The use of high resolution simulations of tropical circulation to calibrate stochastic physics schemes

by

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Credits: Tim Palmer, Martin Miller and Anton Beljaars

‘Stochastic Physics’

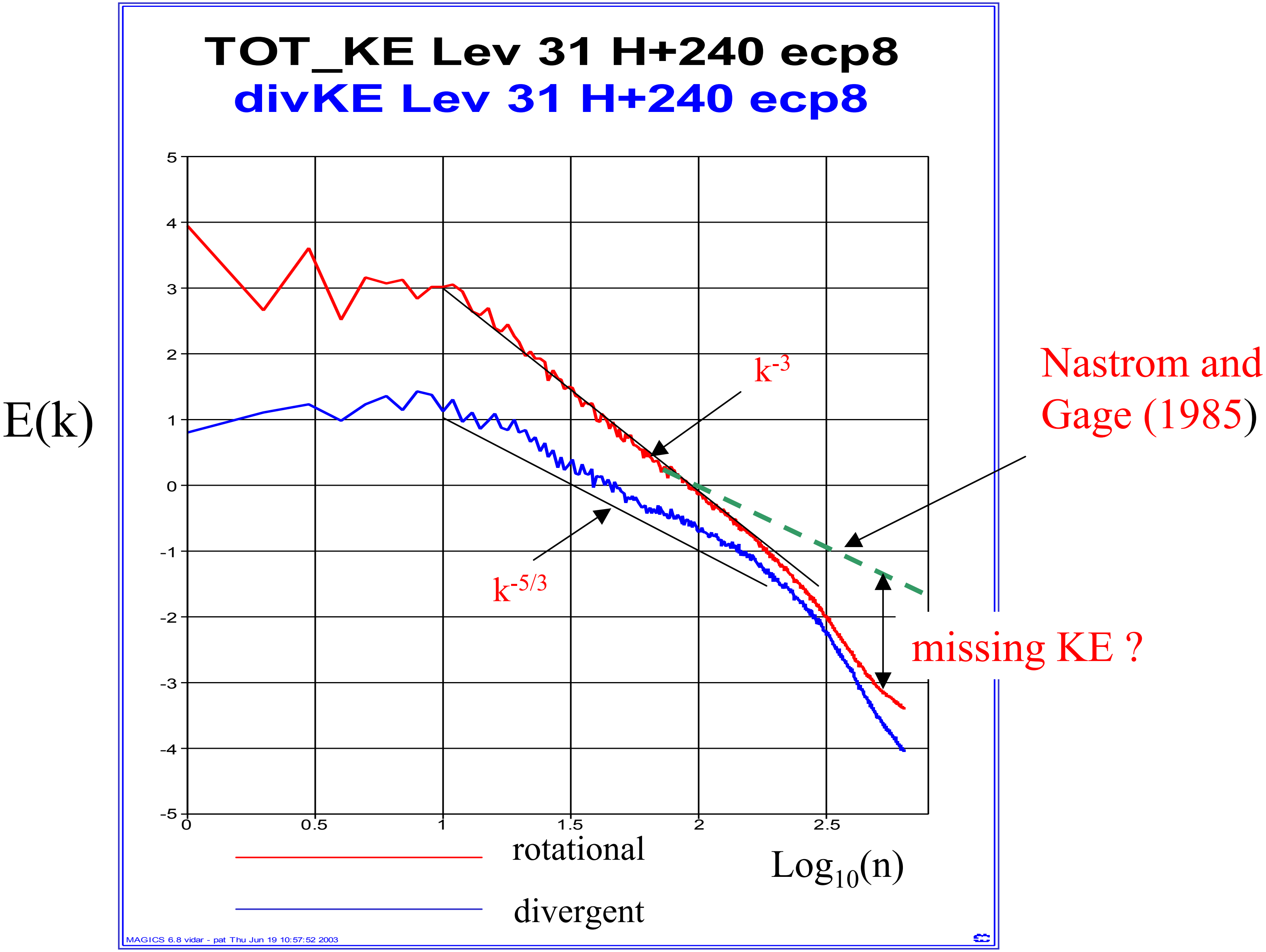
purpose:

- represent unpredictable statistical fluctuations in parametrized physics
- ‘backscatter’ kinetic energy into the near-gridscales of forecast model

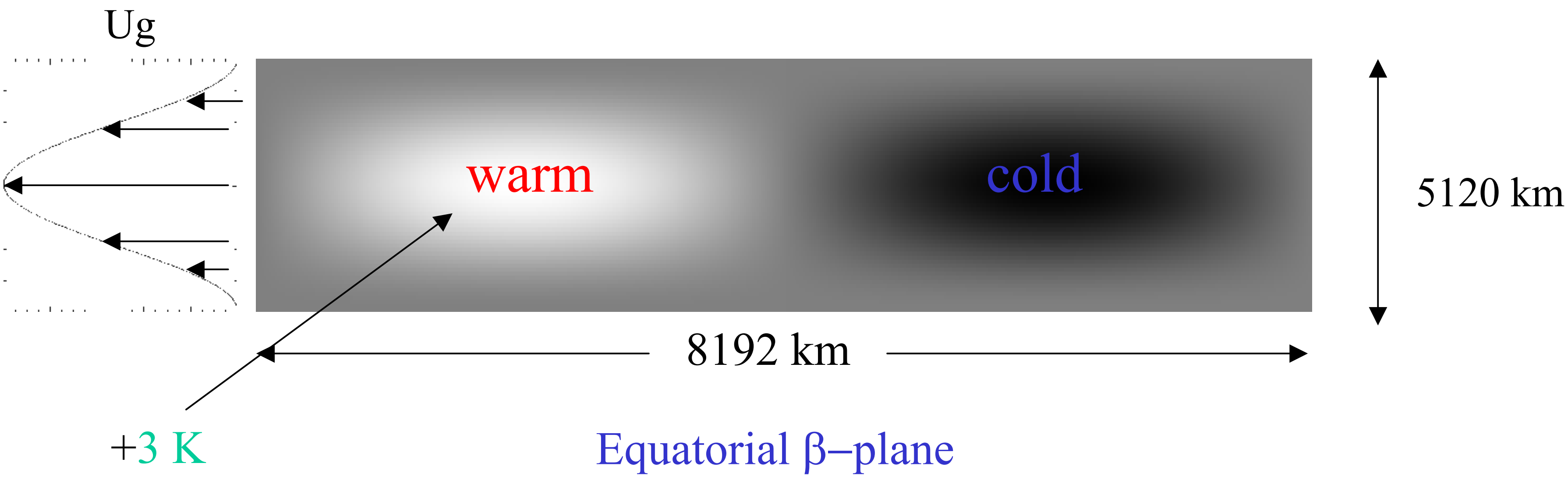
expected/desired impacts:

- broader ensemble member spread in EPS
- statistically more realistic near-gridscale flow features e.g. frontal waves, mesoscale vortices, small PV features
- improved tropical flow variability (MJO)
- reduced systematic error, better model climate simulation

Kinetic energy spectra in T799 ECMWF forecast (day 10)

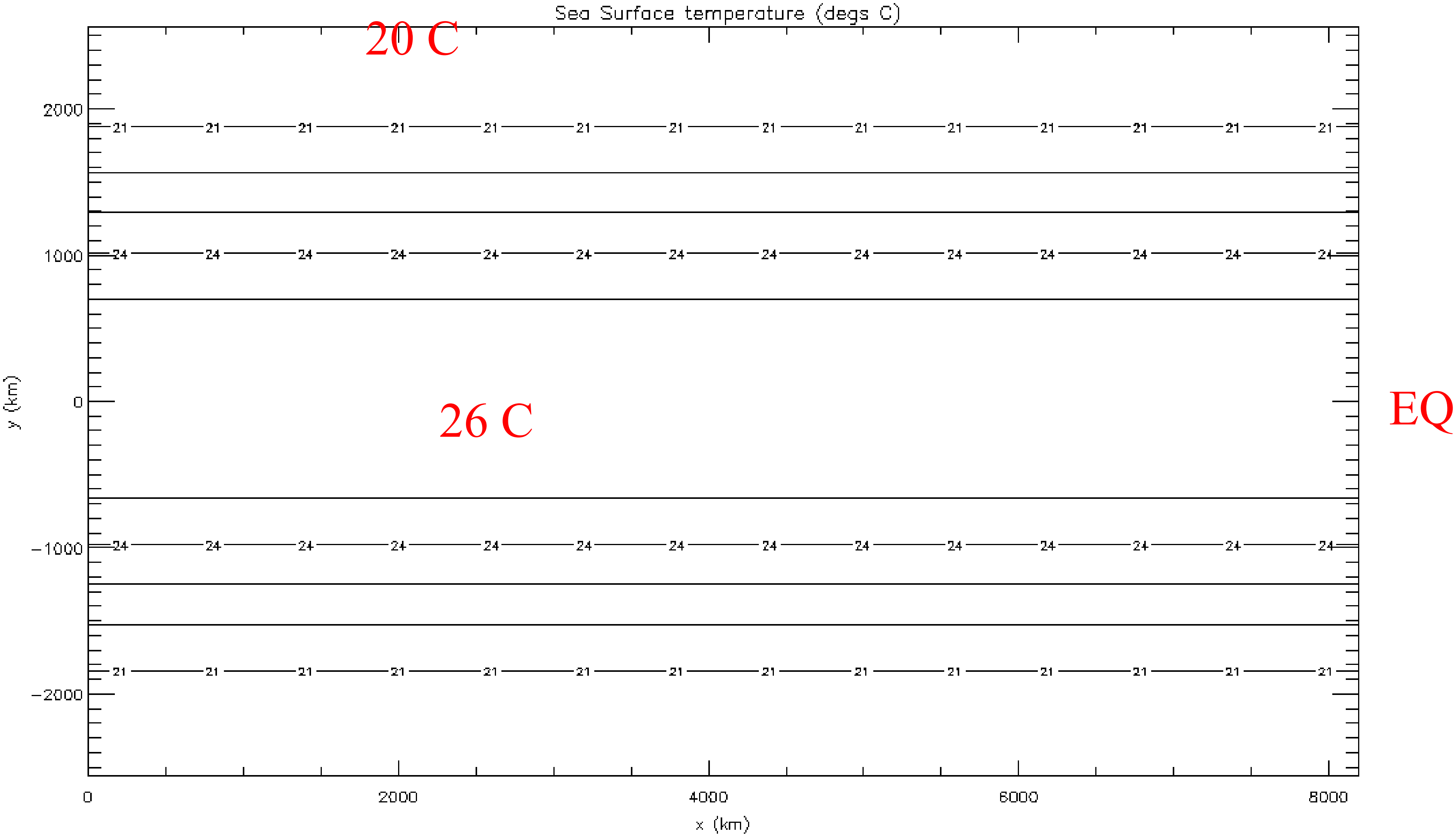


Cloud-resolving model of tropical convection over variable SST



- use anisotropic grid: e.g. dx= 1 or 2 km, dy=40 km
- derive statistics of mesoscale cloud forcing at the `filter scale' of an NWP model
- repeat simulation at NWP resolution e.g. dx=dy=40 km with convective parametrization

