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CONSORTIUM FOR SMALL SCALE MODELING

Testing & Tuning of Revised Cloud Radiation Coupling $T^2(RC)^2$ PP: Status Report

Harel Muskatel (IMS)

COSMO General Meeting - September 2016

Outline

- Final set of tuning parameters for the new RC scheme
- Revised sub-grid scale clouds in the radiation scheme
- CAMS/MACC (ECMWF) prognostic aerosols in COSMO
- Observational verifications of radiation & aerosols in COSMO
- Single/Double precision in radiation scheme
- Radiation temporal resolution

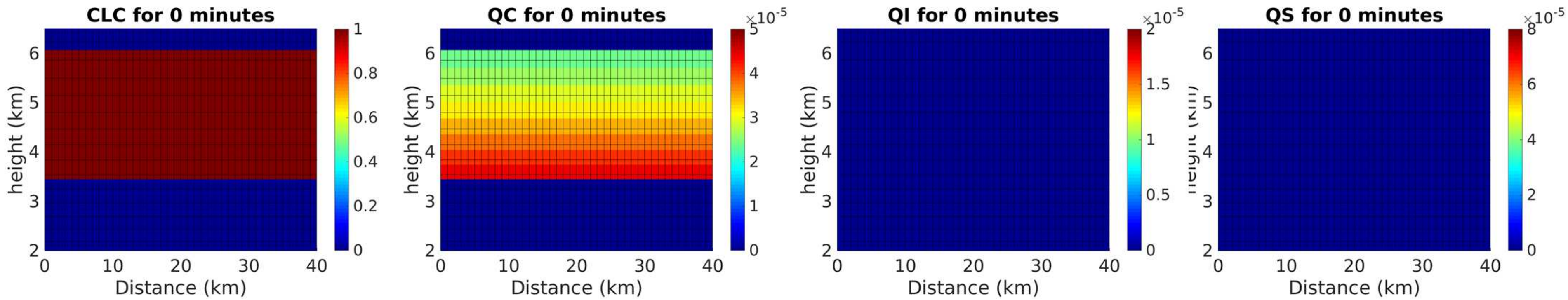
Determination of governing parameters in the new radiation scheme

(Pavel Khain)

- 32 new parameters in (RC)2 PT
- Use idealized COSMO framework to create different cloud types
- Decide which parameters are the most important for each cloud type
- True/False switches & continuous parameters

Cirrus	Warm Stratus	Mixed phase	Fair weather Cu	Anvil of CB
p1,p2,p3,p6,p7,p9,p10,p11,p14,p16,p23,p24,p25,p29,p30,p31,p32	p1,p2,p6,p8,p15,p17,p18,p19,p26,p27, p28,p32	p1,p2,p3,p6,p7,p8,p9,p10,p11,p14,p15,p16,p17,p18,p19,p23,p24,p25,p26,p27,p28,p29,p30,p31,p32	p2,p6,p7,p8,p15,p17,p18,p19,p32	p1,p2,p3,p6,p7,p9,p10,p11,p14, p16,p23,p24,p25,p29,p30,p31,p32

Mixed phase cloud



Warm Stratus: True / False switches - summary

Time averaged global radiation reduction (%)

case:	1	2	3	4	5	6	7	8	9	10	11	12	13
Warm Stratus	87	77	69	77	69	77	69	74	65	74	65	74	65

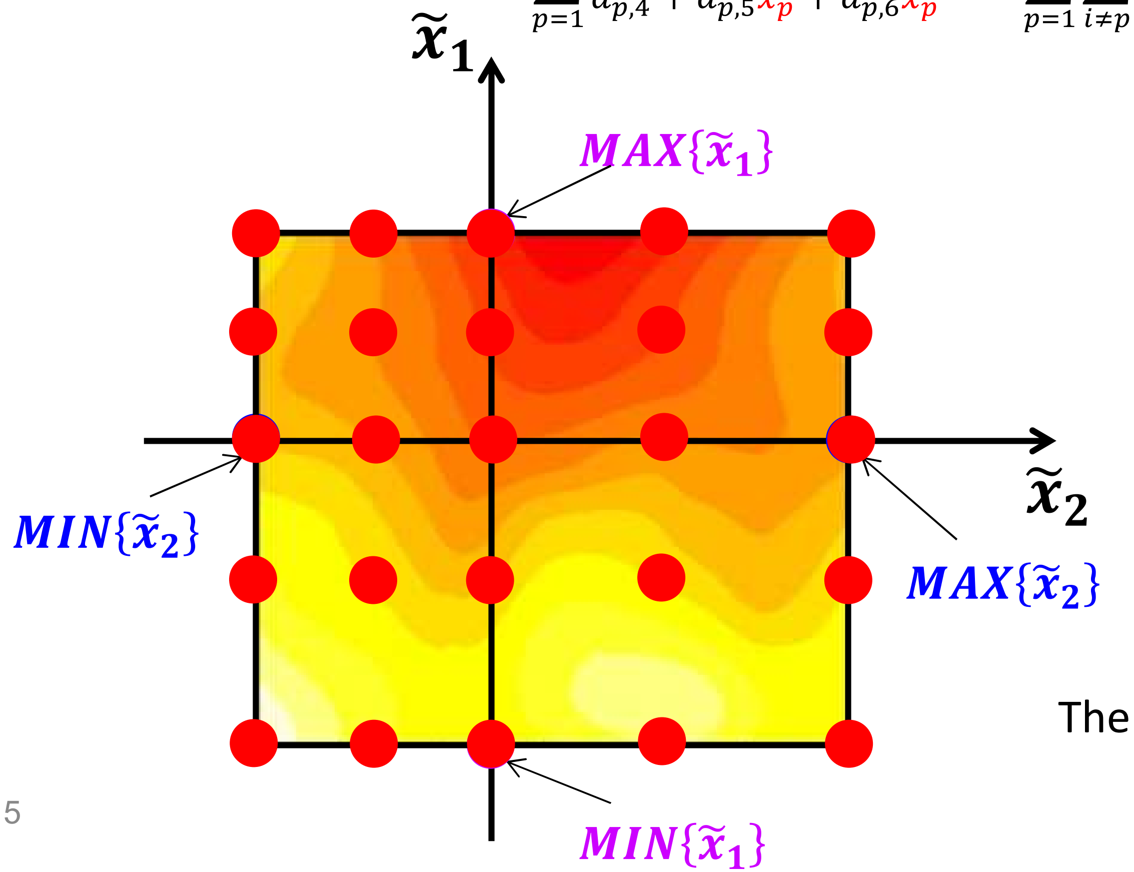
Global radiation sensitivity (%)

switch:	iradpar_cloud	lrad_incl_qrqsqg	lrad_ice_smooth_surfaces	lrad_ice_fd_is_gsquared	lcloud_num_type_rad
Warm Stratus	~22%	~4%	0	0	~9%
	Operational ⇕ New scheme	Neglect rain ⇕ Account for rain	Smooth ice ⇕ Rough ice	SW forward scattering formula 1 ⇕ SW forward scattering formula 2	Droplets concentration constant ⇕ Droplets concentration Segal-Khain

Sensitivity analysis in continuous parameters space

- STEP 1: Perform several idealized simulations to "fill the parameters space"
- STEP 2: Read the global radiation reduction at each point
- STEP 3: Perform fit of the global radiation reduction in parameters space

$$\tilde{R}(\tilde{x}_1,\tilde{x}_2,\tilde{x}_3,\tilde{x}_4) \cong \sum_{p=1}^{4} \frac{a_{p,1} + a_{p,2}\tilde{x}_p + a_{p,3}\tilde{x}_p^{\,2}}{a_{p,4} + a_{p,5}\tilde{x}_p + a_{p,6}\tilde{x}_p^{\,2}} + \frac{1}{2}\sum_{p=1}^{4}\sum_{i\neq p} b_{p,i}\tilde{x}_p\tilde{x}_i$$



$\frac{\partial \tilde{R}}{\partial \tilde{x}_p}$ = Sensitivity to parameter $\tilde{x}_p$

The most important → highest $\left|\frac{\partial \tilde{R}}{\partial \tilde{x}_p}\right|$

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COSMO

Parameter	No.
lrad_incl_qrqsqg	.1
iradpar_cloud	.2
lrad_use_largesizeapprox	.3
lrad_ice_smooth_surfaces	.4
lrad_ice_fd_is_gsquared	.5
itype_aerosol	.6
icloud_num_type_rad	.7
radqcfact	.8
radqifact	.9
rad_arearat_ls_i	.10
rad_arearat_ls_s	.11
rad_arearat_ls_g	.12
rad_arearat_ls_h	.13
rhobulk_ls_ini_i	.14
reff_ini_c	.15
reff_ini_i	.16
cloud_num_rad	.17
zref_cloud_num_rad	.18
dz_oe_cloud_num_rad	.19
tqc_thresh_rad	.20
tqi_thresh_rad	.21
tqs_thresh_rad	.22
rhos_n0shigh_rad	.23
rhos_n0slow_rad	.24
n0s_low_rad	.25
rhoc_nchigh_rad	.26
rhoc_nclow_rad	.27
ncfact_low_rad	.28
rhoi_nihigh_rad	.29
rhoi_nilow_rad	.30
nifact_low_rad	.31
qvsatfact_sgscl_rad	.32

true / false switches (.1–.7)

continuous parameters (.8–.32)

A List of 8 most important parameters

(2) Operational / new scheme

(1) Include rain, snow & graupel

(7,17) Number concentration of cloud droplets

(15,32) Sub-grid water clouds properties

(8,9) Sub-grid scale variability

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Effective radius of subgrid scale water clouds in T2RC2 (Uli Blahak)

- Currently we treat all subgrid scale water clouds with a fixed R_{eff} : Tuning parameter reff_ini_c
- To improve this a little, two existing options for grid scale water clouds are extended towards the pure subgrid scale (SGS) water clouds **luse_reff_ini_c_as_reffc_sgs = .FALSE.:**
    1. If **icloud_num_type_rad = 1**

       Tuning parameter n_{C0} cloud_num_rad ():

       $n_C(z)$ has assumed exponentially decreasing vertical profile above z0:

$$n_C = n_{C0} \begin{cases} \exp\left(-\frac{z-z_0}{\Delta z_{1/e}}\right) & \text{if } z > z_0 \\ 1 & \text{else} \end{cases} \quad \left[\text{kg}^{-1}\right] \longrightarrow R_e = c_1 \left(\frac{q_C}{n_C}\right)^{c_2}$$

2. Diagnosis of cloud number concentration NC from Tegen / Segal & Khain
   - **icloud_num_ itype_aerosol = 2 & icloud_num_type_rad = 2**
   - Cloud nuclei profile $n_{CN}(z)$ is estimated from Tegen aerosols
   - Activation of n_{CN} to n_{CCN} is estimated from Segal & Khain (2006)
   - Parameterization based on the estimated vertical velocity at cloud base
   - n_C is assumed equal to n_{CCN}

$$n_C(z) = \begin{cases} n_{CCN,SK}\Big(n_{CN}(z_{cb}), w_{nuc}(z_{cb})\Big) \exp\left(-\frac{z-z_{cb}}{\Delta z_{a,1/e}}\right) & \text{if } w \geq w_{cb,min} \wedge q_C(z) > 0 \wedge z \geq z_{cb} \\ n_{CCN,SK}\Big(n_{CN}(z), \max[w_{nuc}(z), w_{cb,min}]\Big) & \text{else} \end{cases} \quad \left[\mathrm{kg}^{-1}\right]$$

