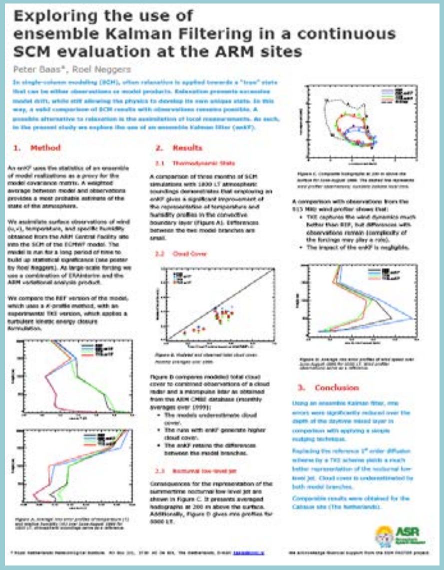
Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

Exploring the use of an ensemble Kalman Filter in a continuous SCM evaluation at the ARM sites

Peter Baas

Roel Neggers



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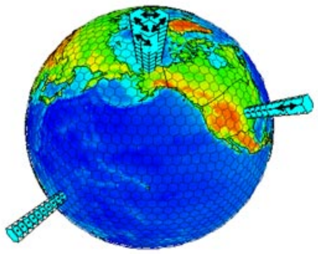
The SCM approach



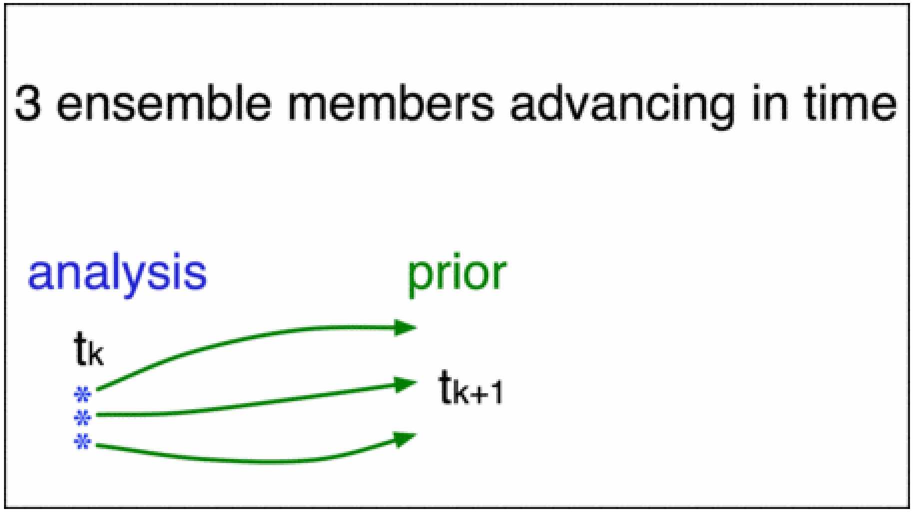
SCM
- Transparent / flexible
- Cheap

What about the forcings?
- Go with uncertainty
- Nudging towards some “true” state
- Alternative: assimilate observations! → enKF

Motivation
- Improve the ability to compare SCM results with observations
- Compare different parameterizations
- Compare results of SGP with Cabauw, The Netherlands

Ensemble Kalman Filter (enKF)

- Weighted average between model and observations
- Based on statistics of ensemble of model realizations
- Model covariances evolve in time



Source: Data Assimilation Research Testbed (NCAR)

SCM details and enKF implementation

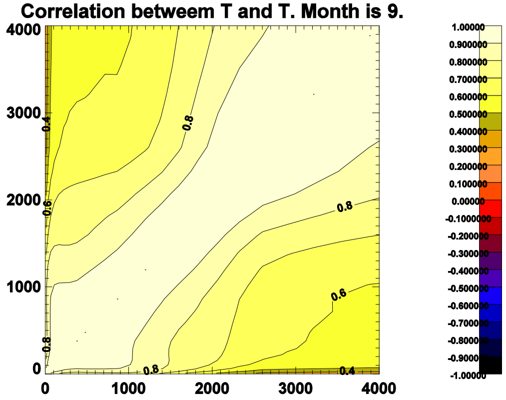
- ECMWF, REF version vs. TKE

- Monthly runs ARMSGP Central Facility with coupled soil/vegetation scheme (here: 1999)