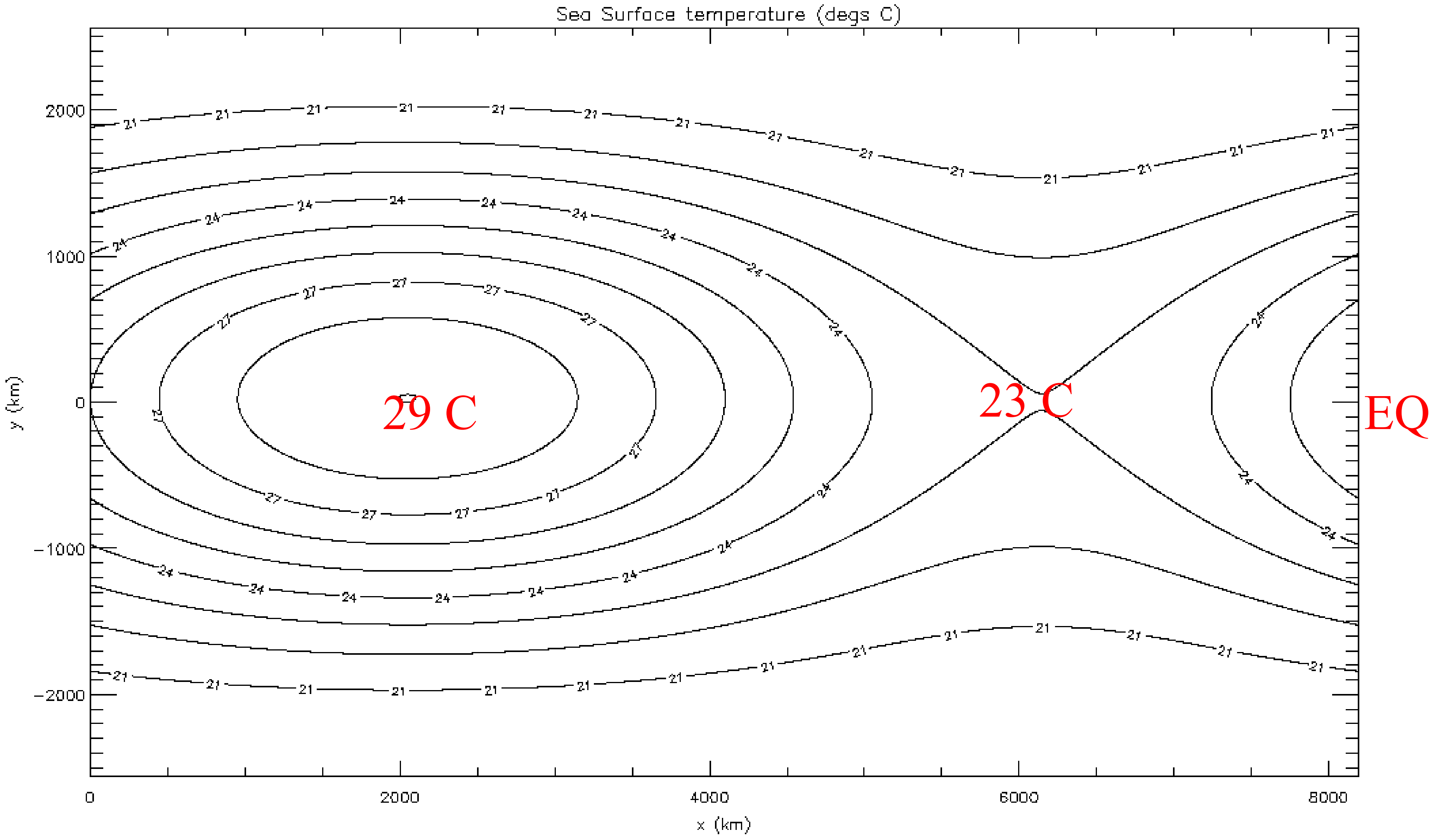
SST fields used



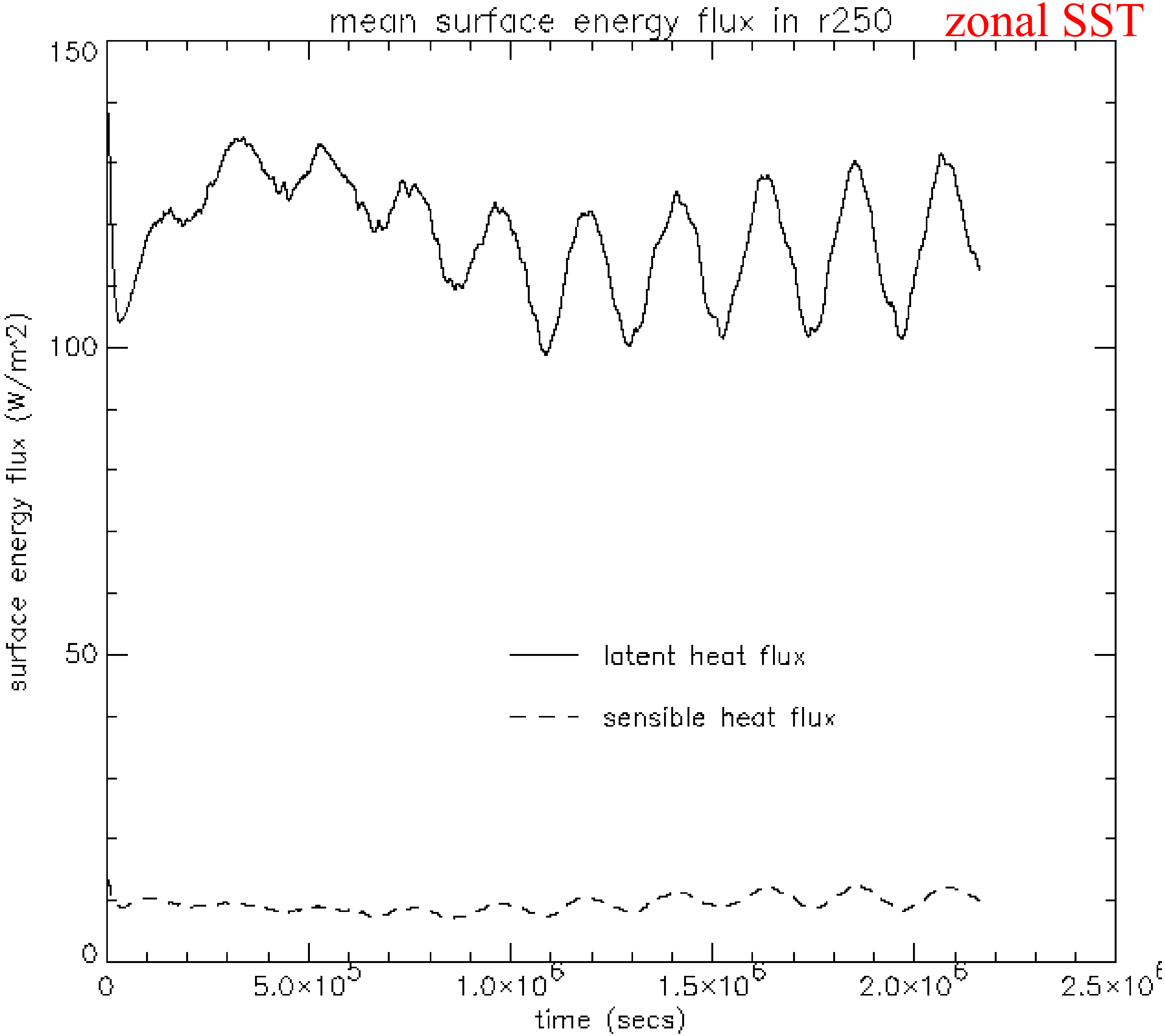
0

8000 km

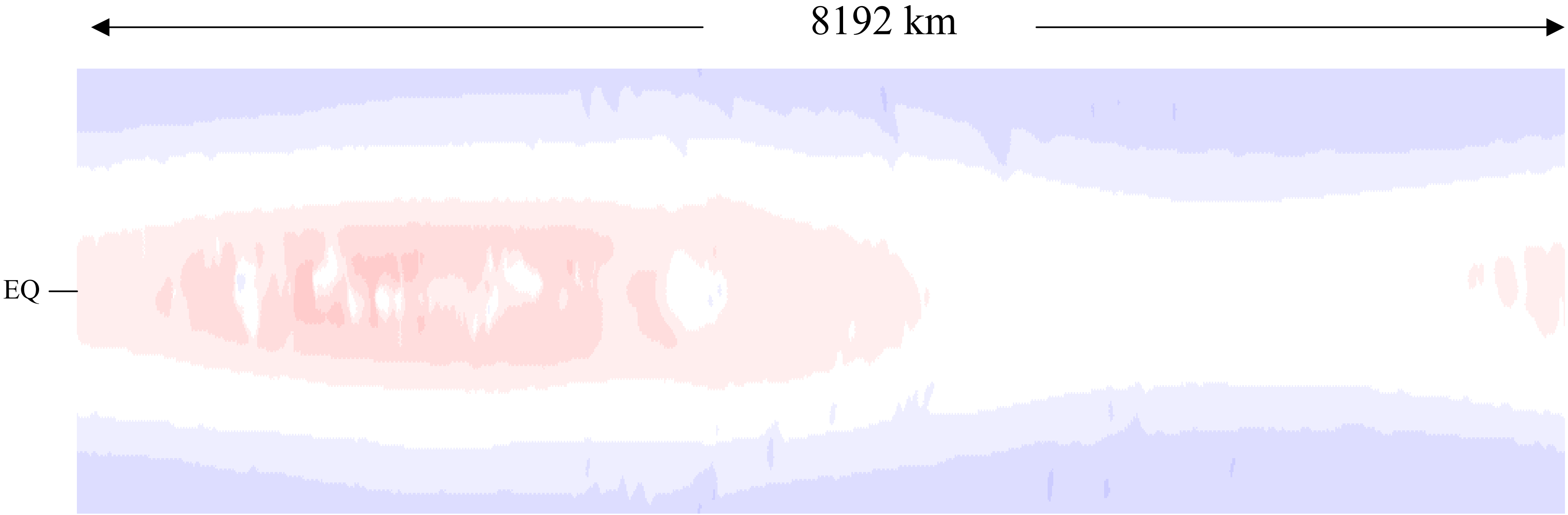
with east-west SST anomaly



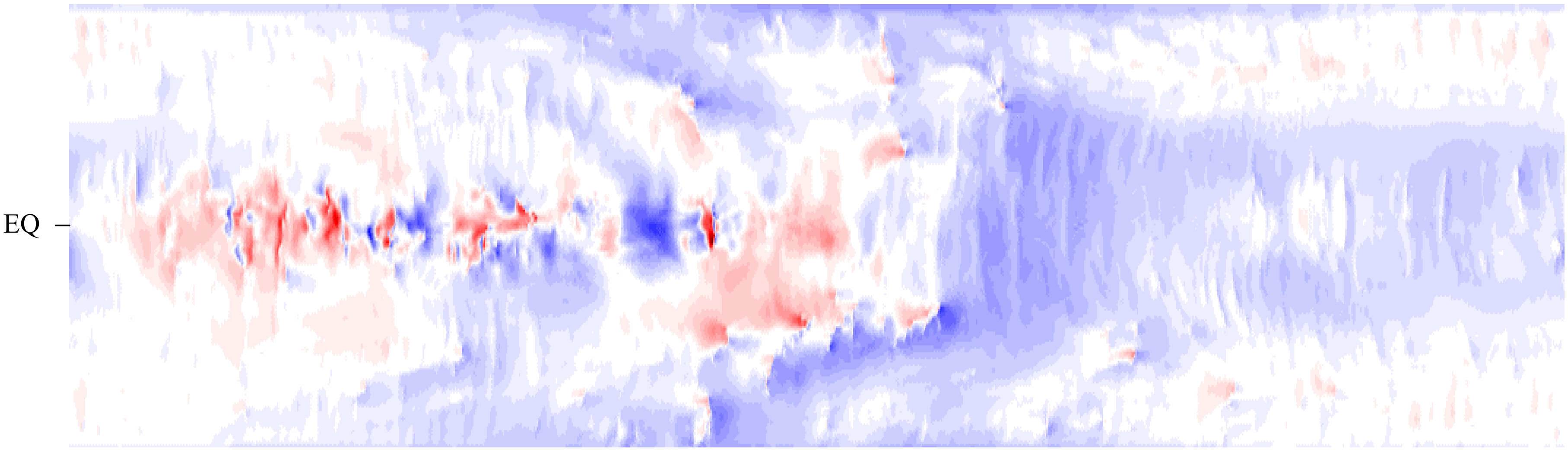
zonal SST


mean surface energy flux in r250
surface energy flux (W/m^2)
150
100
50
0
0
5.0×10^5
1.0×10^6
1.5×10^6
2.0×10^6
2.5×10^6
time (secs)
latent heat flux
sensible heat flux

Surface fields on day 29



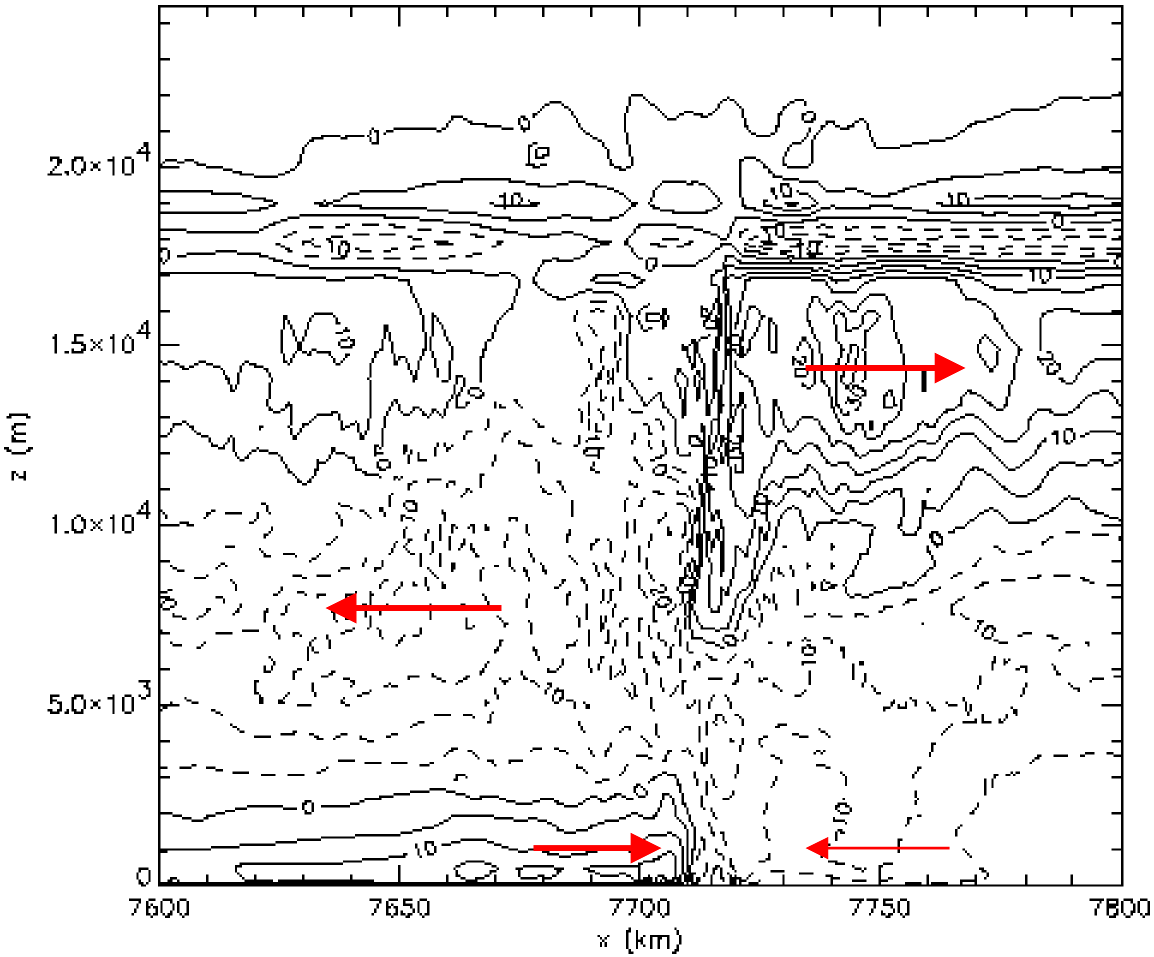
temperature at z=160 m red=30 C blue=23 C



