Student - First Name, Surname

AEROSOL EXERCISE

The Impact of Aerosols Effects on Meteorology

Teacher: Roman Nuterman (Denmark)

Teacher Assistants:
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Model: Enviro-HIRLAM

Odessa, Ukraine
3-9 Jul 2011

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1. AEROSOL EXERCISE: General Information

The Impact of Aerosols Effects on Meteorology

Model used: **Enviro-HIRLAM**

Read, the general description of the HIRLAM (HIgh Resolution Limited Area Model) model at the HIRLAM official website at:
http://hirlam.org/index.php?option=com_content&view=article&id=64&Itemid=101
See for more details the scientific documentation on the HIRLAM model at:
http://hirlam.org/index.php?option=com_docman&task=doc_download&gid=270&Itemid=70

Teacher: **Roman Nuterman** (DMI, Denmark)
Teacher Assistant: **Iratxe Gonzalez-Aparicio** (Spain), **Ekaterina Khoreva** (Russia)

Introduction Background:

The atmosphere is heavily polluted by anthropogenic sources (from urban agglomerations/ megacities) with accumulation mode aerosols which affect cloud formation and precipitation development. Consequently, continental clouds generally include more cloud droplets (by two orders of magnitude) than marine clouds. An increased number of small droplets in warm clouds will lead to an increase in cloud reflectance and also affects cloud lifetime.
A megacity is characterized by large emissions of primary and secondary pollutants such as NO_x, O_3, organic compounds as well as particles of different sizes. However, the direct influence of the emissions is not the only way the city affects air quality. In particular, the interaction between soluble particles and clouds may be of importance. Particles may be transported downwind with the urban plume into clouds where they can activate and contribute to an increase in cloud droplet number concentration (CDNC). Such an increase leads to enhanced cloud-top reflectance through the first aerosol indirect effect and modification of precipitation development through the second aerosol indirect effect. The interaction between anthropogenic aerosols and regional weather has been investigated using the on-line integrated Enviro-HIRLAM model (Environment - High Resolution Limited Area Model; *Korsholm, 2008*). The aerosol feedbacks were implemented in the modified Soft TRAnsition COndensation (STRACO) scheme (*Sundqvist et al., 1989*) and radiation scheme (*Savijärvi, 1990*). The feedbacks induced changes in meteorological parameters and in chemical reactions have been preliminary analyzed and evaluated for specific case studies (*Korsholm, 2009*).

Main Goal:

Study influence of the anthropogenic emissions from selected metropolitan area on a formation of meteorological/ chemical fields in the urban area and surroundings due to inclusion of aerosols feedback mechanisms in the Enviro-HIRLAM model by analysis of temporal and spatial variability of diurnal cycle for meteorological/chemical variables of key importance.

Specific Objectives:

1) Modify the Savijärvi and STRACO schemes of Enviro-HIRLAM model by including (a) the calculation of the activated anthropogenic aerosol number concentration, (b) wet deposition in the condensation scheme, (c) parameterization of the effect of the Cloud Condensation Precipitation Evaporation processes (CCEP) and (d) dry deposition;

2) Perform simulations for selected specific cases/dates (meteorological conditions with convective regimes and typical wind conditions) in two modes - the control run and the modified run (with feedbacks included);
3) Evaluate diurnal cycle variability for – (a) air temperature, (b) sensible heat flux, (c) latent heat flux, (d) surface temperature, (e) cloud reflectivity, and etc. – for two types of runs; estimate the impact of anthropogenic aerosols from metropolitan area, magnitude and signs of changes due to feedbacks, etc.;
4) Summaries findings and results of the exercise in a form of an oral presentation (max 15 minutes).

Literature List:

Before the Summer School, the students should read, at least, the first 2 required publications; the three other papers are highly recommended to read to be useful for the discussions/talks; the additional readings might be useful too.

REQUIRED READINGS

Korsholm U.S., A. Baklanov, A. Gross, A. Mahura, B.H. Sass and E. Kaas, **2008**: Online coupled chemical weather forecasting based on HIRLAM – overview and prospective of Enviro-HIRLAM. *HIRLAM Newsletter, **54**: 1-17.*

Korsholm U.S., **2009**: Scientific Report 09-01, PhD thesis: Integrated modeling of aerosol indirect effects, http://www.dmi.dk/dmi/sr09-01.pdf

RECOMMENDED READINGS

Boucher O., Lohmanmn U., **1995**: The sulfate-CCN-cloud albedo effect, a sensitivity study with two general circulation models. *Tellus*, 47B, 281-300.

Savijärvi H., **1990**. Fast radiation parameterization schemes for mesoscale and short-range forecast models. *J. Appl. Meteor.*, 29, 437-447.

Sundqvist H., Berge E., Kristjánsson J., **1989**: Condensation and Cloud Parameterization Studies with a Mesoscale Numerical Weather Prediction Model, *Mon. Wea. Rev.*, 117, 1641-1657.

ADDITIONAL READINGS:

Albrecht B., **1989**: Aerosols, Cloud Microphysics, and Fractional Cloudiness. *Science*, 245, 1227-1230.

Satheesh S.K., Moorthy K.K., **2005**: Radiative effects of natural aerosols: A review. *Atm. Env.*, 39, 2089-2110.

Stevens B., Feingold G., **2009**: Untangling aerosol effects on clouds and precipitation in a buffered system, *Nature*, 461, 607-613.

2. Schedule for the Aerosol Exercise Team

Day	Period	Total time	Topics to be discussed	Runs	Comments	Assistance
(1) 3 Jul 2011 Sunday	16:00-18:00+	2 h +	INTRODUCTION into exercise SELECTION of specific date TECHNICAL PREPARATION for runs	E, D	Select date for runs Check implementation Start run on computer	T+TA
(2) 4 Jul 2011 Monday	15:00-18:00+	3 h +	VISUALIZATION of modelling outputs	M, L, E, D	Continue runs on computer Start visualization	T+TA (+C)
(3) 5 Jul 2011 Tuesday	15:00-17:00+	2 h +	ANALYSIS of results	M, L, E, D	Continue runs on computer Continue visualization / Start analysis	T+TA (+C)
(4) 6 Jul 2011 ***Wednesday***	15:00-18:00+	3 h +	***TEAM's INDEPENDENT WORK***	M, L, E, D	Continue runs on computer Continue visualization and analysis	TA (+C)
(5) 7 Jul 2011 Thursday	15:00-18:00+	3 h +	ORAL (& POSTER) PRESENTATIONS (outline, structure, content, etc.)	M, L, E, D	Continue runs on computer Continue visualization and analysis / Start preparation of oral presentation	T+TA (+C)
(6) 8 Jul 2011 ***Friday***	09:00-13:00 14:00-18:00+	4 h + 4 h +	***TEAM's INDEPENDENT WORK*** Check oral presentation	M	Finish runs on computer Finish analysis and oral presentation	TA (+T)
(7) 9 Jul 2011 Saturday	09:00-11:00	15'	ORAL PRESENTATION by TEAM (10' to present + 5' for questions)			

Remark*:* *possibilities to submit Enviro-HIRLAM run at: E - official exercise time; M – at morning; L – before lunch; D – after dinner*
T – teacher, TA – teacher assistant, C – consultant (lector)

3. Items of the Aerosol Exercise

Introduction into Exercise (Background Discussions)

Introduction into the aerosol exercise; main items of the exercise (selection of dates, technical aspects and implementations, runs, visualization and analysis of results, making presentation); brainstorming for both teams/groups to outline research and technical tasks required (including main goal, specific objectives, etc.) within groups, etc.