- Assimilated variables (hourly):
  - Surface observations of *u*, *v*, *T* and q_v
  - Soil moisture and soil temperature of ERAinterim

- Initial profiles drawn from Gaussian distribution with correlations derived from climatology

- → *How effective is the enKF in transporting the impact of the assimilated surface observations upwards?*

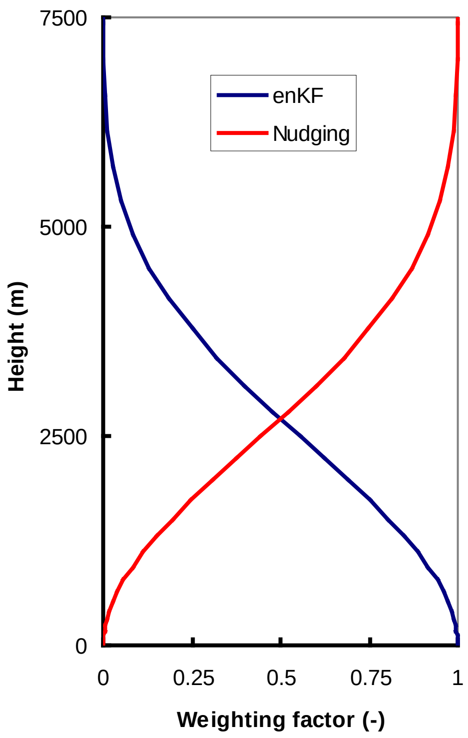


Localization and large-scale forcings

- A localization function* constrains the impact of the enKF to the lowest kms

- In the upper part of the domain relaxation to the forcings is applied (τ = 6h):

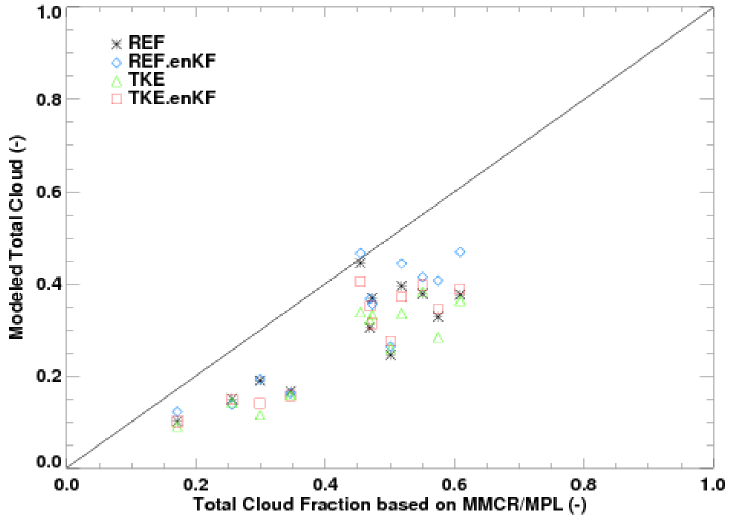
  - Geostrophic wind and subsidence from ERAinterim
  - Dynamic tendencies from ARM variational analysis



* 5th order polynomial by Gaspari and Cohn (1999)