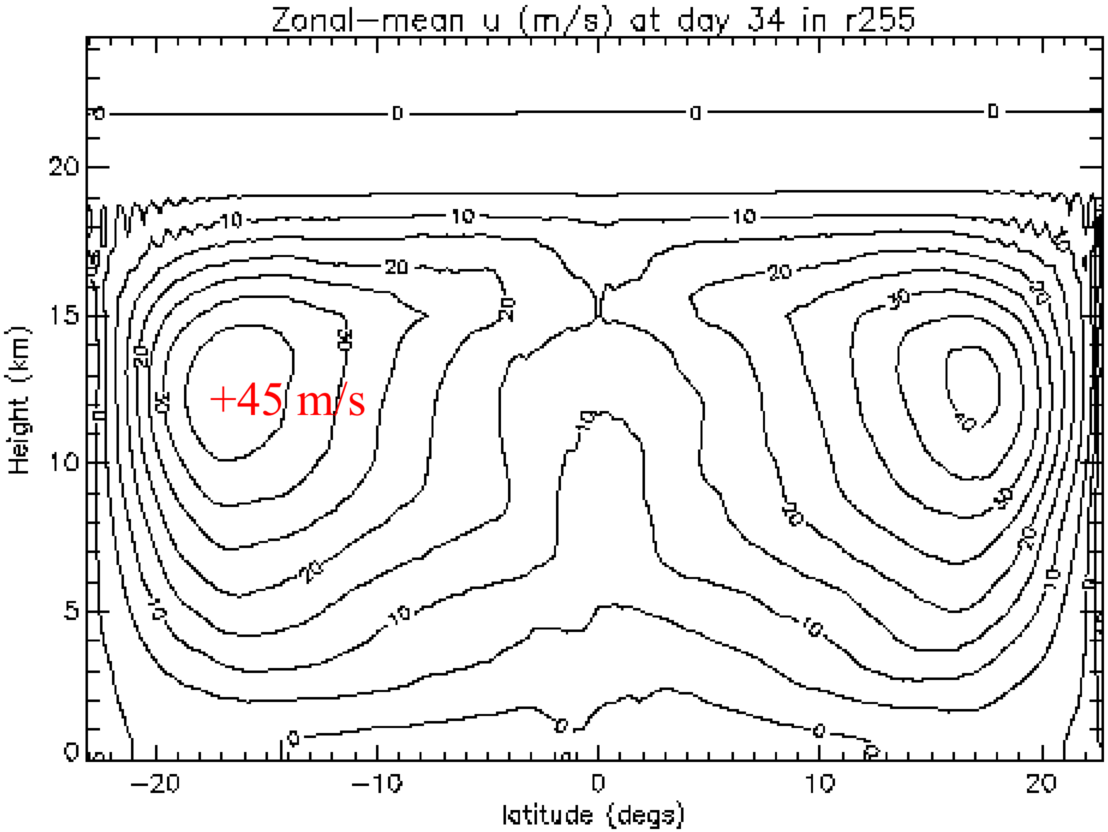
u at z=160 m red=28 m/s blue= - 18 m/s

xz-section of u along equator (day 26)

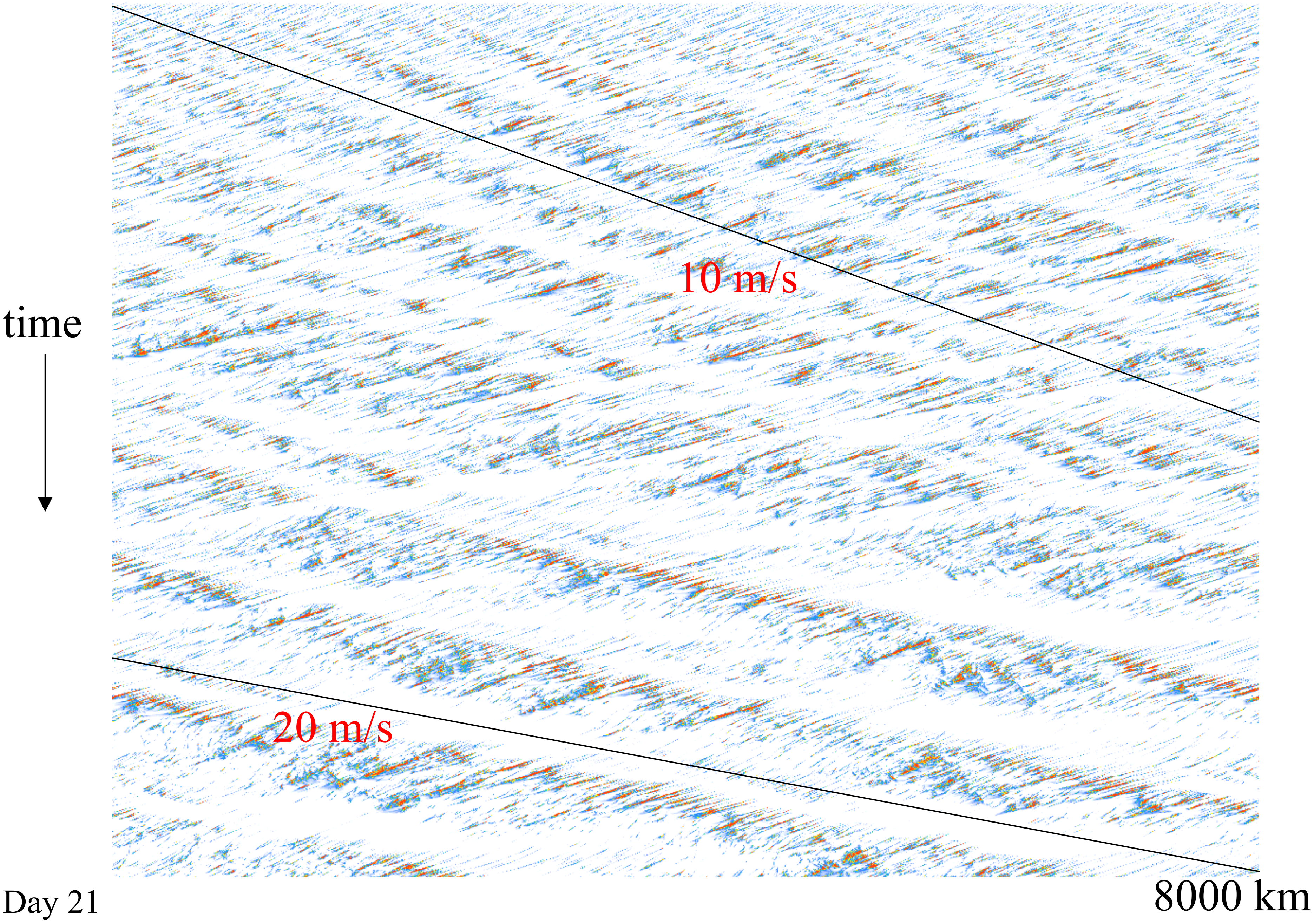
dx= 2 km E-W SST gradient



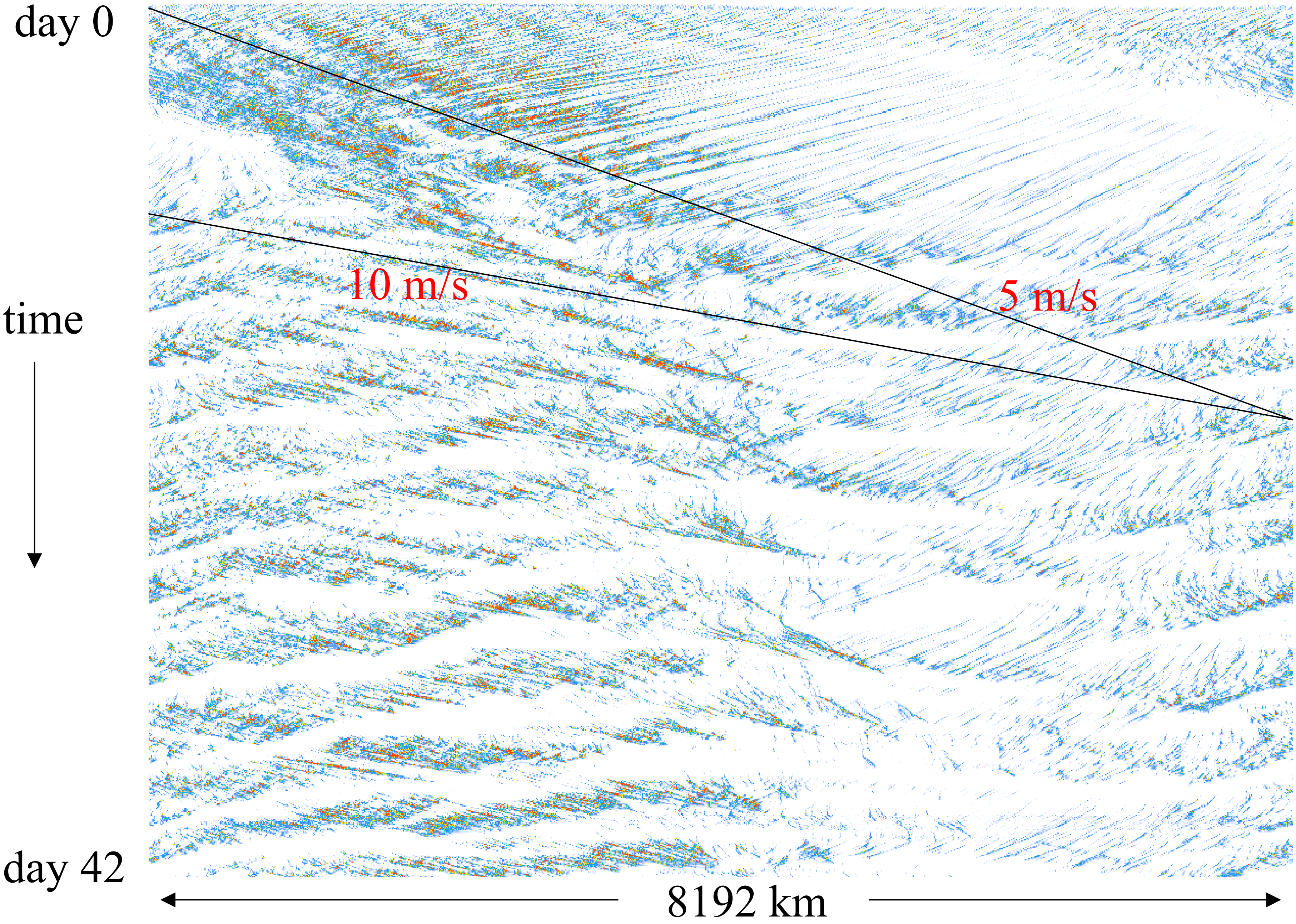
zonal-mean u in latitude-height section on day 34