Make a link with consultants (lectors) asking theoretical questions and consider an exchange between teams of students – as research groups - during the exercise; additional talks/discussions on aerosol feedbacks including (*see Annexes A1-A3*):

- *A1 - Enviro-HIRLAM: NWP-ACT Integrated Modelling;*
- *A2 - Modelling domains (for operational and research purposes);*
- *A3 - Aerosol direct/ indirect effects.*

Meteorological situations for selected cases/ dates

Analyze meteorological conditions in the modelling domain for given dates using available surface maps, diagrams of vertical sounding, and surface meteorological measurements (data are provided from the DMI meteorological archives). Select the specific date (to be used in runs) and make/write a general summary of meteorological conditions (to be used in final oral presentation by the team).

- *Supplementary material for the AEROSOL exercise (meteorological conditions for specific dates)*

Technical aspects of modelling and aerosol feedbacks implementation

Learn practical technical steps/ tasks / activities in order to make necessary changes in the Enviro-HIRLAM code, implementation of the aerosol feedbacks (STRACO scheme, radiation scheme, turbulence scheme, wet/ dry depositions) compile the executable, run the model at different options, save generated output, etc. (*see Annexes B1-B3*):

- *B1 - Model – preparations, setups and runs;*
- *B1 - Implementation of Aerosol Effects;*
- *B3 - Call-Tree for Aerosol Implementation.*

Model runs

Perform simulations (note: use maximum forecast length as 24 hours) for the selected date/s for different aerosol emissions, estimate computational times for different runs. Note, all simulations with the Enviro-HIRLAM model will be performed at a high horizontal grid resolution (*see Table in Annex A2*); as well as *see Annexes B1-B3*:

- *B1 - Model – preparations, setups and runs;*
- *B2 - Implementation of Aerosol Effects;*
- *B3 - Call-Tree for Aerosol Implementation.*

Possible Enviro-HIRLAM runs for the AEROSOL exercise are the following:

- Control (reference) run – without aerosol emissions (Paris/ Bilbao);
- Aerosol feedbacks included – emission file 1 (Paris/ Bilbao);
- Aerosol feedbacks included – emission file 2 (Paris/ Bilbao).

Visualization of results

Learn on how to use the METGRAF software in order to plot results of simulations in different forms (see *Annex C1-C2*):

- *C1 – Visualization of results;*
- *C2 – Examples of visualization and analysis.*

Aerosols impact on meteorology: analysis

Analyse and evaluate possible impact of aerosols on temporal and spatial variability of the simulated meteorological fields for selected meteorological parameters, for example: air temperature, wind speed, relative humidity, surface/ 2 meter temperature, sensible heat flux, latent heat flux, net long/short wave radiation, and etc; evaluate diurnal cycle variability for analysed parameters – for two types of runs – control vs. modified (with aerosol feedbacks); estimate magnitude and signs of changes due to anthropogenic PM emissions from urban areas, etc.;

- *C2 – Examples of visualization and analysis.*

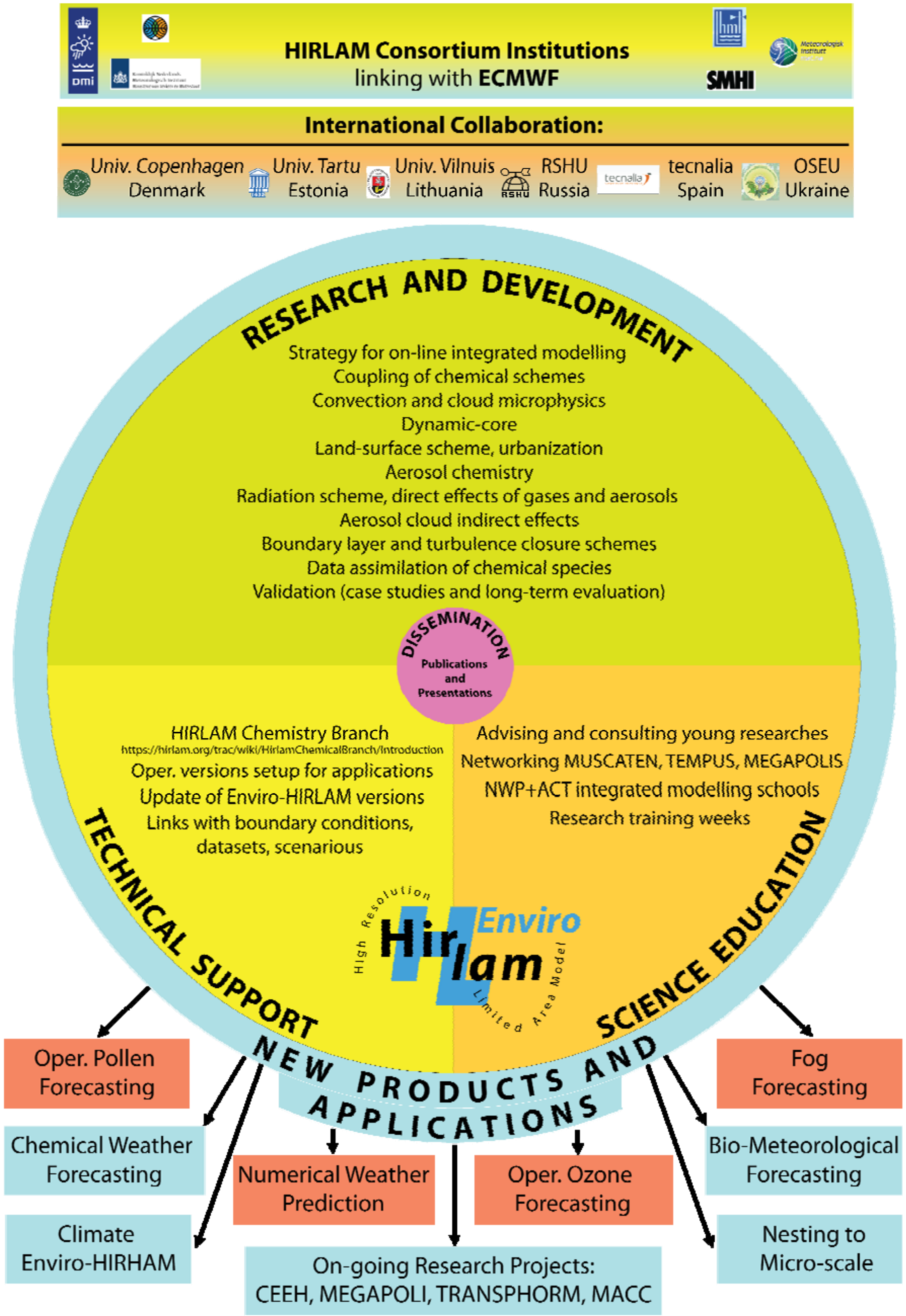
Team presentation

Make your team oral (using any application, preferably MS Power Point) presentation about findings and results obtained; follow the draft guidelines of the presentation, which should, at least, include the title, main aim and specific objectives, methodology and approaches, results and discussions with examples, conclusions, acknowledgements, references, etc.

