

New developments in Soil Moisture Analysis at DWD

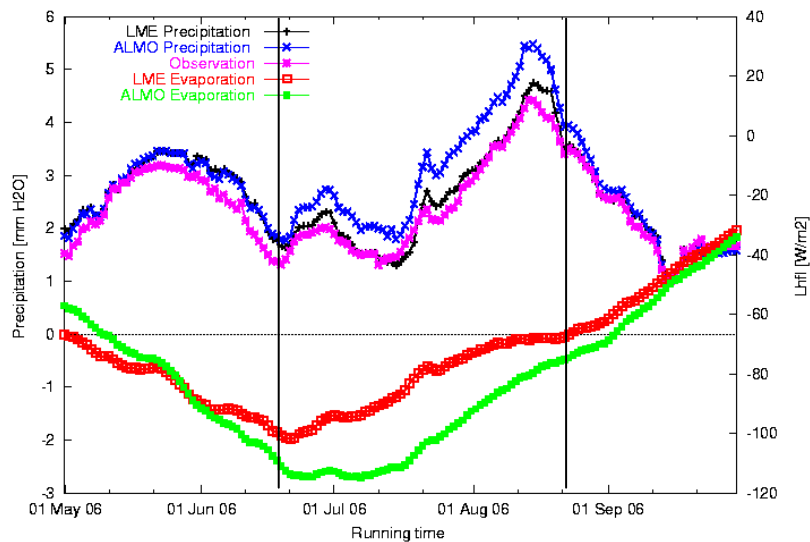
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Outline

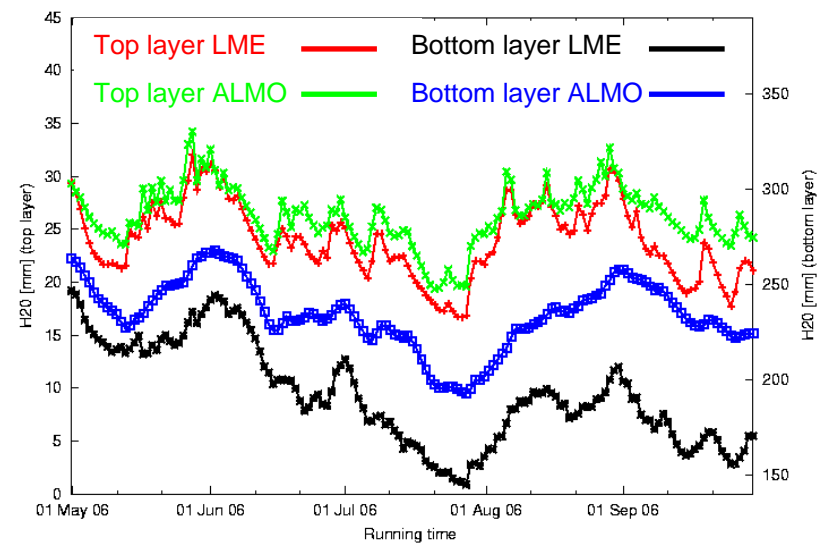
- Motivation for SMA in GME
- Parameterisation of the variational SMA scheme.
- Experiences from operations
 - Impact on screen level temperature
 - Accumulation of soil ice by the SMA

