The representation of boundary-layer cloud transitions in large-scale models:

An evaluation **at process-level**

Presented by Roel Neggers
Many thanks to all participants

Contents

Very short discussion of the WP3 cases *(5min)*

What and why

SCM results

Individual models & ensemble statistics *(20 min)*

Performance & Uncertainty

Special topics – "making sense of the mess" *(20 min)*

Classify models on i) variables relevant for parameterization
ii) aspects unique for these transition cases

Summary & Outlook *(10 min)*

What are we trying to simulate?

Albrecht et al. (BAMS, 1995)

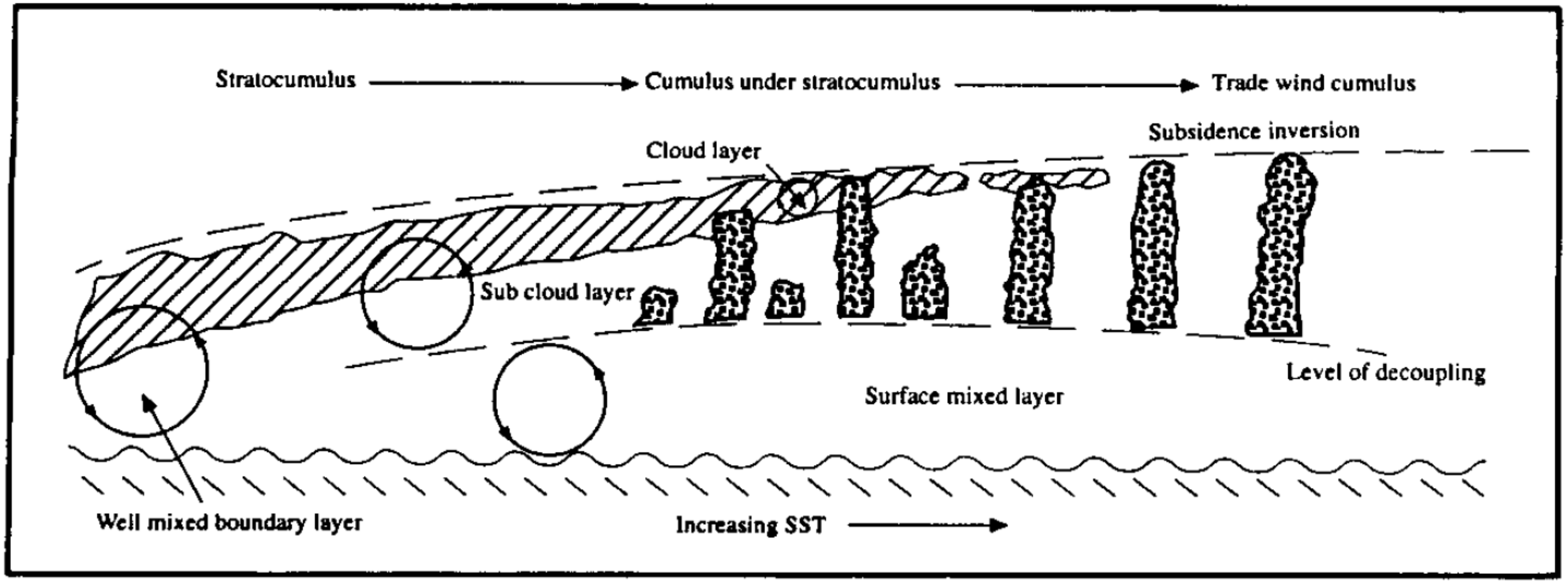

FIG. 4. A schematic of the transition from stratocumulus to trade wind cumulus.

Why are we trying to simulate?

To gain insight into model behavior at process-level

What we ask the models to do right, and what often still goes wrong:

- Thermodynamic state
- Moment of cloud breakup
- Cloud boundaries
- Cloud vertical structure
- Cloud & condensate amounts
- Radiative transfer
- Transport vertical structure (mass flux, TKE, joint-PDFs)
- Decoupling
- Momentum transport
- Time-development of transition (discrete or gradual?)
- Stability (numerics)

A GCSS BOUNDARY-LAYER CLOUD MODEL INTERCOMPARISON STUDY OF THE FIRST ASTEX LAGRANGIAN EXPERIMENT

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(Received in final form 15 June 1999)

… The models all predict the observed deepening and decoupling of the boundary layer quite well, with cumulus cloud evolution and thinning of the overlying stratocumulus. Thus these models all appear capable of predicting transitions between cloud and boundary-layer types with some skill. The models also produce realistic drizzle rates, but there are substantial quantitative differences in the cloud cover and liquid water path between models. …

List of participants

Name	Affiliation	Model	ASTEX	Composite cases
Eric Basile	Meteo France	AROME	✓	✓
		ARPEGE-NWP	✓	✓
Isabelle Beau	Meteo France	ARPEGE-CLIMAT	✓	✓
Vincent Larson	UWM	CLUBB	✓	✗
Sara dal Gesso Roel Neggers	KNMI	EC-Earth	✓	✓
		RACMO	✓	✓
Suvarchal Kumar	MPI	ECHAM6	*Expected soon*	*Expected soon*
Irina Sandu Martin Köhler	ECMWF DWD	IFS cy36r1	✓	✓
Hideaki Kawai	JMA	JMA	✓	✓
Anning Cheng	NASA LaRC	LaRC	✓	✓
Heng Xiao	UCLA	UCLA-AGCM	✓	✓
Ian Boutle	UK Met Office	UKMO	✓	✓

We are still open for new submissions!

GCSS BLCWG model inter-comparison website

The usual prefabricated plots

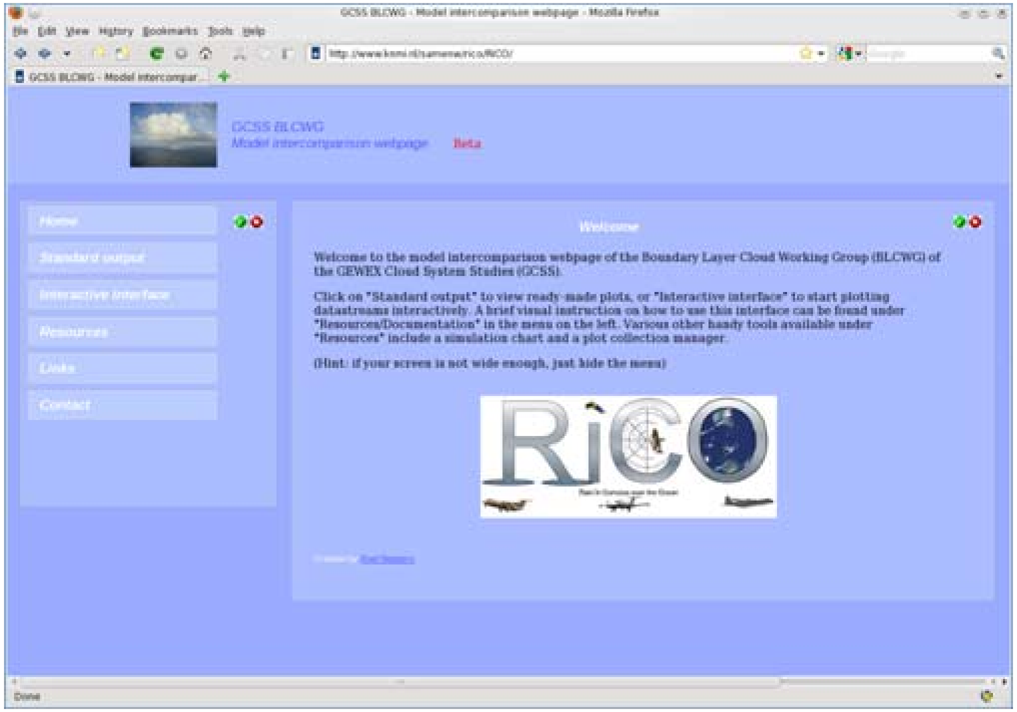
New: Interactive visualization of datastreams

SCM & LES

Could be expanded with obs

RICO,
ASTEX,
composite transitions

Time-series,
Profiles,
Contour plots,
Scatter plots



http://www.knmi.nl/samenw/rico/RICO

ASTEX – time-height contour plots

Only cloud fraction (time-schedule does not allow more)

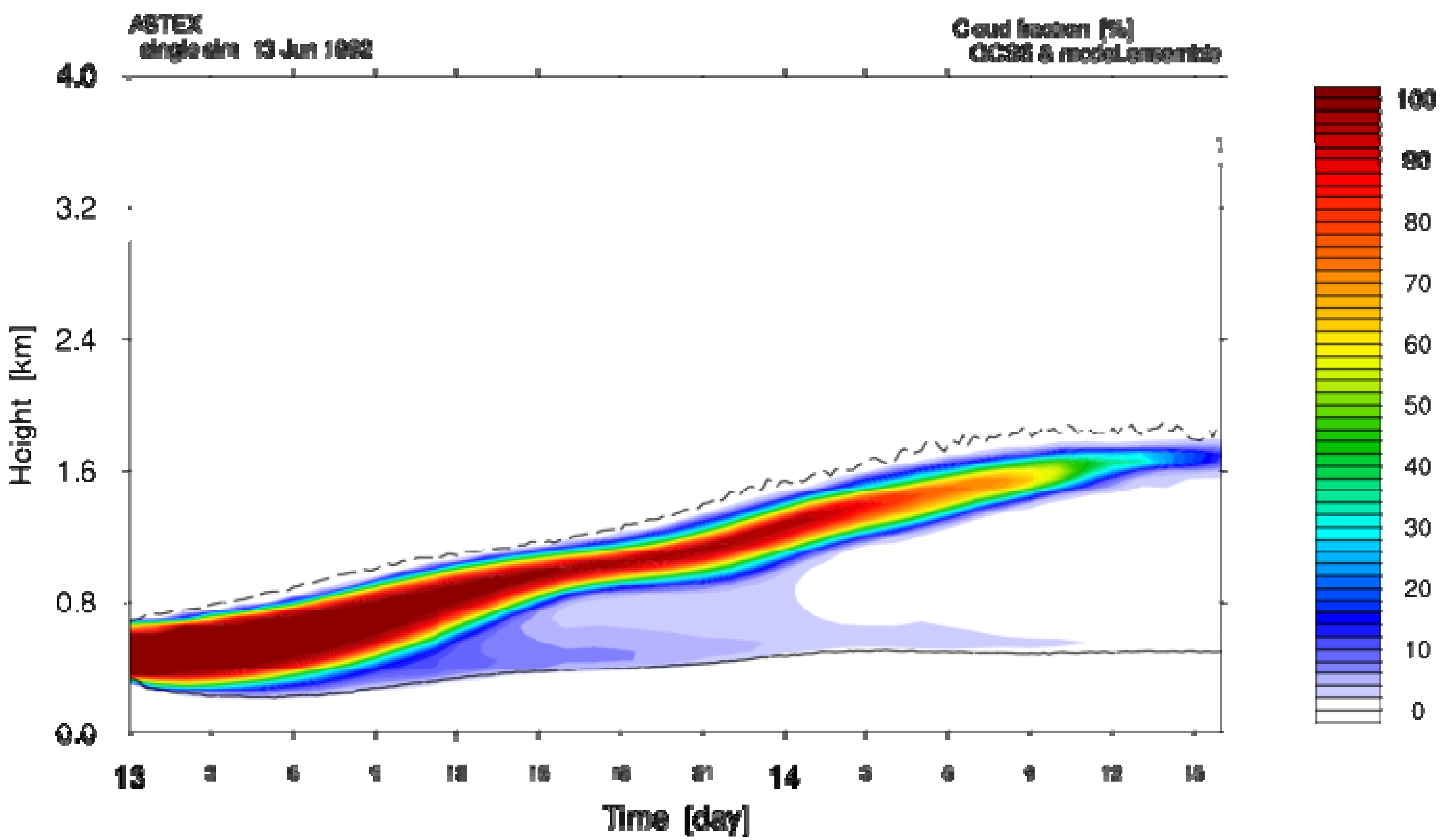
Start with LES ensemble-mean

Then show and briefly discuss all individual SCM results

Grouped presentation

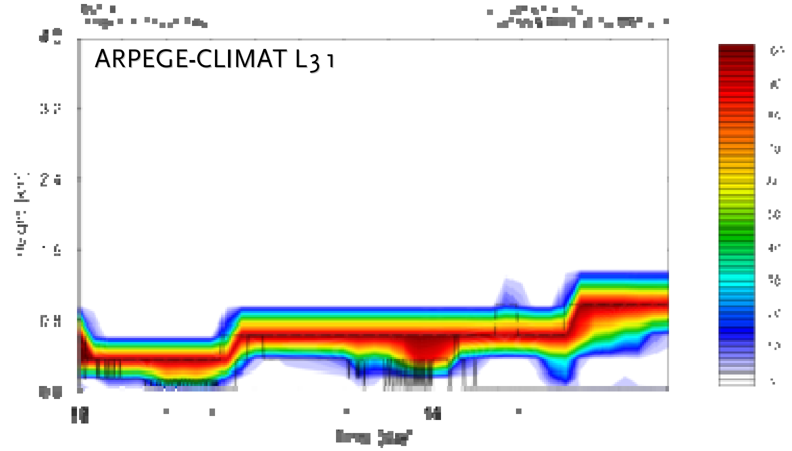
ASTEX – LES results

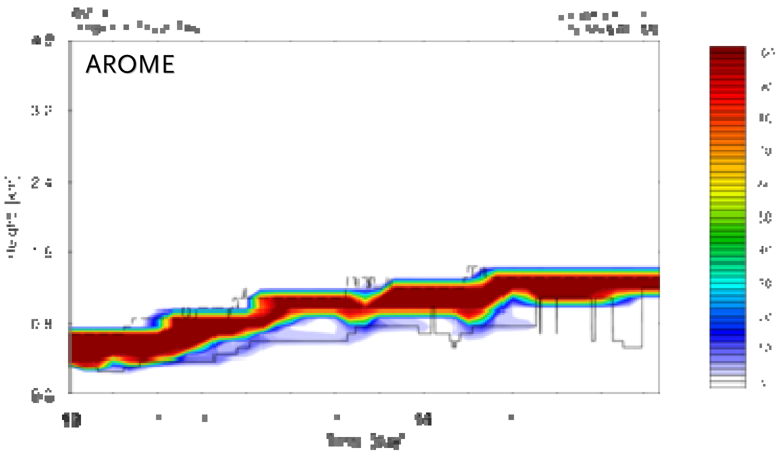
Time-height contour plot of the ensemble-mean cloud fraction
Overplotted by the cloud base and cloud top heights

