A PCRTM-based radiance simulator with full treatment of cloud overlapping and sub-grid variability

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Roadmap

- Motivation
- Implementation
- Comparisons with the model results
  - ECMWF ERA-interim (maximum random overlap)
  - GFDL AM2 (random overlap)
- Sensitivity and speed
- Implications for OSSE and spectral fingerprinting
- Conclusion and discussion

Motivations

- Simulator or OSSE should be designed with maximum consistency with the GCM formulation.
  - Gaseous absorption and emission
    - Both should have been tested against the benchmark LBLRTM
  - Optical properties of Cloud and aerosol
    - In principal, they can be specified in simulator or OSSE
  - Cloud overlap
  - Subgrid variability of other variables

Motivations (II)

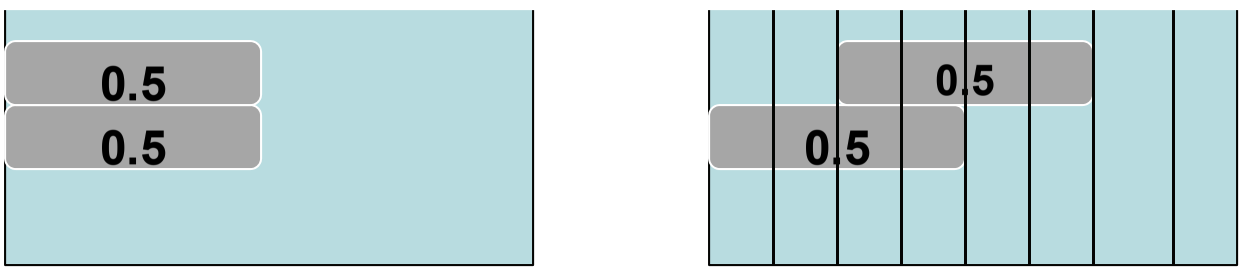
- Cloud overlap assumptions in the GCMs
  - Maximum random overlap
  - Random overlap
  - Pincus' Monte-Carlo scheme

$$\frac{1-C^k}{1-C^{k-1}} = \frac{1-\max(a^{k-1}, a^k)}{1-\min(a^{k-1}, 1-\delta)}$$

$$1-C^k = \prod_{i \le k}(1-a^i)$$

C^k : total cloud fraction at the *k-th* layer (top down)

a^k : cloud fraction of the *k-th* layer

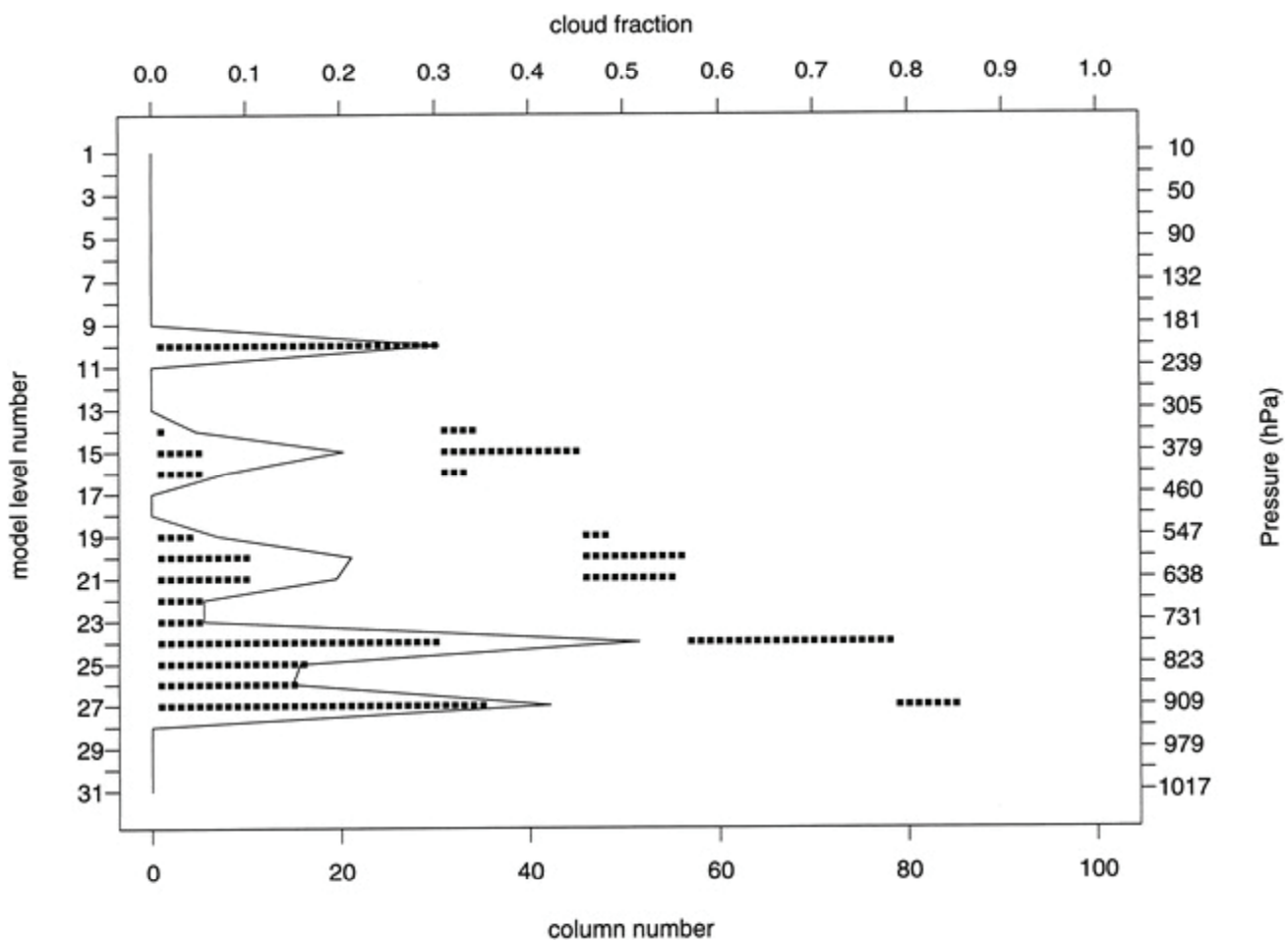


Total cloud fraction: 0.5 **0.75**

Total cloud fraction: 0.75 **0.875**

Question: To what extent such different realizations affect OLR, spectral radiances, and spectral fingerprints, respectively?

