Accounting for co-variances among microphysical variables

Mikhail Ovchinnikov[1],
Vince Larson[2], Jan Hoft[2],
Minghuai Wang[1], Steve Ghan[1], Phil Rasch[1]

[1]PNNL, [2]UWM

Acknowledged support from
DOE "Polar project", SciDAC

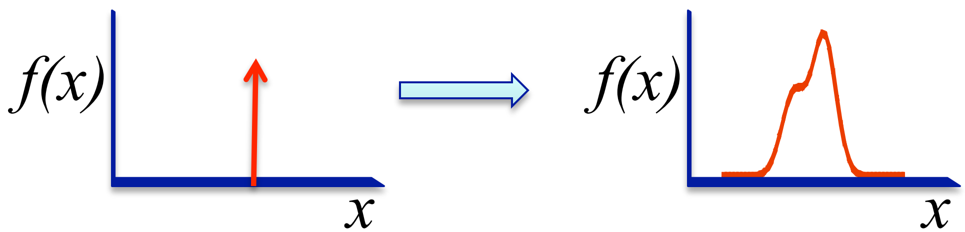
AMWG Meeting, Boulder, CO, 11-13 Feb 2013

PDF approach for sub-grid variability

Sub-grid variability is important for nonlinear processes

$$\langle F(x)\rangle \neq F(\langle x\rangle)$$

From grid-cell means to PDFs



For multivariate processes, both variances and co-variances are needed

$$\left(\frac{dq_c}{dt}\right)_{\substack{auto\\conv}} \sim n_c^a q_c^b \qquad c_{xy} = \frac{\langle x'y'\rangle}{\sqrt{\langle x'^2\rangle}\sqrt{\langle y'^2\rangle}}$$

Co-variances among microphysical variables

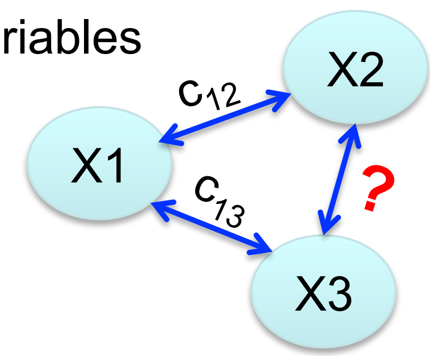
Many variables and processes means many co-variances (correlations)

Predicting all these correlations explicitly is impractical (hard and/or expensive, for *N* variables ~ N^2)

Practical approaches for parameterization of co-variances:

- **Prescribe** based on empirical fits to field data or hi-resolution model results

  Can be inconsistent for different combinations of variables



- **Predict** some, **diagnose** others

Spatial distributions of hydrometeor species and vertical velocity are correlated

Example from LES of Arctic mixed-phase cloud ISDAC, April 26 case

Σ = Correlation matrix

		W	QS	NS	QI	NI	QC	NC
Vertical velocity	**W**	1.00	0.65	0.73	0.44	0.55	−0.01	0.34
Snow mass	**QS**	0.65	1.00	0.95	0.29	0.43	0.06	0.14
Snow number	**NS**	0.73	0.95	1.00	0.49	0.60	0.04	0.21
Ice mass	**QI**	0.44	0.29	0.49	1.00	0.77	−0.08	0.39
Ice number	**NI**	0.55	0.43	0.60	0.77	1.00	0.28	0.29
Cloud mass	**QC**	−0.01	0.06	0.04	−0.08	0.28	1.00	0.09
Cloud number	**NC**	0.34	0.14	0.21	0.39	0.29	0.09	1.00

Dynamics + Mphysics (first row)

Micro physics (remaining rows)

Can the correlation matrix be recreated given the first row (~subgrid vertical flux) ?