- Effective updraft speed w_{nuc} for nucleation, including turbulence, radiative cooling and parameterized convection:

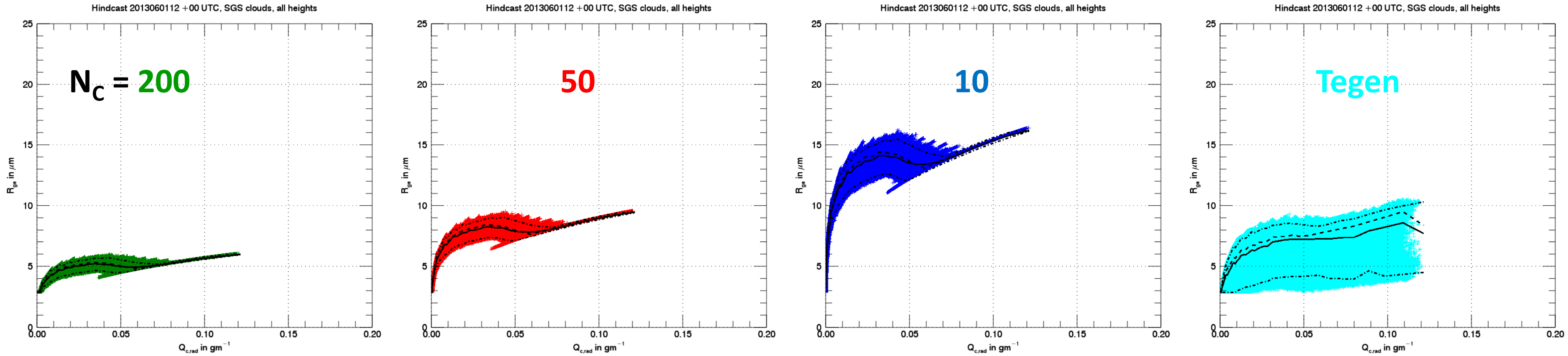
$$w_{eff} = \overline{w} + 0.7\sqrt{\frac{2\,TKE}{6}} - \frac{c_p}{g}\frac{\partial T}{\partial t}\bigg|_{\text{radiation}}$$

$$w_{nuc} = \max\left[w_{eff}\,,\, w^*\right]$$

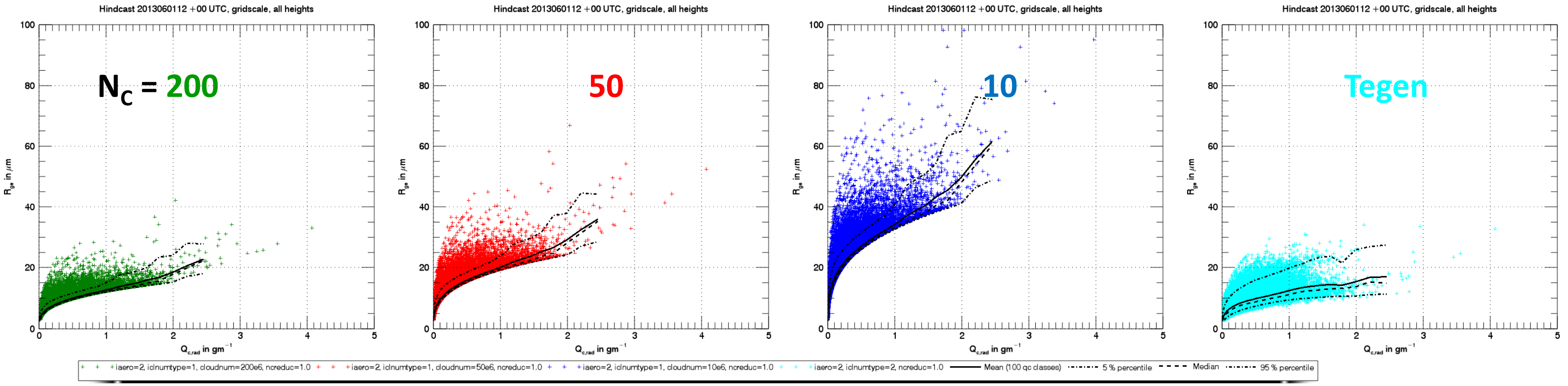
$$w^* = \left(-g\, z_{topcon}\frac{\overline{w'\Theta'_{v,S}}}{\overline{\Theta}_{v,S}}\right)^{1/3}$$

R_e based on $n_c(x,y,z)$ or cloud_num_rad

R_e as function of $Q_{c,rad}$ for pure SGS water clouds in all heights with linear scale (W_{nuc} incl. W*):



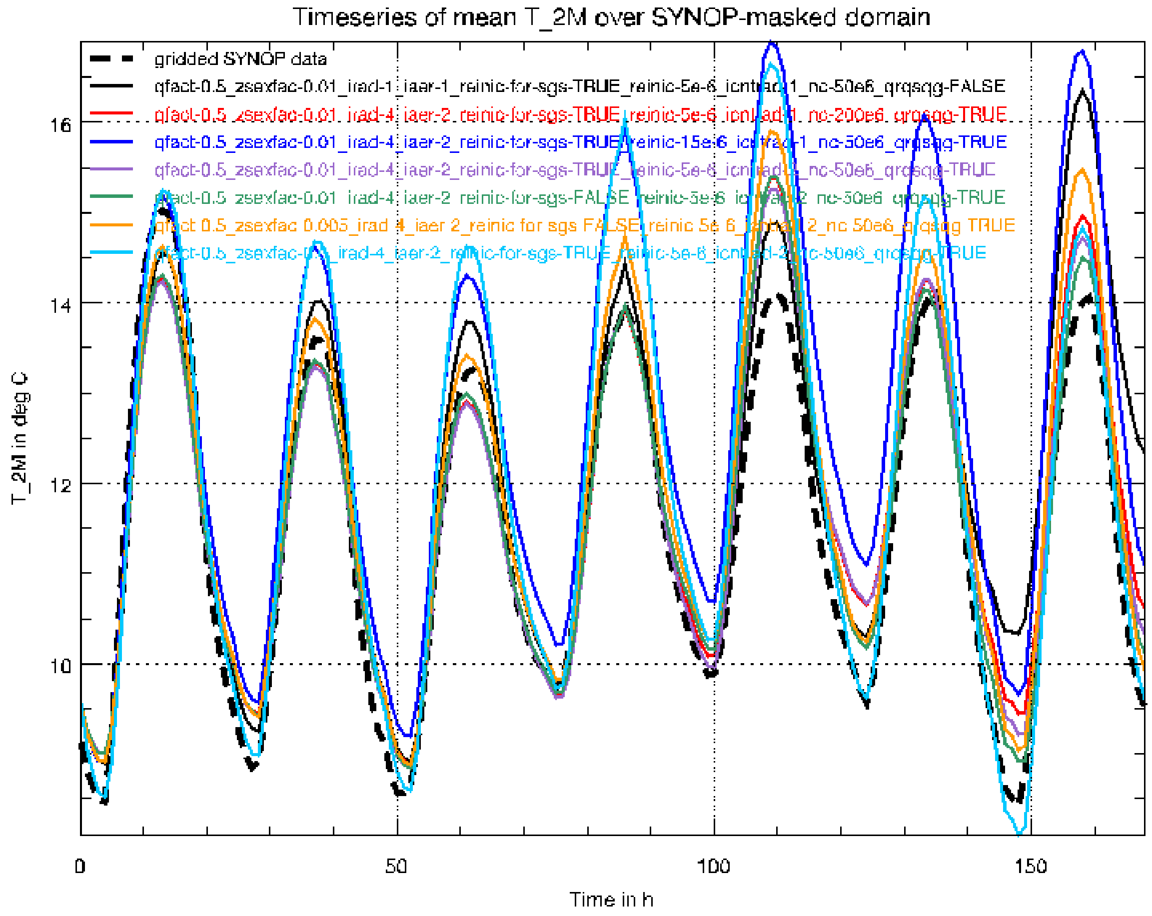
same for pure grid scale clouds ($Q_C > 0$): **(here: no reduction of N_C for larger Q_C)**



COSMO-EU / COSMO-DE setup (1-moment microphysics) COSMO-DE results:

- Tegen method is on the „low side“ of Re
- Model quite sensitive to Re of SGS water clouds

Sensitivity of T2M in 7-day experiment



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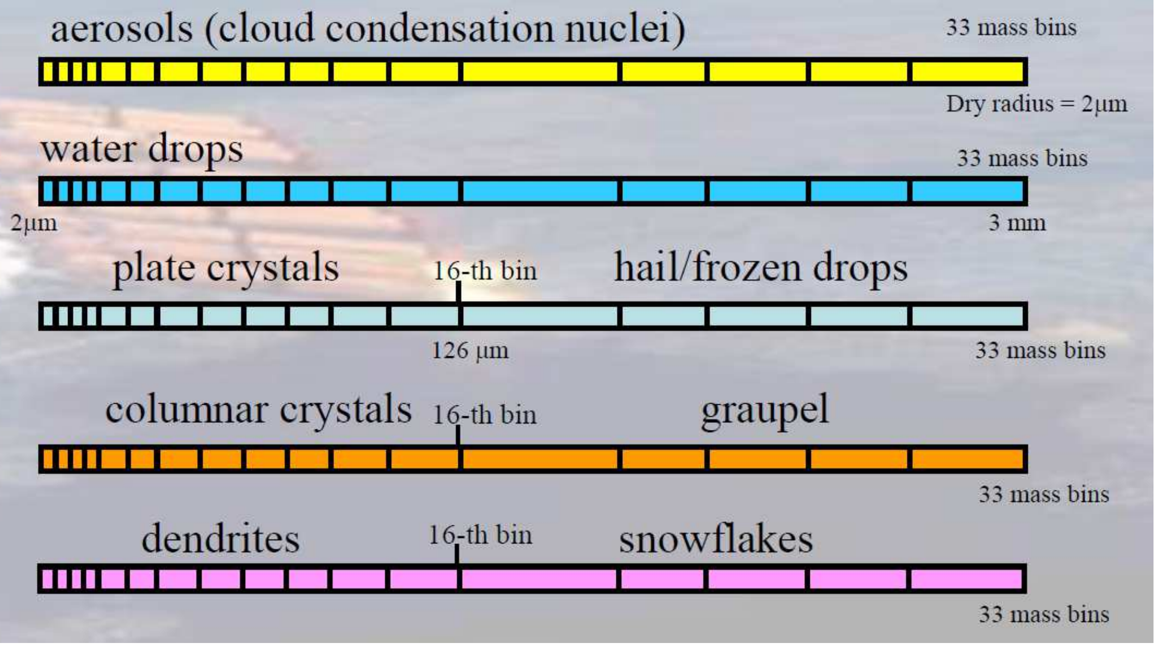
System-Atmospheric-Modeling using Spectral Bin Microphysics model (SAM-SBM)

(Pavel Khain)