Motivations (III): A straightforward solution —sub-column



(Klein and Jakob, 1999, MWR)

Motivations (IV)

Why not compute $\mathcal{T}$ of gas and cloud separately?

- Sub-grid variability not only for clouds
- Total water, **qt** (vapor+condensed), assumed to have a certain PDF
- Joint PDF of **vertical velocity**, **T**, and **qt**

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A PDF-Based Model for Boundary Layer Clouds.
Part I: Method and Model Description

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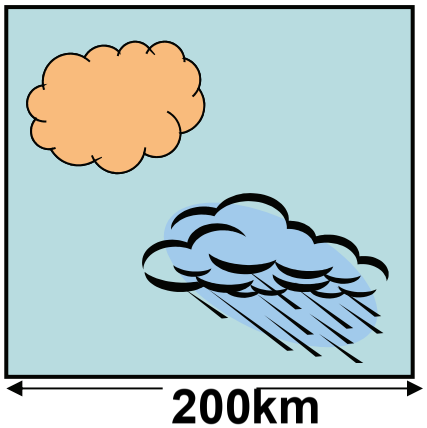


Motivation (V): PCRTM

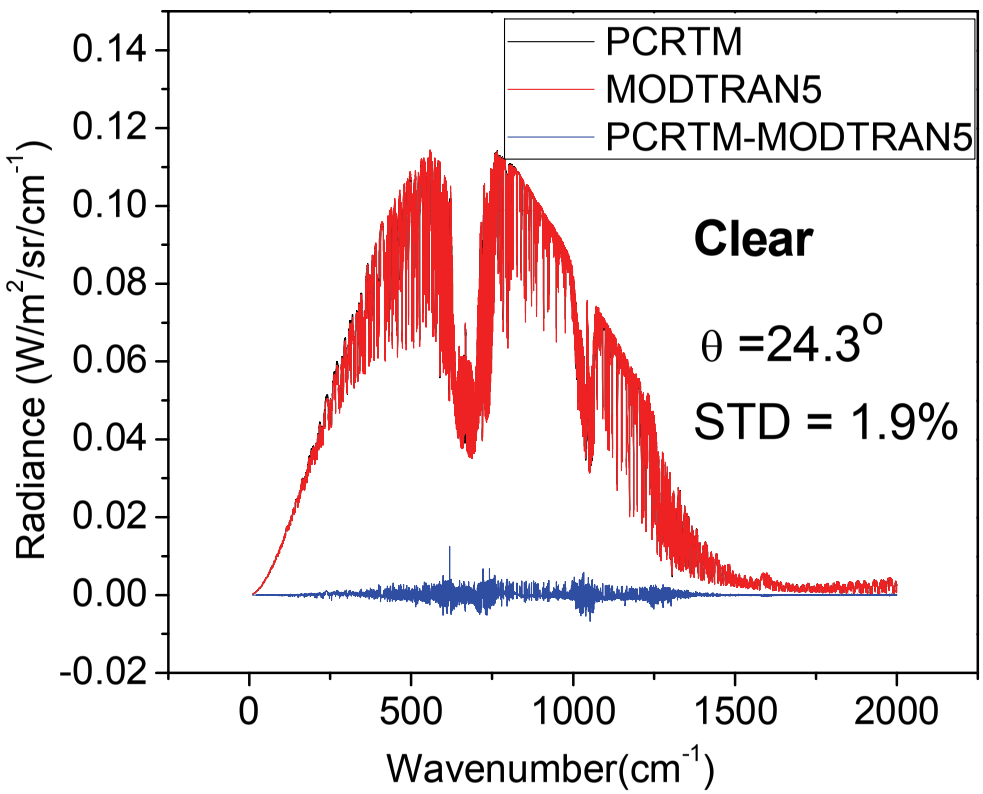
- Computationally expensive for sub-column realization
- PCRTM is very fast and can afford such calculations

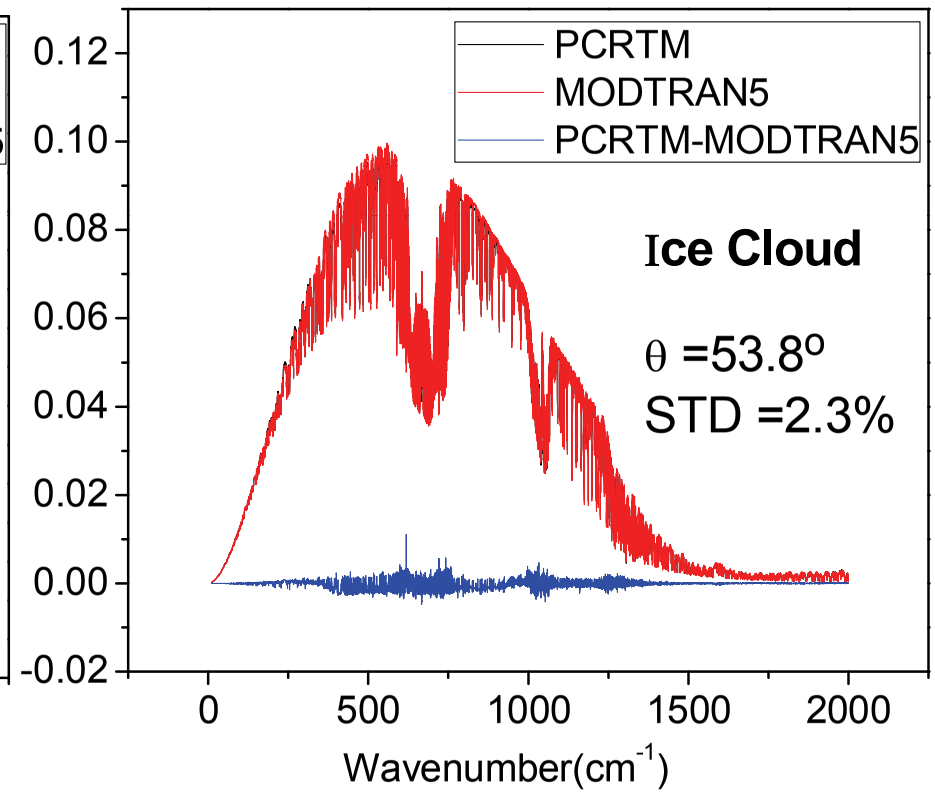
Model	N_{ch}	Number of RT run (N_{RT})	N_{RT} for each channel	Run-time for each channel
PCRTM	19901	964	0.048	0.2 s
MODTRAN5	19901	19901	1	6 s
LBLRTM	19901	8198549	412	224 s

