EDMF evolution at ECMWF – an experience

Martin Köhler

dry EDMF theory & SCM

Pier Siebesma & Joao Teixeira 2000, 2007

stratocumulus EDMF & unified implementation

Martin Köhler, Anton Beljaars, Maike Ahlgrimm 2005, 2011

stratocumulus **inversion entrainment** numerics

Martin Köhler 2008

ECMWF operational

shallow cumulus DUALM EDMF

Roel Neggers, Martin Köhler, Anton Beljaars 2007-2010

also: ECMWF team and Pier

dry boundary layer: specifications

1. Updraft initialization

$$\overline{\phi}^{\,a} = \overline{\phi} + \mathcal{D}(a)\,\sigma_\phi$$

$$\overline{w}^{\,a} = \mathcal{D}(a)\,\sigma_w$$

2. Flexible updraft entrainment

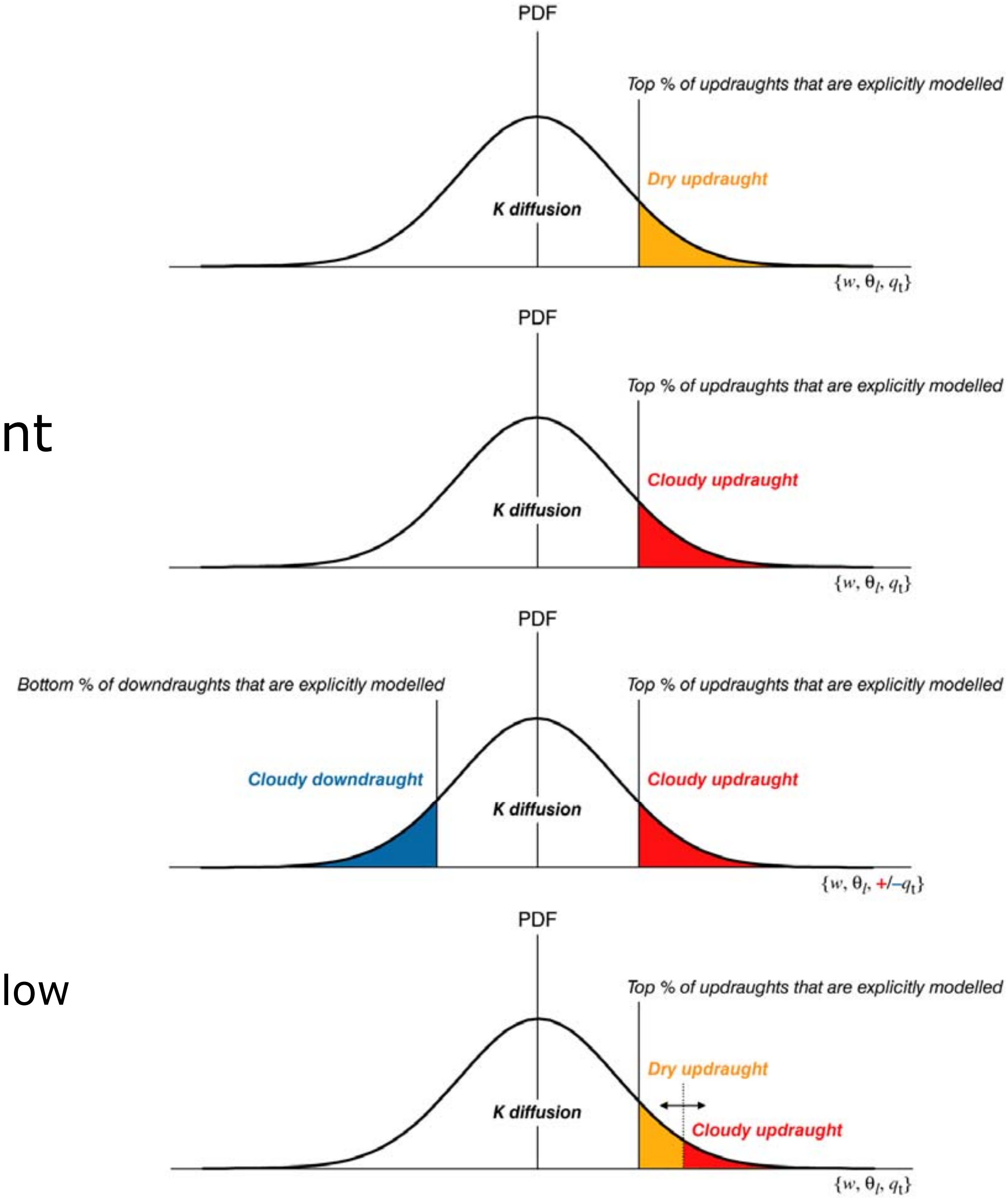
$$\boxed{\varepsilon_u = \frac{1}{\tau\, w_u} + \frac{c_\varepsilon}{z}}$$

3. Mass-flux

$$\frac{1}{M_u}\frac{\partial M_u}{\partial z} = \varepsilon_u - \delta_u$$

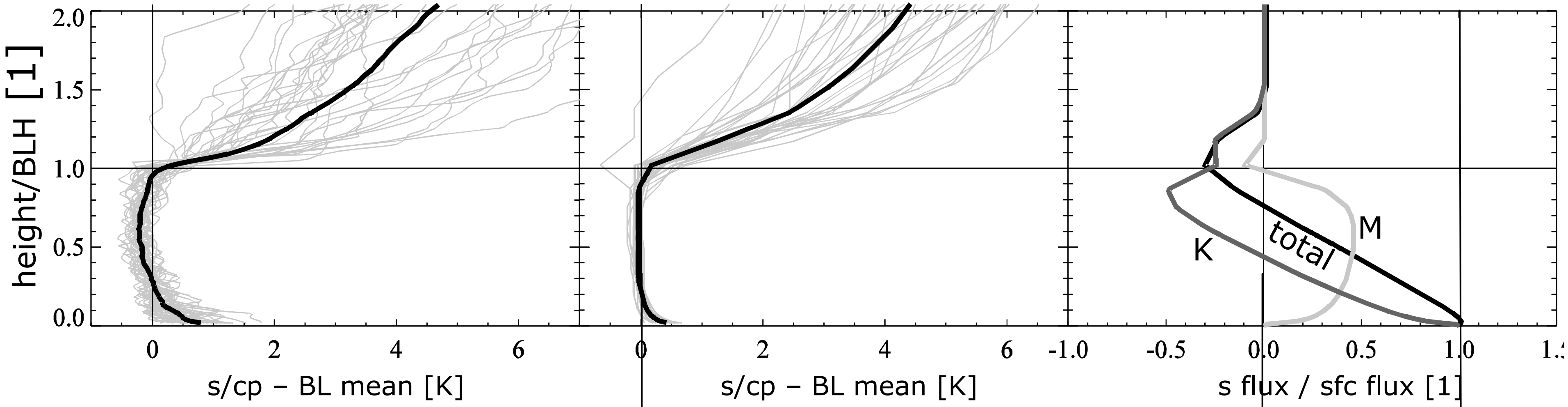
$\delta_u = 3 \cdot 10^{-4}\,\mathrm{m}^{-1}$ in cloud, zero below

4. K-profile (Holtslag 1998)

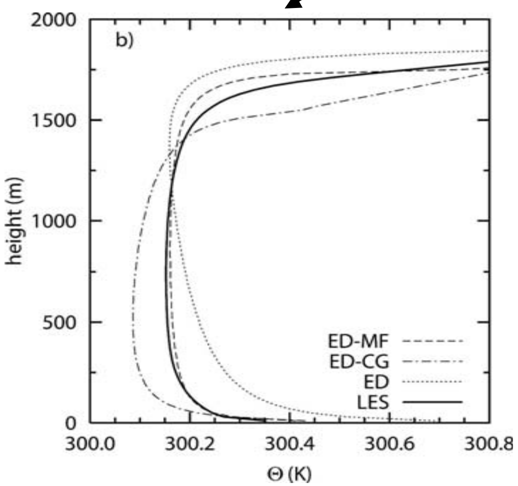


AMMA Niamey temperature profiles

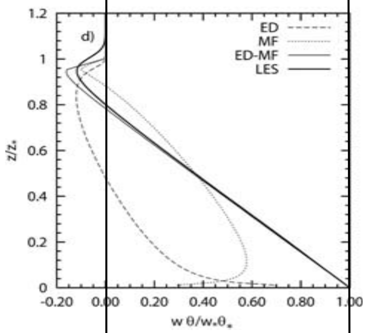
radiosonde (BLH=1152m) model (BLH=1188m) model fluxes



AMMA, Niamey, pre-monsoon

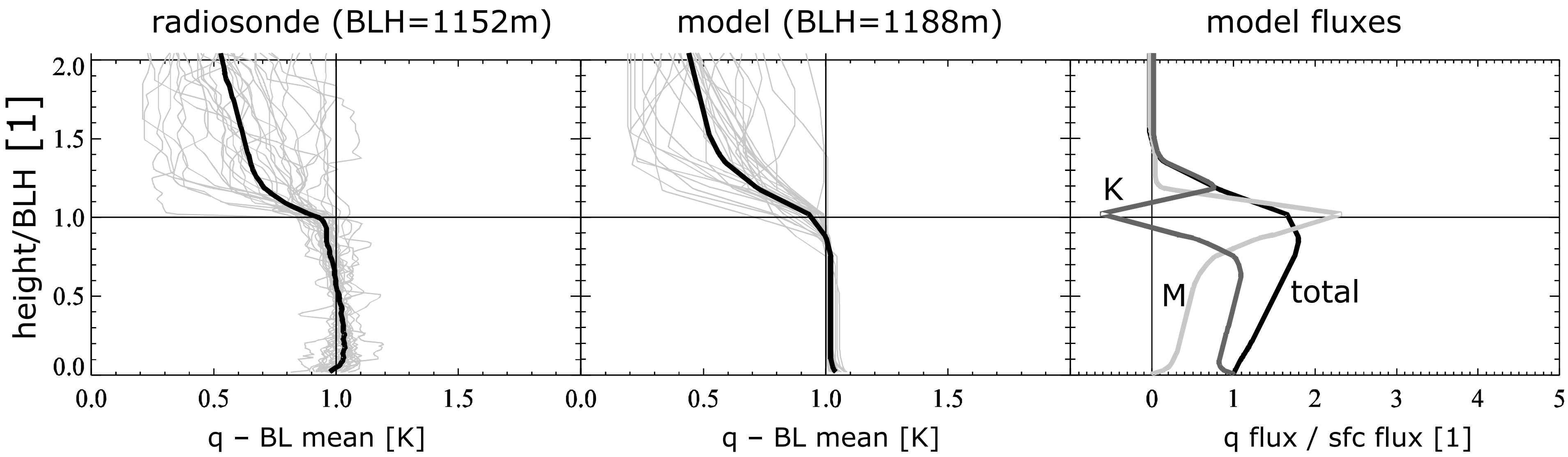


Siebesma et al 2007
LES and SCM



K-diffusion appears too strong

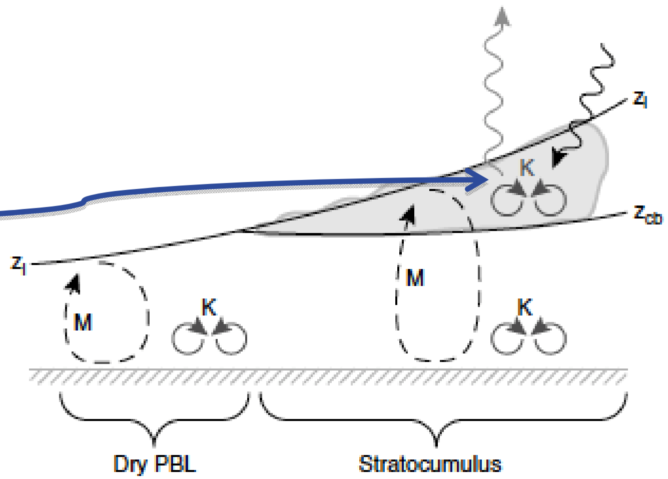
AMMA Niamey moisture profiles



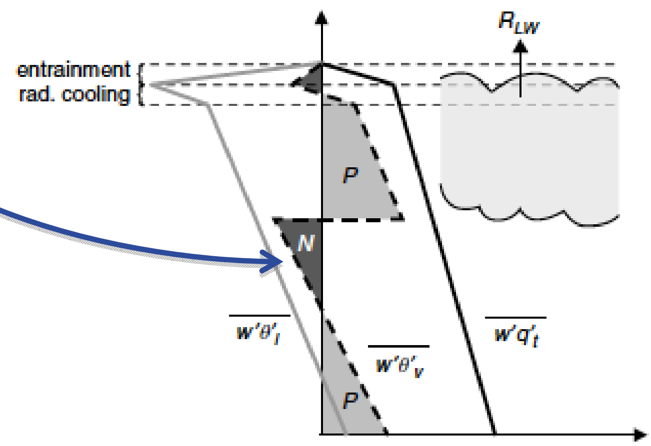
- *moisture convergence: Southerly advection from Atlantic*
- *mass-flux mixes near BL-top*

Stratocumulus: specifications

1. explicit cloud top entrainment
2. cloud top down diffusion



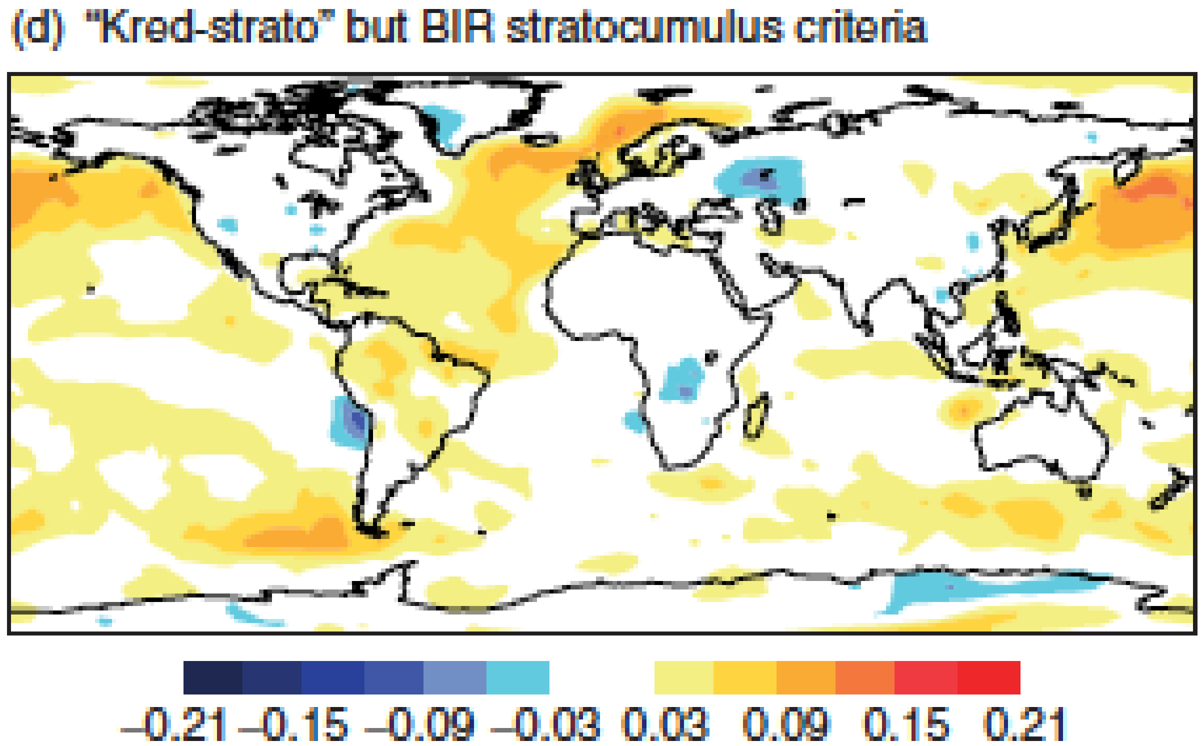
3. reduced K above BL (~MO-values)
4. stability criteria allowing strcu
   - EIS estim. inv. strength)
   - BIR tested
5. cloud:
   - diagnostic σ_{qt} equation
     - interface to Tiedtke 93



6. solver numerics:
   - upwind differencing

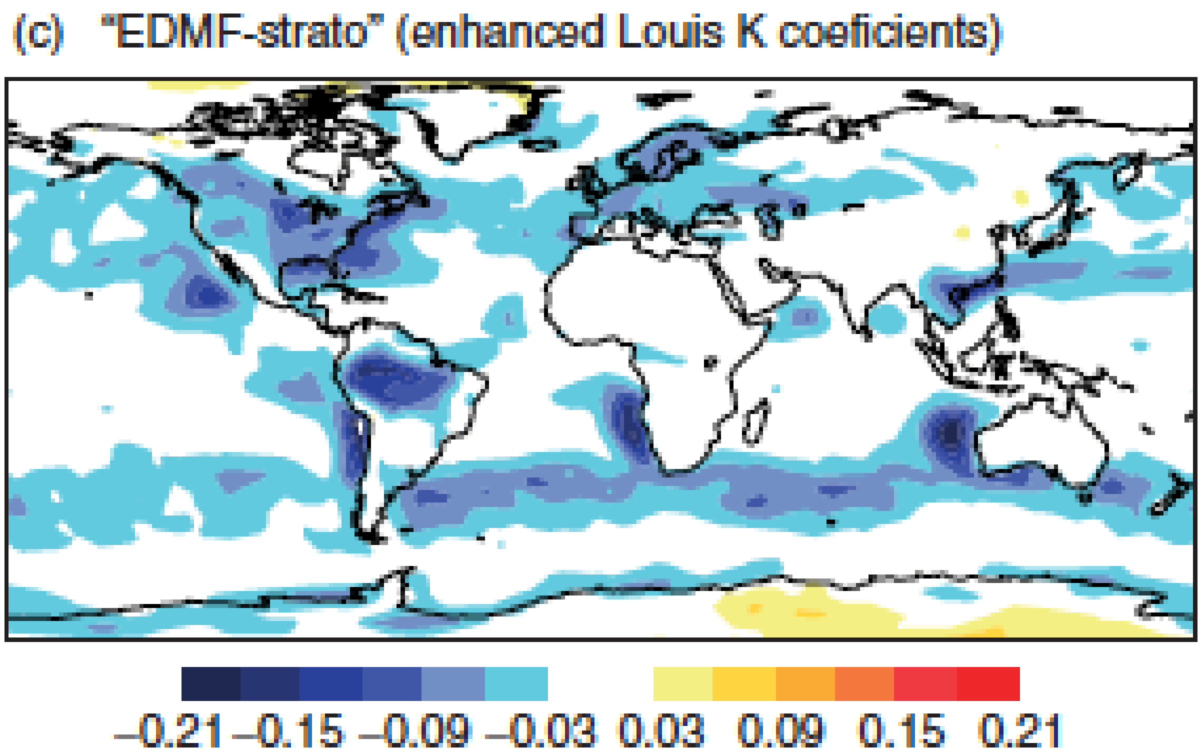
BIR: buoyancy flux integral ratio

Low cloud cover impact of BIR vs EIS to allow stratocumulus



Louis or Monin-Obukov in stable atmosphere

Low cloud cover impact of Louis vs M-O K coefficients



Cloud-top marine strcu versus CALIPSO

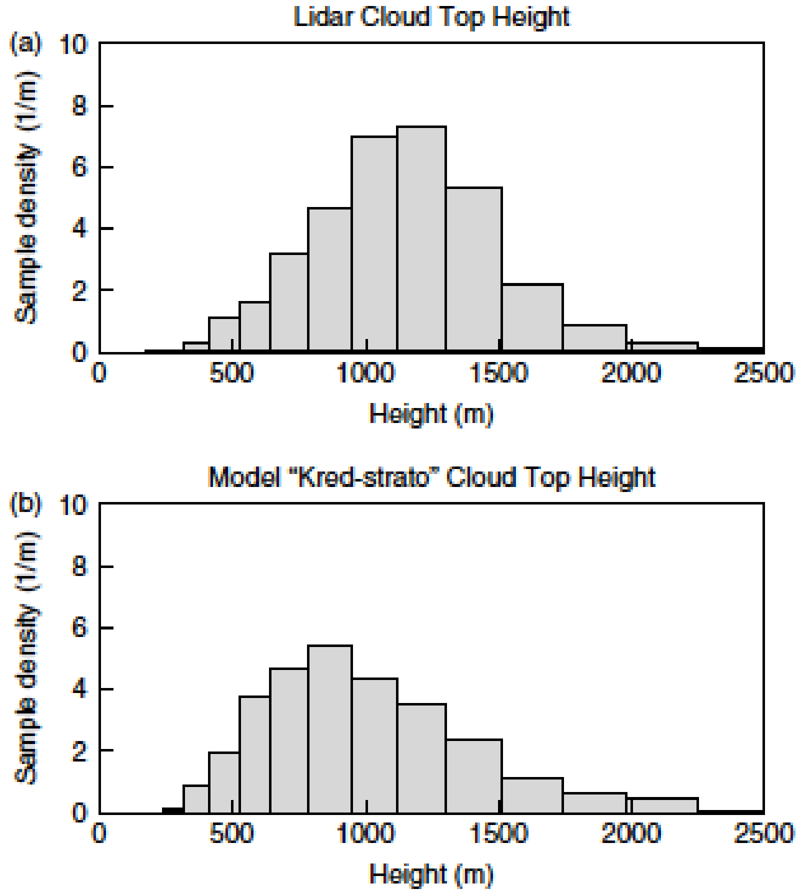


Figure 9. Cloud-top height distributions for marine stratocumulus clouds found in the southeast Pacific (70–100°W, 00–30°S) from (a) CALIPSO lidar observations and (b) the '*K*red-strato' model (cycle 32r3). Grid points with cloud fractions above 80% and cloud-top height below 2.5 km found during July 2006, July 2007 and July 2008 are included. Since cloud boundaries in the model always fall onto model layer interfaces, irregular bins whose width corresponds to the model layer thickness are used. The vertical axis shows the sample density within each bin as the number of samples per width of the bin (m^{-1}).

Maike Ahlgrimm

Low cloud cover: EDMF-strcu version old ECMWF

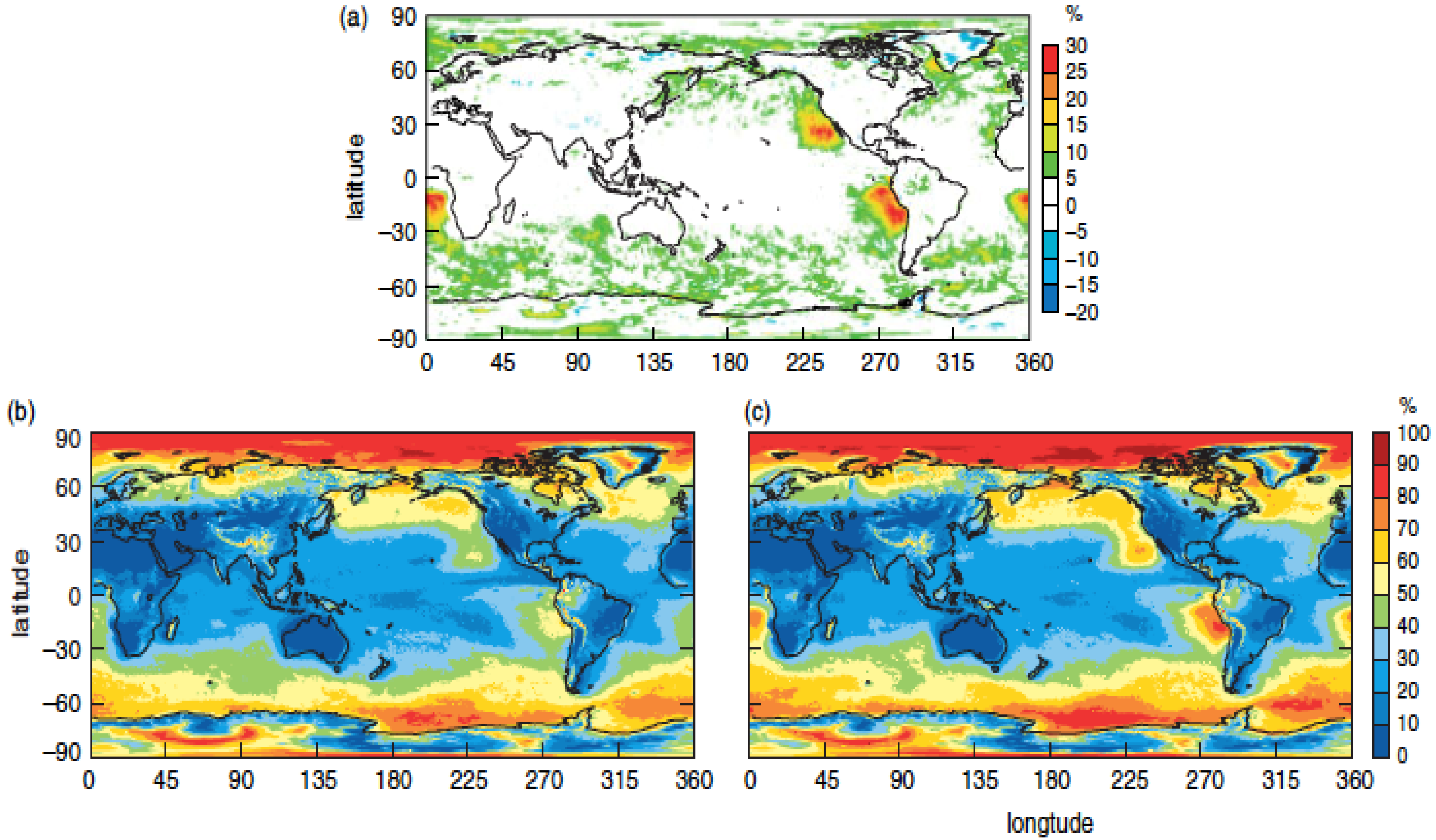
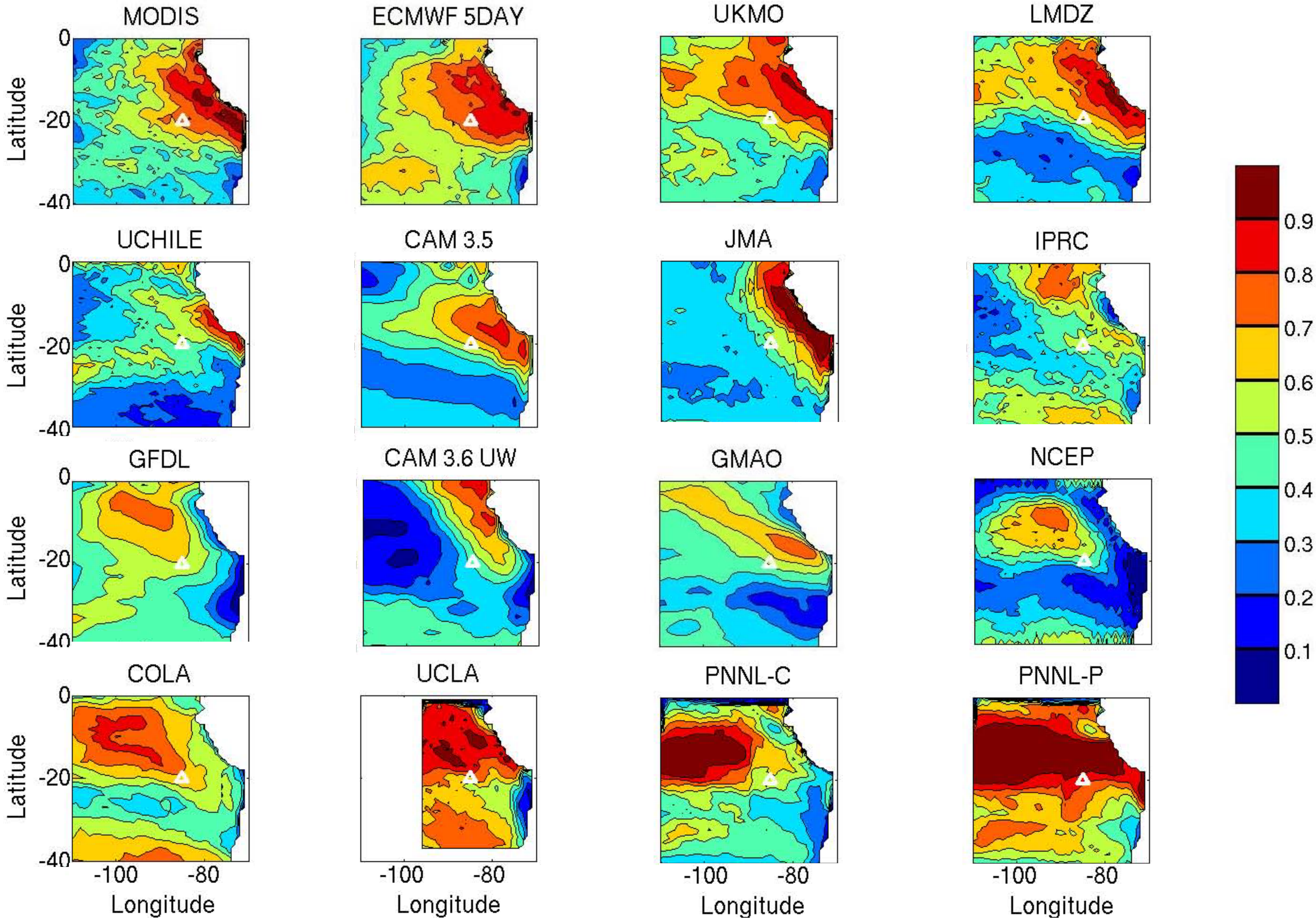


Figure 6. Model climate of low cloud cover from an ensemble of one year T159L60 integrations with (b) the dry boundary-layer scheme and (c) the new boundary-layer scheme. The difference between new and old schemes is shown in (a).

preVOCA: VOCALS at Oct 2006 – Low Cloud

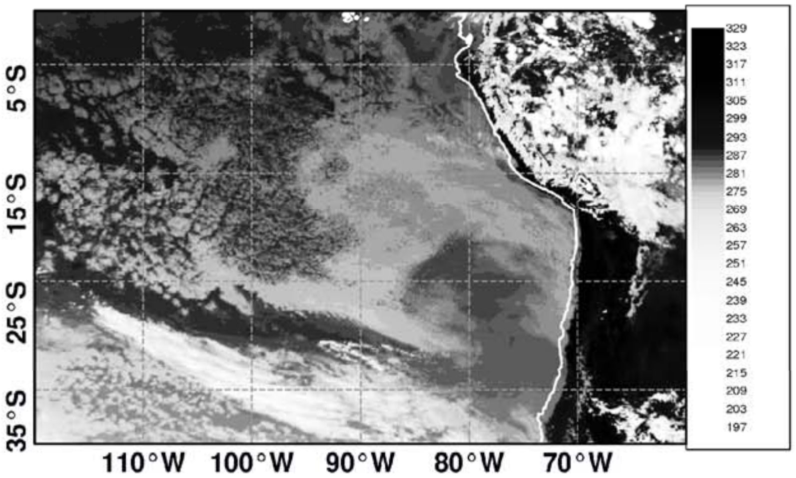


VOCALS: GOES IR satellite images

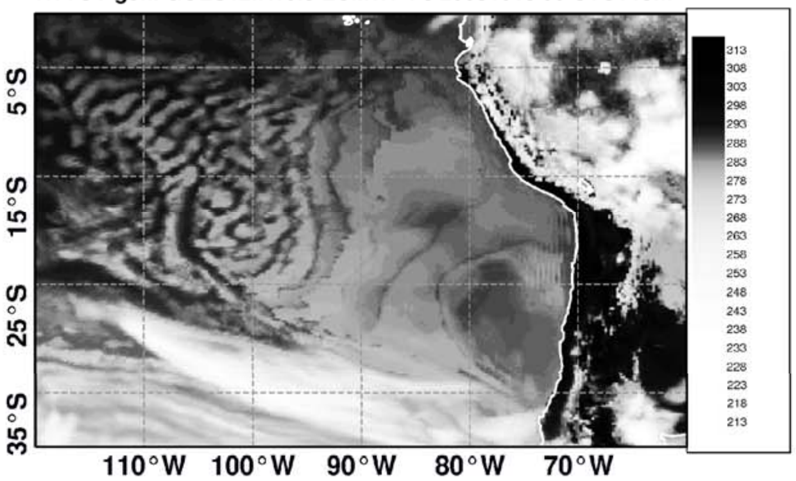
satellite | model

day

GOES12IR10.8 20081018 18 UTC

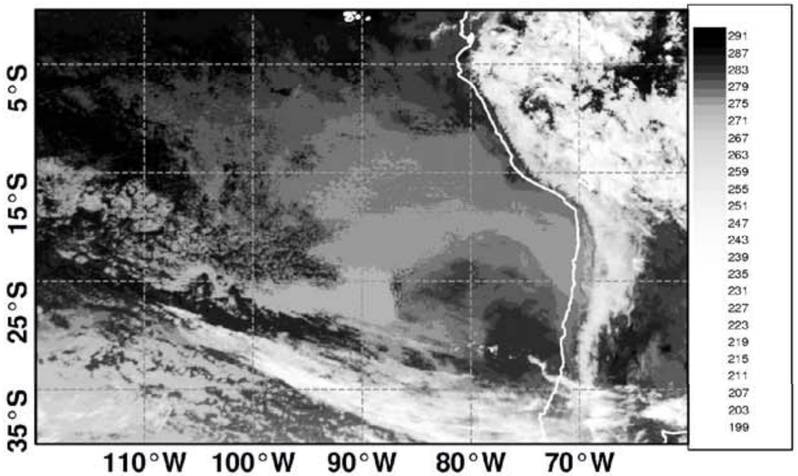


RTTOV gen. GOES12IR10.8 ECMWF Fc 20081018 00 UTC+18h:

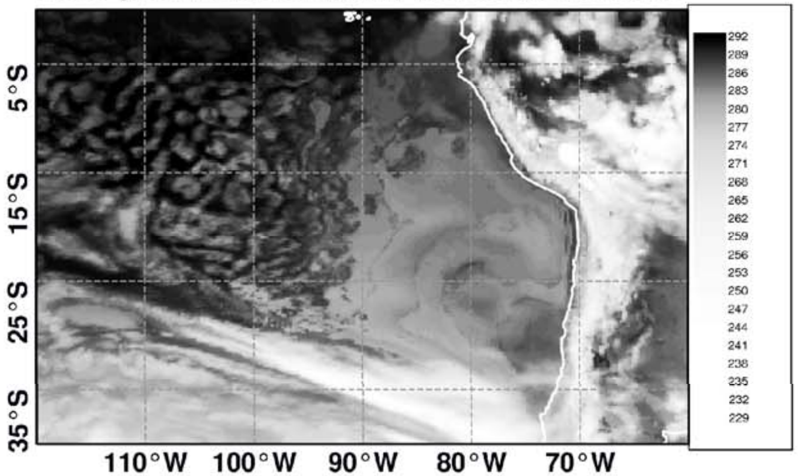


night

GOES12IR10.8 20081019 6 UTC



RTTOV gen. GOES12IR10.8 ECMWF Fc 20081019 00 UTC+6h:



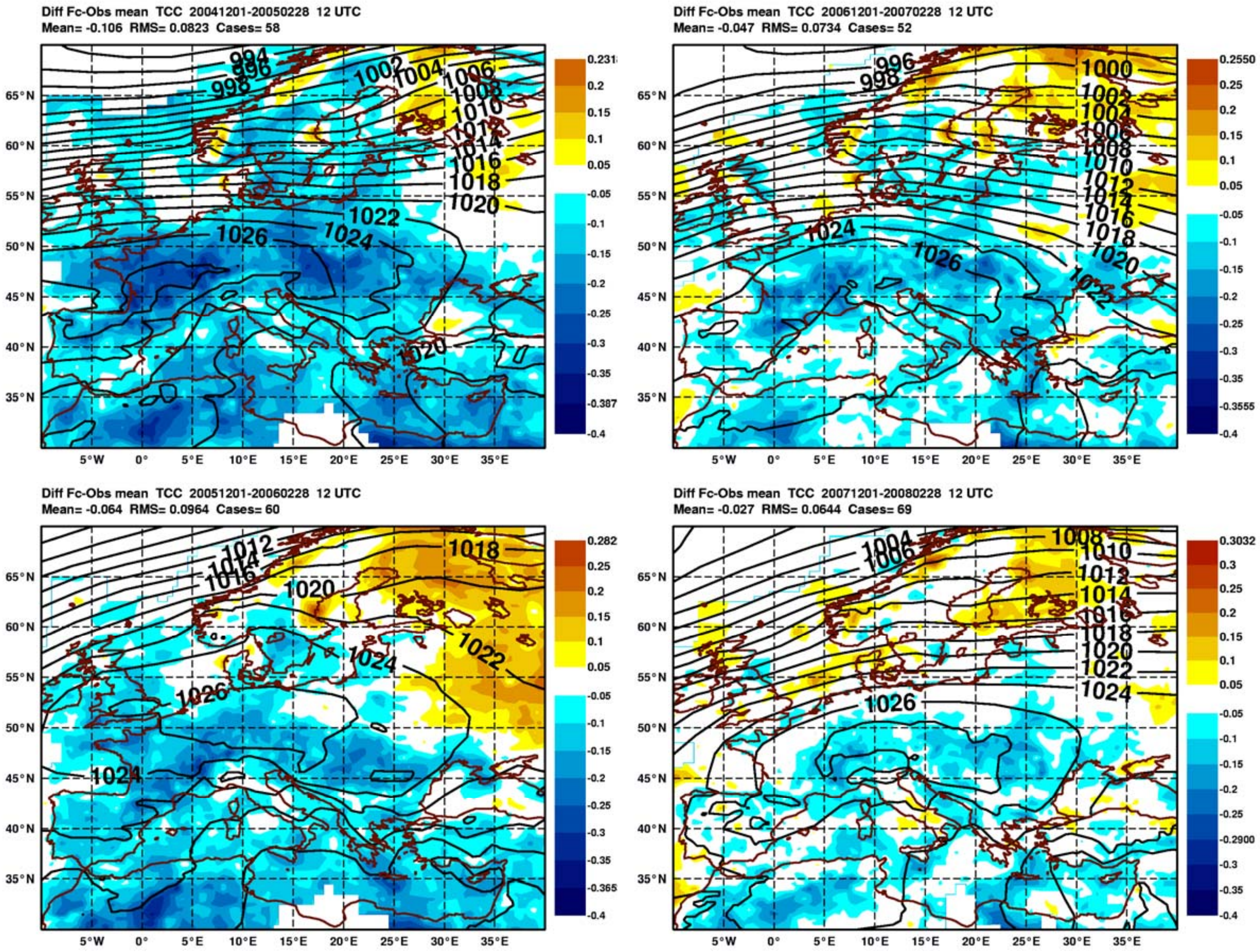
Winter Cloud Cover 36h forecast versus SYNOP observation (high pressure days over central Europe)

DJF
2004/5
58 cases

DJF
2006/7
52 cases

EDMF PBL

M-O diffusion



DJF
2005/6
60 cases

DJF
2007/8
69 cases

Shallow Cumulus: specifications

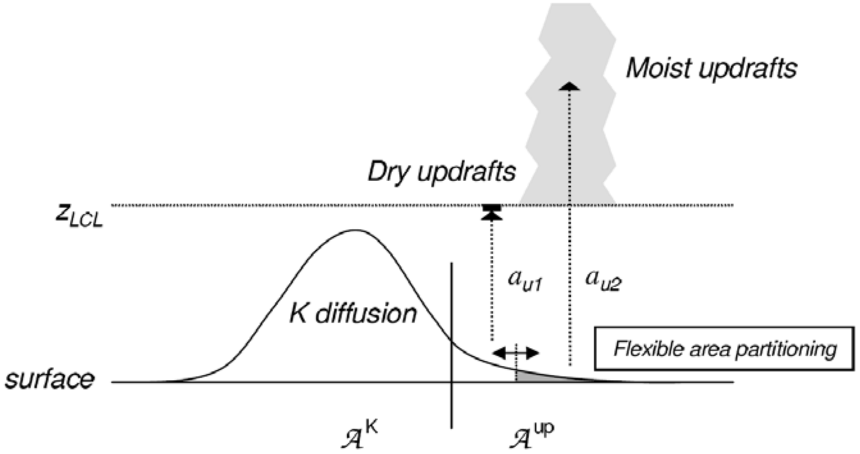
(beyond Neggers et al 2009ab):

1. entrainment: convective pre-moistening

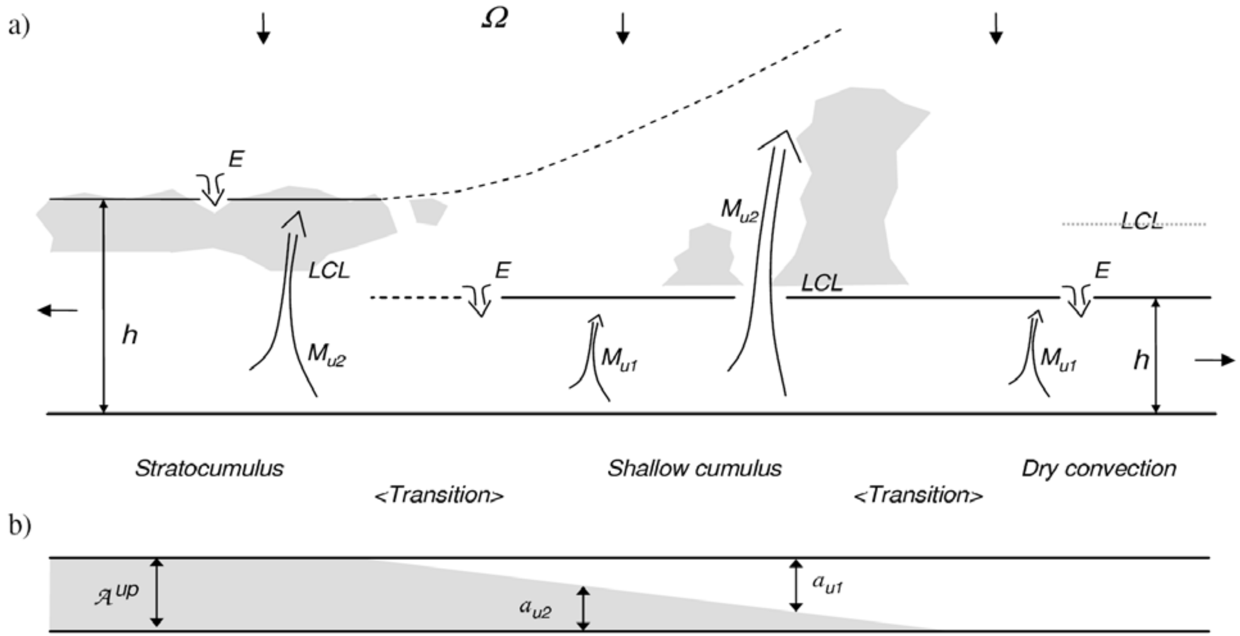
2. cloud overlap: LES based

3. microphysics:
   - precipitation threshold q = 1g/kg
   - evaporation threshold RH = 100%

DUALM concept:
multiple updrafts with flexible area partitioning



$$\mathcal{A}^{up}\,\overline{w'\phi'}^{up} = \sum_{i=1}^{N} a_{ui} w_{ui} (\phi_{ui} - \overline{\phi})$$

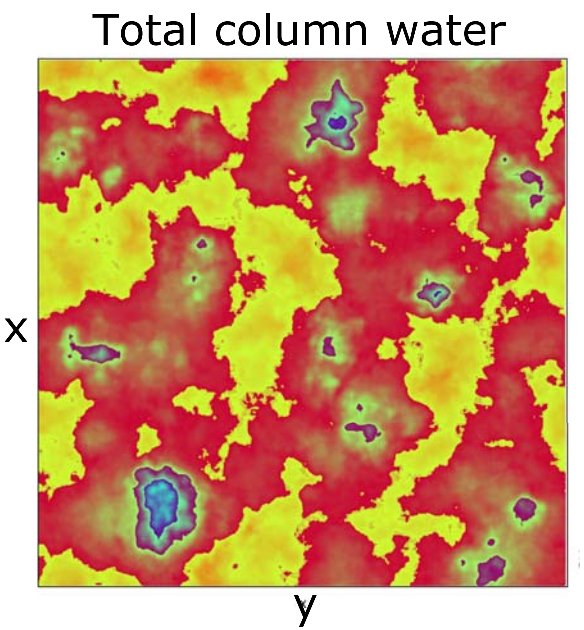


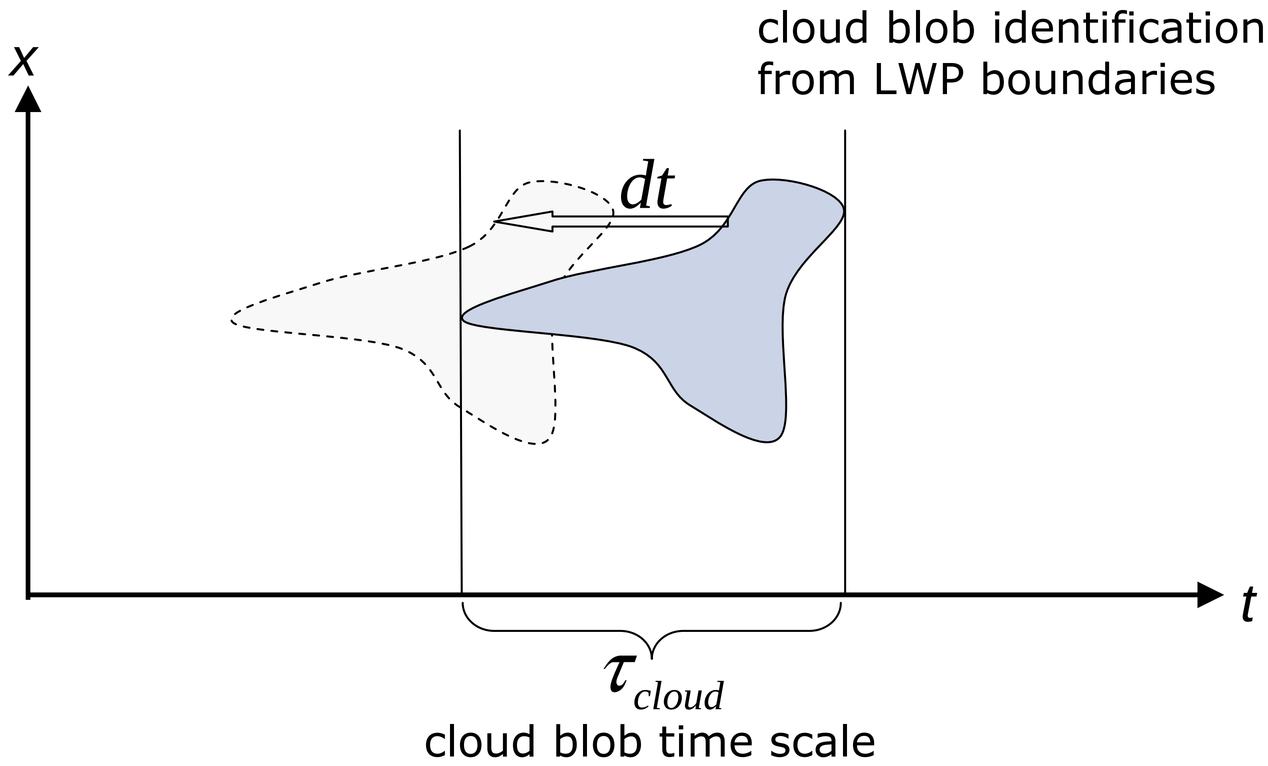
Brian Mapes (~1995 GCSS meeting):
Postulate that convection selects favourable environments.