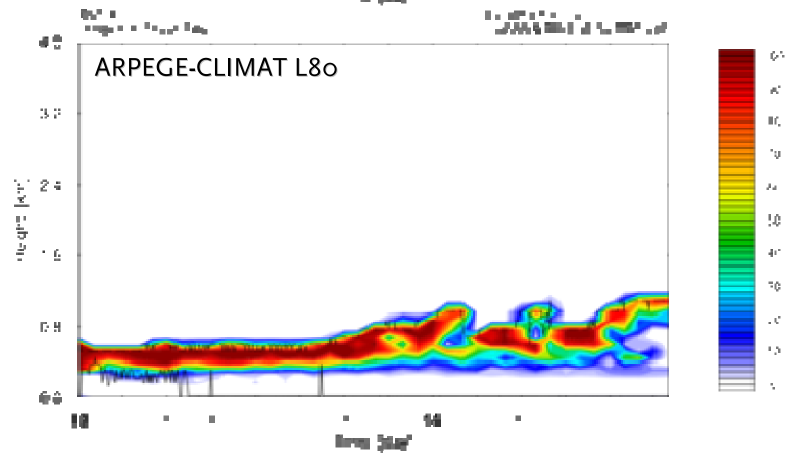


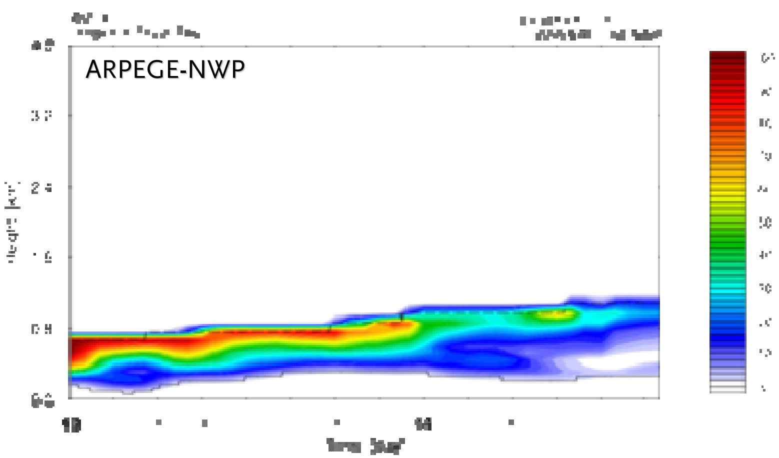
ASTEX – SCM results, group I

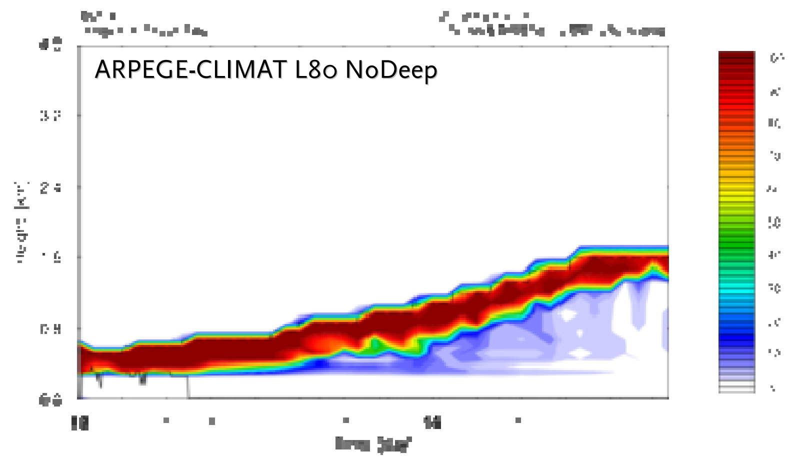
Meteo France





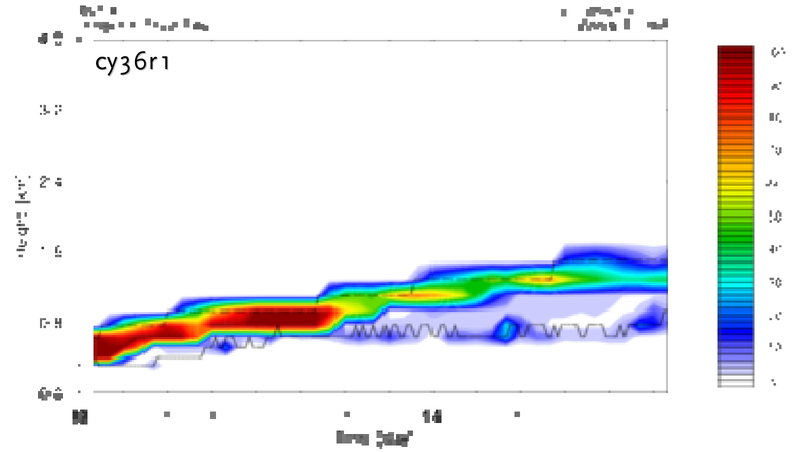


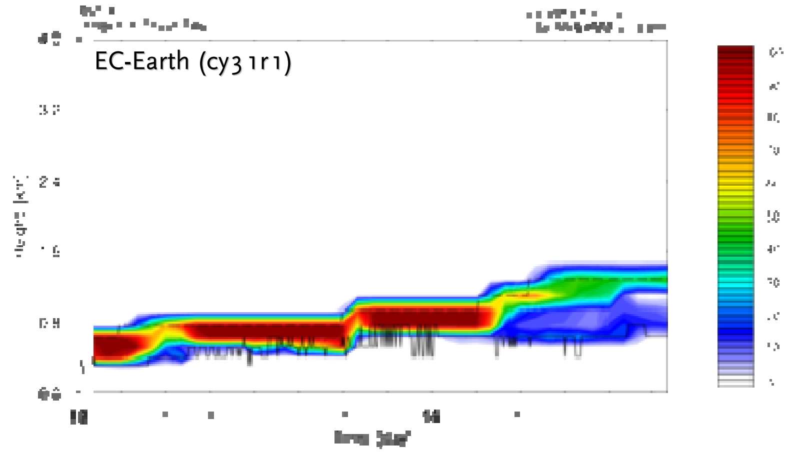


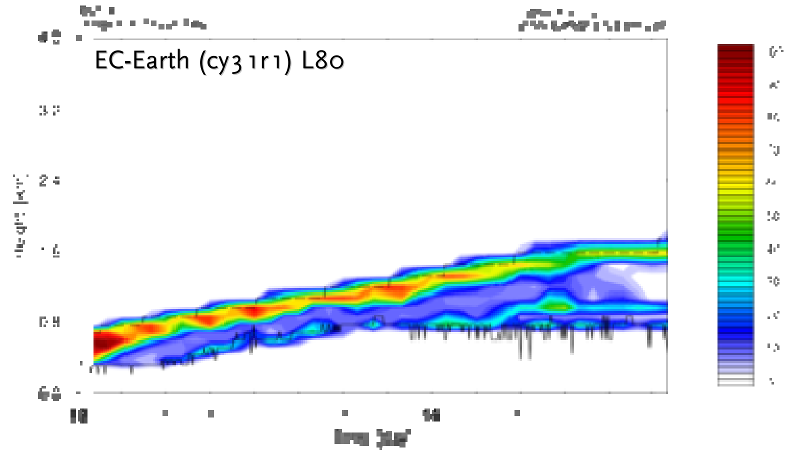


ASTEX – SCM results, group II

IFS

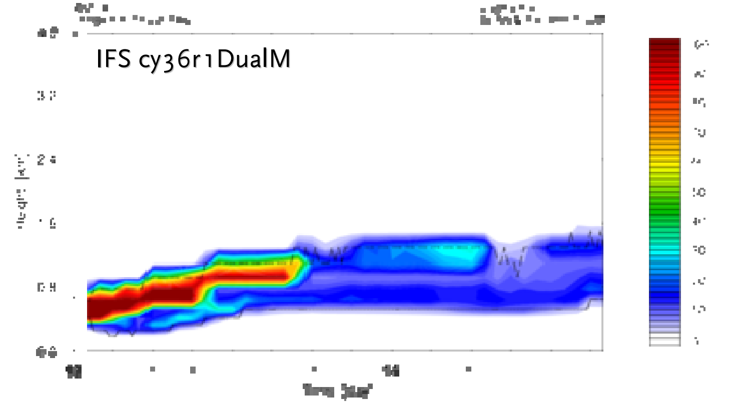


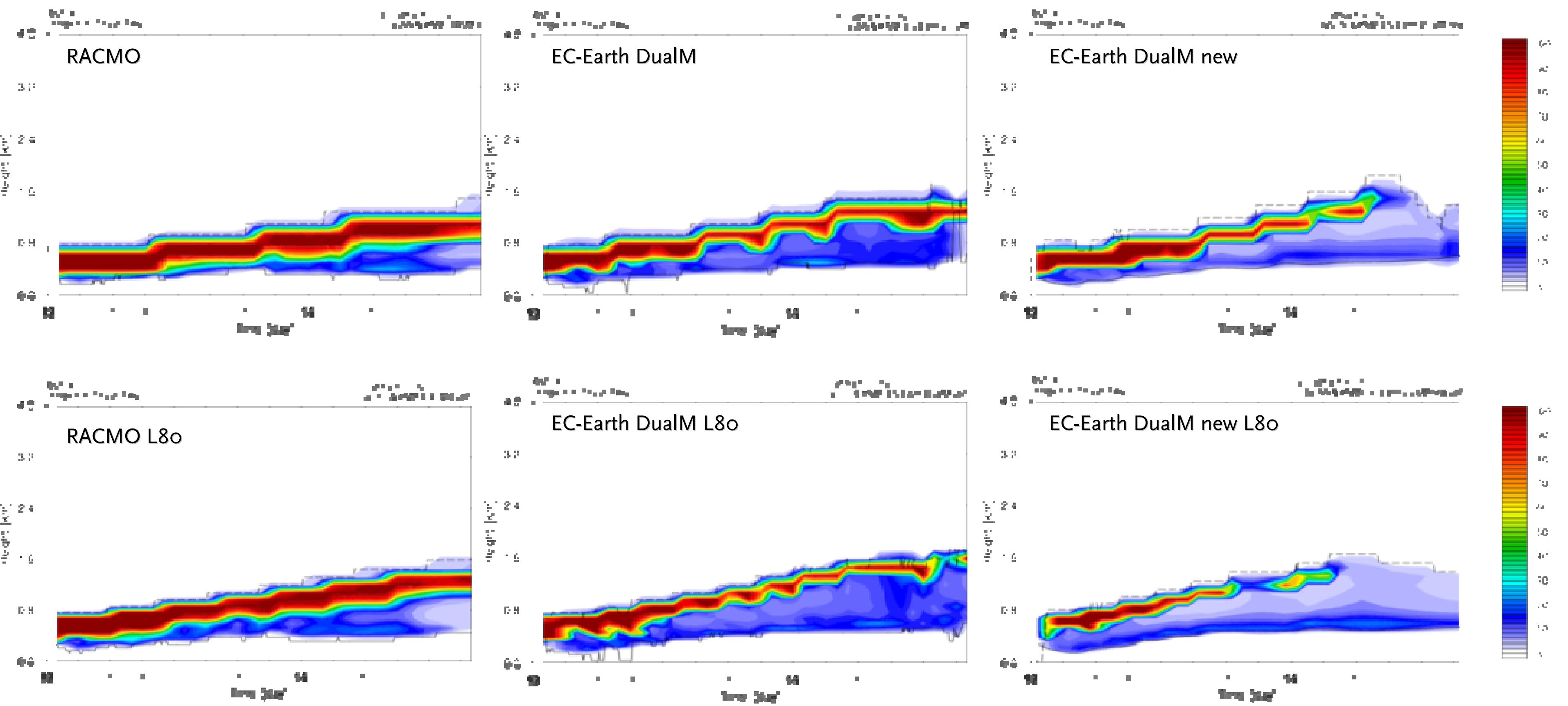




ASTEX – SCM results, group III

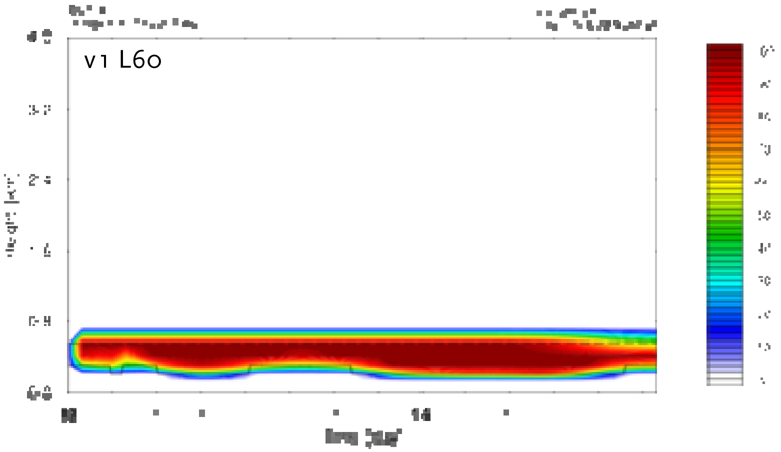
EDMF-DualM

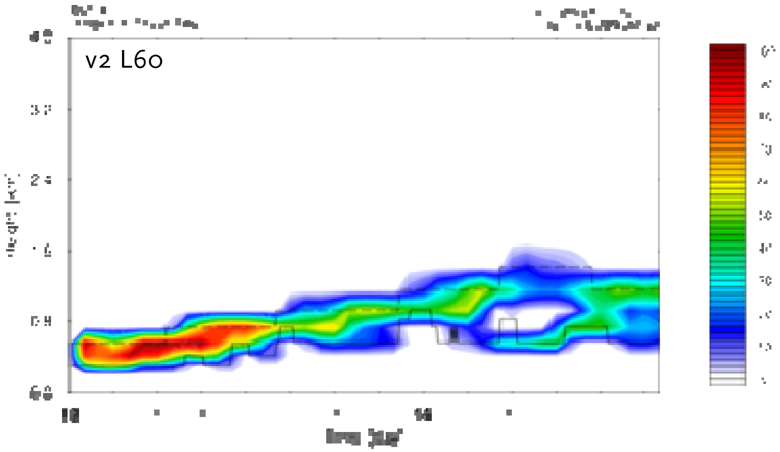


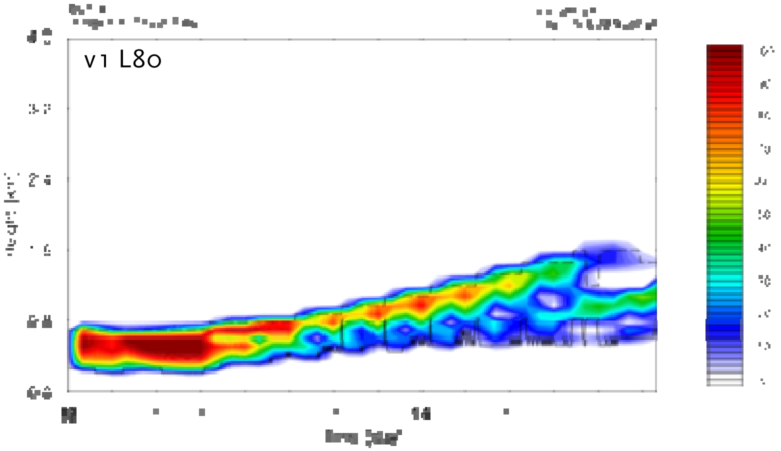


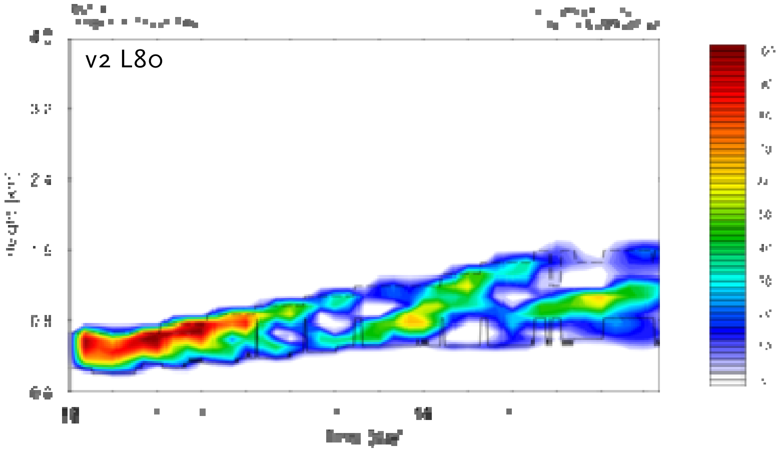
ASTEX – SCM results, group IV

JMA



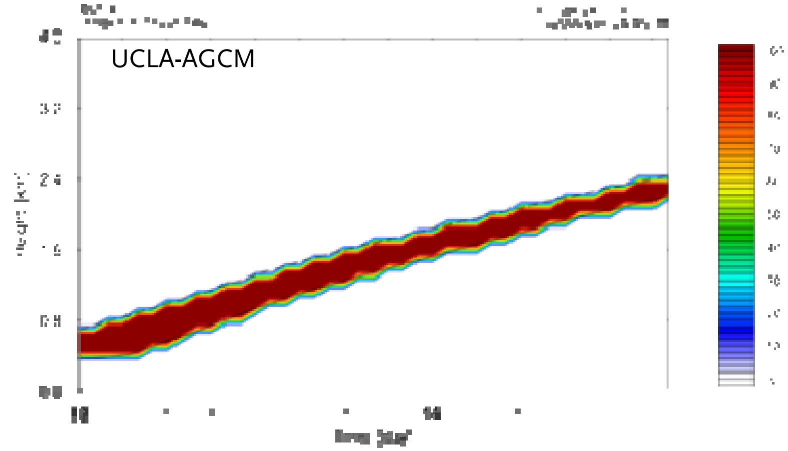


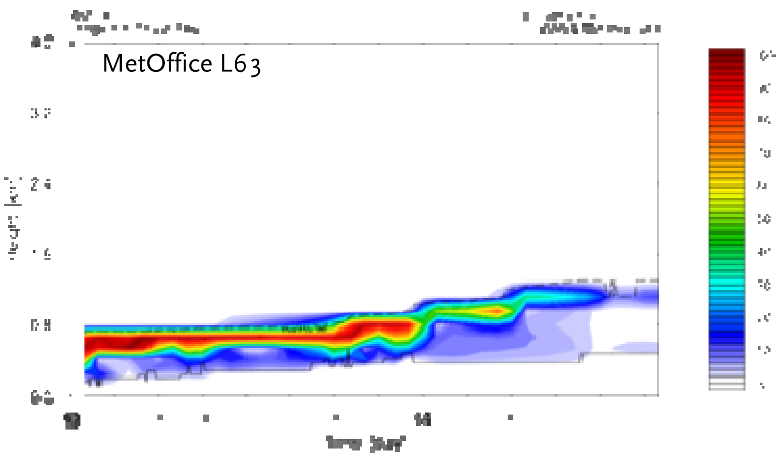


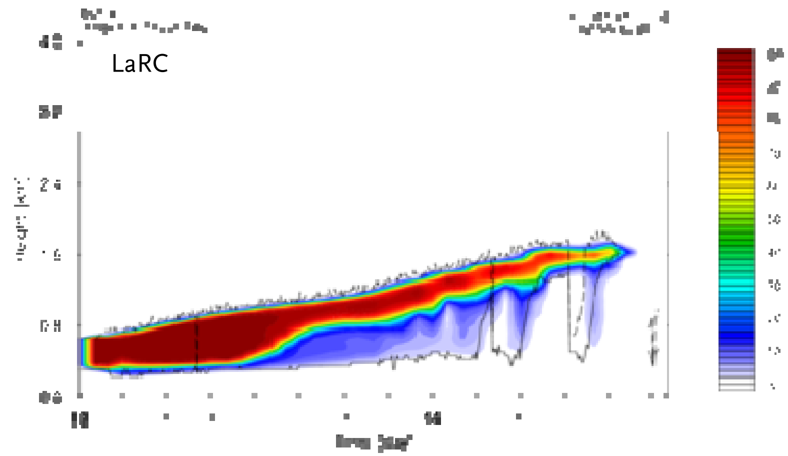


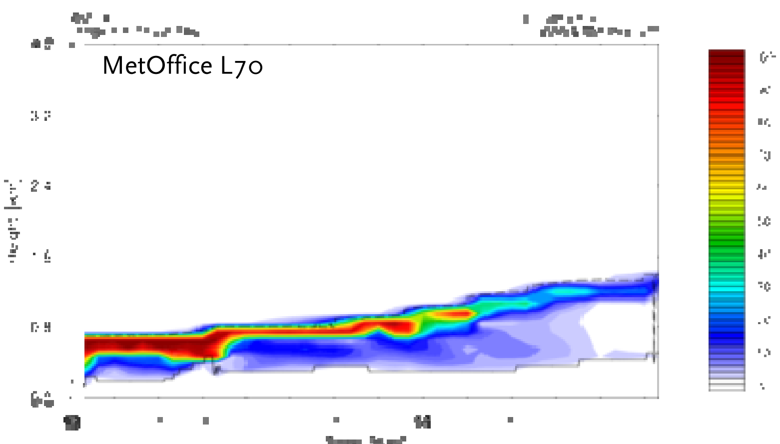
ASTEX – SCM results, group V

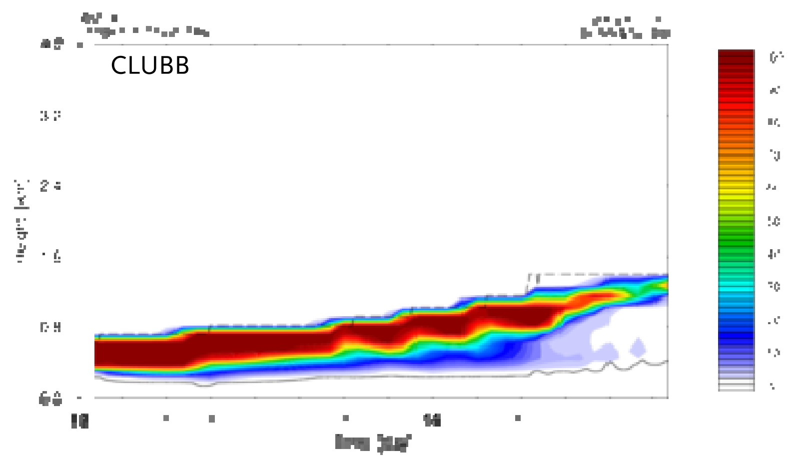
Various











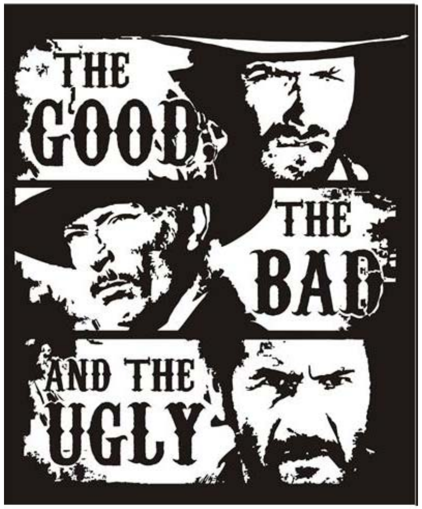
ASTEX - timeseries

Start with only LES results (ensemble mean)

Add SCM spaghetti

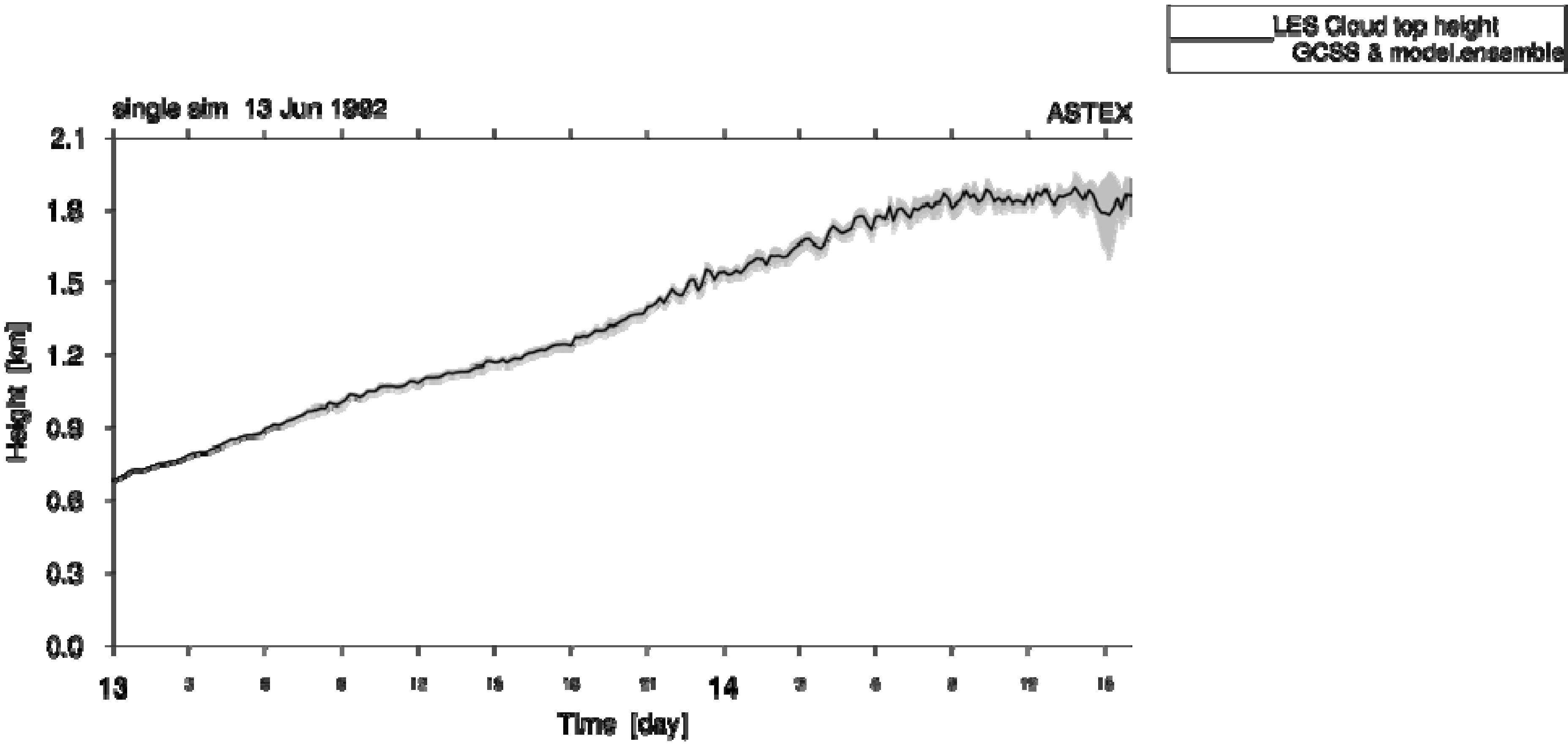
Purpose: Establish model spread (uncertainty)

Identify erroneous outliers &
highlight successful models

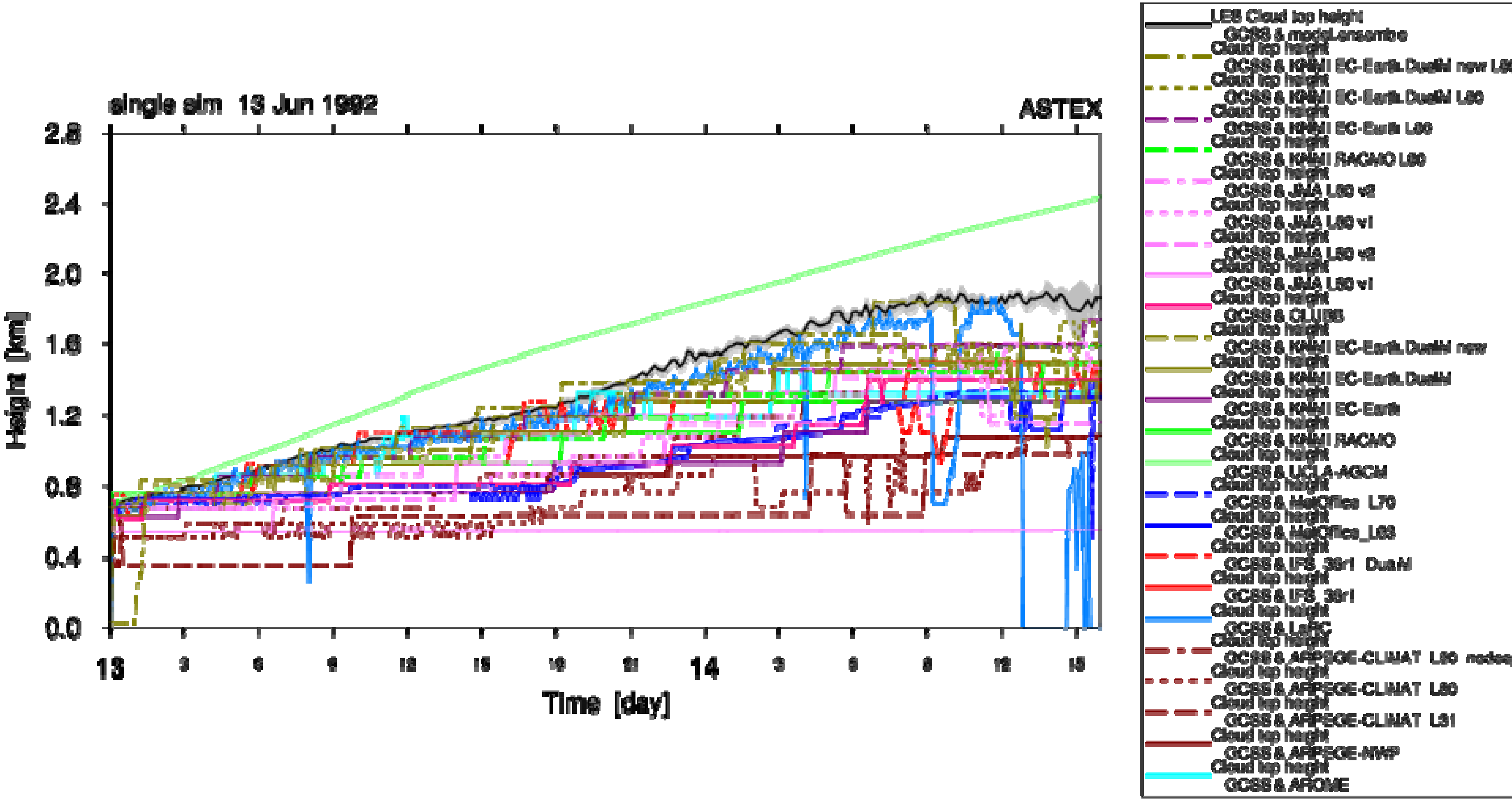


Statistical summary (simple metrics)