MODEL DESCRIPTION

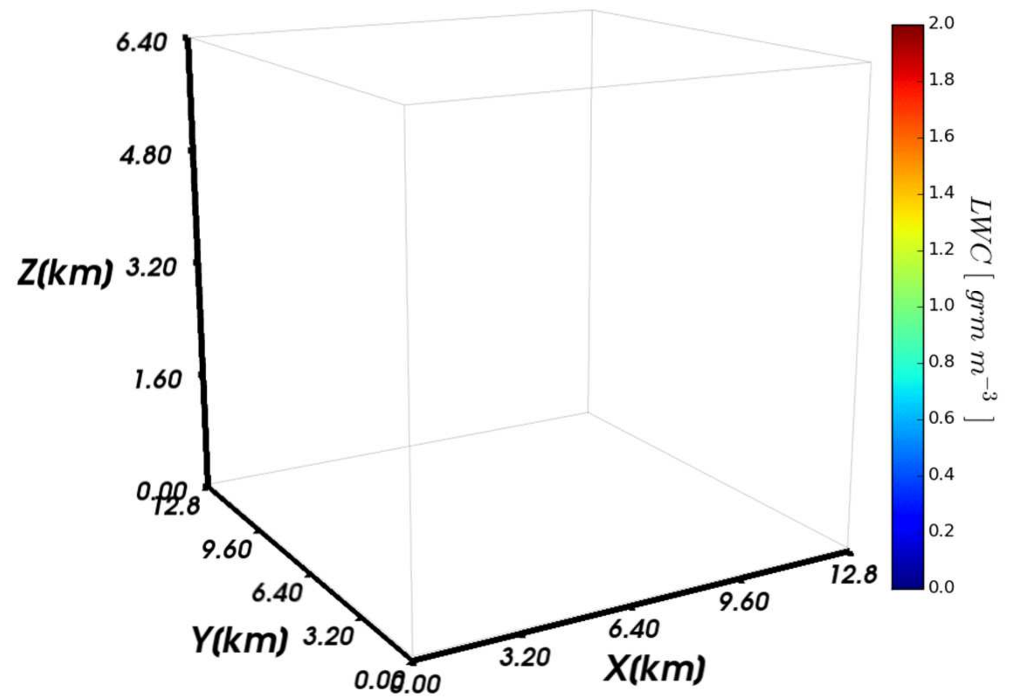
Dynamics: The non-hydrostatic Mesoscale Modeling System, MM5 is chosen as the dynamical platform for the spectral (bin) microphysics.

Microphysics is based on solving kinetic equations for the following size distribution functions:

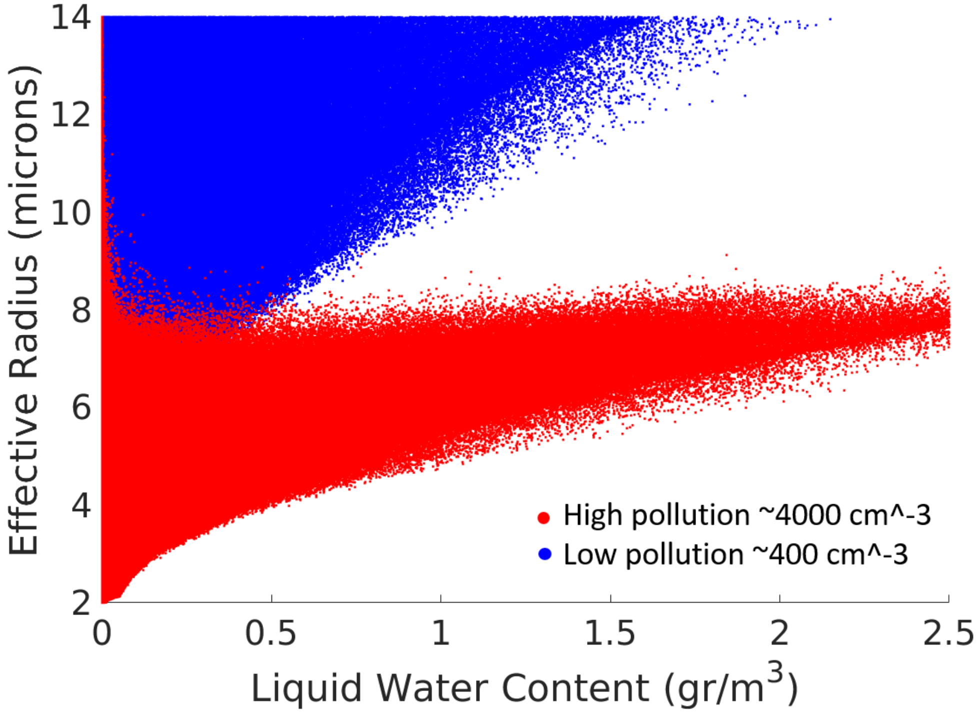


- 100 m horizontal resolution / 50 m vertical resolution
- 13 km X 13 km domain
- Unstable profile below an inversion at about 3km
- 34˚C at the surface and mixing ratio of 16 gr/kg
- Initiate with warm bubble of 0.1 ˚C at the center

SAM-HUJI-SBM fair weather cumulus simulation 100 (Seconds)



SAM-SBM



OBS

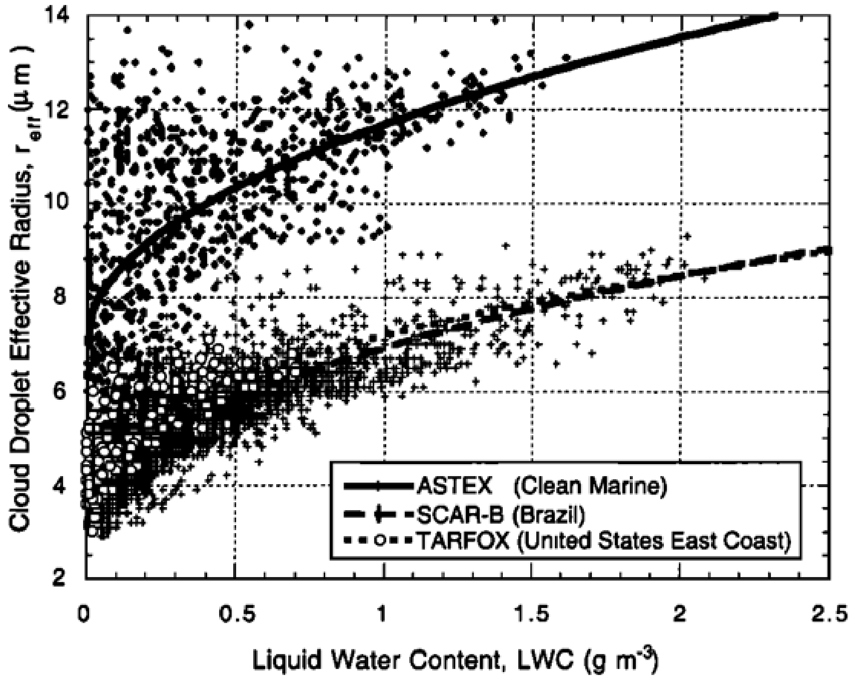


Figure 6. Cloud droplet effective radius (r_{eff}) versus liquid water content (LWC) for cumulus clouds in clean marine air over the northeastern Atlantic Ocean (diamonds, Atlantic Stratocumulus Transition Experiment (ASTEX)), in urban-industrial air off on the U.S. east coast (circles, Tropospheric Radiative Forcing Experiment (TARFOX)), and in air masses dominated by smoke from biomass burning (pluses, Brazil).

Reid et al. 1999

- Parametrization of the SGS-R_{eff}
  f (LWC, $H_{above\_cloud\ base}$, CCN concentration)

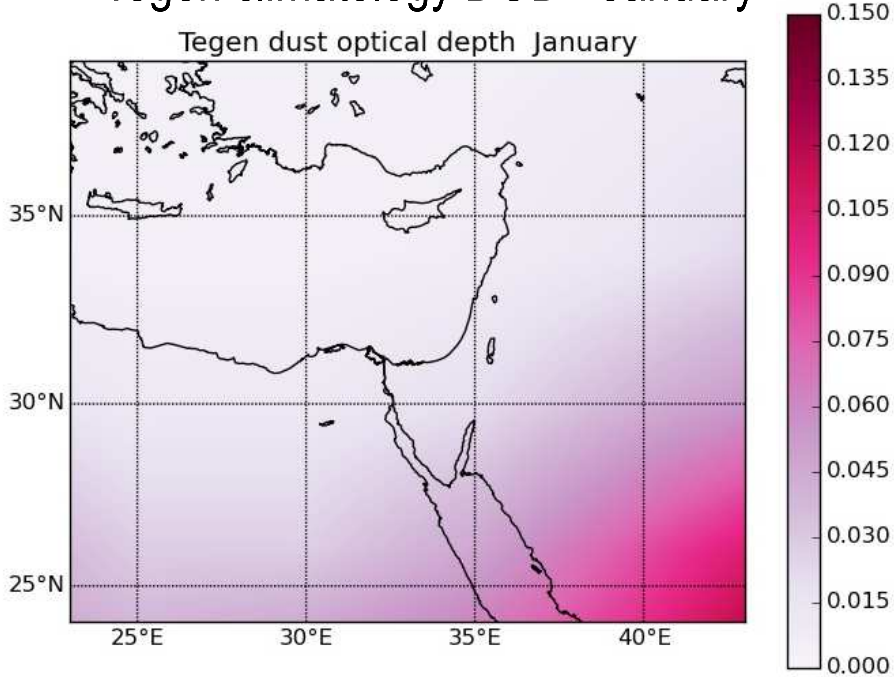
- Benchmark simulation for COSMO

CAMS prognostic aerosols in COSMO (Uli Blahak, Harel Muskatel)
with a support by Alessio Bozo (ECMWF)

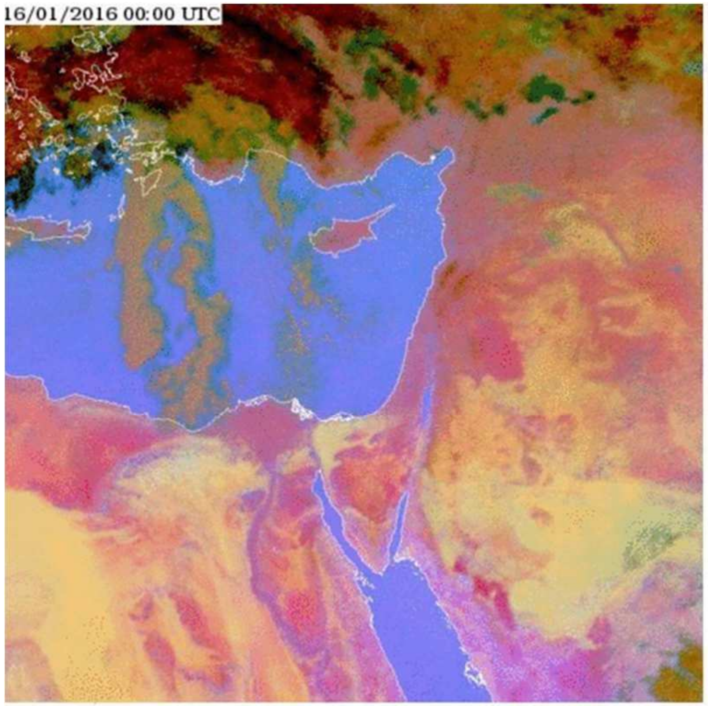
- ✓ In2lm
- ✓ Adaptation of optical properties (ECMWF→COSMO)
- ✓ Implementation in radiation scheme
- ✓ New! 1 hour resolution / twice a day

