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Sensitivity and tuning of parameterisation of precipitation in HIRHAM5

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Abstract

The sensitivity of tuning parameters in HIRHAM precipitation schemes has been investigated, along with resolution depended parameters. A new set of parameters values for the precipitation parameterisation is suggested for used at resolution of ~5 km. The spatial pattern and timing is found robust among the experiments. The timing of events is found to be best simulated with active cumulus convection scheme, compared to without convective scheme.

Resumé

I HIRHAMs nedbørsparameterisering er tuningsparameter identificeret samt parameter der er opløsningsafhængige. Sensitiviteten af tuningsparametrene er blevet undersøgt. Et nyt sæt af parameterværdier bliver forslået til brug ved opløsning omkring 5 km. Det rummelige mønster og timing er fundet robust igennem eksperimenterne. Timingen af events er fundet i bedst overensstemmelse med observationerne ved brugen af cumulus konvektions skemaet i forhold til uden.

Introduction

HIRHAM5 (Christensen et al., 2006) use the physical parameterisation from the general circulation model ECHAM (Roeckner et al., 2003); which is formulated for global coarse resolution use. Thereby, it may not be suitable for high resolution regional climate model use without adjustments. A review and eventual tuning is therefore of interest. A general tendency to more precipitation at higher resolution is found among simulations by HIRHAM (Jacob et al., 2007; Rasmussen et al., 2012). Additional results of Rassmussen et al. (2012) are shown on Figure 1. The results are for summer precipitation over the central US and thereby the focus of warm cloud parameterisation. Temporal comparison is made at the FIFE area (Sellers et al., 1992) as in Rasmussen et al., (2012). Area mean precipitation over the FIFE area is computed by Betts (1994).