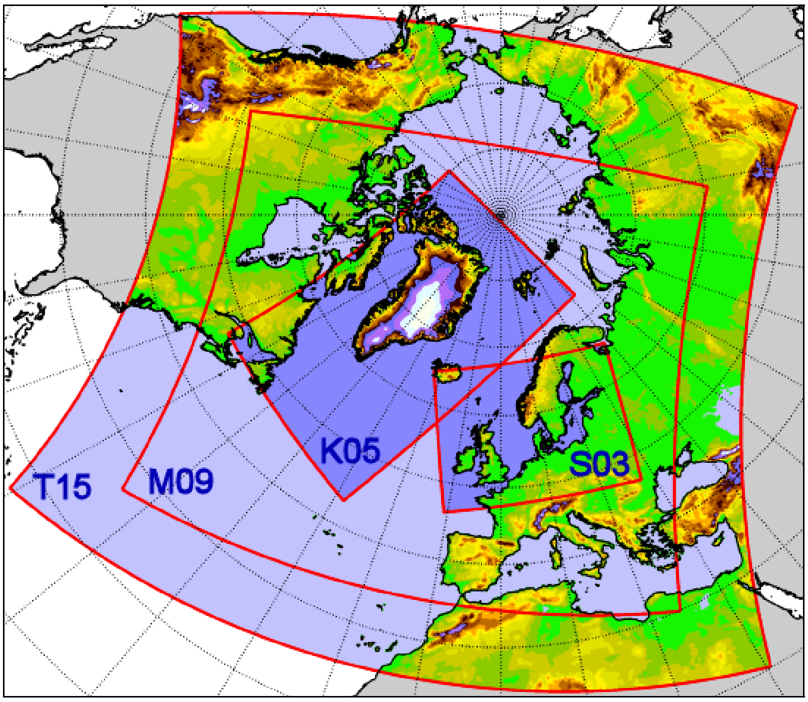
- *C3 – Draft Outline of Presentation.*

ANNEXES

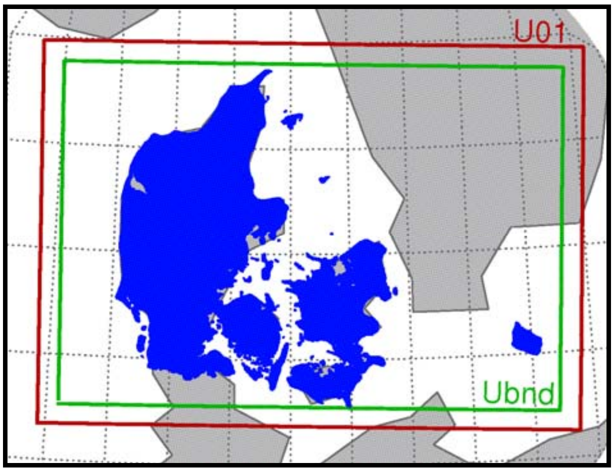
A1. Enviro-HIRLAM: NWP–ACT Integrated Modelling

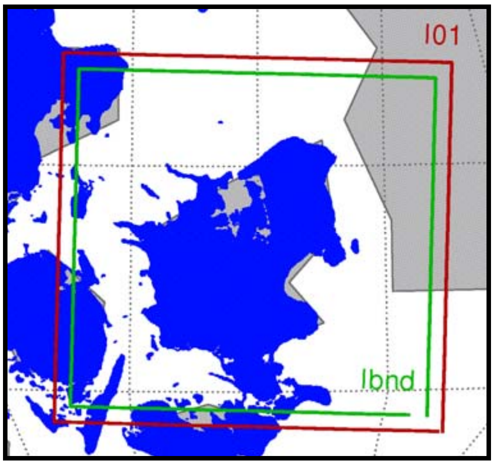


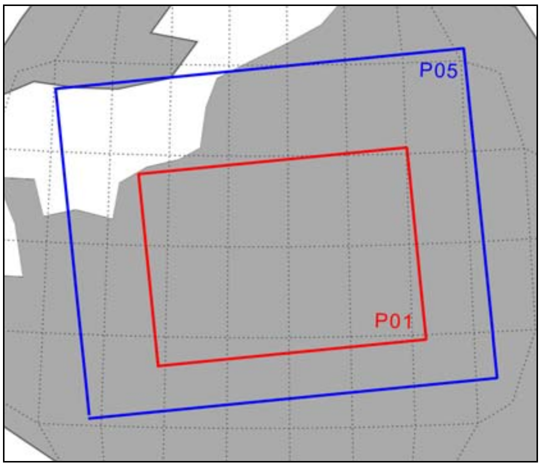
A2. Modelling Domains

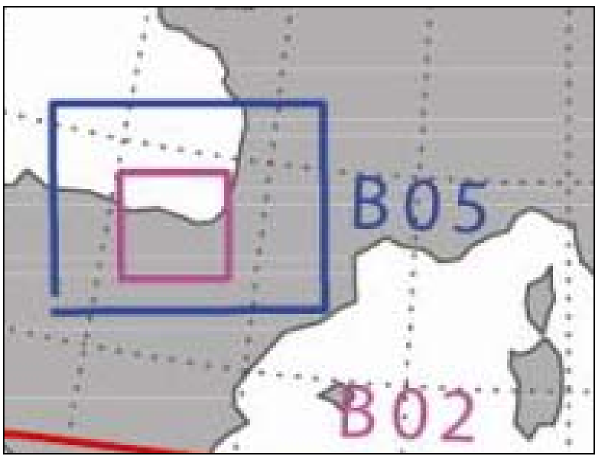


(used for DMI operational and research purposes)









