SSWAP (2010)

The Thermodynamic Control of Tropical Rainfall

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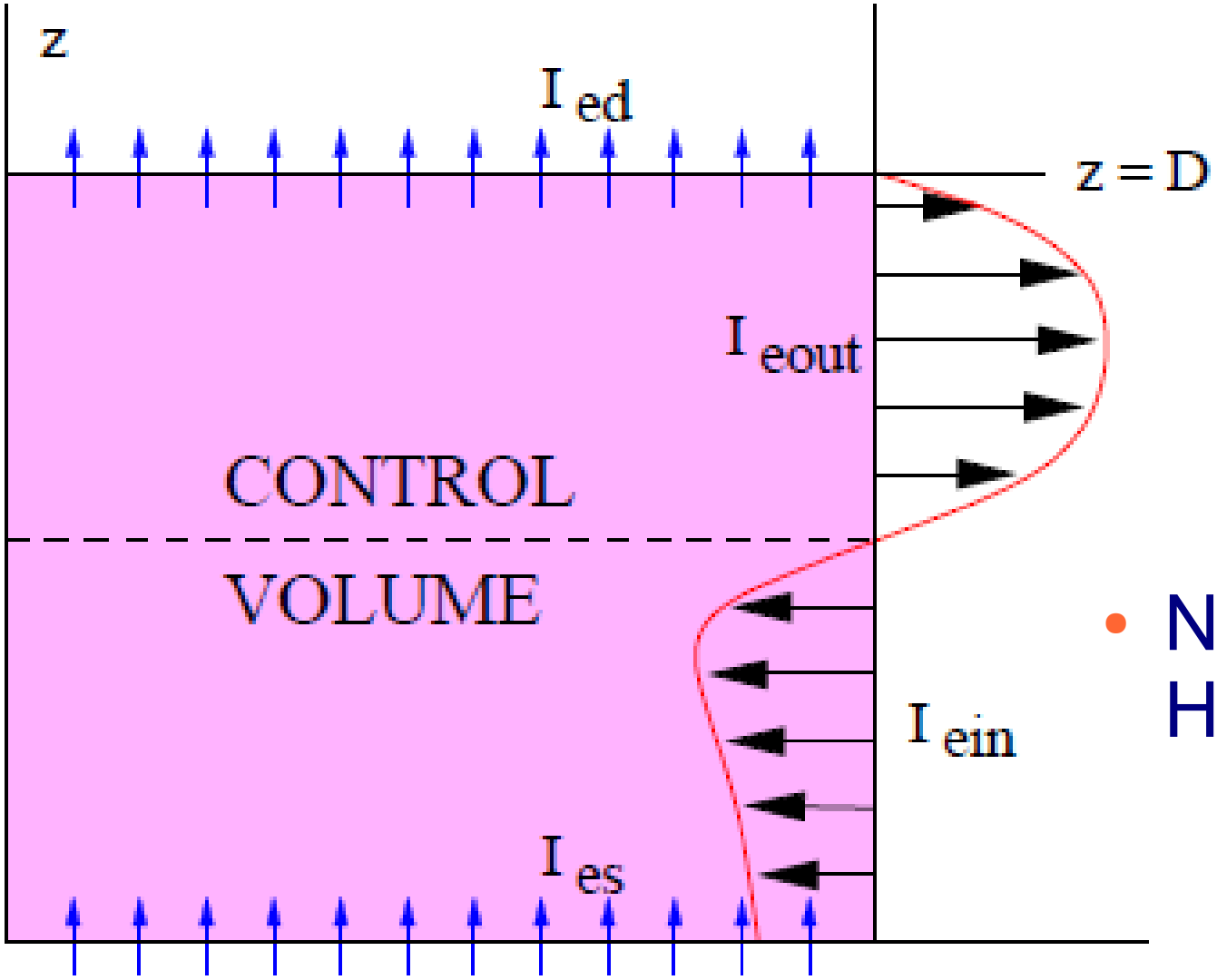
Introduction



- Neelin and Held (1987)

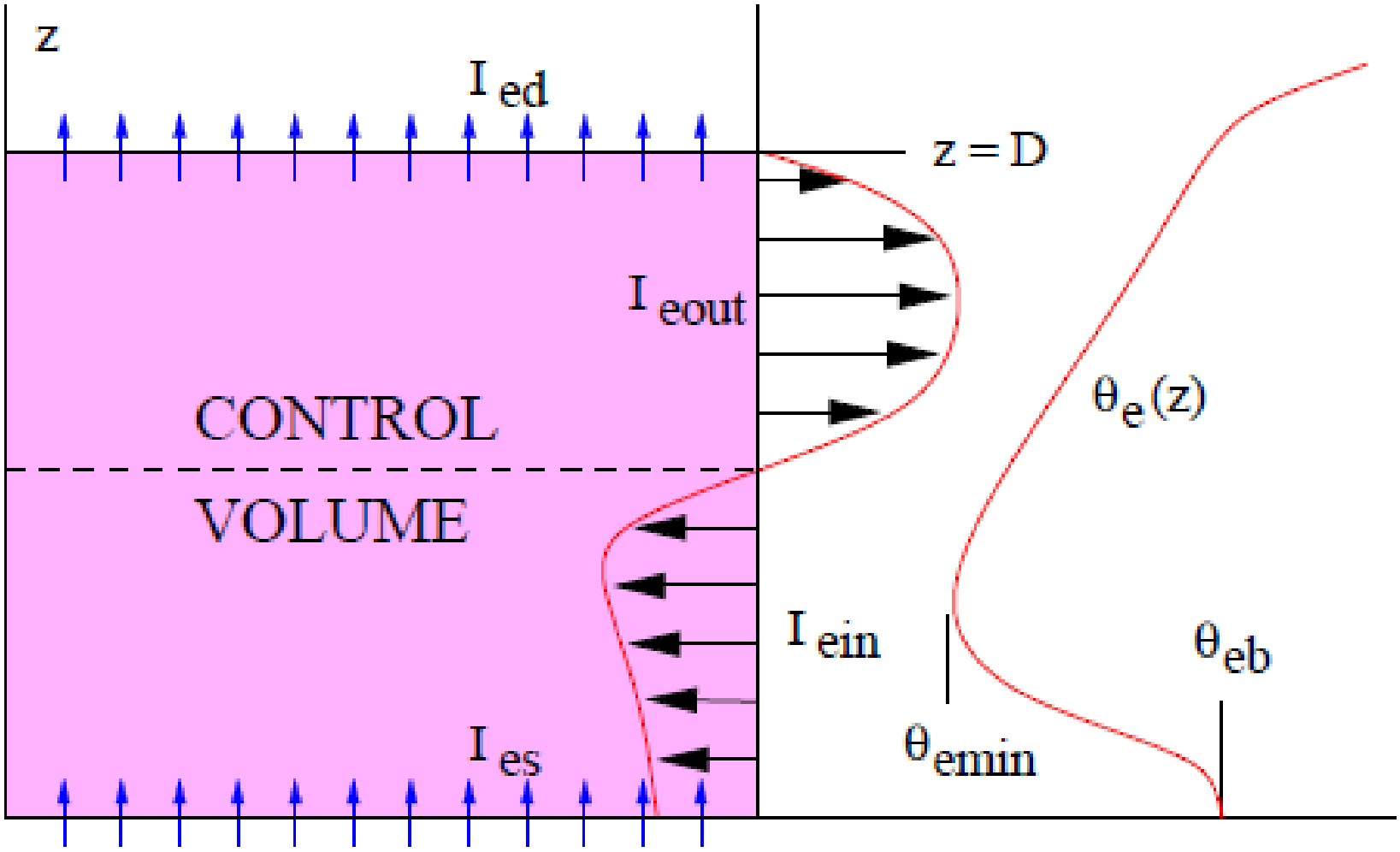
Introduction

- Neelin and Held (1987)