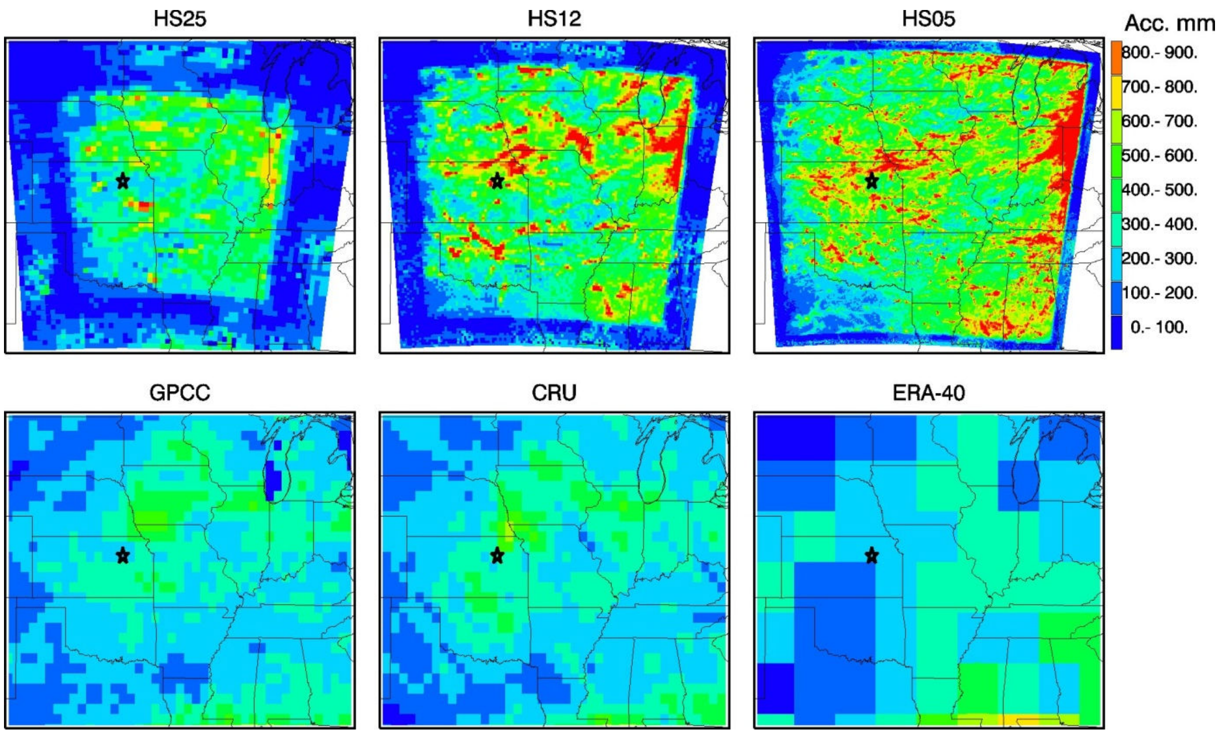

Figure 1. Total summer precipitation, 1987 June, July and August. Results of the simulations are for the whole model domain including the 10 cell relaxing zone. FIFE is located at the star. Bottom row, observed gridded data sets GPCC (Global Precipitation Climatology Centre, Rudolf, 2004), CRU (Climatic Research Unit, University of East Anglia, Mitchell et al., 2004) and reanalysis ERA-40 (Uppala et al., 2005).

Objectives of this study are:

Identify resolution dependent and tuning parameters in the formulation of the parameterisation of precipitation.

Correction of resolution dependent parameters and investigate the sensitivity of tuning parameters.

Estimation of new tuning parameter set of precipitation for use at ~5 km resolution.

Identification of resolution dependent and tuning parameters

Precipitation is parameterised in two schemes of HIRHAM; the cumulus convection scheme and the stratiform cloud scheme. HIRHAM physical parameterisation is taken from ECHAM and documentation is found in Roeckner et al., (2003).

Cumulus convection scheme

(echam-5.2.02.1-hirham-v0.3/src/model/cumastr.f90)

Calculation of cloud base mass flux is dependent on a time (spatial scale) by:
(Equations numbers refer to Roeckner et al. (2003).)

$$M_B = \frac{CAPE}{\tau} = M_B^* \left\{ \int_{base}^{top} \left[\frac{(1+\delta\bar{q})}{c_p \overline{T_v}} \frac{\partial \bar{s}}{\partial z} + \delta \frac{\partial}{\partial z} \bar{q} \right] M^* \frac{g}{\bar{\rho}} dz \right\}^{-1} \qquad (9.25)$$

where

$$\tau[s] = \min(3 \cdot 3600, 2 \cdot 3600 \cdot 63/N)$$

and N denote the spectral resolution. The scheme is optimised for N = 63.

The spectral resolution is set manual in the ECHAM physic, current default value at DMI is T106. The spectral resolution is then used by different schemes in lookup tables for selected parameters. Highest possible spectral resolution at 31 model levels is T255.

(echam-5.2.02.1-hirham-v0.3/ src/interface/mo_echam5_phys.f90)

Stratiform cloud scheme

(echam-5.2.02.1-hirham-v0.3/src/model/cloud.f90)

Five tuning parameters are explicit defined in the stratiform cloud scheme. When the cloud cover fraction excide a threshold then precipitation is formed. The used hardcoded threshold is 0.0.

Tuning parameters are label γ_1 - γ_4 and a cloud ice threshold γ_{th}.

Warm cloud autoconversion of cloud liquid water r_l is calculated by:

$$Q_{aut} = C\gamma_1[a_2 n^{-b_2}(10^{-6}N_l)^{-b_3}(10^{-3}\rho r_l)^{b_4}]/\rho \qquad (10.45)$$

Warm cloud accretion of r_l:

$$Q_{racl} = min(C, C_{pr}) a_3 r_l \rho r_{rain} + \gamma_2 \rho Q_{aut} \Delta t \qquad (10.46)$$