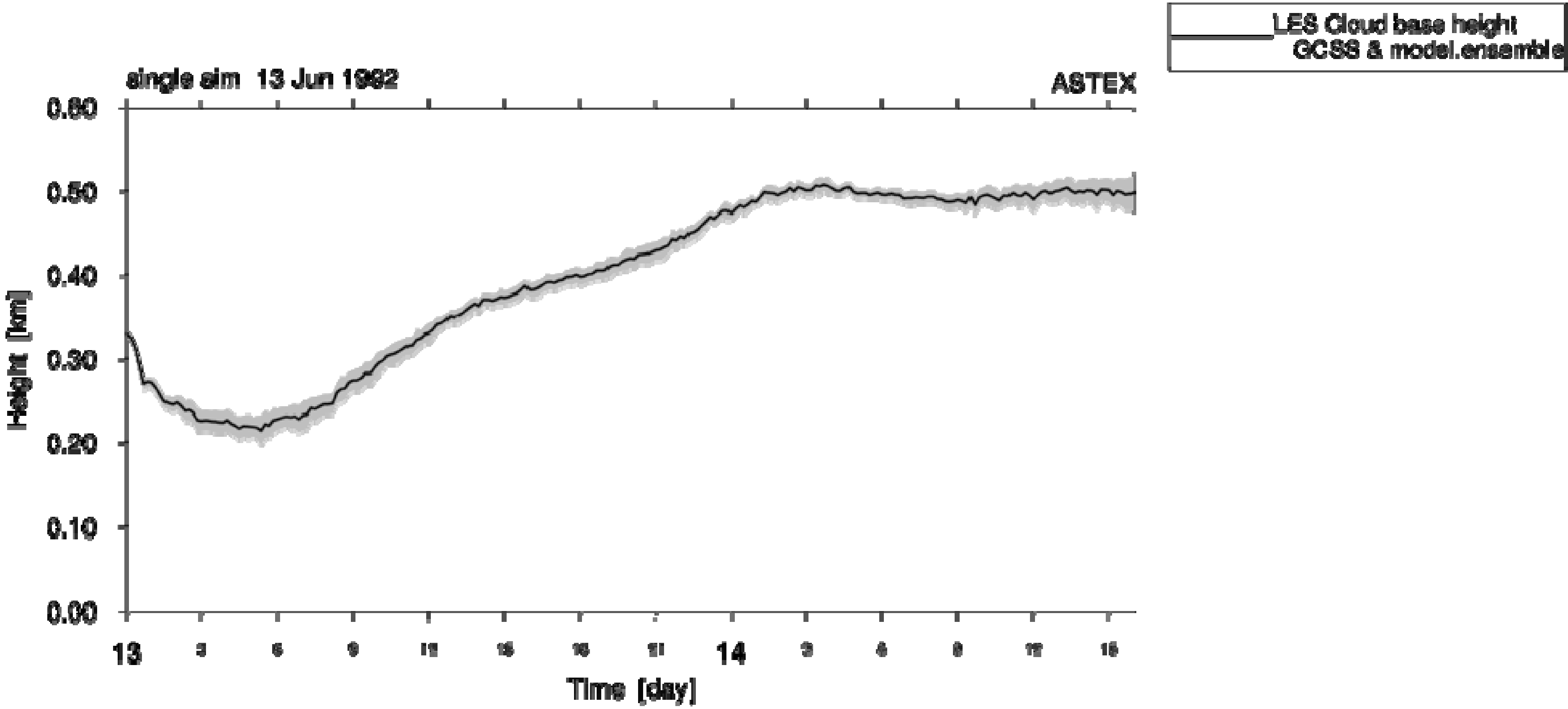
ASTEX - Cloud top height



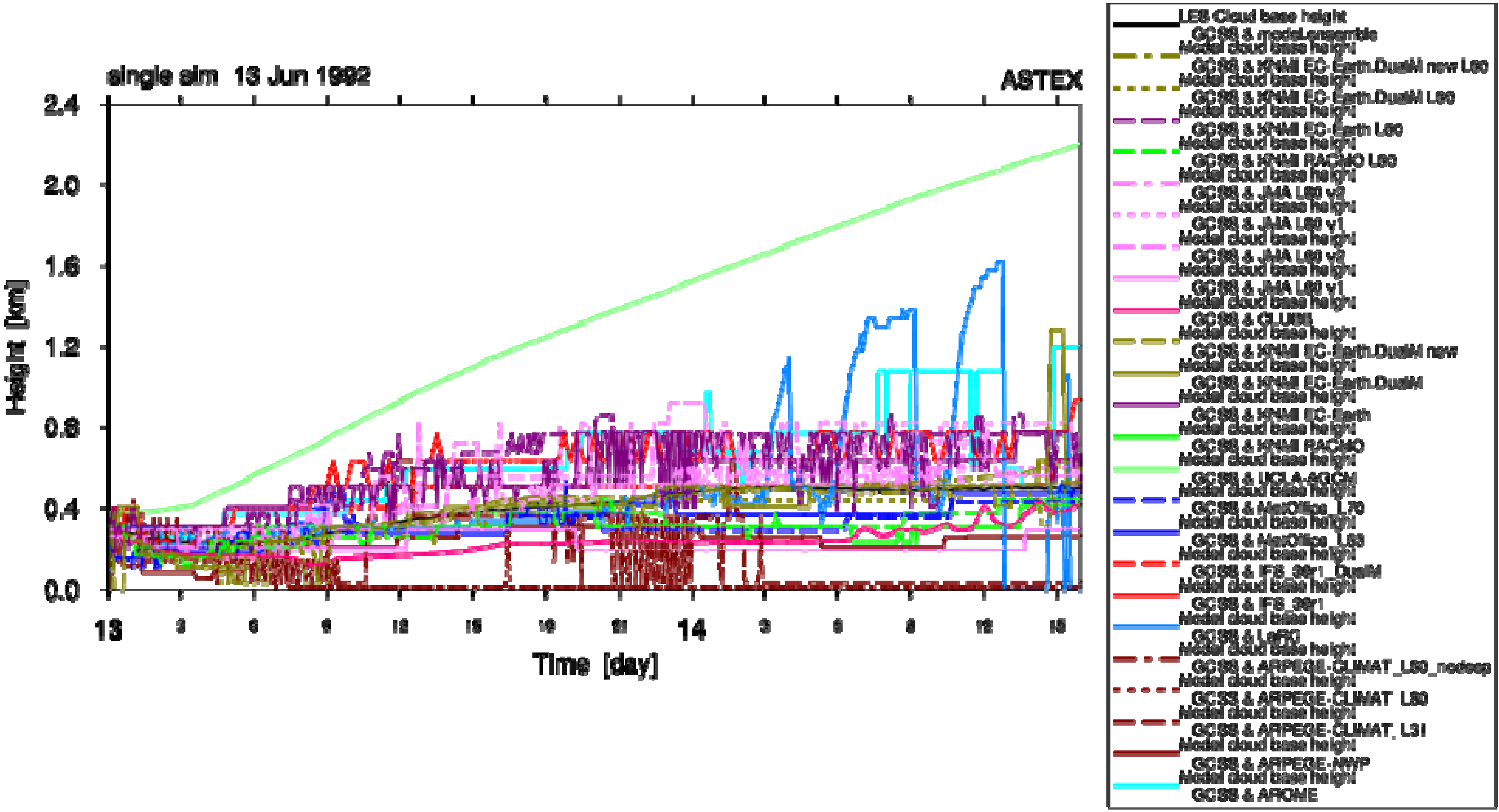
ASTEX - Cloud top height



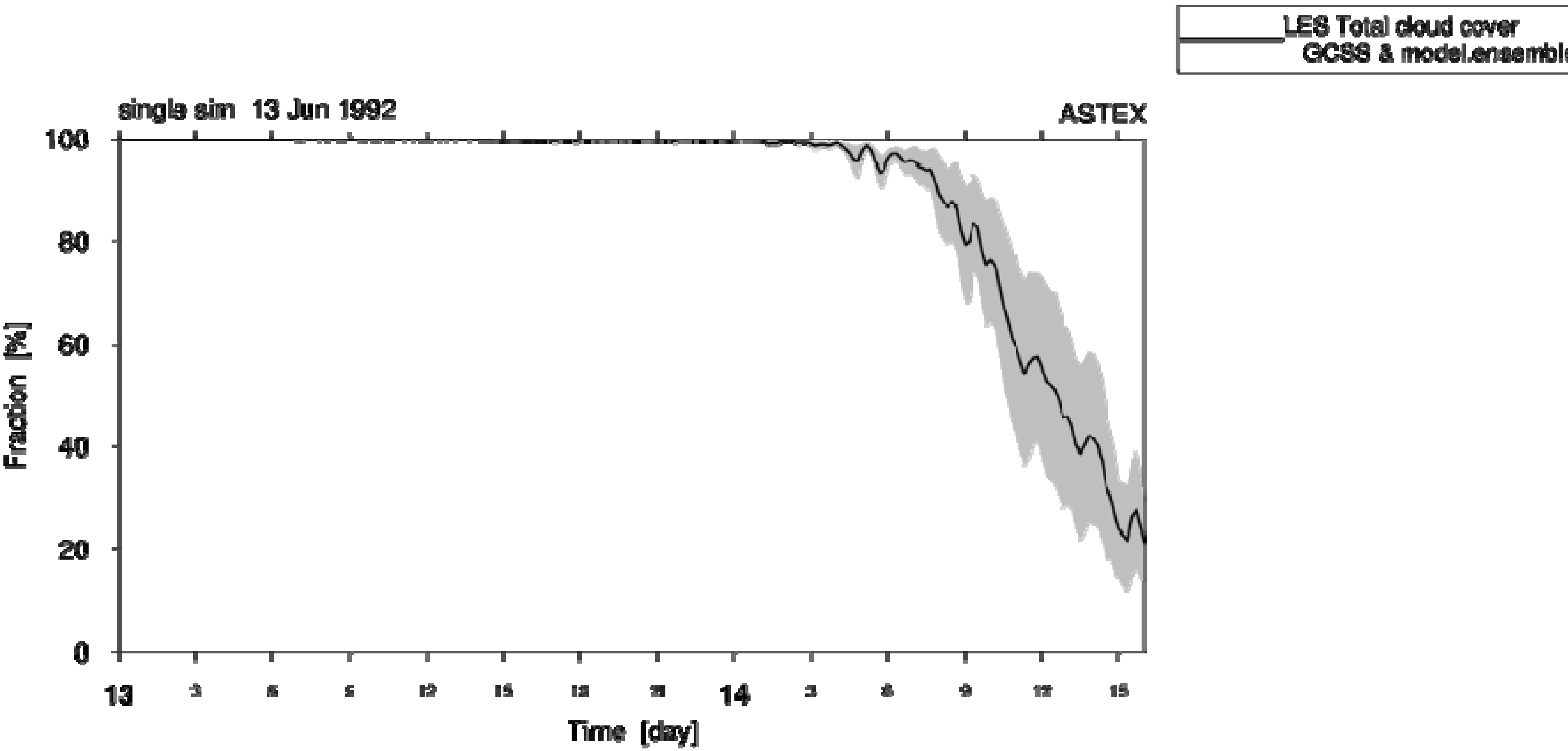
ASTEX - Cloud base height



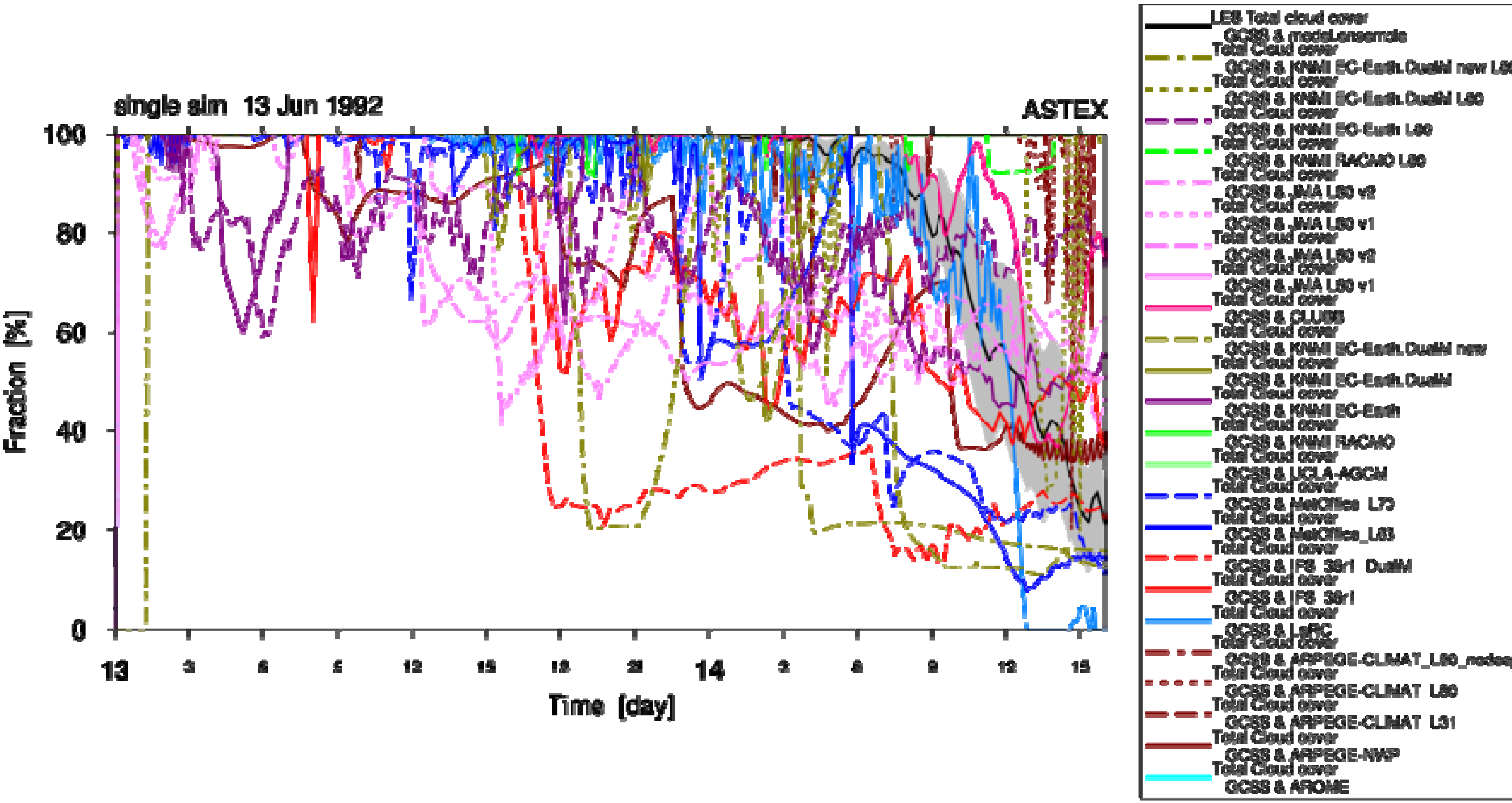
ASTEX - Cloud base height



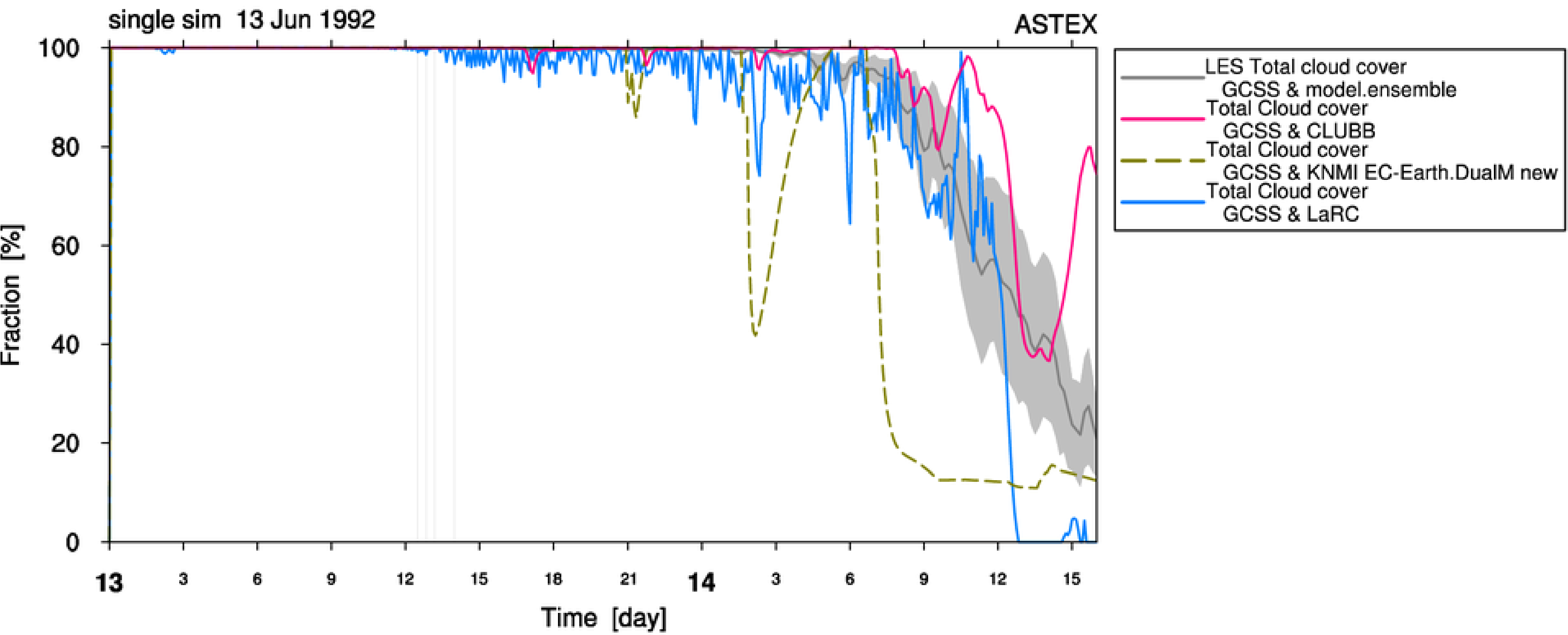
ASTEX - Total cloud cover



ASTEX - Total cloud cover



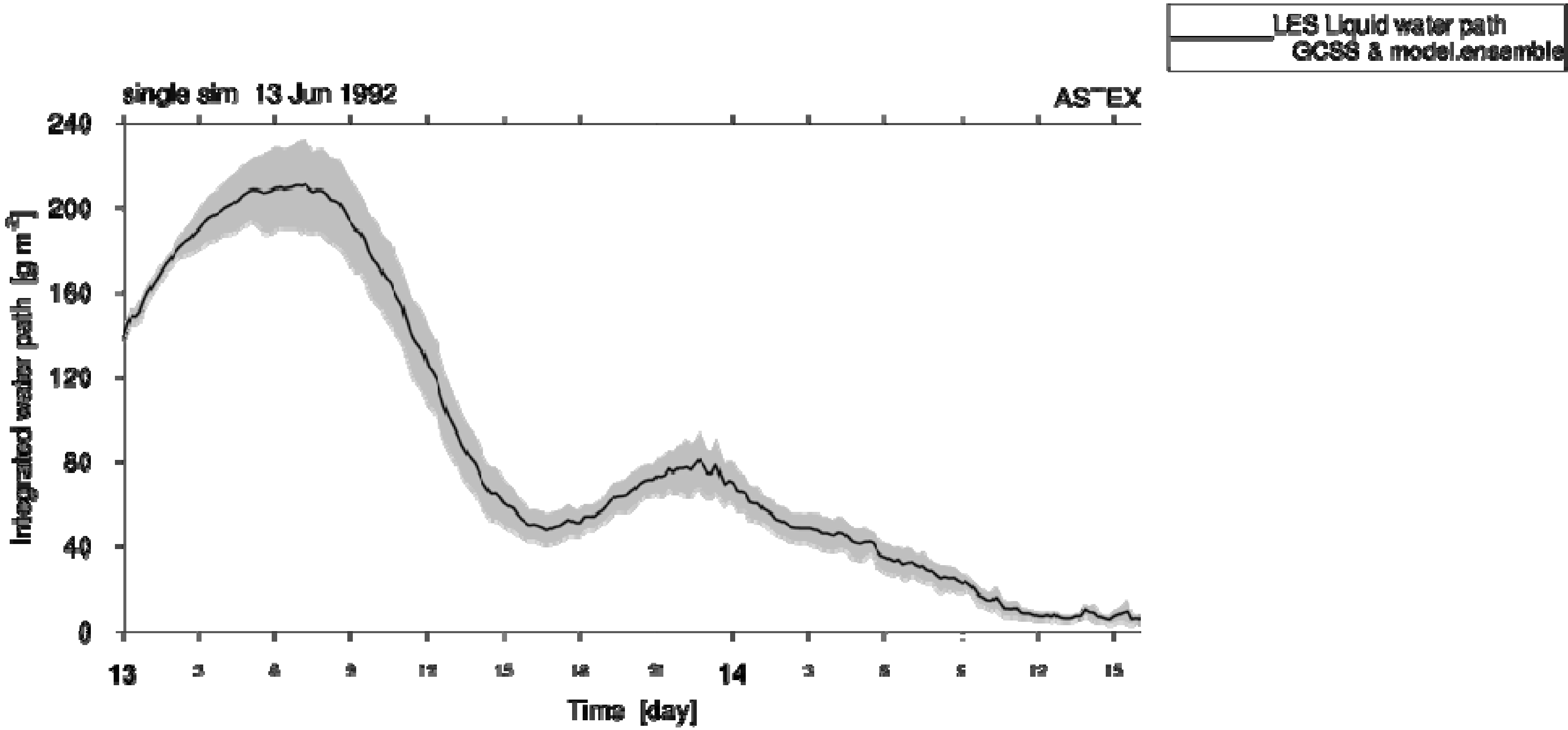
ASTEX - Total cloud cover



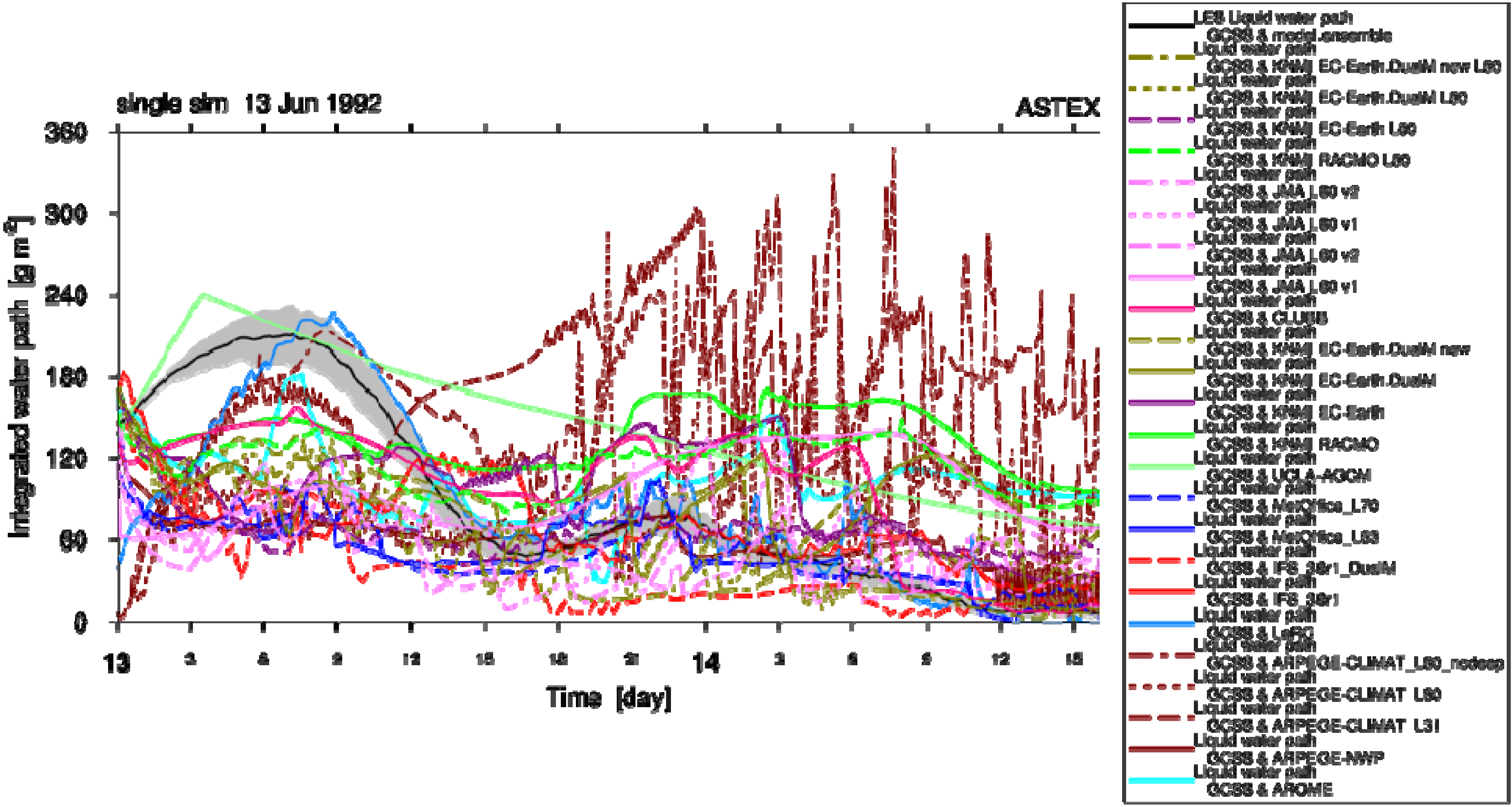
Some models manage to time the breakup correctly

Note: significant spread exists among LES models concerning the speed of the cloud breakup