$$I_{es} - I_{ed} = I_{eout} - I_{ein} = M\,\delta s_m$$

$$M = \frac{I_{es} - I_{ed}}{\delta s_m}$$

Introduction



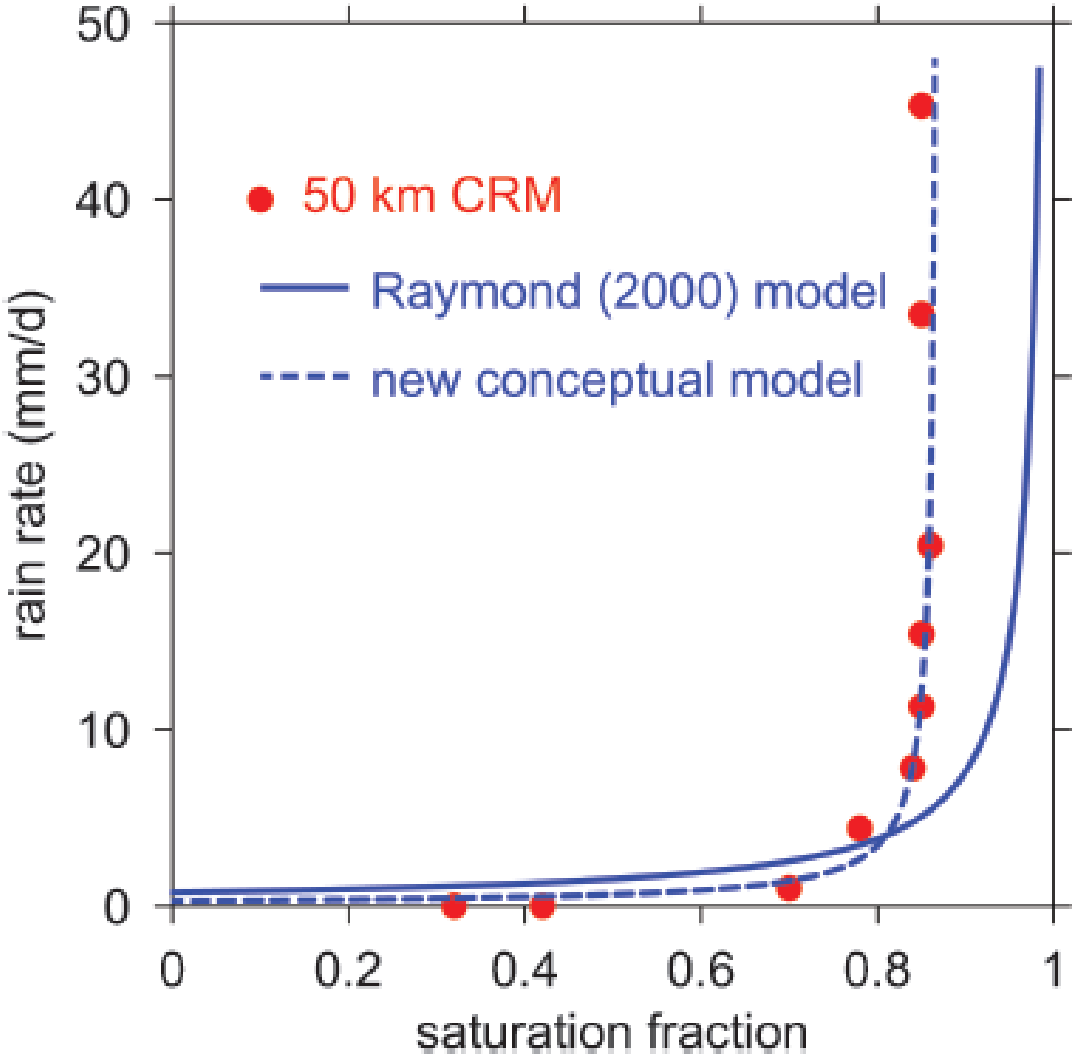
Introduction

Hypotheses:

- precipitation ~ (saturation deficit) $^{-1}$
- temperature profile ≠ f(t)

Non-equilibrium model

- New results: Raymond, Sessions and Fuchs (2007)



Non-equilibrium model

$$\frac{\partial \rho \theta_e}{\partial t} + \nabla \cdot (\rho \vec{u} \theta_e) + \frac{\partial \rho w \theta_e}{\partial z} = \frac{-\partial F_e}{\partial z} + G$$

$$\frac{\partial \rho r_t}{\partial t} + \nabla \cdot (\rho \vec{u} r_t) + \frac{\partial \rho w r_t}{\partial z} = \frac{-\partial F_r}{\partial z} - P$$

Non-equilibrium model

$$\frac{\partial \rho \theta_e}{\partial t} + \nabla \cdot (\rho \vec{u} \theta_e) + \frac{\partial \rho w \theta_e}{\partial z} = \frac{-\partial F_e}{\partial z} + G$$

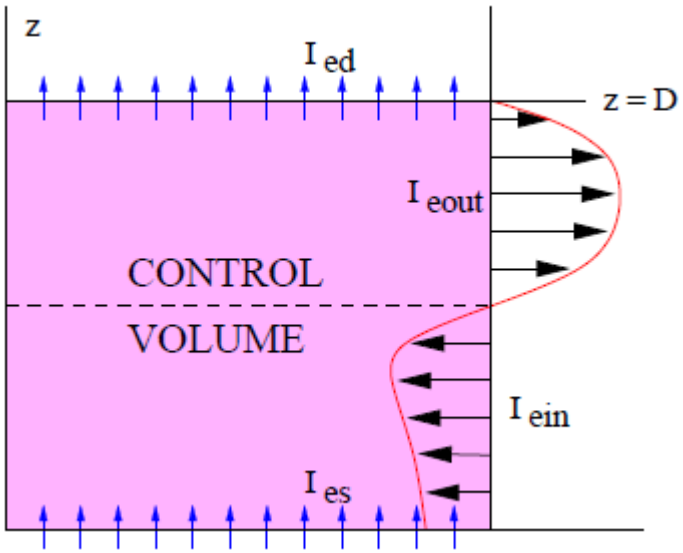
$$\frac{\partial \rho r_t}{\partial t} + \nabla \cdot (\rho \vec{u} r_t) + \frac{\partial \rho w r_t}{\partial z} = \frac{-\partial F_r}{\partial z} - P$$

$$\theta_e = \theta_{es} - \Delta\theta_e$$

$$r_t = r_s - \Delta r$$

Non-equilibrium model

$$\int dV$$



- Rainfall hypothesis + dimensionless =>

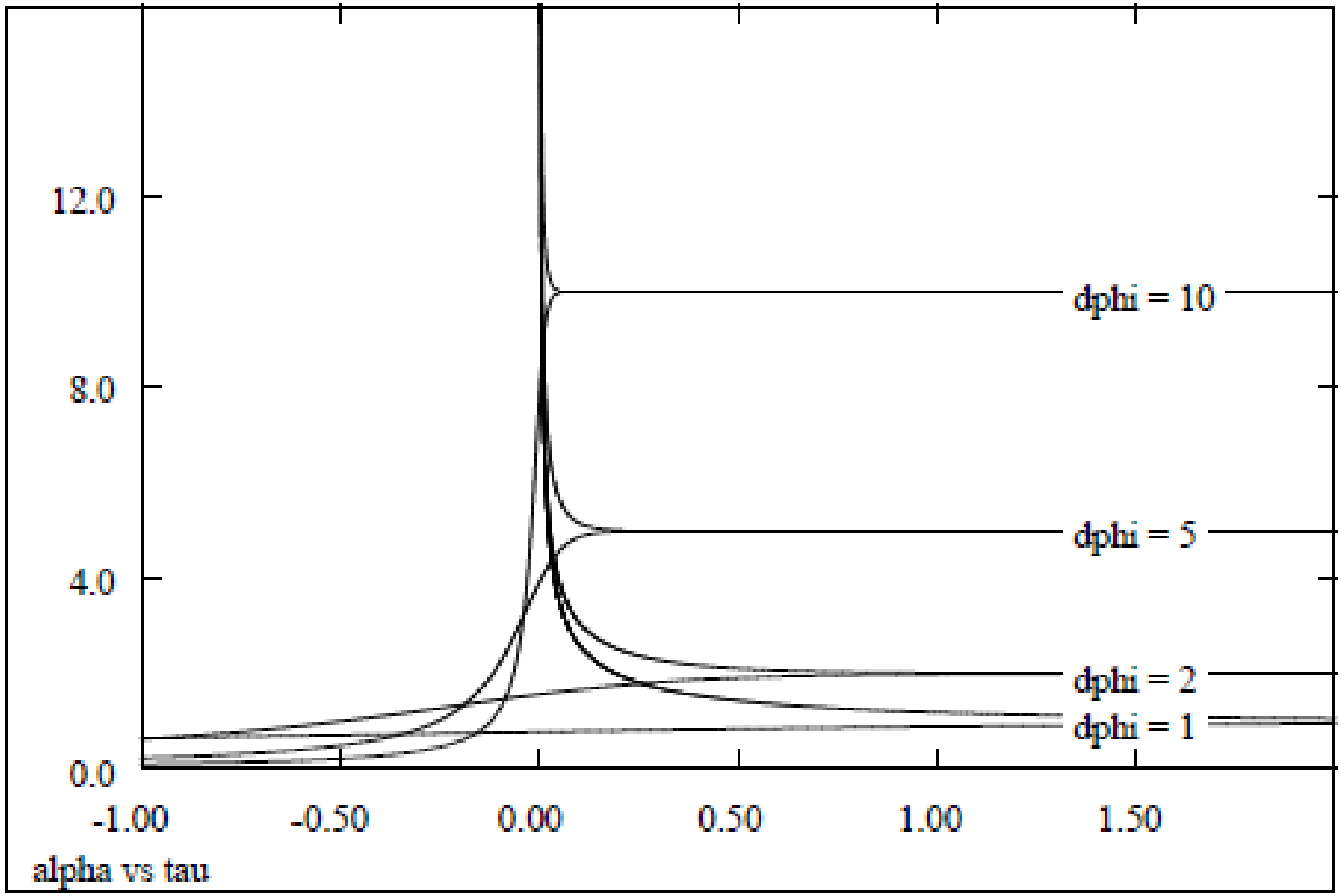
$$\frac{d\alpha}{d\tau} = -\alpha^3 + \alpha^2 \Delta\Phi(\delta\theta_e, \delta r_t, F)$$