Parameterization of correlations

Assume that means, variances, and vertical fluxes ($c_{W,X}$) are known

Define upper and low bounds for other correlations

$$c_{X_1,X_2}\Big|_{\min}^{\max} = c_{W,X_1}c_{W,X_2} \pm \sqrt{\left(1-c^2_{W,X_1}\right)\left(1-c^2_{W,X_2}\right)} = c_{W,X_1}c_{W,X_2} \pm s_{W,X_1}s_{W,X_2}$$

(exact bounds but too loose to be practical)

Diagnose values of each correlation using

$$c_{ij} = c_{1i}c_{1j} + f_{ij}\, s_{1i}\, s_{1j} \qquad -1 \le f_{ij} \le 1$$

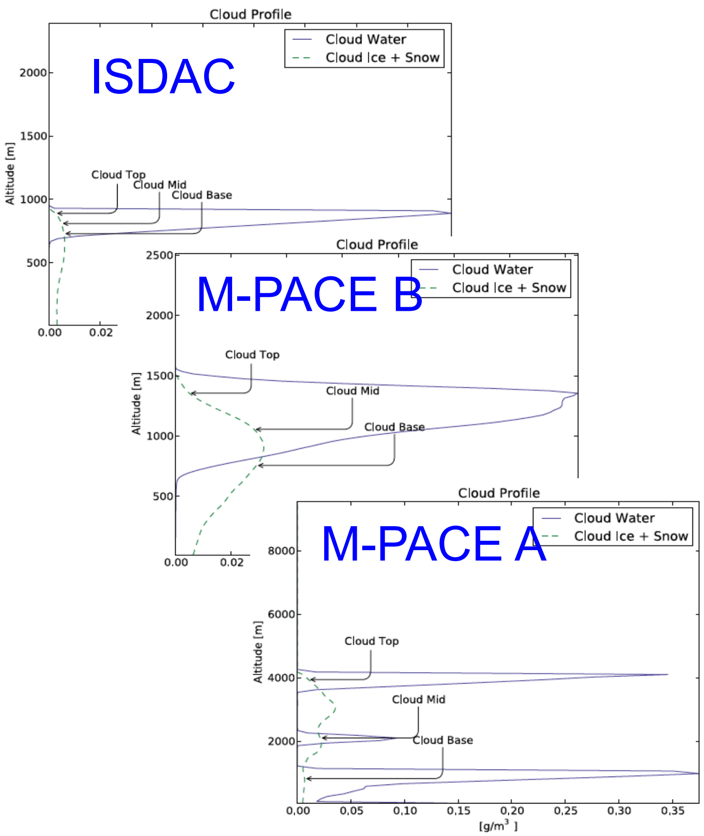
(i=1 for vertical velocity, w)

