Radiative transfer calculations in regular and super-parameterized GCMs

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Two points to be made:

using super-parametrized GCMs to assess radiative transfer models used in regular GCMs

the importance of multi-dimensional radiative transfer and the feasibility of applying it in a super-parametrized GCM

Using super-parametrized GCMs to assess radiative transfer models used in regular GCMs

Radiation codes in regular GCMs

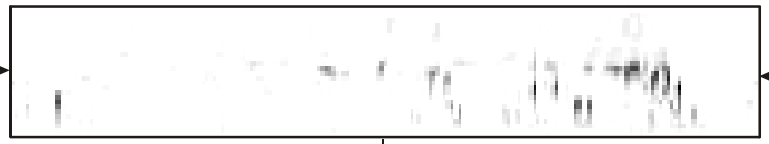
- operate on profiles of cloud fraction, mean water content...
- neglect or make assumptions about:
  - cloud overlap
  - horizontal variability
- then operate on them incorrectly... biases!

SP-GCM

- eliminates guess-work regarding subgrid-scale cloud structure
- focuses on GCM RT model's impact on general circulation

Benchmark

CRM cloud field



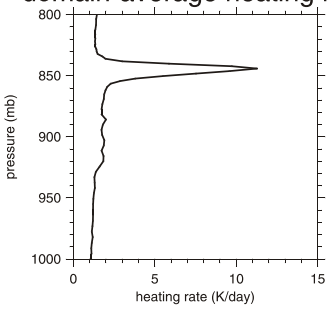
ICA or 3D RT

end of CRM ?

N

Y

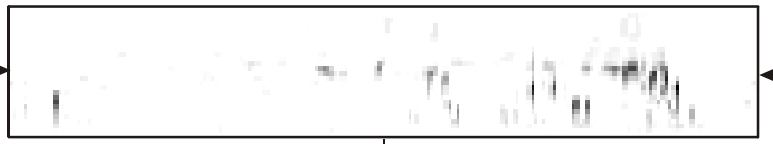
domain-average heating rate



GCM

Experiment

CRM cloud field



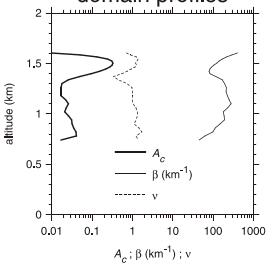
end of CRM ?

N

ICA or 3D RT

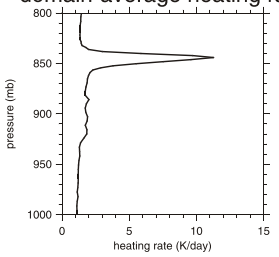
Y

domain profiles



GCM RT code

domain-average heating rate



GCM

The McICA Method

(*Monte Carlo Independent Column Approximation*)

$$\langle \mathcal{F} \rangle \approx (1 - A_c) \sum_{k=1}^{K} c(k) F_{1D}^{clr}(k) + A_c \left[\sum_{k=1}^{K} \frac{c(k)}{N(k)} \sum_{n=1}^{N(k)} F_{1D}^{cld}(s_n, k) \right]$$

clear-sky: regular CKD needed for CRF anyway

cloudy-sky: stochastic sampling / generation of subgrid-scale cloudy columns

- variable clear-sky or surface optical properties:

$$\langle \mathcal{F} \rangle \approx \sum_{k=1}^{K} \frac{c(k)}{N(k)} \sum_{n=1}^{N(k)} F_{1D}(s_n, k)$$

McICA:

- expectation value **is the ICA**...

- unbiased wrt *ALL* assumptions about unresolved clouds etc.