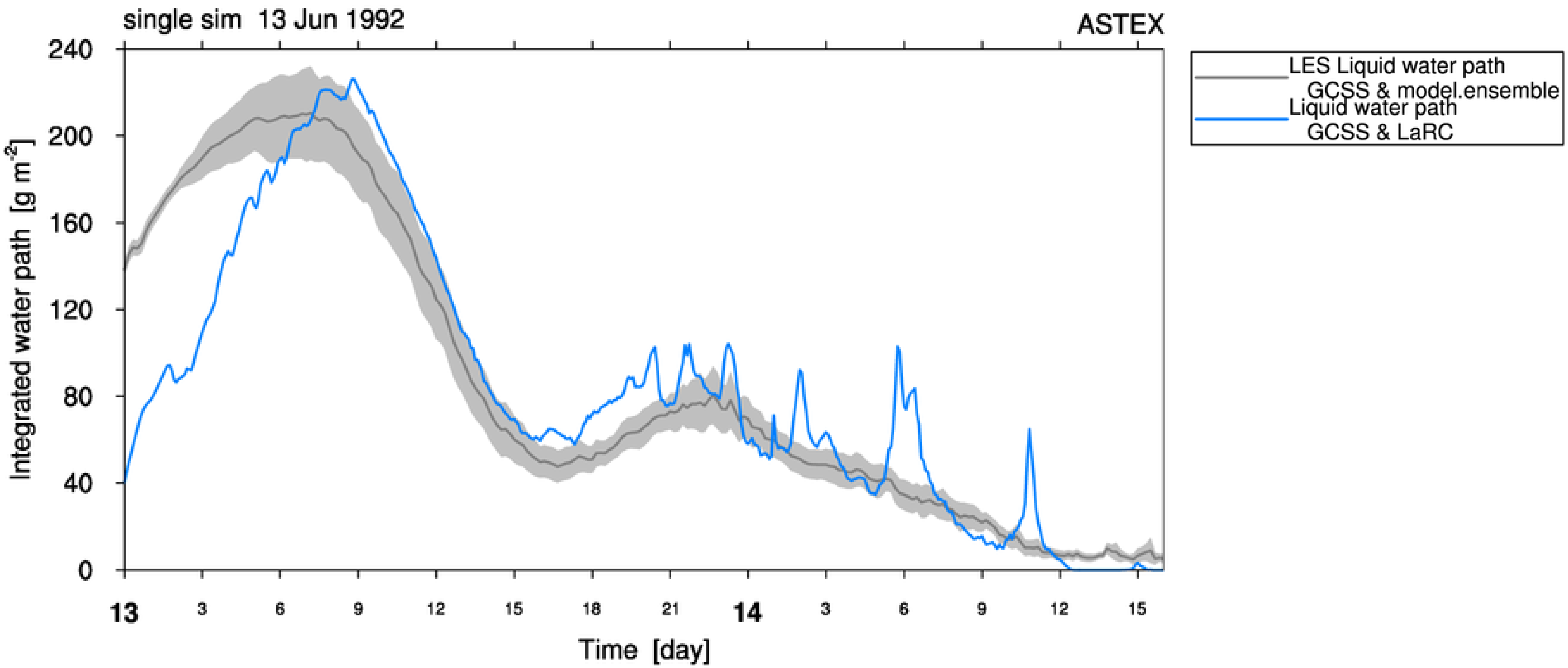
ASTEX - Liquid water path



ASTEX - Liquid water path

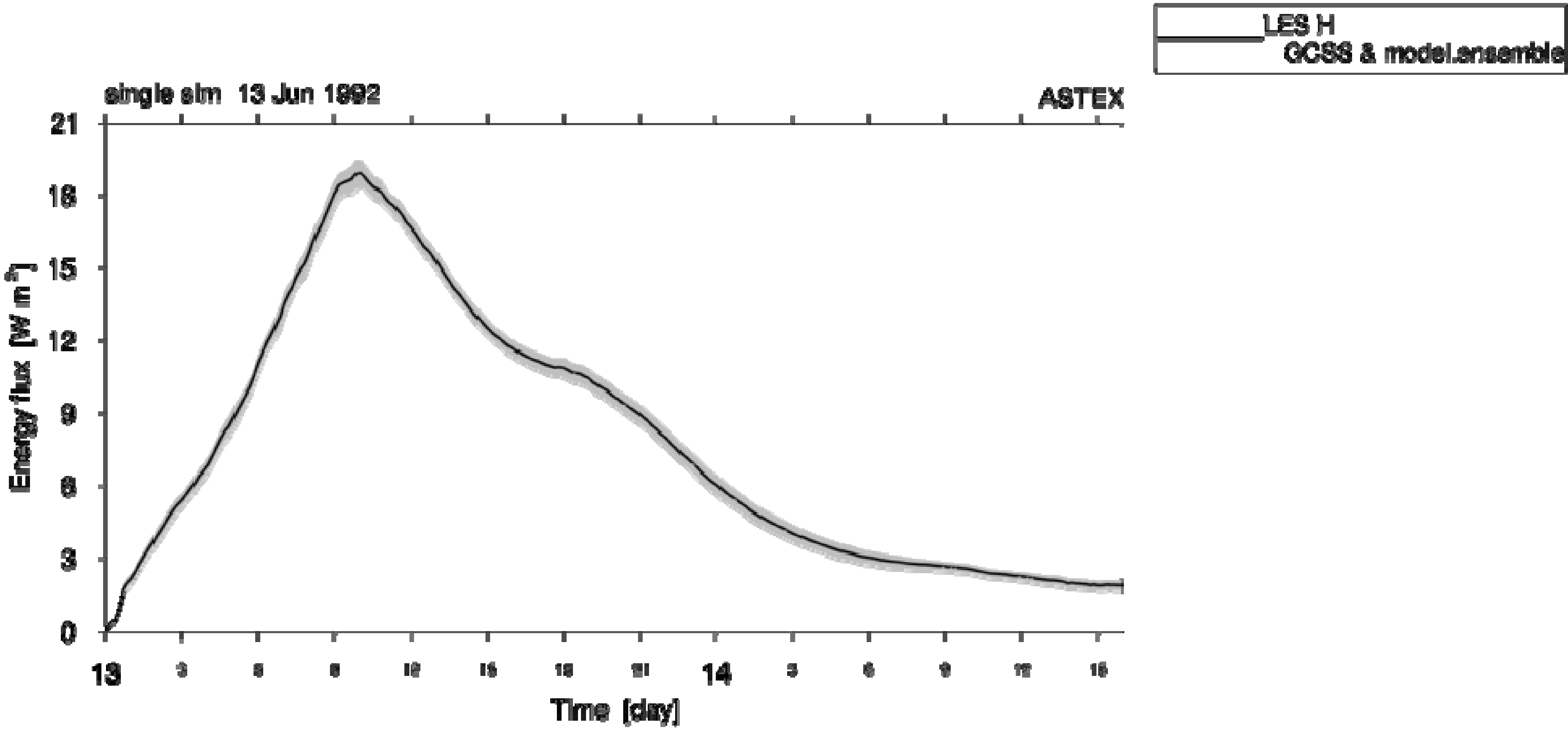


ASTEX - Liquid water path

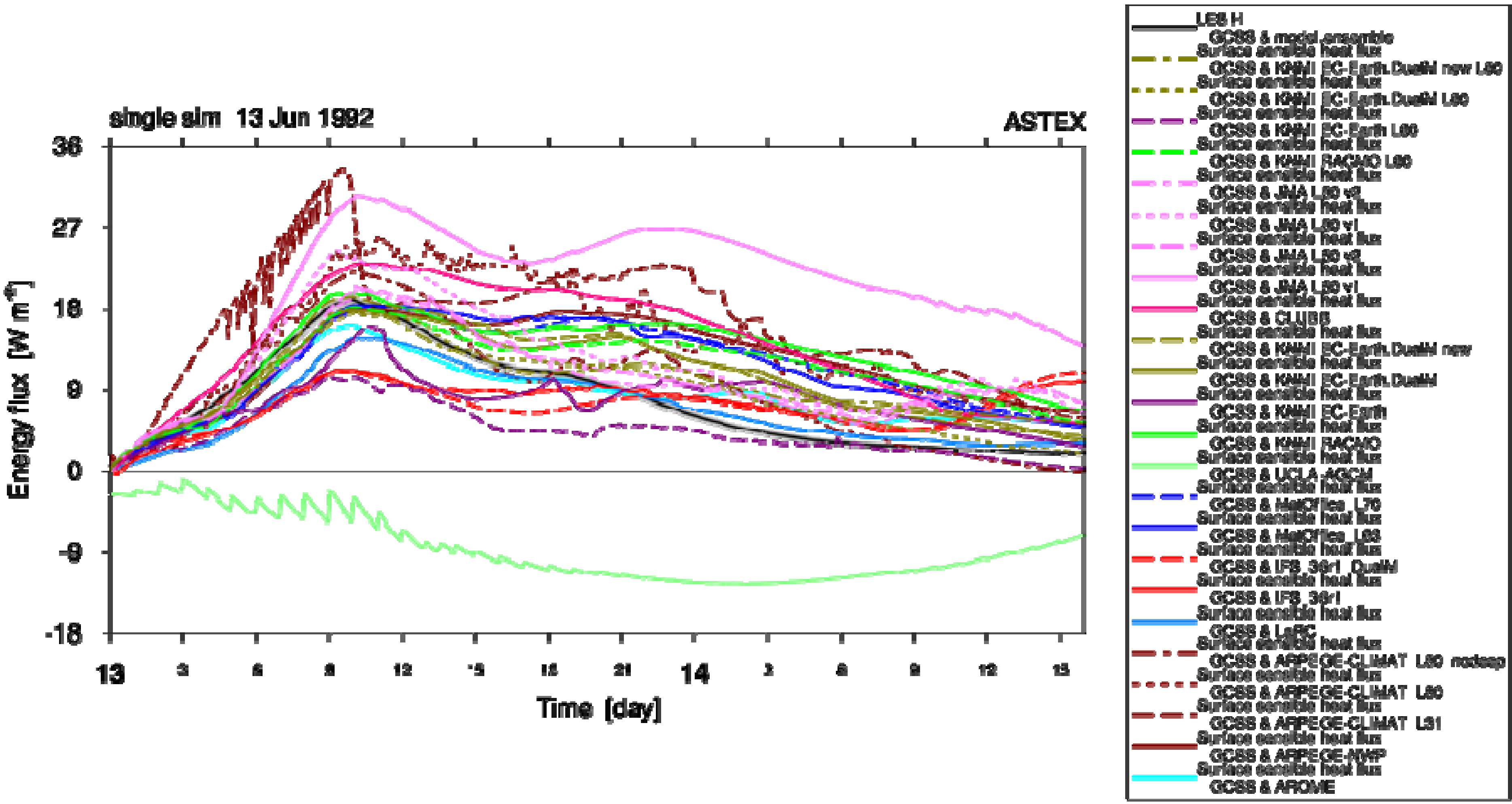


Impressive!

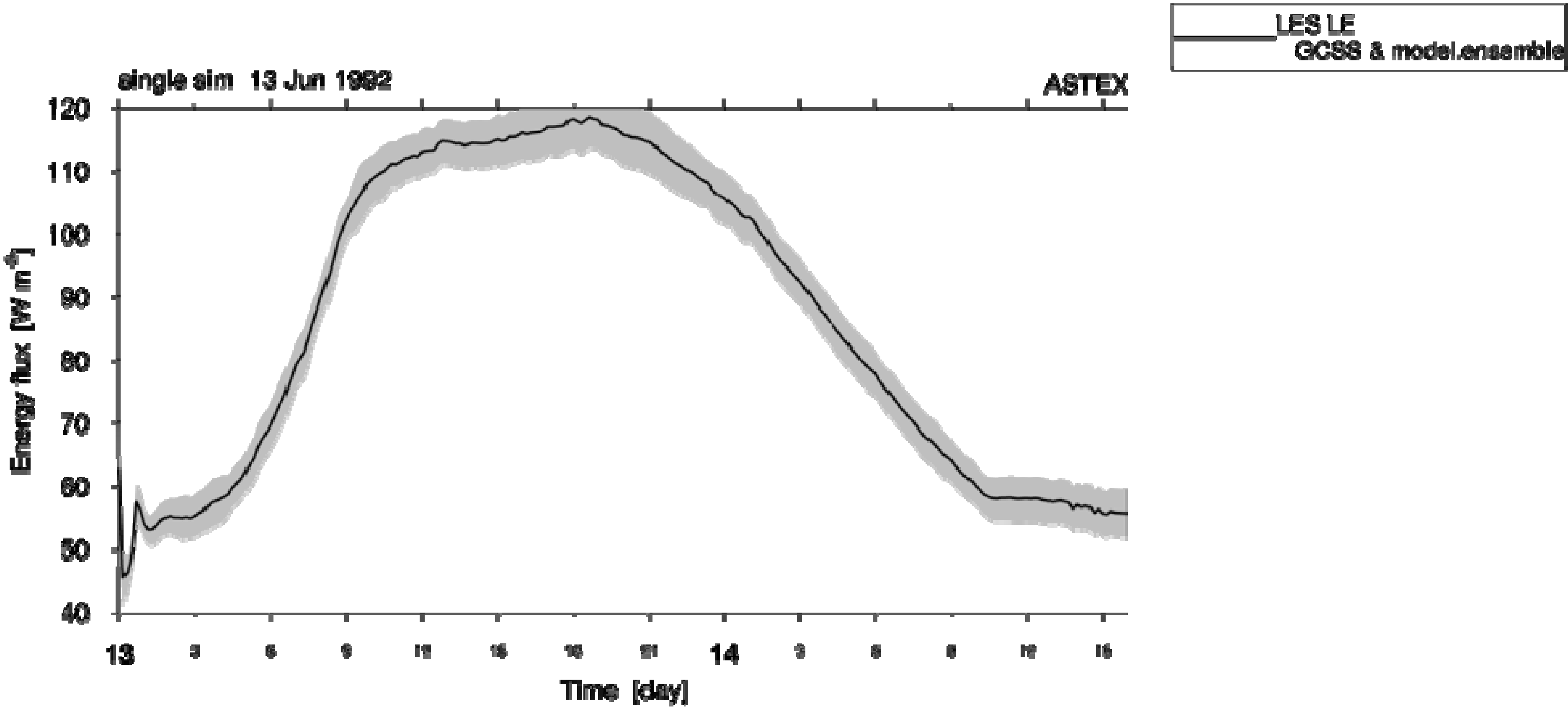
ASTEX - Sensible heat flux



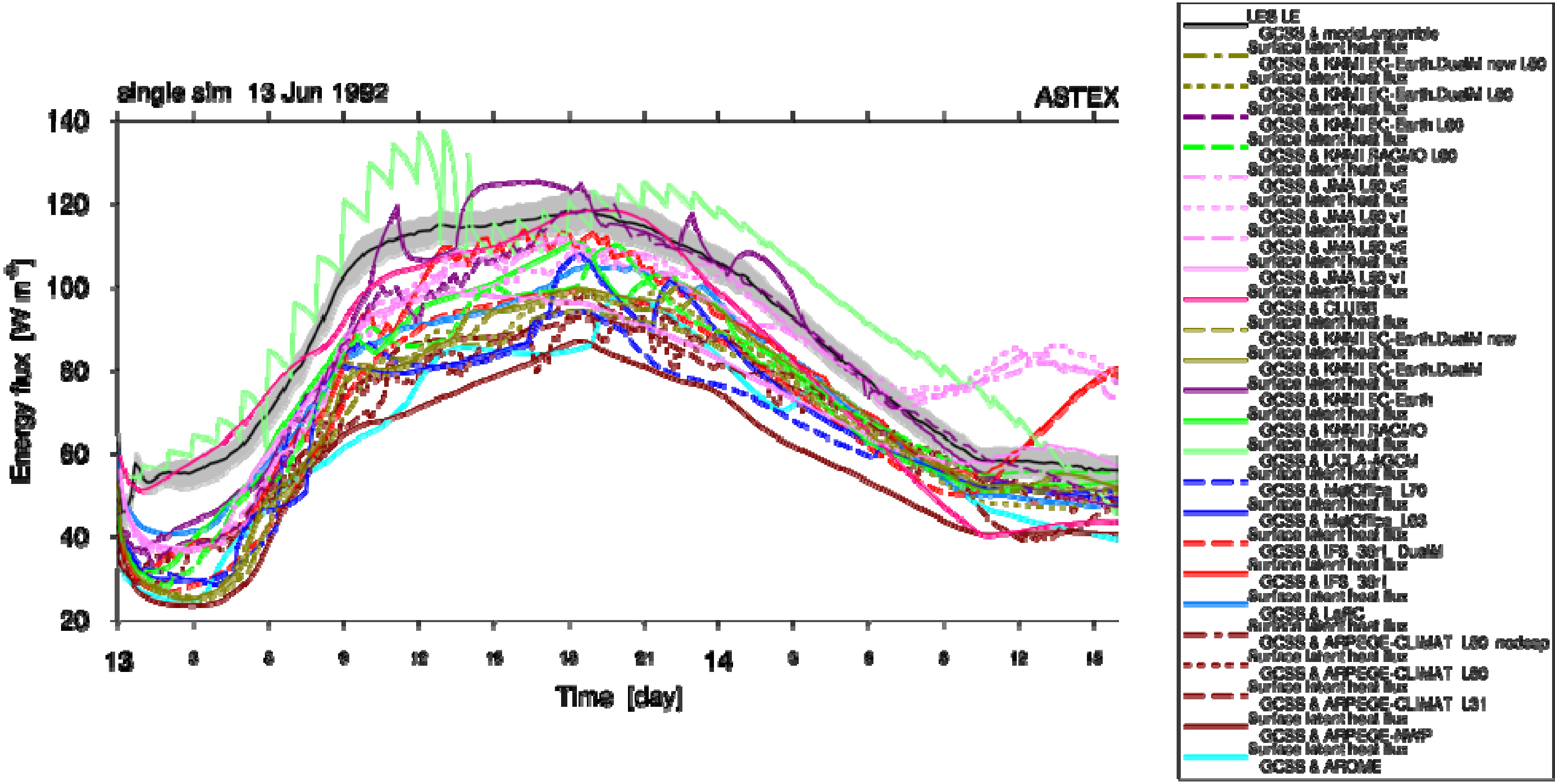
ASTEX - Sensible heat flux



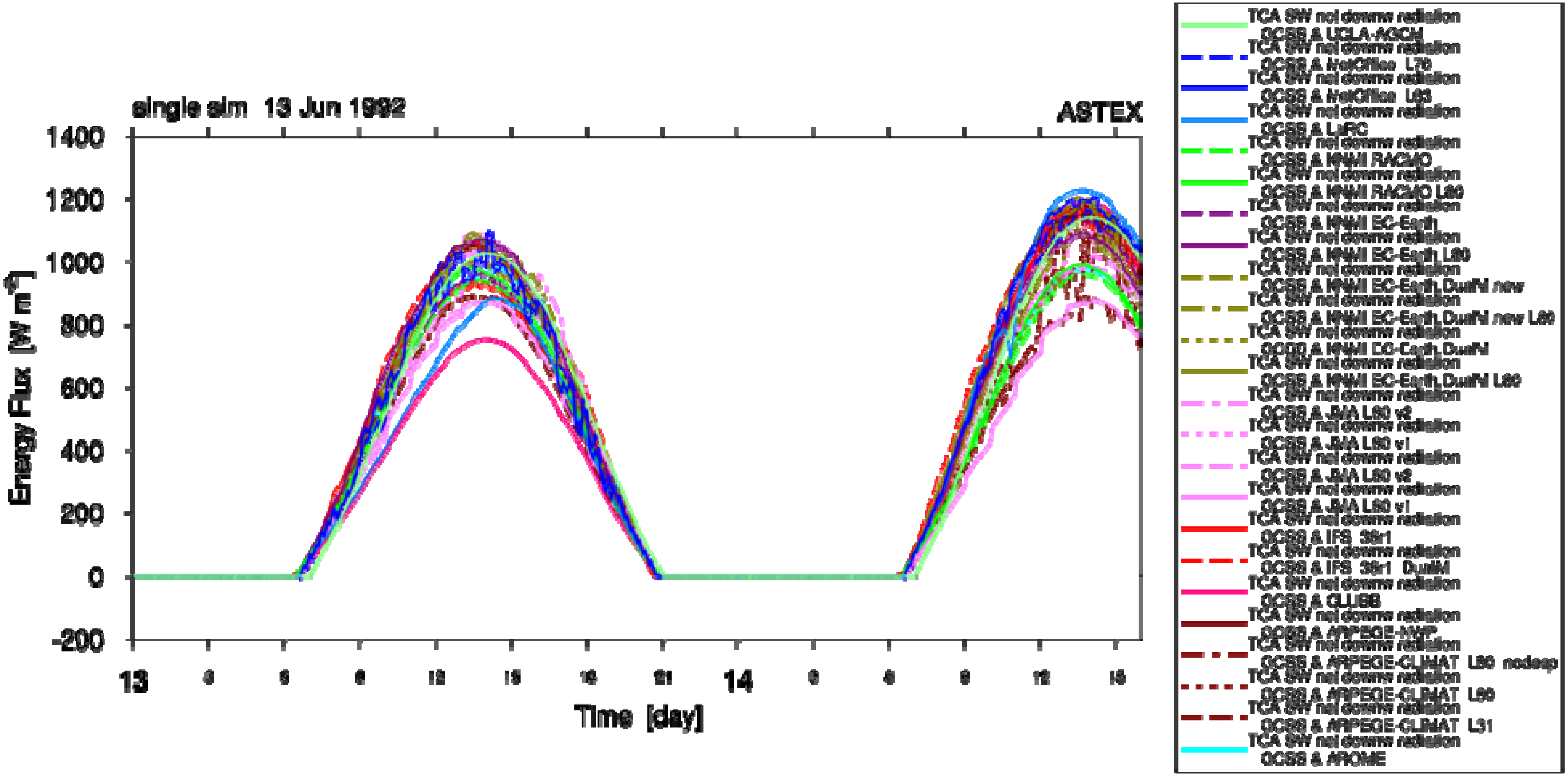
ASTEX - Latent heat flux



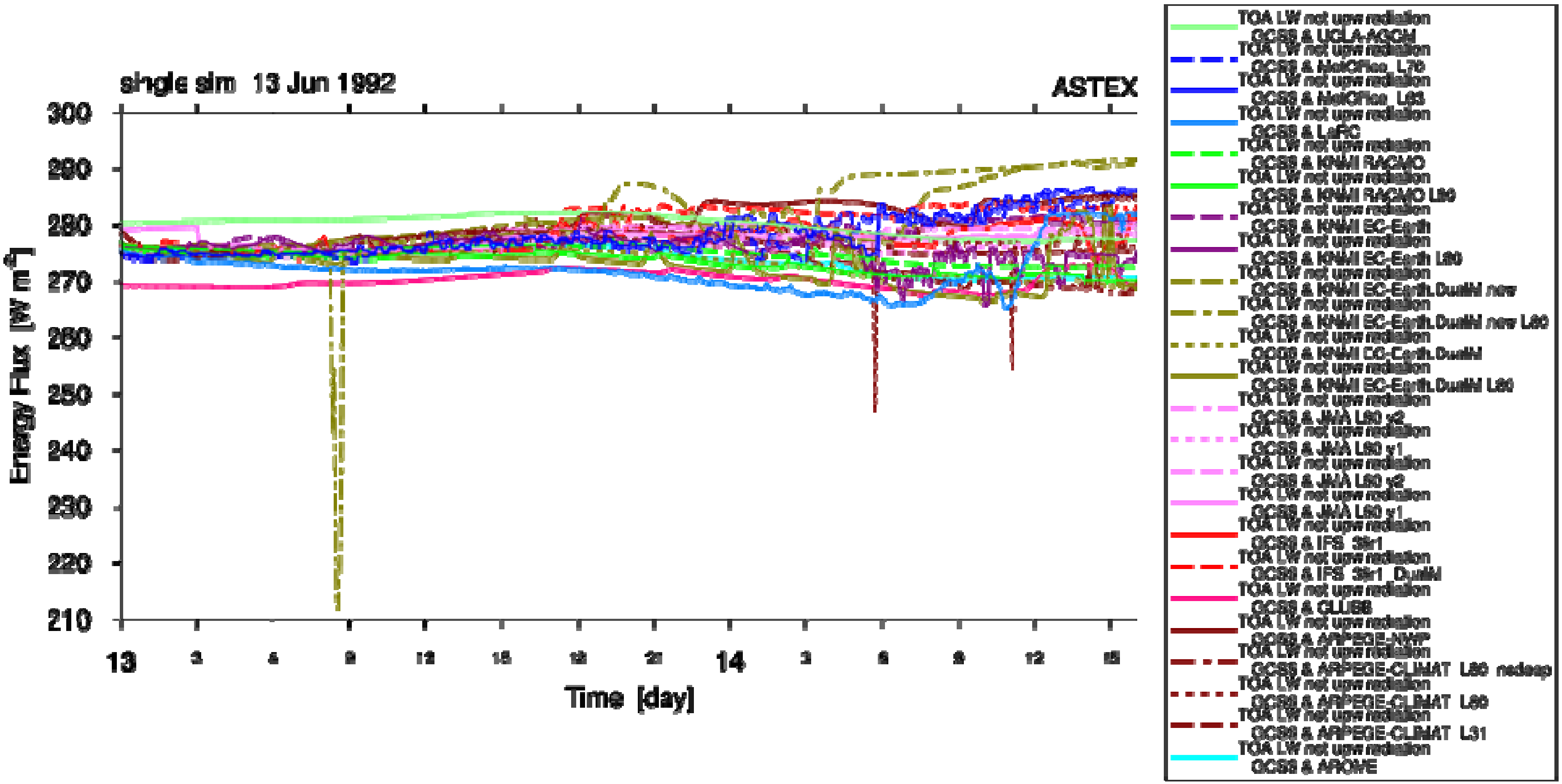
ASTEX - Latent heat flux



ASTEX – TOA net SW

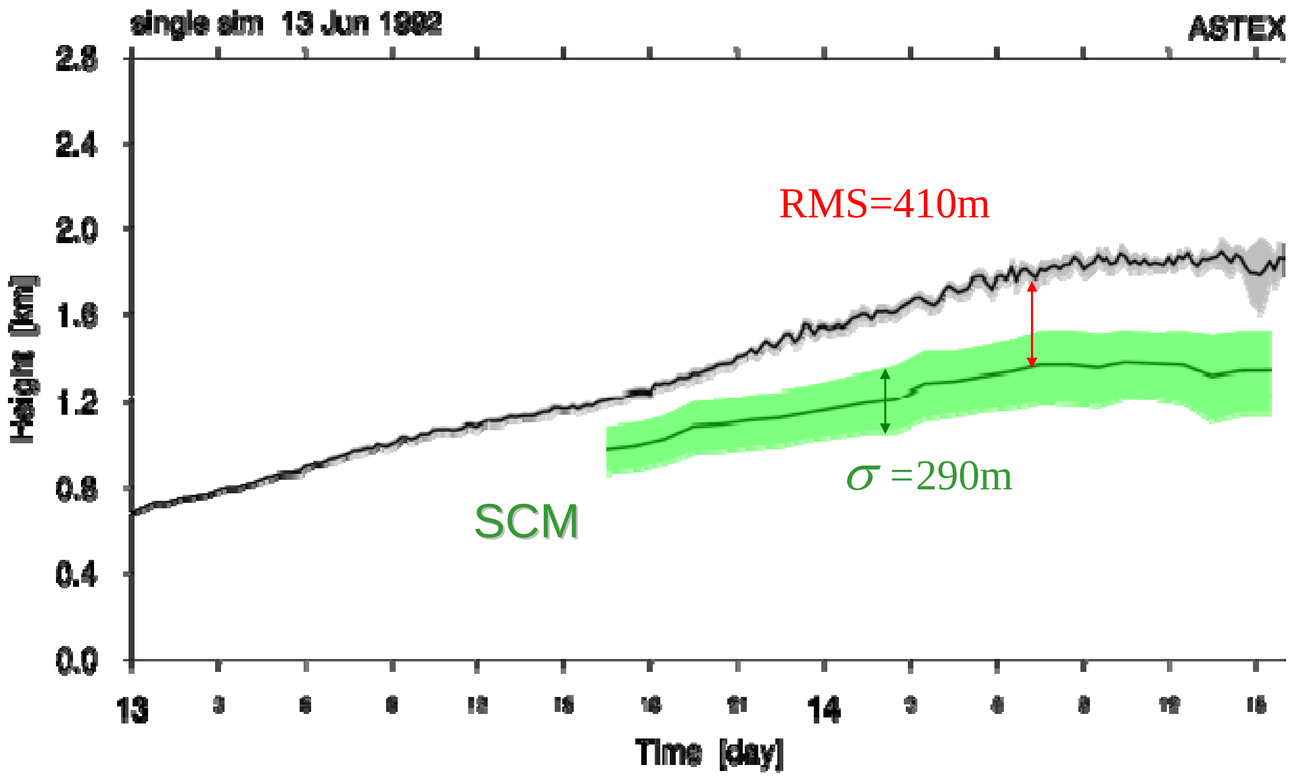


ASTEX – TOA net LW



SCM ensemble statistics

How to quantify the performance of the collective SCM ensemble?