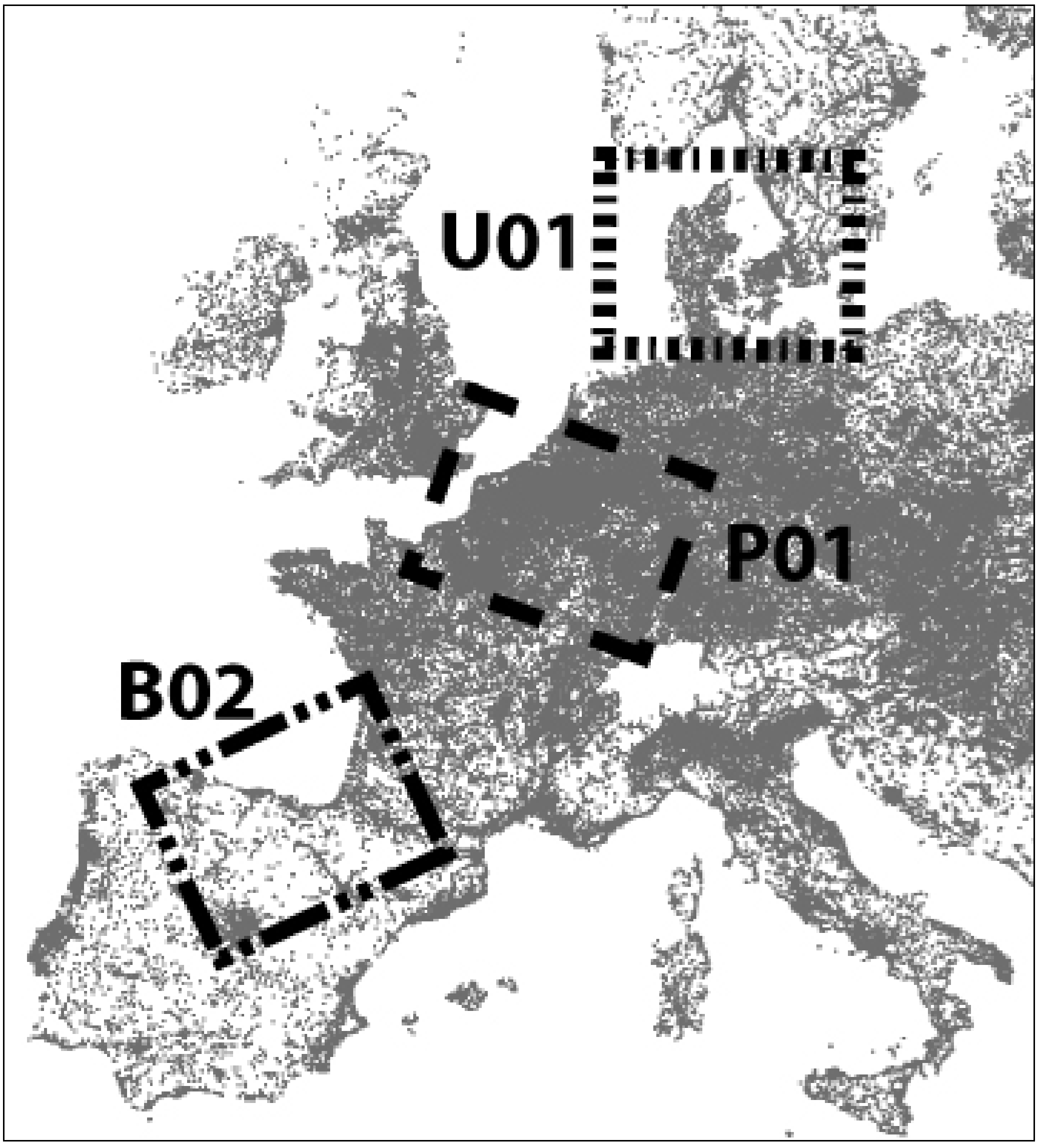


Figure: Geographical boundaries of the modelling domains: B02 - for Bilbao; P01 – for Paris; and U01 –for Copenhagen metropolitan areas located in the centre of domains.

Metropolitan area	Domain	Horisonal Resolution (km)	Total # grid points in domain
Bilbao	**B02**	2.4x2.4	14834
Copenhagen	**U01**	1.4x1.4	65022
Copenhagen	**I01**	1.4x1.4	14632
Paris	**P01**	2.5x2.5	10148

Table: Summary of characteristics of the modelling domains – B02, U01/I01- and P01 – for the Bilbao, Copenhagen and Paris metropolitan areas, respectively.

A3. Aerosol direct/ indirect effects

- **Direct effect:** decrease solar/thermal-IR radiation and visibility
- **Semi-direct effect:** cloud burn-off, affect PBL meteorology and photochemistry
- **First indirect effect:** affect cloud drop size, number, reflectivity, and optical depth via CCN
- **Second indirect effect:** affect cloud LWC/ height, lifetime, and precipitation

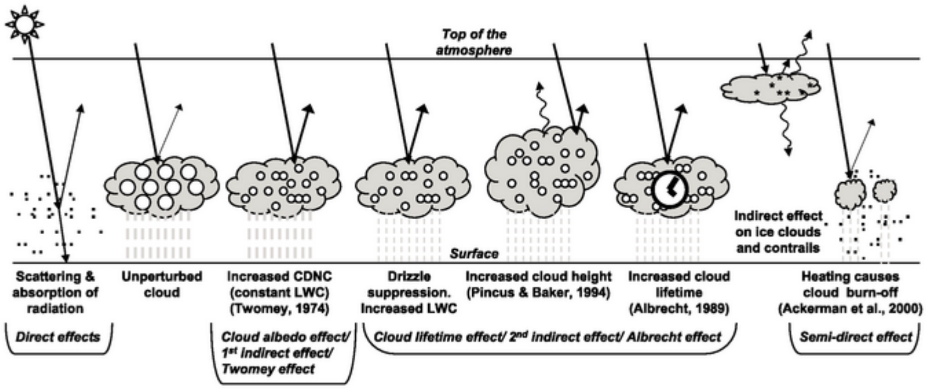


Figure: Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.

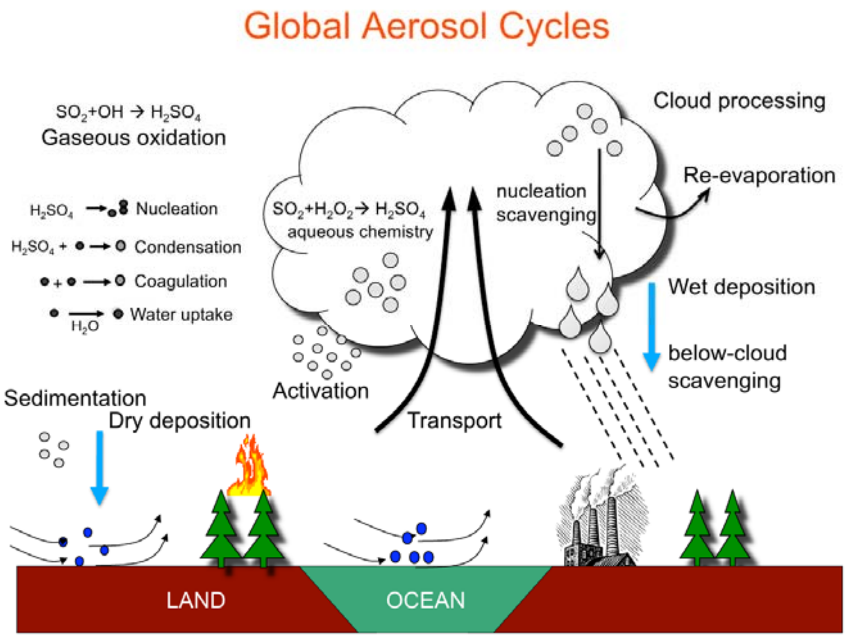


Figure: Illustration of global aerosol cycles and processes involved including chemistry dry/ wet depositions, sedimentation, scavenging, nucleation, condensation, coagulation, water uptake etc.