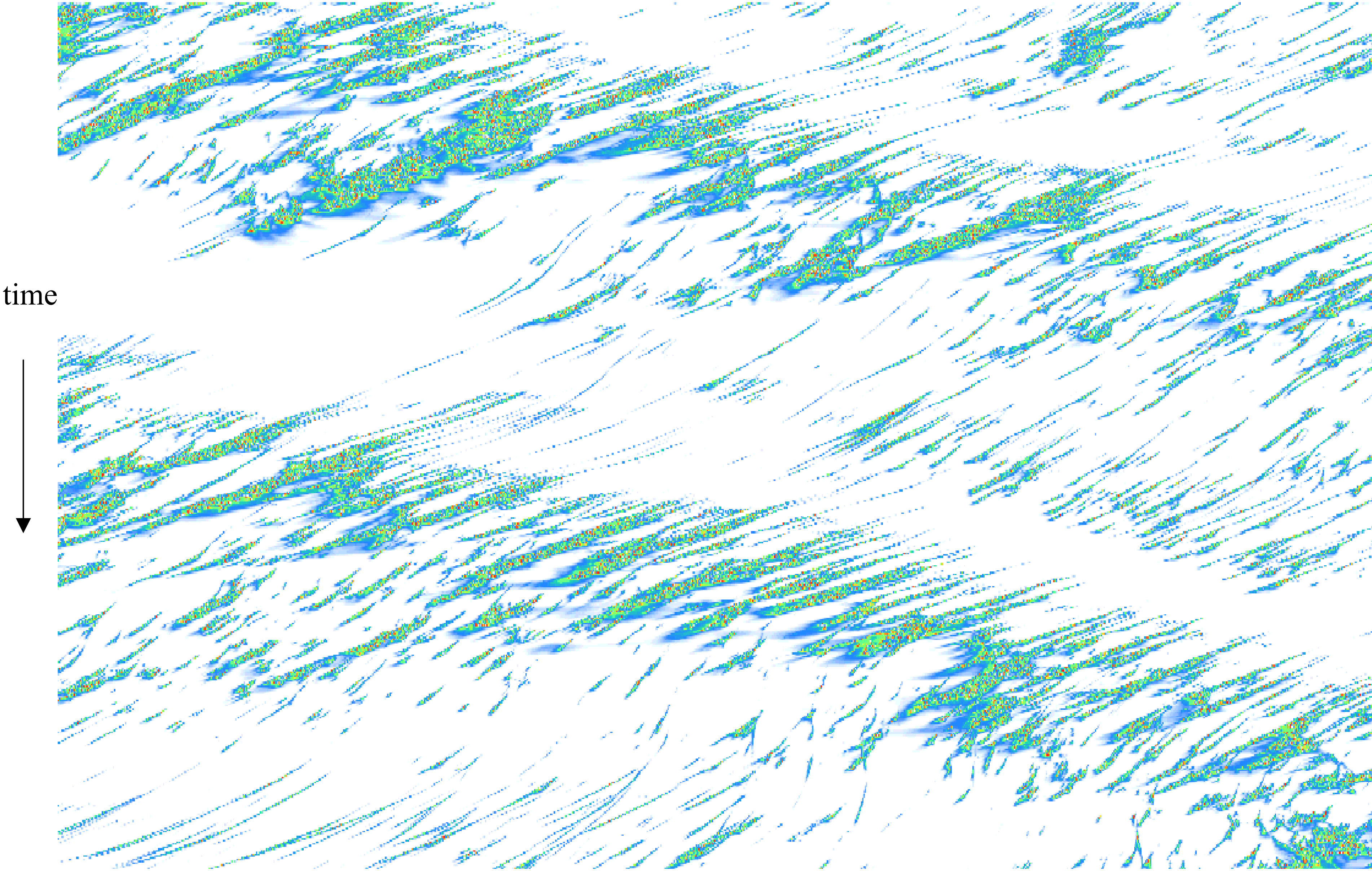
Hovmuller diagram for zonal SST case



-10 to +10 deg. lat mean precipitation as Hovmuller plot

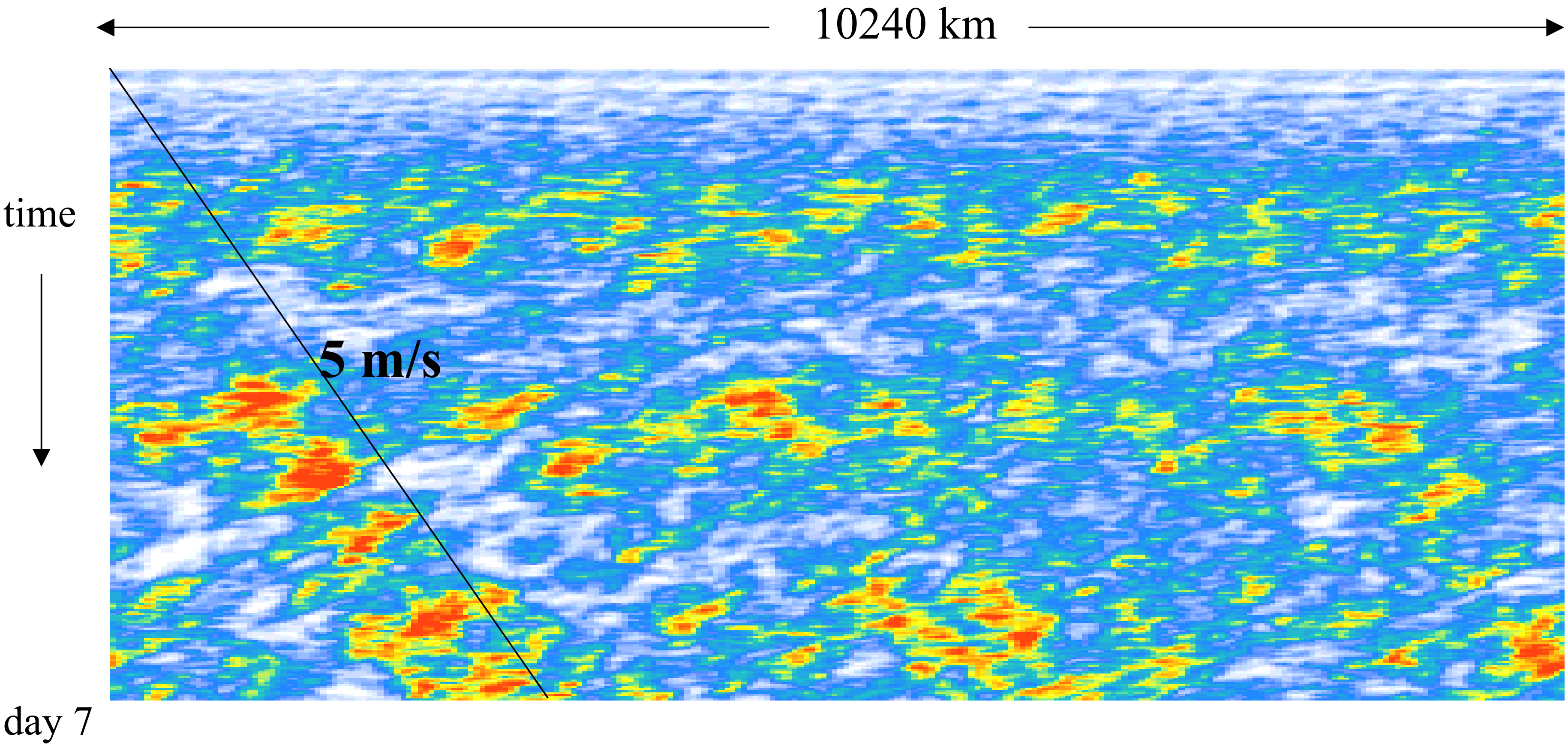


Zoomed view of Hovmuller plot from dx=1 km config.



Hovmuller diagram of precipitation rate with dx=40 km dy=1.5 km

- high resolution in the y-direction



compute apparent convective forcing by coarse-graining model fields

- average fields over coarse grid boxes (e.g. 64 x 80 km)

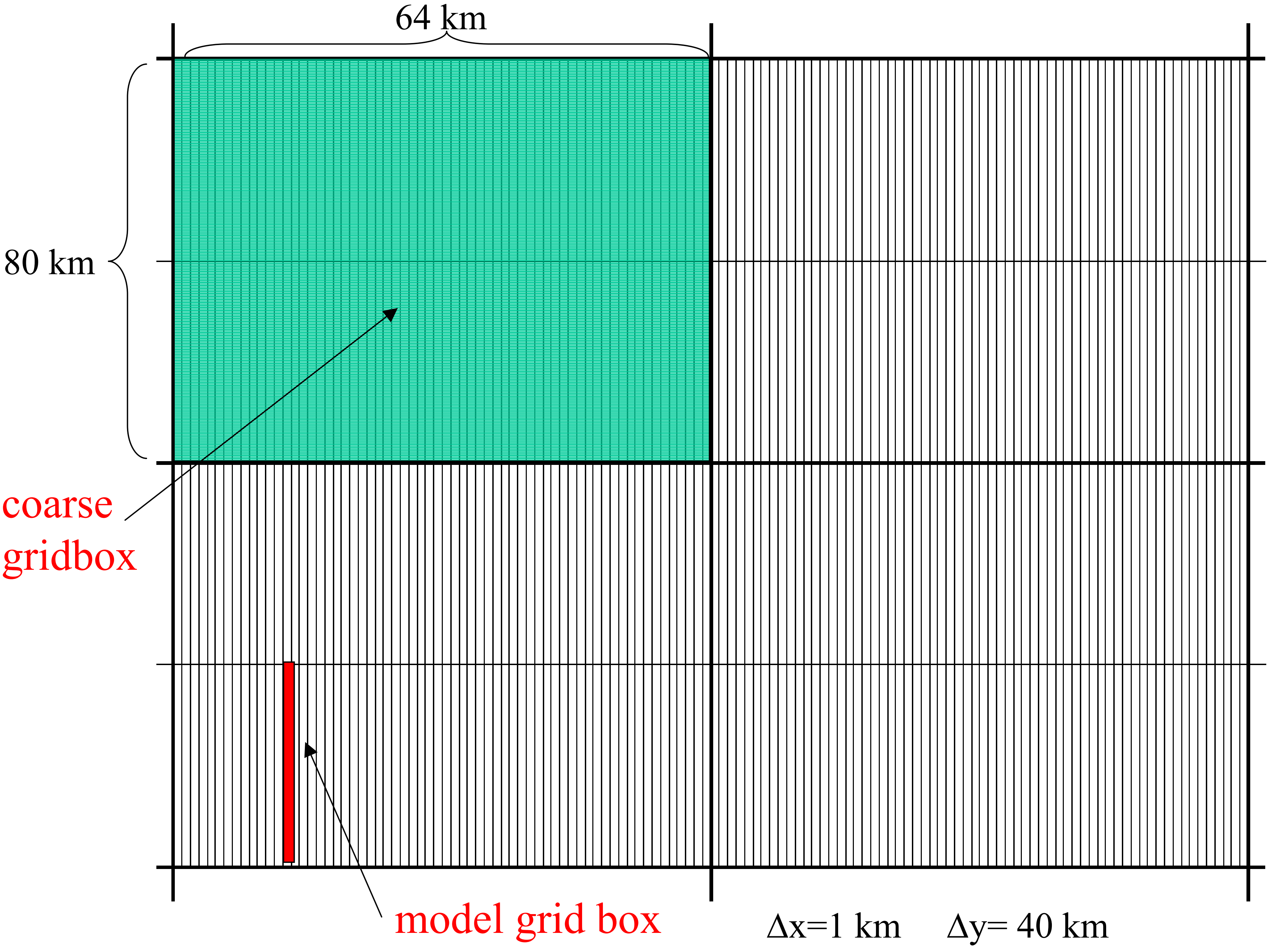
diabatic terms

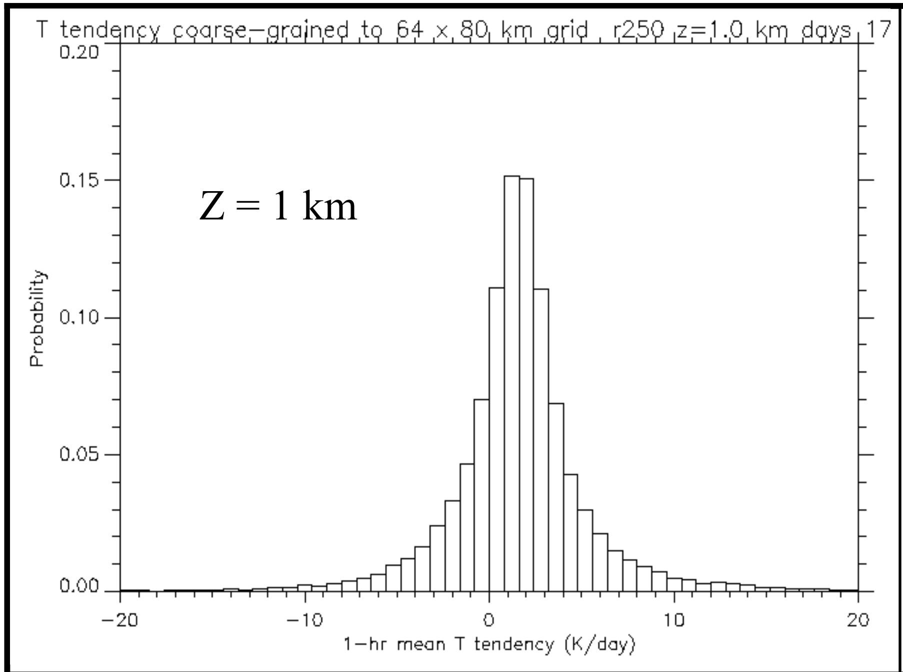
Thermodynamic eq.

