Improving the Representation of SGS Turbulence and Clouds in Coarse-Grid CRMs

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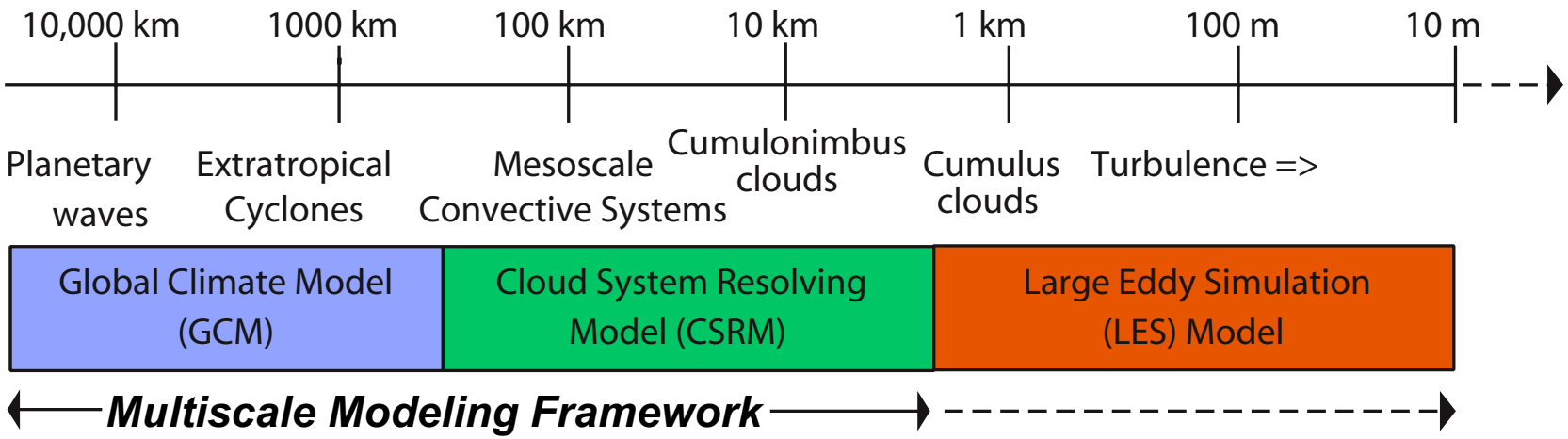
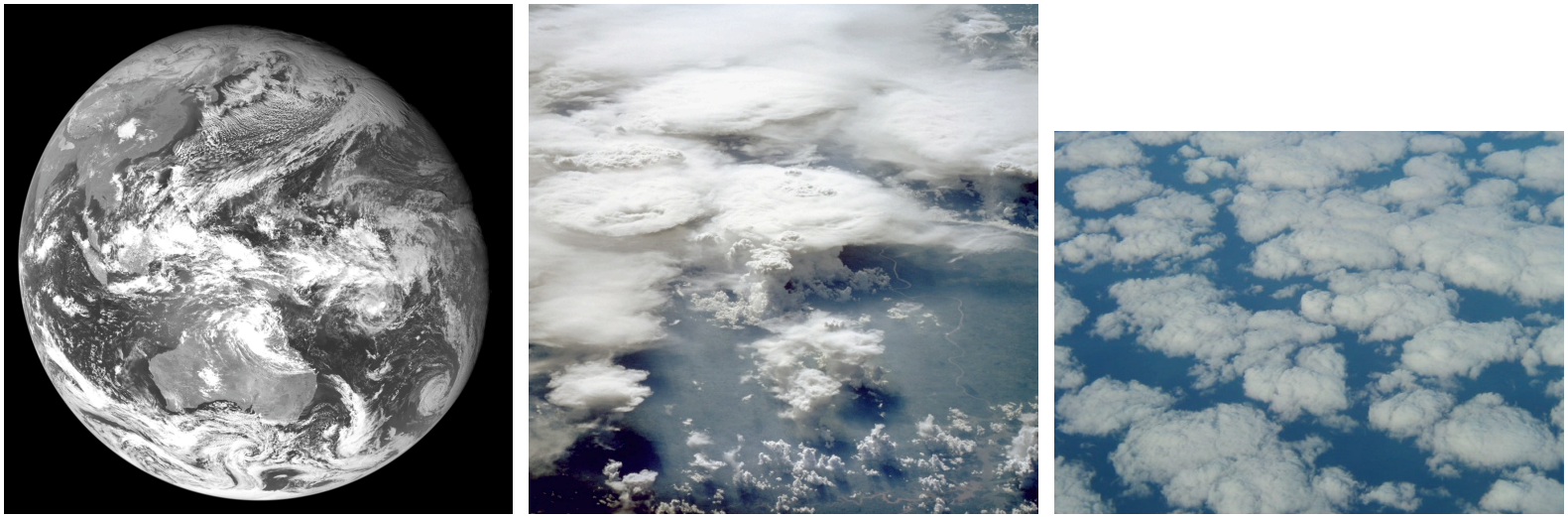
Scales of Atmospheric Motion





Boundary layer clouds and turbulence in deep-convection-resolving models (DCRMs)

- DCRMs are CRMs with horizontal grid sizes of 4 km or more.
- Used in MMF, GCRMs (global CRMs), and tropical cyclone models.
- In MMF and GCRMs, DCRMs are expected to represent all types of cloud systems.
- However, many cloud-scale circulations are not resolved by DCRMs.
- Representations of SGS circulations currently used in DCRMs can be improved.

Our PDF-based parameterization

- We have constructed a 1D parameterization (Golaz et al. 2002b).
- It parameterizes layer clouds and turbulence in a unified way.
- Initially it was developed for boundary layers. It is being generalized further.
- It is based on the Assumed PDF Method.

Our PDF includes several variables

We use a three-dimensional PDF of vertical velocity, w, total water (vapor + liquid) mixing ratio, q_t, and liquid water potential temperature, θ_l:

$$P = P(w, q_t, \theta_l)$$

This allows us to couple subgrid interactions of vertical motions and buoyancy.

Randall et al. (1992)

Steps in the Assumed PDF Method

The Assumed PDF Method contains 3 main steps that must be carried out for each grid box and time step:

(1) Prognose means and various higher-order moments.