10-2000 cm^{-1}, *dv* = 0.1 cm^{-1}

Single processor of a 6-core Opteron 4174 HE

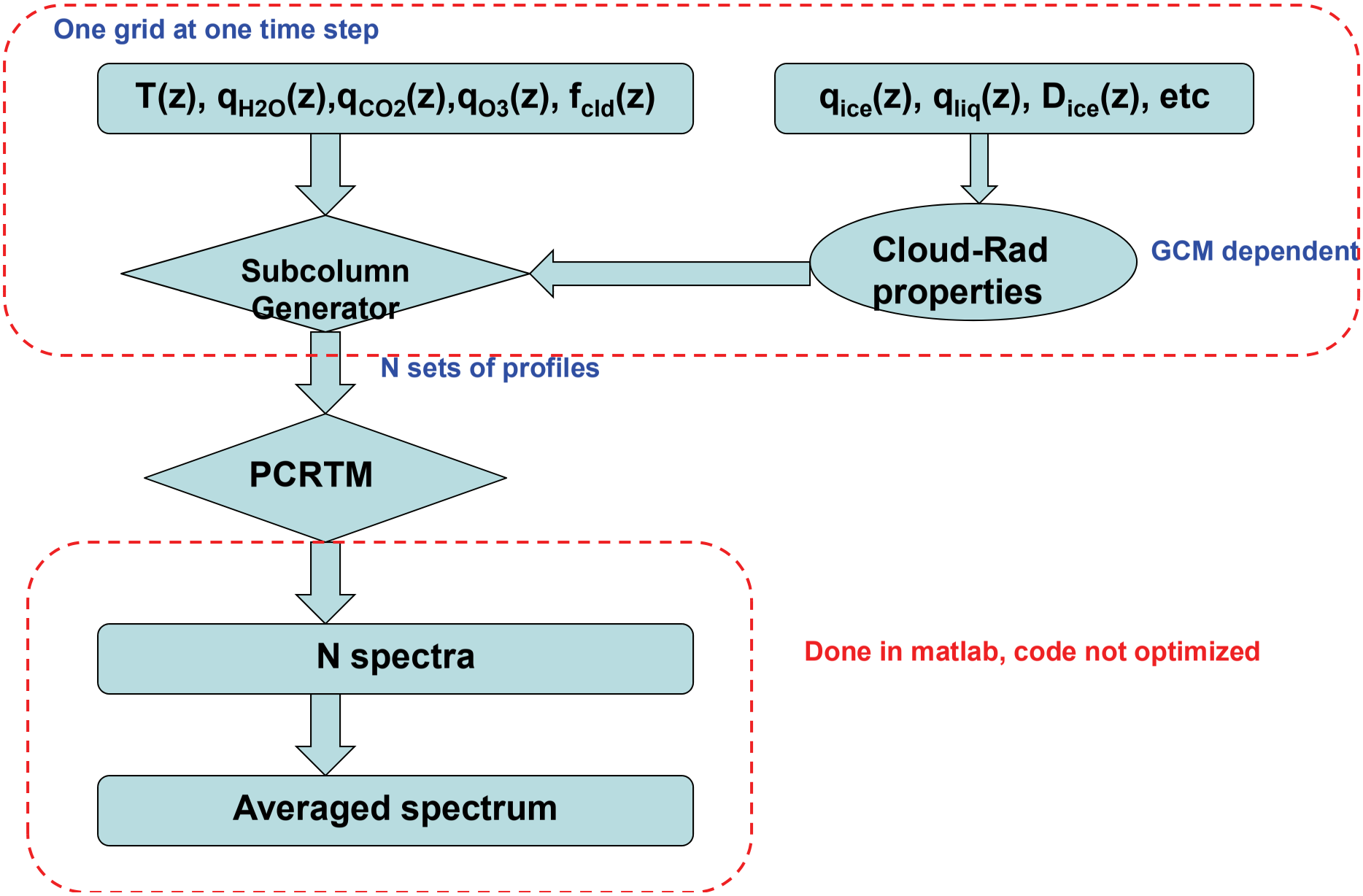
PCRTM .VS. MODTRAN5





τ_{vis}=0.5, H_{top}=10.24km

Implementation



Comparison with model results

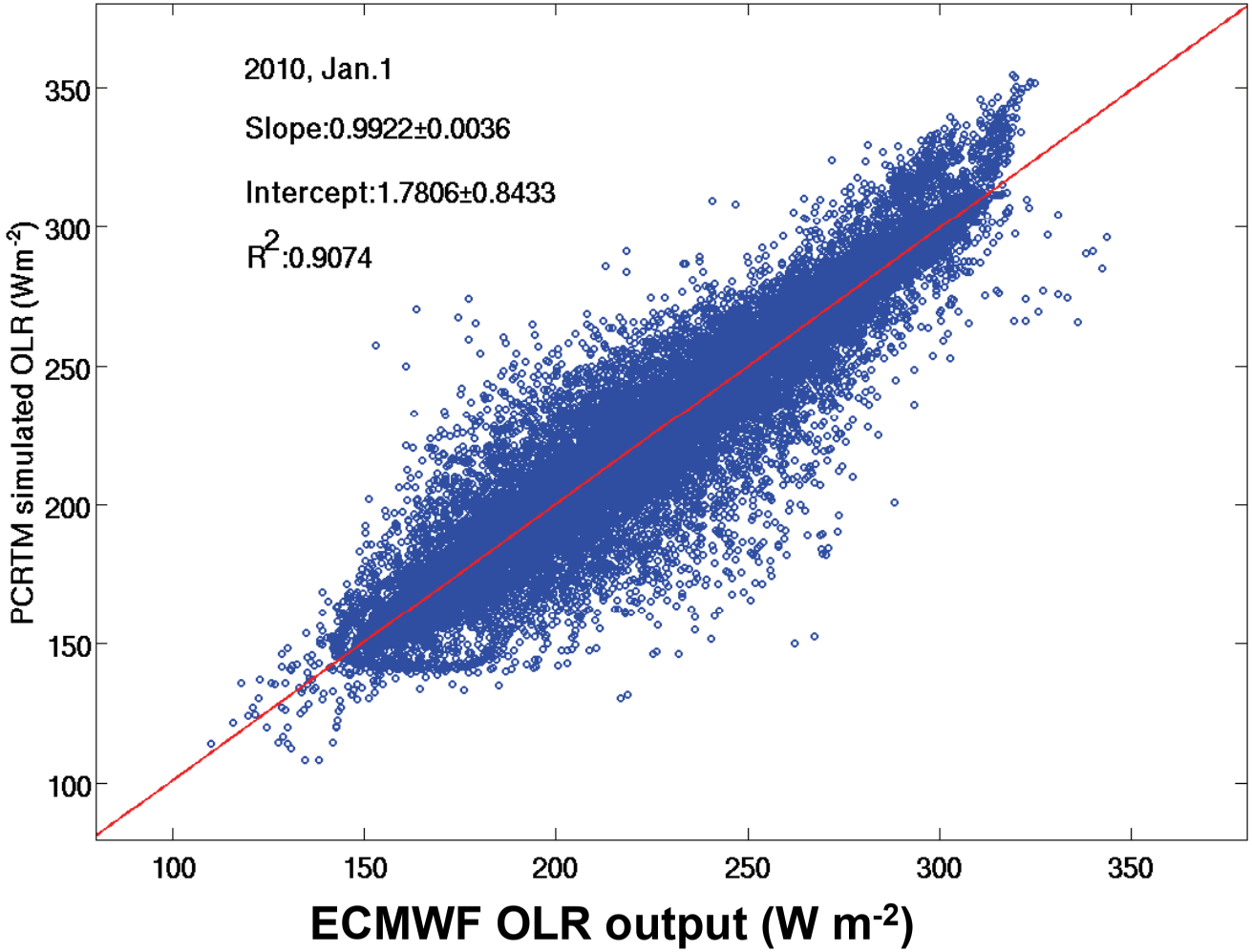
- Use PCRTM to compute OLR
- Compare with the OLR from 6-hourly ERA-interim results (OLR is not an assimilated quantity)
- Do the same thing for the GFDL AM2 simulation