Almo exceeds LME Precipitation due to soil moisture initialisation

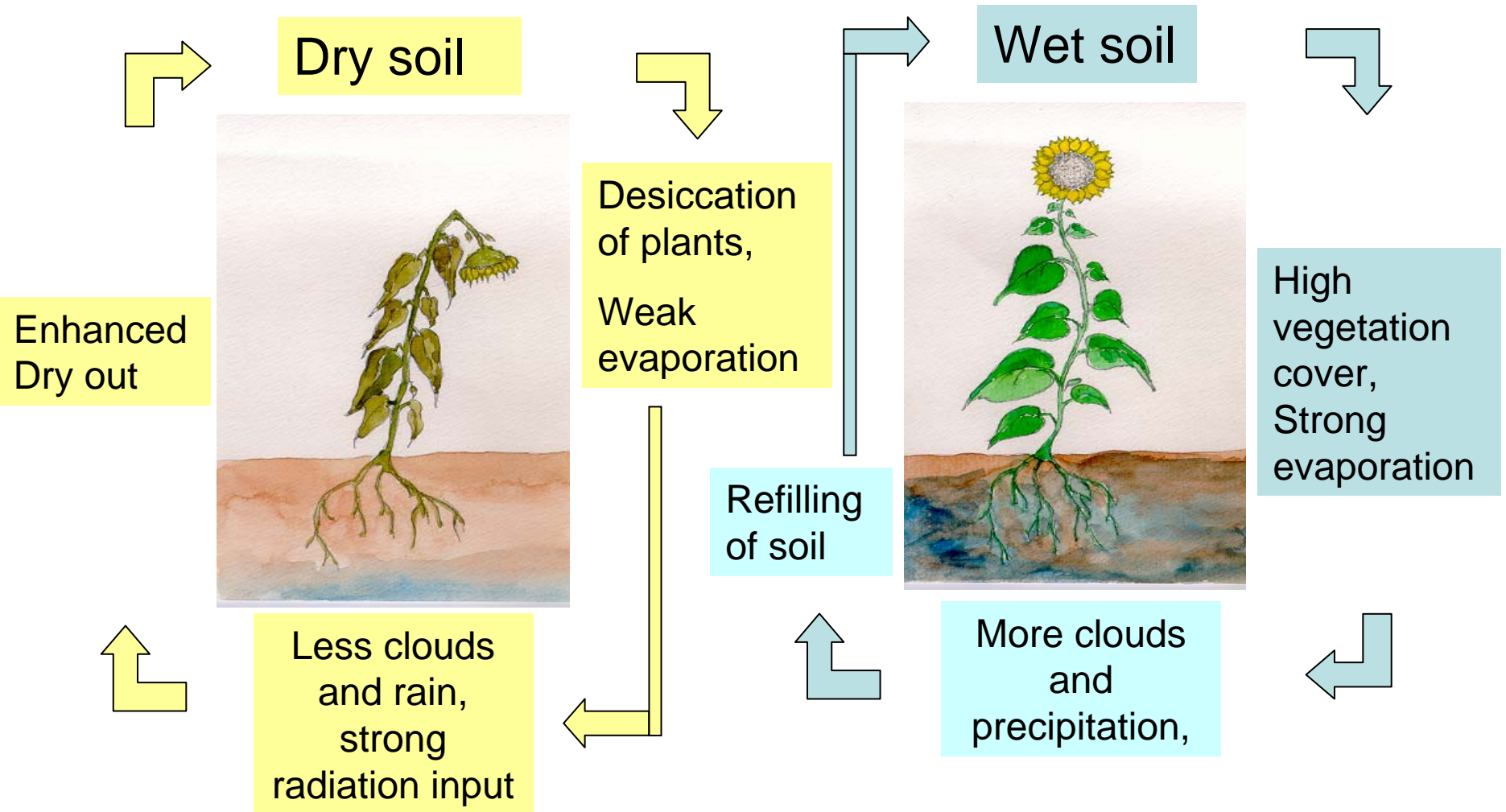
Running monthly mean precipitation and evaporation