- simplest RT solver + $N(k) = 1 \Rightarrow$ requires *LESS* CPU than current codes

- for single-layer homogeneous clouds, conventional solution is recovered

... produces conditional random noise

The SP-GCM should provide crucial evidence as to whether:

- McICA's conditional random noise impacts general circulation

McICA + SP-GCM:

- sample CRM columns directly

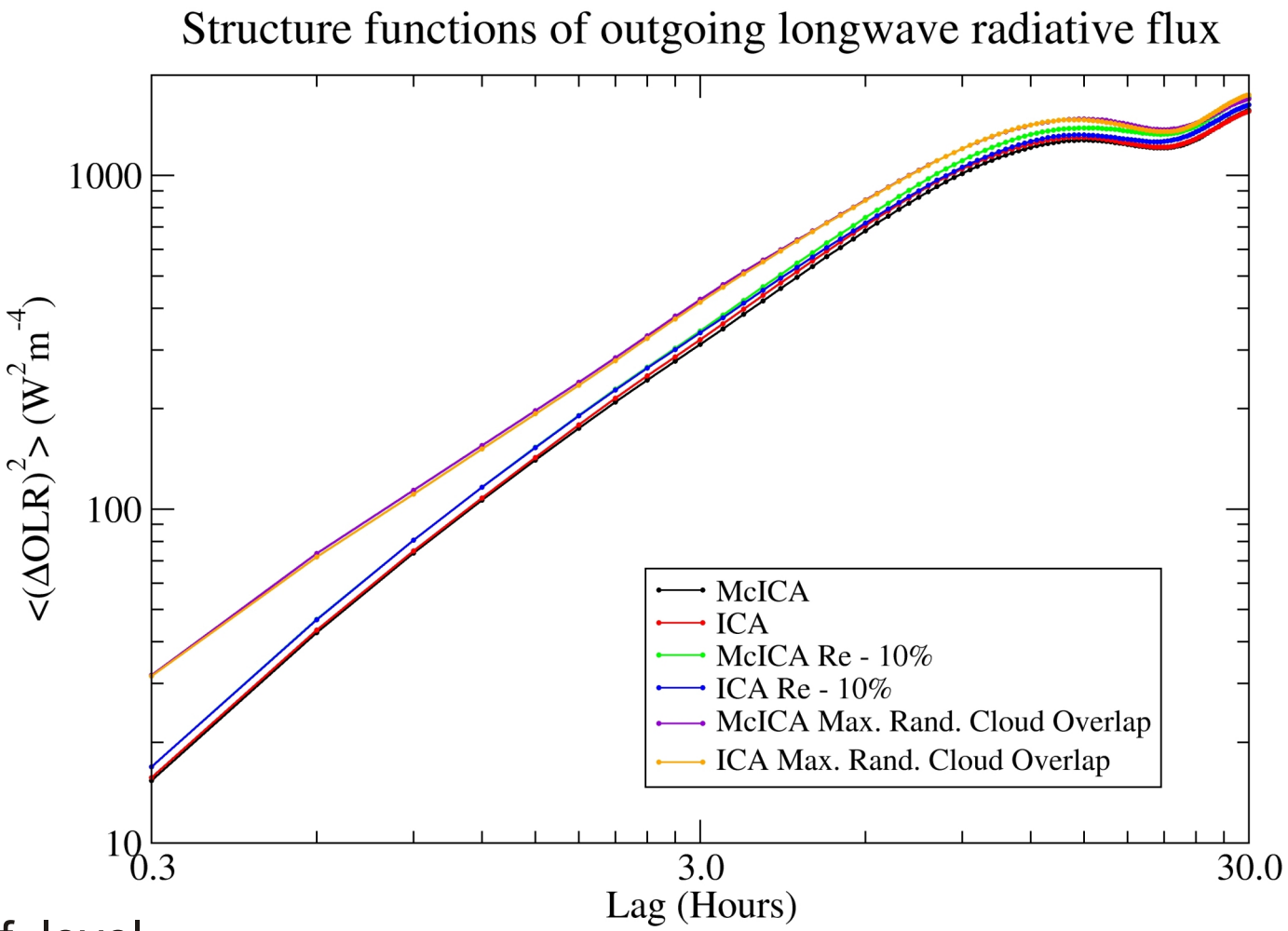
J. Cole:

- preliminary tests with McICA + SP-CAM (ICA as benchmark)
  - ran for 2 trouble-free weeks... very short on CPU time!!!
- tests using McICA + stand-alone CRM (SCM version of SP-GCM)
  - virtually no significant differences between ICA and McICA

- 21 day TOGA-COARE

- 2D CRM - SP config.