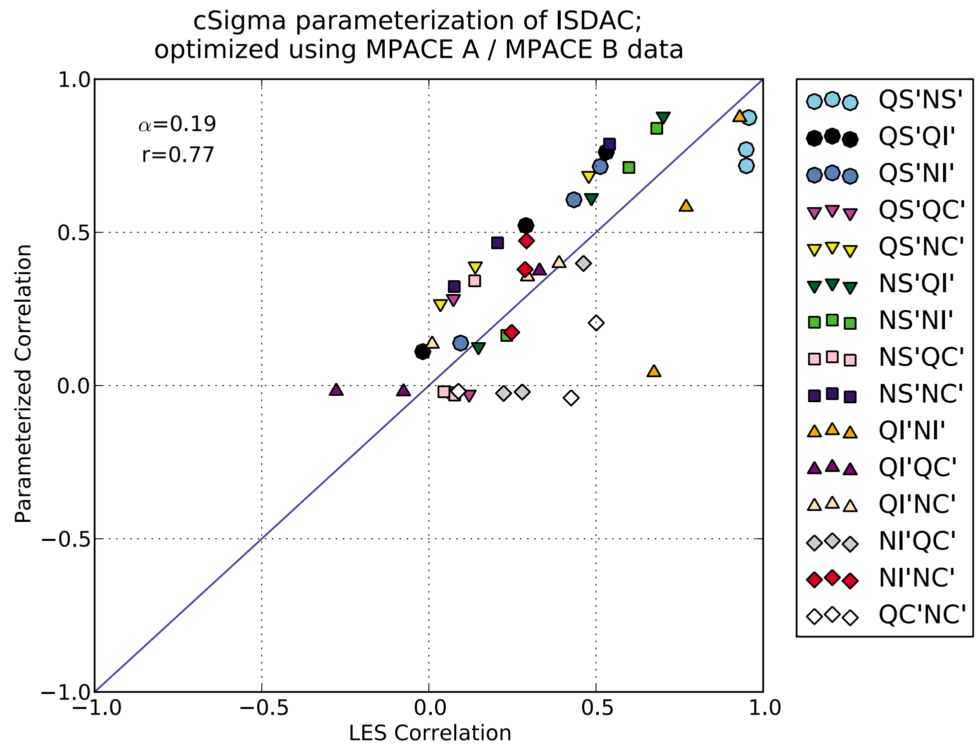
Approaches: **Testing**

- **Prescribe $c_{i,j}$ directly** **Online**
- **Compute c_{1j}, diagnose $c_{i,j}$ using parameterized $f_{i,j}$ (fixed or variable)** **Online, Offline**

Off-line testing of diagnosed correlations

- **Apply method to three simulated cases of Arctic mixed-phase clouds covering a range of conditions**
- **Compare diagnosed and model-predicted ("true") correlations**





Optimal α's are similar for the three cases:
α = 0.19, 0.11, 0.21.
A "general" parameterization could be possible.

(*Larson, et al., 2011, JGR*)

Parameterization of correlations

Diagnose correlations using

$$c_{ij} = c_{1i} c_{1j} + f_{ij} s_{1i} s_{1j} \qquad -1 \le f_{ij} \le 1$$

Approaches: **Testing**

- **Prescribe $c_{i,j}$ directly** **Online**
- **Compute c_{1j}, diagnose $c_{i,j}$ using**

  parameterized $f_{i,j}$ (fixed or variable**)** **Online**, Offline

Interactive testing
Liquid only clouds

Σ = Correlation matrix

		w	s, qc	nc	qr	nr
Vertical velocity	w	1.00				
Cloud water	s, qc		1.00			
Cloud number	nc			1.00		
Rain mass	qr				1.00	
Rain number	nr					1.00

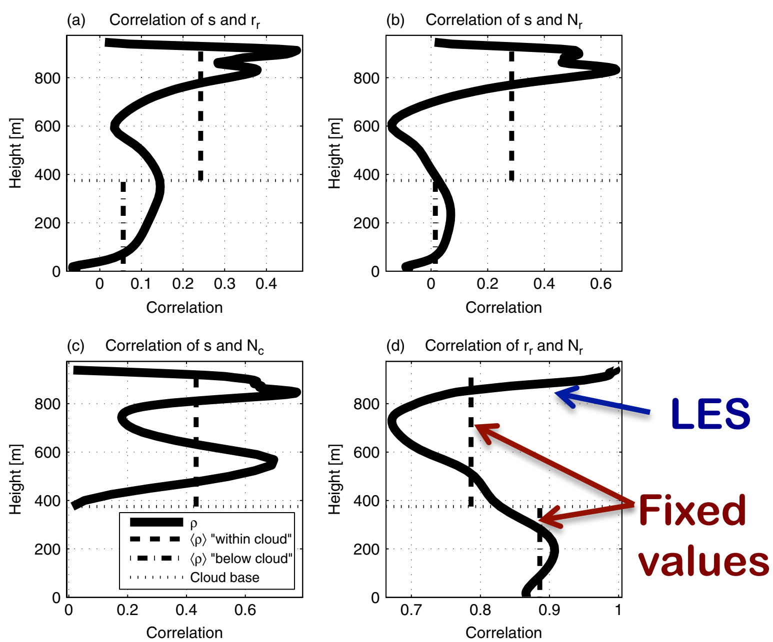
s – extended liquid water mixing ratio (in cloud ~ qc)