Solutions

$$\frac{d\alpha}{d\tau} = 0 = -\alpha^3 + \alpha^2 \Delta\Phi$$

- Equilibrium solution: $\alpha_{eq} = \Delta\Phi$
- Full solution: $\tau = \tau(\alpha)$

Solutions


12.0
8.0
4.0
0.0
-1.00
-0.50
0.00
0.50
1.00
1.50
dphi = 10
dphi = 5
dphi = 2
dphi = 1
alpha vs tau

Discussion

- Clear regions $\Delta\Phi < 0$
- Variably cloudy regions $0 < \Delta\Phi < 1$
- Cloud clusters $\Delta\Phi > 1$

Discussion

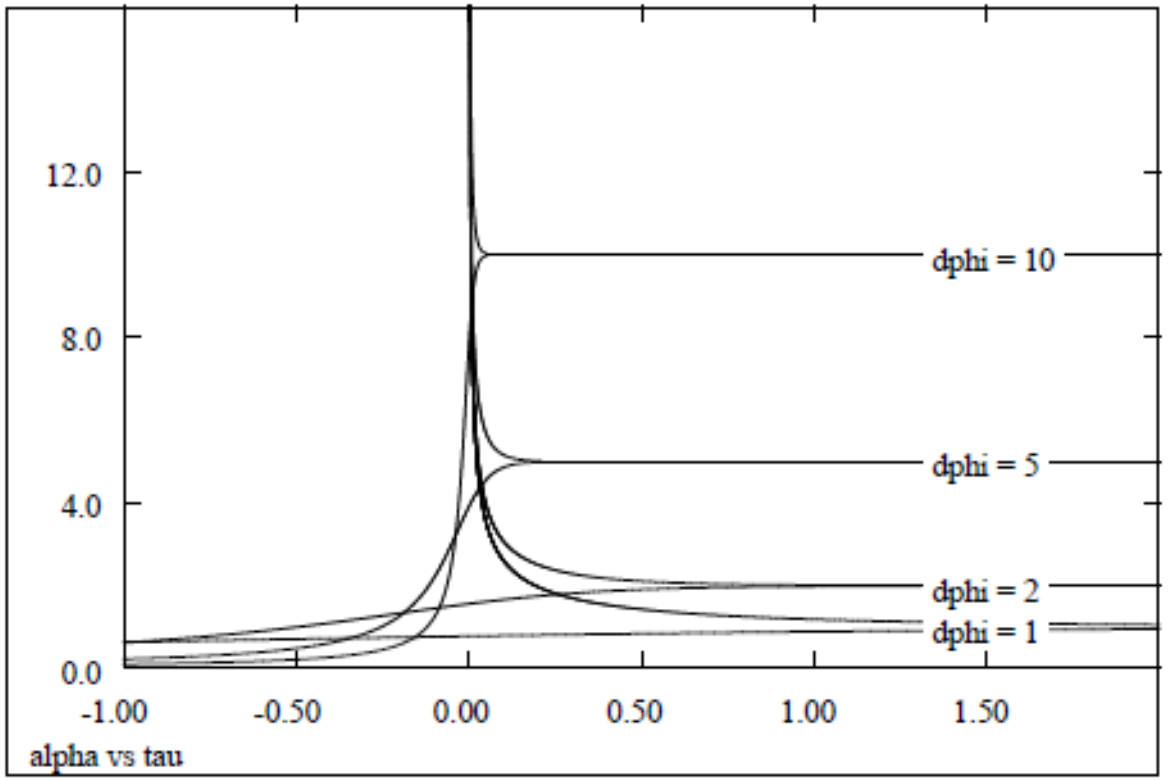
- Radiative-convective equilibrium rainfall rate (t = relaxation time to equilibrium rate):

$$\Delta\Phi = 1 \qquad is \approx 4\, mm/day \qquad t \approx 35\, day$$

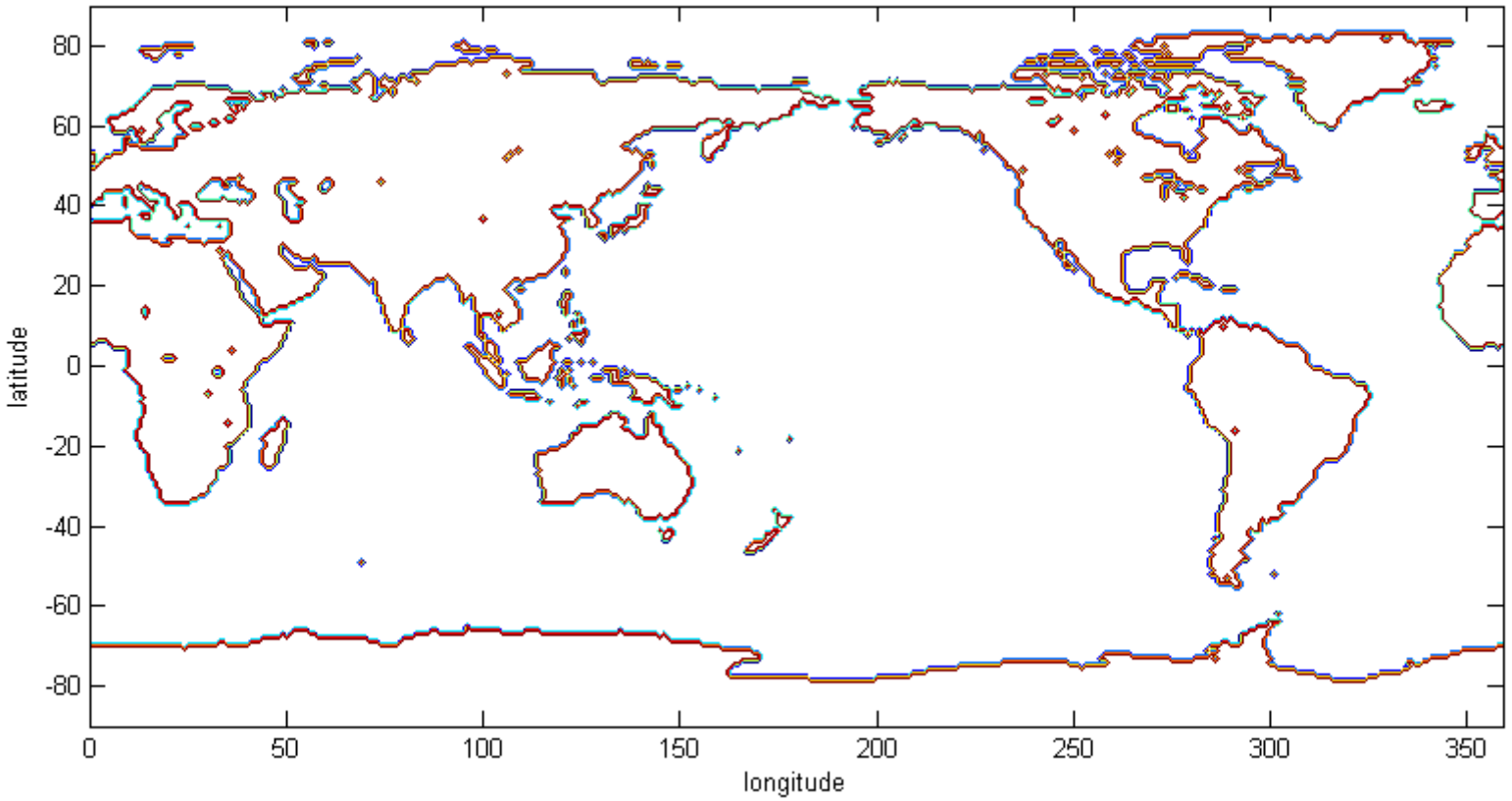
$$\Delta\Phi = 6 \qquad is \approx 24\, mm/day \qquad t \approx 1\, day$$