Could cloud aggregation of cloud ice r_i:

$$Q_{agg} = C\gamma_3 \frac{\rho r_i^2 a_4 E_{ii} X \left(\frac{\rho_0}{\rho}\right)^{1/3}}{-2\rho_i \log\left(\frac{R_{vi}}{R_{s0}}\right)^3} \qquad (10.47)$$

Cold cloud accretion of r_l by snow:

$$Q_{sacl} = min(C, C_{pr})\gamma_4 \frac{\pi E_{sl} n_{0s} k_s r_l \Gamma(3+b_7)}{4\lambda_s^{3+b_7}} \left(\frac{\rho_0}{\rho}\right)^{1/2} \quad (10.53)$$

Note that γ_1 - γ_4 are efficiency or scaling parameters. By setting all four γ values to zero, precipitation can only be formed by warm cloud accretion. γ_2 is between 0 - 0.5 ($\gamma_{2\,min}$ - $\gamma_{2\,max}$) and depends on the geopotential and a resolution depending factor "*cauloc*". *cauloc* at 31 model levels is 2 for spectral resolutions (nn) between 31 – 42 and 5 for nn 63 – 255.

Experimental set ups

Forcing data is ERA-40 (Uppala et al., 2005). The domain is defined in rotated longitude latidue by: W -5.03, E 10.02, N 7.1, S -7.95. Coordinate of south pole Lon: -96.5, Lat: -51. The grid is 302 by 302 cells with a cell size of 0.05 degrees. All simulations is run from January 1st to August 31st. Spatial validation is total summer precipitation in June, July and August. Temporal comparison is done at the FIFE area. An overview of the tested parameter values in the parameterisation of precipitation is given in table 1.

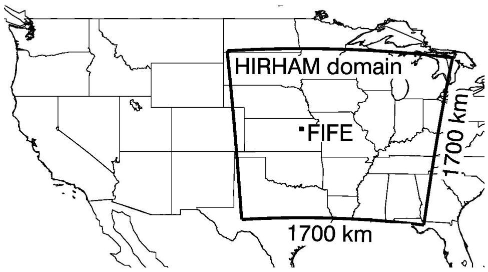

Figure 2. Domain and location of FIFE.

Detailed notes to the experiments listed in table 1:

Adjustment of spectral resolution to the actual used model resolution:

PR1: Lookup tables among the parameterisations schemes are only defined up to T255 of spectral resolution at 31 model levels.

PR2: In the cumulus convection scheme, only, the spectral resolution is set to T3600, which corresponds to ~5 km resolution.

Small turndown of stratiform precipitation efficiency parameters:

PR3: Warm cloud autoconversion efficiency lowered by a factor of 15. The high precipitation areas do mainly occur in the stratiform part of the precipitation by the default parameterisation, Fig. 3 top row. Therefore, the focus is mainly stratiform precipitation.

PR4: Warm cloud autoconversion efficiency lowered by a factor of 150.

PR5: Max warm cloud accretion is reduced by a factor of 150, as well.

PR6: The spatial scale factor between 1.4 degrees (T255) and 0.05 degrees (T3600) is 28 or 14 calculated on spectral resolution. Furthermore, the temporal resolution is 600 sec at 1.4 degrees and 120 sec at 0.05 degrees; which is a factor of 5. Time step length is included in the parameterisation. At higher resolution, with smaller cell sizes, and shorter time step the precipitation amount per cell per time step is also proportional less. Therefore the efficiency factors γ_1 - γ_4 are expected to lower;

but it may not be linear. The temporal-spatial scale factor is 28*5 = 140. A reduction factor of 150 is chosen for all the efficiency factors γ_1 - γ_4.

Total turndown of stratiform precipitation efficiency parameters:

PR7: All efficiency factors γ_1 - γ_4 are set to zero. Precipitation is the only formed by accretion and by the cumulus convection scheme.

Isolation stratiform precipitation contributions:

PR8: Precipitation is only formed by warm clouds.

PR9: Precipitation is only formed by could clouds. First term of warm cloud accretion is active.

