The formation of wider and deeper clouds through cold-pool dynamics

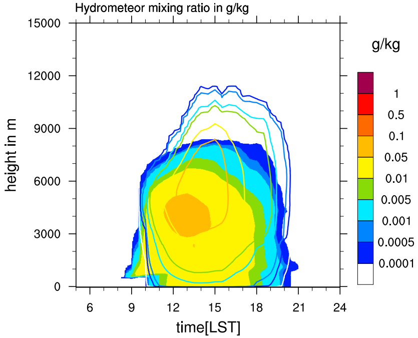
Linda Schlemmer, Cathy Hohenegger

Max-Planck-Institute for Meteorology, Hamburg

2013-05-14

Diurnal cycle of convection over land
How to get deep clouds??

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst



Promotion of deeper and wider clouds that are less affected by entrainment: cold pools
(Khairoutdinov and Randall, 2006, Kuang and Bretherton, 2006, Böing et al., 2012)

Max-Planck-Institut für Meteorologie

Cold pools, driven by evaporation and melting and precipitation

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst
DWD

1. Dynamical lifting of convective cells along the edges of cold pools (e.g. Lima et al., 2008)
2. Occurrence of a band with high equivalent potential temperature and water vapor along the edge of cold pools (Tompkins, 2001)

How do cold pools promote wider clouds? Different in different environments? Shallow <-> deep convection

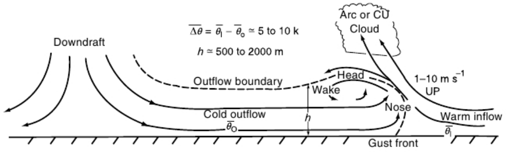


FIGURE 8.23 Schematic structure of a gust front. *(Adapted from Goff (1976), Fankhauser (1982), and Wakimoto (1982))*

Figure from Cotton (2011)

Max-Planck-Institut für Meteorologie

Large Eddy Simulations (LES)

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

UCLA-LES

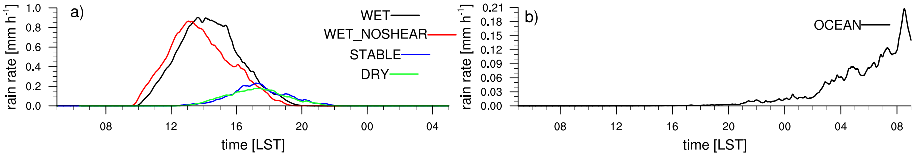
- Anelastic core
- Smagorinsky-type subgrid-scale diffusion
- $\Delta x = \Delta y = 250$ m, Δz stretched grid with a minimum of 70 m
- Domain size 250×250 km, model top at 21020 m
- Two-moment ice microphysics scheme (Seifert and Beheng, 2006)
- Interactive radiation scheme (Pincus and Stevens, 2009)
- Surface heat fluxes prescribed

Max-Planck-Institut für Meteorologie

Different environments: cases

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst
DWD

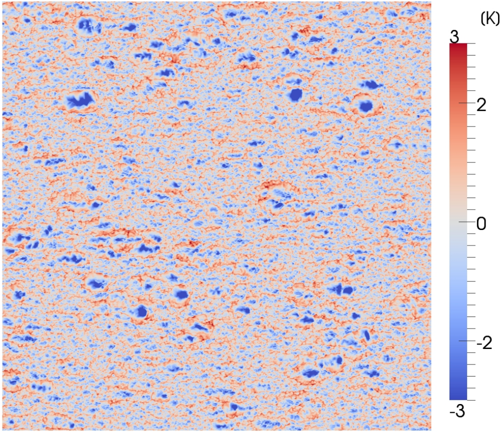
- Mid-latitude continental case (cf. Schlemmer et al., 2011)
  - WET
  - WET_noshear
  - STABLE
  - DRY
- Maritime case (cf. Waite and Khoudier, 2010)
  - OCEAN