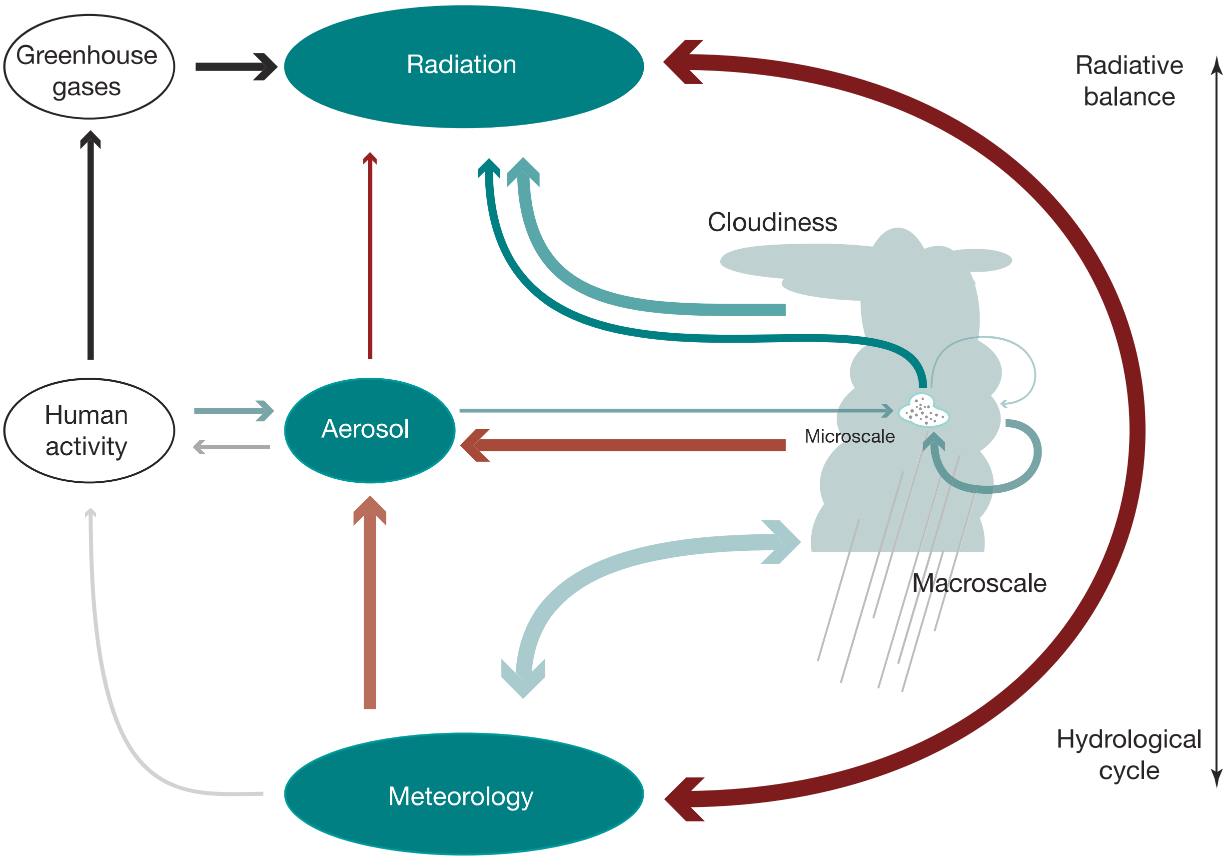


Figure: aerosol–cloud interactions in the context of the atmospheric component of the Earth system. The response of the system to changes in the aerosol is buffered by, or depends on, the strong (as measured by arrow thickness) and in places very uncertain (as measured by arrow transparency) coupling between clouds (microscale, Cm; macroscale, CM) and other components of the cloud system (human activity, H; aerosol, A; radiation, R). Unlike the cloud albedo effect, which is expressed in the H–A–Cm–R pathway, cloudlifetime effects follow H–A–Cm-–CM–R and other components of the system (Stevens B., Feingold G., **2009**).

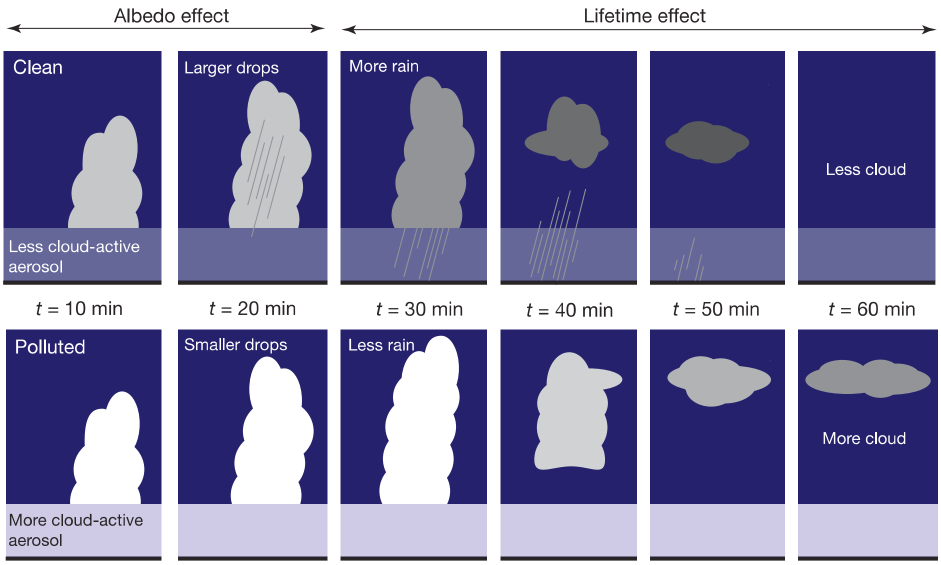


Figure: the lifetime (and albedo) effect. In polluted air masses, clouds consist of more droplets that coalesce into raindrops less effectively, leaving longer-lived clouds (Stevens B., Feingold G., **2009**).

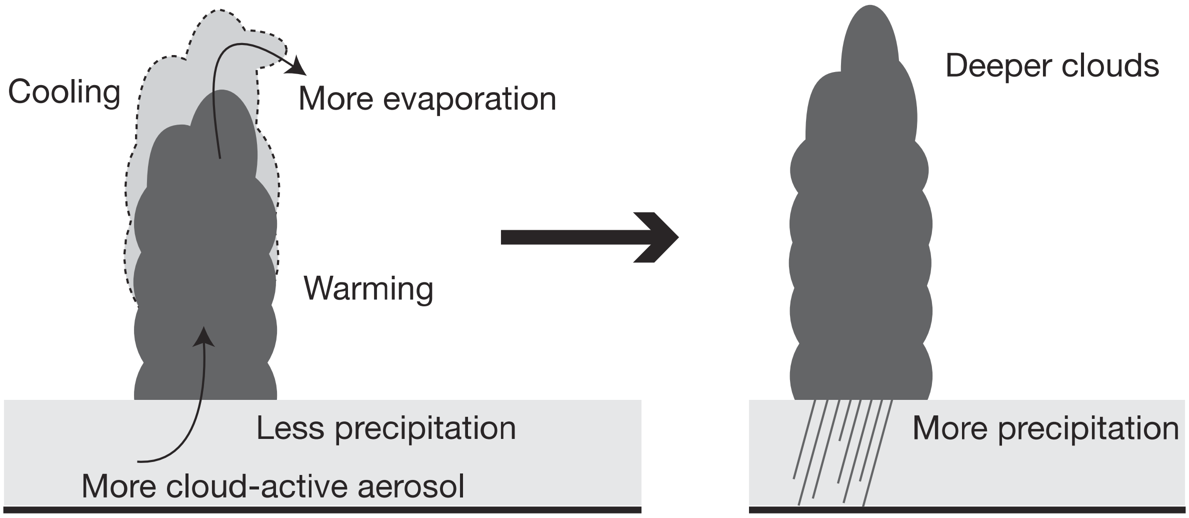


Figure: the deepening effect. The local inhibition of precipitation helps precondition the environment for deeper convection, which then rains more (Stevens B., Feingold G., **2009)**.