PRa: Precipitation by warm cloud autoconversion and first term of warm cloud accretion.

PRb: Preciptation by cold cloud autoconversion. First term of warm cloud accretion and cold cloud accretion are active.

Large turndown of stratiform precipitation efficiency parameters:

PRc: All stratiform precipitation efficiency parameters γ_1 - γ_4 are reduced by a factor of 15,000.

PRd: All stratiform precipitation efficiency parameters γ_1 - γ_4 are reduced by a factor of 15 x 10^6.

PRe: All stratiform precipitation efficiency parameters γ_1 - γ_4 are reduced by a factor of 15 x 10^9.

PRf: Spectral resolution used in the cumulus convection scheme is increased to 36 x 10^5.

PRg: Warm cloud accretion is eliminated. Q_{racl} is set to zero in all time steps.

Sensitivity of cloud cover threshold factor:

PRh: Precipitation is only formed when cloud cover fraction is above 0.5. All stratiform precipitation efficiency parameters γ_1 - γ_4 are reduced by a factor of 150.

PRi: Precipitation is only formed when cloud cover fraction is above 0.7.

PRi: Precipitation is only formed when cloud cover fraction is above 0.2.

PRk: Precipitation and sedimentation is activated when cloud cover fraction is above 0.5 and secondly, 0.2. The model was unstable at both cloud cover thresholds.

Use of convection scheme:

PRl: Cumulus convection scheme is not used.

Isolation stratiform precipitation contributions, continued:

PRm: Warm cloud accretion is eliminated. Q_{racl} is set to zero in all time steps. All stratiform precipitation efficiency parameters γ_1 - γ_4 are reduced by a factor of 150.

Test of suggested parameterisation at 0.125 degrees resolution and at different number of vertical levels:

HS12 new: Similar setup as HS12 (Rasmussen et al., 2012) which is like HS05 but at 0.125 degrees resolution. It used the new proposed parameterisation (PR6), thereby the postscript “new”.

HS12 new 19 levels: As HS12 new but with 19 levels. At 19 levels the spectral resolution defined in lookup tables has a maximum of T159. The global defined spectral resolution in the physical parameterisation is set to T159, instead of T255 as in HS12 new.

Table 1. Experimental set ups. Bold is changes from previous run.

Set up	nn[1]	γ_1	$\gamma_{2\,max}$	γ_3	γ_4	cc[2]	Note
HS05	**106**	**15**	**0.5**	**95**	**0.1**	**0.0**	**Default**
PR1	**255**	15	0.5	95	0.1	0.0	Global
PR2	**3600**	15	0.5	95	0.1	0.0	Only in cumulus convection scheme
PR3	3600	**1**	0.5	95	0.1	0.0	
PR4	3600	**0.1**	0.5	95	0.1	0.0	
PR5	3600	0.1	**0.003**	95	0.1	0.0	
PR6	3600	**0.1**	0.003	**0.633**	**0.000667**	0.0	Factor 150
PR7	3600	**0**	**0**	**0**	**0**	0.0	
PR8	3600	**0.1**	**0.003**	0	0	0.0	No cold pre
PR9	3600	**0**	**0**	**0.633**	**0.000667**	0.0	No warm cloud autoconverstion
PRa	3600	**0.1**	0	**0**	**0**	0.0	
PRb	3600	**0**	0	**0.633**	0	0.0	
PRc	3600	**1x10^{-3}**	**3x10^{-5}**	**6.33 x10^{-3}**	**6.67 x10^{-6}**	0.0	Factor 15,000
PRd	3600	**1x10^{-6}**	**3x10^{-8}**	**6.33 x10^{-6}**	**6.67 x10^{-9}**	0.0	Factor 15x10^{6}
PRe	3600	**1x10^{-9}**	**3x10^{-11}**	**6.33 x10^{-9}**	**6.67 x10^{-12}**	0.0	Factor 15x10^{9}
PRf	**36x10^{5}**	1x10^{-9}	3x10^{-11}	6.33 x10^{-9}	6.67 x10^{-12}	0.0	
PRg	**3600**	1x10^{-9}	0	6.33 x10^{-9}	6.67 x10^{-12}	0.0	**Accretion of warm cloud set to zero**
PRh	3600	**0.1**	**0.003**	**0.633**	**0.000667**	**0.5**	For precipitation
PRi	3600	0.1	0.003	0.633	0.000667	**0.7**	For precipitation
PRj	3600	0.1	0.003	0.633	0.000667	**0.2**	For precipitation
PRk	3600	0.1	0.003	0.633	0.000667	**0.5** **0.2**	For precipitation and sedimentation
PRl	3600	0.1	0.003	0.633	0.000667	**0.0**	**No convective scheme**
PRm	3600	0.1	**0**	0.633	0.000667	0.0	**Accretion of warm cloud set to zero**
HS12 new	**159** (3600)	0.1	**0.003**	0.633	0.000667	0.0	**0.125 degrees resolution 31 levels**
HS12 new 19 levels	159 (3600)	0.1	0.003	0.633	0.000667	0.0	0.125 degrees resolution **19 levels**

