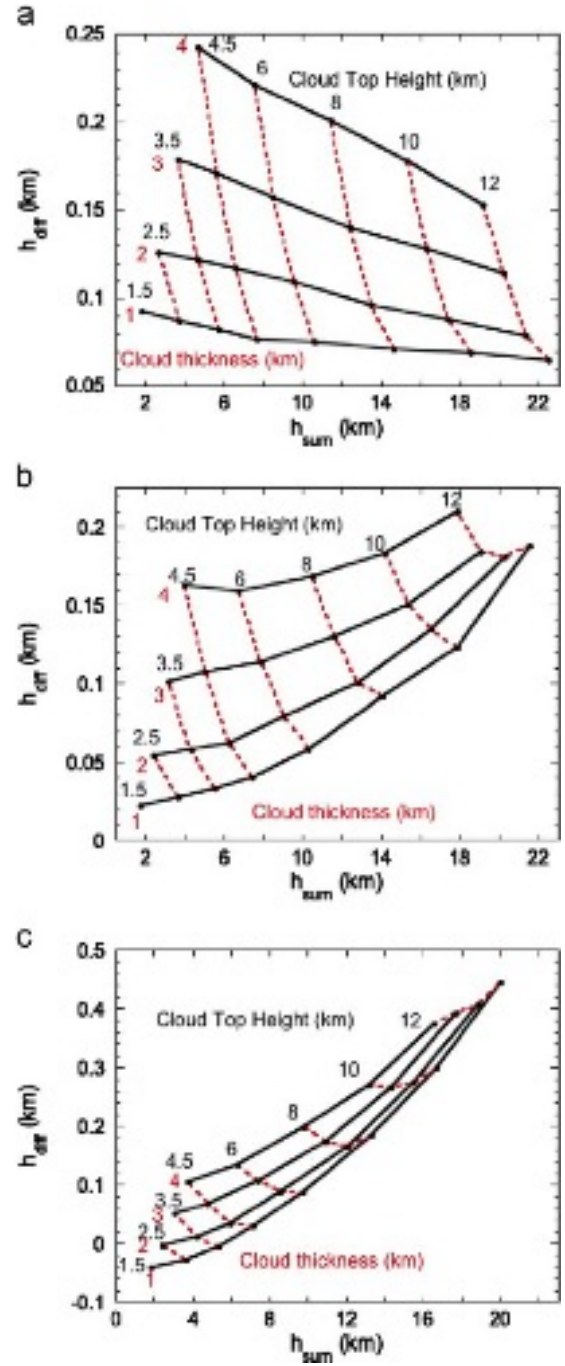
$\tau_c = 10$

ECH: "effective" cloud height

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

$\tau_c = 5$

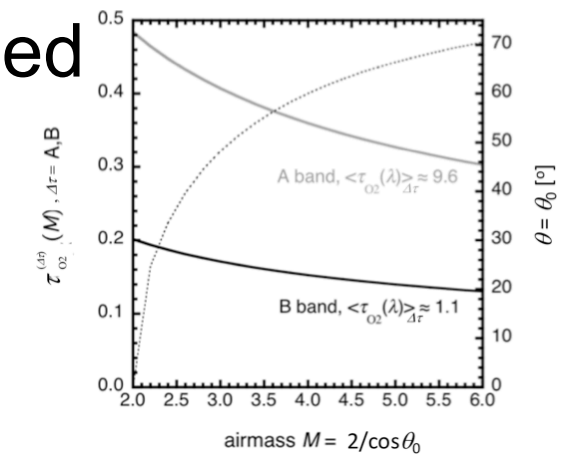
Factoring in sensor error,
uncertainty on h_{diff} is ~ vertical axes
uncertainty on h_{sum} is << horizontal axes