Uncertainty (spread among SCMs):

$$\sigma^2 = \frac{1}{T}\int_t \frac{1}{N}\sum_{i=1}^{N}(\phi_i^{SCM} - \overline{\phi}^{SCM})^2\,dt$$

Performance (deviation from LES):

$$\mathrm{RMS}^2 = \frac{1}{T}\int_t (\overline{\phi}^{\mathrm{SCM}} - \overline{\phi}_t^{\mathrm{LES}})^2\,dt$$

ASTEX
SCM score-sheet

Variable	*Units*	*Sigma*	*RMS*
CC	%	23.5	16.7
LWP	$g\ m^{-2}$	47.9	43.2
ZCB	m	346	75
ZTOP	m	290	407
SHF	$W\ m^{-2}$	5.5	3.4
LHF	$W\ m^{-2}$	10.0	12.0
SMF	$m^2\ s^{-2}$	0.62	-
PRECW	$kg\ m^{-2}$	0.97	-
PREC_SRF	$W\ m^{-2}$	16.5	8.3
SFC net SW	$W\ m^{-2}$	50	-
SFC net LW	$W\ m^{-2}$	16	-
TOA net SW	$W\ m^{-2}$	49	-
TOA net LW	$W\ m^{-2}$	4.5	-
TKE_INT	$m^3\ s^{-2}$	535	109

Composite transitions

What is new and interesting about this case?

* Varying forcing within one case study (SST, q_t^+, θ_l^+)

* Potential evaluation against many observations (yet to be realized)

Potential issue:

Does composite simulation compromise any confrontation against obs?

Should we not simulate each trajectory individually, and so resolve the composite-internal variability?

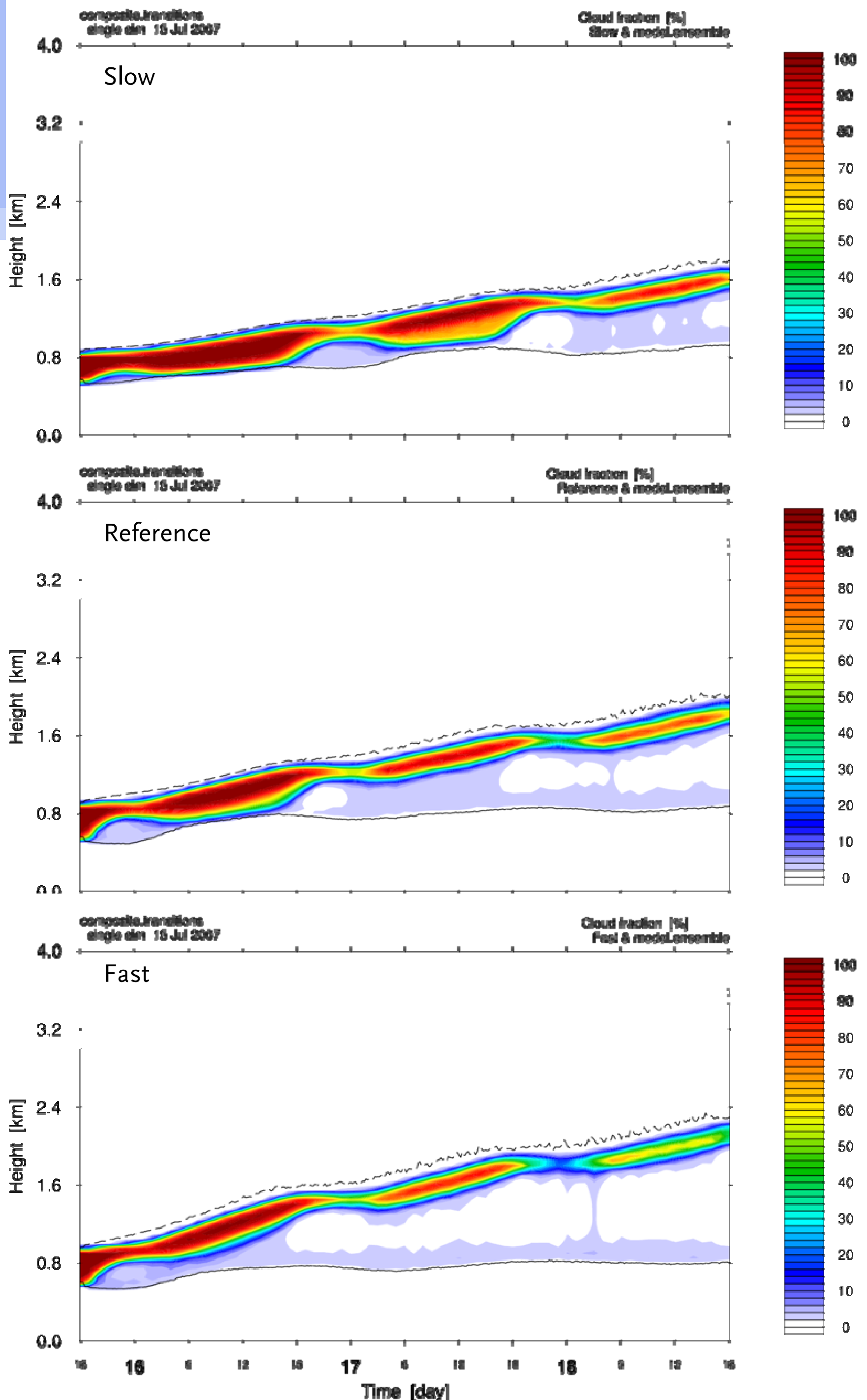
Composite transitions
LES results

Similarities with ASTEX:

* Diurnal cycle in BL deepening
* LCL emerging below a capping cloud deck that is thinning

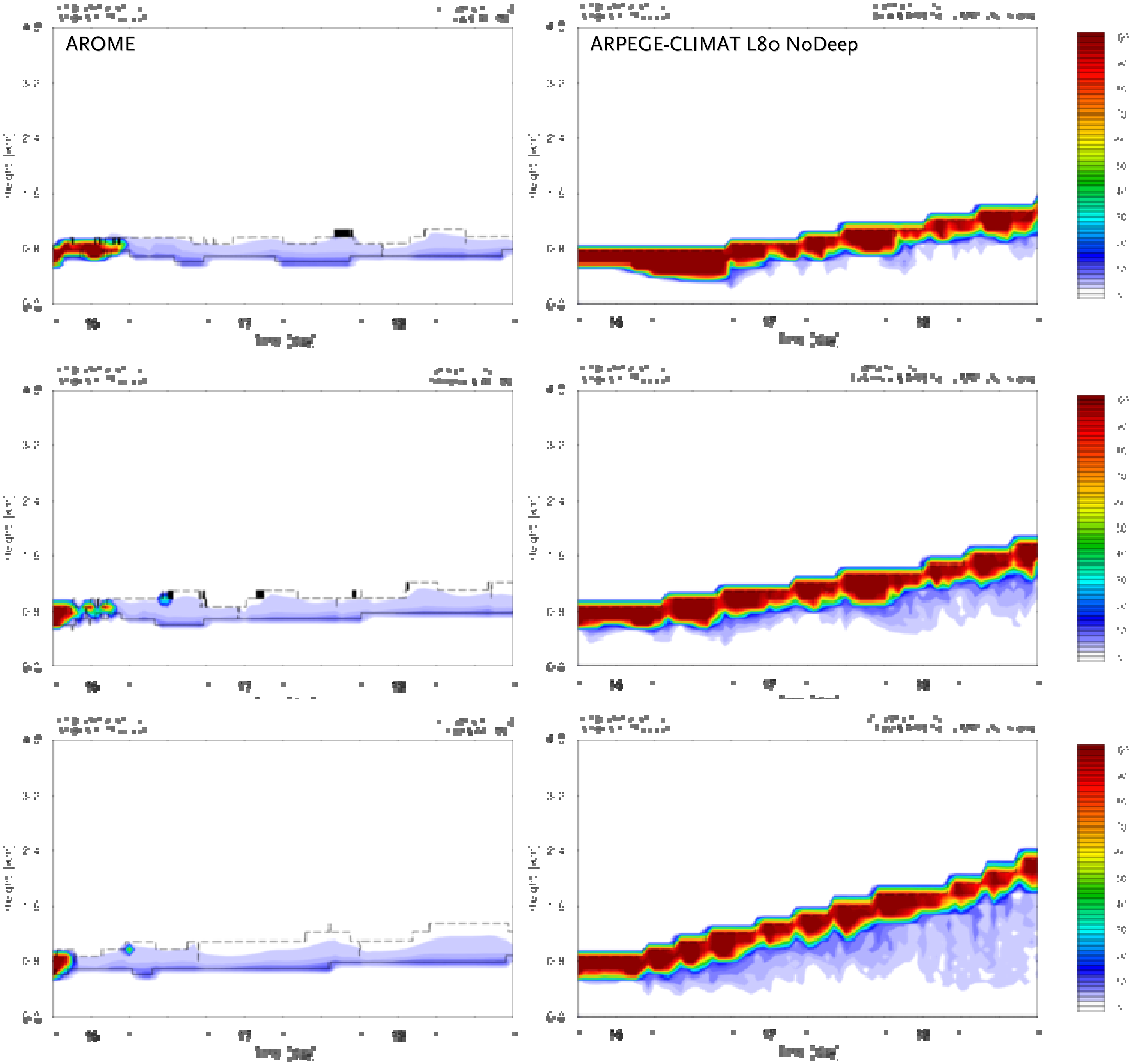
Differences with ASTEX:

* LCL sits higher
* BL deepening does not seem to level off
* No clear breakup materializes in this time-window (although fast case is close)



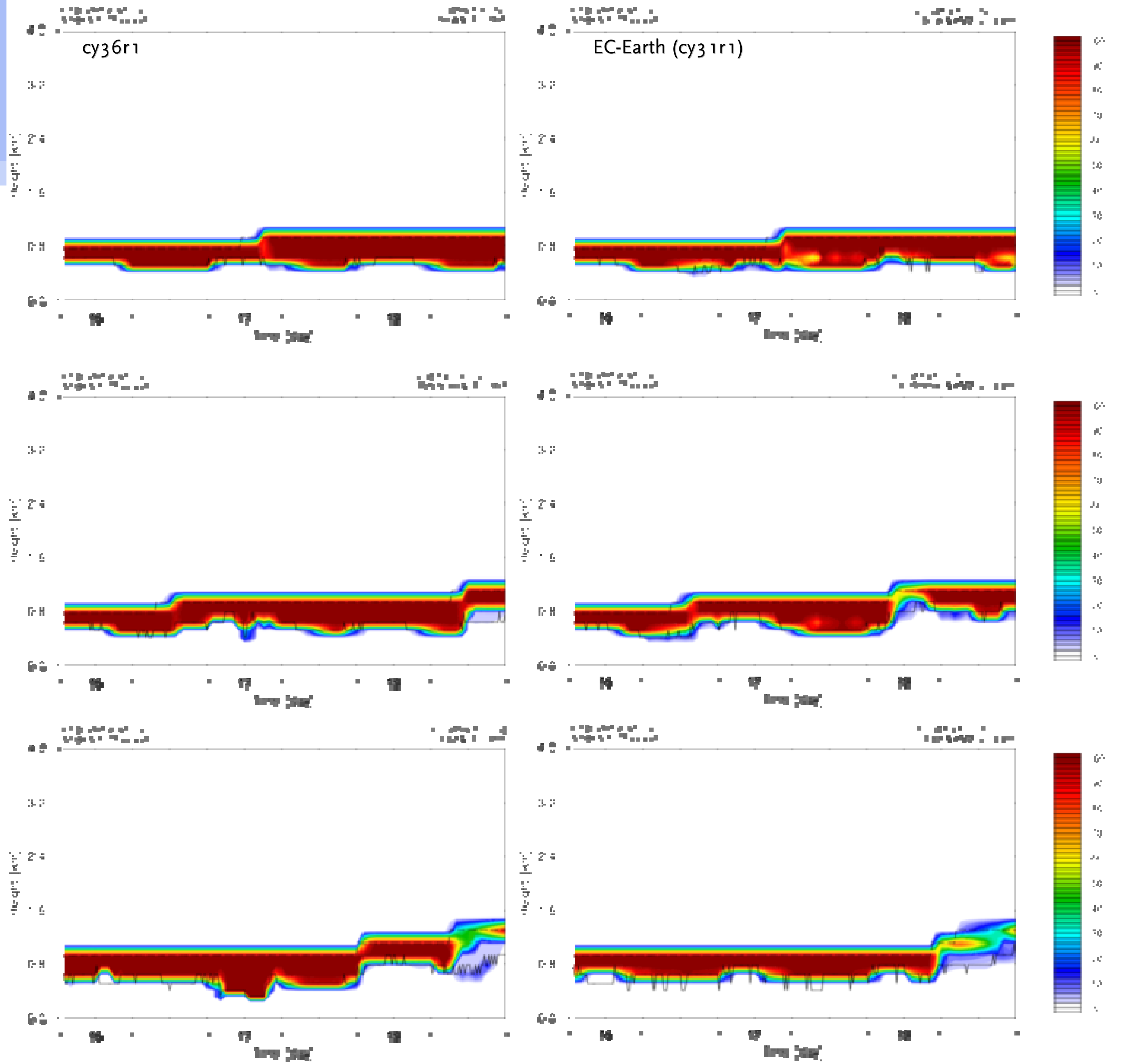
SCM results, group I

Meteo France



SCM results, group II

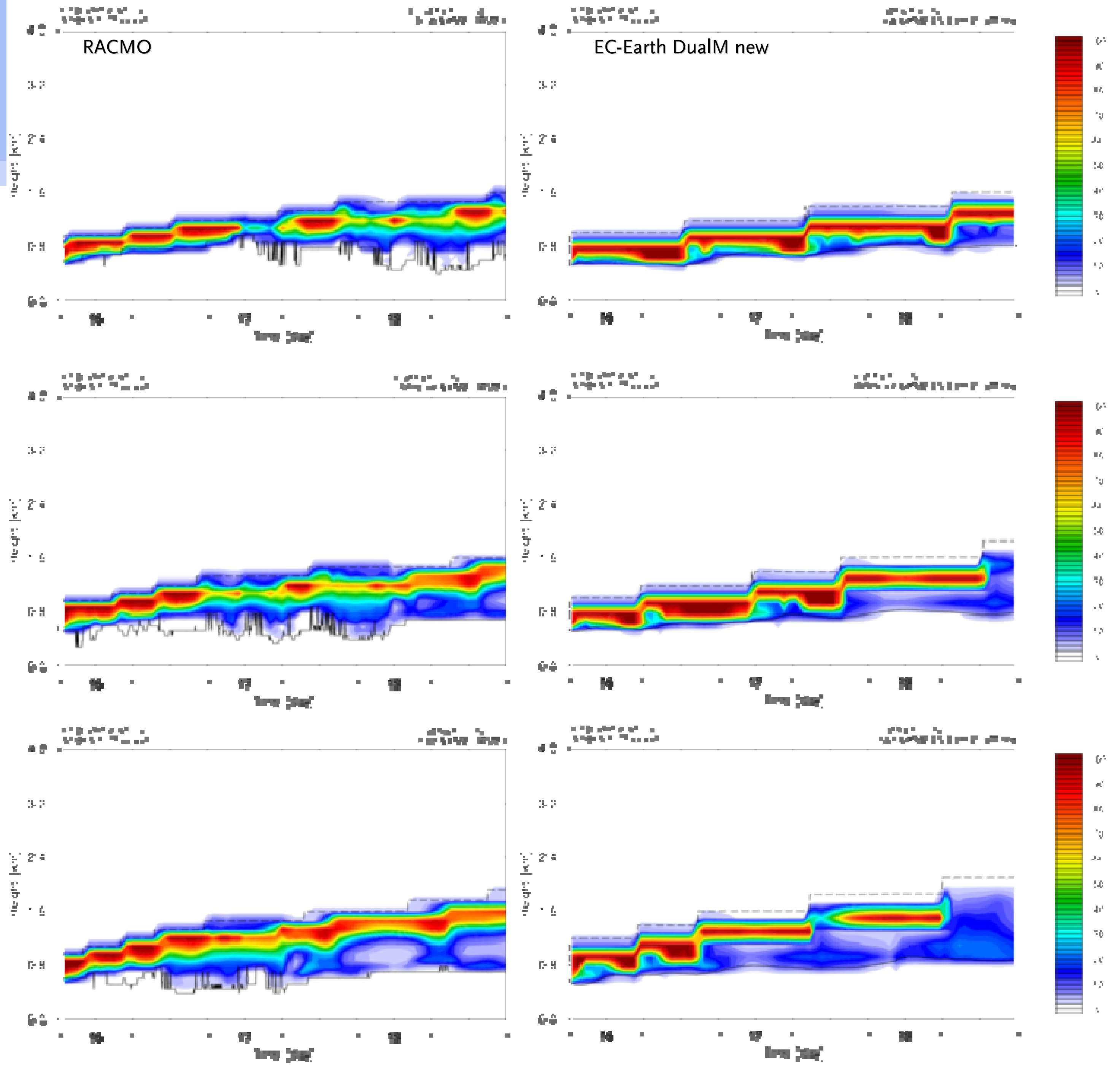
IFS



Delayed transition – due to use of LTS in triggering shallow cumulus scheme?