ERA-interim: maximum-random

GFDL: random

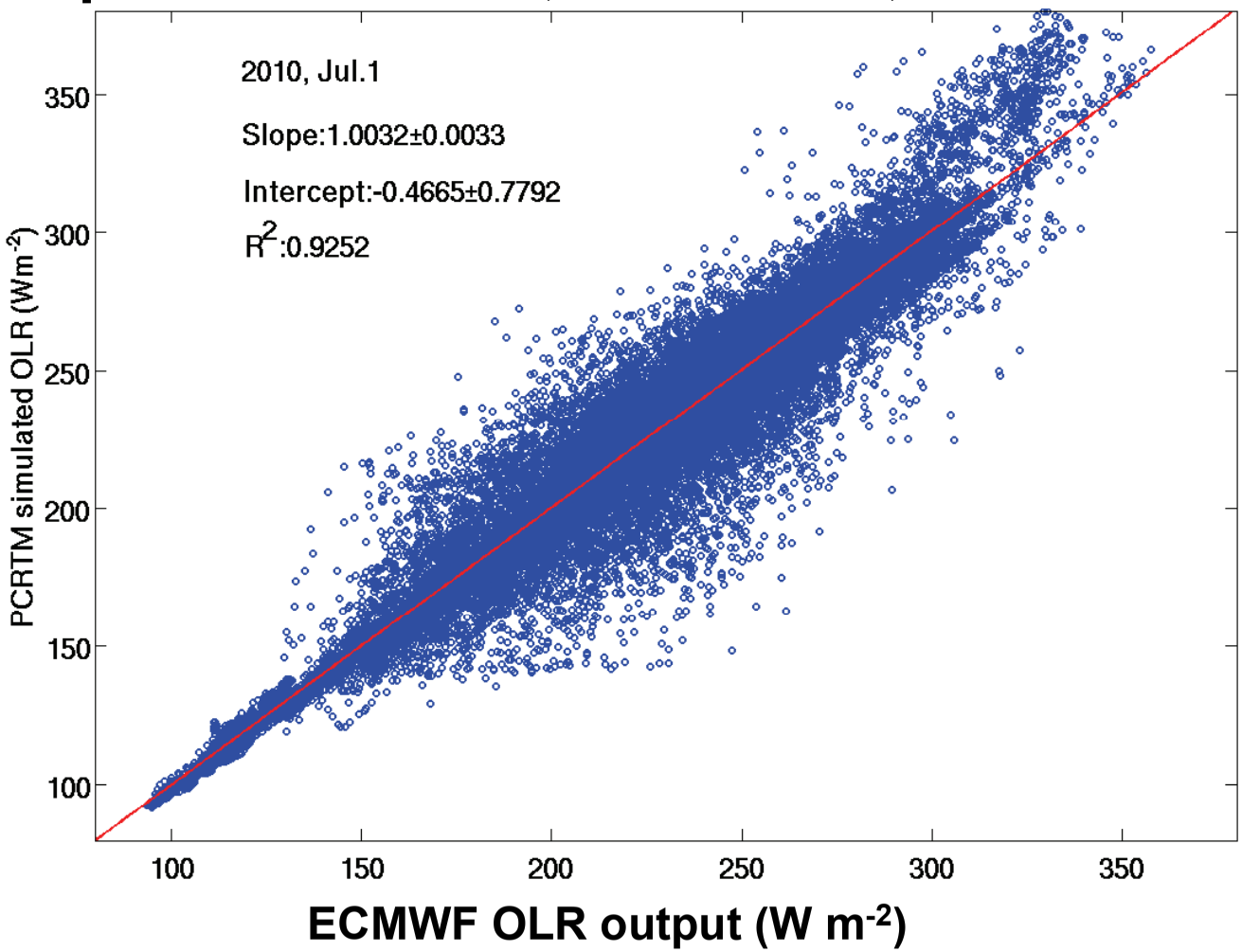
Case of ERA-Interim

90° S-90° N
(one snapshot:12:00UTC, 01-01-2010, 100 sub-columns)