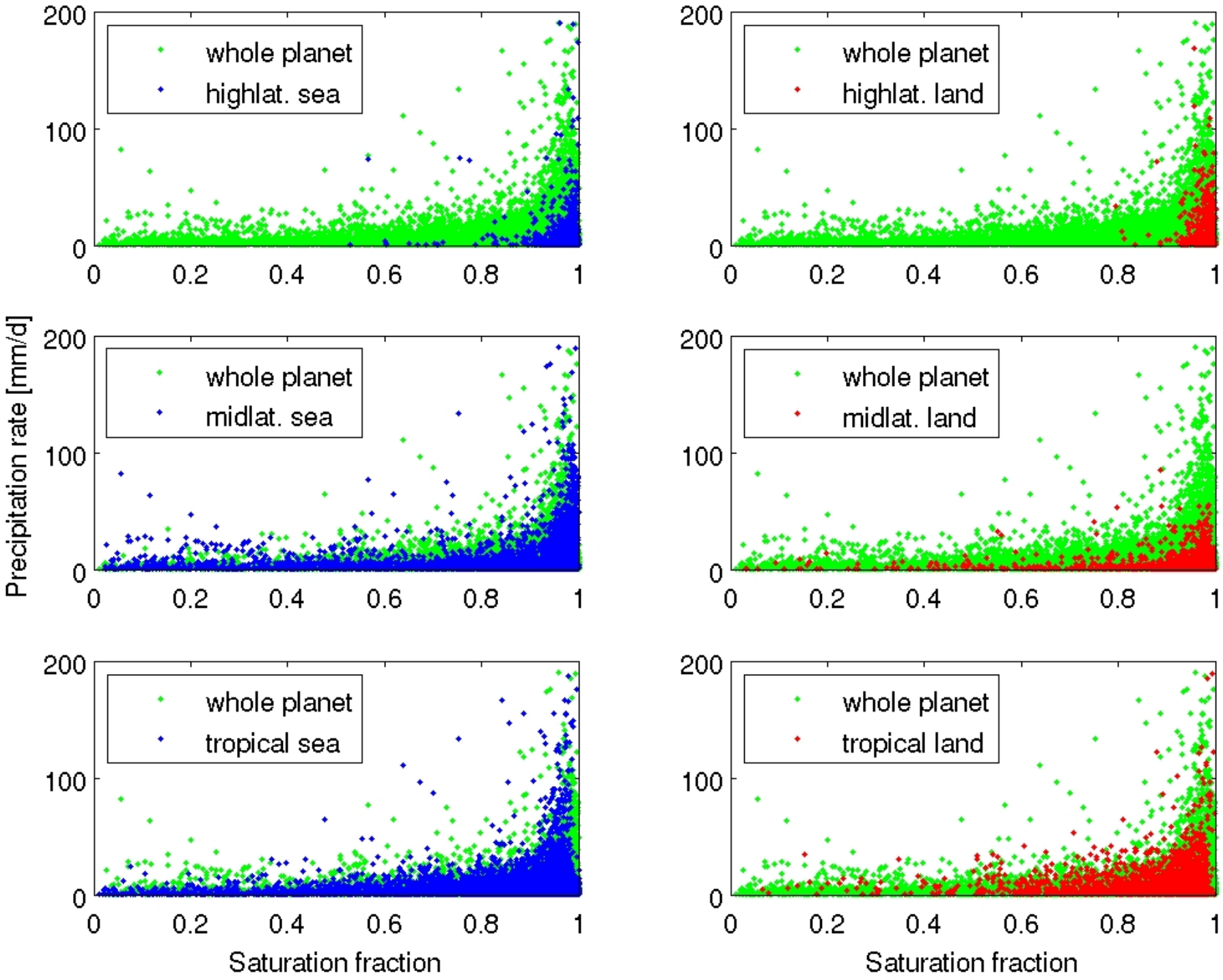
Discussion

- Relaxation time large if initial state dry

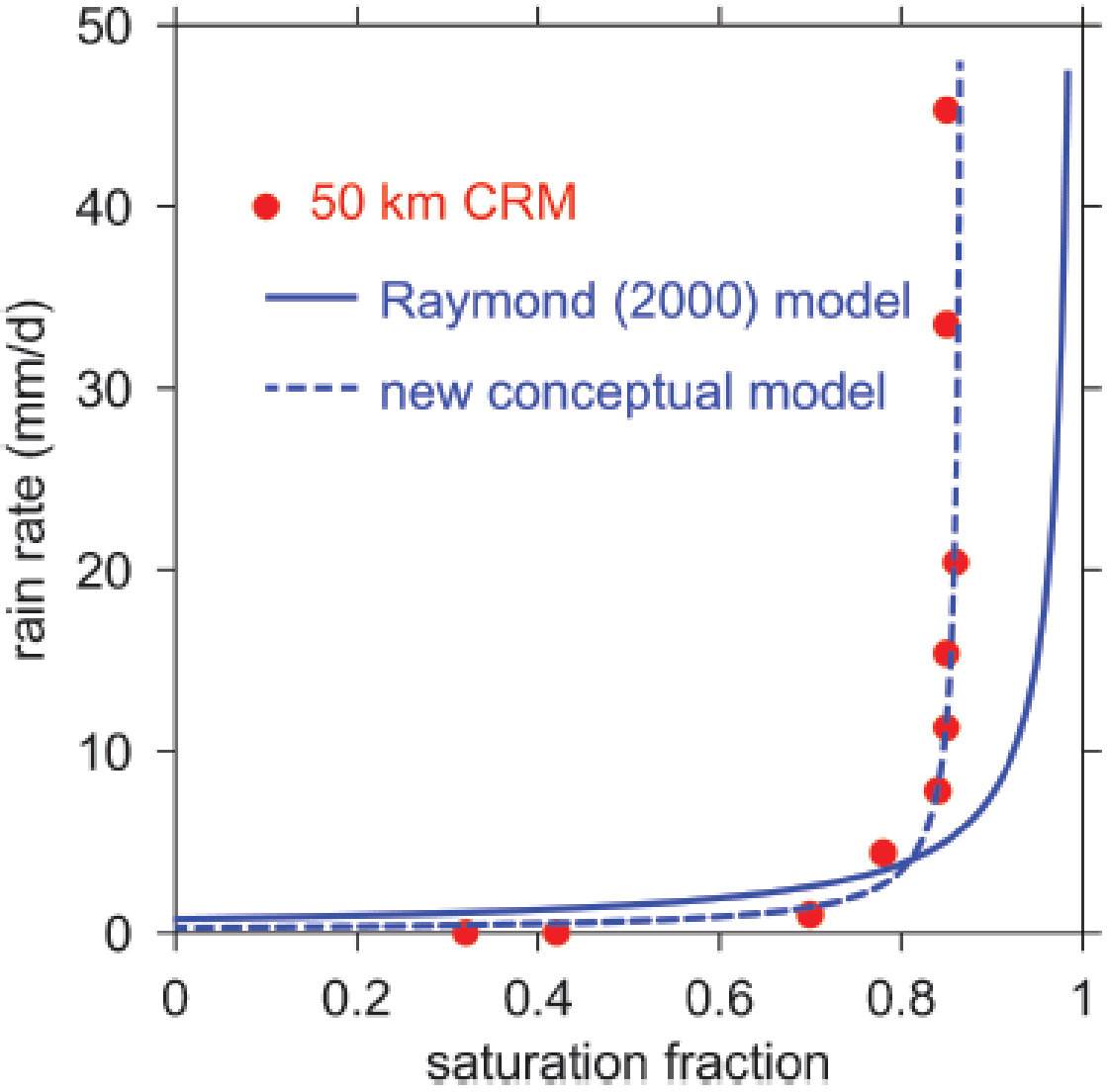


GFS data analysis




whole planet
highlat. sea
whole planet
highlat. land
whole planet
midlat. sea
whole planet
midlat. land
whole planet
tropical sea
whole planet
tropical land
Precipitation rate [mm/d]
Saturation fraction
Saturation fraction
0
100
200
0.2
0.4
0.6
0.8
1