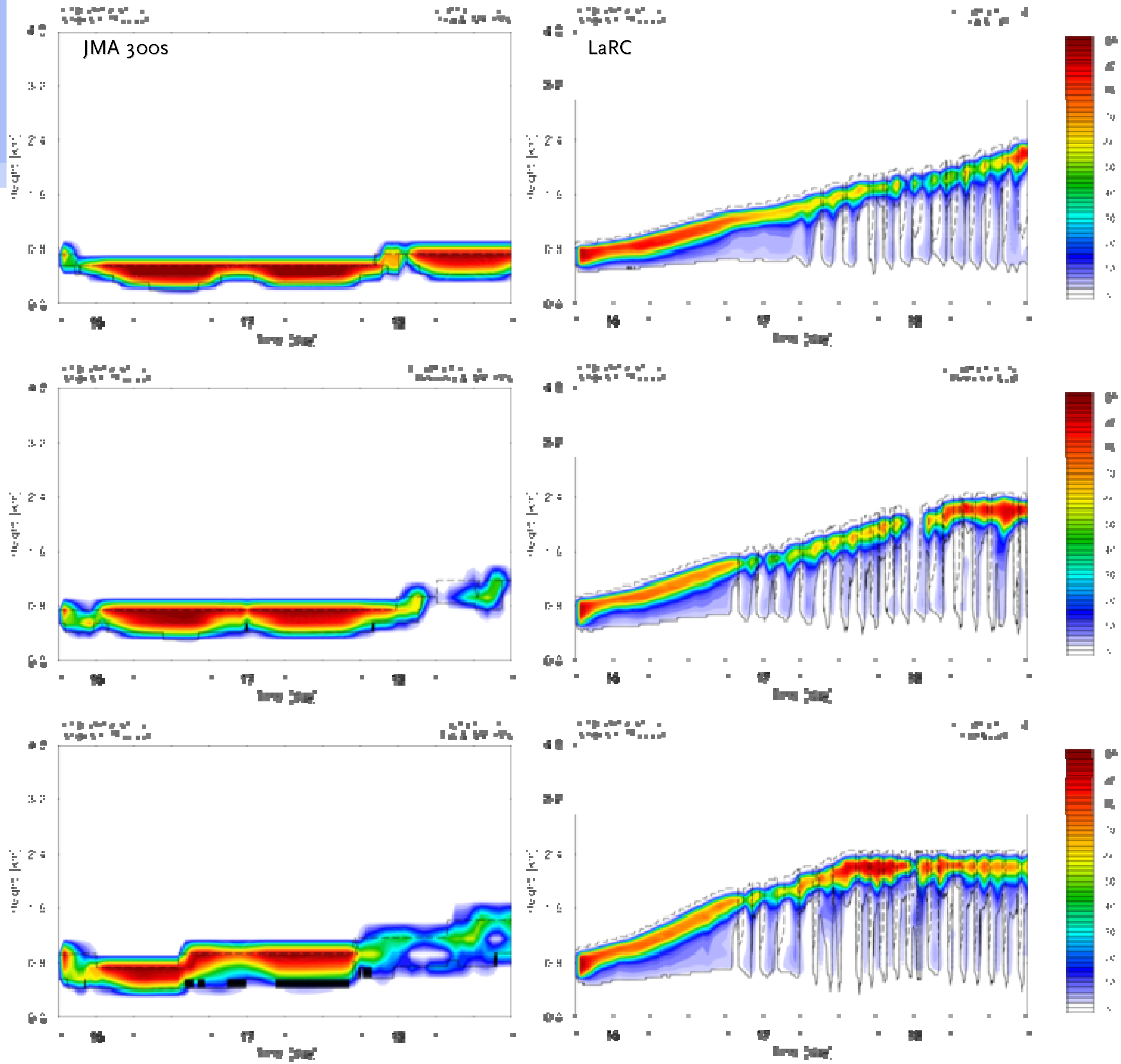
SCM results, group III

EDMF-DualM



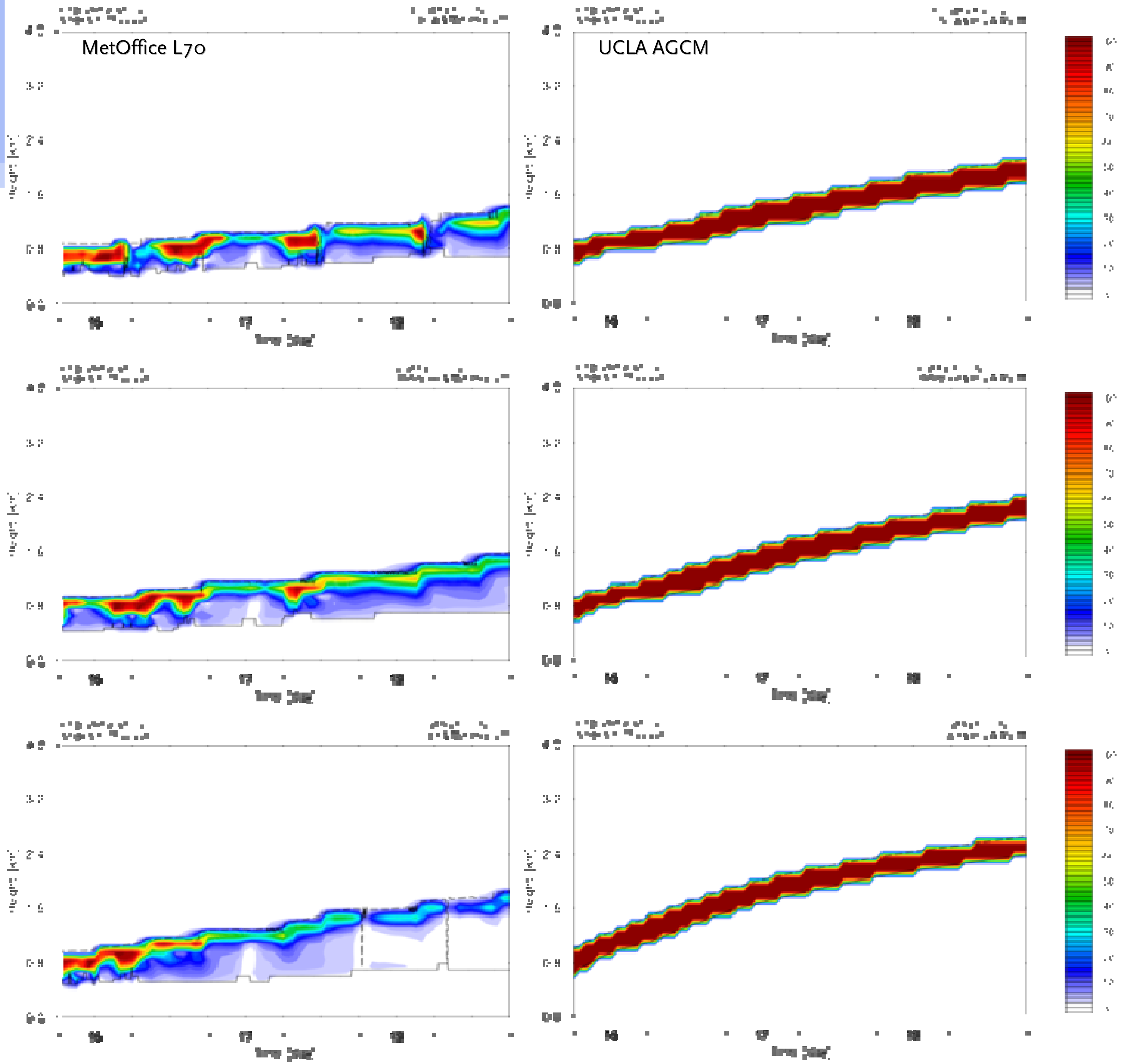
SCM results, group IV

JMA
LaRC

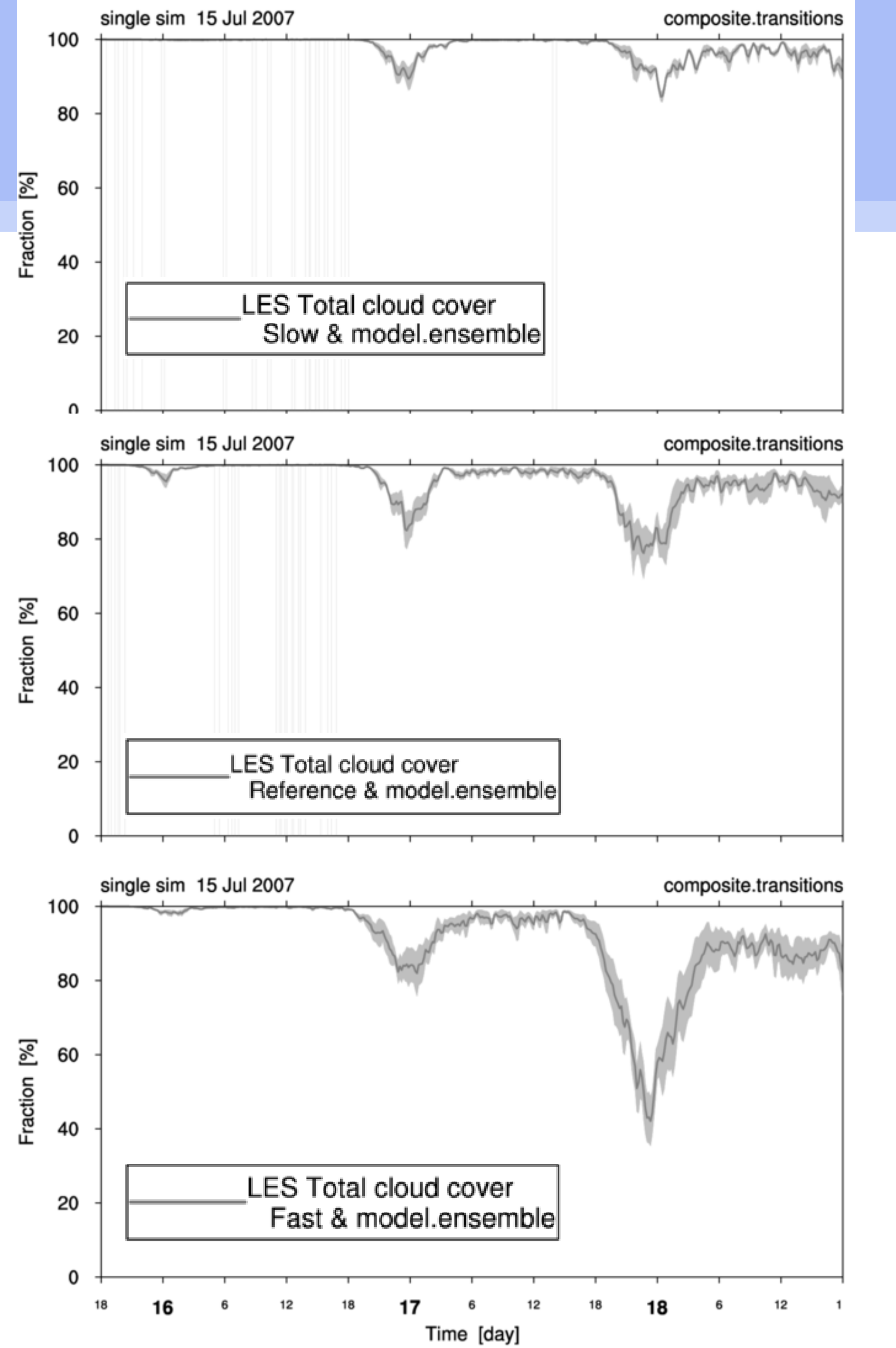


SCM results, group V

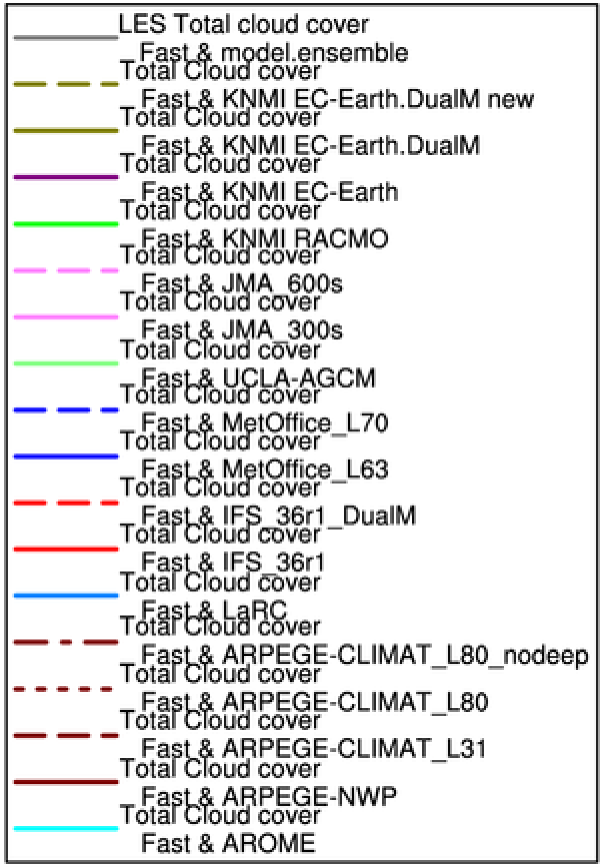
MetOffice
UCLA

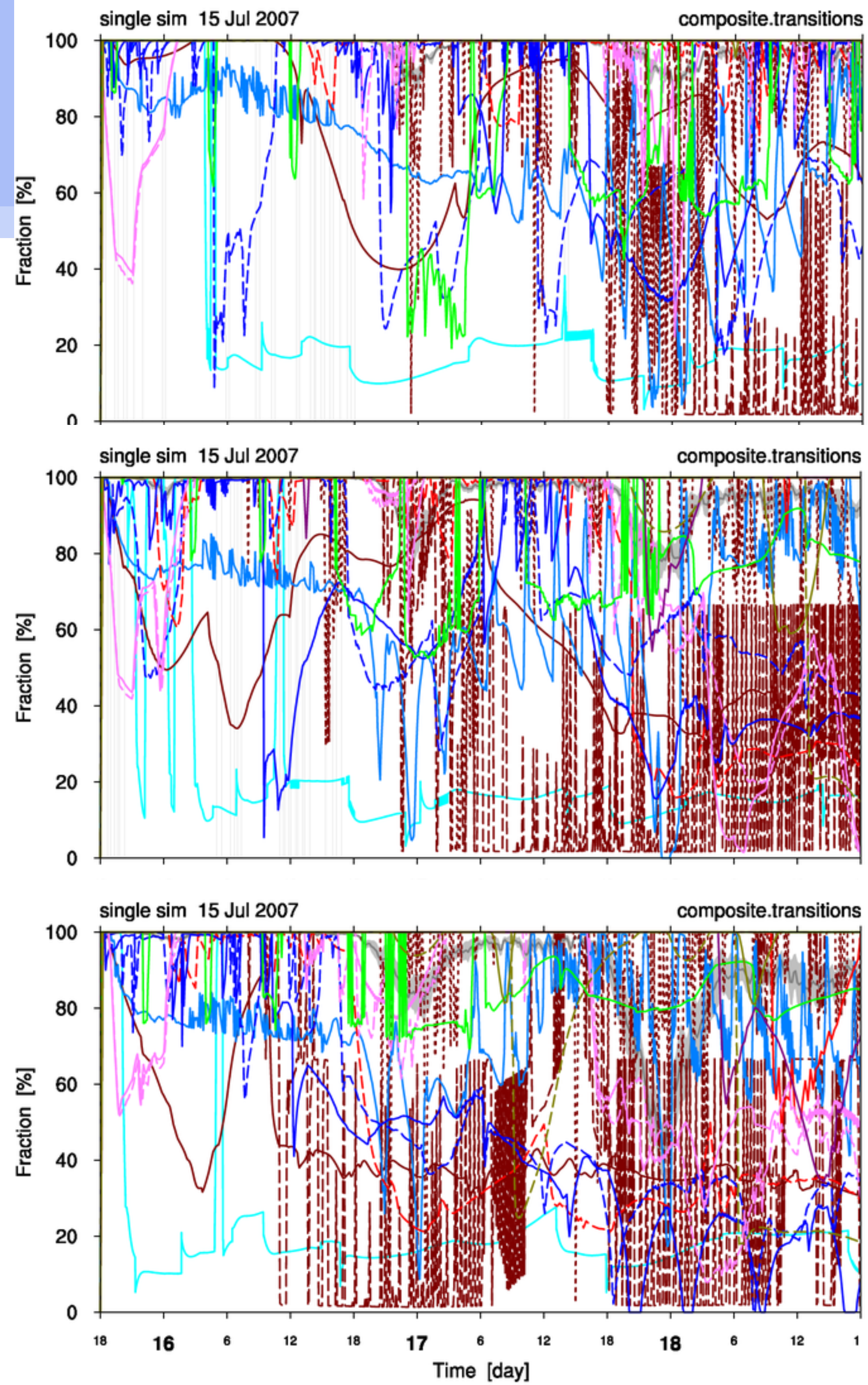


Composite transitions – Total cloud cover



Composite transitions – Total cloud cover





Composite transitions
SCM score-sheet

Variable	Units	Sigma			RMS		
		Slow	Reference	Fast	Slow	Reference	Fast
CC	%	36.6	36.0	36.1	29.0	31.0	35.6
LWP	$g\ m^{-2}$	61.0	60.0	66.3	21.9	29.2	33.8
ZCB	m	291	307	370	213	237	181
ZTOP	m	245	283	381	247	331	443
SHF	$W\ m^{-2}$	5.4	4.8	6.4	4.8	5.7	5.5
LHF	$W\ m^{-2}$	14.3	15.3	15.0	22.5	23.6	28.3
SMF	$m^2\ s^{-2}$	0.48	0.49	0.48	-	-	-
PRECW	$kg\ m^{-2}$	0.97	0.96	0.91	-	-	-
PREC_SRF	$W\ m^{-2}$	11.6	15.6	18.1	5.6	6.8	8.1
SFC net SW	$W\ m^{-2}$	64.3	67.3	68.4	-	-	-
SFC net LW	$W\ m^{-2}$	27.2	25.7	25.4	-	-	-
TOA net SW	$W\ m^{-2}$	65.3	67.9	68.9	-	-	-
TOA net LW	$W\ m^{-2}$	4.9	4.9	5.85	-	-	-
TKE_INT	$m^3\ s^{-2}$	527	484	577	234	188	123

Special topics

Classify models on aspects typical of transitions:

* vertical thermodynamic structure below inversion

* vertical structure of cloud fraction

and diagnose variables relevant for parameterization:

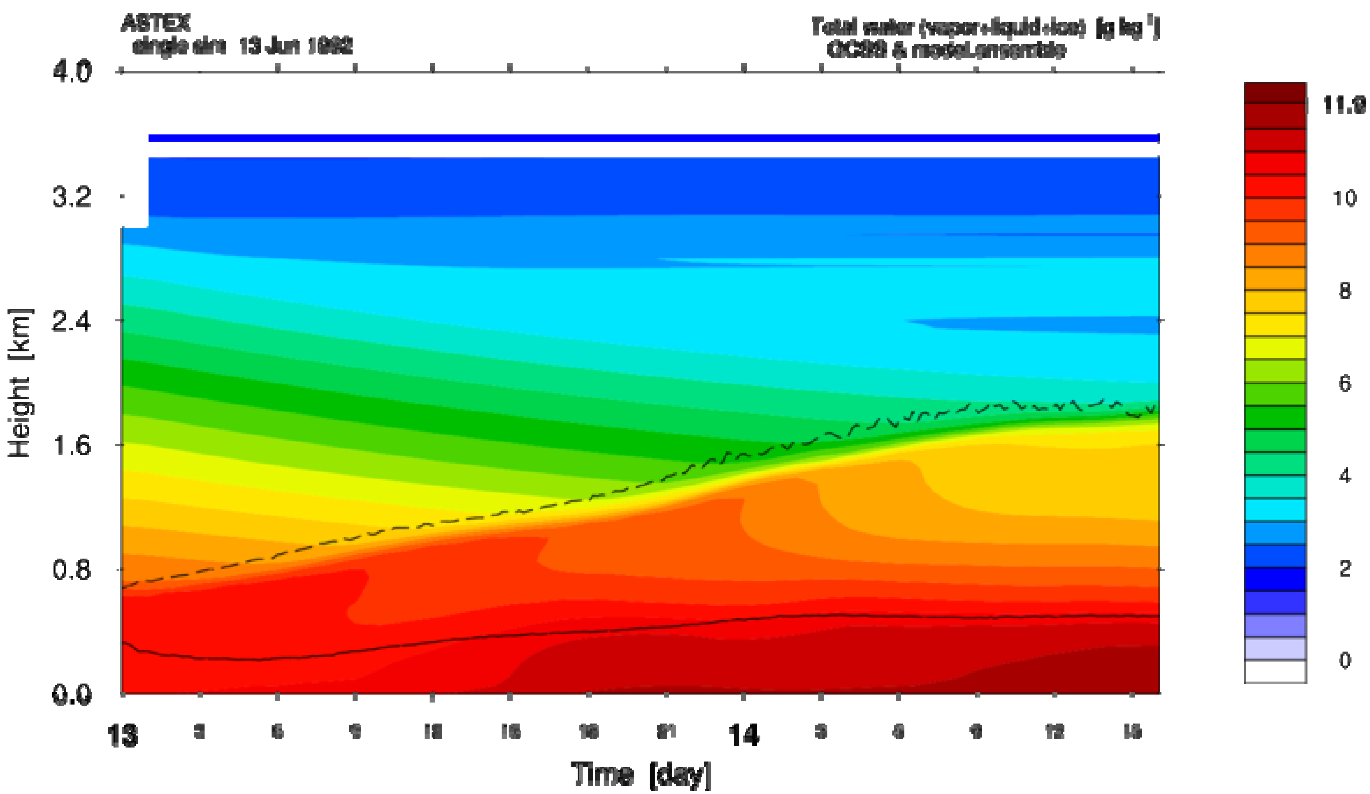
* Effective w_e (top entrainment velocity)

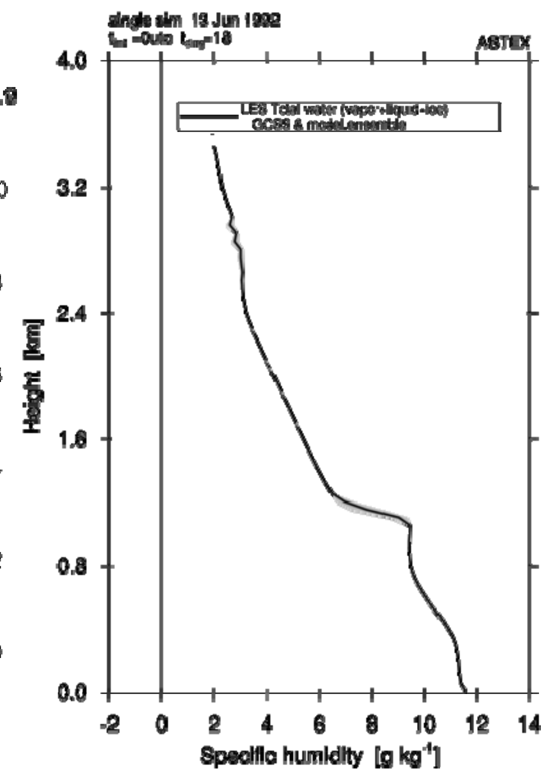
* Decoupling: BIR (buoyancy integral ratio)

* Vertical structure of mass flux

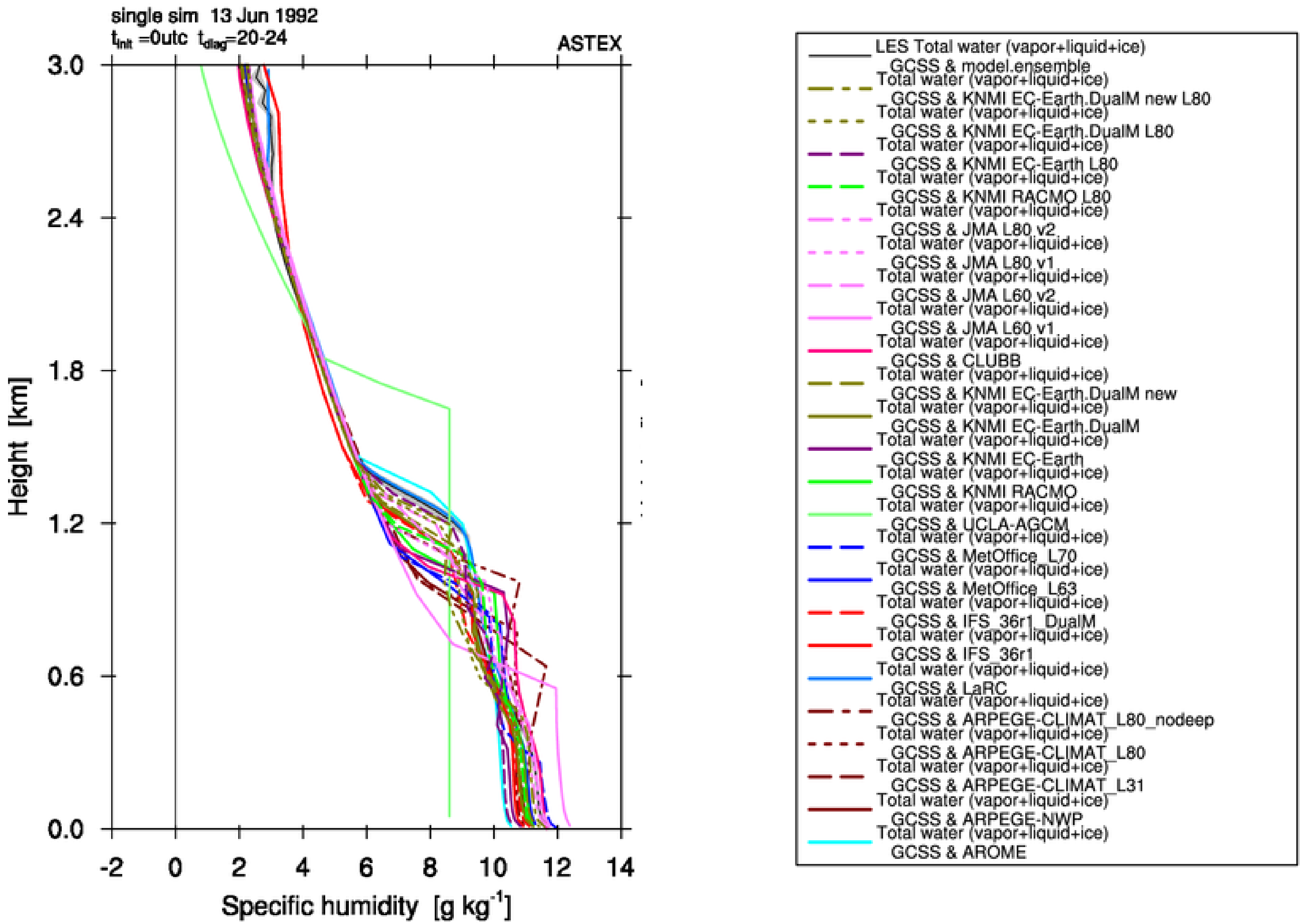
Topic I – Thermodynamic vertical structure