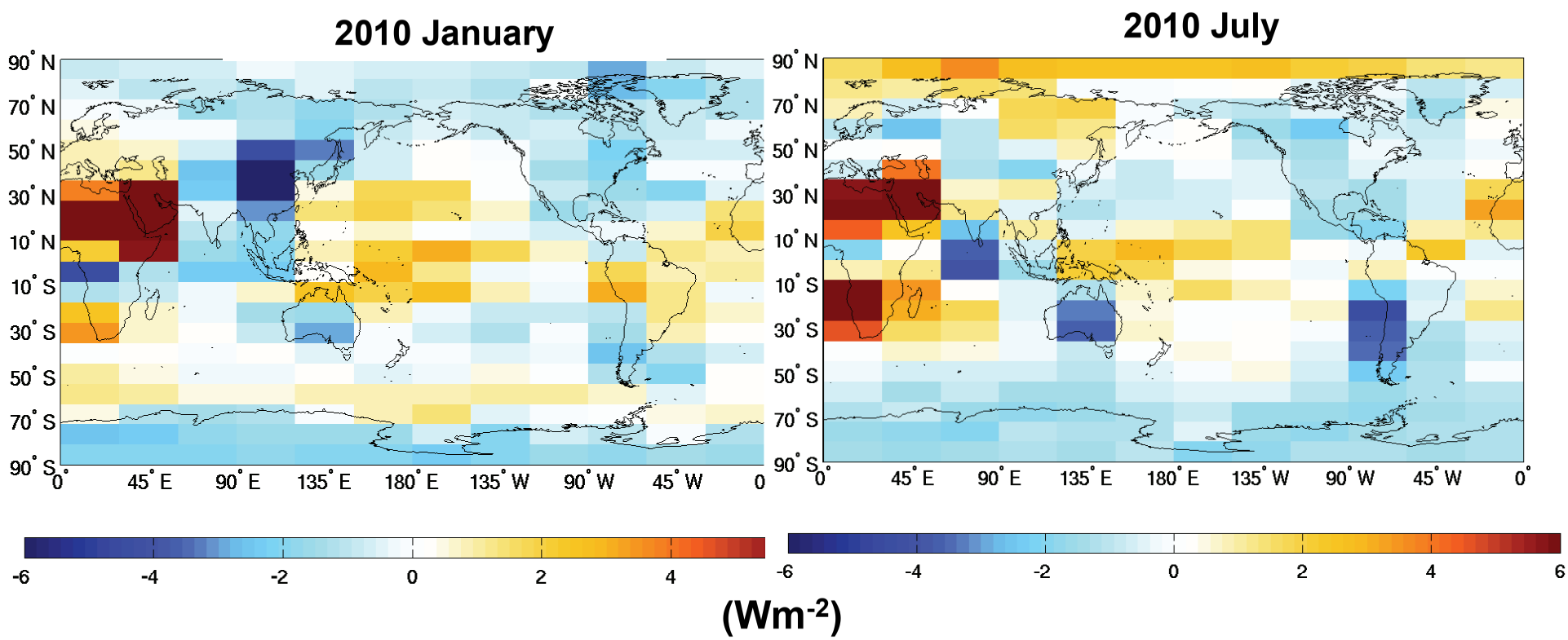
Case of ERA-Interim

90° S-90° N
(one snapshot:12:00UTC, 07-01-2010, 100 sub-columns)



Case of ERA-Interim

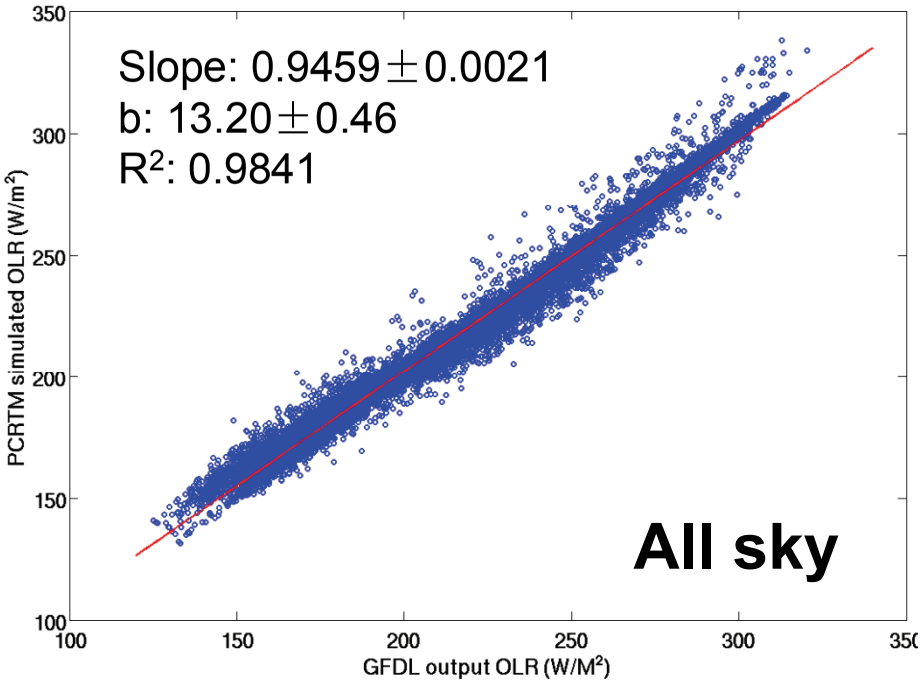
(3) OLR_P – OLR_E (100 sub-columns)