Max-Planck-Institut für Meteorologie

Cold pools

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

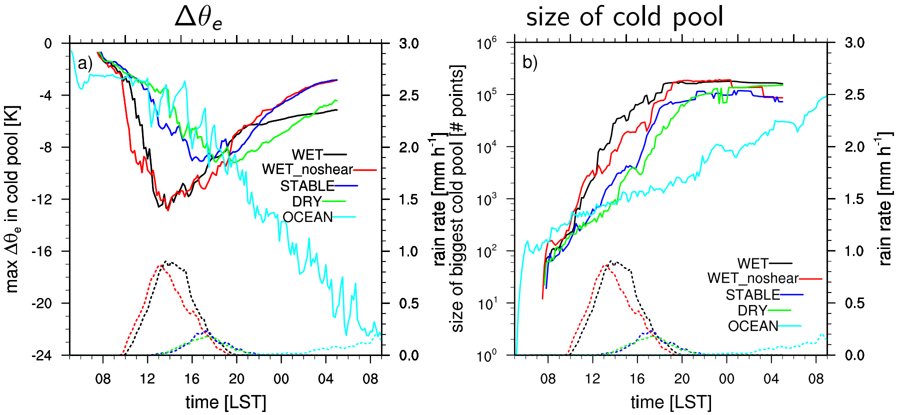


$\Delta\theta_e$ at 35 m height at 12 LST

Max-Planck-Institut für Meteorologie

Cold pools under different conditions

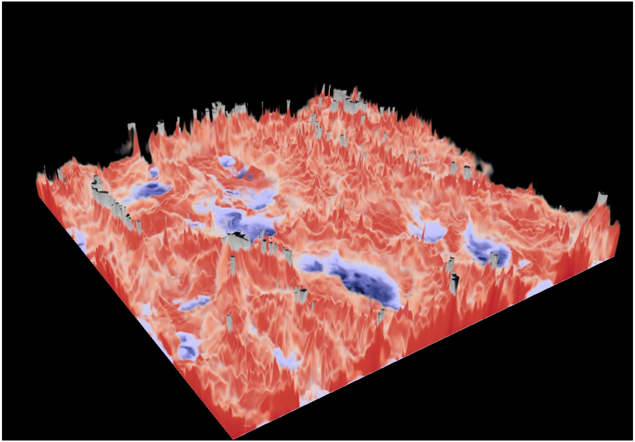
Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst



Max-Planck-Institut für Meteorologie

Signature in moisture field

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

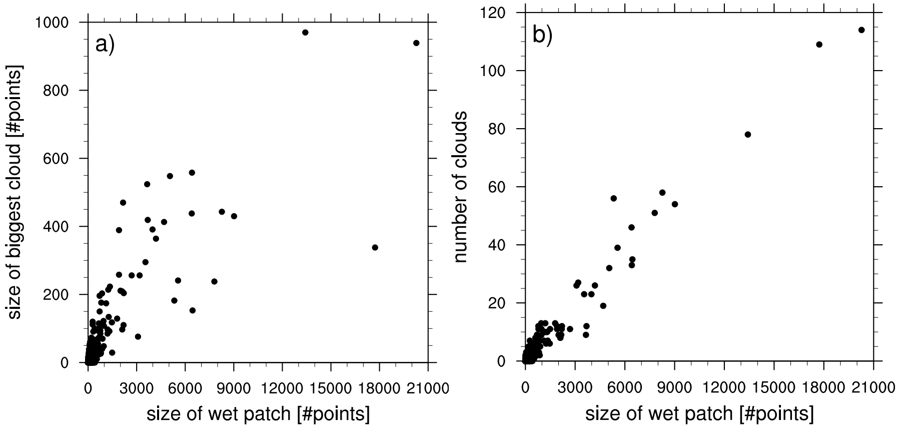


Dry areas in the cold pools and moist damns or patches around them

Clouds are located on these "wet patches."