LES: “Well-mixed layer” below inversion

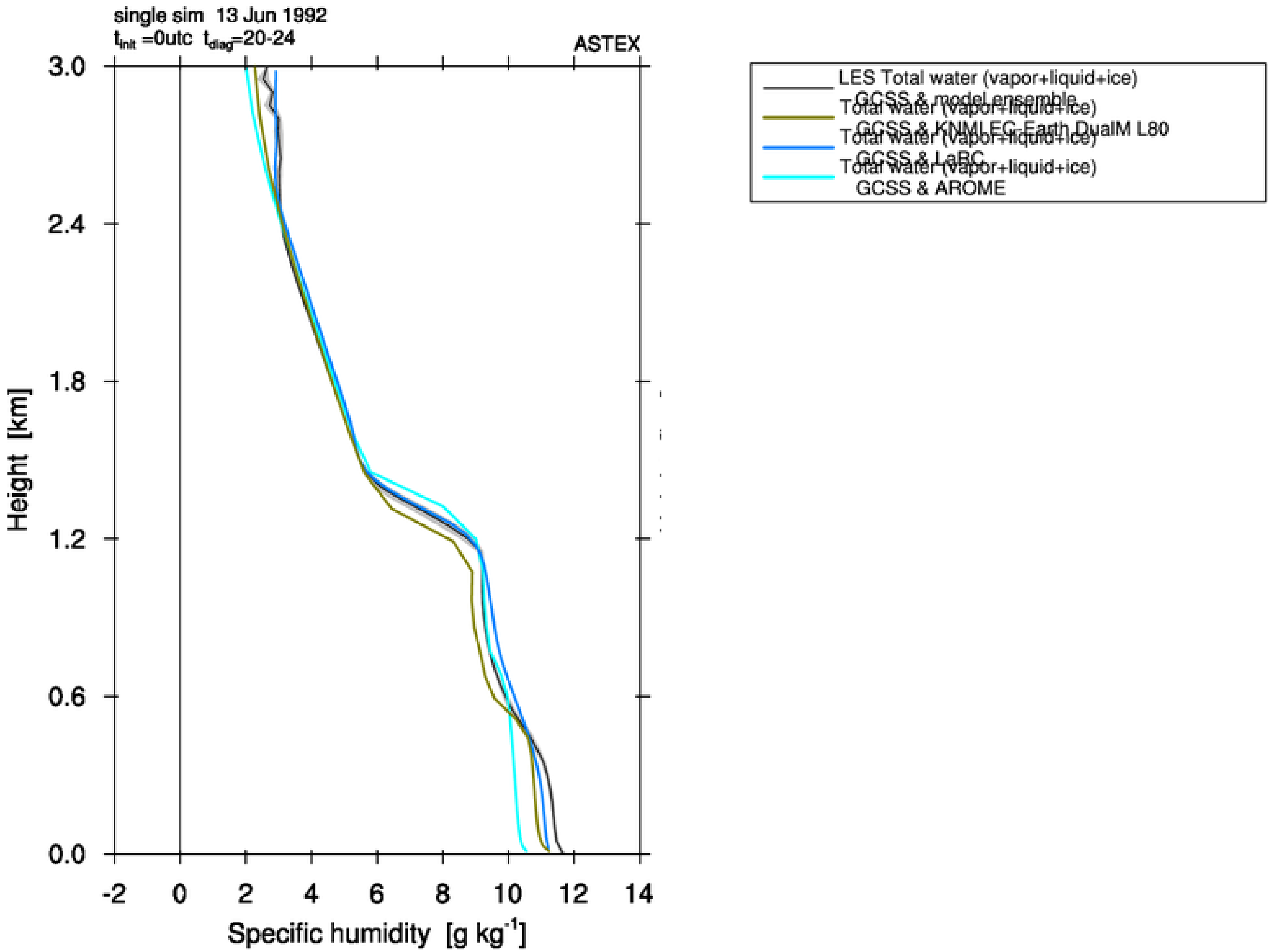




Topic I – Thermodynamic vertical structure

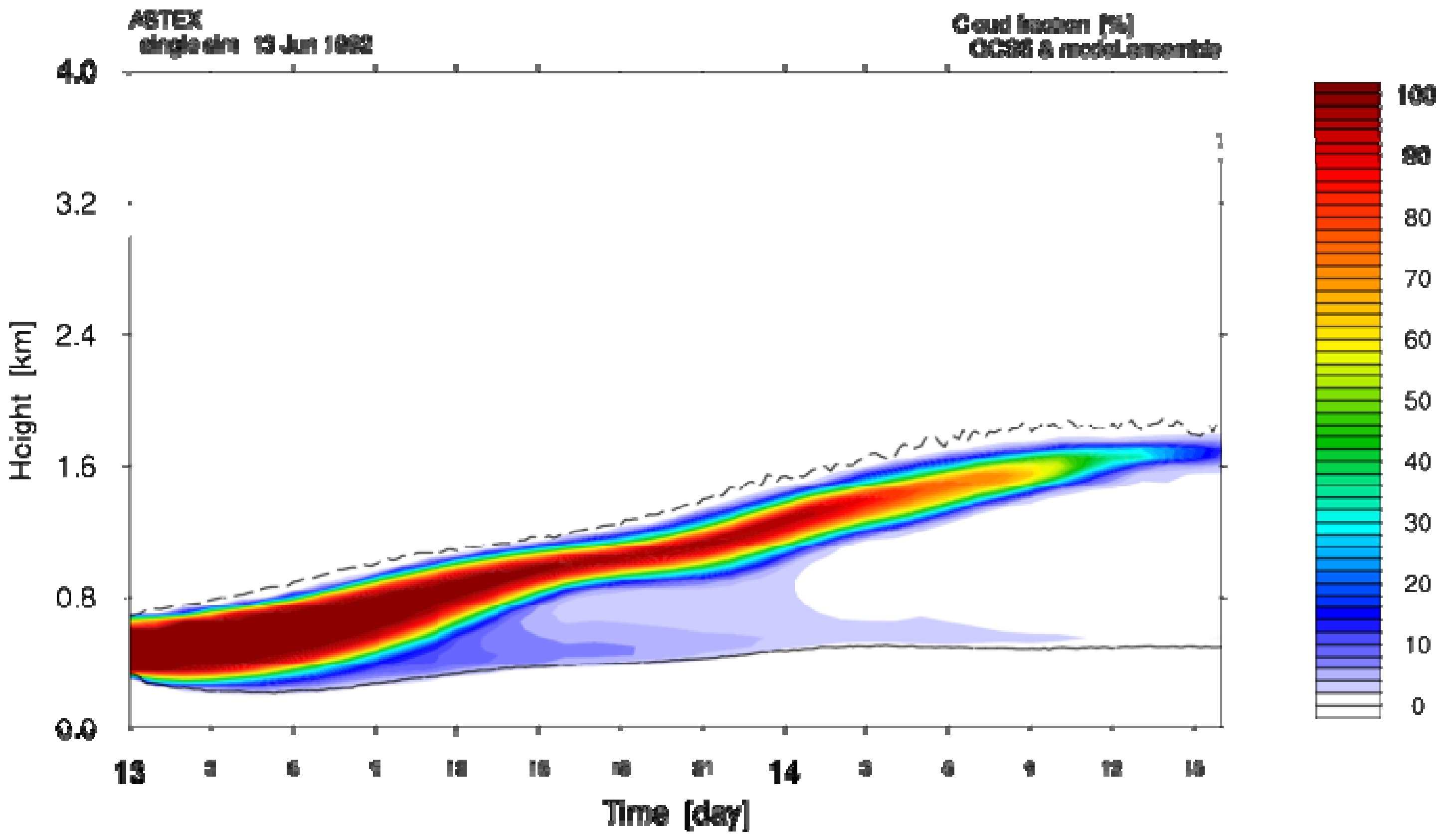


Topic I – Thermodynamic vertical structure

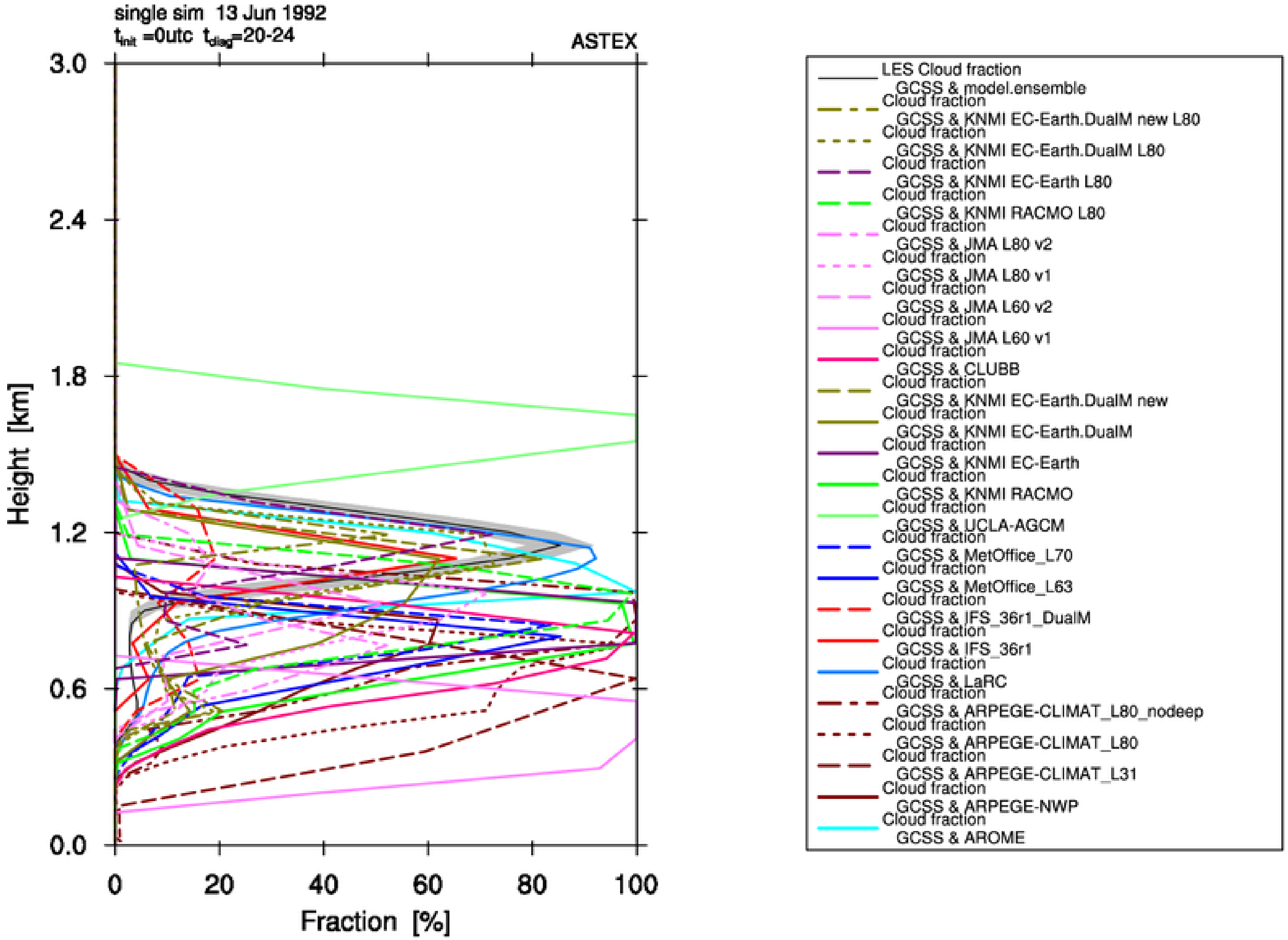


Topic II – Cloud vertical structure

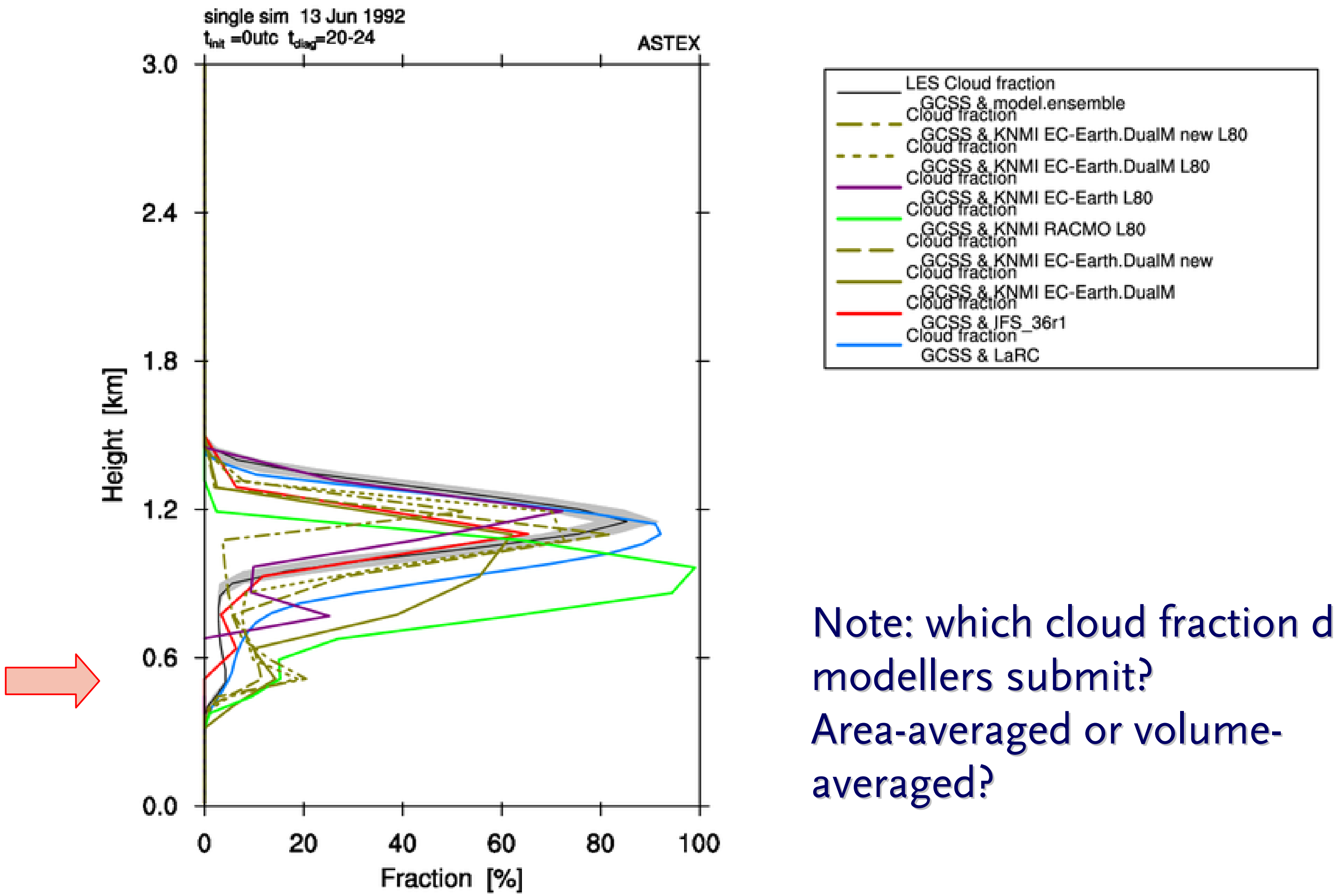
Double peak structure: capping cloud deck (disappearing) &
cumulus 'foot' at LCL (emerging)



Topic II – Cloud vertical structure

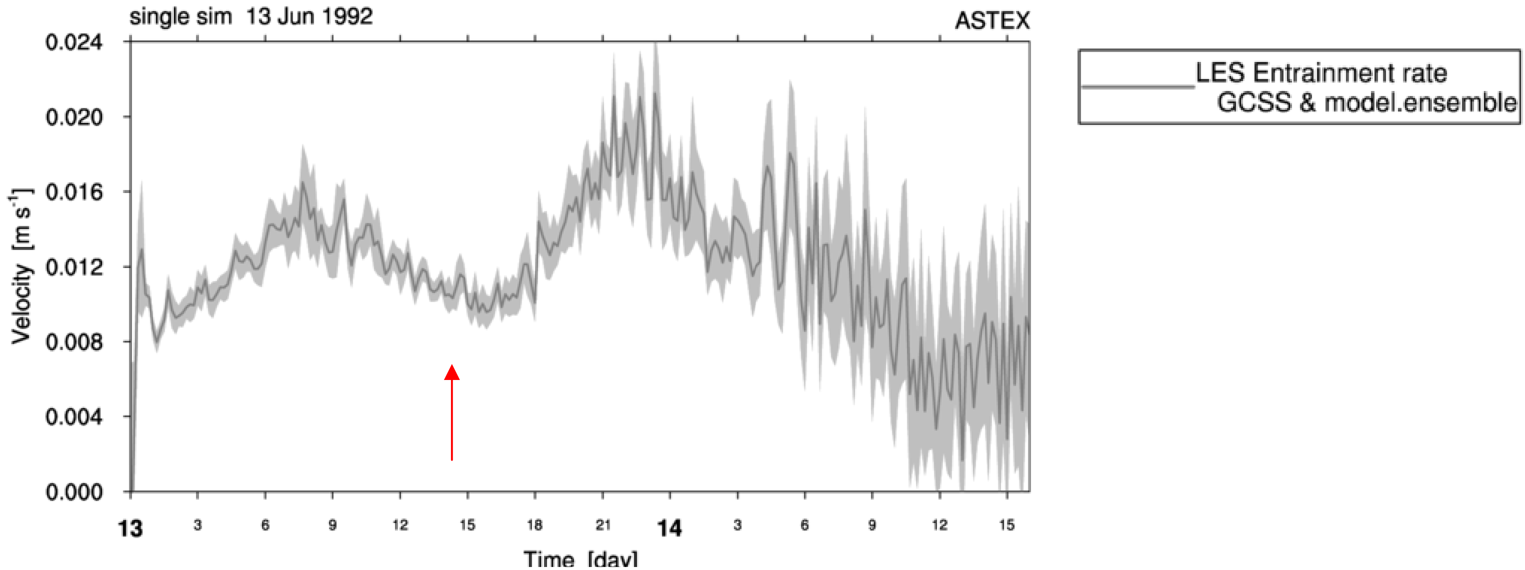


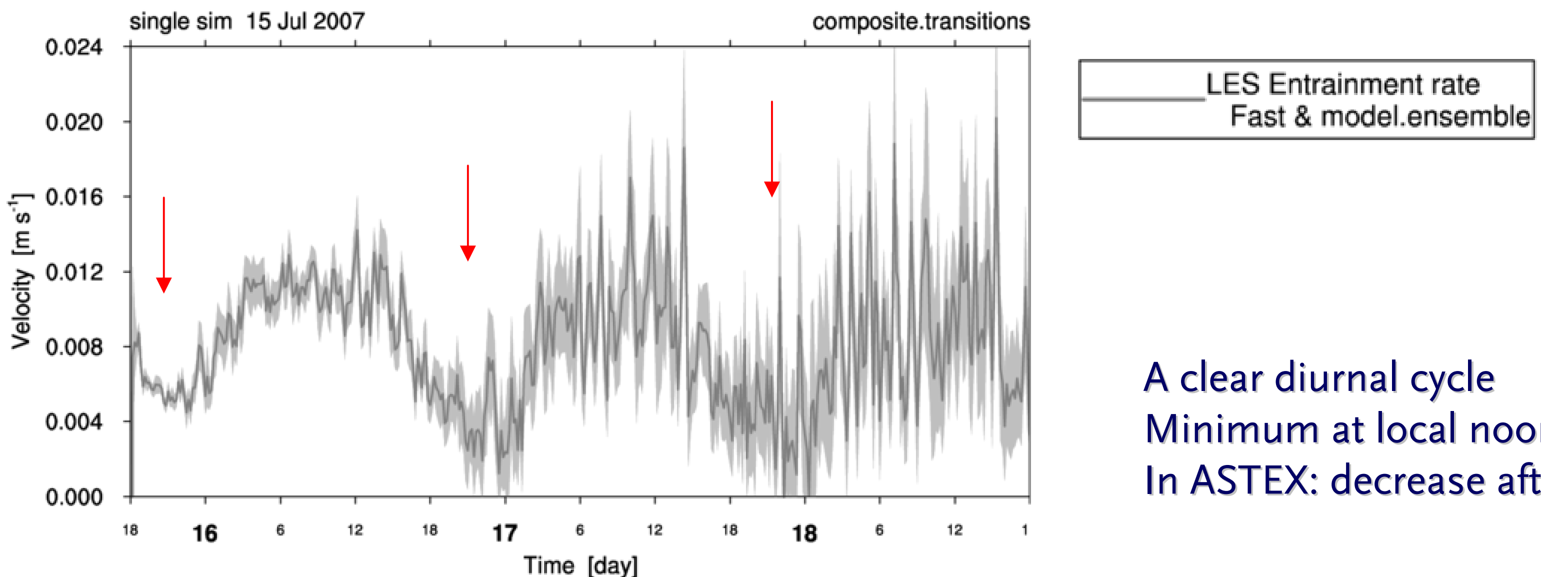
Topic II – Cloud vertical structure



Note: which cloud fraction did modellers submit?
Area-averaged or volume-averaged?

Topic III – Top entrainment



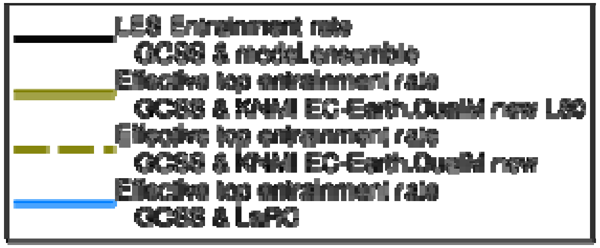


A clear diurnal cycle
Minimum at local noon
In ASTEX: decrease after breakup

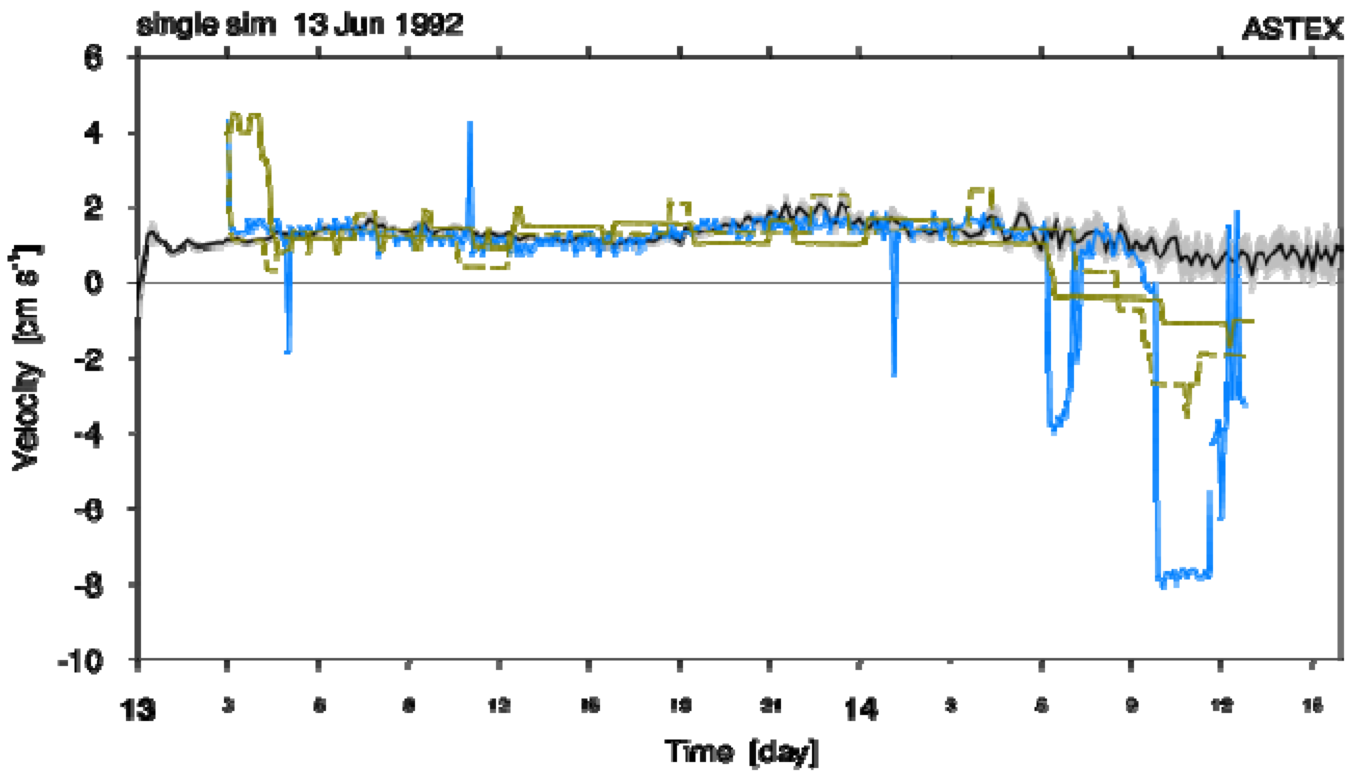
Topic III – Top entrainment

Backing out w_e from the SCM simulations

$$\frac{\partial h}{\partial t} = w_e + w_{LS}$$



A more appropriate diagnostic for evaluating top-entrainment models



6-hr running mean

Topic IV - Decoupling

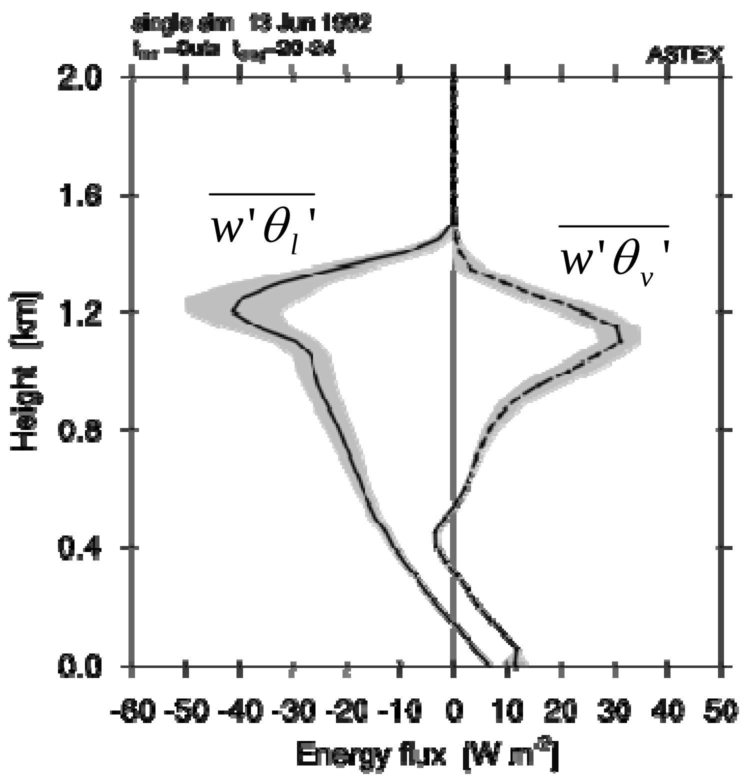
Decoupling: when an initially well-mixed layer tends towards a two-layer structure

Predictor: The Buoyancy Integral Ratio (BIR):

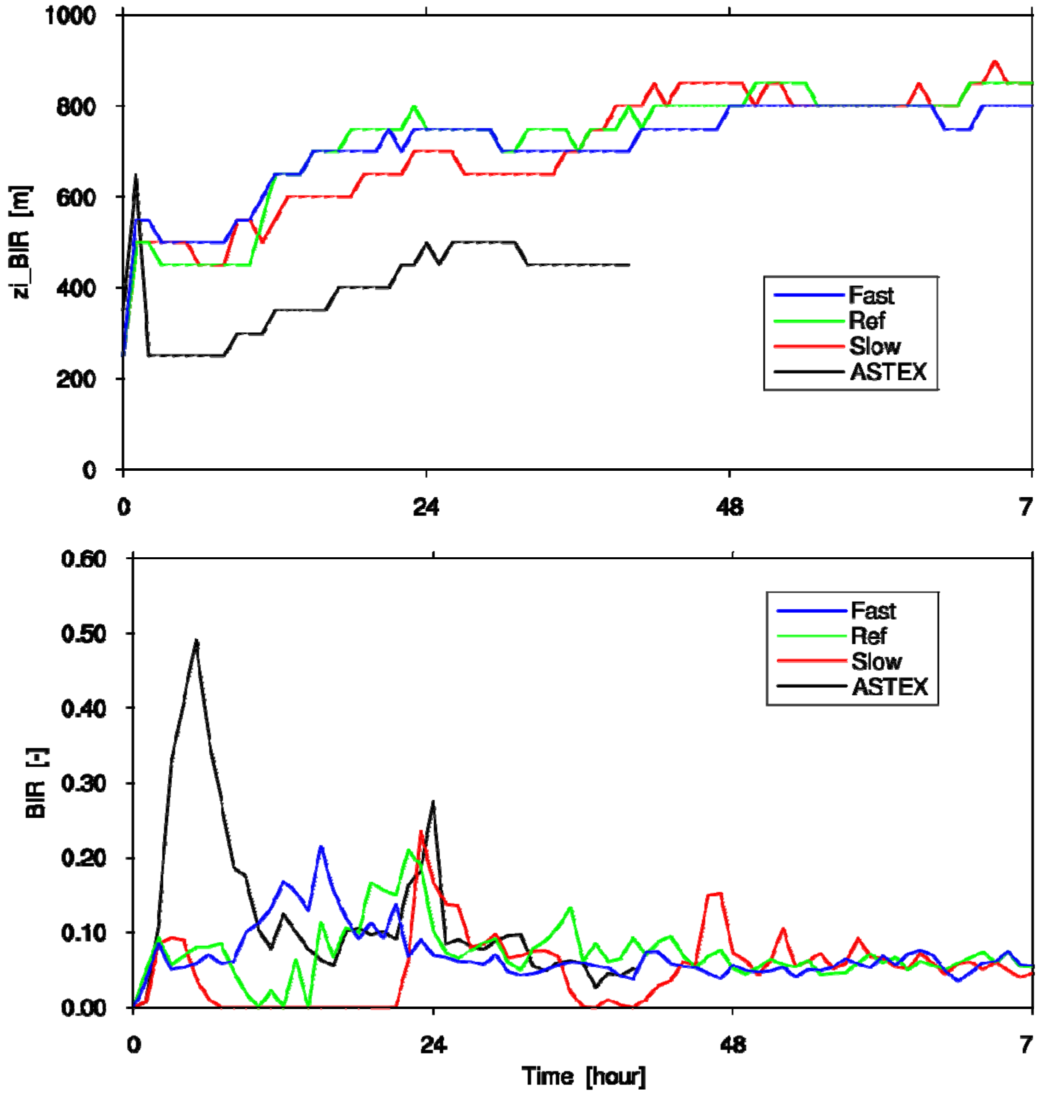
Turton & Nicholls (1987)
Bretherton & Wyant (1996)
Stevens (2000)

$$\mathrm{BIR} = -\int_{\substack{z < z_b \text{ at which} \\ \langle w'b' \rangle < 0}} \langle w'b' \rangle \, dz \Bigg/ \int_{\text{All other } z} \langle w'b' \rangle \, dz$$

> 0.15 for decoupling.