18/01/2016 Dust storm as a test case

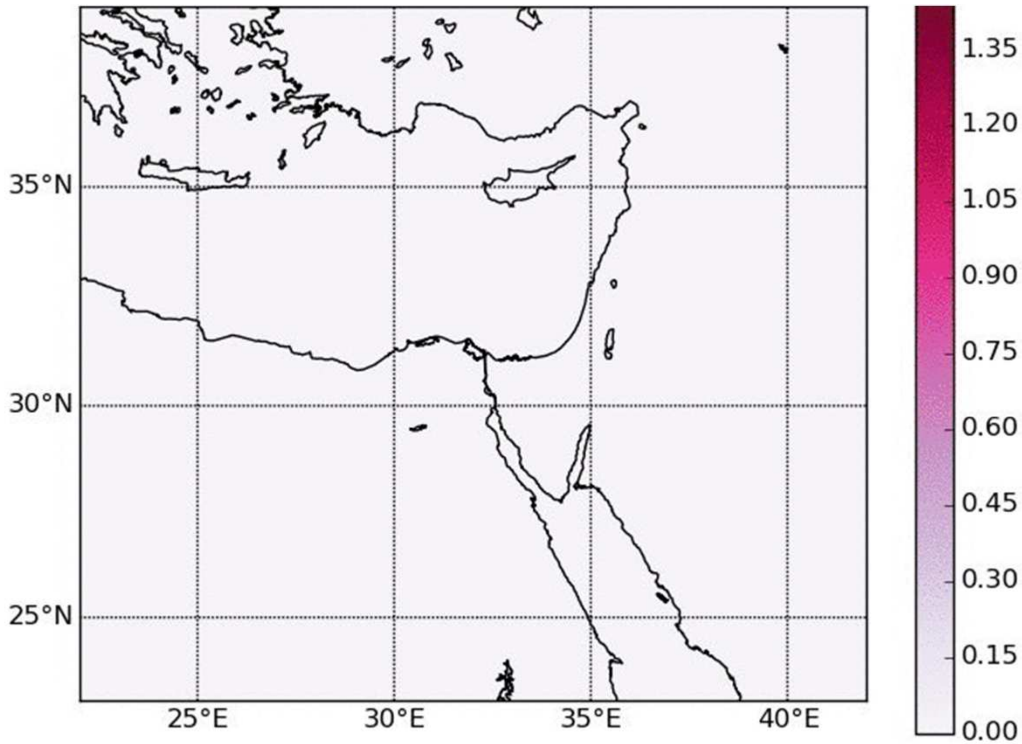
Tegen climatology DOD - January



MSG – dust

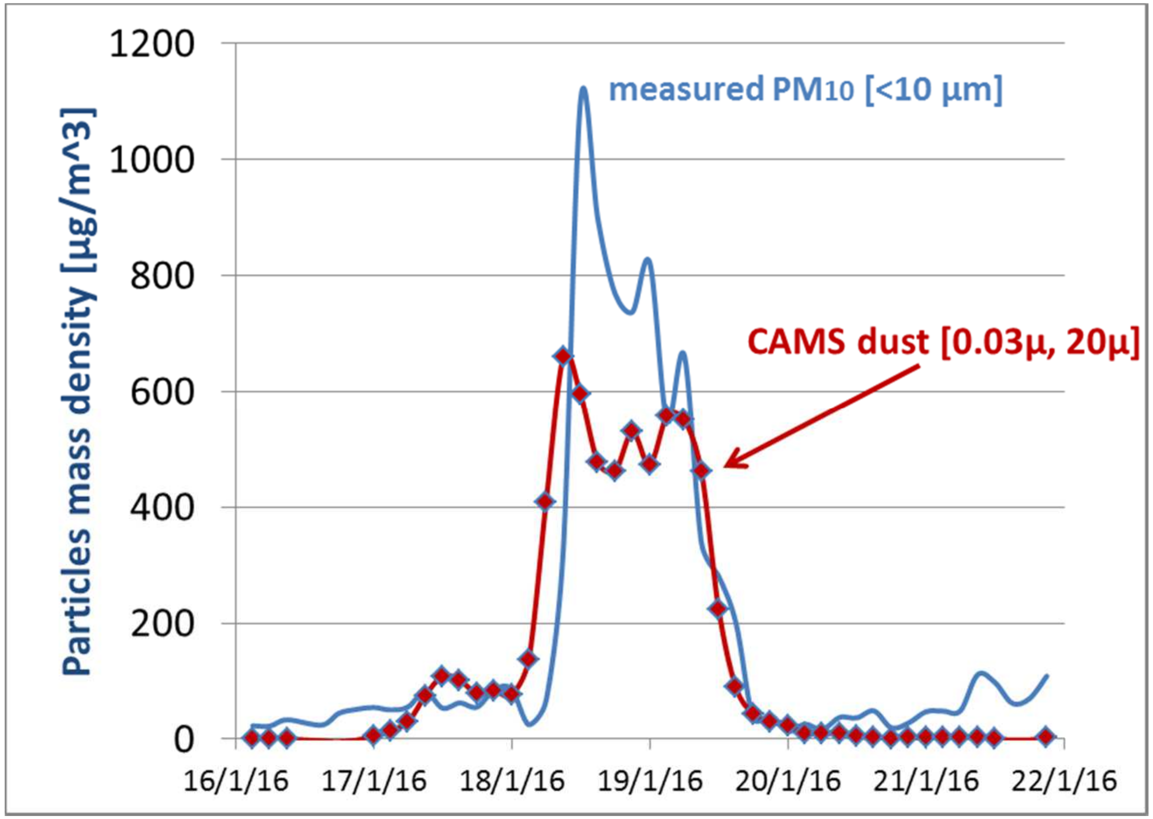


CAMS DOD at 550nm

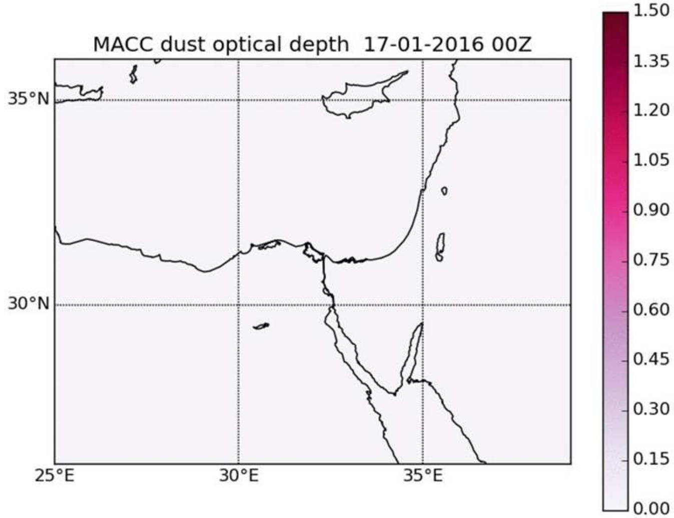


16-20/01/2016

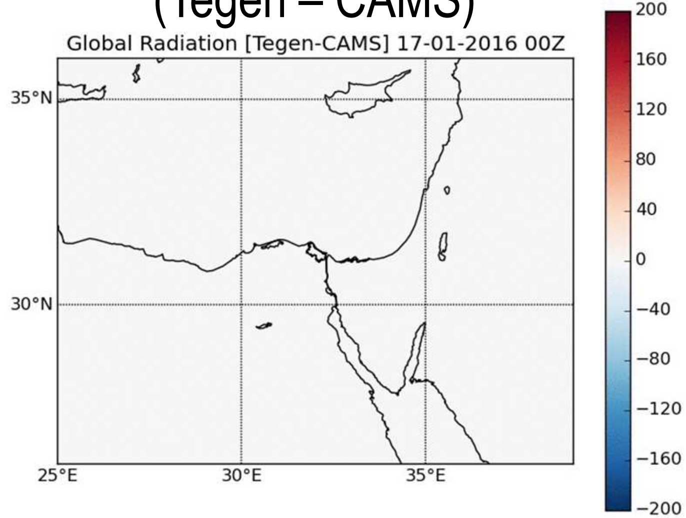
CAMS prognostic aerosols forecast performance vs. measurements in Tel-Aviv City

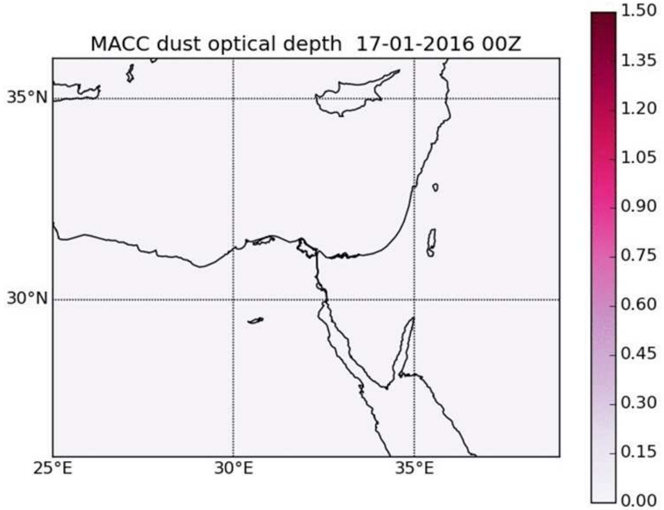


CAMS DOD at 550nm

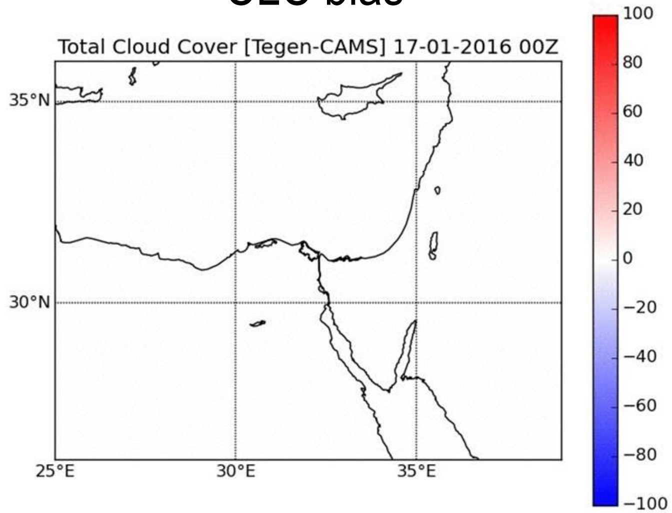


Global radiation bias (Tegen – CAMS)