Max-Planck-Institut für Meteorologie

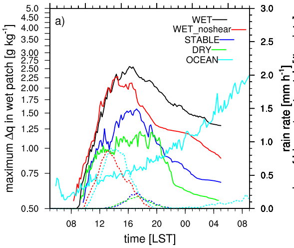
Wet patches and clouds



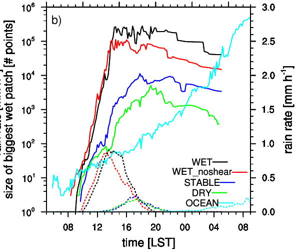
Wet patches and cloud sizes

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

Δq



size of wet patch

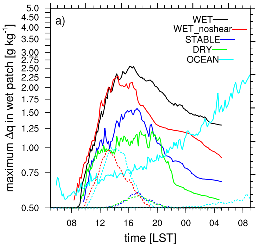


Max-Planck-Institut für Meteorologie

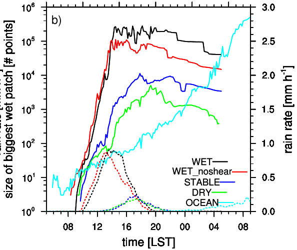
Wet patches and cloud sizes

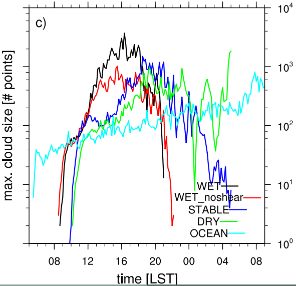
Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

Δq



size of wet patch

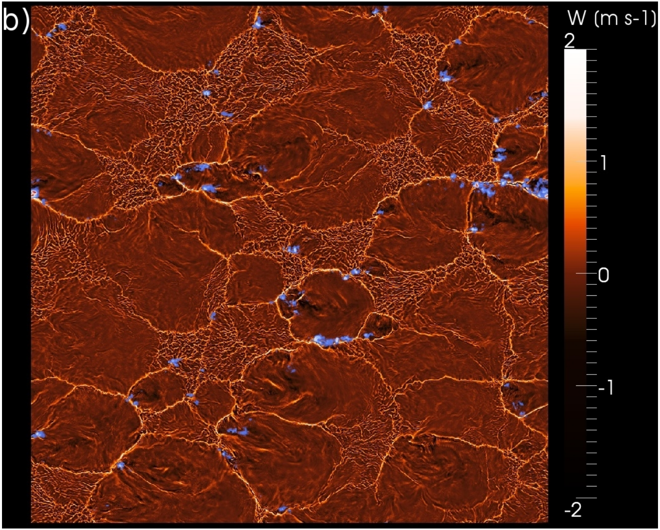




Max-Planck-Institut für Meteorologie

Dynamical lifting

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst



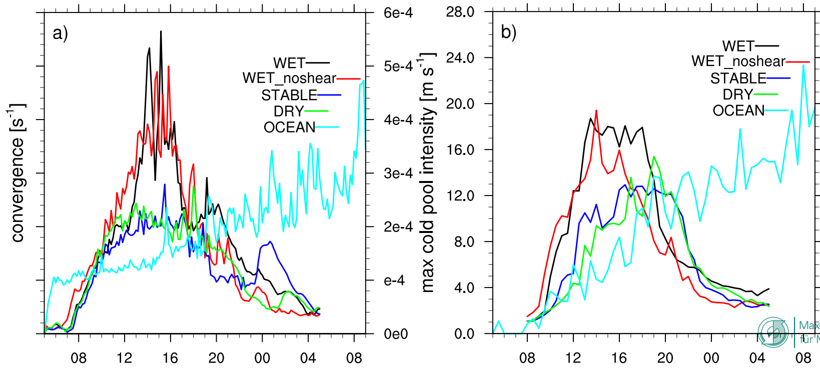
Max-Planck-Institut für Meteorologie

Convergence & propagation speed

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

cold pool intensity c_i (Rotunno, 1988):

$$c_i^2 = 2 \cdot \int_0^{H_{cp}} (-B)\, dz$$



Max-Planck-Institut für Meteorologie

Cold pools - cloud width

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

- Both a dynamical triggering and an accumulation of moisture by cold pools seems to be important for the generation of wider convective cells, mechanisms hard to disentangle.
- Large wet patches yield wider clouds
- Cold pools act in a similar manner in different environments but are stronger and larger in a more humid environment

Max-Planck-Institut für Meteorologie

Pathway to a parameterization

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

Successful attempts to include the effects of cold-pool wakes and associated dynamical triggering into parametrization schemes (e.g. Qian,1998, Mapes,2000, Rio,2009).