[1] nn: spectral resolution
[2] cc: cloud cover fraction

Results

Maps of selected simulations of total summer precipitation are shown at Figure 3. Temporal comparisons of selected simulations, locally at the FIFE area, are shown at Figure 4. Simulations at 0.125 degrees resolution at 31 and 19 levels are seen at Figure 5.

Results of the default parameterisation are shown at the top row Fig. 3; total precipitation (left) and divided on stratiform (middle) and convective (right). High precipitation areas are mainly seen in precipitation from the stratiform scheme. Furthermore, when it rains it rains too much and the large precipitation events is from the stratiform scheme, Fig. 4.

First, the used spectral resolution of the physical parameterisation was corrected to better match the used model resolution (PR1-2). This lead to a small reduction of the general level of precipitation, Fig 3, second row, left and middle.

Small turndown of the stratiform precipitation efficiency parameters (PR3-6) shows a general reduction in the precipitation level. The pattern is kept similar. With a reduction factor of 150 (PR6) most of the very large precipitation areas are reduced and the low levels areas is similar to the observations, Fig 1 and 3.

When all efficiency parameters are set to zero (PR7), precipitation is only formed by convection and accretion, the precipitation pattern is comparable to convective precipitation by the default parameterisation.

Larger reductions of stratiform precipitation efficiency parameters (PRc-e) show general reduction in the precipitation level while the pattern is kept similar, Fig. 3 third row and Fig. 4. Low level precipitation become too low compared to observations. Reduction of precipitation locally at FIFE is not linear with the reduction factor. Further reduction of the spectral resolution in the cumulus convection scheme (PRf) show similar results as PRe. Compare PRc-e to PR6, the general level and especially the lower level is more like observations in PR6. Furthermore, reduction factor of 150 as PR6 can be physical agued in contrast to PRc-e.

Isolation of stratiform precipitation contributions by the tuning parameters γ_1 - γ_4 (PR8-b) cannot solely explain large precipitation events; above 100 mm on one day and more than 600 mm of total summer amounts. Setting warm could accretion to zero (PRg and PRm) did eliminate some of the large precipitation events, Fig. 3 and 4.

Precipitation did not show any specific sensitivity to the cloud cover threshold (PRh-j). All these experiments show around the same timing and amounts as PR6. When applying the threshold to the sedimentation part as well the model became unstable and crash with the error message: lookup table overflow.

The experiment with deactivate cumulus convection scheme (PRl) show a different timing of events but a total summer amount similar to PR6. Timing compare to observation at FIFE is worse than PR6, Fig 4.