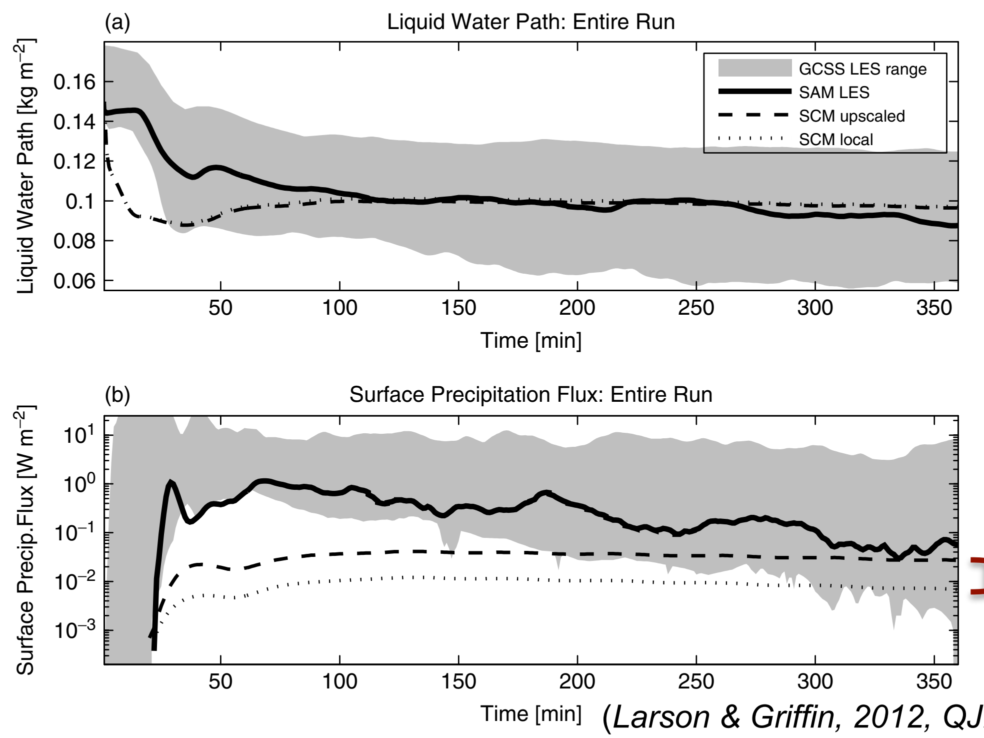
Interactive test 1:
prescribed correlations

	w	qc	nc	qr	nr
w	1.00				
qc		1.00			
nc			1.00		
qr				1.00	
nr					1.00

Drizzling Sc (DYCOMS-II RF02 case)

Limited two-moment bulk microphysics for cloud and rain (fixed cloud number concentration), analytically upscaled