Peter Bechtold (2008):
Moist environments yield less entrainment.

Redelsperger et al (2002) and Burnet, Bregnier (2008):
Observaional evidence: TOGA-COARE and SCMS

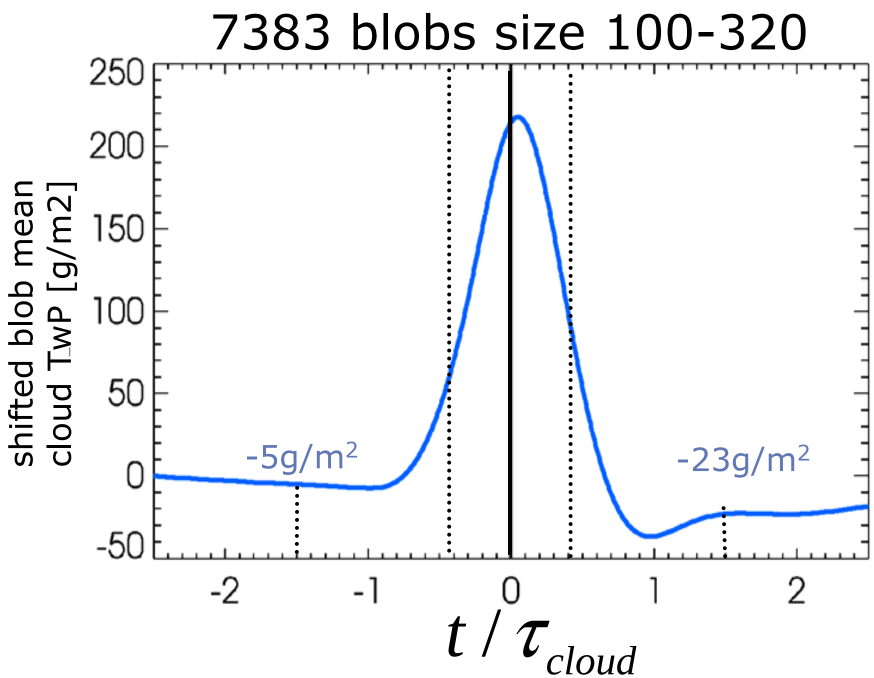
BOMEX LES   cloud blobs



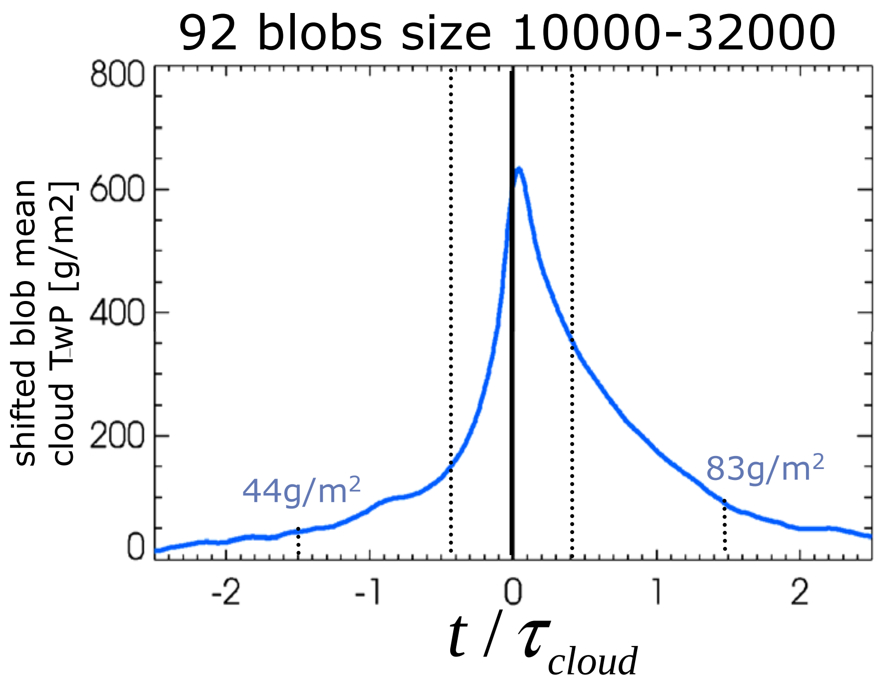


Martin Köhler & Olaf Stiller & Thijs Heus

BOMEX LES   cloud blobs



Time, lagged around blob center, normalized by blob time scale

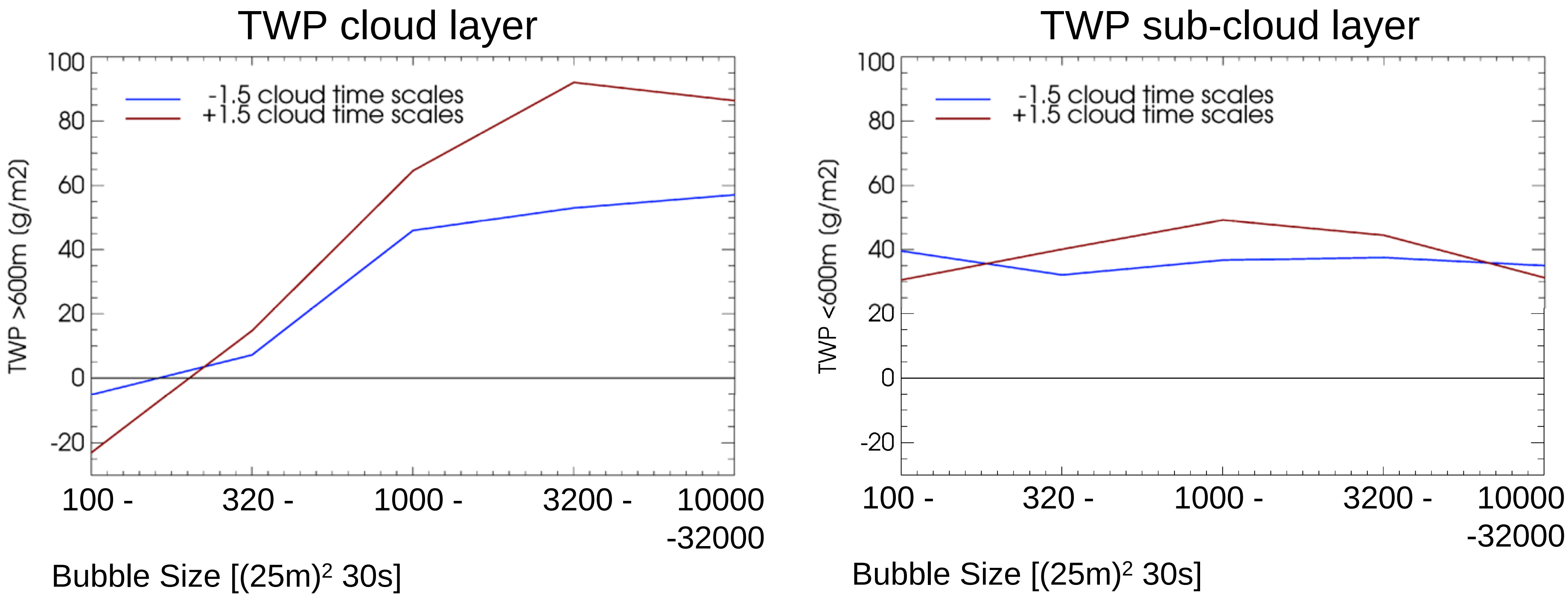


Time, lagged around blob center, normalized by blob time scale

blobs size 1000: $(250\text{m})^2 \cdot 300\text{s}$

$$\sigma_{WVP} = 890\text{g/m}^2$$

BOMEX LES: size



- all clouds live in top half moist environment (TWP>600m)
- smallest clouds consume TWP (>600m)
- big clouds add TWP (>600m)
- sub-cloud layer plays no role in cloud size selection

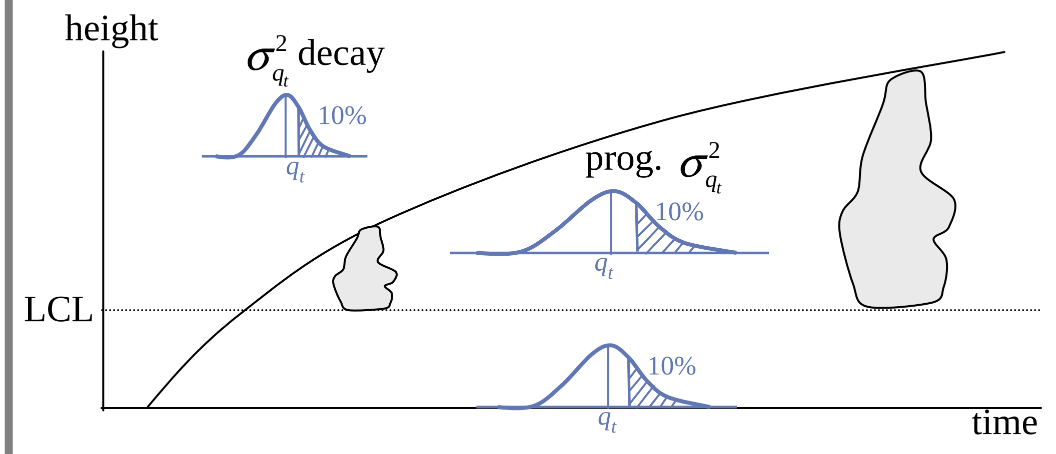
DUALM convective pre-conditioning

- prognostic total water variance equation

$$\frac{\partial \sigma_{q_t}^2}{\partial t} = -2\overline{w'q'}\frac{\partial \overline{q_t}}{\partial z} - \frac{\partial \overline{w'q_t'q_t'}}{\partial z} - \frac{\sigma_{q_t}^2}{\tau}$$

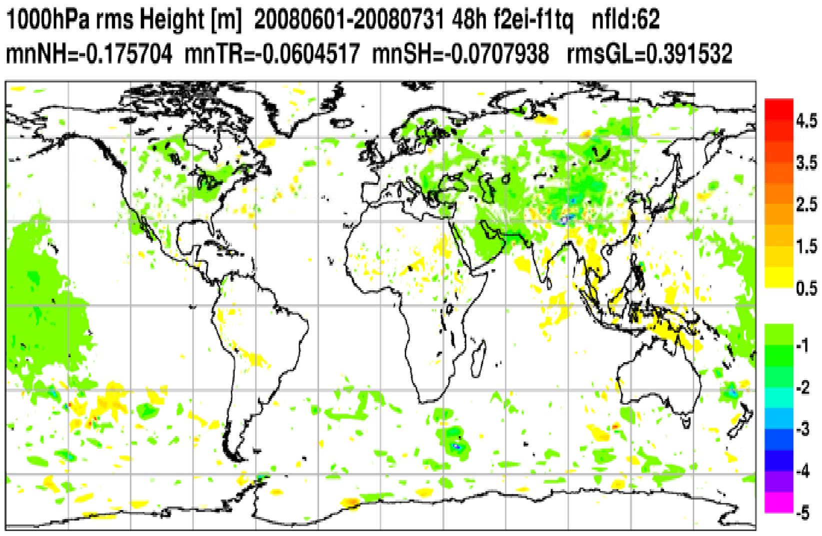
- most moist environment favours shallow convection

$$\frac{\partial q_{t,up}}{\partial z} = -\varepsilon(q_{up} - \overset{\text{moist}}{q_{env}})$$

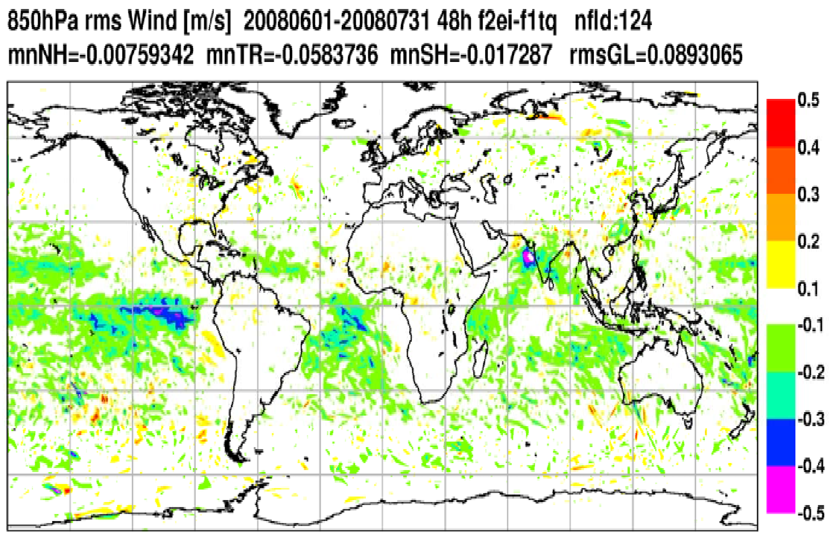


DUALM: impact of convective preconditioning

Z1000

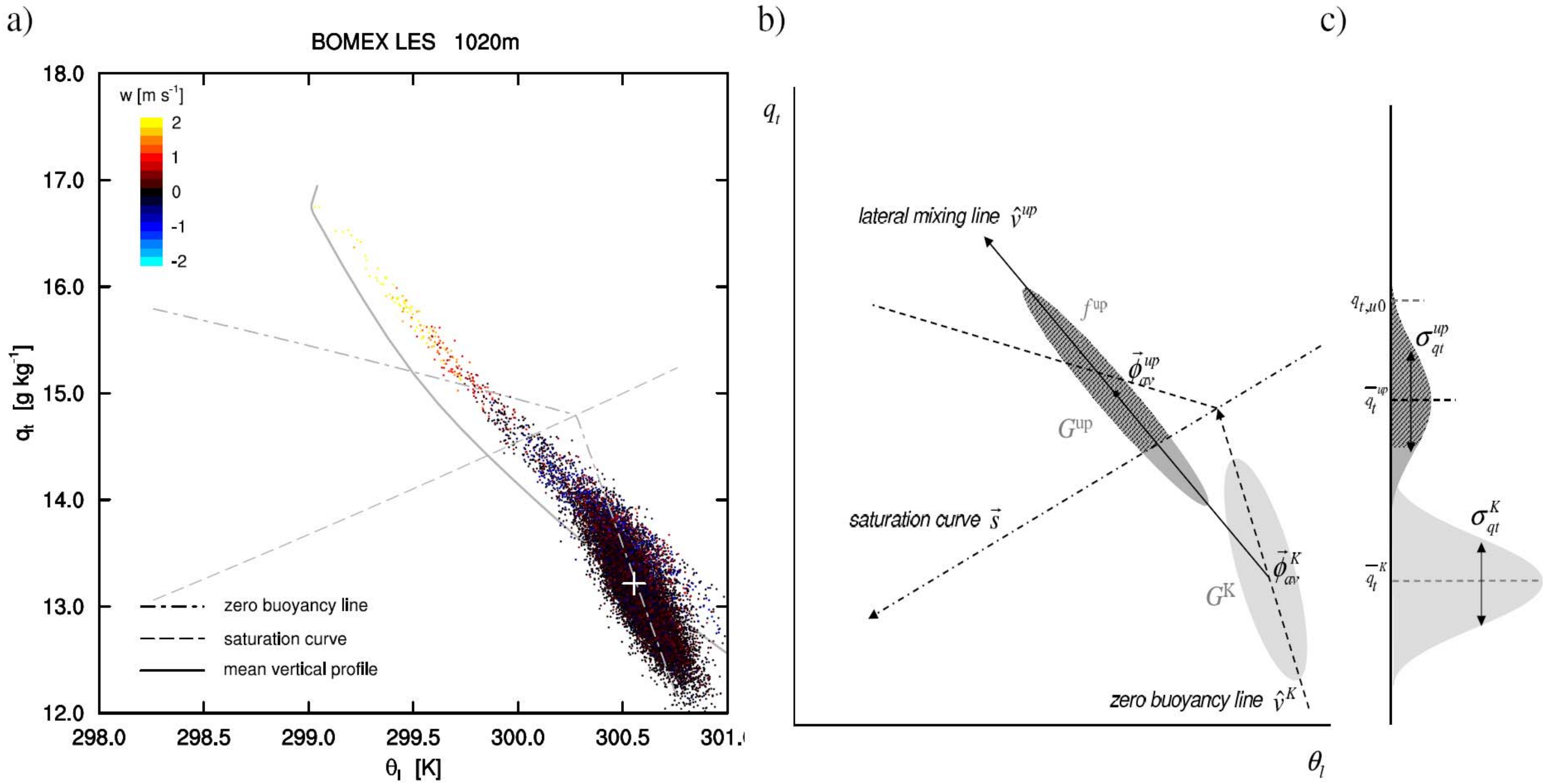


U850



Tests in ECMWF model with DUALM shallow convection.

DUALM cloud concept:
a bimodal statistical cloud scheme

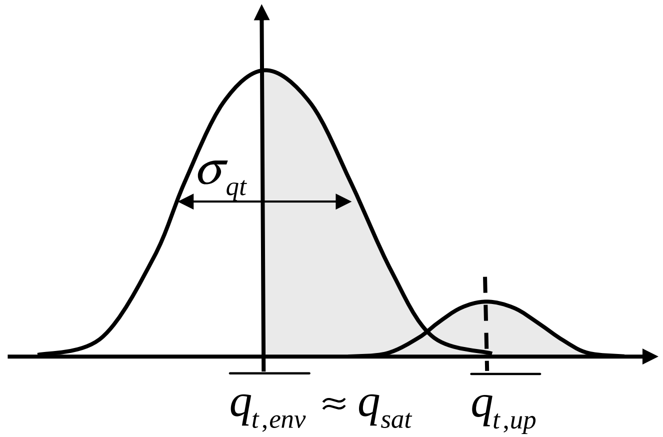


Assigned its independent PDF to diffusive and updraft modes.

Their orientations in conserved variable space express their unique properties.

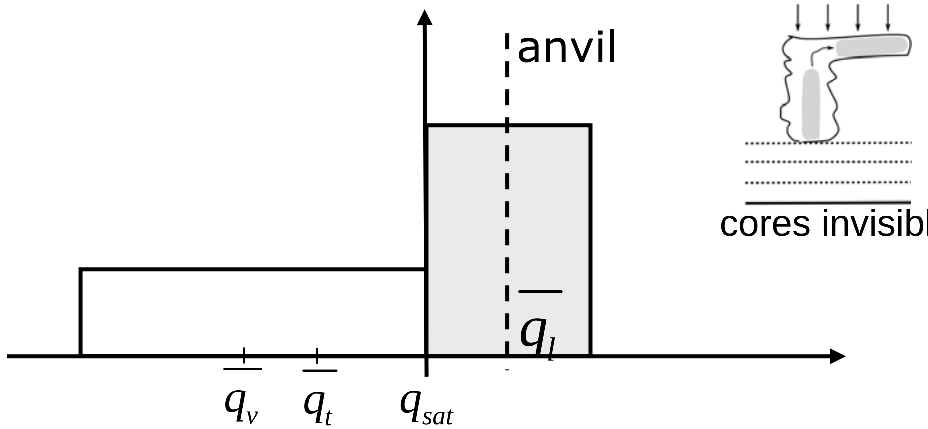
DUALM – Tiedtke unification

DUALM



example:
a=50%

Tiedtke, 1993

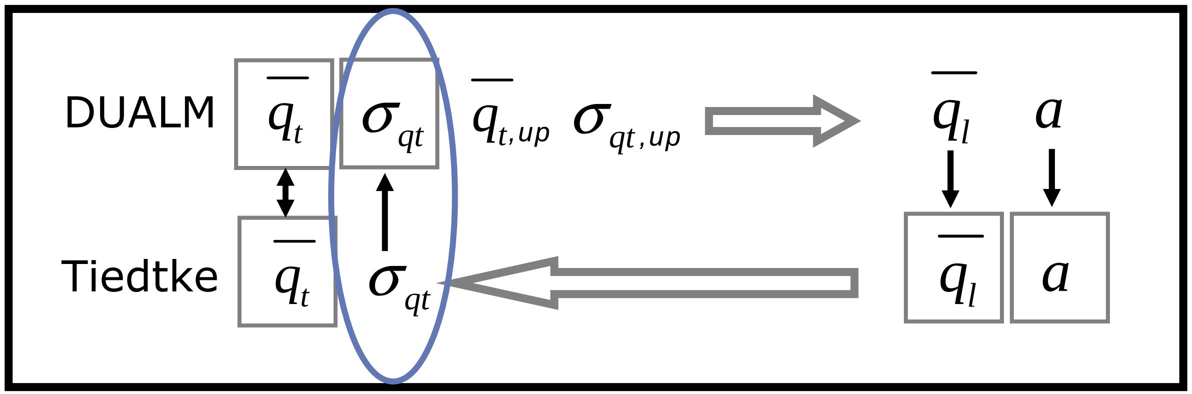


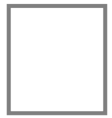
cores invisible

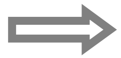
4 moments: $\overline{q}_t$, σ_{qt}, $\overline{q}_{t,up}$, $\sigma_{qt,up}$

3 moments: $\overline{q}_t$, $\overline{q}_l$, a

Unification



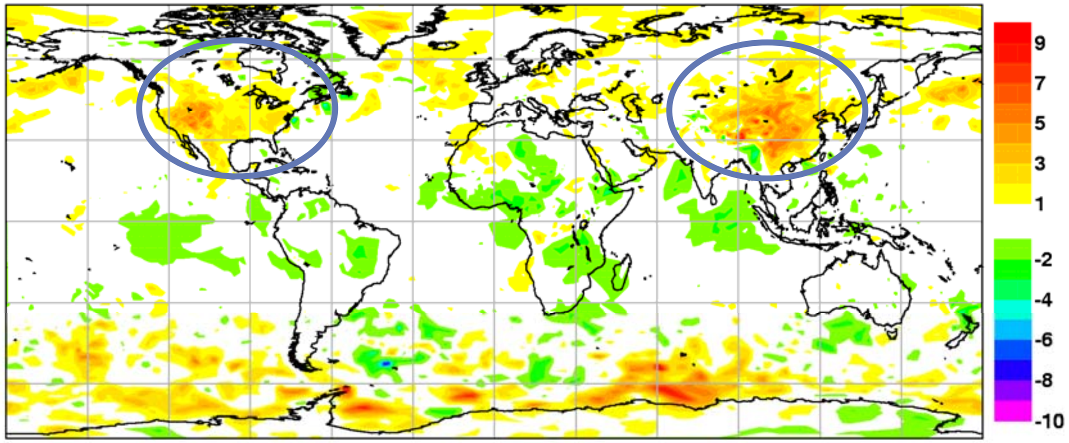
 Prognostic variable

 Diagnostic

DUALM problem: summer land

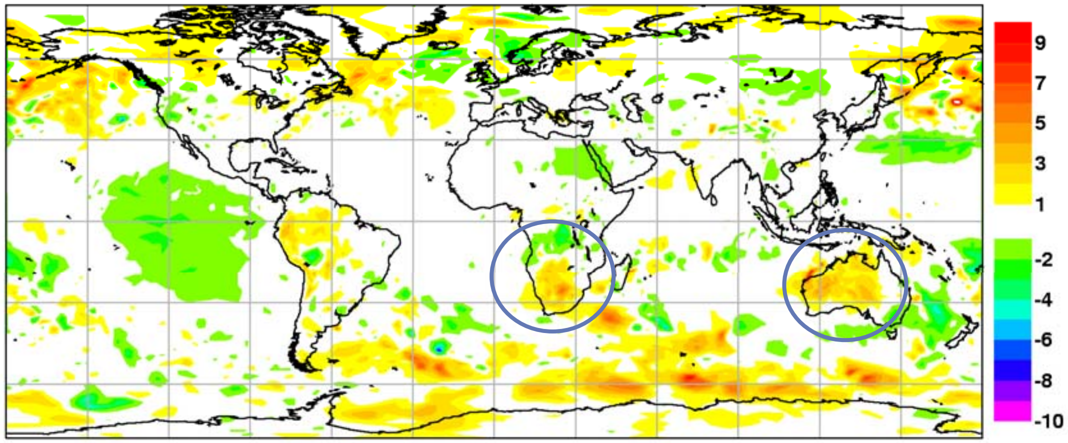
Jul/Aug 2008 Z1000hPa T255 analysis

1000hPa rms Height [m] 20080702-20080829 48h f1zg-f1zc nfld:118
mnNH=0.737154 mnTR=-0.25 mnSH=0.392649 rmsGL=1.14664



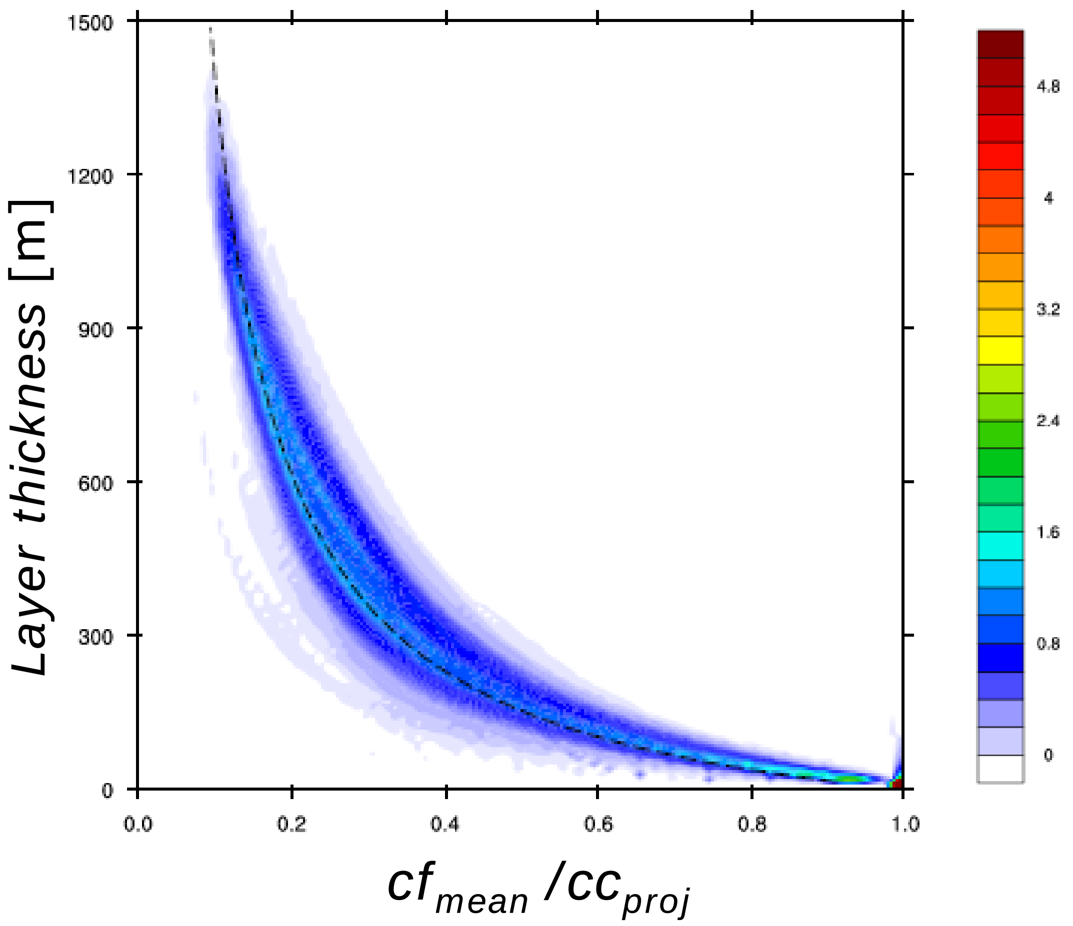
Jan/Feb 2008

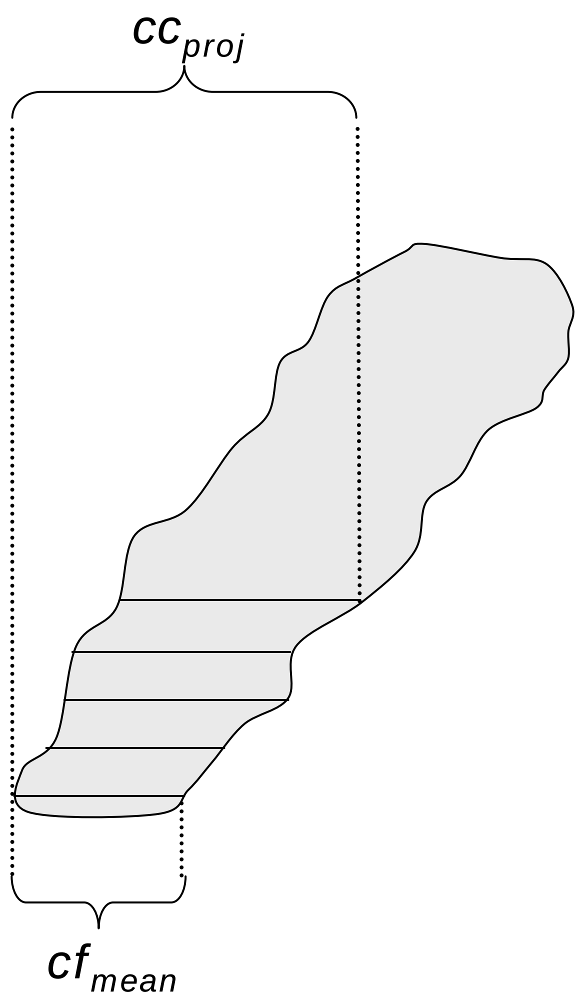
1000hPa rms Height [m] 20080102-20080226 48h f1zf-f1zb nfld:112
mnNH=0.372442 mnTR=-0.158159 mnSH=0.44159 rmsGL=1.18283



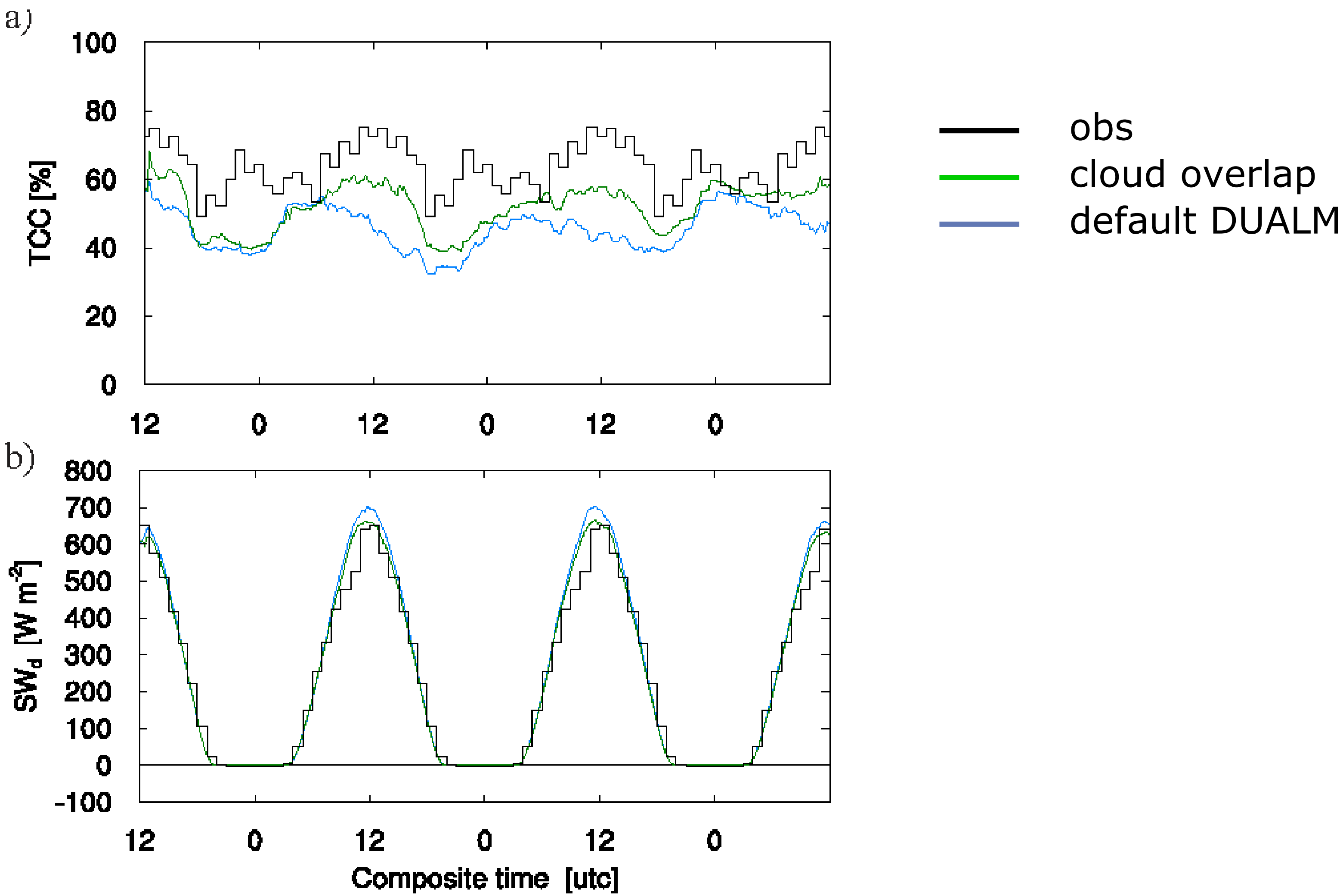
fast diurnal cycle driven by strong sens. heat flux

DUALM at ECMWF:
cloud overlap Roel Neggers, Pier Siebesma, …





Cloud overlap: impact over Cabauw



Norwegian model:

Life Cycle of Cyclones and the Polar Front Theory of Atmospheric Circulation

by

J. Bjerknes and H. Solberg.

(Manuscript received May 27th, 1922).

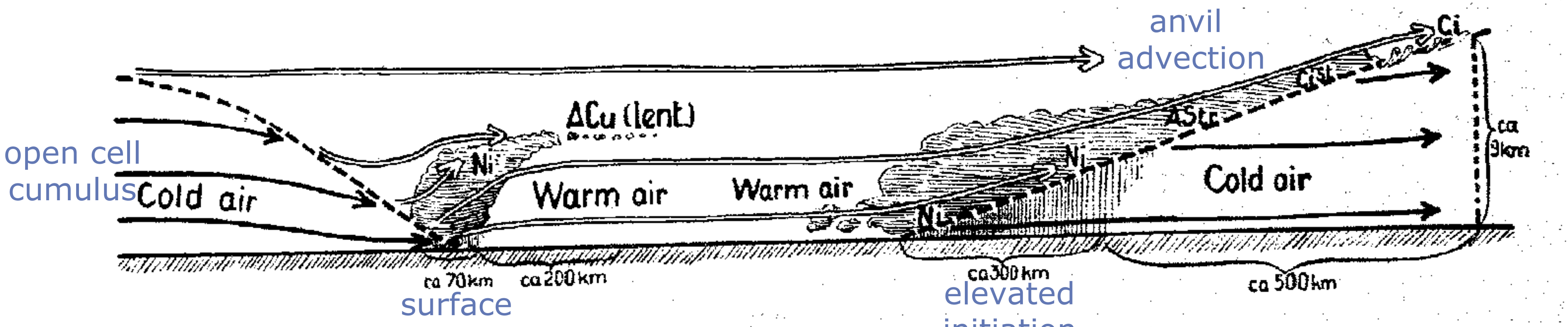
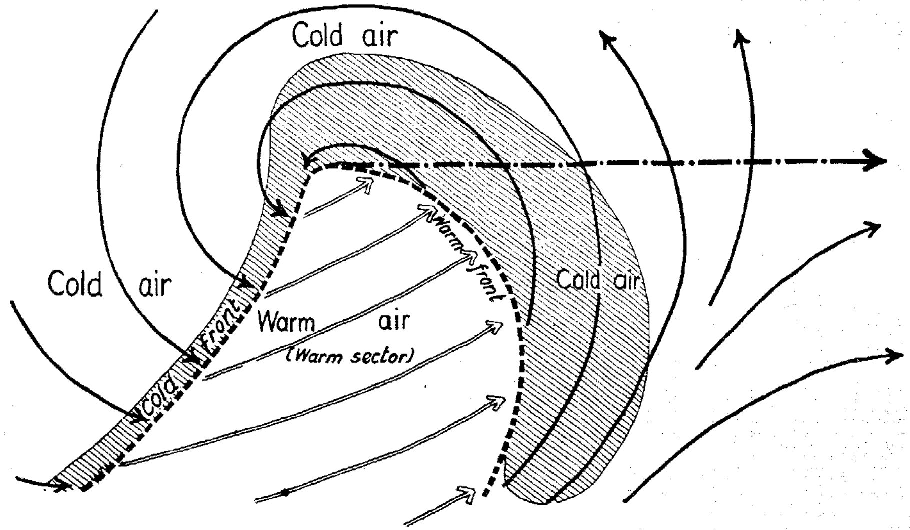
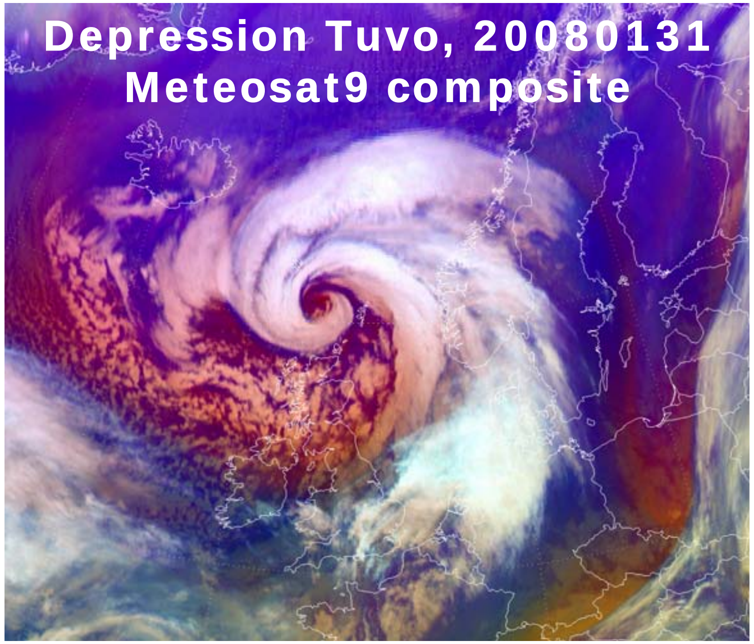


Fig. 1.
Idealized cyclone.