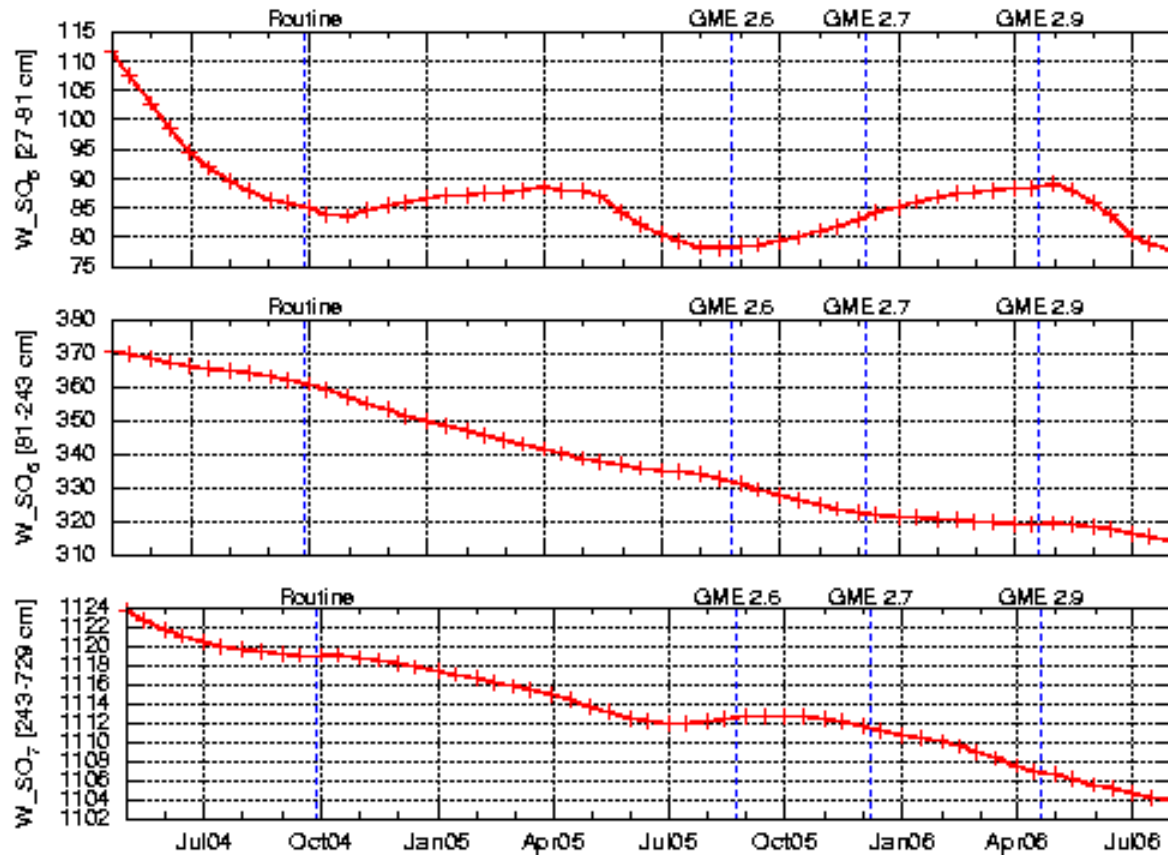
Daily soil moisture top and bottom layers



Positive feedback of dry/wet soil on precipitation forecast



Long term dry out in GME leads to positive Bias in T2m during summer



Development of a soil moisture analysis for GME

- Soil moisture measurements are not available on a dense network, Radar observations even not on the global scale.
- Explore forecast errors in screen level parameter to correct initial soil moisture.
- A variational soil moisture assimilation scheme runs daily for the LME model. This requires at least two additional model forecast runs. This is computationally too expensive for GME.

2d var (z,t) soil moisture analysis applied in LME

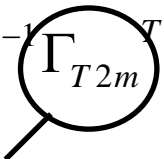
Cost function penalizes deviations from observations and initial soil moisture content

$$J = (w - w_b)^T B^{-1} (w - w_b) + (T_{2m} - T_{2m}^{obs})^T O^{-1} (T_{2m} - T_{2m}^{obs})$$

$$\nabla J = 0$$

Analysed soil moisture depends on T2m forecast error and sensitivity $\partial T_{2m} / \partial w$

$$w_{ana} = w_b + (\Gamma_{T_{2m}}^T O^{-1} \Gamma_{T_{2m}} + B^{-1})^{-1} \underbrace{\Gamma_{T_{2m}}^T O^{-1} (T_{2m}^{obs} - T_{2m}(w_b))}_{T_{2m} \text{ fc error}}$$



 $\frac{\partial T_{2m}(12:00, 15:00)}{\partial w(0:00)}$

Parameterisation of $\partial T_{2m}(12:00, 15:00)/\partial w(0:00)$ with $\partial Lhfl/\partial w$ from penman eqn. at obs time

Surface energy balance equation

$$0 = R_n - Lhfl - Shfl - G$$

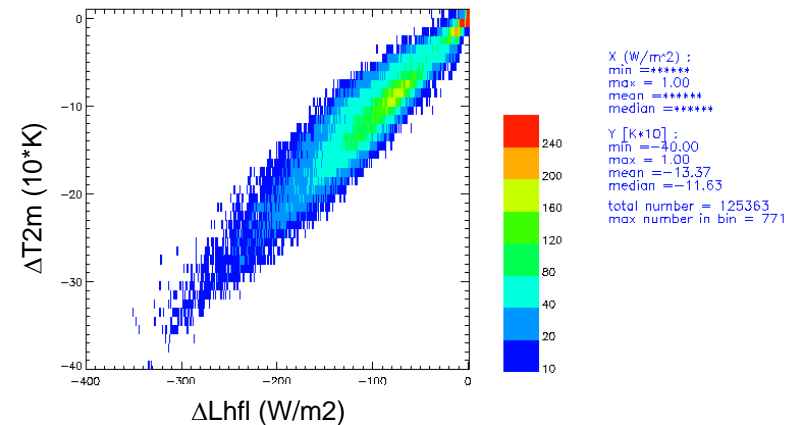
Soil moisture variation:

$$\Delta Lhfl \cong -\Delta Shfl$$

$$\Delta Shfl = \rho c_p \frac{(\Delta T_s - \Delta T_{2m})}{r_a}$$

$$\Delta Lhfl \cong -\frac{\rho c_p}{r_a} \left(\frac{1-\alpha}{\alpha} \right) \Delta T_{2m}$$

$$\Delta Lhfl(12:00) \sim \Delta T_{2m}(12:00)$$



Evaporation from vegetation depends on soil moisture through stomata resistance

$$Lhfl = f_{pl} (1 - f_i) (1 - f_{snow}) E_{pot} \frac{r_a}{r_a + r_f}$$

$$r_f = \frac{r_{la} + r_s}{f_{LAI}}$$

$$r_s^{-1} = r_{s,max}^{-1} + (r_{s,min}^{-1} - r_{s,max}^{-1}) F_{rad} * F_{tem} * F_{hum} * F_{wat}$$

$$F_{wat} = \frac{W_{root} - W_{pwp}}{(W_{fcap} - W_{pwp}) f_{tlp}}$$

Sensitivity of 2m temperature on soil moisture

$$\frac{\partial F_{wat}}{\partial w_k} = \frac{1}{(w_{fcap} - w_{pwp}) f_{tlp}} \frac{dz_{k,root}}{z_{root}}$$

Root density constant with soil depth!

$$\frac{\partial Lhfl}{\partial w_k} = \frac{Lhfl}{(r_a + r_f) f_{LAI}} \frac{1}{r_{s,max}} \left(1 - \frac{r_s}{r_{s,max}}\right) \frac{r_s}{w_{root} - w_{pwp}} \frac{dz_{k,root}}{z_{root}}$$

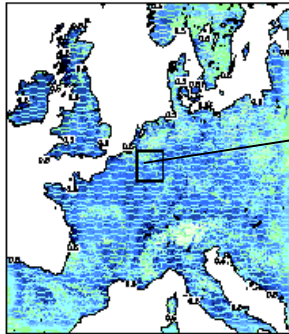
$$\frac{\partial T_{2m}}{\partial w_k} = \frac{\bar{r}_a}{\rho c_p} \left(\frac{\alpha}{1 - \alpha} \right) \frac{Lhfl}{(r_a + r_f) f_{LAI}} \frac{1}{r_{s,max}} \left(1 - \frac{r_s}{r_{s,max}}\right) \frac{r_s}{w_{root} - w_{pwp}} \frac{dz_{k,root}}{z_{root}}$$

Validation against model forecast

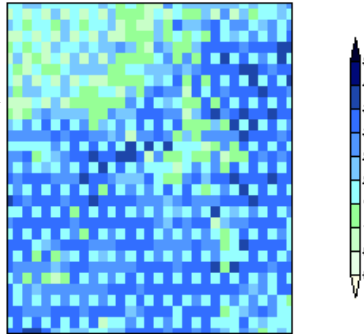
- Variation of initial soil moisture at selected gridpoints in the whole range between plant wilting point and field capacity.
- Compare Sensitivity of T2m on soil moisture with parameterisation.

Horizontal decoupling hypothesis is valid

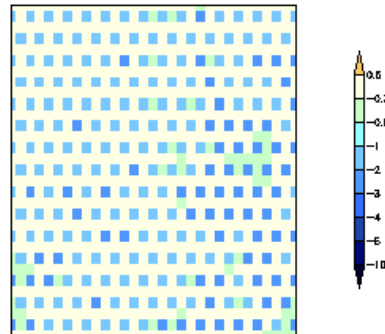
Initial soil moisture wb2(sw2=0.5), date=20050528



Initial soil moisture wb2(sw2=0.5), date=20050528



Difference T2m 12hr fc, swi2=0.75-sw2=0.25, date=20050528

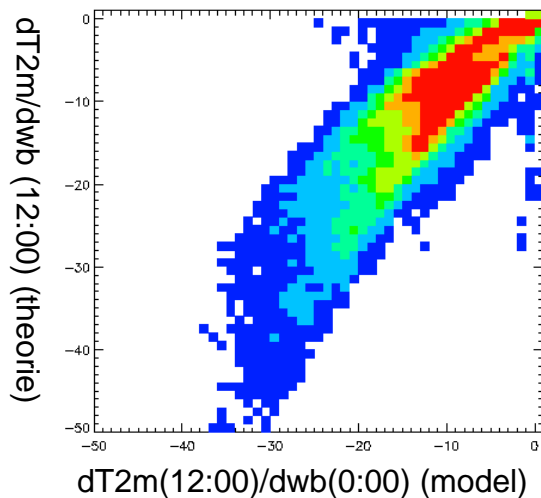


Parameterisation can be applied during radiation conditions in the whole range between plant wilting point and field capacity