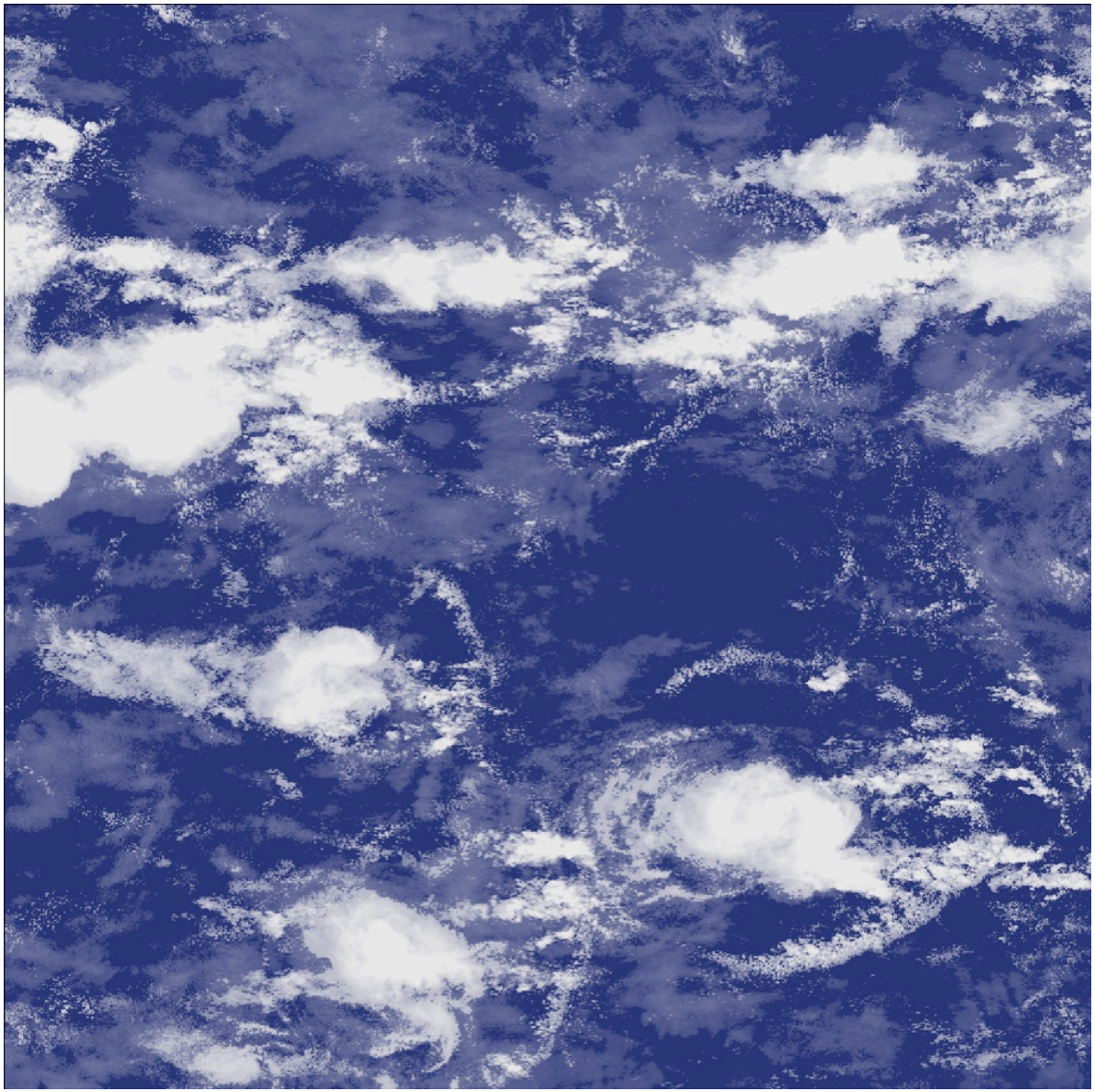
(2) Use these moments to select a particular PDF member from the assumed functional form.

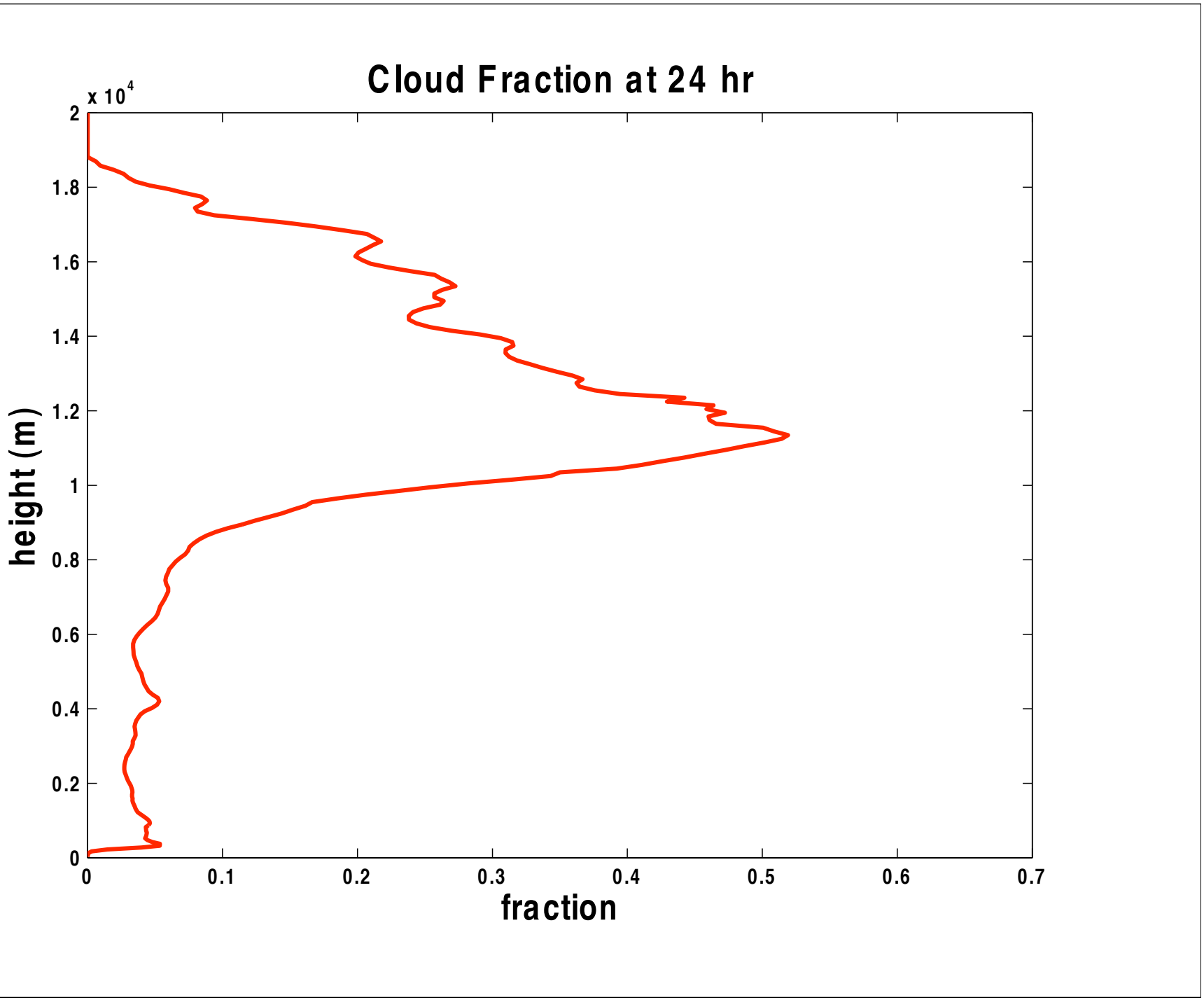
(3) Use the selected PDF to compute many higher-order terms that need to be closed, e.g. buoyancy flux, cloud fraction, etc.