Testing the suggested parameter set (PR6) at 0.125 degrees resolution (HS12 new) show similar precipitation pattern and amounts as PR6, Fig. 5 left. Remarkable divergences are seen when the model is run at 19 levels (HS12 new 19 level), Fig. 5. All high precipitation areas are not seen and the convective precipitation in the south east corner is different.

Discussion and conclusion

It is possible to turn down the precipitation by the stratiform cloud scheme by the tuning parameters γ_1 - γ_4. The pattern of the total summer precipitation amounts is remarkable robust. The timing is also comparable at the FIFE area. There are no direct linear relationship between the tuning parameters γ_1 - γ_4 and the total summer precipitation amount. Anyhow, it is possible to tune down for the precipitation by the tuning parameters. Pattern of total summer precipitation are similar to observational data set like GPCC and CRU, Fig 1, 3 and Rasmussen et al. (2012). The cumulus convection scheme is found to improve the timing of events and thereby reasonable to use at this resolution. The source of large precipitation amounts above 100 mm/day is not located in the precipitation parameterisation. Simulations by WRF (Skamarock et al., 2008) does show similar large precipitations amounts (Rasmussen et al., 2012). Therefore, they might not be attributed to the precipitation parameterisation. The accretion of warm cloud may be too efficient; without accretion large precipitation amounts over 600 mm of total summer is not occurring. Perhaps a tuning factor should be applied? Cloud cover fraction at which precipitation is calculated does not seem to affect precipitation amounts. Areas of large precipitation amounts are not seen in the simulation at 19 levels, as with 31 levels.

The robustness and consistency in timing may indicate some degree of insensitivity to the exact chose of efficiency parameters. Furthermore, the efficiency factors have been scaled several orders of magnitudes in this sensitivity study for showing any larger differences in simulation results. This study suggests an order of magnitude of scaling of the efficiency parameters, but not any exact number. Thereby, the suggested parameter set is suitable at resolutions of 0.125 degrees which is shown on Fig. 5, left.

Note, the default parameterisation has low precipitation in the relaxing zone where the tuned parameterisation has high values.

Suggestion of new parameter set for use at ~5 km resolution

Parameter set used in PR6 is found to perform best and the adjustment can be argued physically. The spectral resolution for the parameterisation should be set as high as possible (T255) and corrected specific in the cumulus convection scheme (T3600). Tuning parameters γ_1 - γ_4 should possibly be reduced from default values by a factor of 150; roughly the spatial-temporal scaling factor between T255 and T3600. New parameter values γ_1, γ_{2max}, γ_3, γ_4 are 0.1, 0.003, 0.633, 0.000667, respectively.

In addition, effects of warm cloud accretion and number of levels have to be noted. Further investments and perhaps adjustments of these are required.