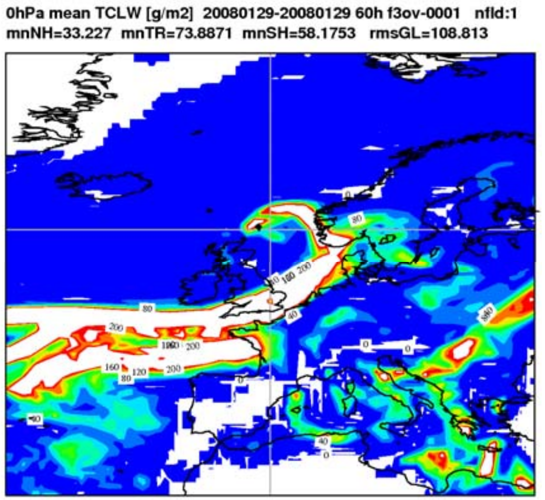


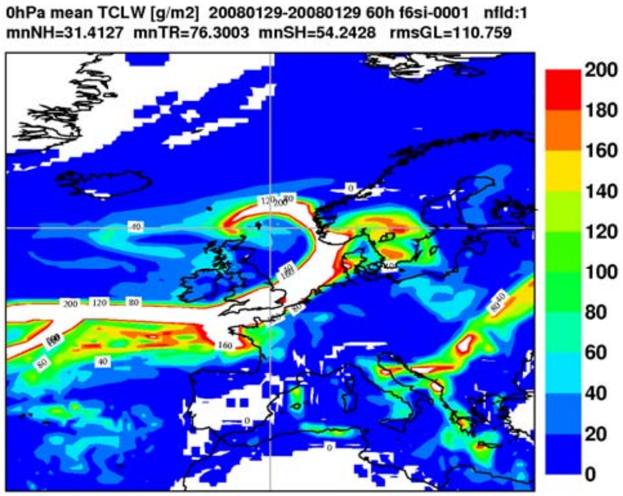


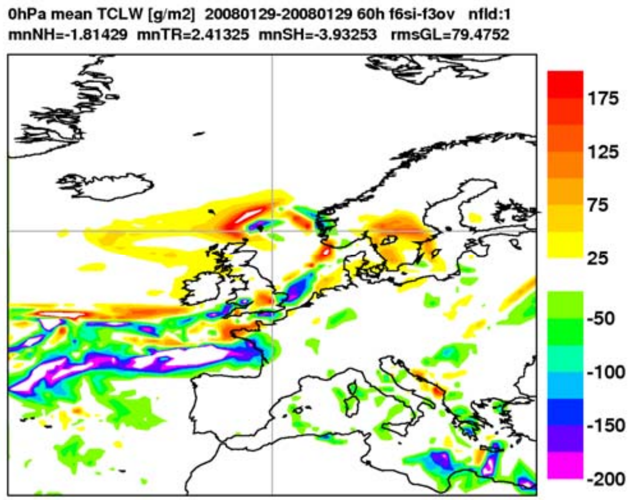
Extra-Tropical Cyclones

2008012900+60h

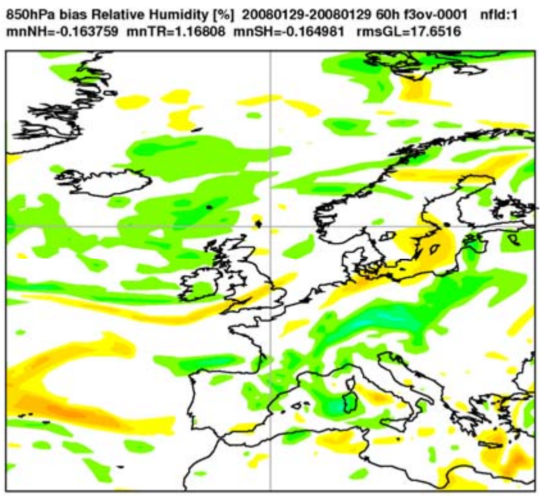
TCLW CY33R1 | TCLW DUALM | TCLW DUALM-CY33R1

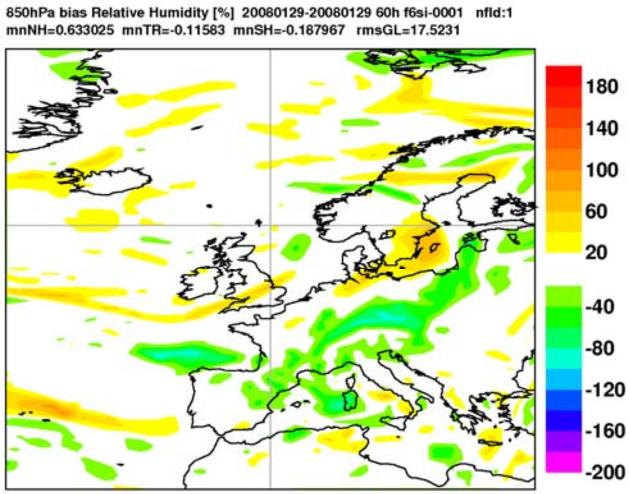


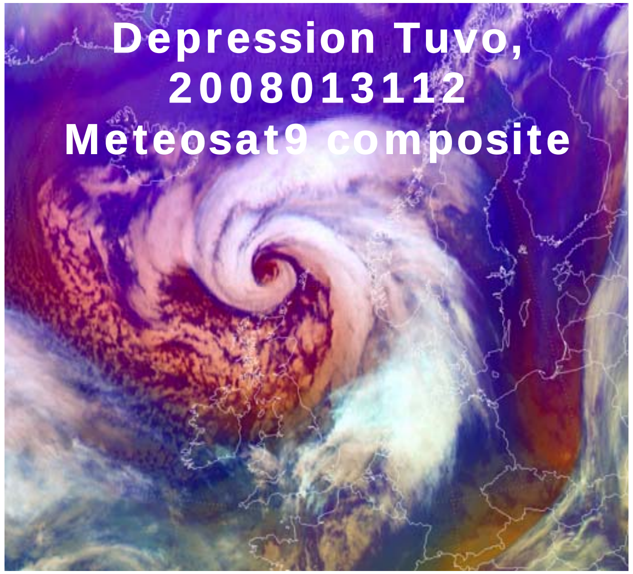




RH850bias CY33R1 | RH850bias DUALM

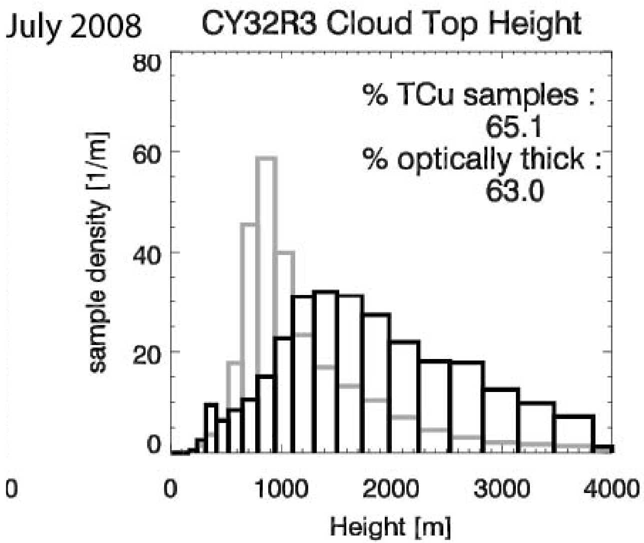




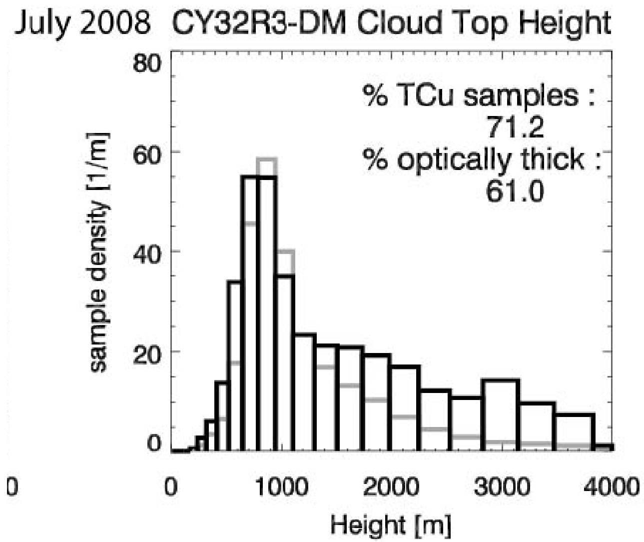


Maike Ahlgrimm: CALIPSO trade cumulus

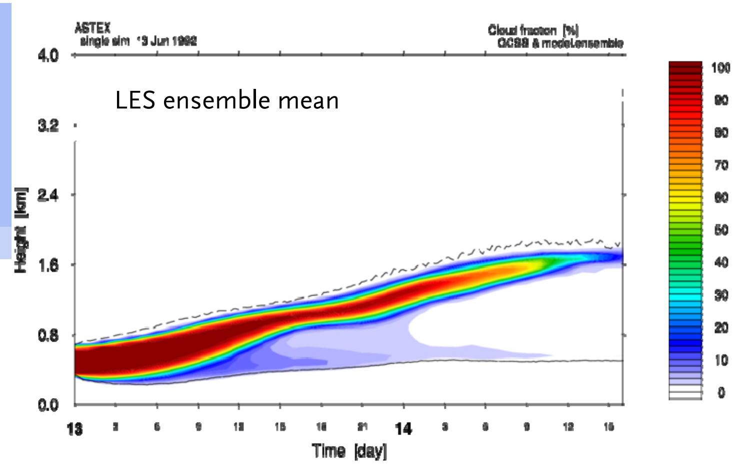
Tiedtke

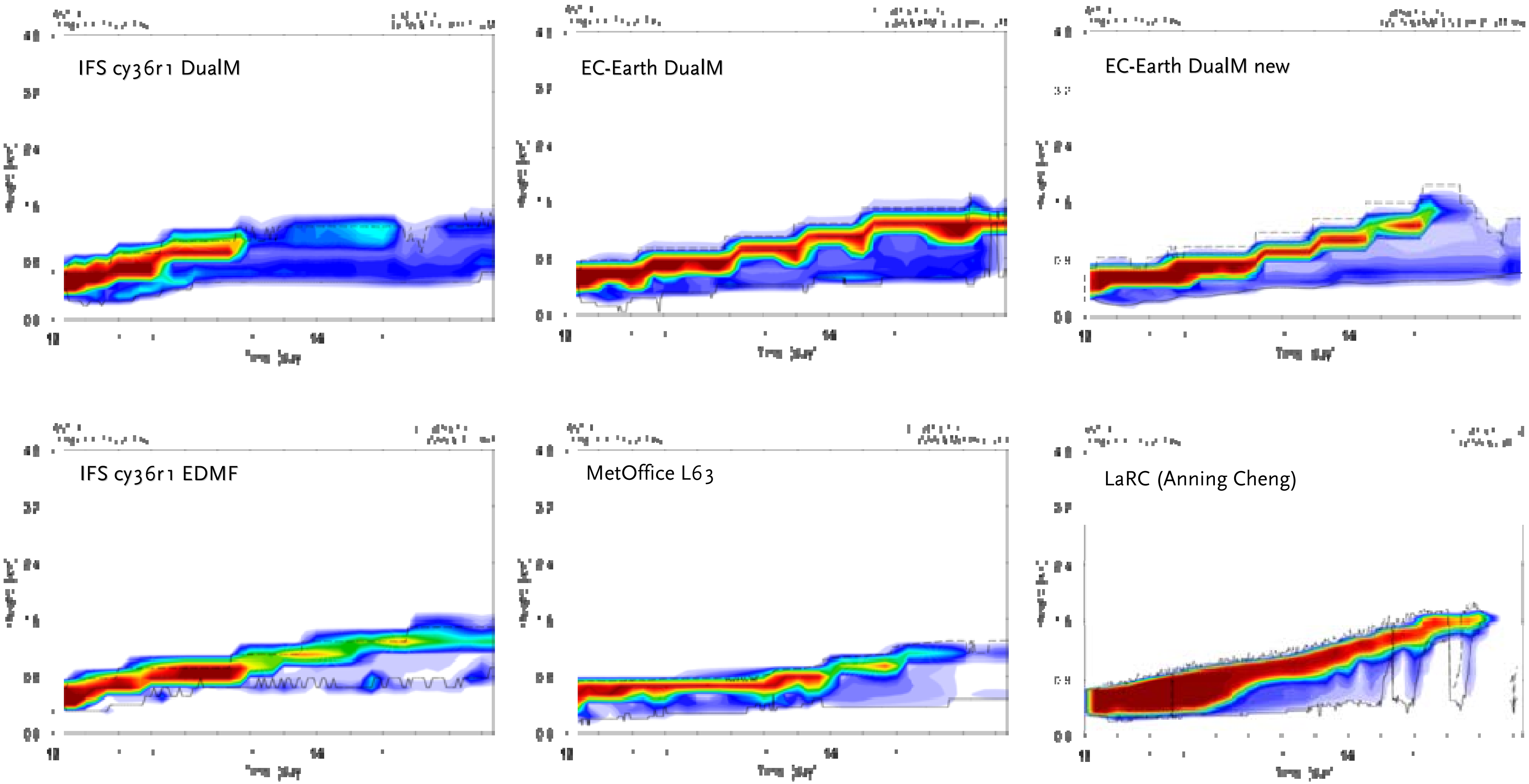


DUALM



ASTEX Lagrange-transition





Unified Boundary Layer: EDMF Stratocumulus and Shallow Cumulus DUALM

DWD

Köhler, 2005
Neggers, Köhler, Beljaars 2009
Neggers, 2009
Köhler, Beljaars, Ahlgrimm 2011

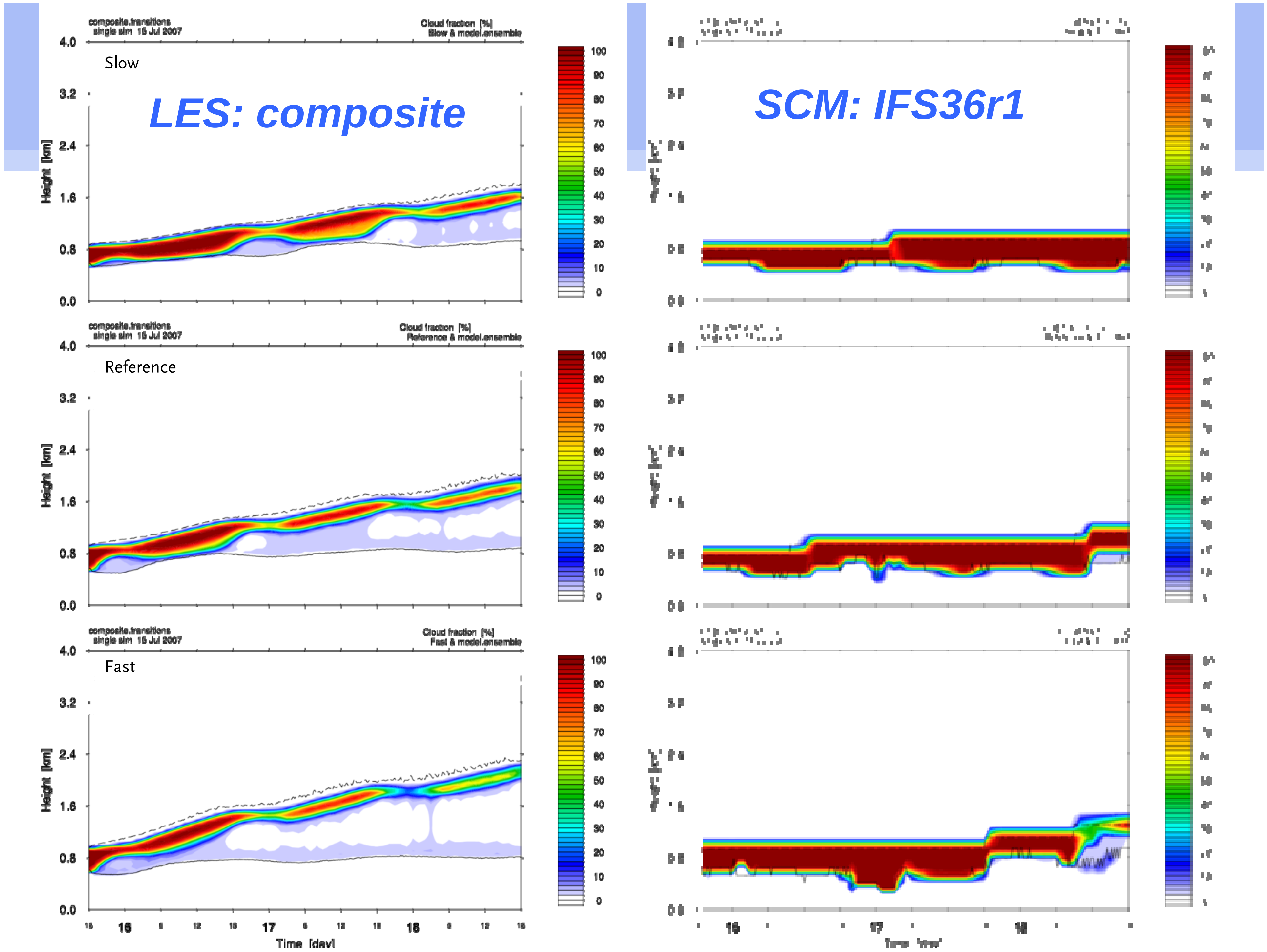
Improvements in ECMWF model:

- stratocumulus and stratus occurrence
- cumulus vertical structure
- wind scores (mid-lat storms and tropics)

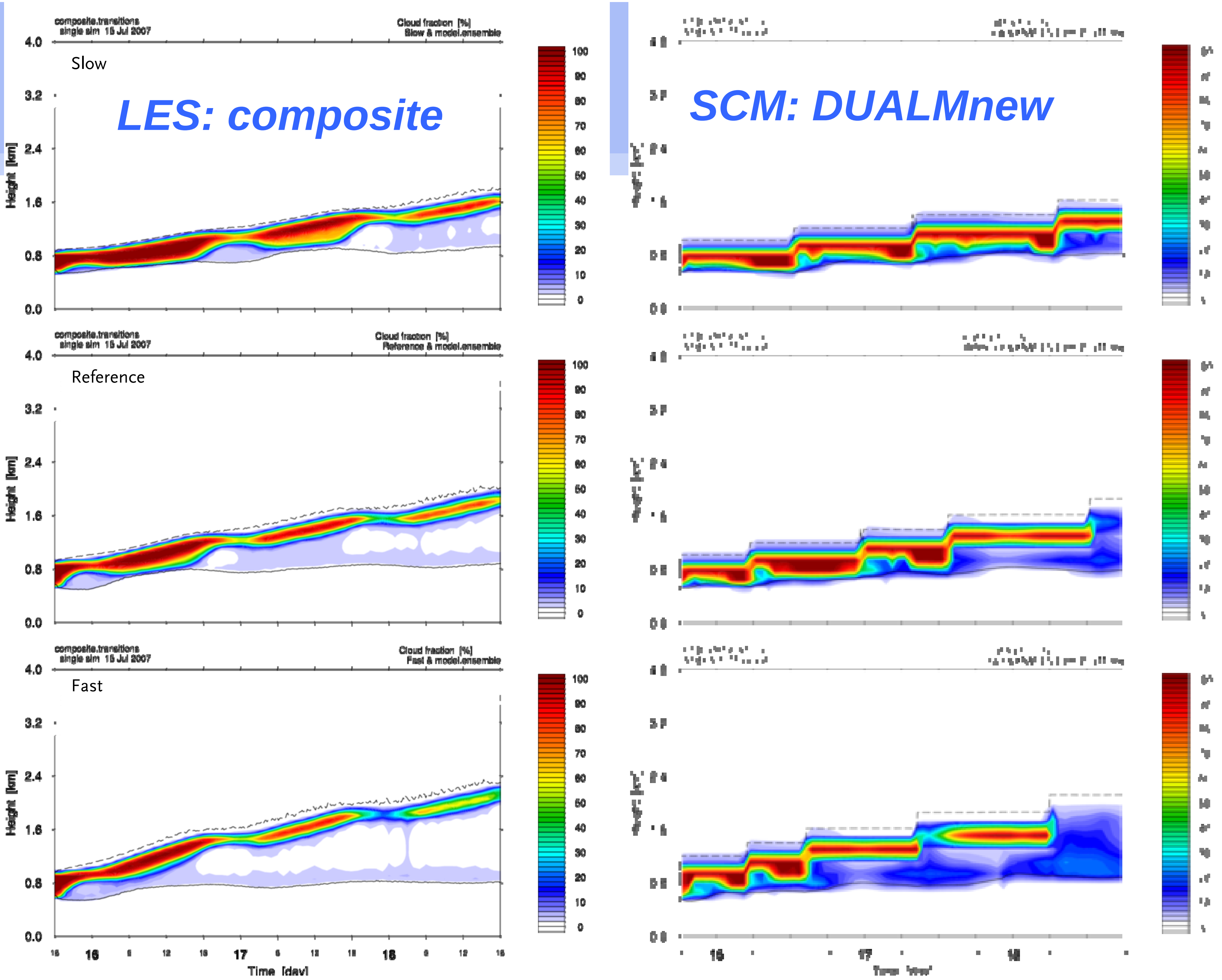
Remaining issues:

- stratus: too low cloud top
- summer land cumulus: too little cloud cover

End



LES: composite
SCM: IFS36r1
composite.transitions
single sim 15 Jul 2007
Cloud fraction [%]
Slow & model.ensemble
Slow
Reference & model.ensemble
Reference
Fast & model.ensemble
Fast
Height [km]
Time [day]


LES: composite
SCM: DUALMnew
composite.transitions
single sim 15 Jul 2007
Cloud fraction [%]
Slow & model.ensemble
Slow
Reference & model.ensemble
Reference
Fast & model.ensemble
Fast
Height [km]
Time [day]
4.0
3.2
2.4
1.6
0.8
0.0
16
17
18
100
90
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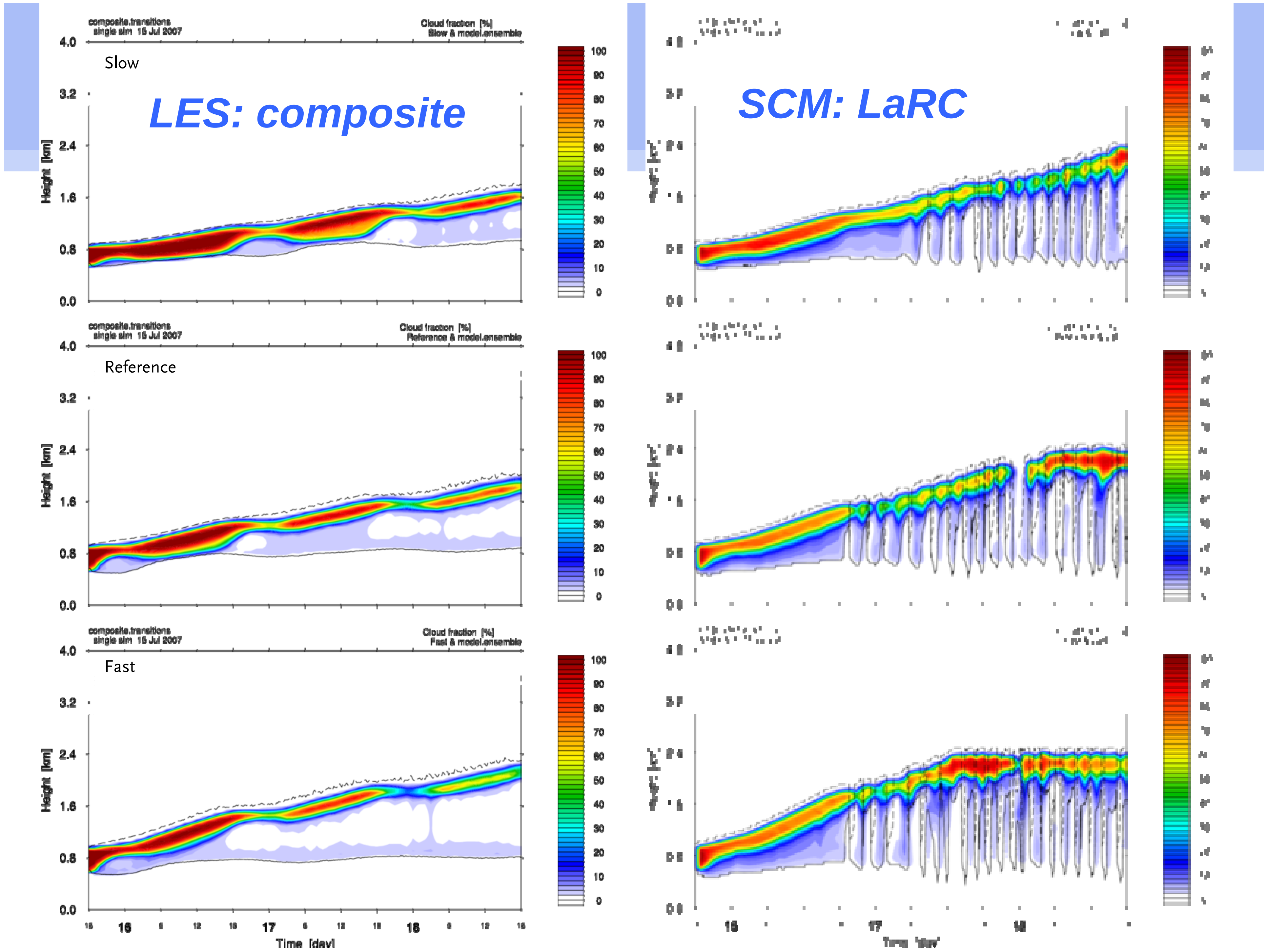
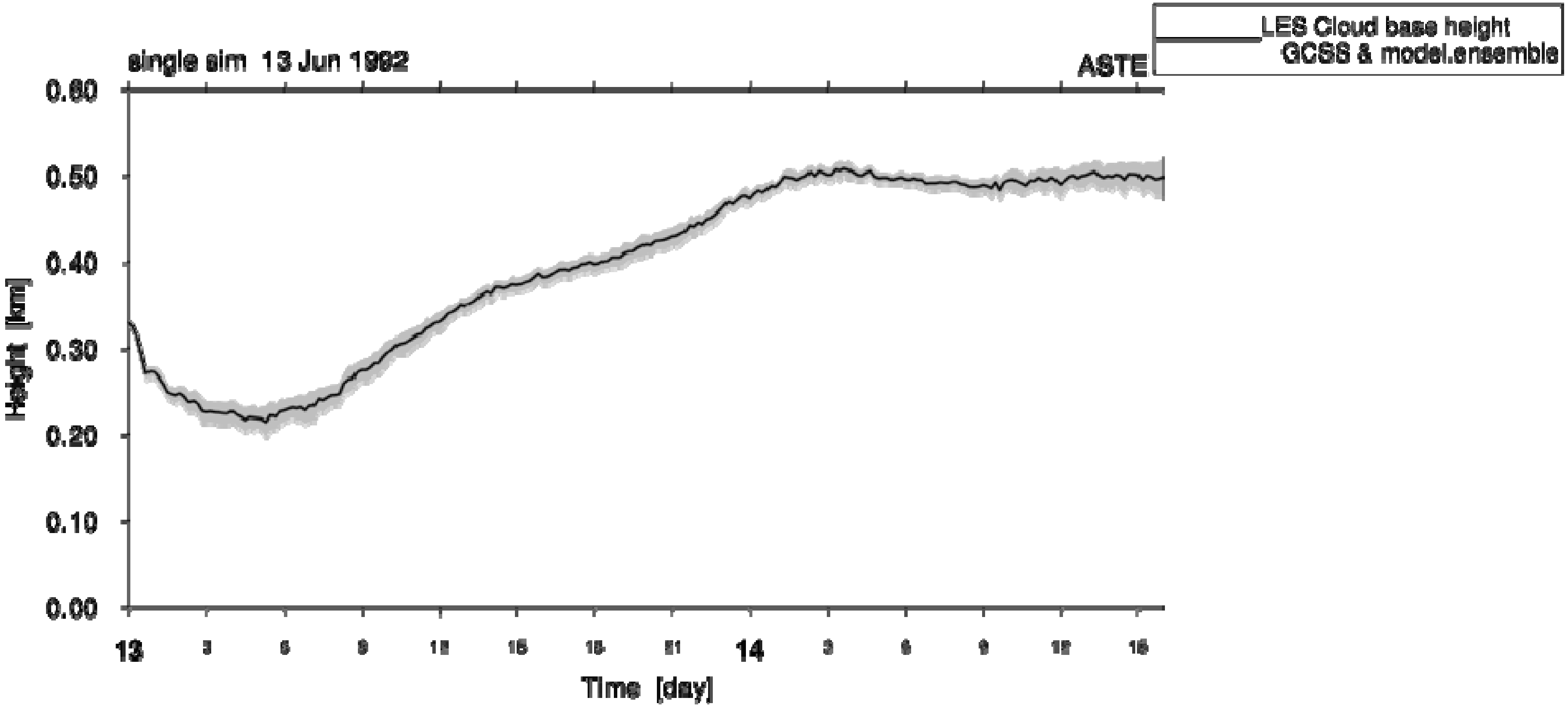
60
50
40
30
20
10
0



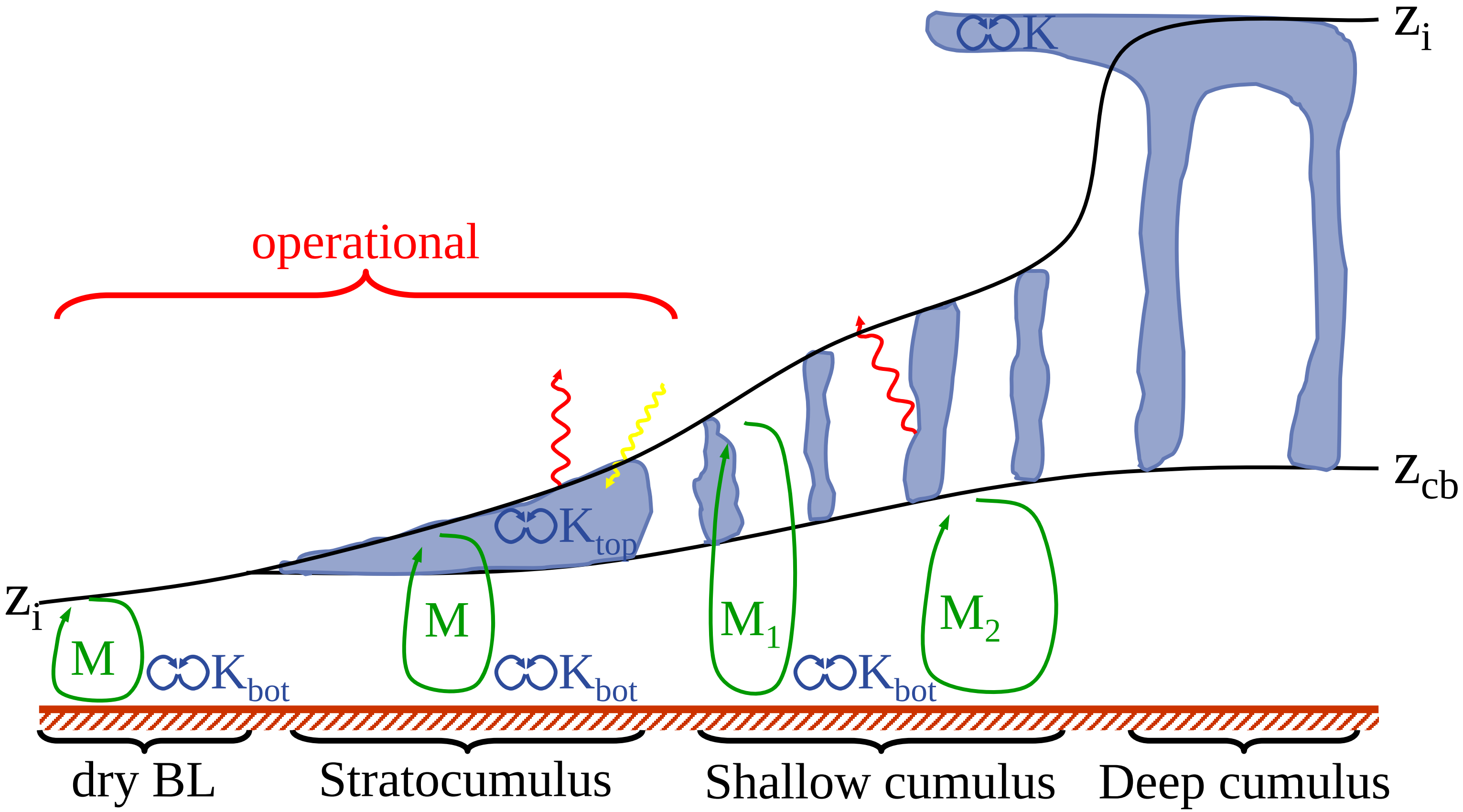
LES: composite
SCM: LaRC
composite.transitions
single sim 15 Jul 2007
Cloud fraction [%]
Slow & model.ensemble
Slow
Reference & model.ensemble
Reference
Fast & model.ensemble
Fast
Height [km]
Time [day]

ASTEX - Cloud base height



Extra Slides

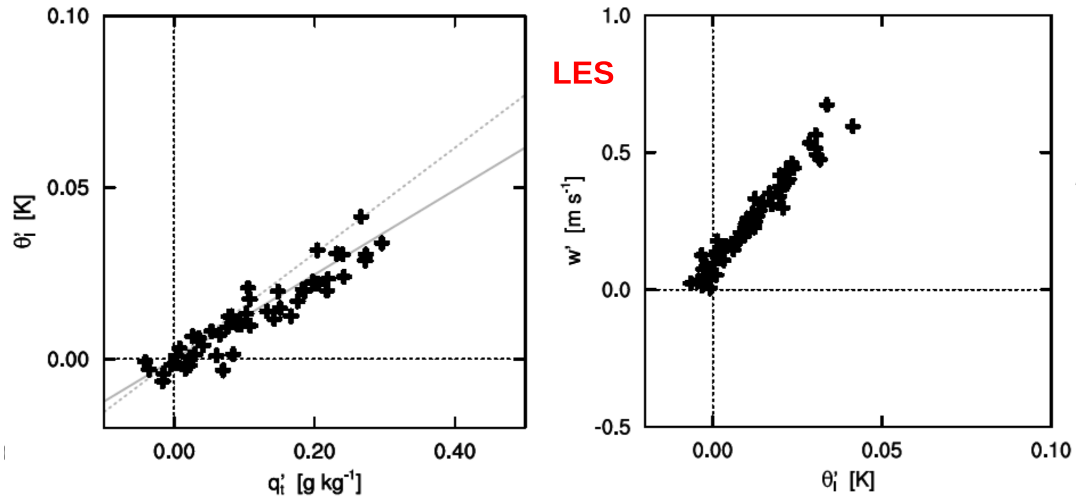
Integral approach to PBL transports: EDMF



EDMF Concepts 1: updraft initialization

Dependence on i) surface fluxes and ii) updraft area fractions:

Assume a *joint Gaussian PDF* in $\{q_t, \theta_l, w\}$ at the lowest model level.

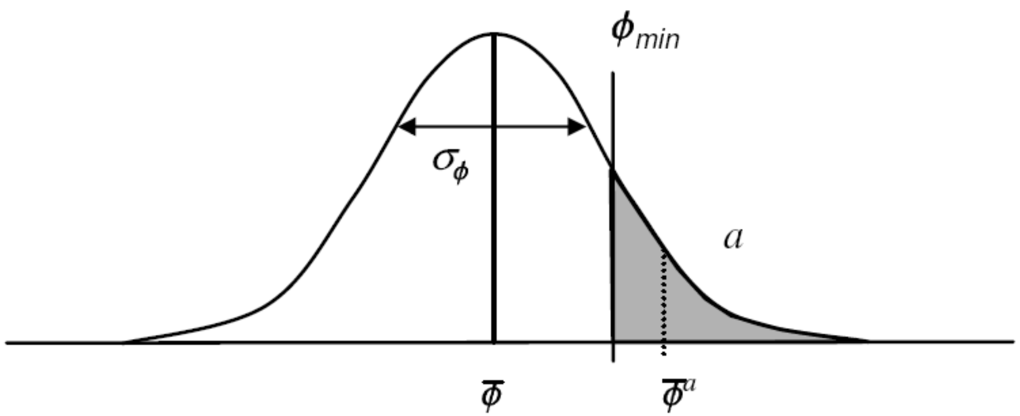


Obtain its width from the surface sensible and latent heat fluxes, using surface layer similarity.

Use the mean of the top segment as the updraft initial value:

$$\overline{\phi}^{\,a} = \overline{\phi} + \mathcal{D}(a)\,\sigma_\phi$$

$$\overline{w}^{\,a} = \mathcal{D}(a)\,\sigma_w$$



EDMF Concepts 2: flexible updraft entrainment

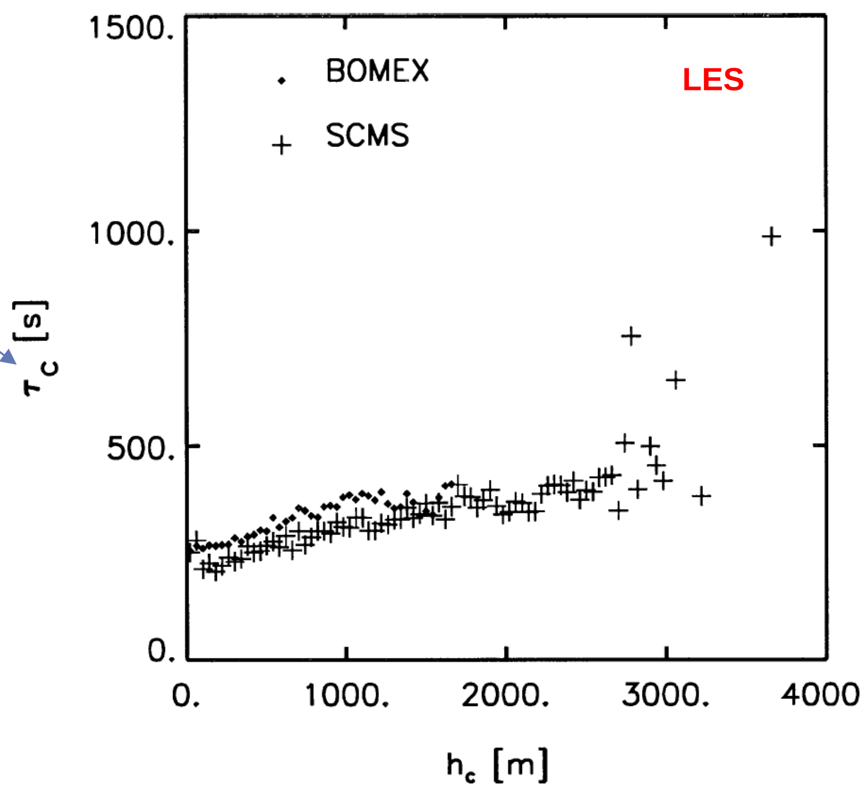
An inverse dependence on updraft vertical velocity:

$$w_u \frac{\partial \phi_u}{\partial z} = \frac{\phi_u - \overline{\phi}}{\tau}$$

Cumulus turn-over timescale (assumed constant)

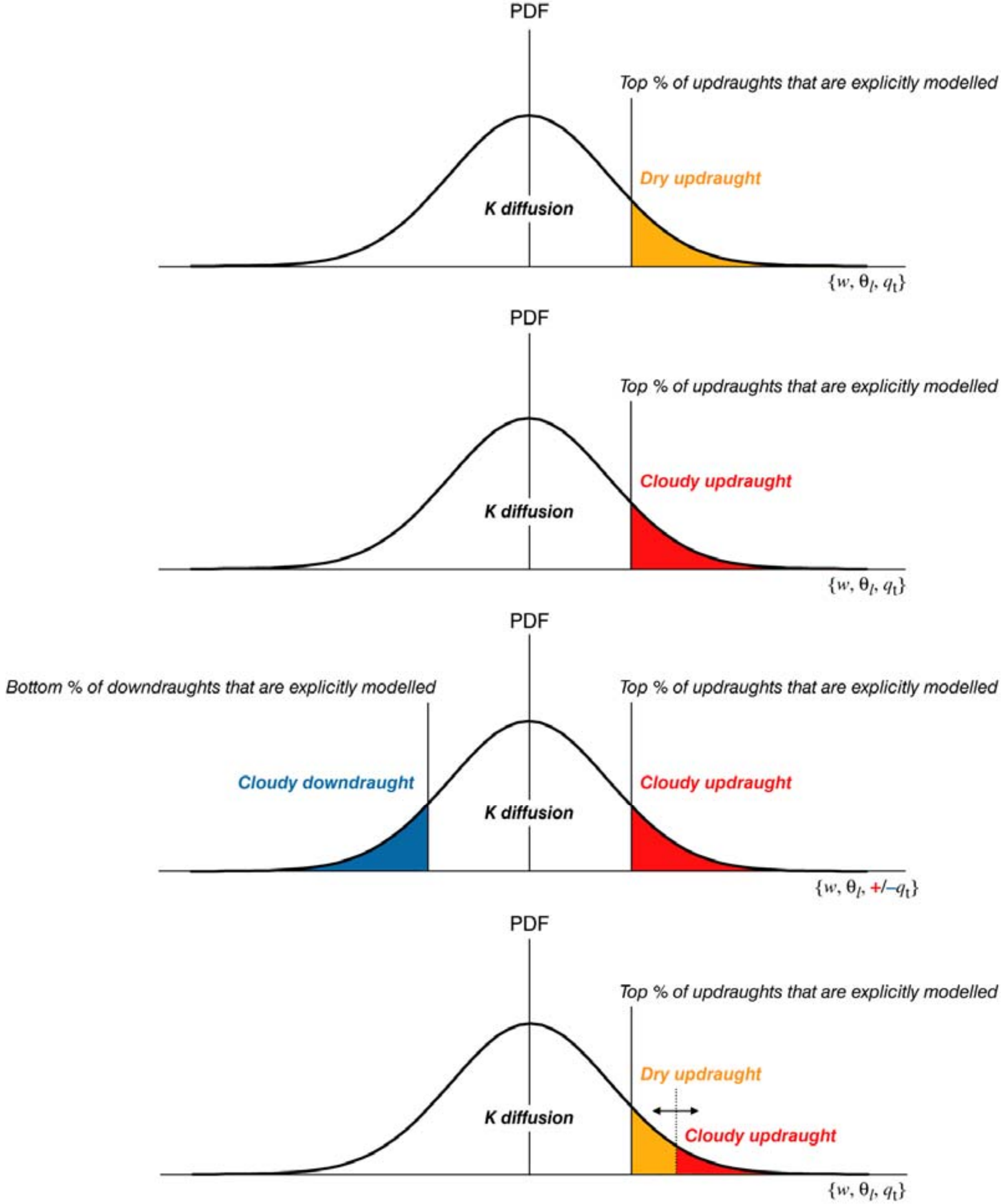
$$\frac{\partial \phi_u}{\partial z} = \frac{1}{\tau w_u}\left(\phi_u - \overline{\phi}\right)$$

$$\boxed{\varepsilon_u = \frac{1}{\tau w_u}}$$



(Neggers et al., JAS, 2002)

parcel initialization



DUALM Concepts 2: moist convective inhibition to parameterize the cumulus updraft area fraction

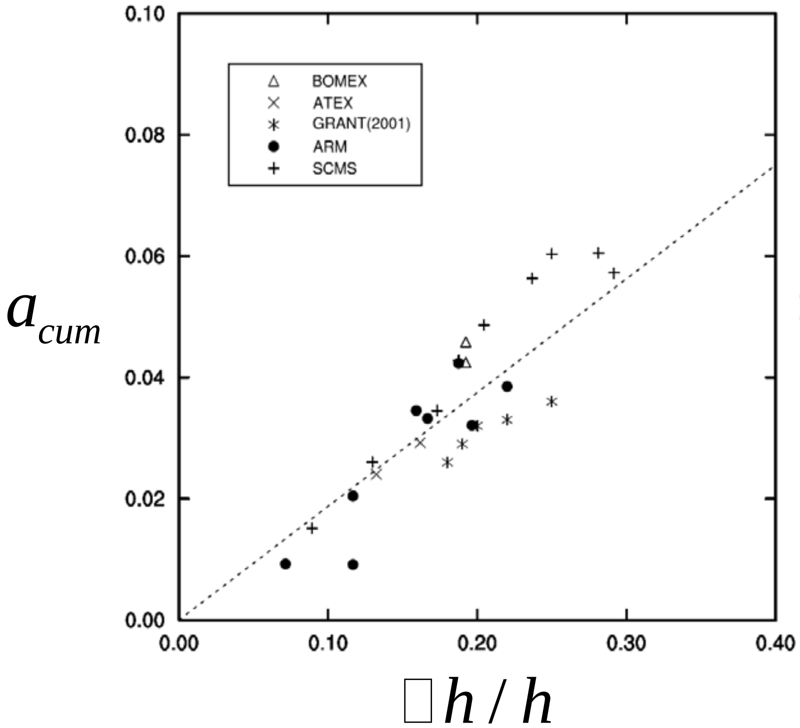
Cloud base transition layer selects strongest parcel from PDF of updrafts. (Neggers, Stevens, Neelin, 1997)

$$a_{cum} = \left(\frac{\Delta h}{h}\right)\frac{1}{2p+1}$$

$$\Delta h \sim \frac{w_*^{2}}{\frac{g}{\theta_0}\Delta\theta_v}$$

Δh - transition layer depth
h - mixed layer depth
p - Beta-PDF shape parameter
$\Delta\theta_v$ - transition layer inversion

LES data

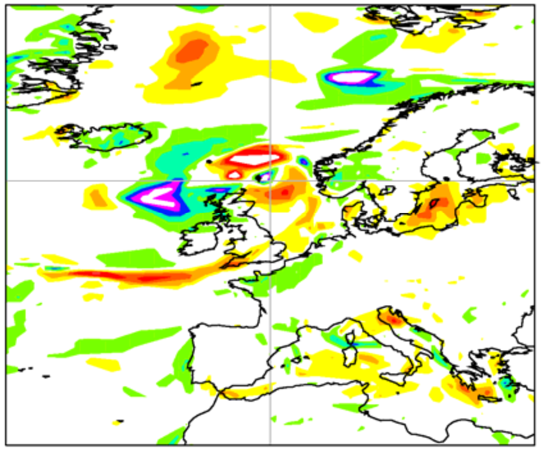


Extra-Tropical Cyclones

2008012900+60h

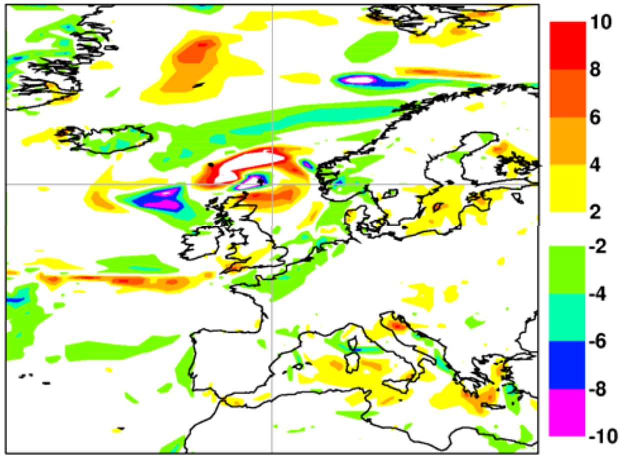
uv10bias CY33R1

0hPa bias 10windspeed [m] 20080129-20080129 60h f3ov-0001 nfld:1
mnNH=0.018247 mnTR=0.00955747 mnSH=-0.132945 rmsGL=1.68503



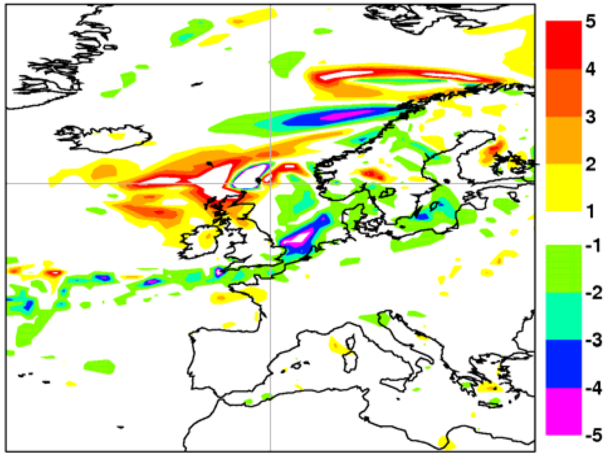
uv10bias DUALM

0hPa bias 10windspeed [m] 20080129-20080129 60h f6si-0001 nfld:1
mnNH=0.023173 mnTR=-0.0278561 mnSH=-0.248215 rmsGL=1.71299



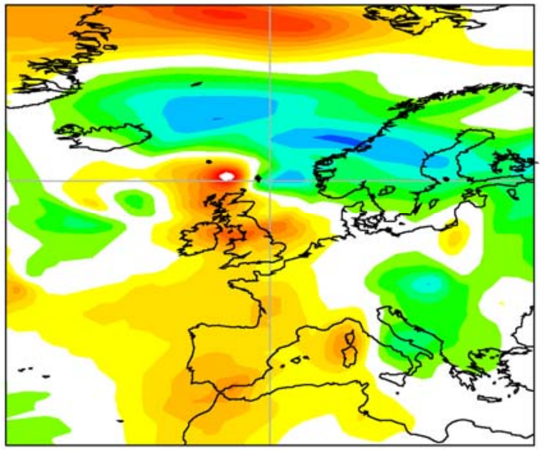
uv10 DUALM-CY33R1

0hPa bias 10windspeed [m] 20080129-20080129 60h f6si-f3ov nfld:1
mnNH=0.00492701 mnTR=-0.0374126 mnSH=-0.115269 rmsGL=0.756265



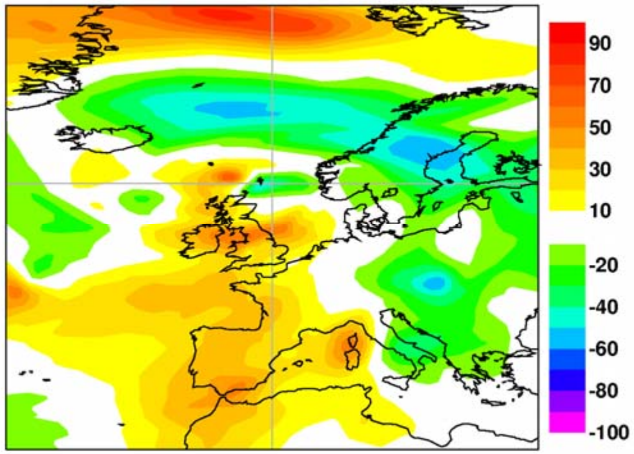
Z500bias CY33R1

500hPa bias Height [m] 20080129-20080129 60h f3ov-0001 nfld:1
mnNH=-0.720078 mnTR=-4.14303 mnSH=1.68947 rmsGL=15.9355



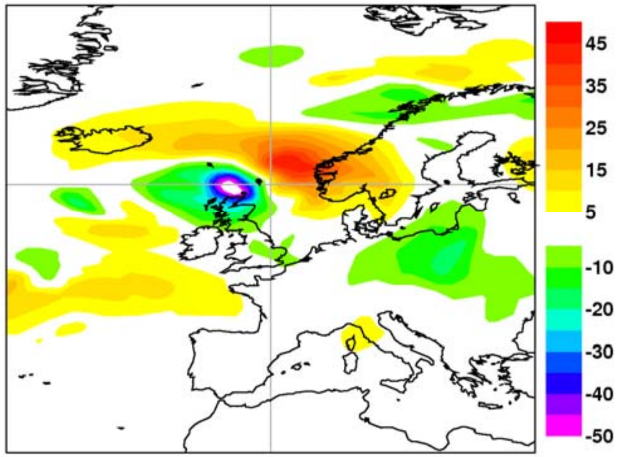
Z500bias DUALM

500hPa bias Height [m] 20080129-20080129 60h f6si-0001 nfld:1
mnNH=-1.40335 mnTR=-4.62248 mnSH=0.468554 rmsGL=16.37



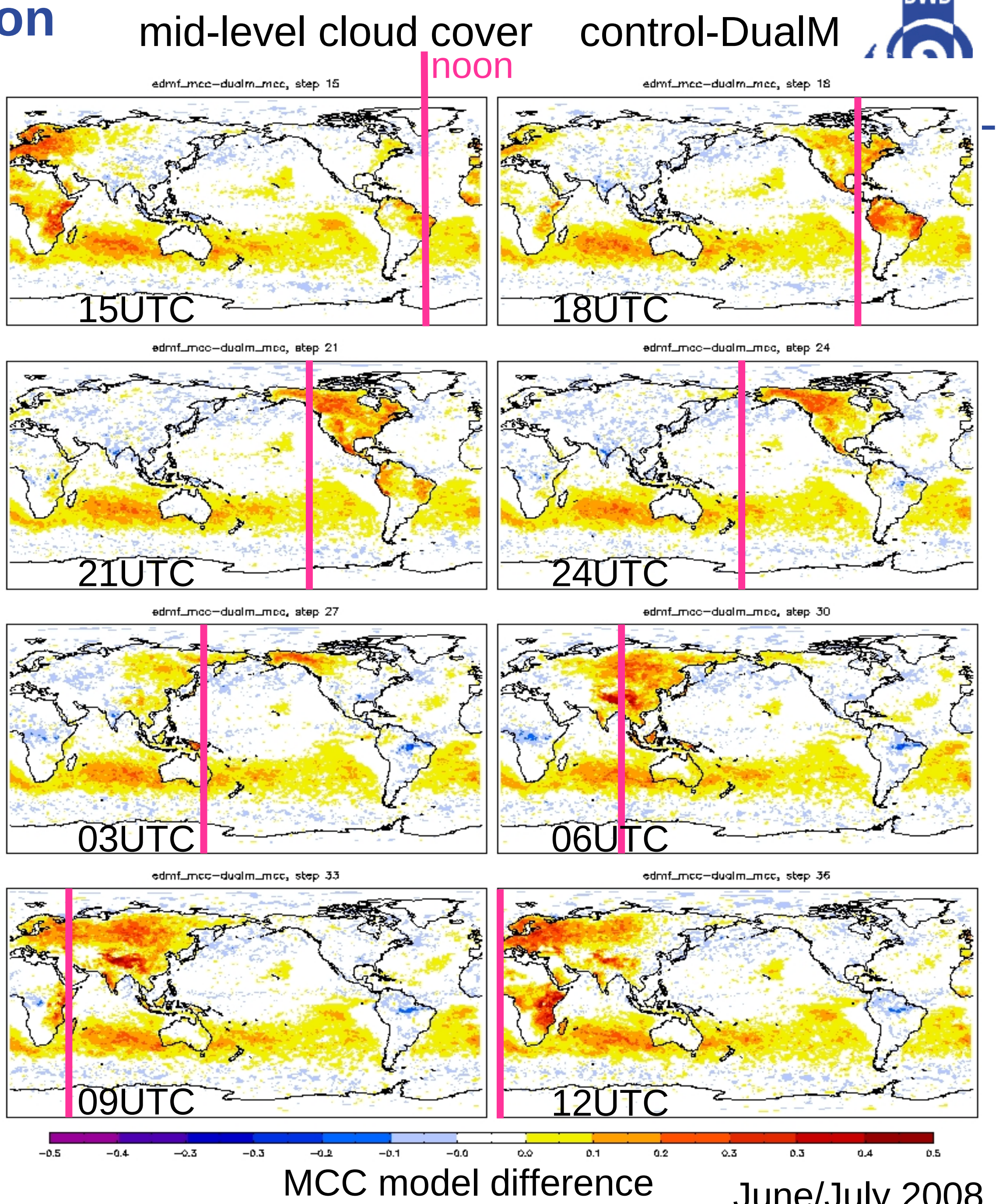
Z500 DUALM-CY33R1

500hPa bias Height [m] 20080129-20080129 60h f6si-f3ov nfld:1
mnNH=-0.683274 mnTR=-0.479458 mnSH=-1.22092 rmsGL=3.93078



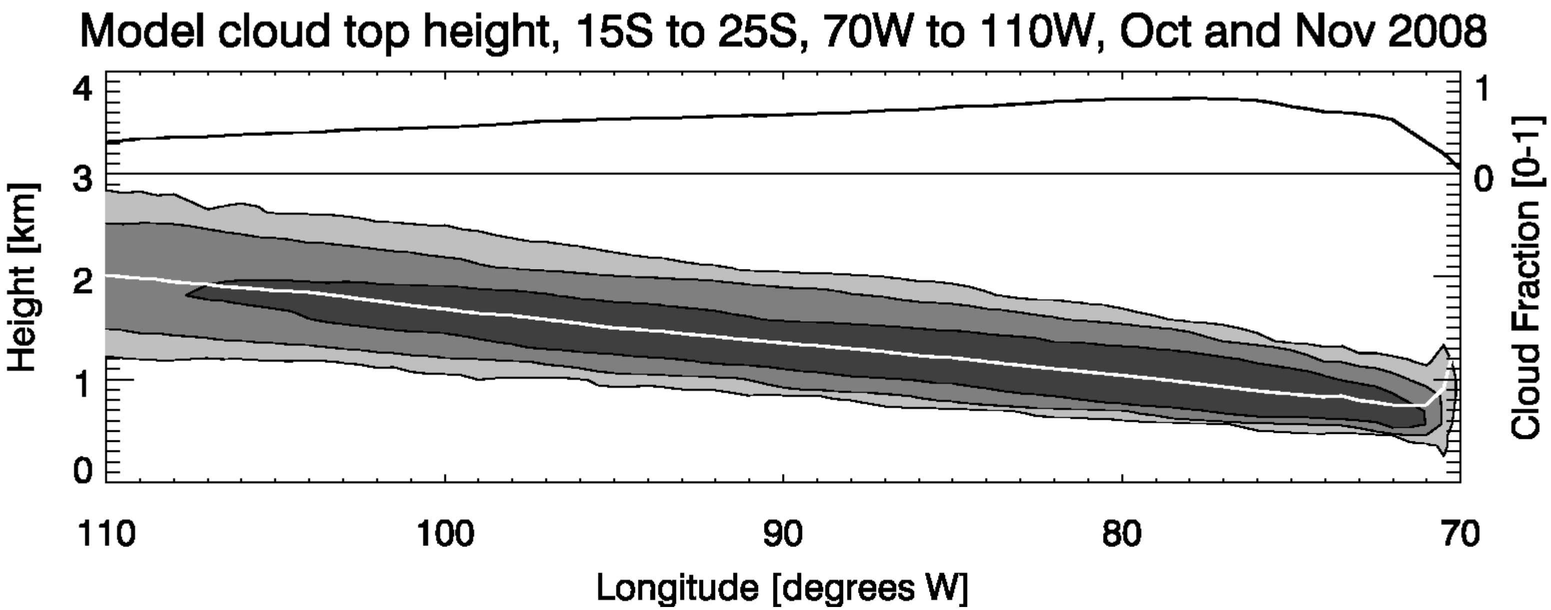
Problem: lack of afternoon cloudiness over land.