- benchmark is ICA



t-test results - 95% conf. level

		McICA C	Re+ D - B	MRO E - A
Upward Longwave TOA		NR	R	NR
Downward Longwave Sfc		NR	R	R
Upward Shortwave TOA		NR	R	R
Downward Shortwave Sfc		NR	R	R
Total Cloud Fraction		NR	NR	NR
Precipitable Water		NR	R	R
Precipitation Rate		NR	NR	NR

systematic alterations to RT calculations have significant impacts on model evolution

McICA: insignificant impact

McICA + Regular GCM:

- subgrid-scale columns are not available for direct sampling

- Stochastic subgrid-scale column generator

Example: Räisänen et al. 2003

- A single day from Randall and Khairoutdinov's super-GCM

- 8 timesteps separated by 3 hrs

- McICA using CKD with SW(31) + LW(46) (J. Li; CCCma)

- basic result:

  - generator fosters minimal biases (clouds and radiation)

  - can accommodate essentially *any* subgrid-scale optical fluctuation

  - **don't use** MR overlap with homogeneous (or inhomogeneous) clouds!!!

    - despite the current trend!!!

Performing multi-dimensional RT it in an SP-GCM

Two main questions:

1. Is it important enough to be essential?... If so, then:

    - ICA for CRM... 3D RT domain-averages for GCM only?

    OR

    - 3D RT for cell-wise heating / cooling in both the CRM and GCM?

2. Is it feasible in a SP-GCM?

    - exact solution with random noise

        - accuracy limited by number of photons;

        - cf. encouraging results thus far for McICA...

Is it important enough to be essential?

- SW and LW Monte Carlo in stand-alone CRM... *ongoing this week*!

- proxy:

  - SW ICA in stand-alone CRM with suitable noise:

$$\sigma = \sqrt{\frac{\alpha\,(1-\alpha)}{N}}$$

where N = number of photons / CRM column

  - indication of tolerable noise (i.e., what N to use)

- TOGA-COARE

  - SP-GCM configuration (2D ; 64 - 4 km columns)