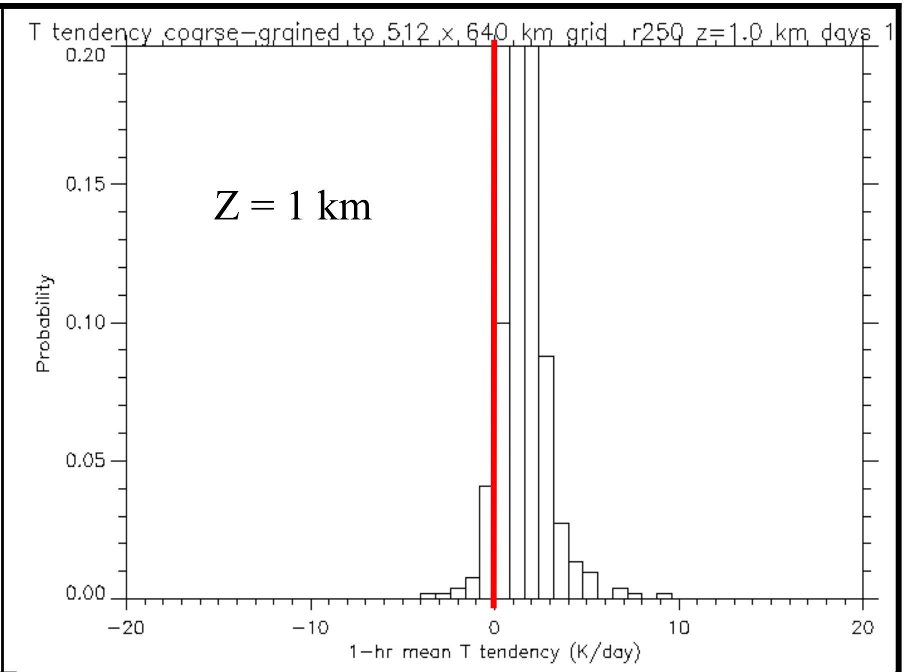
$$\frac{\partial\overline{\theta}}{\partial t} + \overline{\mathbf{V}}\cdot\nabla\overline{\theta} = \underbrace{\overline{\mathbf{V}}\cdot\nabla\overline{\theta} - \overline{\mathbf{V}\cdot\nabla\theta}}_{\text{apparent forcing}} + \overline{D} = \mathbf{Q_1}$$

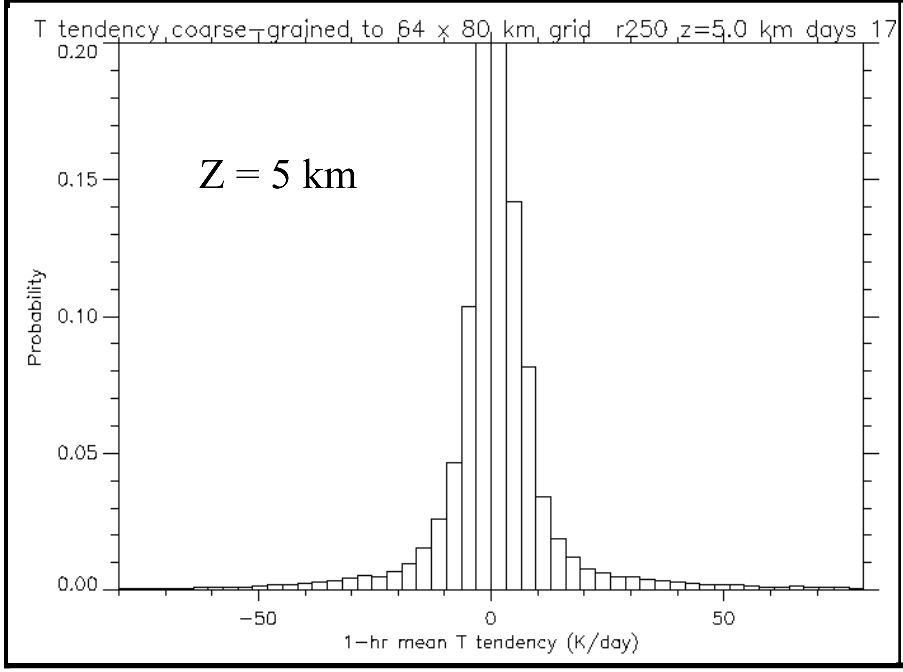
(definition)

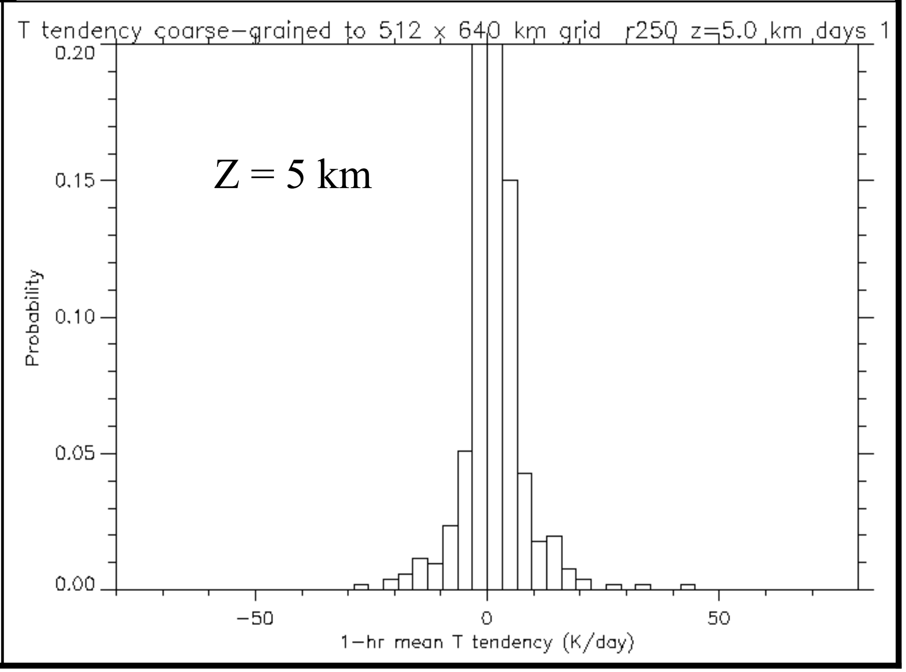
Overbar = 1 hour average over coarse grid box


64 km
80 km
coarse gridbox
model grid box
Δx=1 km
Δy= 40 km

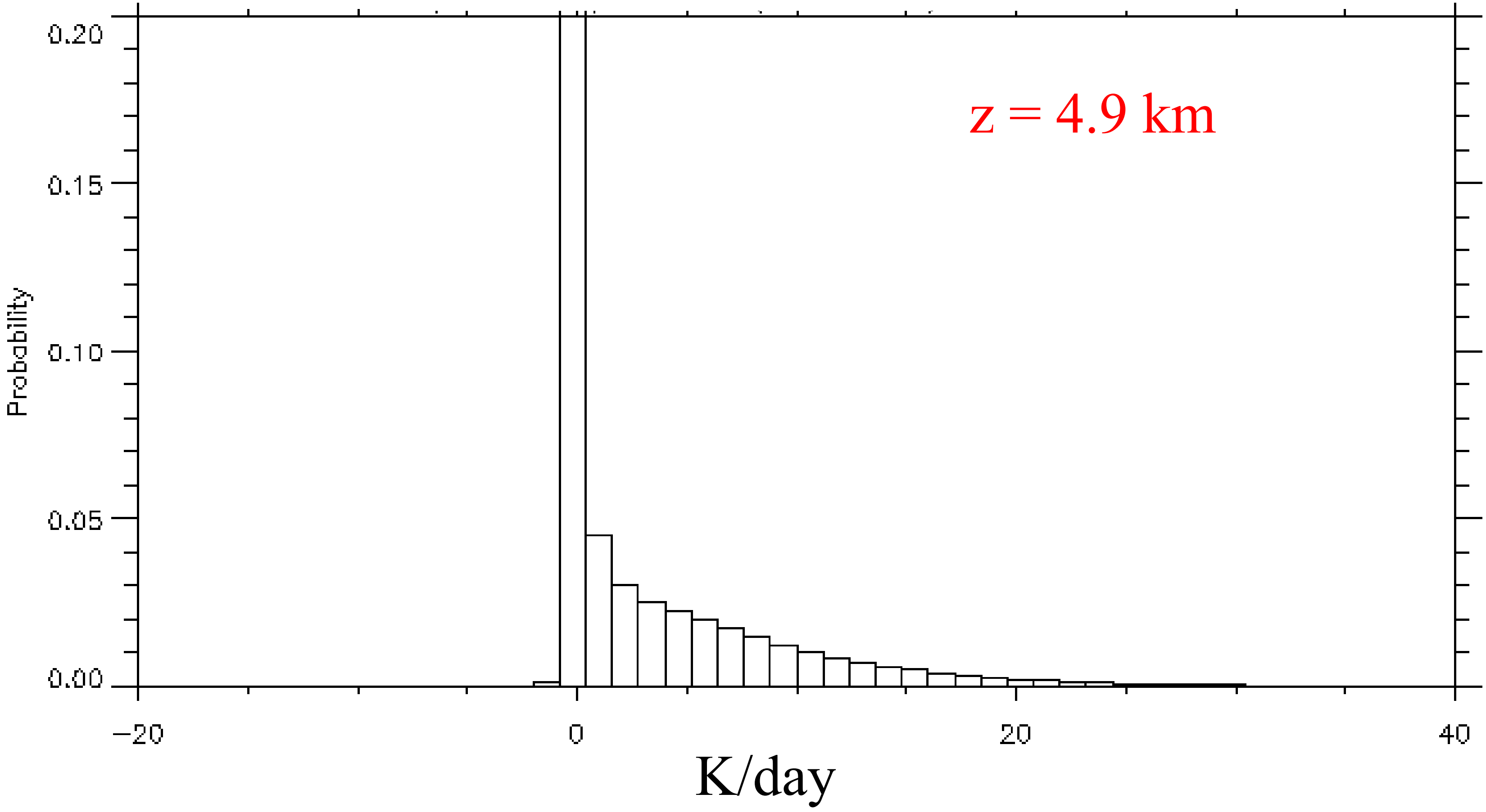

T tendency coarse-grained to 64 x 80 km grid , r250 z=1.0 km days 17
Z = 1 km
Probability
0.20
0.15
0.10
0.05
0.00
−20
−10
0
10
20
1−hr mean T tendency (K/day)


T tendency coarse-grained to 512 x 640 km grid , r250 z=1.0 km days 1
Z = 1 km
Probability
0.20
0.15
0.10
0.05
0.00
−20
−10
0
10
20
1−hr mean T tendency (K/day)

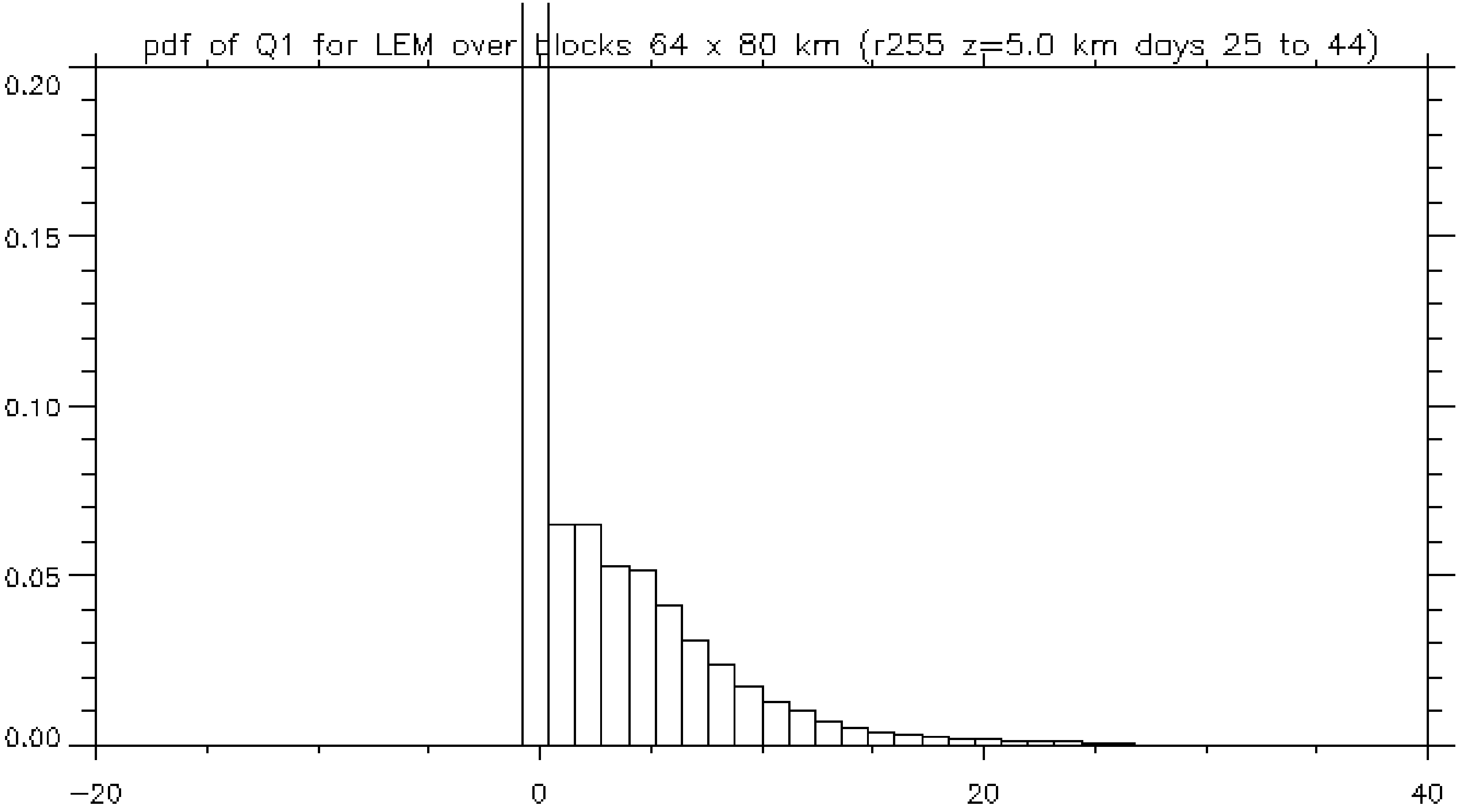

T tendency coarse-grained to 64 x 80 km grid r250 z=5.0 km days 17
Z = 5 km
Probability
0.20
0.15
0.10
0.05
0.00
−50
0
50
1−hr mean T tendency (K/day)