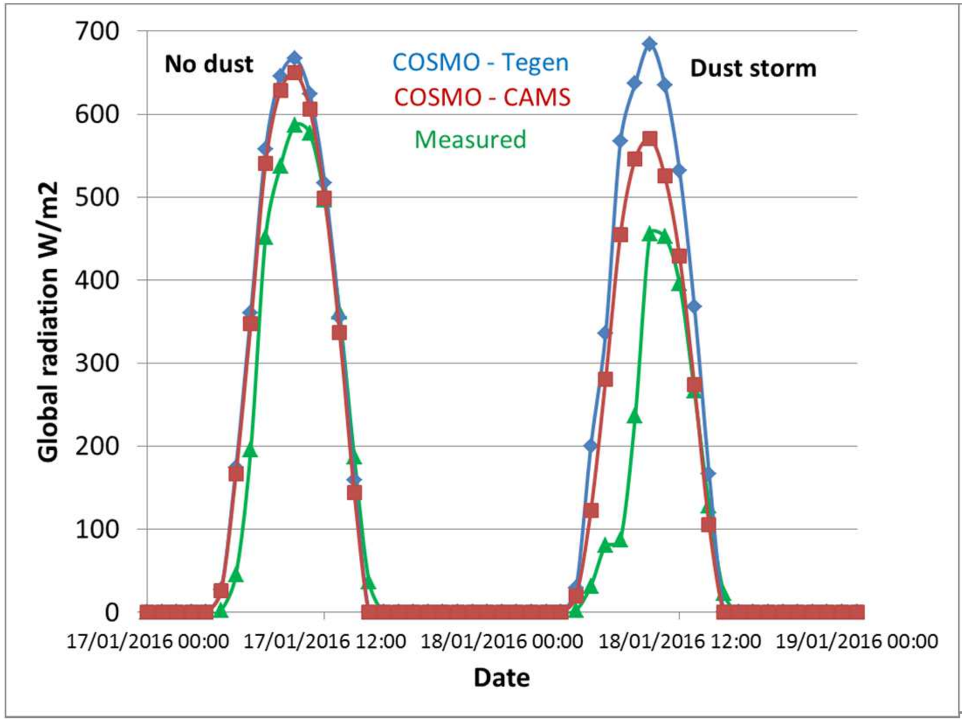


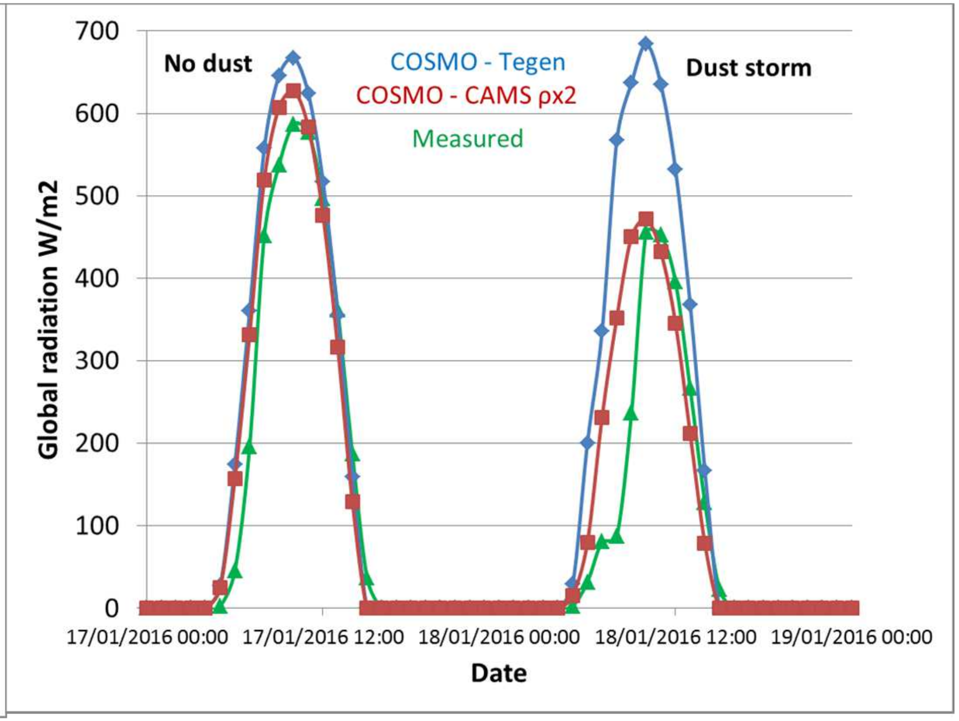


CLC bias

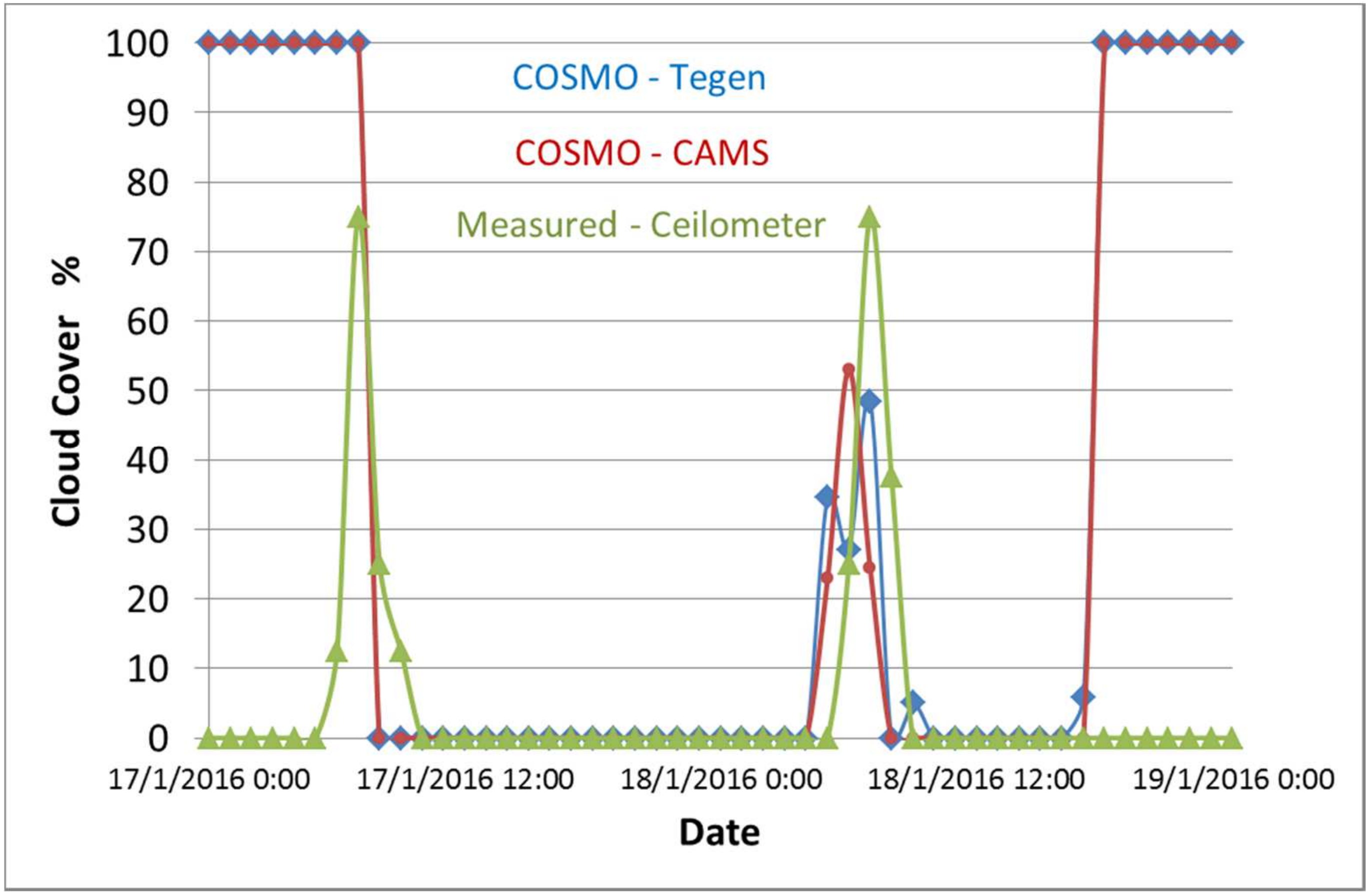


COSMO radiation schemes verification vs. measurements in Bet-Dagan (near TA)





COSMO cloud cover verification vs. measurements in Bet-Dagan (near TA)



Observational verifications of radiation & aerosols in COSMO

(Natalia Chubarova, Marina Shatunova, Alexey Poliukhov, Gdaly Rivin)
With contribution from Ralf Becker, Daniel Luethi & Stefan Kinne

Testing the radiative scheme of the operational Russian COSMO-Ru with different aerosol climatologies in cloudless conditions against:

- Accurate RT simulations – CLIRAD - SW model (Tarasova T.A., Fomin B.A., 2007);
- Ground-based radiative and meteorological measurements:
  - Moscow State University Meteorological Observatory (MSU MO), Russia.
  - Falkenberg site (Meteorologisches Observatorium Lindenberg), Germany.

- Aerosols data sets used:
  - **Tanre** climatology (Tanre et al., 1984) - itype_aerosol = 1
  - **Tegen** climatology (Tegen et al., 1997) - itype_aerosol = 2
  - **Macv2** climatology (Kinne et al., 2013) - itype_aerosol = 3
  - **CAMS** aerosol dataset (Morcrette et al. 2009) - itype_aerosol = 4
  - **AERONET** datasets (Moscow, Lindenberg)

New Kinne aerosols climatology

- MAC-v1 : Monthly aerosol radiative properties,
- With global coverage at a spatial resolution of 1° (2012)