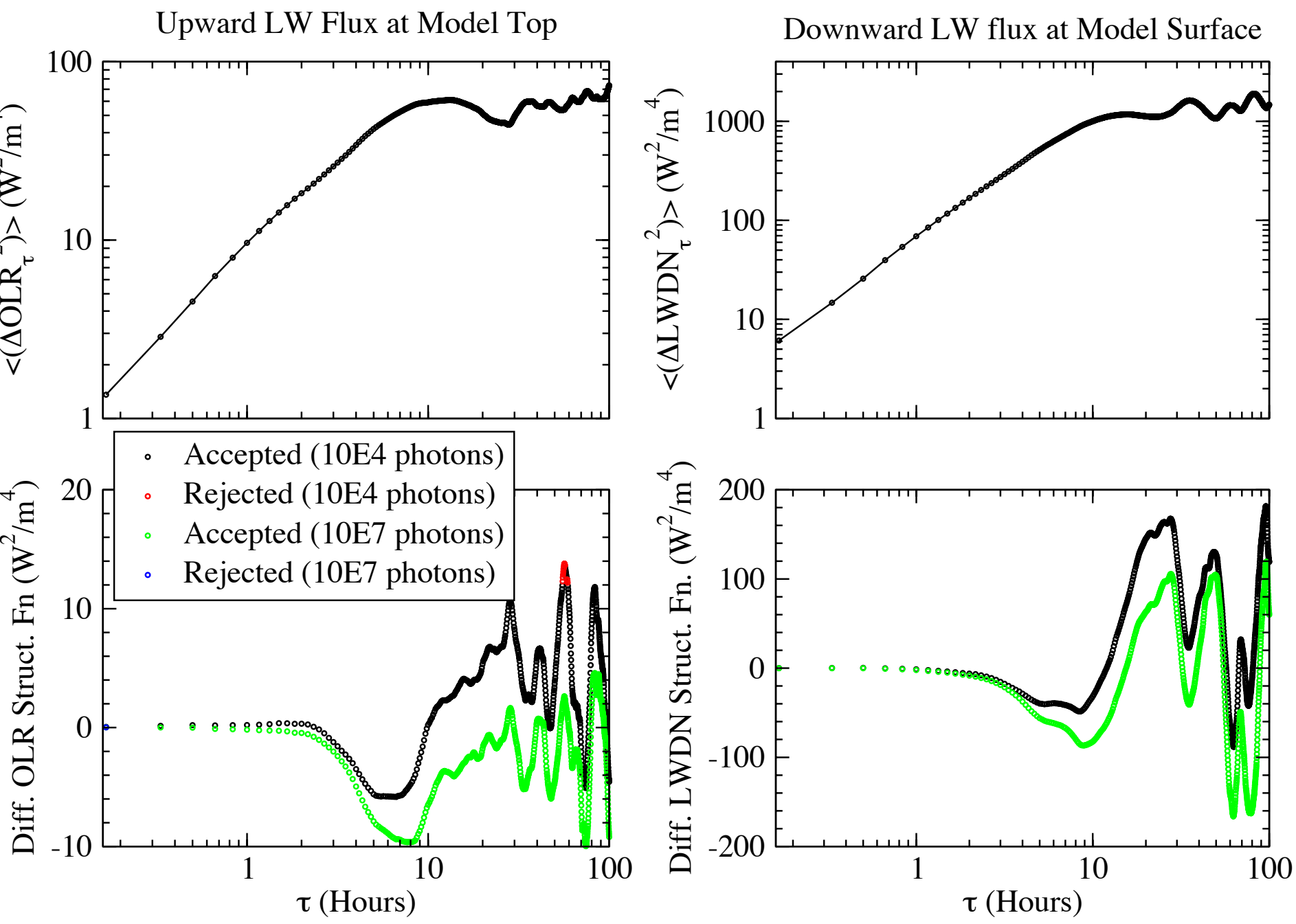
  - 21 days

  - control: ICA updated every 15 minutes

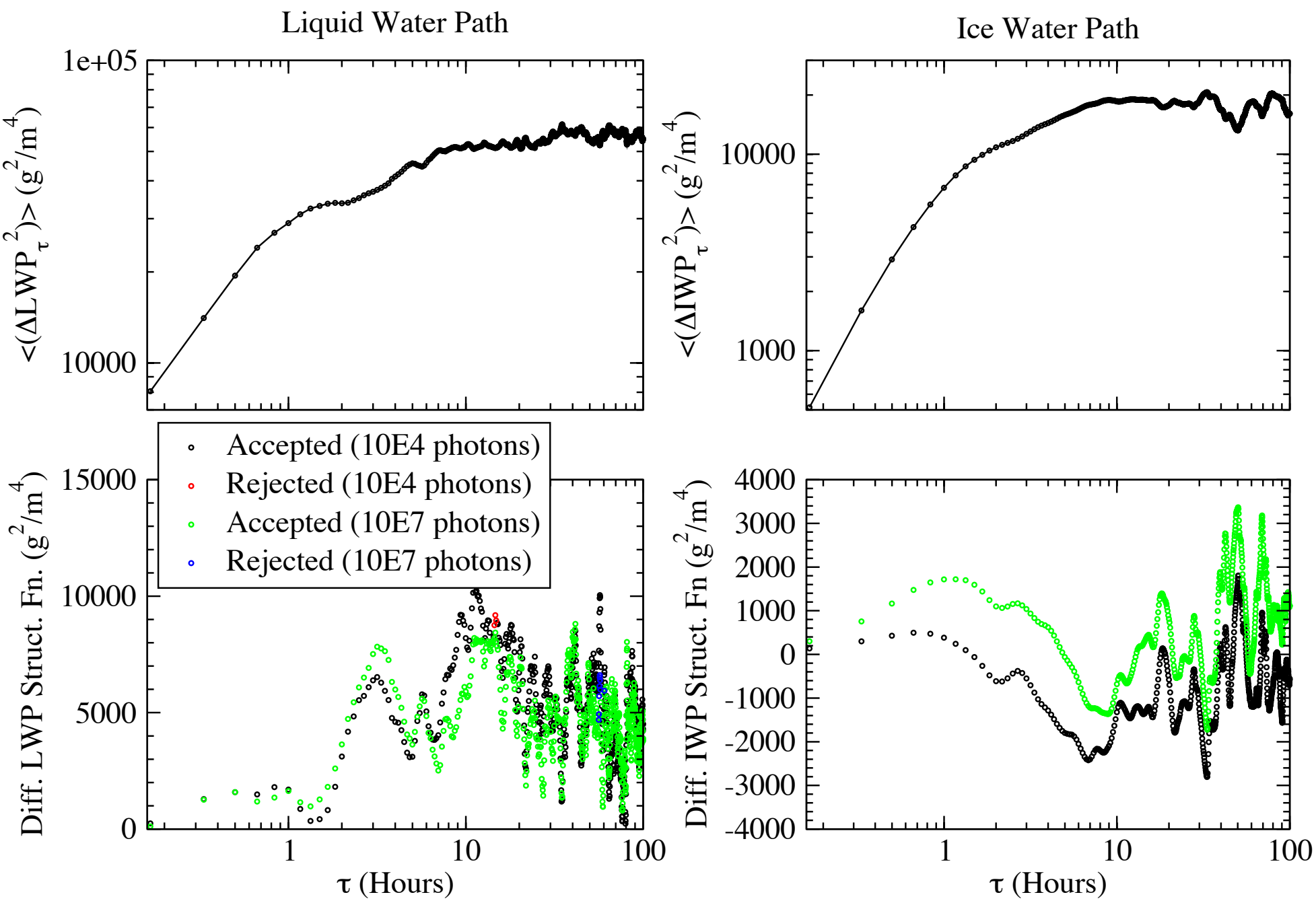
  - experiment:
    - MC updated every 15 minutes
    - solar azimuth = 45 deg. to CRM plane
    - cell-wise heating in a CRM
    - noise levels based on:
      - 10^4 and 10^7 photons/domain

much faster than ICA (156/column)!!!