T tendency coarse-grained to 512 x 640 km grid r250 z=5.0 km days 1
Z = 5 km
Probability
0.20
0.15
0.10
0.05
0.00
−50
0
50
1−hr mean T tendency (K/day)

Q1 (convective) in region 20 N to 20 S in the ECMWF forecast model (T255)

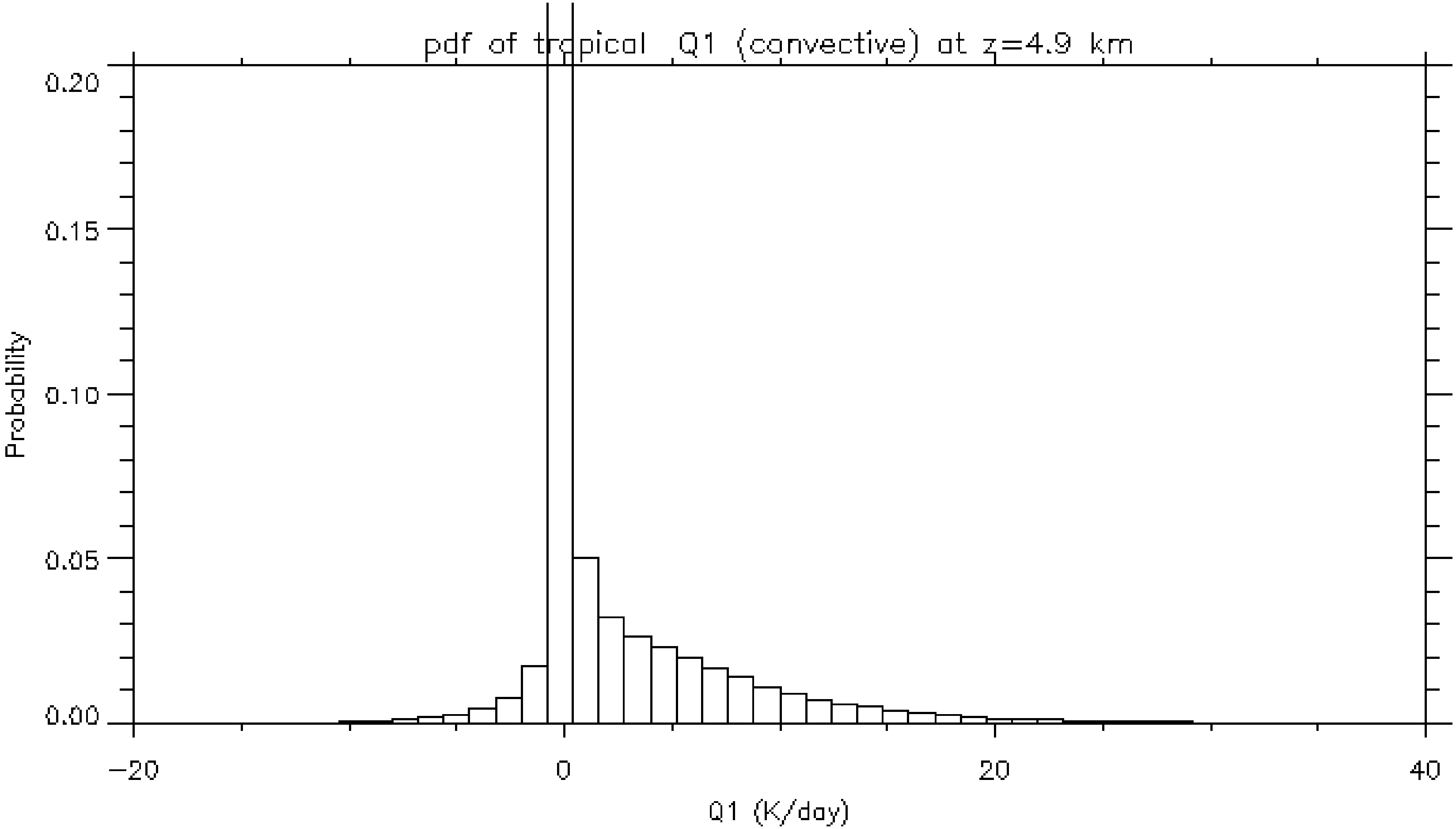


diagnosed pdf of Q1 from CRM from coarse-grained fields

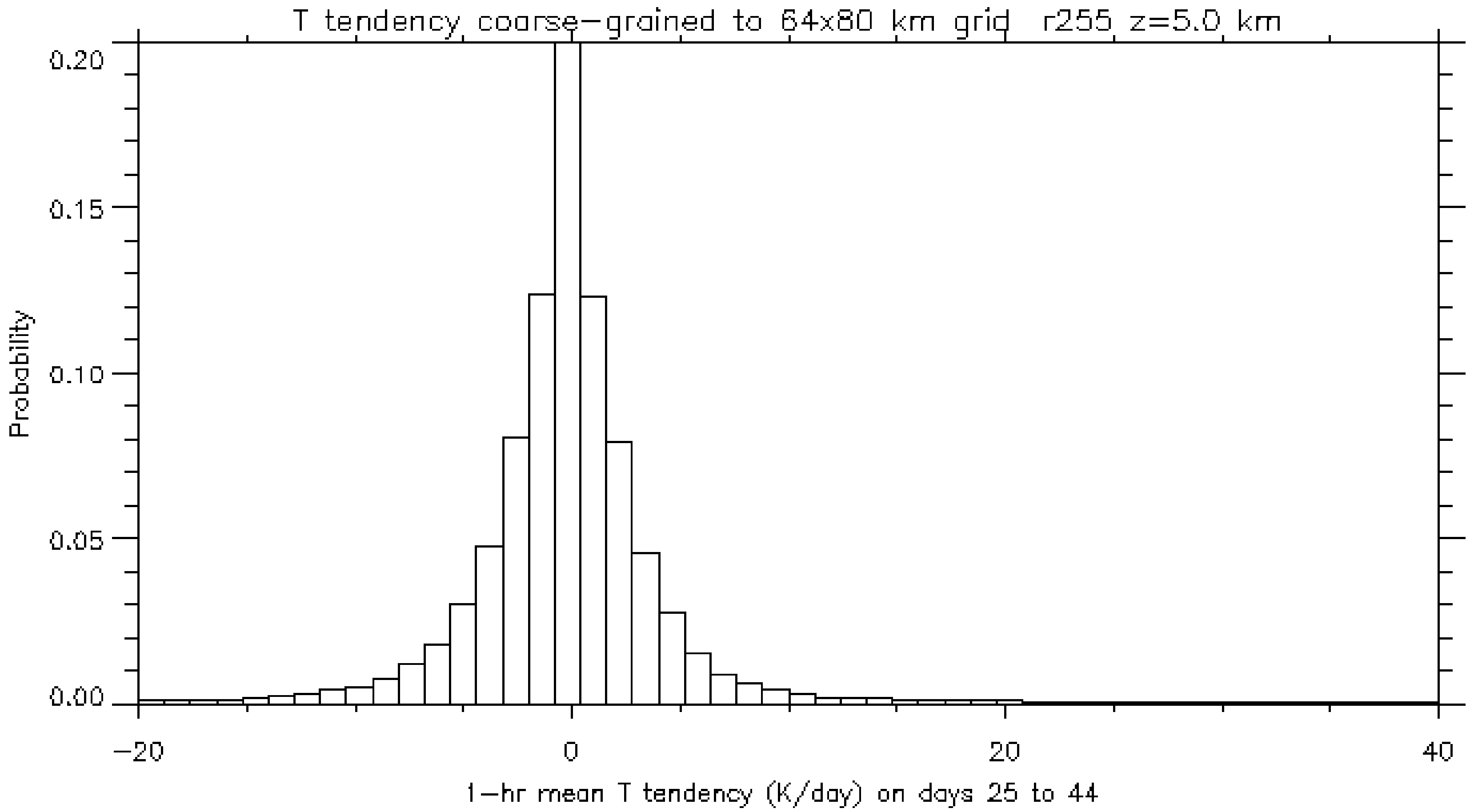


K/day

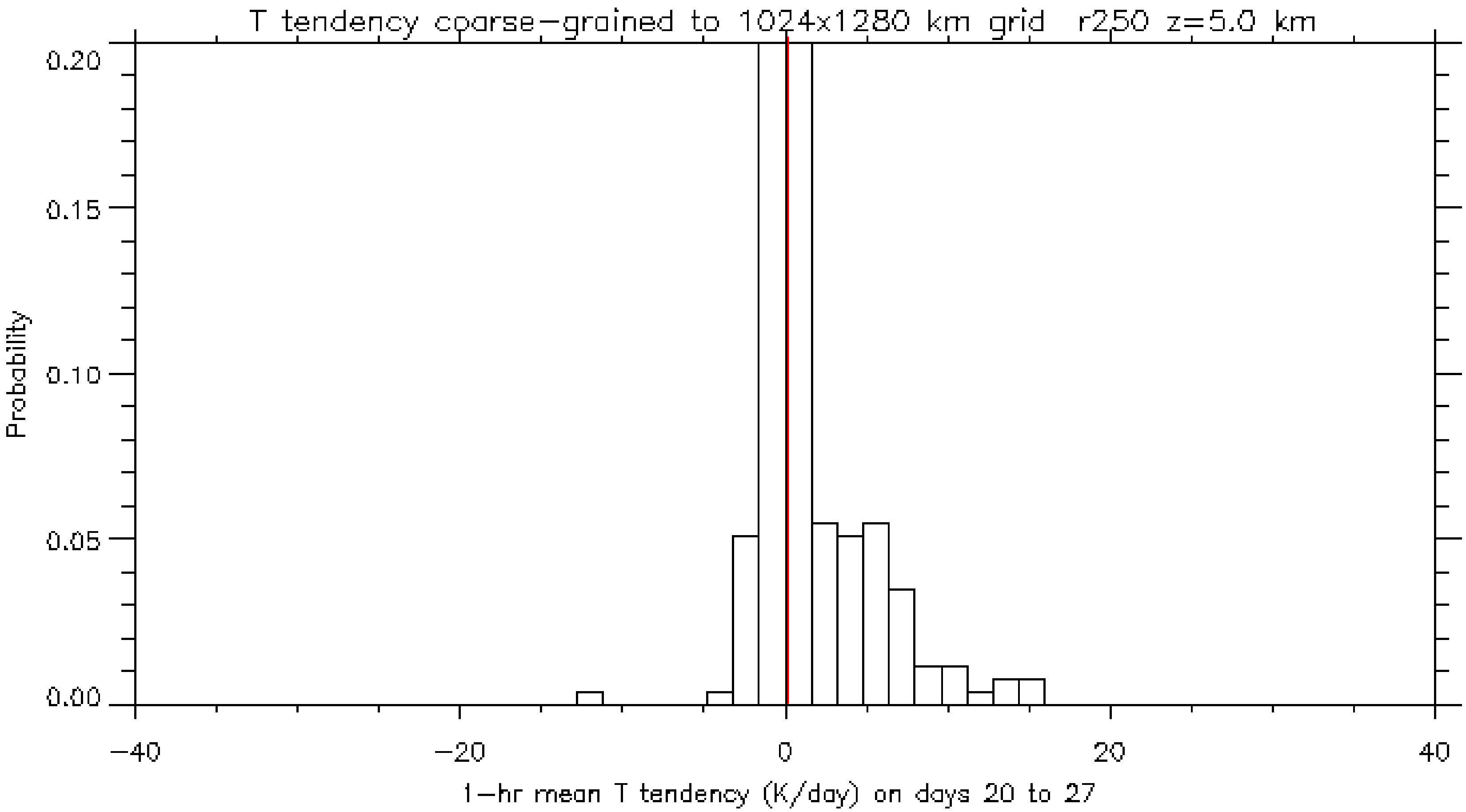
Q1 (total) from ECMWF model at z= 5 km



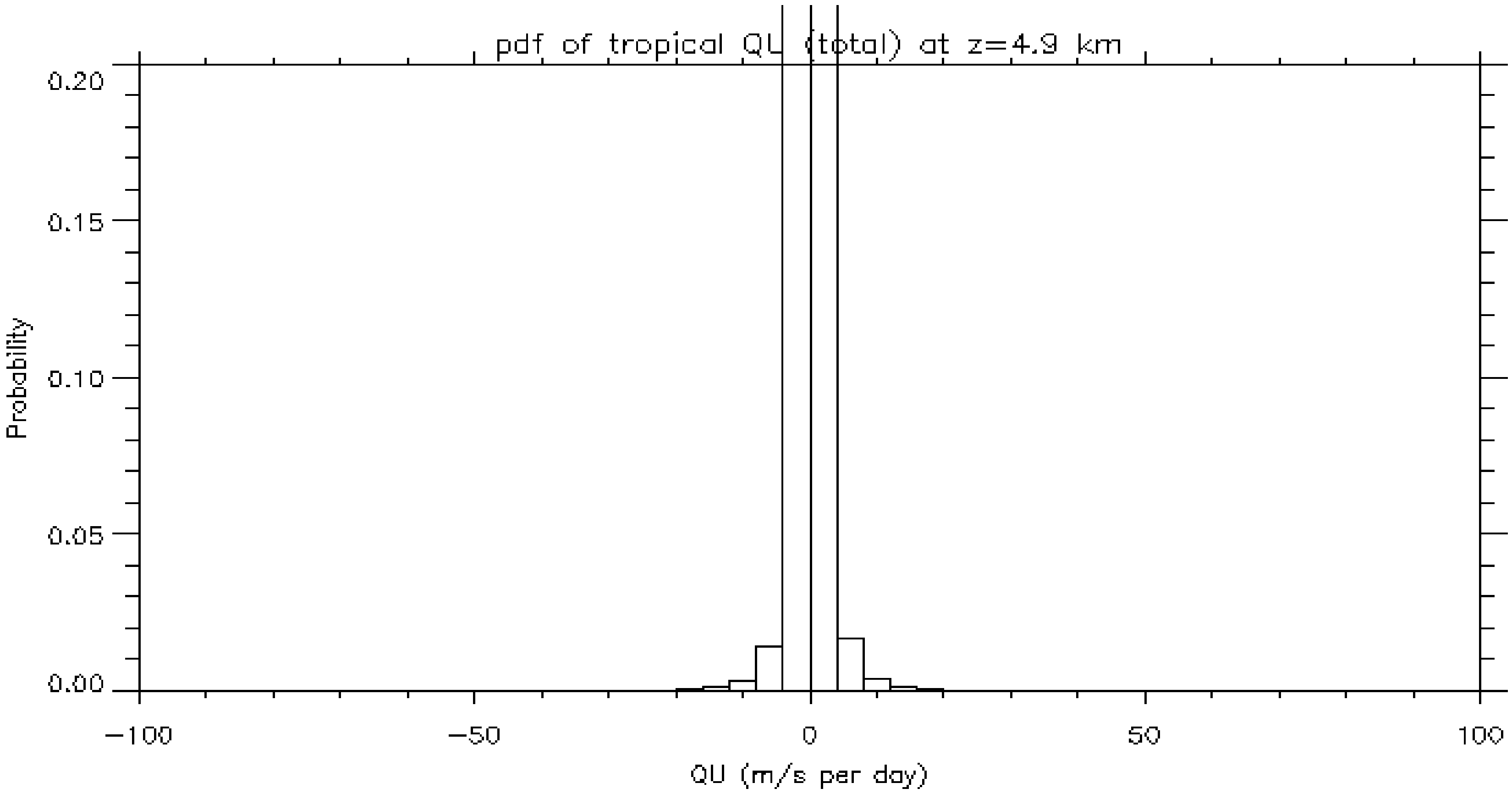
Apparent Q1 from coarse-graining to 64 x 80 km boxes in CRM (dx=2 km)



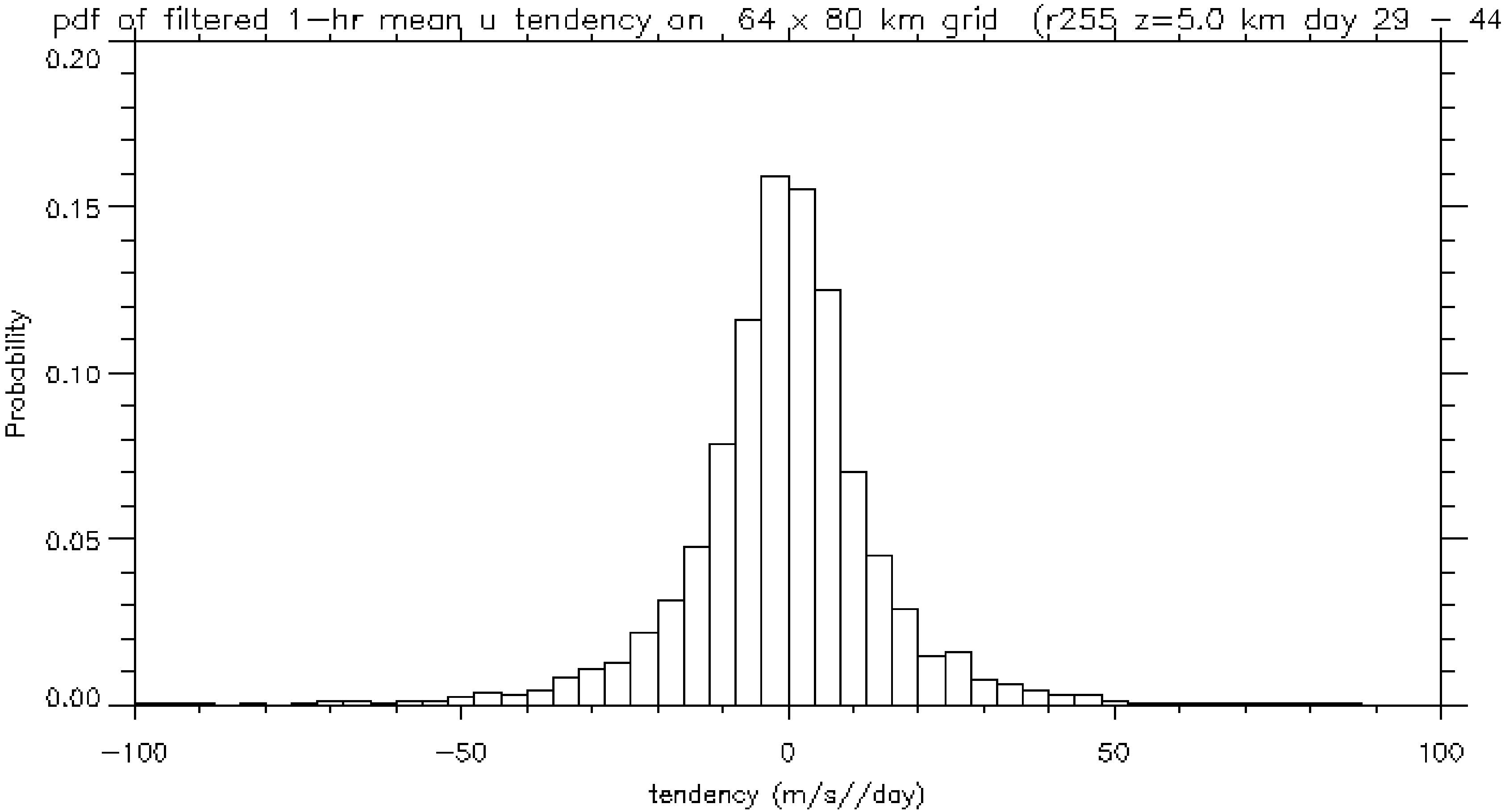
coarse-grained to a 1024 x 1280 km grid z = 5 km



Histogram of QU (total) in ECMWF forecast model at T255