1999 results for cloud cover

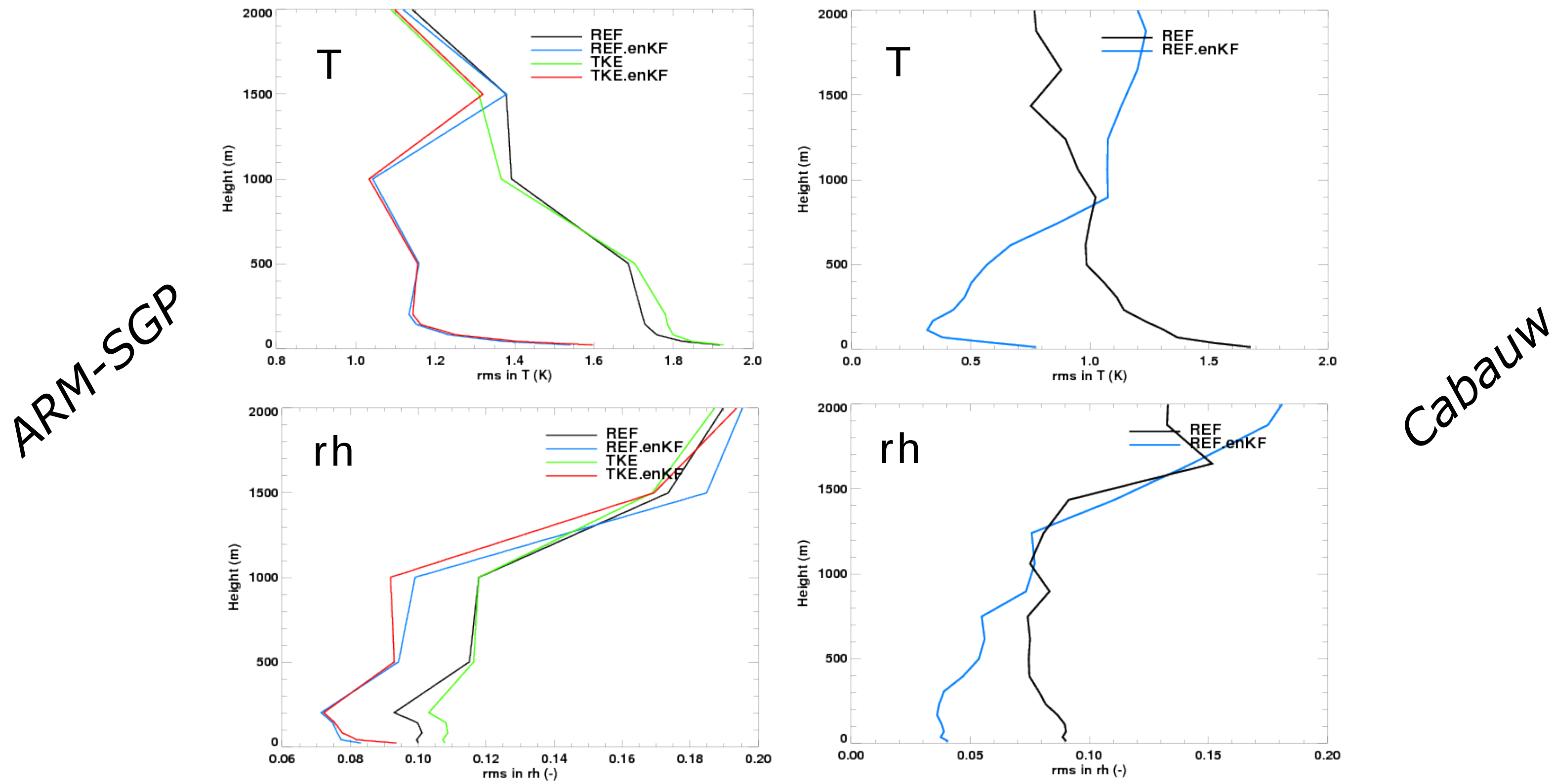
- Model underestimates cloud cover
- REF better than TKE
- Runs with enKF generate higher cloud cover
- EnKF retains differences between model branches



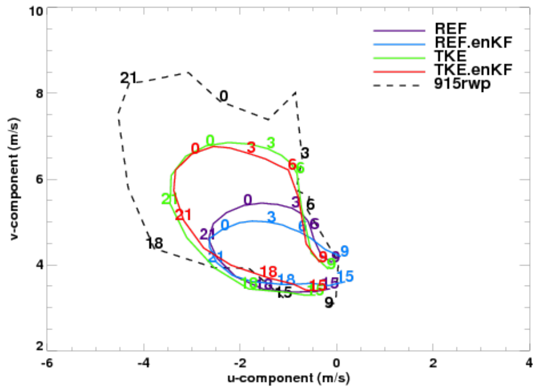
Example: modeled and observed total cloud cover at the ARM site. Monthly averages for 1999.