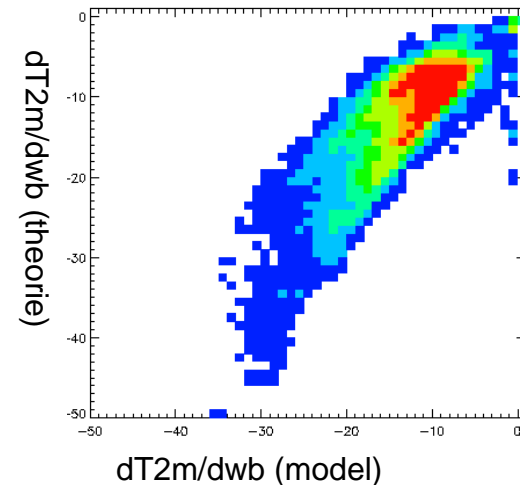
Date: 20050525

Lhfl(11:00-12:00)
> 200 W/m²

All gridpoints



X [K*10] :
min = -50.00
max = 1.00
mean = -14.16
median = -11.88
Y [K*10] :
min = -50.00
max = 0.26
mean = -12.65
median = -9.84
total number = 1247
max number in bin =



X [K*10] :
min = -50.00
max = 1.00
mean = -15.36
median = -13.27
Y [K/mm*1000] :
min = -50.00
max = 0.00
mean = -14.49
median = -11.58
total number = 79152
max number in bin = 1031

No further need for additional model runs !

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Status and further plan

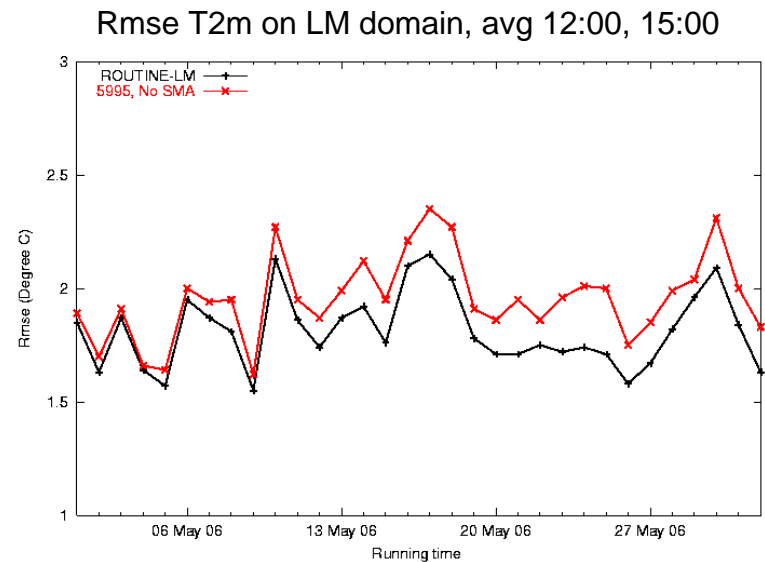
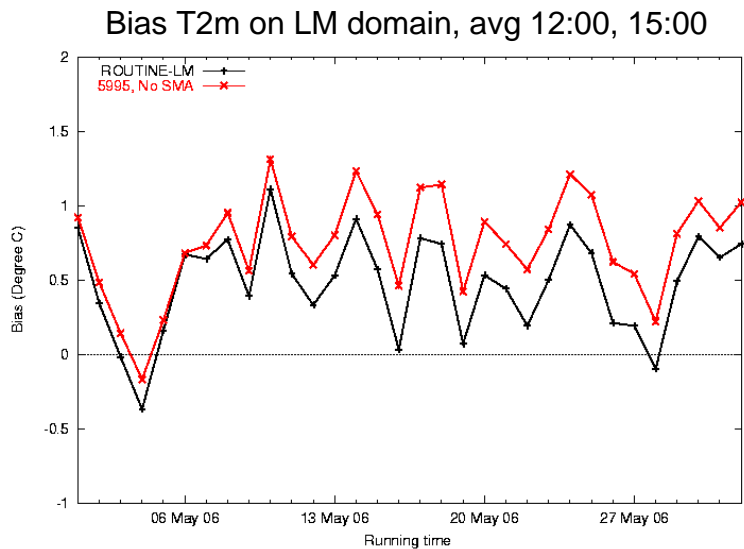
- Development phase almost finished.
- First validation experiments with the LM model are planned to start soon.
- Implementation in GME should be ready end of summer 2007.