Histogram of ‘effective’ QU from coarse-grained CRM fields

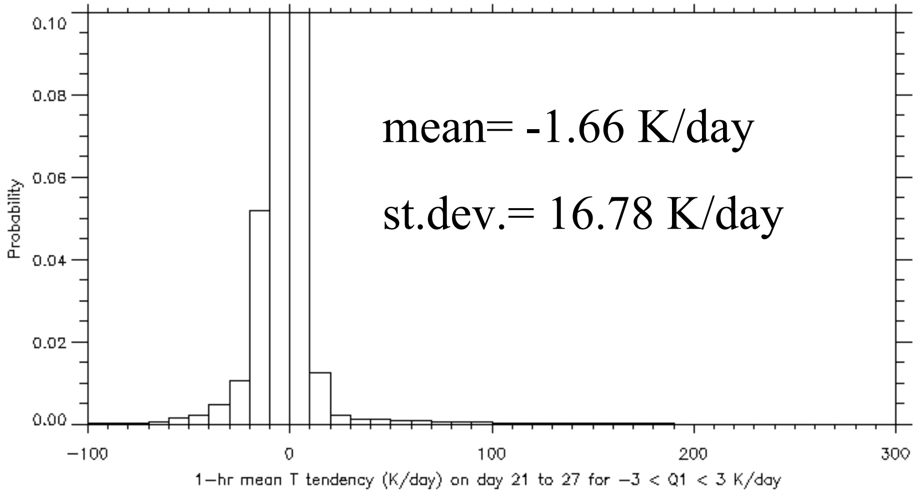


Use convective parametrization scheme (as a diagnostic only) to compute convective forcing and CAPE based on coarse-grained fields (i.e. <Q1> and <CAPE>)

Plot histograms of Q_1 for:

- different levels of grid coarsening
- sub-samples binned according to diagnosed <CAPE> or <Q1>

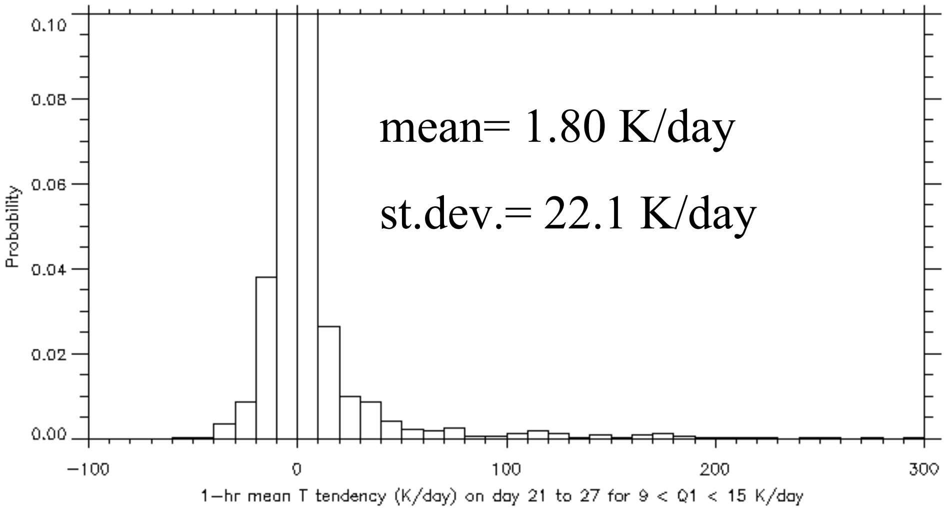
-3 < <Q1> < +3 K/day



mean= -1.66 K/day

st.dev.= 16.78 K/day

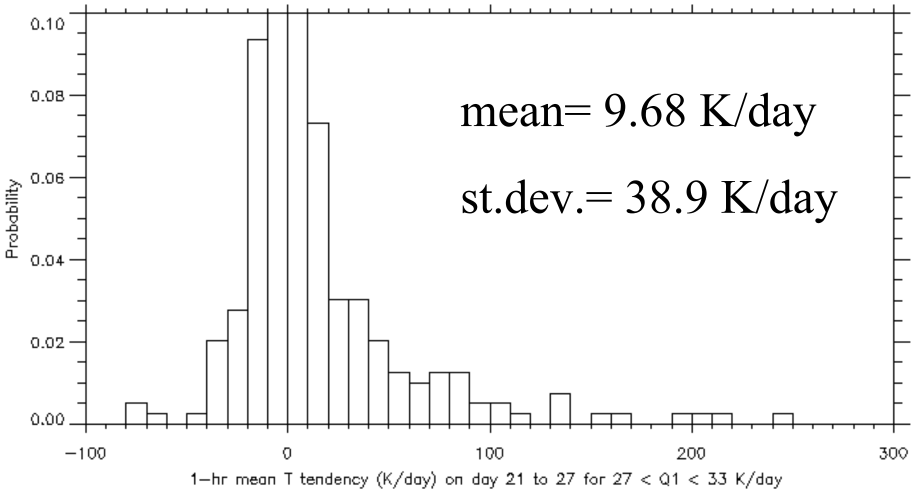
9 < <Q1> < 15 K/day



mean= 1.80 K/day

st.dev.= 22.1 K/day

27 < <Q1> < 33 K/day



mean= 9.68 K/day

st.dev.= 38.9 K/day

pdfs from T tendency sub-samples selected according to their Q1 range .