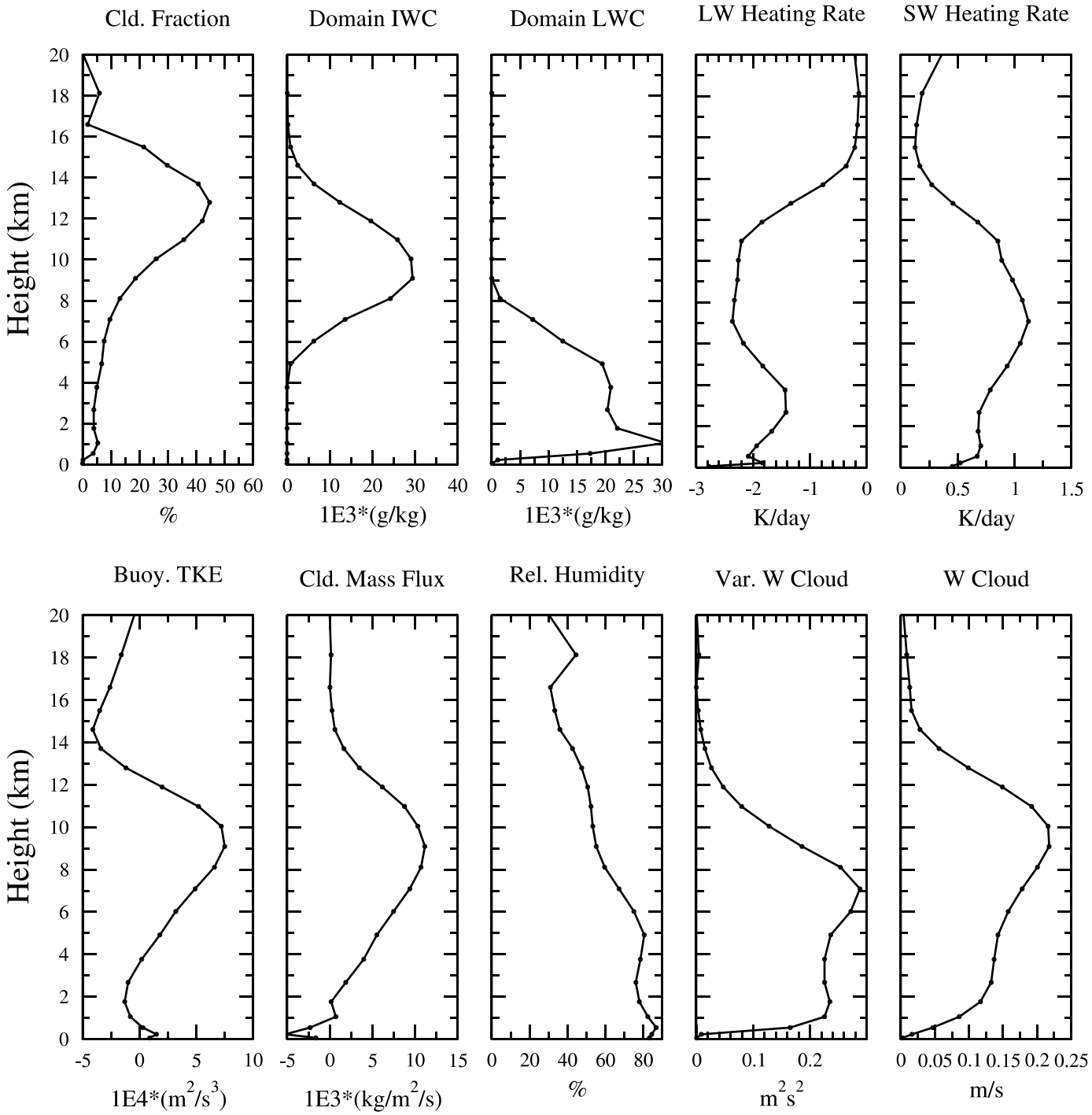
Structure functions of upward LW flux at model top (OLR) and downward LW flux at model surface (LWDN)