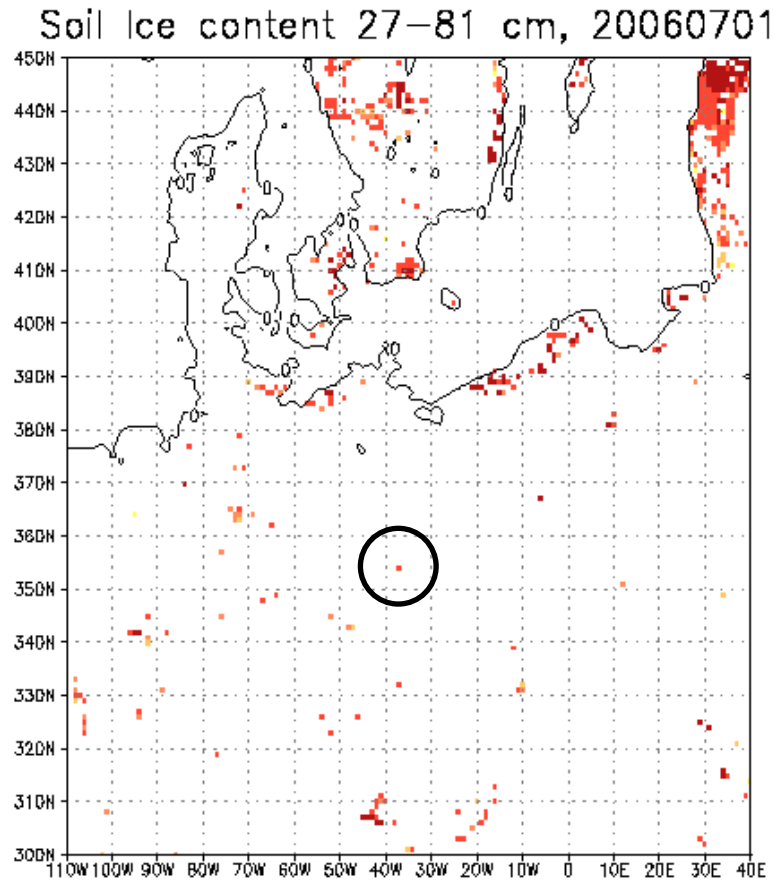
Experiences from operations

- Impact of SMA in LME on bias in 2m temperature.
- SMA affects soil ice content.

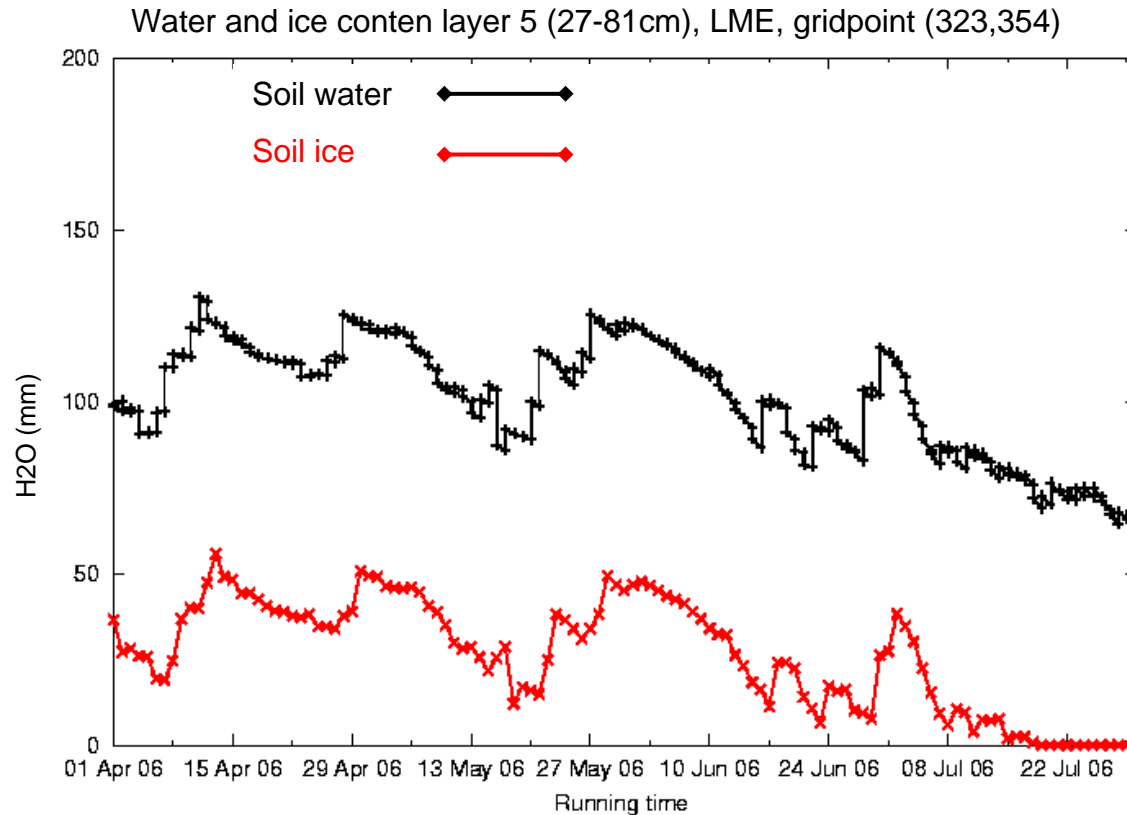
SMA reduces effectively Bias and Rmse of T2m in LME