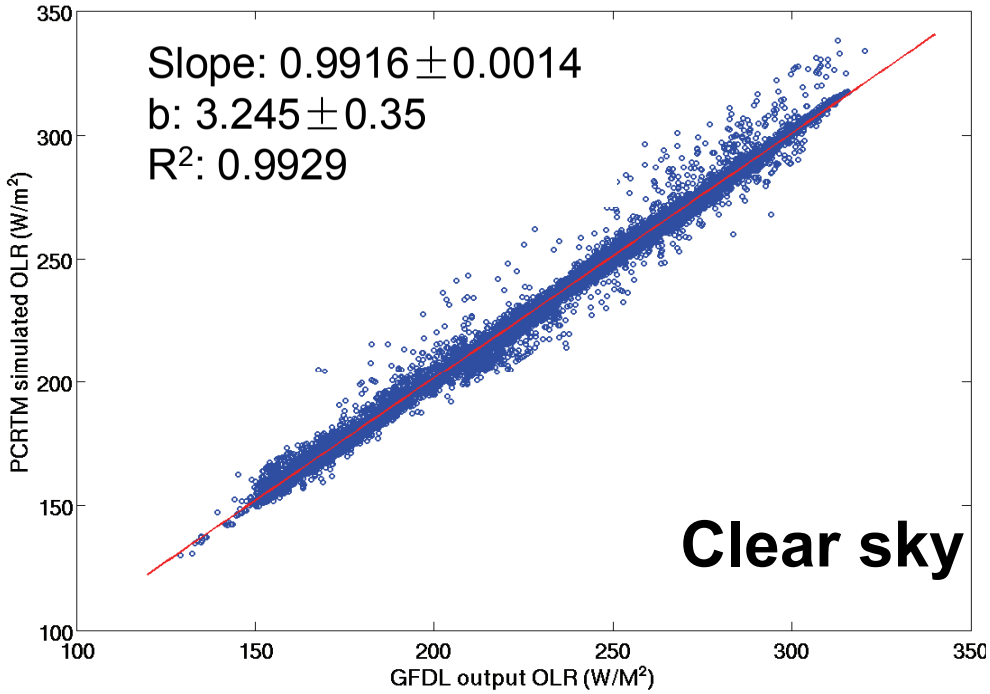


Averaged onto 9°×30° grids

Case of GFDL AM2

90°S-90°N , 00:00 UTC, 02-01-2003

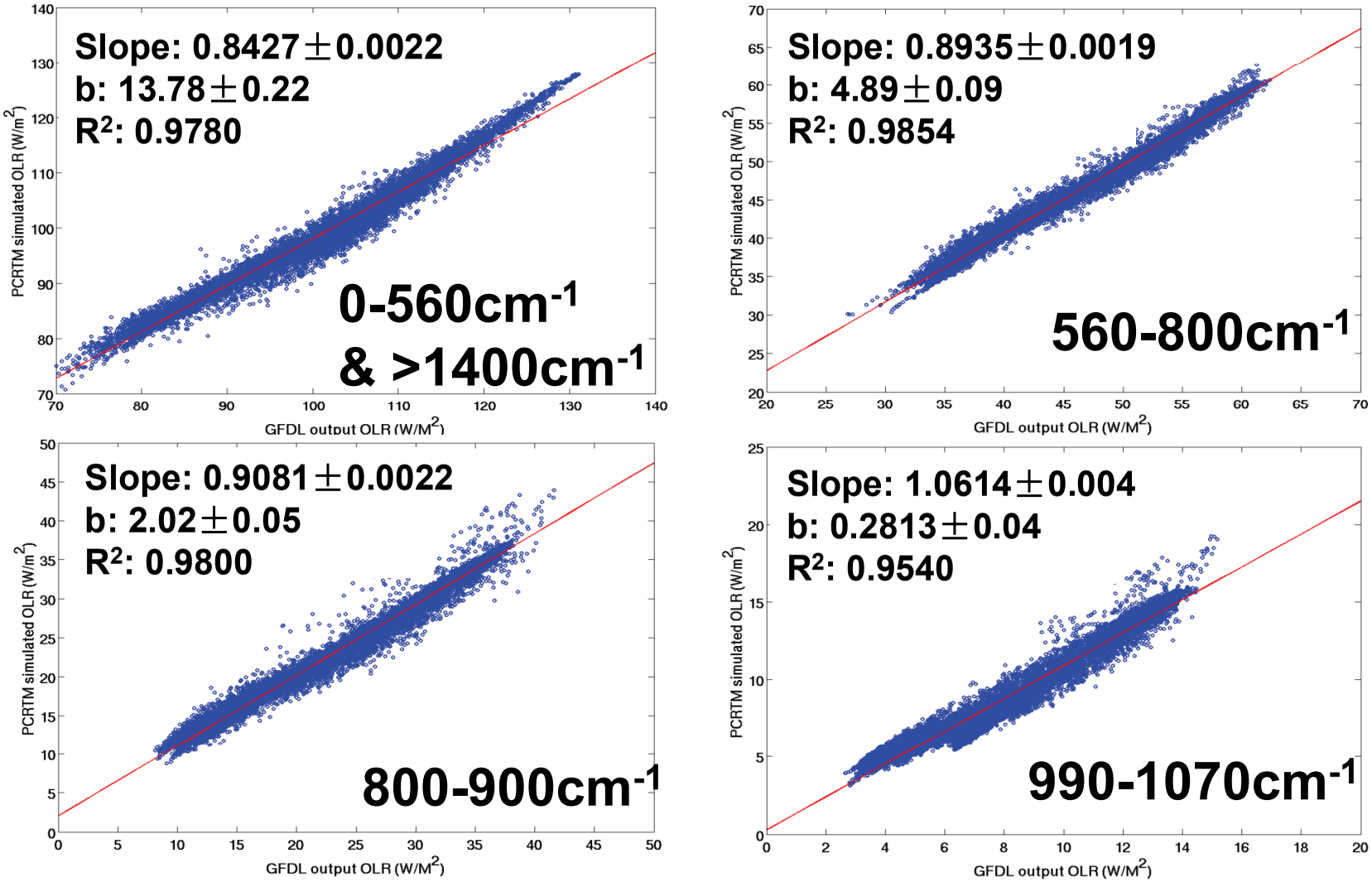




Case of GFDL AM2

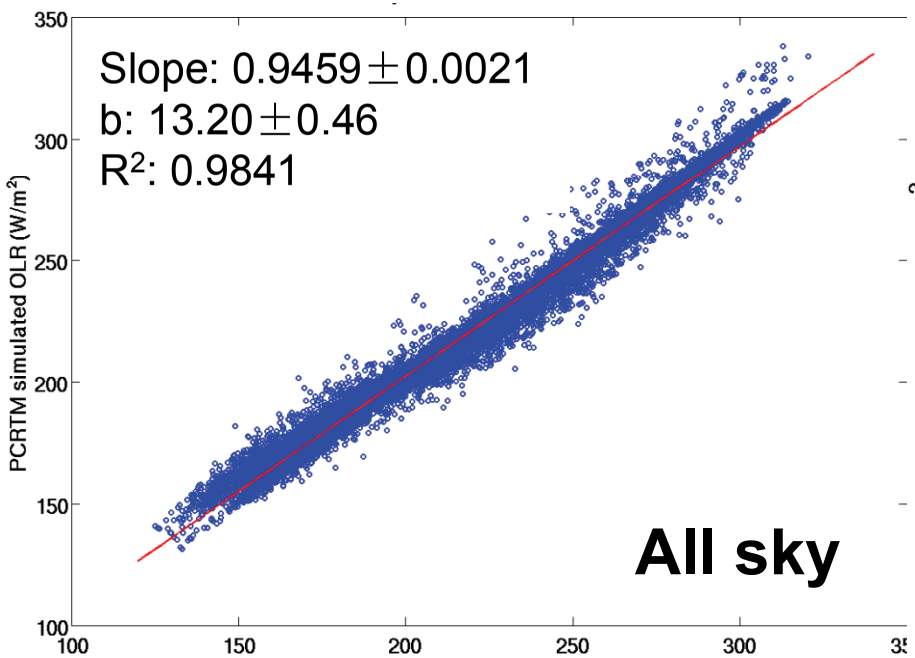
90°S-90°N , 00:00 UTC, 02-01-2003

GFDL AM2 used a different H_2O continuum from the PCRTM (CKD 2.1 vs. MT_CKD 2.4)