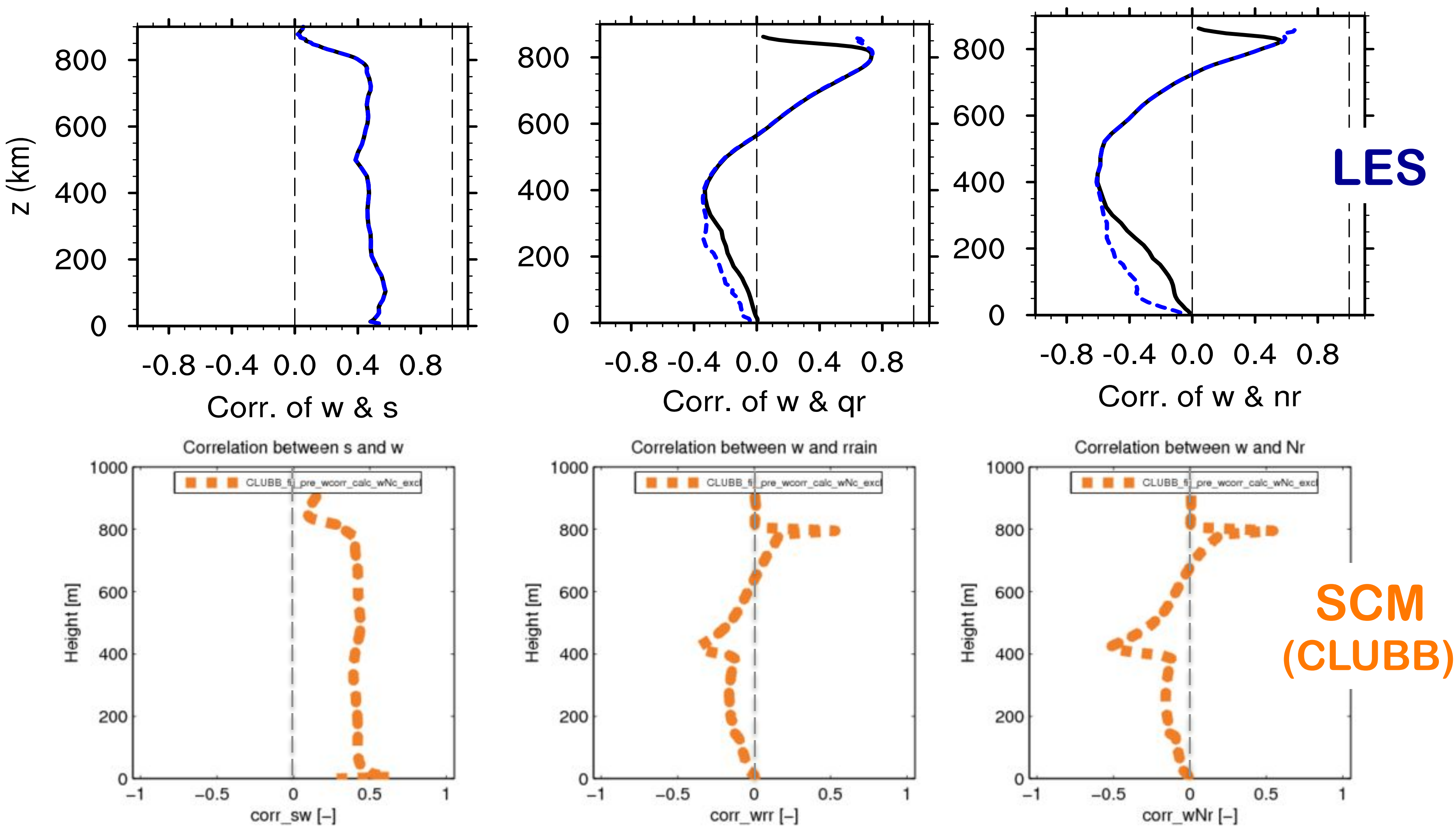
(*Larson & Griffin, 2012, QJRMS*)

Accounting for sub-grid variability improves predicted precipitation.