✓ In2lm
✓ EXTPAR
✓ Radiation scheme

KINNE ET AL.: MAC-v1 FOR CLIMATE STUDIES

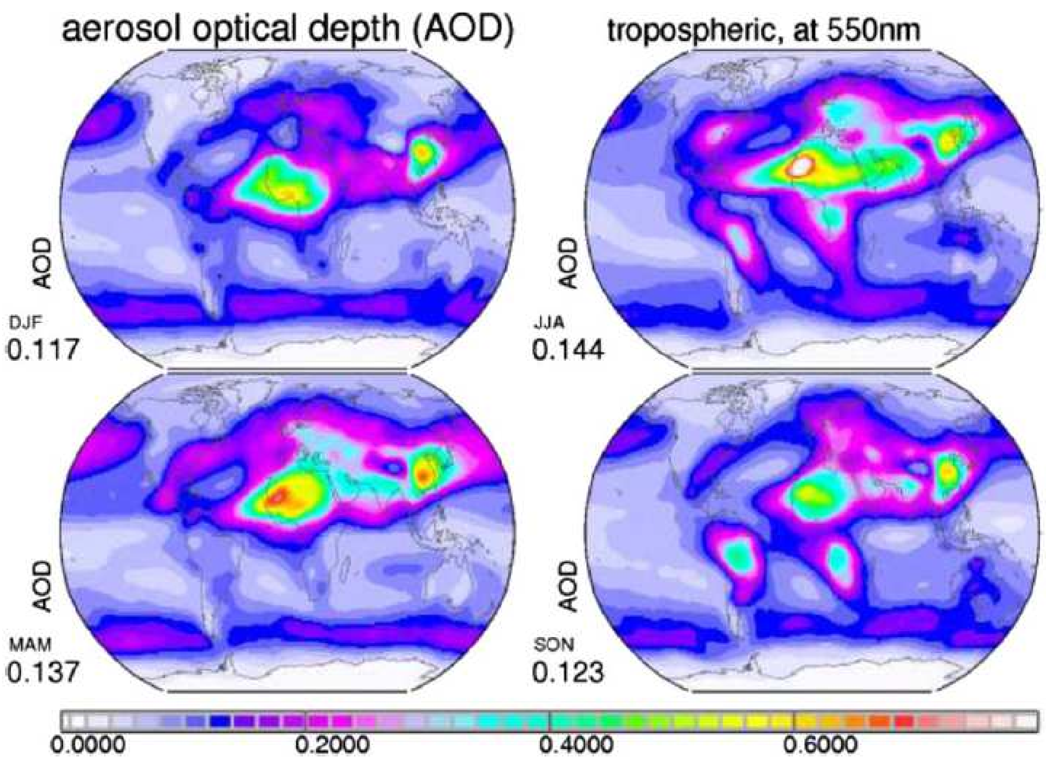
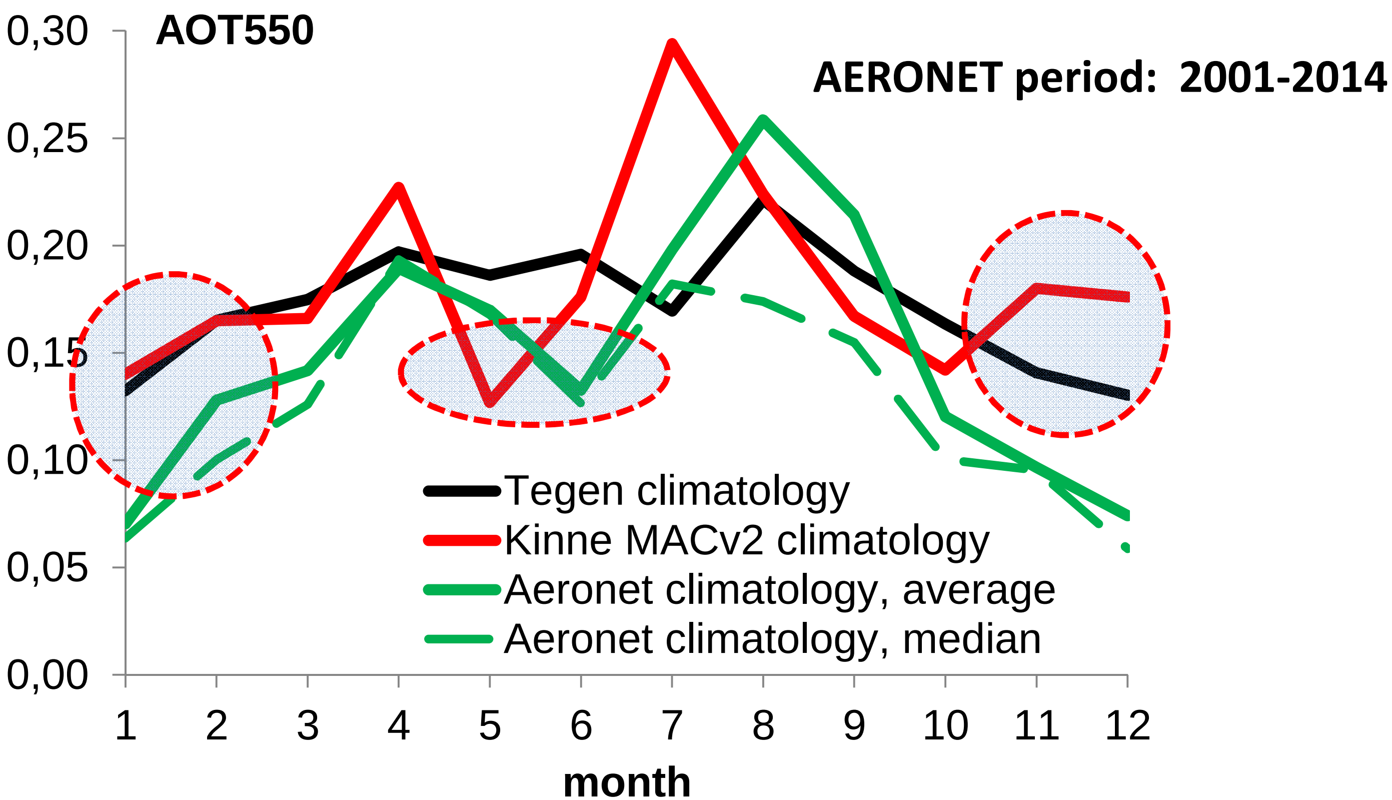
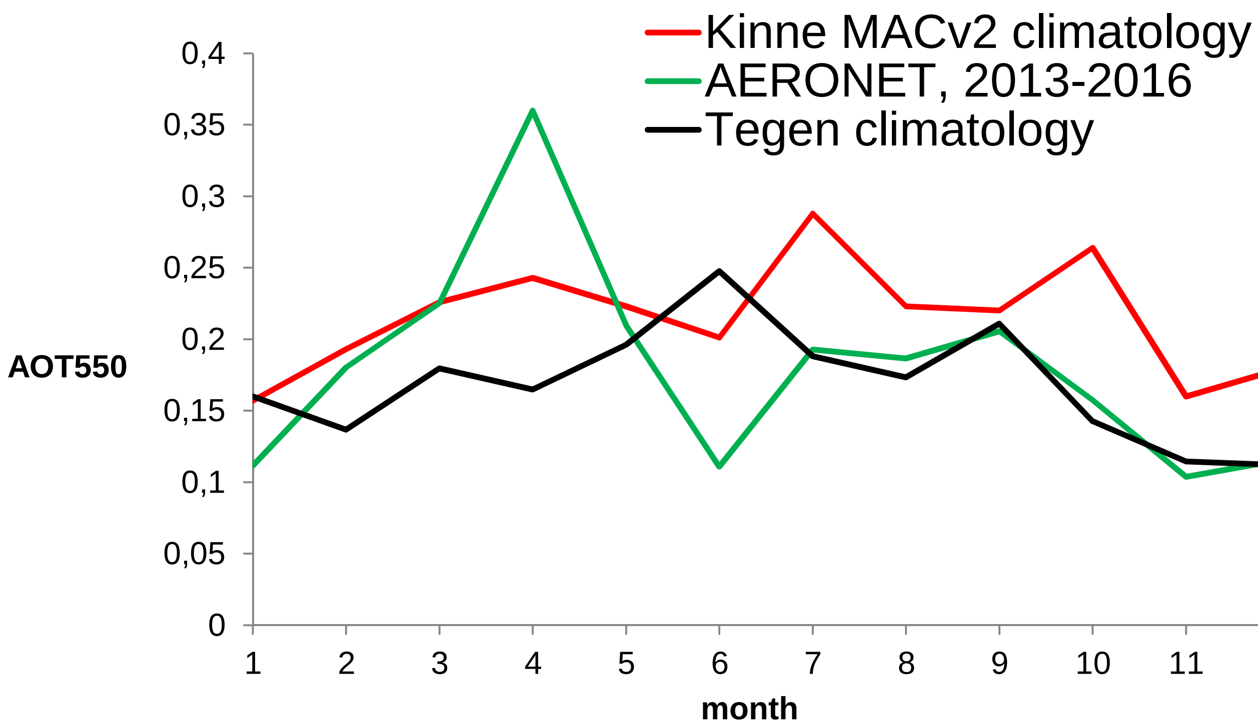


Figure 1. Seasonal average maps for the tropospheric midvisible AOD of the new MAC-v1 climatology for year 2000 conditions. Values below the labels indicate global averages.