⇒include the role of a moisture aggregation.

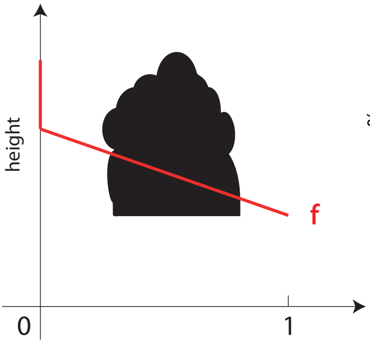
Max-Planck-Institut für Meteorologie

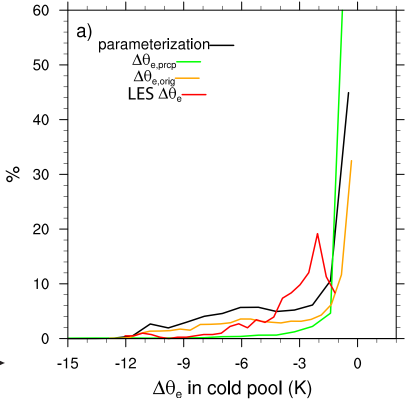
Pathway to a parameterization

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst
DWD

1. Predict θ_e depression in cold pool:

$$\Delta\theta_e = f \cdot \Delta\theta_{e,prcp} + (1 - f) \cdot \Delta\theta_{e,orig} \quad (1)$$





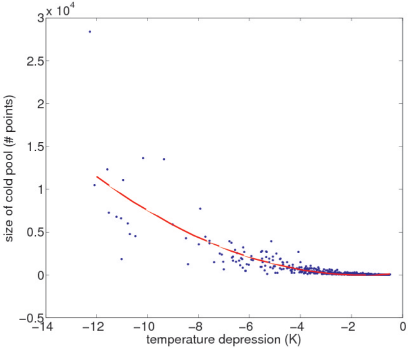
Pathway to a parameterization

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

1. Predict θ_e depression in cold pool:

$$\Delta\theta_e = f \cdot \Delta\theta_{e,prcp} + (1 - f) \cdot \Delta\theta_{e,orig} \qquad (1)$$

2. Relate size of cold pool to temperature depression: $A_{cp} = c_{fit} \cdot \Delta\theta_e^2$



Pathway to a parameterization

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

1. Predict θ_e depression in cold pool:

$$\Delta\theta_e = f \cdot \Delta\theta_{e,prcp} + (1 - f) \cdot \Delta\theta_{e,orig} \tag{1}$$

2. Relate size of cold pool to temperature depression: $A_{cp} = c_{fit} \cdot \Delta\theta_e^2$

3. Assume: size of wet patch = size of dry area = size of cold pool
$A_{cp} = A_{wp}$

Pathway to a parameterization

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

1. Predict θ_e depression in cold pool:

$$\Delta\theta_e = f \cdot \Delta\theta_{e,prcp} + (1 - f) \cdot \Delta\theta_{e,orig} \quad (1)$$

2. Relate size of cold pool to temperature depression: $A_{cp} = c_{fit} \cdot \Delta\theta_e^2$
3. Assume: size of wet patch = size of dry area = size of cold pool
   $A_{cp} = A_{wp}$
4. Size of biggest cloud related to size of wet patch