Routine — No SMA —





Accumulation of soil ice by adding water in SMA



Modification of SMA

1.) Frozen soil at initial time of the next forecast:

$$T_{so}(vv=24hr) < T_0$$

Apply only negative SMA increments:

$$W_{so}(ana) = \text{Min}(W_{so}(mod) + \delta wa, W_{so}(mod))$$

2.) Soil unfreezed at begin of next forecast but soil frozen at time of analysis: $T_{so}(vv=24hr) > T_0$, $T_{so}(t=0) < T_0$

Positive soil moisture increments are possible if maximum liquid water content is not exceeded:

$$W_{so}(ana) = \text{Min}(W_{so}(mod) + \delta wa, WI_{max})$$

Modification of SMA

If soil is frozen at begin of the next forecast:

Apply only negative SMA increments:

$$W_{so}(ana) = \text{Min}(W_{so}(\text{mod}) + \delta wa, W_{so}(\text{mod}))$$

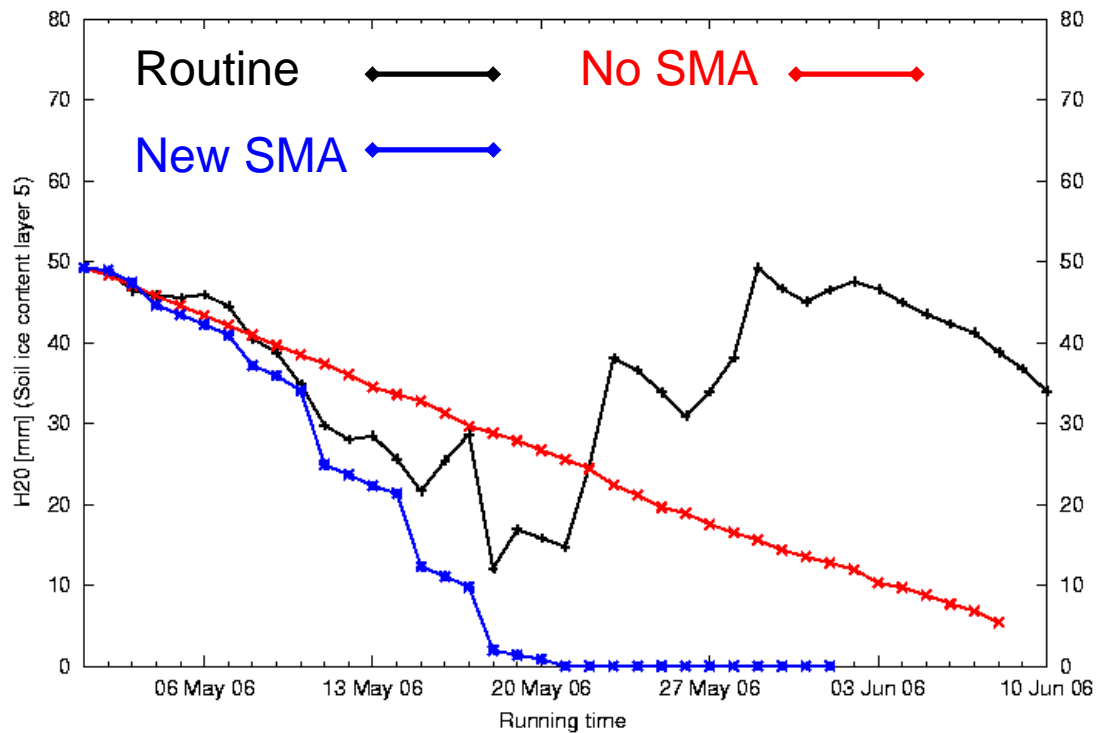
If soil is unfreezed at begin of next forecast but soil temperature below freezing point at time of analysis:

Positive soil moisture increments are possible if maximum liquid water content is not exceeded and soil ice occurs.

$$W_{so}(ana) = \text{Min}(W_{so}(\text{mod}) + \delta wa, WI_{\text{max}})$$

Fast reduction of soil ice when T2m is sensitive on soil moisture

Soil ice content layer 5 (27-81cm)



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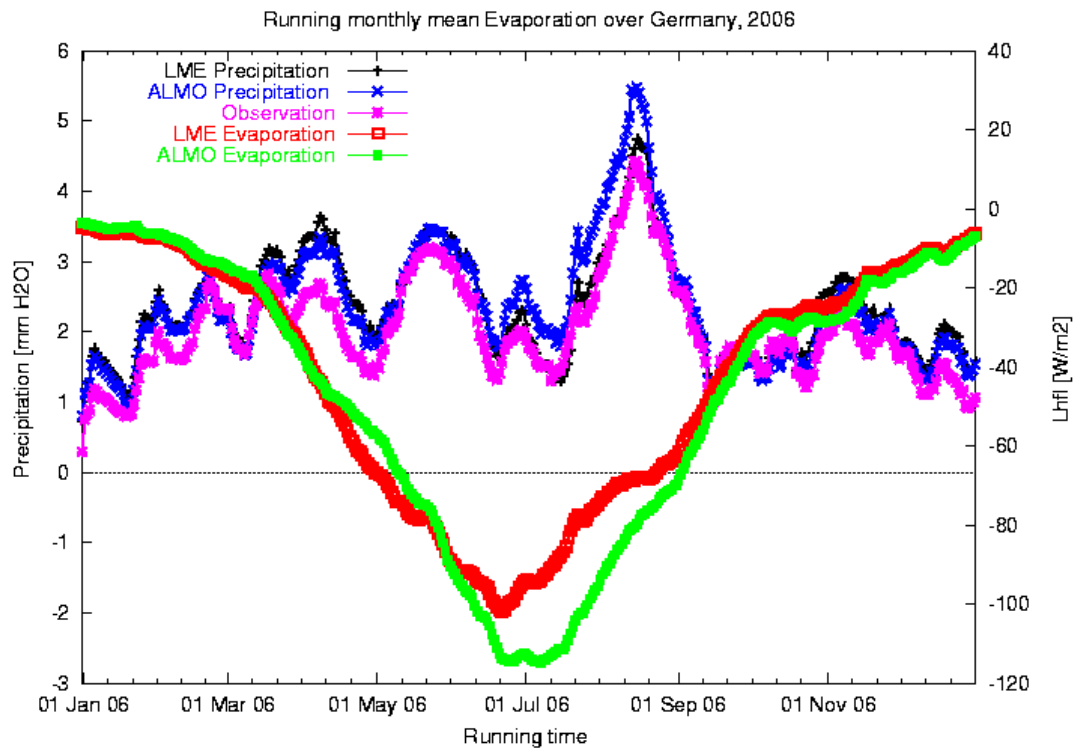
Conclusions

- Soil moisture analysis is appropriate to prevent from permanent drifts and to reduce forecast errors in screen level parameter.
- A parameterisation of the SMA scheme is developed for GME to save computational costs for additional model runs required in the variational method.
- The parameterisation can be applied successfully under conditions when transpiration from vegetation dominates.
- Side effects should be considered when model changes are introduced.
- Accumulation of soil ice through the SMA is fixed by suppressing positive increments in frozen soil.

Acknowledgement

- Thanks to Emanuele Zala from meteo swiss who provided the Almo data for 2006.

Almo exceeds LME Precipitation due to soil moisture initialisation



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