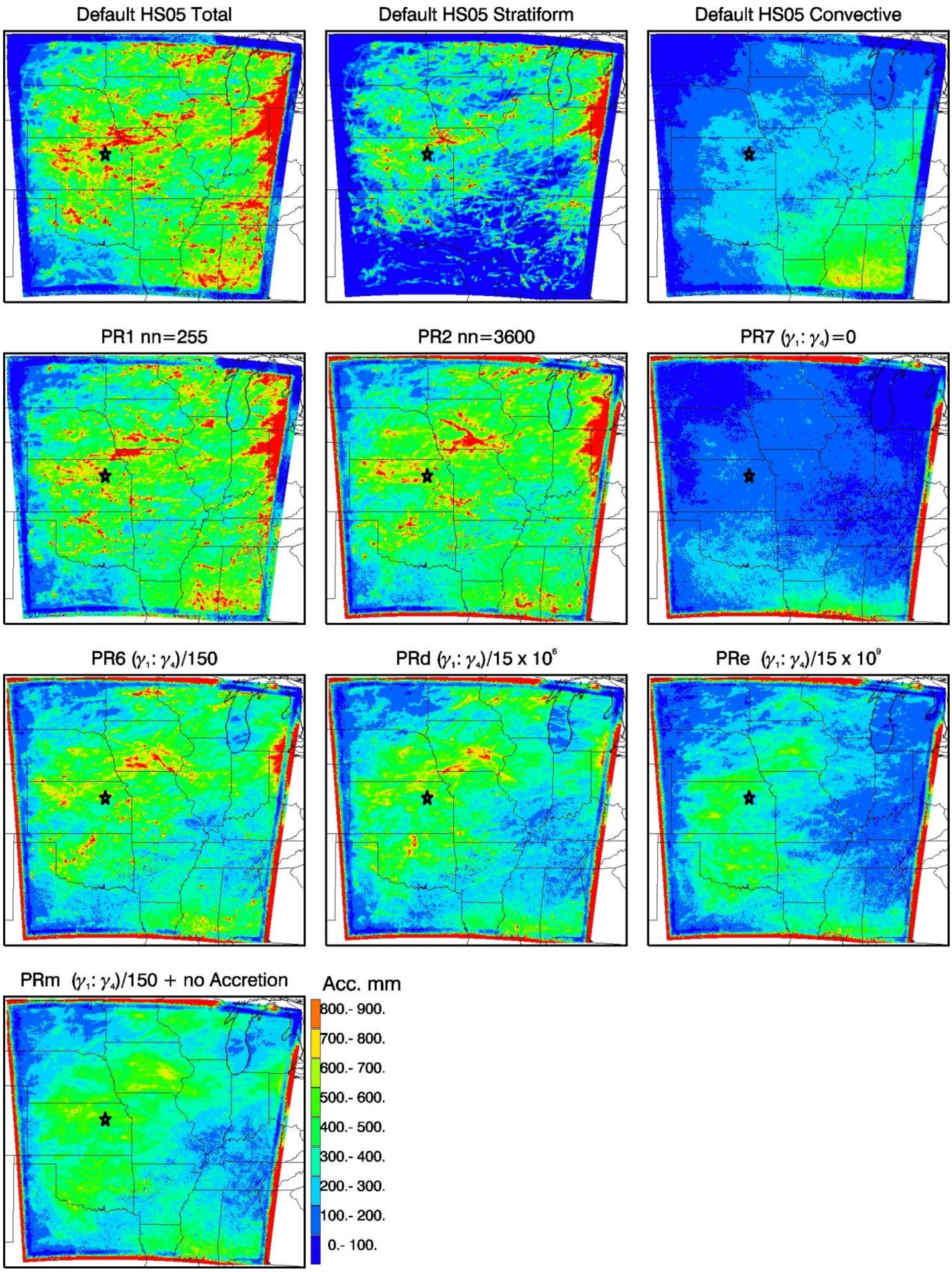

Figure 3. Total summer precipitation, 1987 June, July and August. First row is by default parameterisation; total and divided on stratiform and convective precipitation schemes. FIFE is located at the star.