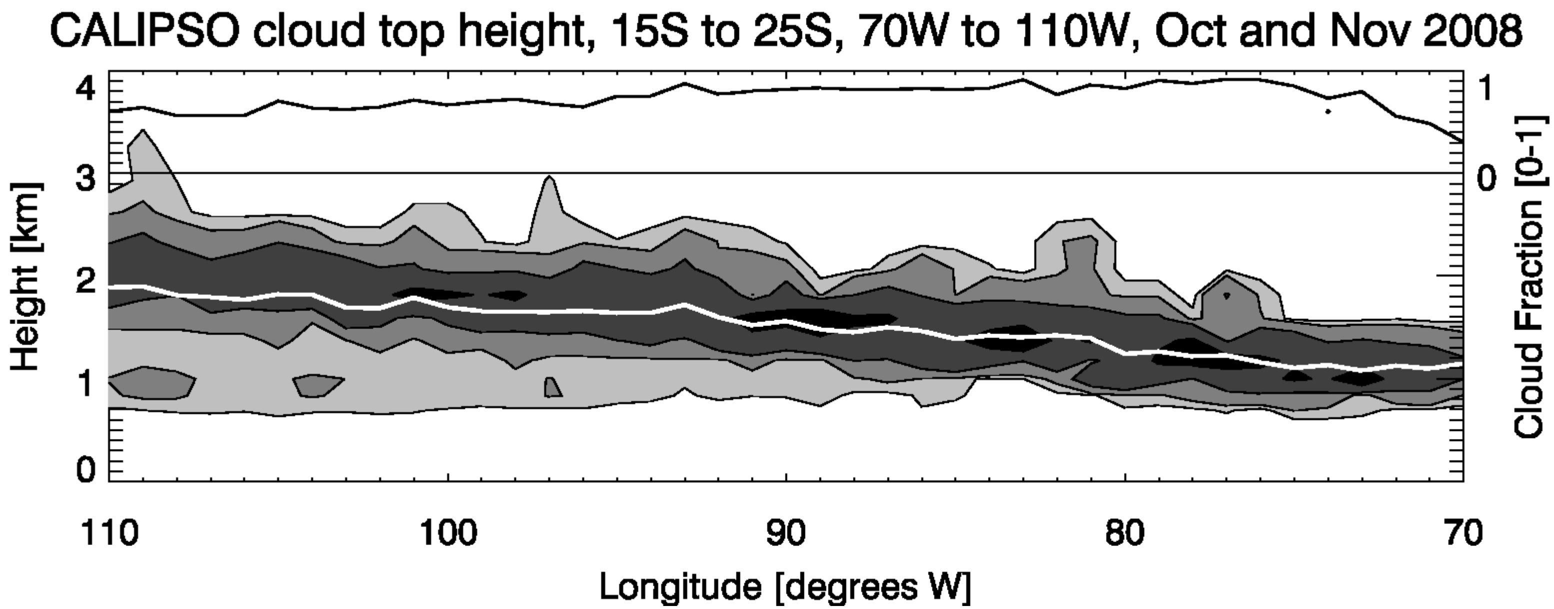
- Immediately evident in 3D run
- Signal in cloud cover, surf. SW, 2m temperature
- around 3pm local time



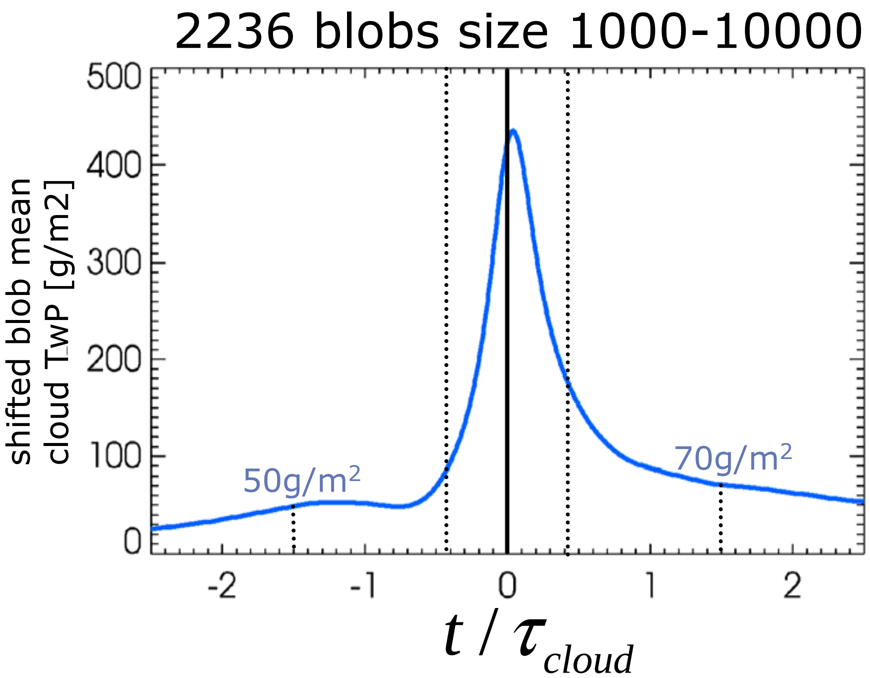
June/July 2008

VOCALS: Cloud top height: Model vs CALIPSO





BOMEX LES   cloud blobs



Time, lagged around blob center, normalized by blob time scale

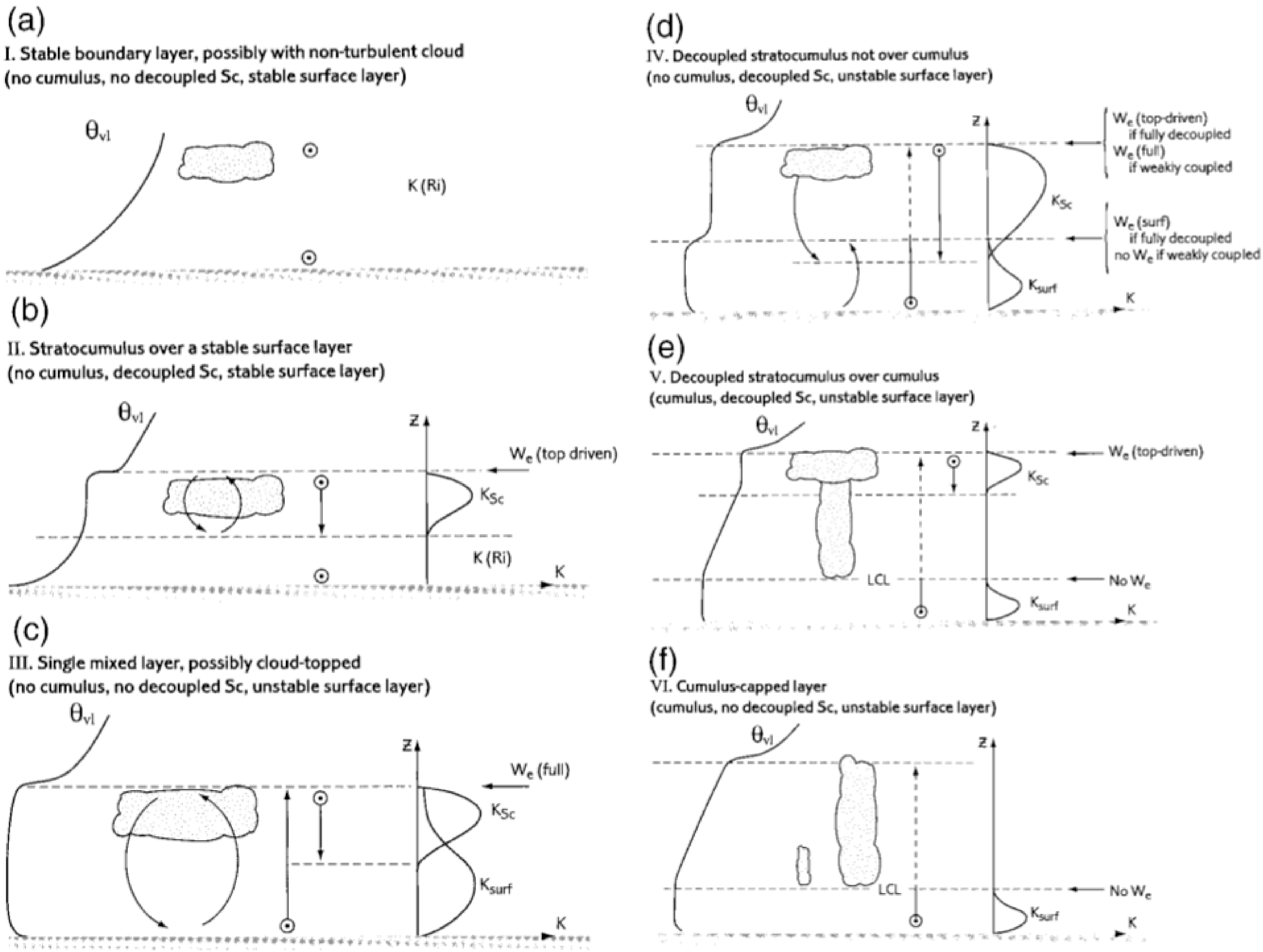
blobs size 1000: $(250\text{m})^2 \cdot 300\text{s}$

$$\sigma_{WVP} = 890\text{g/m}^2$$

Boundary layer framework:
ECMWF vs MetOffice

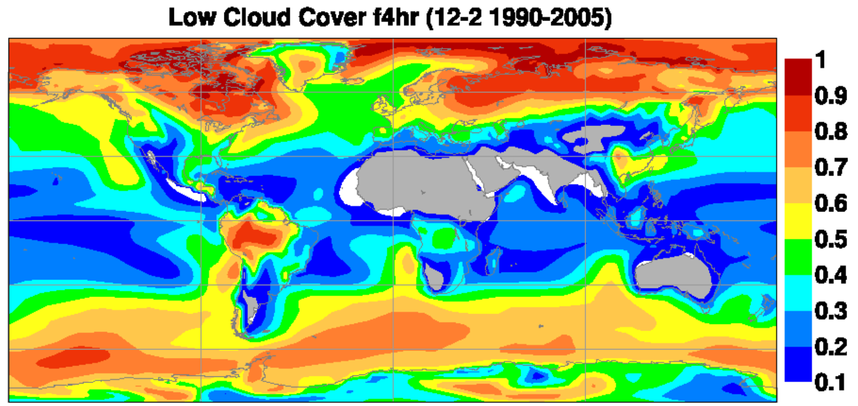
UKMO boundary layer approach

Lock et al 2001

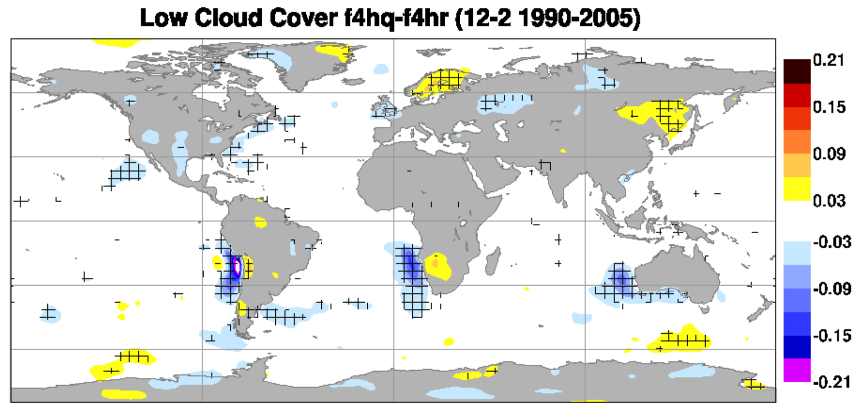


Low Cloud Cover

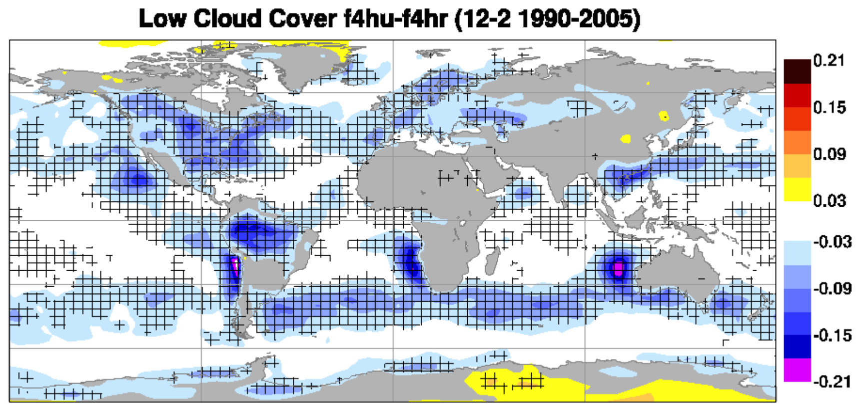
ECMWF model



no stratus

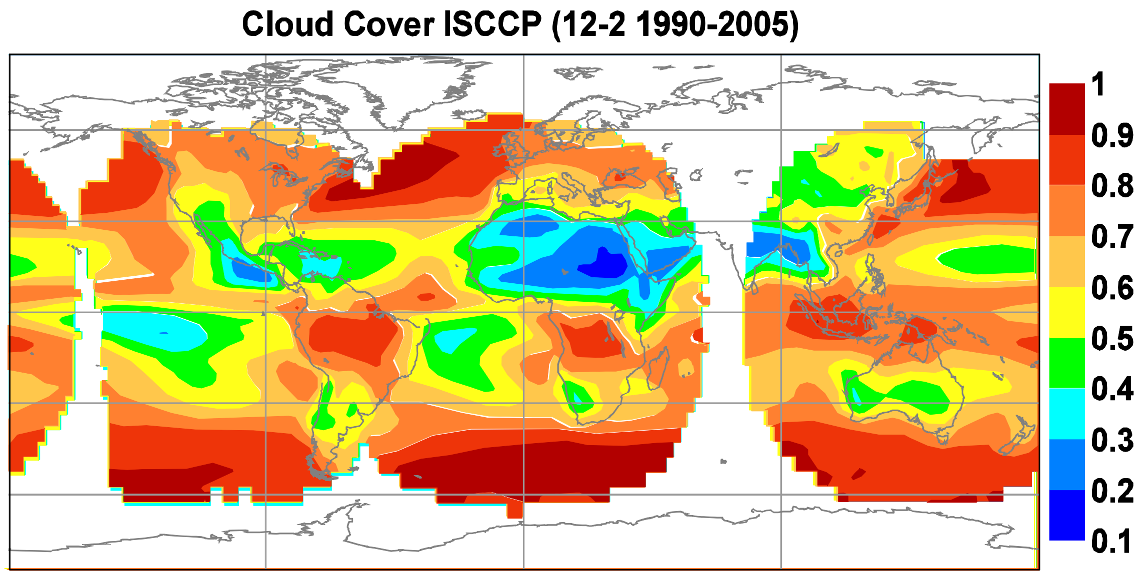


Louis K

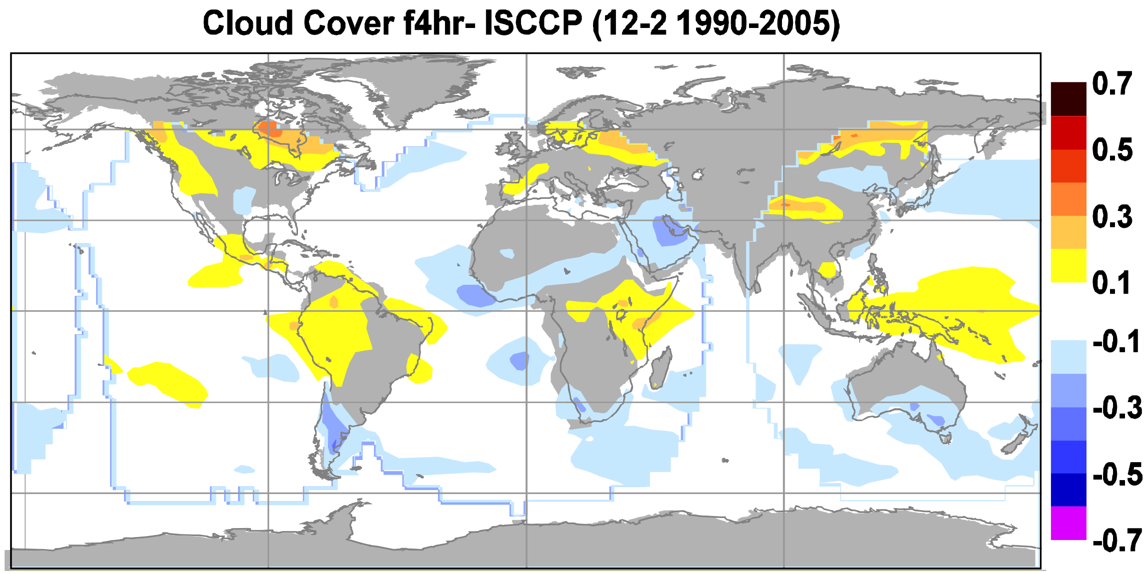


total cloud cover: JJA 1990-2005 climate

ISCCP



model bias

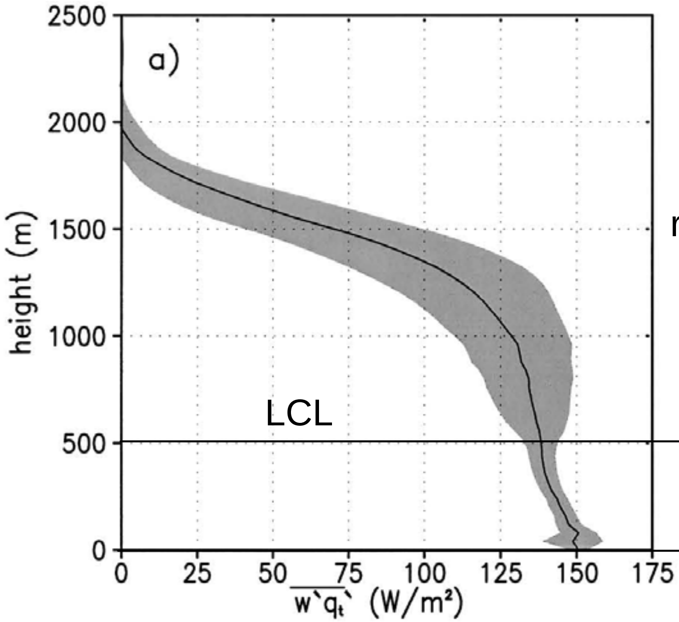


M closure: Tiedtke 1989

Tiedtke, 1989:

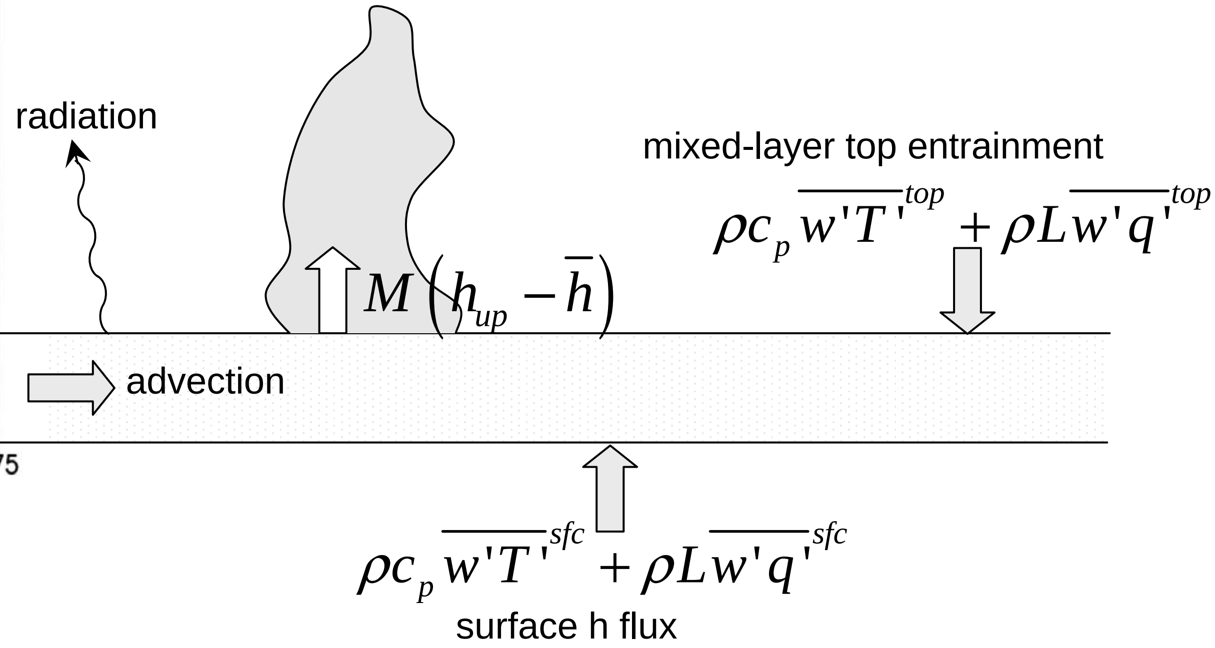
“Trade wind cumuli seem to be effectively controlled by sub-cloud layer turbulence.

The net upward moisture flux at cloud base level is nearly equal to the turbulent moisture flux at the surface.”

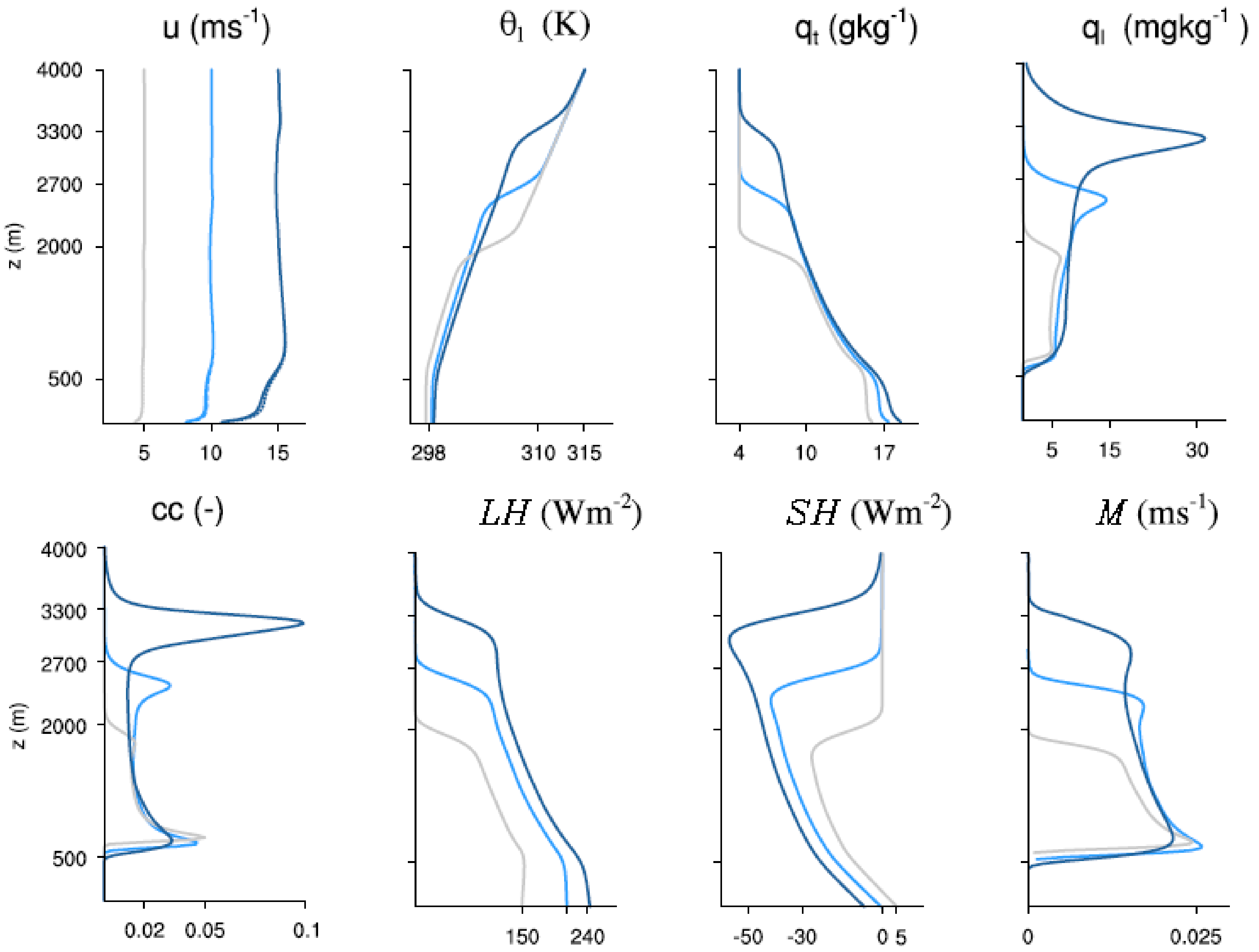


Siebesma et al. 2003:

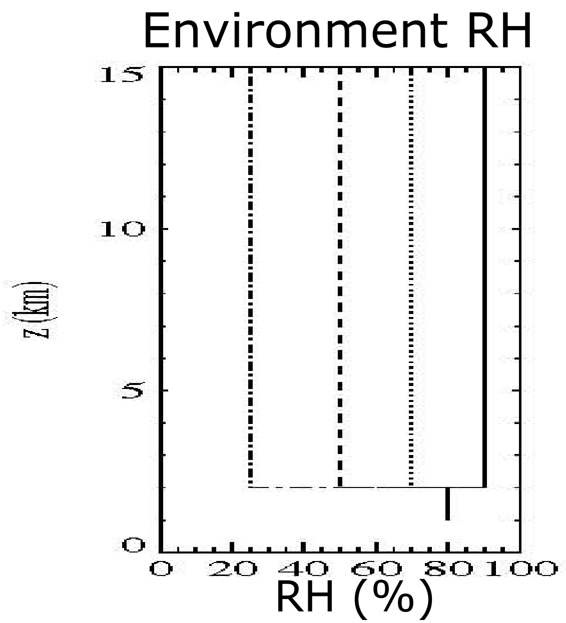
BOMEX LES

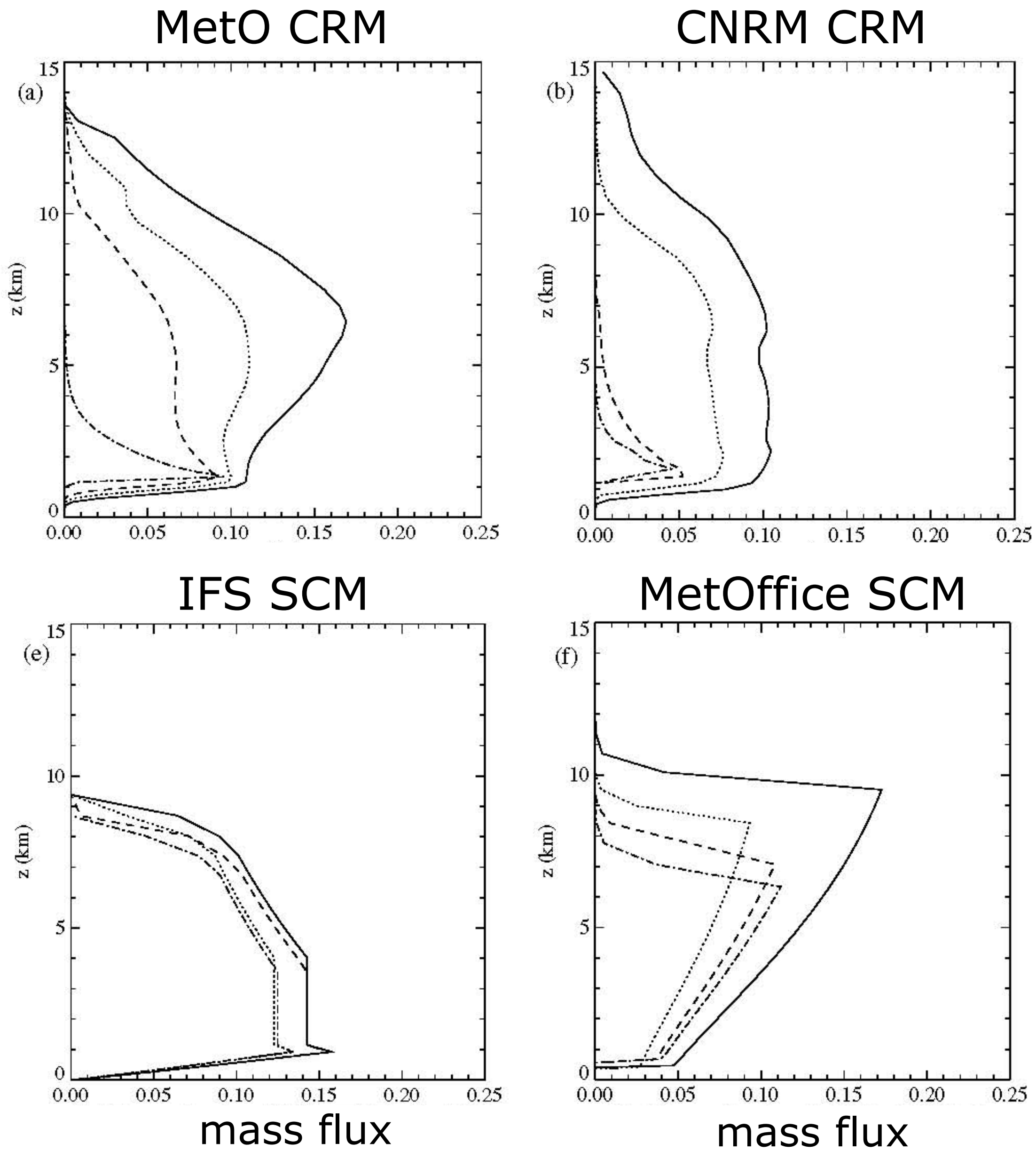


Louise Nuijens: LES of cumulus, influence of wind speed



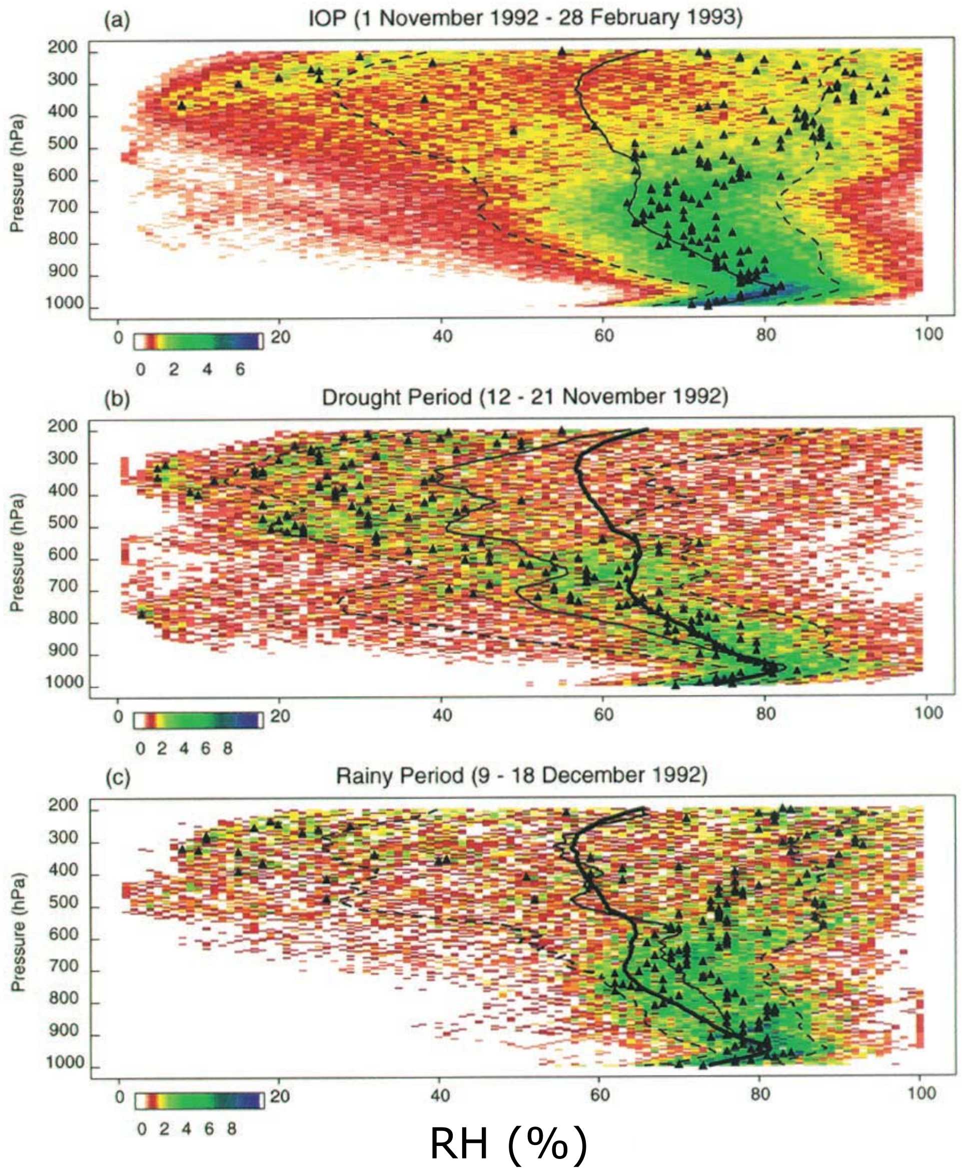
Derbyshire et al 2004





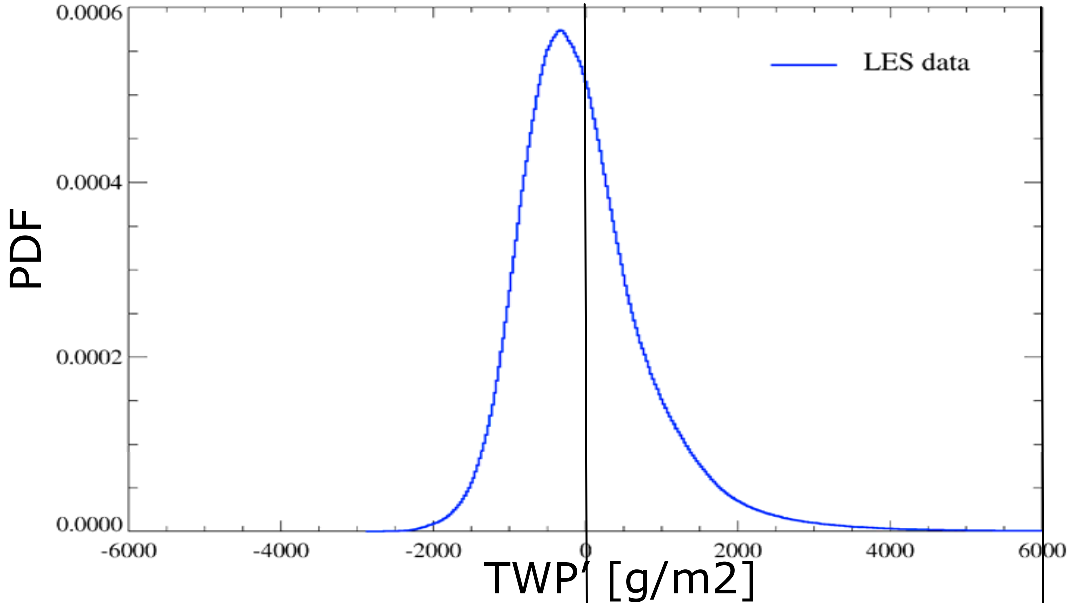
- small ε to get high cloud top
- large ε to get large RH sensitivity

Brown, Zhang 1997: RH during TOGA/COARE



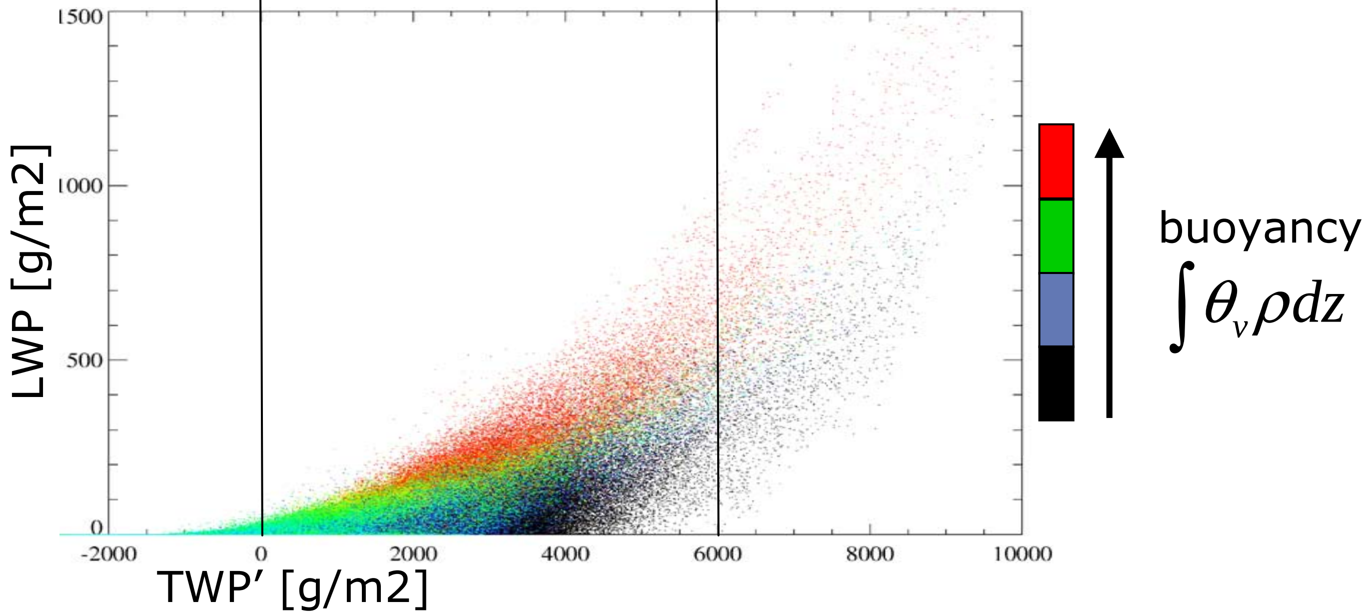
Moist low levels (~800hPa) favour deep convection

BOMEX LES convective moist selection?