Interactive test 2:
diagnosed correlations with *w*

DYCOMS-II RF02

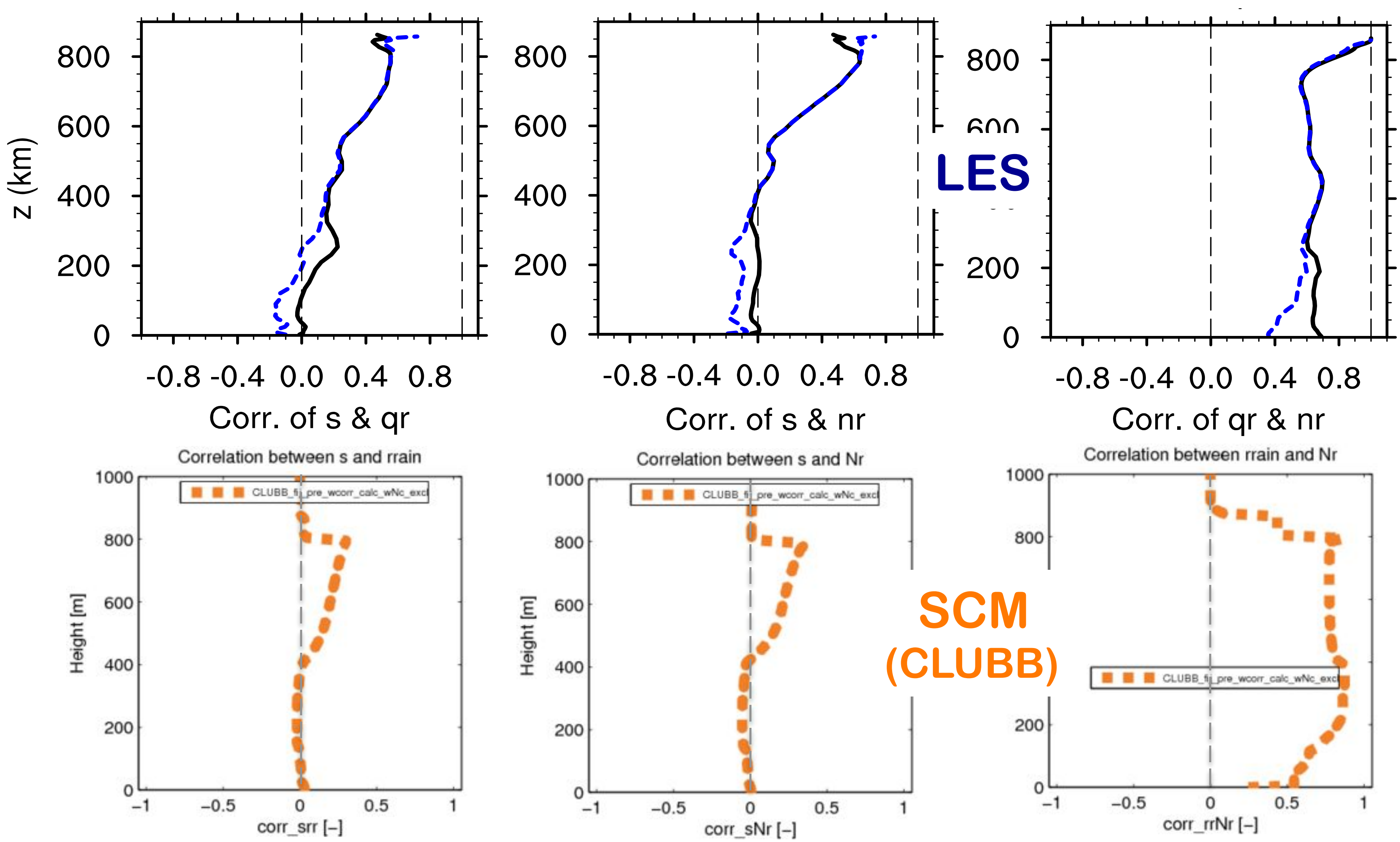
	W	qc	nc	qr	nr
W	1.00				
qc		1.00			
nc			1.00		
qr				1.00	
nr					1.00



Interactive test 2:
diagnosed correlations

	W	qc	nc	qr	nr
W	1.00				
qc		1.00			
nc			1.00		
qr				1.00	
nr					1.00

DYCOMS-II RF02



Summary and next steps

A method for computing a **consistent correlation matrix** for microphysical variables is proposed

Vertical turbulent fluxes are used as input
(can be parameterized as a down-gradient diffusion for some variables)

Encouraging results (compared to reference LES) from

- off-line test for stratiform mixed-phase clouds
- on-line (SCM-CLUBB) tests of warm shallow clouds with two-moment microphysics using either prescribed or computed correlations

Next:

- test other approaches for parameterization of correlations
- apply approach to different cloud types

Questions