B1. Model – Preparations, Setups & Runs

IMPORTANT START REQUIREMET: 1) use: **bash**
2) use: **ulimit -s unlimited**

1. *COMPILE THE EXECUTABLE AND RUN THE MODEL*
- Go to the directory **./hl_home/aerosol/**
- Recompile the executable and run the model using command:
  ~/Hirlam start DTG=YYYYMMDDHH DTGENG=YYYYMMDDHH LL=24
  DTG – starting date
  (YYYY – year, MM – month, DD – day, HH – hour;
  DTGENG - ending date
  LL – forecast length (select 24 hours)

  ... waiting for an executable to be compiled …
  ... follow SMS-window through steps of compilation, initialization, climate files generation, preparation of boundary conditions, and steps of forecasting (depending on LL) … until the run is completed

2. *THE PRODUCED OUTPUT*
- Go to the directory **./hl_arc/aerosol/YYYY/MM/DD/HH**
- The generated output files to be analyzed are the following:
  fcYYYYMMDD_HH+0LL - 3d meteo.fields
  fcYYYYMMDD_HH+0LLmd - surface meteo.fields

IMPORTANT END NOTES:
1) *After each run has been finished **ALWAYS** (!) change the name of the output directory:*
- Go to the directory called **./hl_arc**
- Rename the output directory called **aerosol** to **aerosol_run#_YYYYMMDD**
  Note: # - number of the run

2) *Before making the next runs always (!) change the stack size to unlimited*, for that use the command: **ulimit -s unlimited**

B2. Implementation of Aerosol Effects

1. *MAKE CHANGES FOR THE ENVIRO-HIRLAM MODEL:*

For inclusion AEROSOL effects

- Go to the directory called **./hl_home/aerosol/phys/**
- Using any text-editor make necessary changes in the files:

phys.F
hlradia.F90
drydeposition.F90
hlavcbr.F90
hlvcbr.F90
hlaconds.F90
hlconds.F90
hlprevap.F90
hlapr.F90
wetdeposition.F90

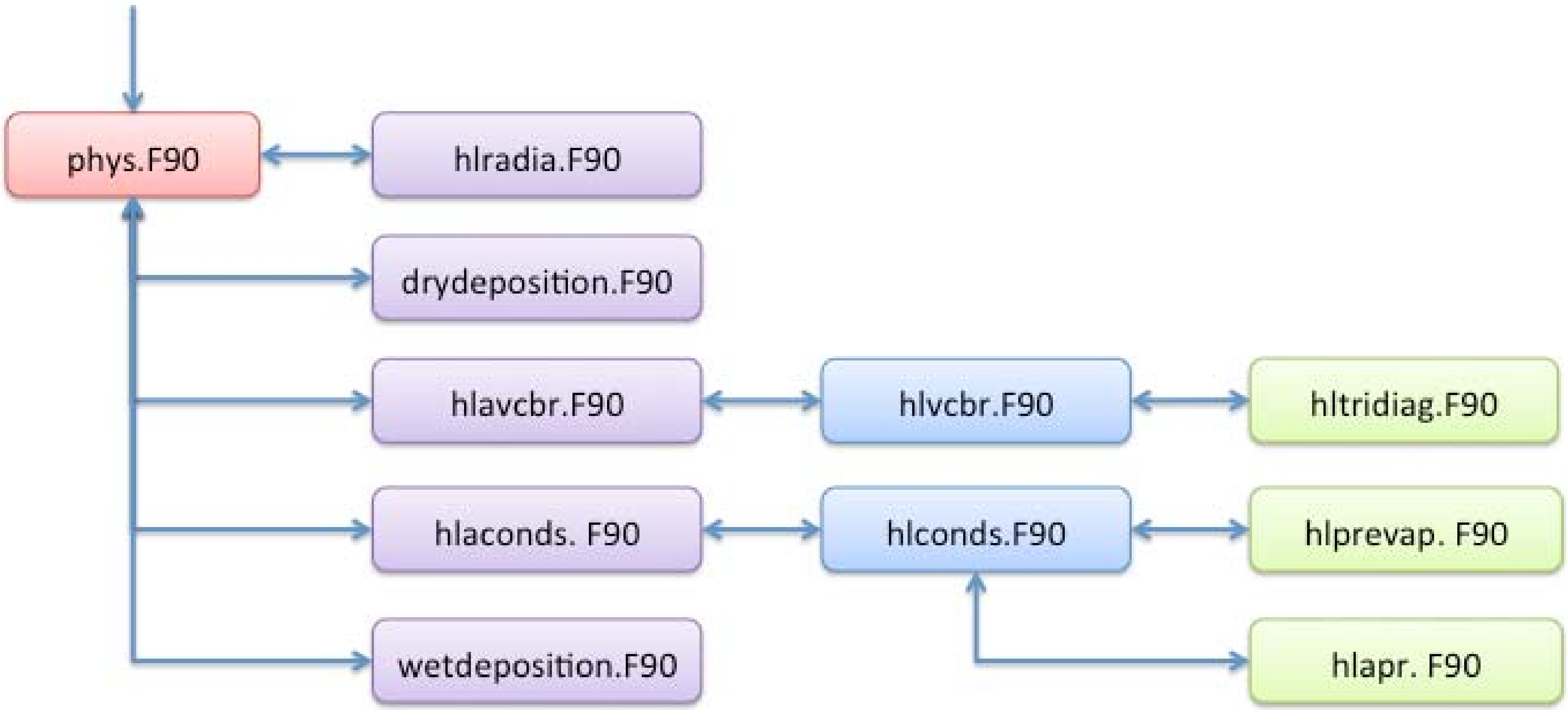
See scheme of implementation (Appendix A4)

HINT: Search text in fortran-files for word **AEROSOL** *and comment/uncomment necessary lines.*

Measurement stations in the metropolitan areas and surroundings for Paris and Bilbao

Metropolitan Area	***Measurement site***	***Type of the site***	***Latitude, deg***	***Longitude, deg***
Paris	LHVP	Urban	2.359 °E	48.828 °N
	SIRTA	Suburban	2.208 °E	48.718 °N
	CHARTES	Rural	1.500 °E	48.500 °N
Bilbao	DEUSTO	Urban	-2.966 °W	43.289 °N
	DERIO	Rural / Inland	-2.852 °W	43.293 °N
	FALRA	Rural / Coastal	-3.033 °W	43.373 °N

B3. Call-Tree for Aerosol Implementation



C1. Visualization of Results

METGRAF software
PRE-STEP:

- Go to the directory called **./metgraf**
- Run the METGRAF application by typing: **gtkmetgraf.x**

Step 1: Select FIELDS / ADD NEW FIELD/ SELECT FILE /
i.e. choose the name of the Enviro-HIRLAM output file to be plotted from directory
./hl_arc/aerosol_run#_YYYYMMDDHH/YYYY/MM/DD/HH/
+
fcYYYYMMDD_HH+0LLmd - surface meteo.fields
fcYYYYMMDD_HH+0LL - 3d meteo.fields

(GRIB file 1: …path to the file …) – for plotting original field for 1 parameter
and by choosing also the second file
(GRIB file 2: …path to the file …) – for plotting difference between 2 fields of the same parameter

Step 2: Select parameter to be printed through GRIB parameters: Table/ Level Type/ Level/ Param

1. for the temperature at 2 meters (T2m, in K or subtract 273 to get in C) - 1/ 105/ 2/ 11
2. surface temperature (in K or subtract 273 to get in C) - 1/ 105/ 0/ 11
3. for the wind at 10 meters (W10m, in m/s) - 1/ 105/ 10/ 33
4. for the latent heat flux (LHF, in W/m^2) - 1/105/0/121
5. for the sensible heat flux (SHF, in W/m^2) - 1/ 105/ 0/ 122
6. for total cloud cover (%) - 1/ 105/ 0/ 71
7. etc.