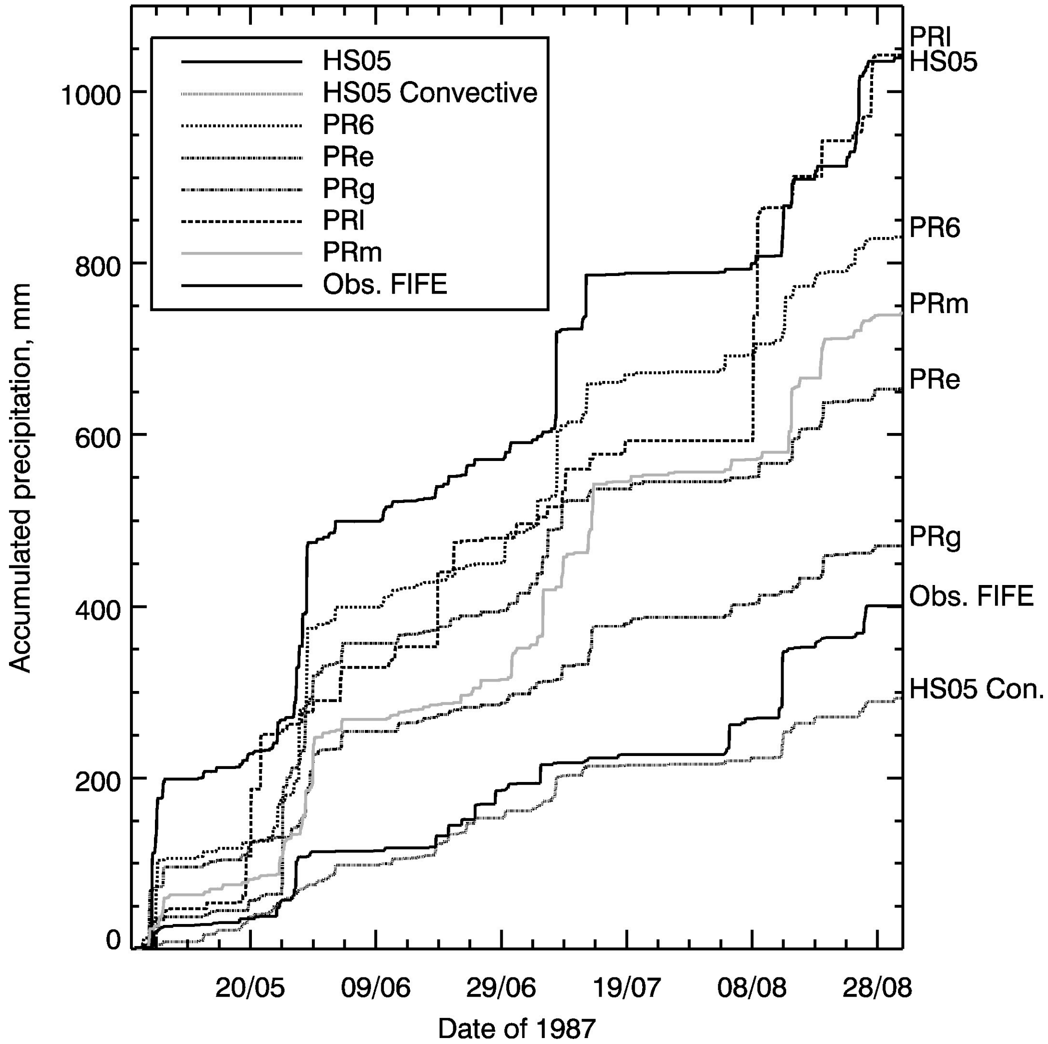

Figure 4. Area mean precipitation at FIFE (15 x 15 km^2).

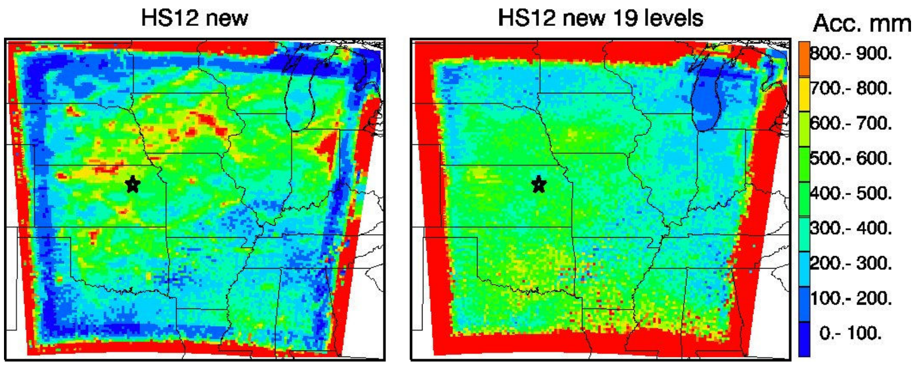

Figure 5. Total summer precipitation, 1987 June, July and August. Simulated at 0.125 degrees resolution, 31 levels (left) and 19 levels (right).

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