Saturation fraction



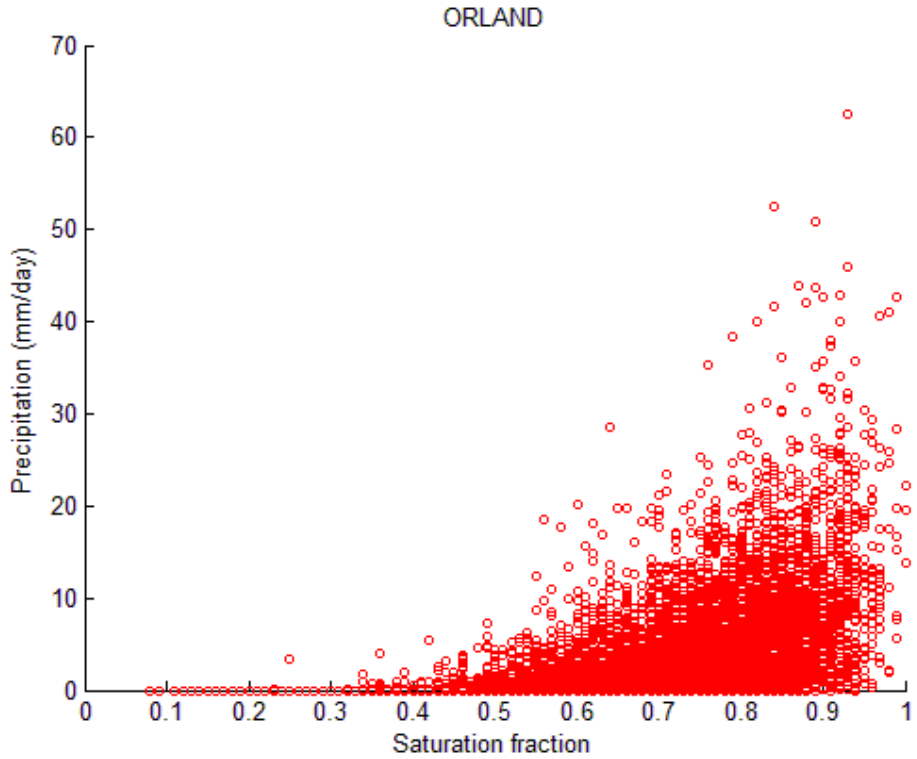
Saturation fraction (> 0.7)

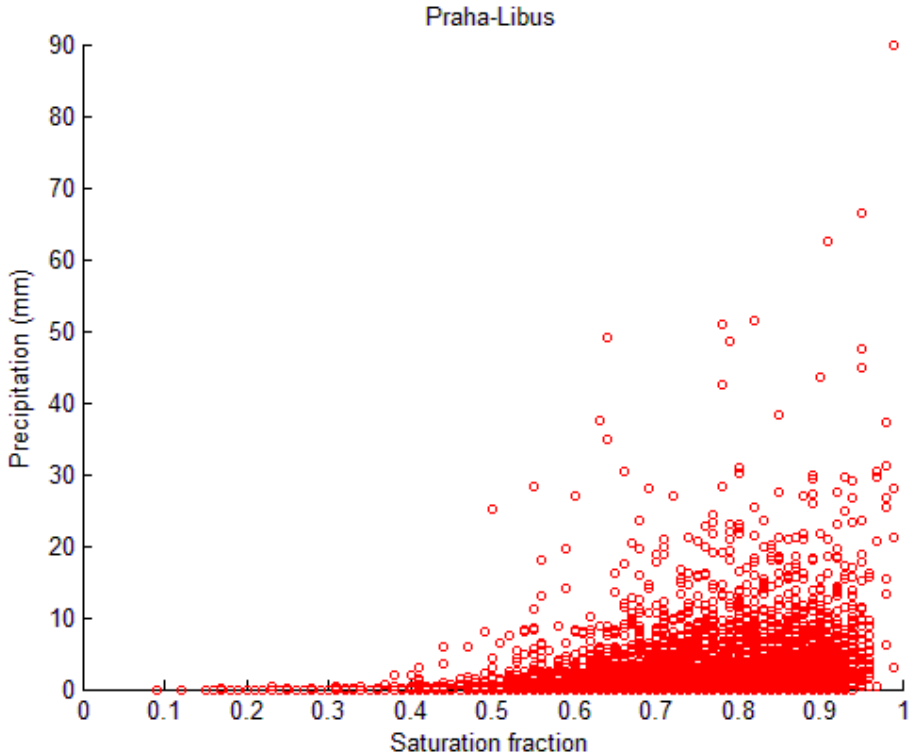
- HLS: 98% +/- 1%
- MLS: 88% +/- 1%
- TS: 80% +/- 3%