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

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

↑

DOAS ratio

… and here

a pre-asymptotic correction term

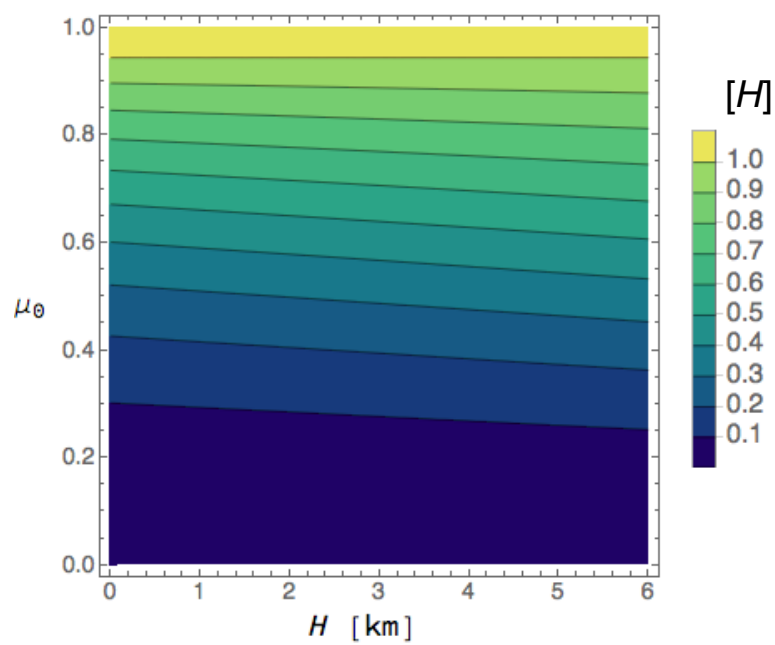
Physical insights …

retrieval bias from ignoring in-cloud path length

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

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

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

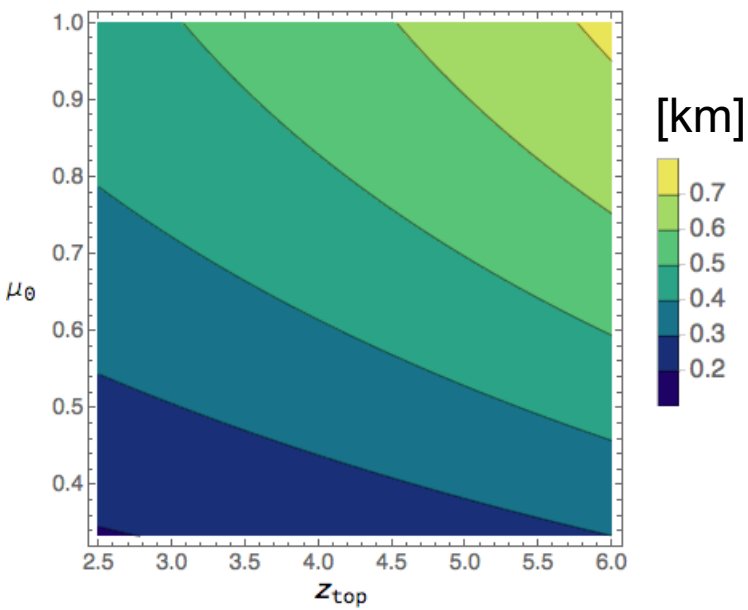


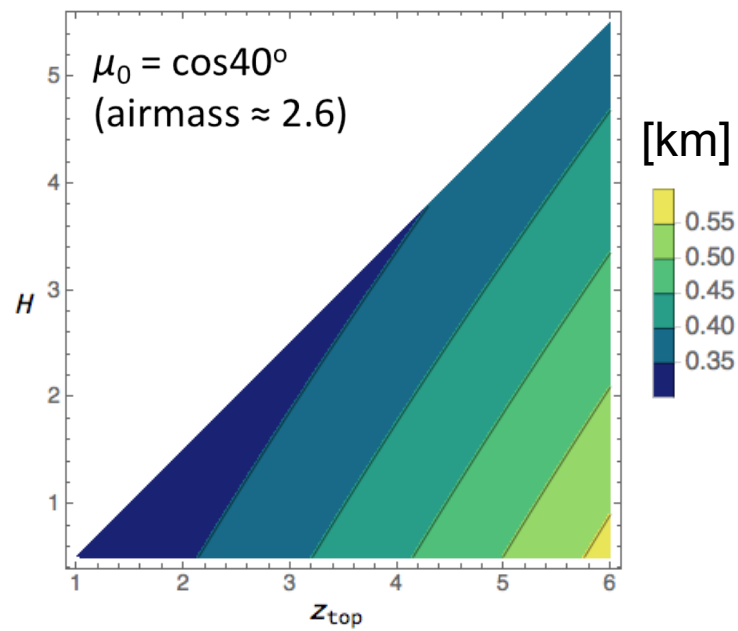
Physical insights …

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

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

$H = 2$ 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