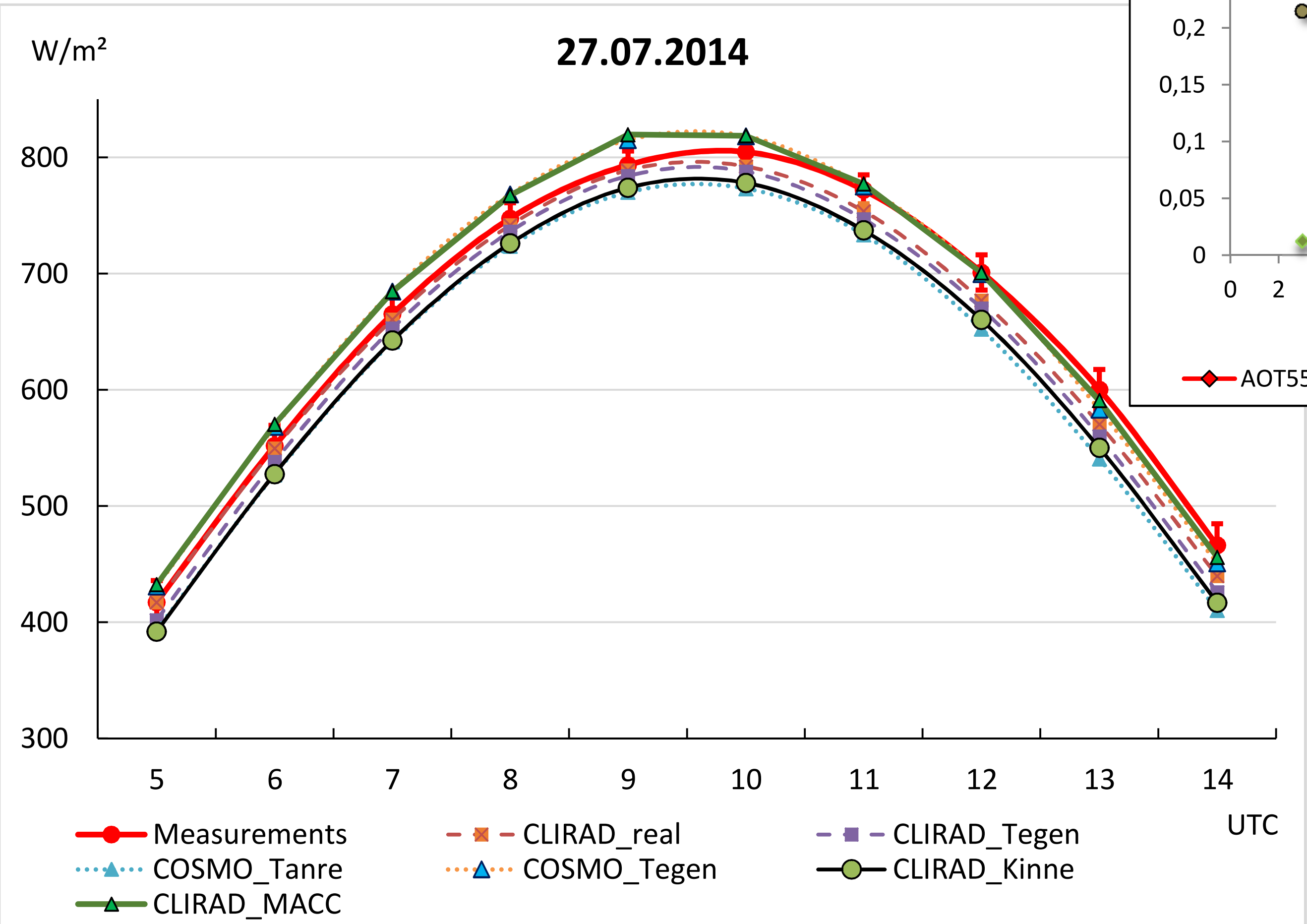
Aerosol climatology in Moscow

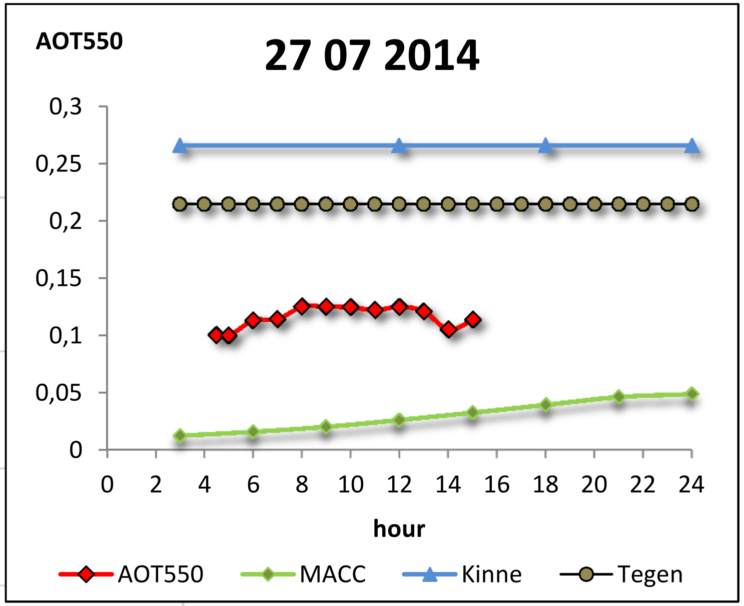


Aerosol climatology in Falkenberg/Lindenberg

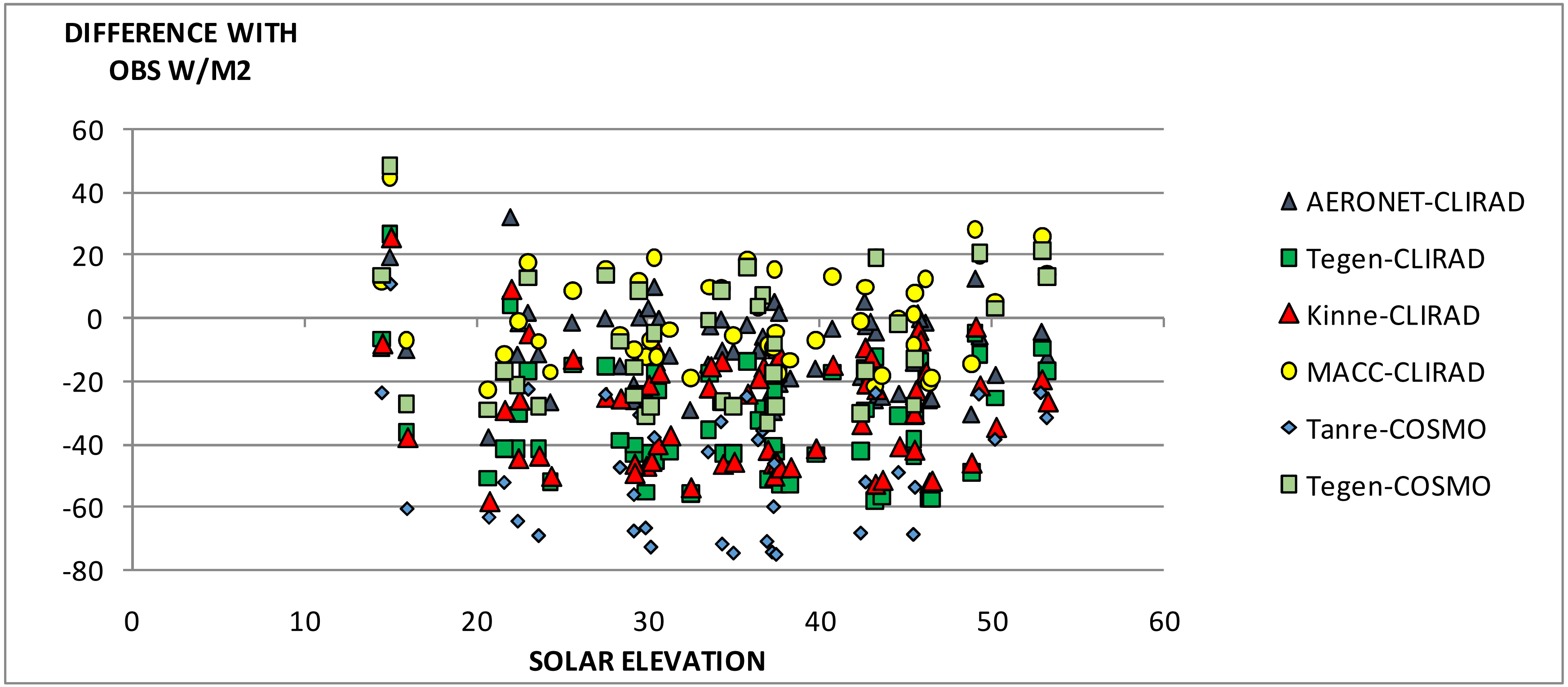


COSMO radiation in clear skies with different climatologies measurements





Global radiation difference between CLIRAD model and observations as a function of solar elevation



For high SZA ~ 5% overestimation in the COSMO scheme against CLIRAD

Single/Double precision in radiation scheme

(Pavel Khain, , Itzhak Carmona , Xavier Lapillonne, Oliver Fuhrer)
with a support of Valentin Clement & Pascal Spoerri

- Radiation standalone scheme was used for one time step runs

    A. Double precision, unperturbed
    B. Double precision, with the some input fields randomly perturbed to 1e-7
    C. Single precision, unperturbed
    D. Single precision, with the input fields randomly perturbed to 1e-7

- 80X60X60 grid points
- 0.02 ° resolution
- Date: 16/6/2014 18UTC

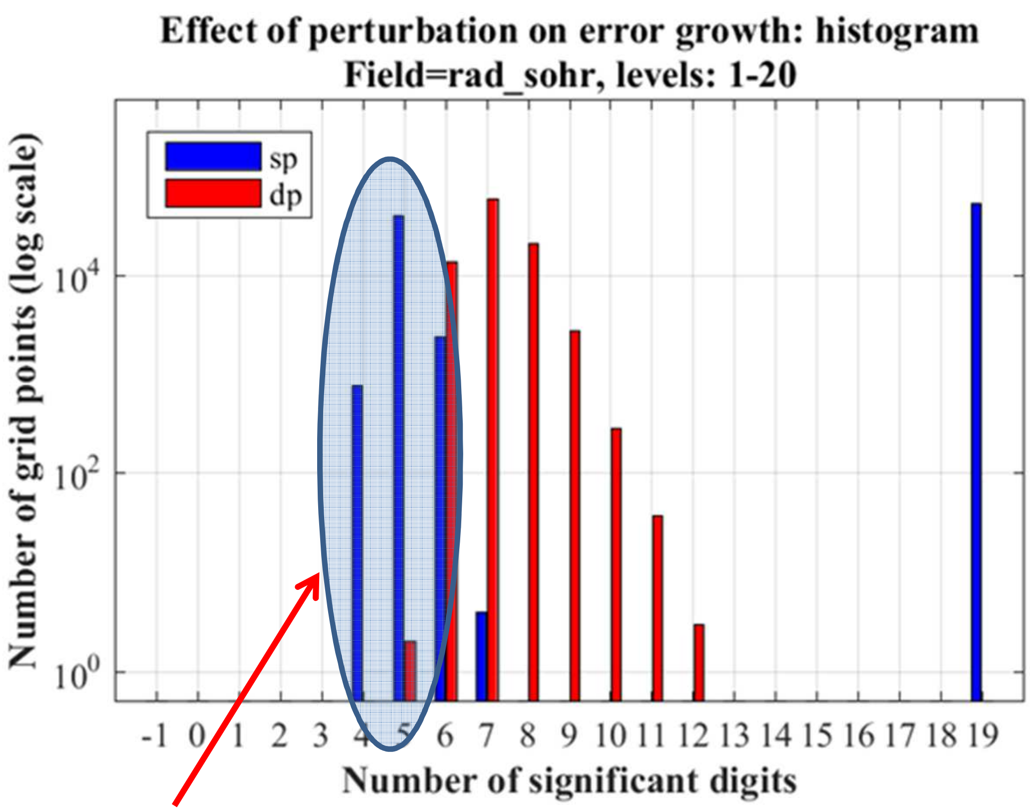
At any grid point the relative error is defined as:
Er_DP=abs((A-B)/max(abs(A),abs(B))
Er_SP=abs((C-D)/max(abs(C),abs(D))

Number of significant digits is defined as:
Nsig_DP=-log10(Er_DP)
Nsig_SP=-log10(Er_SP)

Radiation standalone scheme structure

```
lmorg.f90
 ...
 CALL test_physics
 ...

src_physics.f90
 ...
 Subroutine test_physics   !initialize and run physics test
 ...
   DO iter=1,niter   !multiple iteraton for timing statistics
     CALL init_test
     CALL init_dump_block
     CALL radiation_prepare
     DO ib=1,nblock
       CALL set_current_block_id
       CALL request_copy
       CALL copy_to_block
       CALL radiation_organize   !Run the scheme
       CALL copy_from_block
       CALL finalize_copy
     END DO
     CALL finalize_test
   END DO
   CALL write_output (from src_readwrite.f90)
 ...
 Subroutine init_test
 ...
   CALL read_input (from src_readwrite.f90)
        with option of perturbations
 ...
```



Not Good !