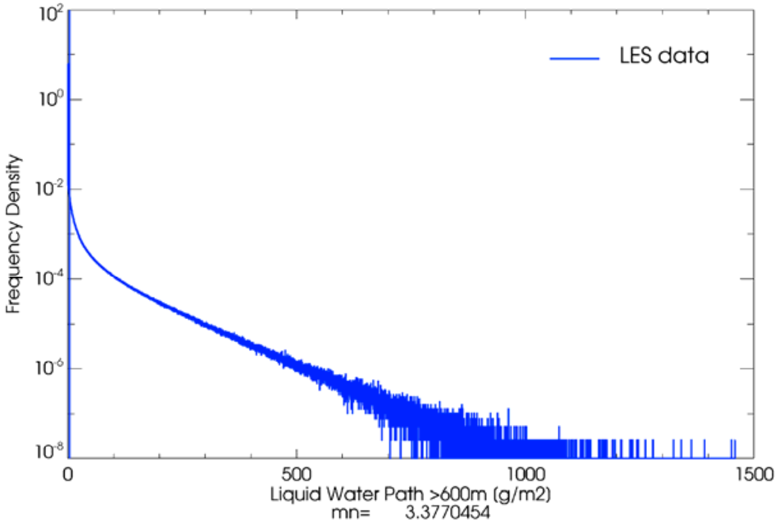
LES:

no shear
dx=*dy*=25m, *dt*=30s
duration: 20h
12.8km x 12.8km

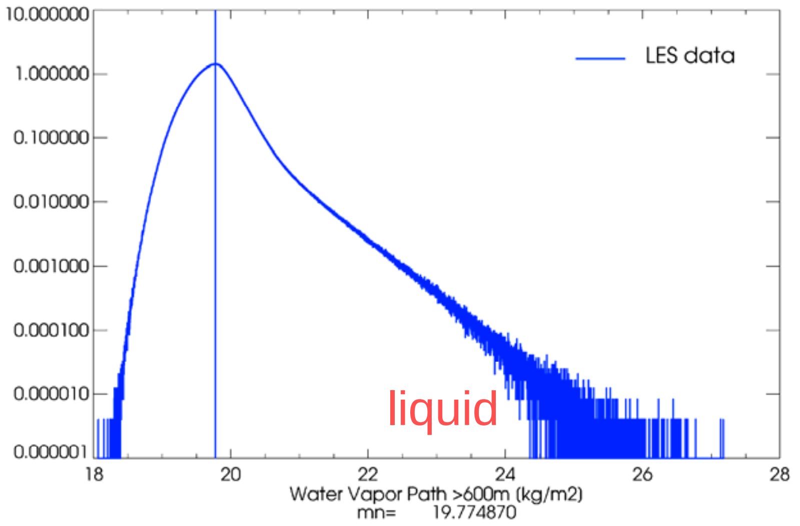


PDF

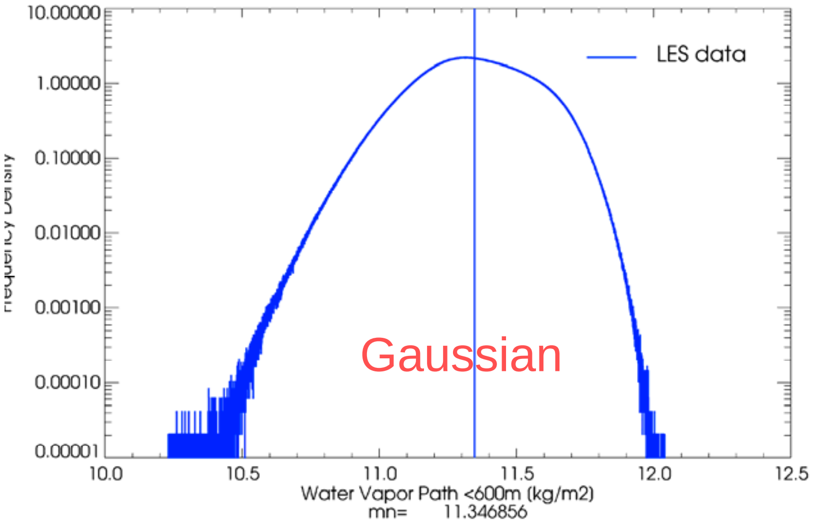
LWP above 600m



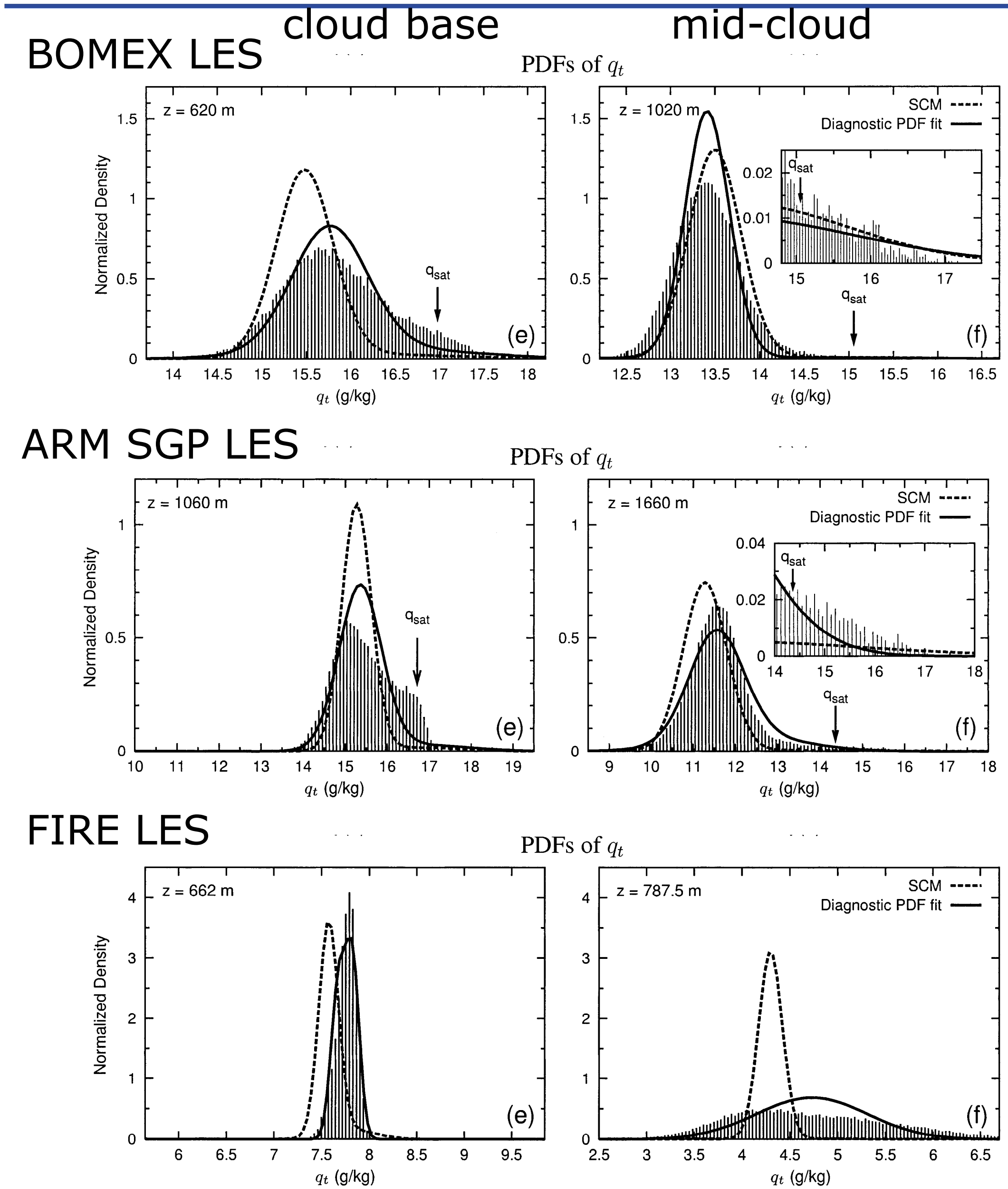
TWP above 600m



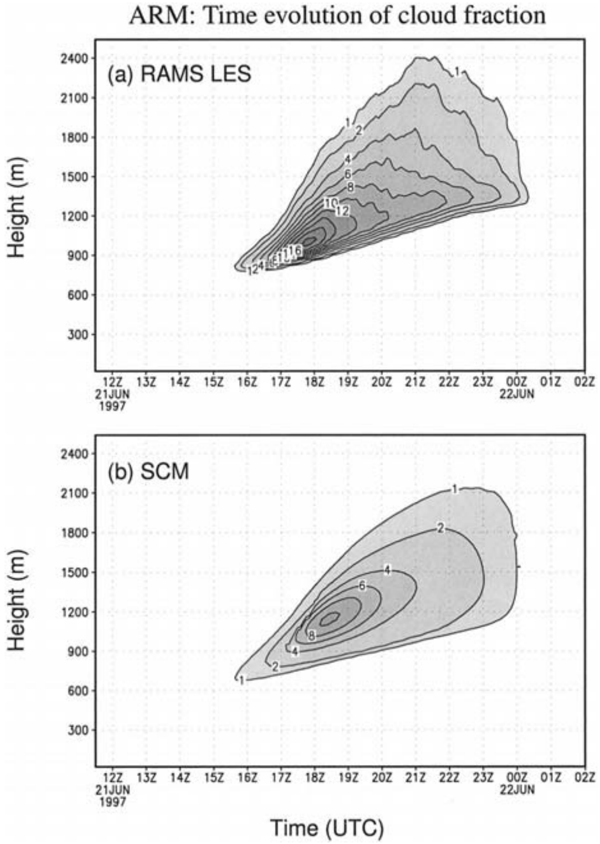
TWP below 600m



clouds: highly skewed PDF near cloud base



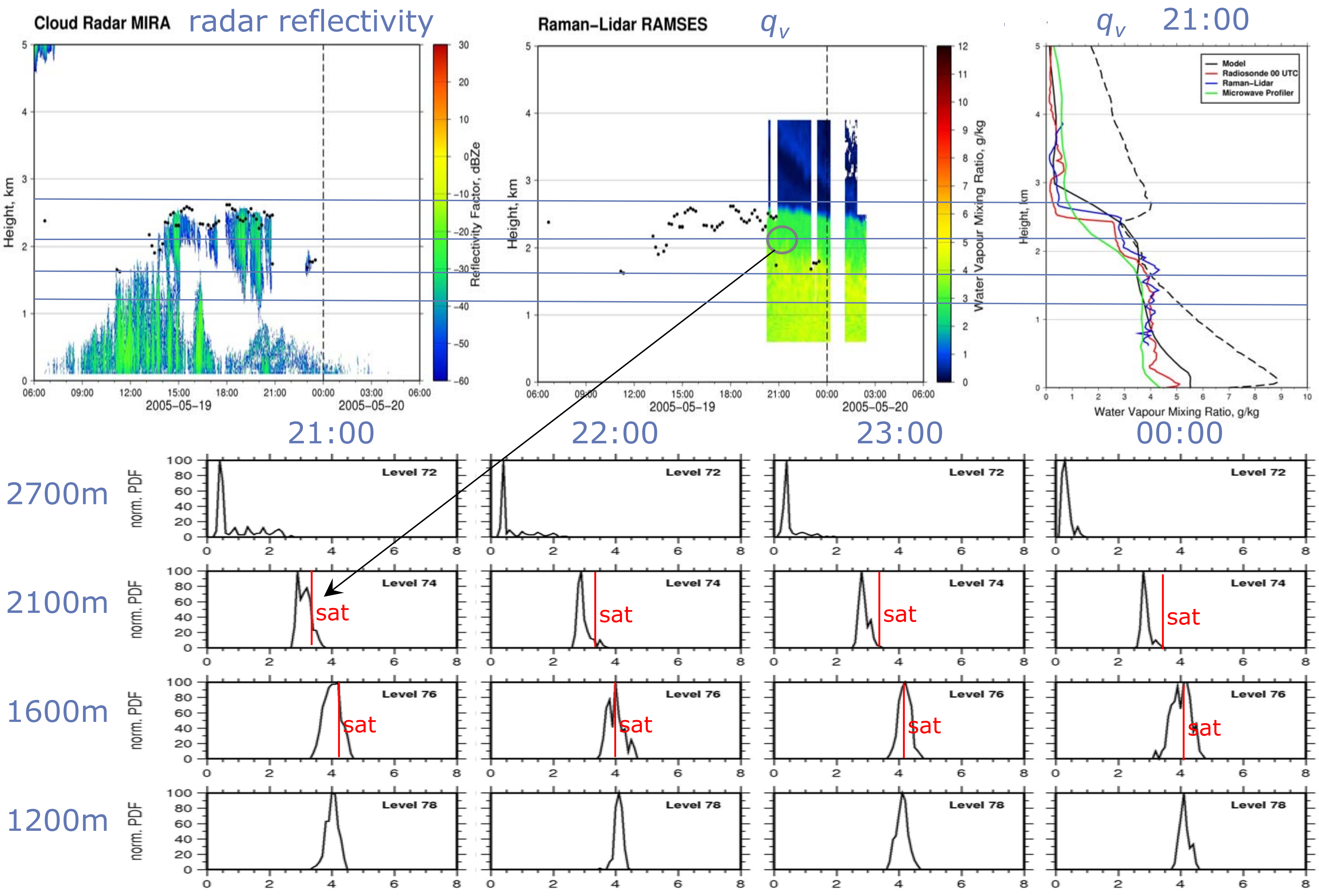
ARM SGP



Golaz et al 2002

Lindenberg Summer 2008 05 19: drizzling cumulus

Franz Berger (with Görsdorf and Reichardt)



Convective premoistening: Some thoughts

- conclusions from LES analysis
  - bigger clouds arise from more moist troposphere
  - bigger clouds add moisture in previous cloud layers („pre-moistening“)

- application to convection parameterisation
  - entrainment of moist patch
  - „direct“ entrainment values based on Romps (2010) most appropriate
  - land deep convective diurnal cycle delayed by period of shallow convection pre-moistening mid-levels
  - convection parameterization based on PDFs will turn off at high resolution because variance goes to 0

Neggers, Heus, Siebesma

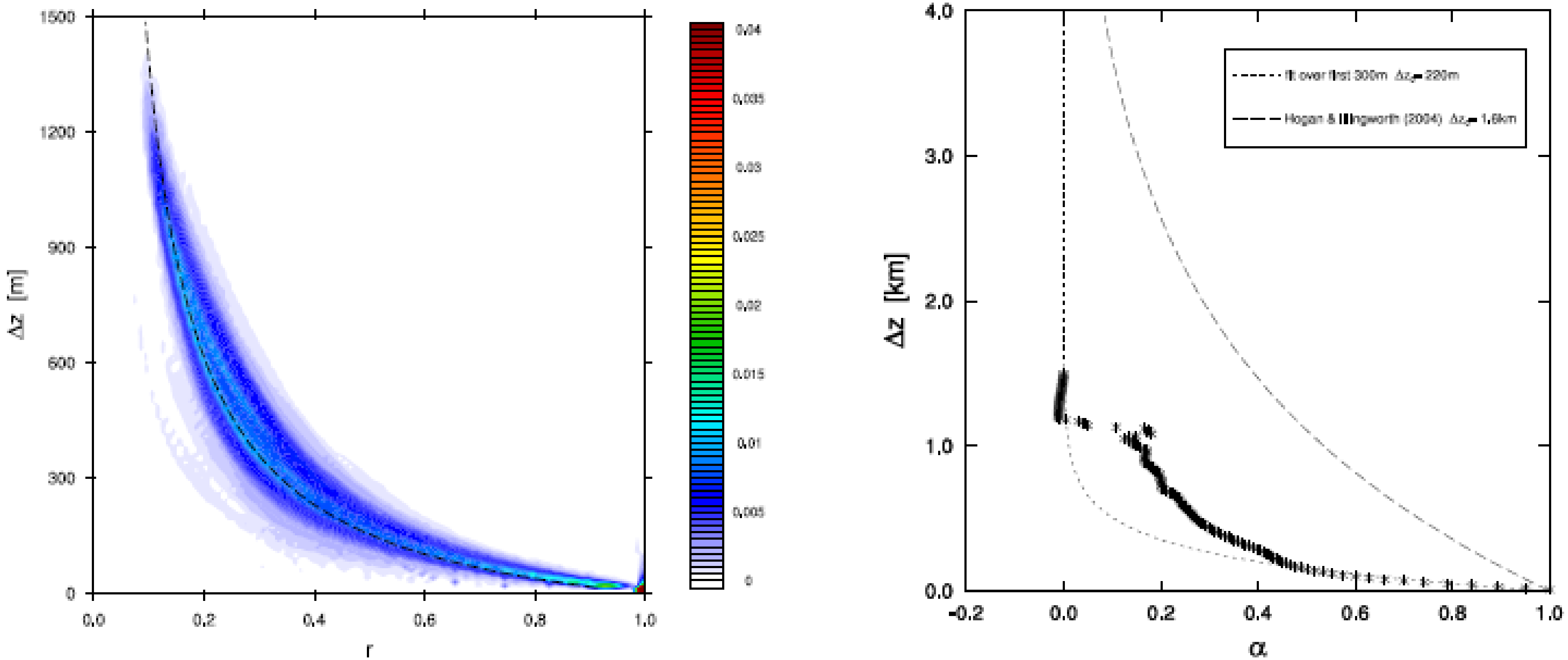
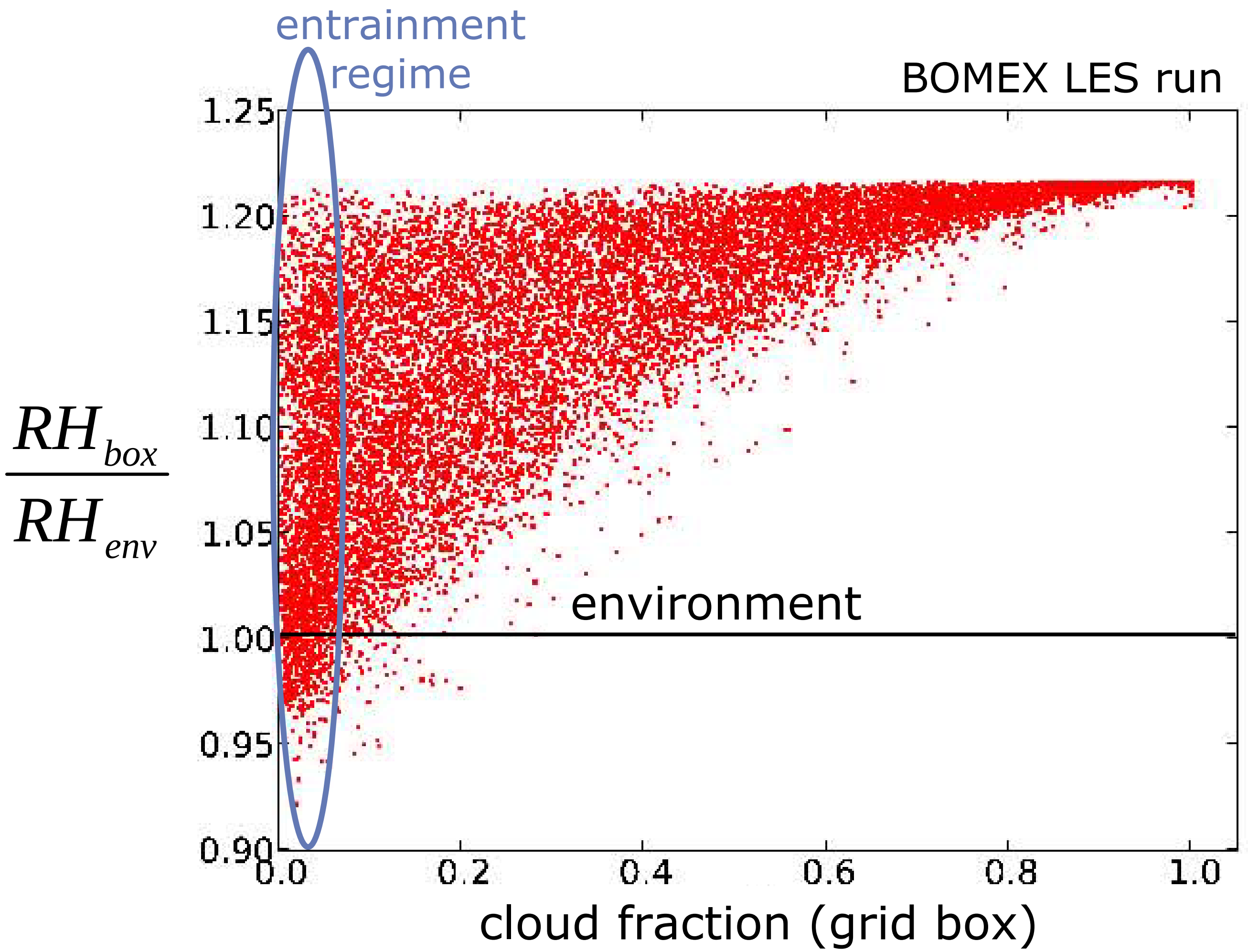


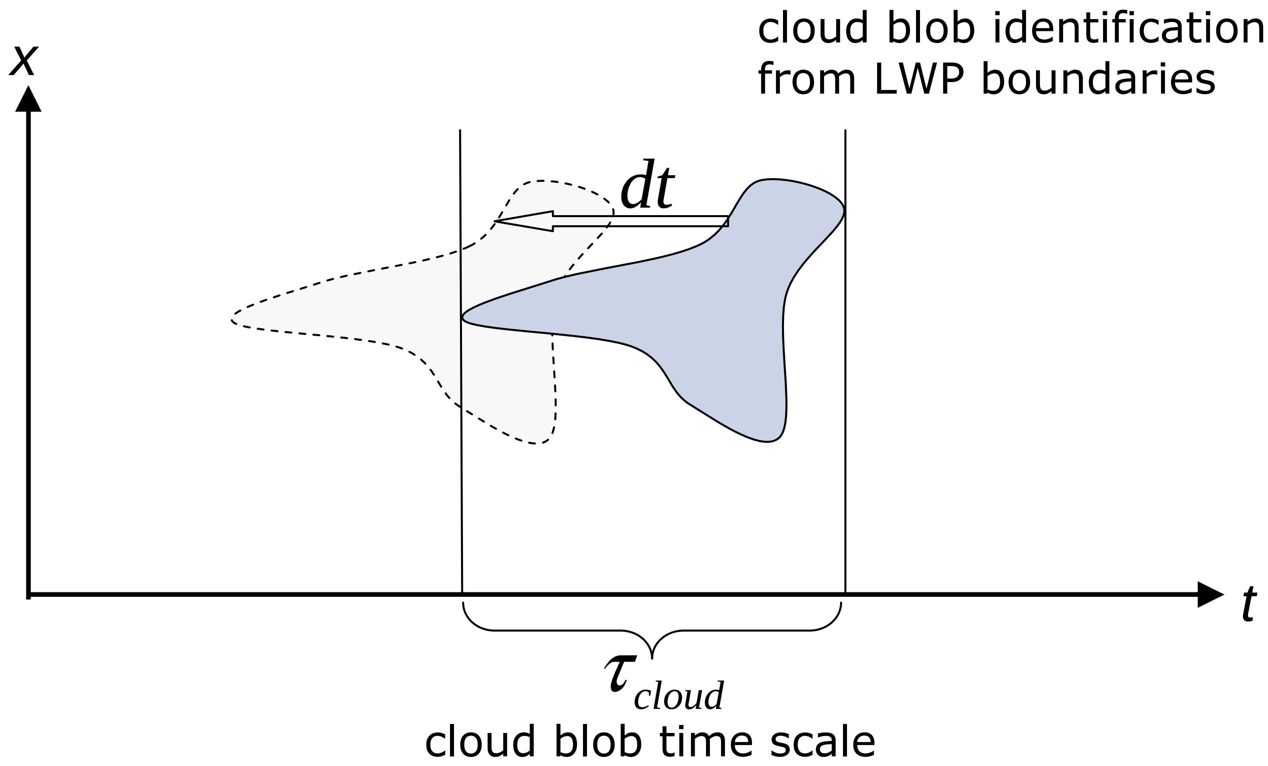
Figure 3. Two visualizations of overlap statistics for the BOMEX case. a) The probability density function P of the cloud overlap ratio r as a function of the layer thickness Δz. The contoured field represents $P\Delta h^{-1}\Delta r^{-1}$, with Δr and Δh the binning-sizes on the horizontal and vertical axes, respectively. The dashed line represents the least-squares fit of the function $r = (1 + \beta\Delta z)^{-1}$, as discussed in Section 4. b) The overlap parameter α as a function of separation distance Δz (asterisks). The dashed and dotted lines are discussed in the text.

Jarecka, Grabowski, Pawlowska, 2009



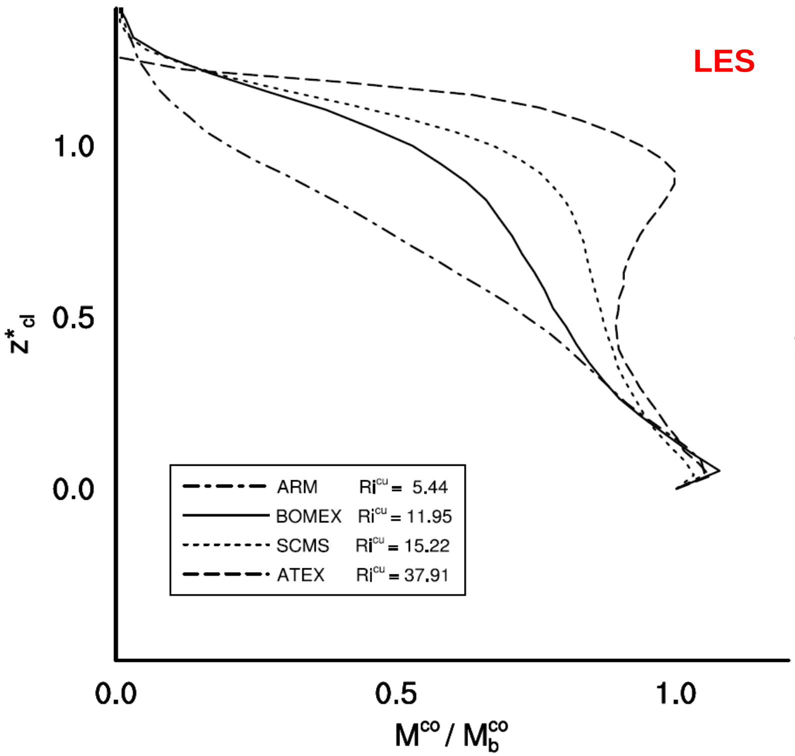
Entrained air is pre-moistened.

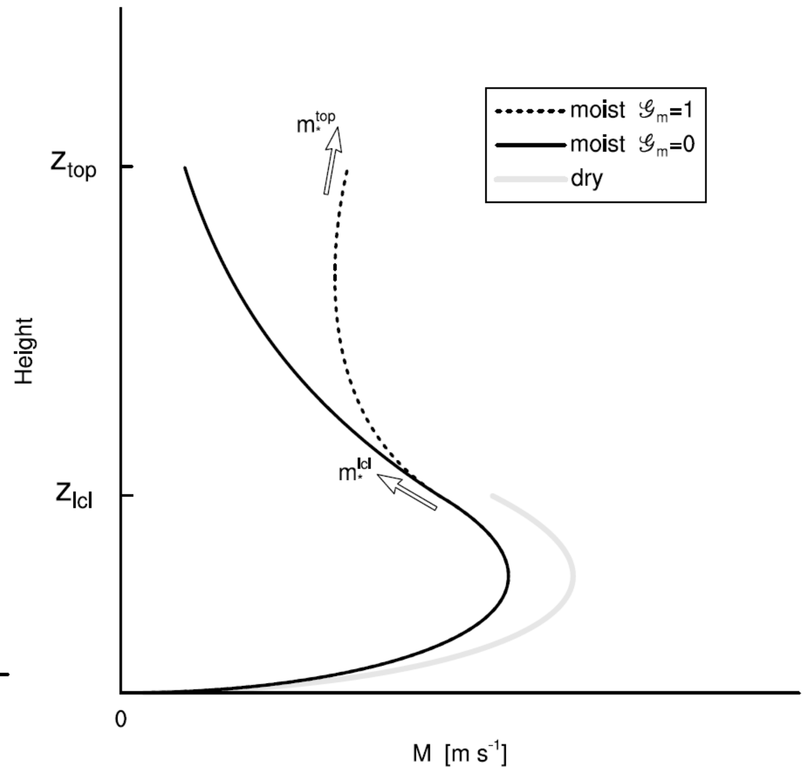
BOMEX LES cloud blobs



Concepts V:
adaptive vertical structure of mass flux

Dependence on relative stability of cumulus inversion for rising updrafts (as expressed by the bulk cumulus Richardson number):





$$\frac{1}{M_u}\frac{\partial M_u}{\partial z} = \varepsilon_u - \delta_u = f(\mathrm{Ri}^{\mathrm{cu}})$$

Instead of modelling entrainment and detrainment separately, their *difference* is parameterized.

Concepts VI:
cumulus top-entrainment efficiency

Problem: advective transport model works poorly at strong vertical gradients

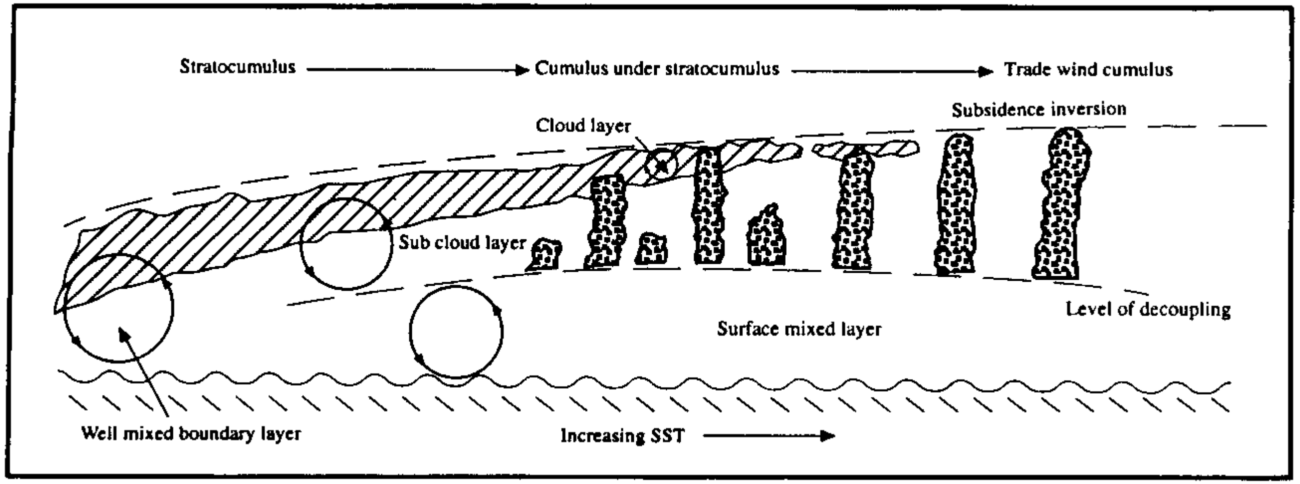


FIG. 4. A schematic of the transition from stratocumulus to trade wind cumulus.

$\overline{w'\phi'}$

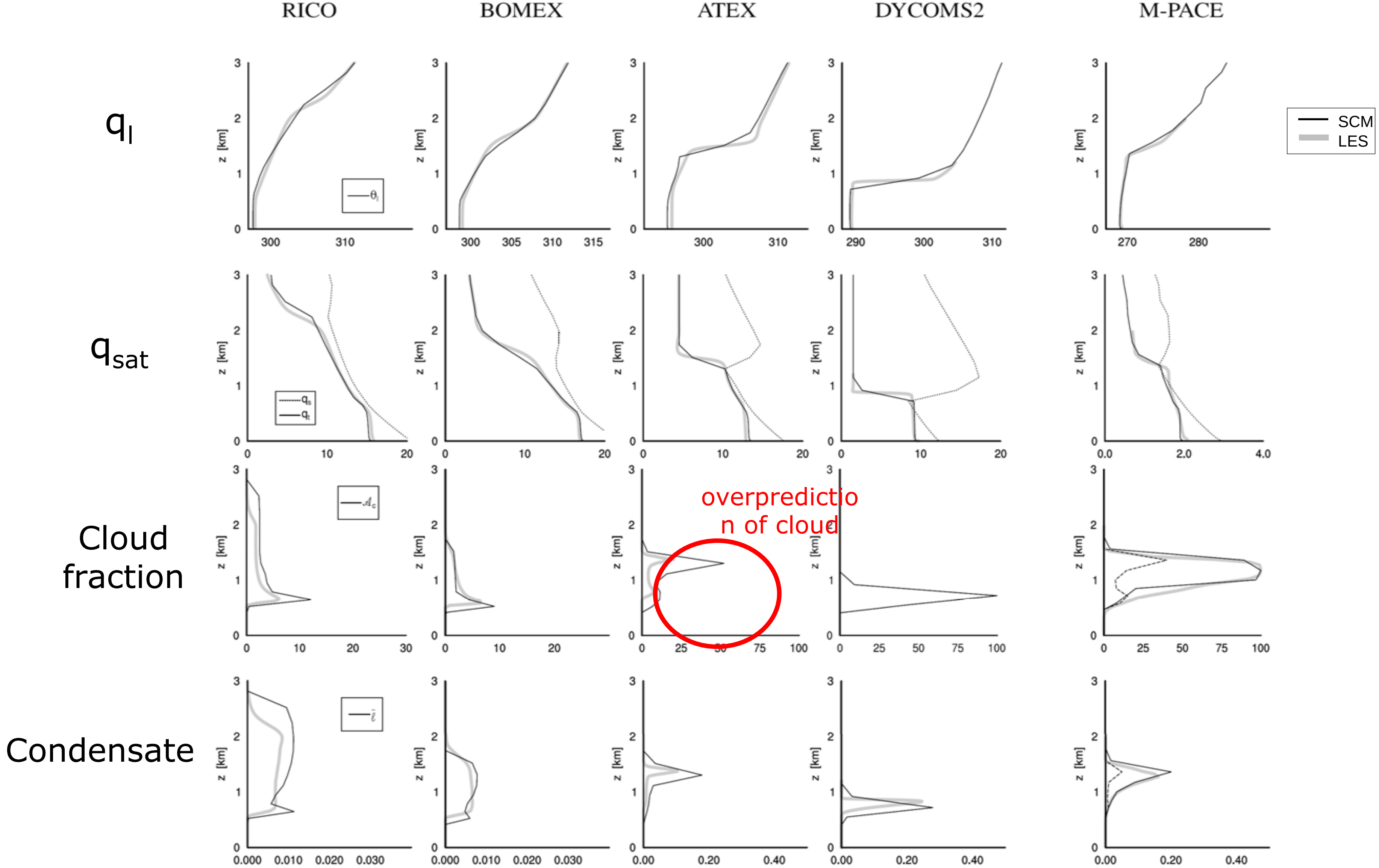
Idea: use the diffusive component of EDMF to represent *all* turbulent fluxes into the potentially strong inversion (avoiding mass flux transport in top layer):

$$\overline{w'\phi'} = w_e^{cu} \Delta\phi^{cu}$$

Make the efficiency of this entrainment process dependent on inversion stability (Wyant et al. 1997):

$$w_e^{cu} = A^{cu} \frac{\left\langle \overline{w'\theta_v'} \right\rangle^{cu}}{\Delta\theta_v^{cu}} \qquad A^{cu} = 0.4$$

DualM evaluation: SCM cases



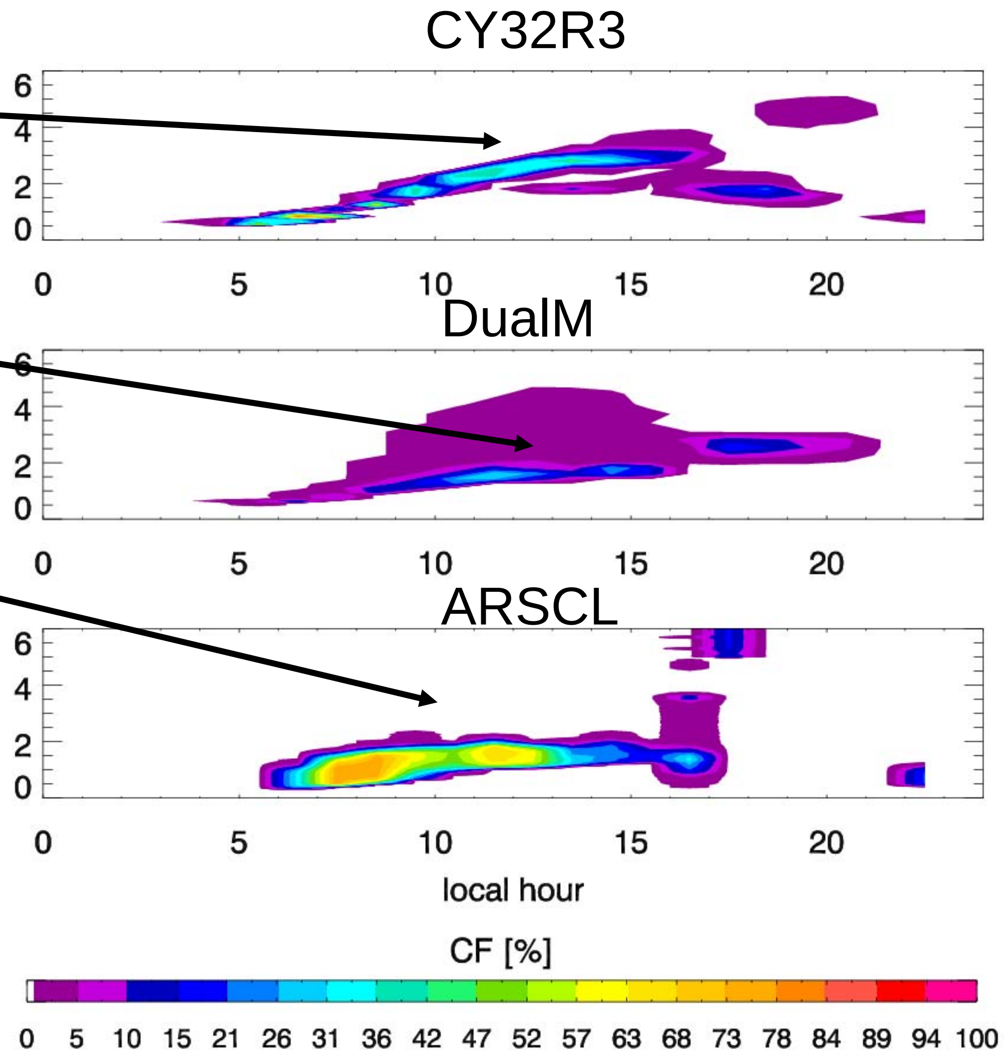
(additionally: ARM land cumulus case)

Is the DualM really missing “anvils”?

higher cloud fraction,
keeps going strong

cloud fraction drops
just after noon

neither one very good!

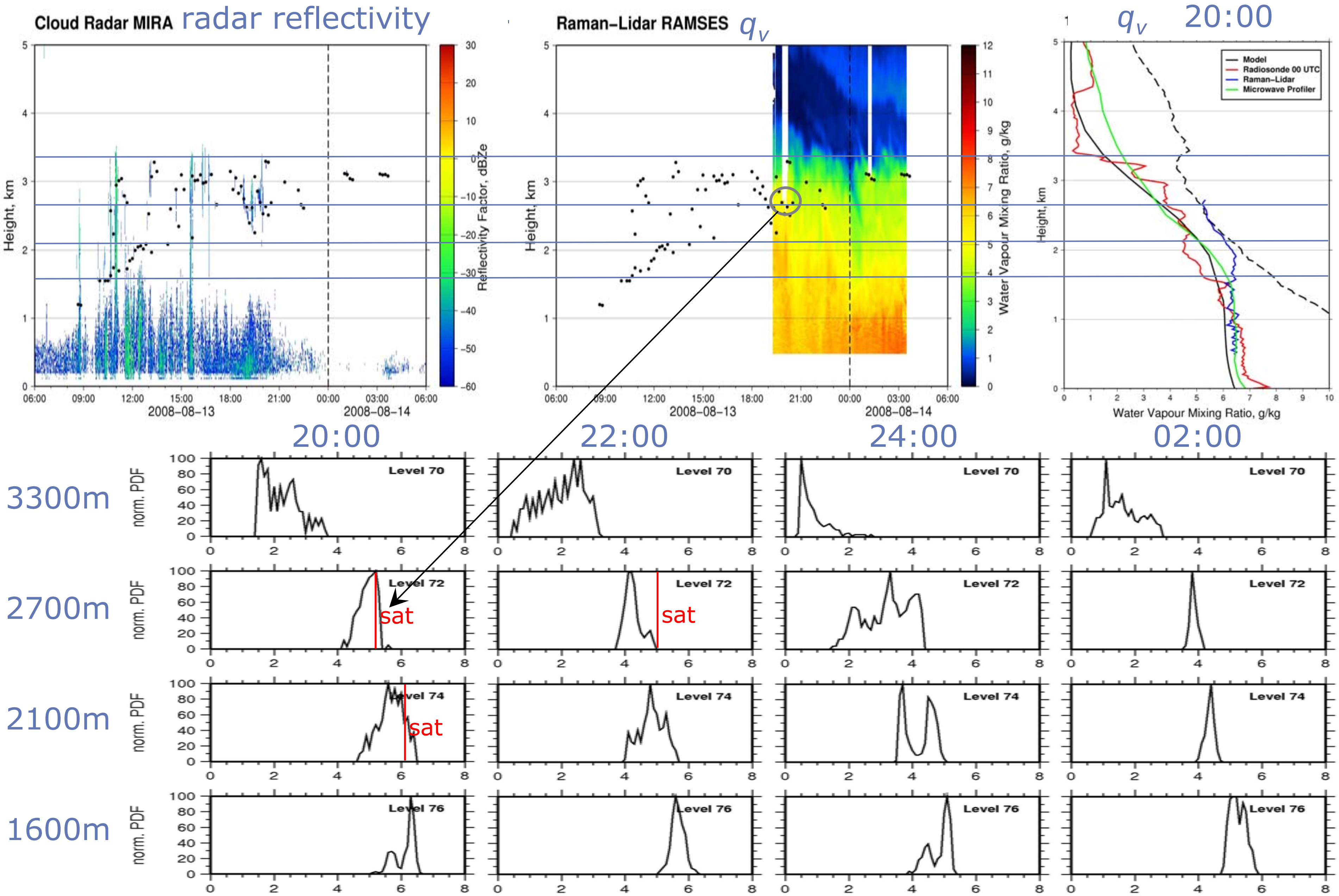


ARM, SGP

Maike Ahlgrimm

Lindenberg Summer 2008 08 13: fair weather cumulus

Franz Berger (with Görsdorf and Reichardt)



NCAR(U.Wash) boundary layer approach

Bretherton et al. 2004

Mass-flux:
all parcels that make it through LFC

Convective inhibition calculation□

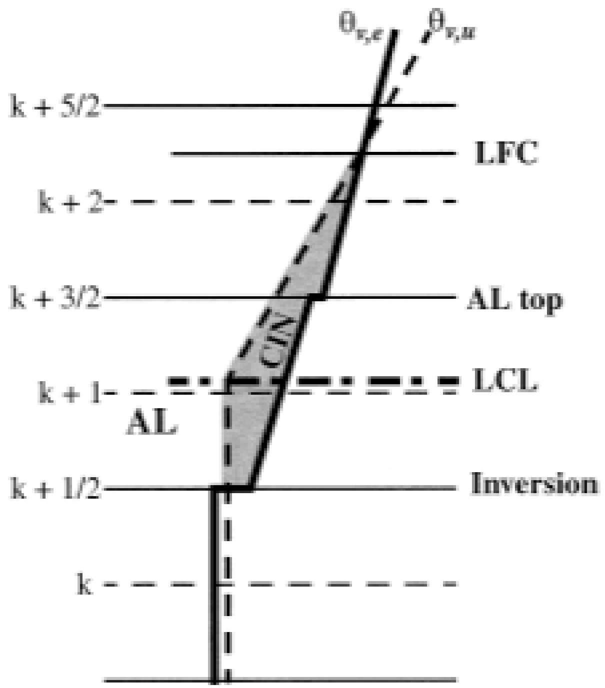


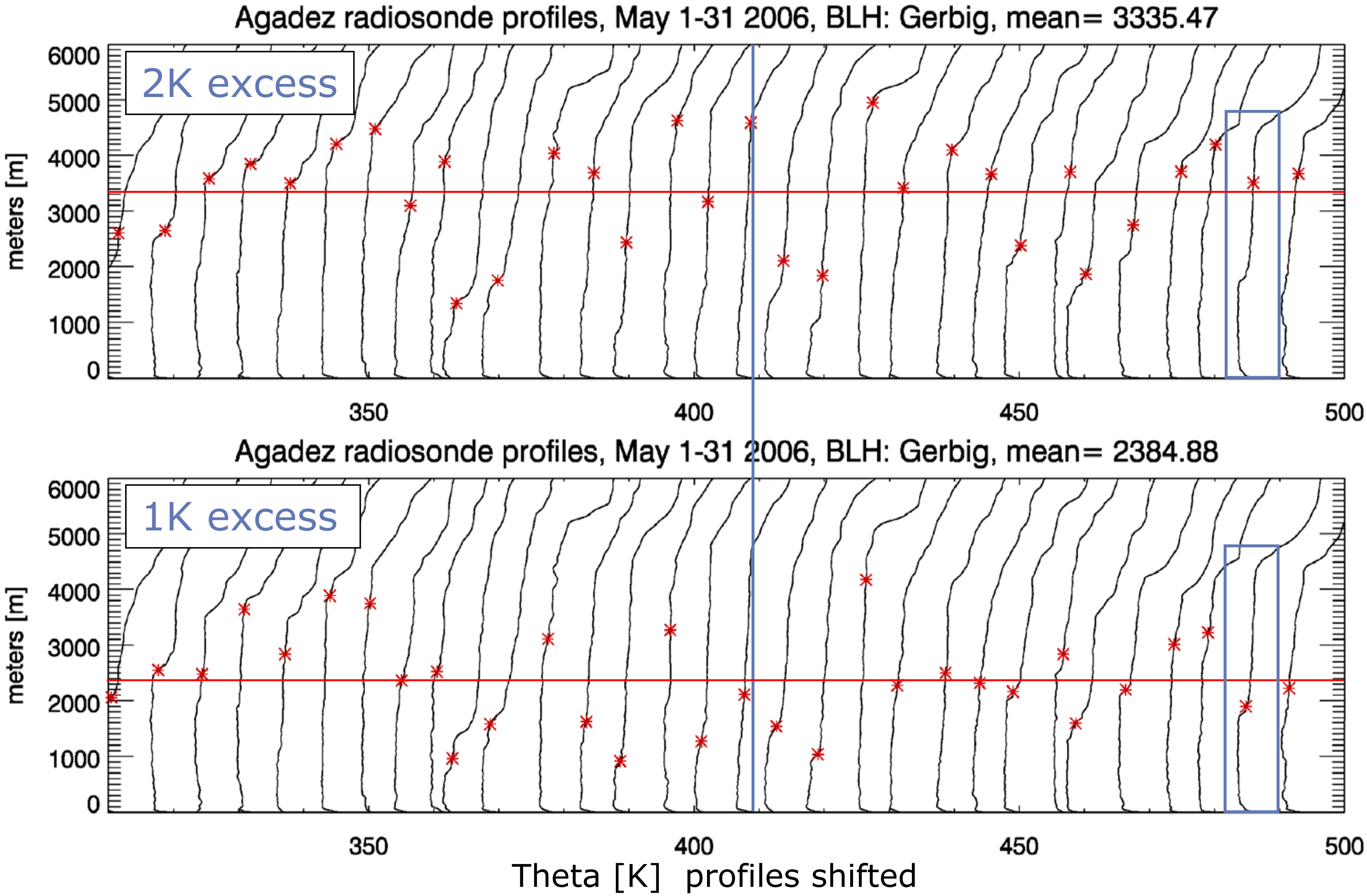
FIG. 2. Calculation of CIN from the virtual potential temperatures of source air (thick dashed line) and environmental air (thick solid line) near the inversion at the top interface of the subcloud convective layer. On the lhs are labels denoting model flux levels (thin solid lines) and thermodynamic levels (thin dashed lines). Average-conserving piecewise linear thermodynamic profiles are used within each model layer. AL denotes the "ambiguous layer" $k + 1$ lying just above the inversion.