Step 3: Select type of the field to be plotted: as an original field or as a difference field (Diffs)

Step 4: Select: Field options, Legend options, Wind Arrow options, Extreme values options, etc., Contours (use the user-defined contours/shades button) to play + choose the best visible and readable presentation of the results obtained

Step 5: Press button - DRAW – to draw/redraw the plot

HINT: Always redraw plot after making changes by pressing button DRAW

NOTE: In order to select the area of domain to be plotted choose from the METGARF menu through the OPTIONS/ AREA *the setting options such as* SCALE/ LAT.MID/ LONG.MID/ etc.

NOTE: To save the newly defined domain: FILE/ SAVE – select path to the directory called **./aerosol/RESULTS/filename**
At the end, use this **filename** *as a template to draw the similar plots*
Do the similar for the OPTIONS/ OPTIONS *and* OPTIONS/ COASTLINES *as needed*

C2. Examples of visualization and analysis

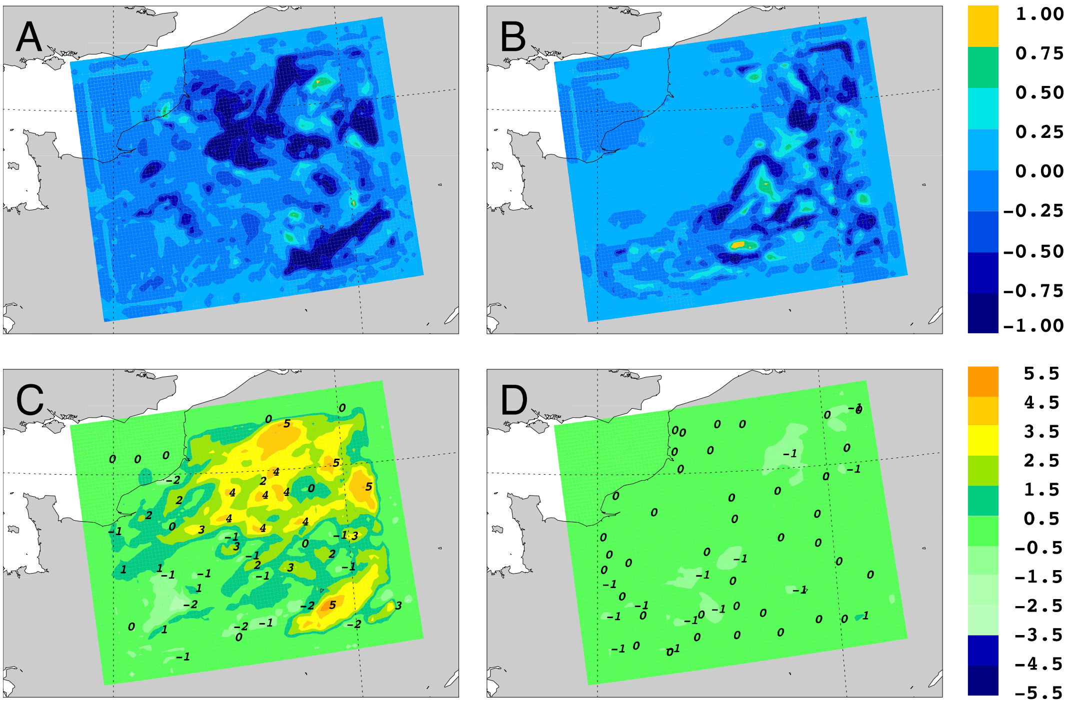


Figure / Example: Difference fields between control run of the model and modified one (with aerosol indirect effects) - A and B: Day (12 UTC 29 June 2005) and night (00 UTC 1 July 2005) - time changes in cloud cover. C and D: Corresponding day and night - time changes in T2m (C) (numbers indicate local maxima). (Korsholm, 2009)

Change in / UTC term	Latent Heat Flux (W/m^2)	Sensible Heat Flux (W/m^2)
1		
2		
3		
…		
23		

Table / Example: Diurnal variation on SELECTED DATE of difference fields (in W/m^2) for the latent and sensible heat fluxes due to aerosol indirect effects.