tendency data drawn from 7 fields (each with 8192 x 128 points) at z=5 km and 24 hours apart

parametrized convection runs

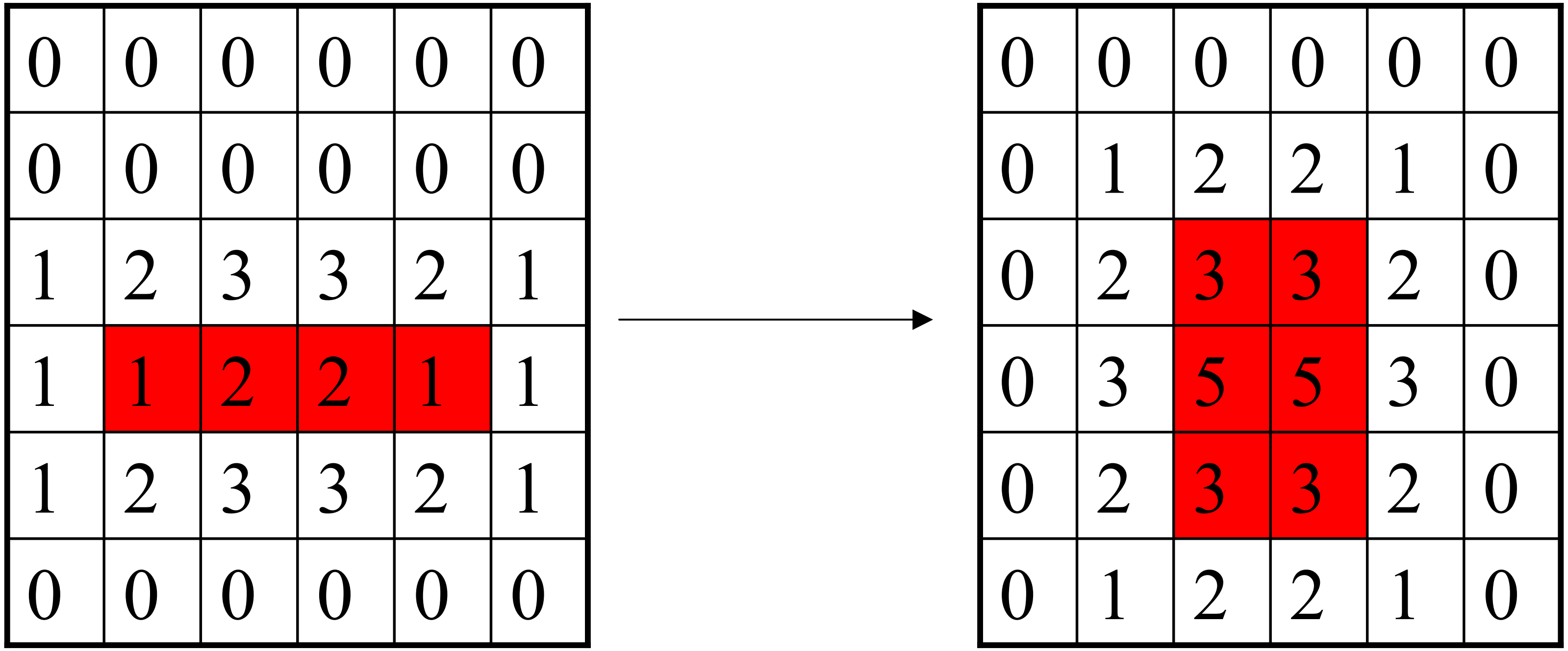
- change dx to 40 km (dy= 40 km as before)
- include the Bechtold-Chaboreau convection parametrization scheme
- test the effect of stochastic forcing at the ‘near-gridscale’

Use a cellular automaton to drive evolving patterns in the near-gridscale convective tendency fields

Simple cellular automaton

Living cells are red

Dead cells are white



0	0	0	0	0	0
0	0	0	0	0	0
1	2	3	3	2	1
1	1	2	2	1	1
1	2	3	3	2	1
0	0	0	0	0	0

0	0	0	0	0	0
0	1	2	2	1	0
0	2	3	3	2	0
0	3	5	5	3	0
0	2	3	3	2	0
0	1	2	2	1	0

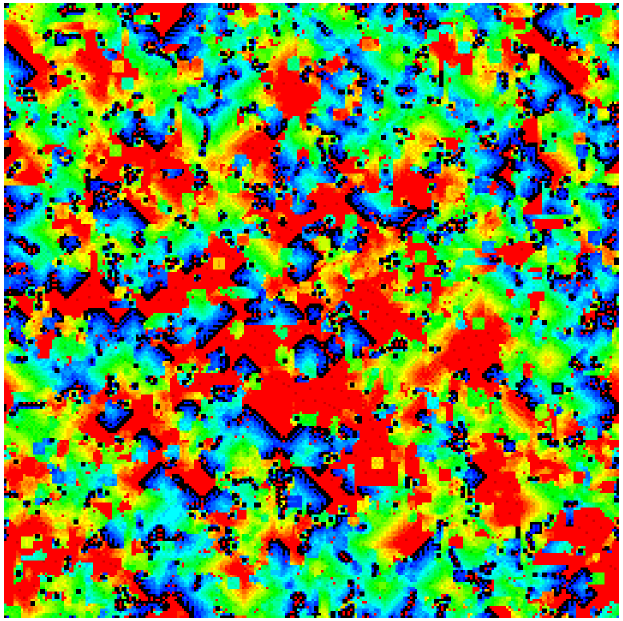
Rules:

Survival:	2 or 3 living neighbours
Birth:	3 living neighbours

CA for `mesoscale patterns’

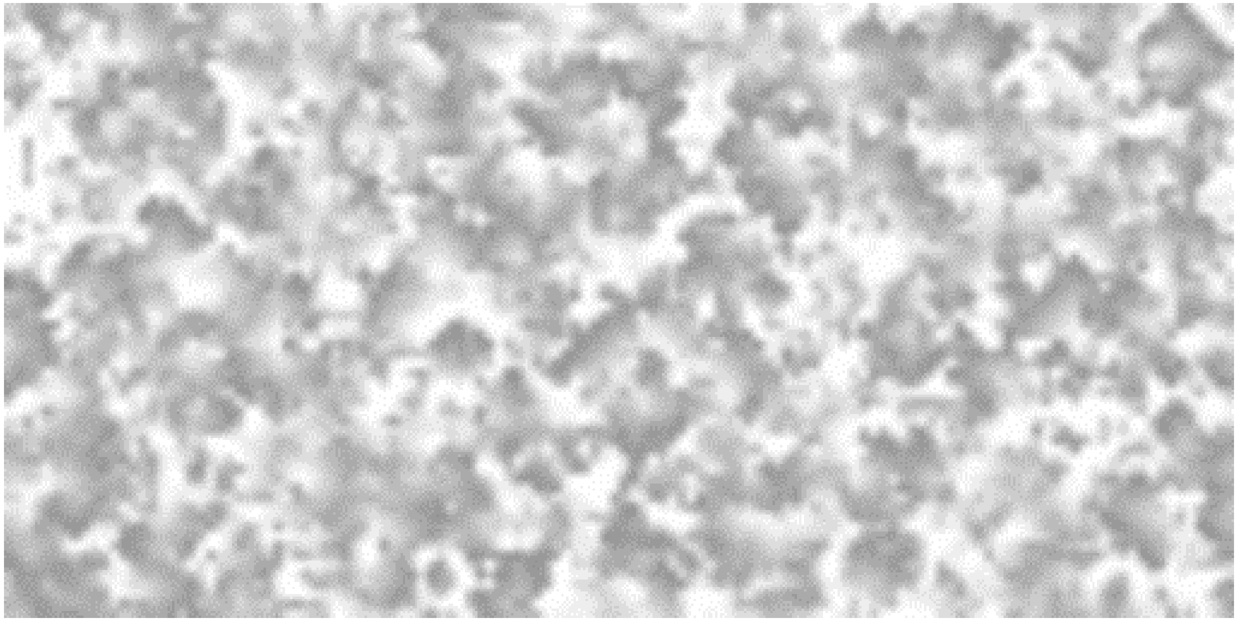
- living cells have 32 lives
- survival (3/4/5)   birth (2/3) counting newly-born neighbours only
- CA works on finer grid than the model
- compute normalized weighting function from CA cell ages functionally-mapped and smoothed to model grid
- associate a time step with successive CA states

animation of CA cell ages



- Blue cells are young
- Red cells are old or dead

CA weighting function



(mapped from cell ages and smoothed)
typically from 0 to ~3

T and q tendency multiplier:

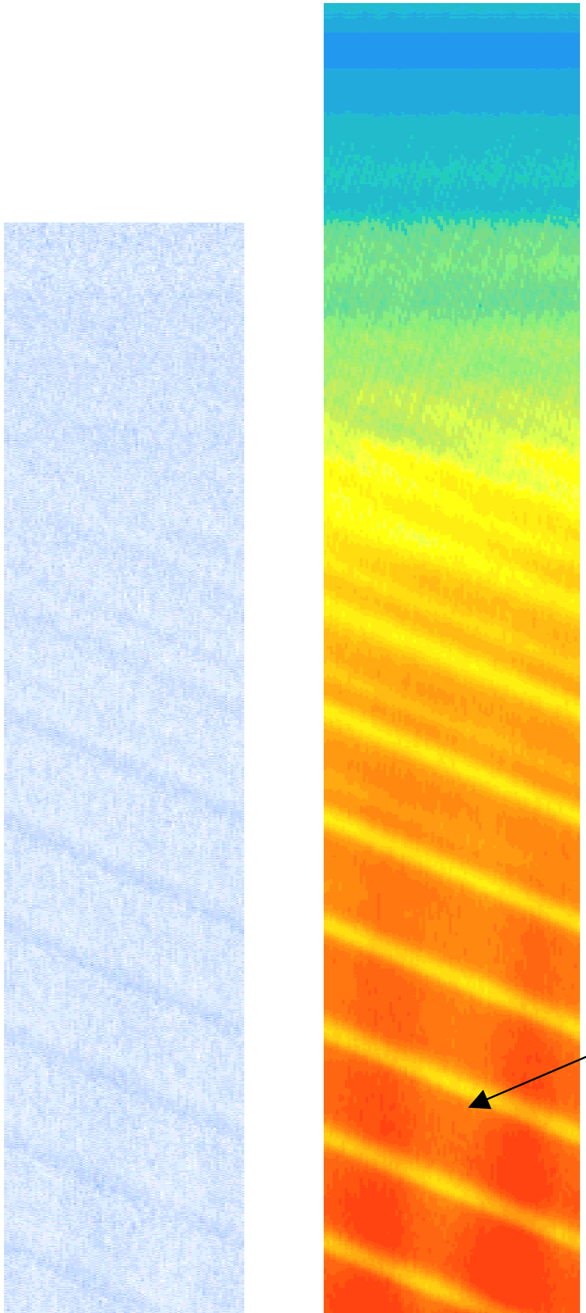
$$1 + 3\,(W(x,y,t)\;-\;1)$$

W(x,y,t) is the normalized weighting function

- time or space mean of multiplier is 1
- treat the convective parametrization tendency as an ensemble-mean value for the local T and q profile

Hovmuller plots of rain rate and u(850 mb) with parametrized convection

time



control

u(850 mb)

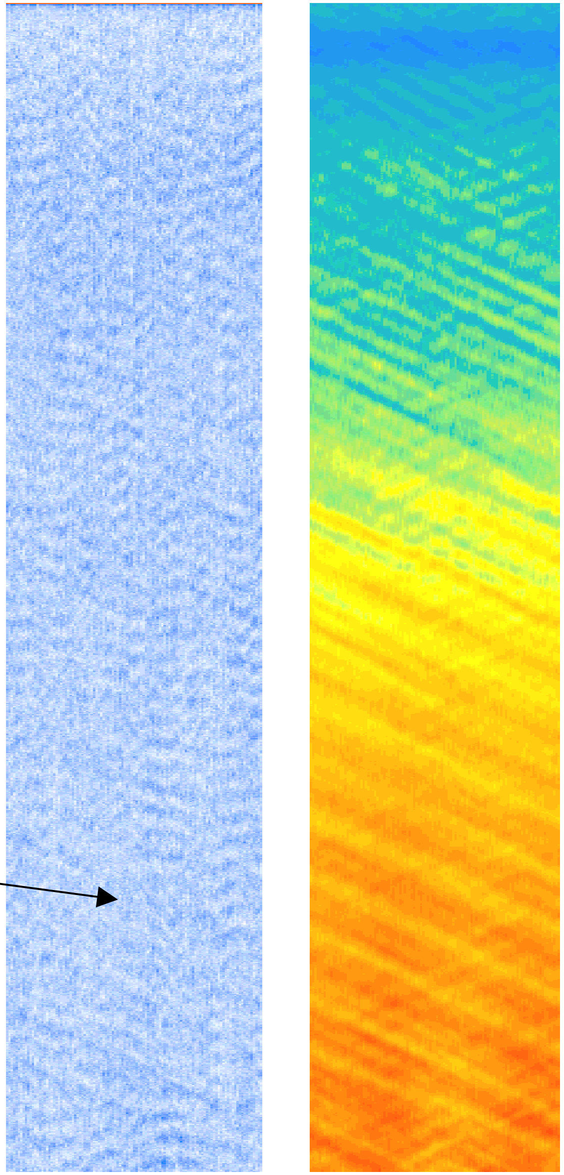
day 32

with CA-based

T and q perturbations

Rain rate

day 25



time

Summary

- anisotropic horizontal grid in CRM allows a mix of explicitly-resolved convective clouds and equatorially-trapped waves
- cloud forcing averaged to typical NWP resolutions shows very broad pdf, particularly for momentum forcing
- convection parametrization needs to reflect the statistical uncertainty associated with low storm cloud population density
- stochastic perturbations can be used to broaden pdf of convective forcing