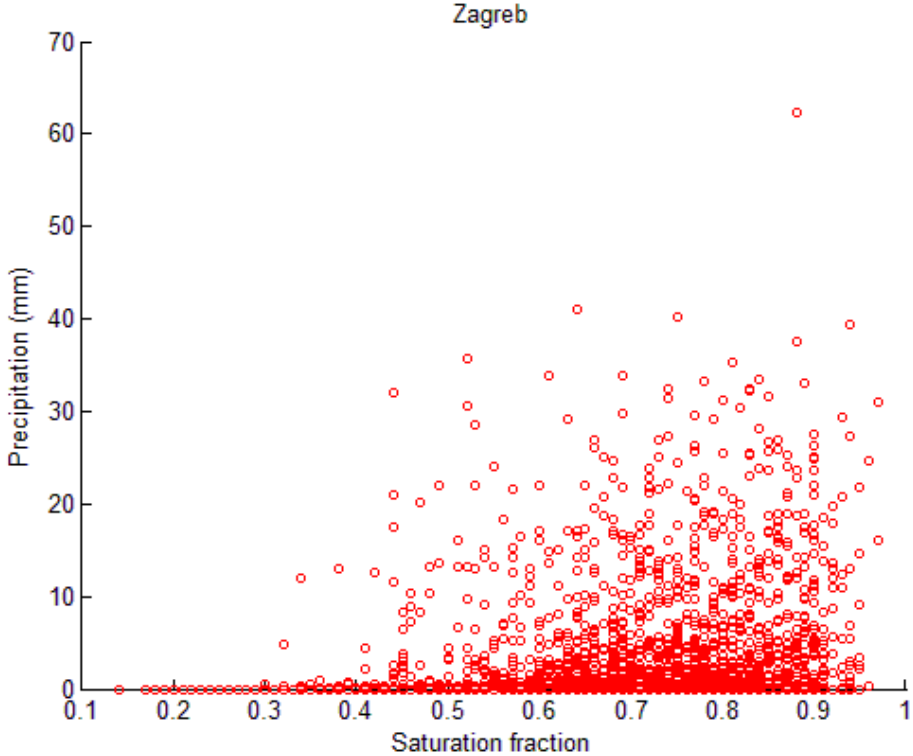
HLL: 99% +/-1%

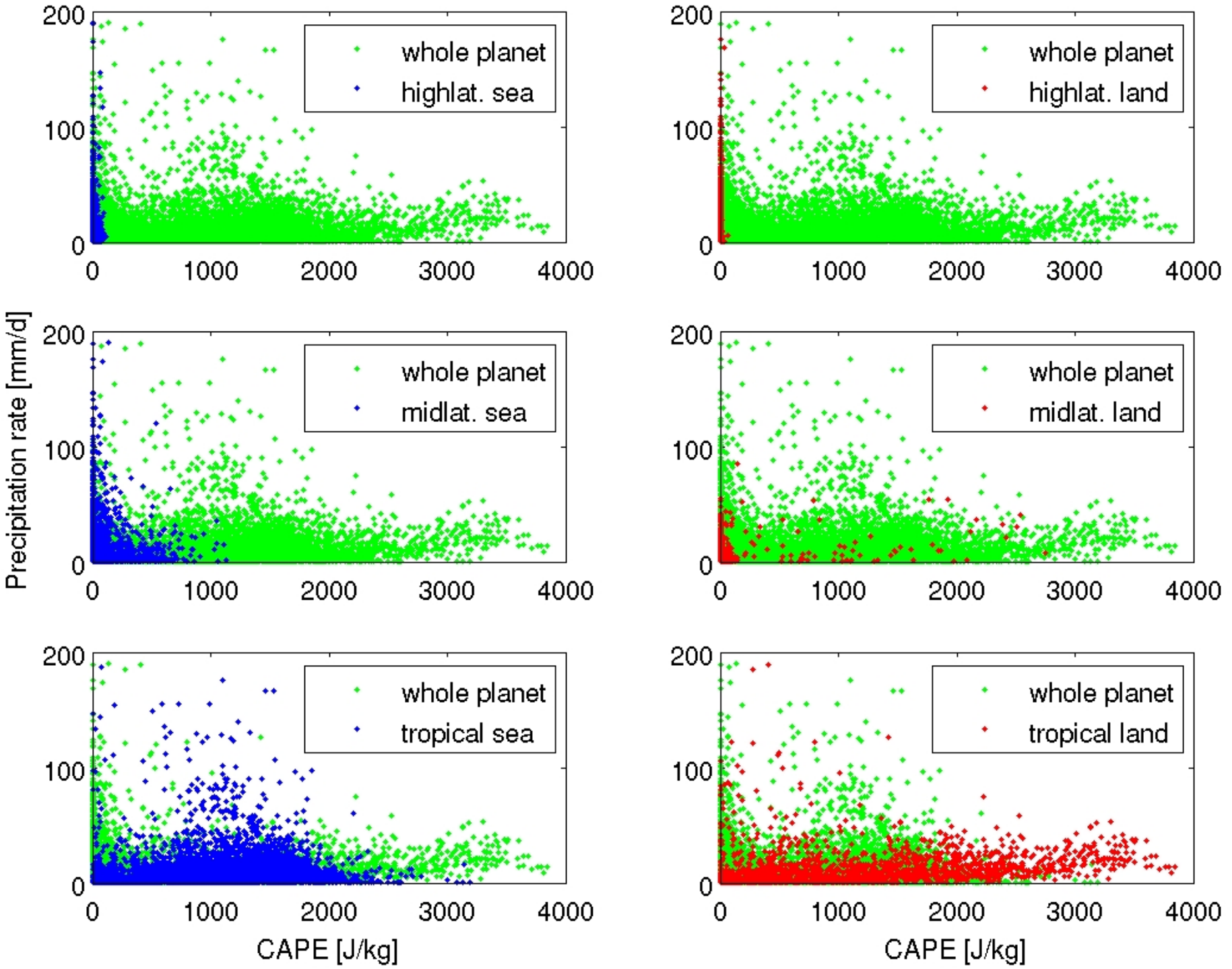
MLL: 94% +/- 3%

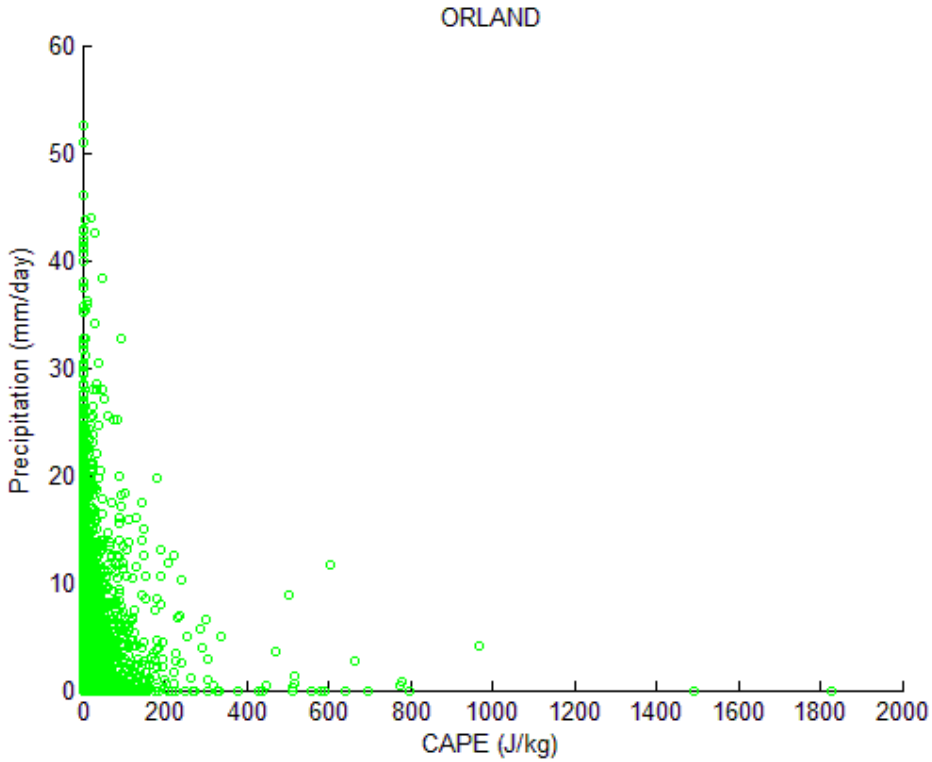
TL: 87% +/- 3%

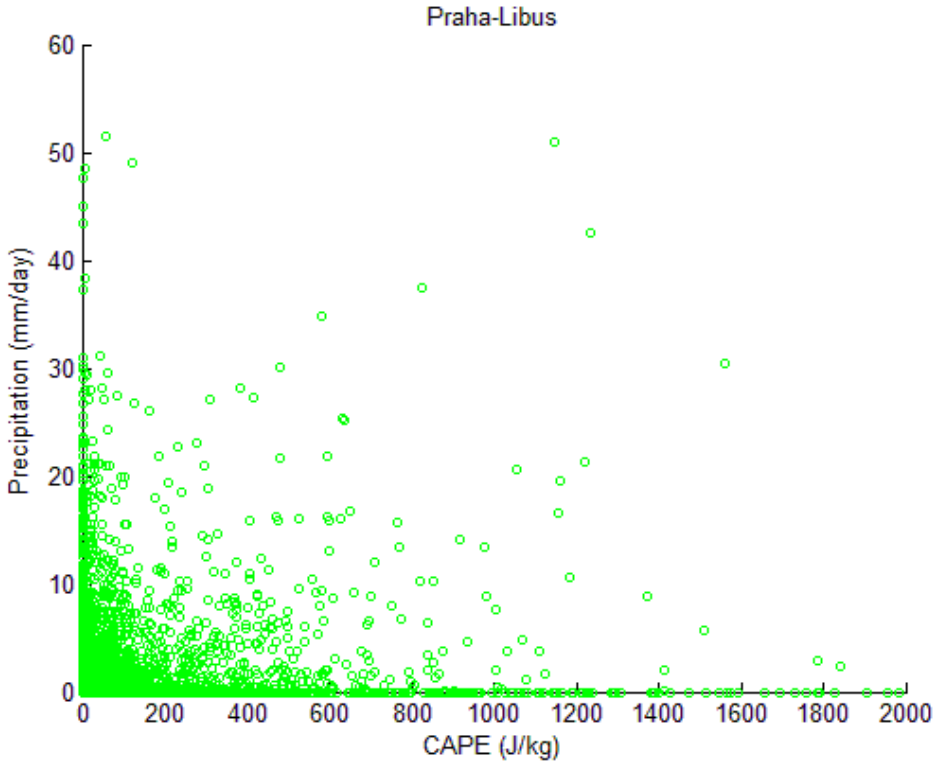

ORLAND
Precipitation (mm/day)
Saturation fraction
0
10
20
30
40
50
60
70
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Praha-Libus
Precipitation (mm)
Saturation fraction
0
10
20
30
40
50
60
70
80
90
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Zagreb
Precipitation (mm)
Saturation fraction
0
10
20
30
40
50
60
70
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


whole planet
highlat. sea
whole planet
highlat. land
whole planet
midlat. sea
whole planet
midlat. land
whole planet
tropical sea
whole planet
tropical land
Precipitation rate [mm/d]
CAPE [J/kg]
CAPE [J/kg]
0
100
200
0
1000
2000
3000
4000


ORLAND
Precipitation (mm/day)
CAPE (J/kg)
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800
2000