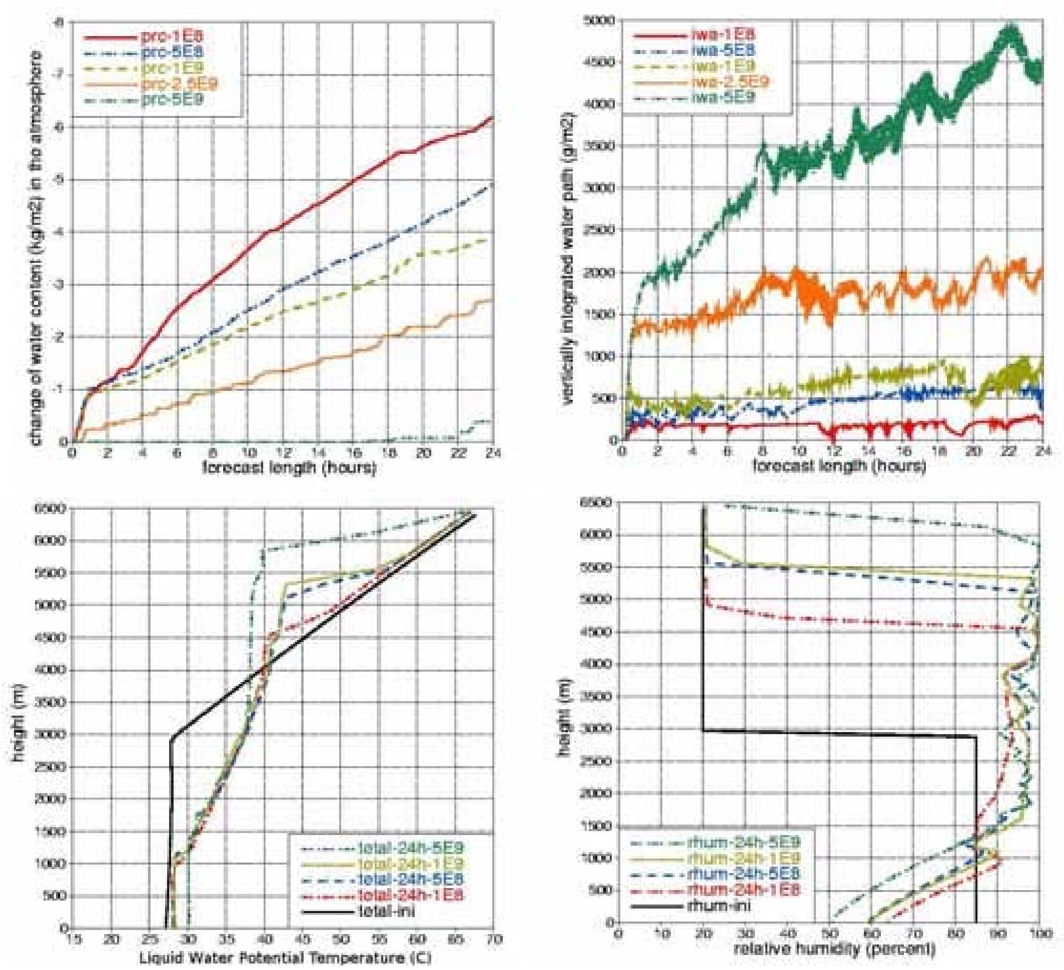
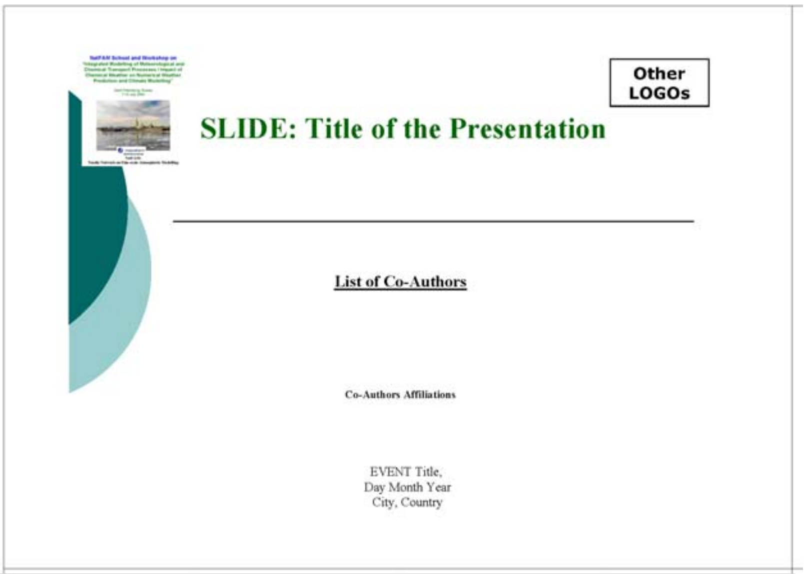
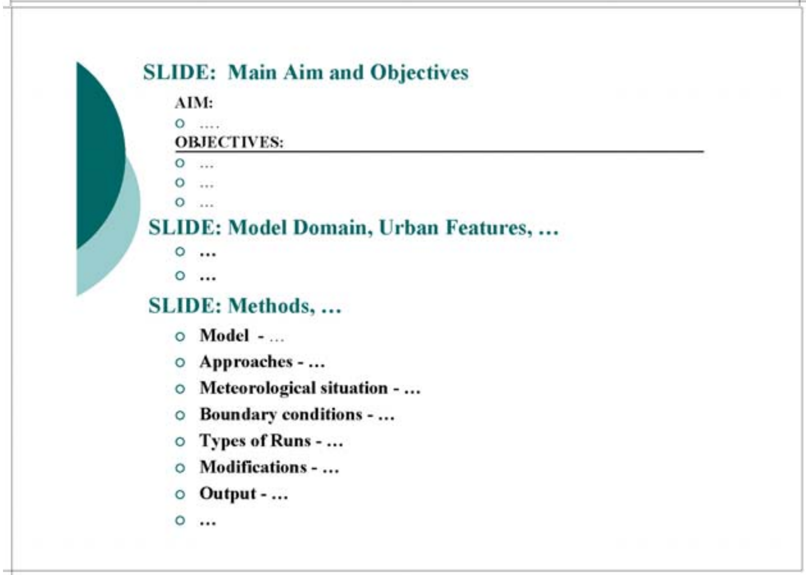
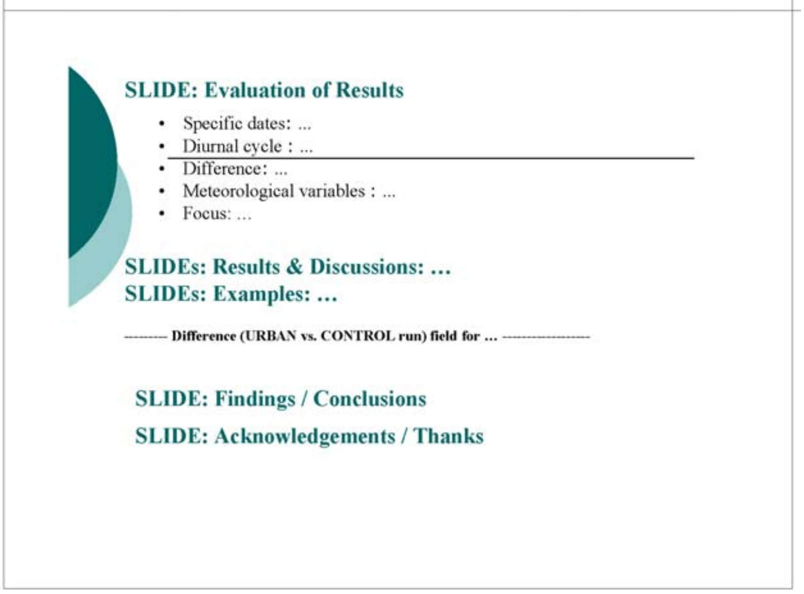


Figure / Example: Top panel: Left hand plot, precipitation release versus time, negative values indicate removal from the atmosphere. Right hand plot, LWP versus time. Bottom panel: Left hand side, liquid water potential temperature (C) as function of height (m). Right hand side, relative humidity (%) as function of height (m). The black line corresponds to the initial conditions. The color code reflects the CCN concentration, red 10^8 m^{-3}, blue $5 \cdot 10^8$ m^{-3}, yellow 10^9 m^{-3}, orange $2.5 \cdot 10^9$ m^{-3} and green $5 \cdot 10^9$ m^{-3}.

C3. Draft Outline of Presentation







D1. Useful readings afterwards

Boucher O., **1995**: The sulphate-CCN-cloud albedo effect. A sensitivity study with two general circulation models, *Tellus*, 47B, 281-300.

Chuang C.C., Penner J.E., **1995**: Effects of anthropogenic sulphate on cloud drop nucleation and optical properties, *Tellus*, 47B, 566-577.

Croft B., Lohmann U., Martin R.V., Stier P., Wurzler S., Feichter J., Posselt R., and Ferrachat S., **2009**: Aerosol size-dependent below-cloud scavenging by rain and snow in the ECHAM5-HAM, *Atmos. Chem. Phys.*, 9, 4653–4675, Web-site: www.atmos-chem-phys.net/9/4653/2009/

Grell G.A., Peckhama S.E., Schmitzc R., McKeenb S.A., Frostb G., Skamarockd W.C., Edere B., **2005**: Fully coupled ‘‘online’’ chemistry within the WRF model, *Atmospheric Environment*, 39, 6957–6975

Jacobson M.Z., Kaufman Y.J. and Rudich Y., **2007**: Examining feedbacks of aerosols to urban climate with a model that treats 3-D clouds with aerosol inclusions, *J. of Geophysical Research*, 112, D24205.

Haywood J, Boucher O. (2000) Estimates of the direct and indirect radiative forcing due to tropospheric aerosols: A review, REV GEOPHYS, volume 38, no. 4, pages 513-543.

Lohmann U. and Feichter J., **2005**: Global indirect aerosol effects: a review, *Atmos. Chem. Phys.*, 5, 715–737, Web-site: www.atmos-chem-phys.org/acp/5/715/

Lu M.-L. and Seinfeld J.H., **2005**: Study of the Aerosol Indirect Effect by Large-Eddy Simulation of Marine Stratocumulus, *J. of the Atmospheric Science*, 62, 3909-3932

Menon S., Saxena V.K., Durkee P., Wenny B.N., Nielsen K., **2002**: Role of sulfate aerosols in modifying the cloud albedo: a closure experiment, *Atmospheric Research*, 61, 169–187.

Menut L. and Bessagnet B., **2010**: Atmospheric composition forecasting in Europe, *Ann. Geophys.*, 28, 61–74, Web-site: www.ann-geophys.net/28/61/2010/

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