Topic IV – Decoupling in LES



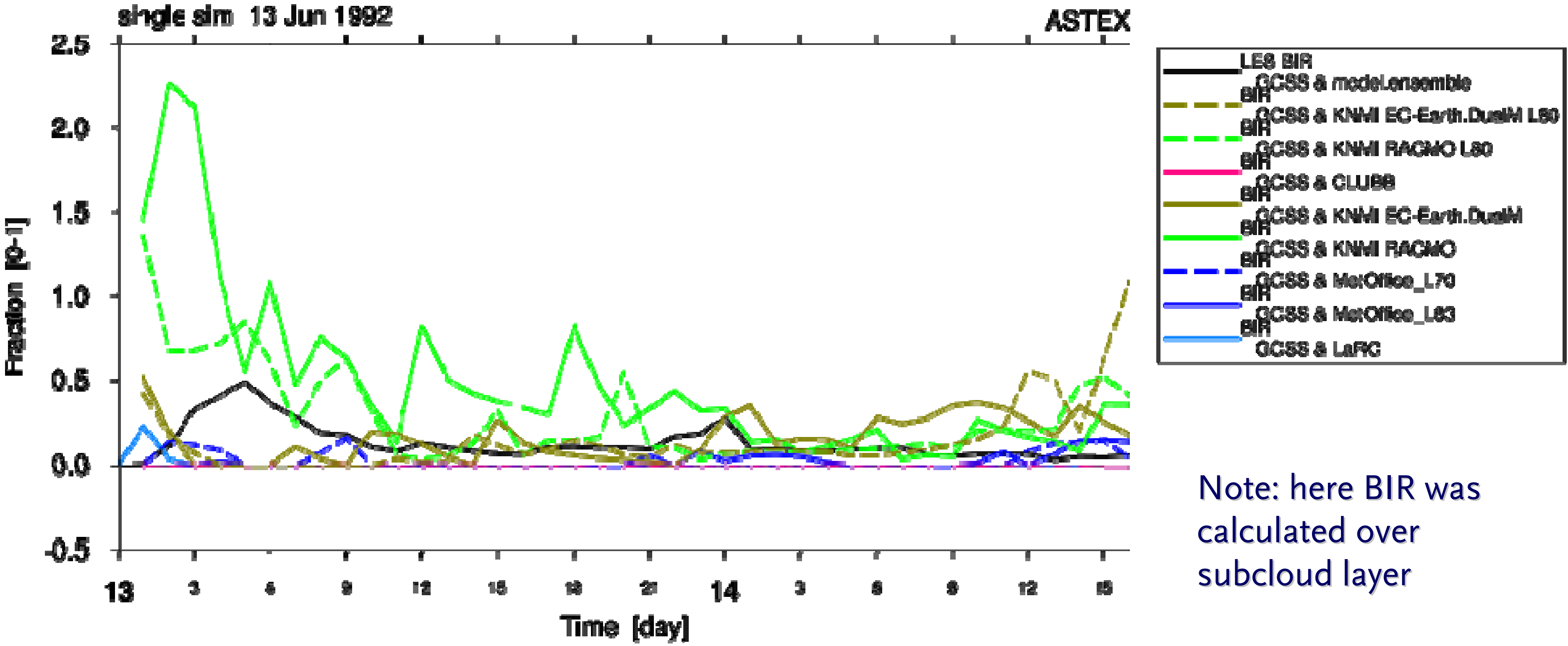
Slow composite case is at times coupled

The other cases are always decoupled

Suggests: BIR can be used as an on/off switch for a two-layer approach (shallow cu transport)

Topic IV – Decoupling in the SCMs

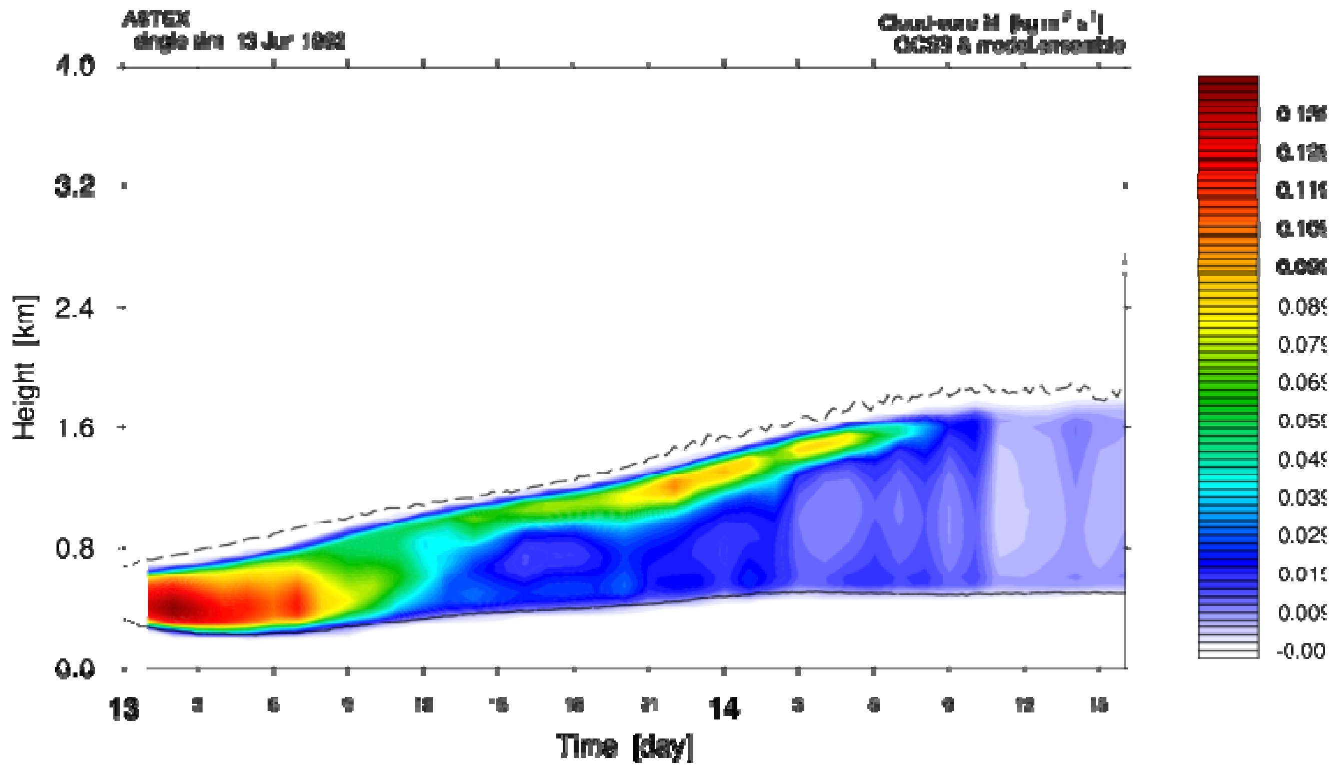
In dry conditions: $$\overline{w'\theta_v'} \approx (1 + 0.61\overline{q}_t)\overline{w'\theta_l'} + 0.61\overline{\theta}\,\overline{w'q_t'}$$



Note: here BIR was calculated over subcloud layer

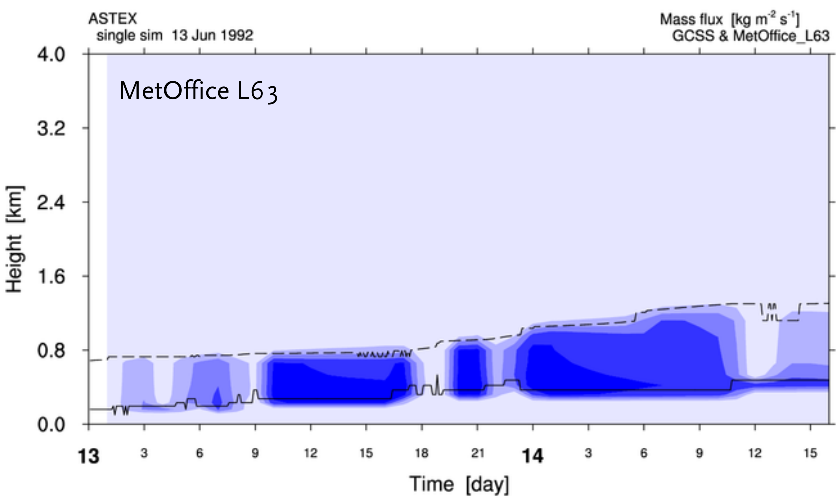
Topic V – Mass flux vertical structure

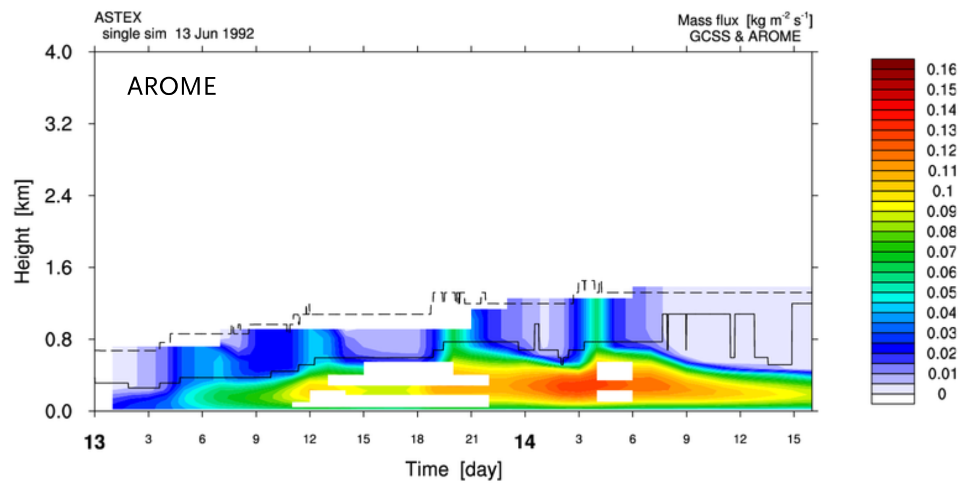
At times increasing with height below cloud top

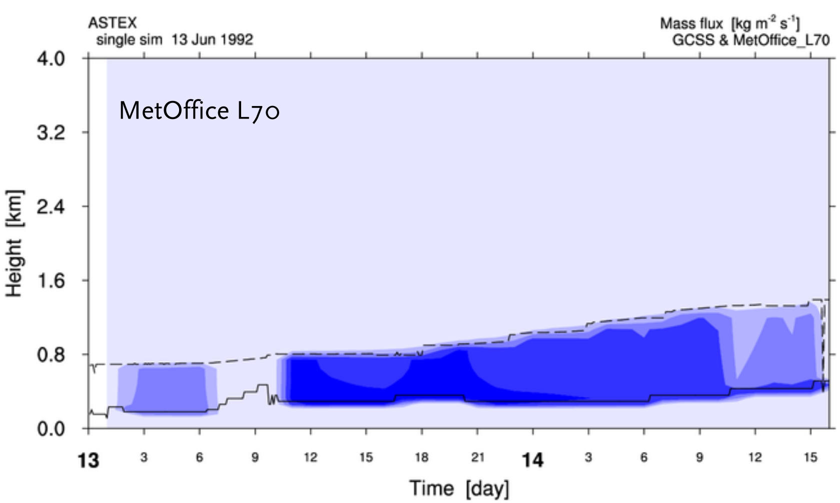


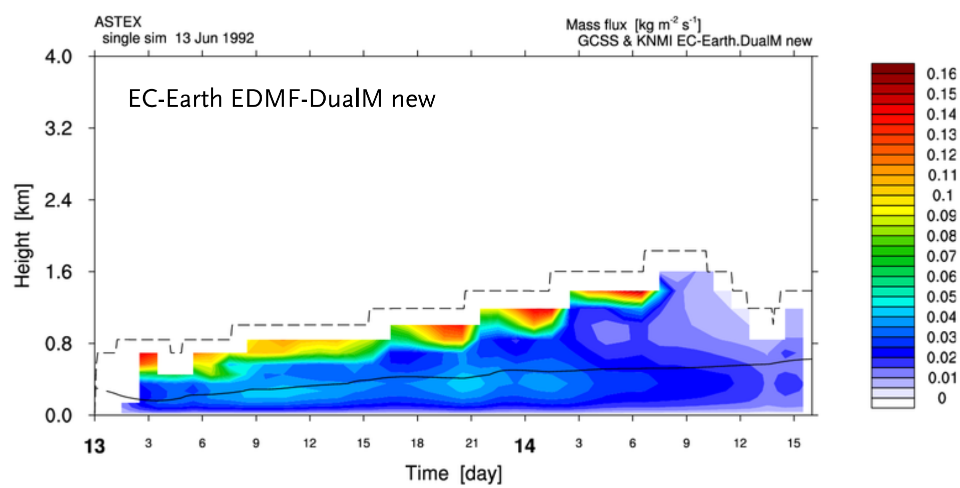
If the transporting bulk model updraft is defined to represent the cloud core, this feature has to be reproduced

Topic V – Mass flux vertical structure

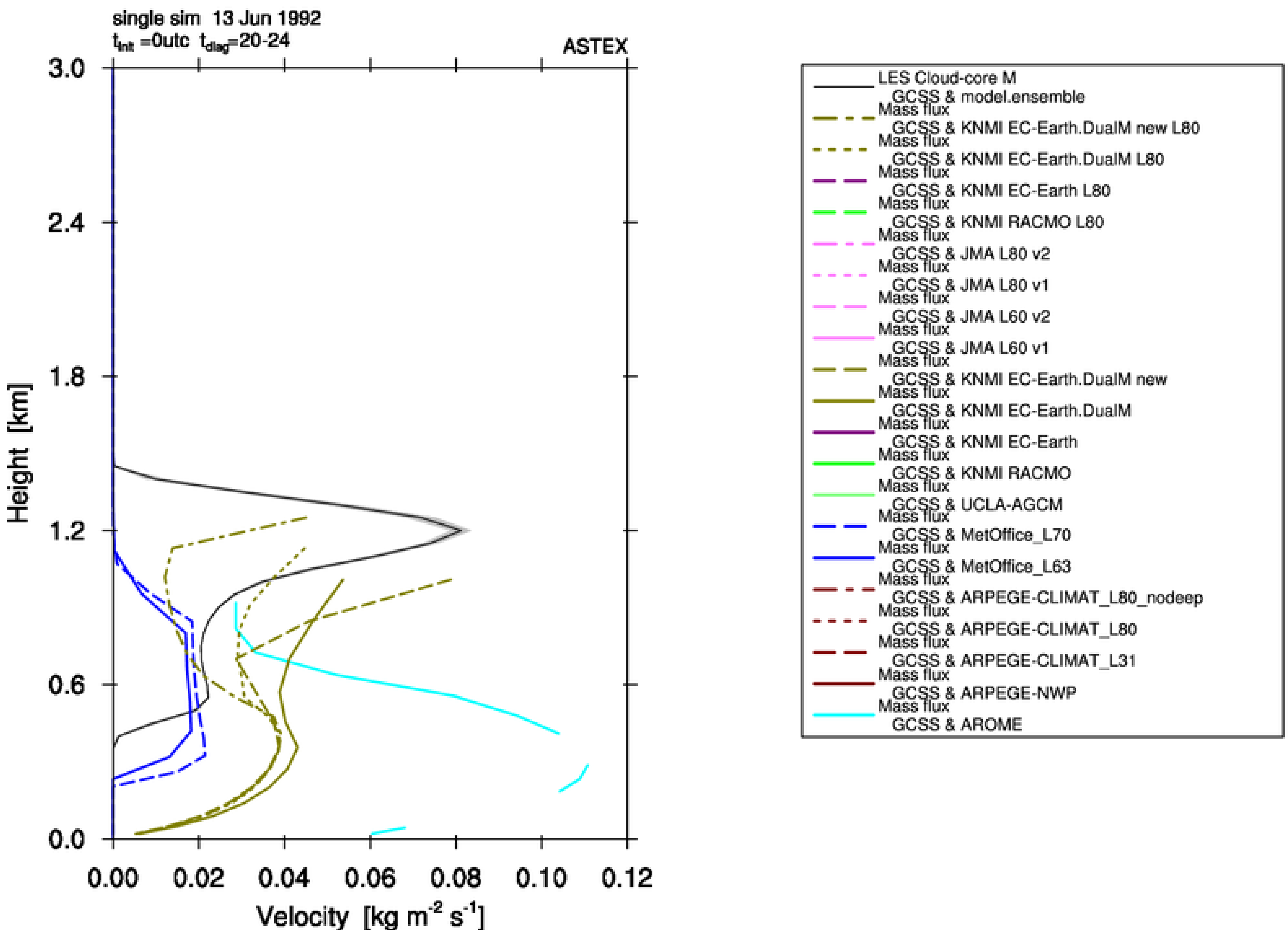






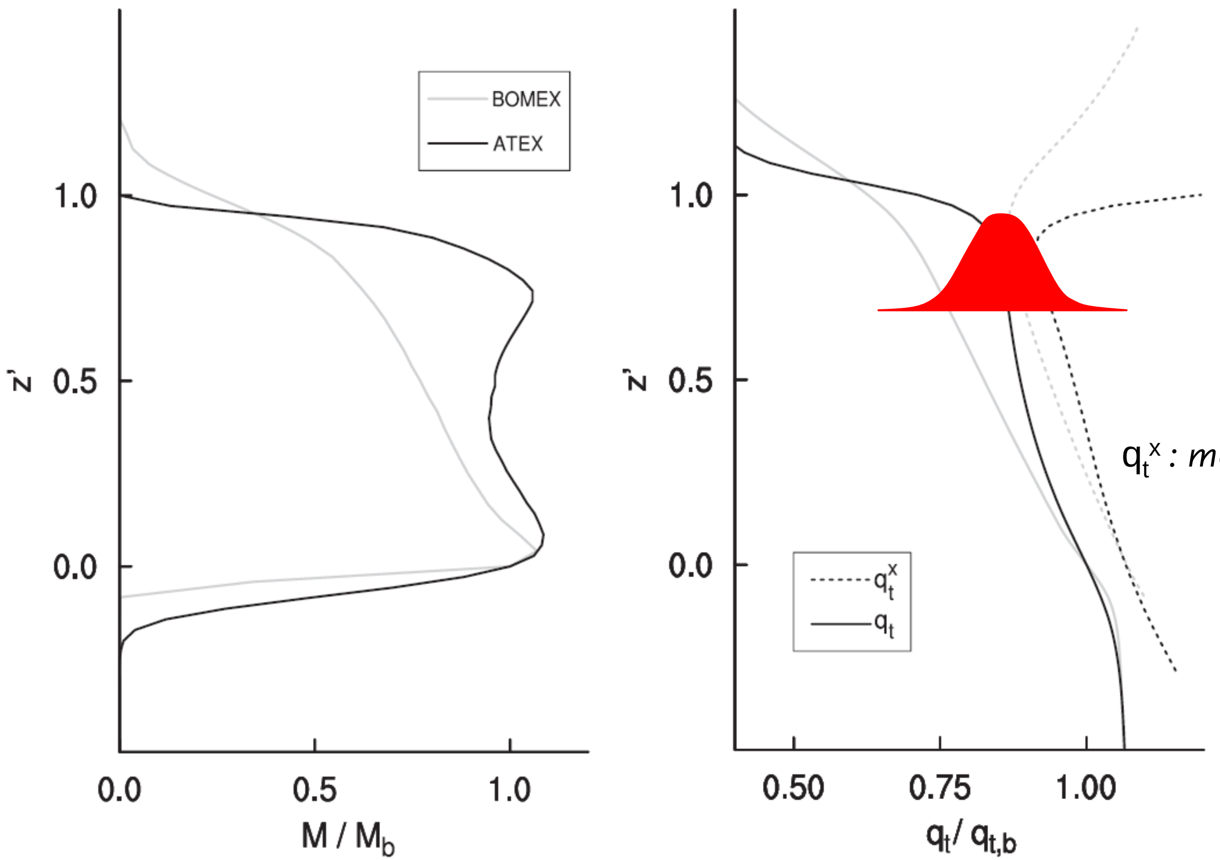


Topic V – Mass flux vertical structure



Topic V – Mass flux vertical structure

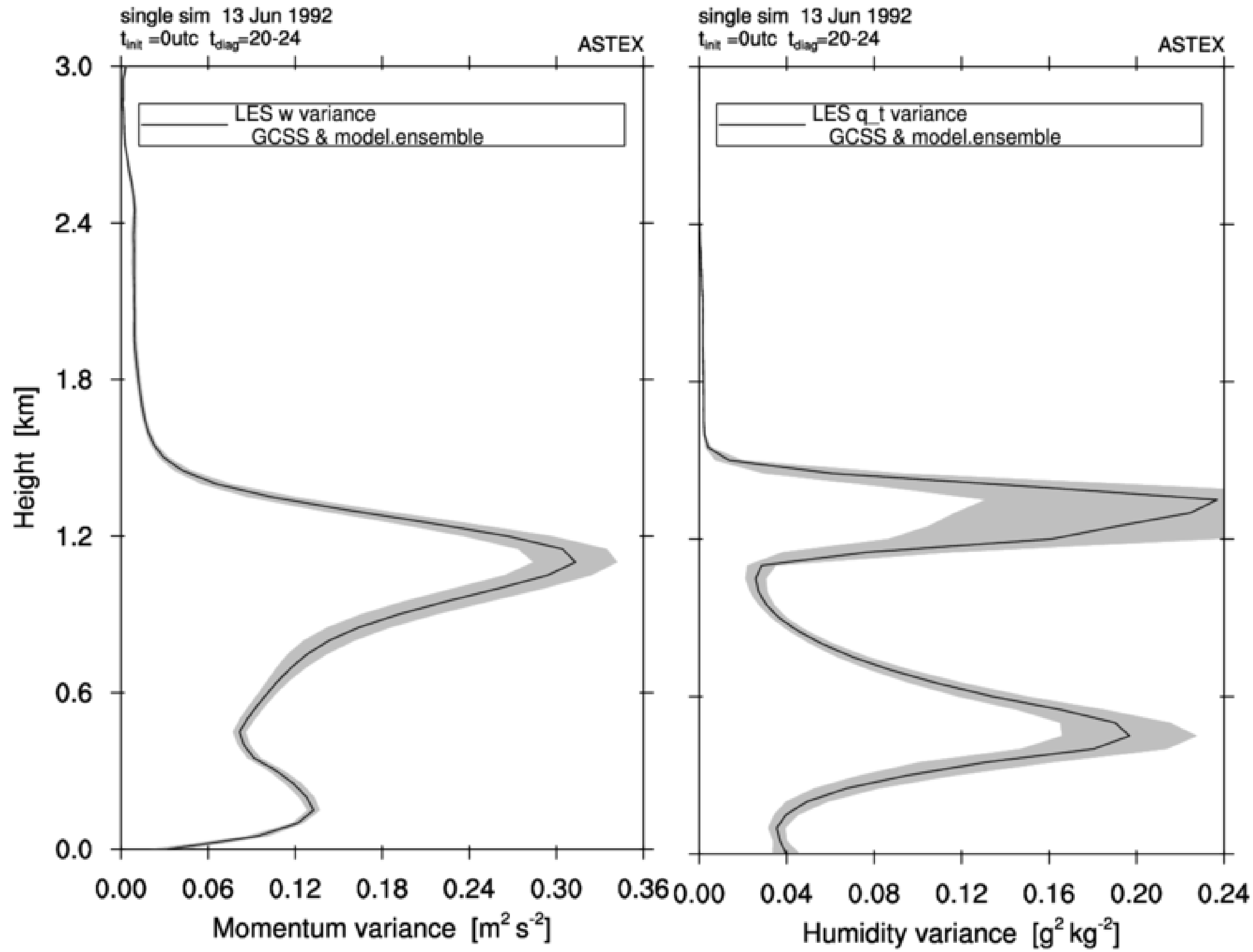
Neggers et al. (JAS, 2009)



q_t^x : *moist zero buoyancy point*

Suggests a PDF-based (mass flux) model should be able to capture this behavior

Topic VI – PDFs & higher moments



SCM output needed ...

Conclusions

This inter-comparison exercise proves effective in providing insight into model behavior at process-level

In general, all SCMs do produce some kind of cloud transition, although a significant inter-model spread exists in relevant parameters for cloud-radiative climate

This conclusion is the same as was reached in the previous SCM inter-comparison study on ASTEX 12 years ago (Bretherton et al 1999)

However, some models now show promising skill in reproducing key aspects of the transitions, such as i) the vertical structure of the thermodynamic and cloudy state, ii) time-development of the transition, and iii) characteristics of vertical transport

In general, these are the models that have either seen significant development and have purposely been made more complex at key points, or are totally new concepts all-together

This progress is what we have to focus on and explore further

Outlook

* Think about links between transition case results and CGILS

Biggest spread in magnitude & sign of cloud feedback at transition point (s11)

* Compare SCM and obs through scatterplots:

e.g. TCC vs EIS

* Ensemble vs composite SCM simulation: each trajectory individually

* Additional SCM output

Needed for evaluation of certain types of models that do well
(PDF-based & higher-order closures)

* Sensitivity to vertical resolution

Outreach

Full 3D fields as generated by the LES will be made publicly available, to support the evaluation and development of parameterizations

* Modellers can sample using specific criteria that correspond to definitions in parameterization schemes

* Available at various time-points in the transition

* http://www.euclipse.eu/

* Could become a common, benchmark dataset