Unified treatment of the convective boundary layer, the EDMF dual mass-flux experience

Martin Köhler (with Roel Neggers)

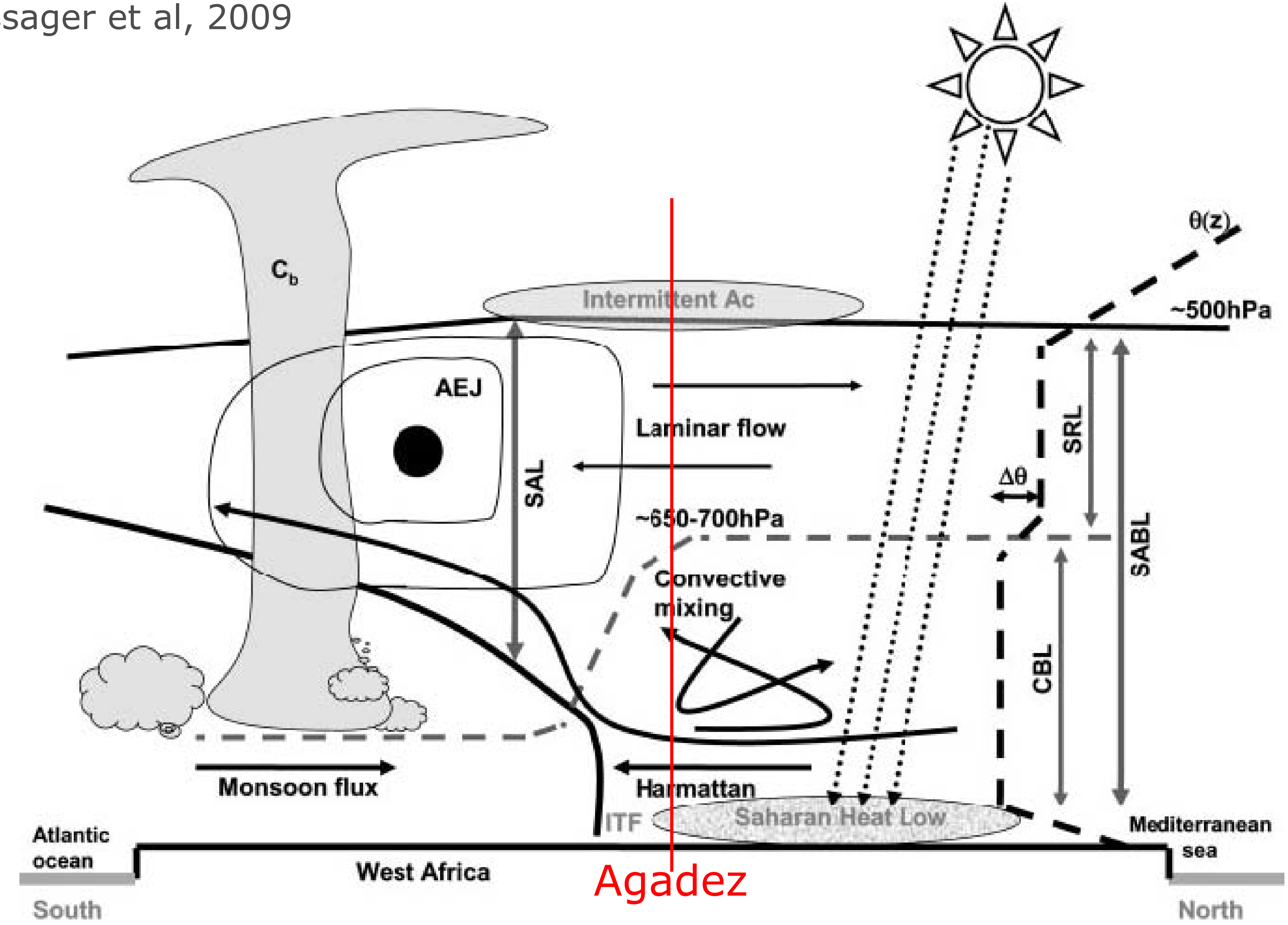
- dry EDMF theory & SCM
- stratocumulus EDMF
- shallow cumulus DUALM EDMF

Challenge: dry conective boundary layer
NW Africa

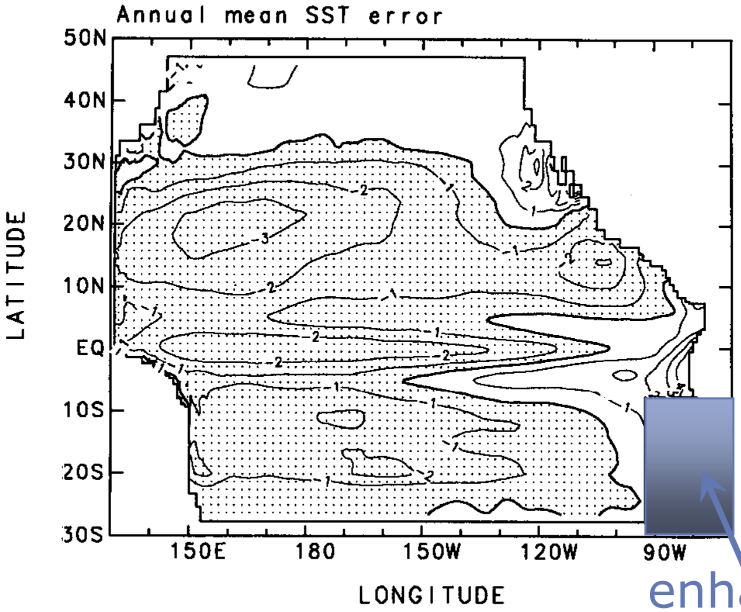


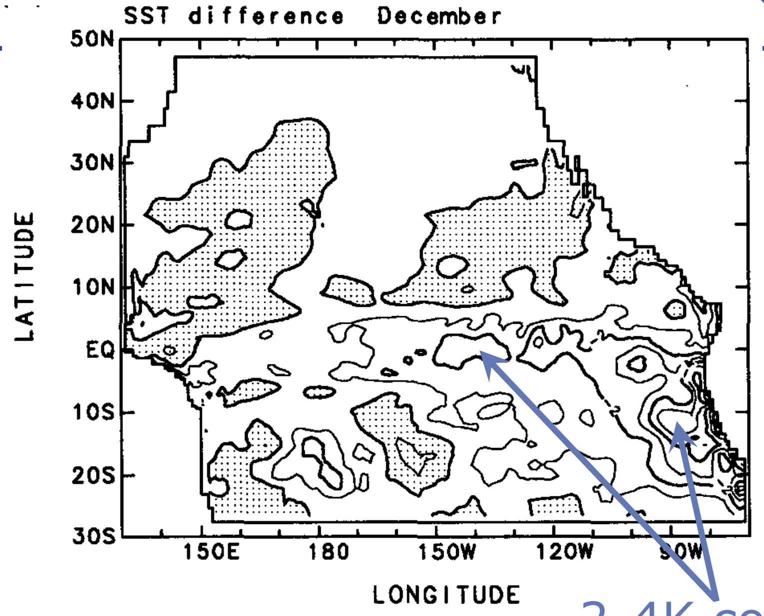
AMMA view of African Monsoon

Messager et al, 2009



Challenge: stratocumulus





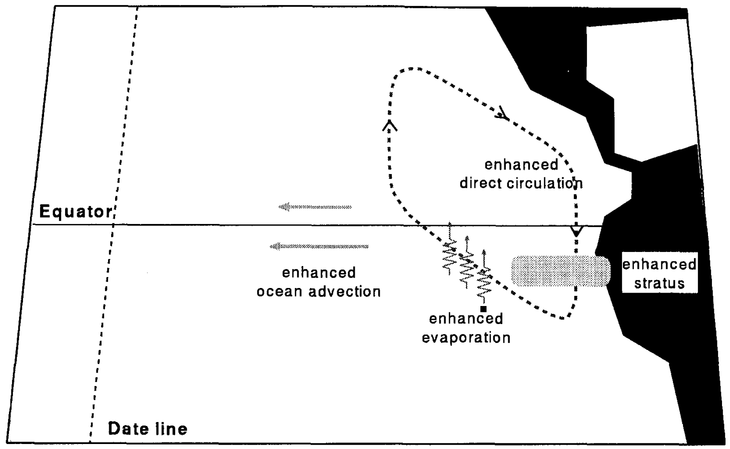
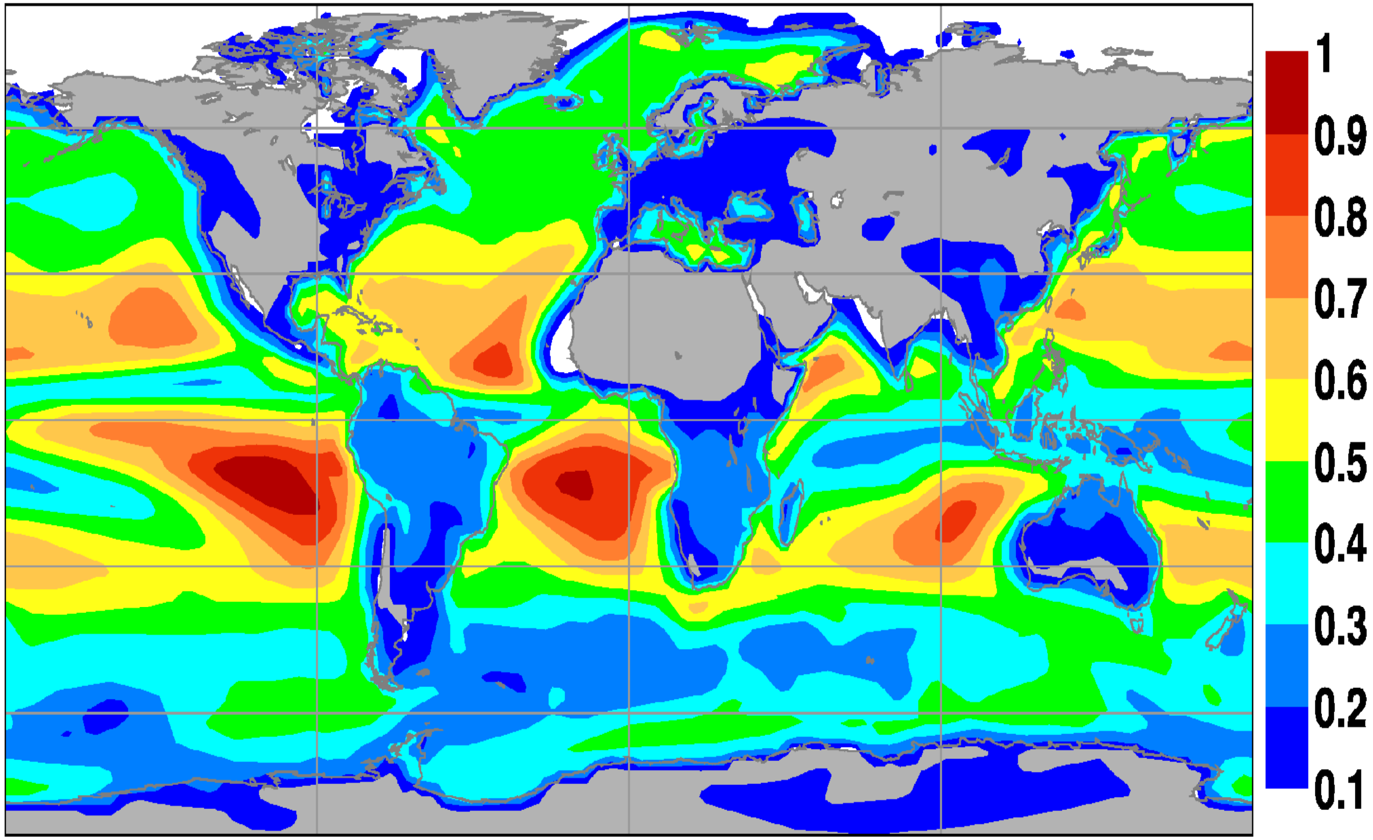


FIG. 10. A schematic illustrating the influence of Peruvian stratus on tropical atmospheric and oceanic circulations as suggested by the coupled GCM experiment.

Ma, Mechoso, Robertson, Arakawa 1996

Challenge: shallow cumulus

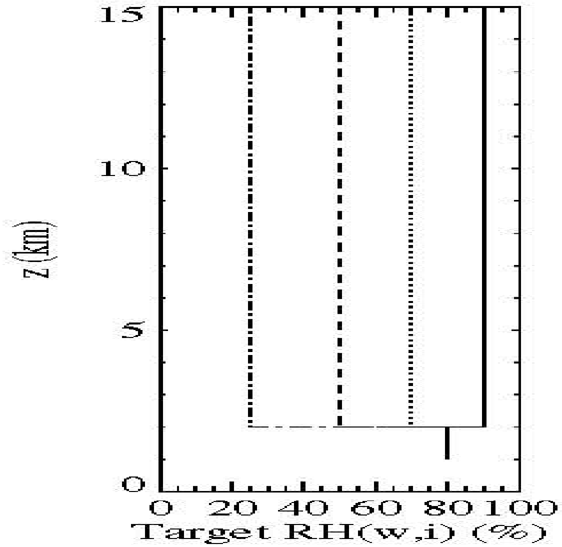
cumulus scheme active: 36.3%



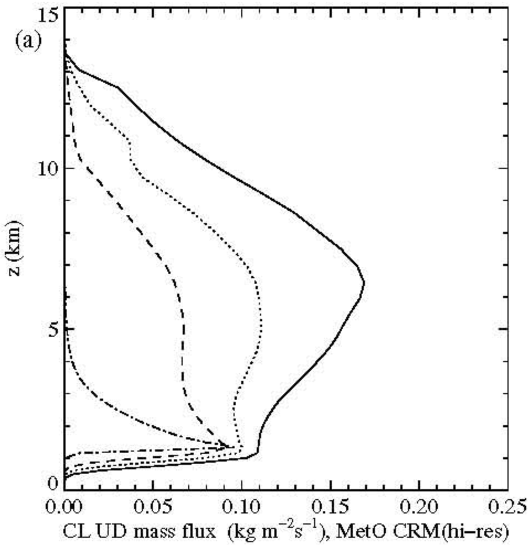
DJF 1990-2005 climate

Derbyshire et al 2004

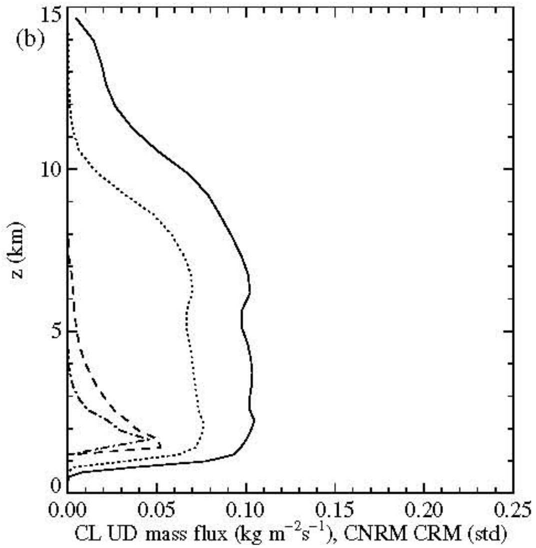
Environment RH



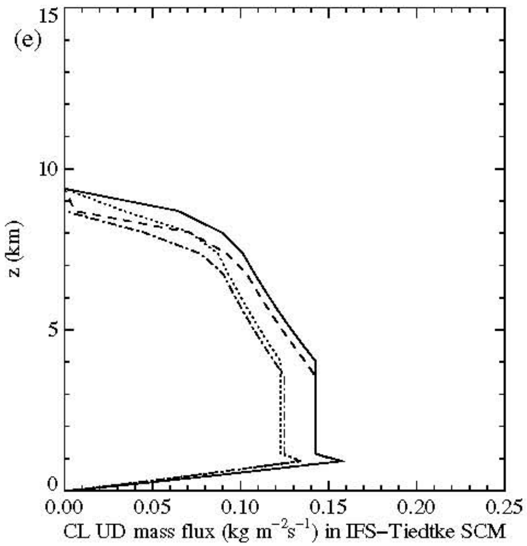
MetO CRM



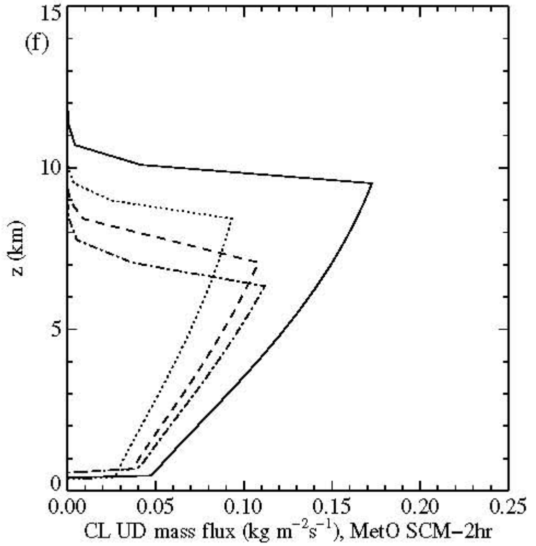
CNRM CRM



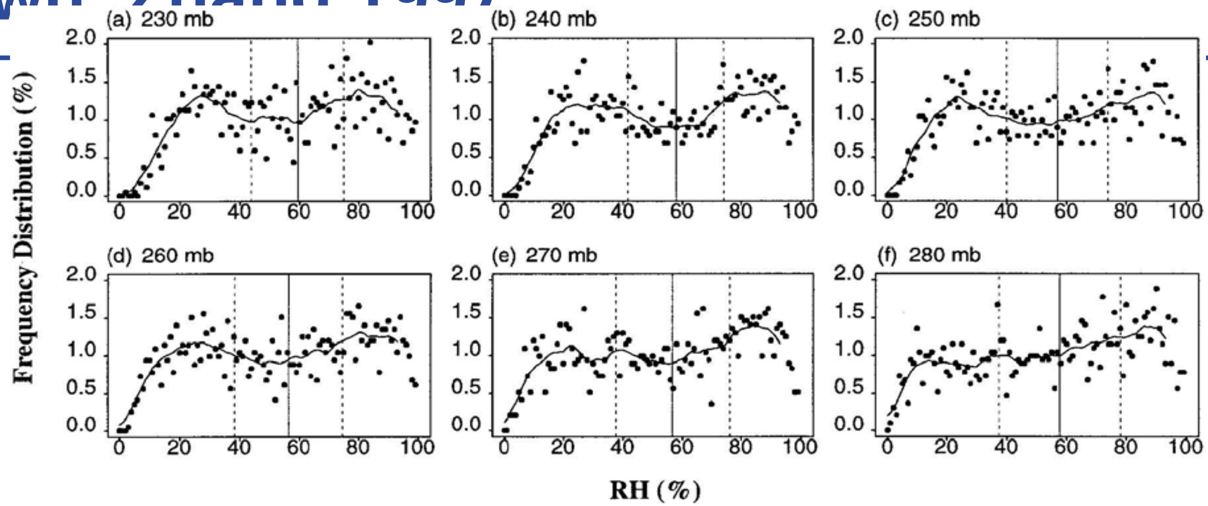
IFS SCM

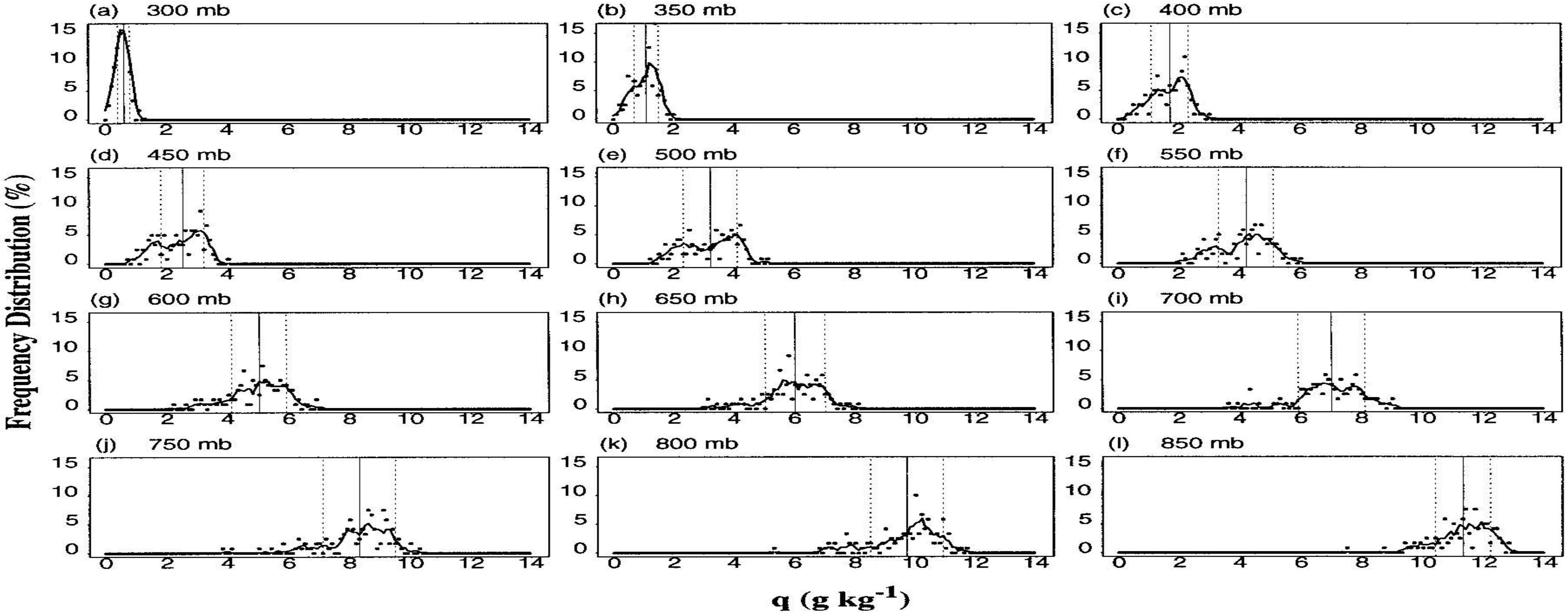


MetO SCM

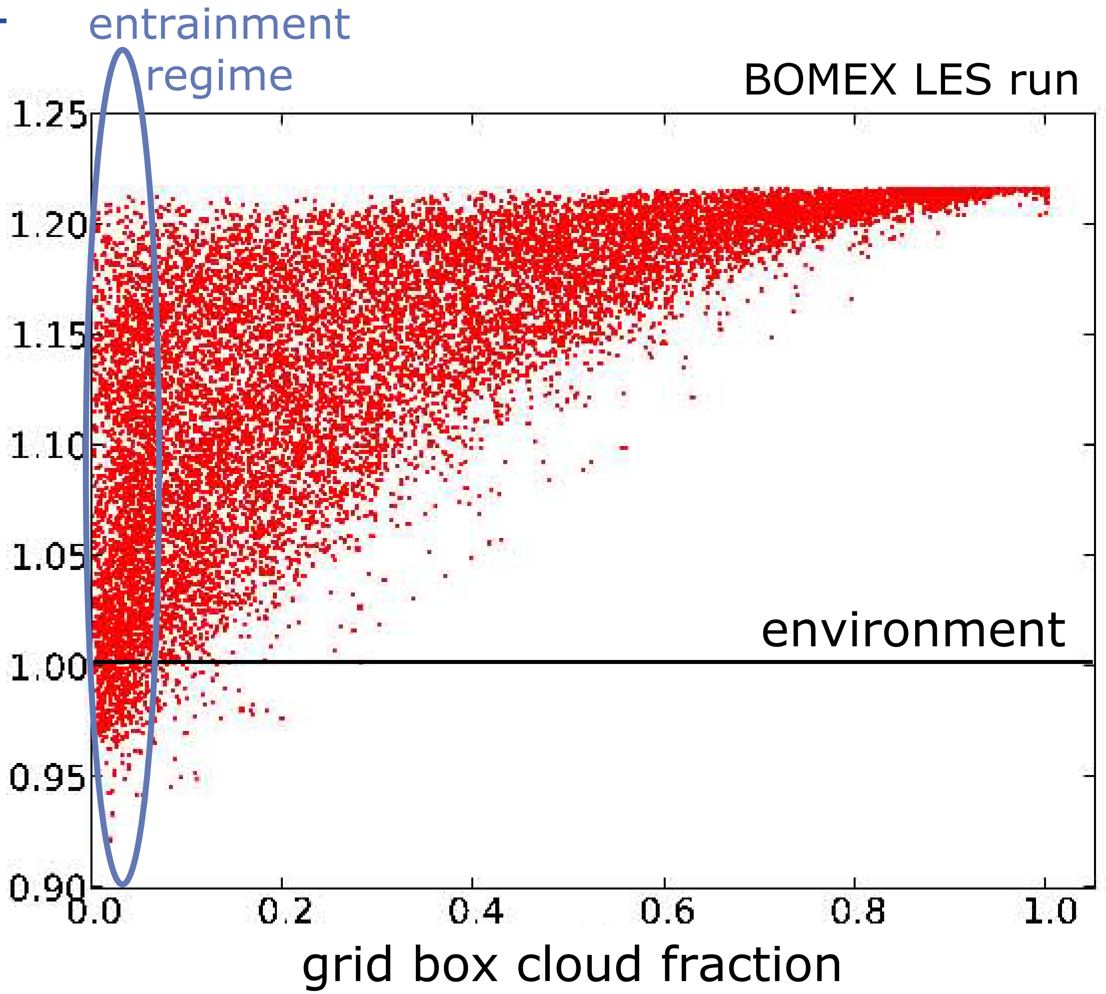


Brown, Zhang 1997





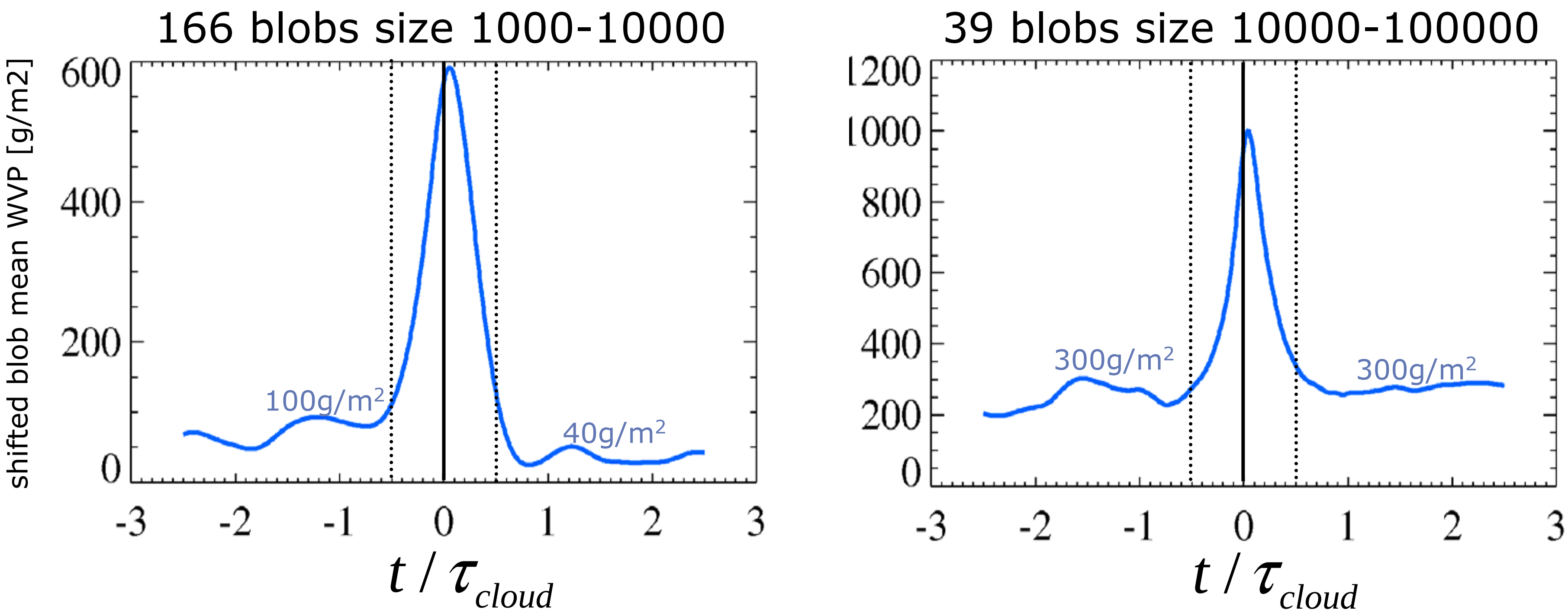
Jarecka, Grabowski, Pawlowska, 2009



$$\frac{RH_{box}}{RH_{env}}$$

Entrained air is premoistened.

BOMEX LES   cloud blobs



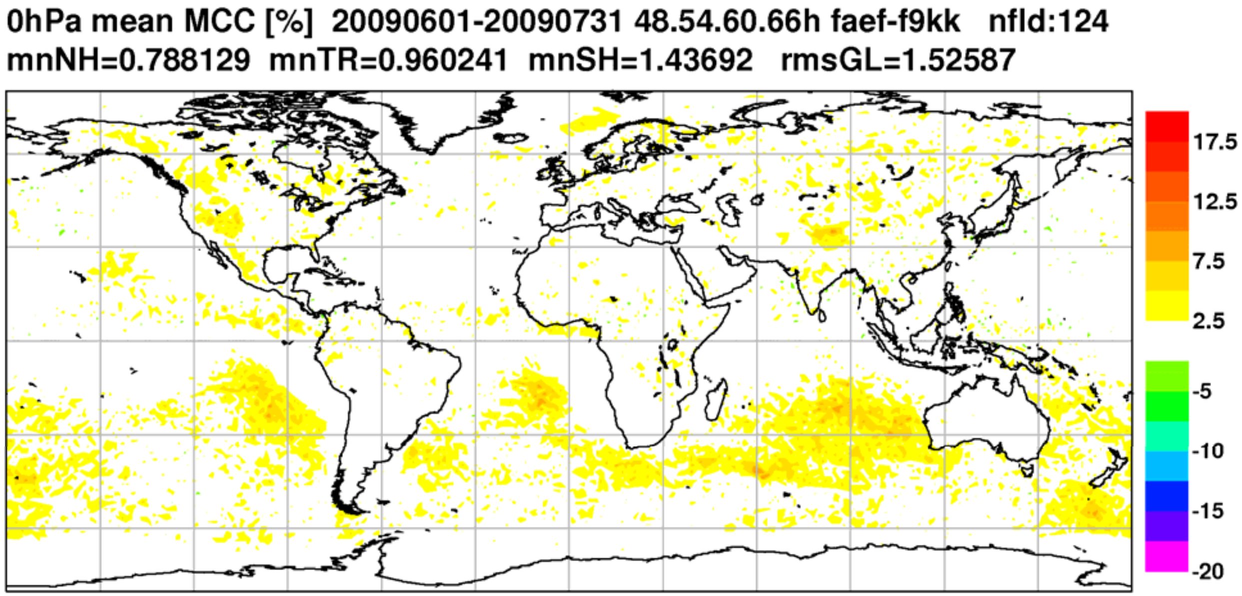
Time, lagged around blob center, normalized by blob time scale

blobs size 1000: (250m)² · 300s
blobs size 1000000: (2500m)² · 3000s

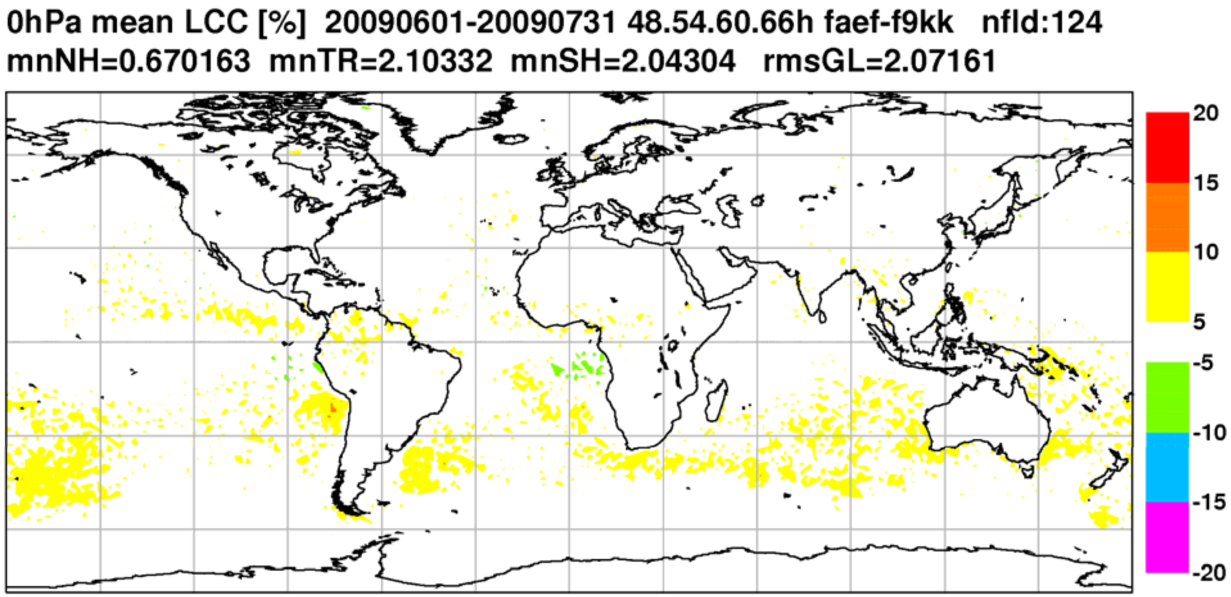
$$\sigma_{WVP} = 890\text{g/m}^2$$

Clou

MCC

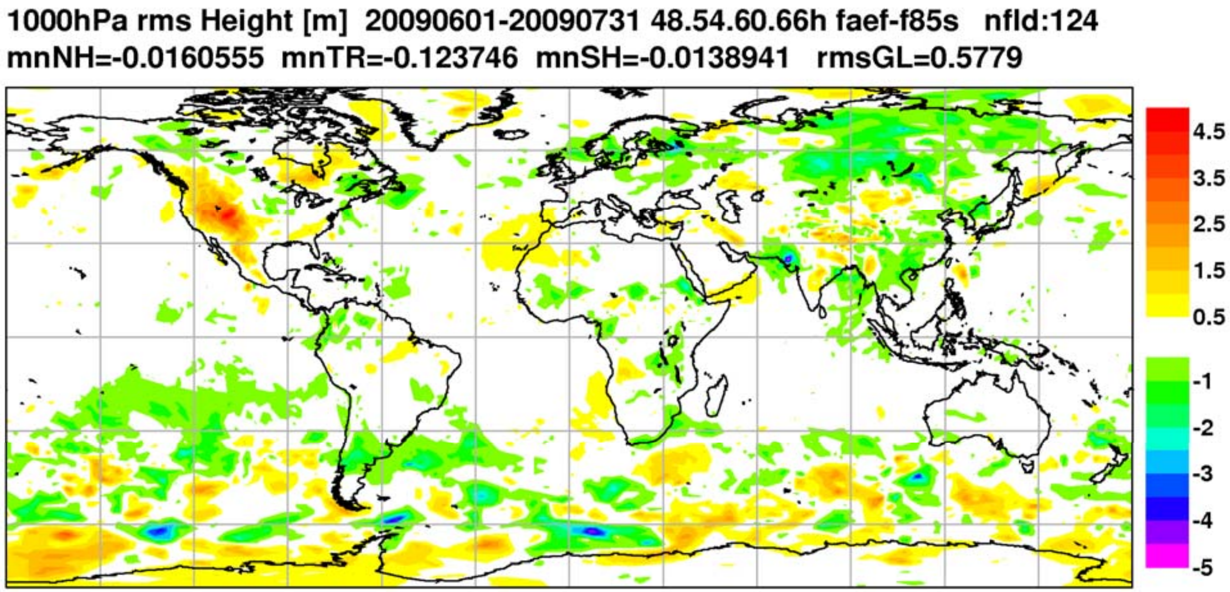

0hPa mean MCC [%] 20090601-20090731 48.54.60.66h faef-f9kk nfld:124
mnNH=0.788129 mnTR=0.960241 mnSH=1.43692 rmsGL=1.52587
17.5
12.5
7.5
2.5
-5
-10
-15
-20

LCC

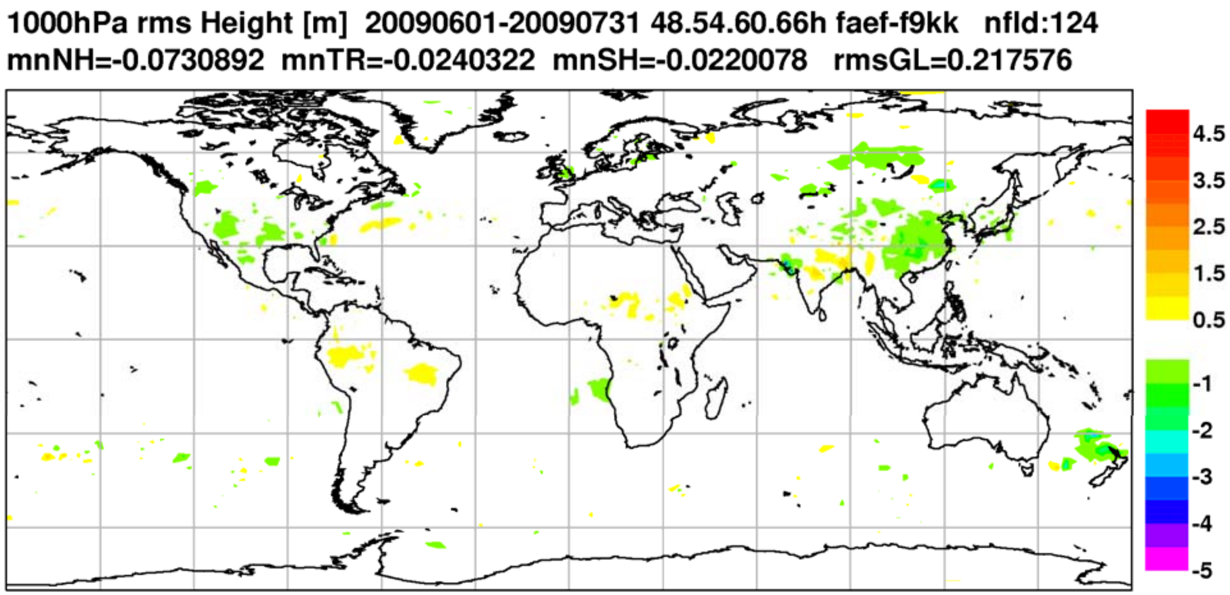

0hPa mean LCC [%] 20090601-20090731 48.54.60.66h faef-f9kk nfld:124
mnNH=0.670163 mnTR=2.10332 mnSH=2.04304 rmsGL=2.07161
20
15
10
5
-5
-10
-15
-20

Cloud overlap: impact

Z1000
DUAL error



Z1000
cloud overlap
impact



EDMF at ECMWF:

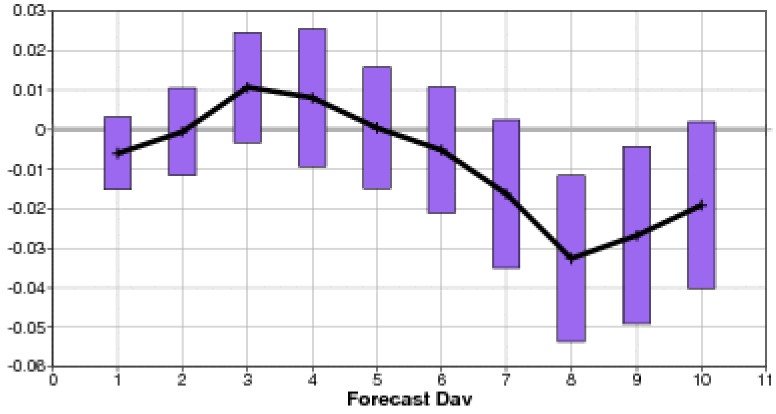
Shallow Cumulus DUALM

Some results

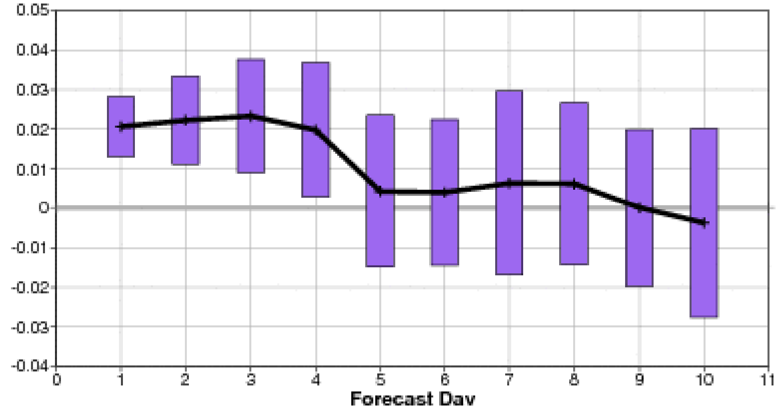
Z1000 scores

(RMS against own AN)

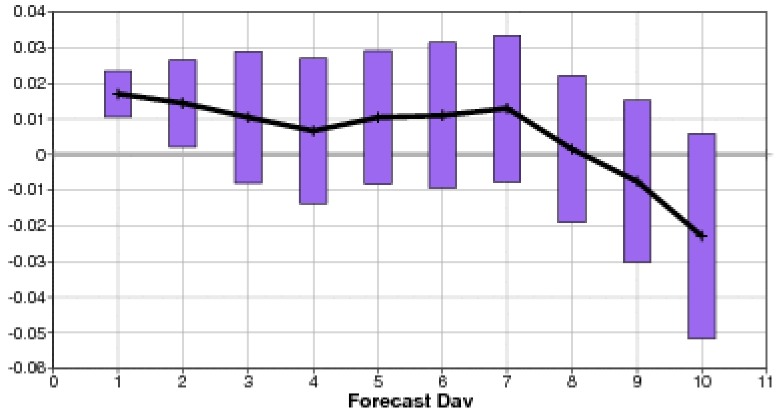
NH summer (99)



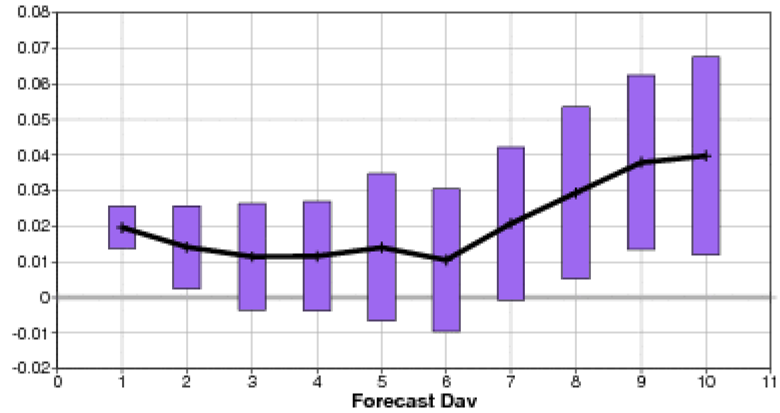
NH winter (80)