Praha-Libus
Precipitation (mm/day)
CAPE (J/kg)
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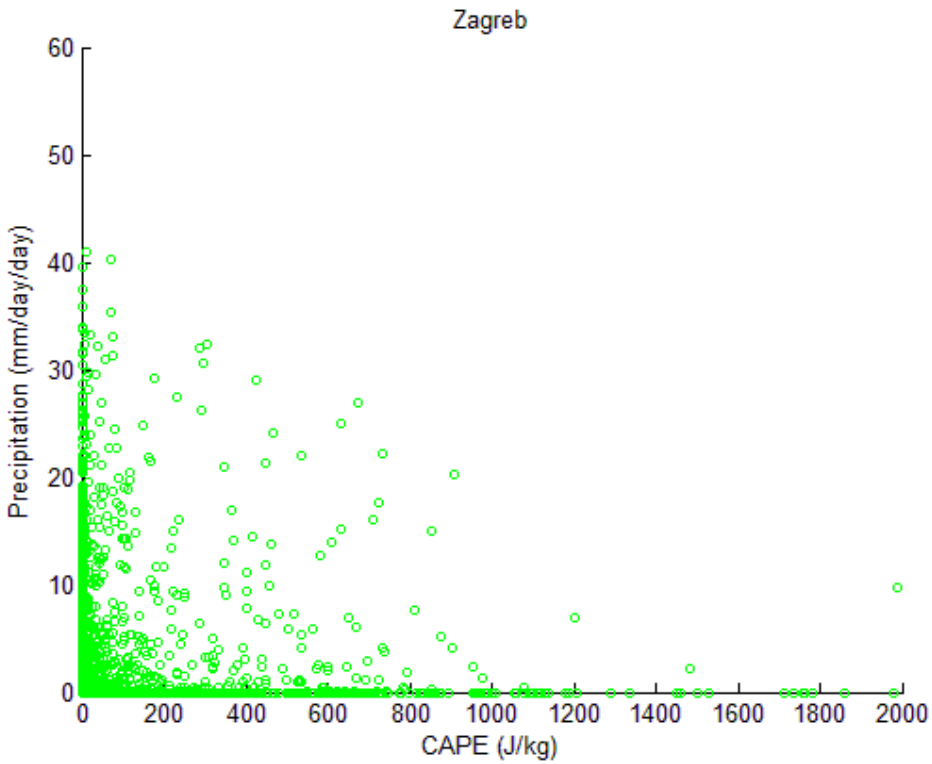
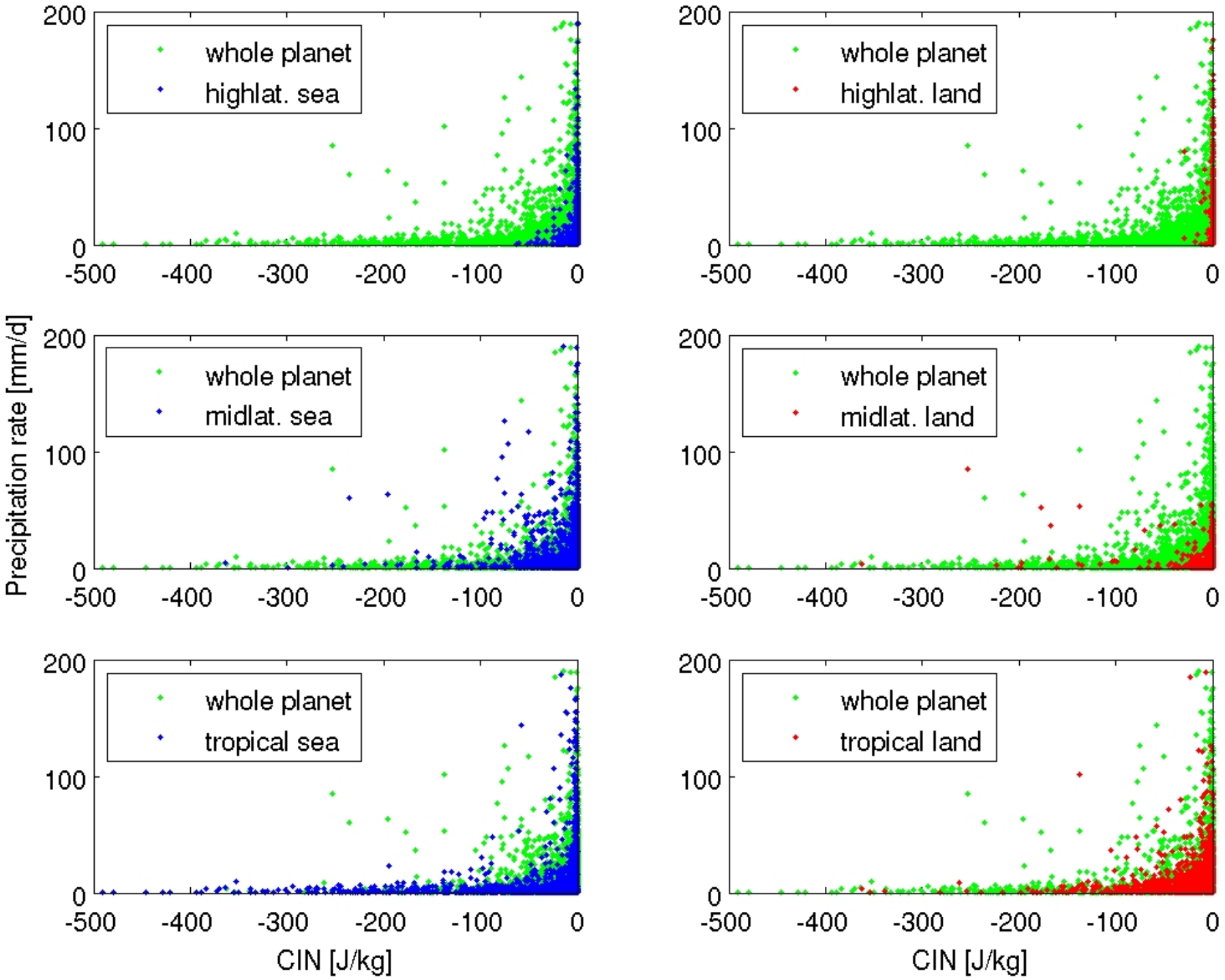
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800
2000


Zagreb
Precipitation (mm/day/day)
CAPE (J/kg)
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800
2000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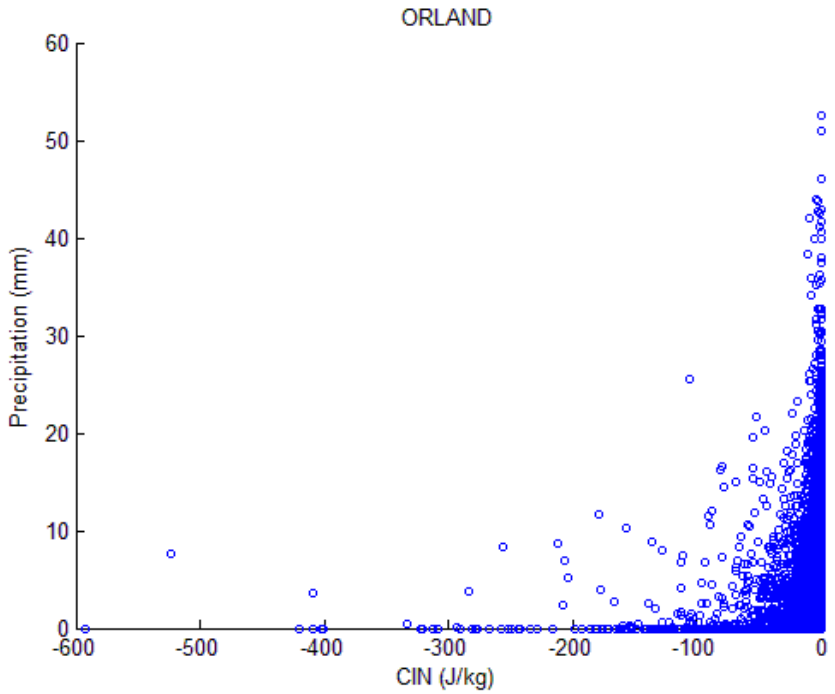
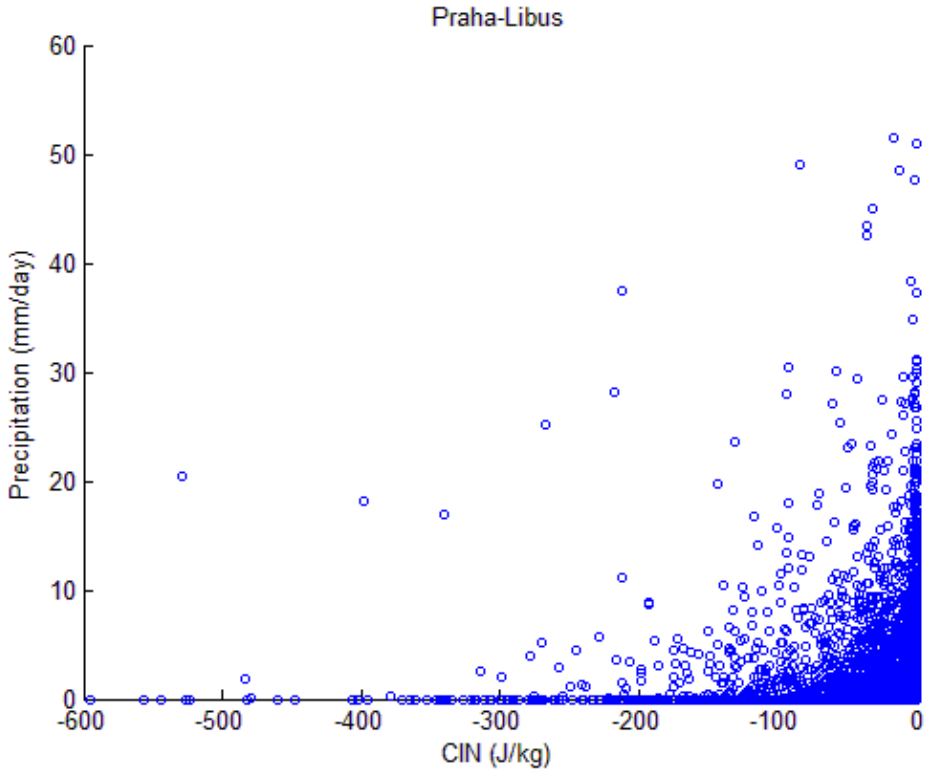
highlat. land
whole planet
midlat. sea
whole planet
midlat. land
whole planet
tropical sea
whole planet
tropical land
Precipitation rate [mm/d]
CIN [J/kg]
CIN [J/kg]
200
100
0
-500
-400
-300
-200
-100
0