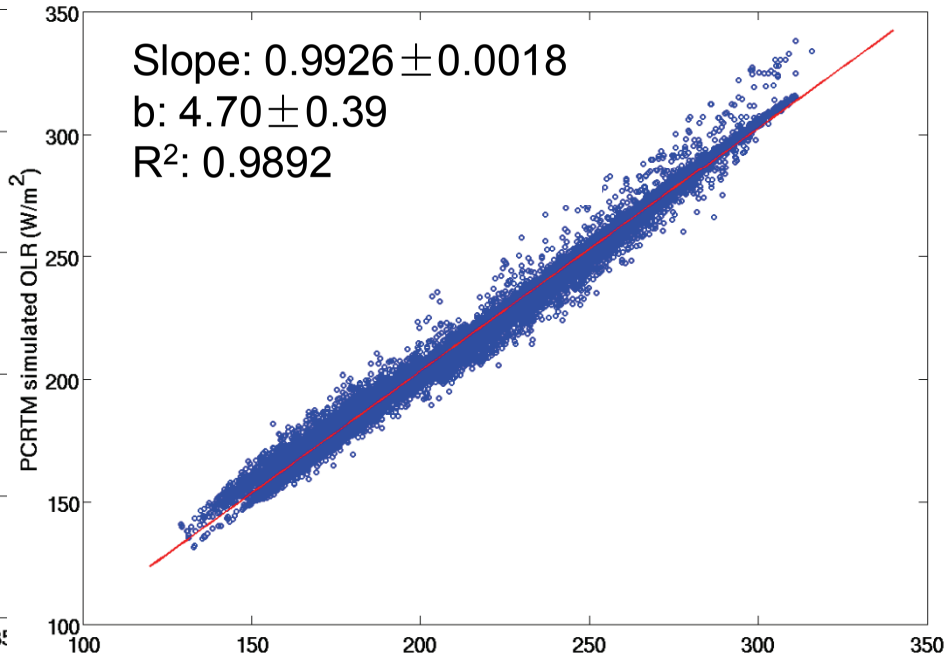


Case of GFDL AM2

90°S-90°N , 00:00 UTC, 02-01-2003



OLR_{GFDL}



OLR_{GFDL}-F_{GFDL}(0-560 cm^{-1},>1400 cm^{-1}) + F_{PCRTM}(0-560 cm^{-1},>1400 cm^{-1})

OLR_{PCRTM} .VS. OLR_{GFDL}

Sensitivity to number of sub-columns

ECMWF: 90°S-90°N, 180°W-180°E
12:00 UTC 07-01-2010

Number of sub-columns	80	40	20
Slope	1.0033±0.0033	1.0028±0.0033	1.0034±0.0034
Intercept	-0.479±0.780	-0.390±0.789	-0.502±0.798
R-Square	0.9251	0.9235	0.9219
Time	6427 s	4810 s	3564 s

Run on an Oracle/Sun *Fire* X2100 workstation
1.5×1.5 resolution, coded in Matlab script (not optimized)