Use results from a large-domain LES of deep convection to test the assumed PDF method

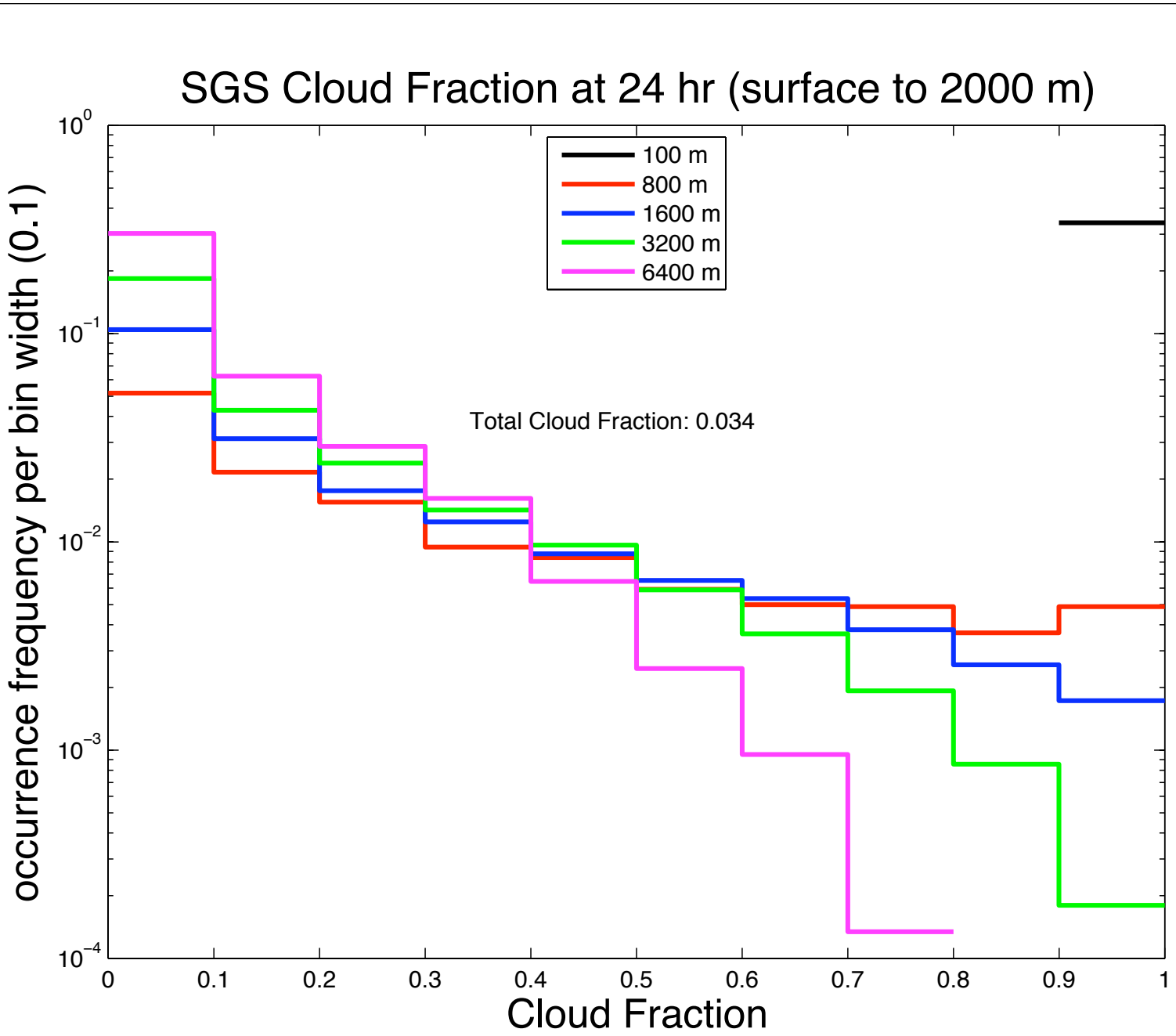
- Idealized GATE simulation with shear.
- Used SAM with 2048 x 2048 x 256 grid points and 100-m grid size for a 24-h LES.
- Equivalent to 1024 6.4-km x 6.4-km LESs.
- Collected statistics for calculating the moments needed to specify assumed PDFs for grid sizes of 800 m x 800 m x 100 m and multiples thereof.
- The statistics also include cloud fraction, liquid water mixing ratio, and its vertical flux, that can be compared to those obtained from the PDF.