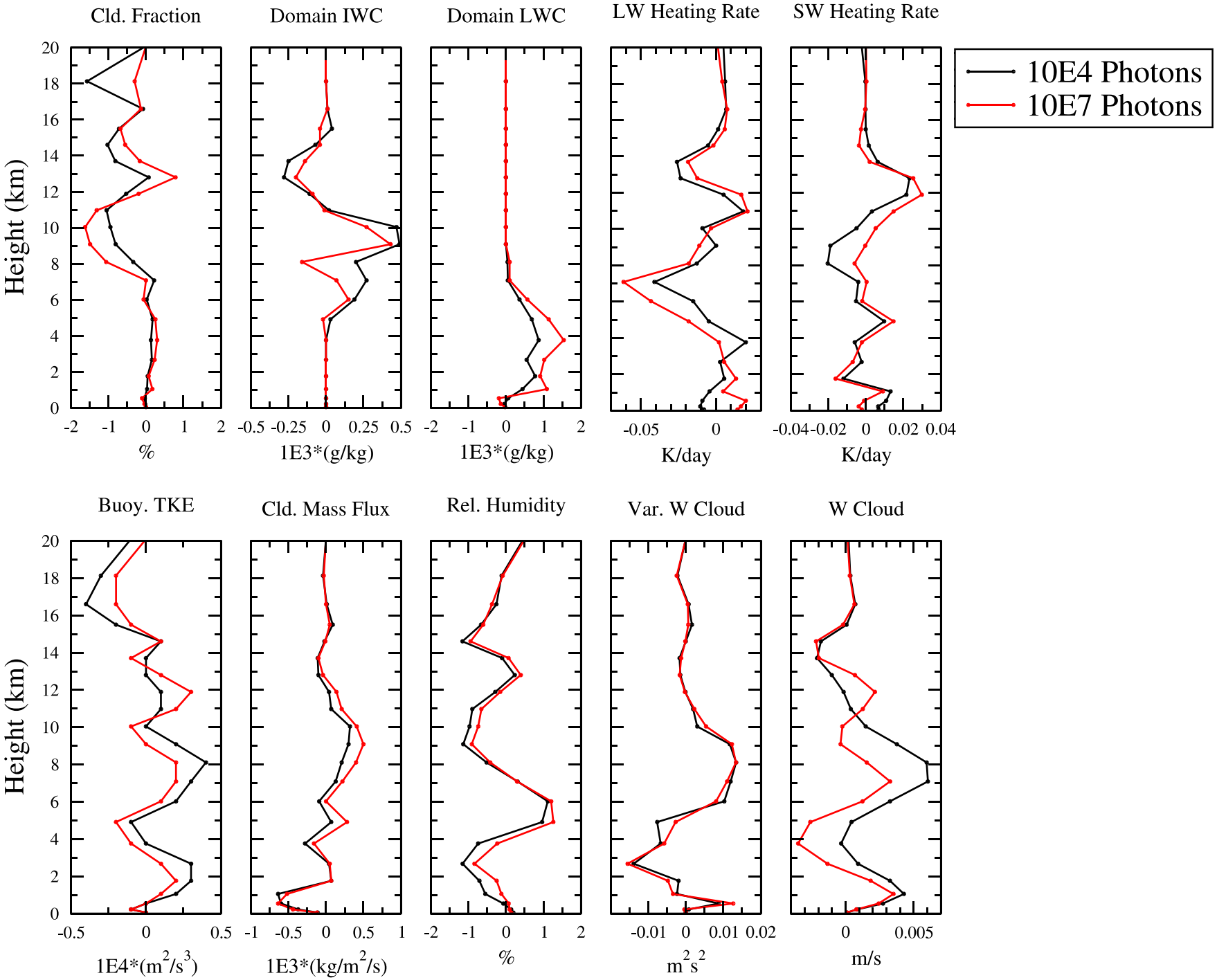
Structure functions of cloud liquid water path (LWP) and cloud ice water path (IWP)



Vertical profiles for control averaged over 21 days (TOGA-COARE)



Differences between experiment and control averaged over 21 days (TOGA-COARE)



- almost no significant differences in evolution... even for 10^4 photons / domain!

- absolutely essential to verify with other CRM simulations and full SP-GCM...

- but it appears that full 3D MC is computationally feasible for the SP-GCM

Conclusion

assessing GCM-style RT codes using the SP-GCM

- preliminary tests with stand-alone CRMs
- so far, McICA has passed all its tests
- main test will come with SP-GCM climate simulation

2D/3D Monte Carlo appears to be entirely feasible for SP-GCMs

- only ICA proxy results to show at the moment
- MC in stand-alone CRM by end of week
- ready to go in SP-GCM... pending CPU time