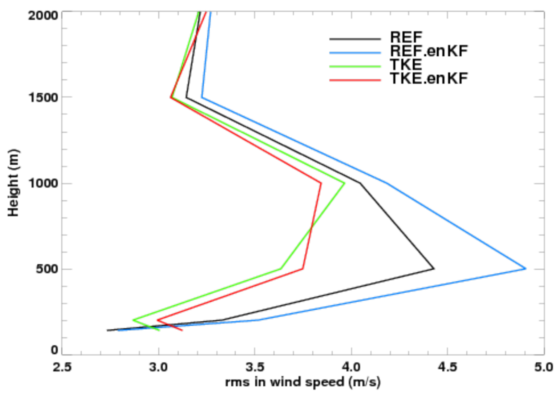
Southern Great Plains versus Cabauw (NL)

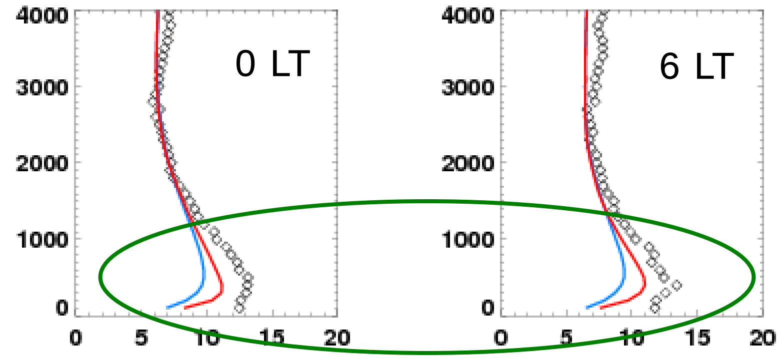
- Rms error profiles of temperature and relative humidity for 12 LT
- Atmospheric soundings serve as a reference



Nocturnal low-level jet (JJA)







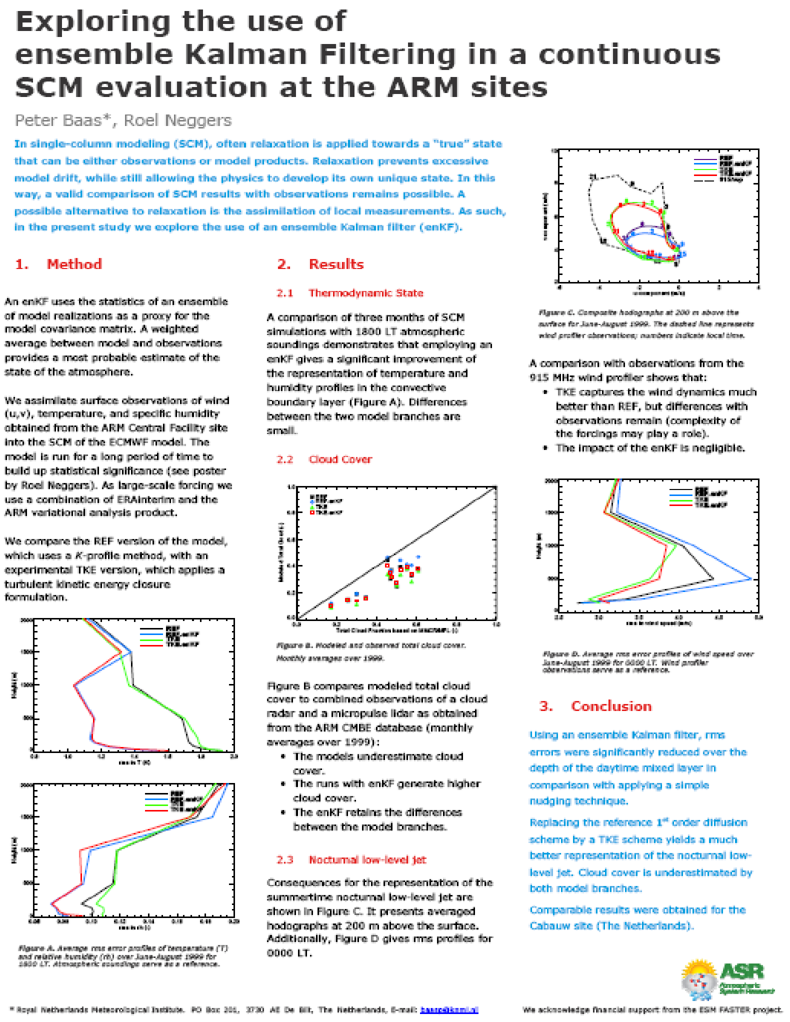
Blue = REF

Red = TKE

Diamonds= ARMSGP radiosondes

Comparison with wind profiler observations

- EnKF improves mixed layer representation
- EnKF retains differences between model branches
- Cloud cover is underestimated (REF better)
- Nocturnal jet is underestimated (TKE better)
- Comparable results were obtained for Cabauw (NLD)