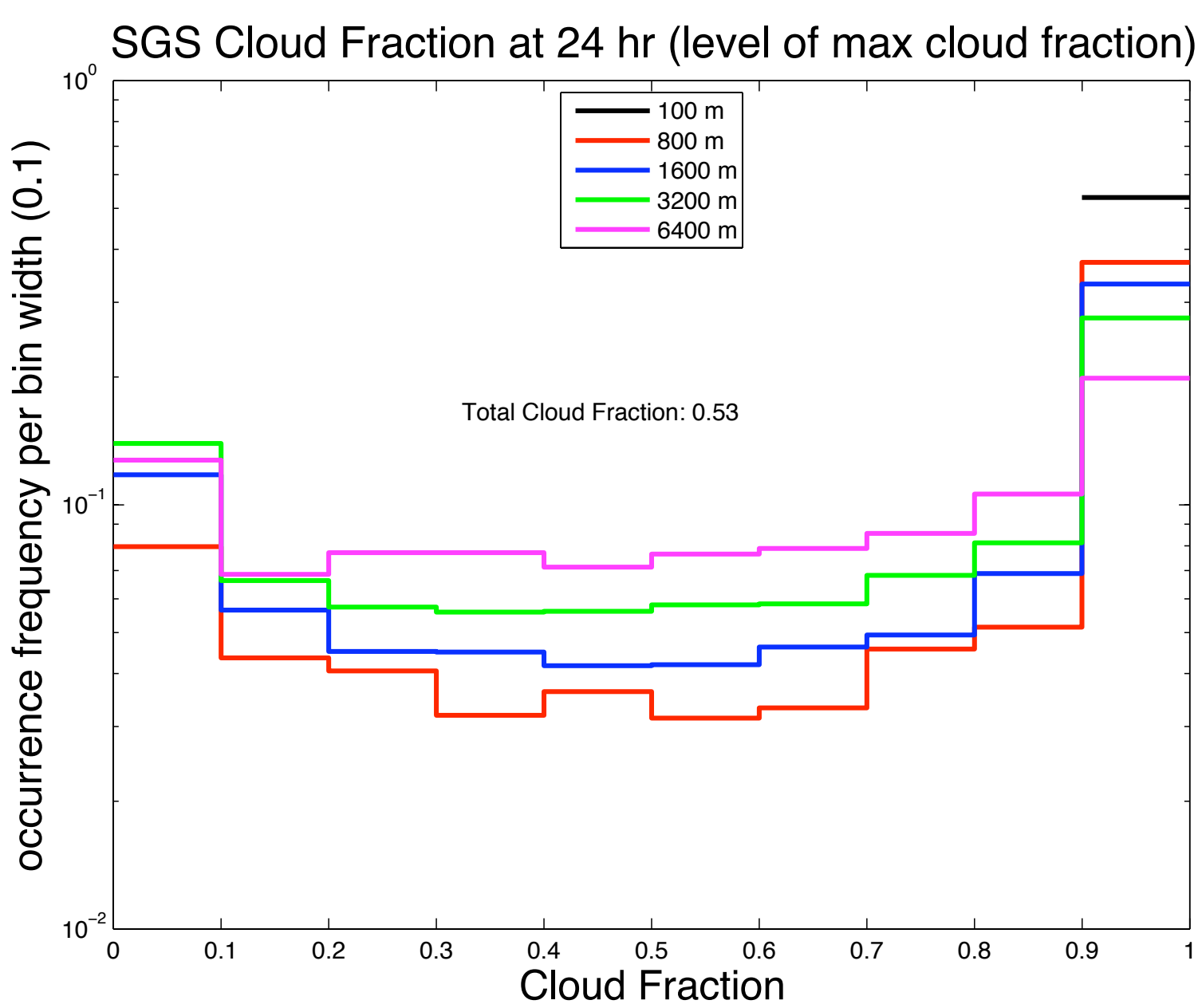
LES “visible image” 180 km x 180 km



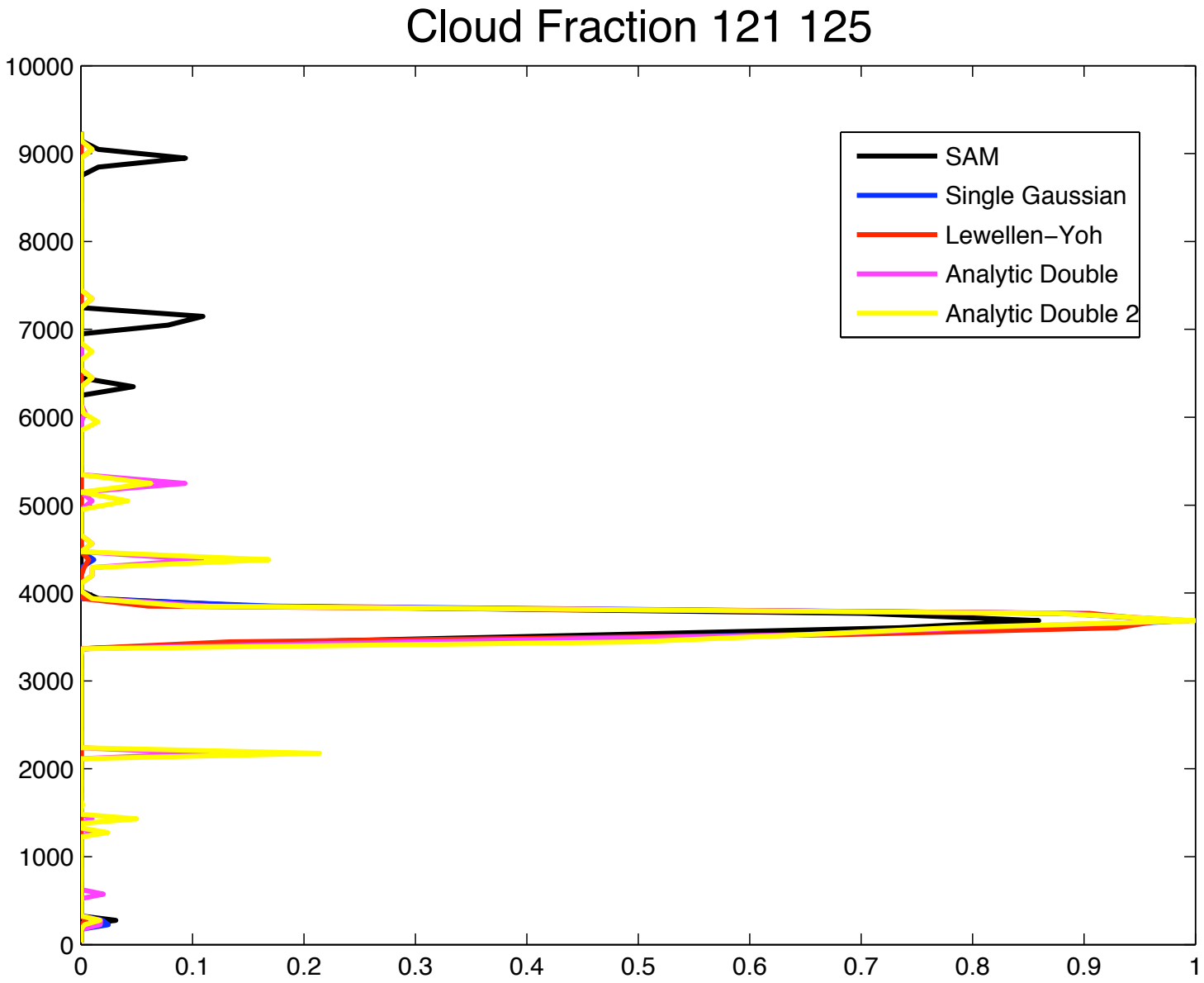

Cloud Fraction at 24 hr
x 10^4
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
height (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
fraction