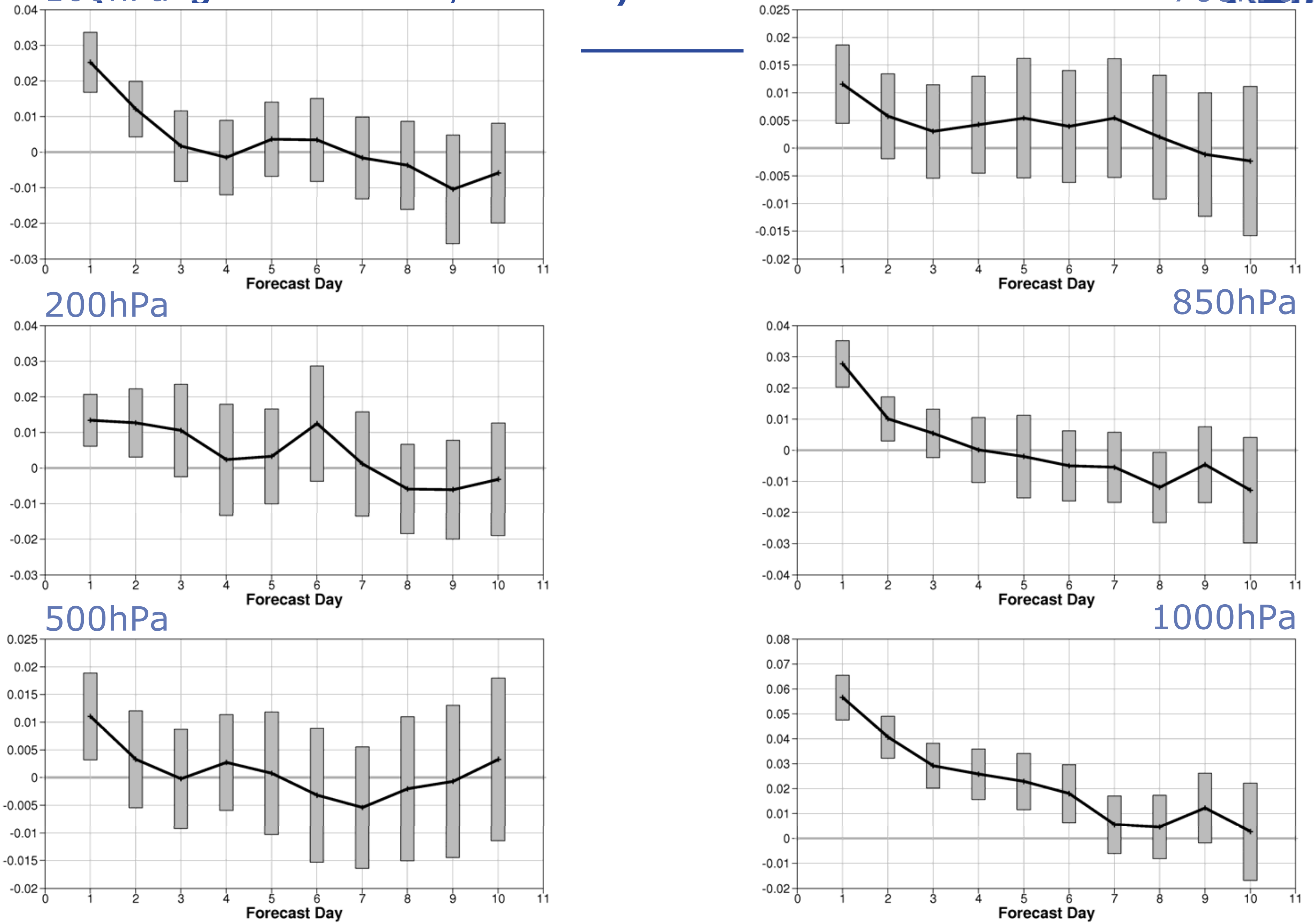
SH summer (80)



SH winter (99)

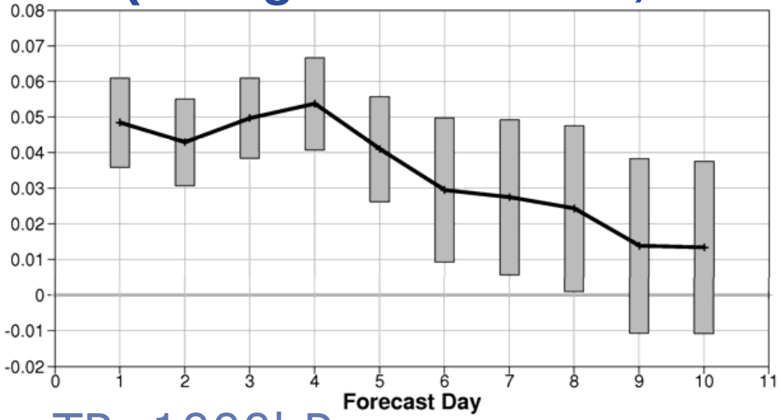


Tropical Winds
(AC against own AN, 179mem)

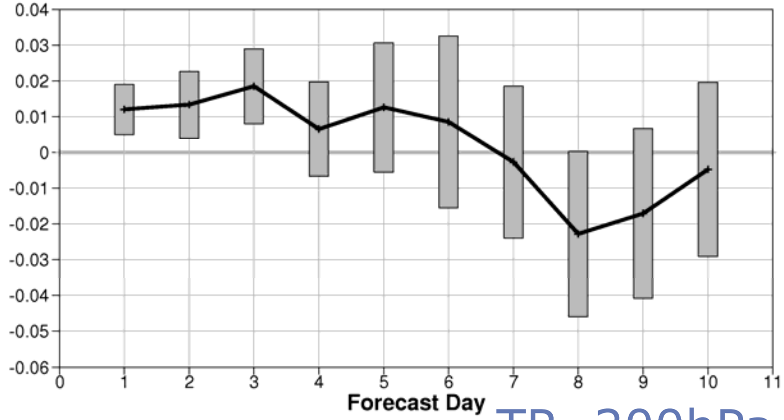


Temperature
(AC against own AN, 179mem)

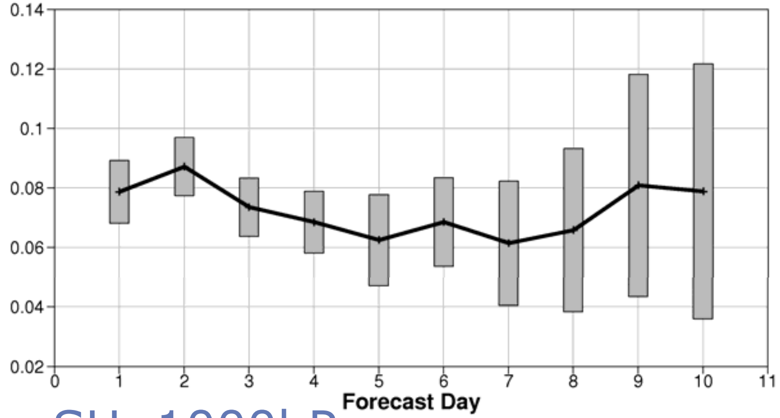
NH 1000hPa



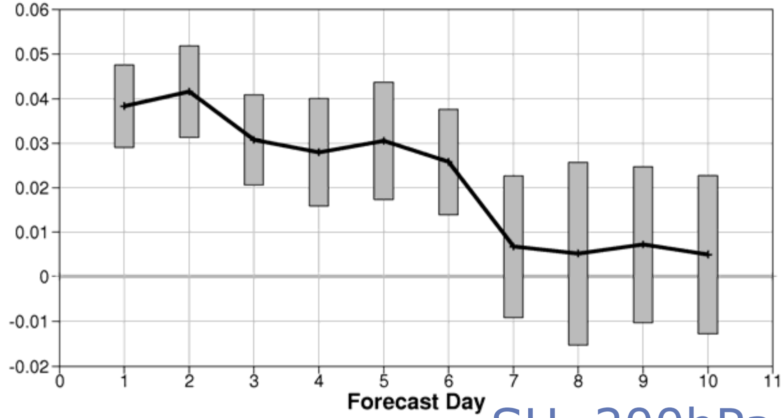
NH 200hPa



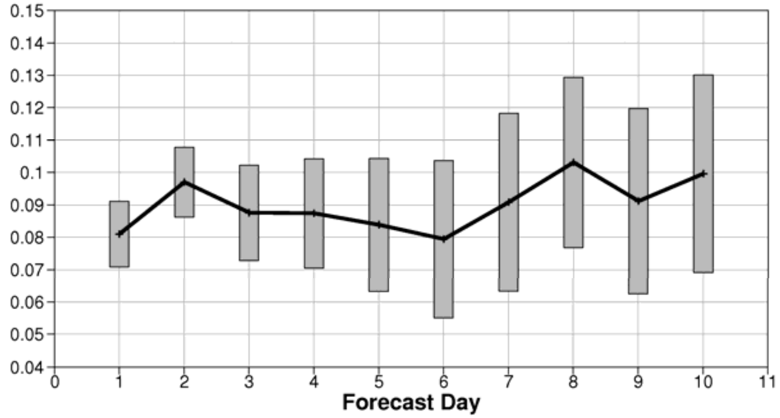
TR 1000hPa



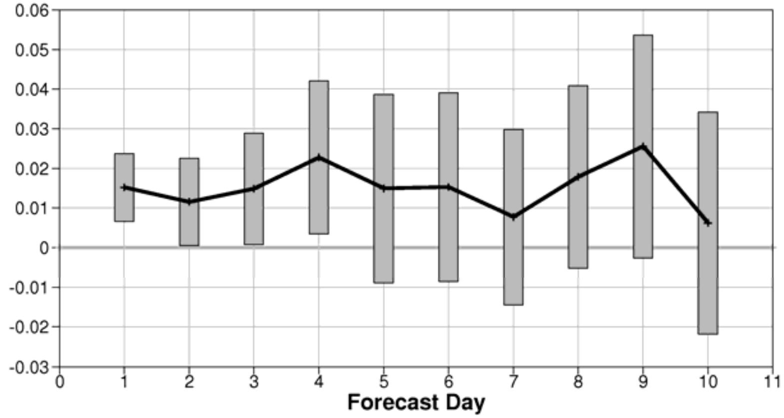
TR 200hPa



SH 1000hPa



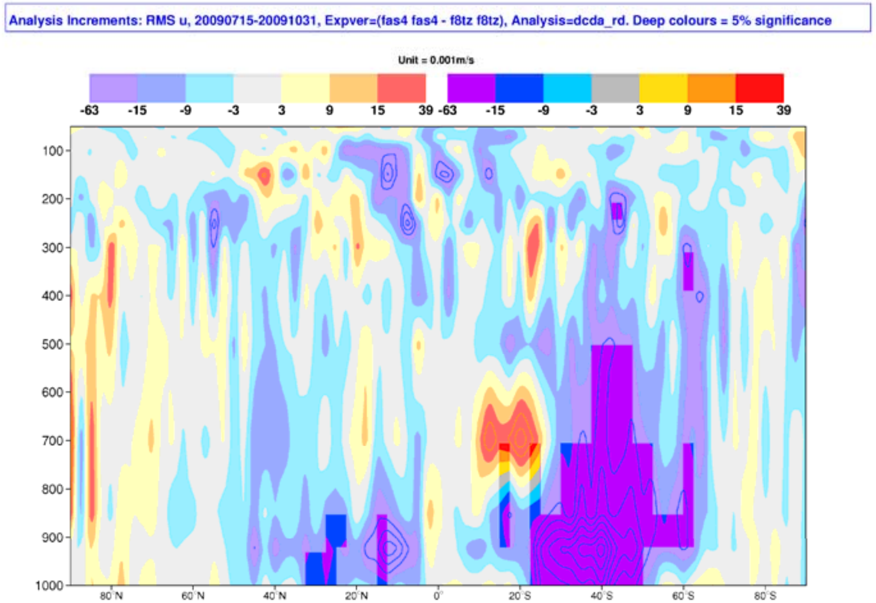
SH 200hPa

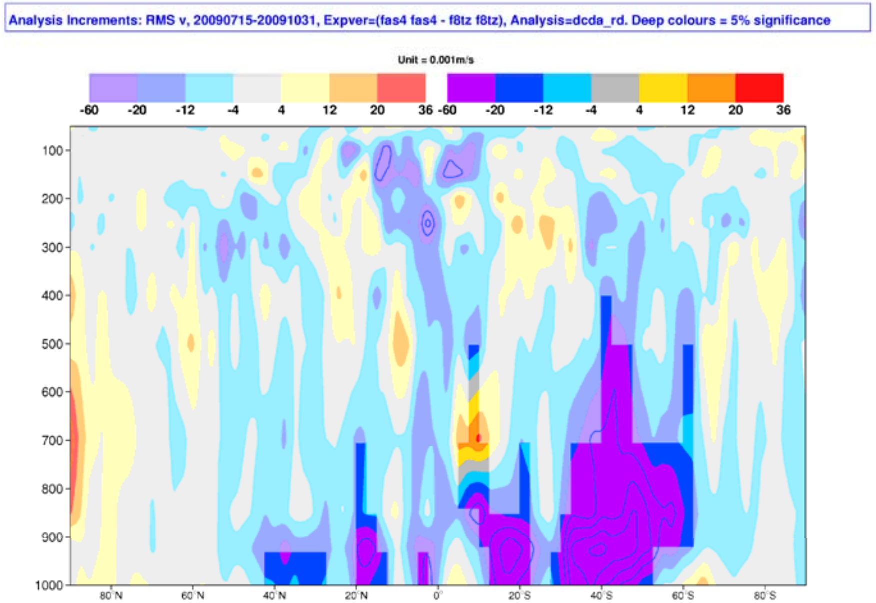


Analysis Increments
Mark Rodwell

U RMS

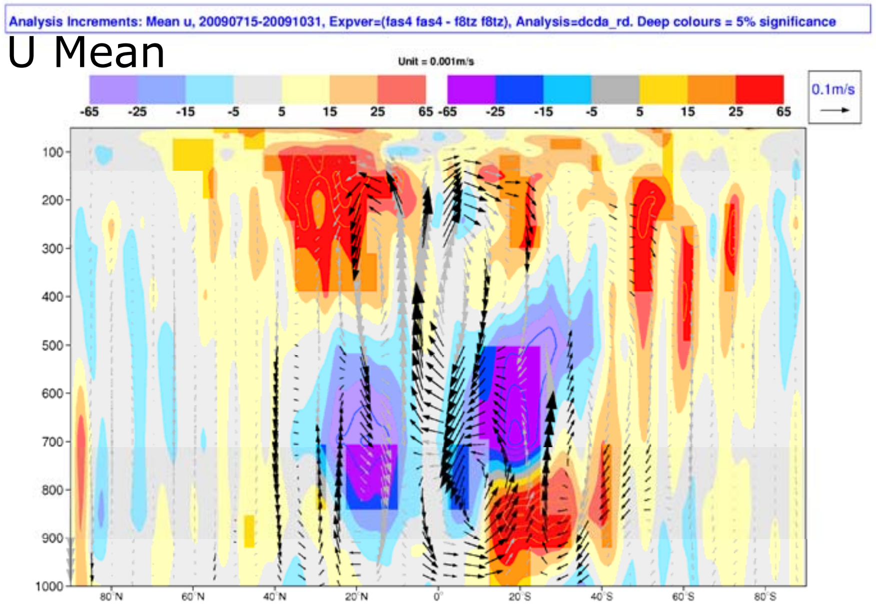
V RMS

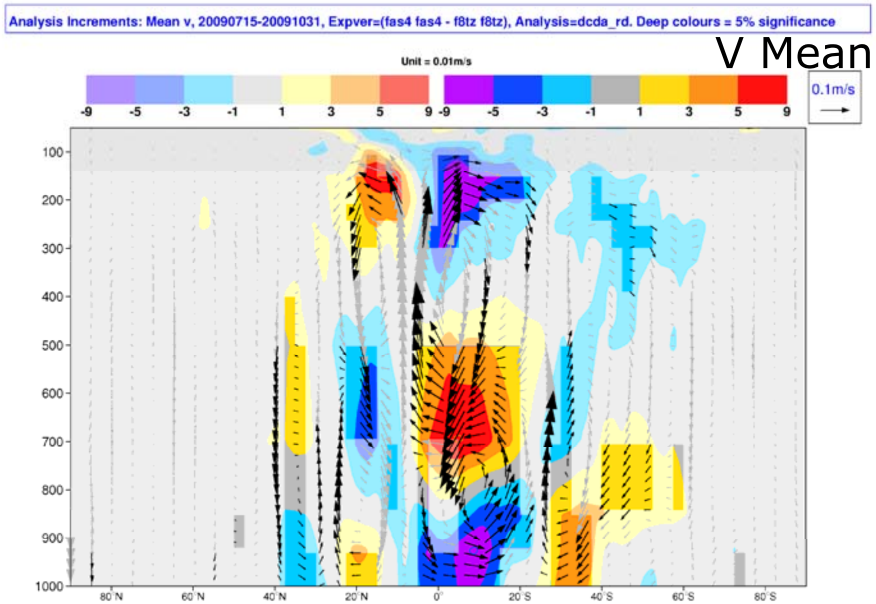




U Mean

V Mean



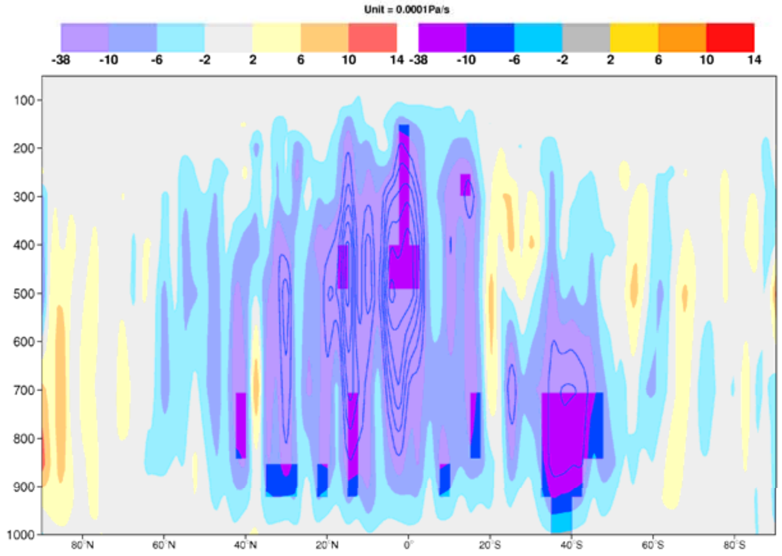


Analysis Increments

Mark Rodwell

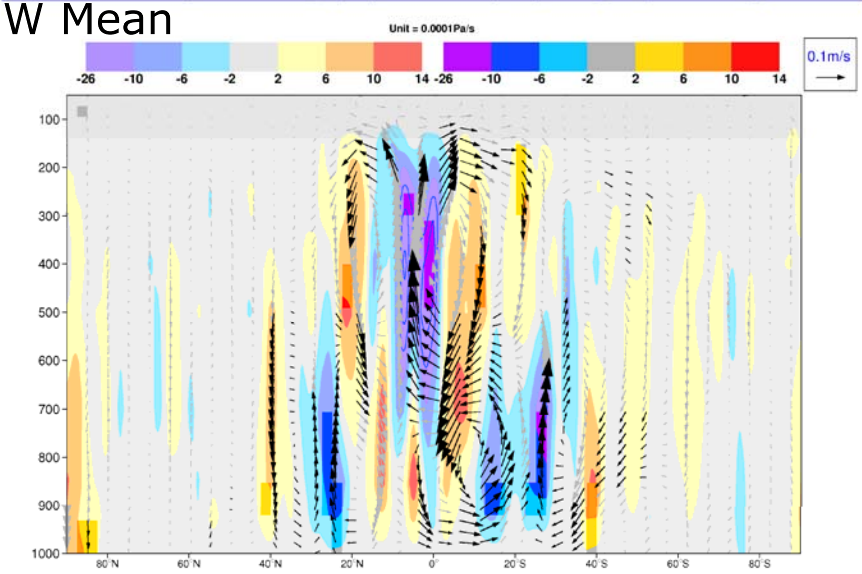
W RMS

Analysis Increments: RMS w, 20090715-20091031, Expver=(fas4 fas4 - f8tz f8tz), Analysis=dcda_rd. Deep colours = 5% significance



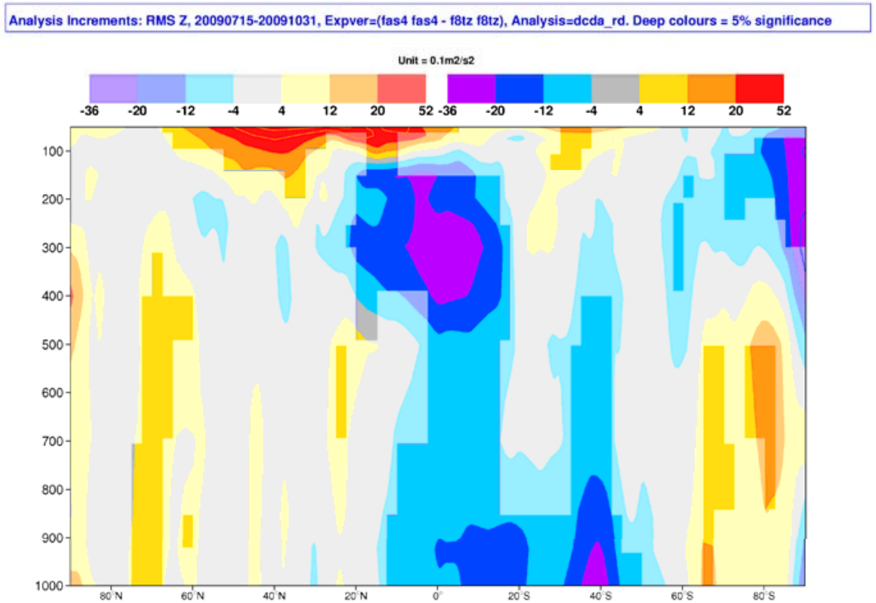
Analysis Increments: Mean w, 20090715-20091031, Expver=(fas4 fas4 - f8tz f8tz), Analysis=dcda_rd. Deep colours = 5% significance

W Mean

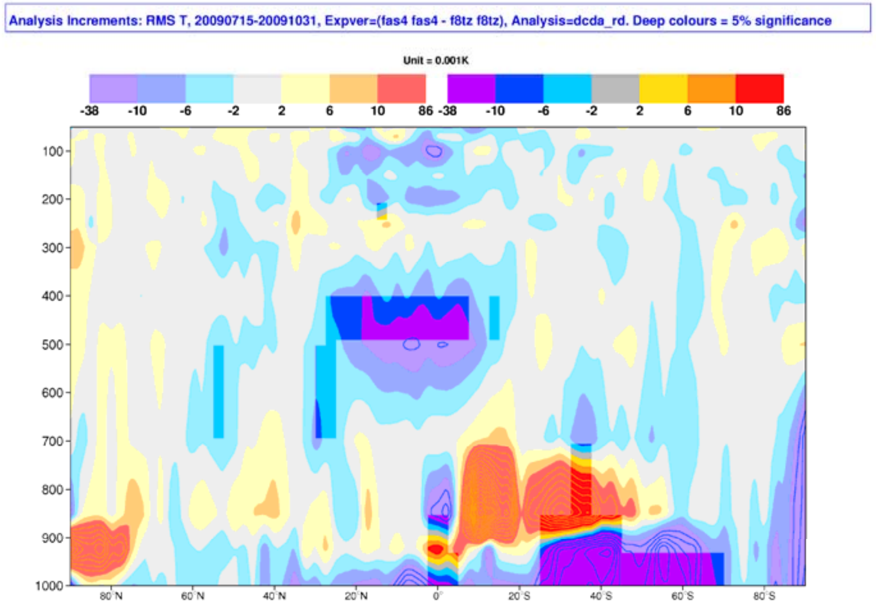


Analysis Increments
Mark Rodwell

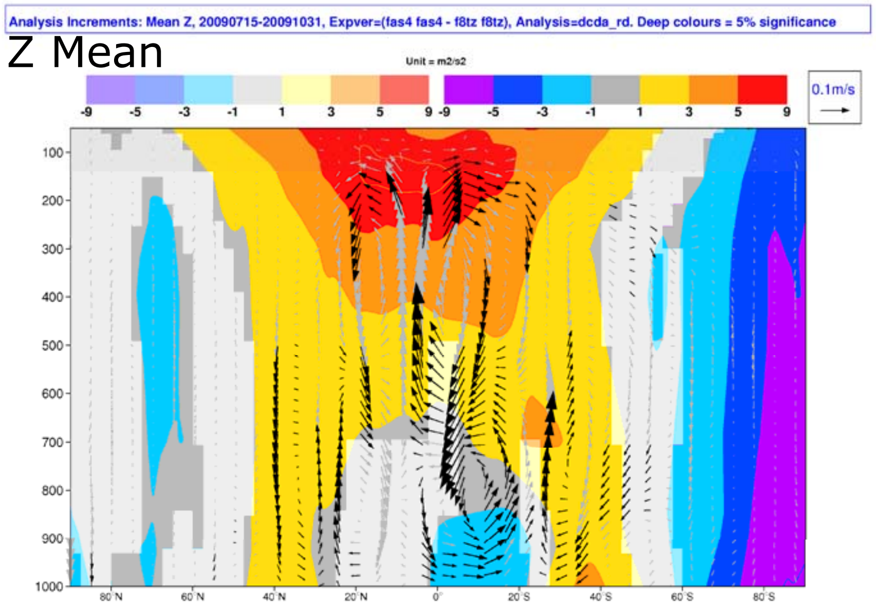
Z RMS



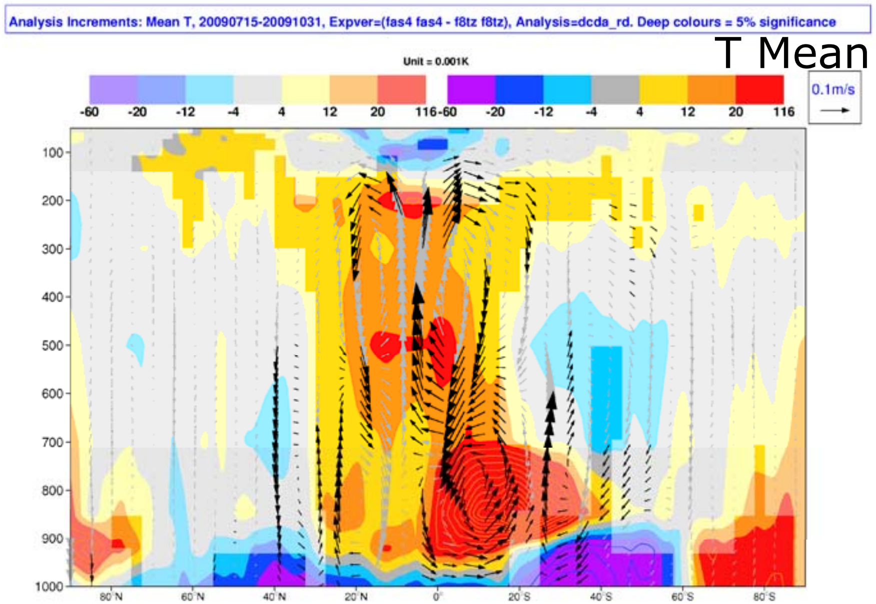
T RMS



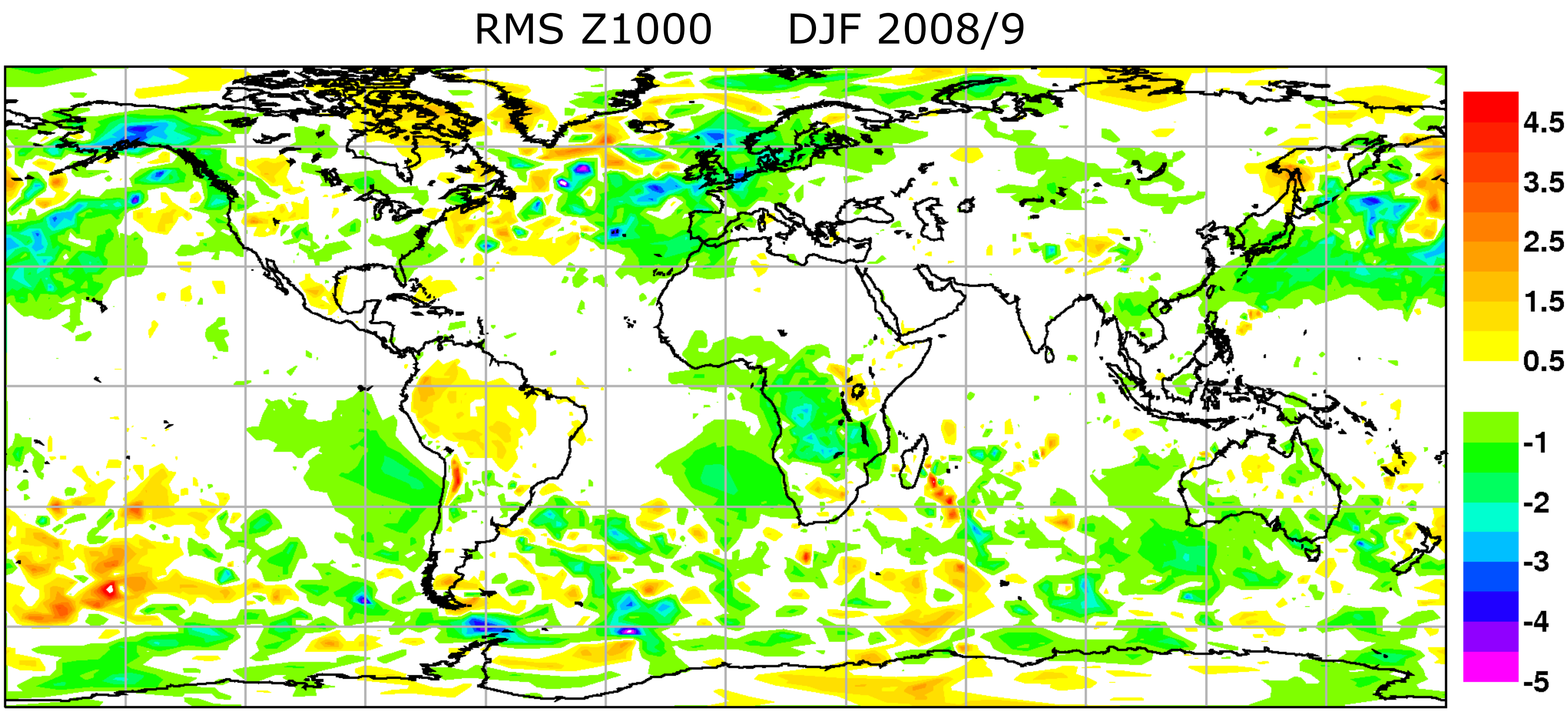
Z Mean



T Mean

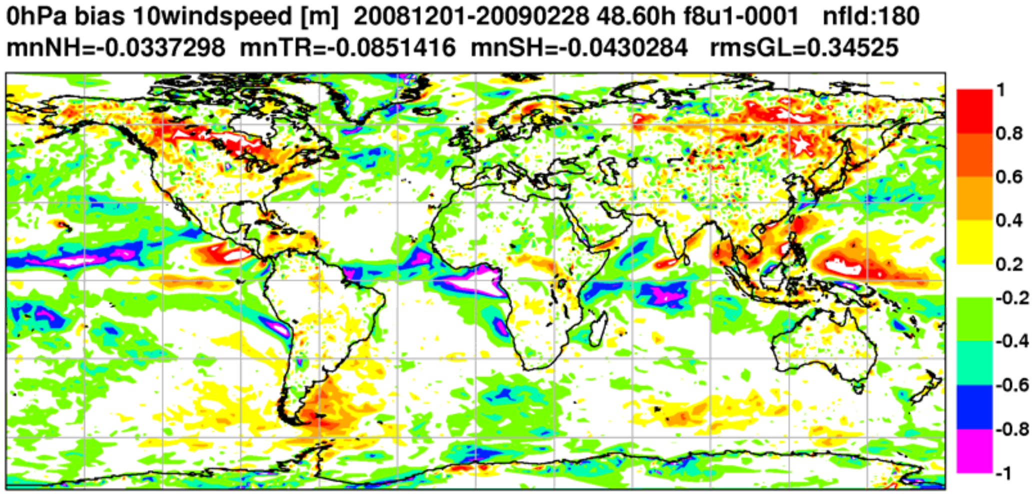


Extra-Tropical Cyclones

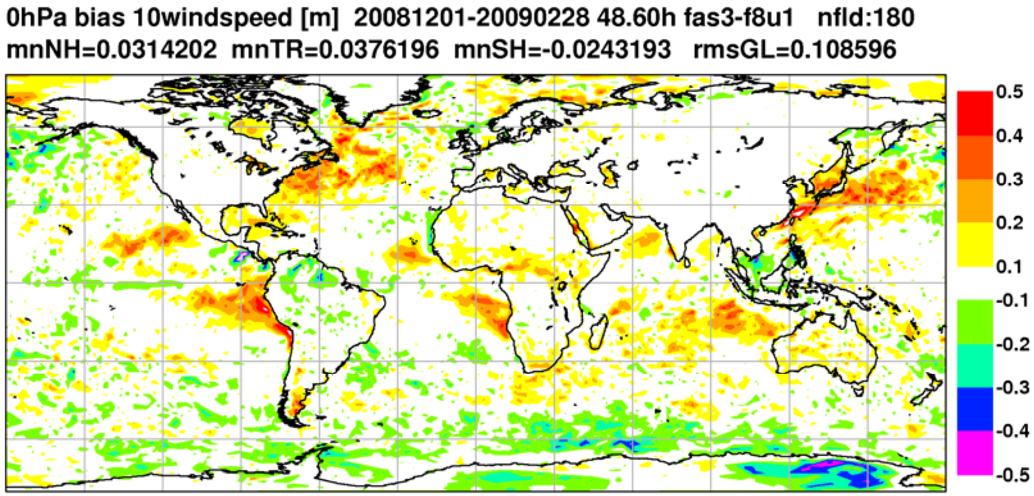


10m wi

bias 36r1



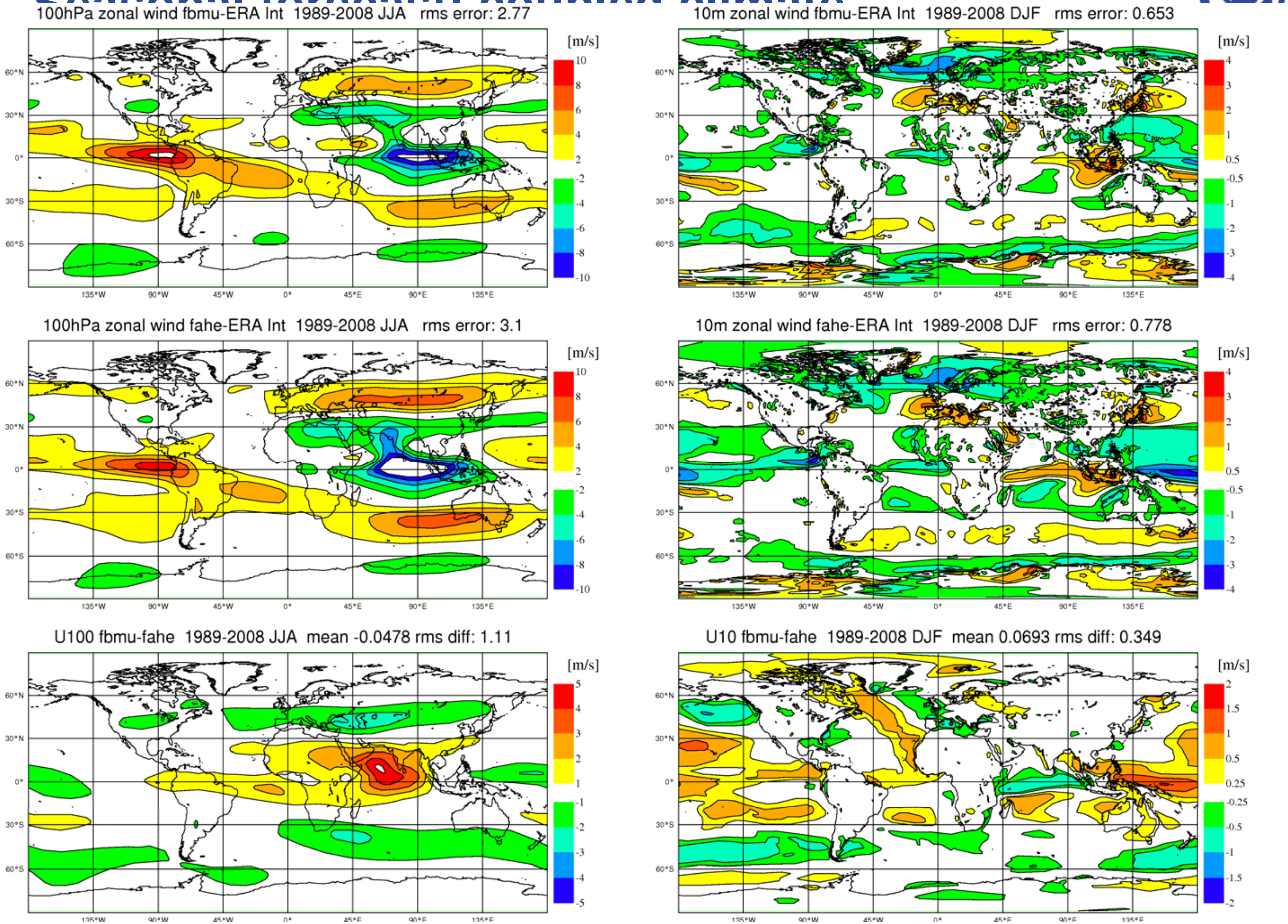
DUAL-36r1



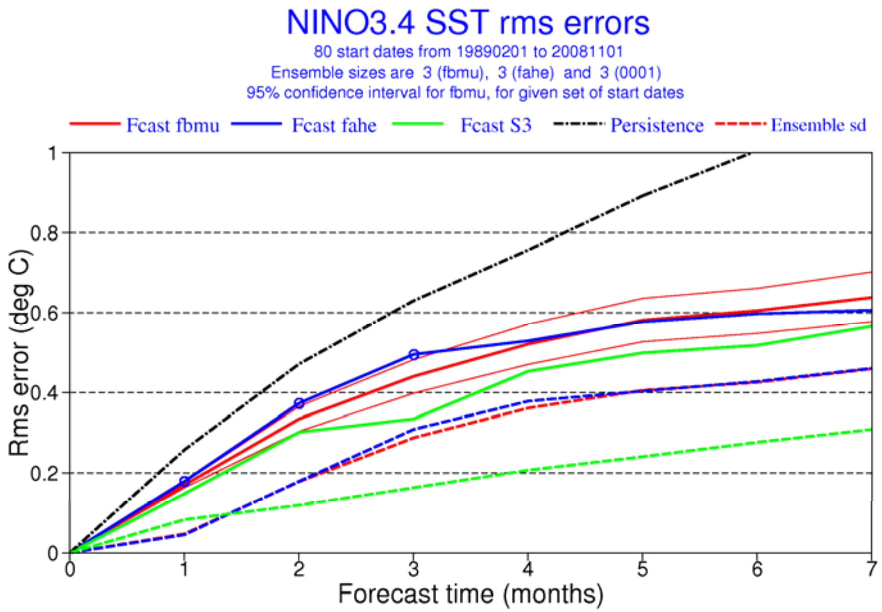
U100 JJA

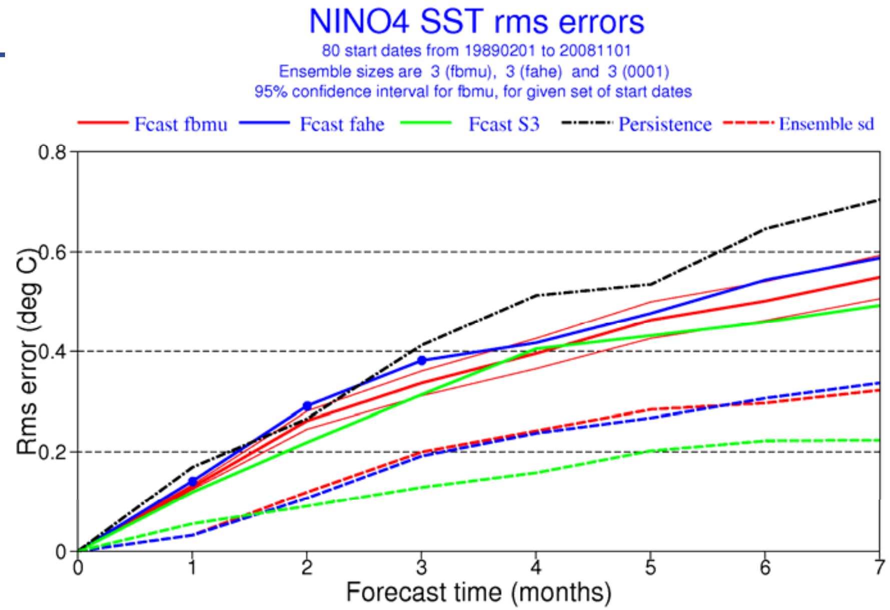
Seasonal forecast: coupled climate

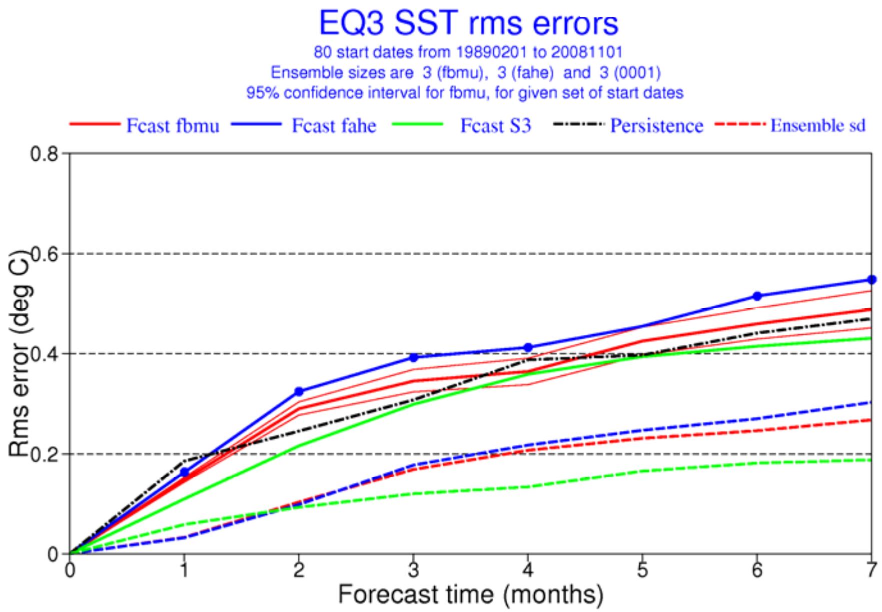
U10 DJF



led

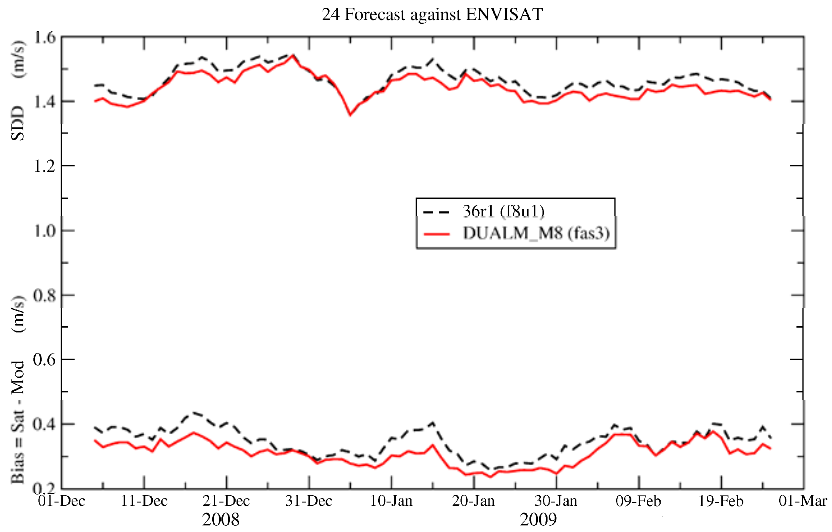

NINO3.4 SST rms errors
80 start dates from 19890201 to 20081101
Ensemble sizes are 3 (fbmu), 3 (fahe) and 3 (0001)
95% confidence interval for fbmu, for given set of start dates
Fcast fbmu
Fcast fahe
Fcast S3
Persistence
Ensemble sd
Rms error (deg C)
Forecast time (months)


NINO4 SST rms errors
80 start dates from 19890201 to 20081101
Ensemble sizes are 3 (fbmu), 3 (fahe) and 3 (0001)
95% confidence interval for fbmu, for given set of start dates
Fcast fbmu
Fcast fahe
Fcast S3
Persistence
Ensemble sd
Rms error (deg C)
Forecast time (months)

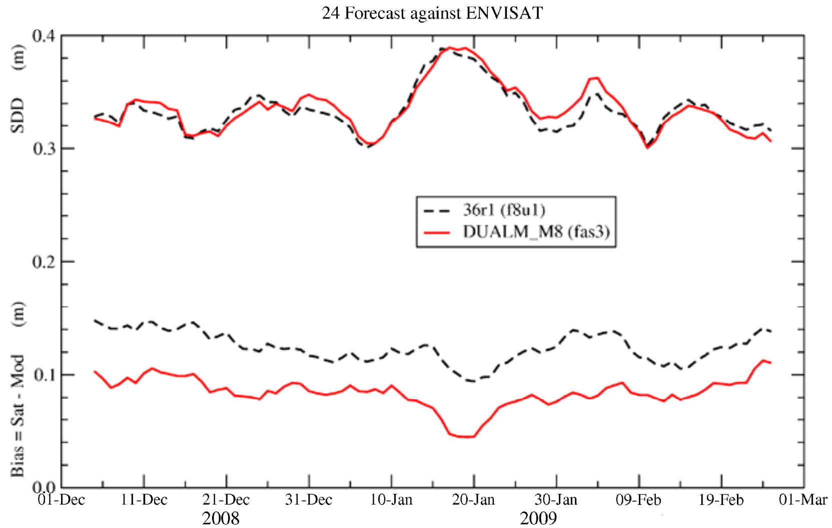

EQ3 SST rms errors
80 start dates from 19890201 to 20081101
Ensemble sizes are 3 (fbmu), 3 (fahe) and 3 (0001)
95% confidence interval for fbmu, for given set of start dates
Fcast fbmu
Fcast fahe
Fcast S3
Persistence
Ensemble sd
Rms error (deg C)
Forecast time (months)

Analysis against Scatterometer winds
Saleh

10m winds



wave heights



Conclusions

- EDMF approach development for dry/strcu/shallow cu

- stratocumulus
  - ECMWF among the top two

- EDMF-DUAL shallow cumulus
  - good cumulus vertical cloud structure
  - good mid-latitude storm prediction (cold air part)
  - good wind scores including tropics
  - summer land: still too little cumulus cloud cover
    - recommend implementation (speed)

- Future development (recommended)
  - unification of cloud interactions by use of one more prognostic variable describing moisture variability
  - further research into summer land cumulus cloud cover

DUALM in ECMWF: more work

- cloud coupling prognostic ql/cc Tiedtke with qt variance/DUALM??
- time-step dependence in total water variance
  - marine low clouds increase for long time-steps
  - Cloud scheme: overlap, anvil/wake,
  - Convective preconditioning
- Speed
- Sigma(qt) variable
- Overlap on vertical grid