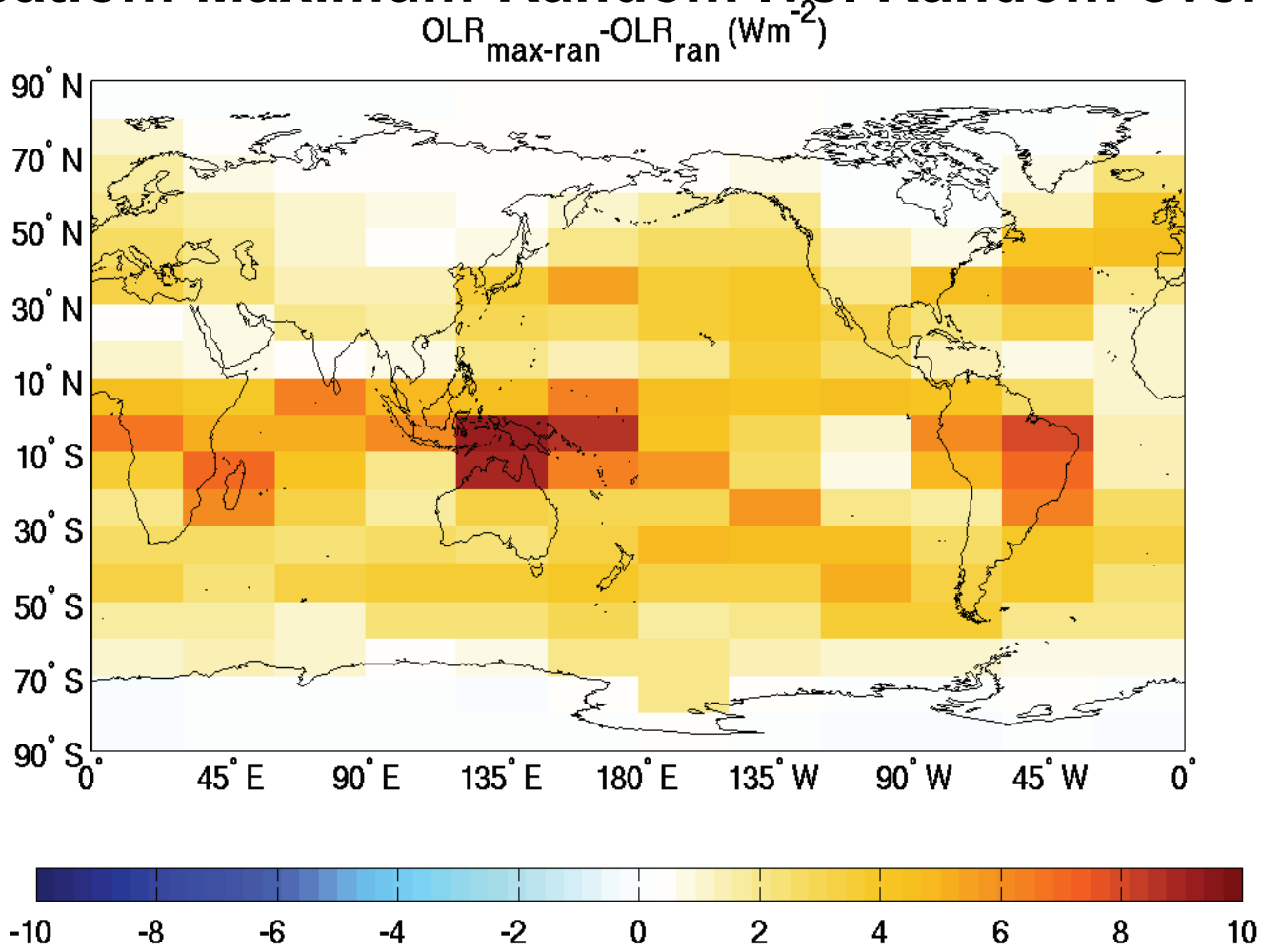
Sensitivity to number of sub-columns

GFDL: 90°S-90°N, 180°W-180°E
00:00 UTC 02-01-2003

Number of sub-columns	**80**	**40**	**20**	**10**
Slope	0.9459±0.0021	0.9459±0.0022	0.9455±0.0024	0.9450±0.003
Intercept	13.204	13.212	13.301	13.37
R-Square	0.984	0.982	0.979	0.971
Time	5429 s	3337 s	2102 s	1376 s

Run on an Oracle/Sun *Fire* X2100 workstation
2×2.5 resolution, coded in Matlab script (not optimized)

Implication: Maximum-Random .vs. Random overlap



One month of 6-hourly results averaged onto 10° by 30° grids

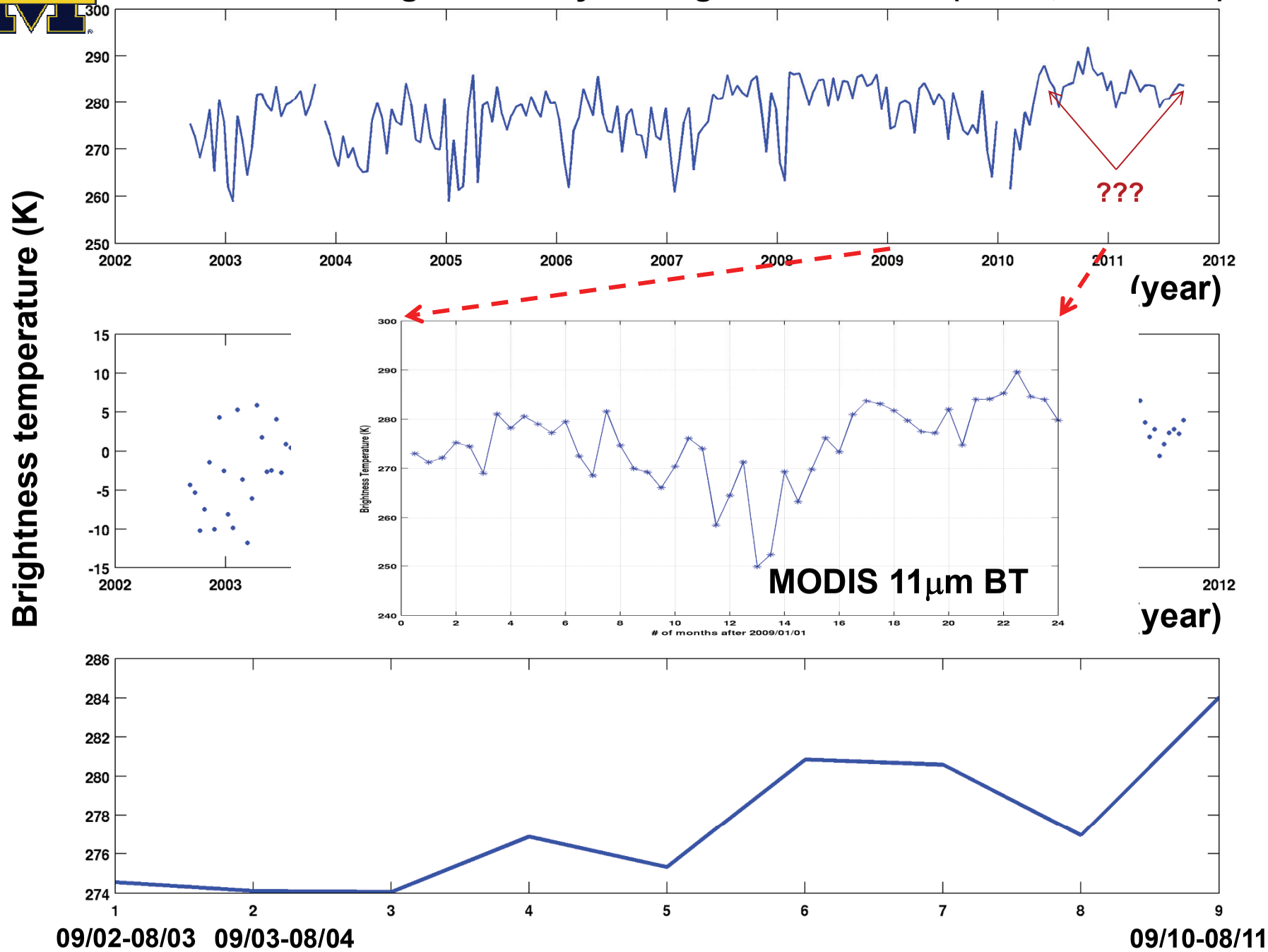
2003Feb., 100sub-columns

Conclusions and discussion

- PCRTM-based simulator
  - Fully accommodate the sub-grid variability for now and for the future
  - Easy to take scattering into account
- Comparison with the modeled OLR show consistency
  - Water vapor continuum can make noticeable differences
- Implications for constructing spectral fingerprints
  - Global mean difference is not prominent, but SHAPES change!
    - Channels are not “equal” though a fit treat each channel equally
  - Regionally it could be significant (more for flux than for difference of flux)
- Future work
  - Radiances from ERA-interim 1989-present
  - GPU-version of the simulator

An update from the talk last Fall

AIRS 900.7 cm^{-1} Original 16-day averaged time series (0-10S, 150-180E)



Thank You!