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In single-column modeling (SCM), often relaxation is applied towards a "true" state that can be either observations or model products. Relaxation prevents excessive model drift, while still allowing the physics to develop its own unique state. In this way, a valid comparison of SCM results with observations remains possible. A possible alternative to relaxation is the assimilation of local measurements. As such, in the present study we explore the use of an ensemble Kalman filter (enKF).

1. Method

An enKF uses the statistics of an ensemble of model realizations as a proxy for the model covariance matrix. A weighted average between model and observations provides a most probable estimate of the state of the atmosphere.

We assimilate surface observations of wind (u,v), temperature, and specific humidity obtained from the ARM Central Facility site into the SCM of the ECMWF model. The model is run for a long period of time to build up statistical significance (see poster by Roel Neggers). As large-scale forcing we use a combination of ERAinterim and the ARM variational analysis product.

We compare the REF version of the model, which uses a *K*-profile method, with an experimental TKE version, which applies a turbulent kinetic energy closure formulation.

Figure A. Average rms error profiles of temperature (T) and relative humidity (rh) over June-August 1999 for 1800 LT. Atmospheric soundings serve as a reference.

2. Results

2.1 Thermodynamic State

A comparison of three months of SCM simulations with 1800 LT atmospheric soundings demonstrates that employing an enKF gives a significant improvement of the representation of temperature and humidity profiles in the convective boundary layer (Figure A). Differences between the two model branches are small.

2.2 Cloud Cover

Figure B. Modeled and observed total cloud cover. Monthly averages over 1999.

Figure B compares modeled total cloud cover to combined observations of a cloud radar and a micropulse lidar as obtained from the ARM CMBE database (monthly averages over 1999):

- The models underestimate cloud cover.
- The runs with enKF generate higher cloud cover.
- The enKF retains the differences between the model branches.

2.3 Nocturnal low-level jet

Consequences for the representation of the summertime nocturnal low-level jet are shown in Figure C. It presents averaged hodographs at 200 m above the surface. Additionally, Figure D gives rms profiles for 0000 LT.

Figure C. Composite hodographs at 200 m above the surface for June-August 1999. The dashed line represents wind profiler observations; numbers indicate local time.

A comparison with observations from the 915 MHz wind profiler shows that:

- TKE captures the wind dynamics much better than REF, but differences with observations remain (complexity of the forcings may play a role).
- The impact of the enKF is negligible.

Figure D. Average rms error profiles of wind speed over June-August 1999 for 0000 LT. Wind profiler observations serve as a reference.

3. Conclusion

Using an ensemble Kalman filter, rms errors were significantly reduced over the depth of the daytime mixed layer in comparison with applying a simple nudging technique.

Replacing the reference 1st order diffusion scheme by a TKE scheme yields a much better representation of the nocturnal low-level jet. Cloud cover is underestimated by both model branches.

Comparable results were obtained for the Cabauw site (The Netherlands).