Summary – Radiation in SP/DP

- May we run the entire radiation scheme in SP? **No!**
- Does SUBROUTINE **fesft** cause the problems? **Yes but not only!**
- Where in **fesft** are the hotspots :
  - Are these **inv_th/inv_so**? **Yes!**
  - Maybe also **opt_th/opt_so**?**No!**

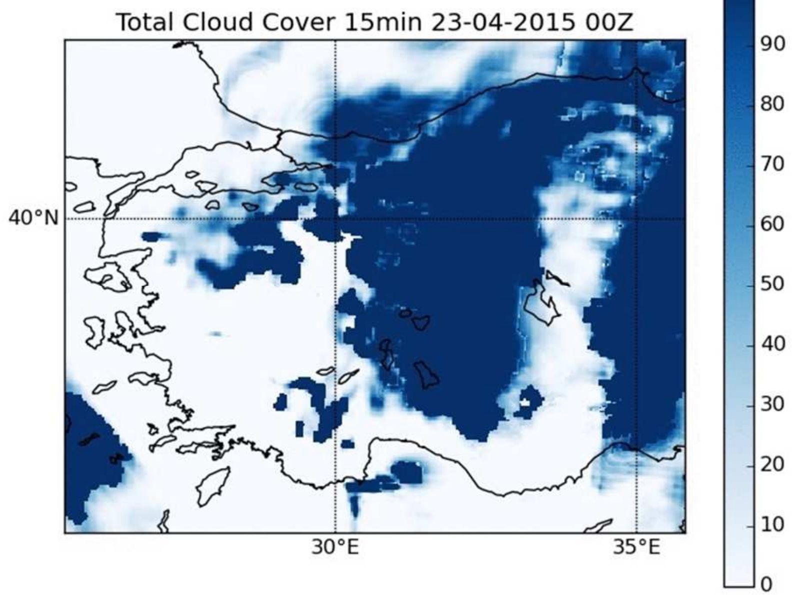
- Plans
  - Check for hotspots outside **fesft**; Find hotspots inside **inv_th/inv_so**.
  - Repeat analysis for cloudy areas; another date; Is bigger domain needed?
  - Check if possible to modify the code to allow running in SP

Radiation Temporal Resolution

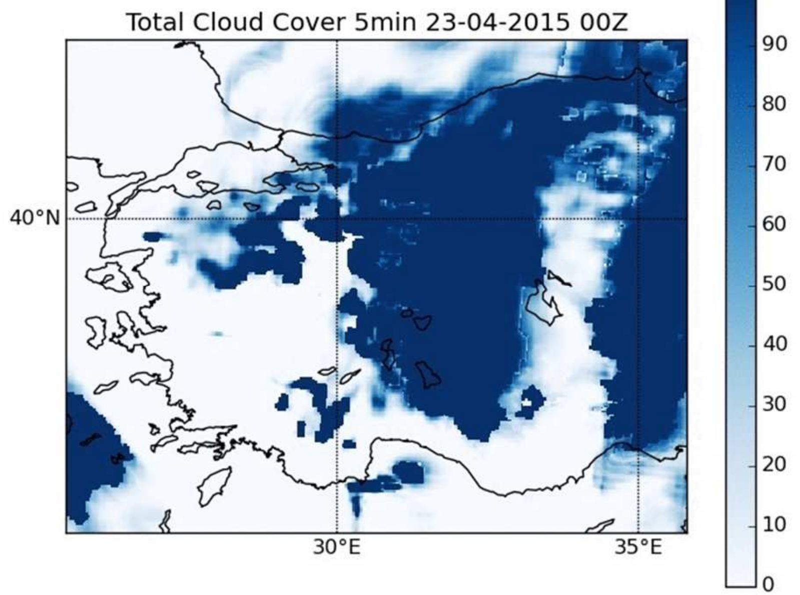
(Alon Shtivelman, Harel Muskatel, Itzhak Carmona)

- COSMO-7km / 2.8km
- 23-25/04/2015 test case
- Partial cloudiness + High wind speeds

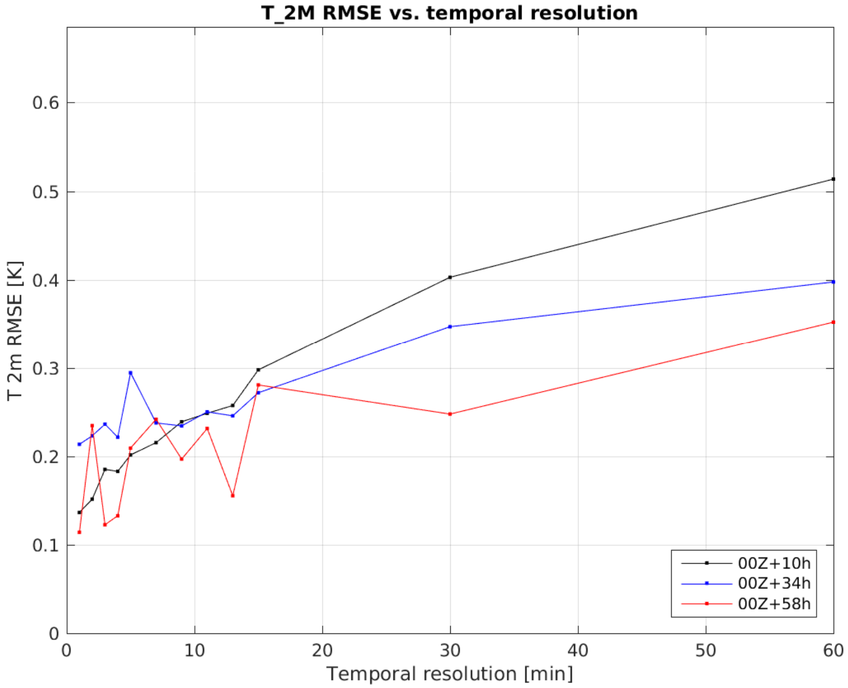
Default - $\Delta t_{rad} = 15\ min$

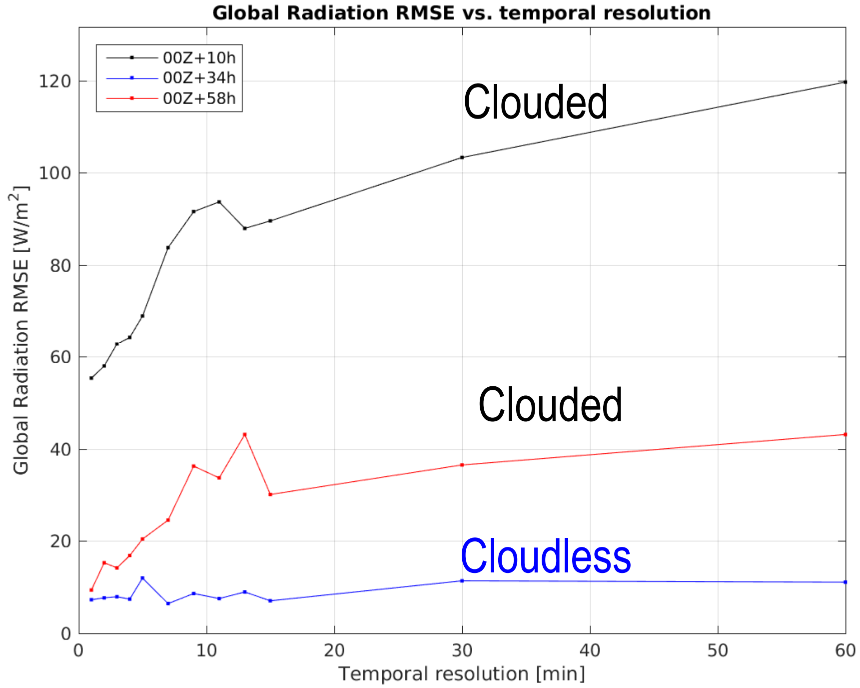


$\Delta t_{rad} = 5\ min$

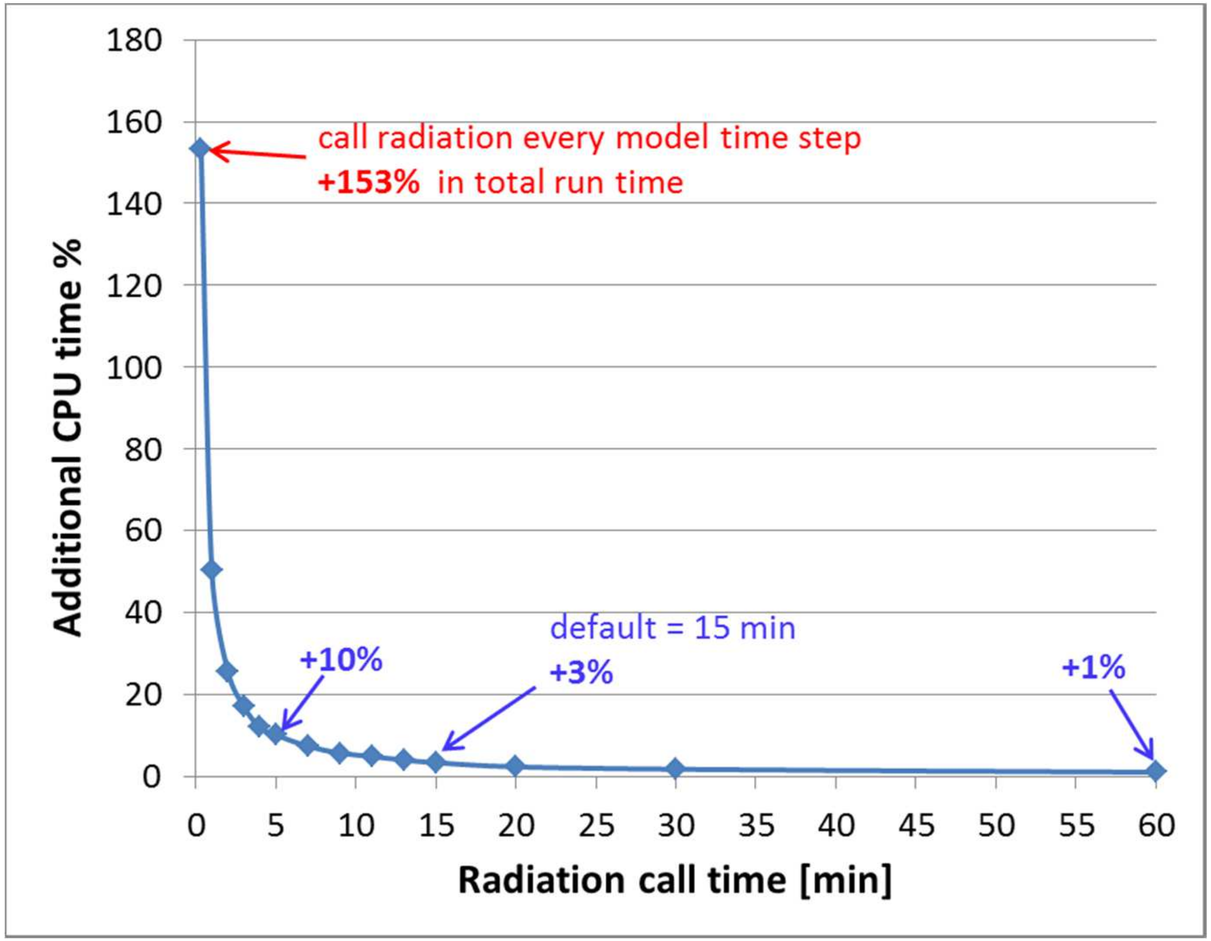


Temporal resolution impact onT2m and global radiation RMSE





Radiation temporal resolution impact on CPU cost



Radiation Temporal Resolution- Conclusions

- The default of 15 min for temporal resolution for COSMO 2.8 km gives a reasonable performance in clouded weather conditions
- The CPU cost of 3% is low enough to allow even a more fine resolution - but not needed.
- We can consider improved schemes i.e. more spectral bins

References:

THANK YOU FOR YOUR ATTENTION!

Harel [illegible]

Aron [illegible]

Itzhak [illegible]

Ulrich Blahak (DWD)

Matthias Raschendorfer (DWD)

Ralf Becker (DWD)

Daniel Luethi (DWD)

Oliver Fuhrer (MCH)

Xavier Lapillonne (MCH)

Gdaly Rivin (RHM)

Natalia Chubarova (RHM)

Marina Shatunova (RHM)

Alexey Poliukhov (RHM)

Alessio Bozo (ECMWF)

Stefan Kinne (MPI-M)

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