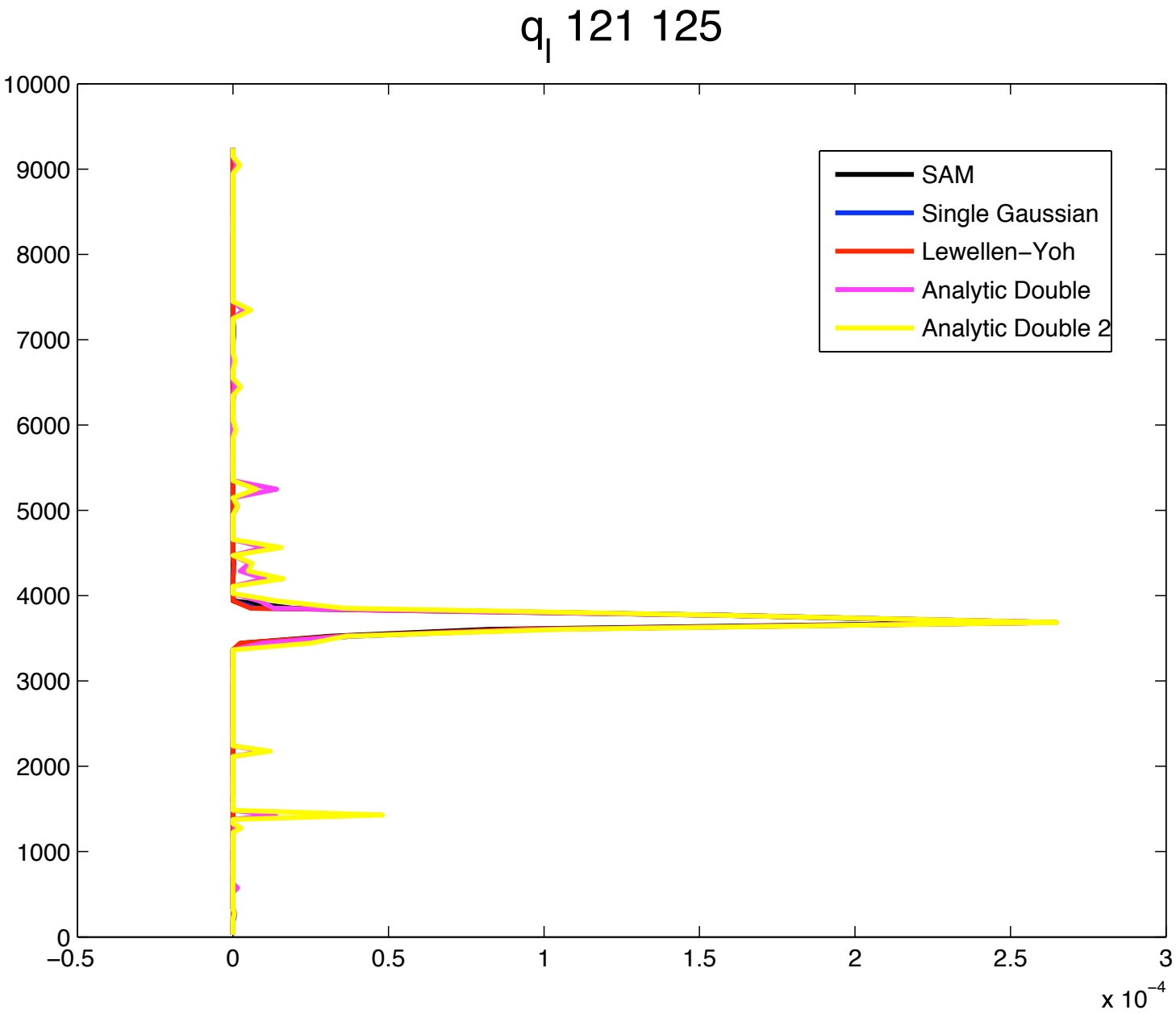
PDFs of SGS cloud fraction for various horizontal grid sizes for low clouds and high clouds obtained from the large-domain LES of deep convection


SGS Cloud Fraction at 24 hr (surface to 2000 m)
100 m
800 m
1600 m
3200 m
6400 m
Total Cloud Fraction: 0.034
occurrence frequency per bin width (0.1)
Cloud Fraction
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

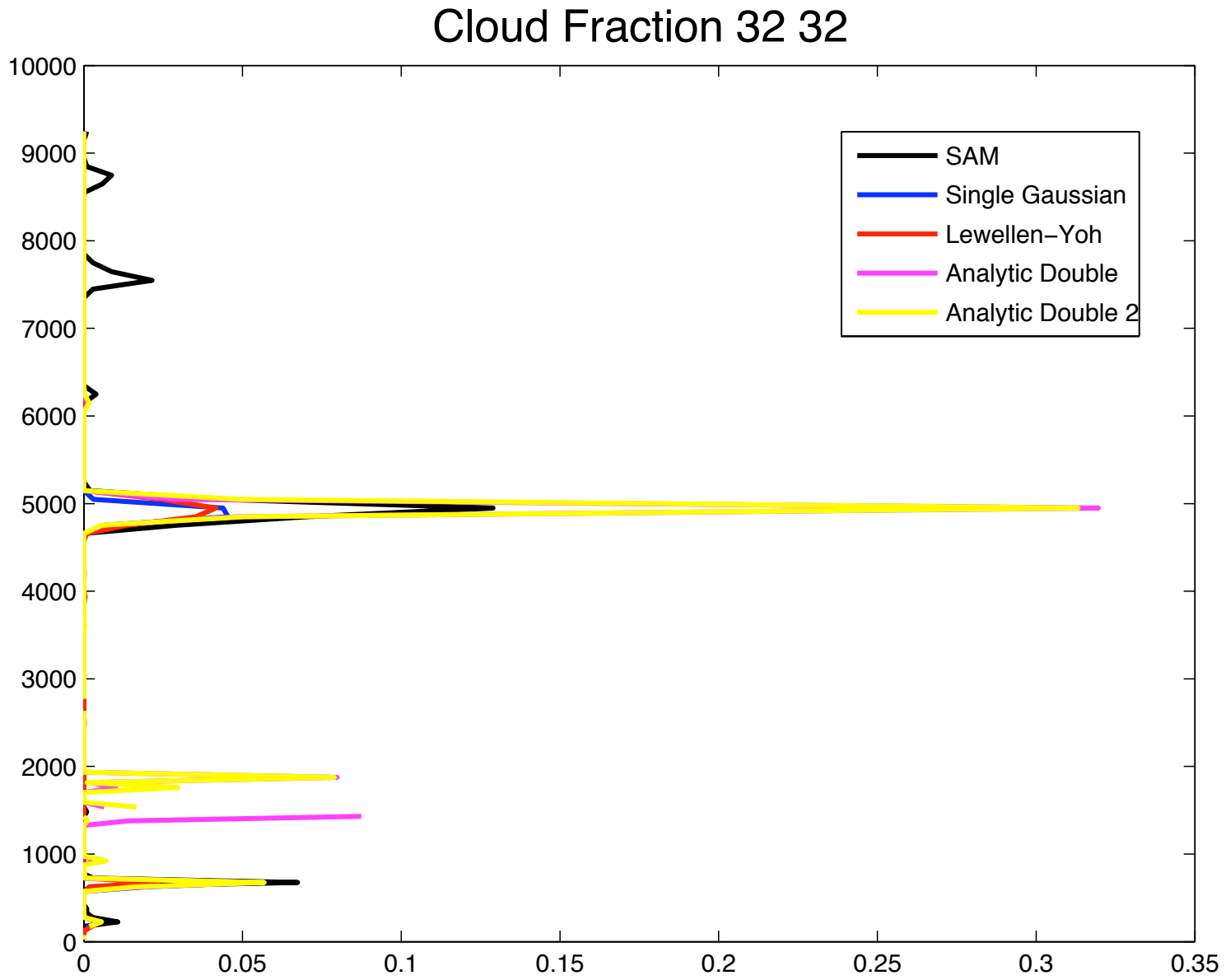

SGS Cloud Fraction at 24 hr (level of max cloud fraction)
100 m
800 m
1600 m
3200 m
6400 m
Total Cloud Fraction: 0.53
occurrence frequency per bin width (0.1)
Cloud Fraction
10^0
10^{-1}
10^{-2}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