DUALM upgrades beyond DUALM paper

TRANSPORT:

- *Convective preconditioning*
- *Momentum transport with Gregory pressure term*

CLOUD AND PRECIPITATION:

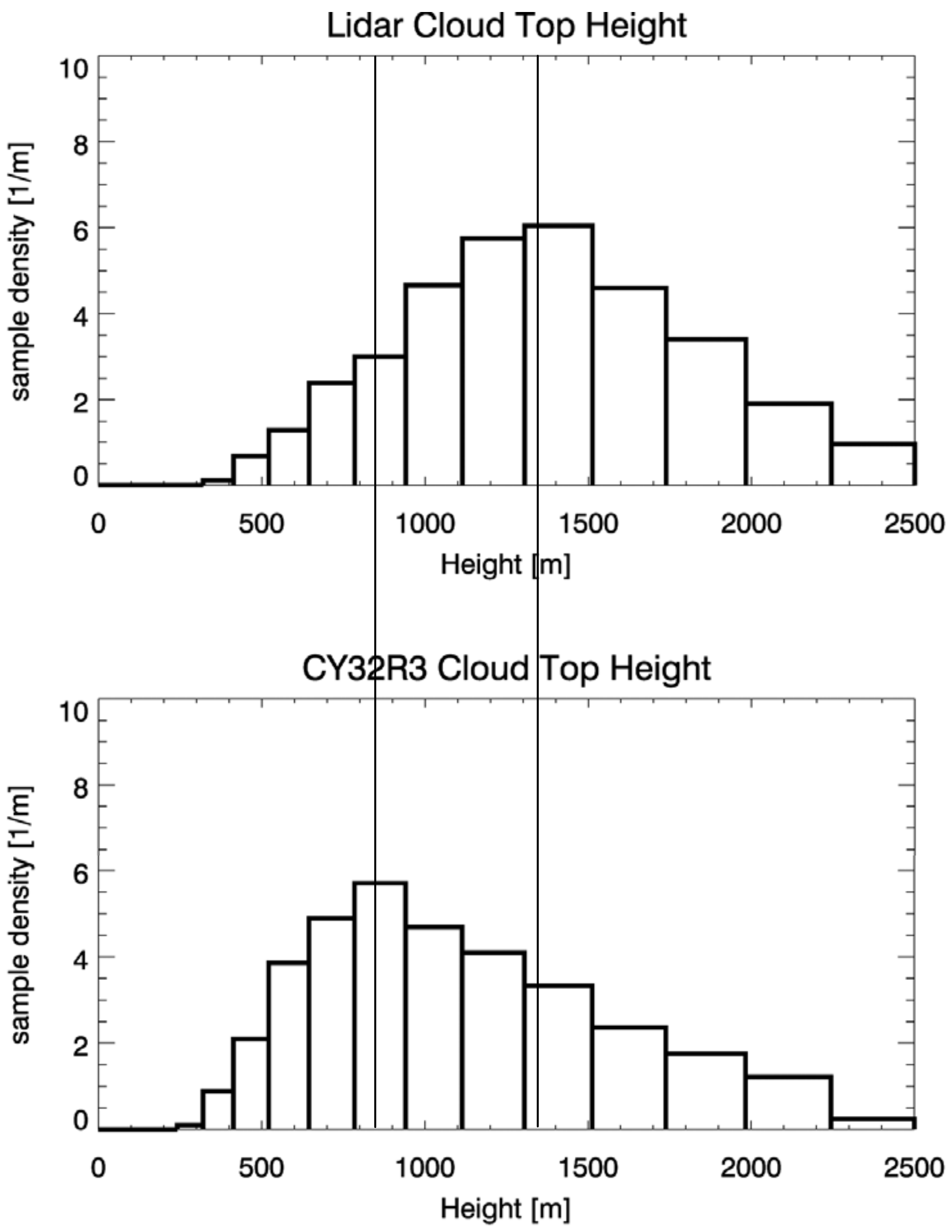
- *Prognostic sigma(q_t)*
- *Precip. evaporation through updraft environment*
- *Prolonged precip. onset over land (large CCN)*
- *Cloud wake/anvil*
- *Cloud overlap (sub-grid)*
- *Wood, Bretherton stratocumulus criterion*

COUPLING WITH CONVECTION/DIFFUSION

- *Multi-level triggering by Tiedtke*
- *No deep DUALM (3km limit)*
- *K in cumulus layer*

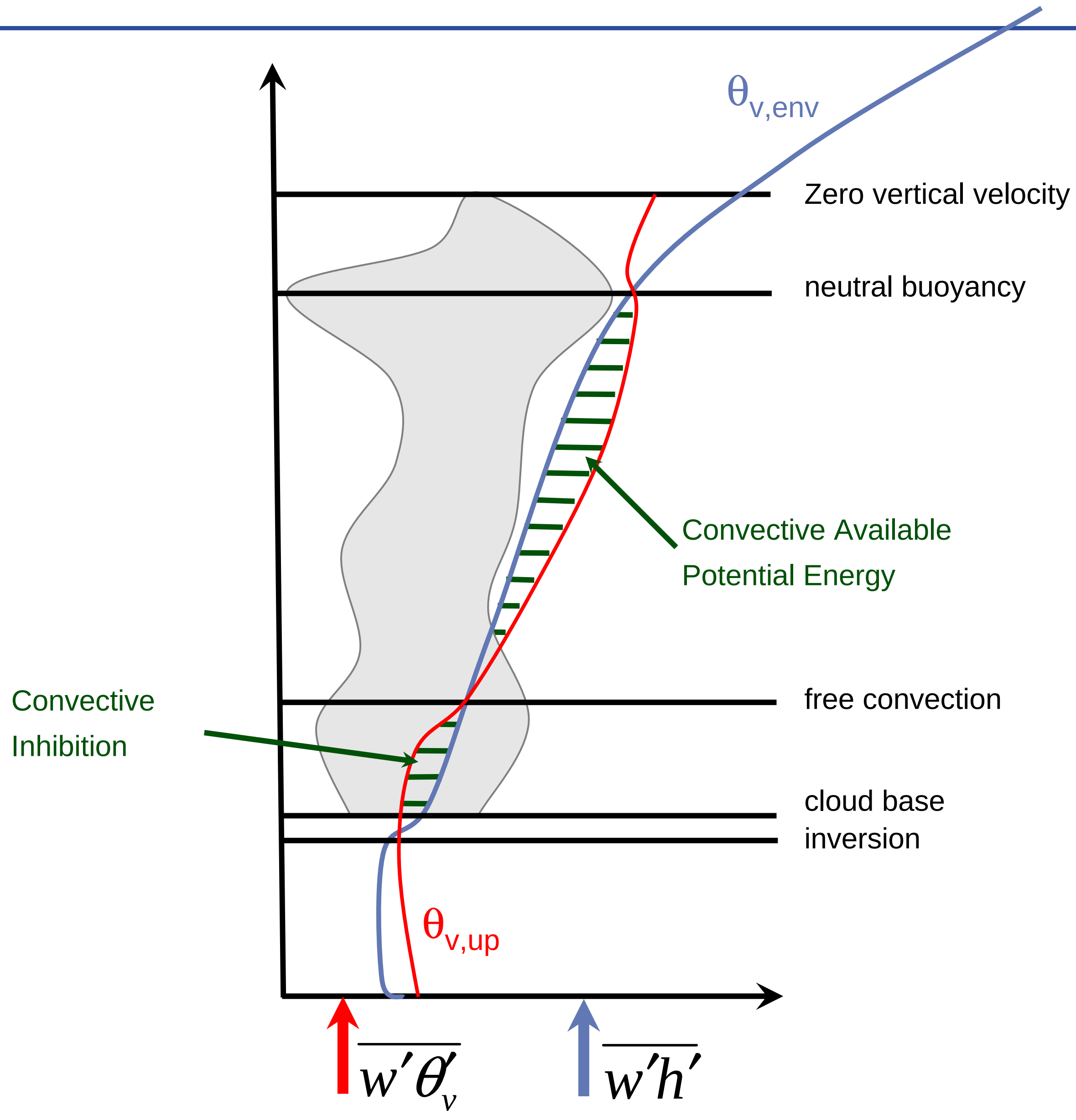
CALIPSO stratocumulus cloud top: off Chile coast

Maike Ahlgrimm



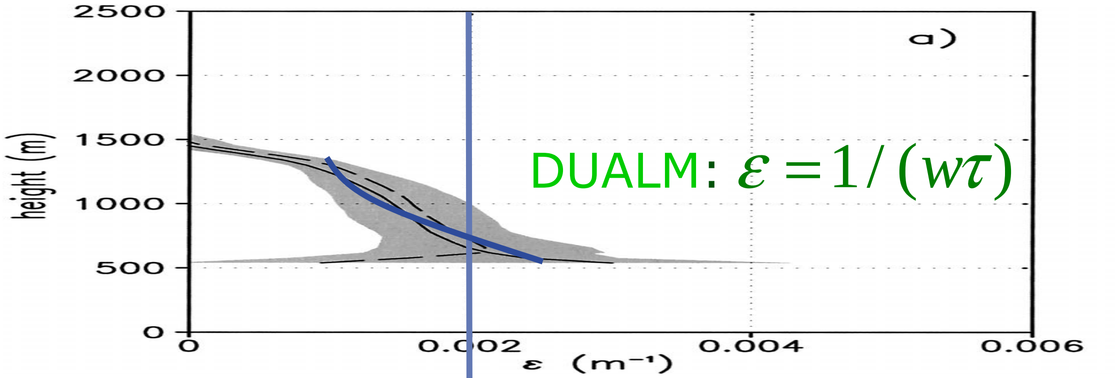
Common challenges 1: Convection closure

- Surface buoyancy flux (w*)
- Moist inhibition (cloud base)
- CAPE equilibrium (cloud)
- Moist static energy equilibrium (sub-cloud)



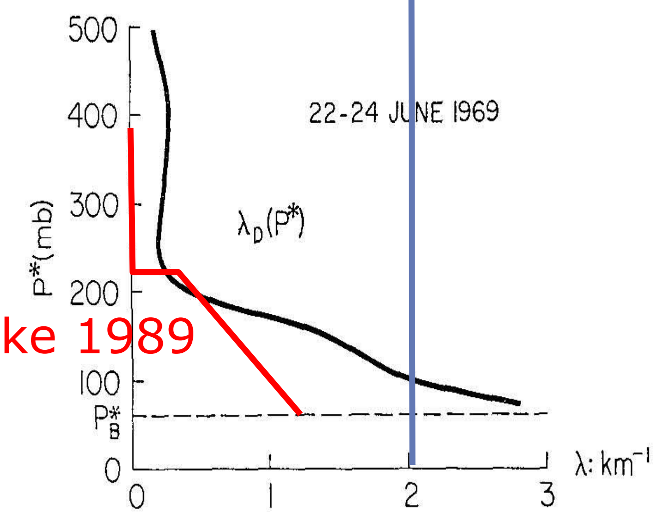
Entrainment BOMEX LES & obs

LES: Siebesma et al 2003

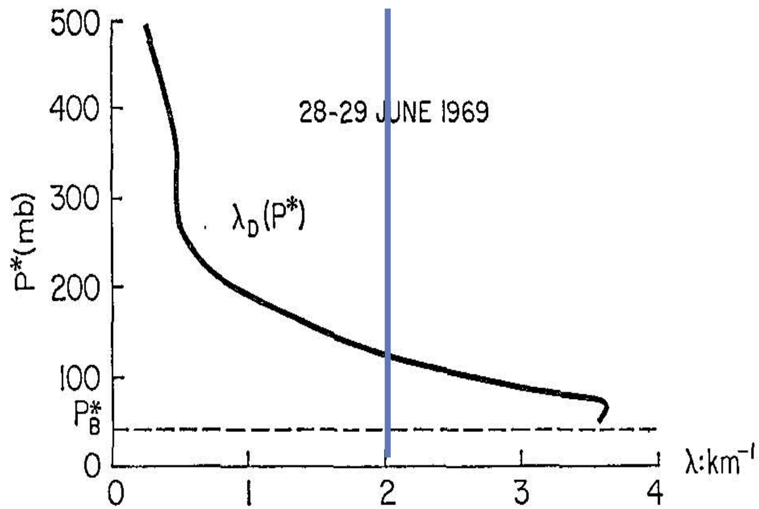


$0.002\ m^{-1}$

obs. analysis: Nitta 1975



period 1: typical trade wind cumulus



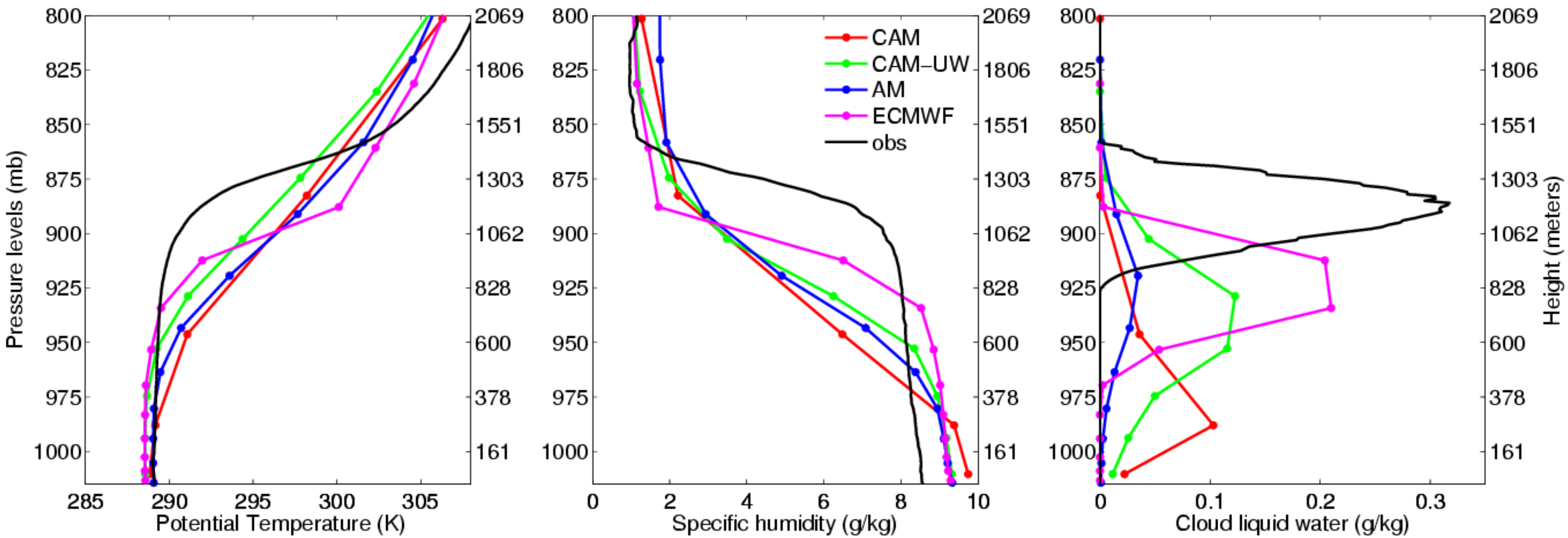
period 3: organized cloud clusters

Tiedtke 1989:
mass-flux scheme for cumulus parameterization

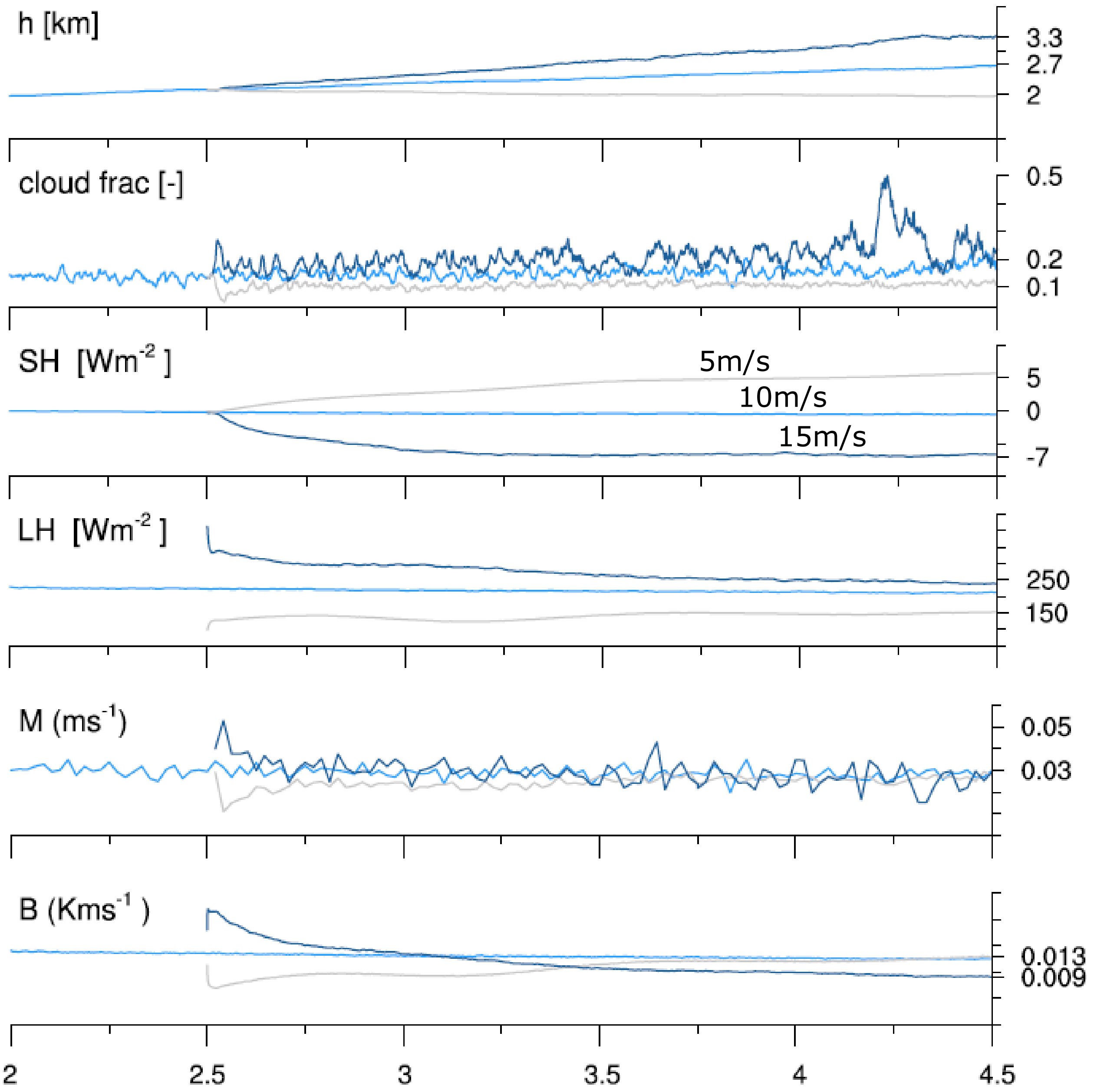
main ingredients:

- deep, shallow and mid-level convection
- cumulus updrafts and downdrafts
- crude cloud processes with freezing and melting
- later: multi-level triggering for frontal convection
- shallow cumulus closure:
    - BL moisture equilibrium (later moist static energy)
- shallow cumulus entrainment:
    - $3\ 10^{-4}\ m^{-1}$ (for large trade wind cumuli, Nitta 1975)

EPIC model comparison
Hannay et al 2008



Louise Nuijens: LES of cumulus, influence of wind speed

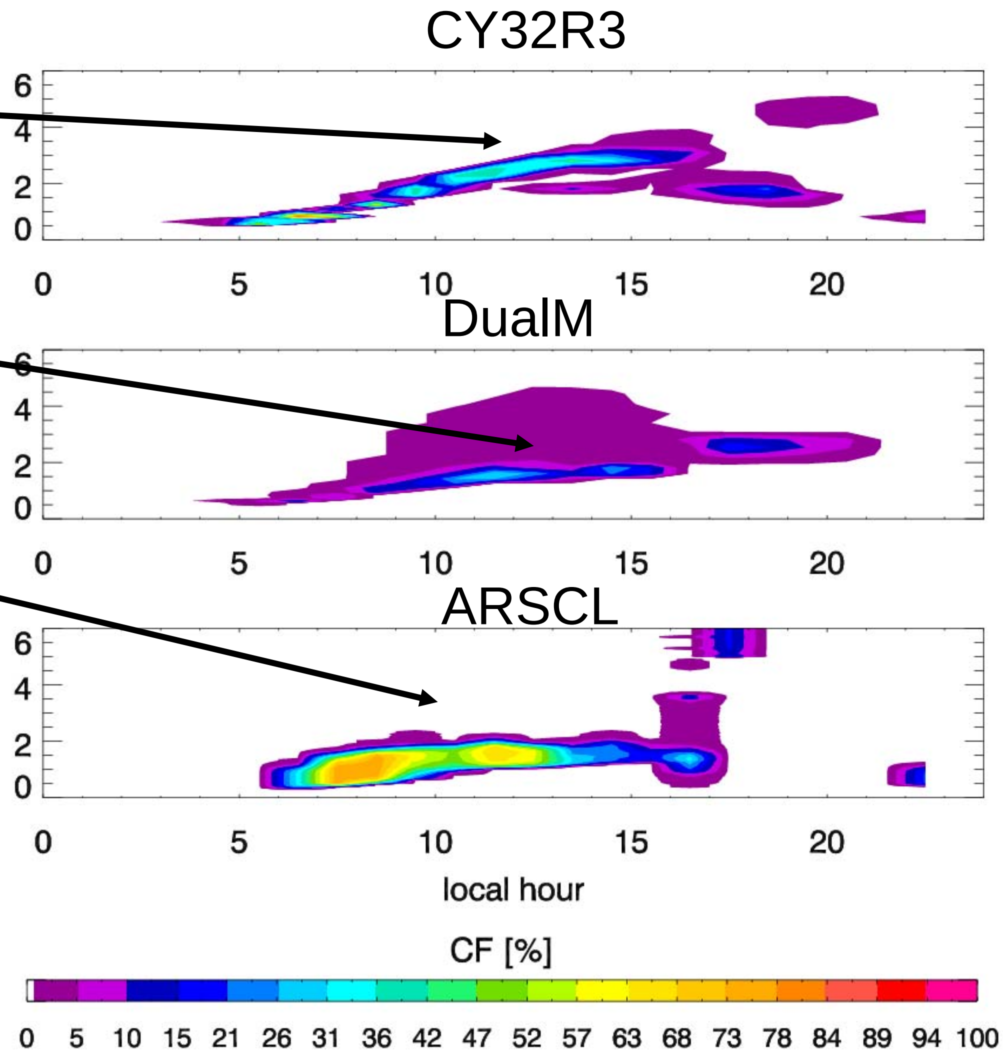


Is the DualM really missing "anvils"?

higher cloud fraction,
keeps going strong

cloud fraction drops
just after noon

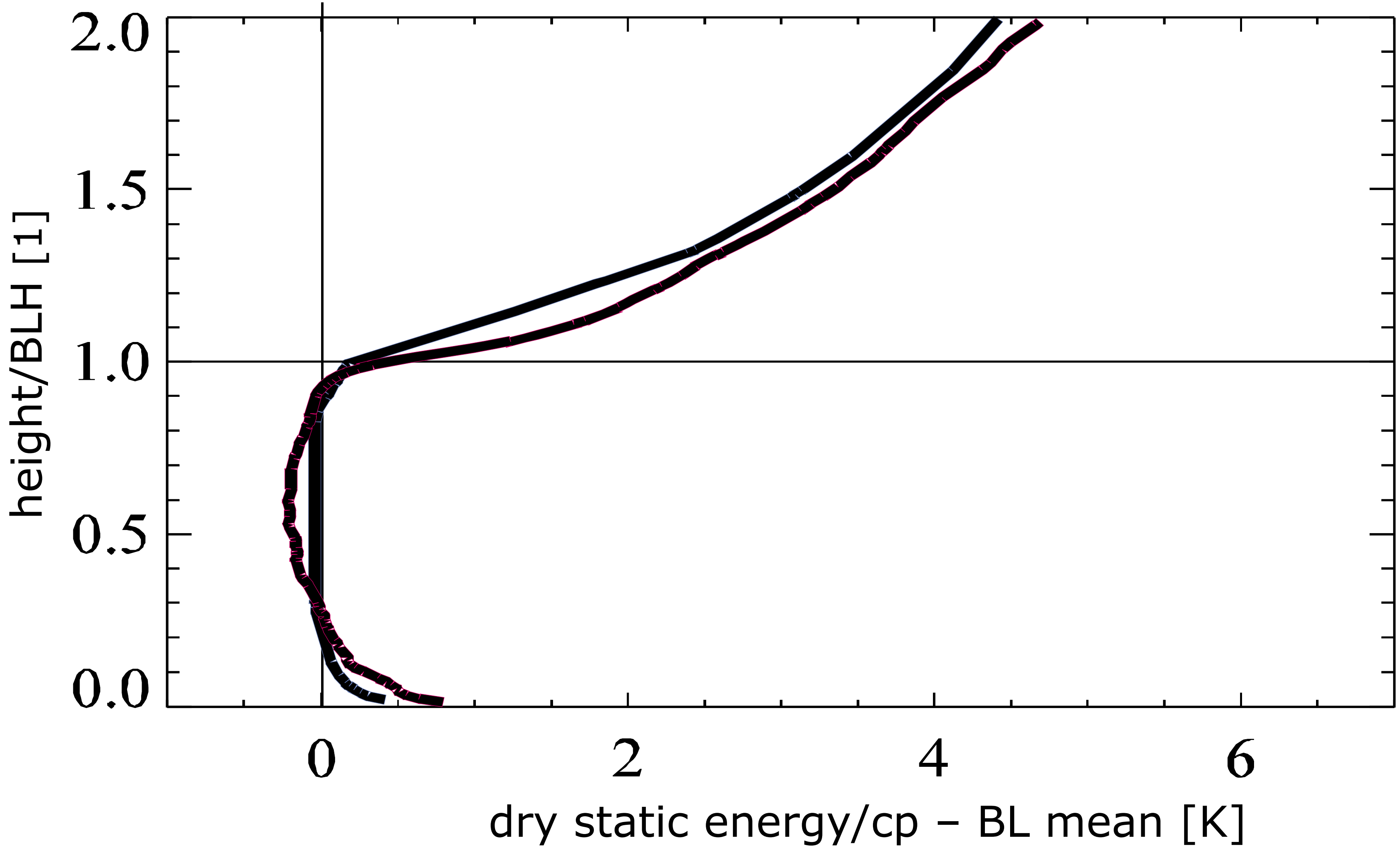
neither one very good!



ARM, SGP

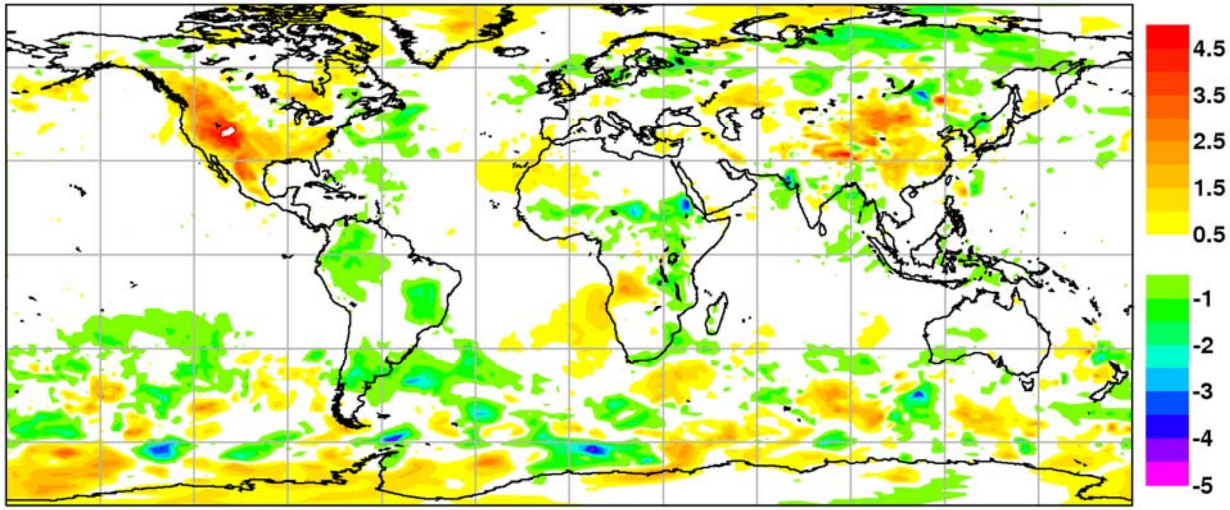
Maike Ahlgrimm

dry boundary layer: EDMF in ECMWF

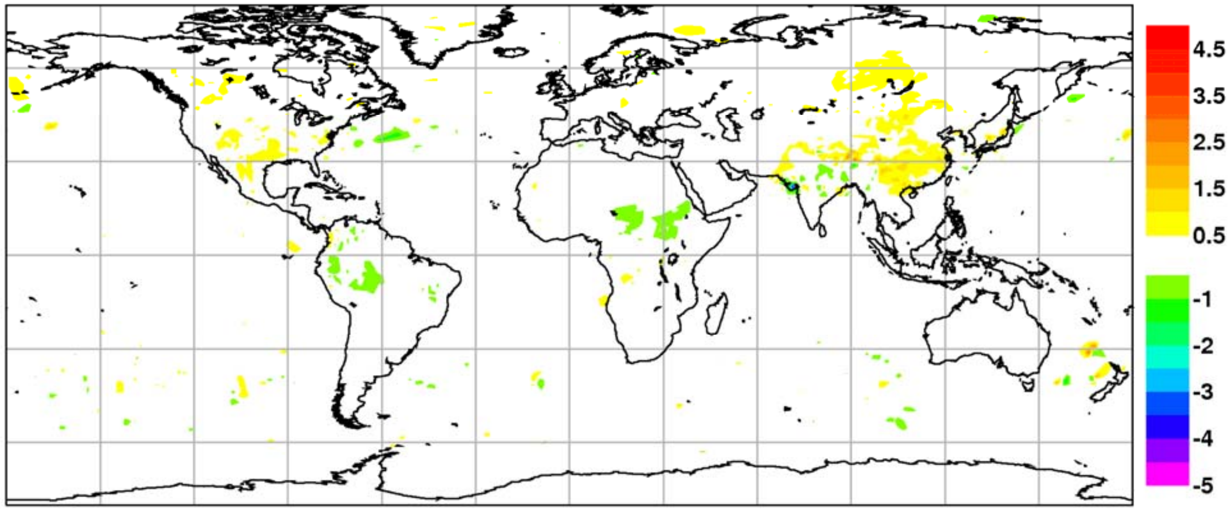


take out DUALM anvil

1000hPa rms Height [m] 20090601-20090731 48.54.60.66h fad4-f85s nfld:124
mnNH=0.199637 mnTR=-0.0399607 mnSH=0.00255049 rmsGL=0.652472

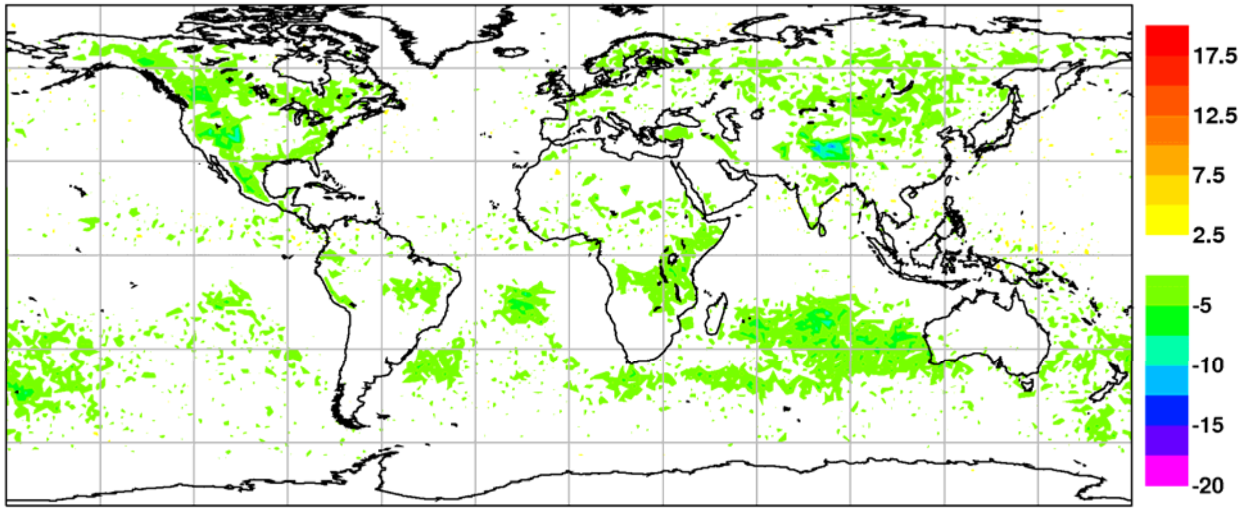


1000hPa rms Height [m] 20090601-20090731 48.54.60.66h fad4-facw nfld:124
mnNH=0.108241 mnTR=0.037236 mnSH=0.00955232 rmsGL=0.212823



take c

0hPa mean MCC [%] 20090601-20090731 48.54.60.66h fad4-facw nfld:124
mnNH=-0.972217 mnTR=-0.908108 mnSH=-1.05638 rmsGL=1.52048



0hPa mean LCC [%] 20090601-20090731 48.54.60.66h fad4-facw nfld:124
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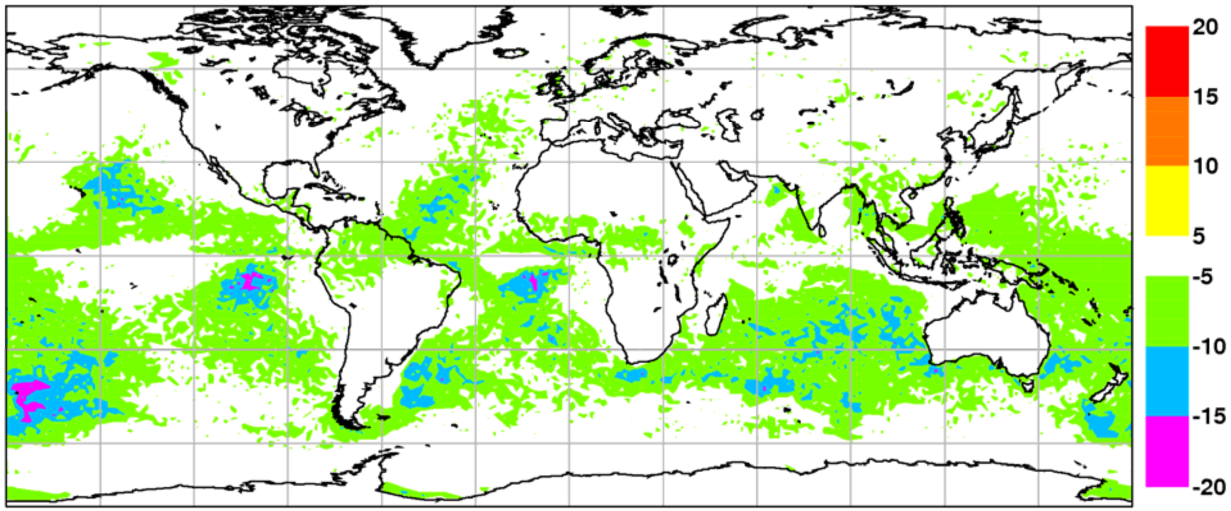
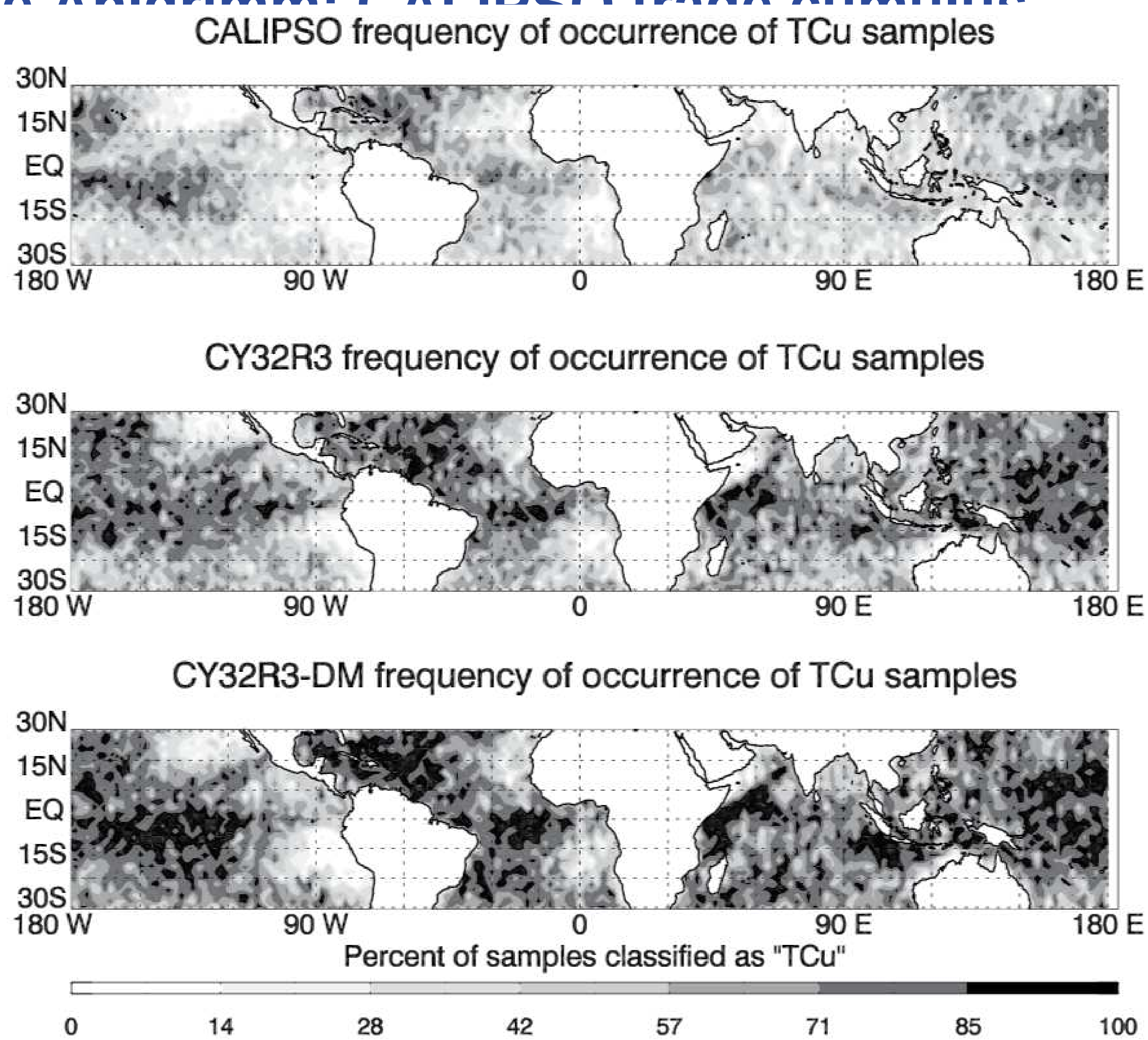
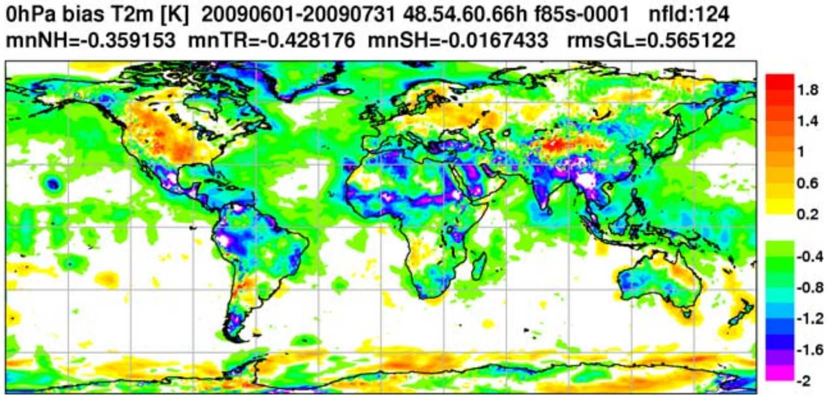


Maike Ahlgrimm: CALIPSO trade cumulus



T2m bias

CY35R1



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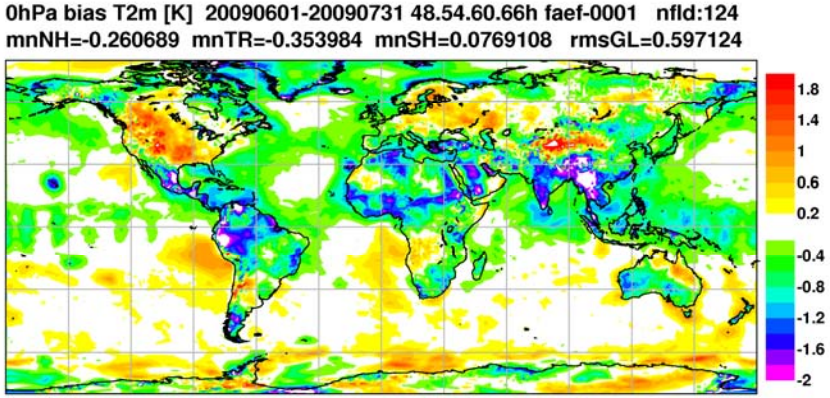

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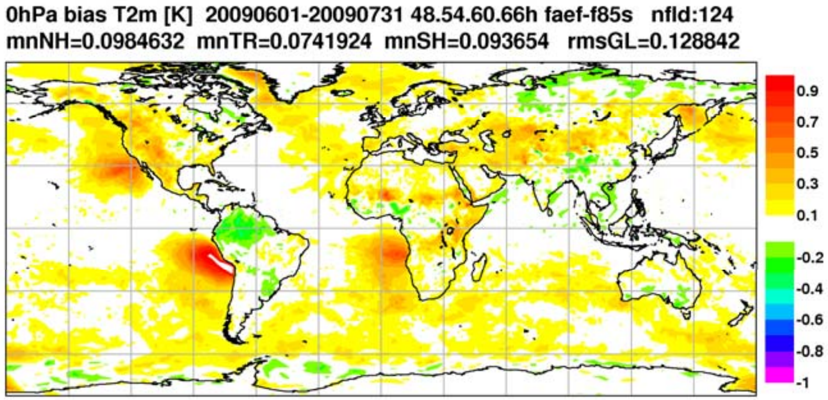

VOCALS: Radiosondes and dropsondes

Ron Brown radiosonde
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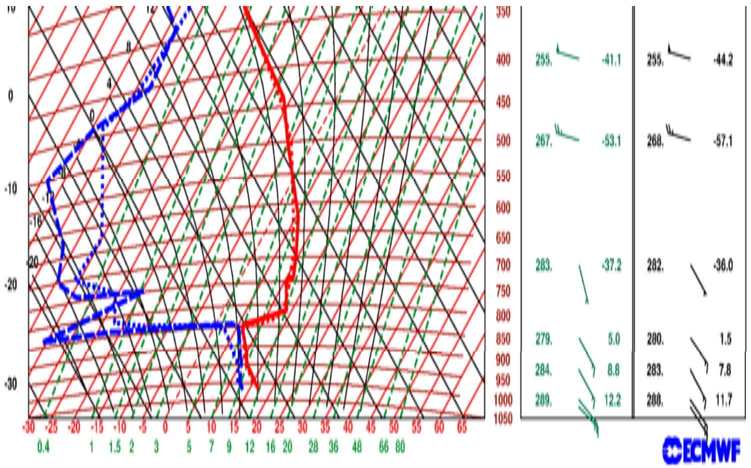

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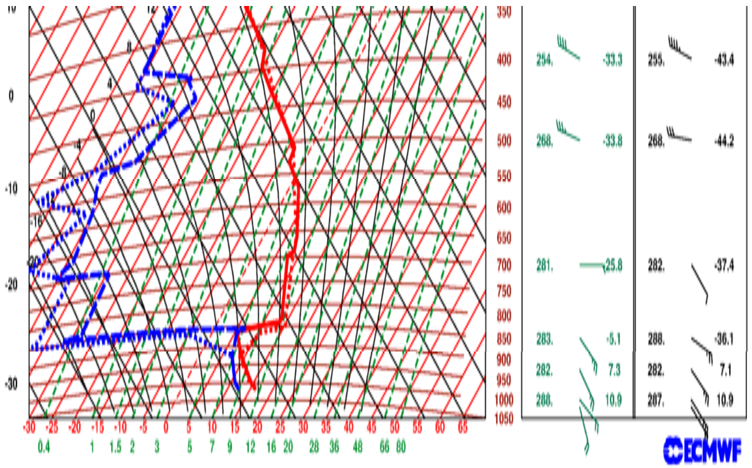

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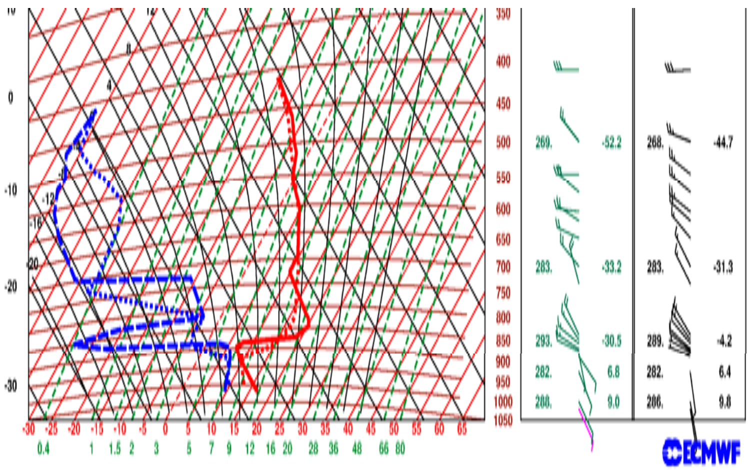

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