ORLAND
Precipitation (mm)
CIN (J/kg)
60
50
40
30
20
10
0
-600
-500
-400
-300
-200
-100
0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CIN (J/kg)
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10
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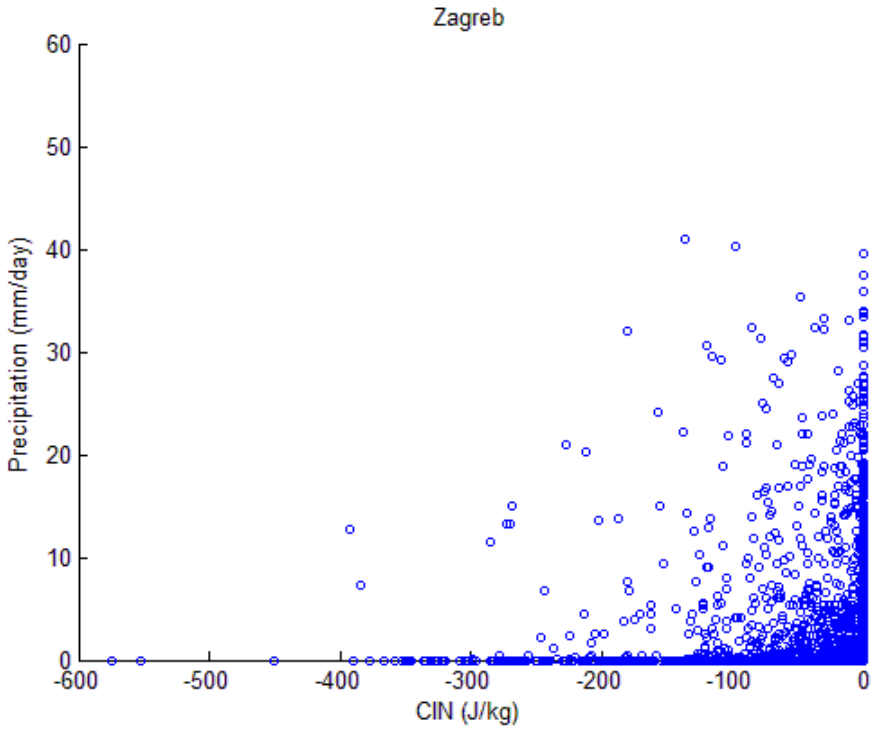
-400
-300
-200
-100
0


Zagreb
Precipitation (mm/day)
CIN (J/kg)
60
50
40
30
20
10
0
-600
-500
-400
-300
-200
-100
0

GFS data analysis

- Animations (removed for file size reduction)
- No considerable change in plots when shown in time, except for CAPE vs Precipitation (for high values of CAPE scatter plot for tropical land different at different times)

Conclusions

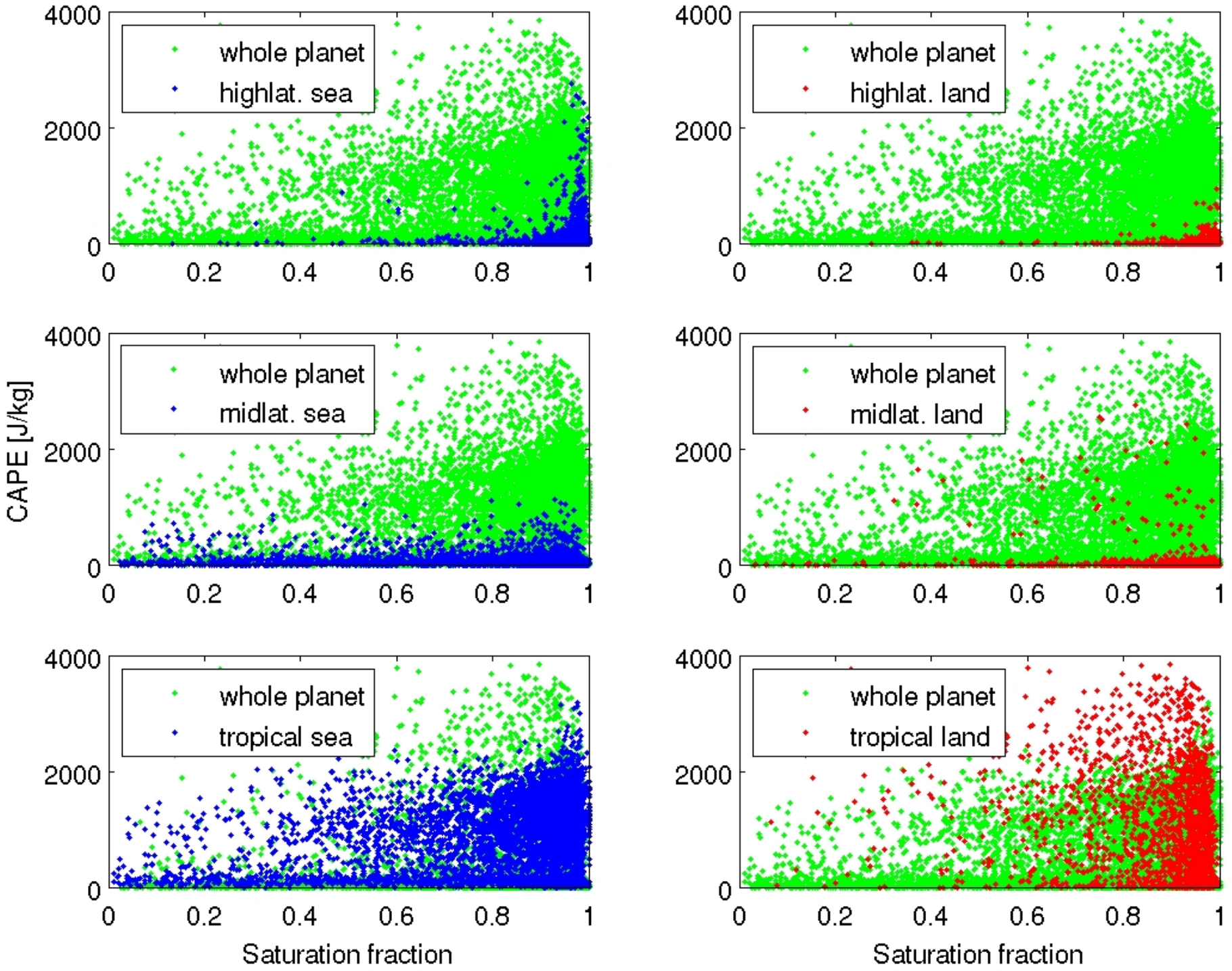
- Saturatin fraction is a good measure for determining the precipitation rate

Conclusions

- Saturatin fraction is a good measure for determining the precipitation rate
- But it is not that simple

Conclusions

- Saturatin fraction is a good measure for determining the precipitation rate
- But it is not that simple
- Or is it?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whole planet
midlat. land
whole planet
tropical sea
whole planet
tropical land
CAPE [J/kg]
Saturation fraction
Saturation fraction
0
2000
4000
0.2
0.4
0.6
0.8
1

Refference paper

- Raymond, D. J., 2000: Thermodynamic control of tropical rainfall. Quart. J. Roy. Meteor. Soc., 126, 889-898.