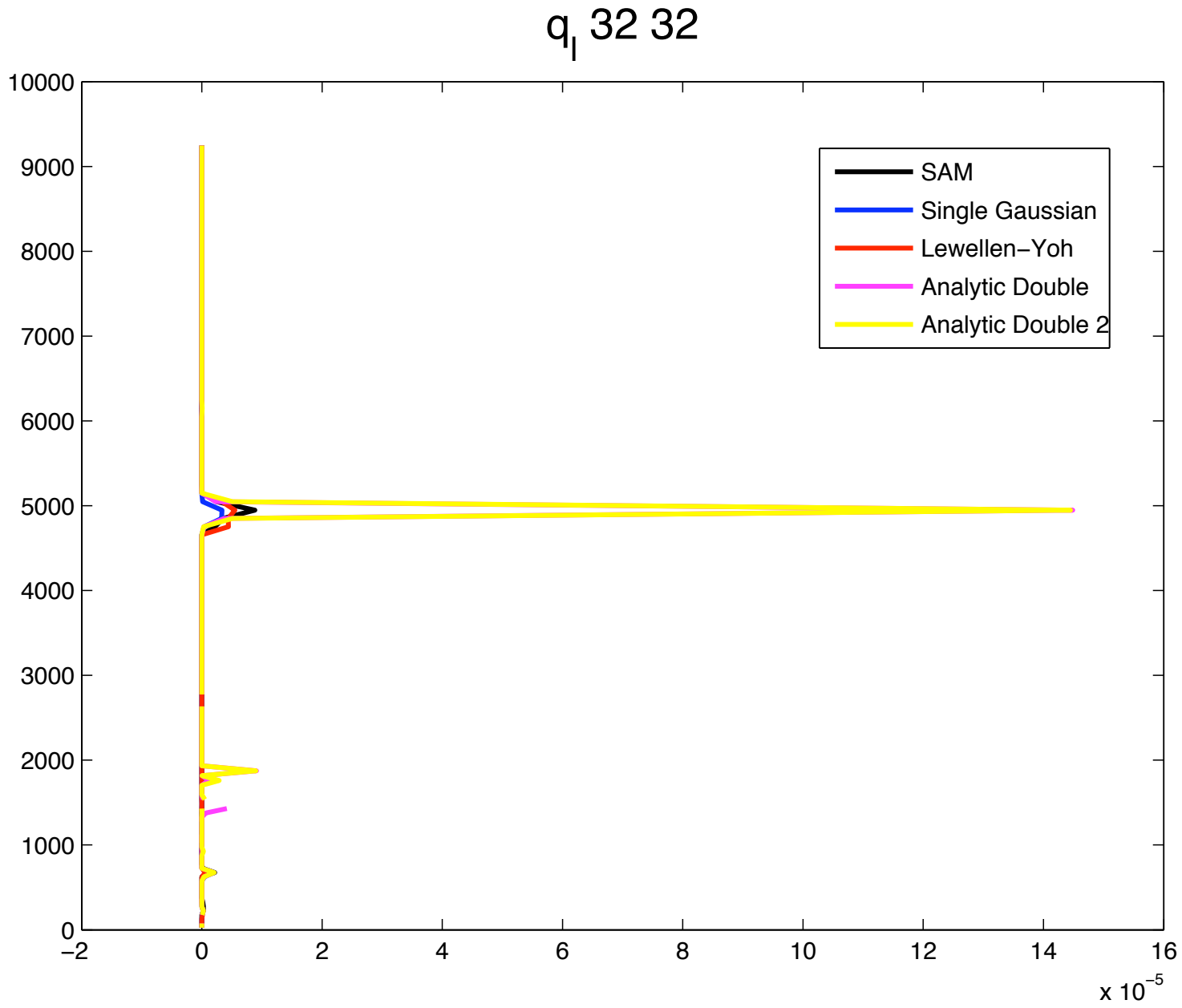
Moments for 800-m x 800-m grid boxes



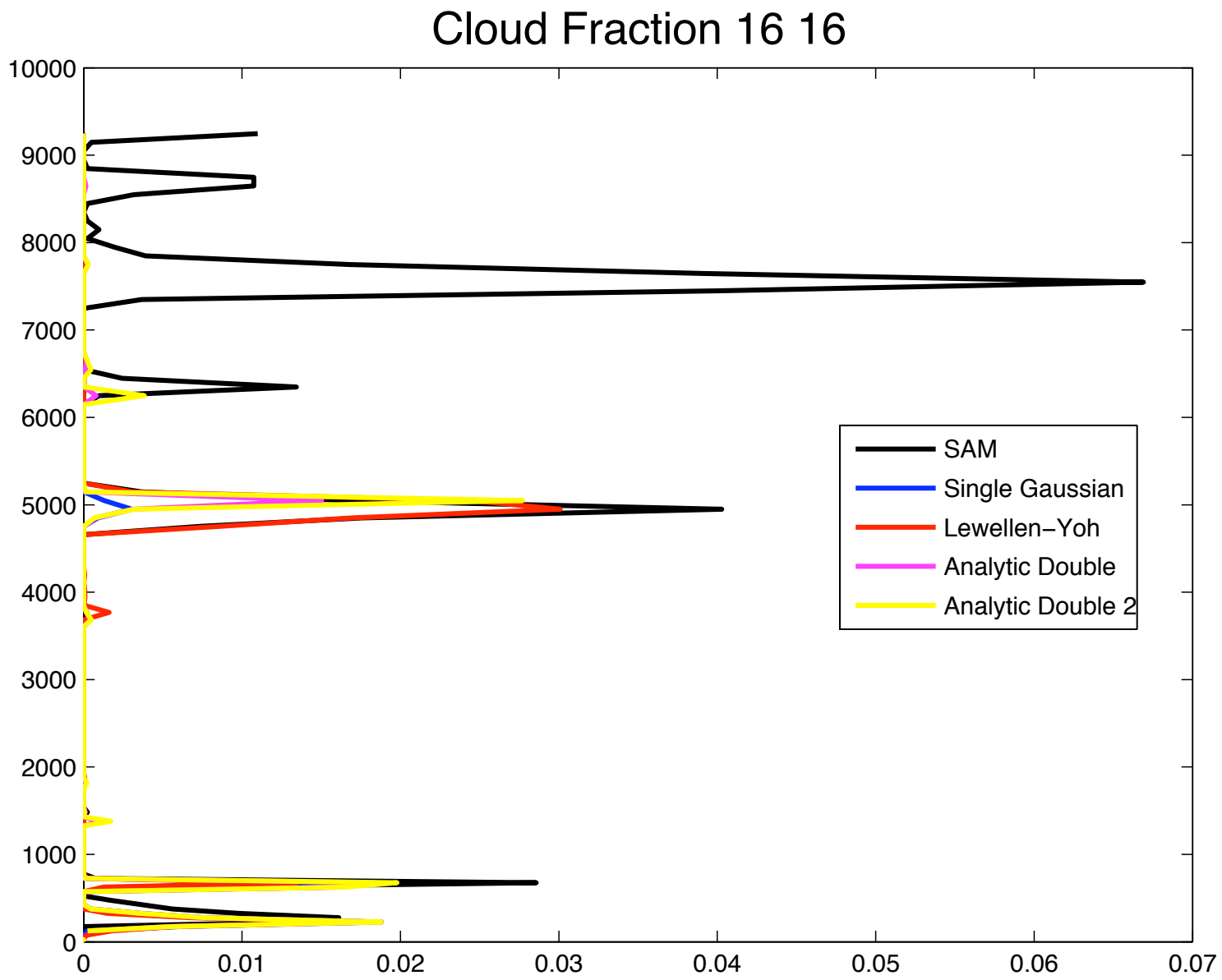

q_l 121 125
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
−0.5
0
0.5
1
1.5
2
2.5
3
x 10^{-4}
SAM
Single Gaussian
Lewellen−Yoh
Analytic Double
Analytic Double 2