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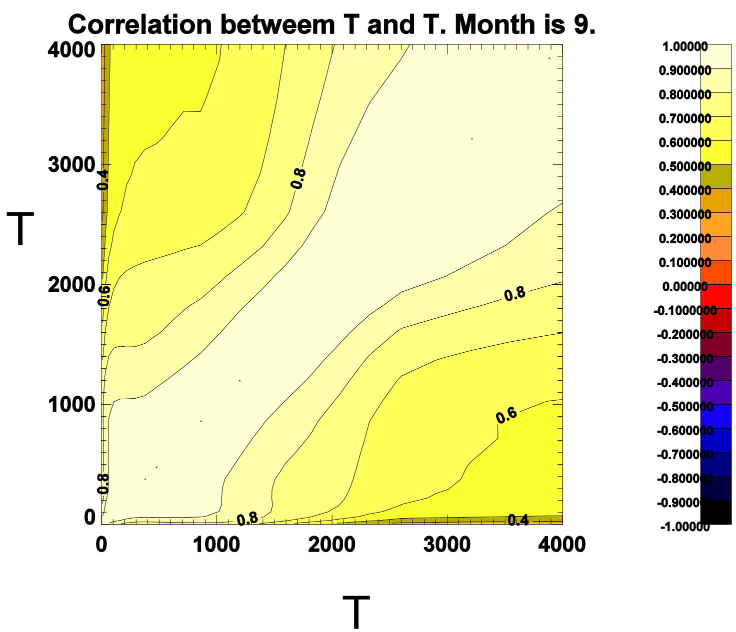
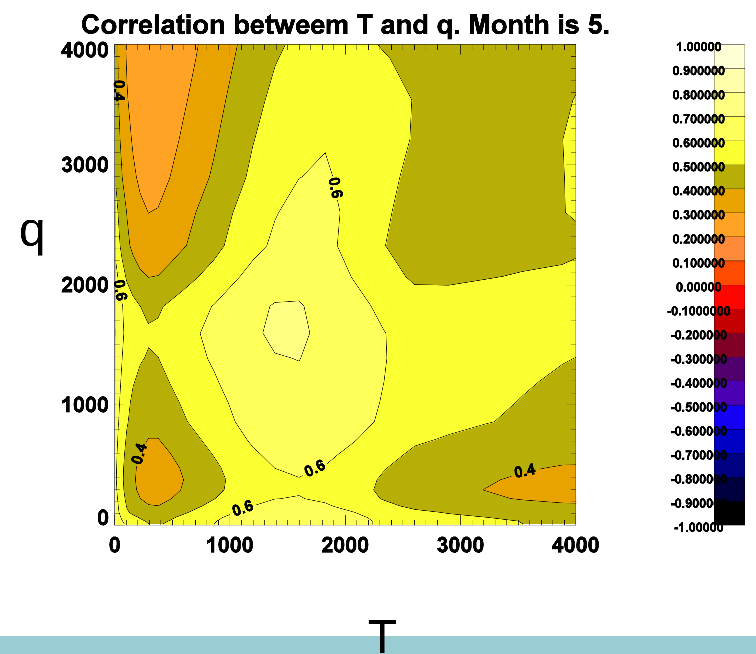
Initial conditions

- Create perturbed profiles of u, v, T, q, T_{skin}, q_{skin}, T_s, q_s for each ensemble member with realistic correlations
- Monthly correlations are derived from 3-year driverfile archive





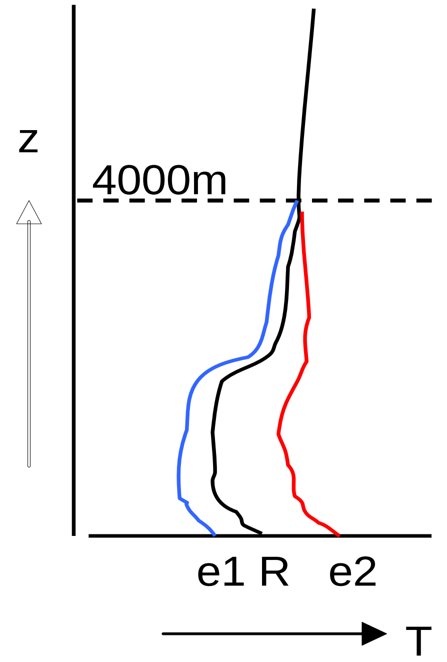
Initial conditions

- Generate random perturbation matrix with correct correlations (derived from driverfile climatology).
- Specify stdevs: $\sigma_u = \sigma_v = 1 m/s$, $\sigma_T = \sigma_{Tskin} = \sigma_{Ts} = 1K$, $\sigma_q = 0.5 g/kg$, $\sigma_{qskin} = \sigma_{qs} = 0.02 m^3/m^3$.

- Calculate profiles

1. E.g. for every ensemble member:

T(z,ens#) = 3D(z) +
RM(T(z),ens#) * std(T) *
max(0 ; 1-z/4000)



Motivation

- Increase statistical significance of SCM studies
- Compare different parameterizations
- Improve the ability to compare SCM results with observations
- Compare results of SGP with Cabauw, The Netherlands

Southern Great Plains

Cabauw