Pathway to a parameterization

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

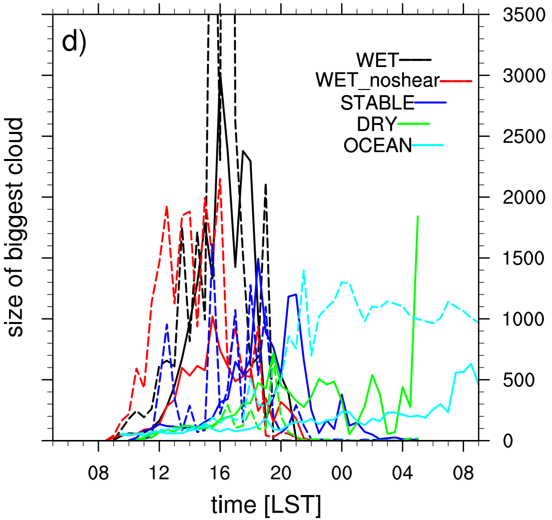
1. Predict θ_e depression in cold pool:

$$\Delta\theta_e = f \cdot \Delta\theta_{e,prcp} + (1 - f) \cdot \Delta\theta_{e,orig} \tag{1}$$

2. Relate size of cold pool to temperature depression: $A_{cp} = c_{fit} \cdot \Delta\theta_e^2$
3. Assume: size of wet patch = size of dry area = size of cold pool
   $A_{cp} = A_{wp}$
4. Size of biggest cloud related to size of wet patch
5. Size of cloud $\Rightarrow$modified entrainment rate

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

Pathway to a parameterization



Max-Planck-Institut für Meteorologie

Conclusions

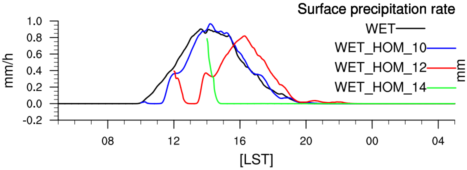
Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

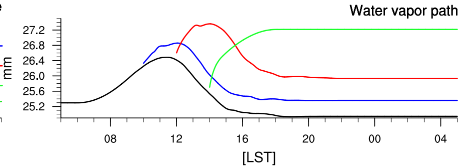
- Both a dynamical triggering and an accumulation of moisture by cold pools seems to be important for the generation of wider convective cells, mechanisms hard to disentangle.
- Cold pools act in a similar manner in different environments but are stronger and larger in a more humid environment
- Promising attempts towards a parameterization scheme

Max-Planck-Institut für Meteorologie

Homogenization

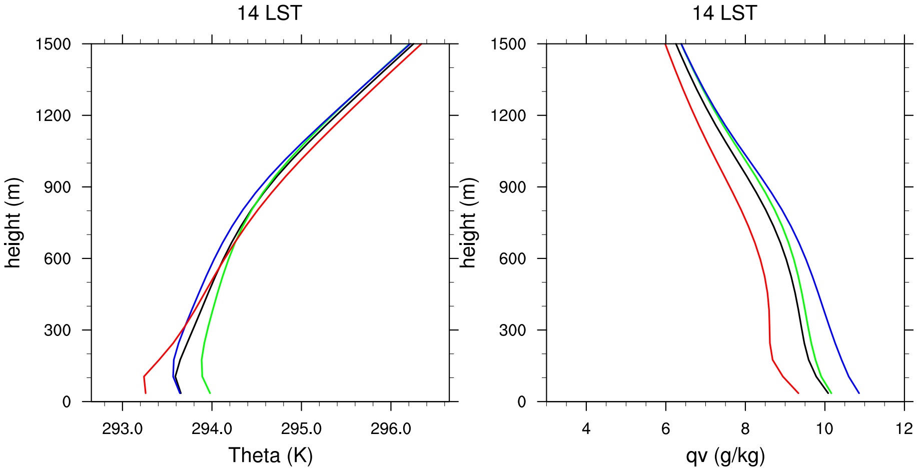
Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst





Max-Planck-Institut für Meteorologie

Vertical Profiles

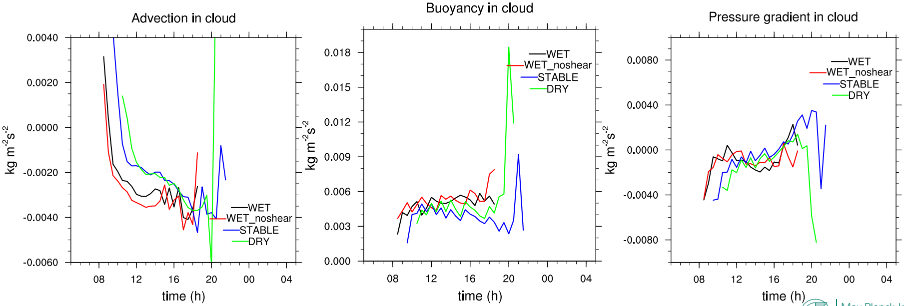


Momentum equation

Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

(neglect viscous terms and Coriolis terms)

$$\rho_0 \cdot \frac{\partial w}{\partial t} = -\left(\frac{\partial}{\partial x}(\rho_0 uw) + \frac{\partial}{\partial y}(\rho_0 vw) + \frac{\partial}{\partial z}(\rho_0 ww)\right) - \frac{\partial p'}{\partial z} + \rho_0 \cdot B$$



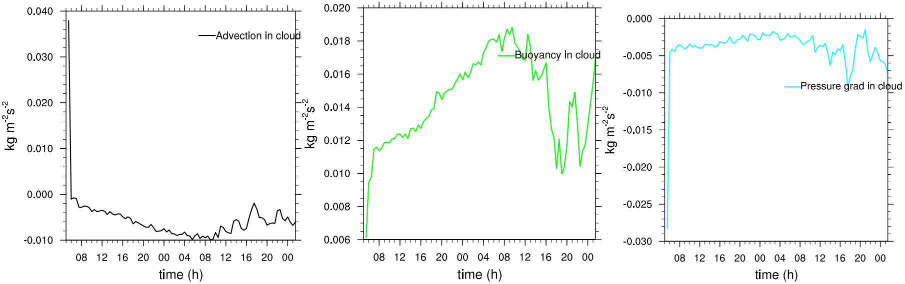
Max-Planck-Institut für Meteorologie

Momentum equation

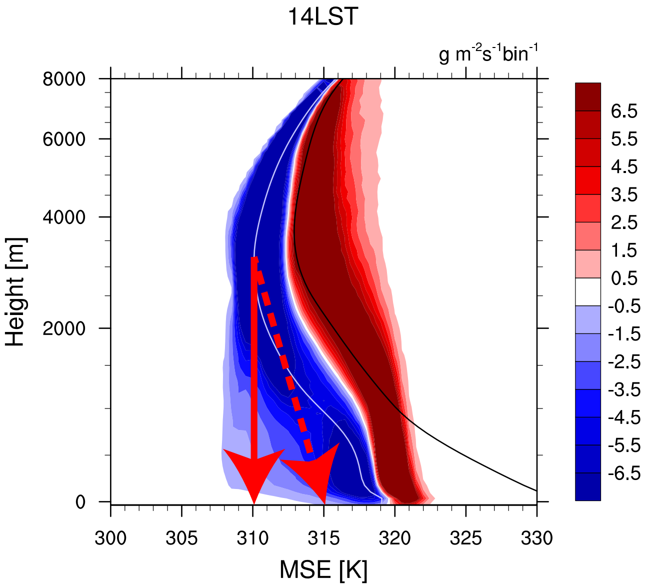
Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

(neglect viscous terms and Coriolis terms)

$$\rho_0 \cdot \frac{\partial w}{\partial t} = -\left(\frac{\partial}{\partial x}(\rho_0 uw) + \frac{\partial}{\partial y}(\rho_0 vw) + \frac{\partial}{\partial z}(\rho_0 ww)\right) - \frac{\partial p'}{\partial z} + \rho_0 \cdot B$$



Max-Planck-Institut für Meteorologie



Max-Planck-Institut
für Meteorologie