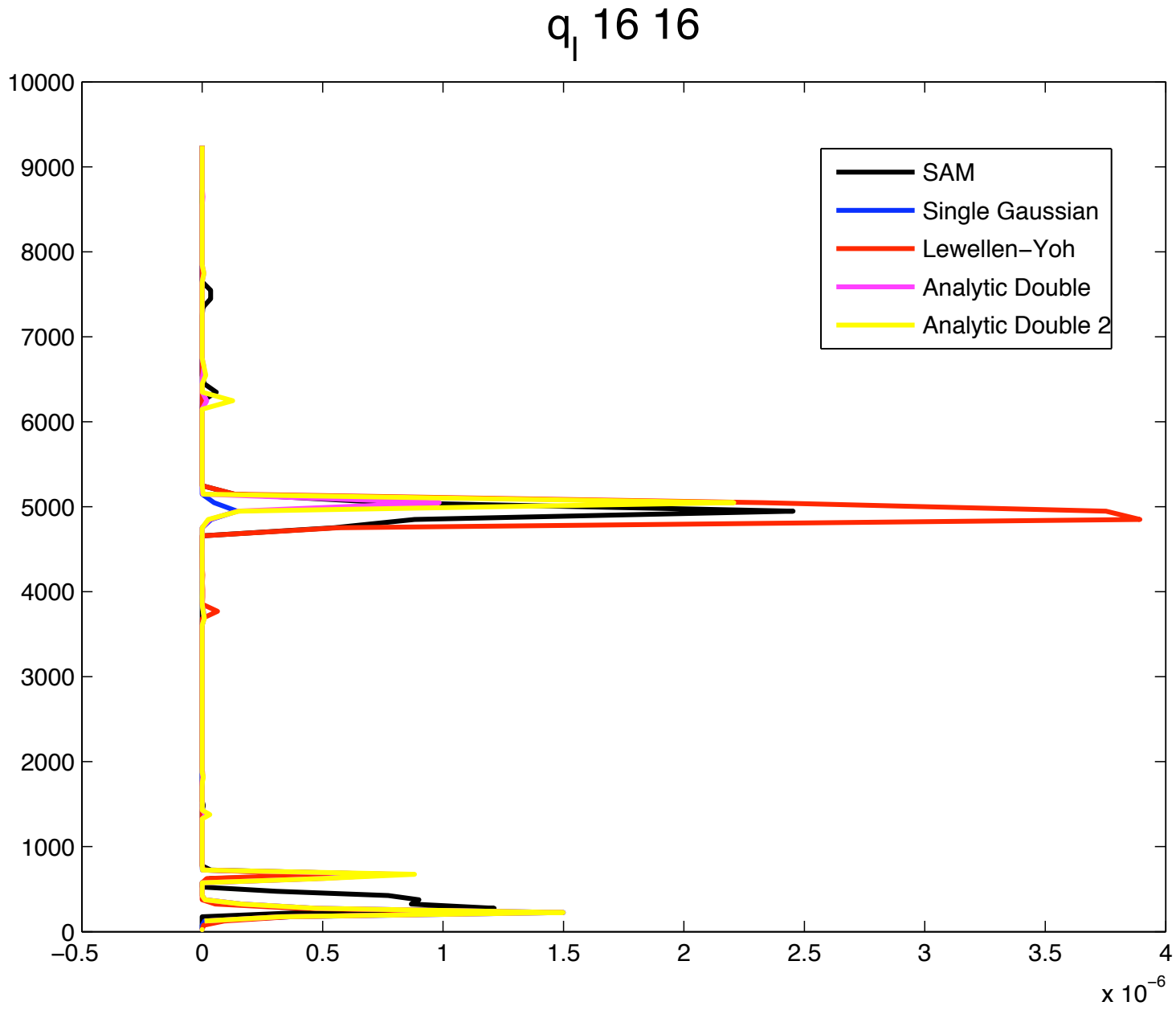
Moments for 3.2-km x 3.2-km grid boxes



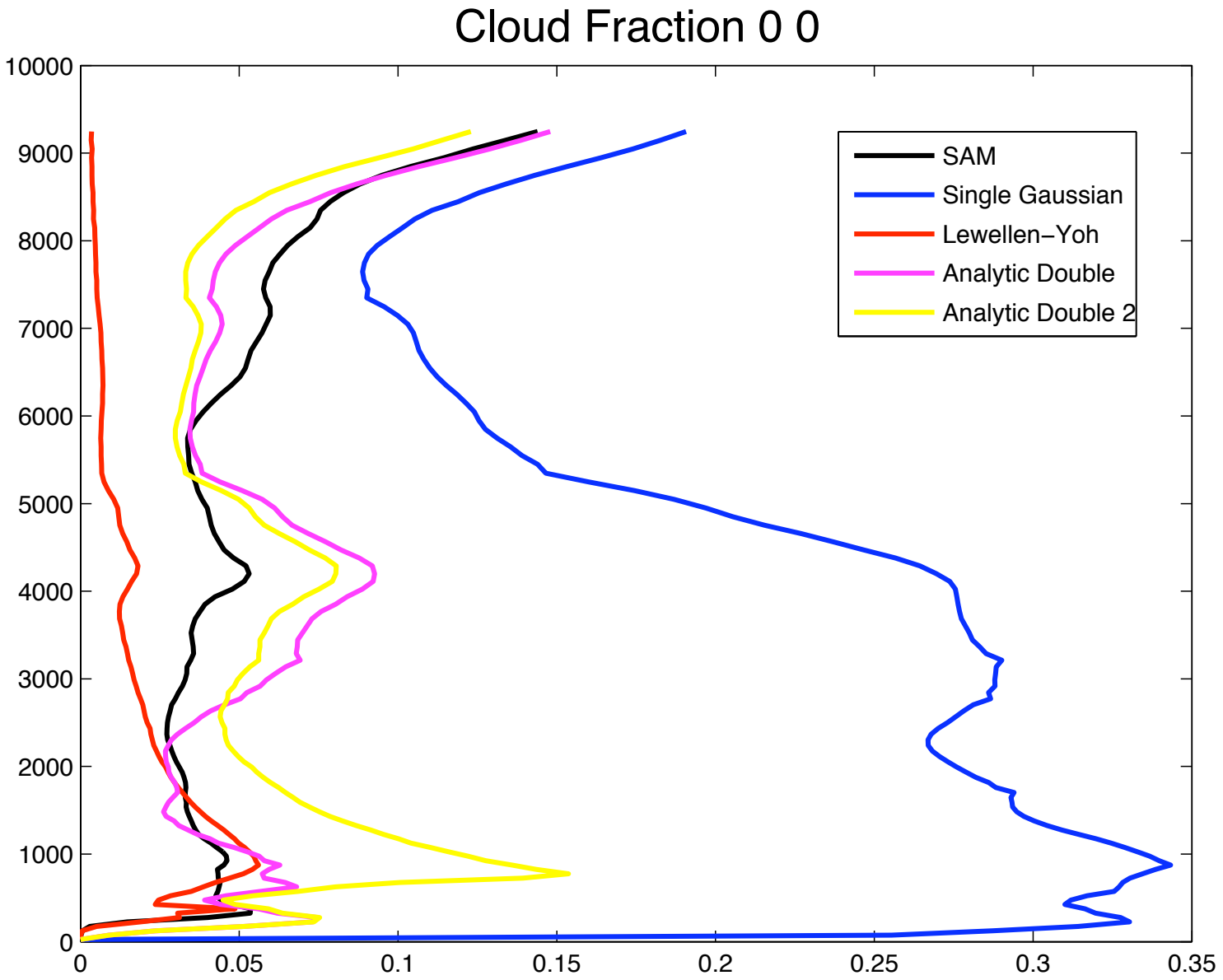

q_l 32 32
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
−2
0
2
4
6
8
10
12
14
16
x 10^−5
SAM
Single Gaussian
Lewellen−Yoh
Analytic Double
Analytic Double 2

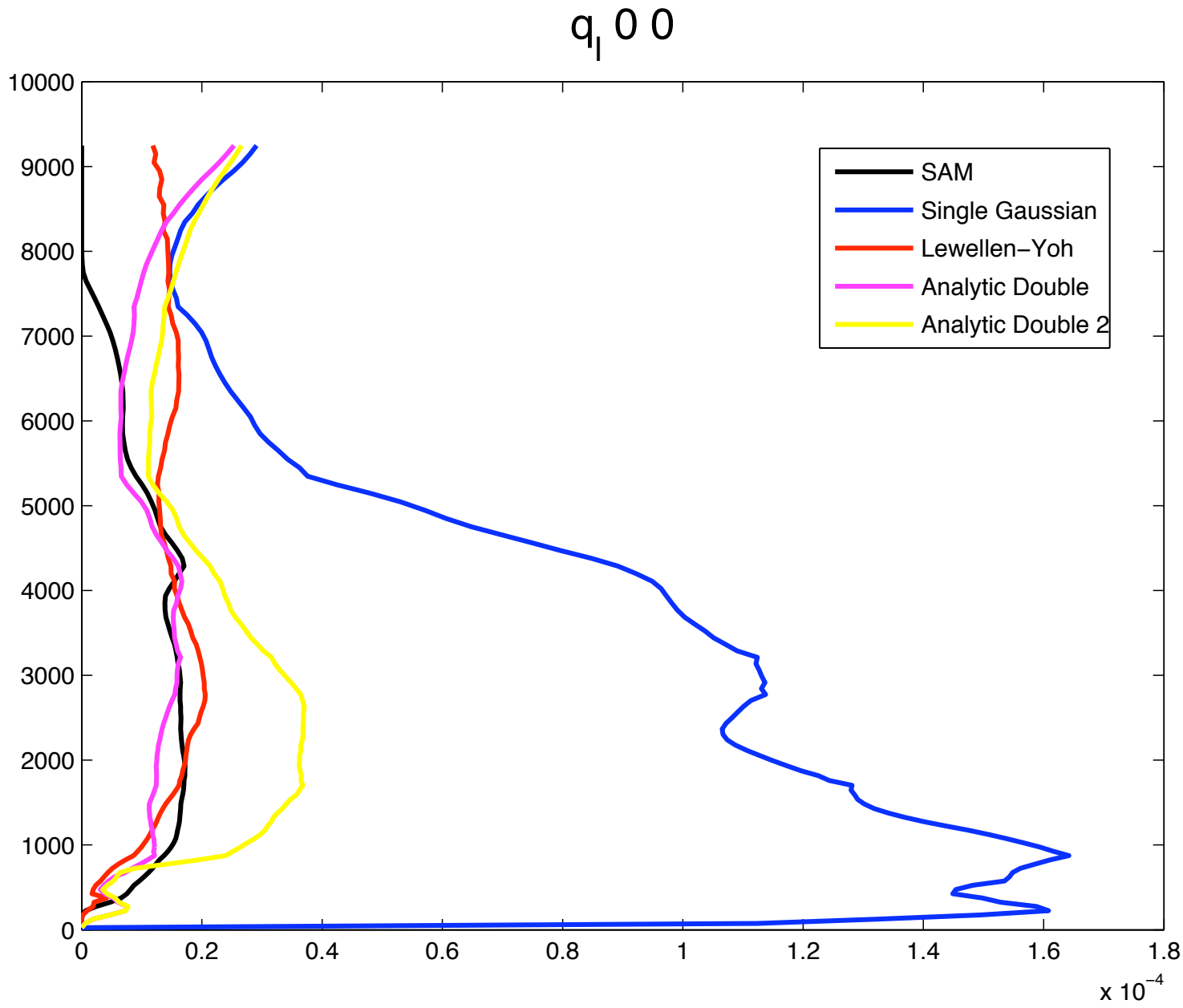
Moments for 6.4-km x 6.4-km grid boxes




q_l 16 16
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
x 10^{-6}
SAM
Single Gaussian
Lewellen−Yoh
Analytic Double
Analytic Double 2

Moments for 200-km x 200-km grid boxes




q_l 0 0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
x 10^{-4}
SAM
Single Gaussian
Lewellen−Yoh
Analytic Double
Analytic Double 2

Summary

- We will use the “benchmark” results from a large-domain LES of deep convection to test the assumed PDF method for various horizontal grid sizes.
- We will also use the “benchmark” results to evaluate DCRMs with various configurations (SGS parameterization, grid size, domain size, and dimensionality).
- Large-domain LES of deep convection can be used to study many multiscale phenomena, such as triggering of new convection, entrainment, gust fronts, and even waterspouts.